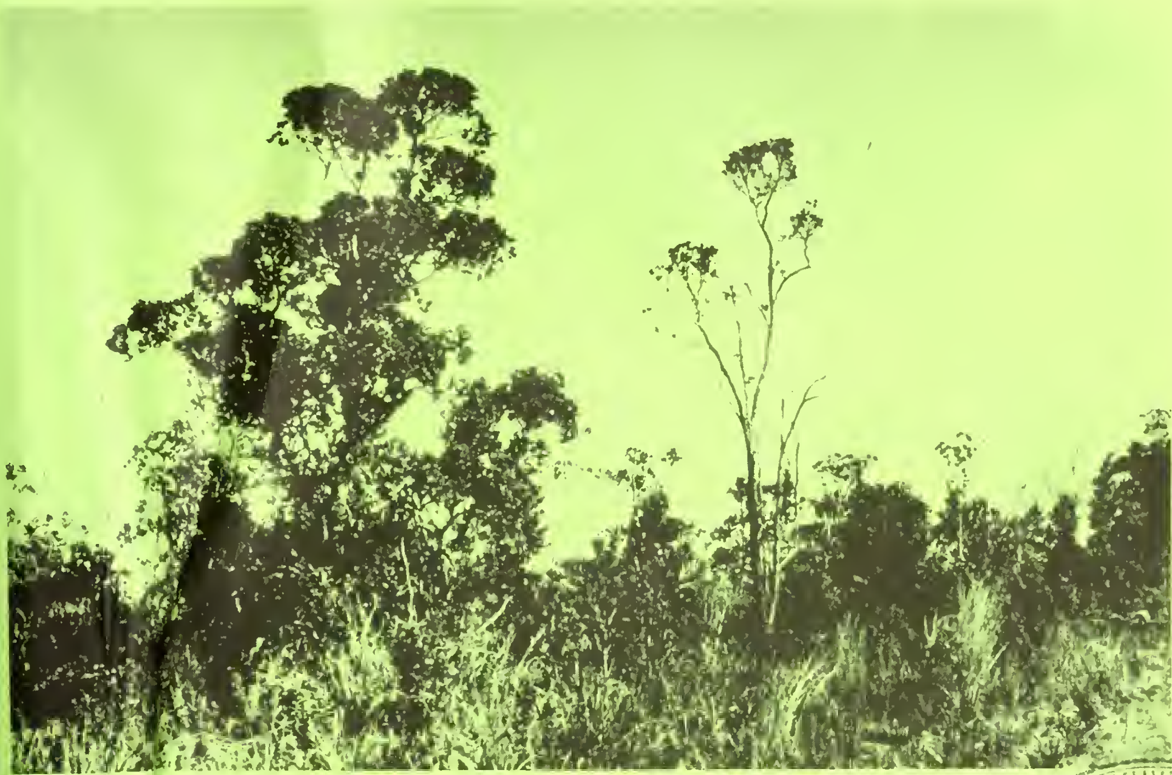
PACIFIC SOUTHWEST Forest and Range Experiment Station

OREST SERVICE
S.DEPARTMENT OF AGRICULTURE
O. BOX 245, BERKELEY, CALIFORNIA 94701



OHIA FOREST DECLINE:
its spread and severity in Hawaii

Edwin Q. P. Petteys   Robert E. Burgan   Robert E. Nelson

USDA FOREST SERVICE RESEARCH PAPER PSW- 105 /197

CONTENTS

THE AUTHORS

EDWIN Q. P. PETTEYS has been with the Hawaii Division of Forestry since graduating from Oregon State University with a bachelor's degree in forestry in 1967. As timber survey forester, he is assigned to the Station's Institute of Pacific Islands Forestry at Honolulu, Hawaii. **ROBERT E. BURGAN** has been on the staff of the Institute of Pacific Islands Forestry since 1969. From 1963 to 1969, he served on the timber sales staff of the Union and later Bear-Sleds Ranger Districts in Oregon. He earned bachelor's and master's degrees in forestry at the University of Montana. **ROBERT E. NELSON** has been in charge of the Station's timber and watershed resource development research in Hawaii since 1957. He joined the Forest Service in 1941 after earning a bachelor's degree in forestry at the University of California, Berkeley.

Cover photo: A healthy ohia-lehua tree, *left*, is in sharp contrast to one in severe decline, *right*.

U.S. Forest Service research in Hawaii
is conducted in cooperation with
Division of Forestry
Hawaii Department of Land and Natural Resources

SUMMARY

Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson
1975. **Ohia forest decline: its spread and severity in Hawaii.** USDA Forest Serv. Res. Paper PSW-105. 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 176.1 *Metrosideros collina:* 48(969)
Retrieval Terms: ohia decline; forest diseases; epidemics; aerial photography; Hawaii.

Thousands of acres of ohia and ohia-koa rain forest on the windward slopes of the island of Hawaii are suffering a severe epidemic. A high proportion of the trees have died on thousands of acres, and the forest decimation is continuing. The epidemic is affecting all ages of trees and forests on widely different sites. The specific cause (or causes) of the forest decline is not known, although both disease organisms and insects have been found associated with the dead and dying trees.

Scientists from several agencies are using a multidisciplinary approach to investigate the problem. This paper deals with the determination of the extent, rate of spread, and severity of the forest decline.

Aerial photographs taken in 1954, 1965, and 1972 of the 197,000-acre (80,000 ha) study area on the island of Hawaii provided a means of comparing forest conditions at these three time periods. A grid of 1450 equally spaced 1-acre plots was marked in the same location on each set of photographs. Each plot on the 1954 photographs was studied stereoscopically, and a "decline condition class" rating assigned, along with an estimate of the percent of the plot area covered by healthy tree canopy. On the 1965 and 1972 photographs, only the percent of plot area covered by healthy tree canopy was determined. Information on forest type, average annual rainfall, elevation, plot location, and land ownership was also recorded. From these data, maps were developed to show decline severity in each of the 3 years. Statistical correlations of decline severity with elevation and average annual precipitation were also developed.

In 1954, only 300 acres (120 ha) of the forest studied had severe decline, whereas 75,500 acres (30,500 ha) were classed as healthy. By 1972, 85,000 acres (34,400 ha) had severe decline, and only 32,500 acres (13,150 ha) were still classed as healthy. The forest decline is continuing, and extends well beyond the original study area boundaries. Virtual elimination of the ohia forest within the study area is possible within 15 to 25 years if present rate of damage continues.

The most severe decline locations in 1954 were in a roadless area in the northern portion of the study area. The data taken from the 1954 photographs provide, in retrospect, a forecast of the later patterns of spread.

Mean annual precipitation and elevation slightly influence the rate of decline and its current severity.

Forested areas on the islands of Oahu, Maui, Molokai, and Kauai have snag patches and forest remnants indicating the presence of former forests. Recent tree deaths are few and scattered except on Kauai Island, where crown dieback can be considered epidemic in two areas.

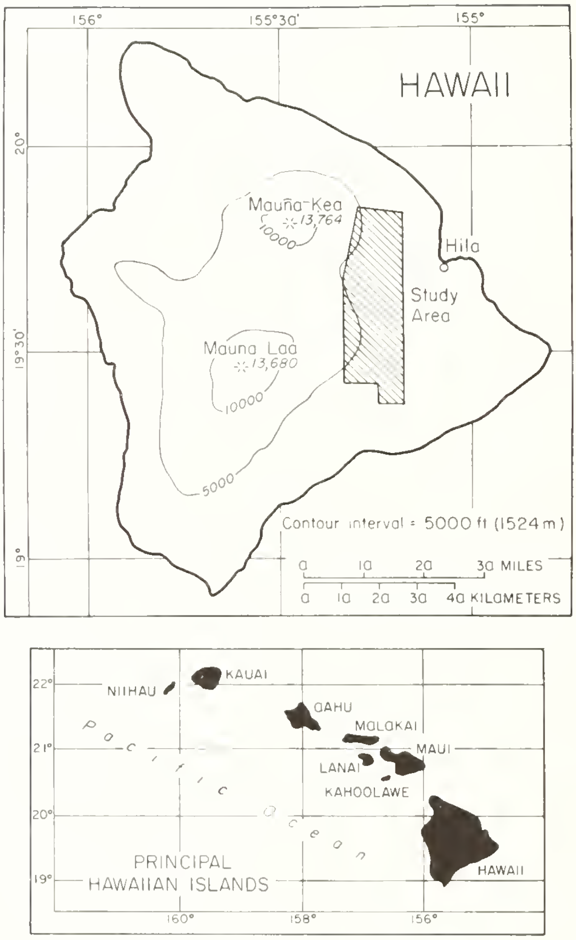


Figure 1—The study area surveyed by aerial and ground techniques for ohia forest decline covers 197,000 acres (80,000 ha) on the island of Hawaii.

Ohia-lehua *(Metrosideros collina)* forests on windward slopes of the island of Hawaii are suffering a severe epidemic. A high proportion of the trees have died on thousands of acres, and the forest decimation is continuing. The epidemic is affecting all ages of trees and forests on widely different sites. The specific cause (or causes) of the rapid forest decline is not known, although both disease organisms and insects have been found associated with dead and dying trees. Scientists from several agencies and disciplines are investigating the problem (Burgan and Nelson 1972; Kliejunas and Ko 1973; Laemmlen and Bega 1972; Gressitt, Samuelson, and Davis 1973). One objective of these investigations is to survey the extent, rate of spread, and severity of the forest decline.

Ohia and ohia-koa *(Acacia koa)* forest types occupy nearly 1 million acres (400,000 ha) in the Hawaiian Islands. The island of Hawaii has over 711,000 acres (287,700 ha) of these forest types. These native forest types occupy a significant acreage on all the major islands *(table 1)*.

The ohia forests provide a variety of resource values, including watershed cover, habitat for game animals and rare wildlife, timber, forage, and recreation opportunities. Loss of the dominant tree cover over large areas of these forests may have serious and long-term consequences. Even if the epidemic stops, regeneration of the native forest is not a certainty. Aggressive adventive plants invading areas of decline may limit or prevent native forest regeneration. Information is needed to help guide management decisions regarding this forest resource. Long-term studies are underway to determine vegetation successsional trends.

To evaluate the severity and rate of ohia forest decline, we focused on a 197,000-acre (80,000 ha) portion of the windward slopes of the island of Hawaii *(fig. 1)*. This area was chosen because it contained the major concentrations of identified epidemic decline and because funds were not available to obtain new aerial photography for other parts of the island or other islands.

This paper compares the severity and rate of decline of ohia-lehua forests in the study area from 1954 to 1973; relates this decline to elevation, mean annual rainfall, and forest types; and considers the prospects for the future.

METHODS

Aerial Photography

Color aerial photography for this study was taken in 1972-73 at a scale of 1:12,000[1]. These photos, hereafter called *1972 photography* provided the most recent information on decline status. In addition, black and white aerial photographs were available for the years 1954 (1:38,000) and 1965 (1:24,000).

The aerial photographs enabled us to compare forest conditions in the area at three time periods. We used the following sampling technique:

1. A grid of points, equally spaced, was marked on topographic maps of the study area and on the 1954, 1965, and 1972 photographs. The points totaled 1450, each representing 136 acres (55 ha) for statistical expansion purposes.

2. Each point was assigned a plot number which applied to the same point on all three photos. The points represented centers of 1-acre circular plots.

[1]Photography had been contracted for by the Hawaii State Division of Forestry in November 1971, but clouds and volcanic haze delayed and interrupted accomplishment of the photo flight missions. The photography was completed in four missions: January 1972, August 1972, September 1972, and February 1973.

Table 1—*Total land area and area occupied by ohia and ohia-koa forest types, six main islands of Hawaii*

Island	Total area		Ohia and ohia-koa types	
	Acres	*Hectares*	*Acres*	*Hectares*
Hawaii	2,584,300	1,045,900	711,000	287,700
Maui	466,000	188,600	89,500	36,200
Molokai	167,100	67,600	23,000	9,300
Lanai	89,300	36,100	500	200
Oahu	380,800	154,100	55,500	22,500
Kauai	352,600	142,700	88,500	35,800
Total	4,040,100	1,635,000	968,000	391,700

3. Each photo plot was studied stereoscopically and a "decline condition class" rating was assigned each plot on the 1954 photos, along with an estimate of the percent of plot area (to the nearest 5 percent) covered by healthy tree canopy. The decline condition classes were defined as:

Condition:		*Class*
Severe:	Over 40 percent of the tree canopy dead or dying	1
Moderate:	11 to 40 percent of canopy dead or dying	2
Slight:	1 to 10 percent of canopy dead or dying	3
No decline:	Entire canopy apparently healthy	4

For the 1965 and 1972 photos, we estimated only the percent of plot area (to the nearest 5 percent) covered by healthy tree canopy. "Canopy loss classes" were developed for the intervals 1954-65 and 1965-72 from calculations from these estimates. Canopy loss classes were as follows:

Canopy loss:	*Class*
None	1
1 to 10 percent	2
11 to 50 percent	3
Greater than 50 percent	4

To aid photo interpretation accuracy, 1972 color photos were studied at various sites in the field. Field checking of the earlier black and white photos was obviously not possible because of changes over time.

Information on forest type, average annual rainfall, elevation, land ownership, and plot location coordinates (X and Y) was also recorded. All data were computer processed.

Table 2—*Acres of forest land within the project boundary, by ohia forest decline class and man-disturbed or nonforest areas, island of Hawaii*

Ohia forest decline class	1954	1965	1972
Forest land:			
No decline	75,500	46,300	32,500
Slight decline	85,400	27,200	10,800
Moderate decline	17,200	65,300	48,700
Severe decline	300	39,600	85,200
Total forest land	178,400 (72,200 ha)	178,400 (72,200 ha)	177,200 (71,700 ha)
Man-disturbed and nonforest land	18,900	18,900	20,100
Total project area	197,300 (79,800 ha)	197,300 (79,800 ha)	197,300 (79,800 ha)

Data Analysis

Because decline class was directly interpreted only for 1954, we had to compute the decline class for each plot for the years 1965 and 1972. We used the formula

$$Dy = D_{54} + \left[\left(1 - \frac{HCy}{HC_{54}}\right)100\right]$$

in which

Dy = percent of dead or dying forest canopy in year y (1965 or 1972)

D_{54} = midpoint percentage of decline class in 1954

HCy = percent of plot covered by healthy tree crowns in year y (1965 or 1972)

HC_{54} = percent of plot covered by healthy tree crowns in 1954

The value of Dy was compared with the class intervals for assignment to the proper decline class. As HCy did not increase with time on any of the plots, the formula was written so that Dy would never decrease.

The number of plots in each decline class was summarized and then converted to acreages with an expansion factor of 136 acres (55 ha) per plot. Summaries of areas in each decline class, by year, forest type, and ownership were developed *(tables 2, 3, 4).*

Table 3–*Forest land within the project boundary, by ohia forest decline class, year, and forest type, island of Hawaii*

Year and ohia forest decline class	Ohia	Ohia-koa	Total
	Acres		
1954:			
No decline	60,700	14,800	75,500
Slight decline	62,000	23,400	85,400
Moderate decline	15,600	1,600	17,200
Severe decline	300	–0–	300
Total	138,600 (56,100 ha)	39,800 (16,100 ha)	178,400 (72,200 ha)
1965:			
No decline	37,600	8,700	46,300
Slight decline	18,200	9,000	27,200
Moderate decline	48,700	16,600	65,300
Severe decline	34,000	5,600	39,600
Total	138,500 (56,100 ha)	39,900 (16,100 ha)	178,400 (72,200 ha)
1972:			
No decline	28,700	3,800	32,500
Slight decline	7,500	3,300	10,800
Moderate decline	32,900	15,800	48,700
Severe decline	68,200	17,000	85,200
Total	137,300 (55,600 ha)	39,900 (16,100 ha)	177,200 (71,700 ha)

Table 4–*Forest land within the project boundary, by ohia forest decline class, year and ownership*

Year and ohia forest decline class	National Park	Hawaiian homes	State	Corporate	Individual
			Acres		
1954:					
No decline	9,520	140	43,670	17,140	5,030
Slight decline	8,030	140	51,830	20,000	5,440
Moderate decline	540	0	10,200	5,850	540
Severe decline	0	0	140	140	0
Total	18,090 (7,320 ha)	280 (110 ha)	105,840 (42,830 ha)	43,130 (17,450 ha)	11,010 (4,460 ha)
1965:					
No decline	7,480	0	25,300	11,290	2,180
Slight decline	1,090	140	17,410	6,390	2,180
Moderate decline	3,950	140	41,080	15,640	4,490
Severe decline	5,580	0	22,040	9,800	2,170
Total	18,100 (7,320 ha)	280 (110 ha)	105,840 (42,830 ha)	43,120 (17,450 ha)	11,020 (4,460 ha)
1972:					
No decline	6,670	0	16,730	7,750	1,360
Slight decline	140	0	7,350	2,580	680
Moderate decline	2,180	140	28,840	14,010	3,540
Severe decline	9,110	140	52,370	18,230	5,300
Total	18,100 (7,320 ha)	280 (110 ha)	105,290 (42,830 ha)	42,570 (17,230 ha)	10,880 (4,400 ha)

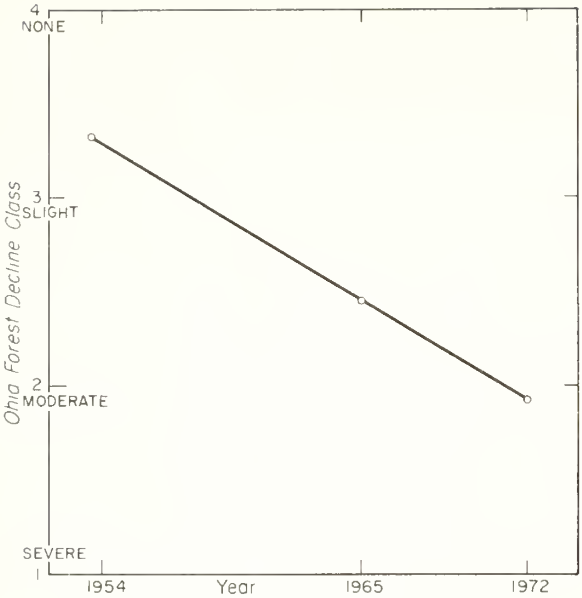


Figure 2—"Average health" of ohia forests in the study area changed from a rating of "slight decline" in 1954 to "moderate decline" by 1972.

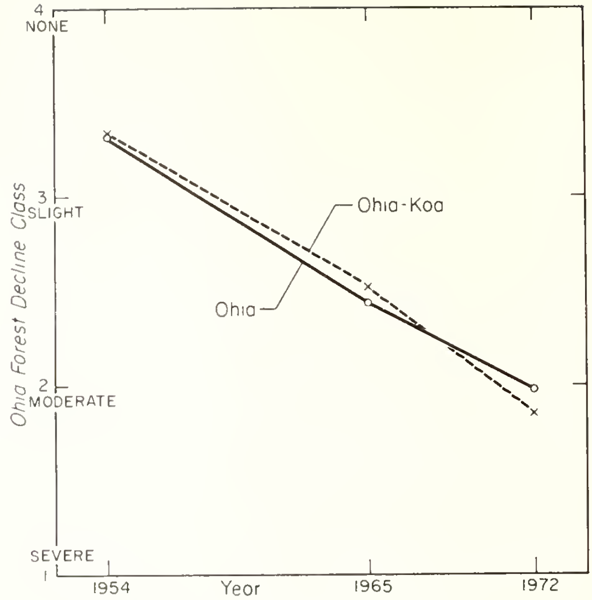


Figure 3—Rate of decline for the ohia forest has been about the same as that for the ohia-koa forests in the study area.

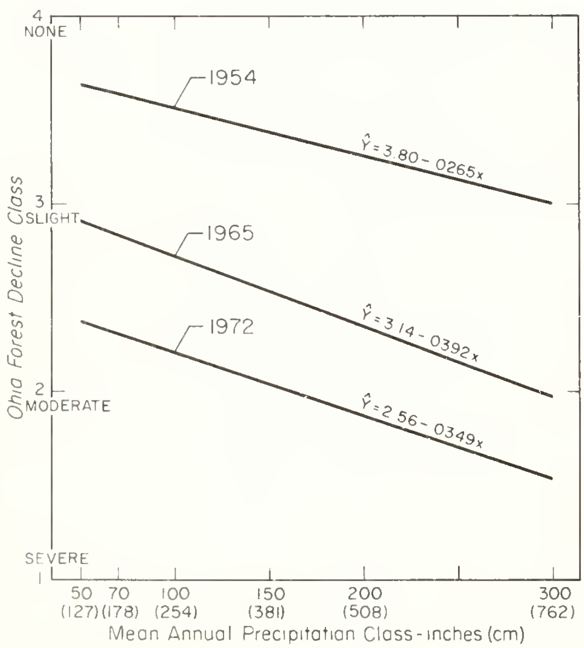


Figure 4—As mean annual rainfall increased, the severity of ohia forest decline increased in the study area. In the regression formula, X equals mean annual precipitation (in inches) divided by 10.

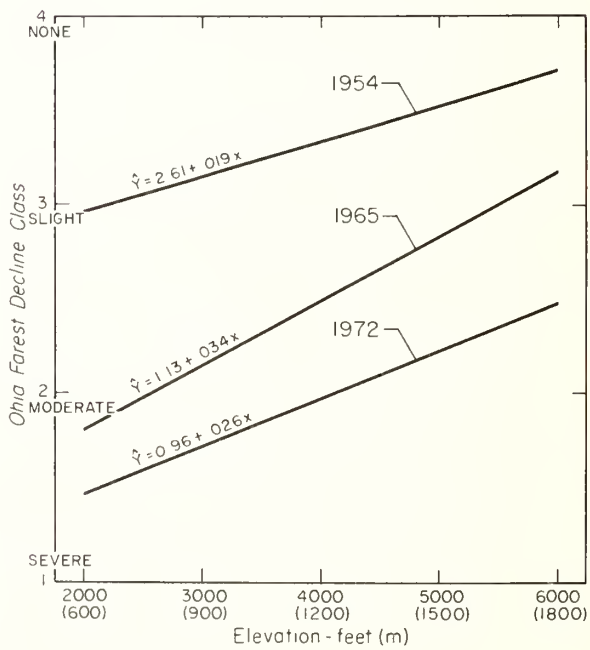


Figure 5—The greater the elevation of the ohia forest in the study area, the less it was affected by decline. In the regression formula, X equals elevation (in feet) divided by 100.

Area statistics are subject to sampling error. The sampling intensity for this survey was such that, for 95 percent confidence limits, area estimates are liable to these errors:

Area estimate (acres):	*Sampling error (acres ±)*
1,000	720
10,000	2,000
20,000	3,100
50,000	4,400
100,000	5,100

Map Compilation

All decline-condition maps were prepared with the aid of a programable calculator and plotter which performed these functions: (a) reduced the scale of the original project area map; and (b) computed the decline class for each point, selected the mapping symbol appropriate to that class, and plotted this symbol at the location identified by the coordinates of the point. Mapping was completed by differential shading around isodecline symbols.

RESULTS

Island of Hawaii

The average forest decline condition was calculated for the years 1954, 1965, and 1972 to provide a measure of the "health" of the forest within the study area for each year. The results were . . .

- In 1954, the average condition of the forest in the study area was rated "slight decline" with an index of 3.32 *(fig. 2)*. Since then, the forest has declined markedly.
- The ohia forest type declined at about the same rate as the mixed ohia-koa forest *(fig. 3)*. Data were not sufficient to allow a comparison with the koa forest type.
- The "health" status of the forest deteriorated as the mean annual rainfall increased *(fig. 4)*. This was true for all 3 years (1954, 1965, 1972). In addition, the regression lines are significantly lower in each of the more recent years, suggesting that the overall average "health" of the forest declines with time.
- The forest was less affected at higher elevations *(fig.5)*. This condition is consistent with the relationship with rainfall because the maximum annual rain-

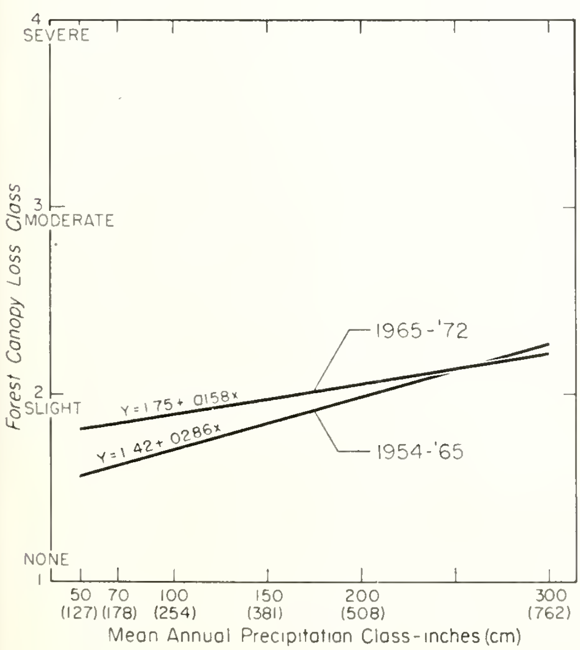


Figure 6—The rate of canopy loss due to ohia forest decline was greater in the higher rainfall areas than elsewhere in the study area. In the regression formula, X equals mean annual precipitation (in inches) divided by 10.

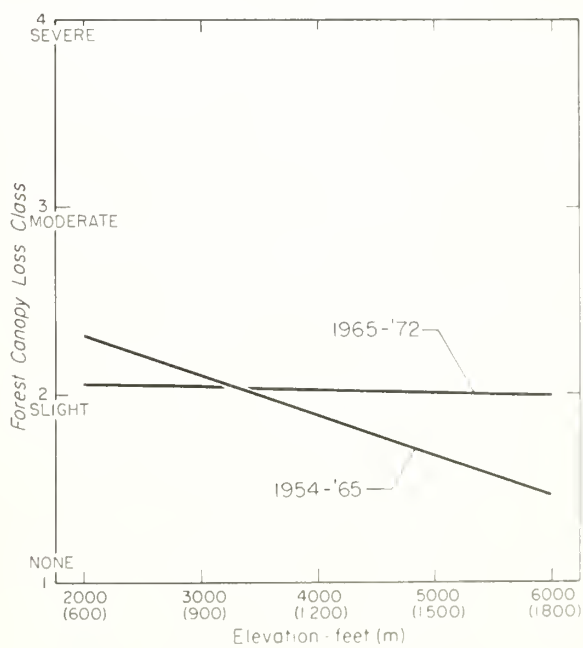


Figure 7—Rate of forest canopy loss due to ohia forest decline decreased as elevation increased in the study area.

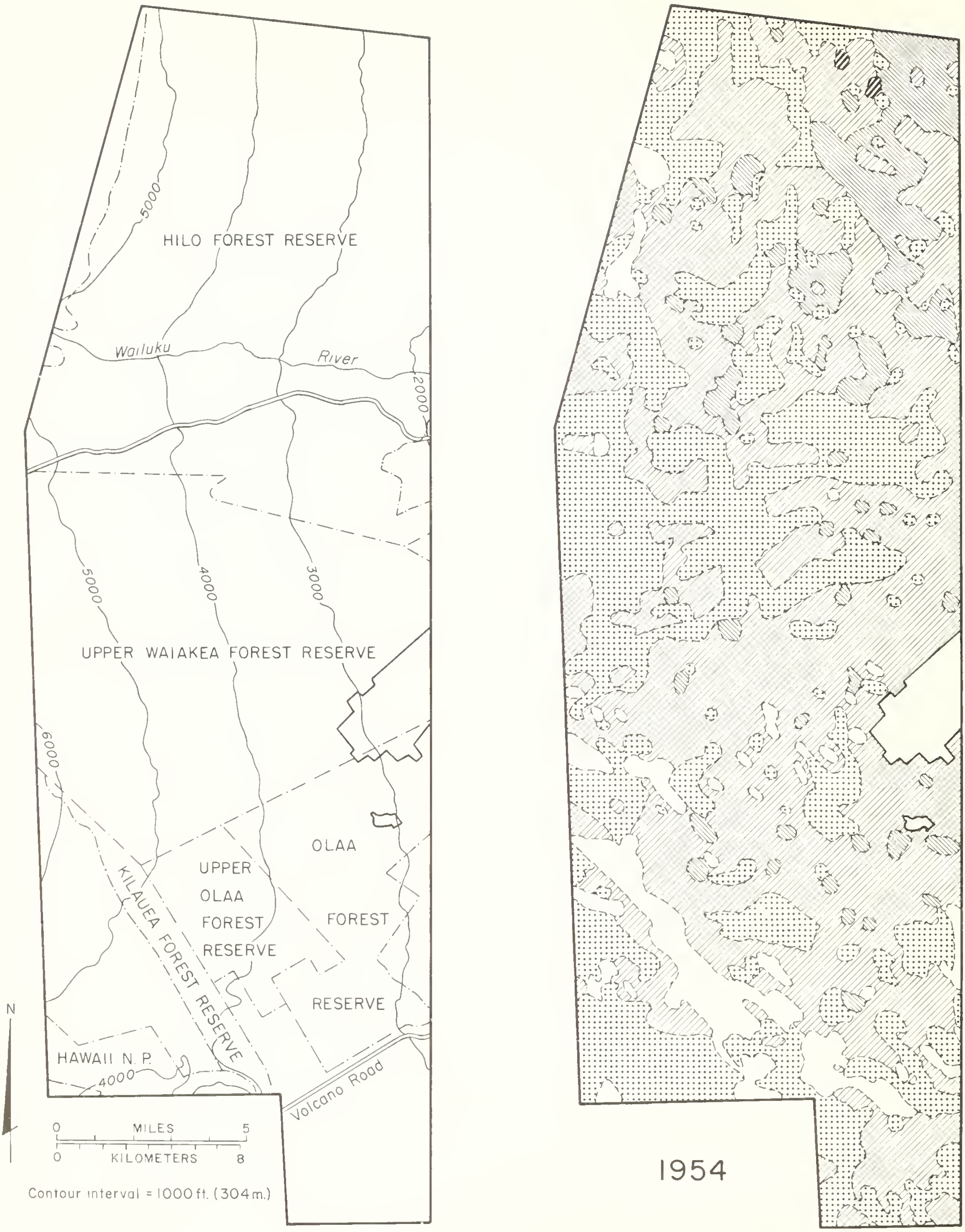


Figure 8—Changes in the condition of forests affected by ohia forest decline are evident from a comparison of areas surveyed in 1954, 1965, and 1972, by the four decline condition classes.


1965
1972
None
Slight
Moderate
Severe
Not surveyed

fall within the project area occurs near the lower boundary, at 2500 feet elevation (760 m). From there, the mean annual rainfall generally decreases as elevation increases.

• The canopy loss was greater in the higher rainfall areas. This loss occurred at a slightly faster rate during the 1954-65 time interval than from 1965 to 1972 *(fig. 6)*.

• The periodic loss of forest canopy was also related to elevational levels *(fig. 7)*. There was less forest canopy loss at higher elevations during the 1954-65 time period. This relationship is consistent with the generally lower rainfall in the higher elevations. However, from 1965 to 1972, the forest was apparently declining at about the same rate at all elevations. Perhaps by then the loss of forest canopy in the lower elevations had already been so severe that the rate of forest decline (canopy loss) had tapered off.

• The severity of decline decreased as elevation increased, although the pattern has anomalies *(fig. 8)*. Regressions of forest health class on precipitation and elevation for each of the 3 years (1954, 1965, and 1972) showed that they explained only 4 to 9 percent of the variation of health, i.e., $0.043 < r^2 < 0.088$. Regressions of data (unclassed) for percent of crown canopy loss on precipitation and elevation for the interval 1954-65 produced r^2 values of only 4.8 and 5.4 percent, and for the interval 1965 to 1972, the respective r^2 values were only 0.09 and 0.13 percent. Thus, although mean annual rainfall and elevation may have some effect on the rate of decline, these factors apparently are not limiting—at least within the boundaries of the study area.

The area of principal concern in this investigation was a portion of the forests on windward slopes of the island of Hawaii, but general aerial and ground reconnaissance indicated that forest decline extends outside the study area.

Reconnaissance surveys show that the occurrence of crown dieback and tree death in the Puna and Ka'u areas is spotty, but extensive. Both single trees and small pockets or clumps of trees are affected. In extensive areas in Ka'u where tree fern is the dominant cover, snags and occasional ohia trees suggest a former ohia forest. These signs point to the possibility of epidemic decline activity in the past.

In the Kohala Mountains there are extensive areas of old top dieback in the scrub ohia forests; but only a few recently dead tree crowns.

Areas in Manuka and North Kona have small patches of presently active decline, especially in the Kahaluu Forest Reserve.

Other Islands

Maui, Molokai, Oahu

Reconnaissance of forest areas of Maui, Molokai, and Oahu in 1972 showed a few places where some trees had died recently. On each of these islands, we found large areas where snags and forest remnants indicate forest decimation many years ago. Areas where recent tree deaths have occurred should be visited to determine the cause, or to determine any similarity to the nature of the decline on the island of Hawaii.

Kauai

Reconnaissance on Kauai revealed that in some places ohia tree death or crown dieback was abnormally frequent. In two areas—the ridge between upper Hanalei and Kalihiwai Valleys, and the Kawaikoi Stream watershed adjacent to Alakai swamp—the forest decline condition could be considered epidemic. Gressitt, Samuelson, and Davis (1973) reported that *Plagithmysus* beetles were fairly consistently associated with tree crown dieback. Further investigations are needed to determine the implications of their findings.

DISCUSSION AND CONCLUSIONS

From the 1954 photography, 42 percent or 75,500 acres (30,500 ha) of native forest in the study area, island of Hawaii, were classified as "healthy," while only 300 acres (120 ha) were classified as having severe decline *(table 2)*. Map portrayal of the 1954 data shows that moderate and severe decline was concentrated in the northern portion of the study area *(fig. 8)*. This area has no roads and is cloud covered most of the time. Therefore, any incipient epidemic decline had little chance of being spotted and interpreted as such at that time.

On the basis of 1965 photography, 26 percent or 46,300 acres (18,700 ha) were classified as "healthy" forest while 39,600 acres (16,000 ha) were classified as having severe decline. Comparison of the 1954 and 1965 data *(fig. 8)* shows that forest decline conditions had extended and intensified. But, and perhaps significantly in retrospect, data from the 1954 photographs forecast the pattern. There was extensive light decline noticeable on the 1954 photos, and decline had intensified markedly in these same areas by 1965. Concentrations of severe decline were generally in the roadless northeast and southern parts of the study area.

The 1972 photographs show that only 18 percent or 32,500 acres (13,200 ha) of the forest were free of decline symptoms, while 85,200 acres (34,500 ha) had severe decline. Much of the area having slight decline in 1954 and moderate decline in 1965 had severe decline in 1972. The extension of forest decline is especially clear when 1954 and 1972 maps and data are compared. The loss of "healthy" forest has been at an average rate of nearly 2400 acres (970 ha) per year. The increase in severe decline acreage occurred at a rate of about 3600 acres (1450 ha) per year from 1954 to 1965 and 6500 acres (2600 ha) per year from 1965 to 1972. North of the Wailuku River in the study area, spots of "healthy" forest are now extremely rare. The tree cover there has been decimated.

The overriding factor dictating the decline severity class of the forest appears to be time. Analyses of the data show a marked extension and increased severity of the ohia forest decline during the period 1954 to 1972. This study suggests that if decline continues at the present rate, remaining ohia forest in the study area will be virtually eliminated in 15 to 25 years.

Other areas of decline have been found on the island of Hawaii, and on other islands. Because of the potentially great losses, investigators should continue the research to determine the cause of the epidemic decline.

LITERATURE CITED

Burgan, Robert E., and Robert E. Nelson.
1972. Decline of ohia lehua forests in Hawaii. USDA Forest Serv. Gen. Tech. Rep. PSW-3, 4 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Gressitt, J. Linsley, G. Allan Samuelson, and Clifton J. Davis.
1973. A study of the borers of koa and ohia trees on the island of Hawaii, 7 p. Bernice P. Bishop Museum, Honolulu.

Kliejunas, John T., and Wen-Hsiung Ko.
1973. Root rot of ohia *(Metrosideros collina subsp. polymorpha)* caused by *Phytophthora cinnamomi*. Plant Dis. Rep. 57(4):383-384.

Laemmlen, Franklin F., and Robert V. Bega.
1972. Decline of ohia and koa forests in Hawaii. Phytopathology 62:770.

The Forest Service of the U.S. Department of Agriculture

... Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

... Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

... Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson
1975. **Ohia forest decline: its spread and severity in Hawaii.** USDA Forest Serv. Res. Paper PSW-105, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Ohia forest decline–its severity and rate of spread–was studied by aerial photographic techniques on a 197,000-acre (80,000-ha) portion of the island of Hawaii. In 1954, only 300 acres (121 ha) showed signs of severe decline; by 1972, the acreage of severely affected forest had increased to 85,200 acres (34,480 ha). Rate of decline and current severity were related to mean annual precipitation and to elevation. The epidemic is continuing. Some forests on other Hawaiian islands also display decline symptoms.

Oxford: 176.1 *Metrosideros collina:* 48(969)
Retrieval Terms: ohia decline; forest diseases; epidemics; aerial photography; Hawaii.

Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson
1975. **Ohia forest decline: its spread and severity in Hawaii.** USDA Forest Serv. Res. Paper PSW-105, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Ohia forest decline–its severity and rate of spread–was studied by aerial photographic techniques on a 197,000-acre (80,000-ha) portion of the island of Hawaii. In 1954, only 300 acres (121 ha) showed signs of severe decline; by 1972, the acreage of severely affected forest had increased to 85,200 acres (34,480 ha). Rate of decline and current severity were related to mean annual precipitation and to elevation. The epidemic is continuing. Some forests on other Hawaiian islands also display decline symptoms.

Oxford: 176.1 *Metrosideros collina:* 48(969)
Retrieval Terms: ohia decline; forest diseases; epidemics; aerial photography; Hawaii.

Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson
1975. **Ohia forest decline: its spread and severity in Hawaii.** USDA Forest Serv. Res. Paper PSW-105, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Ohia forest decline–its severity and rate of spread–was studied by aerial photographic techniques on a 197,000-acre (80,000-ha) portion of the island of Hawaii. In 1954, only 300 acres (121 ha) showed signs of severe decline; by 1972, the acreage of severely affected forest had increased to 85,200 acres (34,480 ha). Rate of decline and current severity were related to mean annual precipitation and to elevation. The epidemic is continuing. Some forests on other Hawaiian islands also display decline symptoms.

Oxford: 176.1 *Metrosideros collina:* 48(969)
Retrieval Terms: ohia decline; forest diseases; epidemics; aerial photography; Hawaii.

Petteys, Edwin Q. P., Robert E. Burgan, and Robert E. Nelson
1975. **Ohia forest decline: its spread and severity in Hawaii.** USDA Forest Serv. Res. Paper PSW-105, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Ohia forest decline–its severity and rate of spread–was studied by aerial photographic techniques on a 197,000-acre (80,000-ha) portion of the island of Hawaii. In 1954, only 300 acres (121 ha) showed signs of severe decline; by 1972, the acreage of severely affected forest had increased to 85,200 acres (34,480 ha). Rate of decline and current severity were related to mean annual precipitation and to elevation. The epidemic is continuing. Some forests on other Hawaiian islands also display decline symptoms.

Oxford: 176.1 *Metrosideros collina:* 48(969)
Retrieval Terms: ohia decline; forest diseases; epidemics; aerial photography; Hawaii.

PACIFIC SOUTHWEST Forest and Range Experiment Station

T SERVICE
PARTMENT OF AGRICULTURE
X 245, BERKELEY, CALIFORNIA 94701

RADIO AND TELEVISION USE IN BUTTE COUNTY, CALIFORNIA: APPLICATION TO FIRE PREVENTION

William S. Folkman

USDA FOREST SERVICE RESEARCH PAPER PSW-106 /1975

CONTENTS

The Author

WILLIAM S. FOLKMAN is responsible for the Station's research on sociological problems in the prevention of man-caused forest fires, with headquarters in Berkeley, Calif. He holds a bachelor's degree in agriculture from Utah State Agricultural College, a master's degree in sociology from the University of Utah, and a doctorate in rural sociology from Cornell University. He joined the Station staff in 1962.

SUMMARY

Folkman, William S.
1975. **Radio and television use in Butte County, California: application to fire prevention.** USDA Forest Serv. Res. Paper PSW-106, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 431.3(794)–U301.15
Retrieval Terms: fire prevention; mass media; radio;television research; community attitudes.

This paper reports the radio and television use habits of Butte County residents, covering the times of day they most often use these mass media and the types of programs they prefer, and also suggests ways the results can be applied to fire prevention work.

The survey was conducted as part of an evaluation of an experimental fire prevention program in Butte County. The sample interviewed is representative only of County residents who are 14 years of age or older. But the findings should be applicable to other nonmetropolitan residents of California's Central Valley-Sierra Nevada foothills. Many of these people have frequent and sustained contacts with wildlands.

Radio and television are much used by the population studied–60 percent reported listening to radio at least 1 hour per day, and 80 percent said they watched television for a similar period of time. Various demographic, social, and economic characteristics were found related to rather marked differences in radio and television use patterns, but not in the same way for the two media.

Differences in education, sex, and marital status particularly related to differences in amount of time spent with these mass media. Those people most involved in wildland activities spent less time using radio and television, but a lower proportion than the general public reported *no* use.

People make much more use of radio during the morning hours, while television, in the main, is used in the evening. There is some variation between weekday and weekend use of both media.

The period of the day in which radio and television were used varied considerably more in terms of the variables studied than did the amount of time used. Age, marital status, education, occupation, and wildland activity all produced variations in the pattern of use.

The programing format for radio differs markedly from that of television. News/weather was by far the most popular program on both media. Music was the only other major type of radio program mentioned. People mentioned a variety of favorite television programs, but comedy/variety and westerns were most frequent second choices.

Variations in program choice for both media were strongly influenced by age. There were also sex, marital, educational, occupational, and wildland activity differences in program choice.

Mass communication is a relatively cheap but not particularly effective means of influencing the behavior of large numbers of people. Much fire prevention effort is dependent on its use. Because of the reliance on donated public service time on radio and television, fire prevention planners have limited opportunity for making optimum effective use of those media for this purpose. By more carefully considering the listening/viewing habits of the high fire-risk audiences that they are most desirous of reaching, fire prevention program planners could more profitably utilize the discretionary power they do have. If they conclude that (a) their fire prevention announcements *are not* shown when desired audiences would see them and more desirable showing times are not feasible or (b) the audience that *is* exposed to the announcements presents no significant risk to the forest resource, then they might consider shifting from mass media to fire prevention approaches with better possibility of payoff.

Agencies responsible for wildland fire protection depend upon radio and television as the mass media for much of their prevention effort. Public service announcements, such as those of the national Smokey Bear campaign, are the principal means used to keep the public sensitive to the forest fire problem. In addition, other types of spot announcements, news releases, and special programs, largely of local or regional origin, seek to educate potential forest users as to appropriate use of fire and to make them aware of specific hazardous situations or periods of time.

How people react to these and other forms of mass communication depends upon a variety of physical, psychological, and social factors affecting the communicator as well as the communicatee. The actual *content* of the message only partly determines a person's responses. The reception of the communication is filtered by the recipient's own values, loyalties, identifications, expectations, defenses, frames of reference, personality, and the particular social setting in which the message is received. A large body of confusing, and sometimes, seemingly conflicting research concerning mass communication has been developed over the past several decades.[1] Some principles derived from this research appear to be too general for application to specific problems and others too specific for more general use. There are, however, some viable pragmatic principles which may be applied to the production of more effective fire prevention communications.

One of these principles is that different audiences react differently to the same communication. Another is that, ordinarily, individuals do not really hear communications that are not in accord with their interests, needs, and opinions. From these principles, it is apparent that the practitioner needs to tailor the message in terms of content, timing, and other considerations to the intended audiences. To do this the practitioner needs to know as much as is feasible about the interests and habits of these specific audiences.

As a practical matter, public agencies have only limited control over the timing of their fire prevention releases. They are dependent on the commercial media for donated *public service time.* This public service time is usually made available at the least-preferred nonprime time. Notwithstanding that limitation, if public agencies knew more about the viewing and listening habits of potential audiences, they could more profitably utilize what discretionary power they do have. In addition, knowledge of the tastes and preferences of those segments of the general population that might be considered high fire risks could provide leads for producing more effective fire prevention programs.

This paper reports the radio and television use habits of Butte County, California, residents, covering the times of day they most often use these mass media and the types of programs they prefer, and suggests ways the results can be applied to fire prevention work.

The survey was conducted as part of an evaluation of an experimental fire prevention program in Butte County.[2] The sample interviewed is representative only of County residents who are 14 years of age or older. But the findings should be applicable to other nonmetropolitan residents of California's Central Valley-Sierra Nevada foothills. Many of these people have frequent and sustained contacts with wildlands.

---

[1] Some comprehensive and critical evaluation of this research includes: Janis, Irving L., and Carl I. Hovland. 1959. *An overview of persuasibility research.* In *Personality and persuasibility.* p. 1-26. Yale University Press, New Haven; Hovland, Carl I., 1954. *Effects of the mass media of communications.* In *Handbook of social psychology,* Vol. 2 p. 1062-1103. Gardner Lindzey, ed. Addison-Wesley, Cambridge, Mass; Davidson, W. Phillips. 1959. *On the effects of communication.* Public Opinion. Quart. 20(111):3; Klapper, Joseph I. 1960. *The effects of mass communication.* 302 p. The Free Press, Glencoe, Ill.; Rogers, Everett M. 1962. *Diffusion of innovations.* 367 p. The Free Press, Glencoe, Ill.

[2] Folkman, William S. 1973. *Fire prevention in Butte County, California . . . evaluation of an experimental program.* USDA Forest Serv. Res. Paper PSW-98, 23 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

RADIO AND TELEVISION HABITS

Radio and television are much used by the Butte County population studied. Three out of five persons reported listening to the radio an hour or more per day, while more than eight out of ten said they watched television at least that long *(table 1)*.

Hours of Use

• **Age**–Variation by age was not significant. Persons under 35 years of age and those between 55 and 65 tended to be the heaviest radio users, while those over 55 were the heaviest television users. One-fourth of those 65 and older reported no radio listening. The group under 25 had the lowest proportion reporting two or more hours per day spent watching television, but even for this group over half (55.5 percent) reported this amount. The 35-to-45 age group had the highest proportion reporting no television use (12.7 percent).

• **Sex**–Females reported heavier use of these mass media than did males. This was especially true for television.

• **Race**–The numbers in various racial categories, other than white, proved too small to be analyzed separately.

• **Marital Status**–The formerly married (widowed, divorced, or separated) reported the heaviest use of radio, and along with the currently married the heaviest use of television.

• **Education**–Heavy radio use tended to increase as the number of years of education increased–through high school. The relationship was inverse for college graduates. On the other hand, heavy television use was inversely related to education at all levels.

Table 1–*Number of hours per day reported spent listening to radio and watching television by Butte County residents, 1970*

Hours per day	Spent listening to radio	Spent watching television
	Percent[1]	
2 or more	44.2	68.9
1 to 2	17.2	16.0
Less than 1	14.6	3.5
Once or twice a week	10.0	6.5
Not at all	13.7	5.1
Not reported	.3	.0
Total	100.0	100.0

[1] n = 663

Non-use of radio was highest among the lower educational levels; for television, non-use was highest among higher educational levels.

Young people currently in school were not markedly different from the general population in the time spent in listening to the radio. Being in school did seem to reduce the time they had available for television watching–contrary to prevailing opinion.

• **Occupation**–Blue-collar workers tended to spend more time listening to radio or watching television than did their white-collar counterparts. However, in terms of occupational status, housewives did the greatest amount of television viewing, although their radio use was among the lowest.

• **Income**–Use of radio and television was somewhat related to income. Those with reported family incomes of less than $4,500 had the highest proportion of heavy radio users, while those with incomes of $8,000 or more had the lowest. The higher income group likewise had the lowest reported television use, but there was no difference in use among the lower income groups. For those who refused to give income data (3.3 percent), the proportion of reports of heavy use of both radio and television was much lower than for the rest of the population.

• **Residence**–Length of residence in present location of less than 1 year was associated with less than average use of both radio and television. Otherwise there was little variation in use.

Respondents reporting previous residence "elsewhere in Butte County" recorded heavier television use than did those reporting other previous residence categories.

Some variation by place of current residence was observed in radio and television use. City residents had the highest proportion of heavy users of radio, while suburban residents had the highest proportion of heavy television users. Small-town residents had the smallest proportion of heavy radio users, while they *and* farm residents had the smallest proportion of heavy television users.

People whose residence was located in a high fire-risk environment (i.e., surrounded by land covered with brush, dry grass, or both) reported somewhat heavier use of radio and considerably lighter use of television than did those in less exposed areas.

• **Wildland Activity**–Those people most involved in wildland activities spent less time using radio or television than other respondents in the study. However, the distinction in heavy use was found to be between those with *any* reported wildland visits and s with *none*. There was no difference between ɿent wildland visitors and infrequent visitors. wildland users reported no use of these media, ver; in fact, the more wildland visits the less se of both radio and television.

people's use of fire in wildland areas is closely ated with their use of wildland, responses ed on this basis quite naturally followed the pattern of radio and television usage as those for nd users.

Hours of the Day

dio and television have come to have distinctly ent functions in the lives of their users. This is ted in differences in the hours of the day in they are most likely to use the two media.

weekdays, nearly half the respondents, for ex-, reported the early morning hours—before 9 as a time when they were likely to listen to the *(table 2)*. In contrast, less than 5 percent re-d use of television during this time period. The ning morning hours—9 a.m. to noon—were the most frequently used hours for radio listening, 29 percent reporting this period. The remaining ds of the day for both radio and television were oned quite uniformly by more than one-fifth of spondents.

ision

contrast to radio use, television use starts off y; less than 5 percent reported use before 9 a.m. *2)*. This usage builds gradually through the ing and afternoon, so that 23 percent reported use between 3 p.m. and 6 p.m. Then during the 6 to 9 p.m. period, the percentage who reported watching television jumps to 78. After 9 p.m., television watching drops back to slightly less than half the population surveyed.

On weekends, there is slightly greater use of television between the hours of 9 a.m. and 6 p.m. than there is on weekdays. Otherwise, the level of use is lower than that on weekdays. There is an especially large decrease in the proportion using radio before 9 a.m. The proportion reporting no use of radio or of television on weekends was more than doubled over that reported for weekdays. More than one-third reported no radio use on weekends.

- **Age**—Respondents' radio use varied according to age. Those 35 through 44 years old were the most frequent users of radio before 9 a.m. on weekdays, while the group under 25 and over 64 had the lowest proportion reporting use at that time. After 12 noon on weekends, and 3 p.m. on weekdays, the youngest age group (under 25) had a considerably higher proportion reporting use of their radios.

Television use by age level was quite variable, but the group 55 and over tended to have the largest proportion reporting use for all periods before 9 p.m. Excluding the under-25 group, which had about average proportion reporting use for that time period, television use after 9 p.m. decreased as age of respondents increased.

- **Sex**—Radio listening during the high use period —before 9 a.m. on weekdays—was the same for both sexes, although it was slightly higher for males during this period on weekends. It was higher for males after 6 p.m. on weekdays and weekends.

- **Marital Status**—Single persons were more likely than married, or formerly married, persons to listen

Table 2—*Times of day radio and television are reported most used by Butte County residents, 1970*

Hours	Listening to radio		Watching television	
	Weekdays	Weekends	Weekdays	Weekends
	Percent[1]			
Before 9 a.m.	48.3	32.3	4.7	3.9
9 a.m. to 12 p.m.	29.3	25.3	11.6	12.8
12 p.m. to 3 p.m.	18.6	18.1	18.4	22.8
3 p.m. to 6 p.m.	19.6	19.2	22.9	25.3
6 p.m. to 9 p.m.	21.6	18.3	77.8	70.1
9 p.m. to 12 a.m.	16.9	15.8	47.5	45.9
None	15.7	35.8	6.8	14.3

[1]n = 663

to the radio between 6 p.m. and midnight on weekdays. The marrieds and formerly marrieds were the most frequent listeners before 9 a.m. weekdays.

Singles were less frequent television viewers at all time periods. Married persons generally had a higher-than-average proportion viewing television except during the midday time periods, when the proportion was about average. The distribution of formerly marrieds was similar to that of the marrieds except for the 9 p.m.-to-midnight time period, when the proportion viewing was almost as low as that of the single group.

- **Education**—Respondents with at least some but not more than a high school education were more inclined to listen to the radio before noon. Listening habits during the middle of the day were quite similar among all respondents. In the evenings, radio use tended to increase as amount of education increased. The group with a grade school education, or less, had the lowest proportion reporting radio use between 6 p.m. and midnight, while the group with at least some college had the highest. The group with some high school education was in an intermediate position. This pattern held true for both weekdays and weekends.

The pattern for television use was quite different. Morning use among respondents at all educational levels was low. Except before 9 a.m., a lower percentage of those with at least some college education reported television use during all periods of the day, while those with grade school education or less reported highest use for the periods before 6 p.m. The groups with grade school and high school education were very close in the proportion of persons reporting television use from 6 p.m. on.

Youths currently in school were much less likely to listen to the radio before 3 p.m. on weekdays (school hours). After that time and on weekends, they had a higher rate of use. Television was more popular among the out-of-school respondents at most hours of the day, except for the period before noon on weekends.

- **Occupation**—Persons with full-time employment were most likely to report radio use before 9 a.m. on weekdays, while those whose occupational status was listed as "student" were highest users during after-school hours. Housewives and those retired or disabled stood out as high television users.

Occupation, whether white-collar or blue-collar, did not distinguish respondents in terms of radio use at various times of the day. High proportions of blue-collar workers reported television use at all time periods during the day except for the hours before 9 a.m. on weekdays and after 9 p.m. on both weekdays an[d] weekends.

- **Income**—Differences in family income were no[t] reflected in major differences in radio use. Respo[n]dents with a family income under $4,500 reporte[d] slightly higher use in afternoons and evenings. Th[e] same group reported higher television use during a[ll] periods of the day before 6 p.m. and less thereafte[r]. The middle income group—$4,500 to $8,000—re[]sembled the low income group in its use of televisio[n] during the period before 6 p.m., but was somewh[at] similar to the higher income group thereafter.

- **Residence**—Length of residence in present loc[a]tion and place of previous residence were not discri[m]inating in terms of radio or television use, except th[at] those who had changed residence within the past [] years were low users of radio before 9 a.m., and tho[se] who had never moved were high users during the[se] early hours.

Differences in location of residence, such as cit[y], suburb, and open country, were not related to radi[o] or television use in any clear-cut pattern.

- **Wildland Activity**—Except for use during wee[k]day mornings, frequency of visits to the wildlan[d] was quite directly related to radio use. The grou[p] reporting the highest number of visits to wildlan[d] areas (11 or more visits) during the previous year ha[d] the highest proportion using radio from noon o[n] through the day on weekdays, and the highest pro[]portion for the entire day on weekends. Those wh[o] reported between one and 10 visits, as opposed t[o] more visits or no visits, were also in an intermedia[te] position as to radio use.

Program Choices

The program choices of radio and television use[rs] further demonstrate the distinctly different use pa[t]terns of these two groups, as well as the differences i[n] the programing format of the two media.

Radio

When asked to name the radio programs listene[d] to most, respondents most often mentioned new[s] weather *(table 3)*. Music was the next most frequen[t]ly mentioned first choice and was the leading secon[d] choice. Indiscriminate listening, as reflected by su[ch] expressions as "whatever is on" or "anything," w[as] the only other major type of listening reported.

Radio preferences were seldom designated b[y] name. Radio listening is often determined more b[y] the character of the particular stations listened [to] than by an interest in specific programs. Stations, pa[]

3–*Percent of respondents reporting types of programs frequently listened to on radio, Butte County, 1970*

am choice	1st mention	2d mention	3d mention
	Percent[1]		
weather	47.2	4.0	2.3
	17.8	22.8	1.0
rograms	5.0	2.8	.2
;	1.3	4.5	1.1
ous programs	1.3	1.1	.8
affairs	–	1.0	.2
n language ograms	.3	.2	–
riminate ening	11.8	–	–
laneous	1.0	–	–
oice	–	49.3	80.1
not apply on-user)	14.3	14.3	14.3
tal	100.0	100.0	100.0

63

ticularly metropolitan stations, often tailor their programs to cater to specific audiences. In addition, people often turn on a radio for background music, whereas television requires more attentive use.

Television

Television viewing presented a much broader range of program preferences, but news/weather was again the only type of program that stood out as the first choice named *(table 4)*. However, comedy/variety and westerns were most frequently named as a second choice.

To facilitate further analysis, the less frequently mentioned program choices shown in *tables 3 and 4* were combined into an "other" category for both radio and television *(tables 5,6)*.

When favorite program choice was cross-tabulated with hours per day of radio and television use, indiscriminate listening and watching were, as might be

Table 4–*Percent of respondents reporting types of programs most frequently watched on television, Butte County, 1970*

Program choice	Mention				
	1st	2d	3d	4th	5th
	Percent[1]				
News/weather	26.1	9.4	5.9	1.1	1.1
Comedy/variety	9.8	12.1	10.0	4.8	3.5
Westerns	9.8	12.1	7.7	5.3	2.0
Detective/crime	5.0	6.0	5.0	2.0	1.8
Sports	9.4	5.9	2.4	.9	.6
Situation comedy	3.9	5.3	4.1	3.5	1.2
Adventure/drama	4.2	5.7	4.1	1.8	1.2
Movies	4.8	5.6	3.6	2.3	.5
Soap operas	7.2	4.7	2.4	.8	.2
Public affairs/documentaries	1.4	2.4	3.2	1.1	.3
Game shows	2.9	2.4	1.2	.6	.5
Talk shows	1.5	1.1	.8	.2	–
Specials	.3	1.2	.3	.8	–
Children's programs/cartoons	.5	.5	.2	–	.2
Travel	.5	.3	.2	.2	.2
Family shows	.9	.3	–	–	–
Religious programs	–	–	–	.2	.2
Opera, ballet, classical music, etc.	–	–	–	.2	–
Miscellaneous	.9	.6	–	–	–
Indiscriminate watching	4.4	2.1	1.4	.2	.2
No choice	–	15.7	41.0	67.5	79.8
Does not apply (non-user)	6.5	6.5	6.5	6.5	6.5
Total	100.0	100.0	100.0	100.0	100.0

[1] n = 663

Table 5–*Radio programs most often listened to by Butte County residents, by amount of time spent listening, 1970*

Item	Respondents[1]	2 or more hrs	1 to 2 hrs	Less than 1 hr	Once or twice per week
		Percent			
News	316	49.1	21.5	19.9	9.5
Music	119	55.5	16.0	15.1	13.4
Other	50	48.0	20.0	10.0	22.0
Indiscriminate listening	87	58.5	20.9	13.6	13.4

[1]n = 572

expected, most characteristic of those reporting the highest number of hours use *(tables 5,6)*. Listening to music was also popular among the heavy radio users. People who mentioned westerns and "other" television programs as favorites were among the heaviest users of television.

The radio and television program choices were related to the characteristics of different respondents.

• **Age**–Although there was not much variation, by age, of respondents in the number of hours per day they reported listening to their radios or watching television, the popularity of different types of programs was quite strongly related to age. News programs on both radio and television were least frequently mentioned first by the youngest age group and increased in popularity up to the 65 and over group. The reverse was true for radio music. Indiscriminate listening to radio, but not indiscriminate watching of television, was most prevalent among the young. "Other" television programs were generally popular with the very youngest age group and also the middle-aged or older groups. Sports programs were least mentioned by the 65-and-over age group. "Other" radio programs were most popular with those over 45, while the opposite was true of the "other" television programs.

• **Sex**–News programs on both radio and television were somewhat more popular with males than with females. Otherwise, there was little difference by sex, in the choice of radio programs. Westerns and sports programs on television were more popular among males than among females; the reverse was true for comedy/variety and "other" programs.

• **Marital Status**–The never-married respondents were most different from the average in their choice of radio and television programs. A high proportion of them favored music and indiscriminate listening on radio, while fewer than average listed radio or television news. Television sports programs were not popular with the formerly married.

• **Education**–The popularity of music programs on radio increased directly with amount of education, while respondents with at least some college education demonstrated the least interest in "other" radio

Table 6–*Television programs most often watched by Butte County residents, by amount of time spent watching, 1970*

Item	Respondents[1]	2 or more hrs	1 to 2 hrs	Less than 1 hr	Once or twice per week
		Percent			
News	174	65.5	24.1	4.6	5.7
Comedy/variety	65	63.1	18.5	3.1	15.4
Westerns	65	78.5	15.4	1.5	4.6
Sports	62	66.1	19.4	6.5	8.1
Other	225	80.9	11.6	2.7	4.9
Indiscriminate watching	39	89.9	13.8	5.7	11.6

[1]n = 630

ms. Among television programs, sports in- l in popularity with education, while the re- vas true for westerns and indiscriminate watch-

dio news was much more popular among those school than among those currently enrolled. elevision news the difference between these oups was not as great. Radio music and televi- ports were particularly popular with the in- population.

Occupational Status—Persons employed full- nd those retired or disabled most frequently oned radio and television news as programs ikely to be heard. On the other hand, these and housewives were least likely to mention music and indiscriminate listening.

white-collar workers group had a higher pro- n watching news on television, while the blue- group had the highest proportion reporting ng to radio news. Comedy/variety, western, and programs on television were also more r with blue-collar workers than with white- workers. The opposite was true for radio music ms.

ncome—Popularity of various radio and televi- rograms was not found to be closely related to income. Television westerns were less popular with those having incomes of $8,000 or more, and sports programs were more popular. Otherwise choice of programs was quite similar.

• **Residence**—The popularity of radio music was inversely related to length of residence in the area. "Other" radio programs and television westerns were particularly unpopular with recent residents (less than 1 year in the area) compared with other residence groups.

Those who had always lived at their present location and those who formerly resided in Southern California most frequently mentioned radio news programs. Former residents of Southern California also more frequently mentioned television news programs.

Open country, farm residents were among the highest listeners to radio news, but were much lower than others in their listening to other types of programs. They also stood out as high watchers of "other" television programs and low users of television news.

• **Wildland Visits**—The most striking variation from the average in terms of frequency of use of wildlands was that those reporting no wildland visits also did not report sports programs on television as a favorite. This variation was also true for those who had not used fire in the wildlands.

CONCLUSIONS

s analysis of the radio and television use pat- of Butte County, California, residents shows ost people do make considerable use of both of media. But their use of radio was markedly dif- from that of television. Most radio listening is n the early morning hours (before 9 a.m.) and television viewing is done during the evening. nd music are the principal attractions on radio, gh indiscriminate listening accounts for consid- use. The selection is much broader for tele- but, again, news programs are by far the most r single category. In aggregate, the various of dramatic productions account for the bulk wing preference. Various demographic, social, onomic characteristics were found related to marked differences in radio and television use ns.

hard-pressed fire prevention officer might well ow this information might be utilized, as his is largely limited to donated public service or the airing of its fire prevention messages. Although the agency's control of the situation is limited, there are still several avenues open to it for improvement within the existing limitations.

In considering alternatives, the practitioner should keep in mind that reception of a communication is filtered through the recipient's own values, expectations, and other attributes. Consequently, different audiences react differently to the same communication. Messages that are not in accord with a listener's or viewer's interests, needs, and opinions may not be heard or seen.

• Greater attention might be given to matching the form, content, and appeal of the fire prevention announcements to the characteristics of those considered to be most likely to start fires. Increased personal efforts with station program directors may improve the chances that such directed announcements will be aired *at the times when such high-risk audiences are most likely to be reached.* (This suggestion presupposes that purchasing time is not feasible.)

• Fire prevention announcements might be more closely designed to fit the characteristics of audiences who *are* listening or viewing at the times the commercials are most likely to be broadcast.

• Finally, if fire prevention planners conclude that (a) their announcements *are not* shown when desired audiences would see them and more desira showing times are not feasible; or (b) the audien that *is* exposed to the announcements presents significant risk to the forest resource, then they mi consider shifting from mass media to fire preventi approaches with better possibility of payoff.

G.P.O. 689-230/44

Folkman, William S.
1975. **Radio and television use in Butte County, California: application to fire prevention.** USDA Forest Serv. Res. Paper PSW-106, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A sample of Butte County residents were interviewed about their radio and television use habits. Their responses were analyzed in terms of demographic, social, and economic characteristics. The findings can be used in developing more effective fire prevention programs. Most people in Butte County listen to the radio or watch television but they differ widely in the way they use these mass media. Fire prevention announcements should seek to capitalize on these differences.

Oxford: 431.3(794)–U301.15
Retrieval Terms: fire prevention; mass media; radio; television research; community attitudes.

Folkman, William S.
1975. **Radio and television use in Butte County, California: application to fire prevention.** USDA Forest Serv. Res. Paper PSW-106, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A sample of Butte County residents were interviewed about their radio and television use habits. Their responses were analyzed in terms of demographic, social, and economic characteristics. The findings can be used in developing more effective fire prevention programs. Most people in Butte County listen to the radio or watch television but they differ widely in the way they use these mass media. Fire prevention announcements should seek to capitalize on these differences.

Oxford: 431.3(794)–U301.15
Retrieval Terms: fire prevention; mass media; radio; television research; community attitudes.

Folkman, William S.
1975. Radio and television use in Butte County, California: application to fire prevention. USDA Forest Serv. Res. Paper PSW-106, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A sample of Butte County residents were interviewed about their radio and television use habits. Their responses were analyzed in terms of demographic, social, and economic characteristics. The findings can be used in developing more effective fire prevention programs. Most people in Butte County listen to the radio or watch television but they differ widely in the way they use these mass media. Fire prevention announcements should seek to capitalize on these differences.

Oxford: 431.3(794)–U301.15
Retrieval Terms: fire prevention; mass media; radio; television research; community attitudes.

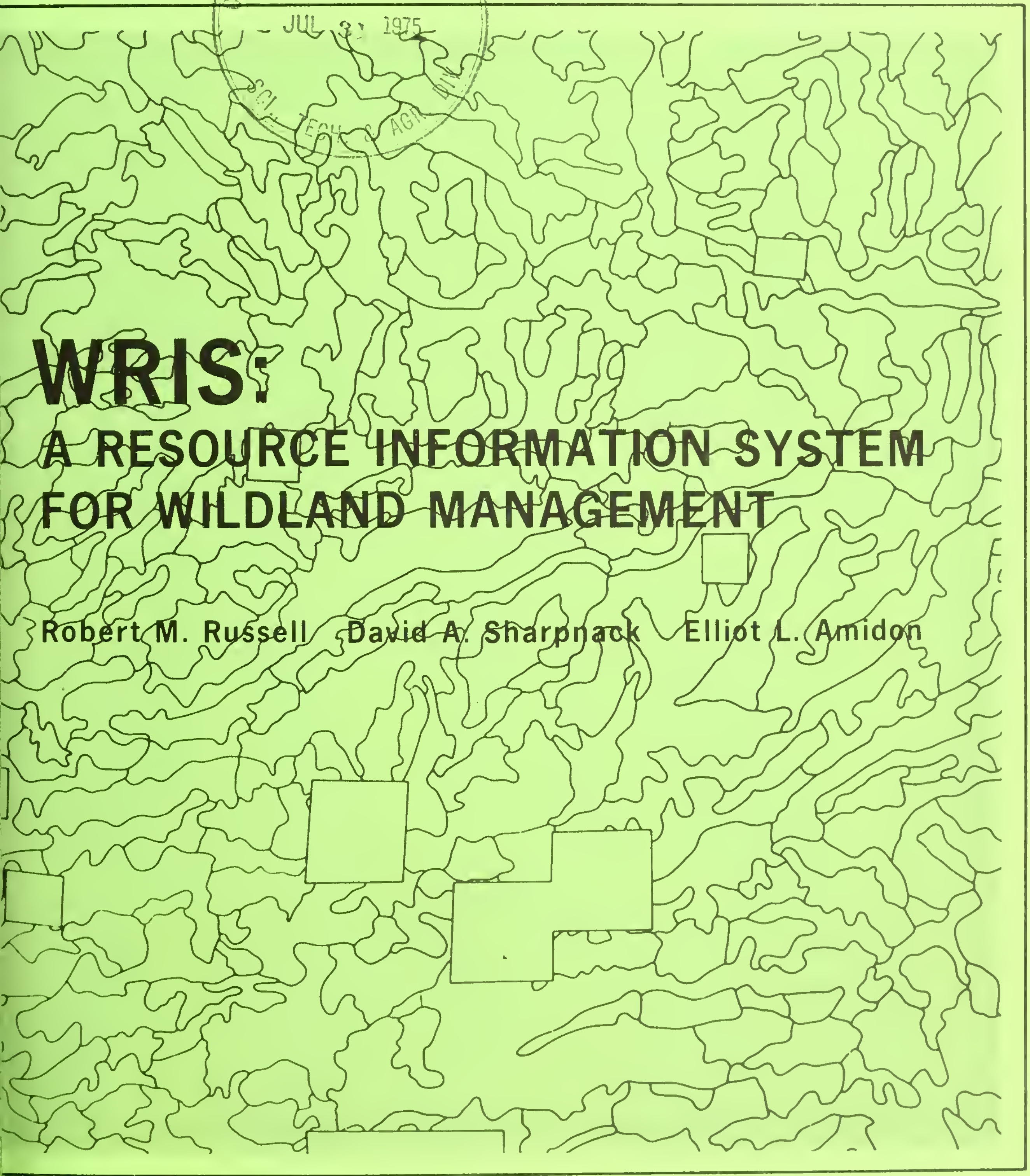
Folkman, William S.
1975. Radio and television use in Butte County, California: application to fire prevention. USDA Forest Serv. Res. Paper PSW-106, 10 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A sample of Butte County residents were interviewed about their radio and television use habits. Their responses were analyzed in terms of demographic, social, and economic characteristics. The findings can be used in developing more effective fire prevention programs. Most people in Butte County listen to the radio or watch television but they differ widely in the way they use these mass media. Fire prevention announcements should seek to capitalize on these differences.

Oxford: 431.3(794)–U301.15
Retrieval Terms: fire prevention; mass media; radio; television research; community attitudes.

PACIFIC SOUTHWEST
Forest and Range Experiment Station

[FORE]ST SERVICE
[U.S. DE]PARTMENT OF AGRICULTURE
[P.O. B]OX 245, BERKELEY, CALIFORNIA 94701



WRIS:
A RESOURCE INFORMATION SYSTEM FOR WILDLAND MANAGEMENT

Robert M. Russell   David A. Sharpnack   Elliot L. Amidon

USDA FOREST SERVICE RESEARCH PAPER PSW-107/1975

CONTENTS

The Authors

are assigned to the Station's research unit investigating measurement and analysis techniques for management planning, with headquarters in Berkeley, Calif. **ROBERT M. RUSSELL**, the unit computer programmer, received a bachelor's degree in mathematics at the University of Michigan (1956), and worked as a programmer at the University of California, Berkeley, from 1958 until 1966, when he joined the Station staff. **DAVID A. SHARPNACK**, a research forester, was educated at the University of Idaho (bachelor's degree in forestry, 1961) and the University of California, Berkeley (master's degree in statistics, 1969), and has been with the Station since 1962. **ELLIOT L. AMIDON** is in charge of the measurement and analysis techniques research unit. He earned a bachelor's degree in forest management at Colorado State University (1954) and a master's degree in agricultural economics at the University of California, Berkeley (1961), and was assigned to production economics research at the Station until he assumed his present position in 1971.

ACKNOWLEDGMENTS

The Wildland Resource Information System (WRIS) was developed by the Station's research unit investigating measurement and analysis techniques for management planning. WRIS was developed primarily for the Branch of Management Plans and Timber Inventories, California Region, Forest Service, U. S. Department of Agriculture, San Francisco.

We gratefully acknowledge the help of the Branch staff; Klaus H. Barber, inventory supervisor, Stanislaus National Forest; and E. Joyce Dye, computer programmer with the Station research unit staff.

At various stages of system development, we used data from the following National Forests in California: Stanislaus, Eldorado, and Sierra.

SUMMARY

Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon
1975. **WRIS: a resource information system for wildland management.** USDA Forest Serv. Res. Paper PSW-107, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 624:U681.3:(084.3)
Retrieval Terms: timber management; wildland management; resource use planning; computer programs; map compilation; WRIS; management information systems.

The Wildland Resource Information System (WRIS) is an operational computerized procedure for acquiring spatial data for management planning. Though designed primarily for timber management use, it has application for land-use planning in general. WRIS is a production tool for which detailed instructions are provided for both manual and computer operations. The system is intended for continuous use by institutions rather than individuals. It is designed to process a workload of 200 to 400 maps a year with a staff of two or three people at a central location, such as a regional office or corporate headquarters. Computation is performed on a medium-sized computer, the UNIVAC 1108, over a high-speed batch terminal. Other mandatory equipment needs include access to a scanning device for automatic digitizing, and an incremental line plotter. A hand digitizer is optional, but highly desirable if source maps vary from simple to highly complex. Software consists of over 20,000 standard FORTRAN statements compiled by UNIVAC's EXEC 2 Executive System.

The publication *Wildland Resource Information System: User's Guide* (USDA Forest Service General Technical Report PSW-10) details the operating procedures for using WRIS computer programs and digitizing hardware.

WRIS provides a means of collecting, processing, storing, retrieving, updating, and displaying geographic data, and makes possible the performance of logical operations on these data. System capabilities include data reduction from maps or orthophotographs at varying scales, printed tabular and plotted graphic display, computer-aided manual editing procedures, and a broad range of data-manipulating features. Logical operations include merging and overlaying of map files, selection of polygons with measurement of their area and perimeter, and extraction of rectangular subsets of data within a map border.

The basic data collection unit in WRIS is the polygon—a plane figure consisting of vertices connected by line segments. Each polygon has a unique number for computer processing and a category such as "red fir, volume category. . .," which has meaning for inventory purposes. This data structure differs from a more common one in which the squares of a fixed grid are labeled. A few other large-scale systems have a similar approach, which minimizes storage but does require more complex data-manipulating algorithms. About 10,000 polygons will cover a National Forest and span 1000 different categories. We report here statistics drawn from experience with three California National Forests because they affect system design and have implications for management planning.

Modifications and extensions of the system described here are inevitable because of the continual flow of new technology. Software conversion to the EXEC 8 version of FORTRAN is already underway. Adaptation to IBM 360-type computers is planned, and conversion to PL/1 is an attractive possibility. Several editing and updating alternatives are available, but more will be tested because these are key procedures in the cost of map data reduction.

Finally, we will seek ways to achieve communication between this and other geographic information systems. We need data format compatibility, standardized terminology, and exchange of methodology before wildland resource information can be routinely available to forest managers.

The rapidly rising value of wildland goods and services in recent years has put increasing pressure on wildland managers to make the most of the resources under their control. "The Environmental Program for the Future" (U.S. Forest Service 1974) provides some measure of the size and scope of the land management job facing the U.S. Forest Service. In order to provide in the next 5 years the same proportion of goods and services it has in the past, it "must conduct silvicultural examinations and prepare prescriptions for 19 million acres; carry out inventories on 50 forests covering 31 million commercial forest acres and prepare timber management plans on 61 forests covering 37 million commercial forest acres." These are major tasks facing those responsible for the proper management of the National Forests.

What kinds of information and capabilities are needed to develop an acceptable management plan? Barber (1973) suggests six requirements:

1. The location and acreage of all stands on the Forest.
2. A means of imposing physical and administrative constraints on the forest practices that will be allowed in individual stands.
3. A description of all stands, covering their structure, composition, volume, growth, and yield.
4. A means of predicting what would happen to each stand if it were harvested or, alternatively, if it were left to grow.
5. A set of techniques for analyzing the Forest's growing stock and land-use patterns to produce a management plan.
6. A means of updating the plan to accommodate changes in land base, stand structure, and management goals.

Of the six requirements, the collection and manipulation of geographic data can be the most costly and time-consuming steps in preparing a management plan. The Wildland Resource Information System (WRIS) was developed to handle this kind of problem.

The WRIS user obtains the location and acreage of all stands on the forest by digitizing maps of forest types. Unlike most earlier map systems, WRIS digitizes the maps by using a scanning microdensitometer and two computer programs: FREQTB converts the scanner output to a binary map; PØLLY extracts stand boundaries, which we call *polygons*, from the binary map, and produces a list of all stand areas and a magnetic tape containing all the stand boundaries.

Constraints are imposed on managing the forest in two steps using WRIS. First, maps delineating areas which impose either physical or administrative constraints on management are digitized in the same way as the stand maps. Second, by using the output for the stand map and the constraint map, a computer program (MØSAIC) overlays the two maps to produce polygons which represent a combination of information on forest types and constraints. The acreages of these polygons are used, along with other data, in the analysis necessary to develop a management plan.

Updating is easily handled by WRIS. Changes in either the forest-type or the constraints layer can be made. MØSAIC can be rerun and the new acreages entered into the analysis. WRIS can plot the original and the overlaid maps by the program CHART, or provide various useful lists by two programs (GØSSIP and RUMØR). These outputs from WRIS are particularly useful for developing a work plan to carry out the new management plan.

An important feature of WRIS is that it is not limited to the sequence of steps just described for developing a management plan. The capabilities of WRIS can be used for any process that begins with more than one layer of maps and combines these layers to provide the data for decisionmaking.

This paper describes the development of the Wildland Resource Information System and its capabilities and characteristics, provides production information about using the system, and considers the outlook for future modifications.

The publication *Wildland Resource Information*

System: User's Guide (USDA Forest Service General Technical Report PSW-10) details the operating procedures for using WRIS computer programs and digitizing hardware. Copies of the report and the computer programs are available on request to: Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701, Attention: Computer Services Librarian. The programs will be copied on a magnetic tape, to be supplied by the requestor. Before sending the tape, the requestor should contact the Computer Services Librarian, giving the tape format desired.

DEVELOPMENT OF WRIS

The potential usefulness of a computerized geographic information system was recognized years ago. But the development of such a system has been hampered by three major obstacles: First, data collection was limited to hand digitizing technology; second, the computational methods available required data to be categorized in a cellular fashion; and third, it was not clear that a system that solved technical problems would also be economically feasible.

Once the need for a geographic information system was recognized, the next step was to establish its scope. This meant considering the degree of centralization, deciding which functions and decisionmaking levels would be assisted, and establishing a production rate in balance with the expected annual map requirements. Compromises had to be made, and the result is considered desirable rather than optimal.

In a highly decentralized organization, such as the U.S. Forest Service, a configuration usable at the National Forest headquarters level may be desirable. Yet the economy of scale yielded by scanner digitizing suggests centralized processing at the regional or multiregional level. Hence, the role of hand digitizing has diminished for economic rather than technical reasons.

WRIS is functionally oriented toward timber in order to minimize the cost of map data reduction, as timber data was most easily available. Any other wildland data, such as geologic and soil classifications, that can be represented on maps, can be handled by the same procedures as timber data. New procedures can be improvised to adjust the system to fairly drastic changes in the input format. Point data such as elevations, or lineal features like roads, might warrant special treatment. We expect the bulk of the work to consist of identification of areas with irregularly shaped but connected boundaries, and the scope of the system reflects this fact.

Within the Forest Service's California Region, timber management planning alone requires about 300 new maps per year. Half of these maps are concerned with biological data—largely timber types. Other management activities collectively generate at least another hundred maps. A minimum processing rate is therefore two sheets per day.

System Design

System design requires the matching of the user's needs to the available resources. The client should be clearly identifiable with definable objectives. This ideal is difficult to attain because there are usually many potential users. It can be approached by selecting the appropriate design strategy. A common one is to conduct surveys of user's information requirements—a method requiring substantial resources (Boeing Computer Service, Inc. 1972; Raytheon Co., Autometric Operations 1973). An alternative, when the designers are already familiar with the user's problems, is to make simplifying assumptions and then provide an information system which seems just adequate. Then the system can be used to reveal the user's decision process. Later, portions of the system can be upgraded incrementally and performance continually evaluated. We took this approach in the design of WRIS.

A major influence on our design was control over the map compilation process, following aerial photography. To allow both automatic scanning as well as hand digitizing, we made slight changes in map annotations and in line widths in map drawings. Another influence on design was the resolution—fineness of detail—required to distinguish lines in aerial photographs. We could place forest-type lines effectively within about 50 feet (15 m) of true ground location. The inaccuracy represented by this distance is not critical, as it would be in depth soundings on navigational charts, for example. The appropriate, much less optimum, resolution could be defined only by substantial analysis.

A further influence on our design of WRIS was the several sources of complexity found in forest maps. One source is the characteristic of lines. Straight lines allow data to be compressed because essentially only changes in direction must be recorded. That fact is undoubtedly helpful in urban geographic information systems. But natural phenomena show few regularities; the only straight lines we encountered were administrative boundaries. The forest-type maps were quite detailed. Polygons are plane figures consisting of three or more vertices connected by line segments. The smallest polygon allowed on a map was 5 acres – about 10,000 polygons occurred on a Forest.

To express the attributes of a polygon, we use a *label*. For each polygon, its coordinate position is recorded and a label assigned. A label consists of from 1 to 36 characters. It is not unique, but may occur many times on a map – once for every polygon with the same attributes.

To describe the attributes of the 10,000 polygons recorded on a National Forest, we needed about 1250 labels to show classifications of forest type. Perhaps the classifications were too fine: almost any management planning would require about a twenty-fold reduction in the number of categories. Yet detail should be in excess of immediate needs. A suggested strategy is to have low-access storage of the original detail so the composition of the groups can be changed. This additional flexibility is worth the additional setup cost.

Clearly, availability of hardware can affect system design. The ubiquitous line printer, designed for printing characters, has served in lieu of expensive graphic output devices since the early 1960's (Thornburn and others 1973). WRIS originated in a multipurpose batch processing environment. The batch operation differs significantly from other installations in that the terminal can communicate easily with varying brands of distant computers. The peripheral graphic devices, digitizers and plotters are single-purpose equipment.

Software availability had little effect on system design. The few computer programs described in the literature were coded mainly by geographers (Tobler 1970). This lack of programs simply reflects the state of the art. There is still uncertainty and disagreement as to the correct method for storage and manipulation of graphic data. The "best" ways change rapidly with new developments in computer technology. We can expect algorithms as well as devices to be continually redesigned.

All large-scale geographic information systems require specialized equipment for map digitizing and graphic display. Often a sophisticated device must be developed before technical feasibility can be demonstrated. A prime example is the Canadian Geographic Information System, which uses a drum scanner designed expressly for the Canada Land Inventory scribed map sheets (Tomlinson 1967). Another Canadian system, on a smaller scale, performs cartographic manipulations without access to a shared computer. The configuration includes a storage display connected to a minicomputer by a specially designed interface (Graphic System Design and Applications Group 1972).

Our approach was to use commercially available services and to avoid hardware modification. For example, the hand digitizer selected was unusual because it did not have any moving parts connected to its cursor, and it was obtained with as few optional "extras" as possible. As a result, this first production model is still in use. All adaptations to changing technology are by means of software.

Maintaining flexibility through software tends to rule out the minicomputer in favor of medium or large computers shared by many users. All development has taken place on a UNIVAC 1108 computer, but conversion to other computers is feasible. The goal of flexibility has also resulted in a modular program structure, in FORTRAN. Similarly, the use of assembly languages or FORTRAN language features peculiar to one computer configuration has been avoided as much as possible. A large production rate may warrant some software specialization, however, to minimize input-output cost.

Testing

Testing has involved the repeated application of two steps. First, the requisite computer programs were debugged separately and as a group by using sample data. Then a series of about 50 maps or one forest overlay was processed. Each repetition suggested changes for the next. The first group of maps caused the most substantial change, from a process centered on hand-digitizing to one relying on an automatic scanner. About 236 township maps, covering two National Forests, have been completely processed.

Because technology is always changing, testing for technical feasibility will follow each change. But the final test, that of economic feasibility, cannot be made in a research and development environment. Only users can provide the stable working conditions needed to rationalize work flow. Cost data should be based on a system operated routinely by experienced personnel. These data should be collected during a year of routine work after the system has been implemented.

Implementation

The major consideration before system installation is the expected volume of work. The computer programs can be compiled and stored for such a small cost that even infrequent use would justify them. But, even for such use, at least one person would be required to operate specialized equipment and assist with occasional complex editing problems. A clearly appropriate workload would be about 200 maps per year processed by a two-person staff.

The source maps are generally prepared under contract, as most of the data processing could be. Within the Forest Service, we recommend that polygon identities be encoded at Forest headquarters, where the resource photography is available to correct erroneous map symbols. All subsequent work can be performed at the Regional level or commercially.

USERS OF WRIS

Most users of this information system are the management planners in a decentralized organization. This practice implies a two-way flow of data between at least two management levels, such as Forest and Region headquarters. Current users include timber management planning staff members, who require facts about the resource, such as the acreage distribution of forest types, the timber volumes and the growth rates associated with them. In turn, these data are interpreted, and in accordance with policy guidelines, are passed forward to successive decisionmaking levels. Often information is prepared as computer input for subsequent analysis by linear or dynamic programming. The formal linking of computerized spatial information and mathematical models has already begun. For example, the combining of "TRI" and "RAM" for compartment management has been described in the report on *The Siuslaw Model,* U.S. Forest Service, Pacific Northwest Region 1973).

The kinds of map information used vary by location in the United States. On the Stanislaus and Eldorado National Forests in California, for example, two types of mapped data are essential to estimating timber inventory. Timber-type maps are prepared from large-scale (1:15,840) resource photography in a General Land Survey, township format. Together with delineations of administrative boundaries, these maps provide spatial information on management possibilities. Next, a management component map is prepared, showing land classifications that will affect harvesting or cultural activities. The combination of these two maps, with corresponding volume and growth data, provides the physical information for computing timber management alternatives.

It is easy to visualize how information from other functions or disciplines could be applied. Soil information could be incorporated as an additional stratum affecting cultural practices. At least three layers of information would be needed for a single function such as timber management; multidisciplinary problems might require several times that amount.

Some shifts can be anticipated in the needs of the users as well as in graphic technology. As demands on the forest resource increase, so will the need for more detailed "in-place" information. Conventional resource photography and mapping may be complemented or replaced by orthophotography. Source negatives may be taken by high-altitude aircraft or satellite. Presumably, classifications for various purposes will still be delineated from this source material, and for that reason few modifications to the existing system will be needed. Large changes will arise when the user expects analytic additions to the system and not just acreage calculations and summations.

CAPABILITIES OF WRIS

WRIS provides the means of collecting, processing, storing, retrieving, updating, and displaying "in-place" resource information, and makes possible the performance of logical operations on it. Two characteristics of these capabilities are notable: First, they cannot be regarded as an optimal mix because the multiple objectives of the land manager, and the many constraints on his decisionmaking, are too complex to allow such judgment. Second, these capabilities exist in other geographic information systems of comparable size (Tomlinson 1972); the major difference is the ease with which they can be exploited.

• Data from maps can be recorded at various scales—provided a few geographic reference marks are provided for alinement. The two scales used so far in processing National Forest data are 4 inches and 2 inches per mile for the same townships. Two coordinate systems are adequate for California: State Plane (Lambert Conformal) and geographic (latitude/longitude) coordinates. Transverse Mercator is included in the system for application in other States, and Universal Transverse Mercator (U.T.M.) is also available.

- Images of a map can be displayed on a line printer, but this is intended only for intermediate or editing purposes. Plots, either for editing purposes or for final use, are drawn by either flatbed or drum ink-line plotters of moderate accuracy.
- Computation is performed on a UNIVAC 1108 Computer in FORTRAN over a high-speed batch terminal.
- Data can be manipulated by editing and by performing logical operations. Editing, the most expensive task, is the hardest to describe because of the diversity of errors possible. A major problem in editing is controlling the quality of the original map data.
- Spatial analytic techniques and logical operations include extraction of data on the basis of political or administrative boundaries; statistical summaries of extracted data, including area and perimeter measurements; merging and overlaying map files; and removing a rectangular subset of data within a map border (windowing).
- Finally, the system can perform routine bookkeeping tasks. For example, maps and magnetic tapes must be logged in and out, digitized data packed for low-access storage, and backup files maintained in case of loss. The procedures allowed for would be adequate for an expected production rate of 200 or 300 maps a year.

Map Data Compilation

Preparation of forest-type maps often begins with aerial photography. In the California Region, resource photography is generally taken in color at a scale of 4 inches per mile (1:15,840). From stereographic coverage of an entire Forest, type maps are drawn by a contractor, who uses standard mapping procedures. Type boundaries down to a minimum of 5 acres are delineated on the photographs in accordance with regional definitions. The lines are rectified and transferred to a plastic map sheet. Width of the black ink lines is determined by scanning considerations: 0.025 inch is typical for a 2- by 2- foot township map.

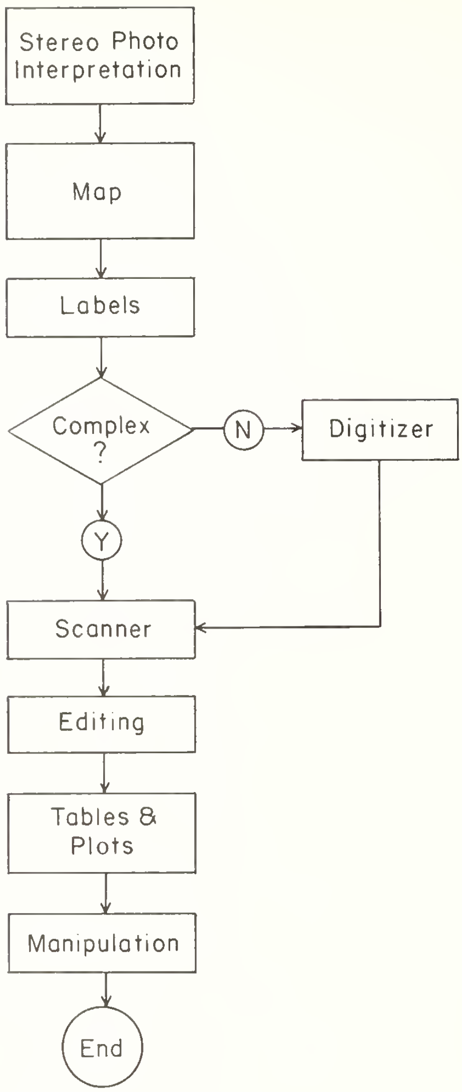
Map compilation results in a closed network of lines, with each polygon identified by a label indicating forest type. (A closed network means that only polygons are on the map sheet. All lines join other lines, including the map (township) border). Labels (attributes) appear on the map in blue, which is not visible in a black-and-white copy negative. The procedure just described is used for the two other types of maps digitized, except that scales differ and paper is used rather than plastic for the base.

Our experience with California Forests should help judge the feasibility of handling other jobs with WRIS. Our forest-type maps were quite detailed, with 200 to 300 polygons per map sheet. Maps corresponding to the same areas, showing management components, had 50 to 100 polygons per sheet. (The components are areas suitable for various types of logging, ownership, use as recreation sites, and similar purposes.) Finally, a simple map was drawn showing only administrative boundaries. More information, particularly soils data, would be needed for timber management planning, but forest-wide "layers" are not now generally available.

Data processing with WRIS can be accomplished using any map format or scale. A township (36 square mile) outline at 2 or 4 inches per mile is used in the California Region. The familiar U.S. Geological Survey quadrangle format would be preferable, however. The public land survey grid is unwieldy because it is an irregular format. Virtually any mathematically defined coordinate system would be more convenient; the township outlines could be included for use, just as any other layer of information could be. Map-scale variations are handled easily. The scale of input can be quite large because maps can be reduced photographically. The only size requirement for the output is that it be convenient for manual editing. This size rarely exceeds that of the original map.

Map Data Manipulation

After the maps have been drawn, the next manual step is to assign each map polygon a label. Because errors, such as missing or conflicting identities, must be corrected, this work is done at the Forest headquarters, where the photography is available for reference. The only problem is that maps often include special characters unknown to the computer. Consequently, a translation scheme must be devised before labeling is done. The labeling itself is a simple process. A polygon is selected arbitrarily. It is identified by a label, and the information is keypunched. A single x, y location falling within the polygon is also recorded and is thereafter associated with the label. Successive polygons are labeled until all have been recorded. Some map errors are corrected, and a few labeling errors are generated—only to be detected during subsequent steps.



The labeled and logically correct map is then ready for digitizing *(fig. 1)*. Like labeling, digitizing is a fairly straightforward process because two digitizers are available: manual or automatic. Simple maps, such as administrative boundary sheets, can be digitized manually by hand-held digitizers; more complex maps are digitized automatically by microdensitometers *(fig. 2)*. For automatic digitizing the map is first photographically reduced to a black-and-white negative. Then it is scanned line by line (raster scan), and the densities are recorded on magnetic tape. The tape is stored for later processing.

Assembling the raster-scan data into valid lines and polygons requires editing, a complex process. Essentially it progresses in steps, with intermediate tabular and graphic output to display errors. The number of steps varies because some errors may require recycling back one or more steps. Editing ceases when the total area is correctly recorded within a specified tolerance. Editing completes the data reduction procedure except for data packing and copying for long-term storage.

Once correct, the map data are available for retrieval and manipulation. In forest inventory work, the usual next step is to lay one map sheet over another to obtain logical combinations. The output from each pair of township maps is acreages. These acreages can be accumulated for an entire forest. This application alone has many variations, depending on the immediate problem.

Figure 1—WRIS produces information from forest-type maps in a multiple-step process. A map derived from resource photography is divided into polygons. Each polygon is labeled by recording its coordinate position. A map is either hand-digitized or is automatically scanned by a microdensitomer. It is then edited to repair data lines and to account for all polygons. The data produced can be manipulated and displayed in various graphic forms.

PRODUCTION INFORMATION

Cost Estimates

The average township map can be processed for a direct cost of about $170. This estimate reflects a number of underlying assumptions and conditions. On the basis of past experience in acquiring data for two National Forests, it assumes two or three trained people operating at a rate of 200 or 300 map sheets a year. The major means of digitizing is by the raster-scanning method. Given these various conditions, estimated costs, by functions, are:

	Cost per township (dollars)
Process:	
Scanning	20
Labeling	20
Editing:	
Labor	15
Computer time	80
Plots (1½)	30
Total	165

The manhour estimates given are net, in that relaxation periods or miscellaneous interruptions are

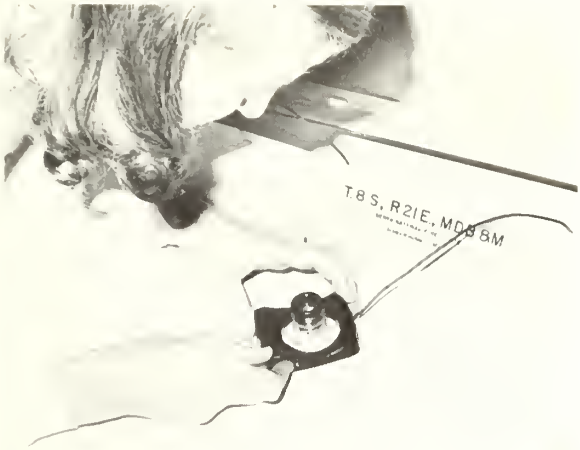
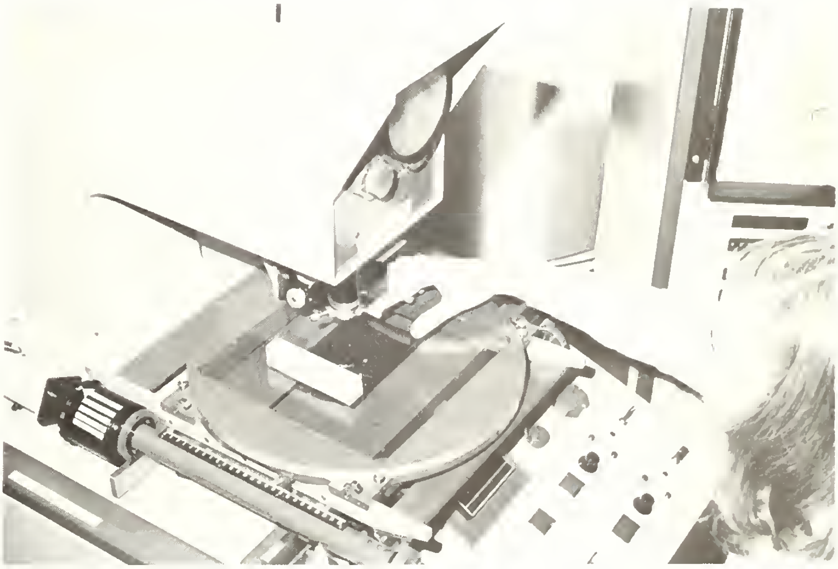


Figure 2—Digitizing is a key step in preparing maps in WRIS. For simple maps, it can be done manually with a hand-held digitizer, *left;* for more complex jobs, optical densities are measured by a scanning microdensitomer, *right.*



excluded. The cost of computer time in 1974 was about $325 per hour. A labor cost of $5.00 per hour is assumed. All hourly data are based on the performance of six well-trained students over a period of 2 years. As experience has shown that individuals vary in performance, only averages and "rules-of-thumb" are warranted.

Cost estimation is greatly simplified because we can ignore fixed or setup costs. All equipment services, with the possible exception of a scanner, can be rented. Consequently, the vexing problems of depreciation, salvage value, and the allocation of joint costs, are not considered here.

Digitizing

Automatic recording of map negative densities in a raster format requires a specialized machine. The PDS-1000 scanning microdensitometer we use was originally purchased for digitizing aerial photographs. Because it is highly accurate, it is unnecessarily slow for our map work. It would cause a bottleneck if production were doubled: the typical million-point scan takes 10 hours. Many other digitizers are now available and, while these have not yet been thoroughly investigated, it is evident that some of the cruder devices can scan in minutes, or even seconds, jobs which now require hours.

Labeling and Editing

Before labeling can begin an encoding scheme is developed. The original map designations usually have characters which cannot be keypunched or replicated by a print chain. Once computer-readable equivalents are memorized, labeling time simply depends on the number of polygons per map. The time requirement has varied between ¼ and 6 hours; 4 hours are needed for a typical map.

Editing requires an ability to visualize spatial relationships, such as is needed to solve jigsaw puzzles. Fortunately, most development effort has been applied to the editing problem, and numerous aids have been documented.

Editing is divided into two parts: repairing the line data, and accounting for all polygons. Line repair begins with printing the scanner output tape, that is, the 0,1 matrix, in strips. This takes 1½ to 3¼ minutes of computer time, depending on the amount of "blank" space. A visual scan of the strips detects gaps in lines, requiring the addition of 1's to fill them in. Deletions are needed occasionally, as when the space between closely adjoining lines has been bridged by the scanner. Recording corrections takes about 2 hours and is clearly affected by the quality and extent of the original ink lines.

During the second phase, the polygon labels prepared earlier are input along with corrections to a polygon-extracting program. The program checks incoming labels, computes areas, and reports various error conditions for editing. The first time through, the more obvious errors are corrected and the job is then resubmitted. Later, as errors become more subtle, a plot may be necessary. This iterative process continues until the total area is within a prescribed tolerance of the area enclosed by the map border. Generally the maps are correct, with the aid of a plot or two, within three or four passes, for an average of 3 hours of work.

Data Manipulation

Once the map data are correct all subsequent expense depends on the extent to which the data are used. The timber inventory work performed is area oriented. The only operation immediately required in our experience was the intersection of all polygons on two or more map layers and the calculation of the polygon areas created. This expense is proportional to the number of input polygons *(fig. 3)*. The demand for other operations, such as selected overlays and plots, is expected to increase soon. We can expect the cost roles of acquiring and manipulating map data to reverse themselves as use increases.

System Maintenance

All cost estimates were based on the assumption that services were rented. Purchasing equipment, particularly digitizers and plotters, may be a better alternative at a production rate of a few hundred maps per year. In that case, the manufacturer's allowance for maintenance (often about 10 percent of purchase price) would be prorated over the expected map output. Buyers have a wide range of choices. A digitizer-plotter combination, for example, could range in price from $30,000 to $80,000.

Software will be maintained indefinitely for use by the National Forests. But available resources may not permit a continual, general distribution of program modifications. All computer programs have documentation in the form of comment cards to minimize maintenance cost. Most users will have to write software to read digitizer output tapes for the various brands available.

FUTURE OUTLOOK

Computerized systems are particularly subject to technological change. Geographic information systems are vulnerable from three directions: (a) graphic hardware alternatives are changing in line with satellite technology; (b) methodology is scarce because little documentation is available; and (c) applications for existing systems are quite rudimentary. Evidently there will be a lag before users drop their mental constraints on possible applications. This bar may be due to past association with the tedious task of extracting graphic information by hand. For example, manual methods for determining line-of-sight or terrain slope from elevation data have been available for decades. Yet, only recently have these applications been computerized (Amidon and Elsner 1968, Sharpnack and Akin 1969).

Software extensions of present capabilities will take priority over hardware modifications. The UNIVAC 1100 Series Executive System (EXEC 8) version of FORTRAN will replace the present EXEC 2. Conversion to IBM 360 computer system is planned and PL/1 language conversion is a possibility.

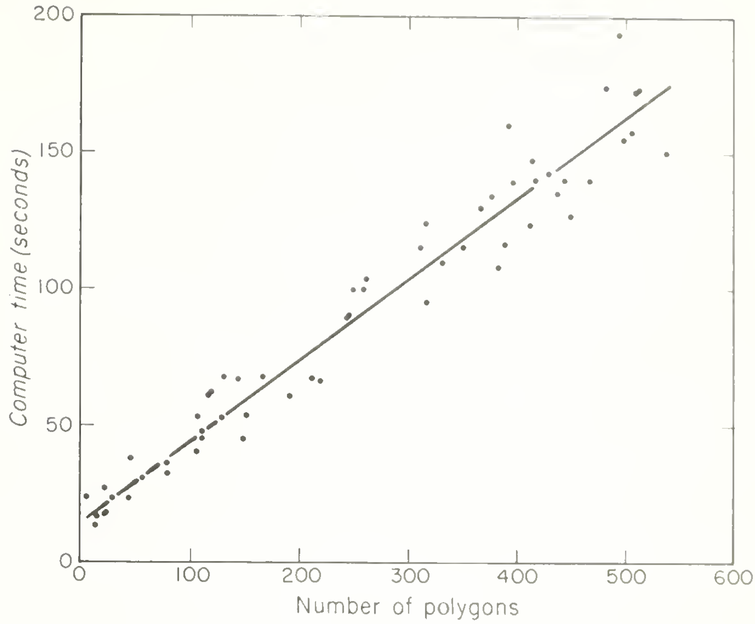


Figure 3—The cost of overlaying maps in WRIS is directly related to the amount of map detail.

Several National Forest data bases are now undergoing changes. It is inevitable, therefore, that more effort will be spent on updating. Several alternatives already exist, such as the overlay procedure, but others will need development as the frequency of updates grows. Hand digitizing methods, less attractive than scanning for capturing initial data, should be useful for modifying local data. Hand digitizing may also prove attractive for adding point and line data.

Once the National Forest data bases are reliable and readily available, requests for storage and retrieval will increase. Then the currently moderate capability of accessing acquired information will require extension. Perhaps an existing general purpose system, such as GIM (General Information Management), can be used, thereby minimizing development costs.

Finally, some means will be found to achieve communication between geographic information systems. This tie-in could begin with tape format compatibility. And eventually, it could evolve into standardization of terminology and software exchange, as well as other areas signifying maturity in this expanding field.

LITERATURE CITED

Amidon, Elliot L., and Gary H. Elsner,
1968. **Delineating landscape view areas: a computer approach.** USDA Forest Serv. Res. Note PSW-180, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Barber, Klaus.
1973. **Inventory and allowable cut calculations.** In Perm. Assoc. Comm. Proc., 1973. West. For. and Conserv. Assoc. Portland, Oreg., p. 170-173.

Boeing Computer Services, Inc.
1972. **Natural resource information system.** Vols. I to IV. Seattle, Wash.

Graphic System Design and Applications Group.
1972. **Preliminary user's notes on interactive display system for manipulation of cartographic data.** 43 p. Univ. of Saskatchewan Electr. Eng. Dep., Saskatoon, Canada.

Raytheon Co., Autometric Operations.
1973. **The development of a natural resource information system.** Vols. I to V. U.S. Dep.. Int. Contract, K5 1C 14200693, Wayland, Mass.

Sharpnack, David A., and Garth Akin.
1969. **An algorithm for computing slope and aspect from elevations.** Photogram. Eng. 36(3):247-248.

Thornburn, G., K. M. Magar, and G. S. Nagle.
1973. An information system for rural land-use planning, BC-X-75. 91 p. Can. Dep. of the Environ., Victoria, B.C.

Tobler, W. R.
1970. Selected computer programs, 162 p. Univ. Michigan, Dep. Geogr., Ann Arbor, Mich.

Tomlinson, R. F.
1967. An introduction to the geographic information system of the Canada land inventory, 23 p. Can. Dep. For. and Rural Dev., Ottawa, Canada.

Tomlinson, R. F., editor.
1972. Geographical data handling. Proc., UNESCO/IGU Second Symp. on Geogr. Inf. Syst., Ottawa, Canada, 1351 p. IGU Comm. on Geogr. Data Sensing and Process., Ottawa, Canada.

U.S. Forest Service, Pacific Northwest Region.
1973. The Siuslaw model: a design for compartment management, 25 p., illus. Portland, Oreg.

U.S. Forest Service.
1974. Environmental program for the future. A long-term forestry plan. Washington, D.C. (unpaginated).

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon
1975. **WRIS: a resource information system for wildland management.** USDA Forest Serv. Res. Paper PSW-107, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

WRIS (Wildland Resource Information System) is a computer system for processing, storing, retrieving, updating, and displaying geographic data. The polygon, representing a land area boundary, forms the building block of WRIS. Polygons form a map. Maps are digitized manually or by automatic scanning. Computer programs can extract and produce polygon maps and can overlay, plot, and store them, as well as aggregate acreages and print summaries. WRIS is functionally oriented toward timber management, but can be used for other types of resource activities.

Oxford: 624:U681.3:(084.3)
Retrieval Terms: timber management; wildland management; resource use planning; computer programs; map compilation; WRIS; management information systems.

Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon
1975. **WRIS: a resource information system for wildland management.** USDA Forest Serv. Res. Paper PSW-107, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

WRIS (Wildland Resource Information System) is a computer system for processing, storing, retrieving, updating, and displaying geographic data. The polygon, representing a land area boundary, forms the building block of WRIS. Polygons form a map. Maps are digitized manually or by automatic scanning. Computer programs can extract and produce polygon maps and can overlay, plot, and store them, as well as aggregate acreages and print summaries. WRIS is functionally oriented toward timber management, but can be used for other types of resource activities.

Oxford: 624:U681.3:(084.3)
Retrieval Terms: timber management; wildland management; resource use planning; computer programs; map compilation; WRIS; management information systems.

Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon
1975. **WRIS:** a resource information system for wildland management. USDA Forest Serv. Res. Paper PSW-107, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

WRIS (Wildland Resource Information System) is a computer system for processing storing, retrieving, updating, and displaying geographic data. The polygon, representing a land area boundary, forms the building block of WRIS. Polygons form a map. Maps are digitized manually or by automatic scanning. Computer programs can extract and produce polygon maps and can overlay, plot, and store them, as well as aggregate acreages and print summaries. WRIS is functionally oriented toward timber management, but can be used for other types of resource activities.

Oxford: 624:U681.3:(084.3)
Retrieval Terms: timber management; wildland management; resource use planning; computer programs; map compilation; WRIS; management information systems.

Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon
1975. **WRIS:** a resource information system for wildland management. USDA Forest Serv. Res. Paper PSW-107, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

WRIS (Wildland Resource Information System) is a computer system for processing storing, retrieving, updating, and displaying geographic data. The polygon, representing a land area boundary, forms the building block of WRIS. Polygons form a map. Maps are digitized manually or by automatic scanning. Computer programs can extract and produce polygon maps and can overlay, plot, and store them, as well as aggregate acreages and print summaries. WRIS is functionally oriented toward timber management, but can be used for other types of resource activities.

Oxford: 624:U681.3:(084.3)
Retrieval Terms: timber management; wildland management; resource use planning; computer programs; map compilation; WRIS; management information systems.

PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
EPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

INCREASING PLANTING STOCK SIZE BY FAMILY SELECTION IN CALIFORNIA PONDEROSA PINE

James L. Jenkinson

USDA FOREST SERVICE RESEARCH PAPER PSW-108 /1975

CONTENTS

The Author

JAMES L. JENKINSON is a research plant physiologist investigating the genetics of western forest trees, with headquarters in Berkeley, California. He earned a forestry degree (1957) and a doctorate in plant physiology (1966) at the University of California, Berkeley. He joined the Station staff in 1966, after working as an Assistant Specialist in the University's School of Forestry and Conservation.

SUMMARY

Jenkinson, James L.
1975. **Increasing planting stock size by family selection in California ponderosa pine.** USDA Forest Serv. Res. Paper PSW-108, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 174.7 *Pinus ponderosa* (794)–232.41:265.5:181.25.
Retrieval Terms: Pinus ponderosa; Sierra Nevada; planting stock; progeny tests; genetic variation; seedling growth.

This paper describes family differences in 1- and 2-year nursery growth of ponderosa pine from natural stands in the northern Sierra Nevada. Wind-pollinated seed was obtained from 48 parent trees selected in eight stands. The stands sampled four geographic areas—three west and one east of the Sierra crest—to represent climates typical for ponderosa pine. In each area, one stand was selected on a fertile soil and the other on infertile ultramafic soil.

Large and significant differences in 1-year height were found among families from every area, and in 2-year height of families from the three west-side areas. Heritabilities of family means varied from 0.35 to 0.50 for 1-year height and from 0.14 to 0.55 for 2-year height. After two seasons, family mean stem volumes ranged from 56 percent below to 61 percent above the native area means. No difference was found between offspring from trees on the two soil types, but differences in seedling growth between areas were significant.

Family height was weakly correlated with family seed weight and was not correlated with germination speed. Two-year family height and stem volume were strongly correlated with 1-year height. Family stem volume was not correlated with stem volume of the seed parent.

The family differences in 1-year height are sufficiently large to justify evaluation of family performance in the nursery. Selecting the tallest half of the total number of families from each area for nursery production could increase mean seedling height by 9 to 13 percent. Small-grade seedling production could be decreased from the average of 15 percent to below 5 percent.

The results indicate that ponderosa pine trees selected to provide seed for artificial reforestation should be screened by nursery testing their wind-pollinated families. Subsequent production nurseries would not include offspring from seed trees whose families showed poor growth, and future seed collections would include trees whose offspring showed average or better growth.

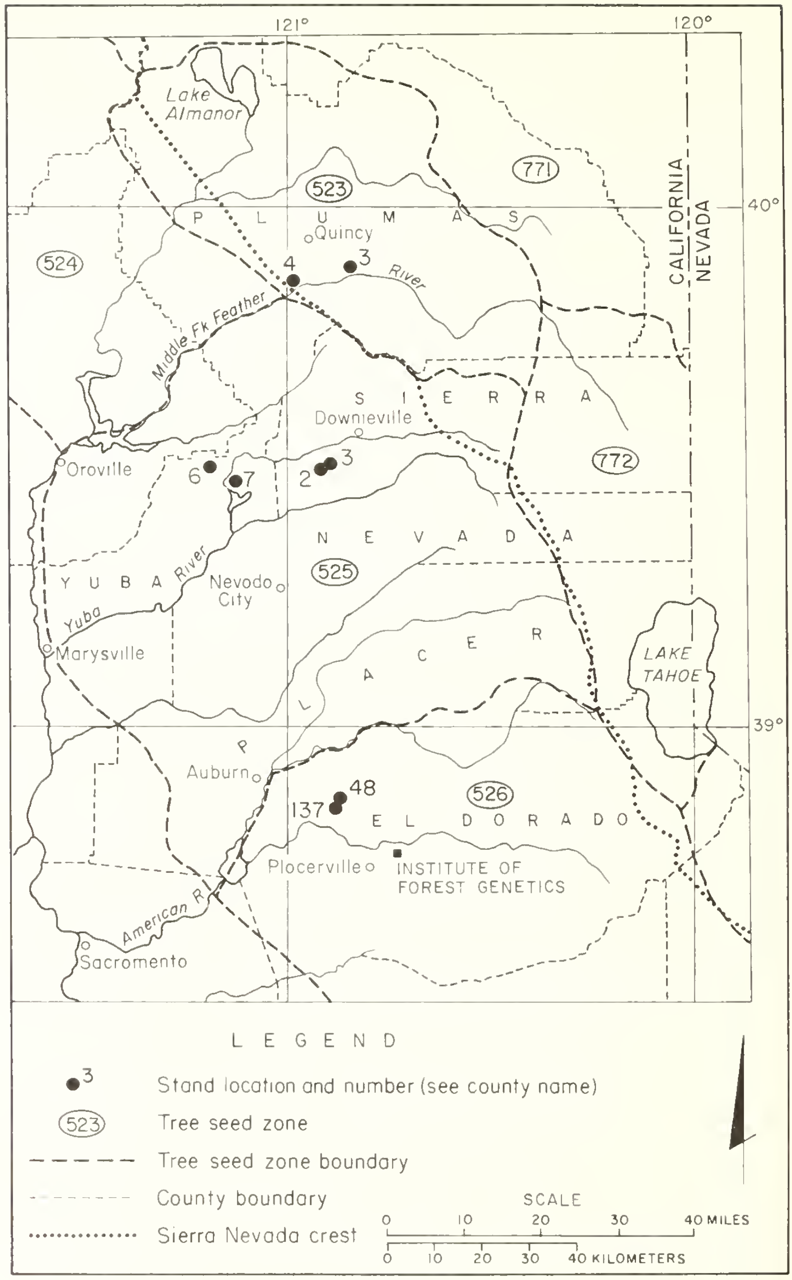


Figure 1—Growth of wind-pollinated families of ponderosa pine from eight stands in the northern Sierra Nevada was evaluated in the Institute of Forest Genetics nursery.

In the absence of test information to the contrary, the accepted guide for selecting seed for reforestation is "local source is best." This guide prevents plantation failures that result from using stock that is not adapted to the local environment, and it reflects the pronounced variation in growth and survival demonstrated in provenance trials (Silen 1970), including those defining elevational variation in ponderosa pine (Callaham and Liddicoet 1961, Conkle 1973, Mirov and others 1952). In California, seed origin is controlled by using revised tree seed zones (Buck and others 1970).

Improved growth of planting stock for reforestation may be gained by nursery selection of wind-pollinated, single-tree families. Work with many conifers[1] has shown that genetic variation in growth is often large among families from individual stands. Because adaptation of a local source is expressed in traits other than growth rate, selection to improve growth should be made among families (seed trees) native to environments that are similar to the planting site (Squillace and Bingham 1958, Squillace and Silen 1962).

This paper reports the inherent variation found in nursery growth of ponderosa pine families from stands selected to represent a wide range of climatic and edaphic environments in the Sierra Nevada.

PROCEDURES

Four areas were chosen to represent diverse climates characteristic of ponderosa pine in the northern Sierra Nevada. Three areas—El Dorado, Yuba and Sierra—were west and one—Plumas—was east of the Sierra Nevada crest (*table 1, fig. 1*). Two natural stands were selected in each area, one growing on fertile soil and one on infertile (ultramafic) soil; other site factors were similar except for associated vegetation.[2]

Twelve trees were selected as seed parents in each stand. The trees were located along transects ranging from 0.3 to 0.6 mile (0.5 to 1 km), were generally of good form, and were fair-to-good cone producers. No effort was made to identify and collect dominants and codominants or to avoid intermediate and smaller trees.

Tree height, age, and diameter at breast height were recorded. In each area, the stand on fertile soil was essentially even-aged, naturally regenerated second growth, and current volumes of individual trees were extrapolated to a common age to estimate their relative growth. The stand on infertile soil consisted of several age classes, and only trees in the dominant age class were considered. Seeds from each tree were extracted in sunlight, cleaned, and stored at 1° to 2° C. The mean seed weight for each family was determined from the air-dry weight of 400 full seeds.

Germination and growth of all families were evaluated in laboratory and greenhouse tests at the U. S. Forest Service's Institute of Forest Genetics, Placerville, California. In those tests, offspring from trees in stands within each area showed large differences in family germination rate and first-year seedling height and weight. No specific adaptation of stand offspring to native soil was identified, although individual families showed significant differential response to soil type.[2]

Subsequently, 1- and 2-year growth of 48 of these families, 6 from each stand in each area, were evaluated in the nursery. Seeds were stratified 60 days at 1° to 2° C, then sown in early May. The experimental

[1] *Picea abies* (L.) Karst. (Dietrichson 1969, Giertych 1969); *P. Glauca* (Moench) Voss (Holst and Teich 1969, Jeffers 1969); *P. mariana* (Mill.) B.S.P. (Morgenstern 1969b); *Pseudotsuga menziesii* (Mirb.) Franco (Silen 1966); *Pinus elliottii* Engelm. (Beinecke and Perry 1966, Webb and Barber 1966); *P. ponderosa* Laws. (Silen and Rowe 1971, Wang and Patee 1974); *P. resinosa* Ait. (Lester 1963, Yao and others 1971); *P. strobus* L. (Kuo and others 1971); *P. taeda* L. (Barber 1966, Brown and Goddard 1959, van Buijtenen 1966); and *P. virginiana* Mill. (Evans and Thor 1971).

[2] Jenkinson, James L. 1975. *Edaphic interactions in first-year growth of California ponderosa pine.* (Manuscript in preparation.)

Table 1—*Paired ponderosa pine stands used as seed sources, represent fertile (F) and infertile (I) soils in four geographic areas in the northern Sierra Nevada*

Area, tree seed zone,[1] and stand no.	Locality	Soil parent material	Average seed-parent elevation	
			Feet	*Meters*
El Dorado, 526:				
48 F	Garden Valley	Marine	1940	591
137 I	Johntown Creek	Serpentinite	1925	587
Yuba, 525:				
7 F	Kennedy Ranch	Granitic	2975	907
6 I	Woodleaf	Serpentinite	3100	945
Sierra, 525:				
2 F	Gleason Spring	Volcanic	4680	1426
3 I	Brush Creek	Slickentite	4600	1402
Plumas, 523:				
3 F	Spring Garden	Marine	4910	1496
4 I	Rocky Point	Peridotite	4975	1516

[1]Buck and others 1970.

design consisted of four randomized blocks, with families grouped by geographic area and a 12-seedling row plot for each family in each block. The seedlings were watered twice weekly the first growing season and monthly during the second. To eliminate nitrogen deficiency in the otherwise fertile Aiken soil, a slow-release ammonium phosphate-sulfate fertilizer was added once during bed preparation and again in midseason at the rate of 100 pounds of nitrogen per acre (112 kg/ha).

Germination speed, expressed as maximum value of the quotient cumulative germination percent/days (Czabator 1962), was determined at 20° to 25° C. Shoot heights from cotyledon scar to shoot apex were recorded in late October after the first growing season. Height and stem diameter at bed surface were recorded following the second season.

Data for each area were subjected to analysis of variance. Heritabilities of family means were calculated from estimates of variance components, and means were compared by least significant difference procedures and Duncan's multiple-range test (Falconer 1960, Steel and Torrie 1960). Regression analyses were run to determine the relation between family growth and seed weight, and between family growth and seed-parent stem volume. To remove the effect of area, family means and seed-parent stem volumes were expressed as percents of the means for native area and stand.

RESULTS

The relation of family growth to family seed weight was found to be poor. The correlation between 1-year shoot height and seed weight was low, with only 19 percent of the variation in family mean heights associated with variation in family mean seed weights (*fig. 2*). Family mean height was not correlated with germination speed (r^2 = 0.00). After the second season, only 10 percent of the variation in height and 6 percent of that in stem volume were associated with seed weight. Significance of r^2 at the 5 (*) and 1 (**) percent levels was as follows:

Growth trait	*Seed weight*	*Height, 1-year*
Height		
1 year	0.19**	–
2 years	.10*	.82**
Stem volume, 2 years	.06	.70**

As expected, significant differences in growth were found between offspring from different areas (*table 2*). Average seedling growth decreased as the elevation and latitude of the area of seed origin increased. After two seasons, mean heights, diameters, and stem volumes for offspring from west-side areas were greater than those for the east-side Plumas area.

Inherent variation in seedling growth was also found among families native to the same area. For each area, variation in family growth traits was significant at the 5 (*) and 1 (**) percent levels or was not

Table 2—*Average nursery growth of twelve ponderosa pine families from each of four geographic areas in the northern Sierra Nevada*[1]

Area	Seedling height, 1 year	Seedling height, 2 years	Seedling diameter, 2 years	Stem volume, 2 years
	Cm	*Cm*	*Cm*	*Cc*
El Dorado	13.2 a	43.7 a	1.13 a	21.7 a
Yuba	10.8 bc	40.0 ab	1.15 a	19.3 a
Sierra	11.5 b	39.2 b	1.12 a	17.6 a
Plumas	9.5 c	34.4 c	1.02 b	12.5 b

[1]Means followed by unlike letters differ significantly at the 5 percent level.

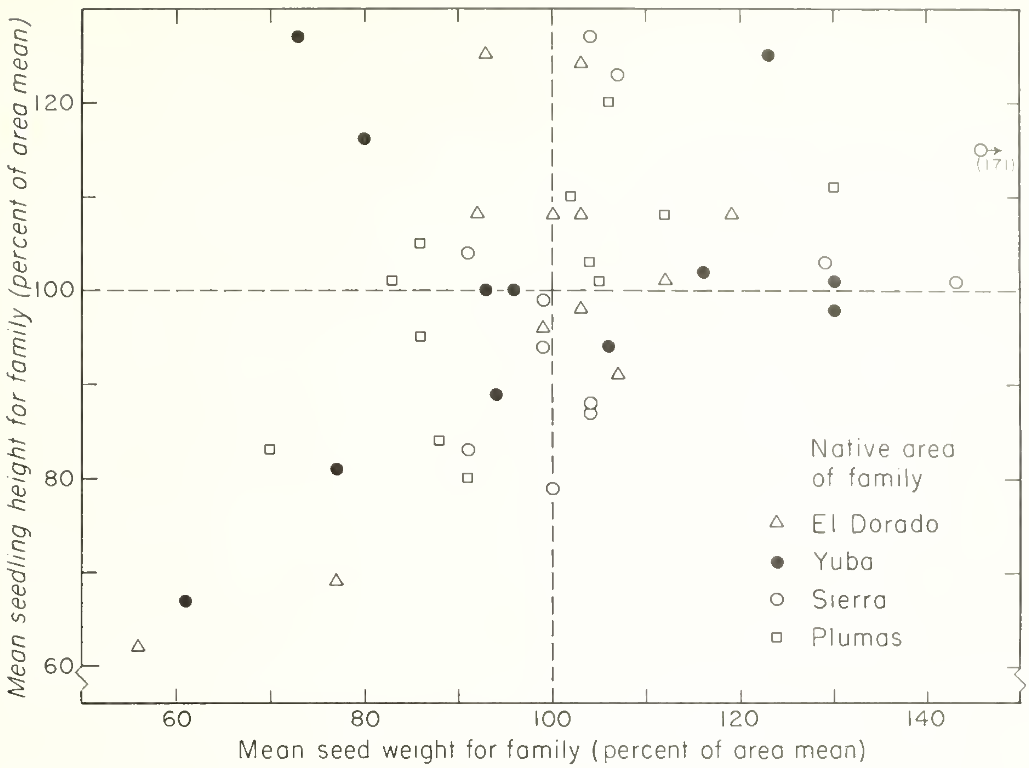


Figure 2—Relation between 1-year seedling height and seed weight of ponderosa pine families grown in the nursery was poor. Family means were expressed as percents of native area means to eliminate effect of area.

significant (n.s.). as follows:

Growth trait:	*El Dorado*	*Yuba*	*Sierra*	*Plumas*
Height				
1 year	**	**	**	**
2 years	*	**	**	n.s.
Diameter, 2 years	*	**	n.s.	n.s.
Stem volume, 2 years	n.s.	*	n.s.	n.s.

Heritability, the estimated proportion of additive genetic variance in the total variance, was between 0.22 and 0.55 for all traits of the El Dorado and Yuba families, and for height growth of the Sierra families (*table 3*). Heritability was 0.36 for 1-year height of families from stands east of the Sierra crest (Plumas area), and dropped to low levels for 2-year diameter and stem volume. The 2-year bud growth of the Plumas families was very different from that of west-side families. With a growing season three times longer than the native season, Plumas seedlings showed abnormally large and variable extension of the terminal and lateral buds after leader elongation was completed.

The variation among families originating within the same stand or area was large. After one season, mean seedling height for individual families ranged from 38 percent below to 27 percent above the means for their native areas, and the tallest family exceeded the shortest by a factor of from 1.5 to 2 (*table 4*).

After two seasons, the absolute height differences between families were double those at 1 year (*table 4*). Stem volume varied from 56 percent below to 61 percent above the native area averages, and the best family surpassed the poorest by factors of 3.7, 2.9, 2.4, and 1.8 for the El Dorado, Yuba, Sierra, and Plumas areas respectively.

Table 3 *Heritabilities of nursery growth traits of wind-pollinated families of ponderosa pine from four geographic areas in the northern Sierra Nevada*[1]

Growth trait	El Dorado	Yuba	Sierra	Plumas
Height				
1 year	0.50	0.47	0.35	0.36
2 years	.34	.55	.30	.14
Diameter, 2 years	.29	.35	.17	.07
Stem volume, 2 years	.22	.37	.14	.03

[1]Heritability estimated by

$$\frac{4\sigma^2_{\text{families}}}{\sigma^2_{\text{families}} + \sigma^2_{\text{families x blocks}} + \sigma^2_{\text{within plots}}}$$

Table 4–*One- and two-year nursery growth of ponderosa pine families from four areas in the northern Sierra Nevada*

Area and Family	Seedling height[1]	Relative height (percent of area mean)	Small-grade seedlings (under 7.5 cm; percent of total)	Area and Family	Seedling stem volume[1,2]	Relative stem volume (percent of area mean)	Seedling height[3]	Seedling diameter[3]
	1-year growth				2-year growth			
	Cm				*Cc*		*Cm*	*Cm*
El Dorado:				El Dorado:				
48-2	16.5	125	8.3	48-2	35.7	161	49.1 a	1.35 a
137-6	16.3	124	0.0	137-6	30.9	139	49.2 a	1.26 ab
48-12	14.2	108	6.1	137-4	29.2	132	47.3 ab	1.27 ab
137-1	14.2	108	4.3	137-9	25.0	113	48.0 a	1.19 bc
137-9	14.1	107	4.3	137-1	21.3	96	41.1 c	1.19 bc
48-11	14.1	107	0.0	48-12	20.2	91	45.1 abc	1.15 bcd
48-8	13.3	101	6.2	48-11	20.2	91	45.7 abc	1.14 bcd
48-4	13.0	99	4.4	48-8	19.5	88	44.6 bc	1.11 cd
137-4	12.9	98	2.1	137-5	18.0	81	41.7 bc	1.06 cde
137-5	12.0	91	29.4	48-4	17.1	77	44.9 abc	1.04 de
137-3	9.1	69	39.4	137-3	13.7	62	35.3 d	.93 ef
48-7	8.1	62	46.7	48-7	9.7	44	31.8 d	.88 f
Yuba:				Yuba:				
6-7	13.8	127	4.3	6-7	30.9	160	46.0 a	1.36 a
7-7	13.5	125	0.0	6-2	28.0	145	49.2 ab	1.28 ab
6-2	12.6	116	2.1	7-7	22.8	118	45.0 b	1.21 bc
7-12	11.0	102	2.1	7-3	22.6	117	43.6 bc	1.23 bc
7-3	11.0	102	4.2	7-6	20.1	104	38.6 d	1.21 bc
7-8	10.8	100	11.6	7-4	19.7	102	38.4 d	1.14 c
7-4	10.8	100	23.3	7-8	19.0	98	41.0 cd	1.15 c
7-6	10.6	98	16.2	6-3	17.2	89	39.4 d	1.14 c
6-3	10.2	94	6.5	7-12	16.8	87	38.5 d	1.13 cd
6-10	9.7	89	23.3	6-10	12.8	66	34.1 e	1.02 de
6-8	8.7	81	27.7	6-8	11.5	60	33.4 e	1.01 e
6-9	7.2	67	62.5	6-9	10.6	55	32.7 e	.95 e
Sierra:				Sierra:				
3-3	14.6	127	4.3	2-7	27.5	157	46.5 a	1.33 a
3-7	14.2	123	2.2	3-3	20.6	117	44.1 ab	1.15 bc
2-10	13.2	115	8.7	2-10	19.7	112	41.0 bc	1.15 bc
2-7	12.0	104	2.3	3-7	19.2	109	42.9 ab	1.13 bc
2-11	11.8	103	2.2	3-4	18.6	106	38.7 cd	1.14 bc
2-9	11.6	101	0.0	2-11	17.9	102	37.5 cde	1.17 b
2-8	11.1	96	22.9	2-8	17.7	101	40.0 cd	1.12 bc
3-4	10.8	94	18.2	2-9	16.7	95	38.9 cd	1.14 bc
3-12	10.1	88	25.5	2-1	15.2	87	36.2 de	1.05 cd
2-1	10.0	87	26.1	3-12	13.9	79	35.6 de	1.01 d
3-2	9.5	83	17.4	3-11	12.6	72	34.0 e	1.05 cd
3-11	9.0	79	17.8	3-2	11.5	66	36.0 de	.97 d
Plumas.				Plumas:				
3-11	11.4	120	2.2	3-8	16.7	133	35.6 ab	1.13 a
3-4	10.5	111	8.5	3-4	15.2	121	37.0 a	1.07 ab
4-2	10.4	110	9.3	3-11	15.1	120	37.3 a	1.08 a
4-12	10.2	108	4.3	4-2	13.8	110	37.7 a	1.04 bc
4-3	9.9	105	9.1	4-12	13.4	107	36.5 ab	1.02 bc
3-7	9.7	103	10.6	3-7	13.1	105	33.8 bcd	1.06 ab
3-5	9.6	102	22.9	3-5	11.6	93	33.1 cde	.99 bcd
3-8	9.5	101	20.8	4-7	11.2	89	31.9 de	1.00 bcd
4-10	9.0	95	20.8	4-10	10.6	85	33.2 cd	.98 cd
4-7	8.0	84	34.8	4-3	10.6	84	33.7 bcd	.96 cd
3-12	7.8	83	41.7	4-11	9.8	78	30.2 e	.92 d
4-11	7.6	80	45.5	3-12	9.5	76	32.2 de	.94 d

[1]Family means not common to a bar differ significantly at the 5 percent level.
[2]Estimated by $0.1\ \pi D^2 H$.
[3]Family means followed by unlike letters differ significantly at the 5 percent level.

One-year height was a good indicator of 2-year height and stem volume. For each area, five of the six tallest families after 1 year ranked among the top six in height and stem volume after 2 years (*table 4*). Two families (El Dorado 137-4 and Plumas 3-8) moved into top volume rankings partly on the strength of increased height growth in the second season, but primarily because of their superior diameter growth.

Seedling stem volume was not correlated with stem volume of the seed parent ($r^2 = 0.01$). Seven of the eight largest seed trees produced only average-to-poor families.

DISCUSSION

Improving Planting Stock

In this study the inherent early growth differences among wind-pollinated families of ponderosa pine from a single stand or geographic area were pronounced. Such family differences offer the opportunity to improve the size of nursery stock and the efficiency of nursery production.

For the El Dorado, Yuba, Sierra, and Plumas areas, selecting the three tallest families in twelve would increase average shoot height of planting stock by 18.9, 23.1, 21.7, and 13.7 percent (*table 5*). If nursery grading were normally practiced and small-grade seedlings were discarded (*table 4*), selecting the three tallest families could still increase height by 14.0, 16.5, 18.0, and 7.8 percent. Small-grade loss would simultaneously be reduced by 62, 85, 58, and 65 percent.

Selecting the six tallest families would increase average height by 12.9, 12.0, 12.2, and 9.5 percent for the four areas. With grading, the six tallest families would still increase height by 7.7, 7.8, 8.2, and 3.9 percent and would decrease small grades by 70, 74, 73, and 62 percent.

Eliminating the three shortest families (in twelve) could increase average height by 8.3, 7.4, 5.2, and 5.3 percent. Compared to growing all families and not grading, growing the tallest three-fourths and practicing grading would increase the average height of planting stock by 12.9, 11.1, 10.4, and 10.5 percent for the El Dorado, Yuba, Sierra, and Plumas areas.

Seedlings were not graded by diameter in these examples. Spacing in the nursery beds was 10 seedlings per square foot, and diameter growth of first-year ponderosa pine in production nurseries is acceptable even at 30 seedlings per square foot (Baron and Schubert 1963). Though closer spacing reduces diameter growth, the effect on height growth is minimal (Baron and Schubert 1963, Shoulders 1961). Thus height remains a valid index to family performance and seedling quality.

Table 5–*Effect of family selection on size of planting stock and efficiency of nursery production calculated from growth of ponderosa pine families from four geographic areas in the northern Sierra Nevada*

Area and family selection method	Mean height: All seedlings	Mean height: Seedlings over 7.5 cm	Small-grade seedlings (under 7.5 cm)
	Cm	*Cm*	*Percent*
El Dorado:			
12 random	13.2	14.3	12.6
9 tallest	14.3	14.9	4.0
6 tallest	14.9	15.4	3.8
3 tallest	15.7	16.3	4.8
Yuba:			
12 random	10.8	11.5	15.3
9 tallest	11.6	12.0	7.8
6 tallest	12.1	12.4	4.0
3 tallest	13.3	13.4	2.1
Sierra:			
12 random	11.5	12.2	12.3
9 tallest	12.1	12.7	9.6
6 tallest	12.9	13.2	3.3
3 tallest	14.0	14.4	5.1
Plumas:			
12 random	9.5	10.3	19.2
9 tallest	10.0	10.5	12.0
6 tallest	10.4	10.7	7.3
3 tallest	10.8	11.1	6.7

Predicting Growth of Families

The literature is replete with investigations reporting positive influence of seed size on seedling growth. But most of these investigations graded seed–by screening, volume, or weight–from mass collections for a single source. The few studies that have examined the dependence of family growth on family seed weight found little or no relationship at the close of one growing season (Brown and Goddard 1959, Hanover and Barnes 1963, Morgenstern 1969a, Righter 1945, Stonecypher and others 1966).

In ponderosa pine, I found family seed weights to be consistent from year to year: the correlation between mean seed weights of 17 Yuba families collected in 1967 and again in 1970 was 0.80. Although seed weight varies widely among families from a single stand or area (*fig. 2*), the nursery trial shows that the influence of family seed weight on height and volume growth is weak and quickly lost. Neither selection of large-seed families within an area nor elimination of small-seed families will increase the size of seedlings produced in the nursery (*fig. 2*).

Nursery growth of families is not predicted by family germination speeds determined at 20 to 25° C. In a highly favorable nursery environment with a long growing season, inherent growth potential obscures any initial advantage expected for either large-seed or fast-germinating families. The contrasts between these results and those in a 1937 ponderosa pine study (Callaham and Hasel 1961) are attributable to spring sowing of unstratified (dormant) seed for the 1937 study.

Seed parent stem volume does not forecast family growth performance in the nursery. In these natural stands, microsite variability was immense and growth of the seed parents may simply reflect the influence of microsite. Within natural stands, trees that show fair-to-good cone production display a wide range in the 1-year growth of their wind-pollinated families whether the stand is unimproved or improved for seed production. The mean 1-year height and the range of means of families from the Plumas stands were the same as those of 44 families from a nearby seed production area (Lees Summit) in which most intermediate, suppressed, and other poor-phenotype trees had been removed. In both instances, heritability of 1-year height was 0.36.

Improving Field Performance

In the present study, both 2-year height and stem volume were strongly correlated with 1-year family height. But will tall families in the nursery continue to perform in a superior fashion in the field? The available evidence is encouraging. A plantation trial with ponderosa and Jeffrey pine in the northern Sierra Nevada (zone 523) demonstrated that spread in height between size classes of both 1-0 and 1-1 transplants increased through the ninth year after outplanting; large stock continued to grow faster than medium stock, which in turn grew faster than small stock (Fowells 1953). In California ponderosa pine plantations ranging in age from 16 to 50 years, the trees first reaching breast height continued as dominants and codominants in the developing stands (Oliver and Powers 1971). Such evidence suggests that the larger trees in a plantation develop from larger transplants. Besides growing faster, stock of medium and larger sizes often survives better than stock of smaller sizes (Bethune and Langdon 1966, Blair and Cech 1974, Burns and Brendemuehl 1971, Fowells 1953). Increasing the size of planting stock by eliminating the poorer families should improve both survival and early plantation growth.

Will the relative growth of consecutive wind-pollinated families from the same trees be consistent? In ponderosa pine I found that family heights in the nursery were consistent from one seed year to another. The correlation between mean heights of 14 Yuba families collected in 1967 and again in 1970 was 0.91 for 1-year height and 0.77 for 2-year height. Though limited, this evidence agrees with that reported for slash pine: For 3 crop years and plantings, the relative rankings of families were constant (based on 5- or 3-year growth) for four seed parents, and were variable for two others; and even for the latter parents three of the six families showed their expected growth (Green and others 1957).

Evaluating Variation for Tree Improvement

The inherent family differences in early growth of California ponderosa pine are sufficiently large to justify evaluation of family performance in the nursery to assist in identification of desirable (or undesirable) seed parents. Seed tree selection ought to depend not only on form and growth of the seed trees, but on progeny testing. That approach has been adopted for ponderosa pine in southern Idaho (Wang 1967).

In California ponderosa pine, seed production should also be a criterion for selection. Flower and cone production are strongly inherited in the southern pines (Barnes and Bengtson 1968, Cole 1963, Shoulders 1967, Varnell and others 1967) and undoubtedly are in ponderosa pine, too. Many phenotypically good trees bear small or no cone crops, even in the best seed years (Krugman 1965, Sundahl 1971).

Alternatives for obtaining improved seed for artificial reforestation in California forests until clonal (or other) orchards are producing include collection from seed trees selected in a wide variety of natural stands in each seed zone, collection of wind-pollinated seed from the Region's superior-phenotype trees, and collection of seed from trees chosen along road systems (Silen 1966). Any of these alternatives easily lends itself to screening families in nursery tests.

For ponderosa pine, I favor delimitation of ecologically defined natural stands throughout California's tree seed zones, and selection among the average-to-good trees in these stands by screening their wind-pollinated families for nursery growth potential. This procedure would ensure that nursery stock is genetically adapted to local planting sites. Nursery production would not include offspring from trees whose families showed poor growth. In addition, future seed collections would include trees whose families showed average or better growth. The immediate returns would be an increase in size of planting stock and an improvement in nursery efficiency through the decrease in small-grade seedling production.

LITERATURE CITED

Barber, John C.
1966. Variation among half-sib families from three loblolly pine stands in Georgia. Georgia Forest Res. Counc. Res. Pap. 37, 5 p.

Barnes, R. L., and G. W. Bengtson.
1968. Effects of fertilization, irrigation, and cover cropping on flowering and on nitrogen and soluble sugar composition of slash pine. Forest Sci. 14:172-180.

Baron, Frank J., and Gilbert H. Schubert.
1963. Seed origin and size of ponderosa pine planting stock grown at several California nurseries. USDA Forest Serv. Res. Note PSW-9, 11 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Beinecke, Walter F., and Thomas O. Perry.
1966. Genetic variation in ability to withstand transplanting shock. Proc. 8th Southern Conf. Forest Tree Impr., Savannah, Ga. 1965:106-109.

Bethune, J. E., and O. Gordon Langdon.
1966. Seed source, seed size, and seedling grade relationships. J. Forestry 64:120-124.

Blair, Roger, and Franklin Cech.
1974. Morphological seedling grades compared after thirteen growing seasons. Tree Planters' Notes 25:5-7.

Brown, C. L., and R. E. Goddard.
1959. Variation in nursery grown seedlings from individual mother trees in a seed production area. Proc. 5th Conf. Forest Tree Impr., Raleigh, N.C. 1959:68-76;

Buck, John M., Ronald S. Adams, Jerrold Cone, and others.
1970. California tree seed zones. U. S. Forest Serv., Calif. Region, San Fransicso; and Calif. Div. For., Sacramento. 5 p.

Burns, Russell M., and R. H. Brendemuehl.
1971. Nursery bed density affects slash pine seedling grade and grade indicates field performance. USDA Forest Serv. Res. Pap. SE-77, 7 p. Southeast. Forest Exp. Stn., Asheville, N. C.

Callaham, R. Z. and A. A. Hasel,
1961. *Pinus ponderosa:* height growth of wind-pollinated progenies. Silvae Genet. 10:33-42.

Callaham, R. Z., and A. R. Liddicoet.
1961. Altitudinal variation at 20 years in ponderosa and Jeffrey pines. J. Forestry 59:814-820.

Cole, Donald E.
1963. Management of pine seed production areas. Proc. 7th Southern Conf. Forest Tree Impr., Gulfport, Miss. 1963:44-49.

Conkle, M. Thompson.
1973. Growth data for 29 years from the California elevational transect study of ponderosa pine. Forest Sci. 19:31-39.

Czabator, Felix J.
1962. Germination value: an index combining speed and completeness of pine seed germination. Forest Sci. 8:386-396.

Dietrichson, J.
1969. Growth rhythm and yield as related to provenance, progeny and environment. Proc. 2nd World Consult. Forest Tree Breeding, Washington, D.C., 1969, Sec. 2, p. 17-35.

Evans, Richard M., and Eyvind Thor.
1971. Estimates of genetic and environmental variances and heritabilities for natural populations of Virginia pine (*Pinus virginiana* Mill). Proc. 11th Southern Conf. Forest Tree Impr., Atlanta, Ga. 1971:11.

Falconer, D. S.
1960. Introduction to quantitative genetics. 365 p. Ronald Press Co., New York.

Fowells, H. A.
1953. The effect of seed and stock sizes on survival and early growth of ponderosa and Jeffrey pine. J. Forestry 51:504-507.

Giertych, M.
1969. Heritability of some growth parametres in spruce *Picea abies* L. Karst. Genet. Pol. 10:138-140.

Greene, James T., Keith W. Dorman, and Eitel Bauer.
1957. Differential growth rate of young progeny of individual slash pine trees. Proc. 4th Southern Conf. Forest Tree Impr., Athens, Ga. 1957:47-50.

Hanover, James W., and Burton V. Barnes.
1957. Heritability of height growth in year-old western white pine. Proc. Forest Genet. Workshop, Southern Forest Tree Impr. Comm. Macon, Ga. 1962:71-76.

Holst, M. J., and A. H. Teich.
1969. Heritability estimates in Ontario white spruce. Silvae Genet. 18:23-27.

Jeffers, Richard M.
1969. Parent-progeny growth correlations in white spruce. Proc. 11th Meet. Comm. Forest Tree Breeding, Canada, 1968, Part 2, p. 213-221.

Krugman, Stanley L.
1965. A seed production area and a seed orchard in California—a progress report. Proc. 4th Calif. Forest Soil Fertil. Conf., Redding, Calif. 1965:69-76.

Kuo, P. C., J. W. Wright, W. A. Lemmien, and others.
1971. Improving Michigan's white pine. Michigan State Univ. Agric. Exp. Stn. Res. Rep. 149, 12 p.

Lester, D. T.
1963. Early height growth in a provenance and progeny test of red pine. Univ. Wis. For. Res. Note 99, 4 p.

Mirov, N. T., J. W. Duffield, and A. R. Liddicoet.
1952. Altitudinal races of *Pinus ponderosa*—a 12-year progress report. J. Forestry 50:825-831.

Morgenstern, E. K.
1969. Genetic variation in seedlings of *Picea mariana* (Mill.) B.S.P. II. Variation patterns. Silvae Genet. 18:161-167.

Oliver, William W., and Robert F. Powers.
1971. Early height growth of ponderosa pine forecasts dominance in plantations. USDA Forest Serv. Res. Note PSW-250, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Righter, F. I.
1945. *Pinus:* The relationship of seed size and seedling size to inherent vigor. J. Forestry 43:131-137.

Shoulders, Eugene.
1961. Effect of nursery bed density on loblolly and slash pine seedlings. J. Forestry 59:576-579.

Shoulders, Eugene.
1967. Fertilizer application, inherent fruitfulness, and rainfall affect flowering of longleaf pine. Forest Sci. 13:376-383.

Silen, Roy R.
1966. A simple, progressive, tree improvement program for Douglas-fir. USDA Forest Serv. Res. Note PNW-45, 13 p. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Silen, Roy. R.
1970. The seed source question for ponderosa pine. In *Proc. Symp. Regeneration of ponderosa pine.* R. K. Hermann, ed. Oregon State Univ., Corvallis. 1969:22-25.

Silen, Roy R., and Kenneth E. Rowe.
1971. Inheritance of stockiness in ponderosa pine families. USDA Forest Serv. Res. Note PNW-166, 12 p. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Squillace, A. E., and R. T. Bingham.
1958. Localized ecotypic variation in western white pine. Forest Sci. 4:20-34.

Squillace, A. E., and Roy R. Silen.
1962. Racial variation in ponderosa pine. Forest Sci. Monogr. 2, 27 p.

Steel, Robert G. D., and James H. Torrie.
1960. Principles and procedures of statistics with special reference to the biological sciences. 481 p. McGraw-Hill Book Co., Inc., New York.

Stonecypher, Roy W., Franklin C. Cech, and Bruce J. Zobel.
1966. Estimates of components of variance and covariance in root and shoot characteristics of loblolly pine after one growing season. Proc. 8th Conf. Forest Tree Impr., Savannah, Ga. 1965:86-95.

Sundahl, William E.
1971. Seedfall from young-growth ponderosa pine. J. Forestry 69:790-792.

van Buijtenen, J. P.
1966. Testing loblolly pines for drought resistance. Texas Forest Serv. Tech. Rep. 13, 14 p.

Varnell, Ray J., A. E. Squillace, and G. W. Bengtson.
1967. Variation and heritability of fruitfulness in slash pine. Silvae Genet. 16:125-128.

Wang, Chi-Wu.
1967. Ponderosa pine seed orchard in Idaho. Proc. 10th Meet. Comm. Forest Tree Breeding, Canada, 1966, Part 2, 3 p.

Wang, Chi-Wu, and Robert K. Patee.
1974. Variation in seed characteristics and seedling growth of open pollinated ponderosa pine progenies. Univ. Idaho Forest, Wildlife and Range Exp. Stn., Stn. Pap. 15, 12 p.

Webb, Charles D., and John C. Barber.
1966. Selection in slash pine brings marked improvement in diameter and height growth plus rust resistance. Proc. 8th Southern Conf. Forest Tree Impr., Savannah, Ga. 1965:67-72.

Yao, Y. N., J. A. Pitcher, J. W. Wright, and P. C. Kuo.
1971. Improved red pine for Michigan. Michigan State Univ. Agric. Exp. Stn. Res. Pap. 146, 8 p.

689—233/4430

Jenkinson, James L.

1975. **Increasing planting stock size by family selection in California ponderosa pine.** USDA Forest Serv. Res. Paper PSW-108, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Wind-pollinated families from four geographic areas in the northern Sierra Nevada were tested in the nursery. For every area, the native families differed significantly from each other in 1-year seedling height, and in 2-year height, diameter, and stem volume. Family growth was poorly correlated with family seed weight; it was independent of germination speed and seed parent stem volume. The size of planting stock can be improved and small-grade seedling production decreased by eliminating from future collections seed trees whose families show poor growth in the nursery.

Oxford: 174.7 *Pinus ponderosa* (794)–232.41:265.5:181.25.

Retrieval Terms: Pinus ponderosa; Sierra Nevada; planting stock; progeny tests; genetic variation; seedling growth.

Jenkinson, James L.

1975. **Increasing planting stock size by family selection in California ponderosa pine.** USDA Forest Serv. Res. Paper PSW-108, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Wind-pollinated families from four geographic areas in the northern Sierra Nevada were tested in the nursery. For every area, the native families differed significantly from each other in 1-year seedling height, and in 2-year height, diameter, and stem volume. Family growth was poorly correlated with family seed weight; it was independent of germination speed and seed parent stem volume. The size of planting stock can be improved and small-grade seedling production decreased by eliminating from future collections seed trees whose families show poor growth in the nursery.

Oxford: 174.7 *Pinus ponderosa* (794)–232.41:265.5:181.25.

Retrieval Terms: Pinus ponderosa; Sierra Nevada; planting stock; progeny tests; genetic variation; seedling growth.

Jenkinson, James L.

1975. Increasing planting stock size by family selection in California ponderosa pine. USDA Forest Serv. Res. Paper PSW-108, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Wind-pollinated families from four geographic areas in the northern Sierra Nevada were tested in the nursery. For every area, the native families differed significantly from each other in 1-year seedling height, and in 2-year height, diameter, and stem volume. Family growth was poorly correlated with family seed weight; it was independent of germination speed and seed parent stem volume. The size of planting stock can be improved and small-grade seedling production decreased by eliminating from future collections seed trees whose families show poor growth in the nursery.

Oxford: 174.7 *Pinus ponderosa* (794) 232.41:265.5:181.25.

Retrieval Terms: Pinus ponderosa: Sierra Nevada; planting stock; progeny tests; genetic variation; seedling growth.

Jenkinson, James L.

1975. Increasing planting stock size by family selection in California ponderosa pine. USDA Forest Serv. Res. Paper PSW-108, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

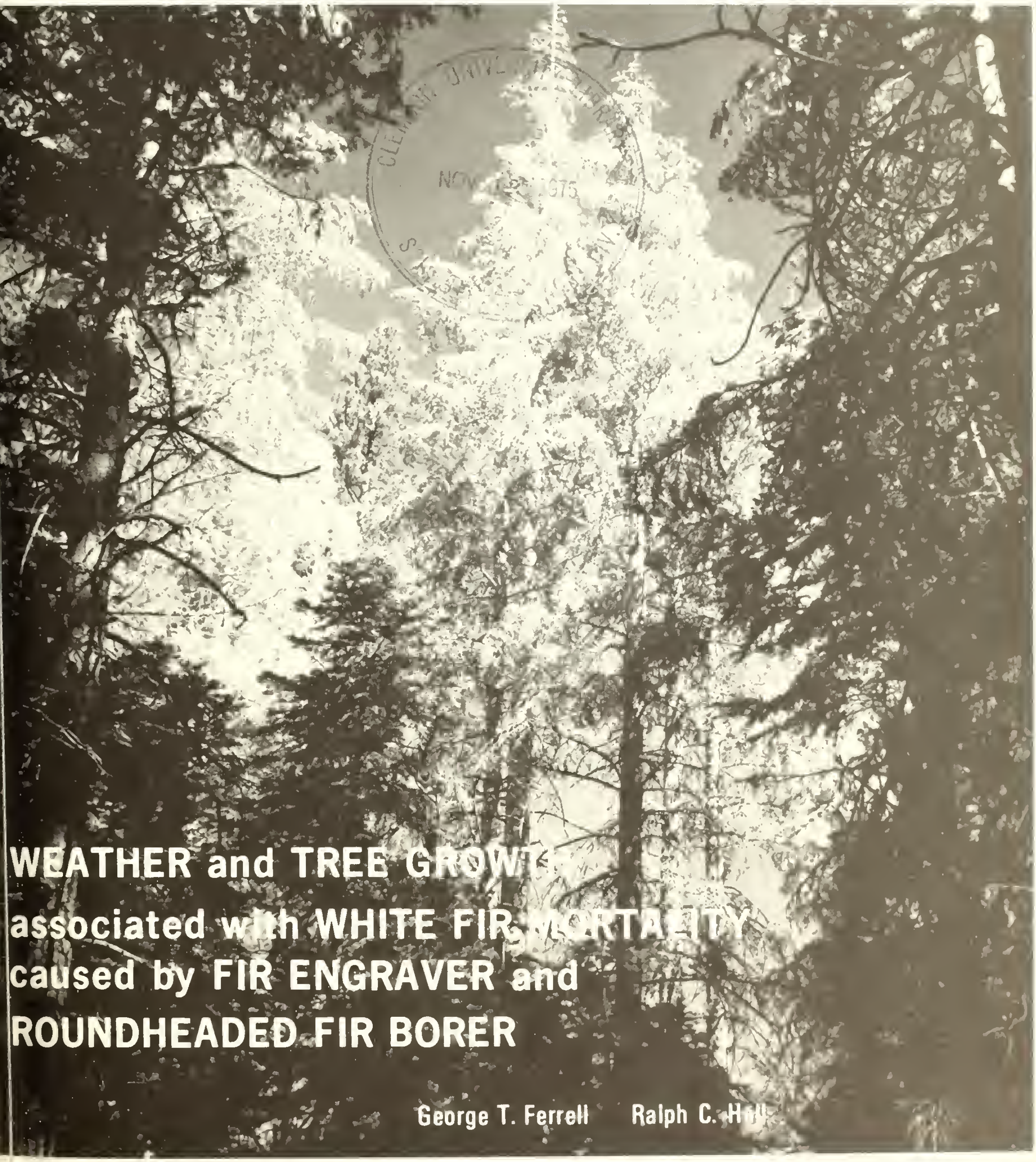
Wind-pollinated families from four geographic areas in the northern Sierra Nevada were tested in the nursery. For every area, the native families differed significantly from each other in 1-year seedling height, and in 2-year height, diameter, and stem volume. Family growth was poorly correlated with family seed weight; it was independent of germination speed and seed parent stem volume. The size of planting stock can be improved and small-grade seedling production decreased by eliminating from future collections seed trees whose families show poor growth in the nursery.

Oxford: 174.7 *Pinus ponderosa* (794)–232.41:265.5:181.25.

Retrieval Terms: Pinus ponderosa: Sierra Nevada; planting stock; progeny tests; genetic variation; seedling growth.

PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701



WEATHER and TREE GROWTH associated with WHITE FIR MORTALITY caused by FIR ENGRAVER and ROUNDHEADED FIR BORER

George T. Ferrell   Ralph C. Hall

USDA FOREST SERVICE RESEARCH PAPER PSW-109 / 1975

CONTENTS

SUMMARY

Ferrell, George T., and Ralph C. Hall
1975. **Weather and tree growth associated with white fir mortality caused by fir engraver and roundheaded fir borer.** USDA Forest Serv. Res. Paper PSW-109, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 174.7 *Abies concolor:* 453:423 + 453–145.7x19.92 *Scolytus ventralis*–174.7 *Abies concolor* + 453–147.19.88 *Tetropium abietis* –174.7 *Abies concolor.*

Retrieval Terms: Abies concolor; Scolytus ventralis; Tetropium abietis; insect attack; mortality; weather; precipitation; radial growth; multivariate analysis.

To assess their value as predictors, fluctuations in growth of white fir (*Abies concolor*) and weather patterns in the Hat Creek region of northeastern California were compared with trends in tree mortality caused by fir engraver (*Scolytus ventralis* Lec.) and roundheaded fir borer (*Tetropium abietis* Fall) beetles. The volume of white fir sawtimber killed annually by the beetles was obtained from yearly surveys of 22 20-acre (8-ha) plots from 1944 to 1954. The stems of suppressed, intermediate, and dominant white fir growing on these plots were bored in 1972 and annual ring widths for these years were measured. To improve comparability of growth measurements in fir growing under a variety of site and stand conditions, two annual growth indexes were calculated: (a) growth index (departure from normal), and (b) growth sensitivity (rate of change). Yearly means of these indexes were obtained for all sample fir, and fir in each crown class, on the plots.

Between-years variation in fir mortality, and in the growth indexes for the dominant, intermediate, and all sample fir was significant compared to within-year (between plots) variation. These were averaged for all plots to obtain regional measures of annual mortality and growth. Because trends in the growth of suppressed fir were not statistically significant, these trends were excluded from further analysis.

Seasonal and annual precipitation and mean air temperatures for the study period were obtained from local weather records. Each year's weather and growth were averaged with those of the previous 1 and 2 years to include previous conditions. The influence of previous and current weather and growth upon the average volume of fir killed annually was examined by stepwise multivariate regression. Weather and growth submodels were developed and variables significant within each submodel were combined to form a final predictive model.

The weather submodel statistically explained 95 percent of the variation in fir mortality, while the growth submodel explained 51 percent. The addition of fir growth to the weather variables failed to increase the amount of variation explained by the final model. Fir mortality increased in years when one or more of the following occurred: (a) radial growth of fir during the current and previous 2 years declined an average of 2.5 percent per year; (b) precipitation during the current and preceding year averaged 11 percent below normal; and (c) the current year's spring precipitation averaged 32 percent below normal. Trends in pine mortality were compared to those in fir on the plots and were found to be similar during the study period.

Regional levels of fir mortality due to the beetles were primarily related to regional, year-to-year fluctuations in the radial growth of both dominant and intermediate fir. This interpretation is based on the finding that indexes of the combined crown classes were superior to those of either crown class by itself and indexes of suppressed trees had been excluded earlier in the analysis.

The results suggest that fir mortality caused by the subcortical insects increases during periods of drought and reduced fir growth, probably because of decreased resistance of fir to the beetles.

White fir (*Abies concolor* [Gord. & Glend.] Lindl.) stands in Western North America periodically suffer extensive tree mortality caused by outbreaks of the fir engraver bark beetle (*Scolytus ventralis* Lec.). The cambial zone of the boles infested by *S. ventralis* is also colonized by the roundheaded fir borer (*Tetropium abietis* Fall) (Struble 1957). Only a few of these outbreaks have been related to underlying environmental factors, such as drought or host tree defoliation (Stevens 1971, Wickman 1963). The dearth of long-term, quantitative estimates of the population levels of these insects and the associated fir mortality has hampered better understanding of factors influencing these outbreaks.

As an index to past levels of fir mortality caused by the fir engraver, year-to-year fluctuations in the abundance of old attack scars embedded in annual rings of living and recently killed white fir were studied (Ferrell 1973). The year of attack was readily determined by noting the annual ring in which the scar was embedded. The scars form a semipermanent record of at least a portion of the interaction between the insect population and the host trees over long periods in the past. Scars were more abundant in annual rings formed in years when precipitation and fir growth during the current and preceding 1 to 2 years were subnormal—especially when these conditions were contemporaneous with logging operations within the stand. Fir killed by the beetles showed rapidly increasing frequencies of scars in the narrow annual rings formed in the last few years before the trees had succumbed. The results agreed with those of Felix and others (1971), who found increased frequencies of fir engraver scars in annual rings formed in years of drought in the upper boles of white fir infected by true mistletoe.

During a study of pine mortality caused by bark beetles from 1938 to 1954 (Hall 1958), records (unpublished) were kept of annual fir mortality caused by subcortical insects on cruise plots 30 miles to the north of the scar study plots. Forest insect surveys had reported that fir engraver damage was generally high in 1939-40 and low in 1948 throughout the region embracing both the scar and mortality plots.[1] This fact suggests the possibility that trends in fir engraver populations on both study areas might be similar. The finding that annual levels of fir mortality were directly correlated with scar abundance over a 15-year period lent validity to the use of the scars as an index to past levels of fir mortality. Trends in the scars and the fir mortality were similar during 12 of these 15 years, but were dissimilar during the other 3 years. These departures may have resulted from sampling error or other variables not studied.

This paper reports a study of multiple regression analysis of the association of weather and tree growth with white fir mortality caused by the fir engraver and roundheaded fir borer beetles in northern California.

METHODS

Fir Mortality

A total of 38 plots, each 20 acres (8 ha), had been established in 1938-39 in forest stands growing in the Pit River drainage within a 20-mile (32 km) radius to the north, west, and south of Burney, Shasta County, California (Hall 1958). Because 16 plots had little or no white fir sawtimber, they were excluded from the present study. The other 22 plots were in mixed conifer stands varying in amount (300 to 42,240 bd. ft./acre or 4 to 591 m^3/ha) and in percentage (1.2 to 68.9 percent) of white fir in the sawtimber volume. The plots also varied in elevation (3300 to 6600 ft. or 1006 to 2012 m) and logging history (virgin to cutover). They probably represented a reasonable cross-section of stands holding white fir in the region.

Tree mortality from 1944 to 1954 was determined by annual 100 percent surveys in late fall or the following spring, when currently infested fir attacked by subcortical insects the preceding summer usually had faded foliage. After the diameter at breast height (d.

[1] Salman, K. A. 1939. *Reconnaissance of west side infestation conditions. Season of 1939.* Engen, E. T. 1950. *Forest insect survey, Lassen National Forest and adjacent private lands. Seasons of 1949 and 1950.* (Unpublished reports on file at the Pacific Southwest Forest and Range Experiment Station, Berkeley, California.)

b. h.) and the height of each dying fir greater than 11 inches (28 cm) d. b. h. were recorded, the bark was chopped into at breast height. Any subcortical insects found were identified from their gallery patterns. Previously unsampled, recently killed fir from which the beetles had already emerged were counted as mortality of the previous year. These trees, evidently infested in late summer, had not faded at the time of the fall survey and therefore had escaped detection in the year of infestation. The merchantable volume of each dead tree was obtained from local volume tables.

Fir engravers or roundheaded fir borers were found in all but a few of the fir sampled. Struble [2] had dissected a representative sample of white fir killed by subcortical insects in mixed conifer stands in the central Sierra Nevada. He found that with few exceptions the upper boles of the larger fir had been infested by fir engraver whereas fir borer had colonized the thick-barked lower boles. In the present study, we thought it likely that sampling at breast height would often fail to reveal the presence of fir engraver—even though both insects had infested the tree. Because these two beetles frequently are found together in dying fir, we did not try to separate them for this analysis.

Fir Growth

Radial growth of white fir during the study period was sampled by boring the stems of nine living trees at breast height on each plot in August 1972. Radial growth in the basal portion of the stem is not only readily accessible for sampling, but also is known to be sensitive to weather variation (Fritts 1966). To study the influence of the tree's crown class upon the usefulness of its growth as a predictor of beetle mortality trends, we obtained an increment core from three suppressed, three intermediate, and three dominant fir trees on each plot. Within each crown class, individual trees and the particular stem radius bored were randomly selected. The cores were stored at room temperature for 3 months before we measured the width (± 0.01 mm) of each annual ring formed during the study period.

Weather

Monthly precipitation and mean air temperature recorded at Hat Creek Powerhouse No. 1 from October 1941 to September 1954 were obtained from annual summaries of California weather published by the U. S. Weather Bureau. The weather station was at a lower elevation (3010 feet or 917 m) than the mortality plots and stands containing fir in the region. We recognized that weather at the plots would vary according to topography and elevation and would differ from that recorded at Hat Creek Powerhouse. Annual and seasonal precipitation at the station was compared with that in the fir zone by means of rain gauges set up on four widely scattered mortality plots ranging in elevation from 3300 to 5300 feet (1006 to 1615 m). Precipitation was recorded from 1939-44 on two of the plots, and through 1948 on the other two.

DATA ANALYSIS

Fir Mortality

Total mortality caused by fir engraver and roundheaded fir borer on the plots (1944-54) was 111 fir trees (>11 inches or 28 cm d.b.h.) containing 188,620 bd. ft. (1068 m^3) of merchantable sawtimber volume. Fir borer was found subcortically at breast height in 80, fir engraver in 29, and both species in two of these trees. The dead fir trees averaged 30 inches (76 cm) in d.b.h. and 1700 bd. ft. (9.6. m^3) in volume, but ranged from 12 to 58 inches (30 to 147 cm) in d.b.h. and 40 to 6850 bd. ft. (0.2 to 38.8 m^3) in volume. More than half the trees were less than 28 inches (71 cm) d.b.h. and 1000 bd. ft. (5.7 m^3) in volume.

Average fir mortality caused by the beetles on the plots fluctuated from a high of 85.18 bd. ft./acre (1.19 m^3/ha) in 1954 to a low of 0.79 bd. ft./ acre (0.01 m^3/ha) in 1948. In all years between-plot variation was high, with no mortality on some plots even in years when average mortality was highest (*table 1*). The variance-to-mean ratio was high, increasing disproportionately with size of the mean, implying that the mortality was distributed among the plots in nonnormal, clumped fashion. To determine if the variation between years was more significant than that among plots, we had to transform the mortalities mathematically. Such a transformation was needed to

[2]Struble, George R. 1931. *The fir engraver beetle and associated insects in white fir, season of 1930.* (Unpublished report on file, Pacific Southwest Forest and Range Experiment Station, Berkeley, California.)

Table 1–*White fir sawtimber mortality caused by fir engraver and roundheaded fir borer on 22 20-acre (8-ha) plots in northeastern California, 1944-54*

Year	Average	Range
	bd.ft./acre (m^3*/ha)*	
1944	25.66 (0.36)	0-339.00 (0-4.7)
1945	84.75 (1.19)	0-408.50 (0-5.7)
1946	72.29 (1.01)	0-588.00 (0-8.2)
1947	50.84 (0.71)	0-708.50 (0-9.9)
1948	.79 (0.01)	0- 17.50 (0-0.2)
1949	51.27 (0.71)	0-432.00 (0-6.0)
1950	35.43 (0.50)	0-525.00 (0-7.3)
1951	11.82 (0.17)	0-215.50 (0-3.0)
1952	5.11 (0.07)	0-112.50 (0-1.6)
1953	16.91 (0.24)	0-272.00 (0-3.8)
1954	85.18 (1.19)	0-409.00 (0-5.7)

satisfy the assumptions underlying analysis of variance (Steel and Torrie 1960). The transformation used, $1/(x + 1)^{-0.1}$, x = annual plot mortality (bd. ft./acre), effectively reduced the mean-variance correlation to zero, implying the variance had been stabilized. Analysis of the transformed mortalities indicated that the variation between years was significant ($F = 3.57$, df = 10,231, $p < .01$). Therefore we used the mean volume per acre of fir killed annually on the plots as the dependent variable to estimate regional level of fir mortality caused by the beetles. Correlation between mean mortality in any year with that occurring the previous year was not significantly different from zero (serial $r = 0.14$), implying that the previous year's mortality had little influence, and we excluded it as an independent variable in the regressions.

Fir Growth

The width of annual rings formed during successive years at a given height in a tree bole is affected by the availability of nutrients and moisture as influenced by spatial and temporal variations in conditions both internal and external to the tree (Fritts 1966). For the analysis, we intended growth to be an indirect measure of many of these influences for which records were not available. We sought to relate year-to-year variations in average levels of growth to those of fir mortality within the region studied. To establish these regional growth variations, the radial growth of many white fir differing in age, size, crown class, growing site, and surrounding forest stand was measured.

To increase comparability of growth measurements and to isolate for analysis year-to-year regional fluctuations in growth due to such conditions as variable weather, two growth indices were calculated by the computer program INDXA (Fritts 1966):

Growth index was calculated by fitting a least-squares regression line with negative, zero, or positive slope to each tree's ring width series. Plotting the ring width series of a subsample of the trees indicated curvilinearity could be ignored because the series being studied was short. Each year's growth index was calculated by dividing the observed ring width by the value estimated by the regression line. Growth indexes of unity represent normal, <1 subnormal, and >1 supranormal growth.

Growth sensitivity was calculated by dividing the signed difference between the current (RW_2) and preceding (RW_1) year's ring widths by the average ring width for the 2 years ($RW_2 - RW_1/\overline{RW}$). This index defined the rate of decline or increase in radial growth between any two successive years. It was standardized by being expressed as a proportion of the average ring width for the period, (that is, a sensitivity of −0.03 denoted a 3 percent decrease in standardized radial growth between two successive years). Summaries including trees in each, and in all, of the crown classes from each plot were then computed, yielding yearly means and standard errors of the indexes.

To screen the growth variables for significant, year-to-year variation, F tests were used to analyze the annual plot values of the mean indexes to determine if between-years variation was statistically significant compared to within-years (between plots) variation. The F ratios obtained for growth index (6.76) and sensitivity (5.27) for the combined crown classes, sensitivity of the dominants (4.98), and growth index of the intermediates (3.32) were all significant (df = 12,273, $p < .01$). We then used yearly averages of these on all plots to construct independent variables expressing regional host tree growth in the regression analysis. Because between-year variation in both growth indexes for suppressed fir was not significant, we excluded them from further analysis.

Weather

The annual weather pattern in the region consists of a distinct wet (usually October to June) and dry season. About 80 percent of the total precipitation occurs in the six winter months, much of it falling as snow. The summer months are normally dry and warm, with precipitation limited to scattered local thundershowers. Thus tree growth in spring and early summer is largely dependent upon soil storage of winter precipitation.

We considered total precipitation and mean air temperature occurring from the preceding October through the current September to represent both the direct and indirect influences of annual weather upon fir mortality caused by the insects during the current (i^{th}) year (i = 1944-54).

Different developmental stages of the insects occur seasonally. Both insect species studied overwinter as larvae and pupate in spring, with adult emergence, flight, and host colonization occurring primarily in summer. The influence of seasonal weather upon the level of fir mortality caused by the insects was assessed by subdividing the year's weather pattern into that occurring in winter (October-March), spring (April-June), and summer (July-September).

Comparison of weather at Hat Creek Powerhouse with that on the mortality plots showed that mean precipitation on the plots exceeded that at Hat Creek at all seasons, but the amount of excess varied widely from plot to plot. These precipitation excesses ranged from 4.5 to 20 inches (11.4 to 50.8 cm) in winter, 1 to 8 inches (2.5 to 20.3 cm) in spring, 3 to 7 inches (7.6 to 17.8 cm) in summer, and 4.5 to 30 inches (11.4 to 76.2 cm) annually. However, correlation of annual and seasonal precipitations at Hat Creek Powerhouse with those recorded on the mortality plots indicated similar weather patterns. The ranges of correlation coefficients obtained were 0.97 to 0.78 for winter, 0.93 to 0.63 for spring, 0.96 to 0.42 for summer, and 0.97 to 0.71 for annual precipitation. Both seasonally and annually the strength of the correlation decreased as distance and elevation change increased between the plot and Hat Creek Powerhouse. We concluded that weather patterns at Hat Creek Powerhouse sufficiently reflected general weather pattern over the region studied for this analysis.

Previous Growth and Weather

To study the influence of previous growth and weather conditions upon fluctuations in fir mortality caused by the beetles, we combined data on the current (i^{th}) year with data of up to two preceding (j^{th}) years ($X_{i,j}$ j = 1,2) and averaged these values. Although we realized that such averages might only approximate the influence of previous conditions upon the current level of insect-induced fir mortality, such averages have been used in similar studies (Felix and others 1971, McManus and Giese 1968) in the absence of known relationships.

Multivariate Regression

Stepwise multivariate regression was used to examine the usefulness of previous and current fir growth and weather (independent variables) in explaining yearly variations in fir mortality caused by the beetles (dependent variable). The independent variables were assumed to be related to the dependent variable in a linear, additive model. Nonlinearity (single peaks or depressions) in the relationships between the dependent and independent variables was at least partially allowed for by including both the independent variables and their squares in the regression. We do not mean to imply necessarily that the real relationships are accurately described by the variables being introduced into such a model in this manner, but only that such would be a satisfactory first approximation.

Computation of the regression coefficients and associated statistics (R^2, t^2, standard error of estimate) was performed by a computer program (RAFL) written by personnel of the Pacific Southwest Forest and Range Experiment Station. The program included a stepping option by which the independent variables could be added one at a time in order of descending efficiency in reducing the unexplained variance in fir mortality (t^2 criterion).

Initially only the growth variables were included in the computations. The variables statistically explaining significant amounts of the variance in mortality (denoted by the coefficient of determination, R^2) comprised a growth submodel. Similar analysis of weather variables yielded a weather submodel. Independent variables significant in each submodel were then combined in a further stepwise analysis. This combination yielded significant variables in the final predictive model. This method allowed the relative value of host tree growth and weather to be compared individually or in combination in explaining year-to-year variation in regional fir mortality caused by the insects.

RESULTS

Significant Variables

Tree growth and weather variables explained significant amounts of variation in annual fir mortality caused by fir engraver and fir borer from 1944 to 1954 (*table 2*). The only variable significant in the growth submodel was the mean sensitivity of all fir sampled, averaged over the current and two preceding years ($MS_{i,2}$). This variable explained 51 percent of the mortality variation ($F = 9.24$, df = 1, 10, $p < .05$).

Three variables were significant in the weather submodel; together they explained 95 percent of the mortality variation ($F = 41.28$, df = 3, 10, $p < .01$). The most important weather variable was the average precipitation during the current and preceding year ($Precip._{i,1}$), which explained about 73 percent of the mortality variation. The second most important variable was the current year's spring precipitation ($Spr.\ precip._i$), which when included in the model increased the amount of mortality variation explained to 85 percent. The last significant variable added to the weather submodel was the square of the mean air temperature during the current and preceding spring ($Spr.\ temp._{i,1}{}^2$), indicating a curvilinear relationship with fir mortality.

Table 2—*Tree growth and weather factors influencing the mean volume of white fir (bd. ft./acre) killed annually by* Tetropium abietis *and* Scolytus ventralis *on 22 plots near Burney, California, 1944-54*

Independent variables[1]	Description	Percent variation in timber loss explained ($100\ R^2$)
Tree Growth:		
$MS_{i,2}$	Mean sensitivity, current and two preceding years	50.65*
Weather:		
$Prec._{i,1}$	Average total precipitation during current and preceding year	72.61
$+Spr.\ precip._i$	Spring precipitation, current year	85.11
$+(Spr.\ temp._{i,1})^2$	Mean spring temperature, current and preceding year squared	94.65**

* F = 9.24, significant at 5 percent level.

** F = 41.28, significant at 1 percent level.

[1] Added in order of descending efficiency in explaining variation in the annual timber loss. Each variable was significant at the 5 percent level (t^2 criterion).

Combining the significant growth and weather variables into a further stepwise regression analysis led to the addition of the significant weather variables and to the exclusion of the growth variable owing to lack of significance in the final model. Not unexpectedly we found much overlapping between the influences of fir growth and weather upon the fir mortality, with weather variables supplanting growth variables because of their greater efficiency (higher t^2) in explaining the mortality variation. Comparison of scatter diagrams and regression equations for the most important growth and weather variables reinforced this finding (*fig. 1*). The superiority of precipitation in predicting fir mortality was evident from the lower scattering of the observed tree mortalities about the regression line, yielding a higher R^2 and a lower standard error of the estimate ($S_{y \cdot x}$) compared to the regression based on the growth variable.

The multivariate regression equation for the final model was

$$Y = 427.55 - 8.90X_1 - 5.42X_2 - .06X_3$$

in which

Y = Mean volume of fir sawtimber killed annually by fir engraver and fir borer (bd. ft./acre)

X_1 = Mean precipitation during current and previous years (inches)

X_2 = Spring precipitation, current year (inches)

X_3 = Mean air temperature during the current and preceding spring, squared (°F)

The coefficient of determination (R^2) was 0.947, and the standard error of estimate was 8.58 bd. ft./acre.

Increased Fir Mortality

The model relates increased fir mortality to years with one or more of the following: (a) decreased mean precipitation during the current and preceding year, (b) decreased precipitation during the current spring, and to a lesser extent, (c) decreased mean temperature during the current and previous spring (*fig. 2*).

The higher levels of fir mortality occurring in the years 1945-7, 1949-50, and 1954 were associated with years of deficient annual or spring precipitation or both. The effect of current spring precipitation in modifying the influence of previous and current annual precipitation upon the level of current mortality was evident in trends between 1946 and 1947. Annual precipitation was low in 1946 and declined further

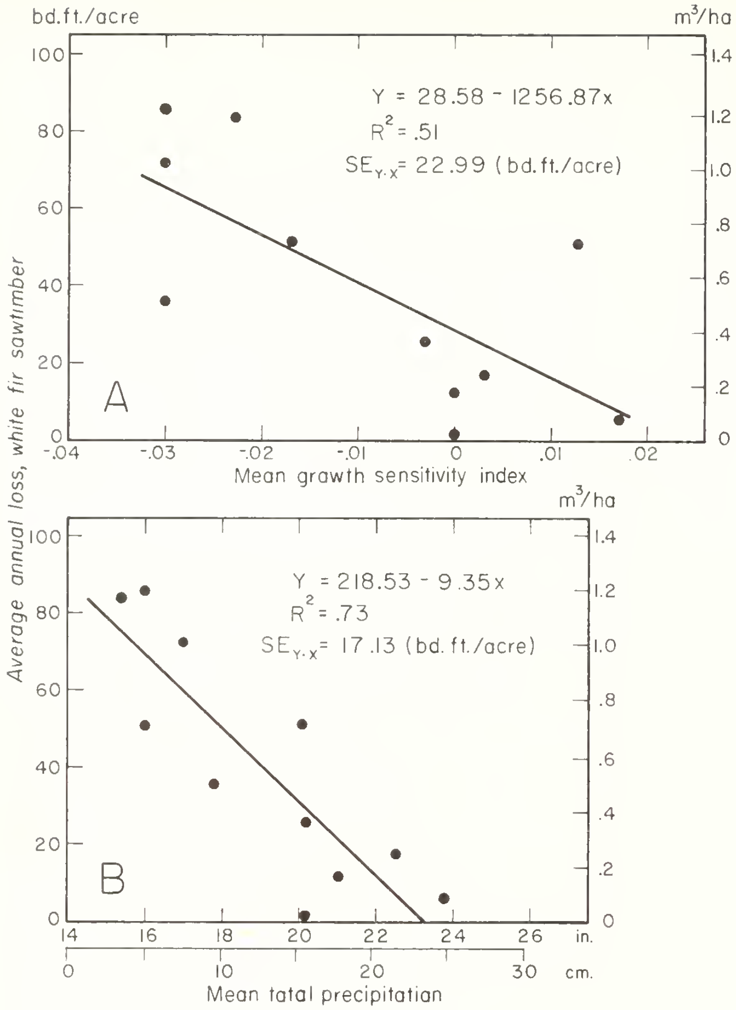


Figure 1—The average volume of white fir sawtimber killed annually by fir engraver and roundheaded fir borer declined, *A*, as the mean growth sensitivity—an index of the radial growth in fir for the current and two preceding years—increased; and *B*, as the total precipitation for the current and previous years increased.

in 1947, but fir mortality continued to decrease in 1947—evidently in response to a twofold increase in spring precipitation in 1947 over 1946. The low mortality and high annual precipitation in 1948 were both attributable to an unusually wet spring in that year. The lesser significance of spring temperature in the model was not apparent from trends in the variables, but was probably associated with the inverse relation of spring temperature to spring precipitation.

Higher levels of fir mortality (>40 bd. ft./acre of 0.56 m^3/ha) occurred in five of the years studied, when precipitation during the current and preceding year averaged 16.90 inches (42.93 cm) or 11 percent less than the average for the study period (19.09 inches or 48.49 cm) and spring precipitation averaged 2.60 inches or 6.60 cm), or 32 percent below the period average (3.81 inches or 9.68 cm). Mortality exceeding 40 bd. ft./acre (.56m^3/ha) also occurred in 4 years, when the average decline in the radial growth of fir during the current and preceding 2 years was 2.5 percent per year (mean sensitivity = −0.025). An exception to this pattern was 1947, when mortality was declining but still averaged 50 bd. ft./acre (0.70 m^3/ha) while radial growth of fir during the current and preceding 2 years increased by an average of 1.3 percent per year. This relatively high mortality during a period of increasing host tree growth was evidently due to the deficient annual precipitation of 1947.

In an earlier study, Hall (1958) analyzed the influence of current weather and soil moisture on volume of pine sawtimber killed annually by *Dendroctonus* and *Ips* bark beetles on 38 plots. He found increased pine mortality associated with dry hot springs and with low soil moisture contents in mid-July. In comparing his findings with ours from 22 of the same 38 plots, we noted that pine losses were higher, but mortality trends of the two tree species were similar during most of the years 1942 to 1950 (*fig. 3*).

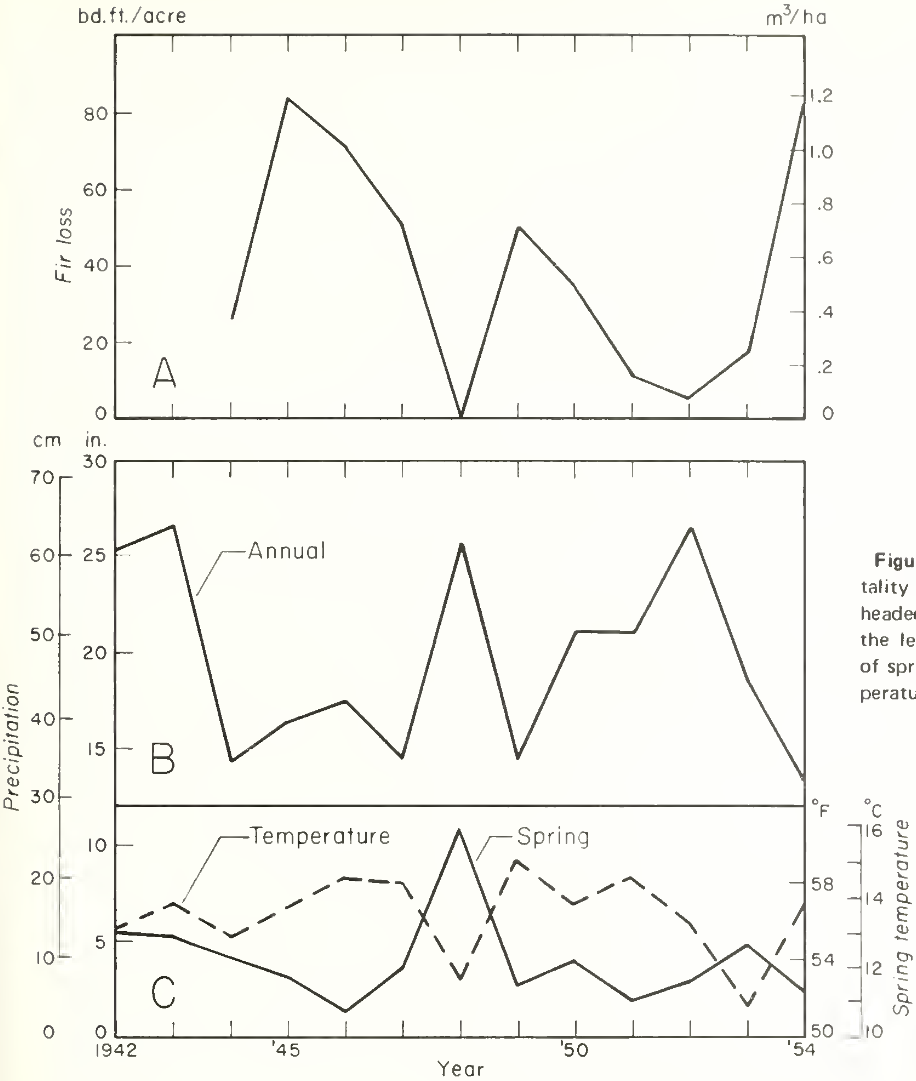


Figure 2—The annual level of fir mortality caused by fir engraver and roundheaded fir borer, *A*, varied inversely with the levels of total precipitation, *B*, and of spring precipitation and mean air temperature, *C*.

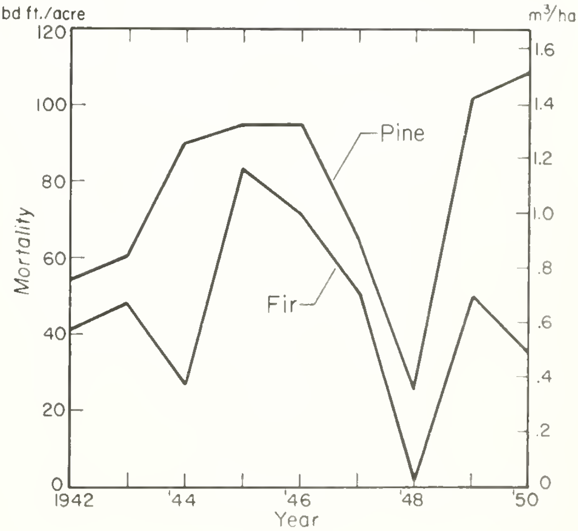


Figure 3—Trends in the mean annual mortality of white fir and pine caused by subcortical insects on the study plots were similar during the years 1942 to 1950.

CONCLUSIONS

White fir mortality increased in years when current and previous precipitation and fir growth were subnormal or declining. This same association was found in the abundance of fir engraver attack scars in both living and recently killed fir (Felix and others 1971, Ferrell 1973). Annual precipitation was a more significant variable than seasonal precipitation. Air temperatures were, by themselves, of minor importance in the analysis.

Higher fir mortality was more closely associated with periods of years with declining radial growth (negative growth sensitivity) than with subnormal radial growth (growth index less than one). Decreased radial growth, even though still above the normal predicted from growth patterns of fir in the region, is evidently a more sensitive indicator of impending increases in beetle-caused fir mortality.

The radial growth of fir in all crown classes was more closely associated with annual levels of regional fir mortality than with the growth of any single crown class analyzed. This relationship corresponds with the observed wide variability in the size (and crown class) of fir killed by the insects. As year-to-year fluctuation in the growth of suppressed fir was not significant, it probably contributed little to the importance of the growth of the combined crown classes in the model. Drought adversely affecting the growth of fir in primarily the dominant and intermediate crown classes is probably required to cause regional increases in fir mortality.

The final model included only weather variables because host tree growth was of lesser value in explaining fluctuations in regional levels of fir mortality caused by fir engraver and fir borer. This study supports what other investigators have established: that weather can influence the fir engraver both directly, i.e., larval mortality from low winter temperature (Berryman 1970), and indirectly through alteration of host tree physiology (Berryman 1972, Felix and others 1971), although many of the exact pathways by which weather influences trends in fir mortality caused by the beetles probably remain to be elucidated.

In this study, general weather patterns adequately explained year-to-year fluctuations in average levels of beetle-caused fir mortality in a forested region. But mortality varied widely among the study plots in most of the years studied. The interaction between the host tree and insect pest is affected by a variety of factors, including weather, site, and stand conditions. Some have already been reported; for example, defoliation (Wickman 1963), root diseases (Stark and Cobb 1969), mistletoe (Felix and others 1971), and logging (Ferrell 1973). The development of models that can predict levels of fir mortality within a particular forest stand will require more extensive investigation.

LITERATURE CITED

Berryman, A. A.
1970. Overwintering populations of *Scolytus ventralis* (Coleoptera: Scolytidae) reduced by extreme cold temperatures. Annu. Entomol. Soc. Amer. 63:1194-1196.

Berryman, A. A.
1972. Resistance of conifers to invasion by bark beetle-fungus associations. BioScience 2(10):598-602.

Felix, Leonard S., E. Uhrendoldt, and J. R. Parmeter, Jr.
1971. Association of *Scolytus ventralis* (Coleoptera: Scolytidae) and *Phoradendron bolleanum* subspecies *pauciflorum* on *Abies concolor.* Can Entomol. 103:1697-1703.

Ferrell, G. T.
1973. Weather, logging, and tree growth factors associated with fir engraver attack scars in white fir. USDA Forest Serv. Res. Paper PSW-92, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Fritts, H. C.
1966. Growth-rings of trees: their correlation with climate. Science 154:973-979.

Hall, R. C.
1958. Environmental factors associated with outbreaks by the western pine beetle and California five-spined pine engraver in California. Tenth Int. Congr. Entomol. Proc. 4:341-347.

MacManus, M. L., and R. L. Giese.
1968. The Columbian timber beetle *Corthylus columbianus.* VII. The effect of climatic integrants on historic density fluctuations. Forest Sci. 14:242-254.

Steel, R. G. D., and J. H. Torrie.
1960. Principles and procedure of statistics. 481 p. McGraw-Hill Book Co., New York.

Stevens, R. E.
1971. Fir engraver beetle. U.S. Dep. Agric. Forest Pest Leafl. 13, 7 p.

Stark, R. W., and F. W. Cobb, Jr.
1969. Smog injury, root disease, and bark beetle damage in ponderosa pine. Calif. Agric. 23(9):13-15.

Struble, G. R.
1957. The fir engraver. U.S. Dep. Agric. Prod. Rep. 11, 18 p.

Wickman, B. E.
1963. Mortality and growth reduction of white fir following defoliation by the Douglas-fir tussock moth. USDA Forest Serv. Res. Paper PSW-7, 15 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

GPO 689-232/4422

Ferrell, George T., and Ralph C. Hall.
1975. **Weather and tree growth associated with white fir mortality caused by fir engraver and roundheaded fir borer.** USDA Forest Serv. Res. Paper PSW-109, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Multivariate regression analysis was used to explore the relationship of weather and tree growth to the average volume of *Abies concolor* sawtimber killed annually by fir engraver (*Scolytus ventralis* Lec.) and roundheaded fir borer (*Tetropium abietis* Fall) beetles. Data for the years 1944 to 1954 from 22 plots in northern California showed that white fir mortality increased in years when (a) fir radial growth during the current and previous 2 years declined an average of 2.5 percent per year, (b) precipitation during the current and previous years averaged 11 percent below normal, or (c) spring precipitation averaged 32 percent below normal. Levels of mortality were related chiefly to regional fluctuations in radial growth of dominant and intermediate fir.

Oxford: 174.7 *Abies concolor:*453:423 + 453–145.7x19.92 *Scolytus ventralis*–174.7 *Abies concolor* + 453–147.19.88 *Tetropium abietis*– 174.7 *Abies concolor.*

Retrieval Terms: Abies concolor; Scolytus ventralis; Tetropium abietis; insect attack; mortality; weather; precipitation; radial growth; multivariate analysis.

Ferrell, George T., and Ralph C. Hall.
1975. **Weather and tree growth associated with white fir mortality caused by fir engraver and roundheaded fir borer.** USDA Forest Serv. Res. Paper PSW-109, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Multivariate regression analysis was used to explore the relationship of weather and tree growth to the average volume of *Abies concolor* sawtimber killed annually by fir engraver (*Scolytus ventralis* Lec.) and roundheaded fir borer (*Tetropium abietis* Fall) beetles. Data for the years 1944 to 1954 from 22 plots in northern California showed that white fir mortality increased in years when (a) fir radial growth during the current and previous 2 years declined an average of 2.5 percent per year, (b) precipitation during the current and previous years averaged 11 percent below normal, or (c) spring precipitation averaged 32 percent below normal. Levels of mortality were related chiefly to regional fluctuations in radial growth of dominant and intermediate fir.

Oxford: 174.7 *Abies concolor:*453:423 + 453–145.7x19.92 *Scolytus ventralis*–174.7 *Abies concolor* + 453–147.19.88 *Tetropium abietis*–174.7 *Abies concolor.*

Retrieval Terms: Abies concolor; Scolytus ventralis; Tetropium abietis; insect attack; mortality; weather; precipitation; radial growth; multivariate analysis.

Ferrell, George T., and Ralph C. Hall.
1975. **Weather and tree growth associated with white fir mortality caused by fir engraver and roundheaded fir borer.** USDA Forest Serv. Res. Paper PSW-109, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Multivariate regression analysis was used to explore the relationship of weather and tree growth to the average volume of *Abies concolor* sawtimber killed annually by fir engraver (*Scolytus ventralis* Lec.) and roundheaded fir borer (*Tetropium abietis* Fall) beetles. Data for the years 1944 to 1954 from 22 plots in northern California showed that white fir mortality increased in years when (a) fir radial growth during the current and previous 2 years declined an average of 2.5 percent per year, (b) precipitation during the current and previous years averaged 11 percent below normal, or (c) spring precipitation averaged 32 percent below normal. Levels of mortality were related chiefly to regional fluctuations in radial growth of dominant and intermediate fir.

Oxford: 174.7 *Abies concolor:*453:423 + 453–145.7x19.92 *Scolytus ventralis*–174.7 *Abies concolor* + 453–147.19.88 *Tetropium abietis*–174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; Tetropium abietis; insect attack; mortality; weather; precipitation; radial growth; multivariate analysis.

Ferrell, George T., and Ralph C. Hall.
1975. **Weather and tree growth associated with white fir mortality caused by fir engraver and roundheaded fir borer.** USDA Forest Serv. Res. Paper PSW-109, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Multivariate regression analysis was used to explore the relationship of weather and tree growth to the average volume of *Abies concolor* sawtimber killed annually by fir engraver (*Scolytus ventralis* Lec.) and roundheaded fir borer (*Tetropium abietis* Fall) beetles. Data for the years 1944 to 1954 from 22 plots in northern California showed that white fir mortality increased in years when (a) fir radial growth during the current and previous 2 years declined an average of 2.5 percent per year, (b) precipitation during the current and previous years averaged 11 percent below normal, or (c) spring precipitation averaged 32 percent below normal. Levels of mortality were related chiefly to regional fluctuations in radial growth of dominant and intermediate fir.

Oxford: 174.7 *Abies concolor:*453:423 + 453–145.7x19.92 *Scolytus ventralis*–174.7 *Abies concolor* + 453–147.19.88 *Tetropium abietis*–174.7 *Abies concolor.*
Retrieval Terms: Abies concolor; Scolytus ventralis; Tetropium abietis: insect attack; mortality; weather; precipitation; radial growth; multivariate analysis.

PACIFIC SOUTHWEST Forest and Range Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701

Plants of the Highest Santa Lucia and Diablo Range Peaks, California

James R. Griffin

USDA FOREST SERVICE RESEARCH PAPER PSW-110 /1975

CONTENTS

THE AUTHOR

JAMES R. GRIFFIN was formerly a plant ecologist on the Station's silvicultural research staff headquartered at Redding, California. He earned bachelor's (1952) and master's degrees (1958) in forestry and a doctorate (1962) in botany at the University of California, Berkeley. He joined the Forest Service in 1962. He assumed his present position in 1967 as associate research ecologist, Hastings Natural History Reservation, University of California, Carmel Valley.

ACKNOWLEDGMENTS

Help in identifying problem plants was generously provided by Loran C. Anderson (Kansas State University), Lincoln Constance, Lauramay T. Dempster, and Pamela Yorks (University of California, Berkeley), Frank G. Hawksworth (Rocky Mountain Forest and Range Experiment Station), Marion Ownbey (Washington State University), Peter H. Raven (Missouri Botanical Garden) and James L. Reveal (University of Maryland). John Thomas Howell (California Academy of Sciences) and Lawrence R. Heckard (University of California, Berkeley) helped with several plant groups and provided much encouragement. Voucher specimens of the interesting or difficult plants were deposited in the Jepson Herbarium, University of California, Berkeley, or with the specialists listed above. Margaret Campbell supplied historical material from the California Academy of Sciences archives.

SUMMARY

Griffin, James R.

1975. **Plants of the highest Santa Lucia and Diablo Range peaks, California.** USDA Forest Serv. Res. Paper PSW-110, 50 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 187x455.7[–(794) (23)]
Retrieval Terms: plant communities; montane disjuncts; elevational distributions; Ventana Wilderness Area; Santa Lucia Range (California); Diablo Range (California); California.

As the first phase of a broader vegetational study, a search for vascular plants was made on six of the highest ridges in the south Coast Ranges of California. The survey covered five prominent peaks in the Santa Lucia Range, Monterey County, and the tallest mountain unit in the Diablo Range, San Benito and Fresno Counties. These peaks, which support depauperate scraps of conifer forest are distant from montane regions with well-developed mixed conifer forest. A major purpose of the survey was to document the distribution of montane disjuncts on these lower elevation coastal peaks.

No detailed vegetational studies have been made on these summits, but the history of plant collecting and the relevant floristic literature were reviewed.

This collection emphasized the disjunct conifer forests, but all types of habitats above the 1200-meter (3937-foot) level were searched. Only vascular plants growing above this elevation on at least one of the six peaks are included in this report. The relative abundance of every species is tabulated within three elevational zones for each peak. Notes provide information about each species (including important varieties and subspecies) on life form, plant community preferences, ecological characteristics, and taxonomic problems.

A total of 449 species were noticed above 1200 m. The relatively low proportion of introduced species on each peak ranged from 3 to 9 percent, with very few introduced species in the dense forest stands. Most species had broad elevational ranges, and only 5 of 13 montane forest disjuncts seemed to be confined to areas above 1200 m: *Chimaphila menziesii, Cycladenia humilis, Holodiscus microphyllus, Raillardella* (*muirii* ?) and *Sanicula graveolens.*

Chews Ridge had the most plants. Of the 267 native species above 1200 m noted there, 26 were not seen on any of the other peaks. Forty-three species which were absent from the Santa Lucia Range peaks grew on San Benito Mountain. This more interior mountain has the driest climate of the study peaks and much highly serpentinized soil lacking on the other peaks. Six Santa Lucia Range endemics grew on the Santa Lucia peaks, and four Diablo Range endemics were in the San Benito Mountain region.

Eight species of limited distribution are recognized by the California Native Plant Society as rare and endangered plants: *Camissonia benitensis, Fritillaria falcata, Galium californicum* ssp. *luciense, Galium clementis, Layia discoidea, Lupinus cervinus, Monardella benitensis,* and *Raillardella* (*muirii?.*) The *Fritillaria* has not been reported from its type locality on San Benito Mountain since its original discovery. This plant may be extinct on San Benito Mountain but surviving in one other Diablo Range locality.

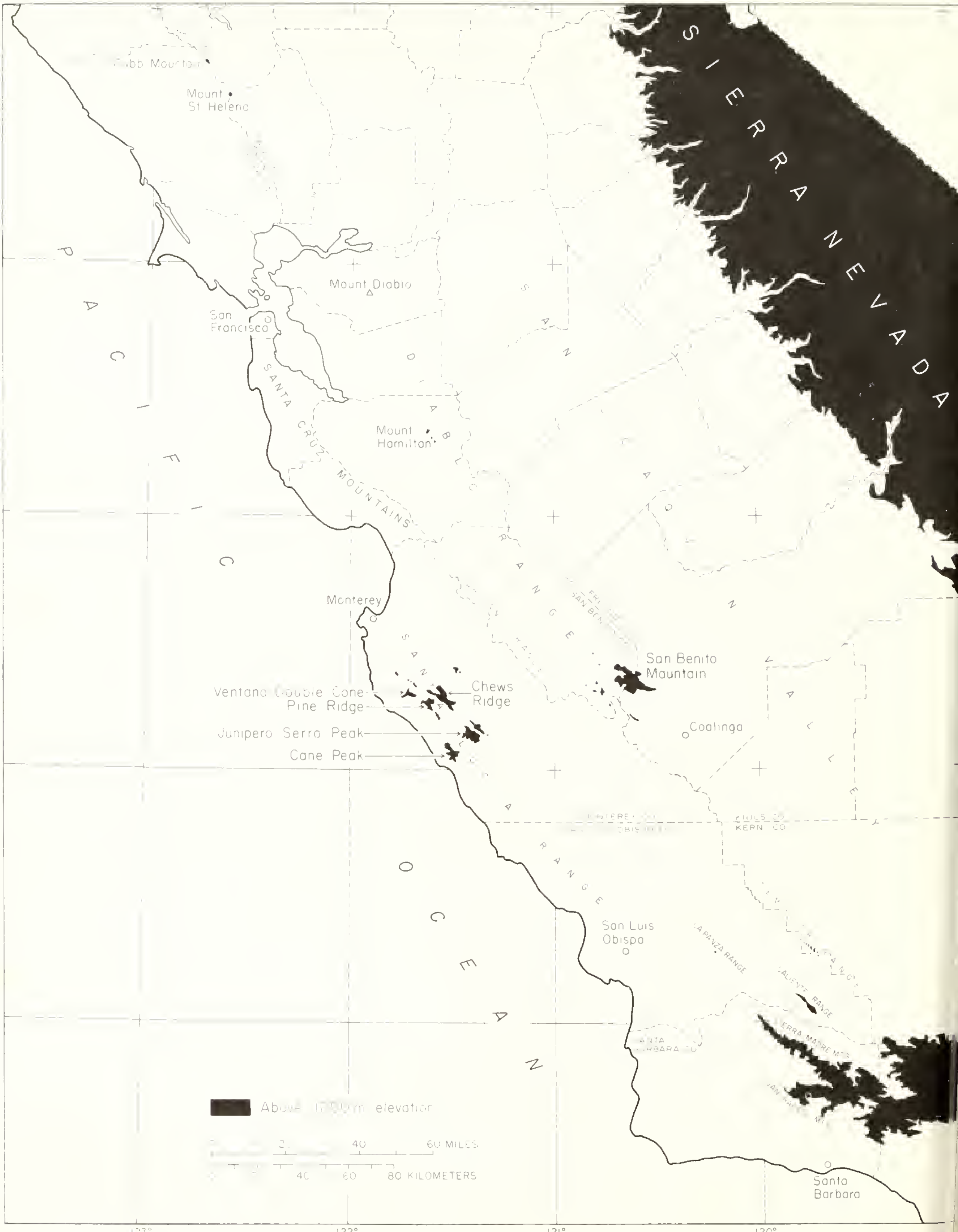


Figure 1—Distribution of montane areas above 1200 m (3937 ft) elevation in central California, and the relative locality of the six study peaks.

Plants on the Santa Lucia and Diablo Ranges of central California have received much taxonomic attention. Professional botanists started collecting along the primitive roads in 1830, and the more accessible spots have remained popular with plant collectors ever since. In recent decades, monographic studies on many genera have included a host of specimens from these mountains. The fund of geographic and ecological information, however, is still limited. Except for the most conspicuous trees, even general distributions for particular plants on specific peaks are poorly known.

This floristic survey is the initial step in a vegetation study that emphasizes the role of "montane disjuncts"–plants that are widely distributed in distant mountain regions, but have only isolated populations on these Coast Range peaks.

The summary of field observations and review of the literature and herbarium records is limited to higher elevations. Six geographically isolated and ecologically important peaks were selected. I confined the intensive search for plants to levels above the 1200-m (3937-ft) elevation. Separate records were kept on species growing between 1200 m and 1400 m (4593 ft) and those continuing above 1400 m. When plants present above 1200 m were noticed at lower elevations, they were also recorded. But data on species extensions below 1200 m are less complete.

The elevational orientation of the survey was prompted by the vegetation study. For a careful analysis of how the montane disjuncts fit into the local vegetation, it was desirable to have as much data as possible on elevational distributions. Although arbitrarily chosen, the 1200-m limit has some ecological merit. In practical terms, this lower limit eliminated much of the grassland, foothill woodland, and redwood forest floras–reducing the survey to a manageable size.

This paper reports the presence–or probable absence–of vascular plants on each of the study peaks. Plants listed in the literature, but which I could not find in the field, are also included. Elevational distributions for all species are suggested. To make the report more helpful to a diversity of users, individual species notes provide information on size, life form, plant community preferences, and other ecological features. Obvious taxonomic problems are summarized.

The scientific names follow Munz (1959, 1968) or later monographs. These are essentially the same names used by Howitt and Howell (1964, 1973). Common names were adapted from central California references: Little (1953) for all trees; Howitt and Howell (1964, 1973), Thomas (1961), and Twisselmann (1967) for most herbs and shrubs.

STUDY PEAKS

The northwestern Santa Lucia Range and the southeastern Diablo Range contain the most significant ridges above 1200-m elevation in the south Coast Ranges (*fig. 1*). These two mountain units, with scraps of coniferous forest on them , are far removed from the montane regions that support well-developed mixed conifer forest. The Santa Lucia and Diablo areas lie more than 320 km (200 miles) south of the sizable high ridges in the north Coast Ranges of Lake County. Both areas are more than 150 km (90 miles) north of the 1200 m high ridges of the Sierra Madre in Santa Barbara County. Forested slopes of the Sierra Nevada are about 130 km (80 miles) east of the Diablo Range across the San Joaquin Valley. The Santa Lucia Range in Monterey County has a number of peaks exceeding 1200 m. Five of the most prominent ridges were selected for study (*fig. 2, table 1*). All these study peaks are within the Monterey Ranger District, Los Padres National Forest. Geographic isolation between the peaks is minor; yet there are distinct climatic, floristic, and vegetational differences between them.

Cone Peak

An outstanding characteristic of Cone Peak is its dramatic proximity to the Pacific Ocean (*fig. 1, table 1*). Few spots in North America can boast of a mountain this tall so close to the coast. The geology includes exposures of ancient Pre-Cambrian rocks (*table 1*). Another attraction is the old-growth sugar pine forest along with many fine bristlecone fir colonies. The presence of these pines and firs may have prompted the officials at San Antonio Mission to send visiting European botanists there. In any case, Cone Peak did gain an interesting historical heritage with visits by David Douglas in March 1831 (Hooker 1836), Thomas Coulter in 1832 or 1833 (Coville 1895, Don 1837), Karl Theodor Hartweg in September 1847 (Hartweg 1848), and William Lobb in 1849 (Ewan 1973, Veitch 1900). Unfortunately, Douglas lost his valuable field notes in the Fraser River, and Coulter's notes seemed to have disappeared in Great Britain. No direct record of their work on Cone Peak is available except for several letters and their herbarium specimens.

Alice Eastwood was probably the first "California" botanist to collect on Cone Peak. In June 1893, she hiked from the Kirk Ranch (Sec. 35, T. 21S, R. 5E) to the Dani Ranch (Sec. 9, T. 22S, R. 4E), crossing the Cone Peak study area somewhere near the summit of the present Gamboa trail (Eastwood n/d). In her reminiscences of this trip, she mentioned sugar pine on the ridge. Eastwood (1897) later alluded to this Cone Peak population as "the only grove of *Pinus Lambertiana* now left in these mountains." Unfortunately, her original notes and specimens were lost in the 1906 San Francisco fire.

Willis L. Jepson crossed the ridge north of Cone Peak in June 1901, and his interesting field notes are

Figure 2—Location of five study peaks in relation to the 1200 m (3937 ft) elevation in the northwestern Santa Lucia Range, Monterey County, California. These peaks are covered on the Chews Ridge, Cone Peak, Junipero Serra Peak, Lopez Point, and Ventana Cones 7.5-minute U.S. Geological Survey quadrangles.

Table 1—*Physiographic and geologic information about the study peaks, Santa Lucia and Diablo Ranges, California*

	Distance from ocean	Maximum elevation	Contiguous area above 1200 m	Predominant rock types[1]
	km	*m*	*ha*	
Cone Peak	5.3	1571	2000	Pre-Cretaceous schist, some limestone outcrops, Cretaceous sandstone (1,2,4,5,13)
Ventana Double Cone	9.8	1479	450	Mesozoic granitics (1,3,6,7)
Junipero Serra Peak	17.7	1787	2200	Mesozoic granitics, Pre-Cretaceous schist (1)
Chews Ridge	18.8	1538	2600	Pre-Cretaceous schist, very small ultrabasic outcrops, Miocene sandstone (1,7)
Pine Ridge	11.7	1513	1100	Mesozoic granitics, Pre-Cretaceous schist, Mesozoic ultrabasic "lherzolite" with minor serpentinization (1,3,6,7)
San Benito Mtn.	85	1597	10000	Mesozoic ultrabasics with much highly sheared serpentine (8,9,10,11,12)

[1] Sources are noted as follows:

1. Hart (1966)
2. Reiche (1937)
3. Wiebe (1970a)
4. Wiebe (1970b)
5. Wyatt (1973)
6. Pearson and others (1967)
7. Fiedler (1944)
8. Forstner (1903)
9. Eckel and Myer (1946)
10. Walker and Griggs (1953)
11. Coleman (1957)
12. Coleman (1961)
13. Compton (1966)

still available (Jepson n/d). He went from the Avila Ranch (near Kirk's) to Dani's, probably on the same trail that Eastwood used. Jepson thought that this ridge must have been the point at which David Douglas first found sugar pine and bristlecone fir. Joseph Burtt-Davy also visited Cone Peak in June 1901.

The study area on Cone Peak included "Twin Peak" and "High Square Peak." "Arroyo Hondo" and "Big Creek" were names used in early notes on the area north of Cone Peak. They probably refer to the south fork of Devils Canyon on contemporary maps.

Ventana Double Cone

This peak in the Ventana Wilderness Area is characterized by extremely steep and rocky slopes. Ventana Double Cone was far too remote to attract early collectors. In 1901, Joseph Burtt-Davy collected in the Little Sur drainage and on "Ventana Cone," but he probably was not on the summit. A 1918 U. S. Forest Service map of the district still did not show a trail anywhere near the mountain. A 21-km (13-mile) hike is now required to reach the summit, and the main ridge has a single access trail with few spots where the traveler is tempted to leave the beaten path. This region remains one of the least botanically explored spots in the Santa Lucias.

Although somewhat further inland, Ventana Double Cone has floristic similarities with Cone Peak. Both share many rock outcrops and talus slope species. Ventana Double Cone is too rocky to have any well developed forest communities. The peak does support large numbers of scattered bristlecone firs. There is virtually no grassland on this ridge above 1200 m.

Junipero Serra Peak

Good astronomical observing conditions were an early attraction to Junipero Serra Peak (formerly called Santa Lucia Peak). Astronomers scratched a trail to the summit in January 1880 to observe a total eclipse of the sun (Davidson 1882). Eastwood (n/d) claimed that observations from the peak were also made on the transit of Venus in 1882. Interest in building an observatory on the summit continues to this day (Walker 1970).

In June 1893, Eastwood (n/d) climbed the "astronomer's trail" to what she described as the "top." Curiously, she did not mention the sugar pine forest on the summit in her reminiscences. In her note on Santa Lucia Range conifers, Eastwood (1897) stated that "*Pinus Lambertiana* is said to have been abundant formerly on the slopes of Santa Lucia Peak, and a few trees are yet left." For someone who claimed to have been on the summit, her statement is rather unsatisfactory. She also suggested that much timber was removed from "Santa Lucia Peak" for construction of Mission San Antonio (Eastwood 1897). I can find no basis for her claim.

William R. Dudley apparently collected plants on the mountain in May 1895. The unlogged sugar pine forest on Junipero Serra Peak was mentioned by Plummer and Goswell.[1] They did allude to some cutting of incense-cedars near the base of the peak, but gave no details. Jepson (n/d) visited the peak in September 1911.

Although by far the tallest of the Santa Lucia Range peaks, Junipero Serra Peak appears to have a drier climate than the others. No long-term weather data are available. Walker (1970), an astronomer who spent several seasons on the summit, measured 51 cm (19.9 inches) of rain plus 93 cm (36.6 inches) of snow during the 1965-66 season. In adjacent regions this was an "average" season. In the wet 1966-67 season he measured 100 cm (39.4 inches) of rain plus 304 cm (119.7 inches) of snow.

It is a steep hike of 10 km (6 miles) up to the summit. The traveler may wander around easily enough in the pine forest on top of the mountain, but the steep sides of the peak with dense chaparral discourage much collecting away from the trail. A vast area on the northern face of the mountain has not been botanically explored. The only "unmapped" spot on Hart's (1966) Monterey County geology map was in this region.

The large Pinyon Peak ridge just east of Junipero Serra Peak was not included in my survey. Pinyon Peak appears to be even drier than Junipero Serra Peak and has a rather limited selection of montane species.

[1] Sloane, N. H. 1914. *Resources and plan of operation of Monterey National Forest.* (Unpublished report on file, Los Padres National Forest, King City, Calif.)

Chews Ridge

William Brewer climbed the lower slopes of Chews Ridge in May 1861 (Brewer 1930). By 1890 Tassajara Hot Springs was accessible by road, and a few botanists stopped on the summit of Chews Ridge on their way down to the resort; e.g., A. D. E. Elmer in June 1901 and William R. Dudley in June 1911. Chews Ridge is now the only high peak in the Santa Lucia Range with a public road crossing the summit. Numerous collectors have been on the mountain in recent years.

Chews Ridge and the contiguous Miller Ridge have highly developed hardwood forest and mixed oak-Coulter pine communities in protected spots. One unique feature of this peak is the extensive savanna with large valley oaks (Griffin 1975). Chews Ridge is the only study peak with clear evidence of Indian activity on the summit. There are some bedrock mortars for grinding acorns in the savanna. Chews Ridge also has far more patches of open grassland or potreros than the other study peaks. A series of tiny ultrabasic outcrops on Chews Ridge provide habitat for several xeric species, but they support no real "serpentine" flora.

The Hastings Natural History Reservation of the University of California lies at the northern base of Chews Ridge. Intensive plant collecting has been conducted in this vicinity since 1937 (Griffin 1974b). The Hastings collections make the record of Chews Ridge plants growing below 1200 m more complete than for the other study peaks.

Pine Ridge

Pine Ridge lies within the Ventana Wilderness Area, some 13 km (8 miles) from Chews Ridge by trail. The trail has been used for a long time, but Pine Ridge still has received little botanical attention. This peak has the only extensive old-growth ponderosa pine forest above 1200 m in the Santa Lucia Range.

The 80-ha (200-acre) ultrabasic plug that outcrops on Pine Ridge provides an interesting "serpentine" habitat (*table 1*). This ultrabasic mass, however, is much less serpentinized than that on San Benito Mountain.

A group of marshy springs near Pine Ridge Camp adds a number of riparian species to the flora of this peak.

San Benito Mountain

Within the Diablo Range the highest mountain unit centers on the San Benito Mountain-Santa Rita Peak portion of San Benito and Fresno Counties (*fig.*

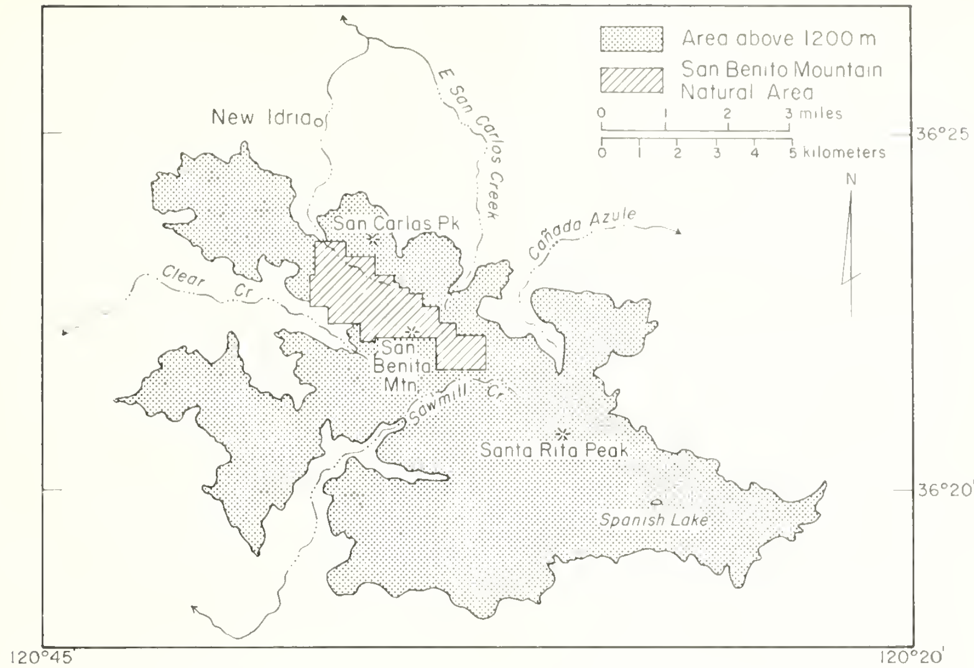


Figure 3—Distribution of area above the 1200 m (3937 ft) elevation in the San Benito Mountain study area of San Benito and Fresno Counties. This peak is covered on the Idria, San Benito Mountain, and Santa Rita Peak 7.5-minute U.S. Geological Survey quadrangles.

3). Most of this ridge is now administered by the Folsom District, U. S. Bureau of Land Management (Griffin 1974a). Between 1907 and 1916, however, this region was managed by the U. S. Forest Service as part of the Monterey National Forest.[2]

Much of the past and present interest in the region stems from its extreme mineralization (*table 1*). The study area included the upper portion of a highly sheared and altered ultrabasic plug which is some 22 km (14 miles) long and 6 km (4 miles) wide. The strange-looking landscape has huge patches of completely bare, "slickentite" serpentine.

In 1853, Mexican prospectors located the Aurora and New Idria mines here. Commercial exploitation of the New Idria mine came quickly, and it became the second most productive mercury producer in North America. The entire region has been intensely prospected for mercury, chromite, and—most recently—asbestos.

Forest habitats are less productive on San Benito Mountain than on any of the Santa Lucia peaks. In addition to the sterile serpentine soil, San Benito Mountain has a drier climate—perhaps half the precipitation of the driest Santa Lucia Range peak. Yet despite the lower rainfall, permanently flowing creeks are more obvious near the 1200-m level on San Benito Mountain than in the Santa Lucias.

William Brewer visited the mines and collected plants on San Benito Mountain in July 1861 (Brewer n/d, 1930). Much of my study area on the mountain was within the upper "San Carlos" region of Brewer's notes. Eastwood (n/d) collected plants between Hernandez and New Idria in May 1898, and William R. Dudley was in the area in late May 1899. Laura Lathrop, a student of Dudley's, collected extensively in the area in 1902-1903 (Elmer 1906). Jepson (n/d) crossed San Benito Mountain in May 1907, and his notes vividly portray the barren serpentine patches and the effect that logging for mine timbers had on the forest:

> The trees spoken of above are about 12 to 20 to the acre where there is stand. Great areas on the summits and ridge slopes are as barren as one's hand, not even herbaceous vegetation. These characteristic spots are rotting sliding shale rock ... The trees have been logged clean for the mines, even the 6-inch stuff taken for logging.

In recent times the main botanical activity in the region has been by those looking for "serpentine" endemic plant species, or by others interested in the hybridization of Jeffrey and Coulter pines.

[2] Plummer, Fred C., and M. G. Gowsell. 1905. *Forest conditions in the Monterey Forest Reserve, California.* Unpublished report on file, Los Padres National Forest, Goleta, Calif.)

SAMPLING METHODS

In my floristic survey, the forest communities—particularly the conifer stands—received the most attention. But I did collect in all types of vegetation and specialized habitats (*table 2*). Essentially all roads and trails above 1200-m elevation on each peak were visited. The more critical areas were sampled at several seasons during 2 different years. I left the trail system whenever topography and vegetation conditions permitted. Notes were taken on study peak species down to the 600-m (1968-foot) level. Elevations were determined with barometric altimeter and topographic maps.

Numerous trips were made to the Santa Lucia peaks between 1972 and 1974. Probably I visited the largest proportion of the landscape on Chews Ridge. On Pine Ridge the study area included South Ventana Cone, but the dense chaparral prevented sampling on the main summit. Ventana Double Cone received the fewest visits.

Tally (1974) also collected on the Santa Lucia study peaks, and the material he gave me contributed significantly to this survey. His collections on Ventana Double Cone were especially helpful.

In the San Benito Mountain region, my trips were scattered from 1971 until 1974. Here the area above 1200 m was too large to cover in detail even though the topography was more favorable than in the Santa Lucias. My greatest efforts were spent in and around the 600-ha (1500-acre) San Benito Mountain Natural Area which the U.S. Bureau of Land Management has established on the main ridge (*fig. 3*). The limited areas of high-elevation nonserpentine soil in the San Benito Mountain study area were not accessible, and the San Benito Mountain collections above 1200 m were essentially all on serpentine. Spanish Lake (*fig. 3*), a large serpentine vernal pool, added several species to the San Benito flora, but sampling of the aquatic species in this pond was not complete.

Table 2—*Conspicuous vegetation types and specialized habitats on the study peaks, Santa Lucia and Diablo Ranges, California*

Mixed Evergreen Forest
- Hardwood phases:
  - *Lithocarpus densiflorus* dominant
  - *Quercus chrysolepis* dominant
- Mixed phase:
  - *Quercus chrysolepis, Arbutus menziesii, Pinus coulteri*

Coniferous Forest
- (may have understory of Mixed Evergreen Forest)
- Nonserpentine phases:
  - *Pinus lambertiana* dominant
  - *Pinus ponderosa* dominant
- Serpentine phases:
  - *Pinus ponderosa, P. coulteri, Libocedrus decurrens*
  - *Libocedrus decurrens, P. coulteri, P. jeffreyi*

Savanna
- Grassland with scattered *Quercus lobata* and *Pinus coulteri*

Potrero
- Well-defined patches of open grassland within the Mixed Evergreen Forest

Chaparral
- Mixed phase:
  - *Arctostaphylos glandulosa, Quercus wislizenii* prominent
- Chamise phase:
  - *Adenostoma fasciculatum* dominant
- Serpentine phase:
  - *Quercus durata, Arctostaphylos glauca* prominent

Riparian Habitats
- Permanent creeks, permanent springs, seasonal seeps, vernal lakes

Rock Habitats
- Outcrops, talus slopes, serpentine bald spots

FLORA OF THE STUDY PEAKS

The study peaks cover a large area with diverse geology and topography, but they support only a modest number of plant species. On all six peaks I noticed only 421 native and 28 introduced species above 1200 m. These numbers may be compared with 465 native and 127 introduced species collected on the small 781-ha Hastings Reservation below Chews Ridge (Griffin 1974b).

Of the 421 native species above 1200 m, only 297 species apparently extend above 1400 m. Many of these species above 1400 m are rare or unimportant in the vegetation. Table 3 lists the number of species in several elevational groupings on each peak. The large number on Chews Ridge reflects a wide range of habitats, including the species-rich potreros. The more intensive sampling on this peak also influenced the number. The small number of species on Ventana Double Cone is largely the result of the steep, rocky nature of the entire summit and the lack of grassland. Additional visits would add to the list, but the peak would continue to have the fewest species.

Few species are confined to the ridgetops. In the

Santa Lucias the montane disjuncts *Chimaphila menziesii, Cycladenia humilis, Holodiscus microphyllus, Raillardella* (*muirii* ?), and *Sanicula graveolens* seem to have no significant populations below 1200 m. Most of the other montane forest disjuncts have broad elevational ranges. A few montane disjuncts in the Santa Lucias are found only below 1200 m. For example, the only colony of *Cornus nuttallii* is well below the study area on the east base of Cone Peak.

Although a large number of endemic plants are scattered about the south Coast Ranges, only a relatively few appear on the study peaks above 1200 m. Six Santa Lucia Range endemics which have substantial populations on the study peaks are: *Abies bracteata, Arctostaphylos hooveri, Galium californicum* spp. *luciense, Galium clementis, Lupinus abramsii,* and *Lupinus cervinus.* Some other Santa Lucia Range endemics such as *Chorizanthe vortriedei* probably have a few plants above 1200 m, but I did not find them.

Four Diablo Range endemics on San Benito Mountain are: *Camissonia benitensis, Fritillaria falcata, Layia discoidea,* and *Monardella benitensis.*

The flora of San Benito Mountain had a greater overlap with that of the Santa Lucia peaks than anticipated. San Benito Mountain had only 43 species that were not found above 1200 m on the Santa Lucia peaks. At least 10 of these species occur in the Santa Lucias at lower elevations. Some 50 of the more "mesic" plants of the Santa Lucia peaks seem to be absent from the southern Diablo Range, e.g., *Acer macrophyllum* and *Alnus rhombifolia.* But additional exploring on nonserpentine habitats above 1200 m in the Diablo Range would probably locate a few of these species.

The percentage of introduced species on these peaks seems to be relatively small (*table 3*). The majority of exotic plants are either trailside weeds or part of the grassland communities. One of the few introduced herbs appearing in the stable forest understory is *Galium aparine.*

Eight of the species on the study peaks have such a small total range that the California Native Plant Society (Powell 1974) and the Smithsonian Institution recognized them as rare and endangered plants: *Galium clementis, Galium californicum* spp. *luciense, Lupinus cervinus* and *Raillardella* (*muirii* ?) on the Santa Lucia peaks and *Camissonia benitensis, Fritillaria falcata, Layia discoides,* and *Monardella benitensis* on San Benito Mountain. All these species should receive some type of administrative protection. No species known to occur on the Santa Lucia peaks has become extinct, but one vandal could destroy all known plants of the *Raillardella* in a short time. On San Benito Mountain, one of the rare species may be extinct. I know of no report of *Fritillaria falcata* since Jepson's original discovery, although this lily survives in one other Diablo Range locality.

Some of the disjunct species—although common elsewhere in California—are endangered on the study peaks and should receive the same protection as the rare species. The tiny populations of *Cycladenia humilis* are a good example.

Table 3 –*Number of species on the study peaks (limited to plants occurring above 1200 m on at least one peak)*

	Cone Peak	Ventana Double Cone	Junipero Serra Peak	Chews Ridge	Pine Ridge	San Benito Mtn.
	Number of species					
Present above 1400 m:						
Native species	108	53	67	188	69	78
Introduced species	7	3	1	16	0	4
Present above 1200 m:						
Native species	152	84	146	267	177	137
Introduced species	10	4	5	22	9	14
Total species present above 600 m	223	140	267	353	219	196
Native taxa noted on only one peak	1	4	6	26	5	43
	Percent					
Introduced species above 1200 m	6	5	3	8	5	9

REFERENCES

Anderson, E., and G. L. Stebbins, Jr.
1954. Hybridization as an evolutionary stimulus. Evolution 8:378-388.

Baker, Milo S.
1953. Studies in western violets VII. Madroño 12:8-18.

Beetle, Dorothy E.
1944. A monograph of the North American species of *Fritillaria.* Madroño 7:133-159, illus.

Bowerman, Mary L.
1944. The flowering plants and ferns of Mount Diablo, California. 290 p., illus. Gillic Press, Berkeley, Calif.

Brewer, William H.
(n/d). Botanical notes 1860-1867–notes of the California State Survey. 521 p. [Copied from original notes in Gray Herbarium by A. V. Stubenrauch in 1897, bound volume on file Univ. Calif. Herbarium, Berkeley.]

Brewer, William H.
1930. Up and down California in 1860-1864: the journal of William H. Brewer. 601 p., illus. Yale Univ. Press, New Haven.

Brown, Carl
1972. A description of selected populations of *Pinus ponderosa* in central California. M.S. Thesis. Calif. State Polytechnic College, San Luis Obispo.

Clausen, Jens
1964. Cytotaxonomy and distributional ecology of western North American violets. Madroño 17:173-197.

Coleman, R. G.
1957. Mineralogy and petrology of the New Idria district, California. Ph.D. Thesis. Stanford Univ., Stanford, Calif. , C. D., 28, 53, 54, 70

Coleman, R. G.
1961. Jadeite deposits of the Clear Creek area, New Idria district, San Benito County, California. J. Petrol. 2:209-247.

Compton, Robert R.
1966. Granitic and metamorphic rocks of Salinan block, California Coast Ranges. Calif. Div. Mines and Geol. Bull. 190:277-287.

Coville, Frederick V.
1895. The botanical explorations of Thomas Coulter in Mexico and California. Bot. Gaz. 20:519-531, illus.

Critchfield, William B.
1971. Profiles of California vegetation. USDA Forest Serv. Res. Paper PSW-76, 54 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Davidson, George
1882. The total solar eclipse of January 11, 1880, observed at Mount Santa Lucia, California. p. 463-464. U.S. Coast and Geod. Surv. Annu. Rep. for 1882.

Dempster, Lauramay T., and G. Ledyard Stebbins
1968. A cytotaxonomic revision of the fleshy-fruited *Galium* species of the Californias and southern Oregon (*Rubiaceae*). Univ. Calif. Publ. Bot. 46:1-57, illus.

Dempster, Lauramay T., and G. Ledyard Stebbins
1971. The *Galium angustifolium* complex (*Rubiaceae*) of California and Baja California. Madroño 21:70-95.

Don, David
1837. Descriptions of five new species of the genus *Pinus;* discovered by Dr. Coulter in California. Linn. Soc. London Trans. 17:439-444, illus.

Eastwood, Alice
1897. The coniferae of the Santa Lucia Mountains. Erythea 5:71-74.

Eastwood, Alice
(n/d) Handwritten memoirs on file in the Eastwood Archives. Calif. Acad. Sci., San Francisco.

Eckel, Edwin B., and W. B. Myers
1946. Quicksilver deposits of the New Idria district, San Benito and Fresno Counties, California. Calif. J. Mines and Geol. 42:81-124, illus.

Elmer, A. D. E.
1906. New and noteworthy plants, III. Bot. Gaz. 41:309-326.

Ewan, Joseph
1973. William Lobb, plant hunter for Veitch and messenger of the Big Tree. Univ. Calif. Publ. Bot. 67:1-36, illus.

Fiedler, William Morris
1944. Geology of the Jamesburg quadrangle, Monterey County, California. Calif. J. Mines and Geol. 40:177-250, illus.

Forstner, Wm.
1903. The quicksilver resources of California. Calif. State Mining Bur. Bull. 27, 273 p., illus.

Griffin, James R.
1964. Cone morphology in *Pinus sabiniana.* J. Arnold Arbor. 45:260-273, illus.

Griffin, James R.
1965. Digger pine seedling response to serpentinite and nonserpentinite soil. Ecology 46:801-807, illus.

Griffin, James R.
1973. Valley oaks–the end of an era? Fremontia 1(1):5-9, illus.

Griffin, James R.
1974a. A strange pine and cedar forest in San Benito County. Fremontia 2(1):11-15, illus.

Griffin, James R.
1974b. Botanical resources of the Hastings Reservation, Monterey County. Madroño. 22:329-32.

Griffin, James R.
1975. Regeneration in *Quercus lobata* savannas, Santa Lucia Mountains, California. Amer. Mid Nat. (In press.)

Griffin, James R., and William B. Critchfield
1972. Distribution of forest trees in California. USDA Forest Serv. Res. Paper PSW-82, 114 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Hardham, Clare B.
1966. Three diploid species of the *Monardella villosa* complex. Leaflets West. Bot. 10:237-242.

Hart, Earl W.
1966. Mines and mineral resources of Monterey County, California. Calif. Div. Mines and Geol. County Rep. 5, 142 p., illus.

Hartweg, Theodor
1848. Journal of a mission to California in search of plants, IV. J. Hort. Soc. London 3:217-227.

Hawksworth, Frank G., and Delbert Wiens
1972. Biology and classification of dwarf mistletoes (*Arceuthobium*). USDA Handb. 401, 234 p., illus.

Heckard, Lawrence R.
1960. Taxonomic studies in the *Phacelia magellanica* polyploid complex. Univ. Calif. Publ. Bot. 32:1-123, illus.
Hooker, William Jackson
1836. A brief memoir of the life of Mr. David Douglas with extracts from his letters. Comp. Bot. Mag. 2:79-182.
Hoover, Robert F.
1970. The vascular plants of San Luis Obispo County, California. 350 p., illus. Univ. Calif. Press, Berkeley.
Howitt, Beatrice F., and John Thomas Howell
1964. The vascular plants of Monterey County, California. Wasmann J. Biol. 22:1-184, illus.
Howitt, Beatrice F., and John Thomas Howell
1973. Supplement to the vascular plants of Monterey County, California. 60 p., illus. Pacific Grove Museum of Nat. Hist. Assoc., Pacific Grove, Calif.
Jepson, Willis L.
(n/d) Field notebooks on file at Jepson Herbarium, University of California, Berkeley.
Jepson, Willis Linn
1925. A manual of the flowering plants of California, 1238 p., illus. Sather Gate Bookshop, Berkeley, Calif.
Keck, David D.
1957. Trends in systematic botany. In Survey of biological progress. V. 3:47-107. Acad. Press, New York and London.
Kruckeberg, A. R.
1958. The taxonomy of the speeies complex *Streptanthus glandulosus* Hook. Madrono 14:217-248.
Lewis, Harlan
1945. A revision of the genus *Trichostema*. Brittonia 5:376-403.
Little, Elbert L., Jr.
1953. Check list of native and naturalized trees of the United States (including Alaska). USDA Handb. 41, 472 p.
Little, Elbert L., Jr., and Francis I. Righter
1965. Botanical descriptions of forty artificial pine hybrids. USDA Tech. Bull. 1345, 47 p., illus.
Lonard, Robert I., and Frank W. Gould
1974. The North American species of *Vulpia* (Gramineae). Madrono 22:217-230.
McMinn, Howard E.
1939. An illustrated manual of California shrubs, 689 p., illus. J. W. Stacey, San Francisco.
Morrison, John L.
1941. A monograph of the section *Euclisia* Nutt. of *Streptanthus*. Ph.D. Thesis. Univ. Calif., Berkeley.
Munz, Philip A.
1959. The California flora. 1681 p., illus. Univ. Calif. Press, Berkeley.
Munz, Philip A.
1968. Supplement to a California flora. 224 p. Univ. Calif. Press, Berkeley.
Pearson, Robert C., Philip T. Hayes, and Paul V. Fillo
1967. Mineral resources of the Ventana Primitive Area, Monterey County, California. U.S. Geol. Surv. Bull. 1261-B, 42 p., illus.
Powell, W. Robert
1974. Inventory of rare and endangered vaseular plants of California. Calif. Native Plant Soc. Spec. Publ. 1, 56 p.
Raven, Peter H.
1957. Plant records from San Benito County, California. Leaflets West. Bot. 8:174-176.
Raven, Peter H.
1969. A revision of the genus *Camissonia* (Onagraceae). Contr. U.S. Natl. Herb. 37:161-396, illus.
Reiche, Parry C.
1937. Geology of the Lucia quadrangle, California. Univ. Calif. Dep. Geol. Sci. Bull. 24(7):115-168.
Reveal, James L.
1970. Additional notes on the California buckwheats (*Eriogonum*, Polygonaceae). Aliso 7:217-230.
Rydberg, Per Axel
1927. *Raillardiopsis.* North Amer. Flora (Corduales) 34(4):319-320.
Sharsmith, Helen K.
1945. Flora of the Mount Hamilton Range of California (a taxonomic study and floristic analysis of the vascular plants). Amer. Mid. Nat. 34:289-367, illus.
Sharsmith, Helen K.
1961. The genus *Hesperolinon* (Linaceae). Univ. Calif. Publ. Bot. 32:235-314.
Smith, Alan R.
1975. The California species of *Aspidotis.* Madroño 23:15-24, illus.
Solbrig, Otto T.
1965. The California species of *Gutierrezia* (Compositae-Astereae). Madrono 18:75-84, illus.
Stebbins, G. L., B. L. Harvey, E. L. Cox, J. N. Rutger, *et al.*
1963. Identification of the aneestry of an amphiploid *Viola* with the aid of paper chromatography. Amer. J. Bot. 50:830-839, illus.
Talley, Steven, N.
1974. The ecology of Santa Lucia fir (*Abies bracteata*), a narrow endemic of California. Ph.D. Thesis. Duke Univ., Durham, N.C.
Thomas, John Hunter
1961. Flora of the Santa Cruz Mountains of California. 434 p., illus. Stanford Univ. Press, Stanford, Calif.
Tucker, J. M.
1953. The relationship between *Quereus dumosa* and *Quercus turbinella.* Madroño 12:49-60.
Twisselmann, Ernest C.
1967. A flora of Kern County, California. Wasmann J. Biol. 25:1-395, illus.
Veitch, J.
1900. Manual of the conifers. 326 p., illus. J. Veitch and Sons, London.
Walker, George W., and Allen B. Griggs
1953. Chromite deposits of the southern Coast Ranges of California. Calif. Div. Mines Bull. 134(2):39-88, illus.
Walker, Merle F.
1970. The California site survey. Publ. Astron. Soc. Pac. 82(407):672-698, illus.
White, Keith L.
1966. Structure and composition of foothill woodland in central coastal California. Ecology 47:229-237, illus.
Wicklow, D. T.
1966. Further observations on serpentine response in *Emmenanthe.* Ecology 47:864-863, illus.

Wiebe, Robert A.
1970a. Relations of granitic and gabbroic rocks, northern Santa Lucia Range, California. Geol. Soc. Amer. Bull. 81:105-116.
Wiebe, Robert A.
1970b. Pre-Cenozoic tectonic history of the Salinan Block, western California. Geol. Soc. Amer. Bull. 81:1837-1842.
Wyatt, G. Gilbert
1973. Franciscan rocks near Sur Fault zone, northern Santa Lucia Range, California. Geol. Soc. Amer. Bull. 84:3317-3328.
Zobel, Bruce J.
1951a. The natural hybrid between Coulter and Jeffrey pines. Ph.D. Thesis. Univ. Calif., Berkeley.
Zobel, Bruce
1951b. The natural hybrid between Coulter and Jeffrey pines. Evolution 5:405-413.
Zobel, Bruce
1952. Jeffrey pine in the south Coast Ranges of California. Madroño 11:283-284.
Zobel, Bruce
1953. Geographic range and intraspecific variation in Coulter pine. Madroño 12:1-7, illus.

APPENDIX

Distribution of Plants

Key to Symbols

Three elevational zones on each peak are indicated by the numbers heading the columns:

1	above 1400 m	(4593 feet)
2	between 1200 m and 1400 m	(3937-4593 feet)
3	between 600 m and 1200 m	(1968-3937 feet)

Relative abundance of plant within an elevational zone is suggested by symbols:

C	COMMON in suitable, relatively widespread habitats
U	UNCOMMON or at least inconspicuous in widespread habitats
L	LOCAL in specialized habitats, such as wet spots or rock outcrops
R	RARE--only a few individuals seen in any habitat
+	recorded from the literature or a herbarium specimen; elevations usually estimated
.	not seen, but insufficient data are available to make a strong case for the plant's absence
-	probably absent; there are no records of the plant in the region and the most promising habitats are missing
*	introduced; usually ruderal or found in disturbed habitats

A few species which could not be readily distinguished in the field are combined for purposes of this tabulation. In most cases varieties or subspecies are not shown in this list, but they are described in the species notes.

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Abies bracteata	CCC	CCC	..U	.UC	CCC	---
Acer macrophyllum	RUU	..+	RUU	UUU	.UU	---
Achillea borealis	..U	..U	..C	UCC	.R.	CCC
Adenostoma fasciculatum	CCC	.CC	CCC	CCC	.CC	CCC
Agoseris grandiflora	UUU	..U	..C	UUC	R.U	UUU
Agoseris heterophylla	...	...	...	.UC	UU.	...
Agoseris retrorsa	.U.	...	..U	UUU	...	...
Agropyron parishii	..+	..U	...	CCC	.UU	...
Agropyron trachycaulon	---	---	---	---	...	LLL
Agrostis exarata	..L	...	..L	LLL	...	.L.
Aira caryophyllea *	...	...	..C	..C	.UU	...
Allium burlewii	R..	---	---	---	---	UUU
Allium campanulatum	...	...	R..	U..	UUU	...
Allium fimbriatum	---	---	---	---	...	UUU
Allophyllum divaricatum	...	...	...	.R.	...	...

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Allophyllum gilioides	.U.	..U	.UU	.UU	.R.	...
Alnus rhombifolia	..L	...	.LL	.LL	.LL	---
Amelanchier pallida	..L	...	...	RR.	...	...
Amsinckia intermedia	...	...	..U	.RC	...	..U
Antirrhinum multiflorum	.UU	..U	.UU	.UU	...	...
Apocynum pumilum	...	...	...	.UU	.UU	...
Aquilegia eximia	---	---	---	---	...	LLL
Aquilegia formosa	..L	...	..+	..L	.L.	...
Arabis breweri	LLL	L..	...	..+	...	...
Arabis glabra	..U	...	..U	UUC	.LU	...
Aralia californica	..L	...	..+	..L	.LL	---
Arbutus menziesii	CCC	CCC	.+U	CCC	CCC	---
Arceuthobium occidentale	R..	U..	U..	CCC	CCC	CCC
Arctostaphylos glandulosa	CCC	CCC	CCC	CCC	CCC	...
Arctostaphylos glauca	..C	...	.UC	.UC	...	CCC
Arctostaphylos hooveri	RUU	---	---	---	---	---
Arctostaphylos pungens	...	...	..U	...	...	CCC
Arenaria douglasii	UU.	..U	UUU	UUU	UUU	...
Arenaria macrophylla	...	.++	...	U..	...	...
Argemone munita	.R.	...	.R+	...	...	..U
Arnica discoidea	.R.	...	...	U..	..U	...
Artemisia douglasiana	..L	...	.LL	LLL	.LL	...
Artemisia dracunculus	...	...	..U	UUU	..L	..U
Asclepias californica	UUU	...	UU.	...	UU.	UUU
Asclepias eriocarpa	...	...	U.C	CCC	.U.	...
Asclepias fascicularis	...	...	..U	R.R	...	..+
Aspidotis carlotta-halliae	---	---	---	---	...	.+.
Aspidotis densa	---	---	---	---	LL.	...
Astragalus clevelandii	---	---	---	---	---	.+.
Astragalus gambelianus	...	...	...	.UC	...	..U
Astragalus purshii	---	---	---	---	---	UU+
Athysanus pusillus	...	...	..R	UUC	...	.U.
Avena barbata *	.U.	...	..U	UUC	...	..C
Avena fatua *	UCC	..U	.UC	CCC	..C	.UC
Barbarea orthoceras	...	...	...	.LL	..L	...
Berberis dictyota	...	...	..+	...	...	UUU
Berula erecta	...	...	...	.LL	.L.	...
Bloomeria crocea	..U	...	..C	..C	..U	UUU
Boschniakia strobilacea	...	...	...	...	...	UUU
Brickellia californica	.LL	...	..L	..L	...	...
Brodiaea lutea	...	..L	...	UCC	.UU	...
Brodiaea pulchella	UUC	R.U	.UC	CCC	UUU	..C
Bromus arenarius *	...	...	...	.UC	...	.UC
Bromus carinatus/marginatus	UUU	U.U	.UC	UUC	UUC	.UU
Bromus diandrus *	UUC	.UU	..C	UCC	.UU	.UC
Bromus grandis/laevipes	UUC	..U	.UC	CCC	UCC	.U.
Bromus mollis *	UCC	...	.UC	CCC	.UC	.UC
Bromus orcuttianus	R..	...	...	CU+	.UC	...
Bromus pseudolaevipes	...	...	...	.UR	...	...
Bromus rubens *	UUU	RUU	.UC	UUC	.UU	.UC
Bromus tectorum *	UU.	UUU	U.U	U.U	.UU	U..

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Calamagrostis rubescens	...	...	...	..L	.L.	...
Calandrinia ciliata	...	...	...	.UC	...	...
Calochortus albus	.UU	..L	..+	UCC	.CU	...
Calochortus invenustus	---	---	---	L.+	UU.	UU.
Calochortus splendens	...	...	..C	UUC	...	...
Calochortus venustus	...	...	...	...	...	RUC
Calycadenia truncata	...	...	...	UUU	...	...
Calyptridium monandrum	...	...	.R.	..U	...	...
Calyptridium parryi	...	...	..+	R..	...	LU.
Calystegia malacophylla	...	...	.UU	UUU	UUU	.UU
Camissonia benitensis	---	---	---	---	---	.U+
Camissonia contorta	...	..+	...	UUC	...	..+
Camissonia graciliflora	...	...	...	.RU	...	...
Camissonia hirtella	..U	.U.	.UU	UUU	...	.+U
Camissonia ignota	...	...	...	.UU	...	...
Camissonia luciae	...	...	...	.UU	...	...
Camissonia micrantha	...	...	.UU	..U	...	...
Capsella bursa-pastoris *	...	...	...	.RU	...	...
Carex alma	...	...	L.+	.LL	...	...
Carex bolanderi	...	...	...	..L	.L.	...
Carex globosa	UUU	.U.	...	.+U	.UC	...
Carex multicaulis	UUU	R.U	+..	UU+	UUU	...
Carex serratodens	...	...	..+	.LL	.L.	.L.
Carex subfusca	..+	...	..+	.++	...	...
Castilleja foliolosa	..U	...	R.U	..U	.R.	...
Castilleja miniata	---	---	---	---	---	LLL
Castilleja martinii	UU.	UUU	UUU	UC.	.U.	.UU
Castilleja stenantha	..+	...	..+	...	.L.	...
Ceanothus cuneatus/ramulosus	..U	UCC	.UC	..C	..C	CCC
Ceanothus foliosus	---	---	---	+..	---	---
Ceanothus integerrimus	UUU	...	CCC	CUU	.UU	RRU
Ceanothus oliganthus	UUC	.UU	...	.UU	UUC	---
Ceanothus papillosus	UUU	.UU	...	UUU	.UC	---
Centaurea melitensis *	.R.	...	..U	..U	...	UUC
Cerastium glomeratum *	...	...	..U	.RC	..U	...
Cercocarpus betuloides	UUC	...	.UC	UUU	...	UUC
Cheilanthes covillei	LL.	...	RL.	.LL	...	...
Cheilanthes gracillima	+..	...	...	...	.+.	---
Cheilanthes intertexta	L+.	LL.	+..	L..	...	...
Chenopodium album *	...	...	...	R.U	...	R..
Chimaphila menziesii	UU.	R..	...	...	...	---
Chlorogalum pomeridianum	..U	...	..C	UUC	..U	...
Chorizanthe douglasii	.UU	..U	..U	UUU	UU.	...
Chorizanthe membranacea	.U.	...	..U	.UU	...	...
Chorizanthe staticoides	..U	...	.UU	..U	...	...
Chrysopsis villosa	UUC	..C	..C	UUC	..C	..+
Chrsysothomnus nauseosus	RU.	R..	...	U.+	...	CCC
Cirsium californicum	UUU	...	.UU	UUU	UUU	...
Cirsium proteanum	...	...	...	..U	...	.UU
Clarkia bottae	...	..U	...	.UC	...	---

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Clarkia modesta	...	...	...	U.+	...	...
Clarkia purpurea	...	..U	...	UCC	...	.UU
Clarkia rhomboidea	.+.	...	...	R..	...	...
Clarkia unguiculata	.UU	...	..C	UCC	...	..C
Clematis lasiantha	.UU	..U	.UU	..U	...	..U
Clematis ligusticifolia	...	...	.L.	..L	.LL	...
Collinsia childii	..+	...	+..	UUU	.U.	...
Collinsia heterophylla	...	..U	..U	UUC	...	...
Collomia grandiflora	...	...	...	UUU	...	...
Collomia heterophylla	.UU	..U	...	.U+	.UU	...
Corallorhiza maculata	...	...	...	UUU	..U	---
Cordylanthus rigidus	UUU	UUU	.UU	UUU	U..	UUU
Corethrogyne filaginifolia	...	...	...	UUC	..U	...
Cornus occidentalis	...	...	...	.LL	...	...
Cryptantha clevelandii	...	..U	...	U.U	.U.	...
Cryptantha mariposae	---	---	---	---	---	U.+
Cryptantha muricata	UUU	.U.	.UU	UUU	...	...
Cuscuta californica	UU.	.UU	...	UUU	.U.	.UU
Cycladenia humilis	U..	---	U..	---	---	---
Cynoglossum grande	..U	...	...	.UC	..U	---
Cystopteris fragilis	...	...	...	.UU	.UU	---
Datisca glomerata	..L	...	..+	.LL	.LL	...
Delphinium nudicaule	.LL	...	...	..+	...	...
Delphinium parryi	.UU	...	..U	U.U	..+	..U
Delphinium patens	...	...	..+	.UC	.R.	R.U
Dendromecon rigida	.UU	...	+UU	..+	...	...
Dentaria integrifolia	...	...	...	..C	.R.	UUU
Deschampsia elongata	..L	...	..+	L.L	..L	...
Dicentra chrysantha	R.+	...	..+	..+	...	..R
Disporum hookeri	...	..U	...	RU.	.UU	---
Dryopteris arguta	..U	..L	..U	.UU	..U	---
Dudleya cymosa	LLL	L..	.LL	..L	.LL	...
Eburophyton austinae	..+	..R	...	...	.RR	---
Eleocharis acicularis	...	...	...	...	...	L..
Eleocharis parishii	...	...	...	...	...	L..
Elymus glaucus	UUC	U.C	.UC	UCC	UCC	.UU
Elymus triticoides	...	...	...	..L	...	.L.
Emmenanthe penduliflora	...	...	.R.	..U	...	.R+
Epilobium minutum	.U.	.UU	...	U.U	UU.	.UU
Epilobium paniculatum	...	...	...	U.C	...	..+
Epilobium watsonii	...	...	...	.L.	.L.	...
Epipactis gigantea	...	...	.L.	...	...	---
Equisetum laevigatum	..L	...	.LL	..U	.LL	...
Equisetum telmateia	...	...	...	..L	.L.	...
Eriastrum densifolium	...	...	UUU	UUU	...	...
Erigeron foliosus	UU.	...	.UU	UUU	..U	...
Erigeron petrophilus	LL.	UU.	...	...	...	...
Eriodictyon californicum	UUU	.UU	.UU	UUU	UUU	.UU
Eriodictyon tomentosum	..+	...	.UU	UUU	...	..U
Eriogonum covilleanum	...	...	...	...	...	.C.

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Eriogonum davidsonii	U..	...	.U.	.U.	UU.	CC.
Eriogonum elongatum	UUU	...	.UU	.UU	...	...
Eriogonum fasciculatum	CCC	UU.	UUC	UUU	...	..U
Eriogonum gracile	U..	...	..+	UUU	.U.	CC.
Eriogonum hirtiflorum	...	...	.++	+..	...	...
Eriogonum nudum	..U	..U	..U	UUU	UUU	..C
Eriogonum saxatile	L..	L..	L..	..+	...	...
Eriogonum spergulinum	...	...	+..	...	...	...
Eriogonum umbellatum	---	---	---	---	UU.	CC.
Eriophyllum confertiflorum	CCC	UUC	UCC	UUC	UUC	.CC
Erodium cicutarium *	.UU	...	..C	UCC	...	.UC
Eryngium aristulatum	...	...	...	...	...	L..
Erysimum capitatum	.U.	...	..U	UUU	...	CCC
Eschscholzia californica	.UU	...	...	UUC	.RU	.UU
Festuca rubra	...	...	...	...	.L.	---
Filago californicum	...	...	.UC	.UU	...	..U
Filago gallica *	...	...	...	..C	.U.	...
Fremontodendron californicum	...	...	..U	...	...	UUU
Fritillaria falcata	---	---	---	---	---	.+.
Fritillaria lanceolata	...	...	...	U.U	UU.	...
Fritillaria viridea	---	---	---	---	...	UUU
Galium andrewsii	...	...	..U	...	...	UUU
Galium angustifolium	UUU	U..	UUU	UUU	...	..U
Galium aparine *	...	..U	.RU	UCC	.UU	.UU
Galium californicum s. flaccidum	UCC	UUC	..U	CCU	.UC	...
Galium californicum s. luciense	UUU	RR.	---	---	---	---
Galium clementis	UUR	UU.	U..	---	---	---
Galium nuttallii	UUC	.U.	.UC	UUC	.U.	.UC
Garrya flavescens/congdoni	UUU	.U.	UUU	RR.	...	UUU
Gayophytum heterozygum	...	...	+..	UU.	..U	...
Gilia achilleaefolia	...	...	..U	UUU	...	...
Gilia clivorum	...	...	...	.UC	...	..U
Gilia splendens	.UU	.UU	.U.	UU.	...	...
Gilia tenuiflora	.++	...	...	..U	...	...
Gnaphalium beneolens	UUU	...	.UU	UUU	.U.	...
Gutierrezia bracteata	...	...	..+	...	...	.R+
Habenaria elegans	RUU	...	...	UUU	.UU	...
Haplopappus squarrosus	LLL	...	..U	..U	...	...
Helenium puberulum	...	...	...	..L	...	.LL
Hemitomes congestum	...	.R.	...	...	...	---
Hemizonia paniculata	...	...	...	...	...	.U.
Heracleum maximum	...	...	...	.L.	.LL	---
Hesperolinon disjunctum	---	---	---	---	---	.UU
Hesperolinon micranthum	---	---	..+	..R	UU.	---
Heteromeles arbutifolia	.UC	...	.UC	.UC	...	..C
Hieracium albiflorum	CU.	U..	...	..R	CCC	---
Hieracium argutum	..U	.UU	.UU	.LL	.UU	...
Holodiscus discolor	...	...	R..	.UC	...	---
Holodiscus microphyllus	U..	R..	...	...	...	---
Hordeum californicum	...	...	..U	R.U	...	..R

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Hordeum glaucum *	...	...	...	..U	...	.UU
Hulsea heterochroma	.+.	...	R.+	.R.	...	...
Hypericum formosum	...	...	.LL	...	.L.	...
Juncus bufonius	..L	...	..U	L.U	...	...
Juncus effusus	...	...	...	.LL	...	...
Juncus patens	...	...	..+	L.L	...	...
Juncus rugulosus	...	...	.L+	.LL	...	...
Juniperus californica	---	---	---	---	---	.RU
Koeleria macrantha	R..	...	...	UUC	UUU	.U.
Lactuca serriola *	...	...	..U	..U	...	.R.
Lathyrus vestitus	UUU	.UC	.UU	UUU	.UU	...
Layia discoidea	---	---	---	---	---	UUU
Lepechinia calycina	...	...	.U+	UUU	...	...
Lewisia rediviva	...	...	...	...	...	R..
Libocedrus decurrens	RUL	---	UUL	---	CCU	CCU
Lilium pardalinum	..L	...	L..	...	.L.	...
Linanthus ambiguus	---	---	---	---	...	.UU
Linanthus androsaceus	UUU	...	..U	CCC	CC.	.CC
Linanthus androsaceus s. lutens	...	...	...	UU.	...	...
Linanthus ciliatus	..R	...	...	.UU	...	...
Linanthus liniflorus	..U	...	..U	U..	.U.	...
Linum lewisii	---	---	---	---	...	UUU
Lithocarpus densiflorus	CCC	CCC	..+	CCC	CCC	---
Lithophragma affine	...	...	...	U.C	..U	..C
Lithophragma heterophylla	..U	..U	..U	UUU	.UU	..U
Lomatium dasycarpum	...	...	..U	..C	.U.	.UU
Lomatium macrocarpum	...	...	...	U..	UU.	U.U
Lonincera hispidula	...	R..	...	...	...	---
Lonicera interrupta	CCC	UUU	UUC	UUC	.UU	...
Lonicera subspicata	...	...	...	..R	...	.UC
Lotus argophyllus	UUU	U..	U.U	UUU	UU	...
Lotus crassifolius	.UU	UUU	UUU	UU.	.U.	...
Lotus grandiflorus	.+.	UUU	UUU	U.U	...	...
Lotus humistratus	U..	...	..U	UUU	UU.	UUU
Lotus micranthus	.UU	..U	..U	.UC	.U.	...
Lotus oblongifolius	...	...	.LL	..+	.L.	...
Lotus purshianus	...	...	..U	UUC	.U.	...
Lotus scoparius	.UU	..U	UUU	UUC	.U.	...
Lotus strigosus	UUU	...	.UU	UUC	.U.	...
Lotus subpinnatus	...	...	...	.UC	..	..C
Lupinus abramsii	CCC	UUU	...	CCU	UUU	---
Lupinus albifrons	...	...	RRU	..+	...	UUU
Lupinus bicolor	.UU	...	..C	.CC	...	...
Lupinus cervinus	UUU	UU.	U.+	..+	.R.	---
Lupinus formosus	...	...	..U	UUU	U.U	...
Lupinus hirsutissimus	...	..L	.LL	..L	...	...
Lupinus nanus	..U	..C	..C	.CC	...	...
Madia elegans	.UR	..C	+.C	UCC	U.U	...
Madia exigua	...	...	..+	..U	.U.	...
Madia gracilis	...	...	..C	UUC	.U.	...

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Madia madioides	...	...	..+	.UU	.U.	...
Malacothrix floccifera	...	...	..+	..U	...	CCC
Malacothrix saxatilis	.L.	...	.L.	...	...	...
Marah fabaceus	.UU	..U	.UC	UUC	.U.	..U
Medicago polymorpha *	...	...	..C	.UU	..	..U
Melica californica	...	...	..U	U.U	...	.UU
Melica geyeri	...	...	...	R..	...	---
Melica harfordii/aristata	UUU	..U	...	UU.	.U.	---
Melica imperfecta	UUU	UUU	.UU	UUU	.UU	..U
Melica stricta	---	---	---	---	---	.R.
Melica torreyana	...	...	...	...	...	L..
Mentzelia gracilenta	...	...	...	...	...	.UU
Mentzelia laevicaulis	...	...	...	...	...	U.U
Mentzelia micrantha	...	...	.UU	..U	...	...
Mentzelia pinetorum	...	...	.++	+..	...	...
Mentzelia veatchiana	...	...	...	R..	...	...
Micropus californicus	...	...	...	..U	.U.	...
Microseris linearifolia	...	..U	.UC	.UC	...	.UU
Microsteris gracilis	...	...	...	UUC	...	.UU
Mimulus bifidus	CCC	UCC	UCC	CCC	.CU	---
Mimulus cardinalis	...	...	..+	.L.	...	...
Mimulus floribundus	...	..L	LLL	LLL	.LL	...
Mimulus fremontii	...	...	...	.UU	...	UUU
Mimulus guttatus	...	...	.LL	LLL	..L	LLL
Mimulus pilosus	...	...	..+	...	...	L..
Mimulus subsecundus	UU.	UUU	+..	...	UU.	...
Mollugo verticillata *	...	...	...	...	..	L..
Monardella benitensis	---	---	---	---	---	CCC
Monardella douglasii	---	---	---	---	...	UUU
Monardella villosa	UUU	..C	CCC	CCC	UUU	---
Montia perfoliata	.UU	.UU	.UC	UCC	UUU	.UU
Montia spathulata	...	...	...	U.U	.R.	.UU
Muhlenbergia asperifolia	---	---	---	---	---	.LL
Navarretia mellita	...	...	...	U.U	...	...
Navarretia pubescens	---	---	---	---	---	.UU
Nemacladus secundiflorus	...	...	.+.	...	...	...
Nemophila menziesii	..U	...	..C	UUC	..U	.U.
Nemophila parviflora	.++	...	...	..C	...	...
Nemophila pulchella	...	...	...	.UC	...	...
Nicotiana attenuata	---	---	---	---	---	+..
Oenothera hookeri	...	...	.L.	...	...	...
Orobanche bulbosa	..R	...	.R.	..R	...	...
Orobanche fasciculata	..R	...	...	RRU	...	.U+
Orthocarpus purpurescens	UUU	...	..C	UUC	UU.	..C
Osmaronia cerasiformis	...	...	...	.RU	...	---
Osmorhiza brachypoda	...	...	...	UUU	.UU	...
Osmorhiza chilensis	..U	..U	.UU	UUU	UUU	...
Parnassia palustris	...	...	..+	...	...	.LL
Pedicularis densiflora	CU.	...	...	..C	..C	..U
Pellaea andromedaefolia	.RU	..U	.UC	.UU	..U	...

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Pellaea mucronata	UUU	UU.	CCC	UUC	UU.	...
Penstemon breviflorus	CCC	UCC	CCC	CCC	.CU	..U
Penstemon centranthifolius	CCC	..C	CCC	CCC	...	..C
Penstemon corymbosus	LL.	LL.	...	..+	.R.	...
Penstemon grinnellii	...	...	...	UU.	...	RR.
Penstemon heterophyllus	UUU	...	..U	UUU	..U	.U.
Phacelia brachyloba	...	...	.U.	R.U	...	...
Phacelia curvipes	...	...	...	+..	...	...
Phacelia distans	...	...	...	.RU	...	..+
Phacelia divaricata	---	---	---	---	---	.U.
Phacelia douglasii	UUU	...	..U	.UU	.U.	...
Phacelia egena/imbricata	UUU	.UU	.UU	UUU	UUU	UUU
Phacelia grisea	.R.	.RR	..+	...	...	...
Phacelia malvaefolia	UUU	UU.	...	.UU	...	...
Phacelia ramosissima	...	...	...	UUU	...	...
Phoradendron juniperinum	...	---	...	---	...	UUU
Phoradendron villosum	UUU	...	.UU	.UU	..R	UUU
Pinus attenuata	.UC	...	..U	---	---	---
Pinus coulteri	CCC	CCC	CCC	CCC	CCC	CCC
Pinus jeffreyi	---	---	---	R--	---	UUU
Pinus lambertiana	CCC	---	CU.	---	---	---
Pinus ponderosa	.UC	.U.	---	RUU	CCC	---
Pinus sabiniana	---	---	..C	---	---	UCC
Pityrogramma triangularis	UUU	..U	..C	RUC	UUU	...
Plagiobothrys nothofulvus	..U	...	...	.UC	...	...
Poa annua *	...	...	..L	L.U	...	...
Poa howellii	...	R..	...	...	...	...
Poa scabrella	UUU	.UU	..C	UUC	UUU	.UU
Polygala californica	...	...	...	...	.UU	---
Polypodium californicum	LLL	.L.	..L	.LL	.L.	---
Polypogon monspeliensis *	...	...	...	LLL	...	...
Polystichum munitum	UUC	UCC	UUU	UUU	UUU	---
Potentilla glandulosa	..U	..U	U.U	UUU	.UU	...
Prunus emarginata	UU.	...	...	..+	.R.	...
Prunus virginiana	...	...	..L	UUU	..L	+ .
Psoralea californica	---	---	---	---	---	UUU
Psoralea macrostachya	..L	...	.L.	.LL	.LL	...
Psoralea orbicularis	...	...	..+	.LL	.L.	...
Psoralea physodes	...	..L	..+	UUU	.R.	...
Pteridium aquilinum	UUU	.UU	UUU	CCC	UUC	---
Pterostegia drymarioides	...	..U	.UU	.UU	...	...
Pyrola picta	...	...	+..	...	...	---
Quercus agrifolia	..C	..C	..C	.UC	..U	...
Quercus chrysolepis	CCC	CCC	CCC	CCC	CCC	RUU
Quercus douglasii	..U	---	..C	..C	..U	.UC
Quercus durata	---	---	---	---	---	CCC
Quercus kelloggii	..C	.U.	..R	UCC	.CC	---
Quercus lobata	..U	---	..C	CCC	---	..C
Quercus turbinella/dumosa	..U	---	.UC	..U	---	.UC
Quercus wislizenii	.CC	.CC	CCC	CCC	CCC	..U

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Raillardella (muirii?)	---	R..	---	---	---	---
Rafinesquia californica	...	...	.R.	..U	...	...
Ranunculus californicus	...	...	..C	UUC	..U	..U
Ranunculus hebecarpus	...	...	..U	.UU	...	...
Rhamnus californica	CCC	UUU	CCC	CCC	CCC	UUC
Rhamnus crocea	UUU	RU.	UCC	UUC	.UC	UUU
Rhus diversiloba	UCC	.UC	.UC	UCC	UCC	RUC
Ribes roezlii	...	...	U..	UR.	.RL	---
Rigiopappus leptocladus	...	...	...	.UU	.U.	...
Rosa californica	..L	...	..L	.LL	.LL	...
Rubus parviflorus	..L	..L	...	...	.R.	---
Rubus ursinus	..L	..L	.LL	.LL	.LL	...
Rumex acetosella *	...	...	..U	U.U	..U	...
Rumex conglomeratus *	...	...	...	U.U	...	...
Rumex salicifolius	...	...	...	R.L	...	...
Salix breweri	---	---	---	---	---	LLL
Salix sp.	..L	...	.RL	.RL	..L	..L
Salvia columbariae	UUU	..U	.UU	UUU	...	..U
Sambucus mexicana	UUU	.UU	UUU	UUU	UUU	...
Sanicula crassicaulis	..U	..C	.UC	UUC	.UU	...
Sanicula graveolens	...	...	...	...	RR.	---
Satureja mimuloides	..+	...	.L+	..L	...	...
Scirpus microcarpus	...	...	...	..L	.L.	...
Sedum spathulifolium	..+	LL.	...	...	...	...
Selaginella bigelovii	LLL	LLL	..L	LLL	LL.	...
Silene gallica *	...	...	..U	.UC	.U.	...
Silene lemmonii	...	...	U.+	UU.	UUU	...
Silene verecunda	...	...	..+	R.R	.R.	R.U
Sisyrinchium bellum	...	...	..U	..C	...	LLL
Sitanion hystrix	...	...	+..	...	.R.	UUU
Sitanion jubatum	UU.	..U	..U	CCC	UUU	UUU
Solanum umbelliferum	.UU	.U.	UU.	UUC	...	..U
Solidago californica	UUU	UUU	.UU	UUU	.UU	...
Solidago guiradonis	---	---	---	---	---	LLL
Stachys bullata	..U	..U	.UC	UCC	.U.	...
Stachys pycnantha	..L	...	.L+	.LL	..L	.L.
Stellaria media *	...	...	..U	.UU	..U	...
Stellaria nitens	...	...	...	..U	...	.UU
Stephanomeria elata	..U	...	...	.U.	...	...
Stephanomeria virgata	.U.	...	..U	.UU	...	..U
Stipa cernua	...	...	..+	..U	...	.UU
Stipa coronata	LLL	...	.LL	.LL	...	...
Streptanthus brewerii	---	---	---	---	---	.+.
Streptanthus glandulosus	..+	...	...	UUU	UU.	...
Streptanthus insignis	---	---	---	---	---	.+U
Streptanthus tortuosus	LL.	U..	...	...	...	---
Stylocline gnaphalioides	...	...	...	..U	.U.	...
Symphoricarpos mollis	RR.	..U	..U	UUU	.UU	...
Tauschia hartwegii	..U	...	UUU	UUU	.U.	...
Thelypodium lasiophyllum	...	.R.	.U.	..U	...	...

Species	Cone Peak 123	Ven. Doub. Cone 123	Jun. Serra Peak 123	Chews Ridge 123	Pine Ridge 123	San Benito Mtn. 123
Thermopsis macrophylla	..L	..U	...	R.U	CCC	...
Thysanocarpus curvipes	..U	...	..U	UCC	...	..C
Thysanocarpus laciniatus	...	...	.R.	..U	...	...
Trichostema lanatum	.UU	...	.UU	..U	...	...
Trichostema rubisepalum	---	---	---	---	---	.LL
Trifolium albopurpureum	.U.	...	..U	UUC	.U.	...
Trifolium ciliolatum	...	...	...	.UU	.U.	...
Trifolium gracilentum	...	...	..C	.UC	...	...
Trifolium microcephalum	.U.	...	..C	.UC	.U.	...
Trifolium tridentatum	...	...	..U	UUC	.U.	...
Trifolium variegatum	.U.	...	..U	UUC	...	...
Triodanis biflora	...	...	...	..U	...	L..
Umbellularia californica	CCC	.CC	UUU	CCC	CCC	---
Urtica holosericea	...	...	...	.LL	.LL	...
Urtica urens *	...	...	...	+.U	...	...
Verbena lasiostachys	...	...	..U	UUU	...	..U
Vicia americana	...	...	...	UUU	...	...
Viola purpurea ssp. mohavensis	---	---	---	L..	UU.	UU.
Viola purpurea ssp. purpurea	...	...	UR.	...	...	---
Viola quercetorum	RRU	...	..C	UUU	UUU	UUU
Vulpia bromoides *	U.+	...	...	UUU	...	..C
Vulpia microstachys	UU+	UUU	..U	UUU	UU.	UUU
Vulpia myuros *	UU.	UUU	..C	UUC	.U.	.UC
Woodwardia fimbriata	..L	...	LLL	.LL	.LL	---
Wyethia helenioides	...	...	...	UUU	...	...
Yucca whipplei	UUC	UUU	UCC	CCC	UUC	.UC
Zauschneria californica	UUU	.UU	U.U	UCC	..U	..C
Zigadenus fremontii	...	...	...	..U	UUU	...
Zigadenus venenosus	...	...	..+	...	...	.LL

Plants of the Study Peaks

Abies bracteata D. Don, bristlecone fir or Santa Lucia fir (*Pinaceae*).

Evergreen tree, conspicuous on fire resistant habitats. The Griffin and Critchfield (1972) distribution map omitted a small stand on the north slope of Junipero Serra Peak. Talley (1974) has conducted a detailed study of the ecology of this fir. SANTA LUCIA RANGE ENDEMIC.

Acer macrophyllum Pursh, bigleaf maple (*Aceraceae*).

Deciduous tree, mostly riparian, but at all elevations scattered maples grow in shady ravines without any surface water.

Achillea borealis Bong. ssp. *californica* (Pollard) Keck, yarrow (*Compositae*).

Perennial herb, scattered in parts of the open forest and savanna. On San Benito Mountain yarrow grows abundantly in the creeks, less commonly on the dry serpentine uplands.

Adenostoma fasciculatum H. & A., chamise (*Rosaceae*).

Evergreen, burl-forming shrub, dominates the driest chaparral slopes, usually on south aspects.

Agoseris grandiflora (Nutt.) Greene, large-flowered agoseris (*Compositae*).

Perennial herb, scattered in open forest and savanna.

Agoseris heterophylla (Nutt.) Greene, mountain dandelion (*Compositae*).

Annual herb, in savanna and grassland.

Agoseris retrorsa (Benth.) Greene, spear-leaved agoseris (*Compositae*).

Perennial herb, scattered in open forest and savanna, less common than *A. grandiflora*.

Agropyron parishii Scribn. & Sm., Parish wheatgrass (*Gramineae*).

Perennial bunchgrass, widely scattered in open forest, locally abundant on edges of the Chews Ridge savanna. As Hoover (1970) suggested, var. *laeve* Scribn. & Sm. is not a useful taxon locally; many plants with long awns and glabrous nodes fit var. *laeve*, but other plants in the same population may have long awns and pubescent nodes; few local plants have consistently short awns. The study peaks are near the northern limit for this species in the Coast Ranges.

Agropyron trachycaulon (Link) Malte, slender wheatgrass (*Gramineae*).

Perennial grass, common along the serpentine creeks of San Benito Mountain. This grass has not been reported from Monterey County, at least not under this name; it might be present on serpentine, for it appears to grow on serpentine in San Luis Obispo County (Hoover 1970) and San Mateo County (Thomas 1961).

Agrostis exarata Trin., spike bent (*Gramineae*).

Perennial bunchgrass, local in wet spots; the two local varieties may be partially separated geographically: (1) var. *exarata* without awns, noticed only on Chews Ridge; (2) var. *pacifica* Vasey with conspicuous awns, more widely distributed, particularly at lower elevations.

Aira caryophyllea L., silver hairgrass (*Gramineae*).

Small annual grass, minor weed in grassland. INTRODUCED.

Allium burlewii A. Davids., Burlew onion (*Amaryllidaceae*).

Bulb, not reported in the Santa Lucia Range until 1972, when Steven Talley found it on a talus slope within the sugar pine forest on Cone Peak. Raven (1957) found the northern-most outpost of this southern Sierra Nevada and southern California species on San Benito Mountain. DISJUNCT, next population to south is in the Sierra Madre, Santa Barbara County. 3/

Allium campanulatum Wats., Sierra onion (*Amaryllidaceae*).

Bulb, locally common on serpentine outcrops on Chews Ridge and Pine Ridge but not confined to serpentine. DISJUNCT, next population to south in the Sierra Madre, Santa Barbara County. 3/

3/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Allium fimbriatum Wats. var. *diabolense* Ownbey & Aase, fringed onion (*Amaryllidaceae*).

Bulb, locally common on serpentine on San Benito Mountain, present on lower elevation serpentine in the Santa Lucias, but not noticed on Pine Ridge serpentine.

Allophyllum divaricatum (Nutt.) A. & V. Grant, (*Polemoniaceae*).

Annual herb, rare above 1200 m in disturbed spots.

Allophyllum gilioides Benth.) A. & V. Grant, straggling-gilia (*Polemoniaceae*).

Annual herb, uncommon in disturbed spots.

Alnus rhombifolia Nutt., white alder (*Betulaceae*).

Deciduous tree, important riparian tree at lower elevations but uncommon along creeks above 1200 m.

Amelanchier pallida Greene, service berry (*Rosaceae*).

Tall deciduous shrub, uncommon in shady ravines or creek bottoms.

Amsinckia intermedia F. & M., common fiddleneck (*Boraginaceae*).

Annual herb, very minor plant in the grassland.

Antirrhinum multiflorum Penn., sticky snapdragon (*Scrophulariaceae*).

Tall short-lived perennial, widely scattered in disturbed spots in the chaparral but never common.

Apocynum pumilum (Gray) Greene, dogbane (*Apocynaceae*).

Perennial herb, not reported in Monterey County until 1972, when I found it in open pine forests on Chews Ridge, Pine Ridge, and Little Pines, probably scattered elsewhere in the Santa Lucias in pine forests. Rare elsewhere in the south Coast Ranges (Hoover 1970, Thomas 1961).

Aquilegia eximia Van Houtte, Van Houtte columbine (*Ranunculaceae*).

Perennial herb, common on all the San Benito Mountain creeks, scattered on serpentine wet spots in the south Coast Ranges (Hoover 1970, Sharsmith 1945, Thomas 1961), but not yet reported for the northern Santa Lucias.

Aquilegia formosa Fisch., crimson columbine (*Ranunculaceae*).

Perennial herb, local in non-serpentine wet spots. Two varieties are reported in Monterey County, the Pine Ridge plants are viscid pubescent and fit var. *hypolasia* (Greene) Munz. (Howitt and Howell 1973).

Arabis breweri Wats. var. *breweri*, Brewer rockcress (*Cruciferae*).

Low perennial herb, local on rock outcrops.

Arabis glabra (L.) Bernh., tower mustard (*Cruciferae*).

Tall biennial herb, scattered in lower elevation grassland, but above 1200 m is uncommon in seasonally wet, open spots.

Aralia californica Watson, elk clover (*Araliaceae*).

Tall perennial herb, local in springs and creeks.

Arbutus menziesii Pursh, madrone or Pacific madrone (*Ericaceae*).

Large evergreen tree, vigorous sprouter, important dominant in the mixed evergreen forest. The fire-scarred remains of one huge individual on Chews Ridge appeared to have a dbh of about 3 m and an intact tree nearby was 152 cm in dbh.

Arceuthobium occidentale Engelm., Digger pine dwarf mistletoe (*Viscaceae*).

Shoot parasite on pines, locally common on Coulter and Digger pines throughout the south Coast Ranges; *A. occidentale*, which is closely related to *A. campylopodum* Engelm., does not usually infect ponderosa pines (Hawksworth and Wiens 1972). But some ponderosa pines on Pine Ridge are infected with *A. occidentale*, which is common on adjacent Coulter pines (personal correspondence with F. G. Hawksworth, Feb. 22, 1974). The same situation may exist on San Benito Mountain where a few Jeffrey pines are infected with a dwarf mistletoe similar to that on the adjacent Coulter and Digger pines. *A. campylopodum* (as recognized by

Hawksworth and Wiens 1972) has not been reported in the south Coast Ranges; they consider the *A. campylopodum* of Howitt and Howell (1964) to be *A. occidentale*.

Arctostaphylos glandulosa Eastw., Eastwood manzanita (*Ericaceae*).

Burl-forming evergreen shrub, important in the chaparral, dominant over *Adenostoma* on the highest ridges. This shrub is extremely difficult to classify taxonomically (McMinn 1939). At low elevations, as near the Hastings Reservation, the *A. glandulosa* complex may not be clearly isolated from the more coastal *A. tomentosa*(Pursh) Lindl. complex, and a few shrubs on Chews Ridge may show this *A. tomentosa* influence. Within *A. glandulosa* many taxa have been described which seem to have little geographic or ecological significance on the study peaks. Plants with glandular twigs and inflorescences approach var. *glandulosa*, plants with only glandular inflorescences approach var. *howellii* (Eastw.) Adams, and the mostly nonglandular plants approach var. *cushingiana* (Eastw.) Adams. The nonglandular, somewhat canescent, plants were mapped as *A. canescens* Eastw. by the Vegetation Type Map Survey (Critchfield 1971). No recognizable *A. glandulosa* shrubs were seen on San Benito Mountain, but it might be part of difficult manzanita problems there.

Arctostaphylos glauca Lindl., bigberry manzanita (*Ericaceae*).

Tall nonsprouting evergreen shrub, scattered in the low elevation chaparral of the Santa Lucias, very conspicuous in chaparral on serpentine in the Diablo Range at all elevations; most plants on the study peaks appeared to be var. *puberula* J. T. Howell.

Arctostaphylos hooveri Wells (*Ericaceae*).

Tall nonsprouting evergreen shrub, scattered in forest and chaparral south of Cone Peak, but a few highly variable individuals grow near the Gamboa trail summit north of Cone Peak. They may be near the northern limit for this SANTA LUCIA RANGE ENDEMIC.

Arctostaphylos pungens HBK., Mexican manzanita (*Ericaceae*).

Evergreen shrub, nonburl-forming, but the branches readily layer, forming large colonies, conspicuous on San Benito Mountain serpentine. This variable manzanita is uncommon in the south Coast Ranges and appears in more typical form south of San Diego. There are suggestions of hybridization between *A. pungens* and *A. glauca* on San Benito Mountain.

Arenaria douglasii Frenzl., Douglas sandwort (*Caryophyllaceae*).

Annual herb, scattered in forest openings, locally common on serpentine.

Arenaria macrophylla Hook., large-leaved sandwort (*Caryophyllaceae*).

Low perennial herb, rare on the study peaks. Uncommon elsewhere in the south Coast Ranges (Bowerman 1944, Sharsmith 1945, Thomas 1961).

Argemone munita Dur. & Hilg., prickly poppy (*Papaveraceae*).

Annual herb, uncommon in disturbed spots.

Arnica discoidea Benth., rayless arnica (*Compositae*).

Perennial herb, scattered in forest and chaparral on the summit of Chews Ridge; the study peak plants do not seem to differ much from the coastal plants called var. *alata* (Rydb.) Cronquist.

Artemisia douglasiana Bess., California mugwort (*Compositae*).

Large perennial herb, often riparian or near dry stream beds, but may be scattered far from any seasonally wet spots as in the Chews Ridge savanna.

Artemisia dracunculus L., dragon sagewort (*Compositae*).

Large perennial herb, distribution similar to *A. douglasiana*.

Asclepias californica Greene var. *greenei* Woodson, round-hooded milkweed (*Asclepiadaceae*).

Prostrate perennial herb, uncommon on open rocky spots or talus slopes. This southern Sierra Nevada and southern California species is uncommon in the south Coast Ranges (Bowerman 1944, Hoover 1970, Sharsmith 1945).

Asclepias eriocarpa Benth., Indian milkweed (*Asclepiadaceae*).

Perennial herb, scattered in grassland at lower elevations, uncommon above 1200 m, one colony under the sugar pine forest on the summit of Junipero Serra Peak.

Asclepias fascicularis Dcne., narrow-leaved milkweed (*Asclepiadaceae*).

Perennial herb, uncommon along dry creekbeds at lower elevation, rare on a serpentine outcrop on Chews Ridge.

Aspidotis carlotta-halliae (W. & G.) Lellinger (*Pteridaceae*).

Small fern, one 1938 collection from San Benito Mountain; either extremely rare there now or perhaps extinct in this locality. (Smith 1975).

Aspidotis densa (Brackenridge) Lellinger, Indian dream (*Pteridaceae*).

Small fern, local on ultrabasic outcrops on Pine Ridge, uncommon in the south Coast Ranges and usually confined to serpentine (Hoover 1970, Sharsmith 1945, Smith 1975). This species has been placed in three other genera: *Cheilanthes, Onychium,* and *Pellaea*.

Astragalus clevelandii Greene (*Leguminosae*).

Perennial herb; Munz (1959) listed a riparian locality on serpentine at 1400 m near San Benito Mountain. DISJUNCT, mainly a serpentine endemic in Napa and Lake Counties.

Astragalus gambelianus Sheld., dwarf loco-weed (*Leguminosae*).

Small annual herb, minor plant in grassland.

Astragalus purshii Dougl. var. *tinctus* Jones, woolly pod (*Leguminosae*).

Prostrate perennial herb, uncommon on San Benito Mountain serpentine. Various forms of this species are widespread in dry interior forests of the West, but it is rare in the south Coast Ranges. DISJUNCT, closest population may be in upper Cuyama Valley, Santa Barbara County. 4/

4/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Athysanus pusillus (Hook.) Greene, sandweed (*Cruciferae*).

Small annual herb, minor plant in grassland.

Avena barbata Brot., slender wild oat (*Gramineae*).

Annual grass, less common in grassland than *A. fatua*. INTRODUCED.

Avena fatua L. wild oat (*Gramineae*).

Annual grass, important dominant in grassland. INTRODUCED.

Barbarea orthoceras Ledeb., American winter-cress (*Cruciferae*).

Biennial herb, local in wet spots.

Berberis dictyota Jeps., Jepson barberry (*Berberidaceae*).

Evergreen sub-shrub, widely distributed in chaparral on San Benito Mountain but never common.

Berula erecta (Huds.) Cov., water-parsnip (*Umbelliferae*).

Perennial herb, local in wet spots.

Bloomeria crocea (Torr.) Cov. var. *aurea* (Kell.) Ingram, golden stars (*Amaryllidaceae*).

Bulb, unimportant or absent above 1200 m except for scattered plants on San Benito Mountain.

Boschniakia strobilaceae Gray, California ground-cone (*Orobanchaceae*).

Root parasite, probably on *Arctostaphylos* widely distributed but never common in San Benito Mountain forests with a manzanita understory.

Brickellia californica (T. & G.) Gray, California brickelbush (*Compositae*).

Low evergreen shrub, local on rock out-crops or boulder piles.

Brodiaea lutea (Lindl.) Mort., golden brodiaea (*Amaryllidaceae*).

Bulb, unimportant in grassland.

Brodiaea pulchella (Salisb.) Greene, blue dicks (*Amaryllidaceae*).

Bulb, scattered in grassland and forest openings.

Bromus arenarius Labill, Australian chess (*Gramineae*).

Annual grass, minor in grassland or disturbed spots. INTRODUCED.

Bromus carinatus H. & A., California brome (*Gramineae*).

Short-lived perennial grass, widely scattered in open forests at lower elevations, probably less common on the study peaks than *B. marginatus* from which it may not be very clearly separated.

Bromus diandrus Roth, ripgut brome (*Gramineae*).

Annual grass, scattered in grassland. INTRODUCED.

Bromus grandis (Shear) Hitch., tall brome (*Gramineae*).

Tall perennial grass, widely distributed in forest openings at all elevations, difficult to distinguish from *B. laevipes*. Hoover (1970) commented on the unsatisfactory separation between the perennial bromes, particularly *B. grandis*, *B. laevipes*, and *B. pseudolaevipes*.

Bromus laevipes Shear, woodland brome (*Gramineae*).

Tall perennial grass, probably more common at higher elevations than *B. grandis*.

Bromus marginatus Nees, mountain brome (*Gramineae*).

Perennial grass, difficult to distinguish from *B. carinatus*. Hoover (1970) assigned all the *B. marginatus*-like plants in San Luis Obispo County to either *B. carinatus* or *B. breviaristatus*. The only bromes on the study peaks hairy enough to suggest *B. breviaristatus* were on San Benito Mountain.

Bromus mollis L., soft chess (*Gramineae*).

Annual grass, probably the most important annual in the grassland. INTRODUCED.

Bromus orcuttianus Vasey var. *hallii* Hitch. (*Gramineae*).

Perennial grass, scattered in open portions of the more productive forests.

Bromus pseudolaevipes Wagnon (*Gramineae*).

Perennial grass; a few plants key out to this species, but they seem to be an integral part of the *B. grandis* complex.

Bromus rubens L., red brome (*Gramineae*).

Annual grass, scattered in the grassland. This is the only introduced annual that has any significant population on the San Benito Mountain serpentine. INTRODUCED.

Bromus tectorum L., cheat grass (*Gramineae*).

Annual grass, widely distributed as a trail-side weed at higher elevations, not important in the grassland. The pubescent var. *tectorum* is more common than the smooth var. *glabratus* Spenner; the two varieties sometimes grow together. INTRODUCED.

Calamagrostis rubescens Buckl., pinegrass (*Gramineae*).

Perennial grass, local in wet spots.

Calandrinia ciliata (R. & P.) DC. var. *menziesii* (Hook.) Macbr., redmaids (*Portulacaceae*).

Annual herb, unimportant in grassland above 1200 m.

Calochortus albus Dougl., white globe-lily (*Liliaceae*).

Bulb, scattered in open forests and savanna; pink colors may be more conspicuous in the corollas of plants closer to the coast, but var. *rubellus* Greene seems to be a vague entity.

Calochortus invenustus Greene, plain mariposa (*Liliaceae*).

Bulb, uncommon in chaparral and forest on serpentine on San Benito Mountain and Pine Ridge; the few plants on the summit of Chews Ridge seem to be on small serpentine outcrops. Uncommon elsewhere in the south Coast Ranges on serpentine (Sharsmith 1945); more common in the southern Sierra Nevada and southern California.

Calochortus splendens Dougl., lilac mariposa (*Liliaceae*).

Bulb, scattered in open forest and savanna.

Calochortus venustus Dougl., butterfly mariposa (*Liliaceae*).

Bulb, uncommon in chaparral and grassland on San Benito Mountain serpentine.

Calycadenia truncata DC., rosinweed (*Compositae*).

Annual herb, scattered in grassland and savanna.

Calyptridium monandrum Nutt., common calyptridium (*Portulacaceae*).

Annual herb, rare in chaparral.

Calyptridium parryi Gray (*Portulacaceae*).

Annual herb, rare in disturbed spots; the few plants collected on Chews Ridge did not seem to fit the south Coast Range var. *hessae* Thomas very well, and the plants around Spanish Lake (fig. 3) suggested the montane *C. roseum* Wats.

Calystegia malocophylla (Greene) Munz ssp. *pedicellata* (Jeps.) Munz (*Convolvulaceae*).

Prostrate, perennial herb, scattered in rocky portions of the grassland and savanna.

Camissonia benitensis Raven (*Onagraceae*).

Small annual herb, scattered on several serpentine alluvial terraces on San Benito Mountain, listed as a rare and endangered species by the California Native Plant Society (Powell 1974). It should receive high priority for administrative protection. SAN BENITO MOUNTAIN ENDEMIC. (Raven 1969).

Camissonia contorta (Dougl.) Kearney (*Onagraceae*).

Small annual herb, unimportant in grassland above 1200 m. (Raven 1969).

Camissonia graciliflora (H. & A.) Raven (*Onagraceae*).

Annual herb, rare in grassland above 1200 m. (Raven 1969).

Camissonia hirtella (Greene) Raven (*Onoagraceae*).

Annual herb, scattered in disturbed spots in chaparral. (Raven 1969).

Camissonia ignota (Jeps.) Raven (*Onagraceae*).

Annual herb, uncommon in rocky spots in chaparral and grassland. (Raven 1969).

Camissonia luciae Raven (*Onagraceae*).

Annual herb, uncommon in rocky spots. (Raven 1969).

Camissonia micrantha Raven (*Onagraceae*).

Annual herb, uncommon in disturbed spots. The species related to *C. micrantha* are difficult to distinguish in the field; *C. intermedia* Raven may have been overlooked or mistaken for *C. micrantha* or *C. hirtella*. (Raven 1969).

Capsella bursa-pastoris (L.) Medicus., shepherd's purse (*Cruciferae*).

Annual herb, rare in grassland. INTRODUCED.

Carex alma Bailey (*Cyperaceae*).

Perennial sedge, local in wet spots.

Carex bolanderi Olney (*Cyperaceae*).

Perennial sedge, local in wet spots.

Carew globosa Boott., round-fruited sedge (*Cyperaceae*).

Perennial sedge, scattered in shady, rocky spots in forest.

Carex multicaulis Bailey (*Cyperaceae*).

Perennial sedge, widely scattered in the forest, not at all riparian. DISJUNCT, next population to the north may be Howell Mountain, Napa County--to the south in the San Rafael Mountains, Santa Barbara County. 5/

Carew serratodens W. Boott., bifid sedge (*Cyperaceae*).

Local in wet places.

Carex subfusca W. Boott., rusty sedge (*Cyperaceae*).

Perennial sedge, local in wet spots.

Castilleja foliolosa H. & A., woolly painted cup (*Scropulariaceae*).

Evergreen sub-shrub, scattered in chaparral.

5/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Castilleja miniata Dougl., great red paint-brush (*Scrophulariaceae*).

Perennial herb, conspicuous along all San Benito Mountain serpentine creeks. Rare elsewhere in the south Coast Ranges, next report to the north is an extinct stand at Russ Gardens marsh, San Francisco (Thomas 1961)--to the south on the Oceano sand dunes, San Luis Obispo County (Hoover 1970).

Castilleja martinii Abrams, Indian paintbrush (*Scrophulariaceae*).

Perennial herb, widely distributed in the more open forest and savanna. (Howitt and Howell 1973).

Castilleja stenantha Gray, large-flowered Indian paintbrush (*Scrophulariaceae*).

Annual herb, local in wet spots.

Ceanothus cuneatus (Hook.) Nutt., buckbrush (*Rhamnaceae*).

Nonsprouting evergreen shrub, common in the more interior chaparral. This small-leaved, white-flowered shrub is not very clearly separated from *C. ramulosus*.

Ceanothus foliosus Parry var. *medius* McMinn, wavyleaf ceanothus (*Rhamnaceae*).

Nonsprouting evergreen shrub, uncommon in chaparral of south Coast Ranges (Hoover 1970, Thomas 1961); the only report from the study peaks was by McMinn (1939) on the summit of Chews Ridge. I have not been able to find the Chews Ridge shrubs.

Ceanothus integerrimus H. & A., deerbrush (*Rhamnaceae*).

Sprouting deciduous shrub, widely distributed in the forest and the more mesic portions of the chaparral.

Ceanothus oliganthus Nutt., hairy ceanothus (*Rhamnaceae*).

Evergreen shrub, difficult to distinguish the southern California *C. oliganthus* from the northern California *C. sorediatus*. There seems to be no real difference between Monterey County plants that have been identified as either species. Hoover (1970) treated *C. sorediatus* as a var. of *C. oliganthus*.

Ceanothus papillosus T. & G. var. *papillosus* wartleaf ceanothus. (*Rhamnaceae*).

Evergreen shrub, widely scattered in the chaparral.

Ceanothus ramulosus (Greene) McMinn, coast ceanothus (*Rhamnaceae*).

Nonsprouting evergreen shrub; this vigorous, large-leaved, pale-blue-flowered shrub seems to be a coastal form of the more interior white-flowered *C. cuneatus*. Hoover (1970) treated *C. ramulosus* as a color form of *C. cuneatus*, but the Monterey County *C. ramulosus* seems to have some geographic separation from *C. cuneatus*.

Ceanothus sorediatus (see *C. oliganthus*)

Centaurea melitensis L., Tocalote (*Compositae*).

Annual herb, minor weed in grassland. INTRODUCED.

Cerastium glomeratum Thuill., mouse-ear chick-weed (*Caryophyllaceae*).

Annual herb, unimportant in grassland. INTRODUCED.

Cercocarpus betuloides Nutt., California mountain-mahogany (*Rosaceae*).

Sprouting evergreen shrub or small tree, widely scattered in the chaparral but seldom dominant. Hoover (1970) treated all the southern Santa Lucia Range shrubs as part of three var. of *C. montanus* Raf. or as *C. minutiflorus* Abrams. All the shrubs examined on the study peaks seemed to fit into a single species.

Cheilanthes covillei Maxon, Coville lip-fern (*Pteridaceae*).

Small fern, local on rock outcrops, uncommon in south Coast Ranges (Hoover 1970).

Cheilanthes gracillima D. C. Eaton, lace-fern (*Pteridaceae*).

Small fern, local on rock outcrops. Uncommon in south Coast Ranges (Sharsmith 1945); the Santa Lucias are the southern limit in the Coast Ranges.

Cheilanthes intertexta (Maxon) Maxon, coastal lip-fern (*Pteridaceae*).

Small fern, local on rock outcrops. Uncommon in the south Coast Ranges (Bowerman 1944, Sharsmith 1945, Thomas 1961); it is difficult to separate some specimens of this species from *C. covillei*.

Chenopodium album L., white pigweed (*Chenopodiaceae*).

Annual herb, rare weed in disturbed spots. INTRODUCED.

Chimaphila menziesii (R. Br.) Spreng., western pipsissiwa (*Pyrolaceae*).

Uncommon in rocky spots in forest. DISJUNCT, next population to the north may be in Napa County--to the south in the San Gabriels, Los Angeles County.

Chlorogalum pomeridianum (DC.) Kunth, soap-root (*Liliaceae*).

Bulb, scattered in grassland.

Chorizanthe douglasii Benth., Douglas spine-flower (*Polygonaceae*).

Annual herb, scattered in grassland, particularly in bare spots or disturbed areas as along trails.

Chorizanthe membranacea Benth., pink spine-flower (*Polygonaceae*).

Annual herb, scattered in grassland.

Chorizanthe staticoides Benth., Turkish rugging (*Polygonaceae*).

Annual herb, uncommon in disturbed or open spots.

Chrysopsis villosa (Pursh) Nutt., hairy golden-aster (*Compositae*).

Perennial herb, scattered in rocky portions of grassland and savanna.

Chrysothamnus nauseosus (Pall.) Britton, rabbitbrush (*Compositae*).

Shrub, partly leafless by late summer, two distinct forms on the study peaks:
1. Ssp. *mohavensis* Hall & Clem. This form with glandular twigs is common in open spots on the San Benito Mountain serpentine, on Chews Ridge it is locally common in savanna along the summit on, or near, the small serpentine outcrops. Uncommon elsewhere in the south Coast Ranges (Sharsmith 1945).
2. Ssp. *albicaulis* (Nutt.) Hall & Clem. This form with tomentose twigs is rare in widely separated rocky spots, sometimes on serpentine as on Pine Ridge. Not previously reported for the south Coast Ranges.

Cirsium californicum Gray, Bigelow thistle (*Compositae*).

Tall annual or biennial herb, scattered in open forest and savanna.

Cirsium proteanum J. T. Howell, red thistle (*Compositae*).

Tall annual or biennial herb, scattered in lower elevation or more interior habitats than *C. californicum*.

Clarkia bottae (Spach) Lewis & Lewis, hill clarkia (*Onagraceae*).

Annual herb, scattered in grassland and savanna.

Clarkia modesta Jeps., modest clarkia (*Onagraceae*).

Annual herb, uncommon in savanna.

Clarkia purpurea (Curt.) Nels. & Macbr. ssp. *quadrivulnera* (Dougl.) Lewis & Lewis (*Onagraceae*).

Annual herb, widely scattered in grassland and savanna.

Clarkia rhomboidea Dougl. (*Onagraceae*).

Annual herb, rare in savanna.

Clarkia unguiculata Lindl., canyon clarkia (*Onagraceae*).

Annual herb, widely scattered in open forest and savanna.

Clematis lasiantha Nutt., pipestem (*Ranunculaceae*).

Deciduous woody vine, scattered in chaparral.

Clematis ligusticifolia Nutt., Yerba de Chivata. (*Ranunculaceae*).

Deciduous woody vine, local in canyon bottoms and riparian habitats.

Collinsia childii Parry, Child blue-eyed-mary (*Scrophulariaceae*).

Annual herb, scattered in forest.

Collinsia heterophylla Buist., Chinese-houses (*Scrophulariaceae*).

Annual herb, scattered in savanna.

Collomia grandiflora Dougl., large-flowered collomia (*Polemoniaceae*).

Annual herb, scattered in savanna.

Collomia heterophylla Dougl., varied-leaved collomia (*Polemoniaceae*).

Annual herb, scattered in forest.

Corallorhiza maculata Raf., spotted coral root (*Orchidaceae*).

Saprophytic herb, scattered from Chews Ridge to Pine Ridge under the densest forest, seems to be missing from many "promising" mesic forest habitats in the Santa Lucias, next population to the south or southeast probably in Kern County (Twisselmann 1967).

Cordylanthus rigidus (Benth.) Jeps., birds beak (*Scrophulariaceae*).

Annual herb, widely scattered in open rocky spots, sometimes as a trail-side weed.

Corethrogyne filaginifolia (H. & A.) Nutt., common corethrogyne (*Compositae*).

Perennial herb, scattered in grassland and savanna.

Cornus occidentalis (T. & G.) Cov., western creek dogwood (*Cornaceae*).

Large deciduous shrub, rare in wet spots above 1200 m.

Cryptantha clevelandii Greene var. *florosa* Jtn. (*Boraginaceae*).

Annual herb.

Cryptantha mariposae Jtn. (*Boraginaceae*).

Annual herb, uncommon on San Benito Mountain serpentine.

Cryptantha muricata (H. & A.) Nels. & Macbr. var. *jonesii* (Gray) Jtn., (*Boraginaceae*).

Annual herb, scattered in open and disturbed spots.

Cuscuta californica H. & A., California dodder (*Cuscutaceae*).

Parasitic herbaceous vine, widely scattered on a variety of hosts; other species of dodder may have been confused with this species or overlooked.

Cycladenia humilis Benth. var. *venusta* (Eastw.) Woodson (*Apocynaceae*).

Low perennial herb; one colony on the summit of Junipero Serra Peak (the type locality for this var.) and three tiny colonies around the head of South Devils Canyon on Cone Peak are known in the Santa Lucias. DISJUNCT, closest population of var. *humilis* to the north is in Napa County--to the south the closest record of this southern California var. *venusta* is in the upper Cuyama Valley, Ventura County. 6/

Cynoglossum grande Dougl., western hounds-tongue (*Boraginaceae*).

Perennial herb, unimportant in forest above 1200 m.

Cystopteris fragilis (L.) Bernh., brittle fern (*Aspidiaceae*).

Small fern, local on shady rock outcrops.

Datisca glomerata (Presl) Baill., Durango root (*Datiscaceae*).

Tall perennial herb, local in wet spots.

Delphinium nudicaule T. & G., red larkspur (*Ranunculaceae*).

Perennial herb, local in shady, rocky spots with some wet spots.

Delphinium parryi Gray, Parry larkspur (*Ranunculaceae*).

Perennial herb, scattered in forest and savanna.

Delphinium patens Benth., coast larkspur (*Ranunculaceae*).

Perennial herb, unimportant in forest and savanna above 1200 m.

6/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Dendromecon rigida Benth., bush poppy (*Papaveraceae*).

Evergreen shrub, scattered in chaparral.

Dentaria integrifolia Nutt., milkmaids (*Cruciferae*).

Perennial herb. Var. *cuneata* (Greene) J. T. Howell is scattered in the pine forest on San Benito Mountain. Var. *sinuata* (Greene) is rare in creek on Pine Ridge. Var. *californica* (Nutt.) Jepson is common in the mixed evergreen forest at lower elevations in the Santa Lucias but may not reach 1200 m elevation.

Deschampsia elongata (Hook.) Munro, slender hairgrass (*Gramineae*).

Perennial grass, local in wet spots.

Dicentra chrysantha (H. & A.) Walp., golden ear-drops (*Fumariaceae*).

Perennial herb, uncommon in widely separated rocky spots.

Disporum hookeri (Torr.) Nichols., fairy bells (*Liliaceae*).

Perennial herb, unimportant in forest above 1200 m.

Dryopteris arguta (Kaulf.) Maxon, coastal wood fern (*Aspidiaceae*).

Perennial fern, unimportant in forest above 1200 m.

Dudleya cymosa (Lem.) Britt. & Rose ssp. *minor* (Rose) Moran, (*Crassulaceae*).

Succulent perennial herb, local on rock outcrops; variable, more than one subspecies may be involved.

Eburophyton austinae (Gray) Heller, phantom orchid (*Orchidaceae*).

Saprophytic herb, rare on the study peaks, rare elsewhere in the south Coast Ranges (Thomas 1961), next population to the south may be in the San Bernardino Mountains.

Eleocharis acicularis (L.) R. & S. var. *bella* Piper, needle spikerush (*Cyperaceae*).

Tiny annual herb, abundant in Spanish Lake (fig. 3), population seems to be the annual montane form of this widely distributed marsh species.

Eleocharis parishii Britt. (*Cyperaceae*).

Perennial herb, abundant in Spanish Lake (fig. 3). (Twisselmann 1967).

Elymus glaucus Buckl., western ryegrass (*Gramineae*).

Tall perennial grass, widespread in the more open portions of the forest. A variable species, the pubescent form ssp. *jepsonii* (Davy) Gould is not common. Howitt and Howell (1973) report one collection from Chews Ridge. Steven N. Talley made one collection on Pine Ridge. Scattered plants with short awns approach ssp. *virescens* (Piper) Gould, some small plants with mostly one spikelet per node may be confused with *Agropyron*.

Elymus triticoides Buckl., beardless wild rye (*Gramineae*).

Tall perennial grass, unimportant above 1200 m.

Emmenanthe penduliflora Benth., whispering bells (*Hydrophyllaceae*).

Annual herb, rare on study peaks, but after a fire or clearing this species might be conspicuous for 1 or 2 years, the San Benito Mountain plants appear to be var. *rosea* Brand, which is usually confined to serpentine (Wicklow 1966).

Epilobium minutum Lindl., minute willow-herb (*Onagraceae*).

Annual herb, uncommon in forest openings.

Epilobium paniculatum Nutt. ex T. & G., summer cottonweed (*Onagraceae*).

Annual herb, unimportant above 1200 m.

Epilobium watsonii Barb. var. *franciscanum* (Barb.) Jeps., coast cottonweed (*Onagraceae*).

Perennial herb, local in wet spots.

Epipactis gigantea Dougl., stream orchid (*Orchidaceae*).

Perennial herb, only noticed in a spring near Roosevelt Creek on Junipero Serra Peak.

Equisetum laevigatum A. Br., California horsetail (*Equisetaceae*).

Perennial herb, local in wet spots.

Equisetum telmateia Ehrhart, giant horse-tail (*Equisetaceae*).

Perennial herb, local in wet spots.

Eriastrum densifolium (Benth.) Mason, many-leaved eriastrum (*Polemoniaceae*).

Perennial herb, scattered in chaparral, the plants approach ssp. *austromontanum* (Craig) Mason, which is the most montane form. The study peaks are near the northern limit for this southern California species.

Erigeron foliosus Nutt., leafy daisy (*Compositae*).

Perennial herb, widely distributed in open habitats.

Erigeron petrophilus Greene, rock daisy (*Compositae*).

Low perennial herb, local on rock out-crops.

Eriodictyon californicum (H. & A.) Torr., Yerba Santa (*Hydrophyllaceae*).

Evergreen shrub, widely scattered in disturbed spots in or near the chaparral.

Eriodictyon tomentosum Benth., woolly Yerba Santa (*Hydrophyllaceae*).

Evergreen shrub, scattered in disturbed spots, the study peaks are near the northern limit for this south Coast Range endemic.

Eriogonum covilleanum Eastw. (*Polygonaceae*).

Annual herb, widely scattered in disturbed or open spots on San Benito Mountain serpentine. (Munz 1968).

Eriogonum davidsonii Greene (*Polygonaceae*).

Annual herb, variable populations widely scattered in open spots.

Eriogonum elongatum Benth. var. *elongatum* long-stemmed buckwheat (*Polygonaceae*).

Perennial herb, uncommon in rocky areas.

Eriogonum fasciculatum Benth. var. *foliolosum* (Nutt.) S. Stokes, California buckwheat (*Polygonaceae*).

Evergreen sub-shrub or shrub, widely distributed in open rocky habitats, one of the few woody plants prominent in the coastal sage scrub that continues upwards in distribution to the tops of the highest ridges.

Eriogonum gracile Benth., slender woolly buckwheat (*Polygonaceae*).

Annual herb, extremely variable populations widely scattered in open spots. The annual buckwheats associated with this and related species in the subgenus *Oregonium* are very difficult to separate, and many specimens do not fit described taxa. James L. Reveal (personal communication, Nov. 14, 1972, Oct. 16, 1973) called this group the most difficult in the genus and suggested that at least one new species might be described from study peak material, the San Benito Mountain populations are particularly confusing.

Eriogonum hirtiflorum Gray, hairy-flowered buckwheat (*Polygonaceae*).

Annual herb, not important above 1200 m. (Reveal 1970).

Eriogonum nudum Dougl. var. *indictum* (Jeps.) Reveal (*Polygonaceae*).

Perennial herb, uncommon in rocky spots.

Eriogonum saxatile Wats., rock buckwheat (*Polygonaceae*).

Perennial herb, local on very rocky spots. Rare elsewhere in the south Coast Ranges (Hoover 1970, Sharsmith 1945, Thomas 1961).

Eriogonum spergulinum Gray var. *reddingianum* (Jones) J. T. Howell (*Polygonaceae*).

Annual herb, not important above 1200 m.

Eriogonum umbellatum Torr. var. *bahiiforme* (T. & G.) Jeps., sulphur flower (*Polygonaceae*).

Perennial herb, widely distributed on serpentine on San Benito Mountain (the type locality), not reported in the Santa Lucias until 1972, when Steven N. Talley noticed it on the Pine Ridge serpentine. The study peaks are near the southern limit for this serpentine endemic variety, which is uncommon elsewhere in the south Coast Ranges (Reveal 1970, Sharsmith 1945).

Eriophyllum confertiflorum (DC.) Gray, golden-yarrow (*Compositae*).

Evergreen sub-shrub, widely distributed in a variety of habitats.

Erodium cicutarium (L.) L'Her., red-stemmed filaree (*Geraniaceae*).

Annual herb, minor in grassland. INTRODUCED.

Eryngium aristulatum Jeps., coyote-thistle (*Umbelliferae*).

Annual herb, vernal pool species common in Spanish Lake (fig. 3).

Erysimum capitatum (Dougl.) Greene, western wall flower (*Cruciferae*).

Perennial herb, widely scattered in rocky spots but never common.

Eschscholzia californica Cham. California poppy (*Papaveraceae*).

Annual or perennial herb, minor in grassland.

Festuca rubra L., red fescue (*Gramineae*).

Perennial grass, rare in wet spots.

Festuca (see *Vulpia* for annual species)

Filago californica Nutt., California cotton-rose (*Compositae*).

Annual herb, unimportant in grassland above 1200 m.

Filago gallica L., narrow-leaved filago (*Compositae*).

Annual herb, unimportant in grassland above 1200 m. INTRODUCED.

Fremontodendron californicum Cov., flannel bush (*Sterculiaceae*).

Evergreen shrub, uncommon in the south Coast Range chaparral (Hoover 1970, Thomas 1961). A colony in upper East San Carlos Creek canyon on San Benito Mountain approaches ssp. *crassifolium* (Eastw.) Munz in form; the Santa Lucia Range shrubs, including those at the western base of Junipero Serra Peak, were referred to ssp. *obispoense* (Eastw.) Munz by Howitt and Howell (1973).

Fritillaria falcata (Jeps.) D. E. Beetle (*Liliaceae*).

Bulb, restricted to serpentine near San Benito Mountain (the type locality) and the Red Mountain region of the Mount Hamilton Range (Beetle 1944, Sharsmith 1945). I have not been able to find any San Benito Mountain plants or even any reports since Jepson's discovery. Listed as a rare and endangered species by the California Native Plant Society (Powell 1974). DIABLO RANGE ENDEMIC.

Fritillaria lanceolata Pursh., checker-lily (*Liliaceae*).

Bulb, uncommon in several forest habitats.

Fritillaria viridea Kell. (*Liliaceae*).

Bulb, widely scattered on San Benito Mountain serpentine (the type locality). The plant also occurs on some Santa Lucia Range serpentine habitats and should be looked for on Pine Ridge. Munz (1959) included this species with *F. lanceolata*.

Galium andrewsii Gray, phlox-leaved bedstraw (*Rubiaceae*).

Low perennial herb; the glabrous diploid (n=11) form, ssp. *andrewsii* is scattered in widely separated parts of both Diablo and Santa Lucia Ranges. All the specimens I collected from the San Benito Mountain serpentine were the variable pubescent octoploid (n=44) form, ssp. *gatense* (Demp.) Demp. & Steb. (Dempster and Stebbins 1968).

Galium angustifolium Nutt. ssp. *angustifolium* (*Rubiaceae*).

Suffrutescent perennial, scattered on rocky south exposures. The study peaks are near the northern limit for this southern California species (Dempster and Stebbins 1971).

Galium aparine L., goose-grass (*Rubiaceae*).

Annual herb, scattered under dense hardwood forests. INTRODUCED.

Galium californicum H. & A., California bedstraw (*Rubiaceae*).

Perennial herb, an extremely variable species complex in the Santa Lucias (Dempster and Stebbins 1968); at least two subspecies occur on the study peaks:

1. Ssp. *flaccidum* (Greene) Demp. & Steb. Widely scattered in a variety of forest habitats, an extremely variable octoploid (n=44) form of the species.
2. Ssp. *luciense* Demp. & Steb. In appearance this tetraploid (n=22) form is sort of intermediate between *G. californicum* ssp. *flaccidum* and *G. clementis*. The bulk of

this subspecies' distribution is on Cone Peak above 1200 m. It is probably the rarest of the Santa Lucia Range endemic taxa on the study peaks. A few plants near *G. clementis* colonies on Ventana Double Cone have been tentatively assigned to ssp. *luciense* by Lauramay Dempster. Listed as a rare and endangered plant by the California Native Plant Society (Powell 1974). SANTA LUCIA RANGE ENDEMIC.

Galium clementis Eastw., Santa Lucia bedstraw (*Rubiaceae*).

Low matted, perennial herb, distribution is largely confined to three study peaks with the most plants on Cone Peak, listed as a rare and endangered species by the California Native Plant Society (Powell 1974). (Dempster and Stebbins 1968). SANTA LUCIA RANGE ENDEMIC.

Galium nuttallii Gray ssp. *ovalifolium* (Demp.) Demp. & Steb., climbing bedstraw (*Rubiaceae*).

Perennial herbaceous vine, scattered in chaparral and dry forest openings.

Garrya congdoni Eastw. interior silk-tassle (*Garryaceae*).

Evergreen shrub, this serpentine endemic has been reported in San Benito County (Sharsmith 1945) and the adjacent Diablo Range of Monterey County (Howitt and Howell 1964) and Fresno County. Some of the San Benito Mountain shrubs approach this species, but they could also be placed in the variable *G. flavescens*.

Garrya flavescens Wats. var. *pallida* (Eastw.) Bacig. ex Ewan, ashy silk-tassle (*Garryaceae*).

Evergreen shrub, widely distributed in the chaparral but seldom common in any one spot. Differences between the Santa Lucia Range shrubs and the Diablo Range shrubs on serpentine that have been called *G. congdoni* appear to be slight.

Gayophytum heterozygum Lewis & Szweykowski (*Onagraceae*).

Annual herb, uncommon in forest openings. DISJUNCT, closest population is probably in the San Rafael Mountains, Santa Barbara County (Smith 1974). (Howitt and Howell 1973).

Gilia achilleaefolia Benth., California gilia (*Polemoniaceae*).

Annual herb, uncommon in savanna and grassland.

Gilia clivorum (Jeps.) V. Grant (*Polemoniaceae*).

Annual herb, minor in grassland.

Gilia splendens Dougl. (*Polemoniaceae*).

Annual herb, uncommon in savanna and forest openings, the study peaks are near the northern limit for the species.

Gilia tenuiflora Benth. (*Polemoniaceae*).

Annual herb, not important above 1200 m, difficult to distinguish from *G. splendens*, Hoover (1970) did not recognize *G. splendens* in the southern Santa Lucias.

Gnaphalium beneolens A. Davids., fragrant everlasting (*Compositae*).

Perennial herb, scattered in rocky spots, difficult to separate from *G. microcephalum* Nutt.

Gutierrezia bracteata Abrams, San Joaquin matchweed (*Compositae*).

Small evergreen shrub, not important above 1200 m (Solbrig 1965).

Habenaria elegans (Lindl.) Boland., slender habenaria (*Orchidaceae*).

Perennial herb, scattered in shady forest habitats.

Haplopappus squarrosus H. & A., sawtooth goldenbush (*Compositae*).

Small evergreen shrub, local on rocky spots.

Helenium puberulum DC., rosilla (*Compositae*).

Perennial herb, local in wet spots.

Hemitomes congestum Gray, gnome plant (*Pyrolaceae*).

Saprophyte, one plant seen under scrubby mixed evergreen forest on Ventana Double Cone at 1200 m elevation, all California reports of this species concern low elevation redwood forest habitats.

Hemizonia paniculata Gray, San Diego tarweed (*Compositae*).

Annual herb, uncommon on San Benito Mountain serpentine. Hoover (1970) assigned some San Luis Obispo plants on serpentine to ssp. *paniculata*. The San Benito collection seems to be a rather interior and northward extension of this typical subspecies (Munz 1959).

Heracleum maximum Bartram, cow-parsnip (*Umbelliferae*).

Tall perennial herb, local in wet spots. (Howitt and Howell 1973).

Hesperolinon disjunctum H. K. Sharsm. (*Linaceae*).

Annual herb, scattered on San Benito Mountain serpentine, a serpentine endemic of the inner Coast Ranges (Sharsmith 1961).

Hesperolinon micranthum (Gray) Small, small-flowered dwarf-flax (*Linaceae*).

Annual herb, scattered on Pine Ridge serpentine, often on serpentine in the Santa Lucia Range (Sharsmith 1961).

Heteromeles arbutifolia M. Roem., toyon (*Rosaceae*).

Evergreen shrub or small tree, scattered in chaparral.

Hieracium albiflorum Hook., white-flowered hawkweed (*Compositae*).

Perennial herb, scattered in coniferous forests.

Hieracium argutum Nutt. var. *parishii* (Gray) Jeps. (*Compositae*).

Perennial herb, local in rocky spots. Some of the most common and variable plants are on Pine Ridge--just above the Big Sur Canyon where hybrids between this species and *H. albiflorum* have been reported (Anderson and Stebbins 1954). The study peaks are near the northern limits for this species.

Holodiscus discolor (Pursh) Maxim., cream bush (*Rosaceae*).

Tall deciduous shrub, an important understory shrub in parts of the mixed evergreen forest at lower elevation but unimportant above 1200 m.

Holodiscus microphyllus Rydb. (*Rosaceae*).

Low deciduous shrub, scattered on rocky ridgetops. There is some question as to how clearly this is isolated from *H. dicolor*. DISJUNCT, the next population to the north may be in Mendocino County--to the southeast in Tulare County. Some Santa Barbara County plants resemble this species. 7/

Hordeum californicum Covas & Steb., California barley (*Gramineae*).

Perennial bunchgrass, uncommon in seasonally wet spots.

Hordeum glaucum Steud., wall barley (*Gramineae*).

Annual grass, minor weed in disturbed spots. INTRODUCED.

Hulsea heterochroma Gray, red-eyed hulsea (*Compositae*).

Perennial herb, rare in disturbed spots.

Hypericum formosum HBK. var. *scouleri* (Hook.) Coult., Scouler St. Johns wort (*Hypericaceae*).

Perennial herb, local in wet spots.

Juncus bufonius L. toad rush (*Juncaceae*).

Annual herb, scattered in seasonally wet spots.

Juncus effusus L. var. *pacificus* Fern. & Wieg. (*Juncaceae*).

Perennial herb, local in wet spots.

Juncus patens E. Mey., common rush (*Juncaceae*).

Perennial herb, local in wet spots.

Juncus rugulosus Engelm. (*Juncaceae*).

Tall perennial herb, local in wet spots.

7/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Juniperus californica Carr., California juniper (*Cupressaceae*).

Large evergreen shrub, scattered in the non-serpentine savanna at lower elevation on San Benito Mountain but unimportant above 1200 m.

Koeleria macrantha (Ledeb.) Sreng., June-grass (*Gramineae*).

Perennial bunchgrass, minor in grassland.

Lactuca serriola L. prickly lettuce (*Compositae*).

Annual herb, minor weed in disturbed spots. INTRODUCED.

Lathyrus vestitus Nutt. ssp. *puberulus* (White) C. L. Hitch. (*Leguminosae*).

Perennial herbaceous vine, widely scattered in forest habitats.

Layia discoidea Keck, rayless layia (*Compositae*).

Small annual herb, restricted to a few serpentine sites on San Benito Mountain, recognized as a rare and endangered species by the California Native Plant Society (Powell 1974). This species was an important example in the development of biosystematics (Keck 1957). It should have high priority for administrative protection. SAN BENITO MOUNTAIN ENDEMIC.

Lepechinia calycina (Benth.) Epl., pitcher sage (*Labiatae*).

Aromatic, suffrutescent perennial, uncommon in chaparral.

Lewisia rediviva Pursh., bitterroot (*Portulacaceae*).

Acaulescent perennial herb, rare on San Benito Mountain serpentine, rare elsewhere in the south Coast Ranges where it is often, but not always, associated with serpentine (Bowerman 1944, Hoover 1970, Sharsmith 1945, Thomas 1961).

Libocedrus decurrens Torr., incense-cedar (*Cupressaceae*).

Evergreen tree, in the Santa Lucias incense-cedar is concentrated in canyon bottoms or shady ravines except for the trees on the exposed serpentine of Pine Ridge. On San Benito Mountain this tree is widely distributed on exposed upland slopes. Alice Eastwood's (1897) suggestion that extensive logging of incense-cedar occurred on "Santa Lucia Peak" seems improbable. If the San Antonio Mission builders used incense-cedar (it is not clear that they did), they may have cut the relatively accessible trees along the Arroyo Seco Creek near Memorial Park. I doubt that the Mission builders used trees from either the Cone Peak or Junipero Serra Peak forests. There remains, however, a problem of who produced the few mysterious stumps near the head of Santa Lucia Creek (H. B. Cahill [personal communication, Jan. 29, 1974]). The San Benito Mountain forest was heavily logged for mine timbers 8/ (Brewer n/d, Jepson n/d, Griffin 1974a). DISJUNCT, closest stand to the north is in northern Napa County--to the south in the Sierra Madre, Santa Barbara County (Griffin and Critchfield 1972).

Lilium pardalinum Kell., tiger lily (*Liliaceae*).

Bulb, local in wet spots.

Linanthus ambiguus (Rattan) Greene, serpentine linanthus (*Polemoniaceae*).

Annual herb, scattered on serpentine on San Benito Mountain, largely a serpentine endemic in the inner Coast Ranges.

Linanthus androsaceus (Benth.) Greene, shower gilia (*Polemoniaceae*).

Annual herb, widely distributed in open spots, most of the described subspecies do not seem very helpful locally, but the bright yellow form, ssp. *luteus* (Benth.) Mason was quite distinct on Chews Ridge although uncommon.

Linanthus ciliatus (Benth.) Greene, wisker brush (*Polemoniaceae*).

Annual herb, unimportant above 1200 m.

Linanthus liniflorus (Benth.) Greene, flax-flowered linanthus (*Polemoniaceae*).

Annual herb, unimportant above 1200 m.

8/ Sloane, N. H. 1914. Resources and plan of operation of Monterey National Forest. (Unpublished report on file. Los Padres National Forest, King City, Calif.).

Linum lewisii Pursh., blue flax (*Linaceae*).

Perennial herb, widely distributed in serpentine on San Benito Mountain, rare elsewhere in the south Coast Ranges (Hoover 1970).

Lithocarpus densiflorus (H. & A.) Rehd., tan-oak (*Fagaceae*).

Evergreen tree, vigorous sprouter, important dominant in the mixed evergreen forest.

Lithophragma affinis Gray., woodland star (*Saxifragaceae*).

Perennial herb, unimportant above 1200 m.

Lithophragma heterophylla (H. & A.) T. & G., hill star (*Saxifragaceae*).

Perennial herb, scattered in savanna habitats.

Lomatium dasycarpum (T. & G.) Coult. & Rose, lace-parsnip (*Umbelliferae*).

Perennial herb, uncommon in savanna and forest openings.

Lomatium macrocarpum (H. & A.) Coult. & Rose, sheep-parsnip (*Umbelliferae*).

Perennial herb, uncommon on serpentine outcrops.

Lonicera hispidula Dougl., hairy honeysuckle (*Caprifoliaceae*).

Evergreen woody vine, appears to reach 1200 m only on Ventana Double Cone where it is rare in the chaparral.

Lonicera interrupta Benth., chaparral honeysuckle (*Caprifoliaceae*).

Evergreen woody vine, widely distributed in chaparral.

Lonicera subspicata H. & A. var. *johnstonii* Keck, southern honeysuckle (*Caprifoliaceae*).

Evergreen woody vine, scattered in more interior areas than *L. interrupta*, not very clearly separated from *L. interrupta*.

Lotus argophyllus (Gray) Greene var. *fremontii* (Gray) Ottley, silver-leaved lotus (*Leguminosae*).

Low perennial herb, scattered in rocky spots. Some of the local plants do not fit var. *fremontii* too well. The study peaks are near the northern limit in the Coast Ranges, the next population to the south may be in Kern County (Twisselmann 1967), var. *decorus* (Jtn.) Ottley occurs in Santa Barbara County. 9/ DISJUNCT.

Lotus crassifolius (Benth.) Greene, broad-leaved lotus (*Leguminosae*).

Tall perennial herb, scattered in disturbed spots in the chaparral.

Lotus grandiflorus (Benth.) Greene var. *mutabilis* Ottley, chaparral lotus (*Leguminosae*).

Perennial herb, scattered in rocky spots, sometime appearing as a trail-side weed.

Lotus humistratus Greene, short-podded lotus (*Leguminosae*).

Annual herb, minor in grassland.

Lotus micranthus Benth., hill lotus (*Leguminosae*).

Annual herb, minor in grassland.

Lotus oblongifolius (Benth.) Greene, narrow-leaved lotus (*Leguminosae*).

Tall perennial herb, local in wet spots.

Lotus purshianus (Benth.) Clem. & Clem., Spanish-clover (*Leguminosae*).

Annual herb, minor in grassland.

Lotus scoparius (Nutt.) Ottley, deer-weed (*Leguminosae*).

Suffrutescent perennial, scattered along trails and disturbed spots or in openings in the chaparral.

Lotus strigosus (Nutt.) Greene, bishop lotus (*Leguminosae*).

Annual herb, minor in grassland.

Lotus subpinnatus Lag, California lotus (*Leguminosae*).

Annual herb, unimportant in grassland above 1200 m.

9/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Lupinus abramsii C. P. Smith (*Leguminosae*).

Evergreen mat or low shrub, widely distributed, may not be clearly isolated from *L. albifrons* in some places. Hoover (1970) treated it as a var. of *L. albifrons*. SANTA LUCIA RANGE ENDEMIC.

Lupinus albifrons Benth., silver lupine (*Leguminosae*).

Evergreen shrub, appears in lower, more interior habitats than the nearly prostrate *L. abramsii*, not important above 1200 m.

Lupinus bicolor Lindl. (*Leguminosae*).

Annual herb, scattered in grassland.

Lupinus cervinus Kell., deer lupine (*Leguminosae*).

Perennial herb, widely scattered but never common in forest habitats. First collected by William Lobb in 1850 probably near Cone Peak. Listed as a rare and endangered species by the California Native Plant Society (Powell 1974). SANTA LUCIA RANGE ENDEMIC.

Lupinus formosus Greene var. *bridgesii* (Wats.) Greene, lunaria lupine (*Leguminosae*).

Perennial herb, uncommon in rocky spots.

Lupinus hirsutissimus Benth., stinging lupine (*Leguminosae*).

Annual herb, widely scattered on rocky spots at lower elevations but rare above 1200 m.

Lupinus nanus Dougl., sky lupine (*Leguminosae*).

Annual herb, scattered in grassland.

Madia elegans D. Don., common madia (*Compositae*).

Annual herb, widely scattered. The plants that Willis L. Jepson collected on Junipero Serra Peak have been referred to a montane form, ssp. *wheeleri* (Gray) Keck. (Howitt and Howell 1973).

Madia exigua (SM.) Gray, little tarweed (*Compositae*).

Small annual herb, unimportant above 1200 m.

Madia gracilis (Sm.) Keck, gumweed (*Compositae*).

Annual herb, widely scattered in grassland and savanna on Chews Ridge.

Madia madioides (Nutt.) Greene, woodland madia (*Compositae*).

Perennial herb, uncommon above 1200 m.

Malacothrix floccifera (DC.) Blake, woolly malacothrix (*Compositae*).

Annual herb, widespread on San Benito Mountain serpentine, but unimportant on the Santa Lucia peaks.

Malacothrix saxatilis (Nutt.) T. & G. var. *commutata* (T. & G.) Ferris cliff malacothrix (*Compositae*).

Perennial herb, rare on rock outcrops.

Marah fabaceus (Nand.) Greene, common manroot or wild cucumber (*Cucurbitaceae*).

Perennial vine with annual shoots, widely distributed near chaparral margins.

Medicago polymorpha L., bur-clover (*Leguminosae*).

Annual herb, minor in grassland. INTRODUCED.

Melica aristata Thurb. (*Gramineae*).

Perennial grass, several collections in the University of California Herbarium from Chews Ridge (G. L. Stebbins & L. A. Snyder #3767, and C. Hardham #6191B) have been labeled as this species. But the separation between the long-awned *M. aristata* and the shorter-awned *M. harfordii* is not very satisfactory in the Santa Lucias. A Cone Peak specimen in the Jepson Herbarium was annotated as intermediate between these species. Hoover (1970) treated *M. aristata* as a var. of *M. harfordii* in the southern Santa Lucias. Twisselmann (1967) reported only one colony of *M. aristata* in Kern County.

Melica californica Scribn., western melic (*Gramineae*).

Perennial bunchgrass, minor in grassland.

Melica geyeri Munro, geyer onion-grass (*Gramineae*).

Perennial grass, rare in shady forest habitats on Chews Ridge. The study peaks are near the southern limit, only one colony reported in San Luis Obispo County (Hoover 1970).

Melica harfordii Bol., Harford melic (*Gramineae*).

Perennial grass, scattered in forest habitats (see note on *M. aristata*).

Melica imperfecta Trin., small-flowered melic (*Gramineae*).

Perennial grass, widely distributed, particularly in rocky spots.

Melica stricta Bol., rock melic (*Gramineae*).

Perennial grass, rare along upper Sawmill Creek (fig. 3), probably rare elsewhere in the south Coast Ranges. The next closest locality is in the San Rafael Mountains. 10/ DISJUNCT.

Melica torreyana Scribn., Torrey melic (*Gramineae*).

Perennial grass, scattered on serpentine outcrops on summit of San Benito Mountain. Often associated with serpentine in the south Coast Ranges (Hoover 1970).

Mentzelia gracilenta T. & G., slender stickleaf (*Loasaceae*).

Annual herb, minor in grassland on San Benito Mountain.

Mentzelia laevicaulis (Dougl.) Torr., blazing star (*Loasaceae*).

Biennial herb, uncommon in disturbed spots.

Mentzelia micrantha (H. & A.) T. & G., San Luis stickleaf (*Loasaceae*).

Annual herb, uncommon in disturbed spots.

10/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Mentzelia pinetorum Heller (*Loasaceae*).

Annual herb, unimportant above 1200 m. (Howitt and Howell 1973).

Mentzelia veatchiana Kell., (*Loasaceae*).

Annual herb, rare in disturbed spots on Chews Ridge. (Howitt and Howell 1973).

Micropus californicus F. & M., slender cottonweed (*Compositae*).

Small annual herb, minor in grassland.

Microseris linearifolia (Nutt.) Sch-Bip. (*Compositae*).

Annual herb, scattered in grassland.

Microsteris gracilis (Dougl.) Greene, annual phlox (*Polemoniaceae*).

Annual herb, scattered in grassland.

Mimulus bifidus Penn., ssp. *fasciculatus* Penn., Santa Lucia sticky monkey-flower (*Scrophulariaceae*).

Small evergreen shrub, widely distribute in chaparral and along forest margins. This species is mainly endemic to the Santa Lucias but some plants do occur in San Benito County (Howitt and Howell 1973).

Mimulus cardinalis Dougl., scarlet monkey-flower (*Scrophulariaceae*).

Annual herb, local in wet spots.

Mimulus floribundus Dougl., floriferous monkey-flower (*Scrophulariaceae*).

Small annual herb, local in seasonally wet spots.

Minulus fremontii (Benth.) Gray, Fremont monkey-flower (*Scrophulariaceae*).

Annual herb, scattered in open areas (see note on *M. subsecundus*).

Mimulus guttatus Fisch., common monkey-flower (*Scrophulariaceae*).

Annual or perennial herb, local in wet spots, a small form is very abundant along all the San Benito Mountain creeks.

Mimulus pilosus (Benth.) Wats., downy mimethanthe (*Scrophulariaceae*).

Small annual herb, local in wet spots.

Mimulus subsecundus Gray (*Scrophulariaceae*).

Annual herb; it is difficult to separate this species from *M. fremontii*. Hoover (1970) considered this to be a small flowered form of *M. fremontii*; an undescribed, small, pink flowered monkey-flower may be complicating this situation in the Santa Lucias.

Mollugo verticillata L., Indian chickweed (*Aizoaceae*).

Small annual herb, common around Spanish Lake (fig. 3). INTRODUCED.

Monardella benitensis Hardham (*Labiatae*).

Aromatic perennial herb, an interior serpentine form of the *M. villosa* complex (Hardham 1966). Widely scattered on San Benito Mountain, according to Clare Hardham (personal communication, July 30, 1970) diploid plants are scattered along Clear Creek on "jadeite and asbestos serpentine" with tetraploids on the higher ridges on "ordinary" serpentine. Listed as a rare and endangered species by the California Native Plant Society (Powell 1974). DIABLO RANGE ENDEMIC.

Monardella douglasii Benth., Fenestra monardella (*Labiatae*).

Extremely aromatic annual herb, scattered on San Benito Mountain serpentine, this species is usually restricted to serpentine in the Coast Ranges.

Monardella villosa Benth., coyote mint (*Labiatae*).

Aromatic perennial herb, widely distributed, a variable species with most of the plants on the Santa Lucia peaks approaching ssp. *subserrata* (Greene) Epl.

Montia perfoliata (Donn) Howell, miner's-lettuce (*Portulacaceae*).

Succulent, annual herb, widely distributed in shady habitats, particularly under oaks. A variable species, some populations on San Benito Mountain serpentine fit var. *nubigena* (Greene) Jeps.

Montia spathulata (Dougl.) Howell var. *exigua* (T. & G.) Rob. (*Portulacaceae*).

Small succulent annual herb, uncommon in widely separated localities. The distinctive var. *tenuifolia* (T. & G.) Munz also occurs on San Benito Mountain below 1200 m, perhaps above. This species may hybridize with *M. perfoliata* on Chews Ridge.

Muhlenbergia asperifolia (Nees & Mey.) Parodi., scratch grass (*Gramineae*).

Perennial grass, common along creeks on San Benito Mountain, uncommon elsewhere in the south Coast Ranges (Raven 1957).

Navarretia mellita Greene, honey-scented navarretia (*Polemoniaceae*).

Annual herb, uncommon in grassland.

Navarretia pubescens (Benth.) H. & A. (*Polemoniaceae*).

Annual herb, scattered on San Benito Mountain serpentine, a south Coast Range serpentine endemic.

Nemocladus secundiflorus Robbins (*Campanulaceae*).

Annual herb, unimportant above 1200 m.

Nemophila menziesii H. & A., baby blue-eyes (*Hydrophyllaceae*).

Annual herb, scattered in grassland and savanna.

Nemophila parviflora Dougl., small-flowered nemophila (*Hydrophyllaceae*).

Annual herb, unimportant above 1200 m.

Nemophila pulchella Eastw. (*Hydrophyllaceae*).

Annual herb, scattered in forest and savanna.

Nicotiana attenuata Torr., mountain Indian tobacco (*Solanaceae*).

Annual herb, Raven (1957) found this "basically Great Basin" plant on Santa Rita Peak (fig. 3), uncommon elsewhere in the south Coast Ranges (Sharsmith 1945).

Oenothera hookeri T. & G. ssp. *hookeri* evening primrose (*Onagraceae*).

Perennial herb, local in wet spots.

Oenothera (for annual species see *Camissonia*)

Orobanche bulbosa (Gray) G. Beck., chaparral broomrape (*Orobanchaceae*).

Root parasite, only a few plants seen along chaparral margins, but the plant is probably more common.

Orobanche fasciculata Nutt. var. *franciscana* Achey, clustered broomrape (*Orobanchaceae*).

Only a few plants seen along chaparral margins, but the plant is probably more common.

Orthocarpus purpurascens Benth., escobita (*Scrophulariaceae*).

Annual herb, scattered in the grassland.

Osmaronia cerasiformis (T. & G.) Greene, oso berry (*Rosaceae*).

Deciduous shrub, scattered in shady canyons at lower elevations, rare above 1200 m.

Osmorhiza brachypoda Torr., California cicely (*Umbelliferae*).

Perennial herb, scattered in a variety of forest habitats.

Osmorhiza chilensis H. & A., wood cicely (*Umbelliferae*).

Perennial herb, scattered in a variety of forest habitats, perhaps more common than *O. brachypoda*.

Parnassia palustris L. var. *californica* Gray, California grass-of-parnassus (*Saxifragaceae*).

Perennial herb, uncommon riparian plant, sometimes on serpentine as on San Benito Mountain.

Pedicularis densiflora Benth. Indian warrior (*Scrophulariaceae*).

Perennial herb, locally common on the sandstone ridge north of Cone Peak, not noticed above 1200 m on other parent materials.

Pellaea andromedaefolia (Kaulf.) Fée, coffee fern (*Pteridaceae*).

Perennial herb, scattered on partly shaded rocky spots.

Pellaea mucronata (D. C. Eat.) D. C. Eat., birdsfoot fern (*Pteridaceae*).

Perennial herb, scattered on exposed rocky spots, more common above 1200 m than *P. andromedaefolia*.

Penstemon breviflorus Lindl., bush beard-tongue (*Scrophulariaceae*).

Evergreen shrub, widely distributed in open spots.

Penstemon centranthifolius Benth., scarlet bugler (*Scrophulariaceae*).

Perennial herb, widely distributed in forest or chaparral openings and rocky portions of grassland.

Penstemon corymbosus Benth., red penstemon (*Scrophulariaceae*).

Low evergreen mat-forming shrub, local on rock outcrops. Cone Peak is near the southern limit for this species, it was first collected by Thomas Coulter, probably in the Cone Peak region (McMinn 1939).

Penstemon grinnellii Eastw. ssp. *scrophularioides* (Jones) Munz, Grinnell penstemon (*Scrophulariaceae*).

Suffrutescent perennial, scattered on Chews Ridge, one plant seen on San Benito Mountain, uncommon elsewhere in the south Coast Ranges (McMinn 1939).

Penstemon heterophyllus Lindl. ssp. *australis* (M. & J.) Keck, chaparral penstemon (*Scrophulariaceae*).

Perennial herb, widely scattered but never common.

Phacelia brachyloba (Benth.) Gray, short-lobed phacelia (*Hydrophyllaceae*).

Annual herb, a few plants noticed in disturbed spots. Hoover (1970) described this species as abundant after fires in the southern Santa Lucias. The study peaks are near the northern limit for the species.

Phacelia curvipes Torr. var. *macrantha* (Parish) Munz (*Hydrophyllaceae*).

Annual herb, Howitt and Howell (1964) reported this plant (as *P. davidsonii* Gray) on the top of Chews Ridge. Hoover (1970) treated *P. curvipes* as part of *P. douglasii*, and it is possible that the *P. davidsonii* report is based on the same plants as *P. douglasii* in this list.

Phacelia distans Benth., wild heliotrope (*Hydrophyllaceae*).

Annual herb, unimportant above 1200 m.

Phacelia divaricata (Benth.) Gray (*Hydrophyllaceae*).

Annual herb, scattered on serpentine on San Benito Mountain.

Phacelia douglasii (Benth.) Torr., Douglas phacelia (*Hydrophyllaceae*).

Annual herb, scattered in dry rocky spots in grassland and chaparral openings.

Phacelia egena (Greene) Const. (*Hydrophyllaceae*).

Perennial herb, widely scattered in rocky openings in the forest. This tetraploid (n=22) form is sometimes difficult to distinguish from the closely related, mostly diploid (n=11) *P. imbricata* (Heckard 1960).

Phacelia grisea Gray, Santa Lucia phacelia (*Hydrophyllaceae*).

Annual herb, uncommon in disturbed spots in the chaparral, the study peaks are near the northern limit for this species.

Phacelia imbricata Greene ssp. *imbricata* (*Hydrophyllaceae*).

Perennial herb, widely scattered, often grows with the closely related *P. egena* (see *P. egena* note).

Phacelia malvifolia Cham. var. *loasifolia* (Benth.) Brand, stinging phacelia (*Hydrophyllaceae*).

Annual herb, scattered in rocky openings in the forest.

Phacelia ramosissima Dougl., branching phacelia (*Hydrophyllaceae*).

Perennial herb, scattered in widely separated spots on Chews Ridge, not noticed elsewhere, the plants approach var. *suffrutescens* Parry.

Phoradendron juniperinum Engelm. ssp. *libocedri* Engelm., mistletoe (*Viscaceae*).

Shoot parasite, scattered on incense-cedar on San Benito Mountain (Raven 1957), not reported on the Santa Lucia Range incense-cedars. DISJUNCT.

Phoradendron villosum Nutt., mistletoe (*Viscaceae*).

Shoot parasite, widely scattered on several oak species, above 1200 m the most common host was *Quercus chrysolepis*.

Pinus attenuata Lemm., knobcone pine (*Pinaceae*).

Small evergreen tree, locally common in chaparral at lower elevations, it reaches 1200 m only on the sandstone outcrops north of Cone Peak.

Pinus coulteri D. Don, Coulter pine (*Pinaceae*).

Evergreen tree, widely distributed, the most common pine on the study peaks. Thomas Coulter's type collection probably came from the ridge north of Cone Peak, but Alice Eastwood seems to have been under the impression that Coulter's collection came from Junipero Serra Peak. Her wish to see the type locality was a major reason for climbing the peak in 1893 (Eastwood n/d). (Zobel 1953).

Pinus jeffreyi Grev & Balf., Jeffrey pine (*Pinaceae*).

Evergreen tree, scattered on San Benito Mountain, the only native stand in the south Coast Ranges. Closest trees to the north are in northern Lake County--to the south in the San Rafael Mountains, Santa Barbara County (Griffin and Critchfield 1972). This pine was probably more dominant on San Benito Mountain prior to the heavy logging for mine timbers (Griffin 1974a). In February 1909 Jeffrey pine seedlings were planted on some 4 ha in two spots in the savanna on the summit of Chews Ridge. 11/ These Chews Ridge plantations have been mistaken for native stands (Zobel 1951a, 1952). In October 1910 Jeffrey pine seedlings were planted on some 20 ha of bare serpentine on Clear Creek, San Benito Mountain. 11/ No one in recent times has suspected this addition of nonlocal Jeffrey pines to the native San Benito Mountain forest. The seedlings for these early plantations were probably raised in nurseries on the Santa Barbara National Forest, but no records of the seed origin can be found. DISJUNCT.

Pinus coulteri X *P. jeffreyi*. Hybrids between these two pines are scattered on San Benito Mountain (Zobel 1951b). There may be more hybrids now than "pure" Jeffrey pine parents on parts of the area. Zobel (1951a) found a few hybrids in the Jeffrey pine plantations on Chews Ridge, the oldest hybrids may be the same age as the plantation, and perhaps these hybrids were inadvertently planted along with the Jeffrey pine seedlings in 1909 (see *Pinus jeffreyi* note). (Little and Righter 1965).

11/ Sloane, N. H. 1914. Resources and plan of operation of Monterey National Forest. (Unpublished report on file. Los Padres National Forest, King City, Calif.).

Pinus lambertiana Dougl., sugar pine (*Pinaceae*).

Large evergreen tree, magnificent old-growth trees are common in the Cone Peak region and on Junipero Serra Peak. David Douglas discovered this pine in Oregon, but he first saw the tree in California near Cone Peak (Hooker 1836). The closest stand to the north is near Mt. St. Helena, Lake County--to the south in the San Rafael Mountains, Santa Barbara County (Griffin and Critchfield 1972). DISJUNCT.

Pinus ponderosa Laws., ponderosa pine (*Pinaceae*).

Large evergreen tree, widely scattered in the Santa Lucias, but more often dominant just below the 1200 m level than on the higher ridges. Although no recognizable ponderosa pines have been found on San Benito Mountain, some of the Jeffrey pines there have cones that suggest ponderosa pine characters. A few of the San Benito Jeffrey pines may also have some biochemical relationships with ponderosa pine (Brown 1972).

Pinus sabiniana Dougl., Digger pine (*Pinaceae*).

Evergreen tree, widely scattered on San Benito Mountain, both on and off serpentine; although common in parts of the Santa Lucias, no trees were noticed above 1200 m (Griffin 1964, 1965, 1974a).

Pityrogramma triangularis (Kaulf.) Maxon, gold-back fern (*Pteridaceae*).

Small fern with annual fronds, widely distributed in dry rocky, but partly shaded spots.

Plagiobothrys nothofulvus (Gray) Gray, popcorn flower (*Boraginaceae*).

Annual herb, minor in grassland.

Poa annua L., annual bluegrass (*Gramineae*).

Small annual grass, minor in seasonally wet spots in grassland and savanna. INTRODUCED.

Poa howellii Vasey & Scribn., Howell bluegrass (*Gramineae*).

Annual grass, rare on Ventana Double Cone.

Poa scabrella (Thurb.) Benth., pine bluegrass (*Gramineae*).

Perennial bunchgrass, scattered in grassland and savanna.

Polygala californica Nutt., California milkwort (*Polygonaceae*).

Perennial herb, unimportant above 1200 m.

Polypodium californicum Kaulf., California polypody (*Polypodiaceae*).

Small fern with annual fronds, local on shady rock outcrops.

Polypogon monspeliensis (L.) Desf., rabbit-foot grass (*Gramineae*).

Annual grass, local in wet places. INTRODUCED.

Polystichum munitum (Kaulf.) Presl., sword fern (*Aspidiaceae*).

Fern with perennial fronds, widely distributed in forest habitats but seldom common above 1200 m. Most plants on the study peaks have rachises with reduced scales and probably fit ssp. *curtum* Ewan.

Potentilla glandulosa Lindl., sticky cinquefoil (*Rosaceae*).

Perennial herb, scattered in open forest and savanna.

Prunus emarginata (Dougl.) Walp., bitter cherry (*Rosaceae*).

Tall deciduous shrub, uncommon in rocky ravines or creek bottoms.

Prunus virginiana L. var. *demissa* (Nutt.) Sarg., western choke cherry (*Rosaceae*).

Uncommon in rocky ravines or creek bottoms, more widely distributed than *P. emarginata*; although their habitat requirements seem to overlap, these two cherries were not noticed growing together.

Psoralea californica Wats., California psoralea (*Leguminosae*).

Prostrate perennial, scattered in forest and chaparral openings on serpentine on San Benito Mountain. Uncommon elsewhere in the south Coast Ranges (Hoover 1970, Sharsmith 1945).

Psoralea macrostachya DC., leather root (*Leguminosae*).

Tall perennial herb, local in wet spots.

Psoralea orbicularis Lindl., round-leaved psoralea (*Leguminosae*).

Perennial herb, local in wet spots, not as widespread as *P. macrostachya*, these two psoraleas may grow together.

Psoralea physodes Dougl., California-tea (*Leguminosae*).

Perennial herb, uncommon in forest and chaparral habitats.

Pteridium aquilinum (L.) Kuhn var. *pubescens* Underw., bracken (*Pteridaceae*).

Tall fern with annual fronds, widely distributed in forest habitats, dominates the ground-cover in parts of the Chews Ridge savanna (Griffin 1975).

Pterostegia drymarioides F. & M. (*Polygonaceae*).

Annual herb, unimportant above 1200 m.

Pyrola picta Sm. f. *aphylla* (Sm.) Camp., leafless shinleaf (*Pyrolaceae*).

Perennial herb, root parasite, reported only on Junipero Serra Peak, rare elsewhere in the south Coast Ranges (Thomas 1961).

Quercus agrifolia Née, coast live oak (*Fagaceae*).

Large evergreen tree, important in parts of the lower elevation mixed evergreen forest but only scattered trees grow above 1200 m.

Quercus chrysolepis Liebm., canyon live oak (*Fagaceae*).

Large evergreen tree, vigorous sprouter, important dominant in the mixed evergreen forest, widely distributed in a variety of forest and mesic chaparral situations, rare on the San Benito Mountain serpentine.

Quercus douglasii H. & A., blue oak (*Fagaceae*).

Small to medium sized deciduous tree, important in lower elevation savanna, but only scattered trees grow above 1200 m (White 1966).

Quercus dumosa Nutt. (see *Q. turbinella* note)

Quercus durata Jeps., leather oak (*Fagaceae*).

Large evergreen shrub, widespread in serpentine chaparral on San Benito Mountain. Occurs on lower elevation serpentine in the Santa Lucias, but seems to be absent from the Pine Ridge serpentine.

Quercus kelloggii Newb., California black oak (*Fagaceae*).

Large deciduous tree, widely scattered in the more open forests, probably more important below the 1200 m elevation, conspicuous in the ponderosa pine forests.

Quercus lobata Née, valley oak, California white oak (*Fagaceae*).

Large deciduous tree, important in the savanna along the summit of Chews Ridge where trees up to 206 cm in dbh occur, this tree is absent above 1200 m on all other study peaks (Griffin 1973, 1975).

Quercus turbinella Greene ssp. *californica* Tucker, shrub live oak (*Fagaceae*).

Evergreen shrub or small tree, vigorous sprouter. Important in north-slope chaparral at lower elevations on interior slopes, but only scattered shrubs occur above 1200 m. *Q. turbinella* is sometimes difficult to separate from *Q. dumosa*, and some shrubs on Junipero Serra Peak are intermediate. In the lower Arroyo Seco drainage, *Q. turbinella* is common and clearly recognizable; on the coastal ridge south of Cone Peak *Q. dumosa* is common (Tucker 1953).

Quercus wislizenii A. DC. interior live oak (*Fagaceae*).

Evergreen shrub or tree, vigorous sprouter. Widely distributed as a dominant in the higher elevation mesic chaparral, less common as an understory tree in the forest.

Raillardella (*muirii* Gray ?) (*Compositae*).

Perennial herb, this plant was unknown in the south Coast Ranges until 1962, when Clare Hardham noticed it in the Ventana Double Cone region. In 1972, Steven N. Talley collected it on the rocky summit of Ventana Double Cone. It is closely related to *R. muirii* which is considered a rare and endangered species by the California Native Plant Society in the southern Sierra Nevada (Powell 1974). It appears less closely related to *R. scabrida* Eastw., an uncommon species of the north

Coast Ranges (Rydberg 1927). Several students are working on the relationship of these three *Raillardellas*. If the Ventana population is *R. muirii*, this plant is one of the most restricted and most interesting montane disjuncts in the Santa Lucias; if it is a new species, it is probably the most restricted endemic above 1200 m. These plants should receive the highest priority for administrative protection.

Rafinesquia californica Nutt., California chicory (*Compositae*).

Annual herb, rare in disturbed spots.

Ranunculus californicus Benth., California buttercup (*Ranunculaceae*).

Perennial herb, scattered in the savanna.

Ranunculus hebecarpus H. & A., downy buttercup (*Ranunculaceae*).

Small annual herb, unimportant above 1200 m.

Rhamnus californica Esch. ssp. *tomentella* (Benth.) C. B. Wolf, coffeeberry (*Rhamnaceae*).

Large evergreen shrub, widely distributed in the chaparral and scattered in the forest understory at all elevations.

Rhamnus crocea Nutt., ssp. *ilicifolia* (Kell.) C. B. Wolf, hollyleaf redberry (*Rhamnaceae*).

Large evergreen shrub, widely distributed in the chaparral.

Rhus diversiloba T. & G., poison-oak (*Anacariaceae*).

Deciduous woody vine or shrub, widely distributed at lower elevations but only locally common above 1200 m and rare above 1400 m on any of the study peaks.

Ribes roezlii Regel, Sierra gooseberry (*Saxifragaceae*).

Deciduous shrub, uncommon in the forest understory, shrubs on the summit of Junipero Serra Peak and Chews Ridge are clearly referable to *R. roezlii*, shrubs in Pine Valley below Pine Ridge approach *R. roezlii* in form but suggest hybridization with some other species such as *R. amarum* McClat. The sparse number of plants of this one *Ribes* species above 1200 m on the Santa Lucia peaks is in marked contrast to the rich assemblage of species at lower elevations; for example, eight species of *Ribes* are present on the Hastings Reservations at the foot of Chews Ridge. The next *R. roezlii* population to the north may be in Napa County (McMinn 1939)--to the south in the San Rafael Mountains, Santa Barbara County. 12/ DISJUNCT.

Rosa californica Cham. & Schlecht., California wild rose (*Rosaceae*).

Deciduous shrub, local in creek bottoms.

Rubus parviflorus Nutt., thimbleberry (*Rosaceae*).

Deciduous shrub, local in wet spots.

Rubus ursinus Cham. & Schlecht., Pacific blackberry (*Rosaceae*).

Evergreen woody vine, local in creek bottoms.

Rumex acetosella L., sheep sorrel (*Polygonaceae*).

Perennial herb, minor weed in disturbed spots. INTRODUCED.

Rumex conglomeratus Murr., green dock (*Polygonaceae*).

Perennial herb, minor weed in disturbed spots. INTRODUCED.

Rumex salicifolius Weinm., willow dock (*Polygonaceae*).

Perennial herb, local in wet spots.

Salix breweri Bebb., Brewer willow (*Salicaceae*

Deciduous shrub, common along all serpentine creeks on San Benito Mountain (the type locality). Uncommon elsewhere in the south Coast Ranges (Sharsmith 1945).

12/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Salix (misc. unidentified species probably *S. laevigata* Bebb or *S. lasiolepis* Benth. in most cases, uncommon above 1200 m).

Salvia columbariae Benth., chia (*Labiatae*).

Annual herb, scattered in rocky exposed spots in the grassland and chaparral margins.

Sambucus mexicana Presl., blue elderberry (*Caprifoliaceae*).

Deciduous shrub or small tree, widely scattered but never common.

Sanicula crassicaulis Poepp., gambleweed (*Umbelliferae*).

Perennial herb, scattered in the more weedy portions of several habitats.

Sanicula graveolens Poepp. (*Umbelliferae*).

Perennial herb, not reported in the south Coast Ranges until 1972, when Steven N. Talley found it on the Pine Ridge serpentine. Next population to the north may be on Bartlett Mountain, Lake County--to the south in the San Rafael Mountains, Santa Barbara County. 13/ DISJUNCT.

Satureja mimuloides (Benth.) Briq. (*Labiatae*).

Perennial herb, local in wet spots.

Scirpus microcarpus Presl., panicled bulrush (*Cyperaceae*).

Tall perennial herb, local in wet spots.

Sedum spathulifolium Hook, ssp. *anomalum* (Britton) Clausen & Uhl, Pacific stonecrop (*Crassulaceae*).

Succulent perennial herb, local on rock outcrops.

Selaginella bigelovii Underw., Bigelow moss-fern (*Selaginellaceae*).

Perennial herb, widely scattered on rock outcrops.

Silene gallica L., common catchfly (*Caryophyllaceae*).

Annual herb, minor weed in grassland. INTRODUCED.

13/ Smith, Clifton. 1974. A flora of the Santa Barbara Region. (Unpublished report on file, Santa Barbara Museum of Natural History, Calif.).

Silene lemmonii Wats., Lemmon campion (*Caryophyllaceae*).

Perennial herb.

Silene verecunda Wats. ssp. *platyota* (Wats.) Hitch. & Maquire (*Caryophyllaceae*).

Perennial herb.

Sisyrinchium bellum Wats., blue-eyed-grass (*Iridaceae*).

Perennial herb, apparently absent above 1200 m in the Santa Lucias but locally common along all the creeks on serpentine on San Benito Mountain.

Sitanion hystrix (Nutt.) J. G. Sm. (*Gramineae*).

Perennial bunchgrass, unimportant on the Santa Lucia peaks but scattered on serpentine on San Benito Mountain. This species is much less common on the study peaks than the closely related *S. jubatum*. *S. hystrix* appears to be the more montane in distribution as suggested by Anderson and Stebbins (1954).

Sitanion jubatum J. G. Sm., squirrel-tail (*Gramineae*).

Perennial bunchgrass, more widely distributed at lower elevations than *S. hystrix*. (Anderson and Stebbins 1954).

Sitanion (occasional sterile hybrids, probably with both *Agropyron* and *Elymus* were noticed on Chews Ridge and San Benito Mountain)

Solanum umbelliferum Eschs., blue witch (*Solanaceae*).

Evergreen shrub, widely scattered in disturbed areas.

Solidago californica Nutt., common goldenrod (*Compositae*).

Perennial herb, widely scattered in many habitats.

Solidago guiradonis Gray (*Compositae*).

Common along all the creeks on serpentine on San Benito Mountain. Raven (1957) appeared to refer to this plant as *S. confinis* Gray, but Hoover (1970) treated all the *S. confinis* in San Luis Obispo County as *S. guiradonis* var. *luxurians* (Hall) Hoover.

Stachys bullata Benth., hedge-nettle (*Labiatae*).

Perennial herb, scattered in open forest habitats.

Stachys pycnantha Benth., short-spiked hedge-nettle (*Labiatae*).

Perennial herb, local in wet spots.

Stellaria media (L.) Cyrill., common chick-weed (*Caryophyllaceae*).

Annual herb, unimportant in grassland above 1200 m. INTRODUCED.

Stellaria nitens Nutt., shining chickweed (*Caryophyllaceae*).

Annual herb, unimportant in grassland above 1200 m.

Stephanomeria elata Nutt. (*Compositae*).

Annual herb, unimportant above 1200 m.

Stephanomeria virgata Benth. ssp. *pleurocarpa* (Greene) Gottlieb. (*Compositae*).

Annual herb, widely scattered in disturbed or open spots.

Stipa cernua Steb. & Love, nodding needlegrass (*Gramineae*).

Perennial bunchgrass, unimportant, or perhaps absent, from the Santa Lucia Range grassland above 1200 m. One population was noticed on San Benito Mountain on a partially serpentinized slope at 1300 m.

Stipa coronata Thurb., large needlegrass (*Gramineae*).

Tall perennial grass, local on rock outcrops, not a component of the stable grassland.

Streptanthus breweri Gray (*Cruciferae*).

Annual herb, reported in the San Benito Mountain area (Morrison 1941), but not noticed there during this survey. Arthur Kruckeberg (personal communication, May 6, 1971) refers the early San Carlos Peak collections to var. *tenuis*. San Benito Mountain is near the southern limit for this Coast Range serpentine endemic.

Streptanthus glandulosus Hook. ssp. *glandulosus* Jewel Flower (*Cruciferae*).

Annual herb, scattered on the Pine Ridge serpentine, on Chews Ridge scattered on serpentine and rocky non-serpentine spots (Kruckeberg 1958).

Streptanthus insignis Jeps. (*Cruciferae*).

Annual herb, scattered on San Benito Mountain serpentine. The plants referred to *S. hispidus* Gray by Jepson (1925) from San Carlos Peak were probably *S. insignis* (A. Kruckeberg, personal communication, May 6, 1971).

Streptanthus tortuosus Kell., mountain streptanthus (*Cruciferae*).

Annual or biennial herb, local on rock outcrops. Rare elsewhere in the south Coast Ranges (Hoover 1970), the next population to the north may be Hood Peak, Sonoma County.

Stylocline gnaphalioides Nutt. (*Compositae*).

Annual herb, unimportant in grassland above 1200 m.

Symphoricarpos mollis Nutt., spreading snow-berry (*Caprifoliaceae*).

Low deciduous shrub, scattered in forest understory.

Tauschia hartwegii (Gray) Macbr., (*Umbelliferae*).

Perennial herb, scattered in rocky spots.

Thelepodium lasiophyllum (H. & A.) Greene, cut-leaved thelypodium (*Cruciferae*).

Annual herb, unimportant in grassland above 1200 m.

Thermopsis macrophylla H. & A., false-lupine (*Leguminosae*).

Tall perennial herb, conspicuous in forest understory and chaparral margins on Pine Ridge, elsewhere local or rare in rocky spots or creek bottoms.

Thysanocarpus curvipes Hook., hairy fringe-pod (*Cruciferae*).

Annual herb, unimportant in grassland.

Thysanocarpus laciniatus Nutt. var. *crenatus* (Nutt.) Brewer., narrow-leaved fringe-pod (*Cruciferae*).

Annual herb, rare in open spots above 1200 m.

Trichostema lanatum Benth., woolly blue-curls (*Labiatae*).

Aromatic evergreen shrub, uncommon in chaparral.

Trichostema rubisepalum Elmer (*Labiatae*).

Aromatic annual herb, scattered along San Benito Mountain serpentine creeks, the type locality (Elmer 1906). SIERRA NEVADA FOOTHILL DISJUNCT, known elsewhere only in Mariposa and Tuolumne Counties (Lewis 1945).

Trifolium albopurpureum T. & G., rancheria clover (*Leguminosae*).

Annual herb, widely scattered in grassland.

Trifolium ciliolatum Benth., tree clover (*Leguminosae*).

Annual herb, minor in the grassland.

Trifolium gracilentum T. & G., pin-point clover (*Leguminosae*).

Annual herb, scattered in grassland.

Trifolium microcephalum Pursh, maiden clover (*Leguminosae*).

Annual herb, widely scattered in grassland.

Trifolium tridentatum Lindl., tomcat clover (*Leguminosae*).

Annual herb, scattered in grassland.

Trifolium variegatum Nutt., white-tipped clover (*Leguminosae*).

Annual herb, scattered in grassland.

Triodanis biflora (R. & P.) Greene, venus looking-glass (*Campanulaceae*).

Annual herb, unimportant above 1200 m.

Umbellularia californica (H. & A.) Nutt., California-laurel (*Lauraceae*).

Aromatic evergreen tree, widely scattered in the forest and mesic chaparral on the Santa Lucia peaks. Although often found in serpentine wet spots in the Coast Ranges, this tree seems to be absent from the San Benito Mountain region (Griffin and Critchfield 1972).

Urtica holosericea Nutt., hoary nettle (*Urticaceae*).

Tall perennial herb, local in wet spots.

Urtica urens L., dwarf nettle (*Urticaceae*).

Annual herb, unimportant weed above 1200 m. INTRODUCED.

Verbena lasiostachys Link., California vervain (*Verbenaceae*).

Perennial herb, scattered in grassland and savanna.

Vicia americana Muhl. ssp. *oregana* (Nutt.) Abrams, American vetch.

Perennial herbaceous vine, scattered in the Chews Ridge forest, probably present elsewhere but confused with *Lathyrus*.

Viola purpurea Kell. (*Violaceae*).

Perennial herb, extremely variable.

1. Ssp. *mohavensis* (Baker & Clausen) J. Clausen. Both Baker (1953) and Stebbins et al. (1963) called this diploid (n=6) desert form of the *V. purpurea* complex *V. aurea* ssp. *mohavensis*. Baker (1953) reported this ssp. on Chews Ridge and Santa Rita Peak (fig. 3). Stebbins et al. (1963) accepted this ssp. for Chews Ridge but called all the violets in the San Benito Mountain region *V. quercetorum*. I can see no real difference between the Chews Ridge plants and some of the San Benito Mountain plants, although much of the San Benito Mountain material could be keyed to *V. quercetorum*. The same plant which occurs on small serpentine outcrops on Chews Ridge also occurs on the Pine Ridge serpentine. Clausen (1964) shifted ssp. *mohavensis* from *V. aurea* to *V. purpurea*.

2. Ssp. *purpurea* pine violet. Howitt and Howell (1964) listed this diploid (n=6) montane subspecies on Junipero Serra Peak. But Howitt and Howell (1973) were no longer certain that these plants differed from ssp. *mohavensis* on Chews Ridge. I would support their first view. Stebbins and others (1963) did not recognize ssp. *purpurea* in the Coast Ranges south of Lake County. Clausen (1964) continued to recognize ssp. *purpurea* as far south as southern California. Hoover (1970) reported ssp. *purpurea* in the southern Santa Lucias.

Viola quercetorum Baker & Clausen, oak violet (*Violaceae*).

Perennial herb, widely scattered in forest openings and savanna but never common. A variable population of this tetraploid (n=12) form of the *V. purpurea* complex is conspicuous in the San Benito Mountain region where it is difficult to separate from *V. purpurea* ssp. *mohavensis* (Clausen 1964, Stebbins et al. 1963).

Vulpia bromoides (L.) S. F. Gray, six weeks fescue (*Gramineae*).

Annual grass, scattered in grassland (*Festuca dertonensis* [All.] Asch. & Graebn.) (Lonard and Gould 1974). INTRODUCED.

Vulpia microstachys (Nutt.) Benth. (*Gramineae*).

Annual grass, Lonard and Gould (1974) merged all the native annual fescue species with reflexed spikelets into one species complex. The following varieties are minor grassland plants on the study peaks, there is some geographic separation between the different forms on the peaks, but at the Hastings Reservation all of them occur within a limited area, sometimes in mixed stands.

1. Var. *ciliata* (Beal) Lonard & Gould (*Festuca eastwoodae* Piper, *F. grayi* (Abrams) Piper, and *F. pacifica* Piper).
2. Var. *confusa* (Piper) Lonard & Gould (*Festuca confusa* Piper).
3. Var. *pauciflora* (Beal) Lonard & Gould (*Festuca reflexa* Buckley).

Vulpia myuros (L.) K. C. Gmelin (*Gramineae*).

Annual grass. (Lonard and Gould 1974). INTRODUCED.

1. Var. *hirsuta* Hack. One of the most widespread of the annual fescues (*Festuca megalura* Nutt.)
2. Var. *myuros*. Scattered in grassland (*Festuca myuros* L.).

Woodwardia fimbriata Sm., chain fern (*Blechnaceae*).

Tall perennial fern, local in wet spots.

Wyethia helenoides (DC.) Nutt., gray mule-ears (*Compositae*).

Perennial herb, scattered in Chews Ridge forest and savanna.

Yucca whipplei Torr., Spanish bayonet (*Agavaceae*).

Tall perennial rosette, widely scattered on dry chaparral slopes. The study peaks are near the northern limit for this southern California species. The summit of Junipero Serra Peak may be the highest elevation record for the species. Yuccas on the Santa Lucia peaks appear to be more rhizomatous than those of the Diablo range, the described subspecies do not fit the study peak plants well.

Zauschneria californica Presl., California fuchsia (*Onagraceae*).

Perennial herb, widely distributed in a variety of habitats, leaf and flower characters are variable and do not fit the described subspecies well.

Zigadenus fremontii Torr., star-lily (*Liliaceae*).

Perennial herb, locally common in forest and chaparral at lower elevations but reaches 1200 m only on Pine Ridge.

Zigadenus venenosus Wats., death camas (*Liliaceae*).

Perennial herb, local in wet spots.

GPO 689-233/

Griffin, James R.

1975. **Plants of the highest Santa Lucia and Diablo Range peaks, California**. USDA Forest Serv. Res. Paper PSW-110, 50 p. illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A search for vascular plants was conducted on six of the highest ridges in the south Coast Ranges of California. It covered five prominent peaks in the Santa Lucia Range, Monterey County, and the tallest mountain in the Diablo Range, San Benito-Fresno counties. Listed are all species found above 1200-m (3937-feet) elevation on at least one peak. Relative abundance is estimated for three elevation zones on all peaks. Notes provide information about each species' life form, plant community preference, ecological characteristics, and taxonomic problems.

Oxford: 187x455.7[–(794) (23)]
Retrieval Terms: plant communities; montane disjuncts; elevational distributions; Ventana Wilderness Area; Santa Lucia Range (California); Diablo Range (California); California.

Griffin, James R.

1975. **Plants of the highest Santa Lucia and Diablo Range peaks, California**. USDA Forest Serv. Res. Paper PSW-110, 50 p. illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A search for vascular plants was conducted on six of the highest ridges in the south Coast Ranges of California. It covered five prominent peaks in the Santa Lucia Range, Monterey County, and the tallest mountain in the Diablo Range, San Benito-Fresno counties. Listed are all species found above 1200-m (3937-feet) elevation on at least one peak. Relative abundance is estimated for three elevation zones on all peaks. Notes provide information about each species' life form, plant community preference, ecological characteristics, and taxonomic problems.

Oxford: 187x455.7[–(794) (23)]
Retrieval Terms: plant communities; montane disjuncts; elevational distributions; Ventana Wilderness Area; Santa Lucia Range (California); Diablo Range (California); California.

Griffin, James R.

1975. **Plants of the highest Santa Lucia and Diablo Range peaks, California. USDA** Forest Serv. Res. Paper PSW-110, 50 p. illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A search for vascular plants was conducted on six of the highest ridges in the south Coast Ranges of California. It covered five prominent peaks in the Santa Lucia Range, Monterey County, and the tallest mountain in the Diablo Range, San Benito-Fresno counties. Listed are all species found above 1200-m (3937-feet) elevation on at least one peak. Relative abundance is estimated for three elevation zones on all peaks. Notes provide information about each species' life form, plant community preference, ecological characteristics, and taxonomic problems.

Oxford: 187x455.7[–(794) (23)]
Retrieval Terms: plant communities; montane disjuncts; elevational distributions; Ventana Wilderness Area; Santa Lucia Range (California); Diablo Range (California); California.

Griffin, James R.

1975. **Plants of the highest Santa Lucia and Diablo Range peaks, California. USDA** Forest Serv. Res. Paper PSW-110, 50 p. illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A search for vascular plants was conducted on six of the highest ridges in the south Coast Ranges of California. It covered five prominent peaks in the Santa Lucia Range, Monterey County, and the tallest mountain in the Diablo Range, San Benito-Fresno counties. Listed are all species found above 1200-m (3937-feet) elevation on at least one peak. Relative abundance is estimated for three elevation zones on all peaks. Notes provide information about each species' life form, plant community preference, ecological characteristics, and taxonomic problems.

Oxford: 187x455.7[–(794) (23)]
Retrieval Terms: plant communities; montane disjuncts; elevational distributions; Ventana Wilderness Area; Santa Lucia Range (California); Diablo Range (California); California.

PSW-111

PACIFIC SOUTHWEST Forest and Range Experiment Station

SERVICE
ARTMENT OF AGRICULTURE
X 245, BERKELEY, CALIFORNIA 94701

Natural Seedlings and Sprouts after Regeneration Cuttings in Old-Growth Redwood

Kenneth N. Boe

USDA FOREST SERVICE RESEARCH PAPER PSW-111 /1975

CONTENTS

The Author

KENNETH N. BOE was formerly in charge of the Station's research unit on the silviculture of redwood and associated species, with headquarters at Arcata, California. A native of Montana, he earned bachelor's (1946) and master's (1948) degrees in forestry at Montana State University. He joined the Station in 1956 and retired in March 1974 after more than 33 years in Federal service. He is currently engaged in teaching and consulting work.

SUMMARY

Boe, Kenneth N.
1975. **Natural seedlings and sprouts after regeneration cuttings in old-growth redwood.** USDA Forest Serv. Res. Paper PSW-111, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 174.7 *Sequoia sempervirens*:231:181.33
Retrieval Terms: *Sequoia sempervirens*; regeneration cuttings; natural regeneration; germination; vegetative propagation.

Harvesting of old-growth redwood stands (*Sequoia sempervirens* [D. Don] Endl.) and regeneration to new forests will continue for a decade or more in north coastal California. Prompt and satisfactory forest renewal is mandatory where timber production is an objective. To assist in achieving this objective, I tested three regeneration cutting methods for getting natural regeneration. The cutting trials were on the Redwood Experimental Forest, Del Norte County, California, in the northern part of the redwood type. The methods were clearcutting in small blocks, shelterwood, and selection cutting. The first two methods are intended to perpetuate even-aged stands; the third, uneven-aged stands.

The redwood forest on the experimental area is representative of the northern redwoods, having heavy volumes per acre and a broad age distribution. Understory redwood are more numerous than any other species, with western hemlock, Douglas-fir, Port-Orford-cedar, and Sitka spruce ranking next in abundance. Timber-growing potential is high; the area is mostly site class I, with deep clay loam soils (Melbourne series), rainfall about 76 inches (193 cm) annually, cool summers, and mild winters.

Study methods included sampling seedling germination and establishment on marked plots over several years, and evaluating soil moisture, soil temperature, and competing herbaceous and shrubby vegetation. Mortality of seedlings was determined by marking individual seedlings and then observing them at several different times later and assigning cause of death visually, as supported by moisture, temperature, and vegetation data.

Essentially two major seedbeds were present on all the cutting trials—unburned mineral and burned mineral. The former amounted to about 70 percent and

Stocking by five species on milacre quadrats after 5 and 6 growing seasons, on burned and unburned mineral seedbed, by cutting method, Redwood Experimental Forest, California

Cutting method, year logged, and seedbed	Redwood	Douglas-fir	Western hemlock	Sitka spruce	Port-Orford-cedar	Total
	Percent					
Clearcutting (1959):						
Unburned	100	50	4	8	6	100
Burned	81	5	0	8	2	81
Shelterwood (1959):						
Unburned	95	90	0	10	3	95
Burned	75	15	0	0	0	78
Shelterwood (1960):						
Unburned	87	56	0	10	18	93
Burned	100	20	0	0	27	100
Selection (1959):						
Unburned	98	55	5	8	15	98
Burned	33	0	0	0	0	33
Selection (1960):						
Unburned	100	43	20	17	67	100
Burned	60	0	0	0	0	60

the latter 13 percent of the surface available for new trees. Another 17 percent was undisturbed forest floor and wood covered, but was too fractionated for study purposes.

Although the amount of redwood seed was the same on all seedbeds, the burned mineral seedbed had two to eight times fewer seedlings than did the unburned seedbed. The seedbeds were still very favorable to seedling germination and establishment the second year, but the number of seedlings declined drastically the third year. This drop suggests a much less favorable seedbed. Survival rate after 10 years was about 8 percent on the unburned seedbeds, and probably similar on the burned ones, but destroyed quadrats prevented us from citing a characteristic value.

A high proportion of mortality during the first growing season was attributed to drought and heat. Other investigators have suggested that root rot may contribute to mortality. The present study provided strong evidence that low levels of soil moisture and high surface temperatures were the main causes.

On the two principal mineral seedbeds, the average stocking of milacre quadrats by redwood on all cutting trials ranged from 87 to 100 percent on the unburned seedbed and 33 to 100 percent on the burned seedbed. Similarly, for all other conifers—especially Douglas-fir—the unburned mineral seedbed resulted in better stocking than the burned.

The regeneration methods tried—clearcutting, shelterwood, and selection—were all satisfactory for naturally reproducing new stands after cutting in old growth. Adequate seed for redwood and associated species and mineral soil seedbed were key factors for early success of seedling establishment. Sprouting redwood stumps added many potential crop trees—from 21 to 60 per acre (52 to 148 per hectare).

Throughout the redwood region in California, considerable harvesting is expected for a number of years in stands of both virgin old-growth and partially cutover old-growth redwood (*Sequoia sempervirens* [D. Don] Endl.). The resultant thousands of harvested acres need prompt regeneration to perpetuate timber production. Before turning to extensive seeding and planting, sound forestry practice suggests getting the most out of natural regeneration —especially since the potential for such renewal is considerable.

Show (1932) reported 25 to 35 percent stocking (based on estimated yield) from redwood sprouts that start at any season from cut stumps. He also observed that redwood bears seed abundantly, but seedlings develop under a rather narrow range of conditions. Where Person and Hallin (1942) related restocking to nearness to seed source they reported 50 percent stocking of milacre quadrats at a distance of 2 to 3 chains (40 to 60 m) and 30 percent at 3 to 7 chains (60 to 141 m).

A site will regenerate naturally with the species that were adapted to it. If regeneration can be accomplished quickly and economically through understanding the factors affecting it and then providing favorable conditions, forest managers will have a valuable technique. But if natural regeneration is a partial or total failure, then immediate supplemental or complete seeding or planting will become necessary.

This paper reports a study of natural regeneration by clearcutting, shelterwood, and selection cutting methods. Extent of regeneration was measured by sampling seedlings and sprouts. Preliminary results were reported earlier (Boe 1965). The results reported herein, interpreted in terms of site factors, can contribute to a better understanding of natural regeneration on other redwood timberland—especially in Humboldt and Del Norte counties, in northern California.

STUDY HABITAT

All cutting trials are on the Redwood Experimental Forest, Del Norte County, which is in the northern one-fifth of the 450-mile long redwood belt. The forest is about 1-1/2 miles from the Pacific Ocean. The precutting cover type was typical old-growth redwood characteristic of this part of its range. Redwood made up 58 to 70 percent of the sawtimber trees per acre on all cuttings (*table 1*).

Other conifers were found here. Douglas-fir trees (*Pseudotsuga menziesii* [Mirb.] Franco) were scarce on the clearcutting and selection cuttings, but exceeded 30 percent of the stand on the shelterwood cutting. Western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.) were somewhat alike in frequency of sawtimber on all cuttings. Sitka spruce trees (*Picea sitchensis* [Bong.] Carr.) were few and spotty in occurrence.

Species composition of poletimber and saplings (*table 1*) showed a definite pattern of redwood maintaining itself on all cutting areas. Only western hemlock followed a similar consistent pattern. The other species tended to vary in occurrence in the understory. Characteristically, many small trees were sprouts on larger redwood—usually as a result of injury.

Understory herbs, shrubs, and hardwoods were dense throughout all cuttings, and certain species occurred on 90 to 100 percent of 0.1-acre (0.04 hectare) random plots within the limited range of site and topography represented. These species were *Rhododendron macrophyllum* and *Vaccinium ovatum* in the tall group, *Polystichum munitum* in the medium group, and *Oxalis oregana* in the low group. These species varied among cutting areas, however, as the shrubs and trees more than 6 feet tall included more species and had greater leafy cover on the shelterwood than on each of the other two cuttings. Further south in the redwood type, Waring and Major (1964) also found that high frequencies of *V. ovatum*, *O. oregana*, and redwood coincided. For two key species—*P. munitum* and *O. oregana*—that I found on all

Table 1—*Stand table before regeneration cuttings on the Redwood Experimental Forest, California*

Cutting method and species	Diameter class (inches d.b.h.)			
	Saplings (1-4.9)	Poletimber (5-10.9)	Sawtimber (11.0+)	All classes
	Trees/acre (hectare)			
Clearcutting:				
Redwood	6.5	2.5	23.5	32.5
Douglas-fir	0	0	3.7	3.7
Sitka spruce	3.0	4.0	1.5	8.5
Western hemlock	5.0	2.0	4.0	11.0
Port-Orford-cedar	0	0	2.5	2.5
Total	14.5 (35.8)	8.5 (21.0)	35.2 (87.8)	58.2 (143.8)
Shelterwood:				
Redwood	19.6	5.0	31.4	56.0
Douglas-fir	2.9	10.3	17.2	30.4
Sitka spruce	0	0	0	0
Western hemlock	2.0	6.0	3.2	11.2
Port-Orford-cedar	1.0	3.0	2.7	6.7
Total	25.5 (63.0)	24.3 (60.0)	54.5 (134.6)	104.3 (257.6)
Selection:				
Redwood	8.2	5.5	31.5	45.2
Douglas-fir	0	0	2.3	2.3
Sitka spruce	0	0	0.2	0.2
Western hemlock	9.0	1.3	5.5	15.8
Port-Orford-cedar	0	1.0	5.3	6.3
Total	17.2 (42.5)	7.8 (19.3)	44.8 (110.6)	69.8 (172.4)

cuttings, Becking (1967) has suggested to describe two topographically and distinct forest alliances the names redwood-oxalis and redwood-swordfern. Other species characteristic of the understory on each cutting but of lower frequency were *Lithocarpus densiflorus, Rubus parviflorus,* and *Vaccinium parvifolium* in the tall group; and *Blechnum spicant* and *Gaultheria shallon* in the medium. *Alnus Rubra* was sampled only on the shelterwood but it was observed elsewhere, especially along stream courses.

Site productivity is mostly site class I[1] on the Melbourne soil and for the prevailing climate. The soils are deep clay loams (*table 2*), moderately to strongly acid. Many V-shaped water courses and slightly rounded ridges characterize the topography.

These northern redwood stands have a mild and humid climate and a long growing season. Rainfall averaged 76 inches (193 cm) annually for an 8-year period at the Redwood Experimental Forest. The heavy rain months are November through March. During mid-summer when rainfall is scant, the coastal fog keeps relative humidity high. Mean temperatures in the open range from 56° F in August to 43° F in January. The mean maximum is 65° F in July and the mean minimum 37° F in January. On the slopes the coldest temperature recorded over a 3-year period was 23° F.

In an earlier study, I compared temperature and humidity and measured precipitation for two types of cuttings on the Experimental Forest. I found only small differences in temperature and humidity between clearcuttings and selection cuttings in old-growth stands on west-facing and east-facing aspects, and between westerly and easterly clearcuttings (Boe 1970).

[1]Site classes are for redwood–Douglas-fir on *Soil-vegetation maps of California*, available from Pacific Southwest Forest and Range Experiment Station, Berkeley, California.

FIELD METHODS

Regeneration Cuttings

Three regeneration cutting methods were investigated: clearcutting in small blocks, shelterwood cutting, and selection cutting. Cuttings of each kind were made in 1959 and 1960, and again from 1961 to 1964. The results reported in this paper are from the 1959-60 cuttings.

Clearcuttings ranged in size from 10 to 20 acres and were alternated with reserve seed blocks about the same size.

The shelterwood cuttings, like clearcuts, will result in even-aged new stands. About 75 percent of the merchantable volume was harvested in the first cutting. Vigorous intermediate and codominant trees were reserved to help protect the site, furnish seed, and add growth. After reproduction was satisfactorily established, all of the reserved overstory was to be removed on one-half of each shelterwood cutting. On the other half, the overstory was to be removed in two equal cuts—the first after reproduction was established, and the second about 10 years later. Because the 1959-60 shelterwood cutting began to regenerate satisfactorily almost immediately, the area was reharvested in 1965. The next harvest is scheduled for 1975.

Selection cuttings are designed to produce and maintain uneven-aged forests. The first harvest removed about 50 percent of the volume in trees of all sizes. This volume was obtained from large old trees selected on about 10 percent of the area, and from smaller trees that were defective, dying, or cut to provide space to fell the large trees. The reserved trees tend to be arranged either in groups or alone; therefore, they are unevenly spaced throughout the stand. A second cut, mainly a salvage of windfalls, was made in 1965. These cuttings will be harvested every 10 years, with a planned rotation of 80 to 100 years.

Tractor logging was used throughout. For most large redwoods, layouts were constructed by bulldozer to cushion the trees' fall and reduce breakage. The layouts, composed of narrow-graded surface strips that approximated merchantable tree lengths and included cross-mounds of soil, resulted in much mixing of soil and exposure of subsoil. Logging slash was piled by bulldozer before burning on part of each area. The slash burning was a mix of piles, spots, and small broadcast areas. All of these activities provided seedbeds for natural regeneration.

Seedbed

The seedbeds were defined in this study as (a) unburned mineral, (b) burned mineral, and (c) undisturbed forest floor seedbeds. Group (c) was not studied because not enough continuous patches were found to permit a layout of plots.

The unburned mineral seedbed included a variety of soils, including subsoil, mixed subsoil-topsoil, and topsoil (*table 3*). Among cuttings, it ranged from 67 to 74 percent of total seedbed (all ground surface occupied by trees and stumps is excluded). Of this total, however, subsoil covered about 50 percent of the area on the clearcutting and shelterwood and only 14 percent on the selection cutting.

The burned mineral seedbed ranged from light to moderate to heavy burned condition—in total 14 percent or less (*table 3*).

All mineral categories, both burned and unburned, totaled 77 percent in the clearcutting, 82 percent in the shelterwood, and 88 percent in the selection cutting. A mixture of subclasses were usually represented on each of the study transects located on these broad seedbed categories.

Table 2—*Generalized features of soil and topography on the regeneration cuttings, Redwood Experimental Forest, California*

Regeneration cuttings	Soil texture, surface/subsoil (Melbourne series >1.22 m depth	Slope	Aspect	Elevation
		Percent		*Meters*
Clearcutting	Loam/clay loam	30-50	WSW	110-171
Shelterwood	Loam/clay loam	<30	WNW	36-183
	Loam/clay loam with stones	50-70	WSW	183-256
Selection cutting	Loam/clay loam	30-50	WNW	61-232

Table 3—*Seedbed conditions on regeneration cuttings in old-growth redwood stands, Redwood Experimental Forest, California*

Seedbed condition	Clearcutting	Shelterwood	Selection
	Percent		
Unburned mineral:			
Topsoil and mixed	14.9	21.2	60.1
Subsoil	51.8	48.4	13.6
Burned mineral (topsoil, mixed, and subsoil):			
Light to moderate	10.3	8.0	5.8
Hard burn	0	4.9	8.2
Forest floor	19.8	16.6	9.1
Wood covered	3.2	0.9	3.2

Reproduction Sampling

Milacre or smaller plots arranged in transects were examined on unburned mineral and burned mineral seedbeds on each randomly located 0.4-acre growth plot. Each transect on one seedbed per 0.4-acre plot has 10 quadrats. Before the logging, 10 growth plots were installed on each of the selection and shelterwood cuttings and five on one clearcutting. This gave 100 quadrats on each of the unburned and burned seedbeds on each of the selection and shelterwood cuttings, and 50 on each of the two seedbeds on the clearcutting. The data from transects on another clearcutting were omitted because seed trees were present on only one side and part of another.

On the fifth quadrat of each transect, seedlings were marked for subsequent identification. Each seedling was labeled within a few weeks of emergence, and seedling numbers were recorded. Causes of seedling deaths were estimated from visual evidence and recorded at each reexamination—the first in 2 weeks, then fall, spring, fall, and thereafter in the fall.

The principal herb and shrub seedlings were identified and tallied on each sample plot at each examination through the second growing season. By then the vegetation cover for most species was usually well identified.

Figure 1—Soil-related temperatures were measured with this simple supporting device which holds maximum and minimum bulbs at the surface, as well as 1 inch below and 1 inch above the surface (*left*). Ambient air temperatures were measured in a standard Weather Bureau-type shelter (*right*).

Soil Temperature

A study location was selected on one clearcutting and on one selection cutting, and maximum and minimum thermometers were placed on an unburned mineral seedbed and a burned mineral seedbed at these locations to measure temperatures at three positions: 1 inch above, at the surface, and 1 inch below the surface (*fig. 1*). Tempils (pellets that melt at a predetermined temperature) were also placed on the surface to compare with the thermometer readings. Additionally, the ambient air temperature was measured in a standard U. S. Weather Bureau-type shelter.

Tempils with melting points of 113°, 125°, and 138° F were placed on each of 50 intensive-study plots throughout the cuttings and checked at each examination for condition. Tempils melting at 151° F were added later.

Soil Moisture

Two soil depths, 1 to 3 inches and 6 to 8 inches, (2.54 to 7.62 cm and 15.24 to 20.32 cm) were sampled on unburned mineral and burned mineral seedbed at about monthly intervals throughout the summer. Moisture content was determined by gravimetric methods.

RESULTS

Seed

A plentiful seed supply, well timed, is essential to successful natural regeneration. In 5 consecutive years the principal redwood trees in both cut and uncut stands bore fair to good cone crops (Boe 1968). In samples of the seedfall, principally in November through February, about 90 percent of the redwood seeds were found to be unsound or empty, and therefore incapable of germination. Lott[2] reported 87 percent of the redwood seeds were unsound. Hansen and Muelder (1963) found that 58 to 99 percent of the seeds had no discernible embryo.

In the experimental cuttings, more than enough sound seeds were dispersed for ample germination—2,000,000 per acre per year in the shelterwood; 4,000,000 in the selection; 800,000 around edges of the 20-acre (8.1 ha) clearcutting; and 200,000 at the center (Boe 1961, 1968). These seeds came from the first and subsequent seed crops after logging. About 85 percent of the sound seeds germinated in the samples tested in the laboratory.

Redwood seeds are blown only relatively short distances by the wind. But effective dispersal at least 400 feet (122 m) from seed trees is adequate to seed 20-acre (8.1 ha) clearcuttings and would probably extend throughout much of 30-acre (12.1 ha) clearcuttings (Boe 1961). This dispersal characteristic compared well with findings by Person and Hallin (1942) of 30 percent stocking at an average dispersal distance of 330 feet (101 m).

The seed produced by other species varied in amounts. Some seed of all species fell on the cuttings in the first 2 years after harvesting. Generally, 1959 was a much better seed year than 1960—especially for Douglas-fir and western hemlock. Total seedfall by Douglas-fir was 288,600 seeds per acre (per 0.4 ha) on the shelterwood in 1959, but only 9300 the following year. For western hemlock it was 43,500 seeds per acre on the selection cutting in 1959, and 0 the next year. But more seeds of Port-Orford-cedar fell in 1960 than in 1959, except on the shelterwood cutting. Seed dispersal by Sitka spruce did not follow a consistent pattern.

Germination and Survival

The same quantities of redwood seed were available to both unburned and burned seedbeds, but consistently fewer seedlings developed the first year on the burned mineral soil—from two to eight times fewer than on the unburned mineral soil (*table 4*, *figs. 2, 3*). The same pattern of differences prevailed in the second and third crop of seedlings.

On these first cuttings where two good seed years followed the harvesting, the second-year redwood seedling crop was as good as or better than the first-year crop (*table 4*). This is evidence that the seedbed was still very favorable to germination and establishment. The third seed crop, however, was less than half that of the previous year (Boe 1968). Because of fewer seed, probably less favorable seedbed, and increasing abundance of vegetation, the third seedling crop amounted to only 1 to 40 percent of that the second year.

This third reduced seed crop, which preceded the second seedling crop on the 1960-cut area, also resulted in fewer seedlings than were produced by the crop of the preceding year. Although associated species were observed on the study plots, the measurement

[2]Lott, Hugh Carlin. 1923. The production and viability of redwood (*Sequoia sempervirens*) seed. M.S. Thesis. Univ. Calif., Berkeley. 32 p.

Table 4–*Redwood seedlings surviving on principal seedbeds after regeneration cuttings in old-growth stands, by year after harvesting.*

Regeneration cutting (year logged)	1960	1961	1962	1965	1970	1965	1970
	Seedlings per milacre					*Percent of original*	
	Unburned mineral seedbed						
Clearcutting (1959)	264	97	85	42		16	
		501	276	112		22	
			13	6		46	
				25			
Total	264	598	374	185	[1]93(23)	23	12
Shelterwood (1959)	221	91	81	45		20	
		938	678	178		19	
			159	45		28	
				21			
Total	221	1029	918	289	[2]0	22	
Shelterwood (1960)		305	219	49		16	
			135	16		12	
				38			
Total		305	354	103	[2]0	18	
Selection (1959)	612	313	219	70		11	
		1033	536	195		19	
			95	36		38	
				3			
Total	612	1346	850	304	[3]71(18)	17	4
Selection (1960)		678	188	48		7	
			276	121		44	
				92			
Total		678	464	261	[2]0	21	
	Burned mineral seedbed						
Clearcutting (1959)	128	36	31	26		20	
		100	41	26		26	
			1	0			
				0			
Total	128	136	73	52	[1]37(9)	23	16
Shelterwood (1959)	26	8	5	2		8	
		195	76	20		10	
			11	8		73	
				8			
Total	26	203	92	38	[2]0	16	
Shelterwood (1960)		129	93	65		50	
			35	24		69	
				28			
Total		129	128	117	[2]0	61	
Selection (1959)	287	44	32	[3]0			
		201	9	0			
			28	0			
				2			
Total	287	245	69	[3]0			
Selection (1960)		96	54	[3]0			
			23	0			
Total		96	77	[3]0			

[1]Number in parentheses is seedlings per square meter.
[2]Seedlings destroyed by relogging.
[3]Most seedlings were destroyed by uprooted trees during the October 12, 1962 hurricane, a rare phenomenon on the north coast.

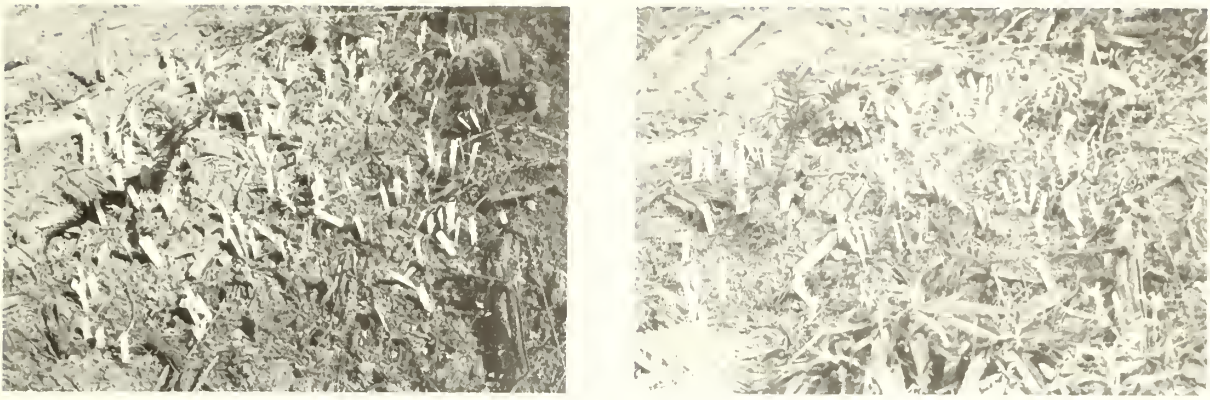


Figure 2—Redwood seedlings (white markers) were dense on unburned mixed mineral seedbed at the start of the first growing season (*left*), and near the end of the first season (*right*). (One-quarter-milacre quadrat, Redwood Experimental Forest, Calif.)

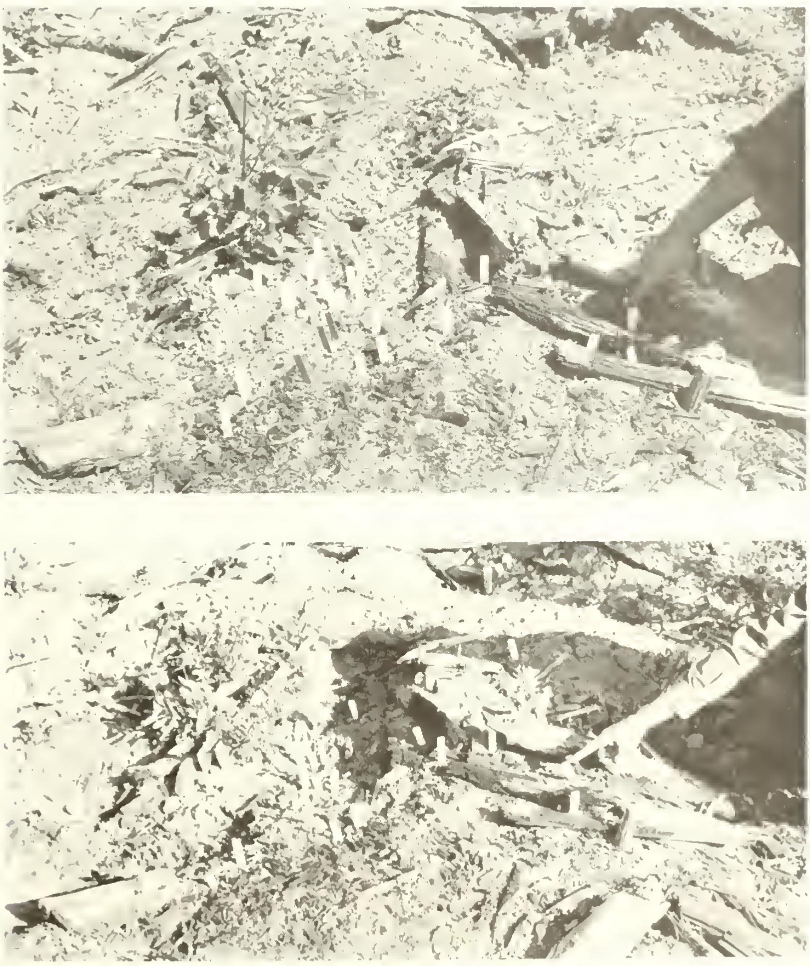


Figure 3—Redwood seedlings (white markers) were numerous on moderately burned mineral seedbed at the start of the first growing season (*top*), and many were still growing near the end of the first season (*bottom*). (Milacre quadrat, Redwood Experimental Forest, Calif.)

of their effects was not included because their scarcity and irregular occurrence prevented any specific patterns from developing.

The proportion (cumulative) of redwood surviving 5 and 6 years after harvesting averaged 20 percent on unburned mineral and 33 percent on burned mineral seedbeds (*table 4*). This rate of survival continued to decline until by 10 and 11 years after harvesting it was 4 to 12 percent on the unburned and 16 percent on the burned seedbeds. The 10th-year data on several study plots in the current study were unobtainable because the plots were destroyed by reharvesting and uprooting of reserved trees (*table 4*). This gap in data has weakened the results. Nevertheless, the available data suggest a lack of any real differences between cuttings on a given seedbed. And although seedling numbers are greatly different between burned and unburned seedbeds, the mortality rates are more nearly alike. Person and Hallin (1942) reported similar survival of about 20 percent at the end of 5 years after cutting.

The extent of seedling losses during the second cutting cannot be reliably stated from the few intensive study plots that were used in this study. Work is now underway with a wide distribution of plots to study the damage related to second cuttings. Data from the few plots used suggest that the reproduction stocking of milacre quadrats declined by 22 percent or more—a change from good stocking to medium stocking on the cuttings. The losses are expected to vary between cuttings and by topography. Replacement seedlings should establish themselves on some of the nonstocked areas caused by the second cuttings. But those cuttings scheduled for other harvests will suffer additional reproduction losses of presently unknown amount.

Site Factors in Mortality

Estimates of mortality were made during the first 2 weeks after plots were installed, and then again each fall, spring, and fall. Because of the relatively long interval between examinations, it was necessary to rely mainly on visual evidence. Drought and heat were recorded as the principal causes of seedling mortality the first year (*table 5*). Other investigators (Davidson; Muelder and Hansen[3]) also found that root rot may be an important factor causing seedlings to succumb to drought. In the present study, mortality of relatively few seedlings was attributed to erosion and insects. On several seedbeds, a large percent of deaths were designated "other," which included smothering and unknown causes.

Soil Moisture

Low moisture in the 1- to 3-inch (2.54 to 7.62 cm) layer (*fig. 4*) contributed significantly to the death of new seedlings during spring and early summer of their first growing season. Live seedlings were initially marked the first week in June, then reexamined 2 weeks later and again in the fall. A 30 percent moisture content in the clay loam Melbourne soils is near permanent wilting point.[4] Soil moisture below 30 percent, together with high surface temperatures, exerted a great stress on redwood seedlings. Furthermore, many seedling roots were damaged by root rot. The roots of dead seedlings measured 1 to 5 inches (2.54 to 12.70 cm) long, averaging about 2 inches (5.08 cm); in contrast, live seedlings of the same age have roots 5 to 9 inches (12.70 to 22.86 cm) and longer. Therefore, many of these seedling roots occupied the 1- to 3-inch zone where soil moisture was below critical on the clearcutting and shelterwood cuttings, and was low on the selection cutting. During the second growing season, similar moisture shortage prevailed, especially on the shelterwood cutting.

On the unburned soil, the soil moisture in the 1- to 3-inch (2.54 to 7.62 cm) depth class (*fig. 4*), dropped the first growing season in June to under 25 percent on the clearcutting, and slightly above 30 percent on the shelterwood and selection cuttings. Moisture declined generally to August. In the second growing season, moisture declined to the lowest levels in September; and minimums on clearcutting and shelterwood cuttings were about 20 percent but slightly above 30 percent on the selection cutting.

In the 6- to 8-inch (15.24 to 20.32 cm) layer on all cuttings, the moisture percent remained 30 percent or higher during the first growing season in June-August. In the second season the moisture was again 30 percent or more on the clearcutting and selection cuttings, but was slightly lower on the shelterwood cuttings.

A similar pattern of soil moisture decline during the growing season was evident for the burned seedbed for both depth classes and for the same respective

[3]Davidson, John G. N. 1971. Pathological problems of redwood regeneration from seed. Ph. D. Thesis. Univ. Calif., Berkeley. Muelder, D. W., and J. H. Hansen. 1961. Biotic factors in natural regeneration of Sequoia sempervirens. Paper presented at Int. Union For. Res. Organ. 13th Congr. Vienna, Austria, Sept. 1961.

[4]Soil laboratory data for Melbourne soil series, Redwood Experimental Forest, 1957, on file at Pacific Southwest Forest and Range Experiment Station, Arcata, California.

Table 5—*Distribution, according to probable cause, of redwood seedling mortality during the first growing season on burned and unburned mineral seedbeds, after regeneration cutting in old-growth stands, Redwood Experimental Forest, California*

Cutting method, year logged, and seedbed	Probable cause of mortality			
	Drought, heat, or both	Erosion	Insects	Other
	Percent			
Clearcutting (1959):				
Unburned	90	1	0	9
Burned	91	1	2	6
Shelterwood (1959):				
Unburned	59	10	0	31
Burned	37	7	0	56
Shelterwood (1960):				
Unburned	90	2	0	7
Burned	92	4	0	4
Selection (1959):				
Unburned	72	3	0	24
Burned	30	37	0	33
Selection (1960):				
Unburned	92	1	0	7
Burned	85	7	0	8

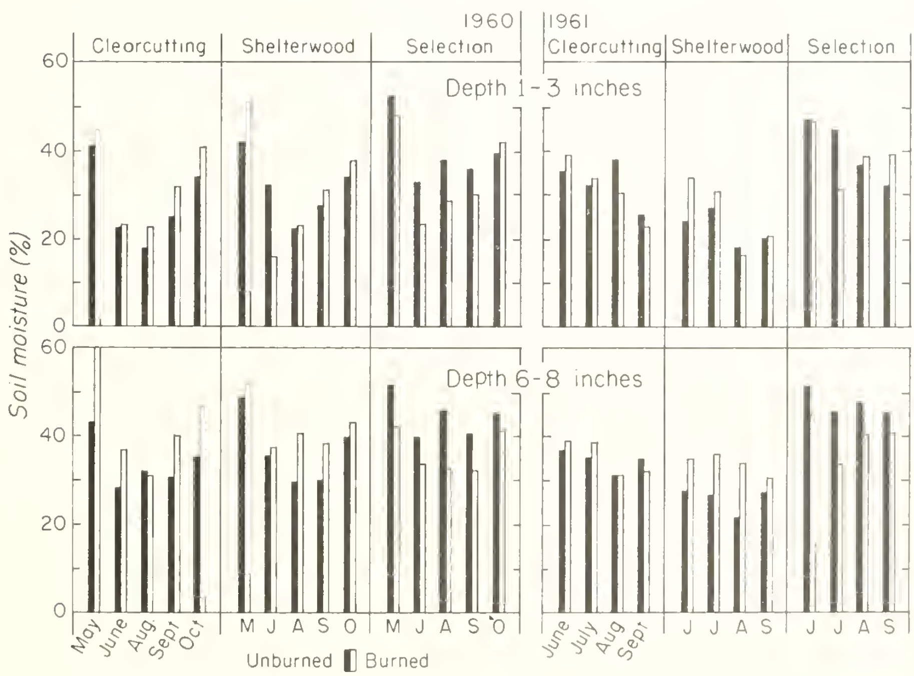


Figure 4—Average soil moisture was low in the 1- to 3-inch depth on the clearcutting and shelterwood during two summers. Higher levels were measured on the selection cutting and on all cuttings for the 6- to 8-inch depth. Differences between burned and unburned seedbeds were variable and generally small. (Redwood Experimental Forest, Calif.)

relationship between the regeneration cuttings as above (*fig. 4*). But the moisture levels of the burned seedbeds relative to the unburned usually tended to be a little higher by months, and for both seasons on the clearcutting and the shelterwood, and lower on the selection cutting. This pattern was evident for both soil depths.

Soil Temperature

Soil surface temperatures reached damaging levels for young conifers during June to August of the first two growing seasons on the clearcutting, but only during the first growing season on the selection cutting (*figs. 5, 6*). Temperatures ranged from 110° to 130° F on the clearcutting and from 104° to 122° F on the selection cutting. On the clearcutting, temperatures tended to be 12° to 16° F higher on the burned surface than on the unburned. And in the selection cutting, they tended to be 4° to 10° F higher. Highest temperature recorded on the clearcutting was 140° F; on the selection it reached 132° F.

Because of their level and duration, these soil surface temperatures could have killed seedlings. If "maximum temperature period" is defined as that within 2° F before and after peak temperature for the day, the duration of such a period—as determined by the hygrothermograph—ranged from 1/2 to 4 hours. Baker (1929) determined that a stem temperature of 131° F would kill young redwood seedlings after a minute or more exposure, and that higher temperatures would damage Douglas-fir. He found the temperature of the sand surface to be about 17° F higher than stem temperatures. For other soils and moisture conditions this differential may vary. Therefore,

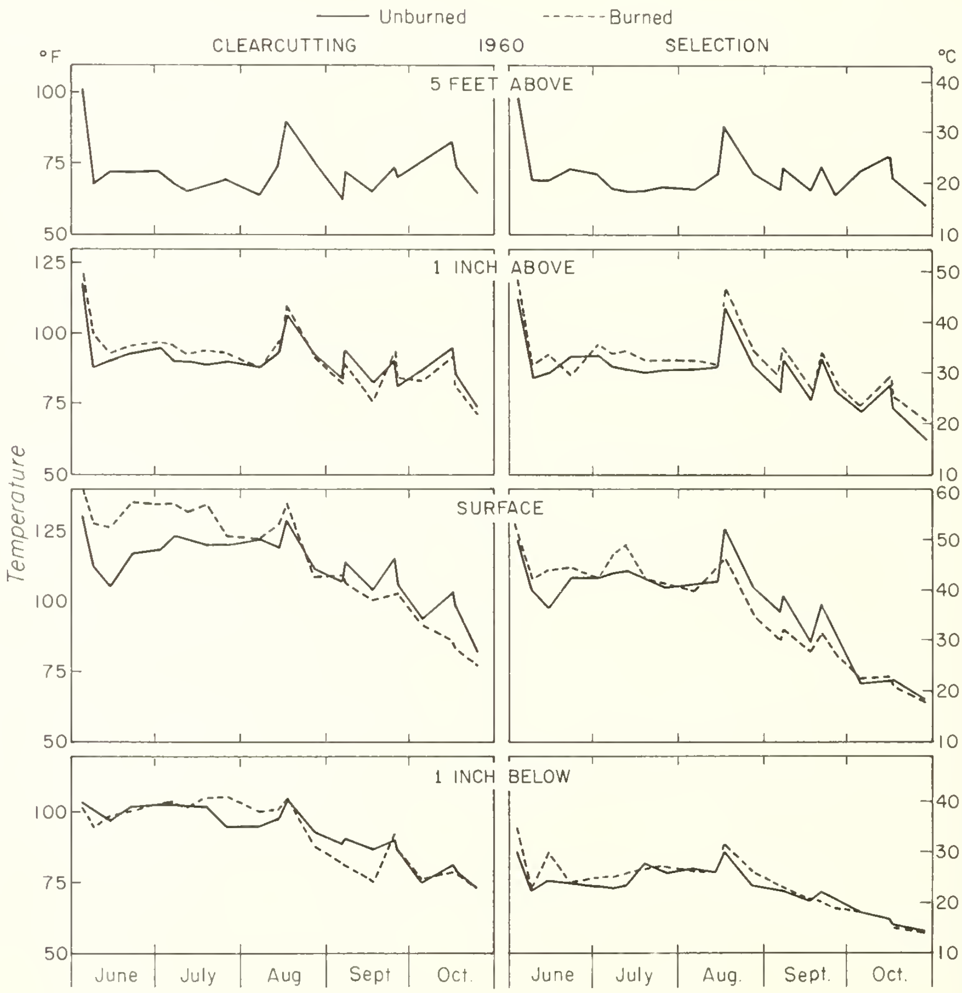


Figure 5—Weekly maximum temperatures during 1960 are shown here for the soil surface and for levels above and below the surface, for two regeneration cuttings on unburned and burned mineral seedbeds at the Redwood Experimental Forest in northern California.

about 145° F surface temperature would cause almost certain death of young seedlings. But if high temperatures lasted one-half hour or longer, a surface temperature lower than 145° F could injure or kill. Baker suggested that injury or mortality could result from stem temperatures of 115° F or 132° F soil surface temperature lasting 30 minutes.

From June to August of the second year (*fig. 6*), the maximum soil surface temperatures of the unburned seedbed on the clearcutting ranged from 112° to 130° F, and on the selection, from 102° to 115° F. Temperatures of the burned seedbed on the clearcutting were 6° to 8° F above that of the unburned seedbed at the start of summer—again, near lethal temperatures for redwood. Temperatures of the burned and unburned seedbeds became about the same during the remainder of the summer as vegetation developed. The lower temperatures of the burned seedbed on the selection cutting were largely the result of rank vegetation.

Ambient air temperatures at 5 feet (1.5 m) were similar on both clearcutting and selection cuttings in 1960 and 1961 (*figs. 5, 6*). The air temperatures were generally 50° F lower than that of the unburned surface in July and August on the clearcutting in 1960 and 1961; they were generally 40° F lower for similar seedbeds on the selection cutting during this same period.

Tempils melted when maximum surface thermometer measurements at the weather study station exceeded the stated melting points, with one exception: the 125° F pellet melted several times when the soil surface thermometer reading was below this temperature. This exception could have been caused by

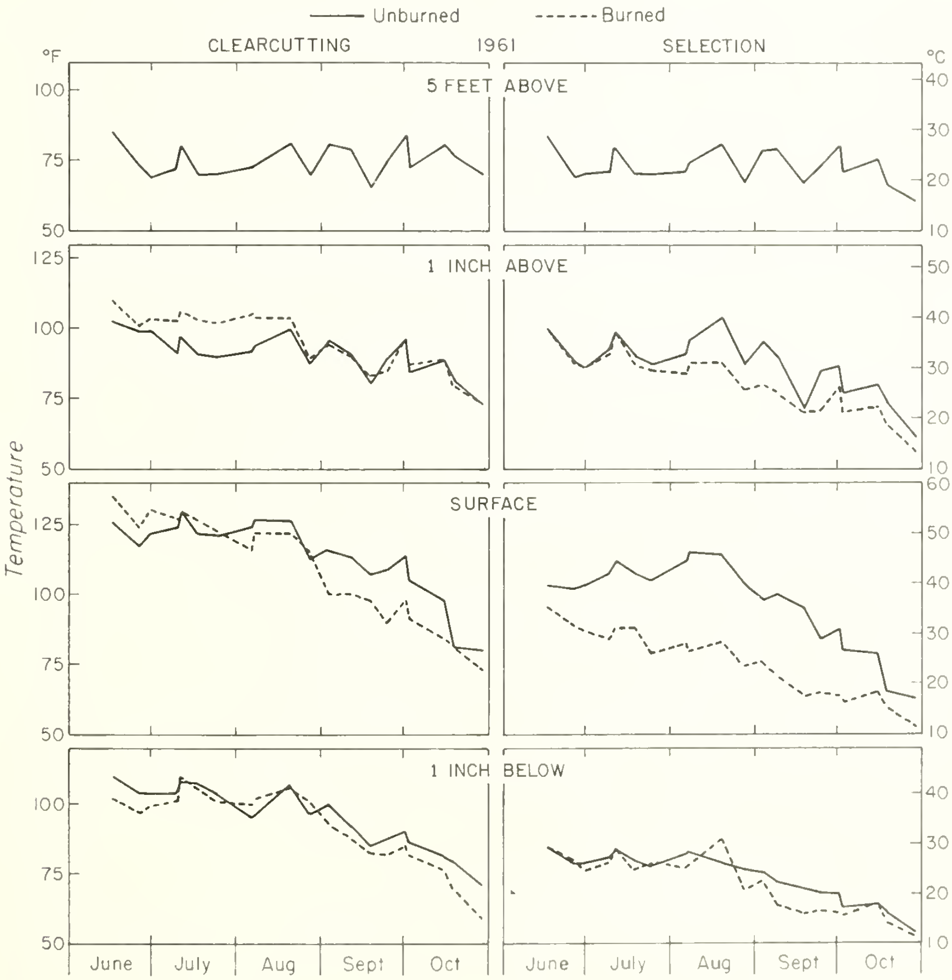


Figure 6—Weekly maximum temperatures during 1961 are shown here for the soil surface and for levels above and below the surface, for two regeneration cuttings on unburned and burned mineral seedbeds at the Redwood Experimental Forest in northern California.

slight differences in microsite temperatures, or by inaccuracies in both tempils and thermometers.

By placing tempils beside each reproduction study plot I extended the sampling of maximum temperature range to microsites throughout the cuttings. Only on the unburned seedbed in the selection cutting on WNW and NW aspects was maximum surface temperature greater than 125° F but less than 138° F during the summer. On all the other unburned and burned seedbeds and aspects, maximum temperatures were greater than 138° F but less than 151° F for the summer. These observations indicate that surface temperatures throughout the cuttings, except for unburned seedbeds on the selection area and possibly for north slopes, were high enough to cause seedling damage and death.

Vegetative Competition

Competition from vegetation that develops after logging contributes to mortality of natural regeneration. New species, as well as many that were present in the undisturbed stand, became abundant on the disturbed sites. One of the first plants to appear, and one present on all cuttings, was *Erechtites*, the Australian burn weed. Other plants that developed quickly during the first growing season were *Montia, Oxalis, Iris, Stachys, Gaultheria,* and *Rubus.* The *Erechtites prenanthoides* reached greatest density on the burned seedbed, but it also grew vigorously on the unburned seedbed. In contrast, *Stachys* seems to be more prevalent on the unburned seedbed—on two of the cuttings it was entirely absent on the burned seedbed during the first growing season. *Iris* and *Oxalis* seem to grow equally well on either the burned or unburned. Other species seem to be scattered randomly on all cuttings and all seedbeds.

During the second growing season, the vegetation increased in size and density. *E. prenanthoides* generally thrived on all seedbeds, in contrast to Fritz's (1950) finding of decreases after the first year, but had greatest frequency and density on the burned seedbed. *E. arguta* increased greatly in density and frequency, and was present on both seedbeds—especially those on the clearcutting and shelterwood. The perennial plants such as *Oxalis, Gaultheria, Rubus,* and *Iris*, which were present before harvesting, assumed greater prominence in the vegetation cover. And although *Alnus rubra* was a minor competitor during the first 2 or 3 years of seedling establishment, it soon became a major competitor as the stands developed, especially on cool moist habitats.

The post-harvest vegetation encroachment contributed to seedling deaths—mainly because it created droughty conditions. Especially on hard burned seedbed, the highly dense *E. prenanthoides* smothered seedlings at times when plant stems fell over in late fall. This condition contributed to poorer stocking on burned seedbeds. The rapid reinvasion and growth of vegetation on harvested areas provides additional hindrance to delayed natural regeneration. Each year's delay in adequate seed dispersal and germination means a substantial loss of optimum seedbed.

Seedling Stocking

On the unburned mineral seedbed, and for all cuttings, the average redwood stocking of milacre quadrats after 5 and 6 years ranged from 87 to 100 percent (*table 6*). Stocking ranged from 33 to 100 percent on burned mineral seedbed. These results cannot be compared to those reported by Person and Hallin (1942), who found that reproduction on medium to heavily burned areas was five to 10 times that on unburned or lightly burned areas, because the latter were on undisturbed litter—not mineral seedbed. Where mineral soil was exposed mechanically, Person and Hallin (1942) found density of seedlings nearly as heavy as on burned seedbeds—results more nearly comparable to mine. If we base the comparison on unburned mineral seedbed—the optimum condition—we find that no significant differences in stocking result from the different regeneration methods. On burned seedbeds, however, differences in results are probably due to seedbed variations rather than regeneration method.

For the associated species and all regeneration methods, the unburned mineral seedbed also proved superior to burned seedbed (*table 6*). Douglas-fir was especially well stocked on the unburned seedbed. Western hemlock produced limited stocking on the unburned seedbed, but none on the burned.

Redwood Sprout Stocking

Some of the new forest will develop from redwood sprouts. Only part of the old-growth stumps will sprout. The percent sprouting was 56 in the clearcutting, 42 in the shelterwood, and 53 in the selection. These values are slightly different from those reported by Neal (1967); here all stumps were tallied, but Neal omitted them if stump age could not be determined. I estimated that there were 12 sprouting stumps per acre on the clearcutting and just over four each on the shelterwood and selection. There were

Table 6–*Stocking by five species on milacre quadrats after 5 and 6 growing seasons, on burned and unburned mineral seedbed, by cutting method, Redwood Experimental Forest, California*

Cutting method, year logged, and seedbed	Redwood	Douglas-fir	Western hemlock	Sitka spruce	Port-Orford-cedar	Total
	Percent					
Clearcutting (1959):						
Unburned	100	50	4	8	6	100
Burned	81	5	0	8	2	81
Shelterwood (1959):						
Unburned	95	90	0	10	3	95
Burned	75	15	0	0	0	78
Shelterwood (1960):						
Unburned	87	56	0	10	18	93
Burned	100	20	0	0	27	100
Selection (1959):						
Unburned	98	55	5	8	15	98
Burned	33	0	0	0	0	33
Selection (1960):						
Unburned	100	43	20	17	67	100
Burned	60	0	0	0	0	60

fewer sprouting stumps on the two latter cuttings because fewer trees per acre were cut, and the sprouting percentage was lower.

Only a few sprouts on each sprouting stump will become the final crop trees. The number of crop trees per stump will probably range from 1 to 10 or more. An average of five per stump is a reasonable estimate. At this rate there would be 60 sprout crop trees per acre (148 per hectare) on the clearcutting, 21 (52) on the shelterwood and 22 (54) on the selection cutting. And between the stumps and reserved trees are the seedbeds where nearly full stocking of seedlings have become established to develop well-stocked stands by all regeneration methods.

CONCLUSIONS

The clearcutting, shelterwood, and selection methods are all satisfactory for reproducing new stands on habitats similar to those on the Redwood Experimental Forest. But the high soil surface temperatures and droughty upper soil layers on many microseedbeds can cause high seedling losses. Nevertheless, old-growth redwoods will regenerate rapidly under a variety of conditions after harvesting if a satisfactory seed source is present. Large reserved trees should produce sound seed frequently and abundantly. But small understory trees are usually poor producers, initially, and do not improve much after release (Boe 1968). Two or three larger intermediate, codominant, or dominant redwood trees per acre (per 0.4 ha) that were previously cone bearers will provide ample seed for regeneration. If clearcuttings are used, however, up to 10 seed trees per acre are needed in the marginal stand. The effective distance from marginal seed trees will be about 400 feet (122 m). Seed trees of other species will be needed in proportion to objectives for growing them and to compensate for their irregularity of seed production. Douglas-fir appears to be particularly aggressive in establishing itself and is a desirable component of redwood cutover stands.

On both principal seedbeds–unburned mineral and burned mineral–redwood will establish adequately except that it will be somewhat poorer on the burned mineral seedbed because this gets hotter the first growing season, and dense vegetation regrows more quickly. This regrowth may cause droughty conditions and conditions favorable for smothering by dead vegetation. The other tree species appear to do much better on unburned than on burned mineral seedbed. Usually a variety of seedbeds will be found on tractor-harvested areas, including subsoil, topsoil, mixed subsoil-topsoil, burned soils, and undisturbed forest floor. This mix of seedbeds, except the hard burn and forest floor, will be satisfactory for conifer seedling establishment. The trend towards full utilization of timber and less slash burning favors the establishment of both redwood and associated conifers.

Redwood seedlings should become established readily for the first 3 years after cutting but in diminishing numbers. Mortality rates of 90 percent during the first 5 years after cutting will likely occur, but this rate diminishes thereafter. Therefore, about 7500 to 10,000 germinants per acre (18,500 to 24,700 per hectare) would be initially needed to produce a desirable density of established seedlings after mortality has declined. Furthermore, the distribution of seedlings, as measured by stocked quadrats, will be usually more than satisfactory on the amount of mineral seedbed created by tractor logging.

Redwood sprout stocking will contribute significantly to new stands. The redwood stumps should not be destroyed, debarked, nor severely burned because any of these actions would greatly reduce sprout stocking (Neal 1967).

Redwood seedlings should grow better after establishment on clearcuttings, with full sunlight and warm air and soil, than on selection cuttings, where some habitats are cool and shaded. The warmer soils favor redwood growth (Hellmers 1963). Although both clearcuttings and selection cuttings had summer air temperatures much alike, soil temperatures in clearcuttings were generally warmer. Hellmers and Pharis (1968) found that redwood decreased in height growth and dry weight as the total amount of light energy decreased. Redwood seedlings also showed optimum growth under controlled conditions of 67° F day and 59° F night temperatures (Hellmers 1966), but there was only slight difference when they were grown at 67° F constant temperature.

The first reharvesting of the shelterwood and selection cuttings resulted in 22 percent and more reduction of seedling-stocked milacre quadrats. Although what this means in terms of stocking by 15- to 20-year old trees or the amount of seedling replacement in nonstocked areas is not known, it seems obvious that each time additional old-growth trees are harvested from the same area, some destruction of young growing stock will result. Therefore regeneration cuttings such as small clearcuttings, seed-tree cuttings, or two-cut shelterwood cuttings should be favored methods for converting old-growth redwoods to natural regenerated young stands.

A major consideration in natural regeneration is that the area will be restocked with trees that are adapted to the site. In the natural competition that follows, the stronger seedlings usually survive. When cultural practices are undertaken to encourage the growth of the stronger and best quality seedlings, the resulting growing stock should approach optimum for the site.

LITERATURE CITED

Baker, Frederick S.
1929. Effect of excessively high temperature on coniferous reproduction. J. For. 27:949-975.

Becking, Rudolph W.
1967. The ecology of the coastal redwood forest and the impact of the 1964 floods upon redwood vegetation. Final report, National Science Foundation Grant GS 3468, 1965. 91 p., illus.

Boe, Kenneth N.
1961. Redwood seed dispersion in old-growth cutovers. U.S. Forest Serv. Res. Note 177, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Boe, Kenneth N.
1965. Natural regeneration in old-growth cuttings. U.S. Forest Serv. Res. Note PSW-94, 5p., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Boe, Kenneth N.
1968. Cone production, seed dispersal, germination in old-growth redwood cut and uncut stands. USDA Forest Serv. Res. Note PSW-184, 7 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Boe, Kenneth N.
1970. Temperature, humidity, and precipitation at the Redwood Experimental Forest. USDA Forest Serv. Res. Note PSW-222. Pacific Southwest Forest and Range Exp. Stn. Berkeley, Calif. 11 p., illus.

Fritz, Emanuel
1950. Spot-wise direct seeding for redwood. J. For. 48:334-338.

Hansen, J. H., and Muelder, D. W.
1963. Testing of redwood seed for silvicultural research by x-ray photography. For. Sci. 9:470-476, illus.

Hellmers, Henry
1963. Effects of soil and air temperatures on growth of redwood seedlings. Bot. Gaz., 124 (3):172-117, illus

ellmers, Henry
1966. Growth response of redwood seedlings to thermoperiodism. For. Sci. 12:276-283, illus.

ellmers, Henry, and Pharis, Richard P.
1968. Influence of photoperiod and photoperiodic cycles on the growth of coastal redwood seedlings. Bot. Gaz., 129 (1):53-57, illus.

eal, Robert L. Jr.
1967. Sprouting of old-growth redwood stumps first year after logging. U. S. Forest Serv. Res. Note PSW-137, 8 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Person, Hubert L., and Hallin, William
1942. Natural restocking of redwood cutover lands. J. For. 40:683-688.

Show, S. B.
1932. Timber growing and logging practice in the coast redwood region of California. U. S. Dep. Agric. Tech. Bull. 283. 33 p., illus.

Waring, R. H., and Major, J.
1964. Some vegetation of the California coastal redwood region in relation to gradients of moisture, nutrients, light, and temperature. Ecol. Monogr. 34(2):167-215, illus.

GPO 689—233/4433

Boe, Kenneth N.

1975. **Natural seedlings and sprouts after regeneration cuttings in old-growth redwood.** USDA Forest Serv. Res. Paper PSW-111, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Natural regeneration of harvested old-growth stands of redwood *(Sequoia sempervirens)* is one way to start a new forest that is needed quickly for continuous timber production. Natural seedlings and sprouts developing after stands were cut were studied on the Redwood Experimental Forest, northern California. Three types of regeneration cuttings were investigated: small clearcutting, shelterwood, and selection. All three types provided satisfactory results—chiefly in redwood, but also in Douglas-fir and other conifers. Redwood sprouts added many potential crop trees. Of the two main seedbeds created by logging disturbance, the unburned mineral was more productive than burned mineral seedbed for all conifer species.

Oxford: 174.7 *Sequoia sempervirens:*231:181.33
Retrieval Terms: Sequoia sempervirens; regeneration cuttings; natural regeneration; germination; vegetative propagation.

Boe, Kenneth N.

1975. **Natural seedlings and sprouts after regeneration cuttings in old-growth redwood.** USDA Forest Serv. Res. Paper PSW-111, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Natural regeneration of harvested old-growth stands of redwood *(Sequoia sempervirens)* is one way to start a new forest that is needed quickly for continuous timber production. Natural seedlings and sprouts developing after stands were cut were studied on the Redwood Experimental Forest, northern California. Three types of regeneration cuttings were investigated: small clearcutting, shelterwood, and selection. All three types provided satisfactory results—chiefly in redwood, but also in Douglas-fir and other conifers. Redwood sprouts added many potential crop trees. Of the two main seedbeds created by logging disturbance, the unburned mineral was more productive than burned mineral seedbed for all conifer species.

Oxford: 174.7 *Sequoia sempervirens:*231:181.33
Retrieval Terms: Sequoia sempervirens; regeneration cuttings; natural regeneration; germination; vegetative propagation.

Boe, Kenneth N.

1975. **Natural seedlings and sprouts after regeneration cuttings in old-growth redwood.** USDA Forest Serv. Res. Paper PSW-111, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Natural regeneration of harvested old-growth stands of redwood *(Sequoia sempervirens)* is one way to start a new forest that is needed quickly for continuous timber production. Natural seedlings and sprouts developing after stands were cut were studied on the Redwood Experimental Forest, northern California. Three types of regeneration cuttings were investigated: small clearcutting, shelterwood, and selection. All three types provided satisfactory results—chiefly in redwood, but also in Douglas-fir and other conifers. Redwood sprouts added many potential crop trees. Of the two main seedbeds created by logging disturbance, the unburned mineral was more productive than burned mineral seedbed for all conifer species.

Oxford: 174.7 *Sequoia sempervirens:* 231:181.33
Retrieval Terms: Sequoia sempervirens: regeneration cuttings; natural regeneration; germination; vegetative propagation.

Boe, Kenneth N.

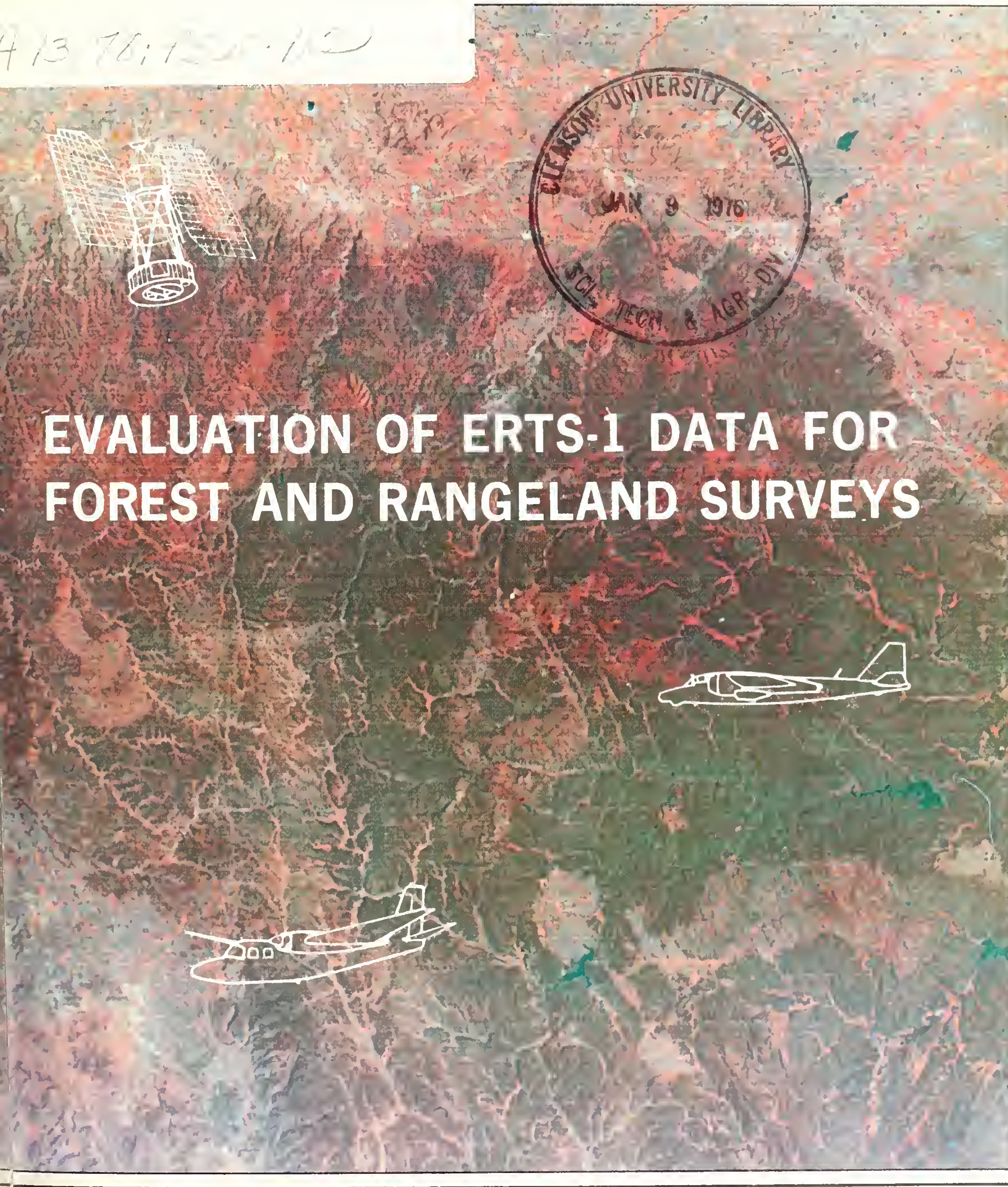
1975. **Natural seedlings and sprouts after regeneration cuttings in old-growth redwood.** USDA Forest Serv. Res. Paper PSW-111, 17 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Natural regeneration of harvested old-growth stands of redwood *(Sequoia sempervirens)* is one way to start a new forest that is needed quickly for continuous timber production. Natural seedlings and sprouts developing after stands were cut were studied on the Redwood Experimental Forest, northern California. Three types of regeneration cuttings were investigated: small clearcutting, shelterwood, and selection. All three types provided satisfactory results—chiefly in redwood, but also in Douglas-fir and other conifers. Redwood sprouts added many potential crop trees. Of the two main seedbeds created by logging disturbance, the unburned mineral was more productive than burned mineral seedbed for all conifer species.

Oxford: 174.7 *Sequoia sempervirens:* 231:181.33
Retrieval Terms: Sequoia sempervirens: regeneration cuttings; natural regeneration; germination; vegetative propagation.

PACIFIC SOUTHWEST Forest and Range Experiment Station

SERVICE
ARTMENT OF AGRICULTURE
245, BERKELEY, CALIFORNIA 94701



EVALUATION OF ERTS-1 DATA FOR FOREST AND RANGELAND SURVEYS

USDA FOREST SERVICE RESEARCH PAPER PSW-112/1975

EVALUATION OF ERTS-1 DATA FOR FOREST AND RANGELAND SURVEYS

Technical Coordinator
ROBERT C. HELLER

USDA FOREST SERVICE RESEARCH PAPER PSW-112

Pacific Southwest Forest and Range Experiment Station
Forest Service U.S. Department of Agriculture
Berkeley, California 94701

1975

Technical Coordinator

ROBERT C. HELLER, formerly in charge of the Station's Remote Sensing Research Work Unit, at Berkeley, is now a research professor of forestry, University of Idaho, Moscow. He earned a bachelor of science degree in botany (1940) and a master's degree in forestry (1941) at Duke University, and was employed by the U.S. Department of Agriculture from 1947 until his retirement in 1974.

The Authors

ROBERT C. ALDRICH, who heads the Station's Remote Sensing Research Work Unit, joined the Berkeley staff in 1965. He is a graduate of the State College of Forestry, Syracuse, New York (bachelor of science, 1944; master of forestry, 1948). **ROBERT W. DANA**, a physicist, has been a member of the Unit since 1969. He earned a bachelor's degree in physics (1963) and master's degree in geophysics (1969) at the University of Washington. **RICHARD S. DRISCOLL** is in charge of the Range Inventory and Evaluation Research Work Unit at the Rocky Mountain Forest and Range Experiment Station, Fort Collins. He studied at Colorado Agricultural and Mechanical College (baccalaureate in range management, 1951), Colorado State University (master's degree in range management, 1957), and Oregon State University (doctorate in range ecology, 1962). **RICHARD E. FRANCIS**, an associate range scientist, is also assigned to range inventory research at the Rocky Mountain Station. He earned a bachelor's degree (1967) in wildlife management at Humboldt State College, California. **WALLACE J. GREENTREE** also attended Humboldt State College (bachelor of science degree in forest management, 1961). A forestry technician, he has been with the Pacific Southwest Station's Remote Sensing Research Work Unit since 1967. **RICHARD J. MYHRE** is staff photographer and operates the Unit's photography laboratory. He joined the Berkeley staff in 1965. Unit mathematician and statistician since 1966, **NANCY X. NORICK** holds bachelor's (1964) and master's (1969) degrees in statistics from the University of California, Berkeley. **EDWIN H. ROBERTS**, a research forester with the Unit, is a forestry graduate of the University of California, Berkeley (bachelor's, 1965, and master's degrees, 1969). He joined the Station staff in 1974. **THOMAS H. WAITE**, a forestry technician with the Unit,is also a graduate of the University of California, Berkeley (bachelor of science in forestry, 1970), and has been with the Station staff since 1970. **FREDERICK P. WEBER**, formerly with the Unit, is now remote sensing coordinator, Forest Economics and Marketing Research Staff, Forest Service, Washington, D.C. He was educated at the University of Minnesota (baccalaureate in forestry, 1960) and the University of Michigan (master's degree in forestry, 1965; doctorate in forestry, 1969).

Cover: An enlarged portion (X 10) of an Earth Resources Technology Satellite (ERTS) color composite, MSS bands 4, 5, and 7 (green, red, and near infrared, respectively), obtained June 22, 1973 over part of the Black Hills. South Dakota. Snow is covering the ground but is not in the treetops. Scale is approximately 1:375,000.

FOREWORD

When the Earth Resources Technology Satellite (ERTS-1) was launched in 1972, new and exciting applications of satellite imagery in resource management were expected. Although many of these exciting possibilities have materialized or show promise, this report shows that satellite imagery has limitations as well as positive aspects.

The report describes experimental uses of ERTS-1 imagery for inventorying forests and rangelands and for detecting areas of forest disturbance or stress—either because of adverse natural phenomena or activities of man. It suggests the levels of success a resource manager might expect if he uses ERTS-1 data for any of a number of inventory objectives.

The work was done under Contract S-70251-G (May 1, 1972 to October 9, 1974) between the Goddard Space Flight Center of the U.S. National Aeronautics and Space Administration, and the U.S. Department of Agriculture.

NASA provided funds and the Forest Service provided resource scientists from the Pacific Southwest Forest and Range Experiment Station, through its Remote Sensing Research Work Unit at Berkeley, California, and the Rocky Mountain Forest and Range Experiment Station, through its Range Inventory and Evaluation Research Work Unit at Fort Collins, Colorado.

Robert C. Heller was principal investigator, and Robert C. Aldrich, Richard S. Driscoll, and Frederick P. Weber were coinvestigators during the 29-month study. This Research Paper is based on the final report submitted to NASA in fulfillment of the contract.

Various portions of the ERTS-1 data products were processed and analyzed at the Pacific Southwest Station, Colorado State University, Fort Collins; and the Purdue University Laboratory for Applications of Remote Sensing.

Although this Research Paper points out limitations in the use of satellite imagery in its present stage of development, the overall success of ERTS-1 was such that a second satellite—LANDSAT-2—was launched in 1975. Data currently being beamed from LANDSAT-2 will be even more useful in developing better ways to inventory and manage forests and related natural resources.

ROBERT W. HARRIS, *Director*
Pacific Southwest Forest and Range Experiment Station

ACKNOWLEDGMENTS

We gratefully acknowledge the contributions of the following cooperators in this study:

Goddard Space Flight Center, NASA, Greenbelt, Md., for ERTS-1 data products.

Johnson Space Flight Center, NASA, Houston, Tex., for color and color infrared transparencies and aircraft multispectral scanner data.

Irving Case, district ranger, Nemo Ranger District, Black Hills National Forest, S.D.; Richard P. Cook, district ranger, Spearfish Ranger District, Black Hills National Forest, S.D.; and David L. Hessel, sales group leader, timber management staff, Rocky Mountain Region, Forest Service, Denver, Colo., for maps, vehicles, personnel, and use of property.

Forestry Department, Homestake Mining Company, Spearfish, S.D., for use of property.

James A. Smith, associate professor of earth resources, Colorado State University, Fort Collins, for assistance in processing ERTS-1 computer-compatible tapes.

Roger Hoffer, professor of forestry. Michael D. Fleming and Tina Cary, research assistants, and Harry C. Hitchcock, graduate assistant, Purdue University, Lafayette, Ind., for assistance in processing and analyzing ERTS-1 computer-compatible tapes.

Edward W. Crump, technical monitor, Goddard Space Flight Center, for technical advice, and for expediting shipments of ERTS-1 imagery and computer-compatible tapes.

Wilmer F. Bailey, aerial survey specialist, State and Private Forestry, Forest Service, Rocky Mountain Region, Lakewood, Colo., for cooperation in furnishing ground truth data.

Robert Mattson, forester, Black Hills National Forest, Deadwood, S.D., for assistance in maintaining the field data collection system.

CONTENTS

GLOSSARY

Band: For ERTS, one of four wavelength bands of the electromagnetic spectrum sensed by the multispectral scanner (MSS). Band 4 = 0.5 to 0.6 μm, band 5 = 0.6 to 0.7 μm, band 6 = 0.7 to 0.8 μm, band 7 = 0.8 to 1.1 μm.

Bulk Data: (Also called System-Corrected data.) ERTS data as reconstructed by NASA in a form which has only fair positional accuracy but excellent scene radiance and excellent registration. Available in 70-mm or 9.5-inch positive or negative transparencies and prints, color composites, or computer-compatible tapes. One scene covers 100 by 100 nautical miles. (See **Precision Data.**)

Color Composite: A false-color reconstruction of ERTS data in photographic form, created from two or more bands for one scene. The colors assigned to the three bands used by the NASA Goddard Space Flight Center were: band 4, blue; band 5, green; band 7, red. Color composites made at PSW combined only bands 5 and 7, as band 4 was felt to cause a hazy appearance and to supply little additional information.

Computer-Compatible Tape (CCT): A reconstruction of ERTS data in magnetic tape form suitable for computer analysis. Available in 7- or 9-track, 556 and 800 BPI respectively. Only 7-track tapes were used in this study.

Digital Element: (Also called **Pixel.**) A single picture element of digital image data recorded on an ERTS computer-compatible tape. The land area represented by a digital element is considered to be approximately 56 m horizontal and 79 m vertical.

ERTS: Earth Resources Technology Satellite

LARS: Laboratory for Applications of Remote Sensing

Multispectral Scanner (MSS): For ERTS, an electronic-optical line scanning device with an oscillating mirror continuously scanning perpendicular to the satellite path. Radiance detectors collect reflected energy in four spectral bands simultaneously. Radiance information is transmitted by telemetry to ground stations, where it is reconstructed for use.

Pixel: See **Digital Element.**

Precision Data: (Also called **Scene-Corrected Data.**) ERTS data as reconstructed by NASA in a form which has good positional accuracy at the expense of registered radiance. Available as 9.5-inch black-and-white individual band transparencies, 9.5-inch color composites, or computer-compatible tapes. One scene covers area 100 by 100 nautical miles. (See **Bulk Data.**)

PSW: Pacific Southwest Forest and Range Experiment Station

Radiance: The brightness of an object as seen from a remote observation point. In physics, it is a measure of the power radiating from a unit area of a source through a unit solid angle. Typical units of radiance are watts/meter^2- steradian.

Remote Sensing Unit (RSU): A single digital element which has been geometrically corrected, registered, and combined; the basic unit on which all statistical and spectral signature analyses are performed. (Term used and defined by R. Hoffer.)

Scene: Term used for ERTS imagery (in photographic or tape form) covering an area approximately 100 nautical miles square. Scenes are identified by number and date.

Scene-Corrected Data: See **Precision Data.**

Spectral Signature Analysis: Analysis of the relative radiance from objects in several visible and infrared wavelength bands. Objects are often discriminated and classified by their spectral patterns or signatures.

System-Corrected Data: See **Bulk Data.**

SUMMARY

Heller, Robert C., *technical coordinator*
1975. **Evaluation of ERTS-1 data for forest and rangeland** surveys. USDA Forest Serv. Res. Paper PSW-112, 67 p. Pacific Southwest and Range Exp. Stn., Berkeley, Calif.

Oxford: U629.19[+585+268+4]
Retrieval Terms: Earth Resources Technology Satellite; multi-spectral imagery; photointerpretation; remote sensors; forest stress; forest inventory; range inventory; plant communities; land classification; Atlanta, GA. (Test Site); Black Hills, SD (Test Site); Manitou, CO. (Test Site).

The potential value to forestry of the Earth Resources Technology Satellite ERTS-1 was explored in a 29-month study. Applicability of the low-resolution satellite data to resource management was studied in tests of classification of land use and forest and range vegetation, identification of disturbances of forest patterns, and detection of effects of stress on forest vegetation. Sites previously used for remote sensing studies were chosen near Atlanta, Georgia; Manitou, Colorado; and the Black Hills, South Dakota.

ERTS data were supplied by NASA in reconstructed form for analysis by photointerpretive and computer-assisted techniques. Slightly different instrumentation and methods were used at the different sites, and conditions and problems encountered also varied, but in general the approach was similar.

At all three sites, ERTS-1 data were found useful for broad classification. Land-use classes, such as Forest or Nonforest, and range vegetation classes at the Region level were distinguished with acceptable accuracy as checked against ground truth. Forest disturbances could be successfully detected on ERTS color composites when compared with 6-year-old aerial photography. Further breakdowns of cover types could not be made with acceptable accuracy, however, except for certain classes. The results varied considerably among the sites. Forest stress from insect infestation could not be detected. In another, more limited study, however, large stands of dying eucalyptus trees were distinguishable on combined imagery for two dates.

Additional conclusions drawn from the studies:

1. Classification can be done most effectively by computer, but photointerpretation produces equally accurate results. Choice would depend on availability of trained people and equipment.

2. Managers of large ownerships (more than 4000 ha or 10,000 acres) would benefit by using ERTS enlargements for planning. Color composites are preferable and scales of 1:125,000 to 1:250,000 are most useful. For black-and-white enlargements, the best band is MSS-5. (Such enlargements, to scales of 1:125,000, can be effectively used for high-altitude aerial navigation, especially in remote areas, where existing maps are inadequate.)

Summaries of the individual studies composing this report follow. Further investigation is needed to clarify and extend the information gathered.

Forest Inventory—Eight land-use classes, at two levels, and nine disturbance classes were defined. Because seasonal coverage allows closer discrimination between uses, ERTS scenes for fall, spring, and early summer were chosen. Photographic techniques allowing control of image quality of color composites were developed at PSW Station, Berkeley. Geometric quality was tested to determine methods for locating sample points; positional errors averaged more than 200 m. Ground truth was established from high-altitude NASA aircraft underflights and from ground checks.

After preliminary training, photointerpreters viewed simultaneously two sets of imagery representing different seasons or time periods. Results were summarized by number and percent of correct identifications. Computer-assisted analysis covered three test blocks within the site. Techniques involving computer programs to convert the raw ERTS digital tape output to a final color-coded map product were developed at PSW, Berkeley, and at LARS, Purdue University. Accuracy evaluations used area classified in each land-use class and a point-by-point check to compare LARS and PSW results with ground truth.

On 1:1,000,000-scale color composites, interpreters consistently distinguished Forest and Nonforest classes with 96 percent accuracy, regardless of combination of seasons used. Interpreters could not classify Level II cover-type classes to acceptable accuracies. Pine was identified with 60 to 65 percent accuracy, and Hardwood, 50 percent; other classes ranged from 7 to 85 percent.

Computer-assisted analysis by both LARS and PSW systems distinguished Forest from Nonforest 94 to 96 percent of the time. Performance on Pine and Hardwood cover types was better than that of the interpreters; on other land-use types, performance was similar–only fair. On point-by-point check, the LARS system was found about 20 percent more accurate than the PSW system. The best average–achieved on only one block–was 74 percent, not good enough for land-use classification. Attempts to use seasonal data to improve computer classification were not successful.

In general, tests in Atlanta showed ERTS-1 data provide a good Level I forest classifier and can be useful for detection of U.S. Forest Survey inventory plot changes or disturbances where there is much human activity.

Range Inventory–Classification of range plant communities at the Manitou site was based on the ECOCLASS system. Identification at two levels–three Region and eight Series classes–was attempted. Three ERTS scenes were used–August 1972 and 1973 and June 1973. Ground truth included photos from two NASA underflights (June and September 1972) as well as Forest Service CIR photos. In addition to visual interpretation of photos, analysis by microdensitometer was tested. Computer-assisted analysis was done by LARS and Colorado State University.

Photointerpreters classified Conifer and Grassland on June-to-September ERTS imagery and high-flight aerial photos with 95 to 99 percent accuracy. Deciduous forest–mostly aspen–was difficult to separate from Conifers; accuracy was only 63 percent on ERTS and 65 percent on aerial photos when averaged for all three dates. August was best for Region level classification on ERTS imagery; then the Deciduous class was correctly distinguished 92 percent of the time. Interpreters achieved no acceptable results in classifying to the Series level. Most errors on both satellite and aircraft imagery were made on north-facing slopes. Grassland classes were more accurately separated at this level than Forest classes. One experienced range ecologist had significantly more correct calls than the others–from 83 to 100 percent. Shortgrass and Wet Meadow classes were identified correctly from 88 to 99 percent of the time; Mountain Bunchgrass only 50 percent, except by the experienced interpreter. Stereo aircraft photos were better for discrimination of Grassland classes than was nonstereo satellite imagery.

Analysis by microdensitometer showed highly significant differences between all vegetation combinations at two dates (July and August). Thus it appears possible to do automatic scanning of an ERTS color composite and relate density levels to Region level vegetation classes. At the Series level, there was much overlapping of densities except for Aspen and Wet Meadow classes.

Computer-assisted analysis on training samples by LARS was more successful (90 percent or better at both levels) than total performance on entire units (70 percent at Region level, 48 percent at Series level). Effects of slope, aspect, and shadows were pronounced. Improvements in computer signature analysis are needed to make computer-produced maps usable. For one Series class, Ponderosa Pine, adjusting spectral response to a midslope response level improved computer performance. Further tests are needed.

Forest Stress–For the Black Hills study, general methods were similar to those used for forest inventory tests. Classification was attempted at Levels II and III, with Dead Ponderosa Pine and two categories of crown closure in Level III. Cloud-free ERTS imagery was difficult to secure; scenes for August and September 1972 covering two blocks on the site, with three sub-blocks for intensive study, were used. Ground truth data were available from earlier studies.

Attempts to study radiance sensing by ERTS by means of transmission of ground data to the satellite encountered operational difficulties, but some useful spectral data were gathered: (1) A 51-percent increase in scene radiance occurs on satellite imagery in MSS band 4–a result of atmospheric scattering; (2) the atmosphere affects MSS band 5 less than band 4; (3) bands 6 and 7 have reduced radiance, primarily because of absorption by the intervening atmosphere.

Photointerpretation was 100 percent correct for Conifer, Wet Pasture, Bare Soil, and Water. Most errors were in Dry Pastures and Hardwood. Errors in separating dense stands of Pine from open stands were excessive (50 percent). No Dead Pine was detected, regardless of size, season, or processing technique. Best results in classifying seven cover types were achieved by specialists familiar with the site.

Computer-assisted techniques did not improve results in identifying Dead Pine. The 3 percent of land area identified by PSW as Dead Pine did not coincide with ground truth. Both LARS and PSW systems were reasonably successful in classifying cover types at Level II; accuracy was just acceptable at Level III. The PSW performance was better for distinguishing density of Ponderosa Pine by area; point-by-point checks showed similar accuracy for both systems.

Large stands of eucalyptus killed by freezing weather could be delineated on a combination of imagery for two dates. This technique may be useful in developing countries where access is difficult.

The use of remote sensing techniques has long been accepted in forestry. At an early stage of development, aerial photography was recognized as a valuable tool in land resource management, and advantage has been taken of improvements in techniques. The launching of the ERTS-1—Earth Resources Technology Satellite—in June 1972 introduced a new element. The assessment of its potential value to forestry became an urgent need.

For application to forestry, ERTS-1 data must be in a usable form. The satellite's multispectral scanners (MSS) transmit photometric data received from the earth's surface; the data must be reconstructed for visual interpretation. The NASA Goddard Space Flight Center (GSFC) converts the raw data into photographic form as black-and-white or color transparencies. Also, GSFC provides magnetic tapes capable of producing, through computer-assisted analysis techniques, graphic representations of the earth as viewed by the satellite. Both the transparencies and tapes are low in resolution of detail, compared with conventional aerial photography.

The study reported here was designed to explore the applicability of this low-resolution satellite data, supported by conventional aerial photography and ground data, to forest and range management. Specifically, the study dealt with the applicability of ERTS data to certain ongoing Forest Service programs:

1. Inventory of forest and rangelands, including (a) classification of land use, (b) classification of forest and range vegetation, and (c) identification of disturbances of forest patterns by both natural causes and human activity.

2. The detection of effects of various stresses (insects, disease, temperature, moisture, etc.) on forest vegetation.

Objectives

The original objectives of the study, as outlined in the NASA contract proposal, were these:

1. To test the hypothesis that ERTS multispectral imagery will permit identification of forest, rangeland, nonforest, water resources, and forest stress.

2. To determine the gains to be made in using satellite imagery as a first level of information when coupled with aircraft underflights and ground examination in a multistage and multiseasonal sampling system for quantification of the forest-related resources.

3. To compare the utility and cost effectiveness of various data and interpretation modes—such as single-channel versus multispectral-channel data, and human versus automated interpretation—to separate and identify forest and rangeland resources.

The contract objectives were somewhat modified during the course of the study. An experiment based on data from a new remote sensing system presents problems that are difficult to forecast even in carefully thought-out study plans. Many difficulties did not become evident until the interpreters actually received and began working with ERTS photography, and the programmers began to analyze the computer-compatible tapes (CCT's). As a result, procedures were changed and new techniques were developed. It was not feasible to carry out some of the objectives of the original contract proposal. Lack of appropriate underflight imagery on the Atlanta test site and lack of seasonal ERTS imagery prevented our analyzing the multistage-multiseasonal part of the proposal. Part of the range inventory site was used, however, to investigate the use of several stages of small- and large-scale aerial photos coupled with ground samples for multistage inventories.

Also, because most of the successful procedures and techniques in handling the data were developed only after many trials, we felt it would be unrealistic to show development costs in making technique comparisons (computer-assisted analysis versus visual or microdensitometric photointerpretation, etc.). Therefore, no iso-cost and iso-error curves were developed.

Study Areas

To test applications of ERTS-1 data, three widely separated representative areas (*fig. 1*) were chosen. These had already been the sites of remote sensing studies, and the investigators had gained much experience and firsthand knowledge of ground conditions there. The sites selected were near Atlanta, Georgia;

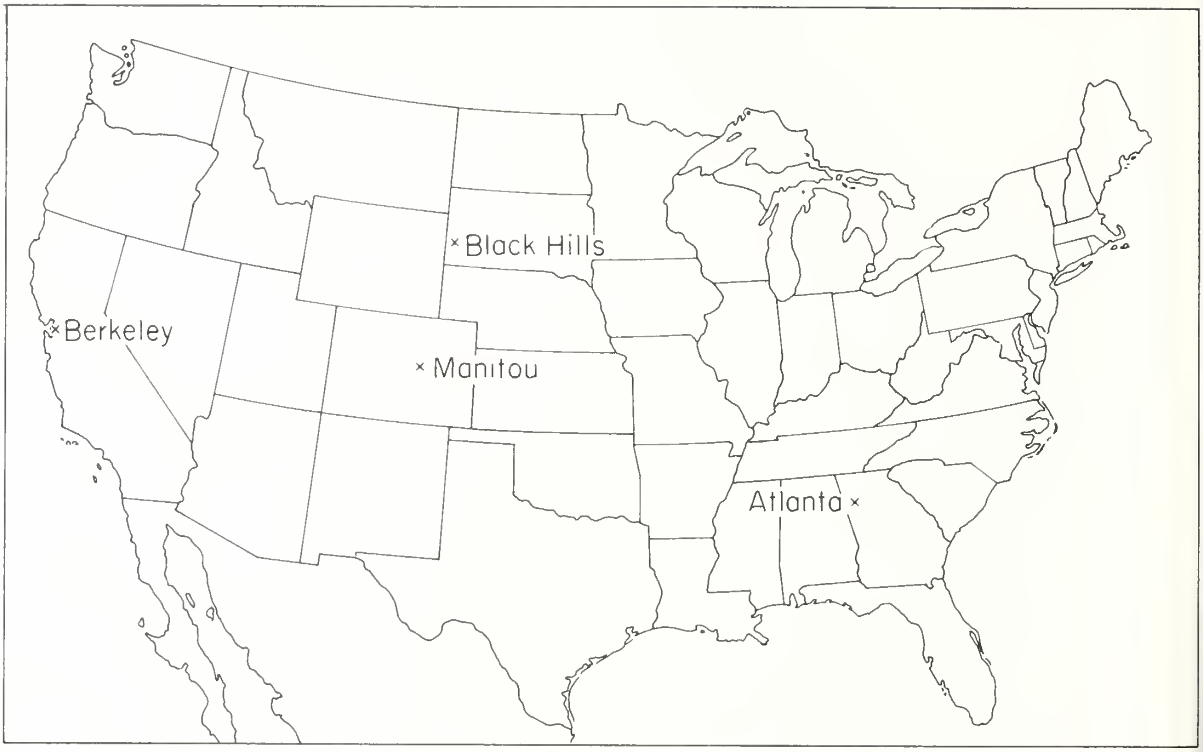


Figure 1—The study areas indicated on this map were used for different phases of the ERTS-1 data evaluation: Atlanta, Georgia—forest inventory; Manitou, Colorado—rangeland inventory; Black Hills, South Dakota—forest stress from mountain pine beetle; Berkeley, California—forest stress from cold temperatures.

near Manitou, Colorado; and in the Black Hills, near Lead, South Dakota. In many phases of the work, the investigators in each area proceeded independently of the others; however, the three studies were similar in general approach.

The forest inventory site just west of Atlanta, Georgia, was selected as a representative area in Southeastern United States where a high level of forest management is taking place and where rapid changes to forest land are occurring. Forests here occupy about 60 percent of the land area, but they are broken up into small units by agricultural fields, pastures, and water bodies. Most of the forest ownerships are small (less than 200 hectares or 500 acres) which results in a checkerboard pattern on aerial imagery. Such an area, with many field and forest borders, presented a challenge to the investigator to properly classify forest land use.

Rangelands such as the Manitou, Colorado, site are important national resources and need to be inventoried, protected, and managed. They are becoming more valuable as our food and fiber supplies diminish. An orderly system of classifying vegetation according to its relation to other plants and animals and its potential for vegetative development (ECOCLASS) has been devised by Forest Service ecologists[1] and this hierarchical system was used to determine the level at which ERTS-1 data can accurately assess range vegetation types.

On the third site, in the Black Hills of South Dakota, a severe outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) has killed severa[l] hundred thousand ponderosa pine trees (*Pinus ponderosa* Laws.) over the past 10 years. Early detectio[n] of the dying pines, which discolor to a yellow an[d] yellow-red hue, would assist forest managers in asses[s]ing the severity of the outbreak and in plannin[g] control and salvage operations—particularly if th[e] assessment could be done accurately and quick[ly] from satellites. Experience from analysis of aircra[ft] photos showed that color infrared film taken at [a] scale of 1:32,000 could be used to detect all but t[he] smallest target infestations of 1 to 2 trees (3 to 6 m

[1] Pfister, Robert D. and John C. Corliss, task force c[o-]chairmen. 1973. ECOCLASS—a method for classifying e[co]systems. Report on file at Forestry Sciences Laborato[ry,] Intermountain Forest and Range Experiment Station, M[is]soula, Montana.

10 to 20 ft in size) with better than 90 percent accuracy. This part of the experiment tested the null hypothesis that ERTS-1 data could not detect insect infestations of any size. The coinvestigator at this site also established a biophysical station which transmitted ground sensing data (including ERTS-matched spectral radiance) to ERTS via three data collection platforms (DCP's) and thence back to the Goddard Space Flight Center where the data were encoded on punchcards for analysis.

A limited study of temperature stress effects was made in Berkeley, California, when the Remote Sensing staff was asked to investigate mortality of eucalyptus trees from low temperatures during the winter of 1972.

Materials and Techniques

The ERTS-1 materials used in this study for photographic interpretation were received from the Goddard Space Flight Center as black-and-white transparencies and as *color composites*—false color transparencies made from the black-and-white materials. The multispectral scanner collects reflectance data in four wavelength *bands* representing four portions of the electromagnetic spectrum. The color composites are a combination of the data from two or more of the bands, each band being assigned a color. The transparencies, and also the tapes used in the computer-assisted analysis, are identified as *scenes*, each covering 100 by 100 nautical miles. Transparencies and tapes are available as *bulk* or *precision* data. (For further explanation and specifications for the italicized terms, see the Glossary.)

The ERTS-1 transparencies were combined and enhanced at the laboratory of the Remote Sensing Research Work Unit of the Pacific Southwest Forest and Range Experiment Station. The methods developed there for producing color composite internegatives are described in Appendix 1.

The computer-compatible tapes were analyzed by various methods described in the body of this report and in Appendix 2. Essentially, these techniques consisted of conversion of the ERTS data into a visual composite of *digital elements* (also called *pixels*), each representing a land area of specified dimensions. The result was a map produced on a line plotter equipped with color pens, or by photographing a cathode-ray tube display.

Slightly different photointerpretation instruments and techniques were used at each of the three test sites. For example, all three coinvestigators used Bausch and Lomb Zoom 70 microscopes to examine and classify cover types on color composites. However, a Variscan rear-projection viewer was also used to advantage with the Black Hills imagery. An overhead projector was used at all sites for comparisons of color composites with previously drawn cover-type maps. At the Atlanta site, comparisons of the bulk color composites at three time periods were made with an Old Delft scanning stereoscope, while disturbance detection was best accomplished on a Zoom Transfer Scope. Similarly, at the Atlanta and Manitou sites many replicated training and test sets were randomly selected for each of the land-use and vegetative classes. In the Black Hills, the nine cover-type classes had to be purposively selected because there was insufficient cloud-free imagery during the growing season, so that the necessary replicates were not available.

During the studies described here, covering a period of over two years, large quantities of data were gathered and many techniques were developed and modified in the light of experience. For this report, much detail was necessarily omitted. Both data and techniques require further analysis. The report is by no means definitive, but is intended primarily as an aid to those who will be attempting to use data from earth resources satellites in forestry applications in the future.

FOREST INVENTORY

Land-Use Classification and Forest Disturbance Monitoring

Robert C. Aldrich Nancy X. Norick Wallace J. Greentree

The primary aim of the forest inventory test of ERTS data was to determine the accuracy with which forest land could be classified. Although we recognized that forest land managers require detailed in-place information on volume, stand condition, and growth, the prelaunch specifications for ERTS data resolution did not encourage use of the output for these purposes. We reasoned that we could classify land use accurately enough, however, and we might be able to obtain forest area statistics for small political units such as counties. This test would also indicate the true capabilities of ERTS-type data and allow us to develop techniques and acquire skills for handling these unusual kinds of data.

The forest disturbance phase of the inventory was included because at various times a resource manager or a resource inventory analyst needs to know where and how much forest land has been disturbed—either by natural causes or by human influences. Logically, ERTS would be a proper and beneficial tool for monitoring these changes if the ground resolution were good enough, although the ERTS 18-day cycle is more frequent than would normally be required for the purpose.

Study Area

The site near Atlanta, Georgia (*fig. 2*) is the one used for the Apollo 9 inventory study in 1969 (Langley and others 1969) and for the high-altitude aircraft studies sponsored by NASA's Earth Resources Survey Program between 1970 and 1972 (Aldrich and Greentree 1971, 1972). The area is typical of a large part of the Southern United States in its "checkerboard" land-use pattern, complex enough to test any remote sensing system. Principal land uses in the area are forest, grassland (pasture), and urban. Agriculture is not a major use of land on this site but some scattered grain and soybean crops are grown. The major forest types in the area are loblolly pine, oak-pine, oak-hickory, and oak-gum-cypress. Commercial forest occupies approximately 60 percent of the land area and is found primarily in small farm woodlots. Changes between forest and nonforest categories occur quite rapidly, influenced by the pulp and paper industry and the expansion of metropolitan Atlanta.

Classification System

For government agencies concerned with land use, the U. S. Geological Survey Circular 671, *A Land-use Classification System for Use with Remote-Sensor Data* (Anderson and others 1971) has become the accepted reference for definitions of generalized land-use classes at two levels of precision. Using Circular 671 as a basis, we developed our own hierarchy for the piedmont area of Georgia (*table 1*), for use in evaluating remote sensing at three levels. Levels I and II of our hierarchy designate eight classes of resource data obtainable from ERTS. Level III designates more restricted classifications definable from high-altitude aircraft photography or from some higher resolution satellite imagery. Knowledge of the location of these classes is helpful in distinguishing variations over time in the ERTS imagery, and in clarifying the reasons for differences in interpretation at Levels I and II by both human and machine classification systems.

The eight land-use classes recognized on ERTS data for this study are defined according to Munsell Color notations (Munsell 1920-60), converted to ISCC-NBS color designations (ISCC-NBS 1955). The definitions take into account the temporal variation discernible on the simulated color infrared (CIR) composites for the three ERTS scenes used in this study.

In the forest disturbance tests, we were concerned with identifying shifts in use between forest and non forest classes, as well as timber harvesting, and natural disturbances such as fire, insect damage, disease, or flooding. Disturbance classes we hoped to identify were established as follows:

No disturbance—Areas showing no detectable changes in the forest cover.

Harvesting—Forest areas where timber has been removed, usually resulting in a rather severe disturbance. Area shows numerous interlacing woods roads, skidways, and either complete or almost complete removal of the merchantable trees.

Silvicultural treatments—Forest areas, such as pine plantations or natural hardwood stands, given a cultural treatment to improve vigor or growth. Although high-grading is a poor practice and not considered a silvicultural treatment in the normal sense, it wo

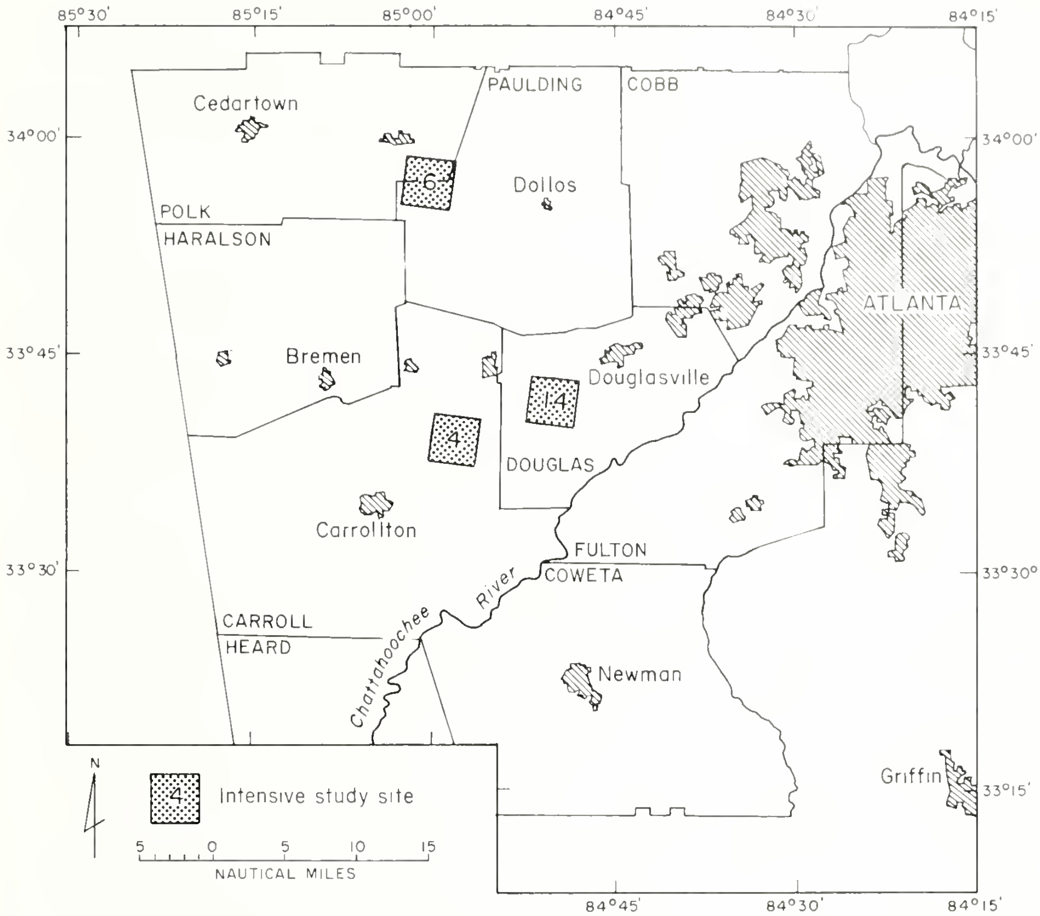


Figure 2–The Atlanta site, used for evaluating ERTS-1 data in forest inventory, includes nine counties. The three intensive study sites were used for computer-assisted mapping.

appear the same as partial removal or intermediate selective cutting.

Land clearing–Usually areas where timber removal or harvesting has been followed by site preparation, including slash and stump removal, with eventual replanting with tree seedlings. This category may also include tree removal, site preparation, and conversion to nonforest land uses. Land that has been cleared but not converted usually shows windrows of slash and tree trunks; usually this land is still considered commercial forest.

Insects and disease–Areas showing evidence of damage by these agents. Under endemic conditions, attacks may mean the mortality of a single tree. Under epidemic conditions it may mean mortality of hundreds of trees in a single spot. Faded tree crowns or openings in the stands are indicative of tree mortality.

Wildfire–Areas showing evidence of fire. Crown fires as well as ground fires are included. Prescribed burns, which are restricted to the ground, may appear exactly like wildfires. The actual "going" fires may be detected, but usually the noninfrared-reflective burned vegetation and humus material show as blackened areas on remote sensing imagery.

Flooding–Areas where man-caused or natural floods have inundated forest land and caused tree damage or death. Permanently flooded areas must be removed from the forest area base. The extent of these areas is obvious on infrared imagery. Intermittently flooded forest may be permanently damaged or may survive after the water recedes.

Regeneration–Areas that indicate an increase in the forest area base because nonforest land has been converted to forest land, either naturally or artificially. Areas of regeneration may be apparent in early years by evidence of fire breaks built by the landowner to protect his investment from wildfire. Indications of tree growth will appear in 3 to 5 years after planting.

Table 1–*A land classification hierarchy for remote sensing and ground information sources compatible with current nationwide Forest Survey objectives; colors discernible on simulated color infrared ERTS composites.*

Classification	Color definitions (based on Munsell 1920-60, ISCC-NBS 1975)
I FOREST LAND	
II Conifer III Pine Pine-Hardwood	Density of conifer stands and number of hardwoods mixed in stand influence color value and chroma. Dense stands are darker with less chroma. In the fall, before advanced hardwood coloration and leaf fall, conifer stands appear dark purplish red. Separation between Conifer and Hardwood classes is less distinct in fall than in winter or early spring. Where hardwoods and conifers are mixed in stands, hardwood color predominates, and stand is usually classified as Hardwood. In spring before hardwoods are foliated, conifers appear moderate to dark purplish red.
II Deciduous Hardwood III Upland Hardwood Bottomland Hardwood	Stands appear moderate grayish purplish red in fall and pale purple to moderate purplish red in spring. In fall, upland hardwoods cannot be distinguished from bottomland hardwoods. In spring, before foliation, upland hardwoods appear pale purple to light grayish purplish red. Bottomland hardwoods are generally a moderate purplish red.
I NONFOREST LAND	
II Grassland III Undisturbed Grass Disturbed Grass Dead Grass (Annual) New Improved Grass	Grassland appears deep pink in both fall and spring; sometimes mistaken for immature cropland in spring.
II Cropland III Immature Grain Immature Row Crop Mature Crop Harvested Crop Orchard Farmsteads	Mature crops in fall appear bluish gray to grayish blue. In spring, immature crops appear deep pink and may be mistaken for grassland.
II Bare Soil III Plowed Fields Erosion Urban (site preparations) Rock Outcrop	In fall and spring bare soil appears cream colored. There is no distinction between plowed agricultural fields and sites prepared for new commercial developments. Generally in spring most areas of bare soil are newly plowed fields either recently or soon to be planted.
II Wild Vegetation III Idle Land Abandoned Land Transitional Kudzu Marshland Alder Swamp	In fall, areas range from grayish purple of idle land to grayish purplish red of abandoned land to deep pink of wild Kudzu vine. Marsh and alder swamps are a moderate purple because of wet background. In spring, idle land becomes light grayish red to dark pink because of influx of new infrared reflectant vegetation. Abandoned-transitional land (reverting to forest), on the other hand, is grayish purplish red and marsh and alder swamps are grayish violet. Deciduous Kudzu vine, purplish gray in the spring, easily separates itself from all other vegetation when fall and spring images are viewed together.
II Urban III Transportation & Utilities Home Developments Commercial Developments Recreation	Areas are light blue in the fall and very pale blue in the spring. Unfortunately, because of low resolution of ERTS data, secondary roads, minor roads, and most utility lines are not resolved.
I WATER	
II Water III Clear Lakes & Ponds Turbid Lakes & Ponds Rivers & Streams	Water is darkish greenish blue in fall and light greenish blue in spring. Farm ponds of less than 1 acre can be seen on ERTS images if there is sufficient contrast with background.

Other—Land suspected of being disturbed, but yet not fitting into any of the above categories. This includes, for example, land being worked for turpentine. On remotely sensed imagery, such land would appear similar to silvicultural cuttings but with little or no removal, and only slight disturbance of the ground cover.

ERTS Data

Collection of forest resource data by ERTS at regular intervals is useful for forest inventory because it almost guarantees cloud-free coverage more than once each year over the same area. During the first 12 months of operation, for example, ERTS passed over Atlanta 21 times. Weather was particularly bad that year, yet 3 passes out of the 21 were completely free of clouds and fulfilled study requirements: scenes 1084-15440, October 15, 1972; 1264-15445, April 13, 1973; and 1336-15441, June 24, 1973.

Three stages of phenological development are represented by the three scenes: (1) fall before the leaf fall, (2) spring before new leaf development, and (3) early summer after complete leaf development. Seasonal coverage such as this is valuable because it makes possible closer discrimination between land uses.

Two methods of data analysis were used in the Atlanta study. The first, conventional photointerpretation, made use of the ERTS false-color photo composites on transparency film, which we tested for image quality and geometric quality, as described below. The second, computer classification, used spectral data in digital form on the computer-compatible tapes (CCT's), by means of two systems, one developed by LARS, Purdue, and the other developed at PSW, Berkeley. Computer techniques were used only in the land-use classification portion of the study. For this, all four spectral bands of the October 1972 and April 1973 scenes were used.

Image Quality

False-color photo composites of the ERTS bulk data used in this part of the evaluation were produced at the PSW facilities in Berkeley. Originally we intended to use false-color composites produced by the Goddard Space Flight Center (see Introduction) in the photo analysis. We soon found, however, that without some degree of control over the image enhancements as well as the photo processing, we could not make valid comparisons between seasons. This was evidenced by extreme variation in the film density as well as other characteristics that led to many incorrect interpretations made on Goddard color composites. To overcome this problem, we combined and enhanced the ERTS images and produced our own color composites, using an International Imaging Systems (I^2S)[2] additive color viewer and a specially designed copying system (Appendix 1). This system enabled us to scale the ERTS scenes to match 1:1,000,000 map overlays, a capability that proved a distinct advantage later on during interpretation. Another advantage was the lower contrast values of the Berkeley composites. Although they were less pleasing to the eye than the Goddard products, they were more effective for extracting information.

Geometric Quality

The value of ERTS data for forest inventory is affected by the positional accuracy of points within the image, particularly when timber stands, sample plots, or other specific areas of interest are to be located precisely. For example, location of a perfectly square 4-hectare (10-acre) stand of timber requires a positional accuracy of at least ± 120 m (390 feet). Relocation of a circular 0.4-hectare (1-acre) permanent sample plot requires a positional accuracy of only ± 30 m (100 feet). Location of a 100-meter-square sample, randomly selected and identified on an overlay, as called for in the original experimental design for this study, required a positional accuracy of ± 50 meters (164 feet).

To check the geometric fidelity of both precision and bulk color composites, we made a test using over 90 random control points. These points were located within a rectangle formed by 30-minute geographic plane coordinate intersections—longitude 84°00′W, 84°30′W, and latitude 33°00′N, 33°30′N. The points were transferred from 1:120,000 scale CIR transparencies (dated October 2, 1972) to a copy of the original 1:250,000 Atlanta map sheet using a Zoom Transfer Scope (See Photointerpretation Procedures, below.) An overlay of the point locations made on stable base material was copied photographically to a 1:1,000,000 scale. From this negative, a transparent template was printed and attached to the color-composite ERTS image, also at a 1:1,000,000 scale. The template included 15-minute plane coordinate intersections, 50,000-m UTM grid intersections, and major natural and cultural features. The template was then matched to a bulk color-composite image

[2] International Imaging Systems is now known as Stanford Technology Corporation.

(1102-15442, bands 4, 5, and 7). The ERTS image with template attached was mounted on the ZTS illuminator. Then the 1:120,000-scale CIR transparencies were scaled and oriented with the ERTS image on the ZTS mapping surface. The distance between the true image locations scribed on the photographs and the locations of the same points on the ERTS image was measured.

The results showed that the locational accuracy of this ERTS image was approximately 200 m (656 ft), but only when the work lay within one 30-minute quadrangle of the ERTS scene. Thus, we found the positional accuracy to be inadequate (the error is approximately four times greater than acceptable--200 m (656 ft) instead of 50 (164 ft)—for conducting our experiment as originally designed. Instead, we made our interpretation on the center point of the randomly selected 100-m square samples on the overlay where they fell on the ERTS imagery.

Ground Truth

Two high-altitude aircraft underflights were made by NASA's Earth Resources Aircraft Program in direct support of this study. The first flight was made on June 1, 1972—about 7 weeks before the ERTS-1 launch. A second flight was made on October 2, 1972, following the launch and during the first of three requested seasonal coverages. These two flights were the only aircraft support flights received during the ERTS experiment. Flights requested for April and June 1973 were not flown. This meant that our photointerpretation test data and computer classification accuracy checks had to be based on ground truth acquired for October 1972.

At the time of each aircraft underflight, a two-man crew was on the ground. Over 100 samples selected from 400 in a pre-ERTS photo training set were verified. On each forest point, the tree species, forest type, stand size, and crown closure were recorded. Other information included understory vegetation, ground cover, and soil type, where the latter would be helpful in interpretation. Nonforest points were classified by land use and other supporting information, such as crop type and crop maturity. A 35-mm color photo (negative) was taken at each ground sample point to record existing conditions.

As explained below under Procedures, photo keys were prepared to illustrate the eight land-use categories and used to train interpreters. Ground truth maps were drawn for three small test areas from 1:120,000 CIR transparencies and ground inspections, and later used to check the accuracy of computer classification maps made from the ERTS CCTs. Land-use data collected on the ground and on small- and large-scale aerial color photographs from previous studies were invaluable in constructing the land-use maps. This was true particularly when correlative seasonal data were needed to compare with ERTS imagery, and aircraft support flights were canceled.

To verify forest disturbances detected on the ERTS scene of April 1973, 40 ground points in Carroll County (other than the 100 land-use sample points verified earlier) were visited in January 1974. Eighteen of these locations were regular Forest Survey plots on which some type of disturbance had been recorded, either during the reinventory of 1972 or by the interpretation of current photography in 1973. Twenty-two additional locations were selected from a listing of 64 "off-plot" disturbances that represented harvesting and silvicultural treatments, natural regeneration, artificial regeneration, and the "other" category. We did not sample the "cleared" category because we concluded that the photo verification for these would be correct.

On each ground plot, the type of disturbance was observed and recorded. Also recorded were the conditions of the forest cover and ground cover, years since disturbance, and other information pertinent to interpretation by remote sensing. A photograph was taken to record these ground conditions at the time of year the plot was visited.

Photointerpretation Procedures

Preliminary studies showed that conventional photointerpretation of single-season ERTS data resulted in low classification accuracy (less than 40 percent). However, when two scenes of different dates were viewed together, the accuracy increased to 67 percent. In these tests, therefore, interpretations were made on this basis.

For the land-use classification, the two interpreters making the tests were given special preliminary training that included looking at several examples of each resource class on high-altitude color infrared (CIR) photography (1:120,000) and on the ERTS color composite, coupled with ground truth (*fig. 3*).

An overlay (*fig. 4*) was prepared showing 292 of an original 400 random sample points selected on 1:120,000-scale photos to test interpreters. (Not all of the 400 points were inside the coverage of the three ERTS scenes used.) The overlay was attached to the April 1973 color composite (ERTS scene 1264-15445) and mounted in the center of a light table. The composite for October 1972 (scene

Photo Key 6

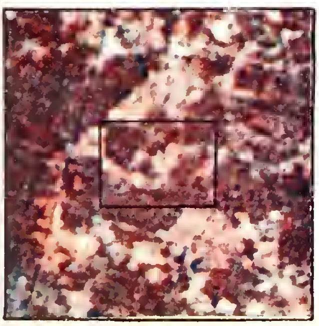
Code	Classification
2	GRASSLAND
21	GRAZED

Description: A closely grazed pasture with vegetation consisting mainly of Bermuda grass (Cyndon sp.) and lespedeza (Lespedeaz sp.). Small blackberry patches and persimmon seedlings are scattered throughout this pasture.

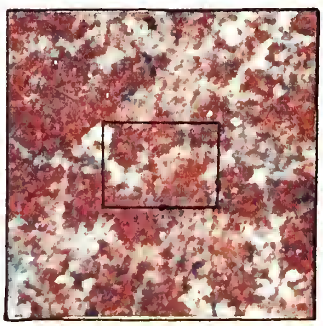
Location: Coweta County, Georgia
Latitude 33°21'N
Longitude 84°38'E
Elevation 270.4 meters (900 ft.)

Date: October 7, 1972

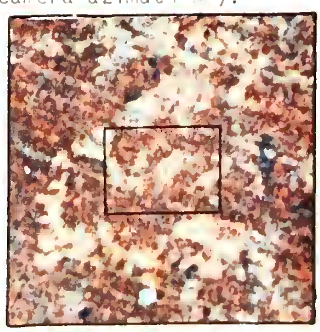
High-altitude color IR--Oct. 2, 1972
Ground photo angle is marked with an indicator (camera azimuth 6).



ERTS Scene 1264-15445
Spring-April 13, 1973



ERTS Scene 1336-15441
Summer-June 24, 1973



ERTS Scene 1084-15440
Fall-October 15, 1972

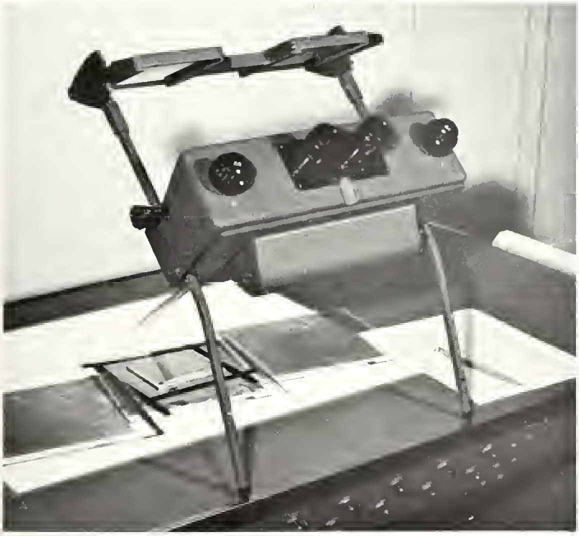
Simulated color IR composites from two bands (5 & 7) of ERTS imagery. The high-altitude photo coverage is outlined on the ERTS photos.

Figure 3—A photointerpretation training aid was prepared to show closely grazed grassland on high-altitude and ERTS photography. Seasonal changes are evident on the three ERTS photos.

Figure 4–An overlay for the color composite for the ERTS scene for April 13, 1973 was prepared to locate 292 random sample points for identification of eight land-use classes.

1084-15440) was mounted to the left of the April scene and the composite for June 1973 (scene 1324-15441) was mounted to the right. Using an Old Delft stereoscope with 4X magnification, each interpreter examined the center point of each sample square on the April-October combination (*fig. 5*). When this was completed, the stereoscope was moved to the right to view the April-June combination. Thus two independent interpretations of land-use classification were made by each interpreter.

Interpretation results were summarized to show both the number and the percent of interpretations that were correct, by class, and the number of points misclassified, by class. To determine whether there were significant differences between interpreters or between seasonal combinations, an analysis of variance was made using a system of weights from 1 to 5. A correct call received a weight of 1. Calling a Forest point Nonforest or calling a Nonforest point Forest were the most serious errors and received a weight of



5. This was in keeping with our experimental objective to determine how accurately we could estimate forest area using ERTS data.

For the test of ERTS potential in detection of forest disturbances, we prepared a set of sample points for the test site, Carroll County, Georgia (*fig. 6*). Using 1:120,000 CIR transparencies taken in June 1972 and 1:63,360-scale Department of Agriculture photo index sheets for panchromatic photography dated February 1966, we viewed the two images simultaneously with a Bausch and Lomb Zoom Transfer Scope (ZTS) (*fig. 5*). We circled and numbered 209 disturbed areas on the photo index sheet and recorded the type of disturbance and number of acres for each. Also, 36 points, where no disturbance had occurred, were circled.

Figure 5–Optical equipment used in photointerpretation varied with the aim of the test. ***Above,*** **for land-use determinations, interpreters used an Old Delft stereoscope to view simultaneously the center point of each test sample unit on the overlay and the corresponding points on April-October and April-June combinations of ERTS color composites.** ***Below,*** **to locate forest disturbances, interpreters used a Bausch and Lomb Transfer Scope to view simultaneously the ERTS scene for April 1973 and the 1:63,360-scale photo index sheet for February 1966.**

Figure 6–To monitor forest disturbances, Carroll County was outlined on the color composite for April 13, 1973. (Approx. scale 1:500,000)

An experienced photointerpreter, not familiar with the study, was first given a short orientation in the identification of disturbances using photo aids (*fig. 7*), and an opportunity to practice using the ZTS. He was then asked to examine the 245 locations circled on the February 1966 photo index sheets simultaneously with the April 13, 1973, ERTS color composite (scene 1264-15445). He was instructed to be as objective as possible and was told that not all of the 245 points were real disturbances. He was to record the following information for each area:

Type of disturbance: (a) no disturbance, (b) harvesting (tree removal), (c) land clearing, (d) natural regeneration, (e) artificial regeneration, or (f) other (undecided).

Land-use trend: (a) no change, (b) forest to agriculture, (c) forest to urban, (d) forest to water, or (e) agriculture to forest.

The results of this interpretation were summarized by disturbance class, land-use trend, and size class. (Size class was determined from 1:120,000-scale photographs on which the disturbances had been positively identified.) The classes were:

Acres	*(Hectares)*
1-5	(0.4- 2.0)
6-25	(2.4- 10.1)
26-50	(10.5- 20.2)
51-100	(20.6- 40.5)
101-500	(40.9-202.3)
Over 500	(Over 202.7)

Computer-Assisted Mapping Procedures

The computer-assisted mapping technique was tested using three test blocks in the Atlanta site, each approximately 8,000 to 10,000 acres (3,240 to 4,050 ha) as shown in *figure 2*. Under contract, the Laboratory for Applications of Remote Sensing (LARS) at Purdue University mapped the three blocks. Techniques were also developed by the PSW Remote Sensing Work Unit, and the results were compared with those of LARS.

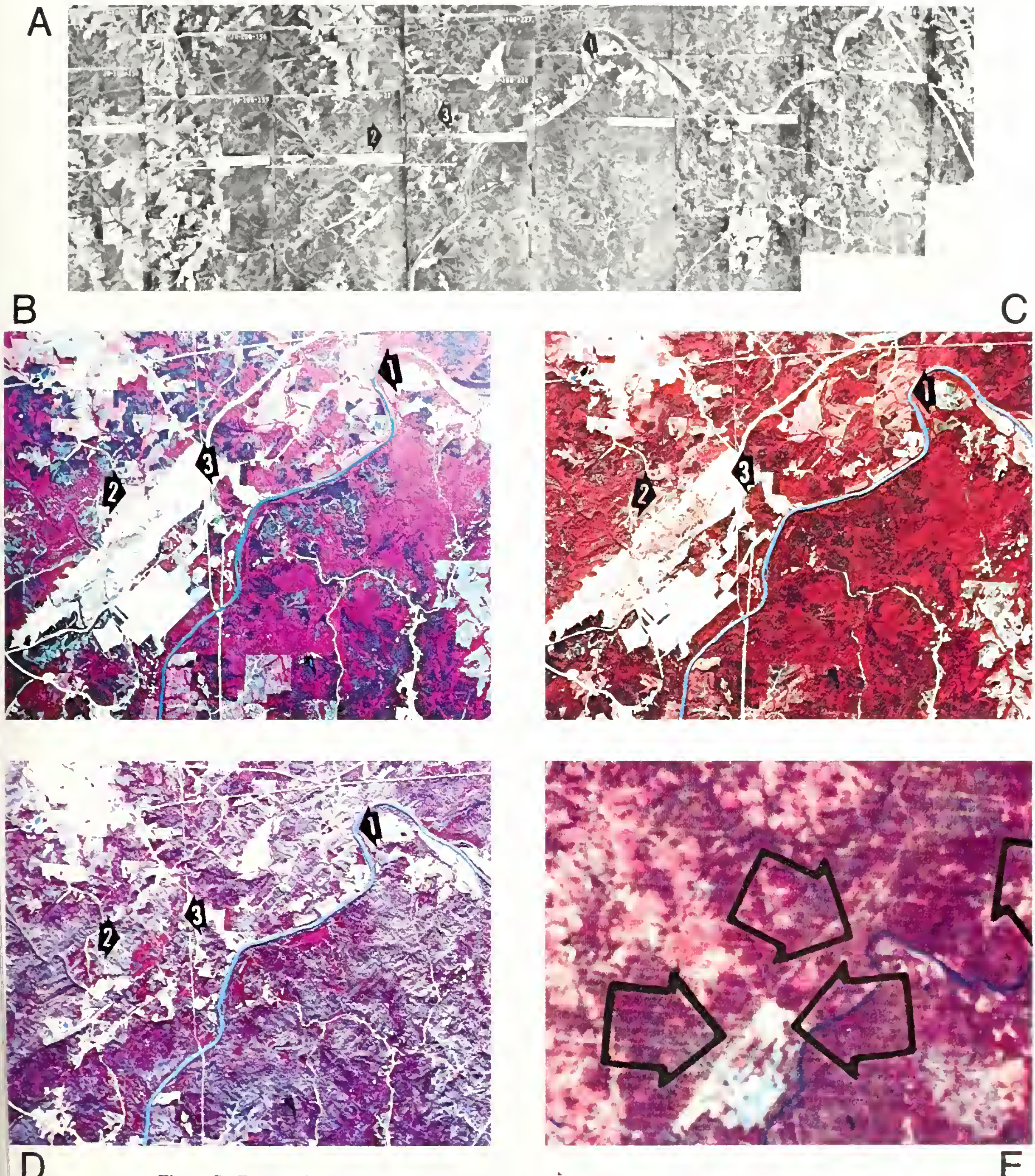


Figure 7–Forest disturbances are detected by comparison of a current image with one taken at an earlier date. Forest areas pointed out on the photo index sheet for February 1966 (A) appear disturbed on color infrared photography for June 1, 1972 and October 2, 1972 (B,C). In November 1971 (D), when the deciduous trees were leafless, the forested areas were not as clearly separable. On the enlargement of a portion of the ERTS scene for April 13, 1973 (E), all three disturbed areas are visible; points 1 and 2 were pulpwood cuttings and point 3 was cleared for a new power station.

LARS Procedure

For the LARS test, instructions on land-use classification categories to be used, area maps, and photographic aids were furnished by PSW. Ground truth classification maps for two blocks (4 and 14) were also furnished as a source of computer training fields (i.e., training samples). No ground truth was furnished for block 6, because, by the terms of the contract, LARS procedures were to be tested on block 6, using classification techniques developed on blocks 4 and 14.

Because of the complexity and detail of land-use categories in the Atlanta site, LARS used a supervised classification procedure. This meant that computer training fields were selected for each class to be mapped. At least 40 remote sensing units (RSU—a modified digital element) were required in each class to generate valid statistics for each class. This is equal to 10 times the number of features (the number of features equals the number of channels, 4, times the number of dates, 1).

To be selected, the RSU's for training fields had to fall at least two RSU's inside a vegetation-type line. By this criterion, all areas less than 5 acres were automatically eliminated from the selection process. For LARS use, 23 Level III land-use classes were originally developed, but only 12 of these could be used because there was an insufficient number of training fields to select from. The 12 classes were then reduced to 9 after an initial performance test showed that 3 out of the 12 contributed significantly to errors. The final 9 classes with the 8 approximately corresponding PSW classes were:

Forest Service class (Level II)	*LARS class*
Pine	Pine
Hardwood	Hardwood
Grassland	Grazed Grassland
	Undisturbed Grassland
Cropland	
Bare Soil	Plowed Fields/Borrow Pits
Wild Vegetation	Idle
	Abandoned
	Transitional
Urban	
Water	Water

As many training fields as possible were selected in each of the 9 classes, and the number of training RSU's per class was therefore roughly proportional to the class size. A drawback to this procedure was that too few areas remained to meet the requirements for a test set. Thus, to measure classification accuracy, it was necessary for LARS to use training field performance. Justification for this was that

1. Training field size was roughly proportional to class size.
2. Training field distribution appeared to be related to class distribution.
3. Training fields were selected from the ground truth maps, not aerial photographs.
4. There was no area remaining from which to draw test fields for some subclasses.

PSW Procedure

The Forest Service computer classification system utilized a CDC 7600 computer at the University of California Lawrence Berkeley Laboratory. Computer input and output were handled by a remote batch terminal, with primary components a Westinghouse 2500 and a line printer, at PSW. An off-line Electronic Associates Incorporated (EAI) 430 data plotter was used to plot land use and forest maps in any number of color combinations, using eight pens.

Basically the classification system consists of groups of computer programs which allow for flexibility in handling an ERTS bulk CCT. Five basic steps in the system between the raw digital data input and the final map product are as follows:

1. Using the raw data for each spectral channel, histograms and gray-scale computer maps are printed out on the line printer. These printouts are used to determine the range in spectral radiance values and to locate the corners of the study area on ground truth maps.
2. Corrections are applied to adjust for inherent distortions in the bulk raw data. These include correcting for missing data and stretching corners of the study area on the ERTS scene to meet corners of the area on the ground truth map.
3. Empirical distribution maps are produced (program EDMAP) to locate ground truth training samples and to screen the four channels of ERTS data as potential discriminators between land-use classes.
4. Three classification procedures are available: (a) a boundary-finding algorithm to locate clusters of spectrally similar and adjacent pixels (digital elements) and assign them to a land use, (b) a procedure that compares the radiance of each pixel with the mean radiance of a sample from each land use, or (c) a linear discriminant analysis which uses maximum likelihood and Gaussian assumptions (as used by LARS). (The computer maps used in this study were made using nearest neighbor theory under procedure (a).)

5. A final color-coded map is made on the off-line plotter and proportions of land area assigned to each land-use class are summarized.

These same procedures were used for the Black Hills test site. A more detailed description of the method is given as Appendix 1.

Accuracy Evaluation

The accuracy of both the LARS and PSW classification procedures was checked independently at PSW, because we felt that the RSU's used by LARS to develop the original classification algorithm should not be used to check the accuracy of the algorithm.

We checked the LARS classification maps against our ground truth maps in two ways: (1) by area classified in each land-use class and (2) by a point-by-point check of map classifications.

Area Check—To be useful to Forest Service programs, the computer procedure must first predict forest land area within specified boundaries with an accuracy better than 95 percent. Furthermore, the procedure should locate the forested areas more than 90 percent of the time. The proportion of area classified in each land-use category was converted to land area and compared with areas in each test block that had been derived from the ground truth maps.

Point Check—We looked at randomly selected pixel locations on a 1:24,000 overlay placed on the 1:24,000 LARS computer printout. We examined each point and determined the LARS classification from three independent observations: (1) the individual pixel at the point, (2) the nearest neighboring category when a boundary was within one pixel distance (a subjective decision) and (3) the greatest proportion of a 3-by-3 matrix of pixels surrounding the point. We then compared the LARS classifications with the ground truth found by projecting the negative of the ground truth map onto the 1:24,000-scale random-point overlay with the Zoom Transfer Scope and recording the ground classification at each point. These same procedures were followed to check the accuracy of the PSW classification procedure.

Results and Discussion

A comparison of results of conventional photointerpretation (human) with results of the two computer classification systems reported here must recognize the differences in the two test designs. These differences may either enhance or detract from the success of computer classification. For example, the small size of a 10,000-acre (4047-ha) area is no problem to a computer using digital data, but it does hamper the human interpreter trying to identify specific data points on 1:1,000,000-scale ERTS imagery. On the other hand, if the computer is to be programmed to work with area data, portions of the digital tape must be printed out on a computer gray-scale map, so that specific digital elements at the corners of the area to be worked on can be located by comparison of the gray-scale map with aerial photographs. This time-consuming task is necessary because geometric errors within the ERTS data are too great to allow locating the area by direct use of the tapes by means of a coordinate system.

Photointerpretation

Land-use Classification—Both photointerpreters correctly classified all but a few of the 171 Forest points on the October and April ERTS combination. Their individual scores were 99.4 and 96.5 percent (*table 2*). In Nonforest land categories, accuracy ranged from 25.0 percent for Bare Soil to 76.9 percent for Urban. All four Water sample points were correctly classified by both interpreters; however, the small sample was not representative, and it is unlikely that small ponds less than 0.4 hectare (1 acre) or streams less than 100 m (328 ft) wide will be resolved on ERTS data. By the same reasoning, the high score for Urban classification was due primarily to the large number of samples falling within the metropolitan limits of Atlanta and other cities. Single-lane highways, secondary roads, and power lines are not usually resolved on ERTS unless they are over 100 m wide or follow the same course taken by a scan line of the multispectral scanner (MSS). This fact is even more apparent in the computer classification results.

For the April-June ERTS combination, there was little difference in classification accuracy (*table 2*). Most notable among the differences is a 20 percent increase in accuracy of classifying Grassland, coupled with a similar decrease in the accuracy of classifying Cropland. Almost 45 percent of the Cropland samples were called Grassland. This seems to substantiate the interpreters' observation during the test that Grassland and Cropland cannot be easily separated on the June image because of the strong infrared reflectance from the vegetative ground cover. When the separation was made correctly, it was usually based on the information in the April imagery. When Grassland and Cropland are combined in the analysis as one class, 75 percent of the sample points are correct on the April-June combination; only 44 percent are correct on the October-April combination.

Table 2—*Accuracy of Level I and II land-use classification by two photointerpreters for simultaneous viewing of ERTS color composites for October and April and for April and June*

Land-use class (Levels I and II)	Samples per class	October-April percent correct		April-June percent correct	
		Interpreter 1	Interpreter 2	Interpreter 1	Interpreter 2
I Forest	171	99.4	96.5	97.1	95.9
II Pine	77	67.5	64.9	51.9	59.7
Bottomland Hardwood	28	10.7	21.4	21.4	7.1
Upland Hardwood	59	55.9	30.5	64.4	33.9
Cutover	7	100.0	14.3	100.0	100.0
I Nonforest	117	96.6	88.9	96.0	96.0
II Grassland	40	62.5	57.5	85.0	75.0
Cropland	15	33.3	26.7	13.3	6.7
Wild Vegetation	15	40.0	40.0	20.0	20.0
Urban	39	76.9	66.7	76.9	71.8
Bare Soil	8	25.0	50.0	50.0	50.0
I Water	4	100.0	100.0	100.0	100.0

The data on misclassification errors indicate conflicts between Nonforest classes at the different seasons of the year. Of course, some errors are caused by incorrect borderline decisions; this problem plagues photointerpreters even on larger scale aerial photography and is a primary source of error in area estimates based on interpretation of a systematic sample of grid points. On ERTS imagery this type of error is probably more common because of the low resolution and the "blooming" factor caused when one image (lighter in color) bleeds into another. Despite this, only 17 Nonforest points were misclassified as Forest in the October-April combination, and only 11 were called Forest on the April-June combination. By the same token, only 7 and 10 Forest plots were called Nonforest on the two image combinations, respectively. These two types of errors are compensating and would enhance any estimates of forest area made on ERTS by photointerpretation techniques.

The most serious Forest classification errors were identification of Wild Vegetation and Urban as Forest. Wild vegetation in the form of abandoned agriculture and transitional agricultural land are very similar in spectral characteristics to forest land. Also, wooded green strips within suburban metropolitan areas, though technically urban, still appear to be commercial forest land on the low-resolution ERTS imagery. These areas will always be a problem for interpreters unless the resolution of the MSS data is improved.

If only Level I land-use classes are used in the analysis, then the average accuracy of classification for two interpreters is 96 percent. This accuracy level seems to hold for both seasonal combinations, making very unlikely any significant difference for Forest, Nonforest, and Water classification. If these accuracies can be carried over to operational systems, they would be satisfactory as a first-level information source for the most extensive forest inventories. However, errors in locating sample points on the ground for enumerating such things as tree species, tree condition, volume, and growth would be too great. As a result, medium- to small-scale aerial photography would be needed as a first-stage sample. The costs involved for photography would probably far outweigh any gains from using ERTS imagery.

The accuracy obtained for Level II forest classification is also shown in *table 2*. Although there is considerable variation between interpreters, the results indicate that Pine can be interpreted best on the October-April imagery—with an accuracy of about 6[illegible] percent. Only 10 to 20 percent of the Bottomland Hardwood and only 30 to 60 percent of the Upland Hardwood could be identified correctly. When the Bottomland is combined with Upland, however, accuracy is increased to approximately 50 percent—still not a very good record. The largest portion of the misclassified Hardwood was called Pine. Seven points that fell within cutover forest land were correctly identified by interpreter 1 on both seasonal combi

Table 3–*An analysis of variance table for six land-use classes,*[1] *two interpreters, and two seasonal combinations of ERTS scenes*[2]

Source of variation	Sums of squares	Degrees of freedom	Mean squares	F value	Probability level of F
Interpreters (I)	0.1756	1	0.1756	7.1043	0.9824*
Season (s)	.0179	1	.0179	.7249	.5921
I X S	.1089	1	.0189	.7642	.6042
Land use	3.7966	5	.7593	30.7246	1.0000**
Error	.3707	15	.0247	–	–
Total	4.3797	23	–	–	–

[1]Pine, Hardwood, Grassland, Cropland, Urban, Water.
[2]October-April, April-June.
* Significant at 5 percent level.
** Significant at 1 percent level.

tions. Interpreter 2 mistook cutover areas for Hardwood type on the October-April combination.

An analysis of variance based on weighted interpretation errors showed significant differences in accuracy between interpreters and, as might be expected, highly significant differences in results between land-use classes (*table 3*). There was no statistically significant difference in results between the two seasonal ERTS combinations used. This was not surprising, on the basis of the data summaries (*table 2*). Interpreter differences on the other hand are not so easily explained, but the analysis indicates an apparent difference in interpreter ability, particularly for the Agricultural and Urban classes. When all Nonforest classes are lumped together, these errors are of little significance, reinforcing the conclusion that ERTS is most useful as a device for Level I land-use classification.

Forest Disturbances–Three important conditions must be met before recognition of disturbances in a forest environment is possible. First a base photograph taken at some earlier date–perhaps 3 to 5 years prior to the proposed inventory–must be available for comparison (*fig. 7*). Second, the current picture of the same scene must be taken as close to "real time" as possible. This need is particularly acute in areas where changes are occurring most frequently. Third, the two photographs must be compatible in photographic scale. Photos that differ greatly in scale, such as the 1:64,000 photo index sheets and the 1:1,000,000 ERTS imagery, require specialized equipment such as the ZTS to view the imagery simultaneously.

Season of the year is a critical factor in detection of disturbed areas in low-resolution imagery (50 to 100 m), such as ERTS. In high-altitude photography, the better resolution lessens the need for seasonal distinctions as an aid to interpretation. For ERTS, imagery from early spring to late spring is a first choice, and from late fall to late winter, a second choice. During these periods the deciduous trees are either newly leafed out, with high infrared-reflectant foliage in spring, or are leafless in winter, and the discrimination between deciduous and coniferous trees is much better at these times. On the other hand, summer and early fall ERTS images are over-saturated with infrared reflectance from all types of vegetation, and cutover and uncut hardwoods show little difference. Furthermore, site disturbances and the effects of woods roads and log skidways are completely obscured in summer and can be of no help in interpretation.

Of the 209 verified forest disturbances, the interpreter classified 165 or 79 percent on the ERTS color composite (*table 4*). Another 23 disturbances, or 11 percent, were misclassified. Detection is much more important than the correct identification, however, and 90 percent of all disturbed areas were detected.

Omissions and commissions would be the most serious types of error in a monitoring system. In this study, 21 verified disturbances were not detected on ERTS, about a 10 percent error. Two-thirds of the omissions were less than 25 acres (10.1 ha) and more than half of these were less than 5 acres (2.0 ha). In our limited data, most omissions fall in small land clearings and cutover forest areas. Commission errors –calling something disturbed that was not disturbed–

Table 4–*Accuracy of detection of forest disturbances by one photointerpreter on ERTS color composite (1264-15445)*

Disturbance category	Number of disturbances	Percent correct
Harvested Forest Land	41	71
Land Clearing		
No Change	4	100
Forest to Agriculture	100	80
Forest to Urban	23	91
Forest to Water	18	83
Natural Cause	0	–
Regeneration to Forest	8	25
Other	15	93
All categories	209	79

are important because in a survey program, each interpretation error would mean one unnecessary field visit. At the approximate cost of $100.00 per visit, such errors could be expensive unless the field crew could inventory the plot for other information on this occasion. There were 25 commission errors, or in terms of the total number of disturbances, a 12 percent error. Both types of errors, omission and commission, can be reduced by improving the quality of color reproductions, and by giving interpreters additional experience and improved training in the use of low-resolution imagery.

Ground examination of 40 areas called disturbed since 1960 revealed that 33 could be detected and correctly classified on high-altitude photography. These same areas could be detected but not classified on ERTS imagery. The seven misinterpretations were caused by (1) calling dark-toned (wet) fields artificial regeneration, (2) failure to detect ground-fire damage after 1 year, (3) failure to detect single-tree mortality, and (4) failure to detect selective logging or stand improvement cuttings after 2 years.

From the ground check we have learned that the evidence of clearcutting and seed tree cutting can be detected up to 8 years after the harvesting operation. We also learned that there is no time limit for detecting land cleared for nonforest use. Only the size of the clearing is a limitation—less than 0.2 ha (0.5 acre) on high-altitude photography and 1 ha (2 or 3 acres) on ERTS imagery. Nonforest land regenerated to forest land by natural or artificial methods cannot be detected, however, until 3 years after planting. Association with other factors such as fire trails and site preparations can help in interpretation of high-altitude photography, but not low-resolution ERTS imagery.

Computer-Assisted Mapping

LARS System—The results of computer-assisted classification achieved by LARS show surprisingly close agreement with ground truth maps in area of land use. This is particularly true of the Level II classes—Pine, Hardwood, and Water. Table 5 shows the number of ground hectares and the proportion of the total land area mapped by the computer in each class.

When Pine and Hardwood stands were combined for all blocks, it was obvious that LARS slightly underestimated Forest land. It was also clear that with one exception both Pine and Hardwood were underestimated. The one exception was an overestimate of Hardwood (block 4) by 127 hectares (318 acres) or 21 percent. With this one exception, th estimates were all within 15 percent of the groun truth. Even estimates of Pine and Hardwood in bloc 6, based on an extension of the classification algo rithms for blocks 4 and 14, were within 10 percent o ground truth. These results look very encouraging fo automating forest land classification on low resolution imagery.

Excluding the forest land category, however, con siderably reduces the accuracy of land-use classifica tion. Grassland, for instance, was underestimated i both blocks 4 and 14, but in block 6 it was over estimated. The errors all exceeded 25 percent. Ther was no reasonable estimate of Bare Soil in any block This is difficult to understand because soil has unique spectral signature. Wild Vegetation was esti mated within 20 percent of the ground truth o blocks 4 and 14, but on block 6 the error was almos 90 percent high. This error can be explained in par by the cutover Hardwood stands that occur over larg areas and were classed by LARS as Wild Vegetation

PSW System—The PSW computer classificatio system, with a different classification algorithm an much less sophisticated computer hardware, was rea sonably successful in this test (*table 5*). For example the areas of Pine and Hardwoods were within 25 per cent of the ground truth areas, regardless of whic block was examined. Total Forest land area was with in 3 percent of the ground truth for blocks 4 and 1 and within 15 percent in block 6—the latter despit use of a combination of the training sets from block 4 and 14. Unlike the LARS system, the PSW classif cation overestimated Pine area and underestimate Hardwood, in every study block.

There seemed to be no special pattern for the e rors in Nonforest classification. Grassland was unde estimated and overestimated. Cropland acreag varied considerably and both Bare Soil and Wi Vegetation were overestimated in all three block Like LARS, PSW badly overestimated Wild Veget tion in block 6 because cutover Hardwood stands h spectral signatures similar to Abandoned and Tran tional agricultural land. Urban areas were und estimated, as would be expected because of the res lution limitations of ERTS. Water was und estimated for the same reason. The estimates of Wa were fairly good, however, considering the small a of water in these study blocks.

Comparison of LARS and PSW Systems

The displays of LARS and PSW classification m in *figures 8* and *9* allow a visual comparison of

Table 5–*Comparison of percent accuracy of area estimates and sample point classification for LARS and PSW computer mapping procedures for three test blocks, ERTS scene 1084-15440, October 15, 1972*

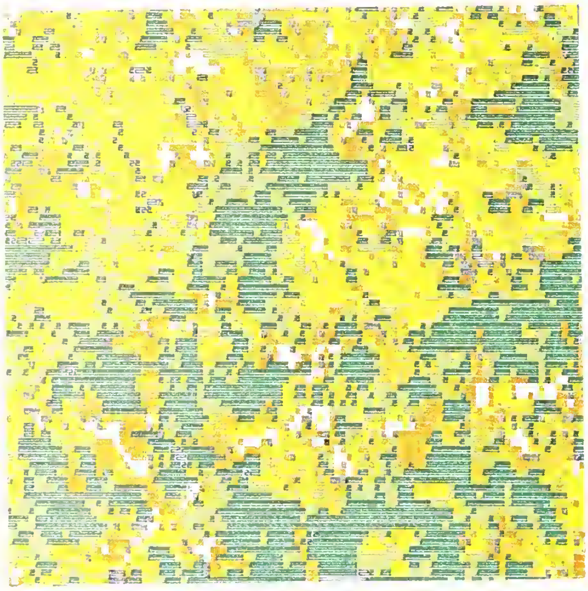
Block and land-use class (Levels I & II)	Ground[1] area		Area Accuracy		Number of points	Point accuracy[2]	
			LARS	PSW		LARS	PSW
	Ha	——— *Percent* ———				— *Percent* —	
Block 4							
I Forest	1713	48.4	47.1	49.2	78	63	45
II Pine	1093	30.9	26.0	35.9	48	63	58
Hardwood	620	17.5	21.1	13.3	30	62	23
I Nonforest	1767	49.9	51.6	49.9	93	56	33
II Grassland[3]	917	25.9	16.8	26.1	47	53	40
Bare Soil[4]	457	12.9	4.8	5.7	15	33	7
Wild Vegetation	393	11.1	30.0	18.1	31	69	35
I Water	60	1.7	1.3	0.9	7	70	43
Block 14							
I Forest	2642	66.6	63.8	68.4	128	77	56
II Pine	1476	37.2	35.3	44.1	69	80	59
Hardwood	1166	29.4	28.5	24.3	59	70	53
I Nonforest	1309	33.0	35.6	31.4	61	59	41
II Grassland[3]	417	10.5	5.0	13.1	21	43	52
Bare Soil[4]	456	10.8	6.2	6.9	14	57	50
Wild Vegetation	436	11.0	24.4	11.4	26	70	27
I Water	16	0.4	0.6	0.2	6	100	67
Block 6							
I Forest	3229	83.3	74.9	72.1	144	77	59
II Pine	764	19.7	18.0	24.4	20	55	42
Hardwood	2465	63.3	56.9	47.7	124	81	61
I Nonforest	632	16.3	24.5	27.5	28	54	32
II Grassland[3]	245	6.3	3.2	13.4	7	43	0
Bare Soil[4]	255	6.6	2.5	3.3	10	20	20
Wild Vegetation	15	0.4	0.6	0.4	2	100	50

[1] Areas were determined by dot count on ground truth maps at an intensity of two dots per acre.
[2] Classification for a single pixel at the point.
[3] Includes Cropland to compare with LARS.
[4] Includes Urban to compare with LARS.

wo systems with ground truth maps. Probably the rst impression is that agreement is very good. Be-use the human eye and brain are not capable of anning, assimilating, and sorting all of the data in a ance, more objective techniques had to be used to aluate the systems.

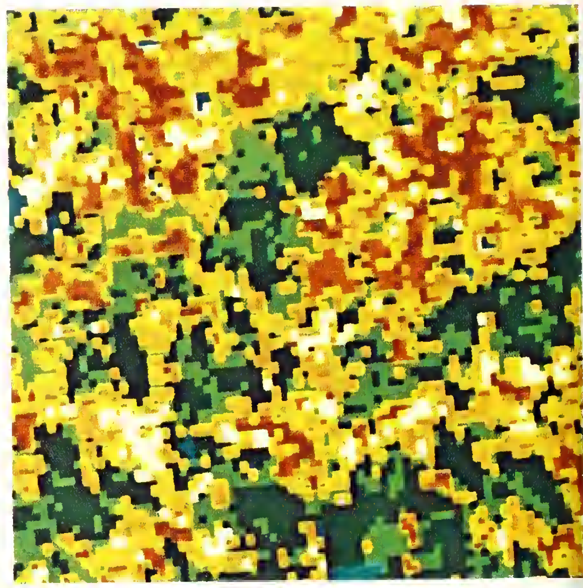
The report of results, above, showed that both stems estimated forest land areas within reasonable nits. Estimates of area by individual Level II classes ere poor, however. This implies that ERTS-1 is real- a Level I land-use sensor system. It is not surprising en, that when Level I area estimates are compared class with areas measured on ground truth maps, y good agreement is seen (*table 5*). For example, rest areas in both blocks 4 and 14 were within 2 rcent of ground truth using either system. LARS underestimated Forest and PSW overestimated it. Forest area estimates in block 6, made on the basis of training sets from blocks 4 and 14, indicated, however, that both systems underestimated forest land–LARS by 8 percent and PSW by 11 percent. This larger error was probably due to several differences between the blocks. Block 6 had a higher proportion of forest land, a higher proportion of hardwood type, and greater topographic relief, and there were also large areas of cutover forest land. The latter were misclassified as Wild Vegetation. In any future work all of these differences should be better defined for the computer systems.

When the classified areas were combined by class for all three blocks (*table 5*), the PSW estimate of Forest for a 11,383-ha unit (28,129 acres), is 7250 ha



PSW (Berkeley) Computer Map

Pine		Cropland	
Hardwood		Wild Vegetation	
Grassland		Urban	
Bare Soil		Water	



LARS (Purdue Univ.) Computer Map

Pine	Idle
Hardwood	Abandoned
Grazed Grass	Transitional
Undisturbed Grass	Water
Bare Soil	

N

PSW Ground Truth Map Atlanta, Ga. Block 4

Data source:

1:60,000 CIR photo by NASA ERAP Mission 214, Oct. 2, 1972

Classification method:

Photointerpretation (4X) and ground check

0 | 2 Miles

0 1 2 3 Kilometers

Computer maps

Data source:

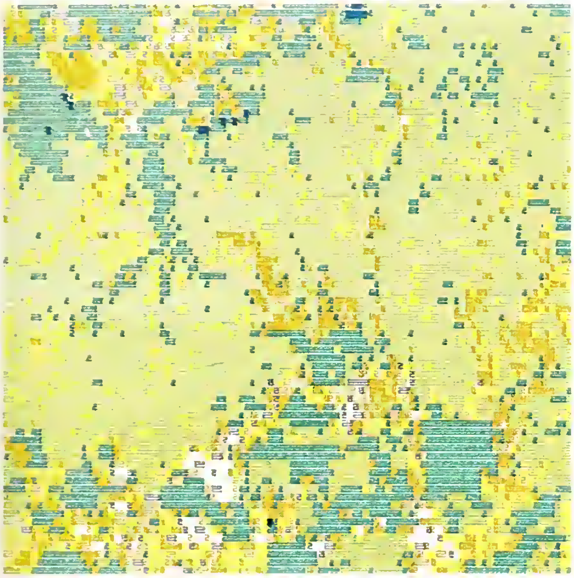
System-corrected CCT's for ERTS-1 scene 1084-15540, Oct. 15, 1972, spectral bands 4,5,6,7

Classification method:

PSW—nearest neighbor procedure

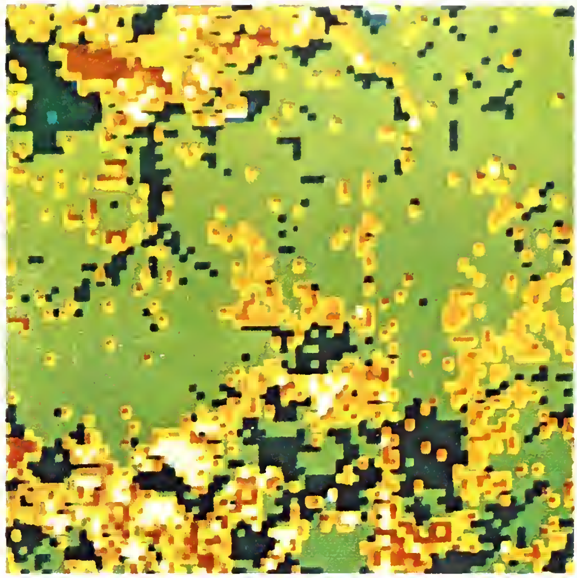
LARS—maximum likelihood theory (Gaussian statistics)

Figure 8—Examples of the output of two computer-assist mapping systems for block 4, using an October ERTS sce are shown here for comparison with the ground truth a with each other. The PSW map was produced by an off-l tape-driven plotter with eight colored marking pens. T LARS map was made photographically from a cathode- tube display using a filtering technique. Both computer m were made using training sets selected from each land- class within the mapped area. Point-by-point evaluations be made with the ground-truth map.



PSW (Berkeley) Computer Map

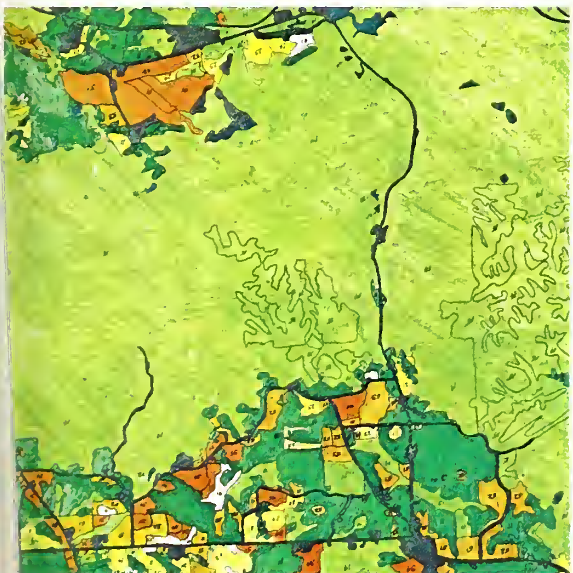
Pine	Cropland
Hardwood	Wild Vegetation
Grassland	Urban
Bare Soil	Water



LARS (Purdue Univ.) Computer Map

Pine	Idle
Hardwood	Abandoned
Grazed Grass	Transitional
Undisturbed Grass	Water
Bare Soil	

N



PSW Ground Truth Map Atlanta, Ga. Block 6

ata source:

1:60,000 CIR photo by NASA ERAP Mission 214, Oct. 2, 1972

assification method:

Photointerpretation (4X) and ground check

0 1 2 Miles

0 1 2 3 Kilometers

Computer maps

Data source:

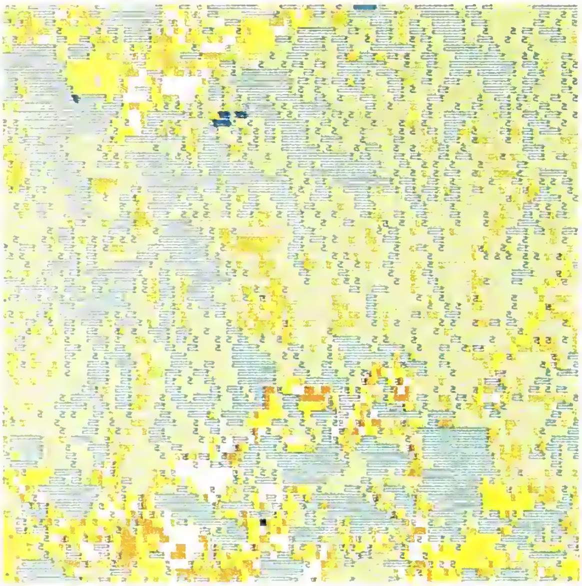
System-corrected CCT's for ERTS-1 scene 1084-15540, Oct. 15, 1972, spectral bands 4,5,6,7

Classification method:

PSW–nearest neighbor procedure

LARS–maximum likelihood theory (Gaussian statistics)

Figure 9–The computer-assisted mapping systems illustrated in figure 8 were applied to block 6, using an October ERTS scene. Both computer maps were made using a combination of the training set data for blocks 4 and 14.



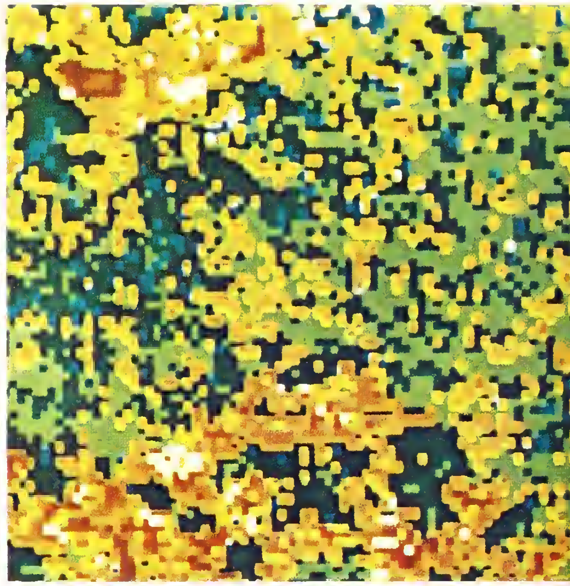
PSW Computer Map — Atlanta, Ga. Block 6

■	Pine	■	Cropland
■	Hardwood	■	Wild Vegetation
■	Grassland	■	Urban
□	Bare Soil	■	Water

Data source:
System-corrected CCT's for ERTS-1 scene 1264-15445, April 13, 1973, spectral bands 4,5,6,7

Classification method:
PSW—nearest neighbor procedure
LARS—maximum likelihood theory (Gaussian statistics)

0 1 2 Miles
0 1 2 3 Kilometers



LARS Computer Map — Atlanta, Ga. Block 6

■	Pine	■	Idle
■	Hardwood	■	Abandoned
■	Grazed Grass	■	Transitional
■	Undisturbed Grass	■	Water
□	Bare Soil		

Figure 10–The computer-assisted mapping systems illus trated in figures 8 and 9 were applied to block 6, using an April ERTS scene and two different approaches. The PSW map was made using a combination of training sets based on April scene data for blocks 4 and 14. The LARS map wa made using a combination of training sets based on Octobe scene data for the same blocks. When these maps are com pared with the ground truth map in figure 9, the errors ar quite obvious.

(17,916 acres). The ground truth is 7589 ha (18,725 acres). The difference, −327 ha (809 acres), is only 4 percent. This is a very good estimate for such a small unit area.

The LARS estimate of Forest area was almost as good. The difference from ground truth was -476 ha (-1176 acres) or 6 percent. Both systems underestimated the combined block totals. This may be a systematic error that is characteristic in the ERTS-1 data.

Nonforest classification requires little explanation. After all, if Forest Land and Water can be isolated, then what remains should be Nonforest. The accuracy of Water estimates is more important, but Water is not a major land use in the three study blocks. With just 94 ha (232 acres) of Water, as measured from ground truth maps, this hardly seems a fair test. These few acres are usually found impounded in small ponds of as little as 0.4 ha (1 acre). Nevertheless, LARS measured 93 ha (231 acres) of Water—one less than the ground truth. The PSW system could measure only 55 ha (137 acres), still a reasonable estimate for a class occupying only 0.8 percent of the total area.

Probably the most stringent test of either system is a point-to-point comparison (*table 5*). We found th a single pixel unit was the best basis for checking map classifications in areas such as the Atlanta site, where land use is broken up and spotty. Checks based on proportion of a 3-by-3-pixel matrix were almost as effective, but more time consuming.

Generally speaking, by this test, LARS is correct more often than PSW—the totals for all classes reflect a 20 percent difference. Based on Level II land classification, the overall accuracy probably does not exceed 74 percent. The range in accuracy by classes using LARS is from 20 percent for Bare Soil to 100 percent for Water. If Level I land classes are used, the accuracy for Forest land classification is 90 percent by LARS and 80 percent by PSW.

An attempt was made to classify the three test blocks using CCT's for the April 1973 scene 1264-15445. We wanted to know if the spectral data for April were more discriminating than the October data. The LARS and PSW computer maps for block 6 are shown for purposes of comparison (*fig. 10*). Unfortunately, LARS used the algorithms developed for October to classify April spectral data, and many areas were misclassified. The most noteworthy error is the abundance of Water and Wild Vegetation scattered throughout the Hardwood forest type. At PSW we used algorithms developed for April data, but the results were also poor. At this time of year, west sides of hardwood ridges are darker and apparently look like pine to the computer classifier. Also, the lighter (or brighter) sides of the hardwood ridges were classified as Wild Vegetation in many instances. Thus, computer classification using seasonal data presents difficulties not easily solved. More work is needed to isolate seasonal variations and combine seasonal data to improve computer classifications.

Applications

The spatial and spectral resolution of ERTS-1 data limit its application in forestry to providing a base for broad resource planning and to monitoring change. In the Forest Service, the nationwide Forest Survey[3] has the greatest chance of benefiting. The results of this experiment show two possible applications: (1) ERTS could provide an up-to-date area sampling base to measure the forest area in each county within a specified accuracy and (2) ERTS could provide a tool to detect forest and nonforest inventory plot changes, or disturbances, that would permit periodic updates of forest information—particularly in areas where there is a great deal of human activity. To be beneficial, however, ERTS must either provide information that will reduce survey costs or provide information that is needed but cannot be obtained by other means because of the high cost of acquisition.

Forest acreages estimated by computer classification for relatively small areas are better than the accuracies now required by the Forest Survey for counties. Although this is very encouraging, several questions remain unanswered:

1. What is the operational cost of a computer land-use classification system? Present costs of establishing the area base using existing black-and-white photographs are less than 0.0125 cent per hectare (0.005 cent per acre). We could not establish a per-hectare cost based on the research reported here.
2. How can county and other irregular boundary lines be located within the ERTS data to obtain accurate area estimates?
3. How can the ERTS data elements be clustered in a two-stage sampling design that conforms to the Forest Survey design?
4. How can ground samples be selected for the second stage sample?

Future ERTS-type satellites are planned that include a twofold increase in spatial resolution and the addition of a thermal infrared band. With these improvements, it is very likely that the data will find far greater use in forestry.

---

[3] Forest Survey is a group in the staff unit of Forest Economics and Marketing Research, U.S. Forest Service. It was authorized by the McSweeney-McNary Forest Research Act of May 22, 1928.

RANGE INVENTORY

Classification of Plant Communities

Richard S. Driscoll Richard E. Francis

The primary objective of this test was to determine at what level in an accepted hierarchy of plant community classification ERTS-1 imagery could be successfully used in a central Colorado mountainous area. A further objective was to determine the kind of aircraft support photography that would be needed to extend the classifications to the degree of detail required in range resource inventory.

Study Area

The study area is between 38° 30′ and 39° 30′ north latitude and 104° 40′ and 106° 10′ west longitude and includes approximately 14,000 km ^{2} (5400 sq mi) (*fig. 11*). Included within the area was the NASA Manitou Test Site, No. 242, where, from 1969 to 1972, considerable research in aerial photography was done to determine film/filter/scale/seasonal combinations most useful to characterize and quantify plant community systems and components.

This nonurban, nonagricultural area in central Colorado is highly diverse in plant community systems and highly varied in topography. In general, the vegetation changes with elevation, but frequently terrain, slope, and aspect compensate for elevation differences. For example, ponderosa pine (*Pinus ponderosa* Laws.) forests occur mostly on ridges and slopes between approximately 2000 and 2700 m (6500 and 8800 ft), but extend below this zone to 1800 m (5900 ft) and above the zone to 3000 m (9800 ft) depending on local environmental conditions. Other community systems vary similarly.

The vegetation in the area consists of a variety of forests and grasslands (*fig. 12*). The forests, ranging from approximately 1900 m (6232 ft) above mean sea level to tree line at approximately 3500 m (11,480 ft), include (1) ponderosa pine, (2) Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), (3) lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), (4) spruce/fir–primarily a mix of

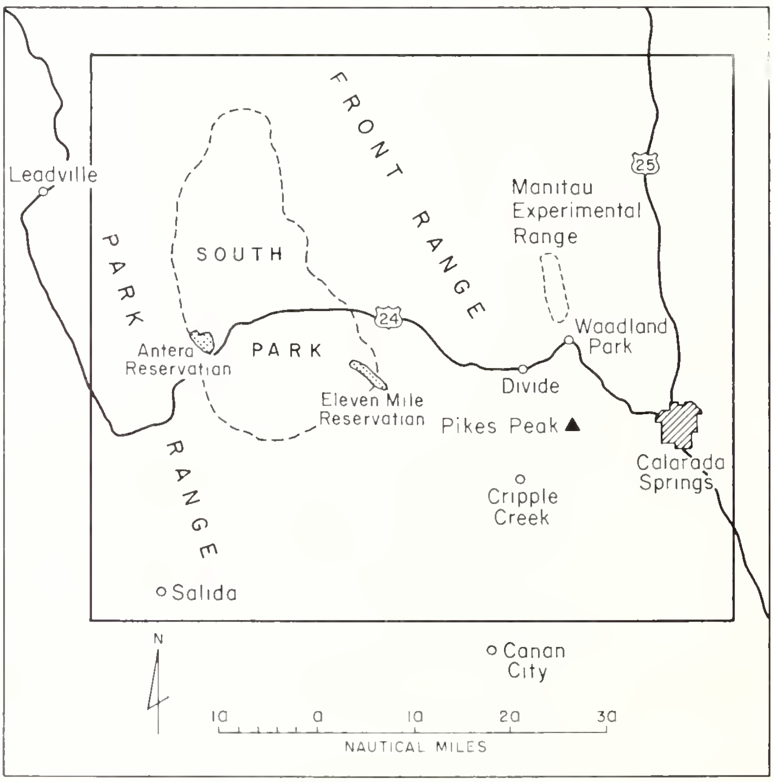


Figure 11–The central Colorado test area includes part of the Colorado Front Range on the east, a large high mountain park (South Park), and part of the Park Range on the west.

Figure 12–The vegetation of the Colorado test site is very complex, including pure stands of species types and subtle gradations between types. Above, the dark tones are coniferous forests and the lighter tones are deciduous forests (quaking aspen). Below, coniferous forest grades into grassland.

Engelmann spruce (*Picea engelmanni* Parry) and subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.)–and (5) pinyon-juniper–primarily pinyon pine (*Pinus edulis* Engelm.) and species of juniper, mainly Rocky Mountain juniper (*Juniperus scopulorum* [Sarg.]). Intermingled throughout the area are deciduous forests of quaking aspen (*Populus tremuloides* Michx.). These forests occur as "pure" types, but frequently there are varying mixtures of species in the natural ecotones between forest types or as a result of plant succession related to disturbance by man. In addition, the tree canopy of these forests varies from very open to very dense. The open tree stands permit the development of an extensive herbaceous and/or shrubby understory; little understory exists within the dense forest stands.

Mountain bunchgrass communities, in which Arizona fescue (*Festuca arizonica* Vasey) and mountain muhly (*Muhlenbergia montana* [Nutt.] Hitchc.) are the dominant grasses, occur in the lower elevation areas primarily as parks surrounded by ponderosa pine forests. At higher elevations these dominants are replaced by other species of fescue (Idaho fescue [*F. idahoensis* Elmer] and Thurber fescue [*F. thurberi* Vasey]) and oatgrass (*Danthonia parryi* Schribn.) and are usually associated with the other forest types. In many instances, the gradation from forest to grassland is subtle, and it is difficult, even at ground level, to establish the line of demarcation between the two systems (*fig. 12*).

Within the central part is South Park, a large, nearly treeless area. The vegetation of South Park is generally of low stature; blue grama (*Bouteloua gracilis* [H.B.K.] Lag.) and slimstem muhly (*Muhlenbergia filiculmis* Vasey) are the most prominent. These and associated species suggest the aspect of a shortgrass prairie. Around the fringes of the Park, and in some places within the Park, where herbaceous communities interface with the forests, mountain bunchgrass communities become prominent.

Wet meadow and stream bank communities are especially well developed in South Park and occur as occasional narrow strips throughout the entire area. Various species of sedges (*Carex* L.), rushes (*Juncus* L.), and bulrush (*Scripus* L.) predominate either as monospecific or mixed stands in the moist areas. Tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.) mixed with species of bluegrass (*Poa* L.) form communities in those areas that are not so moist. Throughout the area, generally in association with the meadows, are shrubby communities dominated by species of willow (*Salix* L.) and shrubby cinquefoil (*Potentilla fruticosa* L.).

The main portion of the study area varies in elevation from approximately 2100 to 4300 m (6888 to 14,104 ft) above mean sea level. Variations are dramatic–as much as 400 m per kilometer (2000 ft per mile) in many places. The average elevation of South Park is approximately 2750 m (9020 ft) above mean sea level.

The eastern portion of the study area, associated geologically with the Pikes Peak and Kenosha batholiths, is composed primarily of granitic mountains and outwash. The mountains in the western portion consist of highly intruded sediments; the intrusions are primarily of granite or granite-gneiss material with some schists. Trachytic and andesitic extrusive flows are relatively common, especially in the southwestern part of the area. The western mountains have been highly dissected by glaciation, and the outwash conglomerate deposits are common within and around the mountains. The northern end of the area is framed by the Kenosha batholith and other intrusive materials. The southern part of the area is associated with the Arkansas Hills, an ancient volcanic region from which extensive andesitic flows originated. Also associated with the southern portion are old uplifted sediments. Igneous intrusions and flows are abundant throughout South Park (Weimer and Haun 1960).

Generally, the mountain ranges in the area are oriented on a north-south axis, but many spurfragments, as well as individual units within the major ranges, are oriented east-west. This presents a complex matrix of slope-aspect relationships that influences vegetation patterns and adds to the complexity of processing and interpreting remotely sensed data.

Classification System

The vegetation classification scheme used to evaluate the effectiveness of the ERTS-1 and supporting aircraft data is ECOCLASS, which was established according to ecological principles of polyclimax concepts (Daubenmire 1952). This system is in current use by the Forest Service to classify plant communities for land management planning, and is in accord with that established by the International Biological Program for classifying terrestrial communities (Peterken 1970). The system defines five categories proceeding from the most general to the most specific, as follows:

V. **Formation**–The most general class of vegetation, characterized by general appearance: Grassland, Coniferous Forest, Deciduous Forest, etc. The basis of this category is continental in scope, i.e., all of the

United States, and is controlled by continental climatic differences.

IV. Region—Subdivisions of the formation, associated regionally and therefore determined by subclimates within continental climates: Montane Grassland, Temperate Mesophytic Coniferous Forest, Alpine Grassland,, etc.

III. Series—A group of vegetation systems within the Region category, with a common dominant climax species: Ponderosa Pine Forest, Fescue Grassland, Herbaceous Meadow, etc.

II. Habitat Type—Units within a series, each with relatively pure internal biotic and abiotic structure: Ponderosa Pine—Arizona Fescue habitat type, Arizona Fescue-Mountain Muhly habitat type, etc. *These are the elemental units of the classification scheme upon which primary management is based.* These units are frequently related to climax vegetation, or to vegetation held in a relatively stable state of high succession by proper management.

I. Community Type—A system that appears relatively stable under management and may be equivalent to the habitat type. Usually the biotic components are dissimilar, but abiotic components are analogous to habitat type.

The whole study area is considered to be within one general physiographic province, the Central Rocky Mountains, in which representatives of three Formation classes occur: Grasslands, Coniferous Forests, and Deciduous Forests. Within these classes, three Region and eight Series categories were defined for this study:

IV - Region	*III - Series*
1. Coniferous Forest	1. Ponderosa Pine
	2. Lodgepole Pine
	3. Douglas-fir
	4. Spruce/Fir
2. Deciduous Forest	1. Aspen
3. Grassland	1. Shortgrass
	2. Mountain Bunchgrass
	3. Wet Meadow

ERTS Data

Three ERTS-1 color composites, secured from the Goddard Space Flight Center, included most of the test site and were selected for analysis: Scenes 1028-17135, August 20, 1972; 1334-17142, June 22, 1973; and 1388-17134, August 15, 1973. The color composites used ERTS multispectral channels 4 (green), 5 (red) and 7 (near infrared). These three scenes were selected because (1) the 1972 scene was the first relatively (95 percent) cloud-free image of the area and was imaged at a time when most vegetation in the area was at peak growth, and (2) the 1973 scenes were relatively (90 percent) cloud free and represented a time when most vegetation was in either primary growth stages (June) or at peak growth (August), allowing us to determine if seasonal plant growth effects assisted classification. The color composites were used for visual interpretation and microdensitometric analyses.

In addition, ERTS multispectral scanner digital tapes of two of the scenes were secured for computer-assisted analysis. Selected portions of the August 1972 data were analyzed in cooperation with the Earth Resources Department, Colorado State University, and selected portions of the August 1973 data were analyzed in cooperation with LARS, Purdue University.

Ground Truth

Color and color infrared (CIR) aerial photographs were secured to assist in interpreting the ERTS-1 imagery for plant community classification. Two aircraft missions, one in mid-June and one in mid-September 1972, were flown by the NASA aircraft support program, to provide photography representing plant phenological conditions corresponding to the selected ERTS scenes. Aerial photo scales were approximately 1:50,000, 1:100,000, and 1:400,000. In addition, CIR photographs at scales of approximately 1:2,000, 1:10,000, 1:20,000 and 1:40,000 were taken from U.S. Forest Service aircraft over parts of the area, to correspond to the August 1972 ERTS scene, so as to aid in determining photo scales required for specific plant community systems.

Photointerpretation Procedures

Within the total study area, five units, each approximately 576 km ^{2} (225 sq mi), were selected for intensive investigation (*fig. 13*). These units were not necessarily replications because the plant community classes in one unit were not completely represented in all other units. All five units were used for visual and microdensitometric interpretation. Only two, units 2 and 4, were used for computer-assisted interpretation.

Visual Interpretation

The June and August 1973 ERTS color composites were used for visual interpretation. Vegetation type maps, topographic maps, the ERTS-support

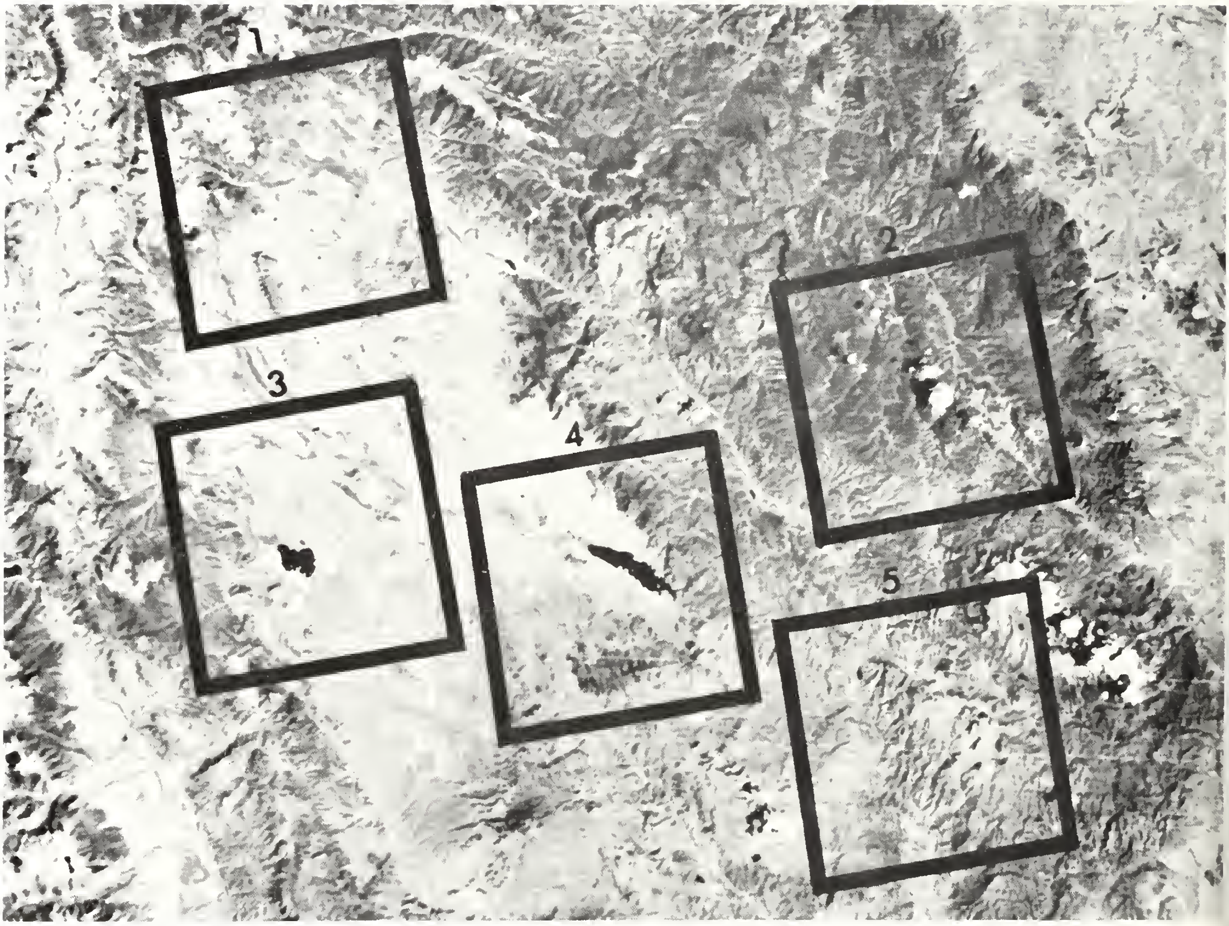
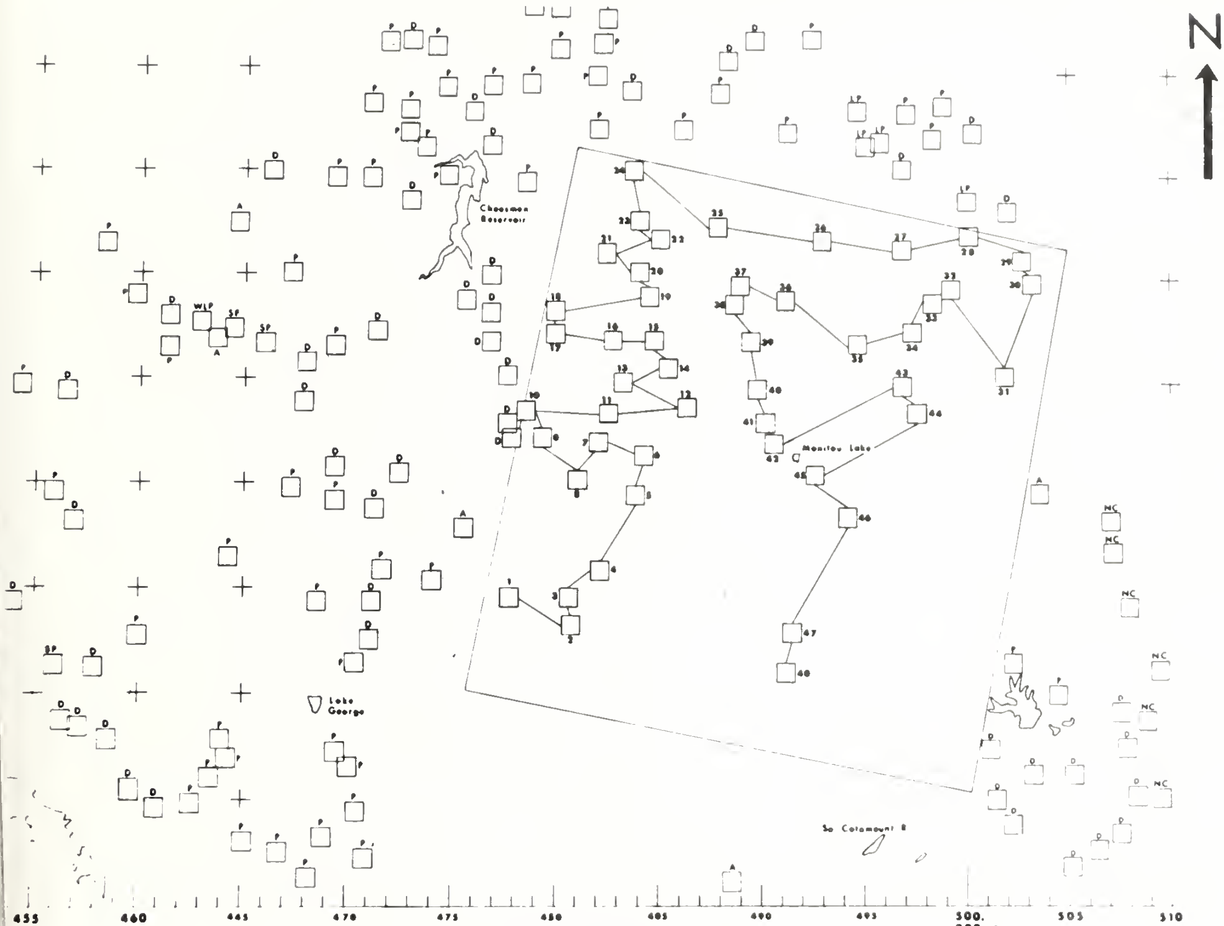


Figure 13–In this ERTS frame (scene 1028-17135) the five units selected for intensive investigation within the Manitou Test Site are outlined. Pikes Peak is at the northeast corner of unit 5. The units are aligned in a true north-south orientation; the skewness in the ERTS imagery is caused by the orbital path of the satellite and the rotation of the earth. White patches in the scene are clouds.

aerial photographs, and ground inspection were used to select sample "cells," or specific areas, for visual interpretation of both the ERTS-1 and support aerial photographs. The sample cells were initially selected and plotted on vegetation type maps and topographic maps to represent an area approximately 500 m^2 (1640 sq ft). The size of the cell selected was determined by two factors: (1) the originally advertised resolution and geographic fidelity of the bulk-data ERTS products, and (2) expected positional errors in both the satellite and data collection systems and in the system used to transfer sample cells from maps to the ERTS-1 and supporting aerial photographs. Ten percent of the sample cells were verified using aerial photographs and ground search. As only three of the field-verified cells required reclassification, the remaining classifications were assumed to be acceptably accurate. No fewer than 20 training and testing cells were selected for each vegetation class, and 660 cells in all were used.

For visual interpretation of the color composite ERTS-1 imagery, transparent overlays were constructed showing sample cell locations for the total study area and for each of the five units (*fig. 14*). The Universal Transverse Mercator (UTM) coordinate representing the location of each cell was precision-plotted to a scale of 1:100,000. These overlays were then photographically reduced on 0.004 mil clear positive film to the 1:1,000,000 scale matching the ERTS-1 format. The plotted cell size at this scale represented an area 900 m^2 (2952 sq ft), larger than the size stated earlier, to minimize edge effect of cell wall lines. In addition, 50-km (31.07-mile) UTM coordinates were plotted to assist in positional location of the overlay on the ERTS frames.

These same cell locations were used to interpret



BLOCK 2

Figure 14–An overlay of sample cells was prepared for visual interpretation of ERTS color composites. Each small square represents an area approximately 900 m^2 (2952 sq ft). The interpreters named the class they believed represented by the signature of the center of the square–300 m^2 (984 sq ft).

he aircraft support photographs. Sample cell locaions were transferred directly from the vegetation nd topographic maps to the aerial photographs.

In data analysis, a factorial design for analysis of ariance was used to test for differences between the ppropriate factors of film type, photo scale, flight ate, photointerpreter, and vegetation class. All facors were considered to be fixed effects. The highest rder interaction term was used as the error term to btain the F statistic.

licrodensitometric Interpretation

A scanning microdensitometer (*fig. 15*) was used evaluate the June and August 1973 ERTS-1 color ifrared composites for classifying the plant comunities. This instrument examines a small piece of the imagery at spectral levels selected to be compatible with the apparent spectral characteristics of the photographic materials. It then measures the optical density of the image by means of an optical system coupled with a photomultiplier-logamplifier measuring device. The hypothesis tested by this portion of the study was that the optical image densities of the plant communities classified to the Region and Series levels were sufficiently discrete to allow discrimination among them.

A red filter was inserted into the light-beam path to enhance the infrared vegetation signatures. The effective circular aperture covered an image area of 41,500 square microns, which on the ERTS image was a circle with a diameter approximately equivalent to the side dimensions of the sample cells used for visual interpretation.

The same sample cells used for visual interpretation were measured by the microdensitometer. Optical image density measurements were made of each sample cell by aligning the scanner light beam with the cell location, with the assistance of the overlay. Prior to making the measurements, the apparent optical density of the transparent overlay measured by the machine was compensated for to remove this effect from the apparent image density values. Values from all sample cells were obtained.

Computer-Assisted Mapping Procedures

In machine processing of the ERTS computer-compatible tapes (CCT'S), two sets of imagery were used—20 August 1972 and 15 August 1973. Only units 2 and 4 (*fig. 13*) were used for this portion of the work. The 1972 imagery was analyzed in cooperation with the Earth Resources Department, Colorado State University, to investigate the effects of topography on classification performance. These effects in conjunction with machine processing of the ERTS-1 imagery had been theoretically recognized, but detailed investigation had not been done (Hoffer and others 1973). The August 1973 imagery was processed in cooperation with LARS, Purdue University, to evaluate the ERTS-1 imagery for classifying the plant communities to the Region and Series Levels.

To determine effects of topography on classification, a photolike image mosaic of units 2 and 4 at approximately 1:90,000 scale was generated from the CCT's using the microfilm capability of the CDC-6400 computer at Colorado State University. An initial classification of all vegetation classes was performed. Topographic maps, vegetation type maps, and 1:100,000-scale CIR aerial photographs were used to select and delineate on this mosaic representative vegetation class areas to "train" the computer to recognize the different classes. Also, training areas for Water, Clouds, and Cloud shadows were selected. The size of these training fields varied because of the natural meandering of the vegetation class boundaries.

The Ponderosa Pine class delineated in the ERTS CCT's by the initial selection procedure was used for detailed investigations on effects of slope steepness on the apparent spectral signatures of the class. Nine computer training fields of equal area were selected to represent different slope steepness classes. A single field was selected for each of three levels of slope. Slope steepness classes were: 0° to 15° (low), 15° to 30° (medium), and greater than 30° (high), as determined from topographic maps.

For the initial classification, we used a supervised program RECOG (Smith and others 1972), a multiphase program patterned after the LARSYS approach (Purdue University 1968), to produce gray-scale maps. Each digital element was forced by RECOG to be classified as one of the plant community classes. The training fields for the slope classes of the Ponderosa Pine class were then located with the aid of aerial photos on the gray-scale maps. Standard statistical t and F tests were used to determine any significant

Figure 15—A microdensitometer (General Aniline and Film Corp. Model 650) was used to measure point-sample image density values of the various plant community systems. The operator is aligning the ERTS sample cell in the view screen before reading the apparent optical image density.

relationships between spectral response and slope steepness.

Classification by LARS used a mixed supervised and unsupervised procedure following the general LARSYS approach. The basic analysis had five phases: (1) locating the area to be studied, (2) selecting computer training fields to be clustered, (3) clustering the fields, (4) combining the statistics into spectral classes which appeared to relate to the classes under test, and (5) classifying the area. Initially, the data were deskewed to correct for earth rotation and satellite orbit paths (Anuta 1973). This put the data in a true orientation for nearly direct correspondence to topographic maps and aerial photos. Also, the computer-generated recognition maps were printed to 1:24,000 scale so that one digital element of ERTS-1 data represented one recognition map symbol. The training fields were selected to provide representative samples of the vegetation classes, so as to train the computer. The computer was then used to classify the total area. Evaluation of this final classification at both levels, Region and Series, was performed by systematically sampling approximately 10 percent of a portion of the computer classification maps representing the unit 2 (Manitou) and unit 4 (Eleven Mile) areas. That portion of each area corresponded to the area covered by one 1:50,000-scale CIR aerial photo.

Two complete computer classifications were done —one at the Region level and one at the Series level. In addition to the vegetation classes at each level, classes for Barren, Water, Cloud Shadows, Clouds, and "bad" data were introduced. Thus, the finished product resulted in classification of all ERTS-1 digital data cells of the selected areas.

Sample cells used for evaluation consisted of a series of 2-by-2 digital element matrices with a two-element buffer on each side to minimize the effect of possible positional errors. The computer-assisted classification of each sample cell within each matrix was compared with the vegetation classes interpreted from the same sample cell locations on the :50,000-scale CIR aerial photographs and vegetation ype maps. To do this, transparent acetate grids were caled to match the evaluation sample cell matrices to he aerial photographs and vegetation maps. Special ttention was given to those evaluation sample cells at he vegetation class boundaries and small, meandering egetation types. In some instances, such as long and elatively narrow Wet Meadow areas, evaluation atrices were subjectively selected to assist in determining not only classification accuracy but positional ccuracy. This was done to determine the influence f edge effects on the computer-assisted classification for the nonuniform patterns of the natural vegetation occurring within the test site.

Results and Discussion

The three procedures—(1) visual interpretation, (2) microdensitometric interpretation, and (3) computer-assisted analysis—provided similar results. In general, plant community classification by computer-assisted analysis to the Region level was acceptable (more than 80 percent accuracy) for most classes. Classification to the Series level was not acceptable (less than 80 percent accuracy). Further work should improve classification at each level, provided variable terrain features such as slope and aspect, and variations in live plant cover in relation to spectral response, are taken into account. The results of classification to either the Region or Series level by the visual and microdensitometric techniques indicated no date dependency between late spring (June) and midsummer (August) ERTS-1 imagery. Variations in these results are discussed below.

Classification to the Region level through visual interpretation of late spring (mid-June) and late summer (mid-September) aerial photos was neither date- nor scale-dependent. Results of interpretation to the Series level were varied as discussed below.

Visual Interpretation

Region Level—Satellite color composites and aircraft photographs provided highly acceptable levels of classification accuracy for the Conifer and Grassland classes regardless of date, film type, photoscale, or interpreter (*table 6*). The lowest level of accuracy (for either class) was 88 percent for one interpreter using the June 1973 ERTS color composite, but this was still within the established limits of acceptability. Interpretation of the Deciduous class using either the satellite composites or aircraft photographs was dependent on date and scale. For the satellite

Table 6—*Accuracy of visual classification of vegetation at Region level from ERTS color composites and from aerial photography*

Vegetation class (Region level)	ERTS	Aerial photography
	Percent correct	
Conifer Forest	95.4	98.2
Deciduous Forest	62.6	64.8
Grassland	96.4	99.0

imagery, the best date (p = 0.95) among the three used was August 1973, with an interpretation accuracy for the Deciduous class of 92 percent. Accuracy for that class in the June imagery was only 31 percent. At that time of year in the Manitou area, the leaves of the trees were only one-fourth to one-half developed and therefore were not producing maximum spectral responses required for classification, considering the resolution of the imagery being used.

Interpretation of the Deciduous class from aerial photography was less accurate than it was from the ERTS composites. The 1:50,000 scale CIR photographs provided 83 percent correct identification of that class as compared to the 92 percent for the ERTS composites. Here the interpreters were looking for more detail in the aerial photos, even to individual trees, and consequently there was more chance for error in classification decisions because of intermixing of the Deciduous class with the other classes.

In most instances there were significant differences (p = 0.90) among interpreters for both the satellite color composites and the aerial photos. The differences were not of sufficient magnitude to alter the classification results. The interpreter most knowledgeable about the vegetation and its distribution in the test site provided the most accurate classifications.

The majority of commission errors for the Conifer classifications was to the Deciduous class, and few commission errors were made to the Grassland class. Deciduous was most often misclassified as Conifer, with a small percentage classed as Grassland in the satellite imagery. Misclassifications from the satellite imagery were due largely to the inability of the interpreters to interpret correlative information, such as changes in terrain relief which play major roles in distribution of the vegetation classes from that imagery. This problem made interpretation difficult between the Deciduous class and the Wet Meadow component of the Grassland category. Those two classes occur occasionally at interfaces around the edges of South Park. The misclassifications between Conifer and Deciduous were caused by the usual intermixing of species between the two classes.

There were no overall significant differences in results between the satellite composites and the aerial photos for classification of the three Region categories provided August imagery was used. On the basis of these results, the satellite composites were satisfactory for classifying those general plant community systems.

Series Level—The satellite color composites visually interpreted provided acceptable classification of the Aspen and Ponderosa Pine classes. However, interpretation for these classes required imagery from di ferent times of the growing season. For Aspen, high est accuracy (92 percent) was achieved using th August 1973 imagery (*table 7*). It must be noted tha Aspen was the only Deciduous class identified in thi work. There were no other deciduous forests in th study area. Whether or not the class can be separate from other Deciduous classes where it occurs wit them in other parts of the United States cannot b stated.

Table 7—*Accuracy of visual classification of vegetation a Series level from ERTS color composites, by interpreter*

Vegetation class (Series level)	Interpreter			
	A	B	C	Mean
	Percent correct			
Aspen (August 1973)	83	100	94	92
Ponderosa Pine (June 1973)	61	95	88	81
Shortgrass	98	98	100	99
Wet Meadow	82	76	91	83
Mountain Bunchgrass	41	22	88	50

Ponderosa Pine was identified 81 percent of th time from all other vegetation classes, all interpreter considered (*table 7*). One interpreter was much les accurate than the others, however, with a score of 6 percent as compared to 95 and 88 percent. Most o the commission errors of the low interpreter were t the Douglas-fir class. In most areas of the test site these classes occur in close association, especially nea ridgetops and on north slopes. In these areas, the tw classes were very similar in canopy cover and visu image differences were subtle. The low-accuracy in terpreter had difficulty in making the necessary di tinctions.

Classification of Shortgrass and Wet Meadow wa acceptably accurate from the satellite color com posites regardless of which date was used (*table 7*). There were significant differences (p = 0.99) amon interpreters for classifying Wet Meadow. One inte preter had difficulty in discriminating that class from Shortgrass and Aspen, especially in the June image At that time of year, when the vegetation was pa tially developed seasonally, there were relative subtle demarcations between the three classes, a viewed in the satellite imagery, where they occur i close proximity.

Only one interpreter provided an acceptable le of classification for Mountain Bunchgrass using t satellite composites (*table 7*). He was well acquain with the test site, especially that area where t Mountain Bunchgrass system was most prevale Therefore he could make judgments based on t knowledge, even though the image signature of the sample cells—primarily color—was highly variable. For example, the color image signature of Mountain Bunchgrass ranged from medium blue to pale reddish purple, but the interpreter called both color signatures to the correct vegetation class. This result supports the conclusion that, at least with visual interpretation, the individual interpreter must be acquainted with the landscape to provide acceptable interpretations of the vegetation resources.

Results were also variable for interpretation at the Series level with the multiscale aerial photographs. In general, the best (p = 0.95) classification was obtained using the 1:50,000 scale CIR photos exposed in middle to late summer (*table 8*). Only the Shortgrass, Wet Meadow, and Aspen classes, however, were correctly identified to the established accuracy standards. There were significant differences (p = 0.99) among the interpreters in classification of most categories. Again, the interpreter who was most familiar with the landscape and its vegetation was most accurate. On the basis of his results alone, five of the eight classes were classified with sufficient accuracy.

Ponderosa Pine was classified more accurately on the satellite composites than on the aerial photographs. Normally, mature forests of that type are quite open-grown, with 40 to 60 percent crown cover, which presents many holes in the forest canopy to a remote sensor. Also, these forests, as compared to other forest classes, generally occur on drier sites, with relatively sparse understory vegetation and larger amounts of exposed soil surface. Consequently, a higher reflectance response is presented to the sensors, and a consequently brighter integrated image is recorded by the sensor, especially with increases in altitude to the height of the ERTS satellite. On the aerial photographs, the canopy holes were clearly visible, and since the apparent reflectance of the conifer trees among classes was similar, the interpreters made more commission errors on the photos when attempting classification of Ponderosa Pine.

Generally, commission errors for the forest classes were similar for both satellite imagery and aerial photos. The apparent major reason for these commission errors was overlapping of areas on the ground where the species classes grow. This caused class mixing, with similar photo textures on the aerial photos and similar color signatures on both satellite and underflight data. The low resolution and lack of stereoscopic coverage of the satellite imagery did not permit interpretation of topographic features important in relation to changes in the plant community classes. The task was further complicated by heavy

Table 8—*Accuracy of vegetation classification at the Series level from 1:50,000 CIR aerial photographs, for two dates*

Vegetation class (Series level)	Photo date	
	June 1973	August 1973
	—— *Percent correct (range)* ——	
Mountain Bunchgrass	70 (40-100)	74 (44-100)
Shortgrass	89 (83-92)	89 (83-92)
Wet Meadow	100	100
Aspen	83 (75-100)	83 (75-100)
Douglas-fir	36 (27-41)	65 (42-77)
Lodgepole Pine	51 (47-67)	44 (22-67)
Ponderosa Pine	65 (53-86)	71 (57-81)
Spruce/Fir	72 (59-77)	67 (64-75)

shadows in steep north slope situations. No commission errors were made into the Grassland classes for the aerial photos because of the added advantage of stereo coverage and better resolution than the satellite imagery.

Commission errors for the Grassland classes were similar for both the satellite imagery and the aerial photos. An exception was that no commission errors were made to the Forest classes on the aerial photos. This was due to the added advantage of stereo coverage and better resolution to allow interpretation of topographic relief and apparent vegetation height.

Most of the commission errors for Mountain Bunchgrass on the satellite imagery occurred through confusion with Shortgrass. Without the aid of stereo coverage and subsequent topographic relief, it was very difficult to determine where the mountain perimeter began in order to correctly classify the Mountain Bunchgrass class. Commission errors for Wet Meadow were about equally divided between Aspen, Mountain Bunchgrass, and Shortgrass. Both high density Wet Meadow and Aspen had very similar color signatures and therefore were most often confused where the two classes occurred side by side. It was especially difficult to separate these two classes in those instances because of the lack of interpretable topographic relief in the satellite imagery. Also, low-density Wet Meadows had a color signature similar to those of high-density Shortgrass and Mountain Bunchgrass and therefore confused the interpreters.

Commission errors for Mountain Bunchgrass were lower on the aerial photos than on the satellite imagery. The stereo coverage allowed the interpreters to relate to topographic features, particularly the interface between the forested mountains and the grasslands. Commission errors to the Shortgrass class for Mountain Bunchgrass were still relatively large, however, because of the continuum between the two Series classes.

The 1:50,000-scale aerial photographs were not entirely satisfactory to develop a multistage sampling scheme in the Manitou area. Vegetation in the area is highly complex, the plant community patterns are intricate, and the similar apparent spectral responses within and among plant community systems did not allow discrimination among all Series classes.

Larger scale, 1:20,000, aircraft CIR photos are required to subsample the Region classes for specific Series categories (*fig. 16*). The crown shapes of trees and the subtleties of Grassland class boundaries become more discrete at this photo scale than at smaller scales. This provides more precise definition of the location of Series boundaries to estimate the areal extent of Series units, and allows definition of some Habitat Types. An example of Habitat Type separation is seen in the figure. The coarse-textured image in the stream area at the bottom of the photo represents a Willow Habitat Type in contrast to the smooth textured Sedge/Bulrush Habitat Type in the same area. Also, tree crown cover, foliage cover classes of Grassland systems, and by interpolation, herbaceous foliage in the openings of the forest can be determined.

The last level of information in a multistage sample to obtain estimates of Series or Habitat Type parameters is secured using 1:2000 (*fig 16*) or larger scale photography. Individual tree crown diameter and tree height are measured to estimate timber stand volume. Relative amounts of plant cover and bare soil for Grassland units can be estimated. Measures of density and dispersion of some individual species in Grassland units can be estimated provided 1:600-scale sampling photography is used. Statistical measures of these parameters were limited and are not specifically reported here, because of the uncertainty of when ERTS data was in fact taken, and the malfunctions of some ground instruments. Previous research substantiates, however, that such parameters about plant communities can be estimated.

Microdensitometric Interpretation

Region Level—Standard t tests for unpaired plots with unequal sample sizes indicated highly significant differences in the apparent image density among all Region classes regardless of which of the two ERTS-1 frames were used (*table 9*). Consequently, at the Region level of classification, those categories could be classified by microdensitometric techniques with a high degree of accuracy regardless

Table 9—*Mean optical image density for Region and Series vegetation classes from ERTS-1 color composites for two dates: June 20 and August 15, 1973*

Classification level, date, and class	Sample size[1]	Mean image density[2]
Region		
June		
Deciduous Forest	36	2.141
Coniferous Forest	307	2.232
Grassland	66	1.079
August		
Deciduous Forest	44	1.983
Coniferous Forest	408	2.294
Grassland	69	0.991
Series		
June		
Mountain bunchgrass	21	1.079
Shortgrass	27	1.069
Wet Meadow	18	1.093
August		
Mountain bunchgrass	22	0.979a
Shortgrass	27	0.931b
Wet Meadow	20	1.086ab
Series		
June		
Spruce/Fir	53	2.300abc
Lodgepole Pine	31	2.254ab
Douglas-fir	83	2.238abc
Ponderosa Pine	139	2.199ab
Aspen	36	2.141a
August		
Spruce/Fir	119	2.341ab
Lodgepole Pine	55	2.296ab
Douglas-fir	90	2.323ab
Ponderosa Pine	144	2.236ab
Aspen	44	1.983a

[1] Sample size for a class varies between dates because clouds or cloud shadows obscured sample points in the June imagery.

[2] For all Region classes, differences between all combinations at each date were highly significant (p = 0.99). For Series classes, any two values with common letters are significantly different (p = 0.95).

of whether late June or mid-August imagery wa used. Similar results have been obtained using small scale aerial photos (Driscoll and others 1974). Th validity of these results with the ERTS photographi products needs to be evaluated, however, using add tional imagery of the same or other locations take during other years.

Series Level—Results of microdensitometric inte pretation for classification at this level varied. Fo the three Grassland classes, there were no significa t differences in image density estimated from the Ju imagery among any of the classes (*table 9*). At th time of year, the grassland vegetation was in the p

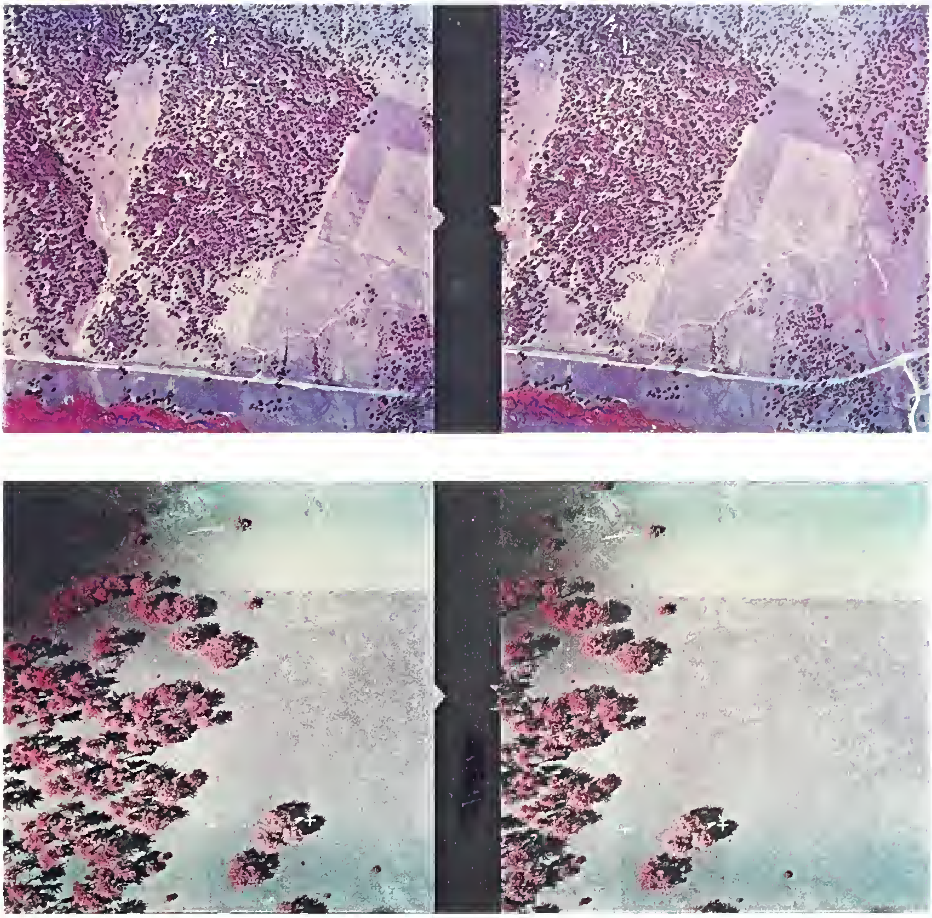


Figure 16–These stereo pairs at different scales illustrate the imagery required for classification and mapping at various levels. The 1:20,000 CIR stereo pair, *top*, allows classification to the Series and in most instances, the Habitat Type level of ECOCLASS. This material is used to subsample the Regional stratification done with ERTS imagery. On the 1:2000 stereo pair, *bottom*, tree heights and crown diameters can be measured. Here the boundary between Ponderosa Pine and Mountain Bunchgrass (Series level) is shown. Relative amounts of herbaceous plant cover and bare soil in the Mountain Bunchgrass unit can be estimated provided the original photography is used.

ary stages of growth, there was little green foliage cver and most of the grassland scene was dead plant iaterial and bare soil. Hence, there was no discrimi- ation among the Series classes.

There were significant differences in the mean otical image densities of the Grassland classes in the Agust imagery (*table 9*). The mean density values b ween Mountain Bunchgrass and Wet Meadow, and S ortgrass and Wet Meadow, were sufficiently differ- e (p = 0.95) to make acceptably accurate discrimi- n ion between the groups highly probable. At that ti e of year, the dense Wet Meadow herbaceous ve tation was at peak growth. This allowed for a hi scene contrast between the Wet Meadow and the much drier upland Grassland classes. There was no significant difference between Mountain Bunchgrass and Shortgrass. These results were similar to those obtained with the computer-assisted analysis evaluations, described in the next section. The reason for this lack of discrimination between the two classes in the ERTS-1 imagery is not fully understood. Mountain Bunchgrass stands are usually of higher stature with more lush vegetation than the Shortgrass stands. Total live herbage cover is similar for both classes, however (35 percent Shortgrass; 45 percent Mountain Bunchgrass). Consequently, the spectral response to the ERTS-1 sensors appears to be influenced more by the amount of live vegetation cover than by the structure of that cover. Also, the amount of vegetation cover in relation to other material (bare soil and plant litter) in the scene would influence the scene spectral response. In parts of both units, more than half the total samples had less than 50 percent live foliage cover, and this could be the threshold in spectral response at which live dry grassland cover has much influence on the spectral signature detected by the ERTS-1 sensors. These are the new concepts that need to be tested to improve recognition of Grassland classes by microdensitometry in areas similar to this test site.

Series classifications by optical density levels of the forest units were also variable within and among the two ERTS-1 scenes (*table 9*). Aspen and Ponderosa Pine were discriminated from the other Forest Series classes for both dates on the basis of optical image density. There was a significant difference (p = 0.95) between Douglas-fir and Spruce/Fir on the June imagery but not on the August imagery. The reason for this difference is not completely understood, but perhaps changes in sun azimuth and elevation between the two dates of the ERTS-1 imagery unequally affected the spectral response of the forest types.

Lodgepole Pine and Spruce/Fir were not differentiated at either date. These two kinds of forests normally grow in very dense stands and in similar terrain locations on north-and-east-facing slopes at relatively high elevations. The combined effects of dense canopy cover and mountain shadows at the time the ERTS-1 imagery was obtained resulted in very similar spectral signatures. Corrections for mountain shadows and apparent minor differences in spectral responses relative to the ERTS-1 sensors may improve classification. These ideas need to be investigated since similar classification problems were encountered at the Series level using the digital tapes.

Computer-Assisted Mapping

Region Level, Training Samples—Training-sample classification was accurate at the Region level for both the Manitou and Eleven Mile Units (*table 10*). For all categories, classification accuracies were in excess of 97 percent.

The main sources of error within the Manitou unit were between the Grassland and Barren and between the Coniferous and Deciduous classes. The primary reason for the confusion between the Grassland and Barren classes was the low cover of vegetation in some of the Grassland areas. The high reflectance of nonvegetated areas dominated the response of live vegetation within the same digital element, and as a result, the total signature was assigned to the Barren category. The confusion between the Coniferous and Deciduous classes was due to a mixing of these Region classes (*fig. 12*). The plant components of the Deciduous class (quaking aspen in this case) frequent

Table 10—*Accuracy of performance of computer-assisted analysis at the Region level, for training class and total evaluation, by vegetation class for two study units*

Unit vegetation class	Training class performance		Total evaluation performance	
	Number of samples	Percent correct	Number of samples	Percent correct[1]
Manitou				
Grassland	382	97.1	257	84.4
Deciduous Forest	78	98.7	21	23.8
Coniferous Forest	1294	97.6	1239	86.1
Barren	60	98.3	–	–
Cloud	384	99.2	–	–
Cloud Shadow	340	98.5	–	–
Water	–	–	3	66.7
All classes	2538	93.0	1520	84.9
Eleven Mile				
Grassland	1193	97.7	433	80.1
Deciduous Forest	173	97.7	94	51.1
Coniferous Forest	1137	99.2	739	66.0
Water	1090	99.3	60	95.0
Barren	41	100.0	54	1.9
All classes	3634	98.7	1380	68.2

[1]Calculated as number correctly classified/total number of samples for each class.

ly occur in different amounts within the Coniferous class, and these mixes, or ecotones, apparently aline themselves spectrally to one or the other of the primary classes. The class of such ecotones is often difficult to determine on the ground without detailed ecological investigation.

In the Eleven Mile unit, the confusion in training sample classification was primarily between the Grassland and Coniferous classes and the Deciduous and Grassland classes. The errors between the Grassland and Coniferous classes were not significant, and were probably due to a mixing of the two categories at the boundaries (*fig. 12*). Such occurrences were more frequent in the Eleven Mile unit than in the Manitou unit. The errors between the Deciduous and Grassland classes were related to the Wet Meadow component of the Grassland class and the Deciduous class. Both these units were highly reflective and produced similar spectral responses in the ERTS-1 sensors at the time the scene was exposed (August 1973).

Series Level, Training Samples—Training sample classification was accurate for all classes for both the Manitou and Eleven Mile (*table 10*) units. To achieve this, however, some false Series classes had to be generated. For example, Ponderosa Pine did in fact include that Series class, but where foliage cover of ponderosa pine exceeded 70 percent, the class was forced into a "Mixed Conifer" category. The Mixed Conifer not only included high-foliage-cover ponderosa pine, but also Douglas-fir and some lodgepole pine. Apparent spectral responses of those units were so similar that they could not be separated in the ERTS-1 digital data analysis. Therefore, even on the basis of training sample classification, the ERTS-1 imagery used for this work and analyzed according to the procedures described is not suitable for classification to the Series level—the individual kind of forest or grassland.

This evaluation indicated how well the training classes were selected, and not necessarily the accuracy of the total classification. The total classification considered all areas within a set boundary of each unit and included the training areas used to establish the statistics for the total classification.

Region Level, Total Classification—Performance of the Manitou unit was acceptable for two categories, Grassland and Coniferous Forest (*table 11*). The Deciduous Forest and Water categories were not accurately classified. In the Water category, however, the area contained only one small water body (approx. 2 ha—5 acres). The Deciduous Forest was identified, but additional digital elements distributed throughout the area were incorrectly classified as Deciduous Forest. Most of these were associated with Grassland and Coniferous Forest class edges.

The Region classification evaluation of the Eleven Mile unit showed that only the Grassland and Water categories were classified with sufficient accuracy to be acceptable (*table 10*). The Deciduous Forest was confused with Grassland, primarily as a result of misclassification between the Deciduous Forest and the Wet Meadow component of the Grassland Region. The accuracy of the Coniferous Forest classification was only 66 percent, owing to the mixing of spectral response described earlier.

In general, classification to the Region level with ERTS-1 digital data is not accurate enough for operational use by itself. Ecotonal situations among Region classes resulted in serious misclassifications, especially between the Deciduous and Coniferous Forests. Also, frequent misclassification between the Deciduous Forest—here Aspen—and the Wet Meadow component of the Grasslands should be expected. It is possible that earlier (June) or later (September) imagery would improve classification of the Deciduous Forest system.

Series Level, Total Classification— Accuracy was sufficient to provide useful information only for the Shortgrass and Water classes (*table 11*) for the Eleven Mile unit. Accuracy for Mountain Bunchgrass (73.8 percent) for the Manitou unit approached the established standards, but it would be risky for the resource manager to base decisions on these results. The accuracy for Mountain Bunchgrass in the Eleven Mile unit was only 1 percent, perhaps because of the small sample size, only 136 points, used in the training statistics. As 66 percent of the computer-classified points of Mountain Bunchgrass in the Eleven Mile unit were verified by photointerpretation to be Shortgrass, the two Series classes are evidently not separable in ERTS-1 digital data, even though accuracy for Mountain Bunchgrass was fairly high in the Manitou unit, where there was no Shortgrass.

Classification at the Coniferous Forest Series level could not be evaluated accurately because of mixing in the training sample classification, described earlier.

Aspen was not classified with sufficient accuracy to provide usable information to the resource manager. This class was called Wet Meadow because the spectral responses of the two units were similar—as noted earlier in discussion of the Region level results. Aspen was also confused with various Coniferous Forests units, because an unknown threshold density of Aspen growing within the Coniferous Forest units resulted in a spectral signature that was closer to

Coniferous Forest than to "pure" Aspen.

The relationships of the computer-aided classification and ground-truth interpretation from aerial photographs provide insight for using the ERTS-1 digital data for this purpose (*fig. 17*). It should be noted that within those units classified as Ponderosa Pine (341.1) in the ground-truth map, there are varying amounts of tree density, as indicated by crown closure (foliar cover) of the trees. Also, the class occurs on slopes of varying steepness and aspect. The effect of slope aspect is especially apparent in relation to the position of Douglas-fir (341.2) to the terrain features. It occurs either on steep north slopes (the northwest quarter on the ground-truth map) or mixed with Ponderosa Pine (the west central area on the ground-truth map). Generally, the gradation between the two classes on the ground is quite sharp, but the tree crown density is very similar. Consequently, the chance of misclassification between the two classes is high.

Edge-effect errors can be observed in detailed examination of the computer map in *figure 17*. One source of edge-effect error was that a particular digi tal element of the ERTS-1 scanner often included the boundary between two vegetation classes. This effec is most noticeable around the black cloud shadow An anomalous Ponderosa Pine class classification oc curs at the edge of the shadow, when in fact there i no ponderosa pine in that area. Similar anomalies car be recognized in the white halos around the edges o the light blue areas—the white areas were coded tc clouds or snow, whereas no clouds or snow occurrec in the area. The effect was also very noticeable or close examination of the digital gray-scale classifica tion maps for evaluation of the Wet Meadow. In the Manitou unit, this class frequently occurs as narrow stringers of vegetation within the Forests (compute map, *fig. 17*). On the gray-scale map, Wet Meadow was misclassified because there was mixing of this and other classes in the scene, creating a spectral signature not related to any of the classes in the scene. Fo example, Wet Meadow was classified as Aspen where no aspen trees occurred.

It must be concluded that the resolution of

Table 11–*Accuracy of performance of computer-assisted analysis at the Series level, for training class and total evaluation, by vegetation class for two study units*

Unit and vegetation class	Training class performance		Total evaluation performance	
	Number of samples	Percent correct	Number of samples	Percent correct[1]
Manitou				
Mountain Bunchgrass	268	97.0	244	73.8
Wet Meadow	144	97.4	11	72.7
Aspen	78	98.7	21	23.8
Ponderosa Pine	333	91.9	930	38.4
Mixed Conifer[2]	874	95.4	294	44.9
Lodgepole Pine	87	100.0	17	29.4
Barren	60	98.3	–	–
Cloud	384	99.2	–	–
Cloud Shadow	340	93.5	–	–
Water	–	–	3	66.7
All classes	2538	96.5	1520	45.3
Eleven Mile				
Mountain Bunchgrass	136	91.9	183	0.5
Shortgrass	863	97.6	188	87.8
Wet Meadow	194	80.9	62	41.9
Aspen	173	97.7	94	51.1
Ponderosa Pine	672	99.3	369	66.9
Mixed Conifer	465	99.1	–	–
Barren	41	100.0	54	1.9
Water	1090	99.3	60	95.0
All classes	3634	97.5	1380	50.8

[1]Calculated as number correctly classified/total number of samples for each class.

[2]The Mixed Conifer class includes part of the Ponderosa Pine, all of the Douglas-fir, and part of the Lodgepole Pine classes.

Computer Map

Color	Class
Red	Wet Meadow
Light gold	Mtn. Bunchgrass
Dark gold	Mixed Conifer[1]
Light green	Lodgepole Pine
Dark green	Ponderosa Pine
Pink	Aspen
Blue	Barren
Black	Cloud Shadow
White	Cloud

[1] Includes Ponderosa Pine/Douglas-fir, Lodgepole Pine/Douglas-fir, and high-density (foliage cover) Ponderosa Pine

Ground Truth Map

Color	Class
315.1	Mtn. Bunchgrass
316.1	Wet Meadow
321.1	Willow Meadow
325.1	Mtn. Mahogany Shrub
319.1	Seeded Grassland
341.1	Ponderosa Pine
341.2	Douglas-fir
341.1 - 341.2	Ponderosa Pine/ Douglas-fir complex
341.3	Lodgepole Pine
342.1	Aspen
210.1	Ponds
520.1	Mtn. Home Development
520.2	Campgrounds

Figure 17–Series classification was attempted in the test of computer-assisted mapping of ERTS scene 1388-17134, August 1973. The ground truth map was made from aerial photography. Some features important to wildland management, the 520 units, are identifiable on the ground truth map but could not be found in the ERTS imagery.

ERTS-1 digital data is excessively coarse to provide the on-the-ground data required for management decisions, at least on the basis of results of the computer-assisted analysis provided. Ways to account for some of the error sources were examined in depth, however, for one class, Ponderosa Pine, within the Manitou unit, where the effects of slope steepness on apparent spectral responses were determined.

There was a significant relationship between spectral response and slope steepness. This response was evident in all four ERTS-1 channels for each of the three slope classes (*fig. 18*). In all channels, there was a linear trend of increasing spectral response with increasing slope steepness. The linear equations to describe these functions were determined to be as follows:

$$Y_4 = 20.16+1.38x$$
$$Y_5 = 16.39+1.79x$$
$$Y_6 = 24.62+1.87x$$
$$Y_7 = 12.77+1.26x$$

where Y_i represents the relative spectral radiance in band i as recorded by the ERTS-1 multispectral scanner, and x is the slope category.

Classification analysis for the selected Ponderosa Pine sets was accomplished using two methods to determine potential improvement in classification by accounting for slope steepness. First, a spectral signature derived from one of the low-slope units and the original computer training statistics for Ponderosa Pine was used. The analysis was then repeated by adjusting the mean spectral response of the original computer training statistics to the regression equations above. It is not entirely clear how the training statistics should be adjusted according to terrain changes in the imagery (Smith and Oliver 1974; Kreigler and Horwitz 1973). In this study, however, the average values for medium slope were used for all three slope classes.

Classification accuracies obtained for the different slope-class training fields, applying the original spectral signatures utilized in the initial Series classification task, are given in *table 12*. In general, the classification performance decreased and commission errors between the Coniferous Series classes increased as slope class increased. This trend is an indication, at least for Ponderosa Pine, that spectral signatures derived from one slope class will not extrapolate to all slope classes. After the means were adjusted according to the regression equations and using the values derived for the medium slope class, classification performance increased and commission errors decreased (*table 12*). It appears evident that in accounting for

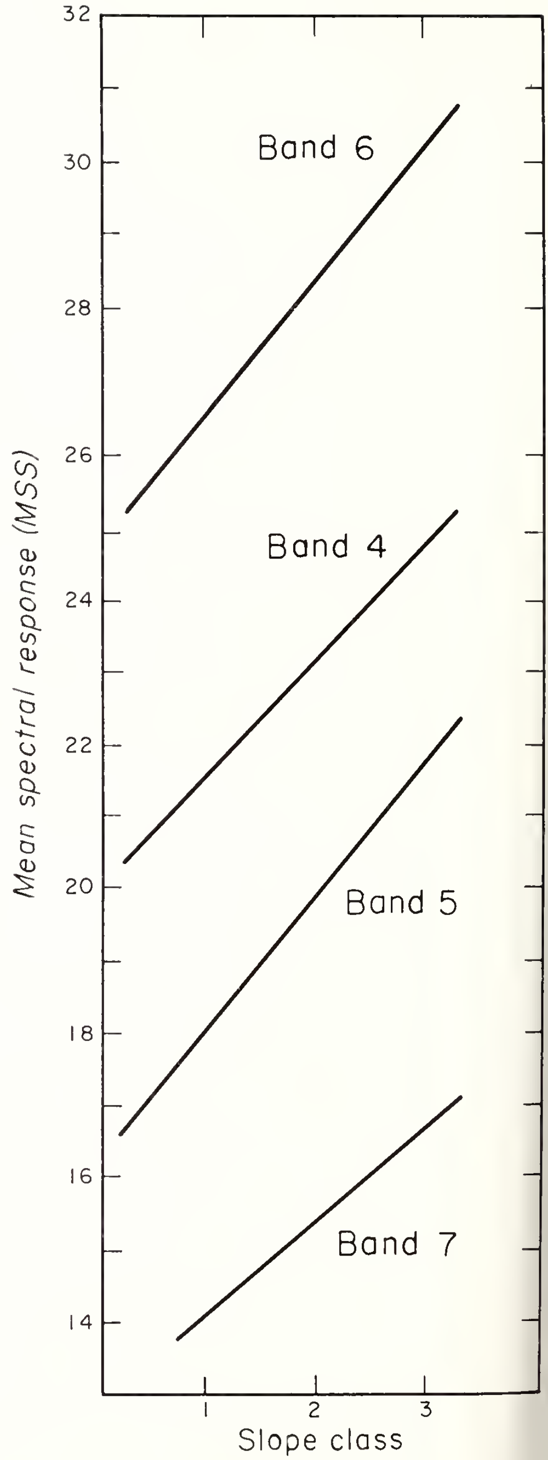


Figure 18—The mean spectral response for a Ponderosa Pine area is represented here by slope classes: 1 = 1-15 degrees, 2 = 15-30 degrees, 3 = 30 degrees. As slope steepness increases in relation to a fixed sun and sensor position, spectral response increases linearly.

Table 12–*Computer recognition of selected Ponderosa Pine sites for three slope classes, before and after signature adjustment*

Accuracy	Slope category		
	Low	Medium	High
Percent correct:			
Before adjustment	81	57	33
After adjustment	83	73	80
Commission errors:			
Douglas-fir			
Before adjustment	10	10	16
After adjustment	17	14	10
Lodgepole Pine			
Before adjustment		4	
After adjustment		3	
Spruce/Fir			
Before adjustment	7	16	14
After adjustment	0	2	2

terrain variances, corrections for both slope and aspect should improve classification accuracy. Intuitively, we can conclude that adjusting for variances in amount of live plane cover and other variables in the scene such as plant litter and kind and amount of bare soil exposed should improve classification. These concepts need to be studied in depth.

Applications

The applications of ERTS-1 multispectral scanner magery for rangeland classification are apparent from his research. Rangeland classification includes for-ested areas as well as grasslands and shrublands where rees are absent or rare. Existing maps of vegetation t the Region level, most of which are more than 10 ears old, are outdated, because of changing land-use atterns or catastrophic events since the original maps vere developed. Using satellite data, changes could be nonitored with a high degree of probable success, ased on the results achieved in classifying vegetation o the Region level by any of the three techniques sed in this study. For example, areas of forest land overing more than 1 hectare (2.5 acres) that have een devastated by fire, purposefully cleared for ur-an or rural land development, or logged for timber arvest, could be removed from or added to a re-urce base depending on requirements of the re-urce manager. Burned or logged would be inserted to a livestock grazing or wildlife habitat resource base, since the initial reaction of those areas to such treatment is increase in herbaceous or shrubby vegetation. These areas would revert to a timber base, once forest regeneration was established. Areas cleared for land development would be removed from all natural resource bases since sustained use for any of the resources is curtailed. Similar severe changes in grassland and shrubland communities classified to the Region level could also be monitored.

In the United States–South Park is an example–and elsewhere in the world there are places where vegetation has either not been mapped or mapped only cursorily. Large expanses of grassland can be mapped with ERTS-1 type data to a high degree of accuracy, and Series-level classes, such as Wet Meadows, can be delineated, provided the width of the high-contrast unit exceeds the width of the apparent ERTS-1 digital element by at least one digital element. Edge effects, vegetation shadows, and terrain shadows, however, prevent determinations of accurate area estimates when vegetation occurs in narrow strips, relative to ERTS-1 resolution.

ERTS-1 imagery is useful as a first level of stratification for multistage sampling of natural vegetation resources. In forested areas similar to those in the Manitou area, Region classes would be the minimum level in the ECOCLASS hierarchy that could be delineated unless concern were limited to the Aspen or Ponderosa Pine Series classes. These can be defined with an acceptable degree of accuracy.

Aerial photo scales of 1:20,000 are required for detailed mapping to the Series level; these large scales are needed to separate such conditions as variance in canopy cover of forest trees and kinds of Habitat Type in Grassland.

Photo scales of 1:2,000 and larger are required to evaluate Habitat Types, especially in Grassland, for plant cover. Our original experiment on classification and quantification of plant cover had no time replication. This experiment needs to be repeated for the same or similar areas using similar procedures to allow full evaluation of the experimental results. More experimental evidence is needed before the results can be applied in a fully operational program. In addition, continued research is needed to determine effects of terrain features, such as slope and aspect, and plant community characteristics, such as amounts of live vegetation cover, plant litter, and bare soil surface, on the apparent spectral response of specific targets as affected by sun elevation and azimuth.

FOREST STRESS DETECTION

Frederick P. Weber Edwin H. Roberts Thomas H. Waite

Ponderosa Pine Mortality from Mountain Pine Beetle

Stress detection in our Nation's wildlands and forests is a multiagency task, costing several million dollars each year in aerial and ground surveys. In the National Forest System, the stress comes primarily from insects or disease, and its impact is evaluated by a count of killed or damaged trees.

The purpose of the third phase of the ERTS testing program was to determine the potential usefulness of low-resolution satellite systems to detect and monitor forest stress. We felt that despite the rather poor spatial resolution indicated in the specifications for the multispectral scanner (MSS) subsystem, stress might be detected by spectral separation of the foliage discoloration resulting from tree damage. We also believed we might be able to detect change in the forest canopy by comparing imagery from successive 18-day cycles of the satellite. Therefore, we established the null hypothesis that the ERTS MSS data could not be used to detect stress in forests, and then attempted to disprove it. As a site for the investigation, we chose the Black Hills, where a 7-year cooperative effort in detection of damage by the mountain pine beetle had been carried on.

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is a threat to ponderosa pine (*Pinus ponderosa* Laws.) throughout the central Rocky Mountain region, and the Black Hills in particular. Aircraft have been used since the mid-1920's to detect and appraise damage caused by the mountain pine beetle. The first remote sensing research to improve aerial detection and appraisal of mountain pine beetle damage in the Black Hills was established in 1952 (Heller and others 1959). After an epidemic outbreak of the mountain pine beetle in the northern Black Hills in 1963-64, the Forest Service Remote Sensing Research Work Unit took aerial color photographs at a scale of 1:7920 over the northern Black Hills. The resulting high-resolution color transparencies were used to train forest resource managers to locate infestation spots and to count dead trees. In 1965 a formal agreement between NASA and the Department of Agriculture launched the Remote Sensing Research Work Unit on 7 years of stress detection research. This work provided invaluable experience in the requirements for insect damage detection. Detailed studies established guidelines for aerial photography and also sorted out complex physiological and environmental relationships affecting interpretation of multispectral data (Weber 1969, 1972; Weber and others 1973).

Study Area

The Black Hills test site (*fig. 19*) is an area o 10,200 km² (3938 sq miles) in western South Dakota and eastern Wyoming. The focus of the site is an elliptical dome extending over 0.75 million ha (1.85 million acres). The most important tree species, providing more than 95 percent of the total commercial sawtimber volume, is ponderosa pine. Geologically the Black Hills National Forest portion of the test site is an exposed crystalline core surrounded by sedimentary formations. The central formation, at an elevation between 1200 and 1700 meters (4000 and 560 ft), is highly dissected, with large areas of expose soil and surface rock. Surrounding the central cor are sedimentary formations of Paleozoic limestone. The topography here is gently rolling, especially i the northwestern Black Hills, where the limestor forms a plateau generally above 1800 meters (590 ft). The eastern part of the Black Hills contains th same formations but generally at lower elevation. The radial-dendritic drainage pattern of the perm nent east-flowing streams in this area is strongly ev dent on satellite imagery. Immediately outside th ponderosa pine zone, which surrounds the Bla Hills, is a circular valley formed from reddish Trias and Permian soft shale and sandstone. The "red v ley," as it is called locally, is highly visible on son ERTS-1 imagery.

The intensive investigation area shown in *figure* covers 653 km² (252 sq miles) surrounding the go mining town of Lead, South Dakota. Two ov lapping study blocks contain three smaller sub-bloc The Lead block, 41,293 ha (102,036 acres), inclu sub-block 2 and the eastern side of sub-blocks 1 a 3. The Lead block contains many moderate- a small-sized mountain pine beetle infestations an important as a transition area where little beetle ac ity is noticeable during endemic conditions. This a

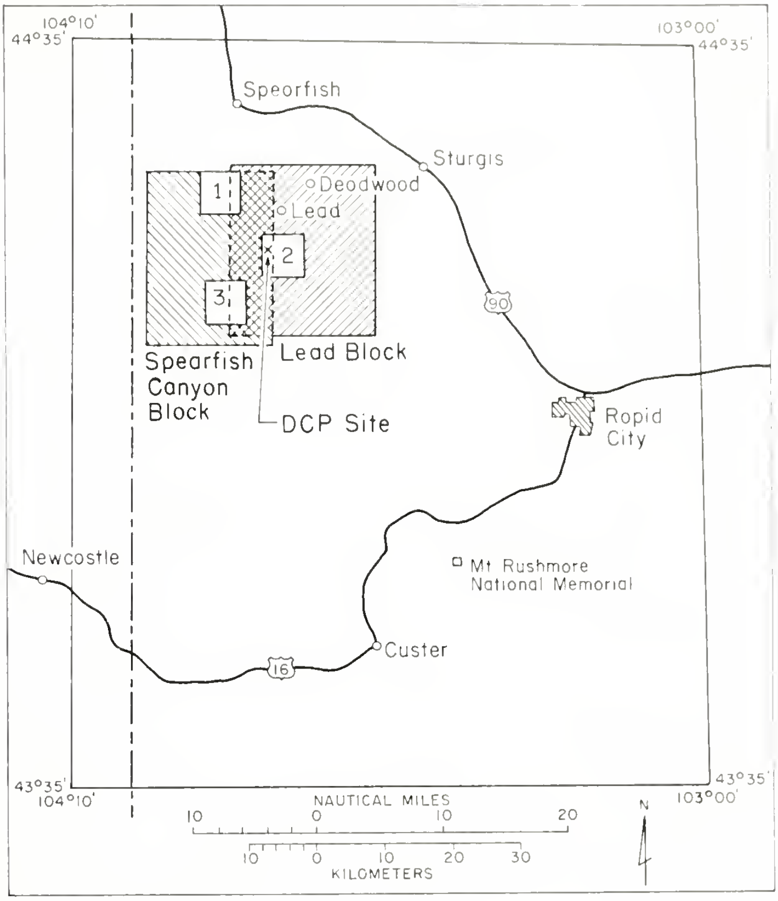


Figure 19–The Black Hills National Forest test site is composed of two study sites, the Lead block and the Spearfish Canyon block. Within the blocks are three sub-blocks used as intensive study sites. Instrumentation for radiance data collection was located in sub-block 2 (DCP).

is first affected, however, during an expanding bark beetle population and thus is a good barometer area for an impending epidemic outbreak. Sub-block 2 is a representative area within the Lead block. The Spearfish Canyon block, 35,648 ha (88,087 acres), is on the west side of the intensive study area. Traditionally it contains a full spectrum of mountain pine beetle activity. Here it is common to have high beetle populations, with large volumes of timber killed on the north side of the area; on the southwest side little residual beetle activity occurs, and mortality problems are sporadic–showing up only during a widespread epidemic. Sub-block 3 to the south is representative of the latter condition. Sub-block 1, by contrast, has been an area of perpetual activity for the last 12 years, and contains the critical mass of the bark beetle population. Beetle populations have remained constantly high in the area and it is apparently a source of beetles which aggravate the control problem in two surrounding National Forest management areas. Sub-block 1 contains the largest infestations, which we hoped to detect and map on ERTS-1 imagery.

Classification System

Interpretation of all Black Hills test site imagery, both in viewing color composites and in analyzing computer classification maps, is based on the hierarchical classification of Black Hills ecosystem cover types. Early in the 7-year remote sensing program we attempted to use an existing classification of the Black Hills ecosystem into 13 habitat units.[4] Although it is very thorough and is especially useful for classifying wildlife habitat, it is not well suited for interpretation of aircraft or satellite imagery. The classification hierarchy shown in *table 13* was devised specifically for such use, and covers the entire Black Hills test site. At Levels II and III, it differs from the classification systems used in the forest and range inventory studies described earlier in this report. A selected grouping of nine cover-type classes, those underscored in *table 13,* was used as a basis for mapping the three sub-blocks in these tests.

[4] Personal communication, John F. Thilenius, Rocky Mountain Forest and Range Exp. Stn.

Table 13—*Black Hills National Forest classification hierarchy for remote sensing imagery*[1]

I Forest
- II Conifer
  - III Dead ponderosa pine
    - Pine, healthy, <50% crown closure
    - Pine, healthy, >50% crown closure
    - Spruce
- II Deciduous[2]
  - III Pure hardwood
    - Predominantly hardwood

I Nonforest
- II Grassland[2]
  - III Wet pasture, on water course
    - Dry pasture, well drained
- II Bare Soil[3]
  - III Rock outcrop
    - Gravel quarry
    - Mine tailings
- II Transition
  - III Logging clearcut
    - Burn area
    - Soil, rock, sparse vegetation
    - Infestation area
    - Other disturbance
- II Urban
  - III Town
    - Isolated building(s)
    - Utilities
    - Improved highway
    - Forest road

I Water
- II Water
  - III Lakes and ponds
    - Reservoir
    - Streams and creeks

[1]Classes used in computer-assisted mapping are underscored.
[2]Included rock outcrop for computer mapping.

Table 14—*Classification of infestation by average spot size (longest dimension)*

Infestation class (meters)	Average number of trees
Less than 10	1 to 3
10 to 25	4 to 10
26 to 50	11 to 20
51 to 100	21 to 50
101 to 300	51 to 100
More than 300	100+

A classification of infestations by size was also set up. Before the ERTS experiment in the Black Hills began, the Remote Sensing Research Work Unit had classified infestations into strata based on the number of trees identified in an infestation spot on aerial photographs. For microscale photography and satellite imagery, spot size in meters was a more useful measure (*table 14*). In the sub-blocks, only those spots greater than 50 meters (165 ft) in the longest dimension were typed.

ERTS Data

The difficulties of obtaining cloud-free ERTS imagery for dates suitable to the test objectives limited our scope in this study. We were obliged to use a scene for August 20, 1972 (scene 1028-17121) covering the Lead block (*fig. 20*) and one for September 8, 1972 (scene 1047-17175) covering the Spearfish Canyon block (*fig. 21*). Ideally, one scene covering the entire study area at two dates—August or September

Table 15—*Tree mortality caused by mountain pine beetle for the years 1972 and 1973, sub-blocks 1, 2, and 3*[1]

Infestation size class (meters)	Total number dead trees					
	Sub-block 1		Sub-block 2		Sub-block 3	
	1972	1973	1972	1973	1972	1973
Less than 10	–	148	–	276	–	218
10 to 25	2702	2653	2552	6811	1583	3682
26 to 50	1198	1207	252	3060	81	1003
51 to 100	1079	435	–	870	–	609
101 to 300	715	845	–	325	–	110
More than 300	–	1050	–	–	–	–
Total	5694	6338	2804	11342	1664	5622
Ratio, 1972/73	1.11/1		4.04/1		3.38/1	

[1]Area of sub-block 1: 3949.2 ha (9758.6 acres), 2: 4142.0 ha (10,235.1 acres), 3: 4087.5 ha (10,100.4 acres).

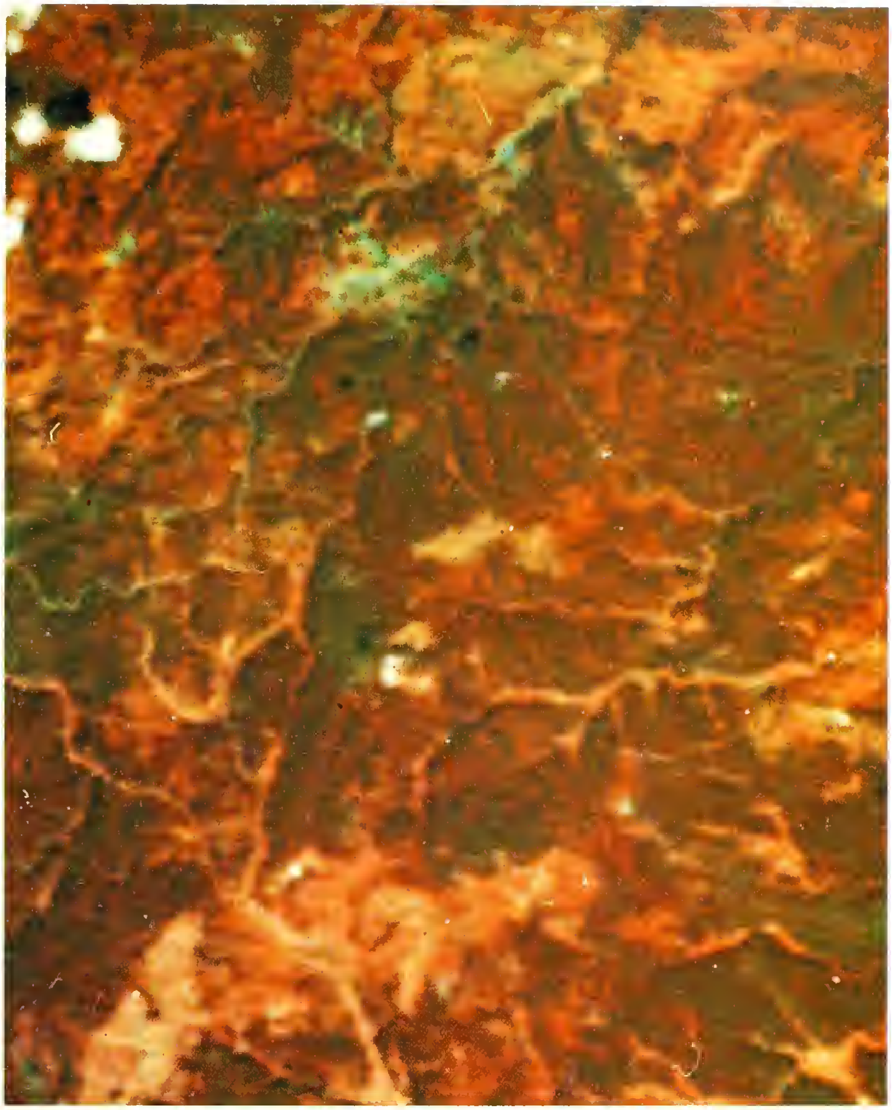


Figure 20–The color composite for scene 1028-17121, August 20, 1972, covers the Lead block of the Black Hills test site. Scale is 1:160,000.

1972 and 1973–should have been used to allow change detection as a feature of the interpretation. No clear-weather images were obtained in August or September 1973, however. The best single scene received of the entire Black Hills test site was taken on June 22, 1973, but June is the worst possible time to detect stress from beetle attack in the Black Hills. Old kills have lost most of their discolored foliage by June and those from the preceding summer have just started visible fading.

By the nature of the plan by which ERTS data is supplied, we did not know until late in 1973 that no comparison would be possible on the ERTS scenes. Hence, our ground truth studies were made in both 1972 and 1973.

Ground Truth

The trend and spread of the mountain pine beetle in the northern Black Hills was monitored for research purposes with 1:32,000 scale color infrared (CIR) aerial photography taken the end of August or early September 1972 and 1973 by the Remote Sensing Research Work Unit. Other yearly surveys are conducted by the Forest Service, Rocky Mountain Region. These generally provide estimates of beetle damage for the entire Black Hills National Forest.[5]

Tree mortality counts within the three sub-blocks

[5] Cahill, Donn B. Information on file, U.S. Forest Service, Rocky Mountain Region, Division of Timber Management.

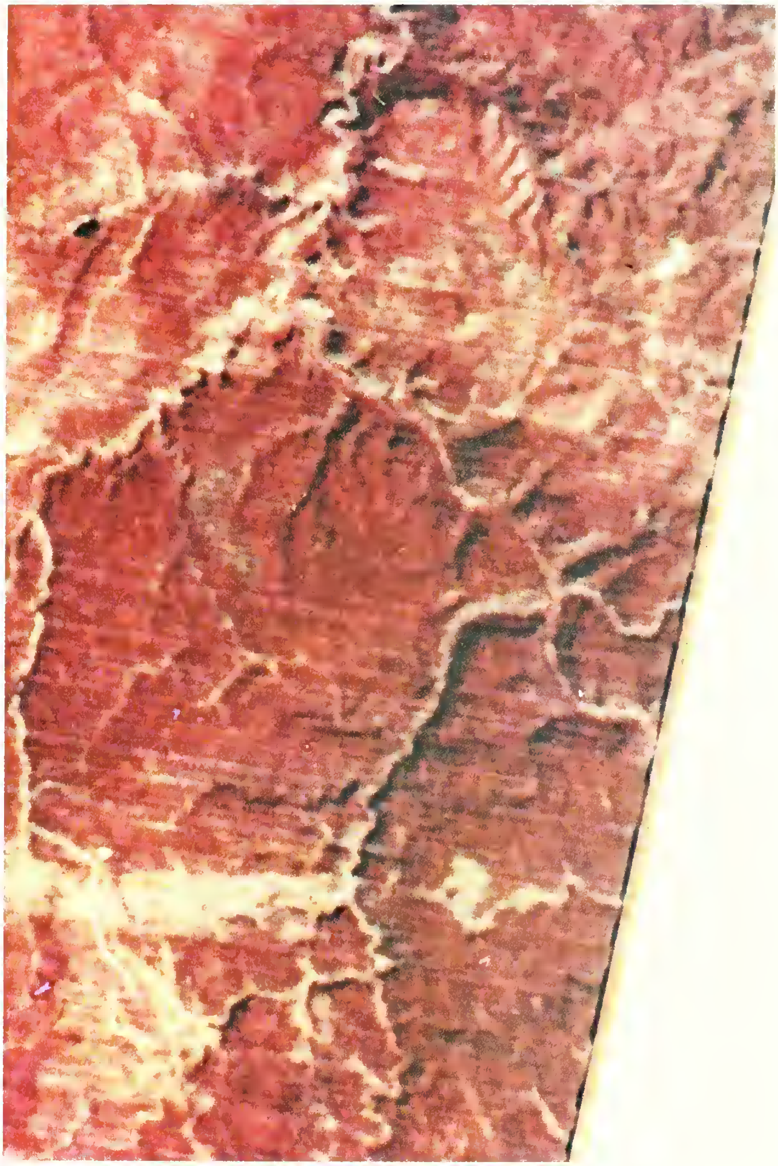


Figure 21–The color composite for scene 1047-17175, September 8, 1972, covers the Spearfish Canyon block of the Black Hills test site. The null area wedge of the scene occupies 18 percent of the block. It was not considered in the computer-assisted analysis. Scale is 1:160,000.

for 1972 and 1973 are shown in *table 15.* These data encompass the period of the ERTS-1 experiment, but only the 1972 mortality could be used in the ERTS data test, because cloud-free ERTS scenes proved unavailable for 1973. Trees which faded during the summer of 1972 were counted on the CIR resource photography taken in early September of that year. These trees had been attacked by the bark beetles the previous summer. Mortality counted for 1973 is therefore the result of infestation during July and August of 1972.

An expanding epidemic is evident in a comparison of the totals in *table 15.* Whereas sub-block 1 had high mortality counts for both 1972 and 1973, a threefold to fourfold increase in mortality is seen in sub-blocks 2 and 3 from 1972 to 1973. The mortality counts in sub-block 2 for 1973 are conservative–many faded trees were removed by salvage logging during July and August 1973, before the photograph were taken.[6]

Infestations varied greatly between sub-blocks (*fig 22*). In sub-block 1, in 1972, there was aggregation c smaller prior infestations into several very large infe

[6] A detailed report, *Ponderosa Pine Mortality from Mounta Pine Beetle: Photointerpretation Prediction Model* by Thor as H. Waite is available on request to Director, Pacific Sout west Forest and Range Experiment Station, P.O. Box 24 Berkeley, California 94701.

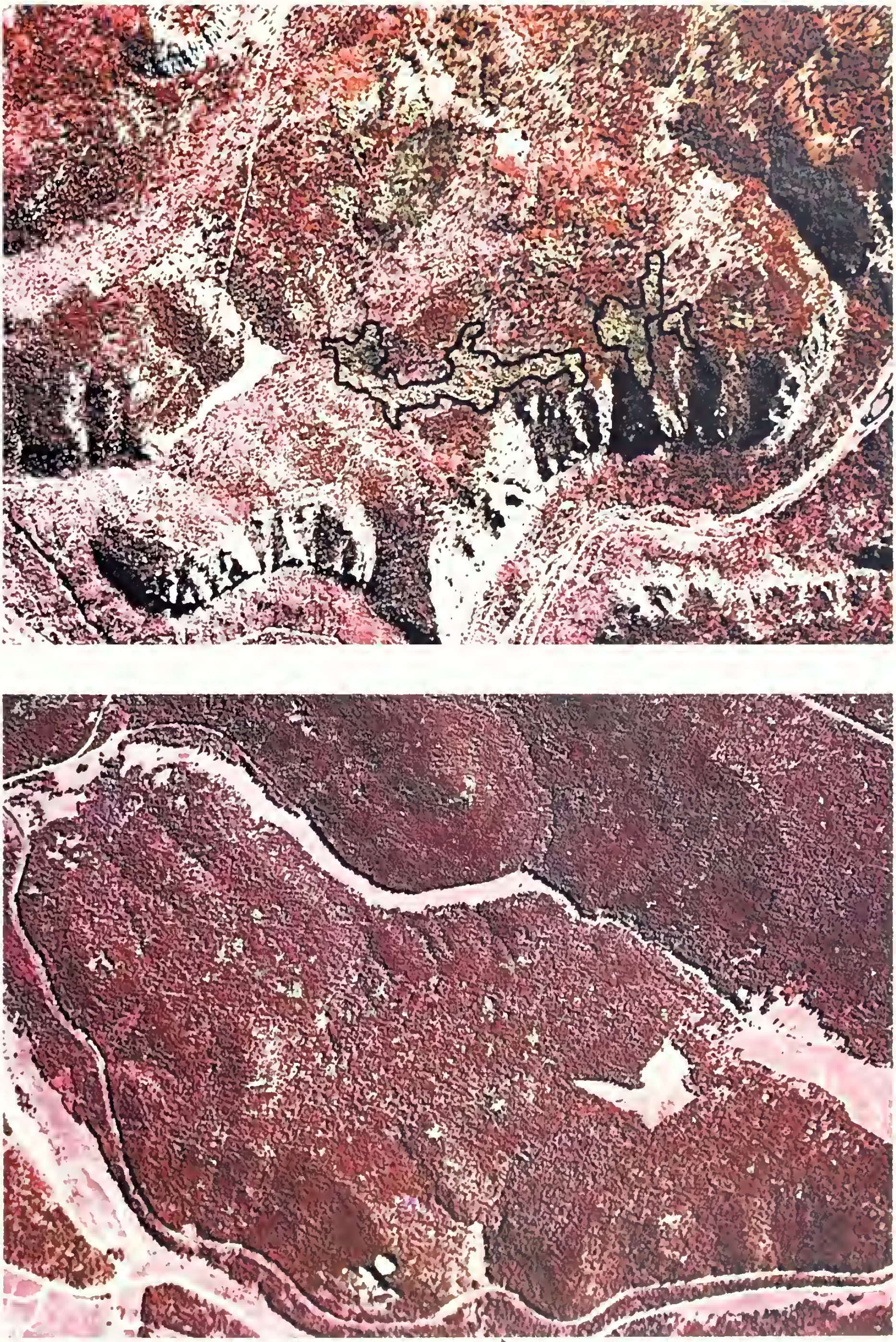


Figure 22—Infestation spots on the two intensive study sites were identified on September 1972 color infrared aerial photographs, scale 1:32,000. Sub-block 1 contained 14 infestation spots greater than 50 m in the longest dimension. Two of the largest spots were in the southwest corner of the sub-block (*top*). Sub-block 2 contained 56 identifiable spots, most of them less than 50 m long. Some of these are shown in the photo (*bottom*) of the southwest corner of the block. The 1973 photography showed aggregation of many of these small spots into infestations more than 50 m long.

Figure 23—A cover type map was drawn for sub-block 2 from 1:32,000 color infrared resource photographs taken September 8, 1972. Scale is 1:70,000.

tation centers. By contrast, most of the numerous infestation spots in sub-block 2 were less than 50 m (165 ft) in size in 1972. With an expanding epidemic of the mountain pine beetle in the area of sub-block 2, the 1973 resource photographs revealed considerable aggregation of the smaller spots, so that many infestations over 50 m were created (*table 15*).

From the CIR photography for 1972, sample points representing each of the nine cover-type classes shown in *table 13* were selected from the entire test site for the ERTS photointerpretation test. Sample point choice was based on the availability of the area for ground check, distribution of the samples throughout the study area, and distinctiveness of the sample point with respect to the surrounding landscape. A map was prepared in the form of an acetate overlay showing the sample points as microdots.

For use as a basis for evaluation of the computer-assisted mapping, a type map (*fig. 23*) was drawn using the nine cover type classes (*table 13*). The type maps for the three sub-blocks were first drawn on acetate overlays using the 1:32,000-scale CIR resource photographs. Distortions in the original type map were rectified by superimposing a 1:110,000-scale color infrared transparency, taken by NASA o September 14, 1972, onto the first type map, usin the Zoom Transfer Scope. The final type map thu had good geometric fidelity and positional accuracy.

Radiance Data Collection

An important part of the Black Hills study was attempt to monitor information as received by ERT through data transmission from the ground to t satellite. These experiments are briefly described he

Procedures

A ground-based data-collection system was stalled within sub-block 2 (*fig. 19*) in the northe part of the Black Hills. Four subsites, one each healthy ponderosa pine, dead pine, pasture grass, rock outcrop, were selected within range of th ERTS data collection platforms (DCP's). Each D included a transmitter and antenna to transmit physical and environmental measurements directly the ERTS satellite when it was within receiving ra of the test site. Under the control of NASA, data

Figure 24—Instruments and equipment for the data collection experiments were set up at four sites within sub-block 2. Shown at the top of the tower (*left*) are the data collection platform (DCP), antenna, incident-energy spectrometer, multiplexer, and light-activated switch. At the end of the 4-m boom arm is the reflected-energy spectrometer. Alkaline battery power packs are at the base of the tower. The interior of a field spectrometer is shown at *right*.

etransmitted from the satellite to a ground station. The nature and scope of this paper does not permit a engthy discussion of the instrumentation used at the ite; however, it is sufficient to say that the entire ystem allowed collecting continuous data from 24 eparate instruments at each of the DCP's.

The most important biophysical and environ-nental measurement in terms of ERTS data analysis vas absolute target reflectance or scene radiance. To neasure scene radiance, five spectrometers (*fig. 24*) vere built as reported by Weber, 1973. The spec-rometers operated in four spectral bands matching ne ERTS-1 multispectral scanner subsystem. One of nese units was set up to monitor radiance reflected om healthy pine. These data are discussed here. The emaining spectrometers were set up to monitor dead ine, pasture grass, rock outcrop, and irradiance in-dent on the scene. These data were either extremely riable or were irrelevant to the discussion that fol-ws and will not be considered further in this paper.

The configuration for a data collection system perating independently at one subsite is shown in *gure 24.* A DCP and antenna are located at the top the tower along with a spectrometer and light tivated switch which limited data collection and ansmission to daylight hours. Because there were ly three transmitters to handle five subsites, data om pasture, rock outcrop, and incident-energy spec-ometers were multiplexed through one DCP. Data from all the spectrometers were relayed via the NASA Data Processing Facility (NDPF) at Greenbelt, Maryland and then to Berkeley.

One question that this experiment was required to answer was, "What effect does the earth's atmosphere have on radiance measured by the ERTS MSS?" Since, in this experiment the field spectrometers were mounted just above the trees, radiance reflected from the forest and measured by these spectrometers is not affected by the intervening atmosphere. Thus, a comparison of the radiance measurements from the field spectrometers and from the ERTS-1 multispectral scanners should show the effects of atmosphere on radiance transmissions.

To compare the radiance data from ground spectrometers with radiance data from orbital altitude, it was necessary to locate uniform targets that could be found on the ERTS CCT's. For this we felt that healthy pine forest with a closed canopy was the most homogeneous of all the target types used in the experiment. Thus, with the aid of aerial photographs and computer display of the data, the sample areas were selected from the CCT's for scene 1028-17121, August 1972. The mean and standard deviation of the count values for nine data points from each of three sample areas were calculated for each MSS channel (*table 16*). These means were pooled and converted to radiance values (*table 17*) so that these could be compared to radiance data collected on the ground.

Table 16–*Multispectral scanner mean count values*[1] *for closed-canopy pine type taken from computer-compatible tape printouts of ERTS-1 image 1028-17121, August 1972*

Sample no.	MSS 4		MSS 5		MSS 6		MSS 7	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	16.9	0.8	11.2	1.1	23.7	1.4	13.4	1.0
2	16.3	.5	11.3	.5	24.8	1.0	13.9	.9
3	17.1	.3	11.2	.7	24.1	2.1	13.4	1.7

[1]Means and standard deviations derived from nine data points for each sample.

The ground radiance data was collected for four clear days as closely representative as possible of the dates when the ERTS data was collected, and at the same time of day.

Results and Discussion

When the radiance values for pine forest from ERTS-1 data are compared with radiance values for healthy pine measured just above tree tops (*table 18*), some effects of the atmosphere become apparent. For MSS channel 4 there is a 50 percent increase in the radiance when measured from ERTS-1 as compared to the ground. This is probably the result of back-scattered solar irradiance and scattering into the view path of radiance from other parts of the scene. At the longer spectral wavelengths of MSS channel 5, the scattering is less, as indicated by a 30 percent increase when ERTS-1 measured radiance is compared with ground-measured radiance. The relatively low ground radiance values in spectral bands MSS 4 and MSS 5 made any radiance scattered into the view path more significant in terms of percent increase.

By contrast, spectral bands MSS 6 and MSS 7 have reduced radiance at orbital altitudes as compared with ground measurements. A 17 percent reduction i revealed for MSS 6 and a 20 percent reduction fc channel MSS 7. At the longer wavelengths of thes spectral bands, scattering is not an important facto so there is little stray radiance to be added to th view path. Absorption by the intervening atmospher becomes the dominant factor operating on the rad ance as measured from ERTS-1.

For a feature such as closed-canopy pine forest the effect of atmosphere on radiance measuremen from ERTS is to increase the apparent radiance i bands MSS 4 and MSS 5 and to decrease the apparen radiance of the feature in bands MSS 6 and MSS 7.

A number of unanticipated problems arose durin this experiment, some of which could be resolved an some that could not. Since the measurement of bic physical and environmental conditions is importan to successful evaluation of multispectral data, som of these problems should be mentioned for considera tion in planning future research.

Most important is the calibration of field spec trometers. Unless calibrations are checked periodi cally during the course of an experiment, there can b errors in the data that cannot be corrected. Fo instance, the spectrometer units used in this experi ment were calibrated September 1, 1973 before bein placed in the field. The calibration was checked agai in April, 1974 after the instruments were returne from the field. For several of the individual channels the system calibration had changed very significantl (*table 19*) and makes the spectral data suspect if nc collected close to calibration. Since the data used i the radiance comparisons in this paper were collecte close to the calibration date, these data are assume to be correct. Because of the lack of baseline data (many of the components, it is not possible to dete

Table 17–*Radiance reflected from healthy pine as measured by ground spectrometer*[1] *for four clear days in September 1973 at the time of day when the ERTS-1 scene used in this study was imaged.*

Date	Radiance[1]			
	MSS 4	MSS 5	MSS 6	MSS 7
	mw/cm²-sr			
Sept. 18	0.2195	0.1200	0.3888	1.1935
Sept. 22	.2195	.1321	.4206	1.2722
Sept. 27	.2195	.1276	.4111	1.2128
Sept. 29	.2151	.1350	.4206	1.2474
Mean	.2184	.1287	.4103	1.2315

[1]Radiance shown for each day is an average of five to nine separate measurements.

Table 18–*Comparison of radiance values from ERTS tapes for scene 1028-17121, August 1972, and radiance values collected on the ground 1 year later (September 1973)*

MSS Band	Mean radiance		Difference	
	ERTS[1]	Ground		
	mw/cm²– sr [2]			*Percent*
4	0.33	0.22	+0.11	+50
5	0.18	.13	+.05	+38
6	0.34	.41	−.07	−17
7	0.99	1.23	−.24	−20

[1]Count averages in Table 16 were converted to radiance values.

[2]Milliwatts per square centimeter of source area per steradians of unit solid angle.

Table 19–*Relative response of the ground-based spectrometers for each scanner (MSS) channel, determined by calibration before placement in field use and after return from field use*

Spectrometer	Relative response			
	MSS 4	MSS 5	MSS 6	MSS 7
RS-2M-1				
Before	0.89	1.88	2.04	1.69
After	0.93	2.16	2.66	2.13
RS-2M-2				
Before	0.88	1.79	2.16	1.75
After	1.59	4.13	1.79	1.82
RS-2M-5				
Before	0.56	0.38	0.43	0.31
After	0.12	0.16	0.20	0.12

mine in each case the cause of the change in system response. However, it appears that much of the change can be traced to deterioration of the spectral bandpass filters. These filters, made of sandwiched combinations of interference and absorption filters, were not adequately edge-sealed by the manufacturer to withstand the field environment.

Another problem that cannot be resolved with the instrumentation used in this experiment is the effect of target size. In most instances, the ground spectrometers were located above single trees or small targets representing various condition classes. On the other hand, the satellite imagery data points integrate approximately one acre. Variation in radiance within one acre can be considerable in some classes and the integration of radiance values may not represent the same small target integrated by the ground spectrometer. In the closed-canopy pine type the variation within an acre may be minimized and this is why we chose to use this type for our evaluation of ERTS radiance values.

Despite the problems, we derived useful radiance data from the study. In future work with satellite data, adjustments can be made for errors in satellite radiance values when the radiance levels on the computer-compatible tapes are analyzed. By this means, information can be gained leading to improvements in computer-assisted classification of land use.

Photointerpretation Procedures

Three visual interpretation methods were used to analyze the ERTS-1 imagery. In the first, the interpreter classified the cover types on both the color composites and the black-and-white single-channel images (scale 1:1,000,000). For the second, the interpreter used only the bulk color composites to detect disturbances. For the third approach, a team of foresters from the Black Hills National Forest viewed color composites projected on a wall screen, and identified both disturbances and ecological site classes.

In the first approach, an interpreter viewed the transparencies with a Bausch and Lomb Zoom 70 microscope mounted on a Richards light table. A viewing scale of 1:83,000 (determined as the optimum obtainable with all instruments) was achieved by means of 10X eyepieces and a 1.2:1 zoom ratio. The interpreter identified the cover type classes at sample points indicated on the acetate overlay previously prepared from aerial photography. Neither of the two ERTS scenes used for the test covered the entire test site free of clouds. If a sample area was not covered on the ERTS imagery or was obscured by clouds, it was not considered in the analysis of interpretation results.

In a second viewing, the interpreter used a Variscan rear-projection viewer, scanning the image at a magnification ratio of 3:1 or 1:333,000-scale. As each sample point was identified, the magnification ratio was changed to 12:1 to give the scale of 1:83,000.

For the second interpretation approach, the interpreter was joined by two district rangers. Using the Zoom 70 as described above, they scanned the color composites and identified any type of disturbance within the test site, including bark beetle infestations, classifying it at Level III within the Level II Transition class (*table 13*). The interpreters relied mainly on deduction in classifying disturbances, although some identifications were probably made on the basis of knowledge of the existence of disturbed areas.

For the third approach, perhaps the most productive, a team was made up of two Forest Service researchers who are working in the Black Hills, two members of the Black Hills National Forest planning team, and the author-interpreter. The ERTS image was projected on a screen with an overhead projector at a viewing scale of 1:83,000. (A rear-projection viewer with a large screen, such as the Variscan, could also be used.) The team was instructed to first identify the cover type sample points and then proceed with a full interpretation of the scene. The only restrictions were that interpretation be limited to the Black Hills National Forest and that the classification system (*table 13*) be used. All disagreements in classification among the members of the team were resolved by reference to the 1:32,000- and 1:110,000-scale resource photography.

Computer-Assisted Mapping Procedures

Although mountain pine beetle infestation spots were small in relation to the resolution of the ERTS multispectral scanner, we hoped to achieve a measure of success in mapping dead and dying pine trees through analysis of the computer-compatible tapes (CCT's). Statistical analysis of spectral characteristics can often yield results unavailable to an interpreter through image viewing alone.

To analyze the two ERTS scenes we had available (late August and early September 1972) we used two different computer classification systems—one devised by the PSW group and the other devised by our contractor, LARS. The two groups worked independently toward the same goals, and their results were compared for accuracy of classification and for the utility of the resulting maps.

General but nonrestrictive guidelines were offered to both groups. The minimum classification suggested for the Black Hills was the selected nine classes shown in *table 13*, but PSW and LARS were encouraged to attempt application of the full hierarchy while maintaining accuracy. A uniform color display of 1:32,000 scale was suggested; the actual scale used was 1:24,000.

The computer-assisted classification and mapping capability developed by PSW and LARS is described elsewhere in this report (see p. 16 and Appendix 2). Adaptations were made for classification of the Black Hills ERTS-1 scenes. The computer training materials provided were detailed type maps of the three sub-blocks. Computer coordinates for the corners of the blocks and the sub-blocks were also provided. The classification system developed on the sub-blocks was tested on the two large blocks—Lead and Spearfish Canyon.

Computer-assisted classification results for the Black Hills test site were evaluated by means of a grid system overlay based on computer-coordinate intersections (see page 17). The starting point for the grid was critical: it had to be a location that could be pinpointed for both blocks and on computer displays for both LARS and PSW. A suitable starting point for each block was found, and the grid intersections were laid out at intervals of six rows and six columns of pixels. The intent was to create a cell, or matrix, of 9 pixels, focused at each grid intersection, and surrounded by a buffer zone, 1 pixel wide, to allow for positional inaccuracies of the ERTS-1 data. As constructed, the grid with the 9-pixel cells permitted a possible 25 percent sample for performance evaluation of the entire block. Cells were selected for th evaluation only if they were determined to occupy a area of pure cover type. To make this determinatior a carefully scaled reproduction of the computer gri was placed over the 1:110,000-scale color infrare resource transparencies. The cover type of each of th 17,000+ cells was determined on the photograph and those cells of pure cover type were selected. Th cell classification determined from the photograph was compared with the classification for the sam cells on the LARS and PSW outputs. A cell wa considered correctly classified if five or more pixel were correct. The cell was called incorrect if five o more elements were placed in a single but incorrec cover type class. The cell was called mixed and in correct if there was no majority classification o pixels within the cell.

Results and Discussion

Photointerpretation

Quantitatively, there were only minor difference in the interpretation results between ERTS black-and white transparencies and the color composite tran parencies. Interpretative method and viewing instru ment did not noticeably affect results. The significar difference was that the bulk color composite tran parencies could be interpreted more quickly. The took up only 20 percent of the time needed for th four individual black-and-white transparencies for th same scene. The expectation in using the black-and white transparencies had been that their better resol tion of the individual images might allow better de tection, and that mountain pine beetle infestatio might be detectable on the red band image, where they might be masked in the color composite. Infes tions were not detected, however, regardless of ima product or method of interpretation. For examp sub-block 1 contained several infestations over 3 meters (984 ft) in longest dimension (*fig. 22*) wh were never detected on ERTS imagery.

In the first of the three interpretative approach interpreters classified cover types. The classificat results using both the Zoom 70 microscope and Variscan viewer were the same—41 correct out of sites for a total of 65 percent. All sample areas three of the nine cover types—Wet Pasture, Bare S and Water—were interpreted correctly. Poorest res were in the classification of Hardwood and Dry ture, which were correctly identified only 20 perc of the time. Each time a Hardwood or Dry Pas site was classified incorrectly, it was called Wet ture. Although Conifer sites were identified corre

100 percent of the time at Level II in the hierarchical system, attempts at separation based on stand density (Level III) introduced 50 percent commission errors. That is, half of the total Pine sites were placed in the wrong density class.

Based on these results, one could expect to do a near-perfect job of classifying the Black Hills cover types on ERTS-1 color composites if stratification is limited to 5 classes: Conifer, Grassland (including Deciduous Vegetation), Bare Soil and Rock, Water, and Transition. The Variscan rear-projection viewer was preferred by the interpreters over the Zoom 70 microscope, although the results were the same.

In the second approach, detection of disturbances was attempted. A total of 30 major disturbances were identified and their boundaries delineated by the three interpreters, independently. The interpretive expertise of the two district rangers was evident in their ability to identify the cause of the disturbance without reference to management records.

The 30 disturbances clearly visible on ERTS imagery and delineated by three separate interpreters were as follows: (1) fires, 18; (2) logging, 3; (3) tornado damage, 3; and (4) disturbance from multiple causes, 6. Unexpectedly, the interpreters clearly delineated timber sale boundaries of active logging areas. These areas were not clearcuts, but pine stands thinned from about 21.8 m^2 (235 sq ft) of basal area to about 7.4 m^2 (80 sq ft). The thinned areas had a distinct bluish gray tone (high response on MSS channel 4) on the ERTS color composites. This level of interpretation might occur if the interpreters are experienced in the area, but it is doubtful that others would consistently identify active logging areas (other than clearcut areas).

Records showed that three of the disturbances correctly identified as caused by fire had occurred before 1900. (The oldest fire boundary, clearly identified on ERTS-1 scene 1028-17121, was the Polo fire which occurred on the Nemo District in 1890.)

In the team approach to interpretation, we discovered that the definition lost in the image display by an overhead projector was more than compensated for by the team interaction.

At Level II, the team correctly interpreted Conifer Forest, Grassland, Bare Soil, and Water 100 percent of the time. Transition and Urban classes were interpreted correctly 83 and 50 percent of the time, respectively, whereas only 20 percent of the Deciduous Forest sample areas were correctly identified.

It was difficult to rate the team results at other levels, but team members were confident that most of the Level III units in the classification hierarchy could be identified throughout the forest. A notable exception was deciduous vegetation, although on-the-ground experience of one or more of the interpreters usually resulted in an accurate classification. The interpreters felt that results would have been better if a winter scene had been available for viewing with the summer images.

There were obvious benefits in the multidisciplinary representation in the team. For example, a forester and a geologist working together decided that deciduous vegetation in an old burn area coincided very well with boundaries of a particular soil type. The balance of the burn had revegetated to ponderosa pine over a different soil type.

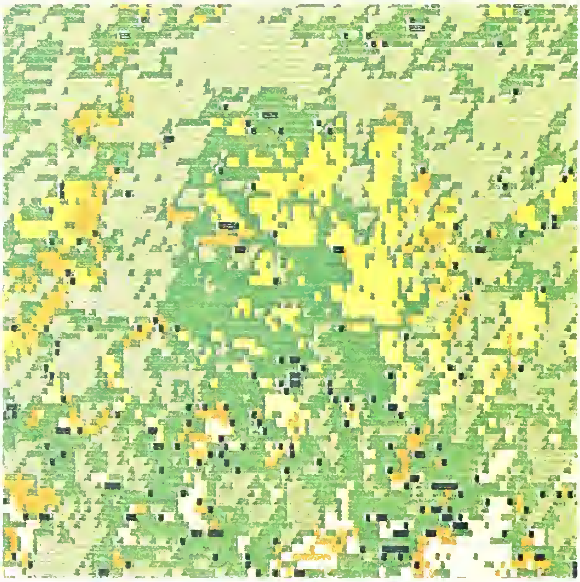
Computer-Assisted Mapping

The results of computer classification from the sub-blocks were expected to be good, as these sub-blocks were used in training the computer. The larger blocks were classified by extension of signatures developed for the sub-blocks, and less accurate classification results might be expected.

The classification maps of LARS and PSW (*fig. 25*) may be compared to the ground truth map for sub-block 1. The displays differ in quality mainly because the PSW classification map is the product of a multicolor pen plotter whereas the LARS map comes directly from a photo printer display. Although the LARS color photo map is difficult to use, the actual results of the classification as taken from output of the 1:24,000-scale rectified line printer are more readable (*fig. 26*).

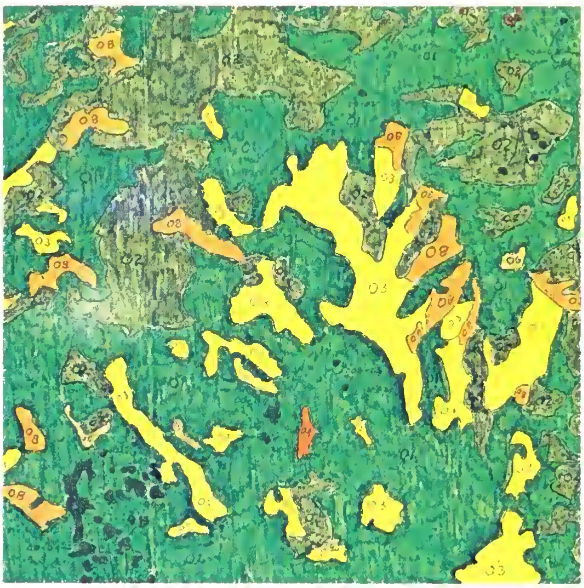
In assessing the classification performance for sub-block 1 (see *table 20*) our focus is on the classification of dead beetle-killed pine. Sub-block 1 contained the largest infestation and the highest number of dead trees in 1972 (*table 15*). The LARS classification did not identify any dead pine. Although the PSW results show 3 percent of the cover type in Dead Pine, a careful assessment of each pixel classified as Dead Pine showed no coincidence with the ground truth classification. Thus, we must conclude that in this test, computer-assisted processing of ERTS-1 multispectral scanner tapes was *not* successful in detecting mountain pine beetle stress in the Black Hills ponderosa pine ecosystem.

Computer-assisted classification maps for sub-block 2 may be compared with the ground truth map (*fig. 27*). In contrast to sub-block 1, which contained the large infestations, sub-block 2 contained only small spots, which we did not expect the computer to detect (see *fig. 23* for an aerial photograph of sub-block 2, and *fig. 22* for location of the mountain pine



PSW (Berkeley) Computer Map

LARS (Purdue Univ.) Computer Map



PSW Ground Truth Map Black Hills, S.D. Sub-block 1

Data source:
1:32,000 CIR photo by PSW, Sept. 8, 1972
Classified by photointerpretation and ground checks

0 1 2 Miles
0 1 2 3 Kilometers

N

- Dead Pine
- Pine < 50%[1]
- Pine > 50%[1]
- Hardwood
- Wet Pasture
- Dry Pasture
- Soil, Rock
- Water
- Transition

[1] Healthy, less than 50% or more than 50% crown closure

Computer maps
Data source:
System-corrected CCT's for ERTS-1 scene 1047-17175, Sept. 8, 1972, spectral bands 4, 5, 6, 7
Classification method:
PSW—nearest neighbor procedure
LARS—maximum likelihood theory (Gaussian statistics)

Figure 25—The results of computer-assisted classification are shown here for sub-block 1, along with the ground-truth map for comparison. The PSW classification display (made with eight color pens) was used for the classification performance evaluation. The LARS map, photographed from the digital display unit, was not suitable for the performance evaluation; the line-printer output shown in figure 26 was used instead.

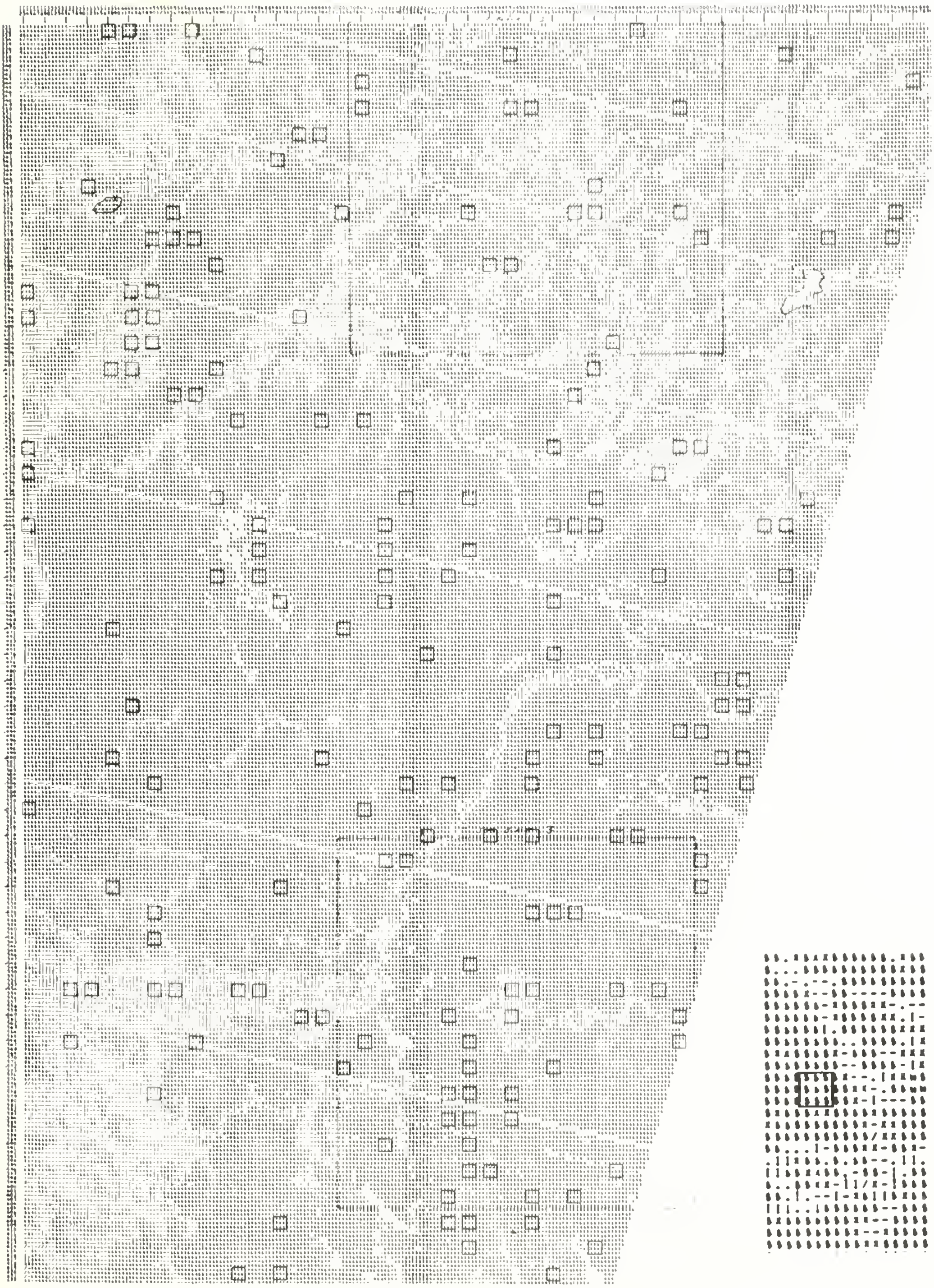
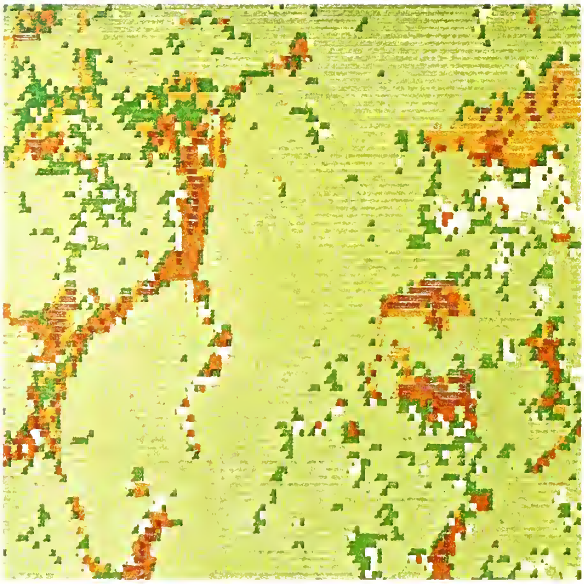
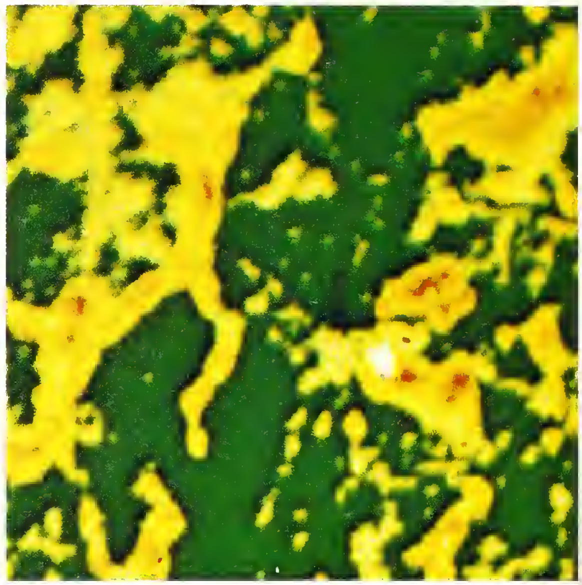


Figure 26–The LARS computer-assisted classification of the Spearfish Canyon block covered sub-block 1 and 96 percent of sub-block 3 at a scale of 1:24,000. The small squares are the 186 nine-element cells selected from the aerial photographs as representing pure cover type, for evaluation of classification performance. One of these units, *right*, is enlarged to show the computer symbols used to represent the classification categories.



PSW (Berkeley) Computer Map



LARS (Purdue Univ.) Computer Map

PSW Ground Truth Map Black Hills, S.D. Sub-block 2

Data source:
1:32,000 CIR photo by PSW, Sept. 8, 1972
Classified by photointerpretation and ground checks

0 1 2 Miles
0 1 2 3 Kilometers

N

Dead Pine	Dry Pasture
Pine < 50%[1]	Soil, Rock
Pine > 50%[1]	Water
Hardwood	Transition
Wet Pasture	

[1] Healthy, less than 50% or more than 50% crown closure

Computer maps
Data source:
System-corrected CCT's for ERTS-1 scene 1028-17121, Aug. 20, 1972, spectral bands (PSW) 4,5,6,7 (LARS) 5,6,7
Classification method:
PSW—nearest neighbor procedure
LARS—maximum likelihood theory (Gaussian statistics)

Figure 27—The results of computer-assisted classification are shown here for sub-block 2, with the ground truth map for comparison. As for sub-block 1, the PSW display was used for the classification performance evaluation but the LARS map was not; instead, the line-printer output for the sub-block was used. The cluster of infestation spots shown in the lower left corner of the ground truth map correspond to the small infestation spots shown in the center of the photograph of sub-block 2 in figure 22.

Table 20–*Computer-assisted classification performance by PSW and LARS as compared with ground truth, for the ERTS data covering three intensive study sites (sub-blocks) within the Lead and Spearfish Canyon blocks*

Sub-block, classification level, and cover type	Ground truth		PSW	LARS
	Hectares	—	*Percent* —	
Sub-block 1 (III)[1]:				
Dead ponderosa pine	55.3	1.4	3.1	0
Pine, healthy, <50%[2]	2290.6	58.0	47.4	29.6
Pine, healthy, >50%[2]	916.2	23.2	33.1	36.2
Hardwood, <25% pine	501.5	12.7	11.4	8.5
Wet pasture	7.9	0.2	0	4.5
Dry pasture	3.9	0.1	0	7.0
Sub-block 1 (II)				
Conifer	3262.1	82.6	83.6	65.8
Deciduous	501.5	12.7	11.4	9.5
Grassland	11.8	0.3	0	11.5
Bare soil, rock	15.8	0.4	0	7.0
Transition	158.0	4.0	5.0	6.2
Water	0	0	0	1.0
Sub-block 2 (III):				
Dead ponderosa pine	8.3	0.2	0	0
Pine, healthy, <50%[2]	666.9	16.1	12.7	26.0
Pine, healthy, >50%[2]	2924.3	70.6	72.9	62.8
Hardwood, <25% pine	29.0	0.7	3.7	1.0
Wet pasture	149.1	3.6	4.1	3.6
Dry pasture	248.5	6.0	2.8	1.8
Sub-block 2 (II):				
Conifer	3599.5	86.9	85.6	89.7
Deciduous	29.0	0.7	3.7	1.0
Grassland	397.6	9.6	6.9	5.4
Bare soil, rock	4.1	0.1	0	0.1
Transition	111.8	2.7	3.8	3.4
Cloud	–	–	0	0.1
Shadow	–	–	0	0.3
Sub-block 3 (III):				
Dead ponderosa pine	4.1	0.1	0	0
Pine, healthy, <50%[2]	964.7	23.6	22.6	12.9
Pine, healthy, >50%[2]	2673.2	65.4	71.2	69.7
Hardwood, <25% pine	4.1	0.1	0	0.1
Wet pasture	61.3	1.5	2.5	1.8
Dry pasture	32.7	0.8	0	2.6
Sub-block 3 (II):				
Conifer	3642.0	89.1	93.8	82.6
Deciduous	4.1	0.1	0	0.1
Grassland	94.0	2.3	2.5	4.4
Bare soil, rock	0	0	0	3.0
Transition	163.5	4.0	3.7	3.5
Water	0	0	0	1.0
Null	183.9	4.5	0	5.4

[1]Total area of sub-block 1: 3949.2 ha (9758.6 acres), 2: 4142.0 ha 10,235.1 acres), 3: 4087.5 ha (10,000 acres). 1 ha = 2.47 acres.
[2]Percentage = crown closure.

beetle infestations). Although we found considerable variation between LARS–PSW and ground truth in the classification performance at Level III for sub-block 2 (*table 20*), there was remarkable agreement at Level II. Allowing for errors in the ground truth determination, especially at Level III, we could judge that classification performance of both systems is reasonably successful at Level II and acceptable at Level III for sub-blocks. For both sub-blocks 2 and 3 (*table 20*), the PSW system appeared better for classifying cover type density of ponderosa pine.

The results for classification of the blocks by PSW and LARS are shown in *table 21*. In reconciling the classifications to the ground truth for the Lead block, one must remember that ground truth does not recognize the classes Cloud or Cloud Shadow. Ground truth is derived from aerial photographs in which no clouds appear; in the ERTS-1 imagery, several scattered clouds appear over the block. The area in question is only about 1 percent, however, and its effect on the classification is slight.

The PSW classification of the Lead block showed greater loss of accuracy than the LARS performance, as compared with the sub-block results. In the simple comparison of areas occupied by cover type, the LARS classification agrees well with the ground truth at both Level II and Level III. As in the photointerpretation, confusion existed between deciduous and grassland cover type, and if these were considered one class the performance would be reasonable.

The area classification results for the Spearfish Canyon block (*table 21*) are a different matter. While the PSW classifier appears to do a better job in identifying ponderosa pine density classes, the overall result is a 10-percent overestimate of conifer type in Level II. Considering the entire Level III classification, neither of the computer systems was good, while the Level II results showed improvement. Again, if the Level II LARS classification had combined deciduous and grassland as one class, the results would have been good.

A check of classification performance was made for the blocks using nine-element computer cells of pure type (*fig. 26*). Here the pixel-by-pixel correctness of the classification, rather than area estimates, was compared. The performance evaluation (*table 22*) showed that the LARS classification for the Lead block was 68.8 percent and the PSW 63.2 percent at Level III. For both, the problem appeared to be with the transition cover type. A total of 10.4 percent of all pixels classified in the Lead block were used in this evaluation.

The Level III classification performance for the

Table 21–*Computer-assisted classification performance by PSW and LARS compared with ground truth, for the ERTS-1 data covering the Lead and Spearfish Canyon blocks*[1]

Block, classification level, and cover type	Ground truth	PSW	LARS
	Hectares	— Percent —	
Lead block (III):			
Pine, healthy, <50%[2]	13,420.1 32.5	12.7	32.1
Pine, healthy, >0%[2]	22,545.8 54.6	66.7	53.3
Hardwood, <25% pine	1,858.2 4.5	6.6	2.1
Wet pasture	743.4 1.8	7.3	4.8
Dry pasture	949.7 2.3	2.4	2.6
Lead block (II):			
Conifer	36,172.4 87.6	79.4	85.4
Deciduous	1,858.2 4.5	6.6	2.1
Grassland	1,693.0 4.1	9.7	7.4
Bare soil, rock	41.3 0.1	0	0.1
Transition	1,486.5 3.6	4.3	3.9
Water	41.3 0.1	0	0
Cloud	– –	0	0.6
Shadow	– –	0	0.5
Spearfish Canyon block (III):			
Dead ponderosa pine	285.2 0.8	1.4	0
Pine, healthy, < 50%[2]	14,793.9 41.5	42.4	20.5
Pine, healthy, > 50%[2]	7,557.4 21.2	29.9	42.5
Hardwood, < 25% pine	2,566.6 7.2	5.3	4.1
Wet pasture	1,069.4 3.0	0	3.6
Dry pasture	320.8 0.9	0	5.2
Spearfish Canyon block (II):			
Conifer	22,636.4 63.5	73.7	63.0
Deciduous	2,566.6 7.2	5.3	4.1
Grassland	1,390.3 3.9	0	8.8
Bare soil, rock	1,069.4 3.0	0	3.0
Transition	1,425.9 4.0	3.1	3.4
Water	178.2 0.5	0	0.5
Null[3]	6,380.9 17.9	17.9	17.2

[1]Area of Lead block: 41,292.7 ha (102,036.1 acres), Spearfish Canyon: 35,647.7 ha (88,087.0 acres). 1 ha = 2.47 acres.
[2]Percentage = crown closure
[3]Area excluded by the ERTS scene edge.

Spearfish Canyon block was much better than that for the Lead block. Here a total of 8.2 percent of the pixels classified was used in the evaluation. The 80.1 percent correct for LARS and 76.0 percent for PSW is good, even though both systems suffered from commission errors in differentiating conifer cover type density (*table 22*).

The Level II classification performance for both LARS and PSW was better (*table 22*), although much more spectacularly so for the Spearfish Canyon block than for the Lead block. A performance of 90 percent or better is very good, but apparently the lack of a good classifier for transition cover type in the Lead block imagery was a great handicap.

Applications

It appears from the results reported that the useful-ness of ERTS-1 imagery is limited to providing infor mation for broad area planning and not for providin specific unit estimates of cover-type acreages Furthermore, the level of classification for whicl satisfactory accuracies were obtained has question able utility for the land planner and forest manager Undeniably, the synoptic view of the entire Blacl Hills such as was received for June 22, 1973, ca provide something of value otherwise unavailable t the land planner or forest manager. We are, however uncertain of how far that use extends in providin quantitative information for developing unit plans o impact statements.

Table 22–*Computer-assisted classification performance b PSW and LARS based on correct identification of samples for the ERTS-1 data covering the Lead and Spearfish Canyo blocks*

Block, classification level, and cover type	Number of samples	Percent correct	
		LARS	PSW
Lead block (III)			
Pine, healthy, <50%[1]	35	71.4	63.2
Pine, healthy, >50%[1]	117	97.4	99.2
Hardwood, <25% pine	12	66.7	16.7
Wet pasture	6	83.3	50.0
Dry pasture	9	66.7	77.8
Over-all performance[2]	253	68.8	63.2
Lead block (II)[4]			
Conifer	152	99.3	96.7
Deciduous	12	66.7	16.7
Grassland	15	86.7	86.7
Bare soil, rock	2	50.0	0
Transition	72	20.8	27.8
Over-all performance	253	74.3	71.9
Spearfish Canyon block (III)			
Pine, healthy, <50%[1]	42	45.2	76.2
Pine, healthy, >50%[1]	102	95.1	83.3
Hardwood, <25% pine	27	74.1	81.5
Wet pasture	3	66.7	0
Dry pasture	3	66.7	0
Over-all performance[2]	186	80.1	76.9
Spearfish Canyon block (II)			
Conifer	144	93.8	99.3
Deciduous	27	74.1	81.5
Grassland	6	100.0	0
Bare soil, rock	4	100.0	0
Transition	4	100.0	100.0
Water	1	100.0	0
Over-all performance	186	91.4	90.0

[1]Percent = crown closure
[2]Over-all performance for Level III was calculated with B soil, Transition, and Water classes included.

Eucalyptus Mortality from Low Temperature

An opportunity arose in February 1973 to apply the ERTS data use techniques to detection of severe stress in the hills of the Oakland-Berkeley area of California. Very large targets of discolored eucalyptus trees (4 km) were available for in mid-December 1972, the San Francisco Bay Area was subjected to a period of extremely cold weather–an average of −8° for 7 days. Eucalyptus trees, which are native to Australia and are not resistant to long periods of freezing temperatures, had been planted by the thousands in the early 1900's along the Oakland-Berkeley hills. By mid-February 1973, the foliage of these trees began to turn yellow. Ground examination revealed that the cambial cells of these now mature trees, which had boles averaging 61 cm (24 inches) in diameter and were 24 to 37 m (80 to 120 ft) tall, had been killed. The vast number of dead trees with highly flammable foliage represented a very dangerous fire situation for residents in the Oakland-Berkeley area.

At this time, the PSW Remote Sensing Research Work Unit was asked to photograph the affected area over the cities of Oakland and Berkeley and the East Bay Regional Park District, and we did so on February 15, 1973, at a scale of 1:12,000.

In some areas along the ridges, the killed eucalyptus stands were as large as 1 by 4 km (0.62 by 2.5 miles); the entire area of killed trees, although not of pure type (*fig. 28*), was about 3 by 30 km (1.87 by 18.7 miles).

In the San Francisco Bay Area, native grassy vegetation changes dramatically from its green wintertime appearance to its yellow and brown appearance in late spring and summer. The change occurs because of a cessation of winter rains. In late spring, the dying eucalyptus foliage appeared very similar to the drying-out native grasses.

We received an ERTS image taken before eucalyptus foliage discoloration occurred (January 2, 1973, scene 1183-18175). The next good image we received was April 22, 1973, scene 1273-18183, taken while the trees were still yellow but the native grasses were still green.

We found we could discriminate the dying timber quite accurately on an ERTS two-date combined image when the stands of timber were over 500 meters (1640 ft). A composite image (*fig. 28A*) from the above two time periods was created on our I^2S viewer by using a blue filter on the January MSS-7 image and a green filter and red filter on the April MSS-5 and MSS-7 images, respectively.

On the portion of the imagery enlarged to 1:500,000 (*fig. 28B*) features around the Bay Area such as water bodies, bridges, and freeways are identifiable, as well as the extent of the eucalyptus killing. These affected stands of timber were located quite precisely from the 1:12,000 underflight color photography, but the dying eucalyptus were distinguishable from surrounding vegetation on this ERTS enlargement as a distinct reddish brown.

Figure 28C shows an enlargement (scale 1:50,000) of the two-date enhanced image of one large eucalyptus plantation about 1 by 4 km (0.62 X 2.5 miles); it is readily detectable at the smaller scale. An enhanced image such as the 1:500,000 enlargement (*fig. 28A*) would be useful for damage assessment in remote areas when catastrophes of this kind occur. In an urban area, however, where millions of dollars for tree removal and fire prevention are to be allocated, a sensor with better resolution, such as medium-scale color photography, is needed.

REFERENCES

Aldrich, Robert C.
1975. **Detecting disturbances in a forest environment.** Photogramm. Eng. and Remote Sensing 41(1):39-48, illus.

Aldrich, Robert C., and Wallace J. Greentree.
1972. **Forest and nonforest land classification using aircraft and space imagery.** In Monitoring forest land from high altitude and from space. Final report for Earth Resour. Surv. Program, NASA Office of Space Sci. and Appl., 36 p., illus.

Aldrich, Robert C., and Wallace J. Greentree.
1971. **Microscale photointerpretation of forest and nonforest land classes.** *In* Monitoring forest land from high altitude and from space. Annu. Prog. Rep. for Earth Resour. Surv. Program, NASA Office of Space Sci. and Appl. 24 p., illus.

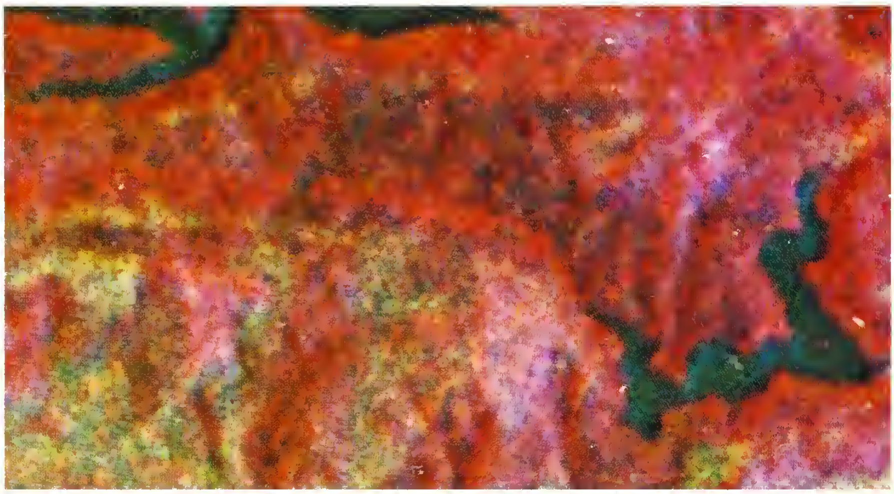
Anderson, J. R., E. E. Hardy, and J. T. Roach.
1972. **A land-use classification system for use with remote-sensor data.** Geol. Surv. Circ. 671, USDI, Geol. Surv., 16 p.

Anuta, Paul E.
1973. **Geometric correction of ERTS-1 digital multispectral scanner data.** LARS Inf. Note 103073, Purdue Univ., 23 p.

Daubenmire, R. F.
1952. **Forest vegetation of northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification.** Ecol. Monogr. 22:301-330.

N

A



B

C

Driscoll, Richard S., Jack N. Reppert, and Robert C. Heller.
1974. Microdensitometry to identify plant communities and components on color infrared aerial photos. J. Range Manage. 27:66-70.

Forest-Range Task Force.
1972. The Nation's range resources—a forest-range environmental study. USDA Forest Serv. For. Resour. Rep. No. 19, 147 p., illus.

Fukunaga, Keinosuke.
1972. Introduction to statistical pattern recognition. Academic Press, New York and London. 369 p.

Heller, R. C., J. L. Bean, and F. B. Knight.
1959. Aerial surveys of Black Hills beetle infestations. Stn. Pap. 46, Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo., 8 p.

Heller, R. C., and J. F. Wear.
1969. Sampling forest insect epidemics with color films. Proc. Sixth Int. Symp. on Remote Sensing of Environ, Univ. of Mich., Ann Arbor, Oct. 13-16, 1969:1157-1167, illus.

Hoffer, R. M., and LARS Staff.
1973. Techniques for computer aided analysis of ERTS-1 data, useful in geologic, forest and water resource surveys. LARS Inf. Note 121073, Purdue Univ., 23 p.

Kreigler, F. J., and H. M. Horwitz.
1973. Investigations in adaptive preprocessing of multispectral data. ERIM Rep. 31650-151-T. Univ. of Mich., Ann Arbor, 31 p.

Langley, Philip G., Robert C. Aldrich, and Robert C. Heller.
1969. Multistage sampling of forest resources by using space photography. *In* Second Annu. Earth Resour. Aircraft Program Status Rev., Vol. 2 Agric./For. and Sens. Studies. NASA Manned Spacecraft Cent., Houston, p. 19-2 to 19-21.

Munsell Color Company.
1920-1960. Munsell book of color. Munsell Color Co., Baltimore.

Peterken, G. R.
1970. Guide to check sheet for IBP [Int. Biol. Program] areas, including a classification of vegetation for general purposes by F. R. Fosberg. IBP Handb. 4. Blackwell Sci. Publ., Oxford. 133 p.

Purdue University.
1968. Remote multispectral sensing in agriculture. Indiana Agric. Exp. Stn. Bull. 844, 175 p.

Smith, J. A., L. D. Miller, and T. Ellis.
1972. Pattern recognition routines for graduate training in the automatic analysis of remote sensing imagery—RECOG. Sci. Series 3A. Dept. of Watershed Sci., Colorado State Univ., 86 p., illus.

Smith, J. A., and R. E. Oliver.
1974. Effects of changing canopy directional reflectance on feature selection. Appl. Optics. 13(7):1599-1604.

Weber, F. P.
1969. Remote sensing implications of water deficit and energy relationships for ponderosa pine attacked by bark beetles and associated disease organisms. Doctoral dissertation. Univ. of Mich. Ann Arbor. 143 p.

Weber, F. P., and F. C. Polycn.
1972. Remote sensing to detect stress in forests. Photogramm. Eng. 38(2):163-175.

Weber, F. P., R. C. Aldrich, F. G. Sadowski and F. J. Thomson.
1973. Land use classification in the southeastern forest region by multispectral scanning and computerized mapping. *In* Proc. Eighth Int. Symp. on Remote Sensing of Environ. Univ. of Mich. Inst. of Sci. and Technol. 1972:351-373.

Weber, F. P.
1973. DCP collected absolute target reflectance signatures assist accurate interpretation of ERTS-1 imagery. Proc. Symp. on Significant Results Obtained from the Earth Resour. Tech. Satellite-1. Vol. 1: Tech. Presentations, Sec. B., P. 1513-1522.

Weimer, Robert J., and John D. Haun, eds.
1960. Guide to the geology of Colorado. 310 p., illus. Geol. Soc. Amer., New York.

Figure 28—Eucalyptus trees killed by prolonged cold temperatures are shown here in two scales on ERTS color composites and on an aerial photograph in natural color. Data from parts of two ERTS scenes (January 23, 1973 and April 22, 1973) were combined to produce an enlarged (1:500,000) color composite (A). The white dashed lines outline the larger pure stands (more than 500 mm) of killed trees, which appear reddish brown on the enhanced print and are distinct from other objects. A further enlargement to approximately 1:50,000 (B) shows a eucalyptus stand near Lake Chabot, Oakland, about 1 by 4 km. A normal color print (C) reduced from an aerial mosaic (1:12,000) to match B shows the affected eucalyptus trees; they appear yellow as compared with the reddish-brown of the ERTS image. The difference in resolution between the ERTS image and the aerial photo is evident here.

APPENDIX

1. Producing Color Composite Internegatives from ERTS Transparencies on an Additive Color Viewer

Richard J. Myhre **Robert W. Dana**

A photographic technique was developed to produce standardized ERTS color composite negatives (8 by 10 inches) at a precise scale of 1:1,000,0000, on the I^2S additive color viewer.[7] The object was to control the enhancement and color saturation of the composites by careful monitoring of the light and filter levels within each ERTS band. Also, from large-format color negatives, enlarged color transparencies and prints could be made for the interpreters. The method described can be used by an investigator having access to a four-band additive color viewer (*fig. 29A*). Either two or three MSS bands are combined on the viewer to produce the most satisfactory normal color- or color infrared-appearing composite. Then, the illumination levels for each channel (and color filter combination), as well as total illumination for the composite, are recorded to determine proper film exposure and also for possible recombining of the image at a later time.

The illumination levels are taken with a portable photometer/radiometer built by Forest Service personnel (*fig. 29B*). This instrument consists of a radiometer box powered by batteries or line voltage and a beamsplitter input optics head with detector. The beamsplitter allows reflex viewing of the spot to be measured concurrent to the luminance measurement.

The low light levels being measured and loss in the beamsplitter required high sensitivity. Long-term stability and ease of calibration are also important. To accomplish this a diffused junction silicon diode detector is used, and its output is amplified with an integrated circuit operational amplifier in the current-to-voltage mode. Seven decades of amplification allow measurement ranges of 10^4 to 10^{-2} footlamberts. The wavelength response curve of the standard observer (photopia) is accurately matched using Wratten 9 and Schott BG-38 filters. Repeated calibration using a standard lamp showed the instrument to be stable to within 1 percent over a period of 1 year.

Through a series of film test exposures, proper exposure time was determined according to the readings obtained with the photometer. A graph was prepared to show the relationship between the composite illumination reading and the required exposure time for the film (*fig. 30*). Assembly of a special timing device was required to handle the short exposure times (less than 1 second) required by the I^2S illumination in conjunction with the internegative film (*fig. 29D*). A standard timer with 1/10-second increments (Lektra model TM-8, decade interval timer) was purchased and interfaced with a specially built relay system (25-amp relay) and switches that would handle the high amperage requirements of the I^2S for extremely short intervals. Such a high amperage timer was not readily available on the market.

The I^2S additive color viewer has a removable screen that can be replaced with an 8- by 10-inch-format film holder. Kodak Ektacolor Internegative film (type 6110) was determined to be best to obtain a color negative image of what appears on the screen. The film is then exposed according to the times computed from the photometer (*fig. 30*).

A special vacuum system for holding the film flat is required to eliminate misregistration because of variations in film flatness within the holder. The vacuum system (*fig. 29C*) consists of an 8- by 10-inch vacuum film holder specially modified to fit the I^2S screen frame. An inexpensive vacuum source was provided by adapting a vacuum hose to the end of a portable vacuum-cleaner hose and connecting it to the film holder. Excess vacuum was bled off by drilling a series of small holes in the vacuum hose.

Once the internegative film was exposed it was processed in a modified C-22 chemical process consisting of a special internegative developer and normal C-22 chemicals. Several products can be produced from the color negative; color transparencies are made on Kodak Ektacolor Print film (type 4109) or color prints are made on Ektacolor paper. With proper color filtration techniques in the photo lab color transparencies or prints can be produced that closely resemble the original color-combined image on the I^2S screen.

[7]International Imaging Systems is now known as Stanford Technology Corporation.

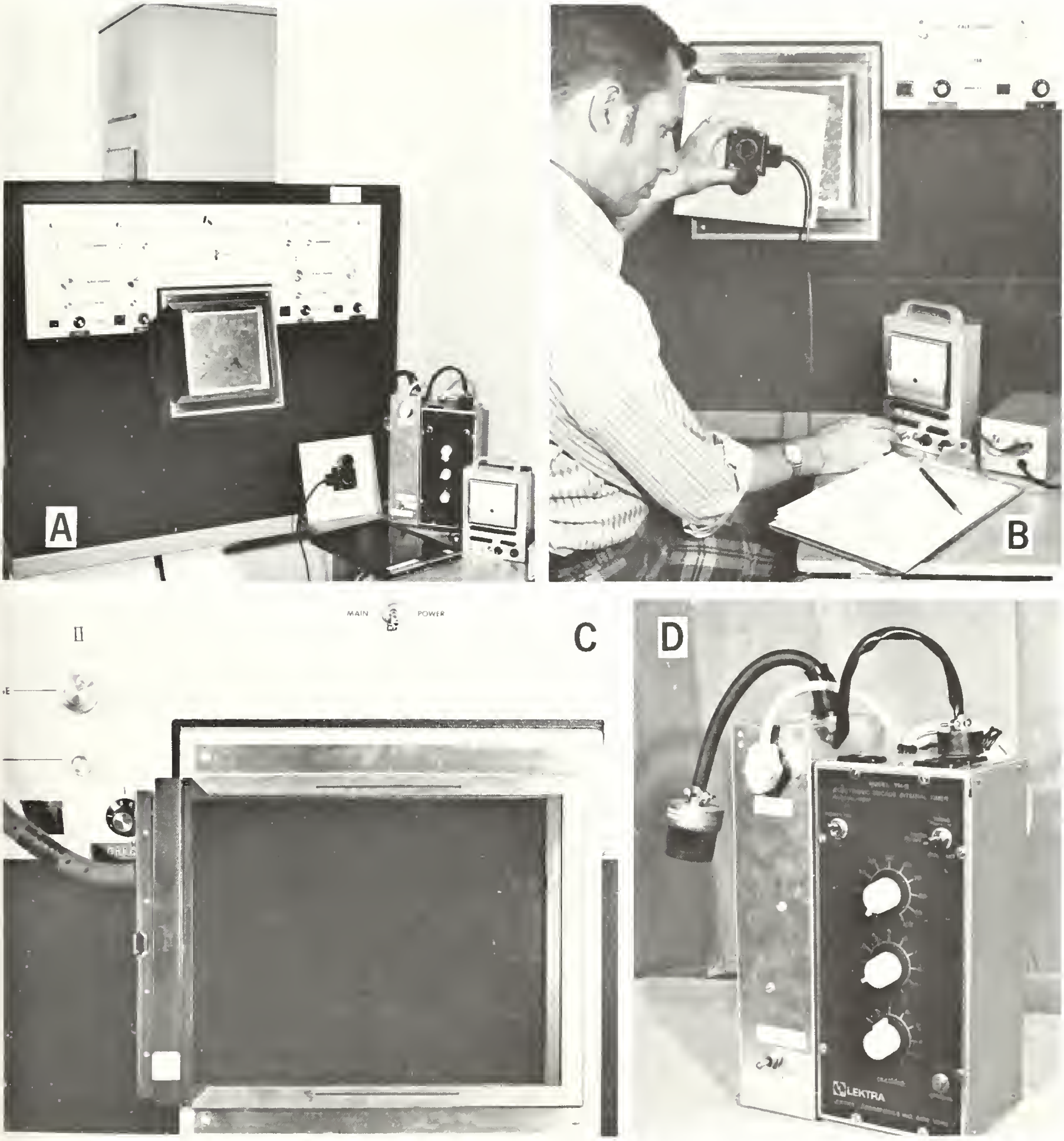


Figure 29–Equipment required to make color internegatives from ERTS 70-mm transparencies included (A) I^2S additive color viewer with photometer and high-speed timer, (B) Forest Service-designed photometer used to measure light intensity of each MSS band and of the color composite, (C) 8 by 10-inch vacuum film holder (vacuum hose, *left*), and (D) Lektra decade interval timer (*right*) with heavy-duty relay and switching circuit box (*left*).

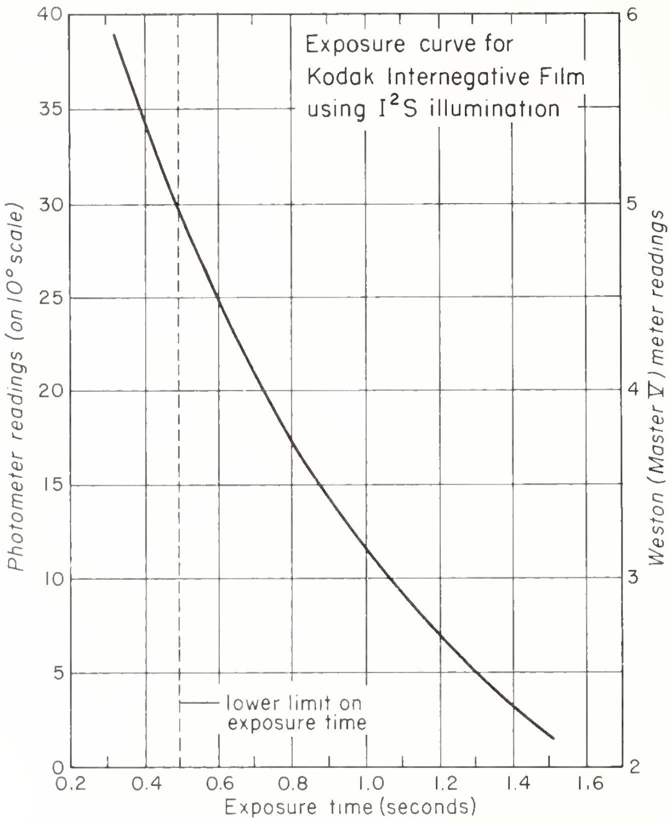


Figure 30—Exposure time is determined from the curve. Readings on the lefthand scale are from the Forest Service-designed photometer. Equivalent light intensity readings may be taken from a Weston Master V lightmeter (righthand scale).

2. Processing of ERTS Computer-Compatible Tapes

Nancy X. Norick

An automatic land-use recognition system, designed and implemented by the PSW Remote Sensing Work Unit was greatly expanded for the processing of ERTS computer-compatible tapes (bulk data). Considerable flexibility was built into the system so that the individual program components can be used in various combinations. The system programs run on a CDC 7600 at the University of California Lawrence Berkeley Laboratory, with input and output from a remote batch terminal at the PSW Forest and Range Experiment Station. The terminal consists of a Westinghouse 2500 with a line printer and other components. An Electronic Associates Inc. (EAI) model 430 off-line plotter is used with combinations of color pens to plot forest and land-use classification maps in the final classification process.

ERTS bulk CCT's are used as the first-step data input. Histograms and gray-scale maps are printed for each channel on a line printer so that study areas can be accurately located. If a study area falls on the boundary between two tapes, the needed portion of the data on the second tape is rewritten onto one tape. An area surrounding and including the study area is plotted for one channel using a color-coded gray scale. The corners of the rectangular study area are then located precisely on this plot.

Three major corrections are applied to the bulk data:

1. Channel 4 is always corrected for its inherent 6th-line periodic distortion. This is done by taking the mean radiance values for all lines of similar sequence number mod 6 (mod is a standard FORTRAN function). These means are then subtracted from every pixel in each scan line of the corresponding sequence number mod 6. The grand mean for the channel is then added to each pixel. Before this correction is made the histogram for channel 4 is bimodal. After the correction, the histogram has a unimodal distribution similar to that of the other three channels. The correction also increases the

correlations between the scan line means for channel 4 and each of the other channels.

2. Next the gray-scale printouts are checked for missing scan lines for every channel. When a missing line is located, the radiance value for each pixel is constructed by averaging the values for the adjacent pixels from the lines just above and below the missing line.

3. The basic "ground truth" units we have been working with for ERTS are rectangular land-use maps of scales between 1:20,000 and 1:30,000 which have been constructed from medium- to small-scale aerial photos and ground checks. The average size of the areas covered is about 4 miles on a side or 12 to 15 inches on a map of this scale. After finding the corners of a rectangular study area on a gray-scale plot, a "rubber sheet-stretching" routine scales the corresponding nonrectangular ERTS area to the rectangular ground truth maps. This routine does a linear transformation of data array coordinates conforming to ground truth map coordinates. Nearest pixel data values are assigned to the new array elements. This is done in such a way that no data element is lost. Here and there an original data element will be used twice.

Upon completion of these corrections and calibrations a new tape is written, which becomes the data input to all subsequent programs.

The next step in the processing is to produce an EDMAP—empirical distribution map. The EDMAP is used to locate ground truth training samples and to visually screen the channels as potential contributors to the discrimination between land-use classes. Using information from the previously mentioned histograms, the range of radiance values for each channel is divided into any number of equal frequency intervals. Cartesian products of these intervals are formed for two or more selected channels. Data points falling into any product interval are assigned a mapping color and the EAI plotter is programmed to map. From the resulting sets of color-coded maps, with varying combinations of channels included or excluded, a subjective evaluation of the potential contribution of each channel for discerning each land-use class can be made. We decided to use all four channels in our classification analyses.

The system has an option of three classification procedures. The first uses a boundary-finding algorithm to locate clusters of spectrally similar and adjacent pixels. A pixel is put into the same cluster as its neighbor if the distance between the two in the spectral space is less than some threshold value. Locations of all cluster elements are kept track of by a sequence of pointers. This storage technique allows the combining of clusters to be very efficient. The sums of radiance values and the sums of their cross-products are accumulated for each cluster during the process of cluster assignment. After all cluster assignments are made, the cluster mean vectors and covariance matrices are used for comparison with mean vectors and covariance matrices of samples of pixels of known land use, by means of the Bhattacharyya distance function (Fukunaga 1972). A cluster is assigned to the land use for which this distance is a minimum.

A weighting factor can be applied conforming to the expected frequencies in each land-use class or conforming to any loss function.

The second classification procedure compares the radiance vector for each pixel with the mean radiance vector for a sample of pixels from each land use. The land-use classification corresponding to the minimum Euclidean distance is assigned to the pixel. This classification can also use any set of weighting factors.

The third and last classification procedure available in our system is a linear discriminant analysis with maximum likelihood and Gaussian assumptions.

The final computer output consists of the listing of acreages of land assigned to each land-use class, confusion matrices for the training and test areas, and color-coded land-use maps. The maps are plotted in any desired scale and color code set on the EAI plotter. There is virtually no limitation upon the number of colors that can be used; however, the plotter can accommodate only eight pens at one time.

All programs are available and documented at PSW.

☆ GPO 693-661

Heller, Robert C., *technical coordinator*

1975. **Evaluation of ERTS-1 data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-112, 67 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Tests used data gathered by the first Earth Resources Technology Satellite. Results on sites in Georgia, Colorado, and South Dakota indicated that ERTS enlargements, preferably color, would be useful to forest managers of large ownerships for broad area planning. Forest land was distinguished from nonforest land with 90 to 95 percent accuracy, in both photointerpretation and computer-assisted analysis. Further breakdowns of cover types could not be made with acceptable accuracy by either method. Forest disturbances from natural causes or human activity could be detected with 90 percent accuracy when ERTS imagery was compared with 6-year-old aerial photos. Stress from mountain pine beetle could not be detected; ERTS wavebands are too broad to identify dying foliage.

Oxford: U629.19[+585+268+4]

Retrieval Terms: Earth Resources Technology Satellite; multi-spectral imagery; photointerpretation; remote sensors; forest stress; forest inventory; range inventory; plant communities; land classification; Atlanta, GA (Test Site); Black Hills, SD (Test Site); Manitou, CO (Test Site).

Heller, Robert C., *technical coordinator*

1975. **Evaluation of ERTS-1 data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-112, 67 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Tests used data gathered by the first Earth Resources Technology Satellite. Results on sites in Georgia, Colorado, and South Dakota indicated that ERTS enlargements, preferably color, would be useful to forest managers of large ownerships for broad area planning. Forest land was distinguished from nonforest land with 90 to 95 percent accuracy, in both photointerpretation and computer-assisted analysis. Further breakdowns of cover types could not be made with acceptable accuracy by either method. Forest disturbances from natural causes or human activity could be detected with 90 percent accuracy when ERTS imagery was compared with 6-year-old aerial photos. Stress from mountain pine beetle could not be detected; ERTS wavebands are too broad to identify dying foliage.

Oxford: U629.19[+585+268+4]

Retrieval Terms: Earth Resources Technology Satellite; multi-spectral imagery; photointerpretation; remote sensors; forest stress; forest inventory; range inventory; plant communities; land classification; Atlanta, GA (Test Site); Black Hills, SD (Test Site); Manitou, CO (Test Site).

Heller, Robert C., *technical coordinator*

1975. **Evaluation of ERTS-1 data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-112, 67 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Tests used data gathered by the first Earth Resources Technology Satellite. Results on sites in Georgia, Colorado, and South Dakota indicated that ERTS enlargements, preferably color, would be useful to forest managers of large ownerships for broad area planning. Forest land was distinguished from nonforest land with 90 to 95 percent accuracy, in both photointerpretation and computer-assisted analysis. Further breakdowns of cover types could not be made with acceptable accuracy by either method. Forest disturbances from natural causes or human activity could be detected with 90 percent accuracy when ERTS imagery was compared with 6-year-old aerial photos. Stress from mountain pine beetle could not be detected; ERTS wavebands are too broad to identify dying foliage.

Oxford: U629.19[+585+268+4]

Retrieval Terms: Earth Resources Technology Satellite; multi-spectral imagery; photointerpretation; remote sensors; forest stress; forest inventory; range inventory; plant communities; land classification; Atlanta, GA (Test Site); Black Hills, SD (Test Site); Manitou, CO (Test Site).

Heller, Robert C., *technical coordinator*

1975. **Evaluation of ERTS-1 data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-112, 67 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

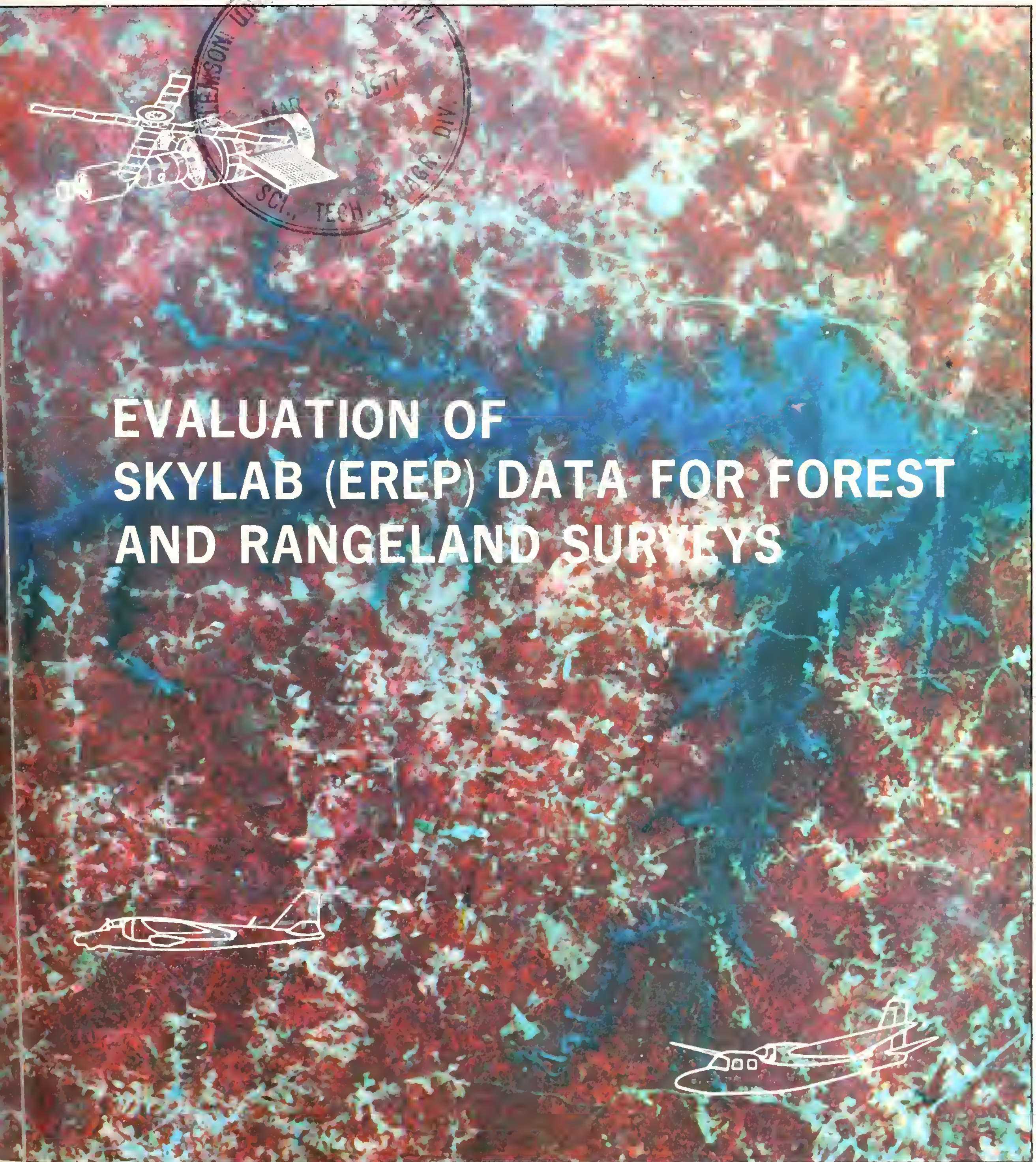
Tests used data gathered by the first Earth Resources Technology Satellite. Results on sites in Georgia, Colorado, and South Dakota indicated that ERTS enlargements, preferably color, would be useful to forest managers of large ownerships for broad area planning. Forest land was distinguished from nonforest land with 90 to 95 percent accuracy, in both photointerpretation and computer-assisted analysis. Further breakdowns of cover types could not be made with acceptable accuracy by either method. Forest disturbances from natural causes or human activity could be detected with 90 percent accuracy when ERTS imagery was compared with 6-year-old aerial photos. Stress from mountain pine beetle could not be detected; ERTS wavebands are too broad to identify dying foliage.

Oxford: U629.19[+585+268+4]

Retrieval Terms: Earth Resources Technology Satellite; multi-spectral imagery; photointerpretation; remote sensors; forest stress; forest inventory; range inventory; plant communities; land classification; Atlanta, GA (Test Site); Black Hills, SD (Test Site); Manitou, CO (Test Site).

PACIFIC SOUTHWEST Forest and Range Experiment Station

ST SERVICE
EPARTMENT OF AGRICULTURE
3OX 245, BERKELEY, CALIFORNIA 94701



EVALUATION OF SKYLAB (EREP) DATA FOR FOREST AND RANGELAND SURVEYS

USDA FOREST SERVICE RESEARCH PAPER PSW-113 /1976

EVALUATION OF SKYLAB (EREP) DATA FOR FOREST AND RANGELAND SURVEYS

Technical Coordinator

ROBERT C. ALDRICH

USDA FOREST SERVICE RESEARCH PAPER PSW-113

Published by

Pacific Southwest Forest and Range Experiment Station

Berkeley, California 94701

in cooperation with

Rocky Mountain Forest and Range Experiment Station

Fort Collins, Colorado 80521

Forest Service, U.S. Department of Agriculture

1976

Technical Coordinator

ROBERT C. ALDRICH, who heads the Station's Remote Sensing Research Work Unit, joined the Berkeley staff in 1965. He is a graduate of the State College of Forestry, Syracuse, New York (bachelor of science, 1944; master of forestry, 1948).

The Authors

ROBERT W. DANA, a physicist, has been a member of the Unit since 1969. He earned a bachelor's degree in physics (1963) and master's degree in geophysics (1969) at the University of Washington. **RICHARD S. DRISCOLL** is in charge of the Range Inventory and Evaluation Research Work Unit at the Rocky Mountain Forest and Range Experiment Station, Fort Collins. He studied at Colorado Agricultural and Mechanical College (baccalaureate in range management, 1951), Colorado State University (master's degree in range management, 1957), and Oregon State University (doctorate in range ecology, 1962). **RICHARD E. FRANCIS**, an associate range scientist, is also assigned to range inventory research at the Rocky Mountain Station. He earned a bachelor's degree (1967) in wildlife management at Humboldt State College, California. **WALLACE J. GREENTREE** also attended Humboldt State College (bachelor of science degree in forest management, 1961). A forestry technician, he has been with the Pacific Southwest Station's Remote Sensing Research Work Unit since 1967. Unit mathematical statistician since 1966, **NANCY X. NORICK** holds bachelor's (1964) and master's (1969) degrees in statistics from the University of California, Berkeley. **EDWIN H. ROBERTS**, a research forester with the Unit, is a forestry graduate of the University of California, Berkeley (bachelor's, 1965, and master's degrees, 1969). He joined the Station staff in 1974. **THOMAS H. WAITE**, formerly a forestry technician with the Unit, is also a graduate of the University of California, Berkeley (bachelor of science in forestry, 1970). He is now employed by Bechtel Corporation, San Francisco, California. **FREDERICK P. WEBER**, formerly with the Unit, is now remote sensing coordinator, Forest Economics and Marketing Research Staff, Forest Service, Washington, D.C. He was educated at the University of Minnesota (baccalaureate in forestry, 1960) and the University of Michigan (master's degree in forestry, 1965; doctorate in forestry, 1969).

NOTE: The Remote Sensing Research Work Unit, stationed at Berkeley at the time this publication was prepared, became in July 1976 a part of the Resources Evaluation Techniques Program at Fort Collins, Colorado. The Program, under the direction of Richard S. Driscoll as program manager, was established to aid in Forest Service compliance with the Forest and Rangeland Renewable Resources Planning Act of 1974, which requires inventory and evaluation of the forest, rangeland, and other renewable resources of the United States every 10 years.

Cover: An enlarged portion (11X) of a false-color composite made from Skylab S190A multiband photographs (green, red, and near infrared bands) taken on September 12, 1973. Clark Hill Reservoir and the Savannah River are shown in the center. Scale is approximately 1:250,000.

FOREWORD

The launching of Skylab in 1973 was linked with the development of large manned space workshops which may orbit the earth in the 1980's. One of these workshops, the reusable space shuttle, would have the exciting prospect of responding to critical renewable-resource problems with near-real-time information. Forest and range investigators, recovering from their disappointment with LANDSAT (ERTS-1) data, turned to Skylab with expectations of improved resolution and greater sensor sensitivity. Some of their expectations were rewarded, but as this report shows, reliability of the sensor systems must be improved before a space shuttle can respond to many forest and range problems.

This report evaluates the usefulness of the Skylab Earth Resources Experiment Package (EREP) data in identifying forest, rangeland, nonforest, water, and forest stress as a first level of resource information. The experiments described here were performed under Contract No. T-4106B (March 7, 1973 to December 7, 1975) between the U.S. National Aeronautics and Space Administration/Johnson Space Center (NASA/JSC) and the U.S. Department of Agriculture. The research was conducted by professional staff members of the Remote Sensing Research Work Unit, Pacific Southwest Forest and Range Experiment Station (PSW), Berkeley, California, and the Range Inventory and Evaluation Research Work Unit, Rocky Mountain Forest and Range Experiment Station (RM), Fort Collins, Colorado.

Robert C. Heller was originally identified as principal investigator and Robert C. Aldrich, Richard S. Driscoll, and Frederick P. Weber were identified as coinvestigators. Robert C. Aldrich was made principal investigator upon the retirement of Mr. Heller in August 1974. Technical Monitors for NASA were Ryborn Kirby and Clayton D. Forbes. This Research Paper is based on the final report submitted to NASA in fulfillment of the contract.

Various portions of the Skylab data products were processed and analyzed at the Pacific Southwest Station and the University of Kansas Space Technology Center, Lawrence, Kansas.

Although this Research Paper points out some limitations of Skylab sensors, these weaknesses probably will be resolved before the reusable space shuttle is launched in the 1980's. Meanwhile, the Forest Service will continue to develop its capabilities to use remote sensing data to inventory and manage forest and related resources.

ROBERT W. HARRIS, *Director*
Pacific Southwest Forest and Range Experiment Station

ACKNOWLEDGMENTS

We gratefully acknowledge the assistance of Professor Robert C. Heller, College of Forestry, Wildlife, and Range Sciences, University of Idaho, who coordinated the original proposal, and until his retirement from the Forest Service in August 1974, gave valuable technical direction to this research.

Members of the staffs of the two cooperating Experiment Stations contributed substantially to the study. Richard J. Myhre, scientific photographer, Pacific Southwest Station, was responsible for all photographic work required by the investigations, and prepared the illustrations included in this report.

The S192 data analysis reported in the Forest Stress Detection section was performed under subcontract by Robert Haralick of the Remote Sensing Laboratory, University of Kansas Space Technology Center, Lawrence, Kansas, with the assistance of Gary Minden, graduate student, Department of Electrical Engineering.

Clayton D. Forbes, technical monitor, Johnson Space Center, was responsible for technical advice, and for expediting shipments of Skylab imagery and computer-compatible tapes.

Robert Mattson, forester, Black Hills National Forest, Deadwood, S.D., assisted in maintaining the field data collection system.

CONTENTS

SUMMARY

Aldrich, Robert C., *technical coordinator*
1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: U629.19[+587.7+44]
Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory, plant communities; forest stress

Skylab photographic and multispectral scanner data products were studied during a period of 2½ years to test potential applications for forest and range surveys. Four separate studies tested classification of land use and forest and range vegetation, detection of stress on forest vegetation, and measurement of solar and atmospheric effects in satellite imagery. Sites selected for these studies were near Augusta, Georgia; Manitou, Colorado; the Black Hills of South Dakota; and Redding, California. The Manitou and Black Hills sites were used in previous remote sensing studies of aircraft photography and LANDSAT-1 (ERTS-1) multispectral scanner data.

Skylab data were supplied by NASA as photographic transparencies or computer-compatible tapes for analysis by photointerpretative and computer-assisted techniques. Photographic products included duplicates of S190B terrain mapping camera exposures on color or color infrared (CIR) films. Also included were color and CIR duplicate transparencies and four black-and-white duplicate transparencies from the S190A multispectral camera. The four black-and-white bands representing four spectral regions of the visible spectrum were combined into false-color composites. Computer-compatible tapes included unstraightened conical scan data recorded from the 13-channel multispectral scanner (S192). Different instruments and methods were used at each site to satisfy separate experimental requirements, and problems peculiar to each study were encountered. The approaches to the experimental objectives also varied considerably at each site.

In general, the Skylab photographic data were found useful at two resource-oriented sites for broad classification. Land use classes, such as forest and nonforest, and range vegetation classes at the Region level (Deciduous, Coniferous, and Grassland) were distinguished with acceptable accuracy when checked against ground truth. Maps produced from digitized optical film densities, measured on color film, were acceptable for forest classes but unacceptable for nonforest. Regardless of interpretation technique, Level II nonforest classes could not be accurately identified on color film, and range plant communities at the Series level could not be classified with consistency on any film/season combination.

Forest stress, in the form of mountain pine beetle-killed ponderosa pine, was detected only on Skylab's terrain mapping camera photography. No individual trees and only infestations over 26 meters (85 feet) in the longest dimension could be detected. Mountain pine beetle infestations could not be detected by analysis of S192 multispectral scanner data. Both photographic data and multispectral data were acquired in June a period of low insect activity and a period when little discolored foliage remains on the trees killed by the previous year's bark beetle population. Had data been available for September, a period of high insect activity and increasing dead-tree discoloration, results might have been more encouraging.

Additional conclusions drawn from the studies:

1. Systematic or random-sampling designs can be overlaid upon digitized photographic data by computer and classified into broad forest-nonforest classes for estimating area proportions. Acceptable results will depend on improving both the classification system and the classification procedure.

2. Enlargements of Skylab terrain camera photographs (1:125,000) can be used with conventional photointerpretation techniques to estimate proportions of broad land cover classes within large political or administrative boundaries in two-stage sampling designs.

3. Skylab and high-altitude aerial photographs can be used to map areal extent of Conifer and Grassland classes with greater than 90 percent accuracy.

4. Paved and gravel roads, utility corridors constructed within the past 10 years, large mining excavations, and clusters of buildings can be mapped on enlarged Skylab photographs.

5. Radiance from Skylab S190B and LANDSAT sensors was linearly correlated with wide-band terrain reflectance. Coefficients of the regression will be useful as linear conversion coefficients for extending spectral signatures in computer-aided classification using satellite imagery.

Summaries of the individual studies composing this report follow. If Skylab-quality data should become available on a recurring basis, further investigation is needed to support, clarify, and extend these results.

Forest Inventory–Three independent studies were made of the potential application of Skylab photographic data in (1) forest resource evaluation, (2) sampling designs for computer application, and (3) automated land classification and mapping. Multispectral scanner data were not analyzed because a change in the test site location was required late in the time period allowed.

Sixteen land use and forest classes, at three levels, were originally defined for both human and computer-assisted classification. Two types of photographic data were used in the tests–multiband false-color composites of S190A data for September 12, 1973, and S190B color for November 30, 1973. These photographs were enlarged to a scale of 1:125,000, 1:250,000, and 1:500,000 for interpretation. Ground truth for forest resource evaluation was provided by a 1971 forest survey. High-altitude CIR photographs (1:120,000) and ground checks were used to map one county into two forest and two nonforest classes for a sampling design study. To evaluate computer-assisted classification, two study blocks were mapped into 31 Level III and Level IV land use classes on high-altitude CIR photographs, and corrected using ground observations.

In one forest resource evaluation, land use proportions were estimated for a four-county area. The estimate of forest area was within 2 percent of the 1971 Forest Survey figure for the four counties. By individual counties, the estimates were within 2 percent for three of the four counties. With the exception of pasture and idle land, the four-county estimates were all close to ±1 percent of the 1971 Forest Survey estimates. A quasi-operational application test using regression techniques in one county estimated forest area 3 percent above the Forest Survey estimate. The sampling error was ±3.53 percent.

Using computer-simulation techniques, sampling designs were tested with a digitized ground truth map and digitized Skylab photographic data for one county. The variance in forest area resulting from systematic sampling was always smaller than that from simple random sampling. When a digitized type-map classified from Skylab S190B microdensitometer data was used in a postsampling stratification strategy, the variance of the forest area estimate was smaller than that from systematic sampling alone–but only when the sample intensity was low.

Computer-assisted analysis of microdensitometer scans made on Skylab S190B color photographs separated forest land from nonforest land with an accuracy of approximately 95 percent. Pine and hardwoods could be separated with an accuracy of approximately 70 percent.

Forest inventory studies in the Augusta, Georgia, site showed that Skylab S190B photographs provide a good base for Level I forest classification. Although conventional photointerpretation can provide acceptable area estimates for some nonforest classes, idle land, pasture, and water were difficult to separate on normal-color film.

Range Inventory–Classification of range plant communities was attempted at two levels of the ECOCLASS system–three Region and eight Series classes. Skylab photographs from the S190A multiband camera and the S190B terrain mapping camera (June and August 1973), high-altitude aircraft photographs (June and August 1973), and Forest Service-acquired large-scale photography were used in the tests. Both visual and microdensitometer techniques were tested.

Procedures were developed for sampling plant communities for use in photointerpretation training and tests. Procedures were also developed to map cultural features from Skylab photographs. In a separate study, foliar cover estimates made on large-scale color photographs were compared with measurements made on ground transects.

Interpreters classified Grassland and Conifer Region classes with a mean accuracy of 98 percent or greater on both Skylab and support aircraft photography, regardless of date or film type. For the Deciduous (Aspen) class, accuracy was 80 percent or greater on the August CIR aircraft photographs, but was not acceptable on Skylab photographs. Coniferous Series class accuracies were dependent on date and film type, but inconsistently so. Accuracies were greater at small scales, probably because mixed tree species formed homogeneous units with a dominant species signature and a lower resolution. Within the grassland Series, Shortgrass was classified with an accuracy of 95 percent or greater on both Skylab and aircraft photographs, regardless of date or film type. For Wet Meadow, accuracy was greater than 90 percent on both June and August aircraft photographs. regardless of film type or scale, and was also acceptable on both color and CIR Skylab photographs taken in August. Mountain Bunchgrass was not accurately classified on Skylab photographs, but on the August aircraft photographs the classification was acceptable regardless of film type or scale. Topographic slope and aspect, mountain shadows, ecotones, season, and class-mixing affected classification of plant communities.

In microdensitometer point-sampling, significant differences in mean optical densities at the 95 percent probability level were a measure of separability. At the Region level, Conifer, Deciduous (Aspen), and Grassland classes were separable. However, the Deciduous class could be separated from the other classes with significant differences only on color film. Ponderosa Pine was the only coniferous Series class that was separable from the other three conifers, regardless of date or film type. Spruce/Fir and Lodgepole Pine were not separable at any date or on any scale or film type. Douglas-fir was separable from the other three conifers on both the June CIR and August color S190A Skylab photographs. Grassland classifications at the Series level varied in acceptability. However, Shortgrass, Mountain Bunchgrass, and Wet Meadow were separable on August S190A color photographs. Optical density was more dependent on community mixing than on the growth stage of the plants at the time (season).

Both Skylab and aircraft photographs were useful to map the areal extent of Conifer and Grassland, but the Deciduous (Aspen) class could not be mapped with acceptable accuracy. Except for Wet Meadow, Series level classes could be mapped with acceptable accuracy only if class-complexes were formed: Ponderosa Pine/Douglas-fir, Lodgepole Pine/Spruce/Fir, and Shortgrass/Mountain Bunchgrass.

Paved and gravel roads, utility corridors constructed within the last 10 years, larger mining excavations, and clusters of buildings could be mapped on Skylab photograph enlargements. On the other hand, 1:100,000 scale aircraft photographs were needed to map dirt roads, minor earth excavations, utility corridors older than 10 years, and individual buildings. Foliar cover and plant litter measured on large-scale CIR photographs of non-diverse grasslands were related to ground measurements with a correlation coefficient of 0.75. This is considered acceptable for range surveys. The relationship for foliar cover of shrubs was acceptable only on diverse grasslands.

Forest Stress Detection—An evaluation of Skylab data in the Black Hills showed that mountain pine beetle infestations in ponderosa pine could not be identified on any S190A multiband camera system photographic product. All positive identifications of bark beetle infestations were made on color photographs taken by the S190B terrain mapping camera. To be detected, infestations had to exceed 26 m (85 ft) in the longest dimension. On one site, only infestations over 50 m (164 ft) in size could be detected. Infestations over 100 m (328 ft) in the longest dimension were located with 100 percent accuracy. The optimum viewing scale with a stereomicroscope was about 1:75,000. Best results were obtained with viewing on a high-quality, variable high-intensity light table; however, stereoscopic viewing was preferred and usually resulted in fewer commission errors than monocular viewing. Interpretation on a rear-projection viewer with high magnification was judged to be inferior to microscopic viewing on a light table.

Because late August through mid-September is the best period for detection of trees killed by mountain pine beetle, the June Skylab imagery used in this analysis was poorly timed. All dead ponderosa pine in the site were killed during the previous year and had lost most of their discolored foliage before the Skylab pass. Since the distinct red-orange color of dead tree foliage is used for recognition, many infestations were missed. Also, the early morning low angle of the sun at the time of the Skylab missions made interpretation difficult. In the steep terrain of the Black Hills, west- and north-facing slopes were in shadow.

Ponderosa pine trees killed by the mountain pine beetle were not detected by computer processing of 13-channel multispectral scanner (MSS) data (S192, June 9, 1973). Only five bands of the MSS were usable, and misregistration of the data seriously detracted from the analysis results. Attempts to correct the registration improved classification somewhat in several instances, but beetle-killed trees were not identified.

The analysis for stress detection in this report was restricted by circumstances beyond the control of the investigators. A Skylab earth resources pass was requested and scheduled during the desirable period (September 18, 1973) and correlative data needed in the analysis were collected by ground-based instruments on that date. However, the Skylab earth resources sensors were turned off unexpectedly during the pass. The results of the analysis in this report are therefore inconclusive, and further investigation is required to determine if forest stress can be detected on Skylab-quality remote sensing data.

Measurement of Forest Terrain Reflectance—Data on terrain radiance and solar irradiance, gathered on or near the Earth's surface, could be valuable for earth resource investigations. Calibrated satellite data might be more easily interpreted and more fully used if investigators could estimate temporal and locational variations in the effects of solar and atmospheric conditions on the satellite imagery.

An effort was made to use measurements of airborne radiance and irradiance to compute terrain reflectance values. These values (when correlated with satellite radiance of the same terrain elements) yield a first-order measure of solar and atmospheric properties at the time of a satellite overpass. Treating satellite radiance as the dependent variable, the correlation procedure produces an additive coefficient which is the path radiance, and a multiplicative coefficient representing the product of total irradiance and beam transmittance.

The airborne system for reflectance measurements consisted of an upward-pointing irradiance meter, a downward-pointing radiometer, a silicon vidicon camera (for support imagery) and associated data-recording instruments. Spectral matching to the bandwidths of the Skylab S190A and LANDSAT-1 MSS sensors was achieved for all three airborne sensors.

The S190A photographs were scanned by a digital microdensitometer. Programs were written to convert microdensity values to diffuse density and subsequently to effective film exposure. Finally, the satellite radiance was computed from film exposure values, using a camera radiance equation. Techniques, as outlined, were developed for use of the film samples and the sensitometric package (provided by NASA) necessary for these conversions.

The analysis of one set of Skylab photographs and one set of LANDSAT-1 images resulted in a high linear correlation between satellite radiance and reflectance. The derived path radiance values are in agreement with other published values.

The reflectance measurement technique presents two possible advantages over other empirical methods. One is that the results are derived in terms of the satellite scale of units, without concern for the calibration accuracy of ground-based or airborne radiometers. The other is that during stable periods in terrain reflectance properties, the reflectance measurements need not be made on the same day as the satellite overpass.

GLOSSARY

Band: One of the wavelength bands of the electromagnetic spectrum sensed by a multispectral scanner (MSS) or passed by a band-pass filter and recorded on photographic film.

Band Pair: Any two defined wavelength bands of the electromagnetic spectrum used in signature analysis.

Band-pass Filter: An optical filter that allows only defined portions of the electromagnetic spectrum to pass to the sensor surface.

Bias: The difference between the expected value of a statistic over all possible samples and the true population value of that statistic.

Color Composite: A false-color reconstruction of multiband photographs created from two or more filtered photographic bands. The four filtered bands on Skylab (S190A) were 0.5-0.6 μm (station 1), and 0.8-0.9 μm (station 2).

Computer-Compatible Tape (CCT): A reconstruction of data in magnetic tape form suitable for computer analysis. In this study, CCT's of Skylab MSS data and of digitized photographic optical densities were used.

Confusion Matrix: A tabular presentation of classification data showing the proportion of actual vegetation types that were classified as each of the predicted types.

Digital Element: A single picture element of digital image density recorded on computer-compatible tape by a microdensitometer. The size of the element varies with the microdensitometer aperture.

Irradiance: The amount of light measured on a surface. In physics, the radiant flux density on a given surface. Usually expressed in watts per square meter.

Microdensitometer (MDT): An instrument used to measure the optical density of an image on a photographic transparency, using a calibrated light source.

Multispectral Scanner (MSS): For Skylab, an electronic optical line-scanning device (S192) that collects reflected and emitted radiation in 13 spectral intervals (bands) of the visible, near-infrared, and thermal-infrared regions of the electromagnetic spectrum. The S192 has a conical line scan which meant line scan data had to be straightened for computer analysis.

Postsampling Stratification (PSS): Stratified sampling in which the strata assignments are unknown or are not used at the time of sample selection.

Radiance: The brightness of an object as seen from a remote observation point. In physics, it is a measure of the power radiating from a unit area of a source through a unit solid angle. Typical units of radiance are watts/meter^2-steradian.

Sampling Fraction: Percent of units sampled to the total number of units in the population.

UTM: Universal Transverse Mercator map projection.

Zoom Transfer Scope (ZTS): An optical instrument for transferring data from a small-scale photograph to a larger scale photograph or map. The scale change range is from 1X to 13X. (Manufactured by Bausch and Lomb Optical Company.)

INTRODUCTION

High-resolution sensors such as those on board Skylab may play an important part in forest and rangeland surveys in the future. Although conventional aerial photographs have been an aid in resource surveys for several decades, recent developments have moved toward more sophisticated photographic and nonphotographic remote sensors and computer-assisted data analysis. The new technology is valuable for several reasons: (1) costs of acquiring resource data are rapidly increasing, (2) more resource data is required at shorter intervals to measure rapid changes in land use that affect the environment, (3) urban and recreational uses of land are encroaching upon available resources and alternate sources must be planned and provided for, and (4) there is a continuing need for up-to-date resource information for day-to-day land management decisions and program planning.

There were three separate Skylab missions between May 1973 and February 1974. These missions were designated SL-2, SL-3, and SL-4. For each mission a three-man crew was launched in a space vehicle to dock with the Skylab Workshop (SWS) already in orbit: SL-2, launched on May 15, 1973, continued for 28 days; SL-3, launched on July 13, 1973, continued 74 days; and the SL-4 mission, launched on November 14, 1973, continued 84 days. The Skylab experiment was completed on February 8, 1974. During each mission, the Skylab Workshop was in orbit approximately 235 nautical miles (435 km) above the earth. Earth resources coverage was confined by this orbit to the Earth's surface lying between the Equator and 50 degrees north latitude and between the Equator and 50 degrees south latitude. During the missions, crew members were instructed to carry out certain experiments each day. Experiments included human physiology, astronomy, space technology, and earth resources. The Earth Resources Experimental Package (EREP) occupied only a small portion of the astronauts' time and had a lower priority than most of the studies.

Skylab's EREP is only one of several projects in NASA's Earth Resources Program, which began in 1965 with NASA support of studies using photographic and multispectral scanner (MSS) data obtained from aircraft flights. These early studies were made to define earth resource parameters and sensor requirements for projected space experiments, such as a series of LANDSAT (formerly ERTS) unmanned satellites, and Skylab and the Space Shuttle, which are manned satellites. The Remote Sensing Research Unit at Pacific Southwest Forest and Range Experiment Station has been involved in the Earth Resources Program since 1965, and the Rocky Mountain Forest and Range Experiment Station became involved in 1969. First, aircraft data were studied (Personnel of the Remote Sensing Research Work Unit 1972; Driscoll and Francis 1972), and then in 1973, LANDSAT-1 (ERTS) MSS data were evaluated (Heller 1975).

The conclusion from the LANDSAT study was that with improved spectral and spatial resolution, satellite imagery could provide the first-level information required in extensive forest inventory sampling strategies. Skylab data provided an opportunity to investigate and substantiate the conclusion, using machine-assisted classification procedures in addition to those dependent on human skill and judgment.

Objectives

The original objectives of this investigation as outlined in the NASA contract proposal were these:

1. To test the hypothesis that Skylab data will permit identification of forest, rangeland nonforest, water resources, and forest stress.

2. To determine if information in satellite imagery, coupled with information in aircraft photography and ground examinations, will increase efficiency of surveys of forest-related resources.

3. To compare the accuracy and cost effectiveness of various types of data and compare direct visual classification techniques with computer-assisted classification to separate and identify forest and rangeland resources.

4. To develop and test a practical method of correcting satellite radiance data for solar and atmospheric effect in computer-assisted classification.

At each of the four study sites, modifications in specific objectives were necessary because operational and technical problems developed. For instance, when Skylab coverage for the Atlanta study site was found to be unavailable, the forest inventory study was moved to an area north of Augusta, Georgia. This move was made in March 1974 after the Skylab experiment had been completed, and so no supporting aircraft flights or ground truth for the actual times of the Skylab passes could be obtained. The multiseasonal data evaluations were therefore eliminated from the study. Omission of proper filters for the multispectral camera during the November 30, 1973, Skylab pass over the Augusta site prevented our combining these data for analysis. In the Black Hills, a Skylab pass scheduled for September 18, 1973, was canceled at the last moment. Although biophysical data were collected on the ground during the period scheduled for the pass, there were no Skylab data in the proper time frame to analyze for stress detection.

Originally the analysis at all sites was to include all data types and all interpretation techniques. Insufficient data and time constraints, however, required that (1) human photointerpretation techniques be used at all sites, (2) microdensitometric analysis of photographic data be used on the Augusta and Manitou sites only, and (3) an analysis of the multispectral scanner data be performed by a subcontractor for the Black Hills site. These modifications made cost comparisons between all methods impossible.

Study Areas

Experiments were conducted in four widely separated locations across the country (*fig. 1*). We had originally planned to use the same sites as those used in evaluations of aircraft imagery and LANDSAT-1 (ERTS-1) data: Atlanta, Georgia, for forest inventory; the Black Hills in South Dakota for forest stress; and Manitou, Colorado, for range inventory. By retaining these sites, we could use in the analysis firsthand knowledge of conditions accumulated over a period of years, and make comparisons between systems. However, problems of data acquisition for the Atlanta site made selecting of two new sites necessary to carry out the studies originally proposed. The study to develop techniques for measuring and correcting for atmospheric interference, originally located at Atlanta, was moved to a new site near

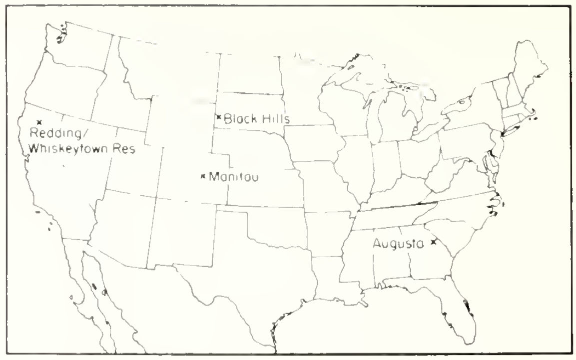


Figure 1—The study areas indicated on this map were used for different phases of the Skylab data evaluation: Augusta, Georgia—forest inventory; Manitou, Colorado—rangeland inventory; Black Hills, South Dakota—forest stress from mountain pine beetle; Redding, California—solar and atmospheric effects on data evaluation.

Redding, California. The site change was made early enough so that both Skylab and aircraft underflights could be scheduled on the same day. The forest inventory study was moved to an area near Augusta, Georgia, and the study was redesigned. New ground truth was collected 1 year following the best SL-4 pass (November 30, 1973), and comparisons between Skylab, aircraft, and ground data were made from this new beginning.

The forest inventory site just north of Augusta, Georgia, is representative of a large portion of the Southeastern United States where a high level of forest management is taking place and rapid changes are occurring. Forests here occupy 75 percent of the land area and are found in large contiguous bodies as well as in small woodlots intermingled with nonforest land. Pulpwood, wildlife, and recreation are three major uses of the forest land in this area. With a major lake, varied forest practices, and many forest and field borderlines, this area is a challenge to the photointerpreter.

Rangelands such as the Manitou, Colorado, site are important national resources and need to be inventoried, protected, and managed. They are becoming more valuable as our food and fiber supplies become more critical. Classification of the predominant vegetation according to its relation to other plants and animals and its potential for development is valuable. The Manitou site is appropriate for determination of the classification level at which Skylab data can be used to accurately assess range vegetation types.

In the Black Hills of South Dakota, the third site, a severe outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopk.) has killed several hundred thousand ponderosa pine trees (*Pinus ponderosa* Laws.) over the past 10 years. Early detection of the dying pines, which discolor to a yellow and yellow-red hue, would assist forest managers in assessing the severity of the outbreak and in planning control and salvage operations—particularly if the discoloration could be detected accurately and quickly from either manned or unmanned satellites.

The Whiskeytown Reservoir-Redding, California site was selected as an alternate site because it was on a Skylab ground track and convenient for low-altitude reflectance measurements. This site consisted of a strip along one east-to-west flight line from the reservoir to the Redding Airport. Measurements of reflectance by land use and vegetation classes were rather limited because of a partial cloud cover. Only mixed oak and digger pine (*Pinus sabiniana* Dougl.), ponderosa pine, brush species, and water were available for reflectance measurements. The topography ranged from rolling hills to moderately steep foothill slopes and deep gullies. A light, variable cirrus overcast was present during both the aircraft and Skylab passes.

Data and Techniques

Six EREP sensors were on board the Skylab Workshop. These consisted of a multispectral camera, S190A, with six high-precision matched lenses, an earth terrain camera, S190B, an infrared spectrometer (S191), a 13-channel multispectral scanner (MSS), S192, a microwave radiometer/scatterometer and altimeter, S193, and an L-Band radiometer, S194. Only S190A, S190B, and S192 data were evaluated in the studies reported here. We originally intended to use S191 infrared spectrometer data to evaluate the effects of the atmosphere; however, owing to a lack of coverage that could be related to the ground truth measurements, this part of the experiment was eliminated.

The S190A data were provided by NASA/JSC in the form of 2½-inch square film transparencies. The original scale of these data was approximately 1:2,800,000, but they were enlarged to suit the needs of the individual studies. Special filters used on the camera lenses separated the visible and reflected infrared spectrum into bands for multispectral analysis. For each EREP pass over a test site, a set of six pictures was received. The bands, expressed as wavelength in micrometers, for each film type were these: color infrared (CIR): 0.5 to 0.88; high-resolution color: 0.4 to 0.7; black-and-white panchromatic film: 0.5 to 0.6 and 0.6 to 0.7; and infrared sensitive film: 0.7 to 0.8 and 0.8 to 0.9.

For each site covered by an EREP pass, a set of contact duplicate transparencies (5 by 5 inches) was received for all S190B coverage. The original scale of these photographs was approximately 1:900,000 but for special purposes they were photographically enlarged to 1:125,000. These photos were taken on either normal color or CIR film; the decision depended on the requirements of the majority of investigators who had requested coverage on each pass, and in some instances we therefore received normal color when CIR was preferred.

Computer-compatible tapes (CCT's) with S192 multispectral scanner data were received only for the Black Hills test site. These tapes were used by a subcontractor to classify stressed ponderosa pine under attack by the mountain pine beetle. The tapes, with 13 channels of MSS data, covered six discrete bands in the visible spectrum, six discrete bands in the reflected infrared, and one single thermal infrared band from 10.2 to 12.5 micrometers.

Techniques and instruments used by the investigators to analyze Skylab photographic data varied from one site to the next. In both the forest and range inventory investigations, a Bausch and Lomb Zoom Transfer Scope (ZTS)[1] was used for mapping and dual image correlations. In the Black Hills investigation, a Bausch and Lomb 240 zoom stereo microscope was used to test a wide range of image magnifications for stress detection—both stereoscopically and monocularly. The investigator here also used a Variscan rear-projection viewer to interpret images at magnifications up to 29.5 times. On the forest inventory site, conventional photointerpretation was carried out with both an Old Delft scanning stereoscope and a lamp magnifier. A Photo Data Systems (PDS) automatic scanning microdensitometer and process computer were also used to scan and record optical density on one S190B color photograph for computer-assisted classification. At the range inventory site a General Aniline and Film Corp. (GAF) microdensitometer was used to relate film density to plant communities. Similarly, a point-sampling technique was used at the Manitou site to classify plant communities by conventional interpretation. Interpretations were verified on ground-truth maps prepared from high-altitude color infrared photography and ground checks. At the Augusta site, existing forest inventory photo samples and ground subsamples provided a basis for land use and forest-type evaluations.

---

[1] Trade names and commercial enterprises or products are mentioned solely for necessary information. No endorsement by the U.S. Department of Agriculture is implied.

The investigator at the Black Hills site systematically scanned each sub-block study site to detect bark-beetle-killed trees—the trees were counted, infested spots were mapped, and the Skylab interpretation verified on aerial photography or by aerial observations.

During the studies described here, large quantities of data were gathered over a long period of time. Many of the techniques used were developed and modified in light of required changes in the analysis plan and from experience. In this report, only enough detail has been included to help the reader understand what was done and evaluate the results. The report is intended primarily to aid those who may be using manned earth resources satellite data in forestry applications in the future. Some additional detailed information is available on request, as noted in later sections of this report. Requests should be addressed to Director, Pacific Southwest Forest and Range Experiment Station, P.O. Box 245, Berkeley, California 94701.

FOREST INVENTORY

Forest Resource Evaluation, Sampling Design, and Automated Land Classification

Robert C. Aldrich Edwin H. Roberts Wallace J. Greentree
Nancy X. Norick Thomas H. Waite

The Skylab studies conducted near Augusta, Georgia, are part of a continuing research program to improve extensive forest inventory techniques. Intensive inventory techniques relate to individual forest stands as small as 2 hectares (5 acres), whereas the research reported here deals with the measurement of resource conditions within broad natural, administrative, and political boundaries using sampling procedures. Additional information about specific locations within the survey boundaries is useful but is not usually required.

Three independent studies were carried out by the investigators to evaluate Skylab photographic data for national forest resource surveys:

1. An evaluation of Skylab S190A (multispectral camera) and S190B (earth terrain camera) photographic data for classifying forest and related land use. This study includes a quasi-operational one-county forest evaluation.
2. A study to determine an effective method for sampling digitized remote sensing data. This study includes a one-county evaluation of sampling designs and sampling intensity, using optical densities from an S190B color photograph.
3. A study of microdensitometer techniques for classifying forest and related land use on Skylab S190B photography. Two 10,000-meter-square (6.22-mile-square) blocks are used as experimental areas to map Level II and Level III land use classes.

Synoptic vertical photographs taken from space platforms are of considerable interest to forest inventory specialists. In March 1969, foresters found that color infrared photographs taken by Apollo 9 astronauts could be used to stratify forest land into broad classes (Langley and others 1969; Aldrich 1971). In a multistage forest inventory in the Mississippi Valley, this first-level stratification increased sampling efficiency by over 58 percent. Interest in multistage sampling strategies using satellite imagery coupled with aircraft photography and ground observations has increased as a result (Draeger and others 1971; Hildebrandt 1973; Kuusela and Poso 1972; Nichols and others 1974).

Since the early 1940's, land use classification has been the first stage in extensive nationwide forest resource inventories. This classification is usually done by photointerpreters on available medium-scale panchromatic aerial photographs. Many times these photographs are 5 to 10 years old at the time they are used. Since the primary purpose of land use classification is to determine an accurate forest area base for expanding forest resource statistics, changes in land use since the photographs were taken can be a serious problem. If the forest area base is not accurate, data from ground subsamples expanded by a forest area expansion factor can be inaccurate. Unless up-to-date photography or other remote sensing imagery is available on a wide area basis, adequate measurement of the changes in the forest area base is very difficult.

In 1969, a research program was begun by the Pacific Southwest Station's Remote Sensing Work Unit to study high-altitude aircraft photography and satellite imagery for land use and forest classification as a first level of information in resource surveys. These studies were conducted under the Earth Resources Survey Programs sponsored by NASA. A study near Atlanta, Georgia, using 1:400,000 and 1:120,000 CIR aerial photography, showed that forest land could be identified correctly over 96 percent of the time regardless of scale (Heller and others 1973). During this study, techniques for classifying land use by optical film density were investigated with only limited success. Multispectral scanner (MSS) data from aircraft flights over two 4049-hectare (10,000-acre) study blocks were also analyzed. Although land use classifications were reasonably accurate, distortions in the processed data were a limiting factor (Weber and others 1973). In 1973, LANDSAT-1 (ERTS-1) MSS data for the Atlanta test site were studied by both conventional photointerpretation techniques and by computer-assisted classification procedures (Aldrich and others 1975). Interpreters could correctly classify Level I information (forest, nonforest, water) over 96 percent of the time on false-color photo composites. Computer-assisted classification using four bands of scanner data was 94 to 96 percent correct for the Level I classes. Neither human nor machine classification could separate Level II information with a high degree of accuracy.

Skylab (EREP) data with ground resolutions of from 10 to 30 meters offered an opportunity to find out whether higher resolution data would improve the accuracy of Level I and Level II information for National Forest resource surveys. We also needed to know if Level I information could be obtained from Skylab photographs by microdensitometry and computer-assisted classification and sampling procedures.

Study Area

The study site near Augusta, Georgia, (*fig. 2*) lies in the Piedmont physical division and is part of Georgia Forest Survey Unit 4.[2] The area is typical of a large part of the Southern United States, with both broad contiguous bodies of forest land and small farm woodlots mingled with nonforest land use. Forest land is 75 percent of the total land area. Major forest types are loblolly pine (*Pinus taeda* L.), oak-pine, oak-hickory, and oak-gum cypress. Topography is gently rolling to hilly, with many narrow stream valleys. Principal land uses are forest, grassland (pasture), urban, and water. Agriculture is not a major land use, though scattered grain and row crops are found throughout the area. The Clark Hill Reservoir forms the eastern boundary and is the site of recreation homes; it is a base for hunting, fishing, and other recreational uses. Major forest disturbances are caused by forest management practices and by development of recreation home sites.

Classification System

The diversity of techniques used in these studies called for a variety of classification systems. Although somewhat different in nomenclature, these systems have the same objective: to measure the forest area within an error of ±3 percent per million acres (404,858 hectares).

The classification system used in the forest resource evaluation study included 10 individual land use classes (*table 1*). Not all of these classes, however, were found within the four-county site. In some portions of the study the five agricultural classes were grouped as "other miscellaneous" to conform to the system used by the Forest Survey in their first-level stratification on aerial photographs.

The forest sampling design study in McDuffie County used a classification hierarchy of three Level I and two Level II classes. Forest land, nonforest land and water were mapped at Level I to build a base for testing computer sampling designs. Two Level II classes—pine and deciduous forest—were also delineated to see if they could be separated and stratified on Skylab data digitized by microdensitometer.

To test the value of computer classification algorithms developed for LANDSAT-1 (ERTS-1), a classification system of four levels was developed for Skylab (*table 2*). The land area in two 10,000-meter-square (6.22-mile-square) blocks was mapped to a 0.4-hectare (1-acre) minimum using this system. On five randomly selected 1000-meter (0.62-mile) subblocks within the test blocks, forest land was classified by three stand-size classes to help explain variations in the Skylab film densities.

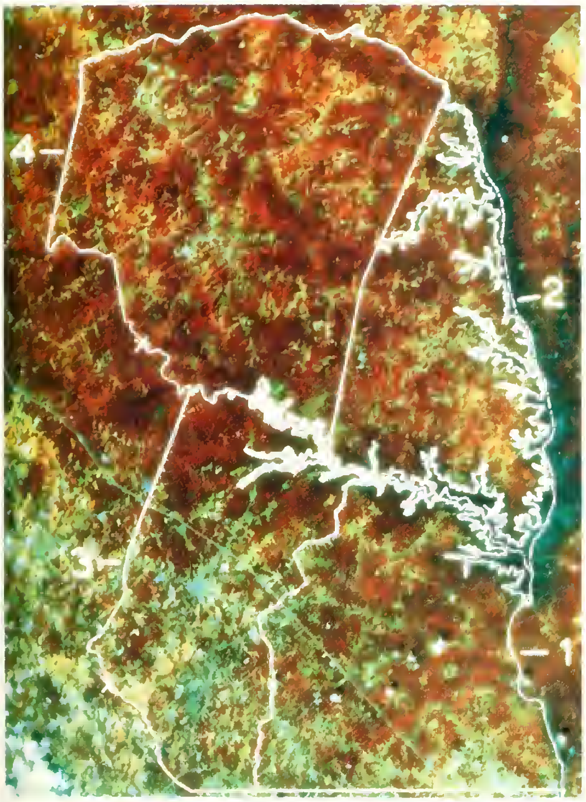
Skylab Data

Restrictions imposed by short missions, seasonal data requirements, and the scientists' lack of control over scheduling reduced the probability of obtaining a clear photographic day for Skylab data collection. For this reason, remotely sensed data were not obtained for the inventory test site near Atlanta, Georgia, where earlier studies had been made. To complete the proposed research using the most suitable Skylab data products, an alternate site was selected after the Skylab experiment had been completed and all data tabulated. By that time, SL-3 and SL-4 data for the new site were already 4 to 6 months old and it was no longer possible to gather any time-dependent ground truth.

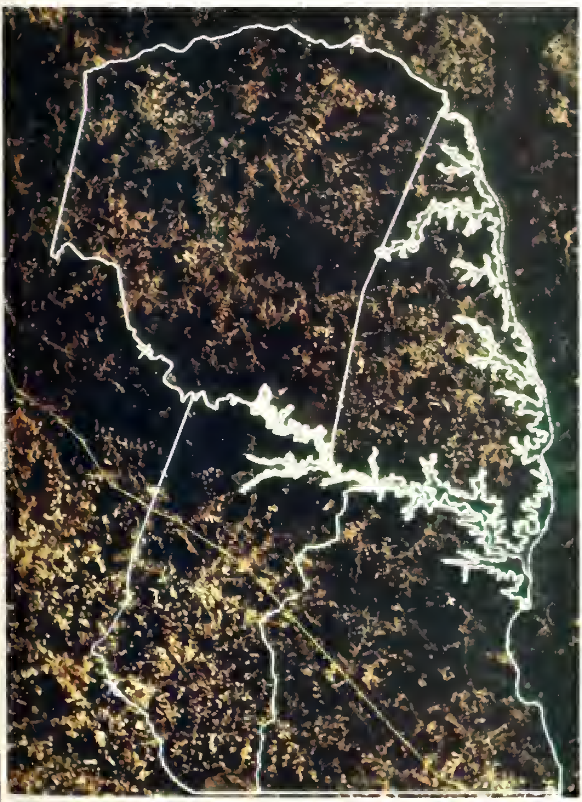
The Skylab data used in these studies include only S190A and S190B photography (*fig. 2*), taken on September 12 (SL-3; Pass 36, Track 43) and November 30, 1973 (SL-4; Pass 54, Track 19).

The panchromatic and infrared SL-3 S190A multiband photography was combined and enhanced on an I^2S (Stanford Technology Corp.) additive color viewer, and a color internegative was made of the combined image following the technique described by Myhre for combining LANDSAT-1 (ERTS-1) film chips (Aldrich and others 1975). From the inter-

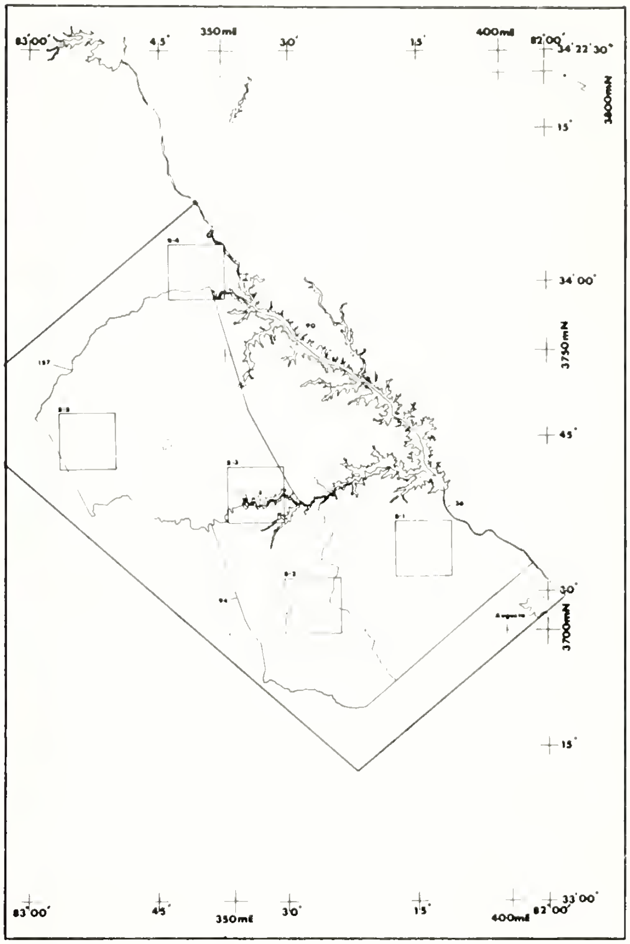
[2] A state-wide forest resource evaluation is made every 8 to 10 years by the Forest Resource Research Unit at the Southeastern Forest Experiment Station, Asheville, N.C. Section 9 of the McSweeney-McNary Forest Research Act of 1928, as amended, and the Forest and Rangeland Renewable Resources Planning Act of 1974 authorize these forest resource evaluations.



Skylab S190A multiband composite, Sept. 12, 1973



Skylab S190B color photograph, Nov. 30, 1973



Augusta site map

Figure 2–The Augusta site, used for evaluating Skylab data in forest inventory, includes four counties. Two intensive study sites (2 and 4) were used for computer-assisted mapping with digitized photographic film densities. The Skylab S190A multiband composite for September 12, 1973, and the Skylab S190B color photograph for November 30, 1973, were used in the data analysis. Photographic scale is approximately 1:850,000.

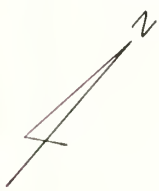


Table 1 *A land-use hierarchy[1] for forest resource evaluation*

Classification	Definition
Forest Land	Areas 0.4 hectare (1 acre) or larger, capable of supporting more than 10 percent cover by fores trees and not developed for nonforest use.
Cropland	Land currently being utilized to produce agricultural crops that are harvested directly and no indirectly as pasture forage consumed by livestock.
Idle farmland	Former cropland, orchards, improved pasture, and farm sites not tended within the past 2 year and presently less than 10 percent stocked with trees.
Improved pasture	Land currently being improved for grazing by cultivation, seeding, irrigation, or clearing o brush and trees.
Grassland	Land other than improved pasture on which the primary natural cover is grass and forbs.
Other agriculture	All other farmland not used for crops, idle, or pasture. Includes farmstead, buildings, anc service areas.
Marsh and swampland	Land temporarily or partially covered by water, and poorly drained land capable of supportin more than 10 percent cover of swamp vegetation (marsh grasses, cattails, etc.). Does not includ spruce bogs, cypress land, or other hydric forest sites.
Urban and other areas	Areas within legal boundaries of cities and towns; suburban areas developed for residential industrial, or recreational purposes; schoolyards; cemeteries; roads; railroads; airports; beaches powerlines and other rights-of-way; or other nonforest land not included in any other specifi land class.
Census water	Streams, sloughs, estuaries, and canals more than 0.2 kilometers (1/8 statute mile) in width; and lakes, reservoirs, and ponds more than 16.2 hectares (40 acres) in area.
Noncensus water	Streams, sloughs, estuaries, and canals less than 0.2 kilometer (1/8 statute mile) in width; anc lakes, reservoirs, and ponds less than 16.2 hectares (40 acres) in area. Minimum width o streams, etc., and minimum diameter of lakes, etc., are 9.1 meters (30 feet).

[1]U.S. Forest Service 1974.

[2]U.S. Forest Service 1968, Definition of Terms, p. D-1 through D-9.

negative, 1:500,000 and 1:250,000 enlargements were made on color transparency film. These films were used in combination with S190B color transparencies for forest and land use classification; however, the lower resolution and graininess of the S190A composite caused eye fatigue, and the effect was to increase interpretation time. Although the spectral information was helpful in making land use and forest-type decisions, we concluded that high-resolution CIR film from the S190B earth terrain camera would have been much more useful. We did not use the S190A CIR or color films in our analysis because, after a careful review of the materials, we felt that they contained only redundant information and at a lower resolution than the S190B imagery.

The S190A multiband photography for SL-4 (November 30, 1973) could not be used in the analysis because the films had been exposed withou filters.[3]

Of the two sets of color photographs produced b the S190B terrain camera, only the SL-4 (Novembe 30, 1973) could be effectively used. The SL-3 photo graphs (September 12, 1973) were low in contras showed a general haze condition, and did not incluc overlap for stereoscopic viewing. The SL-4 phot graphs, on the other hand, were taken on a clear da contained reasonably good contrast between lan uses and forest conditions, and had 60 percent ove lap for stereoscopic viewing. We found this photo

[3] National Aeronautics and Space Administration. 197 *Skylab program, sensor performance report, vol. 1* (S190 MSC-05528. NASA L. B. Johnson Space Center, p. 3-6d.

Table 2—*A land use classification hierarchy for remote sensing and ground information sources compatible with current nationwide forest resource evaluation objectives. Color definitions are based on high-altitude color infrared photography and simulated color infrared composites of LANDSAT data.*

Classification	Color definitions (based on Munsell 1920-60, NBS 1955)
I FOREST LAND	
II Conifer III Pine Pine-hardwood IV Seedling and sapling Poles Sawtimber	Density of conifer stands, number of hardwoods mixed in stand, and stand size influence color value and chroma. Dense stands are darker with less chroma. In the fall, before advanced hardwood coloration and leaf fall, conifer stands appear dark purplish red. Separation between conifer and hardwood classes is less distinct in fall than in winter or early spring. Where hardwoods and conifers are mixed in stands, hardwood color predominates, and stand is usually classified as hardwood. In spring before hardwoods are foliated, conifers appear moderate to dark purplish red. Seedlings and saplings on prepared sites appear lighter than poles and mature sawtimber with closed canopies.
II Deciduous hardwood III Upland hardwood Bottomland hardwood IV Seedling and sapling Poles Sawtimber	Stands appear moderate grayish purplish red in fall and pale purple to moderate purplish red in spring. In fall, upland hardwoods cannot be distinguished from bottomland hardwoods. In spring, before foliation, upland hardwoods appear pale purple to light grayish purplish red. Bottomland hardwoods are generally a moderate purplish red. Stand size class (texture), density of crown canopy, and ground cover influencee color value, density, and chroma but to a lesser extent than in conifer stands.
I NONFOREST LAND	
II Grassland III Undisturbed grass Disturbed grass Dead grass (annual) New improved grass	Grassland appears deep pink in both fall and spring; sometimes mistaken for immature cropland in spring.
II Cropland III Immature grain Immature crop Mature crop Harvested crop Orchard Farmsteads	Mature crops in fall appear bluish gray to grayish blue. In spring, immature crops appear deep pink and may be mistaken for grassland.
II Bare Soil III Plowed fields Erosion Urban (site preparations) Rock outcrop	In fall and spring bare soil appears cream colored on LANDSAT imagery. There is no distinction between plowed agricultural fields and sites prepared for new commercial developments. Generally in spring most areas of bare soil are newly plowed fields either recently or soon-to-be planted.
II Wild vegetation III Idle land Abandoned land Transitional Kudzu Marshland Alder swamp	In fall, areas range from grayish purple of idle land to grayish purplish red of abandoned land to deep pink of Kudzu vine. Marsh and alder swamps are a moderate purple because of wet background. In spring, idle land becomes light grayish red to dark pink because of influx of new infrared-reflectant vegetation. Abandoned-transitional land (reverting to forest), on the other hand, is grayish purplish red and marsh and alder swamps are grayish violet. Deciduous Kudzu vine, purplish gray in the spring, easily separates itself from all other vegetation when fall and spring images are viewed together.
II Urban III Transportation & utilities Home developments Recreation	Areas are light blue in the fall and very pale blue in the spring. Unfortunately, because of low resolution of LANDSAT data, secondary roads, minor roads, and most utility lines are not resolved.
WATER	
II Water III Clear lakes & ponds Turbid lakes & ponds Rivers & streams	Water is dark greenish blue in fall and light greenish blue in spring. Farm ponds of less than .4 hectare (1 acre) can be seen on LANDSAT images if there is sufficient contrast with background.

raphy most useful for forest inventory purposes because (1) a single photograph includes 8 to 10 counties, (2) a photograph can be enlarged to 1:125,000 without loss of information, and (3) a scaled map overlay of county boundaries can be used on the photograph without serious photographic distortion problems.

Generally speaking, forest land can be easily separated from nonforest land on S190B color photographs. There are some conflicts, however, where shadows, small bodies of water, streams, and idle land appear. Where forest land borders on nonforest land, shadows cast by timber stands on west- and northwest-facing edges blend with the forest and can cause misclassification bias in favor of forest land. Small bodies of water within forested areas are not easily separated from the surrounding forest—particularly pine forest—because, to the eye, both features have the same density and hue. Although small bodies of water within hardwood stands show more contrast with surrounding features, they too can be misinterpreted as pine. Idle land in many instances appears very similar to abandoned land stocked with hardwood and pine saplings. The difference is very subtle and can cause a bias in favor of forest land.

Pine land is easily separated from the deciduous hardwoods in November. The separation is made by density (tone) and hue to a limited extent. Pine is much darker than the leafless deciduous forest, and the ground cover under the deciduous forest is a gray-green. Because of a limited range in color hues, pasture, cropland, idle land, and wild range are difficult to separate. Graininess of the film gives the impression of texture that interpreters look for in idle, abandoned, or transitional land use types. Unfortunately, pasture land with this artificial texture appears very much like idle land. This confusion can be a problem in breaking down land use beyond broad classes.

All major roads and secondary roads are clearly visible, as are utility corridors. However, woods roads are difficult to see and secondary roads are not resolved where they pass through areas of little contrast—agricultural land, primarily.

Ground Truth

Ground truth for the forest inventory studies came from a number of sources. High-altitude aircraft (RB-57) color infrared (CIR) photography, Forest Survey ground sample data, and field checks were used independently, or together, as a basis for evaluating Skylab data interpretation. Because we lacked ground observations and aerial photography for these studies taken at the time of the Skylab pass, November 30, 1973, we had to rely very heavily on the RB-57 high altitude CIR photography taken on April 25, 1974. The quality of these photographs was excellent.

In the forest resource evaluation study we used 16-point photo cluster classifications made in 1971 on Agricultural Stabilization and Conservation Service (ASCS) panchromatic photographs, and a subsample of these clusters on the ground. These photographic and ground classifications included first- and second-level information for land use and forest stratification. Because these data were 2 years old at the time of this study, subsamples of locations were checked on the April 1974 CIR photographs, which were taken within 5 months after the Skylab pass. With only minor differences in agricultural use, the ASCS photographs reflected land use conditions at the time of the Skylab pass and showed where changes had occurred since the ground data were collected.

The ground truth for the forest sampling design study was derived from the April 1974 CIR photography and a ground check in December 1974 that included nearly 20 percent of the county.

Initial ground truth for the automated land classification study was obtained by using the April 1974 CIR photography. Photographs were selected from the coverage for two 10,000-meter-square (6.2-mile square) sample blocks to be used in developing and testing digitized Skylab film densities for land classification. These two blocks were located by random selection from the total number of 10,000-meter Universal Transverse Mercator (UTM) intersections within the four-county test site.

Ground truth maps were made for the two sample blocks in the following way:

1. The photo for each sample block was mounted on a Zoom Transfer Scope and enlarged five times to match a USGS 1:24,000 quadrangle sheet used as control (*fig. 3*). A 1000-meter (0.62-mile) grid template (10-by-10 grid) was placed over the outline of block in the control map to facilitate mapping.

2. Four forest and 27 nonforest classes (Level I I[illegible]) were delineated within each grid cell.

3. In five randomly selected cells, forest land was further subdivided into three stand-size classes: (1) seedlings and saplings, (2) poles, and (3) sawtimber. Recognition of the classes was based on a combination of crown closure, crown size, amount of bare soil, and arrangement of vegetation. These refined delineations were needed to explain discrepancies in automated classification.

In early December 1974, we visited the test site to check map classifications and to observe conditio[illegible]

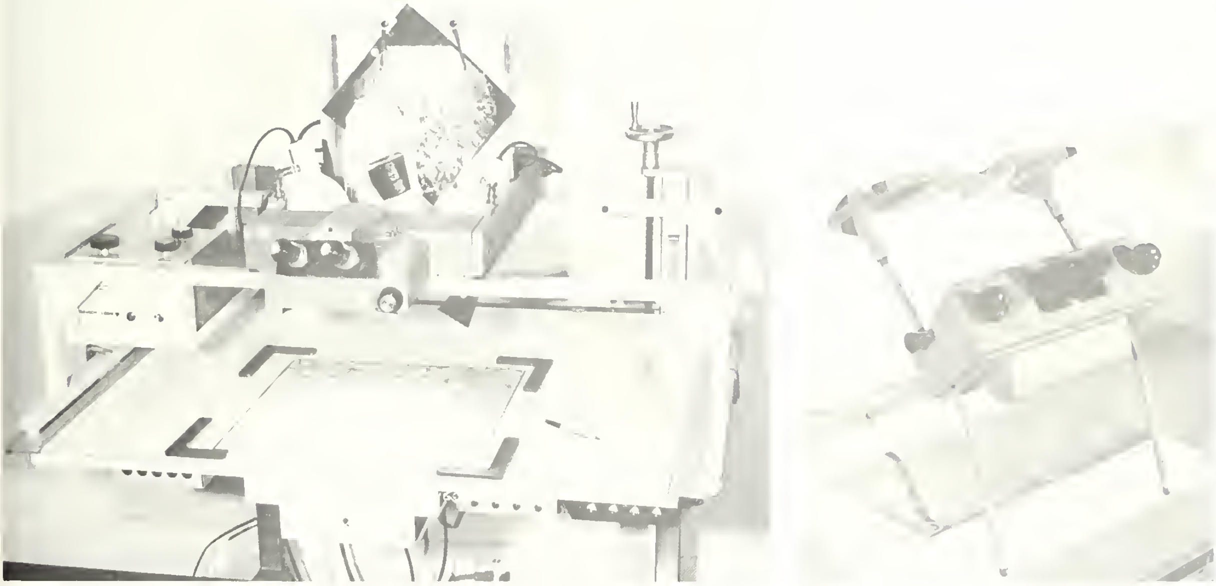


Figure 3–Zoom Transfer Scope (*left*) was used to interpret and transpose forest and related land use classes from 1:120,000 CIR photographs to a map control base. This instrument was also used to verify Skylab interpretations on 1:120,000 scale CIR photographs. An Old Delft scanning stereoscope (*right*) was used at 4X power to interpret overlapping 1:500,000 scale enlargements of S190B color photographs with stereoscopic effect.

that could affect land use interpretation. To aid in this effort, enlargements of the CIR aerial photographs were made on which land use, forest conditions, and other observations could be recorded directly in the field. Several photographic examples of local forest management practices that were found to affect image interpretation are shown in *figure 4*. Examples of land use on Skylab and high-altitude CIR were used in photointerpretation aids (*fig. 5*).

Finally, after the ground checks had been completed, the ground truth maps were adjusted and corrected where necessary. The maps were photographed and both prints and film overlays made to the scale of digital maps produced by the computer-assisted classification procedures. The map for block 4 was used to develop training sets for the computer classification algorithm and the map for block 2 was used to test the system once it was developed.

Procedures

Procedures used for the forest resource evaluation study differed from those for the sampling design study because the objectives were different. One study was geared to the current photo procedures used by the Forest Survey in the Southeastern United States (U.S. Forest Serv. 1968, pt. I, p. I-6). The other was designed to develop the test computer techniques for sampling digitized remote sensing data recorded on computer-compatible tapes.

Forest Resource Evaluation

To evaluate Skylab photographic imagery as a source of first-level information, we adopted the Forest Survey procedure followed in the 1971 inventory of the State of Georgia. This procedure included computing the regression coefficients for the relationship between photointerpretation results and ground truth for land use classes. First, an interpreter examined points in a design printed on 1:20,000 scale panchromatic aerial photographs purchased from the Agricultural Stabilization and Conservation Service (ASCS). The design consisted of 25 clusters of 16 points (4 by 4) in a systematic pattern on each photograph. Each point in a cluster represented a circular 0.4-hectare (1-acre) plot and was classified into one of five classes: (1) forest land, (2) urban and other,

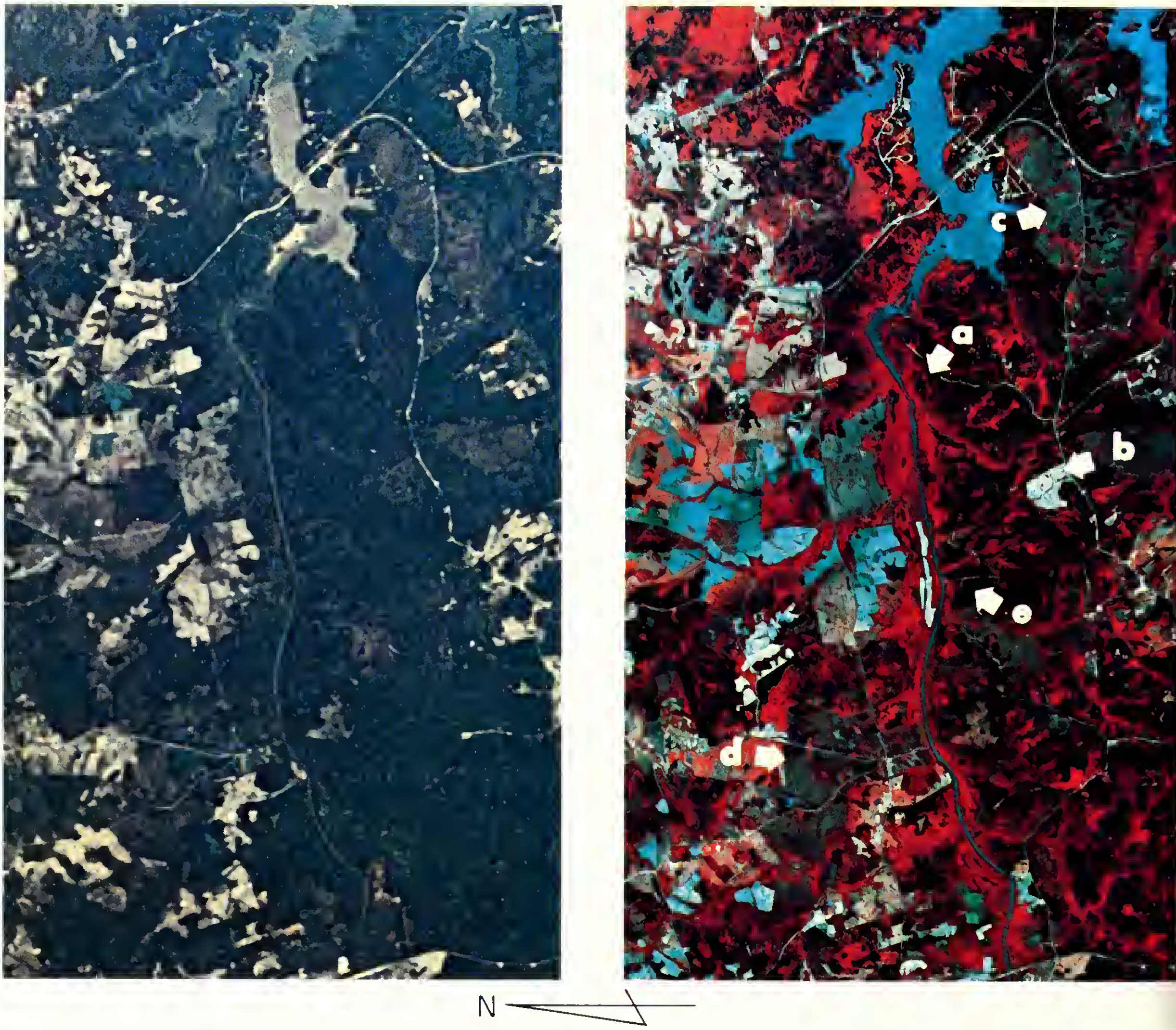


Figure 4–Forest management and other land use practices caused variations in image patterns on Skylab photographs. Examples are shown in the Skylab photo (*left*) and a corresponding CIR aerial photo (*right*), at a scale of 1:120,000. Intensive management of loblolly pine involves pure, even-aged stands. The stand at (*a*) has an average height of 19.8 meters (65 ft) and d.b.h. of 22.9 centimeters (9 in). These stands are the darkest images in the photograph with the exception of water and shadows. The clearcut area at (*b*) shows that debris has been windrowed and burned, and the soil harrowed for machine planting. Pioneering weeds and hardwood reproduction have not yet invaded the areas between rows. In (*c*) the pioneering species have filled in spaces between pine seedlings. Sometimes logging debris is still visible in windrows (*d*) because sapling-size pines are not large enough to completely cover the ground. Thinning operations before stand maturity remove every other row and appear as in (*e*).

(3) census water, (4) noncensus water, and (5) other miscellaneous land uses (a grouping of five agricultural classes). This sample was designed to estimate forest area within a sampling error of ±3 percent per million acres (404,858 hectares).

After interpretation was completed, a subsample of photo clusters was selected for ground examination at the time of the inventory. Each point in the clusters was located on the ground with the aid of the photographs, and the individual land use class was determined according to the Forest Survey hierarchical classification (*table 1*). Because the photographs, taken in 1967, were 5 years old at the time of the inventory, the subsample provided information that reflected changes.

From the photograph and corresponding ground-cluster classifications, the regression coefficients were computed for each land use class in the five-class

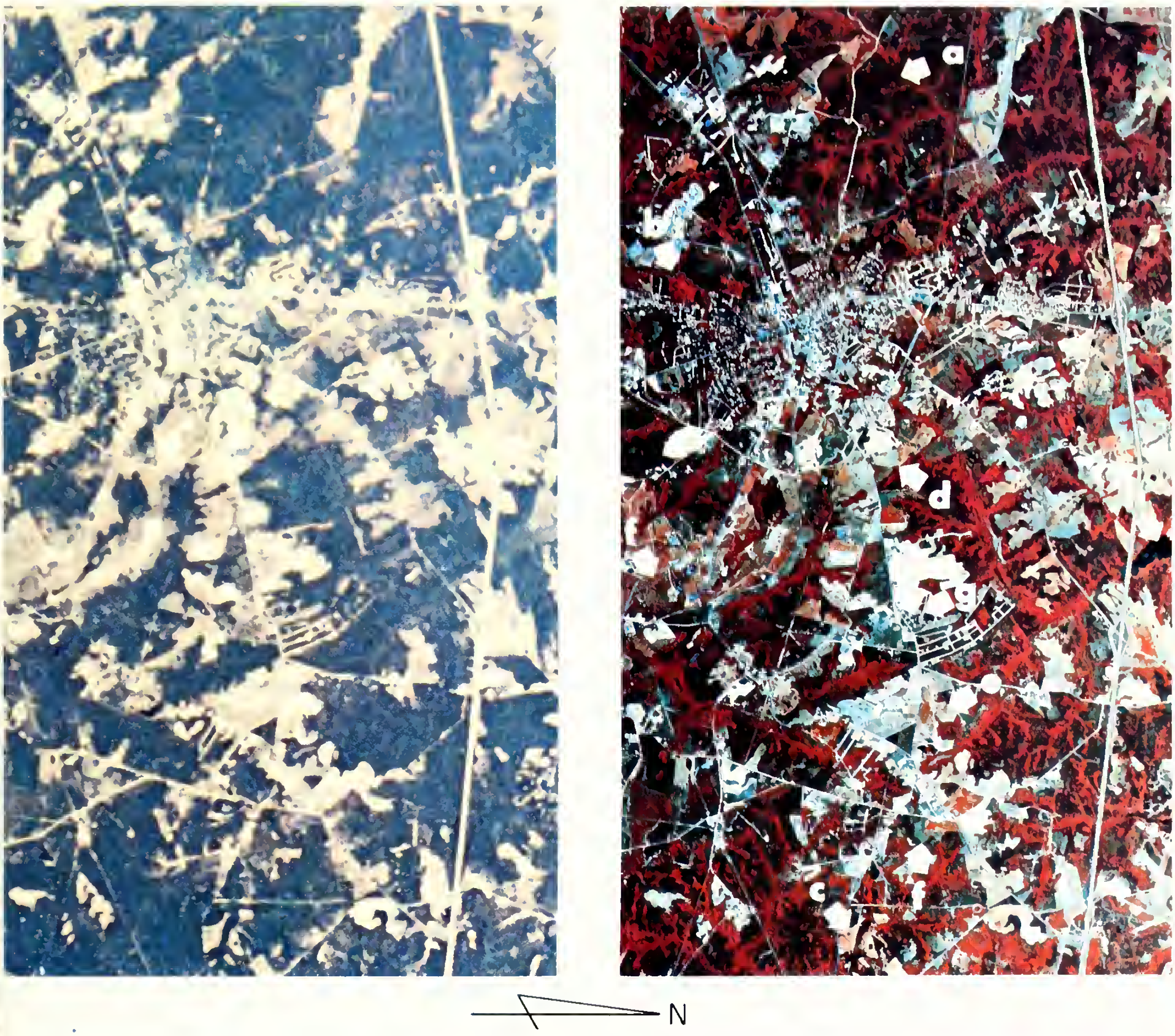


Figure 5–A Skylab sphotograph (*left*) and a 1:120,000 CIR photograph (*right*) were used in interpretation aids to illustrate the forest and related land use classes: (*a*) pine forest, (*b*) hardwood forest, (*c*) grassland, (*d*) cropland, (*e*) bare soil, (*f*) wild vegetation, (*g*) urban, and (*h*) water.

grouping. The proportions of points in the clusters were used as continuous variables in the computation.

Our evaluation of Skylab photographic imagery followed the Forest Survey procedure closely. All photo subsample clusters located on 1:20,000 ASCS photographs had to be located on Skylab photographs and the points classified by individual land use. This was accomplished using an Old Delft stereoscope (*fig. 3*). a scaled cluster template, and a photo illuminator.

Three separate evaluations were made. In the first, Lincoln County was used to test three combinations of Skylab photographic data to find the one most suitable for the remaining evaluations:

Combination 1: 1:250,000 enlargement of an *S190B color* photograph (*November* 30, 1973) made at *PSW*, and a 1:250,000 enlargement of an *S190A false-color* combination (*September* 12, 1973) made at *PSW*. Interpretation was without stereoscopic effect.

Combination 2: 1:500,000 enlargement of an S190B color photograph (November 30, 1973) made by *NASA/JSC*, and a 1:500,000 enlargement of an S190A false-color combination (September 12, 1973) made at *PSW*. Interpretation was without stereoscopic effect.

Combination 3: 1:500,000 enlargement of an S190B color photograph (November 30, 1973) made by NASA/JSC, and an *overlapping* enlargement of an *S190B color* photograph (*November* 30, 1973) made by *NASA/JSC*. Interpretation was with stereoscopic effect.

Forty 16-point photo clusters that had been subsampled on the ground in the 1971 forest inventory were located and interpreted, and the individual land use at each point was recorded. For the center point only, in each cluster, an additional record was made of stand origin, physiographic site, forest type, and disturbance class. This center point corresponds to the plot center used on the ground to record tree and stand conditions. A record of interpretation time was kept for each set of data. The data were then tabulated and processed by computer to determine differences between the three sets and to learn which compared most favorably with the ground truth.

A second evaluation of Skylab photographic imagery was made for the four-county area, using only combination 3, the NASA/JSC 1:500,000 scale color enlargements. We chose this only partly because it gave acceptable results on the first evaluation. In addition, we found that with this combination, the interpretation was faster, and the interpreter felt more confident of his classifications because the stereoscopic effect was helpful in making borderline decisions and the images were sharper.

In this second evaluation we located and interpreted all 210 16-point clusters in the four-county area by procedures identical to those used for the first evaluation. Classifications made on ASCS photography, on Skylab imagery, and on the ground were analyzed by both grouped and individual land use classes.

In the third and final evaluation, Lincoln County was used as a case study to test the hypothesis that Skylab photographic data could be used in the Forest Survey procedure to measure forest area within specified accuracy limits. For this evaluation, a 1:125,000 enlargement was made of one Skylab S190B photograph that covered the entire test site. A grid overlay of 16-point clusters was constructed to sample the photograph at an intensity very similar to that used by the Forest Survey Unit. The boundary of Lincoln County was drawn from a 1:250,000 USGS map sheet and an overlay was made to the scale of the photo enlargement. Interpretation was completed using a lamp magnifier. The grouped land use class was recorded for each cluster point. Forest type and disturbances were recorded for the cluster center. Time to complete interpretation was recorded for cost effectiveness analysis.

Using the proportions in each cluster as a continuous variable, computations were made for each grouped land use class in the photo sample according to procedures described in the Forest Survey Manual for the Southeast. Terms used in the computations were

- x = proportion of land use in a photo (ASCS) subsample cluster
- y = proportion of land use in a ground or Skylab subsample cluster
- p = proportion of land use in the photo sample cluster
- P = adjusted land use proportion in county
- a = regression constant
- b = regression slope coefficient
- n = number of clusters in subsample
- m = total number of photo clusters
- N = total number of sampling units in the population
- L = adjusted area in land use class
- A = total area being sampled

and

SS_y = corrected sums of squares of y

$$= \Sigma y^2 - \frac{(\Sigma y)^2}{n}$$

SS_x = corrected sums of squares of x

$$= \Sigma x^2 - \frac{(\Sigma x)^2}{n}$$

SP_{xy} = corrected sums of squares of cross products

$$= \Sigma xy - \frac{(\Sigma x)(\Sigma y)}{n}$$

$s_y{}^2$ = variance of y

$$= \frac{SS_y}{n-1}$$

Computations were made for

1. The mean proportions for individual land use classes using ground or Skylab data

$$\bar{y}_j = \frac{\Sigma_{i=1}^{n} (y_{ij})}{n}$$

in which

y_{ij} = proportion of the i^{th} cluster in land use class j

$\bar{y}_j$ = mean proportion in land use class j

2. The mean proportions for grouped land use classes using ASCS, Skylab, and ground data

$$\bar{y}_k = \frac{\Sigma_{i=1}^{n} (y_{jk})}{n}$$

in which:

y_{ik} = proportion of the i^{th} cluster in grouped land use class k

$\bar{y}_k$ = mean proportion in grouped land use k

3. Regression constant (a) and slope coefficient (b) as follows: for (1) the relationship between land use proportions on ASCS photographs and the corresponding proportions on the ground, (2) the relationship between land use proportions on the ground and the corresponding proportions on Skylab photography, and (3) the relationship between land use proportions on ASCS photographs and the corresponding proportions on Skylab photographs. The equation for adjusting land use proportions took the form

$$P = a + b\,(\bar{p})$$

4. The squared standard deviation from the regression for each method

$$s_{y.x}^2 = \frac{SS_y - \frac{(SP_{xy})^2}{SS_x}}{n-2}$$

5. The adjusted area for each combined land use class for each method

$$L = (P)(A)$$

6. The standard error of the adjusted forest area for each method expressed as a percent

$$s_p = \sqrt{s_{y.x}^2 \left[\frac{1}{n} + \frac{(\bar{p} - \bar{x})^2}{SS_x}\right]\left[1 - \frac{n}{m}\right] + \frac{s_y^2}{m}\left[1 - \frac{m}{N}\right]}$$

$$SE = \frac{(s_p)}{(P)}\,(100)$$ at the 67-percent level of confidence

Forest Sampling Designs

McDuffie County, in the Augusta site, was used to test the value of using Skylab photographic products in sampling strategies for obtaining Level I and some Level II land use statistics. These statistics are presently obtained for extensive forest inventories from aircraft photography and ground observations.

To provide a data base for evaluating several sampling strategies, a land use map (*fig. 6*) of the county was made by interpretation of 1:120,000 scale CIR photography from RB-57 Mission 274. All Level I land use classes (forest, nonforest, and water) and two Level II classes (pine and hardwood) were mapped at a scale of 1:50,000 from ZTS interpretation. A control base, enlarged from the 1:250,000 scale USGS Athens, Georgia, quadrangle, was placed on the ZTS mapping table (*fig. 3*), and class boundaries interpreted from the CIR photo on the easel were drawn on clear acetate overlaid on the map base. This method eliminated cumulative positional errors.

The photography used allowed rather easy, though time-consuming, interpretation into the four land use classes (pine, hardwood, nonforest, water). A ground check which covered nearly 20 percent of the county showed that the only potential classification problem was the distinction between idle farmland and transitional land reverting to forest. The decision on the ground is made on the basis of the density of natural stocking with commercial seedling species. Lands thus classified as forest are often plowed the following season and returned to farmland. Changes back and forth between forest and farmland can be quite rapid in this part of the country.

Besides the 20 percent sampling checked on the ground, 6 percent of the county was intensively mapped on the ground directly onto 1:10,000 scale photo prints, which were used to check the accuracy of the land use classification and correct the map produced from interpretation of high-altitude CIR photography. The resulting land use map is thus an accurate representation of the actual land use on the ground within the limits of the classification system used.

The land use map was used as a data base to try out different sampling strategies and to compare the results of computer classification from microdensitometer scans of a Skylab color transparency. To do this, however, we first had to digitize the map with a Bendix Data Grid. This was done in three steps: (1) a dot grid of 16 dots per square inch, representing approximately 50.3-meter (165-foot) spacing on the ground, was laid over the completed base map, (2) the map and grid overlay were oriented with the digitizer table, and (3) the digitizer Cursor was placed over each grid point and its mapped land use type was keypunched onto magnetic tape. Once the ground truth map was completely digitized and on magnetic tape, each grid point could be relocated on the tape by its line number and position in the line, using a tape-controlled plotting device (*fig. 7*) and a facsimile map plotted in color. This map could then be used to check against the original hand-drawn map; one data element in the plotted map represents 0.6 hectares (1.5 acres) on the ground.

When the ground truth had been digitized, the next step was to stratify land cover types in McDuffie County on Skylab imagery with a scanning microdensitometer. To determine if stratification would improve the efficiency of sampling, we first tried out a very simple type of land classification for a small

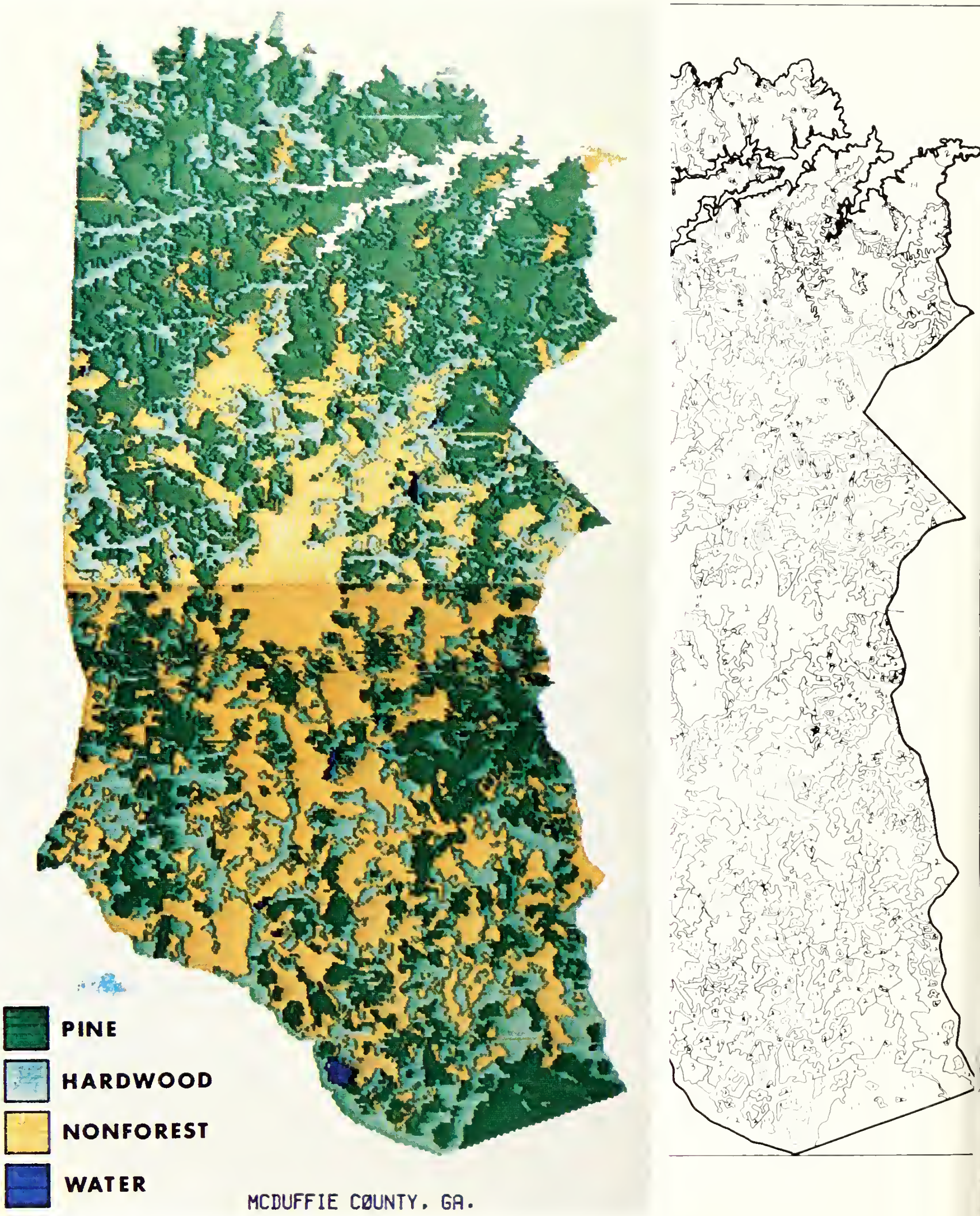


Figure 6–Land use maps of McDuffie County, Georgia, were produced by hand and by machine. The map shown in part at right was produced by conventional interpretation of 1:120,000 CIR photos. Geometric control was obtained by mapping onto a U.S. Geological Survey base map. (Land use classes mapped are 1-1, pine; 1-2, hardwood; 2, forest; and 3, water.) The colored map was produced by digitizing, at a resolution of 0.6 ha (1.5 acres), the hand-mapped data, and replotting with a computer-controlled plotter. The resolution of this map matches that of the microdensitometer data.

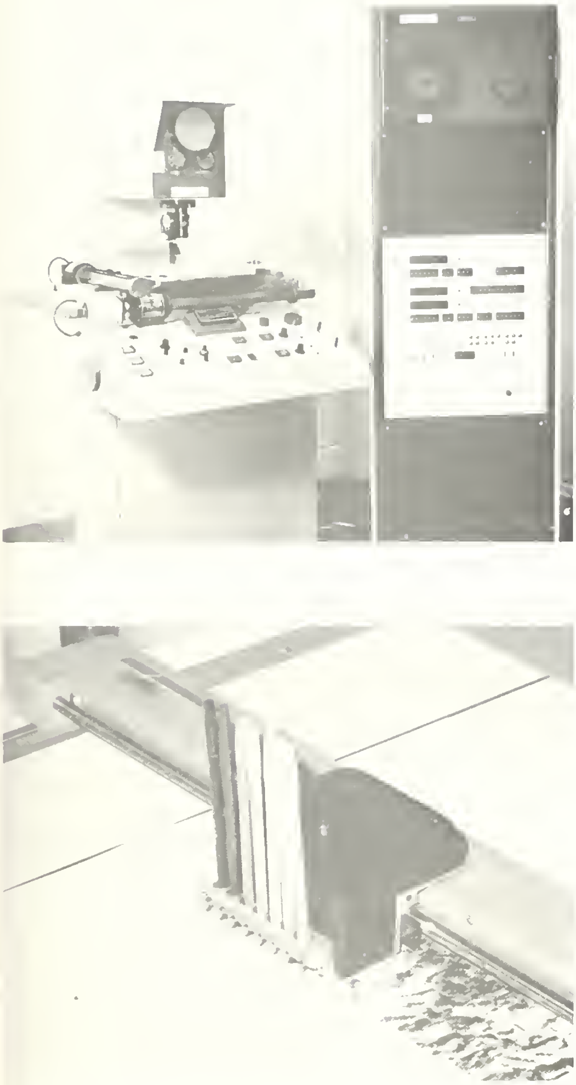


Figure 7—A Photo Data Systems automatic scanning microdensitometer (*above*) and companion model 2300 process computer were used to read and record film densities on CCT tapes. The Electronic Associates, Inc., tape-driven plotter (*below*) was used to plot color-coded classification maps.

portion of the county, using density slicing. Using a 9- by 9-inch (1:500,000) S190B color transparency from November 30, 1973 (mission SL-4), we programmed the microdensitometer to scan the selected area with a red filter (Wratten 92), and record film density at the same intervals and in the same matrix used to digitize the hand-drawn ground truth map; that is, in an array of 278 (x) by 539 (y), or 149,842 data elements. Next, using density ranges we had established on sample areas before the programmed scanning began, we classified each data point into one of the four land use types. The counterpart of each of these points could then be located on the data tape for the digitized land use map to determine the ground classification.

A facsimile gray-scale map was produced on a line-printer from the red-filtered microdensitometer scan of the Skylab S190B color image. Alphabetic characters were used to represent four optical-density ranges (density slices). These maps are stretched in the y direction because the spacing is greater between rows of characters than between characters along a row. Using this same procedure with digitized data from the ground truth map, we produced a geometrically similar line-printer facsimile for comparison. The two facsimile maps were compared and the registration appeared to be good. Based on this result, we went on to try a more powerful classifier using three spectral bands of microdensitometer data.

A more refined method of classification is linear discriminant analysis, using maximum likelihood and Gaussian assumptions. Training sets were located in the microdensitometer scan data matrices for each of the land use types identified on the ground truth map. Optical densities from the red, green, and blue microdensitometer scans, and generated statistics, were used to develop linear discriminant functions to classify the entire county into land use types from the Skylab data. A facsimile type-map was generated on a line printer using this classification procedure. This type-map is compared with the line-printer ground truth map (*fig. 8*). The land use map is stratified according to the resulting classification, and sampling effectiveness is compared with random sampling and with systematic sampling.

Having the ground truth map digitized as a regularly spaced grid of data points at 80.5-meter (264-feet) spacing allowed a comparison to be made among simple random sampling (SRS), systematic sampling (SYS), and systematic sampling with postsampling stratification on Skylab data (PSS) all at 16 different sampling intensities and on a "real" population. Characteristics of the systematic grid sampling at the different intensities are given in *table 3*. A computer program simulated placing of the grids over the ground truth map at all possible placements for each grid spacing. The percent sampling intensity and ground area per sample point in the table are based on the mean number of sample points falling in the mapped area for each grid spacing.

For each grid spacing the expected values of forest and nonforest proportions and the variance of the

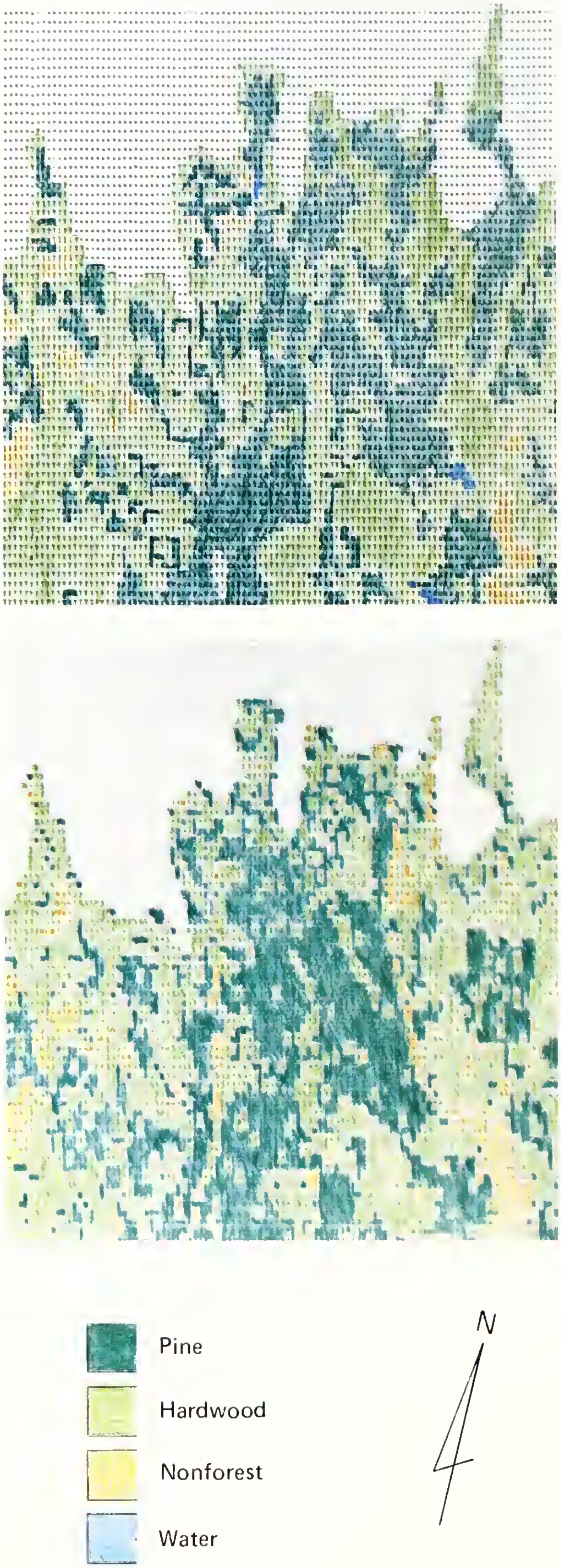


Figure 8–The land use maps shown here cover the northwestern portion of McDuffie County, Georgia, and were used in the test of sampling designs. The "ground truth" map (*above*) was produced from data digitized from the hand drawn land use map (*fig. 6*). The other map (*below*) was produced from the classification of microdensitometer scans on an S190B color transparency. Many nonforest areas, mostly roads or road segments below the minimum mapping size for separation on ground truth map, are shown on the microdensitometer scan map.

estimate were computed for all possible grid placements. From these statistics the sample bias and error of the estimate were measured.

Automated Land Classification

A Photo Data Systems (PDS) microdensitometer and companion Model 2300 process computer (*fig. 7*), a nearest neighbor classification algorithm developed for LANDSAT data (Aldrich and others 1975), and a CDC 7600 computer at the University of California Lawrence Berkeley Laboratory were used to classify land use in two 10,000-meter-square (6.22-mile-square) study blocks. (A more complete description of the procedure is available on request–see the Introduction.) The study blocks were located on one Skylab S190B color transparency (November

Table 3–*Characteristics of grid sizes used to sample a matrix for land use map, McDuffie County, Georgia*

Grid spacing (data elements)	Number of sample points	Ground spacing		Sampling fraction	Ground ar[ea] per sample poi[nt]	
		Meters	*Feet*	*Percent*	*Hectares*	*Ac[res]*
50	43	4,020	13,189	0.04	1,567	[illegible]
42	61	3,377	11,078	.06	1,106	[illegible]
36	82	2,894	9,496	.08	813	[illegible]
25	171	2,010	6,594	.16	392	[illegible]
21	242	1,688	5,539	.23	277	[illegible]
18	329	1,447	4,748	.31	203	[illegible]
14	544	1,126	3,693	.51	123	[illegible]
12	741	965	3,165	.70	90	[illegible]
10	1,066	804	2,638	1.00	63	[illegible]
9	1,317	724	2,374	1.24	51	[illegible]
7	2,176	563	1,846	2.04	31	[illegible]
6	2,962	482	1,583	2.78	23	[illegible]
5	4,266	402	1,319	4.00	16	[illegible]
4	6,665	322	1,055	6.25	10	[illegible]
3	11,849	241	791	11.11	6	[illegible]
2	26,660	161	528	25.00	3	[illegible]

30, 1973). One block was used to develop training sets and forest and nonforest classifiers; the other block was used to test the classifiers on a site some distance from where the classifiers were developed. The study blocks were purposely selected to satisfy two criteria: (1) each had to have a broad representation of land use types with a significant amount of forest and nonforest land and (2) the Skylab photo coverage for each site had to be complete. Boundaries of the two study blocks were delineated on acetate templates. The template was precisely oriented with the photos and fiducial marks; then major highways and other identifiable features were outlined with a fine drafting pen. These templates were used on the microdensitometer to orient the X, Y scans with the block boundaries but were removed before scanning began.

Block 4 was used to develop training sets and classifiers for 16 Level II and Level III forest and nonforest classes to be recognized in the study (*table 2*). Four scanning apertures (28 μm, 37 μm, 56 μm, and 74 μm) were used, and the microdensitometer was programmed to read densities from the photograph at an interval approximating the aperture diameter. This procedure avoided excessive data integration and redundancy: that is, the smallest area of interest for our classification purposes was 0.4 hectare (1 acre), and the range of aperture settings sampled the 1:900,000 scale photograph in units of effective ground area ranging from approximately 0.05 hectare (0.12 acre) at the 28 μm aperture to 0.35 hectare (0.86 acre) at the 74 μm aperture. The 37 μm aperture sampled approximately 0.09 hectare (0.20 acre).

The microdensitometer was calibrated before each run after the proper aperture setting and optical filter were in position. After each filter run, the filter was changed and the microdensitometer recalibrated. A run for the complete block was made for each aperture setting and for four filter settings—blue (Wratten-94), Green (Wratten-93), red (Wratten-92), and clear (no filter)—before continuing to the next aperture. In addition, a step tablet furnished with the SL-4 data package was scanned before the scanning began and again after the scanning was completed. This made it possible to convert microdensitometer optical density readings to NASA/JSC-PTD diffuse densities. The entire procedure was repeated for each of the four aperture scans.

Originally, we intended to evaluate aperture size by producing an eight-class land use map from each aperture scan. Time limitations would not allow this, however, and we had to modify the plan. Instead, we produced an eight-level gray-scale map for each aperture scan. From examination of the gray-scale maps, it was apparent that the 37 μm aperture resulted in a ground resolution that best suited the requirements of this study. Classifiers were then developed for the 16 land use classes and applied to the diffuse densities for block 4 using a nearest neighbor classification procedure.

A color-coded land use map was produced on an EAI tape-driven plotter for block 4 (*fig. 7*). The classifiers developed for block 4 were then extended to the data for block 2 and a plotter map was produced to determine the operational capability of the classification system.

Accuracy of computer classification was checked in two ways. The first method computed the proportional areas in each land use class and compared them with proportions determined from the ground truth map. A second method checked the positional accuracy. That is, the plotter map was overlaid with a systematic grid of 480 points for which the classification on the ground truth map was known. The classification was recorded and compared with its counterpart on the ground. Plotter maps for both blocks were checked in this way and the number of correct calls determined and analyzed. Points falling in five randomly selected 1000-meter cells with detailed classifications were checked to explain any discrepancies.

Results and Discussion

Results of the forest inventory studies—resource evaluation, sampling designs, and automated classification and mapping—varied, and must be compared with caution. Because each of the studies was carried out independently to meet a separate objective, study conditions differed. A recurring source of difficulty, however, was the problem of relating the established classifications used in forest inventory to the actualities of remote sensing data. Such data reveals land cover at a particular time, but does not necessarily indicate the land manager's intention for later use of the land. Ground surveys may determine, for example, that areas lying bare in early spring are in fact designed for agricultural or forest planting, whereas remote sensing can only indicate that the land is bare. A restructuring of land classifications to recognize what is present on the ground, rather than the intended use of the land, would simplify evaluation of the accuracy of remote sensing data for land classification.

Forest Resource Evaluation

The choice of a Skylab data combination for conventional visual interpretation had less effect on accuracy than expected. We reached this conclusion by comparing omission and commission errors for land use classification in one county, using three data combinations (see Procedures). Some omission and commission errors are caused by misinterpretation of the photo images. In many instances, however, the errors are the result of chance judgments. For example, a point falling on a boundary line between forest and cropland may be called "forest" by the interpreter but "cropland" by the field man. Also, the field man may make judgment errors, but they are usually ignored. These facts should be considered in comparing results of the Skylab interpretation with ground truth.

As described in the section on Procedures, combination 3, used to interpret land use in a four-county survey, consisted of overlapping enlargements of S190B color photos produced by NASA, viewed stereoscopically. Scale was 1:500,000.

Four-County Survey—A comparison of individual land use proportions resulting from the four-county survey shows close correlations between Skylab and ground truth for some classes (*table 4*). Only in pasture and idle land are discrepancies much greater than ±1 percent. The differences of −6.61 percent for pasture and +4.34 percent for idle land for the most part represent errors in classification—either on the ground or on the Skylab imagery—attributable to several causes. Some represent borderline judgments where a point falls on or near a field boundary; others reflect seasonal differences between the date of the imagery and the date the field crews located the points, and still others result from changes occurring after the ground data were recorded.

If cropland, pasture, other agriculture, and idle land classes are combined as "other miscellaneous," the difference is less apparent—0.1801 on the ground as compared to 0.1595 on the Skylab data (*table 4*). Because a major purpose of land use classification in forest resource surveys is to measure the forest area base, some inaccuracies in agricultural land use would not be a drawback—the estimate of forest land would be well within the accuracy limit of ±3 percent per million acres of commercial forest land. The data do indicate, however, that either "other miscellaneous" is slightly underestimated or there is a real increase in forest and urban area. This problem is discussed further in a later section of this report.

Increases in urban development during the 2-year span between ground and Skylab data acquisition can account for the greater proportion of urban area estimated from Skylab. Noncensus water measured on Skylab normal-color film is underestimated because small bodies of water cannot be distinguished when background contrast is low. This limitation would be overcome using CIR film.

Land use proportions listed by individual counties in *table 4* show much greater variation between Skylab and ground data than the grouped county data. The smaller sample size and the peculiarities of sampling are responsible. Normally, if area statistics by county are required, they should be based upon a much larger sample.

Table 4—*Summary of individual land use class proportions as determined by ground examination (July 1971) and by interpretation of Skylab photography (November 1973) for four Georgia counties*

Land use class	Proportion of land in use class									
	Columbia Co. (n=49)		Lincoln Co. (n=40)		McDuffie Co. (n=44)		Wilkes Co. (n=77)		All counties (n=210)	
	Ground	Skylab	Ground	Skylab	Ground	Skylab	Ground	Skylab	Ground	Skylab
Forest	0.6812	0.7283	0.6984	0.6812	0.6932	0.7088	0.7597	0.7597	0.7158	0.7268
Cropland	.0293	.0268	.0000	.0187	.0909	.0639	.0130	.0381	.0307	.0372
Pasture	.0867	.0166	.1062	.0304	.0582	.0171	.1542	.0811	.1092	.0431
Idle	.0294	.0867	.0110	.0578	.0356	.0852	.0390	.0682	.0307	.0741
Other agriculture	.0128	.0013	.0094	.0062	.0213	.0071	.0008	.0057	.0095	.0051
Other miscellaneous[1]	.1582	.1314	.1266	.1141	.2060	.1733	.2070	.1931	.1801	.1595
Urban	.0816	.0689	.0313	.0625	.0611	.0824	.0227	.0422	.0461	.0607
Census water	.0548	.0574	.1359	.1391	.0341	.0270	.0041	.0049	.0452	.0473
Noncensus water	.0242	.0140	.0078	.0031	.0156	.0085	.0065	.0000	.0218	.0057

[1] Cropland, pasture, idle, and other agriculture classes, grouped.

In this four-county survey of land use classification, we also attempted to classify certain forest conditions useful in resource evaluations: stand origin, physiographic site, forest type, and treatment class. Classification of *stand origin* into two categories, natural and artificial, was unsuccessful. Failure can be attributed to the ground resolution (20 to 30 m or 66 to 98 ft) of the color film. The effect of the ground resolution was to make all stands within types (pine type particularly) look alike.

Physiographic site was classified for 148 forest plots, but the restricted geographical area within the study site placed 90 percent of the plots in one category—rolling upland. Of these plots, 97 percent were correctly classified. No attempt was made to analyze the remaining data because the observations were too few to be relevant to normal operating conditions. It was observed, however, that stereoscopic coverage is essential to successful classification of physiographic site.

Forest types in the four-county area were classified correctly on Skylab S190B color only 50 percent of the time. Accuracies ranged from a low of 16 percent for mixed pine-hardwood to a high of 59 percent for pine. The distribution of 161 plots by Skylab and ground types is shown in *table 5.*

Two conclusions can be drawn from this test. First, mixed pine-hardwood cannot be separated from pine and hardwood with sufficient accuracy to be useful in resource surveys. The problem here is that a pine-hardwood classification is based on the decision rule, "Does pine comprise more than 25 percent but less than 50 percent of the stocking?" This rule can be tested by stem counts on the ground. On photographs, however, the decision must be based on crown counts, which cannot be accomplished at the resolution of the imagery used here. Second, upland and bottomland hardwood cannot be separated on normal-color film except in the most obvious situations. Experience with CIR film, however, indicates that high moisture content in bottomland sites can be detected during late fall, winter, and early spring seasons, with higher classification accuracies as a result.

On Skylab S190B color, forest types must be combined to maximize their usefulness. For instance, when pine and pine-hardwood plots are combined in a single pine class, the accuracy of classification increases to 73 percent—a much more respectable figure. Combining upland and bottomland hardwoods into a single hardwood class improves accuracy to 69 percent.

Treatment classes, redefined as disturbance classes for remote sensing, were classified for 40 plots in Lincoln County. To compare relative accuracy at three levels of remote sensing, classifications were made on LANDSAT-1, Skylab S190B, and 1:120,000 CIR photographs. The results are shown in *table 6.*

As would be expected, detection varies according to the ground resolution of the sensors and the level of disturbance. The greater disturbances, such as harvesting with artificial regeneration, and clearing or site preparation, are detected on LANDSAT-1 data. However, only 63 percent of the plots were correctly classified on LANDSAT imagery, against 80 percent on both Skylab and the RB-57 imagery. One explanation for failure to detect commercial thinnings and the more subtle disturbances might be the 1½- to 3-year time lapse between the ground observation and the imagery.

One-County Test of Forest Area Estimation—An estimate of the proportion of forest area in Lincoln County was made on a 1:125,000 color enlargement of Skylab S190B (November 30, 1973) using conventional interpretation techniques. As described earlier (Procedures), an overlay with 16-point sample clusters was used for an intensive sampling. The resulting proportion—the number of forest points divided by the total—was adjusted using regression coefficients derived from ground examination of a subsample of the 16-point clusters. The County mean adjusted forest land proportion estimate was compared with existing Forest Survey estimates, which had been determined from ASCS aerial photographs and similarly adjusted. Comparisons were also made between unadjusted grouped land use proportions for Skylab and ASCS, Skylab, RB-57 CIR photographs, and the ground. These comparisons help to evaluate the full potential of the Skylab photography.

The cluster overlay used on Skylab photos for Lincoln County sampled at a slightly higher intensity than the existing Forest Survey design. The Skylab overlay covered the entire county area, whereas the Survey design used every other photograph in alternate flight lines. Our design eliminated the chance of oversampling some classes and undersampling others. The results (*table 7*) show that, according to Skylab, the unadjusted forest proportion is almost 3 percent higher than that obtained from 4-year-old ASCS photographs; also, the "other miscellaneous" class has decreased, urban has increased, and both census water and noncensus water are reduced. These could be real differences detected by the more recent Skylab data and the improved distribution of the photo sample. Unfortunately, there is no way to check this because of the time lapse since the data were collected.

Table 5 *Distribution of forest plots by Skylab*[1] *and ground forest type classes in a four-county area, Georgia (correct calls underscored)*

Skylab class	Ground class					
	Pine	Pine hardwood	Upland hardwood	Bottomland hardwood	Nonforest	Total, Skylab
Pine	<u>54</u>	7	5	1	3	70
Pine-hardwood	20	<u>4</u>	1	1	2	28
Upland hardwood	13	12	<u>13</u>	1	2	41
Bottomland hardwood	1	2	4	<u>4</u>	0	11
Nonforest	3	0	1	1	<u>6</u>	11
Total, ground	91	24	24	8	13	161

[1] Stereoscopic interpretation of overlapping S190B photographs.

Table 6–*Accuracy of detecting disturbances by interpretation of data from four sources, Lincoln County, Georgia*

Disturbance class	Plots correctly classified			
	Ground	RB-57	Skylab	LANDSAT
No disturbance	22	21	21	19
Prescribed burn	1	0	0	0
Clearing, release, or intermediate cutting	5	4	4	1
High grading	1	0	1	0
Commercial thinning	7	3	2	1
Harvesting with artificial regeneration	1	1	1	1
Clearing of site preparation	1	1	1	1
Natural regeneration on nonforest land	1	1	1	1
Artificial regeneration on nonforest land	1	1	1	1
All classes	40 (100%)	32 (80%)	32 (80%)	25 (63%)

Table 7–*Mean proportions for grouped land use classes, computed from an intensive sampling on Skylab and aerial photography, and from a small subsample on Skylab, aerial photography, and ground observation, and used to compute adjusted values (Lincoln County, Georgia)*

Data sources	Total clusters	Forest	Other misc.	Urban	Census water	Non-census water
Intensive sample, unadjusted:		*Proportion of area*				
ASCS (1:20,000)[1]	536	0.6472	0.1351	0.0169	0.1725	0.0283
Skylab (1:500,000)	667	.6747	.1201	.0260	.1636	.0150
Difference		+.0275	-.0150	+.0091	-.0089	-.0127
Subsample, unadjusted:						
ASCS	40	.7094	.1313	.0156	.1375	.0062
Skylab	40	.6812	.1151	.0625	.1391	.0031
RB-57 (1:120,000)[2]	40	.6984	.1266	.0313	.1359	.0078
Ground	40	.7141	.1250	.0187	.1391	.0031
Intensive sample, adjusted:[3]						
ASCS	536	.63753				
Skylab	667	.69229				
Difference		+.05476				

[1] Panchromatic aerial photography, by Agricultural Stabilization and Conservation Service.
[2] High-altitude color infrared aerial photography by NASA.
[3] Adjusted using regression equations developed from small subsample. Adjusted forest area and standard error of estimate are 42,123 ha ±3.17 percent for ASCS and 45,741 ha ±3.53 percent for Skylab.

For the 40-cluster subsample examined on Skylab and ASCS photographs and on the ground to classify land use in Lincoln County by grouped classes, the unadjusted forest proportion estimate from Skylab data was almost 2 percent lower than the ground check and 3 percent lower than the ASCS photo estimate (*table 7*). The latter is a complete reversal from the estimate made from the more intensive sample and reflects differences in the two samples. The subsample apparently fell in areas under development for homes at a greater intensity than the larger sample. The larger proportion of land area estimated in the urban class on both the Skylab photos and the ground seems to indicate this. Interpretation of forested areas within residential developments as urban resulted in an over-estimate of urban and an underestimate of forest land. Errors of this sort can be avoided by improving the criteria for interpreting urban land.

The 40 subsample clusters were examined on 1:120,000 scale CIR photographs to verify the mean Skylab proportions (*table 7*). Here forest proportion was found to be more than 3 percent higher and urban 4 percent lower than on the Skylab imagery. This result seems to support the conclusion that urban developments within forested areas are overestimated on Skylab. Because the ground estimate of urban is higher than either Skylab or ASCS, the CIR estimate can be assumed to be low; the true proportion of urban area is presumably nearer 3 percent.

The adjusted Skylab estimates for forest area, 3600 hectares (8892 acres), were 8.6 percent higher than the ASCS estimates. Despite this, the standard error of the adjusted forest area estimate using Skylab data was ±3.53 percent–slightly higher than the adjusted estimate on ASCS photography. The difference in the estimates can be attributed to differences in sampling intensity, sample distribution, and misclassification of urban areas as forest land.

Forest Sampling Designs

The area of commercial forest land summarized from the digitized land use map for McDuffie County (hereafter called the ground truth map) and the area of commercial forest from the 1971 Forest Survey agree closely (69.6 percent map, 69 percent Forest Survey). The Forest Survey gives no information, however, on the location of commercial forest and other land use types; therefore, no cross-checks can be made with the ground truth map. The area of noncensus water (defined in *table 1*) in the county, according to the survey, is less than 2 percent. The mapped area of noncensus water differs from the Forest Survey figure primarily because much of the water was excluded from the land use map where the

Table 8–*Bias and variance for estimates of forest proportions made by three sampling methods (SRS, simple random sampling; SYS, systematic sampling; and SYS-PSS, systematic sampling with postsampling stratification) for 16 sampling fractions, McDuffie County, Georgia*

Grid spacing (data elements)	Sampling fraction	Bias of forest proportion			Variance of forest proportion		
		SRS	SYS	SYS-PSS	SRS	SYS	SYS-PSS
	Percent						
50	0.04	0	0.0006	0.0008	0.00495	0.00412	0.00334
42	.06	0	.0000	.0005	.00350	.00278	.00241
36	.08	0	.0002	.0007	.00257	.00231	.00181
25	.16	0	.0001	.0003	.00124	.00075	.00074
21	.23	0	.0000	.0000	.00087	.00057	.00052
18	.31	0	.0000	.0000	.00064	.00035	.00032
14	.51	0	.0000	.0000	.00039	.00015	.00018
12	.70	0	.0000	.0001	.00029	.00014	.00015
10	1.00	0	.0000	.0000	.00020	.00011	.00010
9	1.24	0	.0000	.0000	.00016	.00007	.00008
7	2.04	0	.0000	.0000	.00010	.00004	.00005
6	2.78	0	.0000	.0000	.00007	.00003	.00004
5	4.00	0	.0000	.0000	.00005	.00002	.00002
4	6.25	0	.0000	.0000	.00003	.00001	.00001
3	11.11	0	.0000	.0000	.00002	.00001	.00001
2	25.00	0	.0000	.0000	.00001	.00000	.00001

Ground truth map, Augusta, Ga., block 4; 1:120,000 CIR photo by NASA, April 1974

1 Pine
2 Pine-hardwood
3 Upland hardwood
4 Bottomland hardwood
5 Undisturbed grass
6 Disturbed grass
7 Dead grass
8 New improved grass
9 Immature grain
10 Immature row crop
11 Mature crop
12 Harvested crop
13 Orchard
14 Farmstead
15 Plowed field
16 Erosion
17 Site preparation (urban)
18 Rock
19 Idle land
20 Abandoned land
21 Transitional
22 Kudzu
23 Marshland
24 Alder swamp
25 Transportation and utilities
26 Home developments
27 Commercial developments
28 Recreation
29 Clear lakes and ponds
30 Turbid lakes and ponds
31 Rivers and streams

Figure 9–Ground truth, a Skylab photo, and a map made from the Skylab data by computer-assisted methods can be compared point-to-point here. The computer map (*opposite*) was made using diffuse densities converted from optical densities measured on the S190B photograph. The photograph was scanned with a microdensitometer and the optical densities were digitized and recorded on tape. The map was then produced by the computer classification system developed at Pacific Southwest Station, using nearest-neighbor theory and an off-line tape-driven plotter with eight colored marking pens.

Skylab S190B Nov. 1973

Computer map

northern boundary of the county crosses Clark Hill Reservoir, and could not be accurately located. Noncensus water, therefore, is included with all other nonforest for stratification purposes in this study.

Linear discrimination functions used to stratify three Level I and two Level II land use types could not separate pine and hardwood with sufficient accuracy for inventory purposes. Thus, all forest land was aggregated into a single forest type for further analysis. The confusion matrix for the training set shows only 5.3 percent of the total forest data elements (506) called nonforest and only 17.7 percent of the total nonforest data elements (615) called forest. For the entire population, 19.5 percent of the total forest data elements (74,290) were called nonforest; 30 percent of the total nonforest data elements (32,351) were called forest. These classifications were used to test systematic sampling with postsampling stratification in the following comparison of sampling methods.

Systematic sampling and simple random sampling for forest proportions are compared in *table 8*. The maximum bias was 0.0006 for the smallest sampling fraction (0.04 percent); for sampling fractions (0.23 percent and greater, the bias was less than 0.00005. The variance for SYS was smaller than for SRS in every case. The advantage increased as the sampling fraction increased.

The systematic sample was repeated, but this time the type-map classified from microdensitometer scans of Skylab imagery was used for postsampling stratification. The biases again were negligible, although larger than for SYS. The variance using SYS and PSS was smaller than for SYS alone for the smallest sampling fractions. At a sampling fraction of 0.04 percent the variance is 19 percent lower than SYS and 50 percent lower than SRS. The advantage of using postsampling stratification with systematic sampling quickly decreases as the sample size is increased.

The study has shown that forest area proportion is more efficiently determined using systematic sampling rather than simple random sampling when applied to an area with forest distribution as in McDuffie County, Georgia. The precision of the estimate is further increased by using postsampling stratification from the computer classification of Skylab S190B microdensitometer data. However, there is no advantage when the sampling fraction is larger than 0.16 percent. If it had been possible to direct more effort to developing better discriminant functions for the supervised Skylab data classification, an advantage might have been shown for larger sampling fractions.

Ground truth map, Augusta, Ga., block 2; 1:120,000 CIR photo by NASA, April 1974

1 Pine
2 Pine-hardwood
3 Upland hardwood
4 Bottomland hardwood
5 Undisturbed grass
6 Disturbed grass
7 Dead grass
8 New improved grass
9 Immature grain
10 Immature row crop
11 Mature crop
12 Harvested crop
13 Orchard
14 Farmstead
15 Plowed field
16 Erosion
17 Site preparation (urban)
18 Rock
19 Idle land
20 Abandoned land
21 Transitional
22 Kudzu
23 Marshland
24 Alder swamp
25 Transportation and utilities
26 Home developments
27 Commercial developments
28 Recreation
29 Clear lakes and ponds
30 Turbid lakes and ponds
31 Rivers and streams

Figure 10—The computer map (*opposite*) was made by the same method used for the map shown in *figure 9*. Spectral signatures developed for block 4 were used in this classification without modification. Point-by-point evaluations can be made with the ground truth map (*above*).

Skylab 190B Nov. 1973

Computer map

The classification effort pointed out the difficulty of trying to classify photo data into categories which reflect the intent of land use rather than actual ground conditions. With the inevitable revision of resource classification systems into a common and aggregative type of inventory system it should be possible to use unsupervised classification more effectively to provide a useful data stage for future sampling systems.

Automated Land Classification

Optical film densities measured on normal-color film (S190B), and analyzed by the nearest-neighbor classification algorithm, showed promise for computer-assisted land classification. Only broad Level I land classes and Level II forest types, however, could be separated with reasonable accuracy (*table 9*). For instance, in block 4, pine area was classified 17 percent lower and the hardwood area 40 percent higher than ground measurements. The latter difference seems high, but considered as a percentage of the total area it is only about 6.5 percent (22.82 percent vs. 16.28 percent). In block 2, pine area was classified 19 percent lower and hardwood 14 percent higher than ground truth, even though block 2 was classified using training sets derived from block 4–61 kilmoeters (38 miles) away. The total forest area in block 4 was 6 percent higher than ground truth. Pine was always underestimated and hardwood was always overestimated.

Total nonforest area, like total forest area, was estimated within reasonable accuracy–block 4 within 11 percent and block 2 within 7 percent–and both were underestimated. Area estimates by Level II nonforest classes varied considerably from the ground truth and can be explained by seasonal differences between the Skylab data (late November) and the ground truth (late spring). This problem will always arise in machine classification unless land classifications are restructured to recognize what is present on the ground rather than an interpretation of the intentions of local land managers. The best time of year to measure the landowner's intended use is in the late spring, when the fields are plowed or planted and can be separated from grassland and idle land.

Areas of water and urban land estimated in both blocks 4 and 2 in some instances appear to be quite accurate. This is misleading, however, because major bodies of water in both blocks were called bare soil, grassland, and crops. Water was misclassified because high levels of sedimentation created false signatures. Urban areas were misclassified as grassland, bare soil, and crops, because on color film the spectral signatures are very similar. Roads and utility rights-of-way, passing through forested areas, can be detected by the spatial alignment of digital elements but not by their spectral characteristics.

The computer maps shown in *figures 9* and *10* can be visually compared with both the Skylab S190B photograph and the ground truth map. The agreement between Level I forest areas and nonforest areas, and between Level II forest types, is quite apparent. A point-by-point comparison was made between the ground truth map and the computer map. We found that 92 and 93 percent of forest points were correctly classified on the computer map for blocks 4 and 2, respectively, *table 9*). Of the points in pine type, 70 percent (block 4) and 83 percent (block 2) were correct. Points falling in hardwood were correct 68 and 74 percent of the time for blocks 4 and 2, respectively. Although nonforest points were found accurate 74 percent (block 4) and 85 percent (block 2) of the time, the accuracy for individual Level III classes was extremely poor.

The results show that forest area can be stratified on Skylab-quality photographs (20- to 30-meter resolution) with an accuracy of approximately 96 percent. In other words, the forest area can be mapped and an estimate of the area made within the limits that can be met using aerial photographs. We also found this to be true in our LANDSAT-1 experiment (Aldrich and others 1975). Geometric distortions in the LANDSAT image, however, did not allow more than 50 percent accuracy in point-by-point comparisons.

Applications

Under certain assumptions, Skylab-quality photographs will provide a data base for Level I and Level II land use and broad forest-type stratifications (as defined in this report) by both human and machine-assisted procedures. The assumptions are that

1. High resolution color infrared photography is available.
2. Radiometric measurements by supporting aircraft flights are available within a few days of a satellite pass.
3. A high-speed scanning microdensitometer is available for recording optical film density on computer-compatible tape.
4. An off-line minicomputer and interactive display (CRT) are available for preprocessing remotely sensed data for input to a large nondedicated high-speed computer for classification mapping or sampling. If a minicomputer is not provided, an interactive display—on line with a dedicated large, high-speed computer—must be available.
5. A classification system is designed which is based upon land cover rather than land use intent.

In this investigation, normal-color photography taken from orbital altitudes did not allow complete land use classification even at Level I. Here the failure of both human and automated classification procedures to resolve differences between water, grassland, bare soil, and idle land was important. Examples of Skylab CIR photographs for nearby areas indicated, however, that the infrared reflectance and absorption differences for these classes will provide excellent separation. Thus, if CIR film is available, both human

Table 9—*Accuracy, based on ground truth, of area estimates a*
point classification for PSW computer mapping of two test bl
Skylab S190B color photography, November 30, 1973

Block and land-use class (Levels I & II)	Area, ground[1]	Area, Skylab	Number of sample points	C
	Ha	*Percent*	*Percent*	
Block 4	6055 60.55	64.41	290	
Block 4				
I Forest	6055 60.55	64.41	290	
II Pine	4427 44.27	36.62	217	
Hardwood	1628 16.28	22.82	73	
Cutover	--[2] –	4.97	0	
I Nonforest	3616 36.16	32.14	180	
II Grassland	1548 15.48	9.51	78	
Crops	61 0.61	6.57	2	
Bare soil	881 8.81	6.90	52	
Wild vegetation	441 4.41	4.96	26	
Urban	685 6.85	4.20	22	
I Water	329 3.29	3.45	10	
Block 2				
I Forest	5151 51.51	53.48	271	
II Pine	3327 33.27	26.95	150	
Hardwood	1824 18.24	20.84	121	
Cutover	--[2] –	5.69	0	
I Nonforest	4721 47.21	44.04	204	
II Grassland	1473 14.73	8.25	57	
Crops	151 1.51	5.00	23	
Bare soil	700 7.00	22.92	33	
Wild vegetation	805 8.05	4.41	26	
Urban	1592 15.92	3.46	65	
I Water	128 1.28	2.48	5	

[1] Areas were determined by dot count on ground truth intensity of approximately one dot per 0.4 hectare (1 acre).
[2] Cutover land was not classified separately on the ground cutover forest land was placed in the appropriate forest typ

and computer classification of land use and forest type should be more effective.

In operational applications of machine-assisted classification of Skylab-quality photographs, spectral differences within and between photographs, and between seasonal (temporal) coverage, caused by changes in solar angle and atmospheric interference, will be limiting factors (see "Measurement of Forest Terrain Reflectance"). If, however, satellite photographic coverage is either preceded by, or followed by, radiometric measurements from a low-flying aircraft, then correction factors can be computed and applied to the data. This would permit extension of ground truth and reduce costs. The radiometric data must be collected within a few days of an overpass under similar atmospheric conditions.

Although mapping of all the forest and rangeland (610 million hectares or 1.5 billion acres) in the United States may some day be desirable, limitations in computers and computer storage make this somewhat unlikely for extensive inventories at the present time. Instead, it is much more reasonable to think of sampling applications. For example, this report demonstrates that a systematic sample grid can be overlaid upon digitized land use map data by computer to estimate forest area within a county—the variance was always lower than simple random sampling. Using Skylab normal-color film to classify forest and nonforest land in one county (100 percent) resulted in an accuracy of 80 percent for forest land with a 30 percent commission error. Forest cover types and other land cover types may be estimated by sampling digitized data from future satellite coverage if CIR film is made available and if a classification system on the land cover rather than intended use is designed.

Classification System Alternatives

The Forest Survey definition of forest land illustrates the problems and inefficiencies of using a data-gathering system which views present land cover in order to classify use based on the intent of the manager. Using this definition, a clearcut area prepared for planting would be considered forest although no trees were present. Computer-aided classification would probably classify the area as bare soil. In some parts of the country a forest opening of bare soil might be assumed to be a clearcut to be planted, but in the Southeast the area is just as likely to be agricultural land.

There is much greater probability of high accuracy if classification is made in terms of present land cover. The spectral signatures of classification based on present land cover have inherently less variability than those based on intended use, which may include diverse land-cover categories. It is true, however, that a system based solely on land cover, although appealing from the standpoint of identification from remote sensing data, may not be amenable to aggregation and disaggregation into the classes desired by the data users.

An alternative classification system might be one that makes use of information directly attainable from satellite data and calls for a separate subsample of those classes not well characterized by the land cover. Before the system could be implemented, however, it would be necessary to know the land cover types that can be recognized in a given region. To date, most studies have concentrated on determining the accuracies attainable when classifying land into predetermined categories. Results of these studies have often been discouraging because a satisfactory classification accuracy could not be attained for the predetermined categories. At the same time, the possibilities for further subdivision within easily identified categories went unexplored. We feel that operational applications of machine-assisted classification

Table 10—*Comparative cost of land use and forest stratification on Skylab photographs and on 1:20,000 ASCS photographs*

Item and basis		Cost	
		ASCS	Skylab
Photo handling	Ordering, organizing and labeling photographs and transferring plots $5 per hour.	$140.00	$125.00
Photography cost	1974 ASCS price list; cost of one S190B color internegative and one 1:125,000 color print.	366.00	100.00
Photo-interpretation	Land use: ASCS at 5 clusters per minute, Skylab at 3 clusters per minute $5 per hour; forest type classification: ASCS at 40 plots per hour $5 per hour.	36.35	50.90
Total		$542.35	$275.90

will depend on additional research to determine the land cover categories which are, and those which are not, spectrally separable with acceptable accuracy.

Cost Comparisons

The primary advantage of Skylab-quality photography in forest resource surveys is the broad areal coverage within a single frame. In the four counties used in this experiment, 183 aerial photographs (1:20,000) were required to cover an estimated 80 percent of the total area. This was single photographic coverage without the advantages of stereoscopic overlap. A Skylab S190B photograph, on the other hand, can cover these four counties and two to four additional counties as well. Complete county coverage offers better distribution of photo samples and reduces data handling and photo acquisition costs--assuming that only printing and processing costs are considered.

If all other survey costs are assumed equal, the costs of Level I and Level II land use and forest stratification would be 49 percent lower on Skylab photographs than on conventional 1:20,000 scale photographs (*table 10*). The major difference between the two methods is the cost of photographs. The small scale of Skylab photos and the use of normal-color film meant that more time was required to make interpretative decisions on Skylab. However, if color infrared photographs were available on a regular recurring basis, time would be somewhat reduced, and the advantages of up-to-date information would far outweigh any additional interpretation cost.

Because of variations in system efficiency and effectiveness, it is difficult to compare conventional interpretation and computer-assisted classification and mapping techniques. Numerous computer classification procedures are now available for resource analysis, but there have been no comparative tests. Computers and accessories vary widely. There are nondedicated computers accessed through terminals on a time-sharing basis, dedicated computers with on-line interactive displays, and complex systems including off-line minicomputers and interactive displays to preprocess data for classification and mapping on large computers. An analysis of the efficiency of one system over another is lacking.

In this study a system was used that included a nearest-neighbor classification algorithm and tw[o] time-sharing computers. Without an interactive dis[-]play, two or more iterations of the classification[s] were required to improve accuracy. This is more tim[e] consuming than an interactive display and less eff[i]cient. The cost breakdown in *table 11* compares ou[r] PSW computer-assisted technique with convention[al] mapping and transfer procedures on a ZTS. Althoug[h] the computer technique was more expensive ($17[...] more), it required only one-fourth the man-hour[s]. Thus, when manpower and time are short, th[e] machine-assisted system would be beneficial despi[te] the higher cost.

Table 11--*Comparison of cost of producing classification m[...] 40,000 hectare (98,800-acre) area using conventional mappi[...] computer-assisted techniques on CIR photography*

Method and task description	Time used		Cost	
	Man-hours	Machine-time	Man-hours[1]	Ma[...] t[...]
			— dollar[...]	
Conventional interpretation				
Map and transfer class boundaries from 1:120,000 CIR to 1:24,000 map base	100.00	0	617	
Computer-assisted classification				
Microdensitometry	2.00	4 h	12	[2][...]
Computer classification:				
HIST–rewrites raw density tape and interleaves scans	0.50	356 s	3	
IGREY–grey-scale printout; area location, training set selection	16.00	560 s	99	
TAPEJOB–rewrites tape from HIST in BCD	0.25	700 s	2	
PROTO–produces sums of data used in TYPEPIX	2.00	6 s	12	
TYPEPIX–produces classification map (4 parts) on EAI plotter	4.00	389 s	25	[5][...]
Total	24.75	4.56 h	153	

[1] GS-9, $6.17 per hour rounded to the nearest dollar.
[2] Commercial rate, $60 per hour.
[3] Univac 1108; $0.09 per second.
[4] CDC 7600; charged for 34 accounting units (AUS) at $0[...] AUS. Averages out at $0.38 per second.
[5] CDC 7600; average for 4 runs = 218 AUS at $0.07/AUS. A[...] $0.63 per second.

RANGE INVENTORY

Classification and Mapping of Plant Communities

Richard E. Francis Richard S. Driscoll

The primary objective of the research at the Manitou site was to determine at what classification level Skylab photographic products, or their equivalent, can be used for plant community classification in a central Colorado mountainous area. Secondary objectives were (1) to determine the kind of aircraft support photography needed to extend these classifications to other levels in the hierarchy, (2) to determine how both Skylab and aircraft support photography can be used to detect and identify cultural features of a mountainous landscape that could affect resource management alternatives, and (3) to make quantitative estimates of certain plant community characteristics from large-scale aircraft photography.

This is the latest in a series of studies that began in 1967 to evaluate remote sensing technology for range inventories. The Rocky Mountain Forest and Range Experiment Station, located in the center of a variety of range plant community systems, was a proper focal point for this research.

Initial studies conducted in 1967 investigated large-scale 70-mm color and color infrared (CIR) photographs (1:600 to 1:4600) for identifying plant species (Driscoll 1969). The conclusion from this work was that major rangeland species can be identified most consistently on 1:600 and 1:1200 scale CIR photographs.

In 1968, the Rocky Mountain Station entered into a 4-year study under the NASA Earth Resources Aircraft Program to evaluate multiband photography and multispectral scanner imagery taken from both aircraft and spacecraft. Results indicated that CIR photographs taken from space (Apollo 9, 100-meter ground resolution) can be used to map general plant community systems (Driscoll and Francis 1972). Larger scale (1:20,000 to 1:80,000) aircraft photographs with 3- to 10-meter ground resolution were required, however, to determine the areal extent of the individual habitat types. Still larger scale aerial photographs (>1:2400) were needed to analyze community components. Initial efforts to relate optical film density measured on small-scale CIR photographs to plant communities showed promise.

In 1972, the Rocky Mountain Station and its range inventory research team initiated a study to assess the value of low-resolution (65- to 100-meter ground resolution) LANDSAT-1 (ERTS-1) multispectral scanner data for classifying plant communities (Driscoll and Francis 1975). This study showed that LANDSAT imagery acquired in August was best for the first level of classification. Aspen can be reliably separated from conifer only during this time of year (92 percent accuracy). Conifer and grassland, on the other hand, can be classified on June-to-September LANDSAT and high-flight aerial photos with 95 to 99 percent accuracy. Regardless of season, interpreters could not classify to the second level with acceptable results. An analysis of optical film density measured on LANDSAT photographic color composites showed highly significant differences between all first-level vegetation classes. Thus, automatic scanning of LANDSAT photographic data and computer-assisted classification of first-level vegetation classes seemed possible.

Skylab photographs used in this study have better ground resolution (S190A, 30 to 120 meters; S190B, 20 to 30 meters) than either Apollo 9 or LANDSAT images. An evaluation of this improved data was important for planning future earth resources satellite programs for forest-rangeland assessments.

Study Area

The study area lies between 38°30′ and 39°30′ north latitude and 104°40′ and 106°10′ west longitude and covers approximately 14,000 km^2 (5400 sq mi; *fig. 11*). Included within the area is the NASA/Manitou Test Site, No. 242. This nonurban, nonagricultural area in central Colorado is characterized by extreme diversity in plant community systems and extreme variations in topography. The vegetation in the area consists of a variety of forests and grasslands. The forests, ranging from approximately 1900 m (6232 ft) above mean sea level to tree line at approximately 3500 m (11,480 ft), include: (1) ponderosa pine, (2) Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco), (3) lodgepole pine

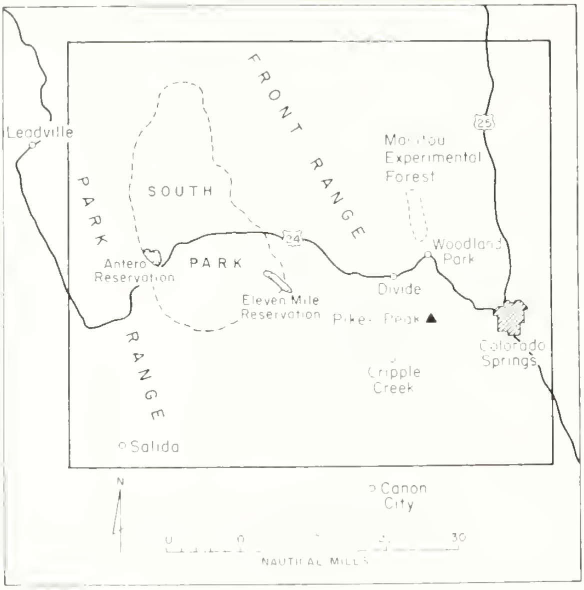


Figure 11–The mountainous central Colorado study area includes two intensive test sites, South Park and the Manitou Experimental Forest. Colorado Springs is near the southeast corner of the area.

(*Pinus contorta* var. *latifolia* Engelm), and (4) spruce /fir (*Abies lasiocarpa* [Hook.] Nutt.) Intermingled throughout the area are deciduous forests of quaking aspen (*Populus tremuloides* Michx.). Mountain bunchgrass parks, in which Arizona fescue (*Festuca arizonica* Vasey) and mountain muhly (*Muhlenbergia montana* [Nutt.] Hitchc.) were the dominant grasses, occur in the lower elevation areas and are principally associated with the ponderosa pine forests. These dominants are replaced by other species of fescue at higher elevations. In many instances the gradation from forest to grassland is subtle, and it was difficult even at ground level to establish the line of demarcation between the two systems (*fig. 12*).

Within the central part of the study area is South Park, a large, nearly treeless area. The vegetation of South Park is generally of low stature in which blue grama (*Bouteloua gracilis* [H.B.K.] Lag.), slimstem muhly (*Muhlenbergia filiculmis* Vasey), and several low-growing shrubs and forbs are the most prominent. These and associated species provide the aspect of a shortgrass prairie. Around the fringes of the Park, and in some places within the Park where herbaceous communities interface with the forests, mountain bunchgrass communities become prominent.

Wet meadow and stream bank communities are especially well developed in South Park and occur as occasional narrow strips throughout the entire area. In association with the meadows there are shrubby communities dominated by species of willow (*Salix* L.) and shrubby cinquefoil (*Potentilla fruticosa* L.).

The main portion of the study area varies in elevation from 2100 to 4300 m (6888 to 14,104 ft) above mean sea level. Elevation variations are dramatic–as much as 400 m per kilometer (2000 ft per mile) in many places. The average elevation of South Park is 2750 m (9020 ft) above mean sea level. (A more complete description of the study can be found in the report of the ERTS studies–Driscoll and Francis 1975.)

Classification System

The hierarchical vegetation classification scheme used to evaluate the effectiveness of the Skylab and supporting aircraft data was ECOCLASS (Pfister and Corliss 1973), which was established according to

Figure 12–The gradation and mixing between and within the forest and grassland vegetation system is evident on the ground. The forest system is a mixture of Aspen and Spruce/Fir; Mountain Bunchgrass (on slopes) and a high elevation Wet Meadow (valley floor) are the grassland systems.

ecological principles of polyclimax concepts (Daubenmire 1952). This system is in current use by the Forest Service to classify plant communities for land management planning, and is in accord with that established by the International Biological Program for classifying terrestrial communities (Peterken 1970).

The system defines five categories proceeding from the most general to the most specific, as follows:

V. **Formation**–The most general class of vegetation, characterized by general appearance: Grassland, Coniferous Forest, Deciduous Forest, etc. The basis of this category is continental in scope, i.e., all of the United States, and is controlled by continental climatic differences.

IV. **Region** Subdivisions of the Formation, associated regionally and therefore determined by subclimates within continental climates: Montane Grassland, Temperate Mesophytic Coniferous Forest, Alpine Grassland,, etc.

III. **Series**–A group of vegetation systems within the Region category, with a common dominant climax species: Ponderosa Pine Forest, Fescue Grassland, Herbaceous Meadow, etc.

II. **Habitat Type**–Units within a Series, each with relatively pure internal biotic and abiotic structure: Ponderosa Pine–Arizona Fescue habitat type, Arizona Fescue–Mountain Muhly Habitat Type, etc. *These are the elemental units of the classification scheme upon which primary management is based.* These units are frequently related to climax vegetation, or to vegetation held in a relatively stable state of high succession by proper management.

I. **Community Type**–A system that appears relatively stable under management and may be equivalent to the Habitat Type. Usually the biotic components are dissimilar, but abiotic components are analogous to Habitat Type.

The entire area is considered to be within one general physiographic province, the Central Rocky Mountains, in which three Formation classes existed: Grasslands, Coniferous Forests, and Deciduous Forests. Within these Formation classes, three Region and eight Series classes were defined for this study:

IV - Region	*III - Series*
1. Coniferous Forest	1. Ponderosa Pine 2. Lodgepole Pine 3. Douglas-fir 4. Spruce/Fir
2. Deciduous Forest	1. Aspen
3. Grassland	1. Shortgrass 2. Mountain Bunchgrass 3. Wet Meadow

Skylab and Support Data

Only S190A and S190B photographic data for June 11, 1973 (SL-2, Pass 8, Track 48) and August 4, 1973 (SL-3, Pass 13, Track 48) were used in this analysis. The June mission covered 85 percent of the area; the August mission covered 100 percent on the S190A and 90 percent on the S190B. Of the S190A multispectral camera system products (scale 1:3,000,000), only color and CIR 70-mm photographs could be used. The S190A material was available for both June and August but the overall image quality was only fair. Photographs from S190B earth terrain camera system (1:950,000) were available only from the August mission. The overall quality of these photographs was very good.

Our initial proposal also called for the analysis of data from both the S191 infrared spectrometer and the S192 multispectral scanner systems. The imagery from both of these systems was excluded from the study because delays in obtaining the rectified data made analysis impossible in the time available. The sampling design we used for testing photographic products was based, however, on the expected resolution of the S191 system (435 m,1427 ft).

Two aircraft missions–June 22, 1973 and August 9, 1973–were flown by the NASA aircraft support program to assist the interpretation of the Skylab products for the defined objectives and provided both color and CIR photographic products at three scales (1:50,000, 1:100,000, and 1:400,000). The quality of the two larger scales was very good, and coverage ranged from 85 to 100 percent. This photography was timed to represent plant phenological conditions on the dates of the Skylab passes. In addition, both color and CIR large-scale 70-mm sampling photography missions were flown by a U.S. Forest Service aircraft at the scale of 1:600, on August 24, 1973–within 3 weeks of the SL-3 photographs. Only the CIR was analyzed to estimate specific quantitative grassland plant community parameters. Film quality was poor because of severe reticulation.

Ground Truth

Base maps made from existing Forest Service range and forest vegetation type-maps were used to verify vegetation maps prepared from Skylab and underflight photographs. To prepare a base vegetation map from Forest Service type-maps, Series level (ECOCLASS) class boundaries were traced directly on the base. Because the Forest Service type-maps were functionally developed, however, they had to be reorganized on an ecological basis. This meant combining and integrating some of the existing type-groups to meet our objectives. As an example, on the forest type-map, Aspen was separated into commercial and noncommercial classes, but for our purposes, the two classes were combined.

The revised vegetation maps were checked on the ground with a 10 percent sample of the 569 samples (each 500 m^2 or 1640 sq ft) used in the photointerpretation study. Less than 5 percent of the ground samples were found to be misclassified.

Foliar estimates made on large-scale color photographs were verified using ground data obtained from two grassland sites within South Park—Eleven Mile and Antero. Five plots were established at the Eleven Mile site and four plots at the Antero site. Each plot was 10 meters (32.8 feet) square. Within each plot, four 10-meter transects were established and marked with white wooden surveyor stakes laid flat on the ground. The transect locations were marked before the photo mission so that they could be located in the aerial photography.

Estimates of plant species foliar cover, litter, and bare soil were obtained using a line intercept technique (Canfield 1942), modified to use 10-meter transects rather than the 100-foot transects specified.

Procedures

Procedures used to meet the study objectives included visual interpretation of photos with high-powered magnifying stereoscopes, mapping with a photo image transfer device, and classification based on machine-measured optical film density.

Plant Community Classification by Photointerpretation

Vegetation type-maps, topographic maps, ground reconnaissance, and aerial photographs were used to select and locate sample cells for interpretation of both the Skylab and support aerial photographs. The sample cells were initially selected and plotted on the maps to represent an area approximately 500 meters (1640 feet) square. The size of the data cell was determined by (1) the expected resolution of the Skylab S191 EREP products (originally part of the analysis but later excluded—see Introduction),(2) the expected positional errors in both the satellite and data collections systems, (3) the probability of plotting errors in transferring sample cells from maps to the Skylab and supporting aircraft photographs, and (4) the need to minimize edge effects of cell-wall lines. For training and testing photointerpretation, at least 20 cells were selected in each vegetation class, for a total of 569 cells class as follows:

	Number of cells
Region and Series class:	
Coniferous	446
Ponderosa Pine	150
Lodgepole Pine	62
Douglas-fir	94
Spruce/Fir	140
Deciduous	50
Aspen	50
Grassland	73
Shortgrass	29
Mountain Bunchgrass	24
Wet Meadow	20

The number of sample cells in each film, scale, or season test may have varied from these totals because photographic coverage was inadequate.

Transparent overlays were constructed for the Skylab photographs to show the training and test cell locations for the study area. The Universal Transverse Mercator coordinates representing the location of each cell were precisely plotted to a scale of 1:100,000 on the overlay. Obvious landmarks were also plotted to assist in positioning the overlays on the Skylab frames. These overlays were then photographically reduced on 0.004 mil clear positive film to the appropriate scale.

Interpretation covered the SL-2 and SL-3 S190A color and color infrared photographic products, the SL-3 S190B color photographic products, and the June and August color and color infrared support aircraft photography.

With the overlays in position on the photographs, each interpreter independently examined the training cells until he was satisfied that he could identify the classes. Next, he examined the available test cells and classified them into the Region Class and then the Series class. In this study design, interpreters were asked to first identify the Region and then the Series level classification for each sample before moving to the next. (Because Aspen is the only prominent Deciduous species in the area, the Region and Series classifications were the same in this instance.)

The same sample cell locations were used again to interpret the aircraft support photographs. Cell locations were transferred directly from the vegetation and topographic maps to overlays on the aerial photographs.

A factorial design for analysis of variance was used to test for differences between the appropriate factors of film type, photo scale, flight date, interpreter, and plant community class. All factors were considered to be fixed effects. The highest order interaction term was used as the error term to obtain the F statistic.

Plant Community Mapping

U.S. Forest Service vegetation type-maps were used as base data to draw plant community classification maps at both the Region and Series level for areal comparison with maps drawn from Skylab and support aircraft photographs. The base map covered 138 km^2 (54 sq mi) within the Manitou area (*fig. 11*) and was initially drawn to the Series level. Region level maps were made by consolidating Series classes into the three Region classes of Coniferous, Deciduous, and Grassland.

The base map underestimated the classes. This was due to the difference in criteria used to identify Wet Meadows in the development of the base maps. For instance, the original timber-type base maps had no Wet Meadow category, and the range type-maps had a very limited Wet Meadow category which did not correspond with ground information from the Manitou site. Therefore, artificial Wet Meadow class boundaries were determined from the original type-maps and ground information.

The photographic products used were the SL-3 (August) S190A color transparencies and the MX-248 1:100,000 scale CIR transparencies. These were not truly comparable film types, but they offered the best photographic quality available from the two sources. The area to be typed was imaged within one frame of the aircraft photography, thereby reducing interframe differences. Photographs from SL-2 S190A and SL-3 S190B could not be used because of cloud cover over the Manitou area.

Vegetation maps were made to the Series level from stereoscopic examination of the Skylab and support underflight photographs separately, and were independent of each other. Once the maps were completed, they were brought to the same scale for comparison using a Bausch and Lomb Zoom Transfer Scope.

Areal comparisons between the base map and the Skylab and underflight maps were accomplished using planimetric methods.

Cultural Feature Mapping

To examine ways of using Skylab photography to interpret and map cultural features, an area of 156 km^2 (61 sq mi) was selected within the study site. Cultural features were mapped from Skylab and underflight photographs and compared with cultural features traced from a 1956 U.S. Geological Survey quadrangle.

Working under the Zoom Transfer Scope (ZTS), interpreters used SL-3 S190B photographic products enlarged to twice their original scale—1:500,000—and underflight CIR photos at 1:100,000. In attempting to map from the Skylab material, the interpreters found that the majority of the detail was lost in transferring information to a map using a ZTS. Therefore, they first placed an acetate overlay directly on the Skylab photo and with the aid of a stereomicroscope and a needle, they etched the location of road systems into the overlay. The overlay, enlarged on the ZTS, was used as a reference to map the other cultural features from the original Skylab photos.

Next, a photo-revised cultural feature map was made, using additional information obtained from the underflight photos. Because resolution on the underflight photography was better, the road system net was transferred under the ZTS directly to the overlay base map without the etching procedure. Then we mapped the other cultural features from the underflight photos.

Foliar Cover Estimation

Large-scale (1:600) 70-mm CIR photographs taken from a Forest Service aircraft were used to determine the proportionate amounts of live vegetative foliar cover and bare ground for selected grassland sites within the study area. The ultimate intent is to use these kinds of data in quantitative sampling of ground surface characteristics as imaged in the satellite photographs.

Transects measured on the ground were located on the large-scale aerial photographs, and foliar cover was measured using three means of image magnification: a zoom stereoscope, a hand-held measuring micrometer, and the viewing screen of a GAF microdensitometer.

Linear regression correlation analysis was used to determine the relationships between image-measured and ground-measured estimates.

Plant Community Classification by Microdensitometer

A GAF model 650 microdensitometer (*fig. 13*) was used to evaluate the Skylab photographic products for classifying plant communities. (A micro-

Figure 13—A microdensitometer (General Aniline and Film Corp. Model 650) was used to obtain optical image density. The photograph on the moveable image-holding stage is scanned by the light beam tube. The operator aligns the Skylab sample cell in the view screen before reading the apparent optical density registered on a digital display. The viewing screen and stage also aided in the estimation of foliar cover from large-scale photos.

densitometer measures the optical density of an image on a photographic transparency using a calibrated light source.) Skylab S190A normal-color and CIR photos from SL-2 (June) and SL-3 (August), and S190B normal-color photos from SL-3 were used in the evaluation.

All normal-color photographs were examined using a green filter in the optical system; the CIR photos were examined with a red filter. These filters were inserted into the light-beam path for enhancement of the color and CIR vegetation signatures. An effective circular aperture covering an image area of 6640 square microns was used with the S190A material. For the S190B material, an effective circular aperture covering an image area of 41,500 square microns was used. These effective areas provided a circular image with the diameter approximating the side dimensions of the sample cells used for visual interpretation.

The same sample cells used in the visual interpretation test were measured with the microdensitometer. Optical image density measurements were made of each sample cell. The calibrated light beam of the microdensitometer was aligned with the cell location by means of the sample-cell overlay used for visual interpretation. (Compensating allowance was made for the apparent optical density of the overlay.) Values from all sample cells were obtained.

A two-tailed t test was used to determine presence of significant difference between optical density sample means for both the Series and Region level classifications. Sample variances were assumed equal.

Results and Discussion

Results indicate that Skylab and support aircraft photographic products can be successfully used for classification and areal mapping of native plant communities to the Region level, by visual interpretation. Results of Series level classification from these same photo products are dependent on date, scale, and film type. Areal mapping at the Series level required formation of class complexes.

Optical densities measured on Skylab photos with a microdensitometer provided acceptable classifications at the Region level. The Series level of classification, however, showed film-type and seasonal dependency.

Visual interpretation provided successful cultural feature mapping from both Skylab and aircraft photographs; however, better resolution of the aircraft photos permitted mapping of finer details.

Very large scale aircraft photos were used to estimate quantitative parameters of specific plant communities. The results were successful, but dependent upon species diversity

The results are discussed in more detail in the following sections.

Plant Community Classification by Photointerpretation

Region Level—Skylab color infrared photographs taken with the earth terrain camera (S190B) should be acceptable for Region level classification in a stratified sampling design. To stratify Series level plant communities, however, high-altitude CIR photographs can be used only if some classes are combined.

Both the satellite and underflight aerial photographs provided acceptable results for interpreting both the Conifer and Grassland Region classes (*table 12*). The lowest accuracy level obtained was 89.8 percent for the Grassland class from the June S190A CIR photos. The remainder of the accuracy levels for these two Region classes were above 95 percent regardless of film, date, scale, or interpreter. There was no significant difference between the color and CIR film.

The Deciduous category, which in this study is Aspen, was date, film-type, and scale dependent; only CIR provided acceptable accuracies (*table 12*). One acceptable level was obtained for the June photos, and the August date provided two acceptable levels, all at different scales. Interpretation accuracy on 1:50,000 scale August photos was not as acceptable as on the June photos of the same scale, probably because of interpreter fatigue or the testing sequence used.

Differences between photointerpreters were generally small and nonsignificant; however, the interpreter most knowledgeable about the physiography and vegetation of the test area was more accurate, though not significantly so.

The great majority of commission errors for both color (41.2 and 52.9 percent aircraft, 59.9 and 72.3 percent Skylab, June and August respectively), and color infrared (24.1 and 15.4 percent aircraft, 56.7 and 51.5 percent Skylab, June and August respectively) occurred when the Deciduous class was identified as Conifer. Because of the heterogeneous mixing of these two classes of vegetation in the Deciduous test cells (*fig. 14*) interpreters had difficulty in deciding whether Deciduous dominated within a test cell. Very few of the Conifer class were committed to the Deciduous class, however, because in most of the Conifer test cells Conifer dominance was obvious. Those test cells that were correctly identified as Deciduous were homogeneous (*fig. 14*). For the June and August dates, on CIR film, there were significantly ($p = 0.99$) fewer commission errors of the Deciduous class to Conifer than on color film. Also on CIR film, for the August date, there were significantly ($p = 0.90$) fewer Deciduous class commission errors to Conifer than for the June date. There was greater separability between Deciduous and Conifer using CIR, and an even greater separation occurred at the August date because leaf-color change of the Deciduous class had begun. Deciduous leaves at the June date were only half to two-thirds developed and

Table 12–*Accuracy of visual classification of plant communities at Region level, Manitou, Colorado, test site*[1]

Date, source, and scale of photographs	Deciduous		Conifer		Grassland	
	Color	CIR	Color	CIR	Color	CIR
			Percent			
JUNE 1973						
Aircraft, RB-57:						
1:50,000		88.9		99.4		100.0
1:100,000	58.8	72.2	99.7	98.9	100.0	100.0
1:400,000		63.9		99.7		98.4
Skylab S190A:						
1:2,800,000	33.4	40.0	100.0	97.3	97.5	89.8
AUGUST 1973						
Aircraft RB-57:						
1:50,000		77.8		98.2		100.0
1:100,000	44.2	88.1	98.9	96.8	100.0	100.0
1:400,000	50.0	87.9	98.2	98.6	98.2	98.2
Skylab S190B:						
1:1,000,000	25.0		98.4		95.8	
Skylab S190A:						
1:2,800,000	20.6	41.5	99.3	97.9	100.0	95.8

[1] Mean percent correct for two interpreters. Not all film types were available for all scales and dates.

gave a low infrared reflectance relative to the sensor altitude. Therefore, deciduous foliage was difficult to separate when mixed with conifers.

Commission errors of the Deciduous class to the Grassland class type were often made on the Skylab photographs (percentages were 6.7 and 7.1 color; 3.3 and 7.0 CIR, for June and August respectively). The extremely small scale resulted in difficulty for the interpreters in separation of these two classes in ecotonal situations. This was further complicated by the subtlety of color differences between the Deciduous class and some members of the Grassland class in both the June and August photographs of both film types. Another reason for commission errors was the lack of topographic (stereo) relief near the mountain/grassland interface. Some misclassification was introduced by misregistration of the photo overlay.

A few Conifer-to-Grassland commission errors were made on both film types. Most of these errors were committed on Skylab photographs, because of class mixing and misregistration of the sample location overlay.

Series Level, *Forest*– In general, of the five tree categories included, only Aspen, the lone Deciduous Series class, was consistently classified with an acceptable level of accuracy and then only on the August CIR aircraft photos (*table 13*). At the 1:100,000 and 1:400,000 scales accuracy exceeded the 80 percent level. On the satellite photos, no acceptable accuracy levels for the Aspen Series class were achieved.

The Douglas-fir, Lodgepole Pine, Ponderosa Pine, and Spruce/Fir classes were occasionally classified with accuracies of 80 percent or greater, and then usually with the early-season and smaller scale photos (*table 13*).

The greater accuracy at smaller scales was achieved because species mixtures blended into a more apparent homogeneous unit, with the dominant species signature predominating. The decreased resolution at these smaller scales allowed the interpreter to classify the dominant characteristics with greater ease. However, some classification difficulty was caused by species mixing and somewhat broad color signatures.

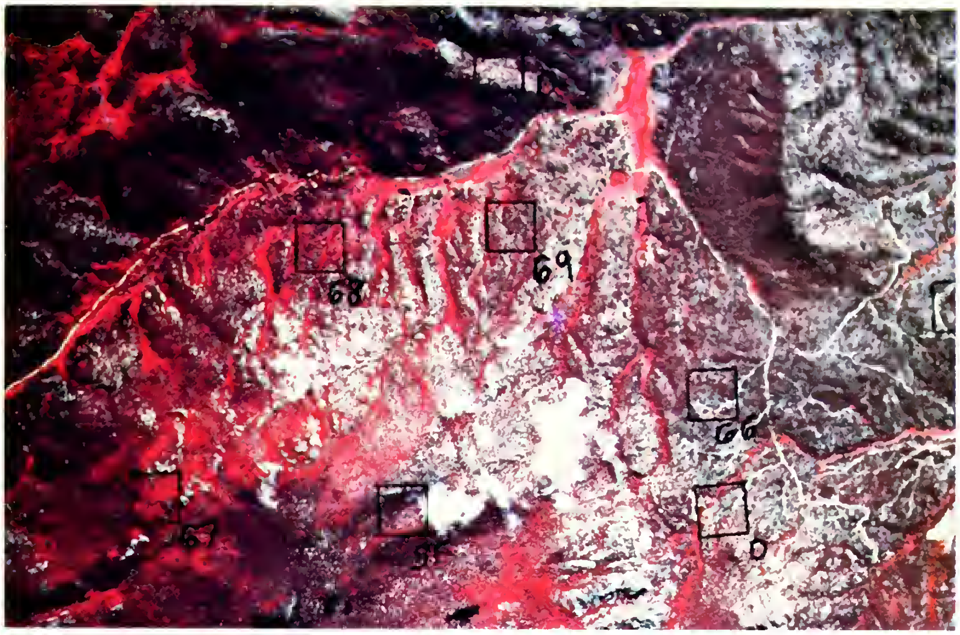
There were commission errors for all categories. The overlap in geographic range caused Aspen to be generally confused with Spruce/Fir regardless of date, scale, or film type. The smallest such error (5.9 percent) was obtained from the August CIR aircraft photos. At this date, CIR provided the necessary separation between the fall foliage coloration of Aspen and the dark green foliage of Spruce/Fir. Douglas-fir and Ponderosa Pine were most often confused with each other for all film types, dates, and

Table 13–*Accuracy of visual classification of plant communities at Series level–Conifers*[1] *and Grassland–Manitou, Colorado, test site*[2]

Date, source, and scale of photographs	Conifers								Grassland					
	Douglas-fir		Lodgepole Pine		Ponderosa Pine		Spruce/Fir		Mountain Bunchgrass		Shortgrass		Wet Meadow	
	Color	CIR	Color	CIR	Color	CIR	Color	CIR	Color	CIR	Color	CIR	Color	CIR
	Percent													
JUNE 1973														
Aircraft, RB-57:														
1:50,000		46.2		21.5		71.8		86.1		78.6		92.9		100.0
1:100,000	40.7	49.1	58.9	58.4	77.5	79.1	82.5	75.7	90.0	72.7	100.0	95.9	88.9	94.5
1:400,000		45.4		45.2		73.1		77.8		83.4		100.0		92.9
Skylab S190A:														
1:2,800,000	78.2	81.3	80.0	70.0	80.3	68.2	75.0	60.7	62.5	54.2	96.9	100.0	77.3	40.9
AUGUST 1973														
Aircraft RB-57:														
1:50,000		48.0		33.4		73.2		69.4		85.7		100.0		100.0
1:100,000	56.9	59.1	52.3	48.4	69.9	70.7	78.3	77.3	88.8	74.5	95.9	95.9	94.5	94.5
1:400,000	43.6	39.2	42.9	54.8	73.1	75.1	83.8	66.8	85.5	80.9	100.0	100.0	92.9	100.0
Skylab S190B:														
1:1,000,000	76.3		66.7		75.7		75.0		38.4		100.0		100.0	
Skylab S190A:														
1:2,800,000	65.9	65.8	72.9	66.7	73.2	82.6	70.0	48.6	71.7	20.0	100.0	100.0	75.0	87.[illegible]

[1] Aspen was the only Series class of deciduous trees; percent accuracy is shown in *table 12*.

[2] Mean percent correct for two interpreters. Not all film types were available for all scales and dates.



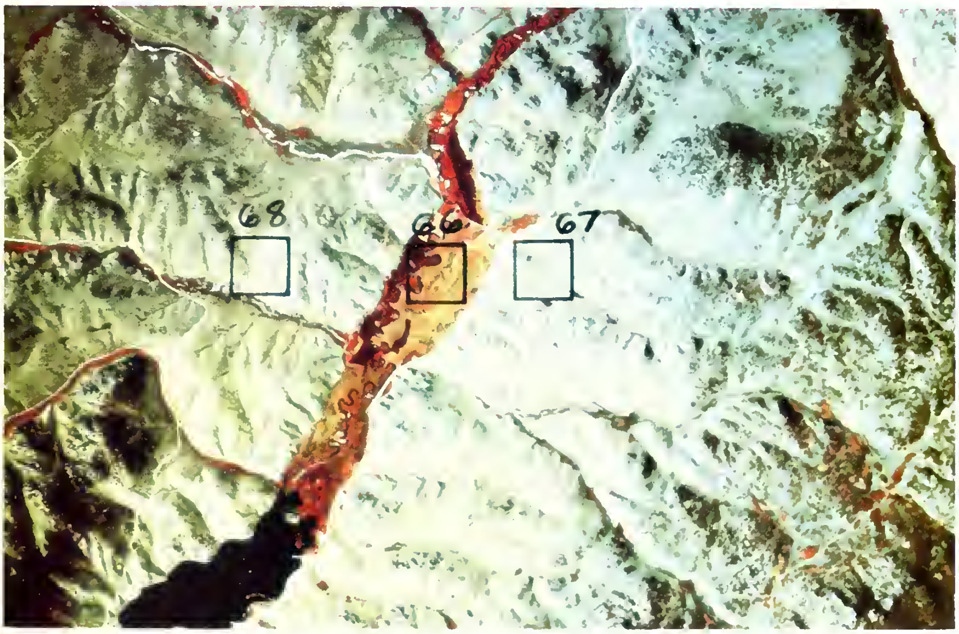


Figure 14—Aircraft support photography (CIR, 1:50,000) was used with acetate overlays showing sample training cells (labeled) and test cells (numbered) for visual classification of native plant communities. In the August photo (*above*), note the Deciduous/Conifer (Aspen/Ponderosa Pine) mixing in cell 68, the variability within and between the Ponderosa Pine cells, and the similarity between the Spruce/Fir (SF) and Ponderosa Pine cell (69). In the June photo (*below*), the test cells represent the three Grassland communities classified: Wet Meadow (66), Shortgrass (67), and Mountain Bunchgrass (68). Here there is maximum distinction between the three Series classes, but cell 68 approaches the ecotone between Mountain Bunchgrass and Shortgrass. The scale of the photo shown is approximately 1:45,000.

scales. Generally, both Douglas-fir and Ponderosa Pine had the least commission errors (15.4 percent) on early-season (June) color and CIR satellite photography. At the same date, and on both color and CIR, commission errors were greatest on the underflight aircraft photos (26.7 percent) and were essentially the same (nonsignificant differences) on the late-season (August) photography.

The large number of commission errors on underflight aircraft photographs resulted because the Ponderosa Pine and Douglas-fir overlap in geographic range but occupy different physiographic positions in the landscape. Douglas-fir generally occurs on north and east slopes while Ponderosa Pine generally occurs on south and west slopes. In some topographic positions, however, depending on the degree of slope and aspect, the two species form a heterogeneous mixture. These facts cause severe interpretation problems in mountainous terrain: (1) where the two species mix, separation is difficult and (2) in heavy shadows on north-facing slopes, it is difficult to determine where Ponderosa Pine forests stop and Douglas-fir forests begin. Therefore, commission errors occur, from one species to the other, on the larger scale photos. Difficulty also arises when the interpreter makes a decision to identify the sample as one type or the other based on crown density. His estimate may in fact be accurate, but the criteria for decision may differ for the vegetation base maps, or the maps may not be entirely accurate; base maps were based upon merchantable timber, not cover-type dominance. Also, the smaller scale (satellite) photos provide a more synoptic view with less resolution, thereby allowing inference to be made based on dominant color signature and topographic aspect, for easier separation of community Series.

Interpretations of the Lodgepole Pine and Spruce/Fir community Series were also often confused. In general, the late-season (August) satellite photos, regardless of film type, provided fewer commission errors (9.9 percent) between the two Series classes. One exception was the lower commission error (2.7 percent) from Spruce/Fir to Lodgepole Pine on late-season CIR underflight photos.

The confusion between the Spruce/Fir and Lodgepole Pine classes most frequently occurred where the geographic range of the two classes overlapped. Within such areas, especially on shadowed north slopes, color signatures and image textures were difficult to separate. Also, the lower resolution on the satellite photos, and the synoptic view they provided, resulted in fewer commission errors between classes. Classification of Spruce/Fir, however, was better on the underflight photos regardless of date (season) or film type. The Lodgepole Pine class was correctly identified more often from the satellite photos. That is, fewer commission errors were made to Lodgepole Pine or Spruce/Fir. More commission errors went to other tree Series that overlapped or were more difficult to interpret without sound orientation and vegetation knowledge. In general, the photointerpreter with the most knowledge of the study area classified the tree Series most accurately, using inference and deductive reasoning as well as image signatures.

Grassland—The three grassland Series classes (*fig. 14*) were correctly classified, with mean accuracies of 80 percent or better from the underflight photos regardless of film type or season (*table 13*).

In both underflight and satellite photos, most of the commission errors occurred between the Mountain Bunchgrass and Shortgrass classes and between the Wet Meadow and Mountain Bunchgrass classes. Mountain Bunchgrass was most often classified as Shortgrass because they form an ecotone or continuum. They were difficult to classify, especially on the satellite photos. The underflight photos, especially the 1:50,000 scale with improved resolution, allowed a better estimate of the Series class boundaries and therefore had fewer commission errors. Even though the satellite photos provided a more synoptic view, the reduced resolution did not allow Series separation. For Grassland, these characteristics appear to be a disadvantage, although for the tree Series classification, they allowed greater accuracy.

The Wet Meadow Series was generally classified at an accuracy of 80 percent or greater from both underflight and satellite photos (*table 13*). Results for the underflight photos were most consistent, however, and were not dependent on date or film type. Few commission errors (2.7 percent) occurred for this Series class on underflight photos. Commission errors that averaged 21 percent did occur for the satellite photos. Errors for this class were made to the Mountain Bunchgrass class, primarily because of natural mixing near mountain slopes. High-density Mountain Bunchgrass provided the same color signature as lower-density Wet Meadows on the very small scale satellite photos.

Plant Community Mapping

Late-season (SL-3) S190A Skylab color photos and late-season (MX-248) underflight CIR photos were used to determine vegetation boundaries and estimate their areal extent (*fig. 15*).

Region Level—The Skylab and underflight photos were both successfully used (accuracy greater than 80 percent) to map the areal extent of the Conifer and Grassland Region classes (*table 14*). The extremely small scale of the Skylab material and its lower resolution caused a reduction from the base map area of about 17 percent in the Grassland class. At the Manitou site, Grassland occurred in long narrow stringers between the tree stands. Manitou Lake was distinguishable in the Skylab photos, but it occurred within one of these narrow stringers and was too small to be measured planimetrically. For comparability, it was included with the Grassland class in all three Region maps.

The Deciduous (Aspen) class was not successfully mapped from either the underflight or the Skylab photos (*table 14*), because of stand sizes and class mixing between Deciduous and Conifer. No Deciduous class areas were mapped from the lower-resolution Skylab photos.

Small areal differences (about 2 percent) between the three maps were attributed to the mapping procedure, planimetric error, and nearly 20 years difference between the original source base map compilation and the current mapping attempts.

Series Level—The Mountain Bunchgrass and Shortgrass Series classes could not be distinguished well enough in the Skylab photos to be mapped separately. Therefore, they were combined into a single

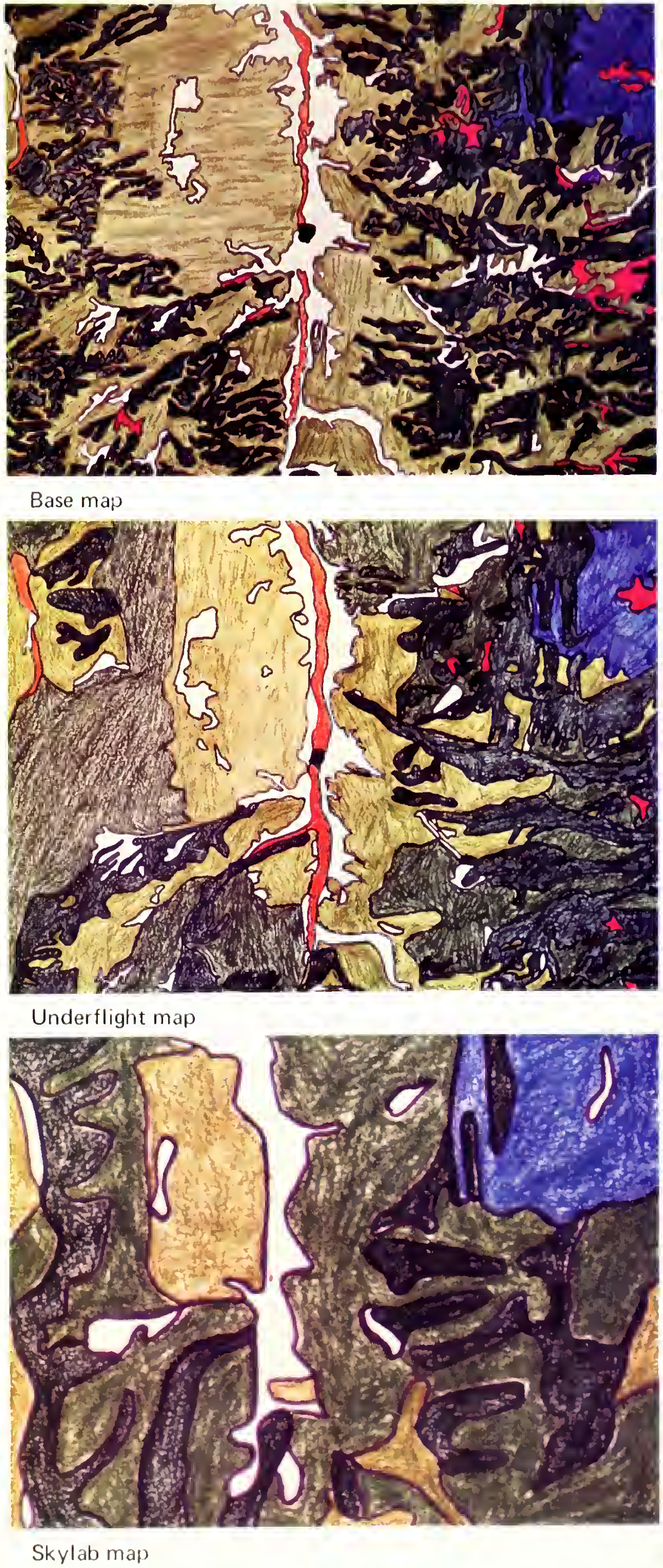


Figure 15—Plant communities were mapped at the Series level by visual interpretation at 1:50,000 for a unit within the Manitou site. The base map was compiled from U.S. Forest Service timber and range vegetation type-maps. The underflight map was compiled from late-season, 1:100,000 scale CIR aircraft photos. The Skylab map was compiled from late-season (SL-3) S190A color photos. Successful mapping required formation of several complexes of the individual Series classes. The map scale as shown is approximately 1:110,000.

Legend

- Spruce/Fir/Lodgepole Pine Complex
- Ponderosa Pine
- Douglas-fir
- Ponderosa Pine/Douglas-fir Complex
- Aspen
- Upland Grassland
- Wet Meadow

Table 14—*Area comparisons between base map, underflight map, and Skylab map for Region and Series classification levels, Manitou, Colorado, test site*

Classification level and type	Base map	Underflight map[1]		Skylab map[2]	
	Acres	*Acres*	*Percent of base*	*Acres*	*Percent of base*
Region:					
Deciduous (Aspen)	786	285	36.3	0	0
Conifer	27,687	28,202	101.9	28,923	104.5
Grassland (w/lake)	2,690	2,676	99.6	2,240	83.3
All classes	31,163 (12,611 ha)	31,163		31,163	
Series:					
Aspen	786	285	36.3	0	0
Ponderosa Pine	15,729	7,744	49.2	4,887	31.1
Douglas-fir	10,269	8,630	84.0	6,546	63.7
Ponderosa Pine/Douglas-fir complex	25,998	26,707	102.7	25,788	99.2
Lodgepole Pine	1,434				
Spruce/Fir	163	([3])		([3])	
Lodgepole Pine/Spruce/Fir complex	1,597	1,495	93.6	3,135	196.3
Grassland[4]	2,297	2,092	87.3	2,240	93.5
Wet Meadow	277	566	204.3	0	0
Lake	16	18	112.5		
All classes	31,163 (12,611 ha)	31,163		31,163	

[1] Late season, CIR, 1:100,000.
[2] Late season, color, S190A, 1:2,800,000.
[3] Area not mapped separately.
[4] Includes Mountain Bunchgrass and Shortgrass.

Series class. With this Series combination, both the underflight and Skylab photos were used successfully (> 80 percent accuracy) to map the grassland areas (*table 14*).

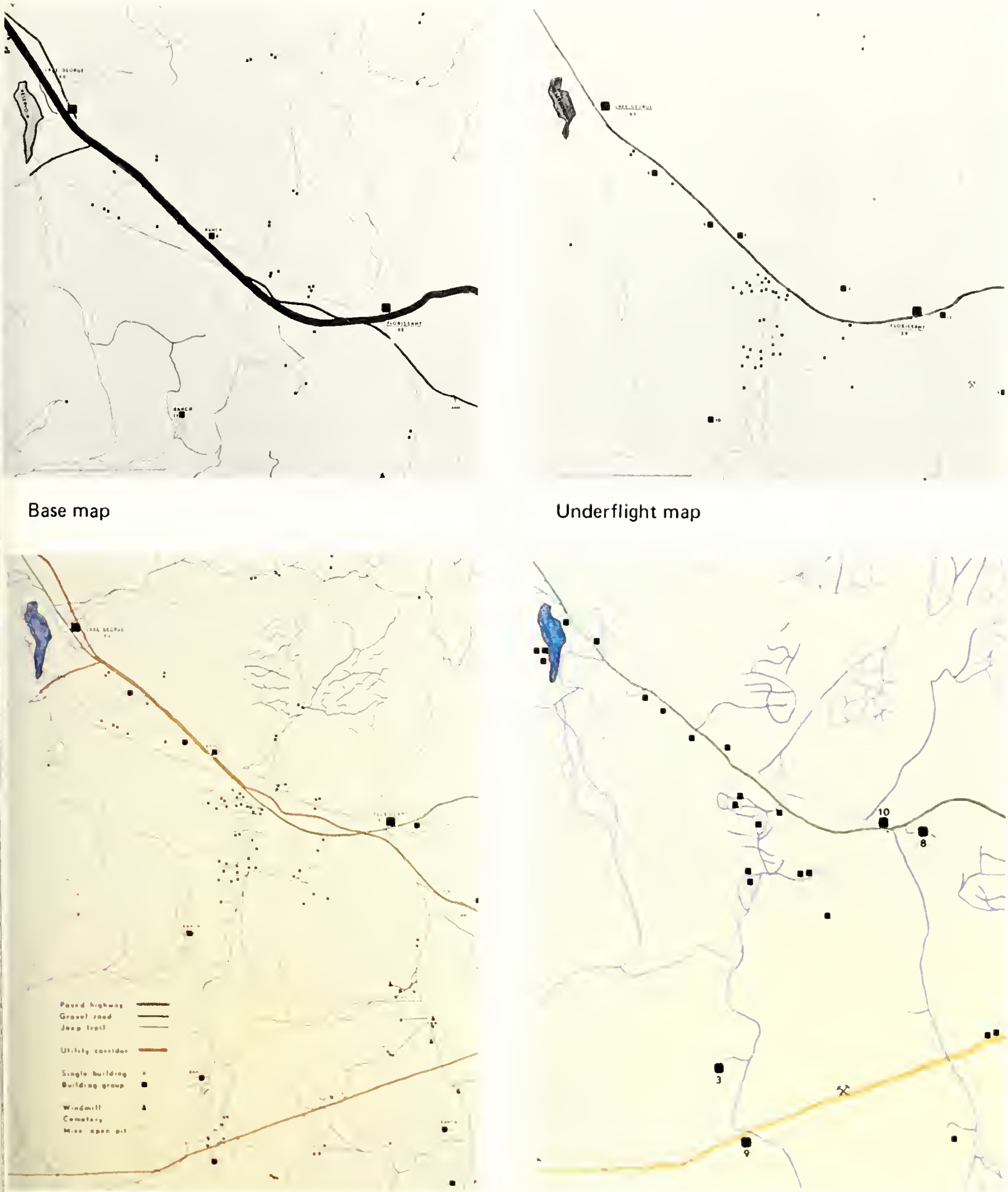
The Wet Meadow class was overestimated from the underflight photos when compared with the vegetation base map (*table 14*). Furthermore, because the Wet Meadow class occurred as long narrow stringers, both within the grasslands and intermingled with the tree classes, the lower resolution of the Skylab photographs would not permit mapping any of the Wet Meadow class (*fig. 15*).

The Douglas-fir Series was the only individual Conifer class that could be mapped successfully (more than 80 percent accuracy) from the underflight photos (*table 14*). Attempts were made to map the Lodgepole Pine and the Spruce/Fir Series but no area figures could be derived. Species mixing at ecotones, and slope/aspect relationships within these groups made class separation extremely difficult.

To map all the tree Series classes with acceptable accuracy, we formed two class-complexes: Ponderosa Pine/Douglas-fir and Lodgepole Pine/Spruce/Fir. The Ponderosa Pine/Douglas-fir complex was mapped within 1 to 3 percent of the base map estimates from both underflight and Skylab photos. These small differences can be explained by mapping and planimetric error. The Lodgepole Pine/Spruce/Fir complex was mapped within 8 percent of the base map estimates from underflight photos, but was overestimated by nearly 100 percent from Skylab photos. This difference was also due to mapping error: Aspen and Wet Meadow classes which were not discernible in the Skylab photos were included in the complex, and areal measurement error increased with smaller mapping units.

The Aspen Series class could not be mapped from either the underflight or Skylab photos at the Manitou site, as explained earlier.

Manitou Lake was successfully mapped from the underflight photos and was distinguishable in the Skylab photos; it was too small, however, to be measured planimetrically (*table 14*). Because Manitou Lake was not included with the grassland complex or Wet Meadow Series classes, the areal estimate obtained for these two classes was more representative



Base map

Underflight map

Photo-revised map

Skylab map

Figure 16–Cultural features were mapped by visual interpretation at 1:24,000 from an area of 156 km² (61 sq mi) within the Manitou site. The photo-revised map was compiled using the 1956 USGS quadrangle and the 1973 aircraft photos. The buildings grouped near the reservoir (*upper left*) in the Skylab map were identified as single buildings in the underflight map, but for simplicity they were considered part of the building complex at Lake George village. Key to features shown on photo-revised map applies to all maps shown.

than that of the Region classification. Water level difference between the two map compilation dates was responsible for the difference between base map and underflight water areas.

Cultural Feature Mapping

Skylab S190B color photographs (August 4, 1973) enlarged two times, and underflight CIR 1:100,000 scale photos (August 9, 1973), were used to update a cultural-feature inventory map (*fig. 16*). Ground truth information was obtained from the most recent (1956) U.S. Geological Survey quadrangle and was revised from the 1973 underflight photography.

The features most easily identified from both Skylab and underflight photos were paved highways and gravel roads. Lack of scene contrast in open areas, however, prevented differentiation of small segments of gravel roads that passed under tree canopies or across treeless areas. The problem was most severe on Skylab photos. Most gravel road systems could be aligned on the underflight photos; larger scale, better resolution, and occasional openings in tree canopies allowed at least partial viewing.

Identification of infrequently used dirt roads or jeep trails was not possible on Skylab photos and was very difficult on the underflight photos, because of canopy cover and related shadows, low scene contrast, and lack of resolution of the narrow tracks.

Utility corridors through forested areas, and those constructed within the past 10 years, were identifiable from both Skylab and underflight photos. The kind of utility corridor could be determined as either pipeline easement or power line from the underflight photos, but not from Skylab photos. Vegetation regrowth usually prevented detection of corridors older than 10 years from Skylab photos.

Earth excavation activities, including underground mining evidenced by refuse dumps, open stone quarries, and sand or gravel pits, could be identified on Skylab imagery only as a group, because of low resolution and lack of scene contrast. The specific activity could usually be identified from the larger scale underflight photos. These excavations were shown on the USGS base map used as ground truth.

Few individual residential or smaller commercial buildings were detectable from Skylab photos, whereas most were detectable from the underflight photos. From Skylab photos, structures could not be differentiated as to kind, except for larger industrial facilities. From underflight photos, most individual buildings could be differentiated except those in close proximity to one another or near gravel and paved areas. In general, identification was based on color and reflectivity of the roofing material, building size, and scene contrast. Buildings with bright-colored or highly reflective metal roofs, located on grassy areas, were the easiest to identify.

Cemeteries could not be differentiated on either Skylab or underflight photos, even though they were generally located in treeless areas and the grassland vegetation inside the site differed from that outside.

Windmills could not be identified on either Skylab or underflight photos; however, areas which appeared to be windmill sites could be detected on the underflight photos. These areas were either more lush in vegetation than surrounding areas, owing to water seepage and little animal use, or they were more denuded because animal use was concentrated there. The mills themselves were too small to be seen.

In cultural-feature detection, to aid identification and differentiation of particular features, convergent and divergent inferences can be made by well-trained, knowledgeable interpreters.

Foliar Cover Estimation

Estimates of plant foliar cover, bare soil, and litter were made from two grassland sites (Antero and Eleven Mile) in the South Park portion of the study area. Estimates made from aerial photos by three viewing methods were compared with ground estimates using linear regression techniques. A coefficient of 0.75 accounts for about 50 percent of the variation in the dependent variable (Y), therefore only correlation coefficients of 0.75 or greater were considered valuable. Attempts were made to estimate foliar cover by plant species; however, strong vignetting at the photo edges and extreme emulsion reticulation limited estimation to three cover classes: shrubs, herbaceous vegetation and litter, and bare soil. Results were as follows:

	Correlation coefficients	
	Eleven Mile	*Antero*
Technique and class:		
Monocular, micrometer		
Bare soil	0.8423	0.0780
Herbaceous/litter	0.6836*	-0.3698
Shrub	0.4246	-0.7906
Stereo, micrometer		
Bare soil	0.8280*	0.1199
Herbaceous/litter	0.8099*	-0.3315
Shrub	0.4951*	-0.8396*
Monocular, microdensitometer		
Bare soil	0.9299*	-0.5285*
Herbaceous/litter	0.8867*	-0.1433
Shrub	-0.0954	-0.7007

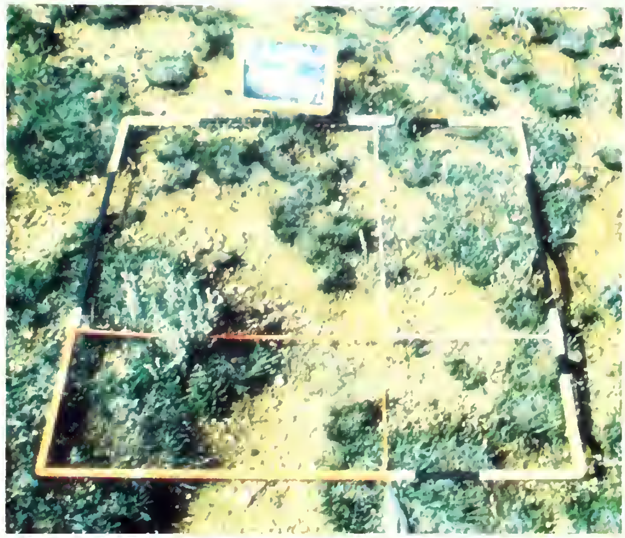
* Significant at 0.05 level.

As shown, the first technique used–the stereoscope and measuring micrometer with monocular optics–provided only two correlation coefficients of 0.75 or greater for the three cover type classes at the two sites. The second technique–stereoscope and micrometer with stereo photos–provided three correlation coefficients greater than 0.75 for the cover classes. Generally the correlation coefficients were higher for all other cover classes within both sites using this technique.

Nevertheless, the micrometer used with the stereoscope was a source of error and inconvenience, for two reasons. First, the micrometer was difficult to align with the imaged transect location markers, and the alignment, once accomplished, was difficult to maintain. The smallest movement of the instrument caused misalignment, and alignment and measurements were difficult or impossible to repeat precisely. Second, the micrometer increments became so large under 20X magnification that it was difficult to "see beyond" the markings onto the image even using stereo pairs.

The microdensitometer, used as a viewing and scanning device, proved most convenient and precise. It allowed the transect location markers to be aligned precisely with the viewing screen crosshairs under 10X magnification and the alignment and measurements were repeatable. The viewing screen also allowed for smaller incremental measurements (0.0001 mm). The major disadvantage was lack of stereo capability. As shown in the tabulation, three correlation coefficients were significantly improved by this technique–the bare soil and litter/herbaceous classes on the Eleven Mile site and the bare soil class on the Antero site.

The test results showed that the correlation coefficients for the three classes were generally higher for the Eleven Mile site than for the Antero site, regardless of technique. The photographs themselves were similar in all respects. Apparently spatial arrangement, stature, and amount of vegetation at the two sites accounted for the difference. Generally, the vegetation at the Eleven Mile site was less complex, less diverse, essentially lacking in shrubs, and of lower stature than that of the Antero site (*fig. 17*). The vegetation at the Eleven Mile site allowed a more precise estimate of the ground-cover classes. That is, the majority of the vegetative association was matte-forming blue grama and fringed sagebrush (*Artemisia frigida* Willd.), interspersed with definite areas of bare soil and litter. The fringed sagebrush and bare areas were readily interpretable; the remainder was left in the herbaceous/litter class. At the Antero site, fringed



Eleven Mile

Antero

Figure 17–These two sites were used to compare on-ground and aerial photo estimates of plant foliar cover at two grassland sites within the South Park portion of the study area. The vegetation at the Eleven Mile site was less diverse, lacked shrubs, and was of a lower stature than that of the Antero site. The plot frame pictured is 1 m² (3.28 sq ft).

sagebrush was scarce and rabbitbrush (*Chrysothamnus* spp. Nutt.) and actinea (*Hymenoxys* spp. Cass.) were the taller components of the system. These taller plants cast shadows which obscured the low-growing herbaceous plants in the understory.

Results also showed that the range in bare soil estimates between transects within sites was significantly different ($p = 0.99$), even though means for the sites were not (p = 0.95). Individual transect estimates ranged from 10 to 54 percent at the Eleven Mile site and 15 to 45 percent at the Antero site.

Indications from these results are that bare soil, shrubs, and total vegetative cover can be estimated from large-scale photos in two-dimensional space avoiding plant shadows. Also, more accurate and precise estimates could be made by using photography that is not vignetted nor severely reticulated.

Plant Community Classification by Microdensitometer

The MDT was used to point-sample the optical image density of vegetation sample cells of established classes imaged on Skylab photographs. Standard t tests for unpaired plots and unequal sample sizes were used to determine whether there was a significant ($p \geqslant 0.95$) difference between optical density sample means for the Region and Series level vegetation classes. If a significant difference found between classes, then the classes can be rated; this is brought out in the following discu of the results.

Region Level—The Region level vegetation c could be separated from each other except fo Deciduous (Aspen) versus Conifer combination. separation depended on film type, primarily be classes, though dissimilar in visual color signature similar optical density on CIR film. Ecotonal m of individual type classes also occurred within two broader classes. Therefore, the mean optical sity seemed to be more dependent upon the mi than the photo date. Deciduous and Conifer c were separable, however, on color film, even th separability depended somewhat on date. The p bility of a correct classification was greater on S190A photos (p = 0.99) than on August S photos (p = 0.95), probably because the Decid

Table 15—*Significance of differences between mean optical density[1] values for plant community classes at the Region (Forest) and Series (Grassland) level on Skylab photographs, Manitou, Colorado, test site*

Classification level and type	Skylab S190A				Skylab S190B, August, color
	June		August		
	Color	CIR	Color	CIR	
Region:					
Deciduous	3.32	3.86	4.08	2.06	3.90
vs.					
Conifer	3.45**	3.94	3.88**	2.23	3.63**
Deciduous	3.32	3.86	4.08	2.06	3.90
vs.					
Grassland	3.01**	3.42**	3.36**	1.79*	3.21**
Conifer	3.45	3.94	3.88	2.23	3.63
vs.					
Grassland	3.01**	3.42**	3.36**	1.79**	3.21**
Series:					
Mountain Bunchgrass	2.98	3.47	3.38	1.86	3.15
vs.					
Shortgrass	2.99	3.42	3.21**	1.75**	3.13
Mountain Bunchgrass	2.98	3.47	3.38	1.86	3.15
vs.					
Shortgrass	2.99	3.42	3.21**	1.75**	3.13
Mountain Bunchgrass	2.98	3.47	3.38	1.86	3.15
vs.					
Wet Meadow	3.12**	3.38	3.77**	1.81	3.63**
Shortgrass	2.99	3.42	3.21	1.75	3.13
vs.					
Wet Meadow	3.12**	3.38	3.77**	1.81	3.63**

* Difference significant at p = 0.95.
** Difference significant at p = 0.99.
[1] Density (D) = $-\log_{10}$ transmittance (T).

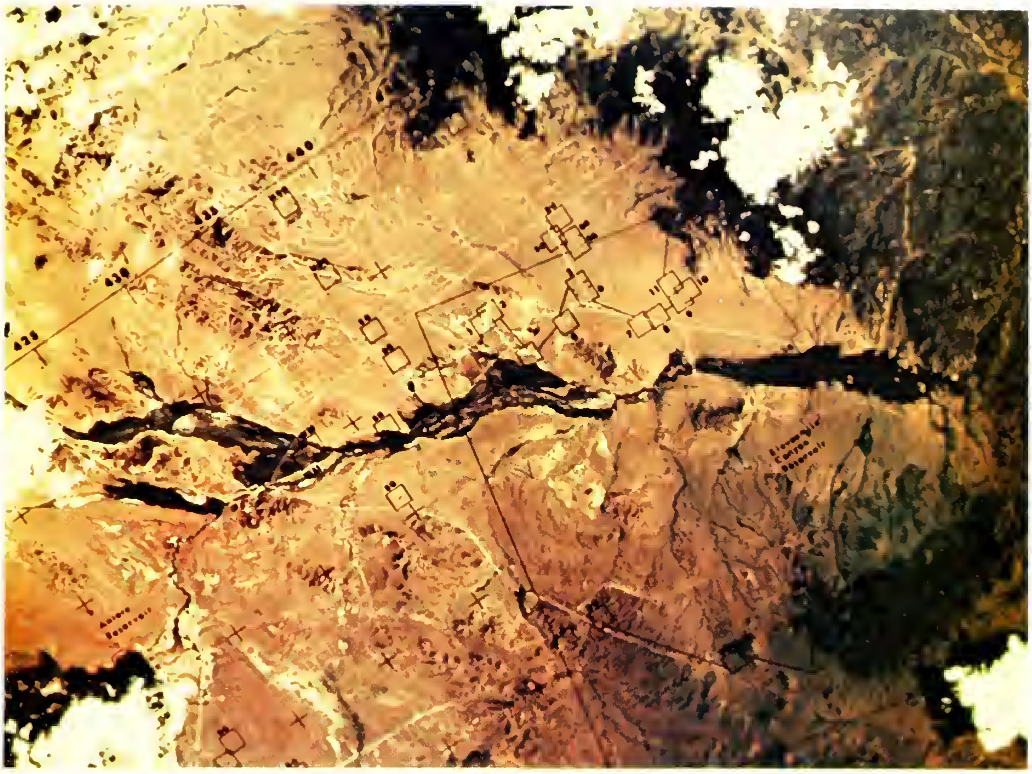


Figure 18—**Skylab color photos with sample-square overlays were used for both visual and microdensitometric classification of plant communities at the Region and Series level. In this example (S190B, August, 1:900,000), note the difficulty in discriminating between squares 1 and 2 (*center*). On the ground, square 1 was identified as Shortgrass and square 2 as Mountain Bunchgrass. The overlap between the two squares forms an ecotone between the two classes along a ridge. Square 39 (*lower center*) is a typical Mountain Bunchgrass site at a higher elevation. Two Wet Meadow sites (WM) can be seen left of center. The area imaged is South Park.**

class was in the midleaf to full-leaf stage at the early date and the actively growing leaves produced a very strong "light green" reflectance. The new deciduous leaves were lower in optical density than the darker needles of the Conifer class. The late-season Deciduous, with mature leaves, cessation of leaf activity, and some leaf drop at higher elevations, had an optical density nearly as high as that of the Conifer.

Series Level—The MDT interpretation results for classification to the Series level were varied. For instance, all three grassland Series tested could be separated from each other on late-season S190A color photos. The differences were highly significant (*table 15*). Mountain Bunchgrass and Wet Meadow, and Shortgrass and Wet Meadow, on both the early- and late-season normal-color photos could be separated with highly significant differences. Mountain Bunchgrass and Shortgrass Series classes could not be separated, probably because of their very close physiographic proximity. These grassland classes are frequently difficult to separate on the ground. The two classes form a broad ecotone; Mountain Bunchgrass communities gradually blend into the relatively flat-terrain Shortgrass communities within South Park (*fig. 18*); both classes are short in stature within the ecotone.

The results from CIR early-season S190A photos showed that the three grassland Series classes could not be separated (*table 15*), but results from late-season photos of this film type did show that there was a highly significant difference between the Mountain Bunchgrass and Shortgrass Series classes. Again, the ecotone was partly responsible, and there was some positional inaccuracy of plot overlays on the very small-scale imagery. Time of year and poor film quality also influenced results. That is, vegetation was in an early stage of growth providing little infrared reflectance, and the film was of very poor quality, with a strong blue color saturation predominating.

Within the tree Series classes, only Ponderosa Pine could be separated from all other tree classes at any time; this distinction occurred on late-season S190A and S190B color photos (*table 16*). Ponderosa Pine could be consistently separated from the other three Conifer classes regardless of date, film type, or scale. Douglas-fir was separated from the other three classes in both the early-season CIR and late-season color S190A photos (*table 16*). But as can be seen, Douglas-fir was not consistently separated from the other classes by any one film type and season combination.

Aspen and the Conifer classes could not be separated with any consistency, and the differences were date, film-type, and scale dependent (*table 16*). For example, Aspen could be separated from Lodgepole Pine in the early-season but not in the late-season S190A color and CIR photos. Aspen was also separable from Spruce/Fir in both the early- and late-season CIR photos and in the early-season color photos. Ponderosa Pine and Aspen could be separated on the late-season S190A and S190B color photos; however, they could not be separated on early-season S190A color and CIR photos.

It is not completely understood why these inconsistencies occurred; however, we believe that the stage of phenological development and Series class mixing are both major factors. For example, Lodgepole Pine and Aspen frequently grow together on the same site. The two classes could be separated on early-season color and CIR S190A photos, but they could not be separated in the S190A late-season photos. Leaf development in the early-season Aspen was only 1/2 to 2/3 complete, and this allowed better discrimination (increased optical density) from Lodgepole Pine. Later season Aspen with mature leaves was not separable from Lodgepole Pine, however, because their reflectance (optical density) was similar. In another example, Lodgepole Pine could not be separated from Spruce/Fir because of class mixing and overlapping of the physiographic range of the two classes; both classes also had similar optical densities. Most inconsistencies in Conifer class separation are caused when the species grow in the same area and have very similar optical film densities. Where the Conifer classes were separable, this could be partly attributed to differences in crown cover and the homogeneity of the stands.

Applications

Areal plant community mapping on an extensive basis appears to be highly successful at the Region level. Intensive plant community mapping at the Series level appears to be applicable if the land manager recognizes the constraints imposed by mountainous terrain and the necessity to form community complexes in some areas to allow for interpretation difficulties caused by a natural mixing of dominant species and by terrain slope and aspect.

Plant community mapping can be done on rangeland and forested areas as well as grasslands and shrublands where trees are not dominant or are absent. This type of information can be useful to update existing vegetation maps, most of which are over 10 years old and are outdated by changes in management schemes or land use patterns and by catastrophic events.

Extensive cultural feature mapping and monitoring can also be accomplished using Skylab-type photo-

Table 16–*Significance of differences in mean optical density between plant community classes, Forest, Series level, Manitou, Colorado, test site*

Forest Series Class	Skylab S190A				Skylab S190B, August, color
	June		August		
	Color	CIR	Color	CIR	
Aspen vs. Douglas-fir	**	ns	ns	*	*
Aspen vs. Lodgepole Pine	**	**	ns	ns	*
Aspen vs. Ponderosa Pine	ns	ns	**	ns	**
Aspen vs. Spruce/Fir	**	**	ns	*	ns
Douglas-fir vs. Lodgepole Pine	ns	*	*	ns	ns
Douglas-fir vs. Ponderosa Pine	**	*	**	**	**
Douglas-fir vs. Spruce/Fir	ns	*	**	ns	ns
Lodgepole Pine vs. Ponderosa Pine	**	**	**	**	**
Lodgepole Pine vs. Spruce/Fir	ns	ns	ns	ns	ns
Ponderosa Pine vs. Spruce/Fir	**	**	**	**	**

* Difference significant at p = 0.95.
** Difference significant at p = 0.99.
ns = no significant difference.

graphic products. Depending on the mapping objectives, cultural mapping, however, can require supplementary aircraft photography at larger scales. For instance, an aircraft photographic scale of 1:100,000 proved highly successful for most of the cultural features mapped in this study. Mapping features requires either larger scale photos or inference by a skilled interpreter trained in ecological principles. One example of the potential application of cultural feature mapping is a dirt road system being developed within the Manitou area for access to a mountain home development. The roads, about 6.1 m (20 ft) wide, were discernible on the S190B color photos. Such mapping shows a land manager the size and extent of developing areas–information not now readily available for large tracts of land, but required for total land management.

In areas where vegetation has not been mapped or has been mapped only superficially, Skylab-type photographs can be useful as a first level of stratification for both mapping and multistage sampling of natural vegetation resources. Stratification was especially successful with vegetation units that display a high scene contrast–such as wet meadows within a grassland system–provided those units do not occur in narrow stringers as ecotones and are large enough to be resolved on Skylab-type photographic products.

Skylab-type photographs, coupled with aircraft underflights, can provide a base for multistage sampling schemes in order to stratify and quantify specific plant community systems through the estimation of plant community parameters. Ground data must be used as a final stage. In this study, large-scale (1:600) aircraft photos and ground measurements were used to sample areas delineated on high-altitude aircraft and Skylab photographs to estimate foliar cover of plants and shrubs. Success appears to depend on the diversity of plant communities in relation to the parameters measured.

Descriptive and dichotomous keys (*table 17*) may also be an aid to the land manager using aircraft and Skylab-type photographic products. These keys can

Table 17–*Descriptive key of plant community characteristics imaged on early-season (June) 1:400,000-scale CIR aircraft photos (image characteristics determined from training sample cells used for visual interpretation)*

Plant community	Color[1]	Aspect	Crown or foliar cover density	Distribution[2]	Texture	Height and resolution[2]
Forest:						
Aspen	Very red (11) or deep red (13)	All; drainages	60 to 90 percent; med. to high	Uniform to clumped; often in stringers	Even or rough	Only rarely apparent unless clumped
Douglas-fir	Very deep red (14) or deep red brown (41)	Generally north, east	50 to 80 percent; med. to high	Generally uniform when pure	Even or mottled	Not apparent–a uniform mass
Lodgepole	Deep red brown (41) or dark gray olive (111)	All; in saddles	70 to 90 percent; med. to high	Generally uniform when pure	Smooth or slightly mottled	Not apparent
Ponderosa Pine	Dark olive brown (96) or deep red brown (41)	All; but usually not north	10 to 60 percent; low to med.	Random, not uniform	Slightly mottled	Rarely apparent
Spruce/Fir	Deep red brown (41) or dark red brown (44)	All; commonly north	50 to 90 percent; med. to high	Generally uniform	Slightly mottled	Not apparent
Grassland:						
Mountain Bunchgrass	Very light bluish green (162)	All slopes to nearly flat	30 to 70 percent; low to med.	Varies with terrain; uniform	Smooth	Not apparent
Shortgrass	Pale purple pink (252) or blue white (189)	Flat	10 to 50 percent; low to med.	Uniform if pure	Smooth to mottled	Not apparent
Wet Meadow	Deep red (13) or dark pink (6)	Flat or drainages	30 to 70 percent; low to high	Uniform; near water	Smooth or broken	Not apparent

[1]Color notation based on National Bureau of Standards System (NBS 1955). Overlap in colors is result of natural mixing of species and terrain slope and aspect.

[2]Distribution, height, and resolution of the dominant plant species within the sample cell are described as they appear to the photointerpreter.

be compiled at various levels of classification to characterize the appearance of plant communities. The keys can be used in stratification of plant community units to measure area and to determine boundaries for sampling with very large scale aircraft photos to quantify foliar cover by individual species. Keys can be effective if the user is aware of their constraints within mountainous terrain—especially with smaller scale photographs which provide synoptic landscap views. Descriptive characteristics, especially imag color signature and texture, are affected by terrai slope and aspect (shadows), degree of plant specie mixing, ecotones, and general "condition" of th plant community or species. It must also be recog nized that image characteristics represent both plan and soil components.

FOREST STRESS DETECTION

Ponderosa Pine Mortality from Mountain Pine Beetle

Frederick P. Weber

The detection of stress in our Nation's wildlands and forests is a large multiagency task for which several million dollars are spent each year in aerial and ground surveys. Stress detection in the National Forest System as well as on State and private lands usually means the detection of insect or disease damage and the evaluation of impact by a count of the number of killed or damaged trees. Only when damage caused by forest pests can be detected early in the development of the pest buildup, can rapid and effective remedial action be taken. Early and reliable detection methods are required where damage or threat of damage extends over large areas and many ownerships.

This part of the Skylab research program was designed to assess the usefulness and comparative effectiveness of data products from three separate systems of the Earth Resources Experiment Package. Data analyses were made to determine the benefits of high spatial resolution (S190B) compared with improved spectral discrimination (S190A and S192), and automatic classification (S192) compared with manual interpretation (S190A and S190B). We established the experimental hypothesis that Skylab could not be used to detect stress in forests, and then attempted to disprove it. The Black Hills National Forest and surrounding lands were chosen as the site of the investigation.

The mountain pine beetle (*Dendroctonus ponderosae* Hopk.) is a threat to ponderosa pine (*Pinus ponderosa* Laws.) throughout the central Rocky Mountain region, and the Black Hills in particular. Aircraft have been used since the mid-1920's to detect and appraise damage caused by the mountain pine beetle. The first remote sensing research to improve aerial detection and appraisal of mountain pine beetle damage in the Black Hills was established in 1952 (Heller and others 1959). During an epidemic outbreak of the mountain pine beetle in the northern Black Hills in 1963-64, the Forest Service Remote Sensing Research Work Unit took aerial color photographs at a scale of 1:7920 over the northern Black Hills. The resulting high-resolution color transparencies were used to train forest resource managers to locate infestation spots and to count dead trees. In 1965 the unit began 8 years of stress detection research. This work provided invaluable experience in the requirements for insect damage detection and evaluation of impact on resources. Detailed studies established guidelines for aerial photography and also identified complex physiological and environmental relationships affecting interpretation of multispectral data (Weber 1969; Weber and Polcyn 1972; Weber and others 1973).

Beginning in 1972, a LANDSAT-1 (ERTS-1) experiment was conducted in the Black Hills to determine the potential usefulness of low-resolution satellite systems to detect and monitor forest stress and map vegetation cover types. The results of the experiment (Weber and others 1975) indicated that LANDSAT-1 imagery can provide information for broad area planning but cannot provide specific unit estimates of cover-type acreages. The level of classification for which satisfactory accuracies were obtained has questionable utility for the land planner and resource manager. We speculated that the best quantitative application for LANDSAT-1 data was in providing the first broad level of stratification of land use and cover-type classes—acres of deciduous vegetation, acres of coniferous vegetation, etc. Stress detection was a failure in spite of our best efforts. Neither computer-assisted processing of digital tapes nor interpretation of LANDSAT-1 data in photographic form with special optical viewers was a successful technique for detecting stress.

The Skylab studies were designed to evaluate products of a different satellite data-collection system, with possible advantages over the LANDSAT-1 System.

Study Area

The Black Hills test site (*fig. 19*) is an area of 10,200 km^2 (3938 sq mi) in western South Dakota and eastern Wyoming. The focus of the site is an elliptical dome extending over 0.75 million hectares (1.85 million acres). The most important tree species providing more than 95 percent of the total commercial sawtimber volume, is ponderosa pine. Geologically, the Black Hills National Forest portion of the test site is an exposed crystalline core surrounded by sedimentary formations. The central formation, at an

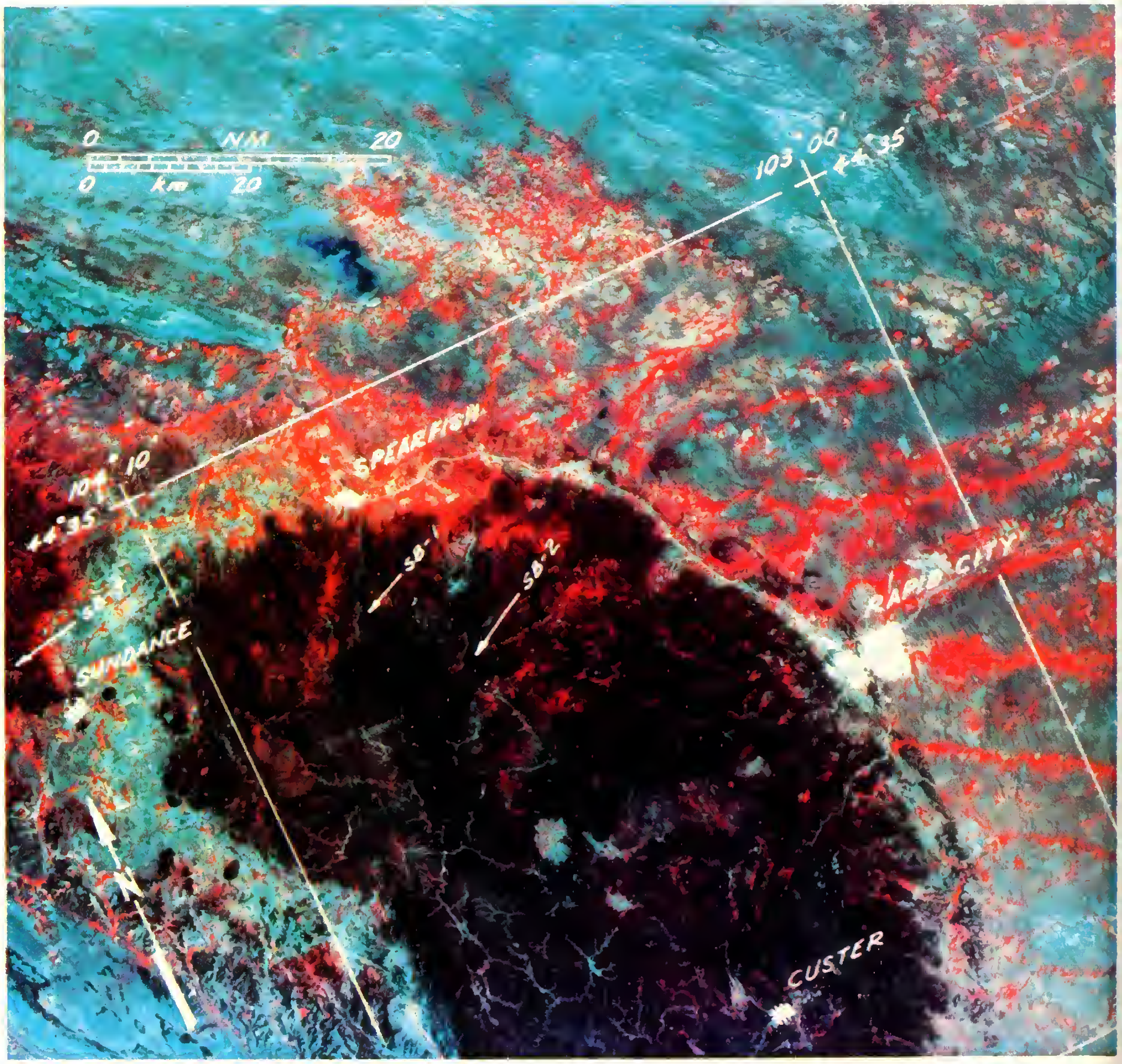


Figure 19–The Black Hills National Forest test site is outlined on this simulated color infrared composite photograph taken with the S190A multispectral camera system on June 9, 1973. Shown within the test site are intensive-study sub-blocks 1 and 2 as well as sub-block 4 in the Bear Lodge Mountains.

elevation between 1200 and 2150 m (4000 and 7000 ft), is highly dissected, with large areas of exposed soil and surface rock. Surrounding the central core are sedimentary formations of Paleozoic limestone. The topography here is gently rolling, especially in the northwestern Black Hills, where the limestone forms a plateau generally above 1800 m (5900 ft). The eastern part of the Black Hills contains the same formations but generally at lower elevations. The radial-dendritic drainage pattern of the permanent east-flowing streams in this area is strongly evident on satellite imagery. Immediately outside the ponderosa pine zone, which surrounds the Black Hills, is a circular valley formed from reddish Triassic and Permian soft shale and sandstone. The "red valley," as it is called locally, is highly visible on Skylab SL-2 photography.

Our primary investigation area covers 653 km^2 (252 sq mi) surrounding the gold-mining town of Lead, South Dakota. Two sub-blocks were chosen within the area–Savoy, with an area of 3949 ha (9759 acres), and Englewood, with an area of 4142 ha (10,235 acres). During the SL-3 mission in September 1973, a third sub-block, Warren Peaks, was established outside the primary area in the Bear Lodge Mountains of eastern Wyoming, northwest of the Black Hills. The Warren Peaks sub-block, though never surveyed on the ground, was studied through aerial reconnaissance surveys and newly acquired aerial color photography. The area of this sub-block was 4144 ha (10,240 acres).

In the LANDSAT-1 study (Weber and others 1975) the mountain pine beetle infestation spots on the two intensive study sites were identified on September 1972 aerial photographs (CIR, 1:32,000). The Englewood sub-block contains many moderate- and small-sized mountain pine beetle infestations and is important as a transitional area where little beetle activity is noticeable during endemic conditions. This area is first affected, however, during an expanding bark beetle population, and thus is a good barometer area for an impending epidemic outbreak. The Savoy sub-block is on the west side of the primary study area. Traditionally it contains a full spectrum of mountain pine beetle activity. Here it is common to have high beetle populations, and large volumes of timber are killed annually. In contrast to the Englewood area, the Savoy sub-block has been an area of perpetual activity for the last 13 years and contains the critical mass of the bark beetle population. Beetle populations have remained constantly high in the area, and it is apparently a source of beetles which aggravates the control problem in two surrounding National Forest management areas. The Savoy sub-block contains the largest infestations, which we hoped to detect and map on Skylab imagery. The Warren Peaks sub-block was added to the study because the SL-3 mission did not satisfactorily photograph the Black Hills test site during the best period for forest stress detection. Although the mountain pine beetle does not cause serious damage in the Bear Lodge Mountains, the Warren Peaks area contains numerous dead ponderosa pine, both singly and in small groups. During September 1973, reconnaissance surveys revealed several moderate-sized infestations, showing 25 or more trees per group, west of Warren Peaks.

Classification System

Interpretation of all Black Hills test site imagery—photographic transparencies, color composites, or computer-compatible tape data—is based on the hierarchical classification of Black Hills ecosystem cover types (*table 18*). This hierarchy was devised specifically for use with aircraft or satellite imagery and is suitable for the entire Black Hills test site. The nine predominant cover-type classes underscored in the table were used as a basis for mapping the sub-blocks in the test site. For analysis using computer-assisted techniques, a somewhat modified classification system was required, as follows:

Table 18 *Black Hills National Forest classification hierarchy for remote sensing imagery*[1]

- I Forest
  - II Conifer
    - III Dead ponderosa pine
    - Pine, healthy, < 50% crown closure
    - Pine, healthy, > 50% crown closure
    - Spruce
  - II Deciduous
    - III Pure hardwood
    - Predominantly hardwood
- I Nonforest
  - II Grassland
    - III Wet pasture, on water course
    - Dry pasture, well drained
  - II Bare soil[2]
    - III Rock outcrop
    - Gravel quarry
    - Mine tailings
  - II Transition
    - III Logging clear-cut
    - Burn area
    - Soil, rock, sparse vegetation
    - Infestation area
    - Other disturbance
  - II Urban
    - III Town
    - Isolated building(s)
    - Utilities
    - Improved highway
    - Forest road
- I Water
  - II Water
    - III Lakes and ponds
    - Reservoirs
    - Streams and creeks

[1] Classes used in computer-assisted mapping are underscored.
[2] Included rock outcrop for computer mapping.

Savoy	*Englewood*
Transition-sunlit	Wet pasture
Bare soil-rock	Dry pasture
Bare soil-sand	Type 1 conifers-sunlit
Type 1 conifers-sunlit	Type 1 conifers-shaded
Type 1 conifers-shaded	Type 2 conifers-sunlit
Type 2 conifers-sunlit	Transition-sunlit
Hardwoods-sunlit	
Dead pine	

Although the major Level III categories in *table 18* remained intact, variations in sunlight caused primarily by topography had to be accounted for.

A system for classifying mountain pine beetle infestations by size was also devised. Before evaluating the earth resources satellite data, the Remote Sensing Research Work Unit had classified infestations into photo strata based on the number of trees identified in an infestation spot. For microscale photography and satellite imagery, however, spot size in meters was a more useful measure, as follows:

Infestation class (meters):	*Average number of trees*
Less than 10	1 to 3
10 to 25	4 to 10
26 to 50	11 to 20
51 to 100	21 to 50
101 to 300	51 to 100
More than 300	100+

In the sub-blocks, however, only those spots greater than 50 m (165 ft) in the longest dimension were classified.

Skylab Data

September was identified in the original research proposal and data requests as the only satisfactory time (SL-3 mission) to collect data for our studies. Extensive cloud cover obscured the Black Hills on the September 13, 1973 pass, and EREP sensors were not activated on the September 18 pass. We elected, however, to go ahead with our research program on a restricted basis with available data.

An excellent and complete data set was received from the SL-2 overpass of the Black Hills test site on June 9, 1973. Although the imagery was of exceptional quality, June is perhaps the worst possible time of year to detect forest stress resulting from mountain pine beetle damage. Any dead trees in the site had lost most of their discolored foliage during the winter.

Although western South Dakota was obscured by cloud cover during the September 13 pass, there was one good frame of S190B color photography with only a wisp of clouds over the Bear Lodge Mountains, and one poorly exposed frame of color and color infrared (S190A) photography. The S190A frame covered the westernmost piece of the Black Hills test site but was badly underexposed and most of the test site was obscured by clouds. In addition, the S190A frame covered the Bear Lodge Mountains but, again, was poorly exposed over the forest. A special processing effort by the photographic laboratories at Johnson Space Center improved the interpretability of the multispectral images.

Table 19–*Tree mortality caused by mountain pine beetle fo the years 1972 and 1973,*[1] *sub-blocks 1, 2, and 4,*[2] *Blac Hills, S. Dakota, test site*

Infestation size class (meters)	Total number of dead trees				
	Englewood (1)		Savoy (2)		Warren Peaks (4
	1972	1973	1972	1973	1973
Less than 10	–	148	–	276	236
10 to 25	2,702	2,653	2,552	6,811	399
26 to 50	1,198	1,207	252	3,060	308
51 to 100	1,079	435	–	870	445
101 to 300	715	845	–	325	582
More than 300	–	1,050	–	–	–
Total	5,694	6,338	2,804	11,342	1,970
Ratio, 1972/73	1.11/1		4.04/1		

[1] No data available for Warren Peaks, 1972.

[2] Area of sub block 1: 3,949.2 ha (9,758.6 acres), 2: 4,142. ha (10,235.1 acres), 4: 4,187.2 ha (10,342 acres).

On January 18, 1974, the SL-4 mission passe over the northern tip of the Black Hills test site an obtained coverage of the Savoy and Englewood sul blocks with the multispectral camera. Although th test area was clear of clouds, the ground was sno covered. As a result, the forest vegetation was unde exposed on both the color and color infrared S190 film. The test site was not covered by the S190B nc S192 systems.

Ground Truth

The trend and spread of the mountain pine beet in the northern Black Hills, which included th Englewood and Savoy sub-blocks, was monitor with 1:32,000 scale color infrared (CIR) aer photography. These photographs were taken in la August or in early September 1972 and 1973 by t Remote Sensing Research Work Unit. The infes tions were delineated and recorded by spot size test detection by satellite and aircraft sensors (*tal 19*). Other yearly surveys were conducted by t Forest Service Rocky Mountain Region.[4] The annual surveys provided estimates of bark bee damage for the entire Black Hills National Forest a were useful in this study.

Forest Service resource photographs for the Be Lodge Mountains (at a scale of 1:15,840) were us to establish ground truth in the Warren Peaks si

[4] Information on file, U.S. Forest Service, Rocky Moun Region, Division of Timber Management, Denver, Colora

block. We were fortunate that these photographs were in color and taken near the date of the SL-3 photography of the Bear Lodge Mountains.

Tree mortality counts within the Englewood and Savoy sub-blocks for 1972 and 1973 are shown in *table 19.* These data cover the period of the Skylab experiment, but could be used only in part to serve as ground truth. Trees identified as dead on the August 1973 CIR photography had not yet begun to exhibit discoloration at the time of the June 1973 SL-2 mission, and as stated earlier, coverage in the later SL-3 and SL-4 missions was inadequate. Mortality counts for the Warren Peaks sub-block (*table 19*) were obtained from the August 1973 color 1:15,840 resource photography.

An expanding epidemic is evident from a comparison of the mortality totals in the table. Whereas the Savoy sub-block had high mortality counts for both 1972 and 1973, a threefold increase in mortality is seen in the Englewood sub-block from 1972 to 1973. The mortality counts in the Englewood sub-block for 1973 are conservative–many faded trees were removed by salvage logging during July and August 1973 before the photographs were taken.

Infestations varied greatly between the Savoy and Englewood sub-blocks. In the Savoy sub-block there was considerable aggregation of smaller prior infestations into several very large infestation centers in both 1972 and 1973. By contrast, most of the numerous infestation spots in the Englewood sub-block were less than 50 m (165 ft) in size in 1972. With an expanding epidemic in this area, the 1973 resource photography revealed considerable aggregation of smaller spots and the creation of many infestations over 50 m (*table 19*).

From the CIR photography for 1972, 439 sample points representing each of nine cover-type classes shown in *table 19* were selected from the entire test site for the Skylab photointerpretation test. Sample point choice was based on the availability of the sample area for ground check, distribution of the samples throughout the study area, and distinctiveness of the sample point with respect to the surrounding landscape. A map was prepared in the form of an acetate overlay showing the sample points as microdots.

To evaluate the maps created from S192 data tapes by computer-assisted mapping, the type map drawn for the LANDSAT-1 study (Weber and others 1975), using the nine cover-type classes (*table 18*), was used. The type maps were drawn on acetate overlays, from interpretation of 1:32,000 scale CIR resource photographs.

Procedures

Photointerpretation

Before interpretation began, all sub-block boundaries were marked on the Skylab photographs. Three methods were used to detect, count, and map bark-beetle-killed trees on the Skylab products. First, photographs were examined on a Richards MIM 3 light table using a Bausch and Lomb 240 Zoom stereomicroscope. Stereo and zoom optics were changed to provide four separate viewing magnifications. All photo products were viewed in ascending order of scale (1:500,000, 1:100,000, 1:25,000) to reduce the possibility of interpreter bias.

Next, the same Skylab products were viewed in the same way as before except that stereo optics were replaced with monocular optics. The same four viewing scales were used.

Finally, a Variscan rear-projection viewer was used to scan the image at a magnification ratio of 12:1. As areas of interest were identified, the magnification ratio was changed to 29.5:1, which provided the largest interpretation scale. Resultant viewing scales ranged from 1:237,500 to 1:16,000.

Multispectral Scanner Data Analysis

The Skylab S192 multispectral scanner data was analyzed by the University of Kansas Space Technology Center. Only five of the thirteen bands of electromagnetic energy were used, as follows:

	Electromagnetic wavelength range (μm)	*Description*
Band:		
3	0.52 to 0.56	Blue-green
6	0.68 to 0.76	Red
8	0.98 to 1.08	Infrared
12	2.10 to 2.35	Infrared
13	10.20 to 12.50	Thermal infrared

These were the bands found to be most useful for stress detection and vegetation mapping when all 13 channels of data were previewed on the Johnson Space Center interactive computer processing system.

The Skylab scanner data, when plotted, follows a circular arc, not a straight line. This geometric distortion occurs because the scanner is pointed at an angle of 5.53° from the vertical. Normally, the resulting conical scan data could be processed by computer without too much difficulty, but when the conical data is displayed on a TV monitor as a straight line, the distortion introduced hinders the location and identification of landmarks and ground truth from aerial photographs and maps. Therefore, geometric distortions were removed and the scan line data straightened in this analysis by a computer procedure developed at Kansas University.

Line-straightened data for the Savoy and Englewood sub-blocks were processed by the KANDIDATS (Kansas Digital Image Data System) interactive digital multi-image pattern recognition system. This system uses nonparametric statistics, the Bayes decision rule, and the table look-up approach to classification. Categories to be recognized by the system are those listed earlier in this report under "Classification System."

Further information regarding the KANDIDATS processing system can be obtained from the University of Kansas Space Technology Center, Lawrence, Kansas, or the Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Results and Discussion

Photointerpretation

From cursory examination of *all* Skylab photographic products received, we significantly reduced the actual number of frames to be subjected to quantitative interpretation. Monocular and Variscan interpretations were performed only on three S190B color photos from SL-2 and one from SL-3. Stereoscopic interpretations were performed on the three S190B color photos from SL-2. The remainder of the photographic products examined did not reveal evidence of dead trees, forest stress, or bark beetle infestations.

Positive results with S190 photographic products were understood simply as identification of mountain pine beetle infestation spots and not as ability to count individual dead trees. Results are given as a count of infestation spots within sub-block study areas. Furthermore, in the preliminary examination, no infestation spots could be identified on color or color infrared products from the multispectral camera system. Therefore, all identifications were made on normal-color products from the earth terrain camera (S190B).

A comparison of results for the Savoy study area (*table 20*) revealed the benefit of stereoscopic viewing, both in terms of high number of identified infestations and fewer commission errors. All of the correct identifications were made from a group of 40 infestations larger than 50 m (164 ft longest dimension) and shown on the ground truth map. In all interpretation attempts, all nine infestations on the ground truth map that were larger than 100 m (328 ft) were located.

Identification within the Englewood study area showed similar results (*table 20*). All correct identifications within the Englewood study area were made from a group of 26 infestations in the ground truth; they were larger than 26 m (85 ft) but less than 50 m (164 ft).

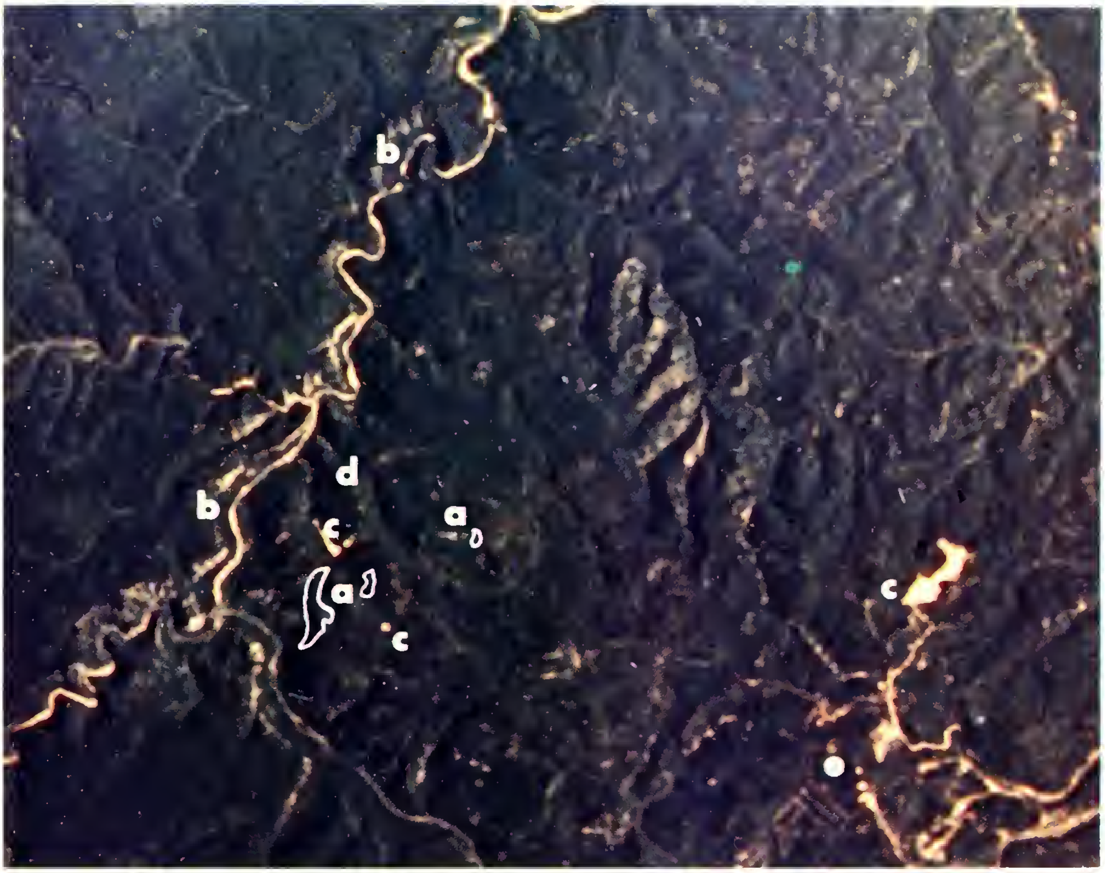
The optimum viewing scale, using either monocular or stereo optics on the Zoom 240 microscope, was about 1:75,000 (*fig. 20*). This scale combined satisfactory magnification with reasonably sharp image definition. It is important to note that identification of the dead ponderosa pine in the S190B color film was primarily by the bright reddish-orange color rather than by recognition of any textural difference from the healthy pine. The sparsity of the dead foliage remaining on the trees at the time of the June 9, 1973 pass, 10 months after the time when the dead and dying trees first became visible, undoubtedly prevented much more spectacular results. Furthermore, the low sun angle during the SL-2 pass early in the morning, made interpretation difficult. In the steep terrain of the Black Hills, most infestations on west- and north-facing slopes were in shadow and were not visible.

The comparison of monocular and stereoscopic viewing revealed a definite interpreter preference for stereo. The most tangible benefit of stereo viewing was a lesser tendency to make commission errors in the interpretation of dead tree groups. Most of the commission errors resulted from calling patches of bare soil or exposed forest floor (in sunlight) infestation spots.

Results of interpretation with the Variscan viewer

Table 20—*Accuracy of infestation count on Skylab S190B photos by monocular and stereoscopic viewing, for two sub-blocks, Black Hills, S. Dak. test site*

Sub-block and viewing scale	Number of infestations			
	Monocular		Stereo	
	Counted	Correct	Counted	Correct
Savoy:				
1:500,000	0	0	4	4
1:100,000	13	12	17	17
1:50,000	18	12	12	12
1:25,000	1	1	3	3
Englewood:				
1:500,000	0	0	1	1
1:100,000	19	14	19	18
1:50,000	22	13	14	14
1:25,000	8	5	4	4



a Infestation area
b Spearfish Canyon
c Mine tailings
d Hardwood forest
e Recreation housing area

Figure 20–Interpretation of photos at a scale of 1:75,000 was determined to be most effective for resource evaluation, including the detection of dead ponderosa pine. Photo SL2-81-157 was generally considered to represent the best possible imagery with the earth terrain camera, but its resolution of 15+ meters was not good enough to resolve individual trees or small groups of dead trees, such as would be counted in a standing dead timber inventory. Photo scale is approximately 1:100,000.

ndicated this technique was inferior to microscopic viewing of transparencies on a good-quality light able. For example, with the Variscan, 1:80,000 was est; at this scale, eight correct identifications were nade in the Savoy sub-block and one in the Englewood sub-block.

From our experience with photos from the SL-2 nission, we concluded that it was unfortunate that luring the SL-3 mission (1) stereo S190B color overage was *not* obtained for the Bear Lodge Mounains, and (2) opportunity was not taken to image the Black Hills test site on the September 18, 1973, pass vhen the entire area was clear of clouds. With nonocular viewing of the earth terrain camera photo of the Warren Peaks area (September 13, 1973), the ollowing results were obtained:

	Number of infestations	
	Counted	*Correct*
Scale:		
1:500,000	1	1
1:100,000	6	5
1:50,000	5	5
1:25,000	0	0

Close examination of the photo revealed that although large portions of the Bear Lodge Mountains were free of clouds, there were several cumulus clouds in the Warren Peaks area. Also, a thin layer of cirrus clouds covered most of the study area. Although this layer did not obscure the area, it served to absorb red/orange reflected light, detracting from successful identification of dead and dying trees. This phenomenon was most apparent on several frames of the multispectral camera facility. All the infestation spots identified were larger than 100 m (328 ft, longest dimension) and were oriented on sun-exposed slopes. Three additional spots greater than 100 m (328 ft) were not located in the S190B photography because of their placement on relatively steep north- and northwest-facing slopes.

Multispectral Scanner Data Analysis

The results of this experiment were disappointing. Poor results can be attributed to four factors: (1) quality of the multispectral data (June 9, 1973) was unsatisfactory, (2) data were not collected during the peak of spectral response of beetle-killed trees (September), (3) several channels of data normally used in forest classification were not usable, and (4) the five bands of usable data could not be accurately registered with one another. Ponderosa pine trees killed by the mountain pine beetle were not detected and therefore they were not classified by KANDIDATS processing. The misregistration of MSS bands was probably the primary reason why the relatively small beetle infestations could not be detected.

Using the June 9, 1973 multispectral scanner data and the KANDIDATS processing system, many procedural variations of the spectral bands and variations were attempted to improve and smooth the data. Various combinations of the spectral bands and variations in the table look-up threshold values were tried in an effort to optimize classification results. All attempts, however, were fruitless. The best classification was in the Englewood sub-block. For instance, with training data and paired MSS bands 3 and 6 and 8 and 12 (see "Procedures") in coordination, the best average misclassification rate for all classes was 12 percent. The poorest misclassification rate was 20 percent for wet meadow. Using test data, the poorest classification was for conifer type 2 with 35 percent misclassified. The average misclassification rate for all test data was 15 percent. Other combinations of MSS data bands and table look-up threshold values resulted in higher misclassification rates.

Attempts to improve classification by trying different data smoothing procedures, band pair combinations, table look-up decision rules, and modified ground truth sets were not very rewarding. In one set of experiments, over-all classification accuracy was improved by removing the dead-tree category, combining all conifer categories, and improving the training set for the transition category. The results were better, but because of misregistration, there remained an unavoidable trade-off between interpreting hardwoods as bare soil and rock or interpreting bare soil and rock as hardwoods. An attempt was made to resolve the conflict between hardwoods and bare soil and rock, by modifying the probabilities of classification based on ground observations—the probabilities were used as weighting factors to improve classification. Results of these different combinations of techniques and processing parameters are quite variable, but the best classification showed only about 70 percent of the 439 sample points correctly identified.

Applications

Of all the Skylab data products, color photography obtained in stereoscopic coverage with the S190B earth terrain camera was best for the location and appraisal of dead ponderosa pine killed by mountain pine beetle. For greatest usefulness, orbital coverage, like aircraft photography, should be obtained in late August or early September during the peak of difference in spectral reflectance between healthy and dying trees. In steep terrain like the Black Hills, where infestations occur independent of slope or aspect, satellite photography obtained in late summer should be planned for midday exposure when the higher sun angles occur. Comparisons of S190B color photography (ground resolution approx. 15 to 20 m or 49 to 66 ft) and higher resolution photographic systems (such as that of the U-2 high-flight aircraft), indicate that satellite photography with a resolution of 1 to 2 m (3.27 to 6.54 ft) ground-resolved distance would be ideal for detection and impact appraisal of stress in forests. Photographic emulsions could be either high-resolution color or color infrared, although the former is preferred.

Although photography from the multispectral camera (S190A) was of no use for stress detection in the Black Hills, both the multiband capability and large area coverage were useful to forest planners and resource managers. They preferred a 28.5X enlargement (1:100,000 scale) of the color infrared band from the multispectral camera system. As a working tool, the CIR print was used to aid in updating existing type-maps, in nonsystem road inventory, and in planning timber sales. All the resource managers and forest planners canvassed in the Black Hills agreed that such a print, received once each year would be effective in carrying out their work. Interpretative aids to enhance the utility of the photograph would be easy to develop, and include such items as template overlay showing administrative boundary locations, a geographic coordinate grid overlay, and ownership boundaries. Although no effort was made to create type-maps with Skylab photo products, they were used successfully to check the type at point locations–as resource managers frequently use photography.

The results of the University of Kansas computer-assisted analysis of S192 multispectral scanner data of the Black Hills showed only limited utility for resource analysis. We recognize that the S192 system was an experimental package, perhaps best thought of as a prototype of a future shuttle scanner. Even so, the scanner performance and resulting image product did not measure up to expectation. Although the gross classification results were reasonable (about 80 percent for most classes), many significant land use classes could not be identified and others had unacceptable errors in point-by-point classification. The pursuit of optimum computer-assisted classification was exhaustive, but the rewards were minimal. A direct comparison of LANDSAT (ERTS) MSS and S192 MSS imagery for the same study blocks was not performed. It is assumed from earlier studies, however, that the classification results would have been similar. Because of the poor quality of band 13 data (thermal IR) the question of whether the benefits of moderate-resolution thermal imagery from space adds significantly to either (1) the detection of stress in forests or (2) the multispectral classification of land use. Analysis of only the two good-quality bands of MSS data was not adequate for our purposes. Detection and classification accuracy suffered because of (1) misregistration of data between bands, (2) inadequate spatial resolution of MSS imagery, and (3) too few bands of usable MSS data for a full and complete analysis.

During the 2½ years since the Skylab launch, we have had the opportunity to test EREP data for several useful applications that are not connected with the Black Hills study objective:

1. Enlargements of S190B color and CIR photography have been used on the east coast of the United States to obtain baseline data from sample locations approved for the national Forestry Incentives Program (FIP). Location and examination of FIP sites has in many instances provided information, otherwise unavailable, on the condition of practice sites before the program was begun. Although S190B resolution was adequate for some examinations, it was inadequate for others. Again, resolution of 1 to 2 m with CIR film would have been ideal.

2. Stereoscopic enlargements of color photos from the earth terrain camera of standing dead Engelman spruce (*Picea engelmannii* Parry) in the Jemez Mountains northwest of Los Alamos, New Mexico, proved useful for forest managers. Because no other resource photography was available, the Skylab photography was used for planning sales of large areas of standing dead timber, accessible from existing roads.

3. Black Hills National Forest planners and resource managers used 1:100,000 enlargements of CIR photos from the multispectral camera system. The photos were used for updating cover type-maps, for nonsystems road inventory, and for planning timber sale layout. All users agreed that continued availability and use of the satellite photos would produce new and cost-effective applications. For greatest utility, new space photos should be available once a year, or at least once each 3 years. Furthermore, almost all requirements for remote sensing data could be met with space-acquired CIR photography having a resolution of 1 to 2 m ground-resolved distance. User preference was for a stereo pair covering a minimum of 240,000 ha (592,800 acres).

MEASUREMENT OF FOREST TERRAIN REFLECTANCE

Determination of Solar and Atmospheric Effects on Satellite Imagery

Robert W. Dana

A practical method of correcting satellite radiance data to account for changes in solar irradiance and atmospheric effects is a continuing need. Such a method would be useful for a number of reasons: to permit the comparison of spectral signatures of different targets at different sites; to allow accurate measures of spectral variations caused by temporal changes in vegetation and water quality; and to improve techniques for extending spectral signatures from one area to another in computer-aided classification of satellite imagery.

One approach to the problem of obtaining normalization coefficients to correct for solar and atmospheric effects is to study the sensor's response to targets of known reflectance. In the simplest description, the satellite-acquired radiance (N_s) is assumed proportional to terrain reflectance (ρ), with a multiplicative coefficient representing the product of total irradiance and atmospheric transmittance. The radiance data also include an addictive term representing the path radiance (N_p) of upward scattered radiation. Specifically, the equation takes this form, assuming the reflector is Lambertian:

$$N_s = \frac{H\tau}{\pi} \rho + N_p \qquad (1)$$

in which H = irradiance and τ = beam transmittance.

Reflectance values of two or more areas that vary greatly in brightness when plotted against their corresponding satellite radiance values yield a first-order measure of atmospheric effects at the time of the satellite overflight.

The reflectance measurement technique has an advantage over some other methods in that the data acquisition need not be temporally coincident with the satellite overflight. This technique does not probe the atmosphere but studies the reflection properties of the terrain. During some seasonal periods, terrain reflectance probably does not vary over time. Therefore, the reflectance data might be acceptable if acquired within a week or two of the satellite overflight. An important consideration would be the stability of important target aspects such as plant phenology, soil moisture, and water turbidity. Of course, it is advisable to work under the same solar irradiation conditions that the satellite sensor experiences (same time of day and similar cloud and haze conditions)—particularly if the targets are non-Lambertian.

This paper reports results of the analysis of one set of Skylab (EREP) photos and one scene of ERTS-1 (LANDSAT-1) multispectral scanner data, offers some conclusions about this experiment, and suggests some possible applications of this type of radiance measurement. All data show a high correlation between satellite radiance and aircraft reflectance, with reasonable values of path radiance resulting from the calculations.

The investigation of solar and atmospheric effects stems from earlier attempts to use near-ground-level radiometric measurements as aids in analyzing satellite imagery (Heller and others 1975). For similar targets, large differences in LANDSAT-1-measured radiance values were noted between different dates of coverage. LANDSAT-1 radiance values also differed by as much as 30 percent from ground-measured values. These examples, combined with past evidence of haze effects in aerial photography, led us to search for a method of accounting for variations in solar irradiance and atmospheric interference.

The prospect of using existing complex atmospheric modeling techniques with their detailed computational procedures did not appeal to us. They would require too much software development and costly wavelength-by-wavelength computations to derive meaningful atmospheric coefficients. Also, accurate modeling probably requires some kind of in situ radiometric measurement. With satellite-matched reflectance measurements, we hoped to devise simpler means of finding two coefficients that could linearly transform satellite data.

Instead of tower-mounted instrumentation as used in the LANDSAT-1 study, a low-flying aircraft was used in this study to collect reflectance. Thus we avoided two problems—the difficulty of maintaining an unattended field site in an often harsh environment, and the difficulty of relating a few small tower sites to the large satellite study area. One tower instrument viewed only a small portion of one LANDSAT picture element, whereas a low-flying aircraft could have adequately sampled dozens of targets easily resolved by LANDSAT.

Study Area

The possibility of acquiring Skylab coverage on more than one date for the Black Hills, South Dakota, and the Atlanta, Georgia, sites gave us hope of demonstrating the use of atmospheric corrections to data in these two areas. One possible application was measurement of temporal changes in vegetative spectral signatures. Another application was signature extension from one sub-block to another in computer-aided classification work.

The aircraft system for terrain reflectance measurement was flown over the Savoy and Englewood sub-blocks in the Black Hills study area on July 27, 1973. A mission was also flown over two study blocks of approximately 4050 hectares (10,000 acres) near Carrollton, Georgia (in the original Atlanta study area) on January 13, 1975. Because Skylab imagery did not prove to be available for our underflight coverage, no attempts were made to compute atmospheric effects on Skylab data for these two sites. The Black Hills flight data, however, were analyzed and compared with LANDSAT-1 data.

During the final days of the Skylab program we were able to obtain coverage for a secondary site in northern California. With only a day's notice, a test site was selected 15 km (24 miles) west of Redding, California *(fig 21)*. It was a narrow strip along Skylab track 63 extending from a point 8 km (5 miles) northwest of Whiskeytown Reservoir to the airport on the southeast edge of Redding—a distance of 35 km (22 miles).

The western end of the test area is moderately steep terrain with wooded slopes of mixed ponderosa and digger pine (*Pinus sabiniana* Dougl.), California black oak (*Quercus kelloggii*), and canyon live oak (*Quercus chrysolepis* Liebm.). Patches of manzanita (*Arctostaphylos* sp.) and other chaparral species are also present. The central portion and eastern end of the strip are predominantly mixed oak, chaparral, and pastureland, with some rural homesites.

A few fallow fields and fields of winter crops were noted at the time of the Skylab coverage. The waters of Whiskeytown Reservoir and the Sacramento River appeared relatively turbid during the overpass.

Instrumentation

The instrumentation for gathering the necessary data was installed in a twin-engine Aero Commander 500B aircraft modified for aerial photography. The equipment consisted primarily of a radiometer, irradiance meter, highspeed recorder, vidicon (video) camera, video tape unit, and wide bandpass filter sets *(fig. 22)*. Power for most components was provided by a stabilized (frequency and voltage) inverter rated at 500 watts, running off the 28-volt d.c. aircraft supply.

Reflectance was measured by an upward-pointing irradiance meter and a downward-pointing radiometer. The silicon diode detectors were filtered to match the bandwidths of LANDSAT-1 multispectral scanner and Skylab S190 sensors. The reflectance was derived from the aircraft radiance N_a using equation 2, in which the altitude is assumed to be low enough to minimize the effects of atmospheric path:

$$\rho = \frac{\pi N_a}{H} \qquad (2)$$

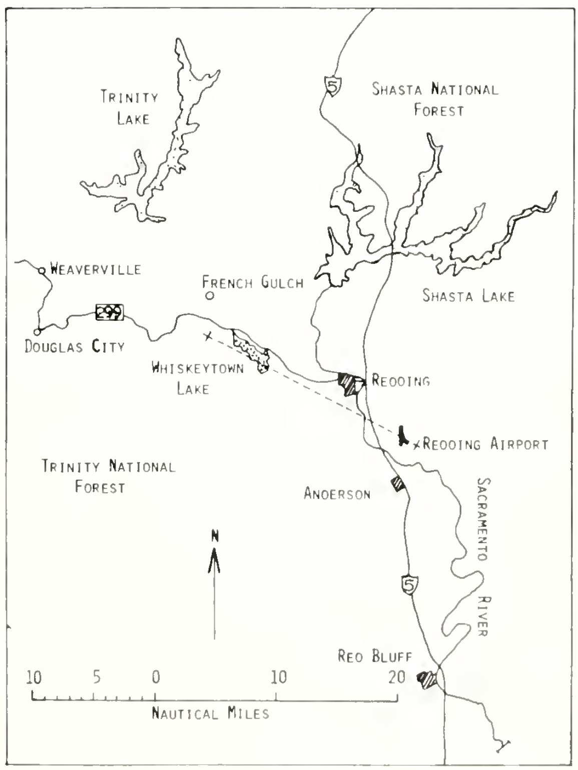


Figure 21—The test site for measurement of forest terrain reflectance was a strip 35 km (22 miles) long between Redding Airport and Whiskeytown Reservoir.

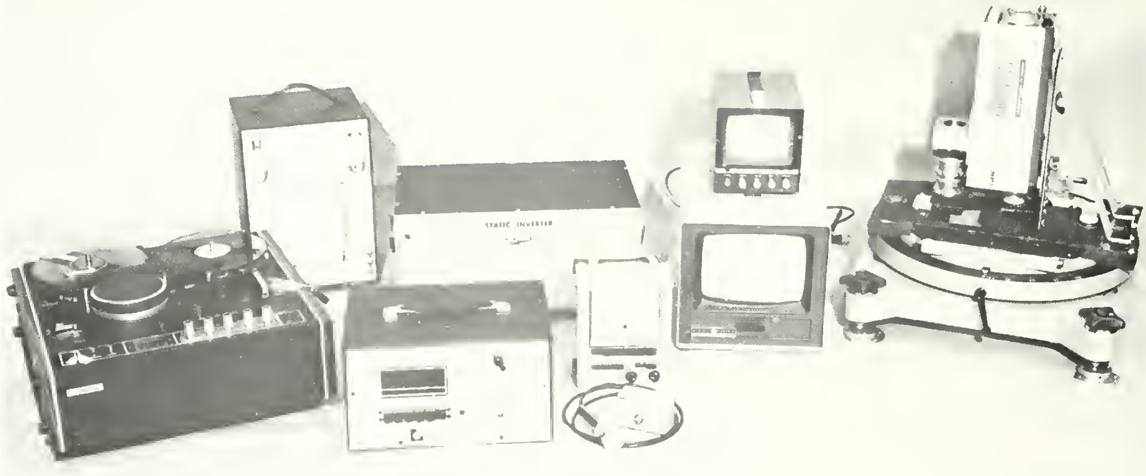


Figure 22–Equipment for aircraft target measurement of terrain reflectance included (*left to right*) video tape recorder, strip chart recorder, radiometer, static inverter, irradiance meter with input probe and filter chamber, TV monitors, vidicon camera, and radiometer input probe on aerial camera mount.

When H or N_a are known at the time of satellite overflight, equations 1 and 2 can be used to find the beam transmittance:

$$\tau = \frac{\pi(N_s - N_p)}{H\rho} = \frac{N_s - N_p}{N_a} \qquad (3)$$

The Skylab S190A photos to be compared with the reflectance data were scanned by a digital microdensitometer. Programs were written to convert the microdensity values to diffuse density and subsequently to effective film exposure at the film plane.

Radiometer

The radiometer employed for measurement of terrain radiance is an Optronic Laboratories Model 700F with digital and analog output. It amplifies the signal from a silicon photodiode in a photovoltaic current-to-voltage mode and provides six decades of linear amplitude. The full-scale value of the most sensitive range is about 1×10^{-8}A or about 3×10^{-8}W of light energy on a silicon detector. It is more sensitive than necessary for this experiment because our normal operation was about 1 microamp.

The radiometer was custom built for low noise and high frequency response. For a square-wave input at the 1 microamp level, the total of the rise and fall times and the transient effect of any underdamping conditions in the output wave is less than 1 millisecond. Therefore, this instrument is responsive enough for measurements at aircraft speeds up to 45 meters per second (100 mi/h).

The input optical probe was constructed from a machined aluminum block linking a 135-mm camera lens and a planar-diffused junction silicon diode, which is masked by a 6-mm diameter aperture. The resultant field of view (FOV) is 44 milliradians or a full angle of 2.6°. At the designed experimental altitude of 300 m, the ground resolution is 13 m. Light filtration is accomplished with 50-mm filters mounted on the front of the lens.

Irradiance Meter

Total irradiance at aircraft altitude was measured with an electronics package designed and built in our laboratory. It essentially matches the performance characteristics of the unit used for gathering radiance data. Light from a diffuser mounted in the top surface of the aircraft was carried by a fiber optics ligh guide to a filter and detector chamber. An identical optical assembly was constructed to use in laboratory calibrations. Necessary cosine correction of the data for low sun angle effects was accomplished by a laboratory goniometric technique. (Details of the technique for cosine correction for the irradiance probe are available on request; see Introduction.) This correction is in the order of +10 percent for a zenith angle of 60°.

Data Recorder

The radiance and irradiance data were recorded on a Brush Mark 222 portable chart recorder. This battery- or a.c.-powered recorder accommodates two independent channels of analog data at a fast rate. Full response for a moderate amplitude takes less than 14 milliseconds, which means that the ground track being sensed has moved only about 0.6 m or less than 5 percent of the diameter of the spot being measured.

Video Equipment

To locate precisely the flight path corresponding to a narrow FOV radiance measurement, support imagery showing the surrounding terrain is required. A vidicon camera with magnetic tape recording was chosen for its capability of real-time measurement. The cameraman can see in a monitor the picture being recorded and replay the tape immediately after completing a flight line to be certain he has flown the right area and recorded the necessary imagery.

In addition to its real-time capability, the vidicon camera can approximate the spectral response of the radiometer and irradiance meter by use of filters and a silicon diode array pickup tube in the camera. The silicon target in an RCA model 4532 tube had a spectral sensitivity curve similar to the curve of the photodiodes used in the radiometer and irradiance meter *(fig. 23).* The silicon vidicon camera is so sensitive in the absolute sense that normal operation in the plane required a lens opening of f/11 and a neutral-density filter of 10 percent transmittance in combination with the bandpass filter.

The vidicon camera was vertically mounted on a mapping camera mount with the boresighted radiometer secured to the camera housing. Two small closed-circuit TV monitors were used—one in the front of the aircraft to aid the pilots in navigating along the flight line, and the other in the rear for the instrument operators.

The video signal was recorded on a commercial-quality half-inch tape recorder (VTR). Although the image resolution with this device is limited to about 300 TV lines per picture height (the camera itself is capable of 700), this low-cost recorder does allow playback of useful pictures. Analysis can be conducted at normal speed, variable slow speeds, or at a stop-action setting.

The VTR employed in this study had two available audio channels. One channel was used for housekeeping data introduced by a microphone. On the other channel, a timing signal was introduced by an audio pulse generator, which synchronously excited an event marker on the chart recorder. This provided time-base synchronization of the VTR with the chart recorder.

Filter Sets

In matching the Skylab S190A bands, we were limited by the time and funds available. We attempted to match the spectral responses of the four bands that utilized black-and-white film. Three sets of filters were required—one each for the irradiance meter, radiometer, and vidicon imager. We selected off-the-shelf absorption glass filters in stock thicknesses to meet the time and cost constraints. For each spectral band a cut-on filter was combined with a glass filter for absorption of long wavelengths. The filter sets and their thicknesses, in millimeters, were:

A. Hoya Y-50 (2.5) and Schott BG-18 (1.0)
B. Hoya R-60 (2.5), and Hoya HA-30 (3.0), and Schott BG-20 (2.0)
C. Hoya R-70 (2.5) and Hoya HA-30 (3.0)
D. Hoya IR-80 (2.5) and Hoya B-370 (2.5)

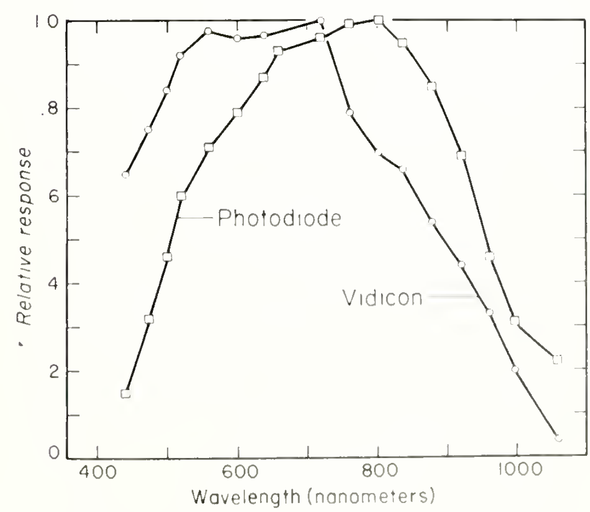


Figure 23—The spectral response of the silicon vidicon is similar to that of the photodiode. Each curve was separately normalized to its highest value.

The spectral responses of the vidicon and photodiodes were combined with filter transmittance data to arrive at curves of system spectral response. The spectral response of the S190A camera stations employing black-and-white film was also computed (computation available on request). The film spectral sensitometry data were taken into account, as well as spectral transmittances of all optical components in the system. The bandwidths are summarized in terms of the locations of the half-power points where the response reaches 50 percent of the peak value *(table 21)*.

Although mismatches between the Skylab cameras and the radiometric instruments are apparent, they may not cause large errors in wideband measurements of terrain reflectance. The most important difference occurs between filter set B and station 5, where the radiometer and vidicon pick up excess energy from the strong infrared reflection band of live vegetation, beginning at about 700 nanometers (nm). This condition would result in a higher reflectance value from some aircraft measurements than that to which the satellite camera responds.

Skylab Data

For the northern California site we requested and received photographic data from mission SL-4, pass 93 (January 27, 1974), ground track 6. The data included duplicate films for S190A, magazines 73 through 78, and S190B, magazine 94. The western 40 percent of the aircraft flight path over which we obtained reflectance data was cloudfree on the S190A photos. The S190B camera was turned on too late to include any of the test site.

All camera stations of the S190A package were operable except station 5. The critical frame (number 214) was blank for this red band. The green band (station 6) and the normal-color band (station 4) were well exposed, but the three infrared-sensitive bands (stations 1, 2, and 3) were slightly underexposed.

High-resolution images from stations 6 and 4 supported meaningful microdensitometer scanning increments as small as 8 microns *(fig. 24)*. The black-and-white infrared images of stations 1 and 2 were very granular and did not merit scanning increments smaller than 32 microns. Features smaller than 100 m (327 ft) across were rarely detected by eye on the infrared images.

Procedures for Data Analyses

The experiment produced two kinds of data to be reduced and analyzed. The first consisted of aircraft radiance and irradiance data, recorded on a strip chart; these data had to be reduced to average target reflectance values for specific areas on the ground. Conventional manual and computer-aided techniques were used. The second kind of data was Skylab imagery, which required the conversion of photographic density to apparent radiance values. A new computer technique was developed utilizing sensitometric data provided by the Photographic Technology Division of NASA/JSC. Data gathered earlier during the study of the LANDSAT-1 satellite was also analyzed, as described below under "Results and Discussion."

Aircraft Radiance and Irradiance Data

Before analyzing the radiance data, we reviewed the video tapes of the flights and plotted the flight paths on available maps and aerial photo coverage. To find the large-scale video paths on 1:2,900,000-scale space photos, it was often necessary to transfer the paths to a medium scale, such as 1:15,000 resource photography. Thus, it was possible to determine

Table 21–*Relation of spectral response bandwidths for Skylab camera stations and Forest Service instruments, using filter sets with either silicon vidicon or Pin 10-DB diffused silicon photodiode*

Camera station/ filter set	Bandwidth			
	Skylab		USFS instruments	
	Design	Actual	Photodiode	Vidicon
	Half-power points, nanometers			
Station 1/filter C	700 to 800	713 to 814	689 to 779	690 to 780
Station 2/filter D	800 to 900	805 to 882	810 to 956	805 to 965
Station 5/filter B	600 to 700	601 to 695	605 to 723	605 to 720
Station 6/filter A	500 to 600	517 to 594	497 to 622	495 to 615

Figure 24–Microdensitometer scanning at 8-micron increments was feasible for the northern California site imaged by S190A camera station 6.

which parts of the radiance data stream represent relatively homogeneous areas that are resolvable on the satellite imagery.

The strip chart data were sampled with a digitizer at intervals equaling approximately 20 m on the ground. The ratios of radiance to irradiance were calculated by computer to generate a data stream of reflectance values. Calibration coefficients for the radiometer, irradiance meter, and chart recorder were derived in our laboratory near the time of the aircraft flights by using a light source with calibration traceable to a National Bureau of Standards source. We selected portions of the data stream that transected 6 to 13 homogeneous areas of interest on the photos, and computed mean values of reflectance.

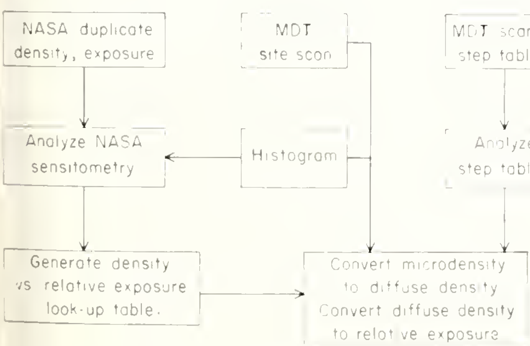


Figure 25–The density calibration program had three parallel paths, as shown.

Skylab Photographic Data

The satellite radiance data were derived from digital microdensitometer (MDT) scans made on duplicate photos of the test site, using a Photometric Data Systems Model 1010 unit. The NASA sensitometric data is given in terms of macroscale diffuse density. Cross-calibration scales between microdensity and diffuse density differ considerably for variations in film properties, MDT numerical aperture, and general internal optical design (Weiss 1973; Schmitt and Altman 1970). Hence it was necessary to calibrate microdensity against the diffuse density scale by using calibrated samples of copy films provided by JSC. Working in diffuse density units, we chose not to use the intermediate steps dealing with the original film sensitometry, but to compare measured duplicate densities with those produced by the exposure values applied to the original film. The system response curve was obtained by polynomial modeling techniques described by Dana (1973).

The analysis and data flow proceeded generally in three parallel paths *(fig. 25)*. From the microdensitometer scan of the test site, a histogram was generated in the first path to establish the range of density values which must be calibrated. This data tape was then ready for the final processing step. In the second path a separate tape containing the JSC step-tablet scans was analyzed by a program called RNSTAB. A least-squares fit of the microdensity M (in digital counts) to diffuse density D produced a second-order equation with a standard error always less than 0.01 diffuse density units for the three copy films used. (A linear form was tried, but it produced standard errors of about 0.04.) Conversion to diffuse density could then be made with an equation of the form

$$D = C_2 M^2 + C_1 M + C_0 \tag{4}$$

in which C_2, C_1, and C_0 are modeling coefficients.

In a third path, modeling of the photographic system response generally resulted in an equation for duplicate density that was third order in $\log_{10}$ of relative exposure. Some of the narrower ranges of density could be fit to a second-order curve. From these equations, look-up tables were generated to do the actual conversion.

The look-up table, the coefficients of the density conversion equations from RNSTAB, and the site-scan tape were put into a program named XCAL, which derives and prints out a relative exposure value for each microdensity value. Another program, DENCAL, combines the functions of RNSTAB and XCAL, utilizing the look-up table and both MDT input tapes in one computer run. DENCAL writes an exposure tape, as well as a printout, but does not have the flexibility of selecting different combinations of scanning runs from the MDT tapes as do RNSTAB and XCAL.

Once the relative exposure printout was obtained, the data corresponding to particular image blocks were identified and mean values computed for each. The absolute exposure E at the film plane was computed by using additional data provided by NASA. A conversion to equivalent radiance N in engineering units (Jenson 1968) was made by the equation

$$N = \frac{4F^2}{\pi t T} E \tag{5}$$

in which F = camera lens f-number, t = integrated exposure time, and T = total transmittance of camera lens, filter, and window.

Results and Discussion

For the Whiskeytown Reservoir site covered by Skylab photos, the distributions of reflectance (measured on the same day) were recorded and satellite radiance values were computed *(fig. 26)*. The green band results indicate the possibility of two distinct populations of reflectance—one around 0.04 and another around 0.14. Possibly a high linear correlation is forced on the data, but exclusion of the two high points yields a difference in path radiance of only 3 percent from linear regression. The slope of the new regression line would be 11 percent less. How the reflectance data should be used for classification depends on the distribution of radiance and reflectance values in the training and test areas. Multimodal data might present problems.

Camera station 5 (red band) malfunctioned momentarily over the Whiskeytown area and the photo in that band was not taken. But it was possible to compute the relative exposure values from red-filtered densitometer scans of the normal-color film (SO-356) from camera station 4. Since the red-sensitive layer in color film is not exclusively sensitive to the red wavelengths, we did not try to convert exposure to absolute radiance. Nevertheless, reflectance and exposure were closely correlated in the red region *(fig. 26)*, as they were in the other wavelength regions.

Further evidence of the linear relationship between reflectance and satellite radiance came from a test flight in the Black Hills on August 27, 1973 *(fig. 26)*. Because of anomalies in calibration data, reflectance is shown here in normalized form. The satellite radiance values were from LANDSAT-1 image 1028-17121 of the same area taken on August 20, 1972. No LANDSAT data from August to September 1973 were usable because of cloud cover. Average radiance values were computed from the system-corrected computer tapes and converted from digital counts to engineering units using conversion data from appropriate NASA publications (NASA 1972; Thomas 1973).

All correlation coefficients exceeded 0.94, suggesting that the radiance equation 1 is valid *(table 22)*. The path radiance values are all within the range of those reported by Rogers and others (1973) for four different LANDSAT images. We do not understand why camera station 2 recorded more path radiance than camera station 1, as station 2 represents longer wavelengths and has a narrower bandwidth. One possible source of error is the large factor (roughly 1.5 to 2.3) used in the NASA sensitometry pro

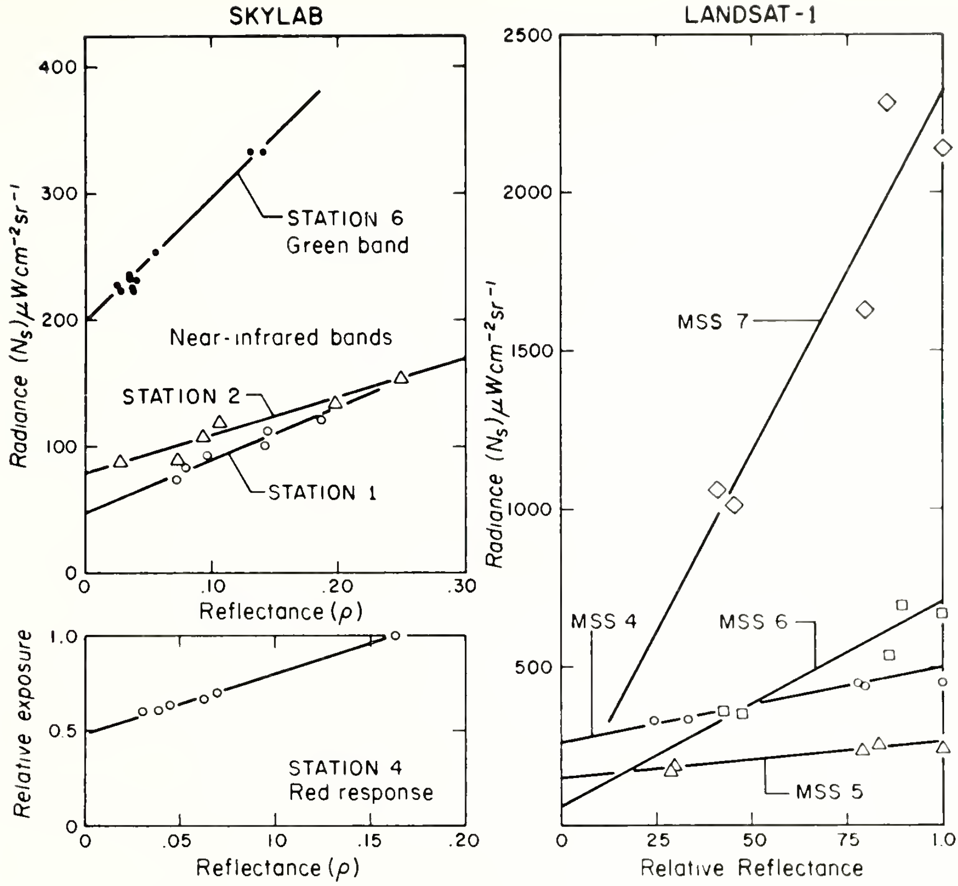


Figure 26–Relationships between radiance and reflectance are graphed here for Skylab and ERTS for various bands. For Skylab camera station 5, because no photo was available, relative exposure and reflectance for the red response of the normal-color film of camera station 4 were calculated. For LANDSAT multispectral scanner data, reflectance in each band was separately normalized to its highest value.

Table 22–*Path radiance values and correlation coefficients derived from analysis of the relation between satellite radiance and terrain reflectance*

Space platform, sensor, camera station or band, and bandwidth (nm)	Path radiance	Correlation coefficient
	$\mu w\ cm^{-2}\ sr^{-1}$	
Skylab S190A:		
6–517 to 594	196	0.98
4[1]	–	.99
1–713 to 814	51	.96
2–805 to 882	78	.97
LANDSAT-1, multispectral scanner:		
4–494 to 598	289	.98
5–604 to 700	153	.96
6–693 to 799	77	.95
7–808 to 987	76	.94

[1] Relative exposure of red response.

cedure to correct for a wider band Kodak Wratten 89 filter used in the sensitometer rather than the actual flight filters. We also found other unexplained discrepancies in comparing ground-measured radiance data with values from S190A film density, amounting to as much as 40 percent.[5] The matter deserves further study.

The space photos indicated semitransparent cirrus or cirrostratus clouds in the vicinity of the test site. Also, a very light and variable cirroform veil was noted about 1 hour after the Skylab overflight when the aircraft flight was performed. Therefore, undetected ice crystals or other aerosols might have contributed to the anomaly in near-infrared path radiance.

[5] National Aeronautics and Space Administration. 1974. *Skylab program, sensor performance report, vol. I* (S190A). MSC-05528. NASA L. B. Johnson Space Center, p. 5-8p to 5-8q.

Despite the increasing cirrus veil, the appearance of strong shadows in the forest at the time of the aircraft flight suggested that the reflectance data would be valid for a clear sky. However, only the radiance and irradiance data acquired early in the flight for the green band could be considered valid for beam transmittance calculations using equation 3. The result was 0.86 ±0.05.

Applications

This reflectance measurement technique shows much promise as a means of obtaining valid values of the path radiance components of satellite imagery and probably of high-altitude aircraft imagery. Although this method may not be the least expensive one, it may be a valuable adjunct to computational methods or to methods using ground-based instrumentation requiring measurements coincident to the satellite overpass. Plans are underway to compare the aircraft reflectance method with the groundbased method developed by Rogers and Peacock (Rogers and others 1973). This comparison should at least help determine the relationship of the slope of the regression line to total irradiance and beam transmittance.

Several variables affecting the aircraft measurement technique need to be investigated. Most of them concern the question of how closely the flight conditions must match those at the time of satellite overflight. These variables include solar zenith angle, viewing angle, time of day, aircraft altitude, and spectral effects.

Equation 1, which is concerned with spectral effects, is strictly valid only at individual wavelengths or for narrow bandwidths. The factors τ, H, ρ, and N_p are all spectrally dependent. Since the broadband measurements are actually integrals over wavelength, the results should be checked against measurements made with spectroradiometers (Hulstrom 1974).

Possible applications of linear atmospheric transformation in computer classification have been discussed in the literature (Rogers and others 1973; Potter 1974; Kan 1972). The objective is to extend spectral signatures from a classified scene or data set to a similar unclassified set when the main differences are due to solar and atmospheric effects. Rewriting equation 1 we have

$$N_i = a_i \rho_i + b_i \tag{6}$$

in which the subscript i refers to the wavelength band. Knowing the correct coefficients a_i and b_i, one could convert the radiance sets N_i to reflectance sets ρ_i before classification. Also, new sets of radiance data N_i' (with coefficients a_i' and b_i') could be converted to the scale of previous sets by the equation

$$N_i = \frac{a_i}{a_i'} N_i' + \frac{a_i}{a_i'} b_i' + b_i \tag{7}$$

In a supervised classification scheme requiring training sets, one could transform the discriminant function used in the analysis of the old data set to the scale of the new data set. This method should require the least amount of computation. For example, using a Gaussian linear classifier implies the transformation of the mean vector and the covariance matrix to new functions that are applicable to the new data set.

LITERATURE CITED

Aldrich, R. C.
1971. Space photos for land use and forestry. Photogramm. Eng. 37(4):389-401, illus.

Aldrich, R. C., N. X. Norick, and W. J. Greentree.
1975. Forest Inventory: Land use classification and forest disturbance monitoring. *In* Evaluation of ERTS-1 data for forest and rangeland surveys. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Canfield, R. H.
1942. Sampling ranges by the line-interception method. Res. Rep. 4. 28 p. USDA Forest Serv., Southwest Forest and Range Exp. Stn., Tucson, Ariz.

Dana, R. W.
1973. Digital sensitometry of color infrared film as an aid to pattern recognition studies. *In* Remote Sensing of Earth Resour., 2:435-452. Space Inst., Univ. of Tennessee, Tulahoma, Tenn.

Daubenmire, R. F.
1952. Forest vegetation of northern Idaho and adjacent Washington and its bearing on concepts of vegetation classification. Ecol. Monogr. 22:301-330.

Draeger, W. C., L. R. Pettinger, and A. S. Benson.
1971. The use of small scale aerial photography in a regional agricultural survey. *In* Proc. Seventh Int. Symp. on Remote Sensing of Environ. Univ. of Mich., Ann Arbor. 2:1205-1217.

Driscoll, R. S.
1969. Aerial color and color infrared photography–some applications and problems for grazing resource inventories. *In* Proc. Aerial Color Photogr. in Plant Sci. Aerial Color Photogr. Workshop, Univ. of Florida, Gainesville. p. 140-149.

Driscoll, R. S., and R. E. Francis.
1972. Multistage, multiband, and sequential imagery to identify and quantify non-forest vegetation resources. Final report Earth Resour. Surv. Program, NASA Office Space Sci. and Appl., 49 p.

Driscoll, R. S., and R. E. Francis.
1975. Range Inventory: Classification of plant communities. *In* Evaluation of ERTS-1 data for forest and rangeland surveys. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Heller, R. C., Tech. Coord.
1975. Evaluation of ERTS-1 data for forest and rangeland surveys. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Heller, R. C., J. L. Bean, and F. B. Knight.
1959. Aerial surveys of Black Hills beetle infestations. Stn. Paper 46, 8 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Hildebrandt, G.
1973. Use of earth satellites for supranational inventories of forest and agricultural areas. Raumfahrtforschung, 17:164-168.

Hulstrom, R. L.
1974. Spectral measurements and analyses of atmospheric effects on remote sensor data. Proc. of the Soc. of Photo-optical Instrum. Eng. Semin. on Scanners and Imagery Syst. for Earth Observ. [San Diego, Calif., August 10-20, 1974], 51:90-109.

Jensen, N.
1968. Optical photographic reconnaissance systems. p. 73-76. John Wiley and Sons: New York and London.

Kan, E. P. F.
1972. Effects of atmospheric correction on classification. Lockheed Electron. Co., Inc., Houston Aerospace Syst. Div., Houston. Publ. LEC Number TM642-620. 9 p.

Kuusela, L., and S. Poso.
1972. Multi-stage acquisition of forest information from space and aircraft imagery and ground sampling. *In* Space Research III. Proc. of the Fifteenth Plenary Meet. 1:113-117.

Langley, P. G., R. C. Aldrich, and R. C. Heller.
1969. Multistage sampling of forest resources by using space photography. *In* Second Annu. Earth Resour. Aircr. Program Status Rev. Vol. 2, Agric./For. and Sens. Studies. NASA Manned Spacecr. Cent., Houston. p. 19-2 to 19-21.

Munsell Color Company.
1920-1960. Munsell book of color. Munsell Color Co. Baltimore.

National Aeronautics and Space Administration, Goddard Space Flight Center.
1972. Data users handbook: NASA Earth Resources Technology Satellite. Doc. No. 71SD4249. NASA Goddard Space Flight Center, Greenbelt, Md. p. G-14.

National Bureau of Standards.
1955. The ISCC-NBS method of designating color and a dictionary of color names. U.S. Dep. of Comm., NBS, Circular 553.

Nichols, J. D., M. Gialdini, and S. Jaakkola.
1973. A timber inventory based upon manual and automated analysis of ERTS-1 and supporting aircraft data using multistage probability sampling. Vol. 1: Tech. Presentations, Sec. A. Third Earth Resour. Tech. Satellite-1 Symp. NASA Goddard Space Flight Center, Greenbelt, Md. p. 145-157.

Personnel of the Remote Sensing Research Work Unit.
1972. Monitoring forest land from high altitude and from space. Final report for Earth Resour. Surv. Program, NASA Office of Space Sci. and Appl., 192 p., illus.

Peterken, G. R.
1970. Guide to check sheet for IBP [International Biological Program] areas; including a classification of vegetation for general purposes by F. R. Fosberg. IBP Handb. 4. Blackwell Sci. Publ., Oxford. 133 p.

Pfister, R. D., and J. C. Corliss, Co-chairmen.
1973. ECOCLASS–a method for classifying ecosystems. USDA Forest Service Ecosystems Task Force. Rep. on file at Forestry Sci. Lab., Intermountain Forest and Range Exp. Stn., Missoula, Mont. 52 p.

Potter, J. F.
1974. Haze and sun angle effects on automatic classification of satellite data-simulation and correction. Proc. Soc. Photo-optical Instrum. Eng. Semin. on Scanners and Imagery Syst. for Earth Obs. [San Diego, Calif., August 19-20, 1974], 51:73-83.

Rogers, R. H., K. Peacock, and N. J. Shah.
1973. A technique for correcting ERTS data for solar and atmospheric effects. Proc. of Third ERTS Symp., Washington, D.C. vol. 1, sec. B, p. 1787-1804.

Schmitt, H. C., Jr., and J. H. Altman.
1970. Method of measuring diffuse RMS granularity. Appl. Optics. 9(4):871-874.

Thomas, V. L.
1973. Generation and physical characteristics of the ERTS MSS system corrected computer compatible tapes. Publ. No. X-563-73-206. NASA Goddard Space Flight Center, Greenbelt, Md. p. E-1 to E-4.

U.S. Forest Service.
1974. Forest Service Handbook: Inform (FSH 1309.13). U.S. Forest Serv., Washington, D.C., Chap. 20 [148 p.].

U.S. Forest Service.
1968. Forest Survey Manual for the Southeast. Southeastern Forest Exp. Stn., Asheville, N.C. [317 p.].

Weber, F. P.
1969. Remote Sensing implications of water deficit and energy relationships for ponderosa pine attacked by bark beetle and associated disease organisms. Ph. D. thesis, Univ. of Mich., Ann Arbor. 143 p.

Weber, F. P., R. C. Aldrich, F. G. Sadowski, and F. J. Thomson.
1973. Land use classification in the southeastern forest region by multispectral scanning and computerized mapping. *In* Proc. Eighth Int. Symp. on Remote Sensing of Environ., Univ. of Mich., Environ. Res. Inst. of Mich., Ann Arbor. 1:351-373.

Weber, F. P., and F. C. Polcyn.
1972. Remote sensing to detect stress in forests. Photogramm. Eng. 38(2):163-175.

Weber, F. P., E. H. Roberts, and T. H. Waite.
1975. Forest stress detection. *In* Evaluation of ERTS-1 data for forest and rangeland surveys. USDA Forest Serv. Res. Paper PSW-112, 67 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Weiss, J. P.
1973. Densitometry. *In* SPSE Handb. of Photogr. Sci. and Eng. p. 829-877. John Wiley & Sons: New York and London.

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant communities; forest stress.

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant communities; forest stress.

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant

Aldrich, Robert C., *technical coordinator*

1976. **Evaluation of Skylab (EREP) data for forest and rangeland surveys.** USDA Forest Serv. Res. Paper PSW-113, 74 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Data products from the Skylab Earth Resources Experiment Package were examined monocularly or stereoscopically using a variety of magnifying interpretation devices. Land use, forest types, physiographic sites, and plant communities, as well as forest stress, were interpreted and mapped at sites in Georgia, South Dakota, and Colorado. Microdensitometric techniques and computer-assisted data analysis and sampling procedures were developed and tested against ground truth. Results indicate that only Skylab S190B color photographs are good for classification of forest and nonforest land (90 to 95 percent correct). Both visual and microdensitometer techniques can separate range plant communities at the Region level (ECOCLASS system) with over 90 percent accuracy. Only mountain pine beetle infestations more than 26 m (85 ft) long could be detected. In a study near Redding, California, radiance from Skylab S190B and LANDSAT sensors was found linearly correlated with terrain reflectance.

Oxford: U629.19[+587.7+44]

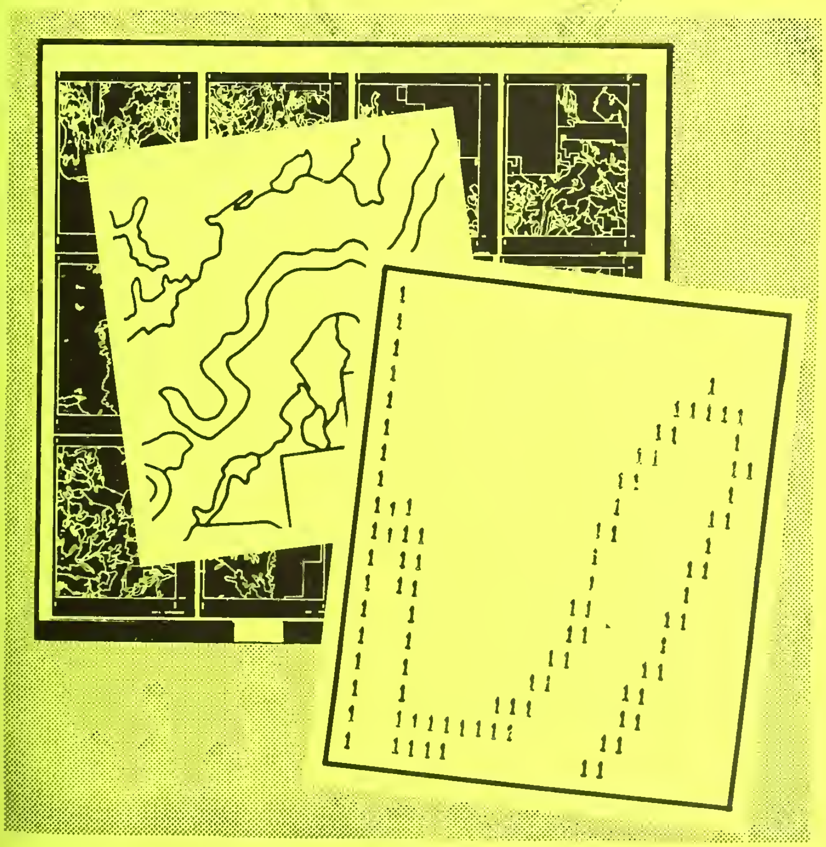
Retrieval Terms: Skylab; Earth Resources Experiment Package; photointerpretation; microdensitometric analysis; remote sensors; forest classification; range inventory; plant

PACIFIC SOUTHWEST
Forest and Range
Experiment Station

ORST SERVICE
S. EPARTMENT OF AGRICULTURE
O. OX 245, BERKELEY, CALIFORNIA 94701

MICROCOPYING WILDLAND MAPS FOR DISTRIBUTION AND SCANNER DIGITIZING

Elliot L. Amidon E. Joyce Dye



USDA FOREST SERVICE RESEARCH PAPER PSW- 114/1976

CONTENTS

The Authors

are assigned to the Station's research unit investigating measurement and analysis techniques for management planning, with headquarters in Berkeley, Calif. **ELLIOT L. AMIDON** is in charge of the measurement and analysis techniques research unit. He earned a bachelor's degree in forest management at Colorado State University (1954) and a master's degree in agricultural economics at the University of California, Berkeley (1961), and was assigned to production economics research at the Station until he assumed his present position in 1971. **E. JOYCE DYE**, a computer programmer, earned a bachelor's degree in geography (1973) at the University of California, Berkeley. She joined the Station staff (Support Services) in 1961 after nine years on National Forests in Oregon. She has been in her present assignment since 1970.

This publication is available in paper copy (PC) or microfiche (MF) from the National Technical Information Service, U.S. Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. For further information, write to NTIS, or consult *Government Reports: Announcements & Index.*

SUMMARY

Amidon, Elliot L., and E. Joyce Dye.
1976. Microcopying wildland maps for distribution and scanner digitizing. USDA Forest Serv. Res. Paper PSW-114, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 91–(084.3):UDC 778.142
Retrieval Terms: wildland planning; maps; micrographics; computer mapping; digital techniques.

Maps for wildland resource inventory and management purposes typically show vegetation types, soils, and other areal information. For field work, maps must be large-scale. For safekeeping and compact storage, however, they can be reduced onto film, ready to be enlarged on demand by office viewers. By meeting certain simple requirements, film images are potential input to computer-mapping systems.

Microform is a collective term for reduced images called microimages, stored on transparent or opaque stock. Two popular microforms are microfilms and microfiche. A variety of form sizes and image reductions complicates selection of films for maps and text. Both maps and page-size text must be accommodated to obtain the savings possible from joint use of the same equipment.

In a study of current literature on microcopying, several competing types of microforms were considered. Among the several, only roll microfilm and microfiche were judged acceptable for application to wildland maps. Each alternative should be considered in the light of the likelihood of its becoming widely available and standardized, suitability for automatic scanning, cost for film storage and reproduction, quality of projection equipment, and archival durability. The widespread popularity of roll microfilm stems mainly from the fact that standardized film and projection equipment abound. Although microfiche is less widely used, it may in time grow in importance relative to other microforms.

With the choice narrowed to two basic forms, the next step is to match the most common resource map sizes to a few film formats. About 50 combinations are available if only a few reductions, map sizes, and film formats are selected. The number of possibilities is much greater if the marked variation in map size by latitude is used to calculate microimage sizes. Allowing for the extreme case, i.e., all contiguous United States, a standard double-frame 35-mm microfilm at a twenty-fourfold reduction (abbreviated 24X) will serve all purposes. Microfiche alternatives are more complex. At low reduction ratios, either nonstandard formats are necessary or maps must be sectioned in one of several ways.

The smaller the microimage the more important the film for a given resolution. Four types of microfilm were investigated: silver halide, diazo, vesicular, and color. Silver film is the most common and only one to meet archival standards. Diazo is the most economical of all for numerous distribution copies. Neither vesicular nor color film have marked advantages over the other two and were excluded from scanning experiments.

Ocular viewing of map microimages is far less demanding than digital conversion by a scanning microdensitometer. Variable widths or uneven line densities, which are visually tolerable, increase the cost of computer input. Consequently, the resolving power of silver and diazo microfilms was measured by scanning the U.S. National Bureau of Standard's Microcopy Resolution Test Chart 1963-A. The results reflected the characteristics of the scanning microdensitometer more than the film properties for a given line width and resolution. Test scans ranged from intervals of 2 μm to 12 μm. Despite the complications introduced by scanner mechanisms, it seems evident that 24X is the limit for fine lines (0.01 inch or 0.25 mm). A reduction of 42X is attainable only if exceptional environmental conditions are provided. An economic choice will probably be 24X reduction onto microfiche or roll microfilm for most users.

Most wildland users are familiar with maps produced by the U.S. Geological Survey. The USGS produces large-scale topographic maps at a representative fraction (RF) of 1:24,000. Forest resource maps are often enlargements of them, and a typical township map at 4 inches per mile (RF 1:15,840) requires a 30-inch square sheet of paper (6 sq. ft.). In California, several thousand of these large-scale maps are used on the National Forests for timber resource management each year. Such large maps are needed for sketching in plot locations or logging operations and general field work. But in the office, a small map would save space and still be useful for measurement and general reference.

Technology is available to greatly reduce the awkwardness of handling maps. Various types of microforms were brought into practical use more than 30 years ago (Veaner 1971). Almost all equipment is designed for page-size material–the most common input. An important exception is a decade-old development–computer-output-microfilm (COM). In this automated process, paper is eliminated by directly writing on film. Another recent innovation is the use of color–despite its cost and low resolution.

Microform is a collective term for storing microimages, generally on fine grain film (U.S. Dep. of Commerce 1969). A well-known form is microfilm, widely available in 16- and 35-mm rolls. Another important form is microfiche, in which images in a grid pattern are recorded on a short length of wide (105 mm) film. Only these two forms are considered here.

Not discussed are methods of handling microfilm, forms intended primarily for library cataloging (micro-opaques), storage/retrieval apparatus, or software. Reduction ratios greater than 48:1 (48X) are excluded in our study because separate equipment would be required for text and map material.

Can microform technology be extended from text to maps? It would be uneconomic to use microforms just for maps. But once the setup cost is incurred to distribute and enlarge microforms, then the added cost of a special use is relatively small. Moreover, benefits will be greatest when microform technology can be applied to map data without substantially changing existing procedures. Selecting the best method for microfilming maps for ocular use requires only a general understanding of microforms. Additional facts are required if the images are to be automatically digitized for input to computer-mapping systems.

This report describes a study of microcopying techniques for processing wildland maps for distribution and for digitizing. The application of microfilm and microfiche to map processing is described.

MICROIMAGE DIGITIZING

Automatic Digitzing is Required

A decade ago, input to computer-mapping systems was prepared by using paper and pencil. As a step toward automation, the pencil was replaced by recording coordinates on magnetic tape. With either method a large map format is necessary. Microcopying would reduce map storage cost, but this gain would be offset later by enlargement to the map's original size. Hard copy could be avoided if the microimage were projected from the rear onto a translucent screen. The saving of paper is attained at the additional cost of optics and mechanical linkage in the digitizer hardware. Clearly, manual line tracing is not materially assisted by reducing maps onto film.

Two new methods of digitizing maps–automatic line following and scanning–require a microimage. Unlike manual line tracing, both methods allow only lines; it is necessary to record all other map details on a separate layer or in a color which the film cannot detect. Automatic line following is done under computer control with an operator deciding the digitizing sequence when ambiguities occur. The method is being tested on census data, but has not as yet proved suitable for digitizing forest maps (Amidon 1974).

Automatic scanning collects optical densities or "gray levels" at successive intervals on the microimage by using a microdensitometer. Major application areas are in medicine and aerial photography. The grey levels are input to pattern recognition computer programs. The scanning equipment is useful for the simpler problem of map digitizing in which the grey levels are divided into two groups: lines and background. The success of this approach depends heavily on the preparation of the original maps. Extraneous details, shading or dust can complicate this basically simple binary discrimination.

An Operational Scanning System

The Wildland Resource Information System (WRIS) routinely processes several hundred maps each year (Russell and others 1975). The system relies on automatic scanning, although simple maps can be digitized manually. National Forest maps of timber types, land-use categories, and administrative boundaries are drawn on stable plastic with ink lines ideally 1.2 mm wide. Each map is reduced 10X onto a 4- by 6-inch copy negative and scanned with a spacing and aperture of about 40 (formerly 60) μm. Computation cost is almost directly related to the number of density readings. A finer spacing decreases the manual labor in computer image editing, but increases scanning and computer time. The trade-off is an economic decision, subject to the threshold imposed by resolution limitations.

Automatic digitizers with a comb (one-directional) scanning pattern are faster with smaller images because nonfunctional time intervals between lines, while the stage is returning, are shortened. In using a Photometric Data Systems PDS 1010 microdensitometer,[1] we have saved 4 to 5 hours for a 1¼ million-point scan by going from a 10X to a 20X reduction. For other digitizers the gain will be less because the scanning paths, such as spiral or boustrophedonic (two-directional as in plowing), were designed to minimize nonfunctional time. If the recording rate is kept constant, digitizing time will vary directly with the area scanned.

Aside from digitizing time, the principal gain from increased image reduction is reduced storage space, with a tenfold reduction easily obtainable. Other advantages are not attributable just to micrographics but to microforms in general and to COM in particular.

PREFERRED MICROFORMS AND STORAGE METHODS

Microfiche and Roll Microfilm

Even with the microform field narrowed to two types—microfilm rolls and microfiche—there are still important choices.

Microfilm (35 mm) has rectangular frames, either single or double (1 or 2 pages). Frames can be positioned in two ways on the film. In *cine* orientation, the sides of the image are parallel to the long edge of the film. In strip orientation, the top and bottom of the image are parallel to the long edge of the film. This arrangement is also called *comic*, because frames are side-by-side on the roll.

Microfiche sizes and formats vary widely, but in recent years certain forms have become dominant. The microfiche considered here are limited to 105- by 148.75-mm or roughly 4- by 6-inch negatives or positive transparencies. A fiche has an identifying header, about ½ inch wide along the top edge, with room for one to three lines of titling. Color stripes may be placed behind the header as selection keys. Below the header, which is legible without magnification, are rows and columns of frames. Any single frame may contain a few eye-legible characters but most hold data unreadable without magnification.

Frame sizes vary, and therefore, the number of images per fiche is not standard. Recent trends in government use, particularly defense documentation, suggest consideration of just two frame sizes and four reduction factors. Since a frame can be single or double, there are 16 possibilities for microfiche in addition to the 8 for microfilm. As we explain later, matching conventional map sizes and reduction factors results in just a few alternatives.

Serial and Random Storage

Data on 35-mm film can be stored either sequentially or randomly, but not by the same equipment. High-speed serial searches are possible with motor-driven reels. At the opposite extreme microfilm can be handled as short strips stored in jackets or even singly in aperture cards.

Microfiche is a compromise between serial and random storage. Depending on the frame size selected, each fiche can store from 1 to 60 single-page images at 20X or 1 to 98 images at 24X. These are commercially available, popular reduction ratios. Computer-controlled writing in single frames and at 48X allows 270 frames on a 4- by 6-inch fiche. These are conservative reductions. Books are available at 75X, and ultrafiche is defined as more than 90X. Libraries can purchase 3- by 5-inch fiche with 100(

[1] Trade names and commercial enterprises or products are mentioned solely for information. No endorsement by the U.S. Department of Agriculture is implied.

images in a 50-by-20 matrix. One ultrafiche format accommodates 3280 pages of 8½- by 11-inch original size at 150X on a single 4- by 6-inch fiche (National Microfilm Assoc. 1973). At such high densities, the distinction between sequential and random storage methods, i.e., by reels and fiche, starts to blur.

SELECTION OF MICROFORM FORMATS FOR MAPS

Page-size Material Determines Choices

Reducing page-size documents usually involves few decisions because the process has already been designed for this purpose. There is abundant information available on the advantages of microfilming conventional text material. Major factors to be considered are space savings, suitability for reproduction, amount of use, availability of viewing and copying machinery, and preservation of materials (Lynden 1975). Despite decades of experience with microphotography, the use of microforms is still largely directed toward libraries. There is a tendency to identify microfilms "as substitutes for crumbling and unwieldly volumes of newspapers and for out-of-print material not available elsewhere" (Salmon 1974, p. 194). This retrospective viewpoint is a hindrance to the effective use of microfiche. Certainly there is a need for preserving and reissuing rare or fragile works and for general maintenance of research libraries. Yet microforms are not restricted to archival purposes.

The greatest growth potential lies in the direction of original publication on microform—particularly microfiche. The gain is achieved by adapting text composition to micropublication technology, which is the opposite of past practice. The principal advantage for publishers is a negligible inventory because copies are made on demand. Users benefit not only from lower storage and distribution costs, but also by selecting only those fiche containing desired chapters or sections of a set of volumes.

The publication of technical reports and periodicals on microforms is growing in popularity. Options include roll film or microfiche available separately or in addition to the paper copy. A notable exception is a periodical of interest to wildlife resource managers, "Wildlife Disease." Individual articles are not available on paper but only on 60-frame microfiche and occasionally in color (Presidente and others 1974).

The most recent development in the use of microforms as a medium of original publication is the substitution of film for paper. Text material is assembled and revised by computer programs and stored on magnetic tape. Instructions on the tape control electronic writing on film at 32,000 lines per minute. This rate is at least 15 times faster than an impact printer (National Microfilm Assoc. 1974). A study of COM use by the U.S. General Accounting Office showed that conversion of reports to microfilm at eight federal installations would save $1 million annually (Comptroller General of the U.S. 1974).

COM is suitable for dynamic applications requiring frequent updating such as directories, parts lists, and catalogs. An excellent example is maintenance of computer system documentation which requires frequent, scattered changes. At the Lawrence Berkeley Laboratory, Berkeley, Calif., over 2000 pages of system documentation are available to any user on 11 microfiche at 48X for a setup cost of about $25. Most of this cost is due to the labor of determining which files are current and updating the request program accordingly. Each additional set of silver halide microfiche produced under computer control costs about $5. For sets of 50 or more, it is more economical to make diazo copies.

Forest Map Sizes

Since maps are usually larger than text pages—the size for which most equipment is intended—the reduction ratio must be greater for maps than text to fit within a microform frame. Excess reduction will deteriorate resolution to the point where map details become illegible. Some maps cannot be reduced directly to one frame. They must be either sectioned or reduced to an intermediate negative, with loss of detail inevitable.

Theoretically a township is square—each side is 6 miles on the ground or 2 feet on a map at a representative fraction of 1:15,840. But few townships actually are square. Township shapes vary considerably, and a microform frame must be selected to cover all possibilities. This variation requires an extensive advance search and measurement of all irregular townships—a major inconvenience. Instead, an allowance for some distortion can be specified in advance, with occasional exceptions handled by sectioning. Lineal distortions of up to 30 percent could be tolerated with double-frame, 48X COSATI (Council on Scientific and Technical Information) microfiche. Single-frame 35-mm microfilm (48X) has enough extra space to accommodate slightly greater distortion. Allowing for a 40 to 50 percent waste of film space essentially defeats the microimage approach.

The systematic approach offered by all mathematical projections is almost a necessity to gain any advantage from miniaturization. Although many map sizes and scales are available, some variation of the USGS 7½′ quadrangle is generally used. Instructions for making polyconic projections at selected scales, in the contiguous United States, are readily available (U.S. Geological Survey 1964). We limit ourselves to the familiar 7½′ maps, and the two RF's of 1:24,000 (2.64 inches per mile) and 1:31,680 (2 inches per mile). An RF of 1:15,840 (4 inches per mile) is not considered both because it usually occurs in a township format, and it is an awkward size for a quadrangle (about 35 inches, in longest direction).

Quadrangle widths get narrower as latitude increases (*table 1*). It must be decided in advance of filming whether coverage will be statewide, regional or national. For example, at latitude 42 degrees and greater as in Oregon and Washington, a 7½′ 1:24,000-scale map can be reduced 24 times onto a single frame of 35-mm film. But a double-frame format would be needed to cover all quadrangles in the continental United States.

The final step is to calculate quadrangle dimensions at commercially available reductions and see if the map "rectangle" will be accommodated by the microform frame.

Reduction Ratios

For each map scale there are 24 possible microimage recording layouts; the product of four reduction ratios and six microformats. The 24X and 48X reductions should be favored, if possible, because their use should increase after recent standardization efforts. In 1971, the Council on Scientific and Technical Information (COSATI) voted to drop 20X in favor of 24X. The Department of Defense (DOD) changed from 42X to 48X, gaining 62 frames, for a total of 270 page-size frames per 4- by 6-inch fiche under computer control (Gordon 1971). Despite these changes, both 20X and 42X systems continue to be widely used in business applications. Therefore they cannot be disregarded. The document size containable by a frame depends on the reduction ratio.

For 35-mm with a strip orientation, the document dimensions (inches) are:

A. Single frame (18 by 24.5 mm or 0.7087 by 0.9646 inch)

Reduction ratio:	*Width*	*Height*
20	14	19¼
24	17	23
42	29¾	40½
48	34	46¼

B. Double frame (36 by 24.5 mm or 1.429 by 0.9646 inch)

Reduction ratio:	*Width*	*Height*
20	28½	19¼
24	34¼	23
42	60	40½
48	68½	46¼

For microfiche, commercial format, the document dimensions (inches) are:

A. Single-page format, 98 images/fiche (10 by 12.5 mm or 0.3937 by 0.4921 inch)

Reduction ratio:	*Width*	*Height*
20	7¾	9¾
24	9¼	11¾
42	16½	20½
48	18¾	23½

B. Double-page format, 49 images/fiche (20 by 12.5 mm or 0.7874 by 0.4921 inch)

Reduction ratio:	*Width*	*Height*
20	15½	9¾
24	18¾	11¾
42	33	20½
48	37¾	23½

For microfiche, COSATI format, the document dimensions (inches) are:

A. Single-page format, 60 images/fiche (11.75 by 16.5 mm or 0.4626 by 0.6496 inch)

Reduction ratio:	*Width*	*Height*
20	9¼	12¾
24	11	15½
42	19¼	27¼
48	22	31

B. Double-page format, 30 images (23.5 by 16.5 mm or 0.9252 by 0.6496 inch)

Reduction ratio:	*Width*	*Height*
20	18½	12¾
24	22	15½
42	38¾	27¼
48	44¼	31

Table 1–*Dimensions of 7½′ quadrangles, at two representative fractions, by selected latitudes*

Latitude North	1:24,000		1:31,680	
	Width (E-W)	Height (N-S)	Width (E-W)	Height (N-S)
	inches			
25° Florida	20.7	22.7	15.7	17.2
32° Mexico-California	19.4	22.7	14.7	17.2
42° California-Oregon	17.0	22.8	12.9	17.3
49° Washington-Canada	15.0	22.8	11.4	17.3

Table 2–*Reduction ratios for which any 7½′ quadrangle in the contiguous United States will fall within a microform frame*

Microform	*Reduction Ratio*[1]			
	20	24	42	48
35-mm Microfilm:				
Single frame	–	B	A,B	A,B
Double frame	B	A,B	A,B	A,B
Microfiche:				
Commercial:				
98 images	–	–	B	B
49 images	–		B	A,B
COSATI:				
60 images	–	–	B	A,B
30 images	–	–	A,B	A,B

[1] A=RF 1:24,000
B=RF 1:31,680

Any map would fit within a frame if reduced repeatedly, but at a one-step reduction only half of all possible combinations meet the specified sizes and ratios (*table 2*). For the two representative fractions all maps but one will fit within a single frame at a 48X reduction. Yet at 42X only the COSATI double-page format allows both scales. This table also shows that all quadrangles for the contiguous 48 States fall within a double-frame, 35-mm microfilm, at 24X or more.

Microfiche cannot be used at 24X, given the conventional frame sizes assumed. Sectioning of maps into 3¾′ quarters or smaller with 24X reduction is an alternative to massive reductions of entire maps. Of course, quartering a map may result in a more than fourfold increase in fiche area. The commercial, double-page fiche has 49 frames (24X) and could store nine maps conveniently with 13 or 49–(9 x 4) frames either wasted or perhaps used for titling (*fig. 1*).

Another alternative is to split the quadrangle in two with the most advantageous orientation for the cut being east to west. Then any 3¾′-(latitude interval)-by-7½′ quadrangle at either scale would fit with a 24X reduction in a COSATI double frame. Only maps of RF 1:31,680 would fall within the smaller, commercial format frame at 24X.

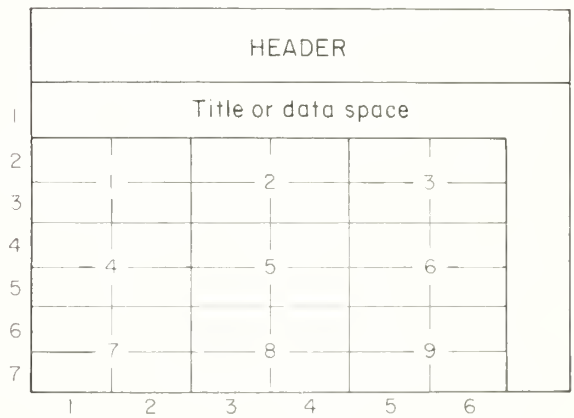


Figure 1–Nine 7½′ maps, each sectioned into four 3¾′ quadrangles to fit in 36 of 49 microfiche double frames.

Maps need not be sectioned either physically or exactly. Each frame could include a narrow strip of each neighbor. The overlap helps because the micro-image frames are separated by a narrow margin.

CONVENTIONAL MICROFORM FILMS

Silver Halide Film

Archival permanence is attainable only with silver halide film and correct processing. Standard methods are followed to determine durability of silver images. Comparable standards do not exist for diazo and vesicular film. Test procedures are particularly needed for judging the potential durability of nonsilver films. Although nonsilver forms *may* be satisfactory for many years, longevity cannot be assured. It is lack of information, rather than contrary evidence, that rules against nonsilver films.

Nonsilver Diazo Film

The camera and intermediate copies are made of silver halide, but distribution copies are often diazo or, less frequently, vesicular. Choosing diazo over halide copies can result in cost savings of 20 to 25 percent.

Diazo is a dye image produced by an ultraviolet light and developed by an ammonia process. Blue images are most common, but other colors are available. Diazo is a nonreversing film. A copy of a negative is a negative. The microimages have several properties favoring scanner digitizing at great reduction ratios. The grainless image results in a very high resolution–exceeding 1400 lines/mm. The image is homogeneous and the dye molecules permeate the entire coating–not just the surface. This characteristic in combination with the plastic used for fiche (which is tougher than camera film) makes diazo less susceptible to scratches. In addition, flat forms receive less wear than roll films which may be driven at high speeds through reader transport systems. Special coatings to make roll films resistant to abrasion have not, to date, proved successful (Williams 1970).

The advantages associated with a dye image also lead to its principal limitation. The dye is subject to fading, particularly with prolonged exposure to ultraviolet light. And so another copy may have to be made from the halide original. Halftone or shaded areas in general are difficult to reproduce to specified density levels with either halide or diazo film. The problem is greater with diazo, although other types of contrast films are available. In any case, shaded maps are excluded from consideration; sharp ink or scribed lines and characters are necessary.

Vesicular Film

Nonsilver vesicular film is used for distribution copies when information ages rapidly and entire film sets are frequently replaced. Ultraviolet light creates vesicles or "bubbles" which scatter light, rather than absorb it, to create images. The film has been used for storing maps in a motorized retrieval system for military use (Goodwald 1968). More than 28,000 maps were microfilmed to a 35-mm format and then transferred to a scroll of vesicular film 17 inches wide by 400 feet long. Both continuous tone capabilities and a resolution of 150 lines/mm were maintained. This unique system, although too specialized for civilian use, indicates the technical feasibility of using vesicular film for duplication purposes. Vesicular does not seem to have any outstanding advantages over diazo. The attraction of vesicular film is that if certain hurdles are overcome, it may be used for recording, i.e., as camera film.

Color Film Capabilites

Color films for recording microimages are available in both roll and flat forms, but have not yet been widely used for that purpose. The major application is for educational purposes, such as medical slides. Other micrographic uses include color-coded drawings or maps.

Besides lacking permanence because it uses dyes, color film has two other disadvantages. Color duplication is a costly process requiring the training of personnel or waiting for service at commercial film processing laboratories. More serious, the best conditions for line images work against those for color. High contrast yields more legible lines; low contrast favors good color fidelity. A compromise must be struck. As a result, resolution is reduced in comparison to that of black-and-white films. Reductions greater than 24X should be avoided. An original color negative has a resolving power of 90 lines/mm, but a print (second copy) has about 70 lines/mm as determined by tests at a 20:1 reduction (Rickman 1973, p. 358). In practical terms, a 7½-minute, 1:31,680 quadrangle is the largest scale map that will fit in a 35-mm double frame at 20X. Reducing color microfiche requires special consideration of type size and face to maintain legibility. For these reasons, as well as the potential focusing problem for microdensitometry created by three dye layers, we do not consider color film a desirable microimage storage medium.

RESOURCE MAP IMAGE RESOLUTION

Resolution Test Chart

The problem of finding a suitable reduction from map to microimage is solved by finding the most compact form with a process that is reversible to the eye and a scanning digitizer. Resolution–the ability of the microfilming system to distinguish fine details sharply–is the key consideration. Statements concerning resolving power are approximate unless contrast and other test conditions are specified (Altman 1961). A controversial, but nevertheless standard, basis for judging resolution is a test chart provided by the National Bureau of Standards (Fouquet 1963) (*fig. 2*). The targets are usually placed in the first or last frame of each microfiche for quality control. Resolution is defined as the ability of a system to separate images of closely spaced lines. A set of five charts costs $18 (1975 prices) (U.S. Dep. of Commerce 1974).

Each of the patterns contains five vertical and five horizontal stripes and a number. A line is defined as a dark stripe with a light stripe of equal width alongside it. Each number is the count of lines/mm for that pattern. The eye can resolve 10 lines/mm at a normal reading distance. Fine-grain microfilm has a resolution of at least 600 lines/mm and, with a well corrected lens, the net resolution is likely to exceed 200 lines/mm. The largest value on the NBS chart is 18, which provides 432 lines/mm at 24X or twice the resolution needed to test the finest microfilm and lens combinations.

Resolution of Map Lines

Ink lines on forest resource maps, at the customary scales considered so far, are usually 0.01 inch (0.25 mm) or wider. Detecting and separating these fine lines can be simulated by scanning black stripes of the same size on an NBS test chart. The target of two lines/mm, before reduction, represents 0.01-inch (0.25-mm) lines. The NBS definition of a line includes both the black and white portion (0.5 mm) so the black line is half that, or 0.25 mm. Theoretically, the density sampling interval cannot be more than one-half the width of a map line to assure a line will not be broken. This is an upper limit for density spacings. The lower limit is indefinite because two or more map lines can almost touch but be separated by an infinitely small amount.

The only reductions of maps onto films or fiche considered relevant are 20X, 24X, 42X, and 48X. A 0.25-mm line on the original map reduces to 12.5 (i.e., 0.25/20), 10.4, 6.0, and 5.2 μm. Actually 48X is not attainable commercially as a one-step reduction. The planetary cameras which are both suitable for precision cartographic work and generally available cannot exceed 42X.

The difference between 42X and the 48X standard COM reduction ratio can be accommodated in one of two ways. First, a 42X nonstandard arrangement of frames on a microfiche can be used in a microfiche reader with zoom lens capability. Adjustable magnification is preferred to the second choice, which is to achieve a 48X in two reductions at the cost of lost resolution.

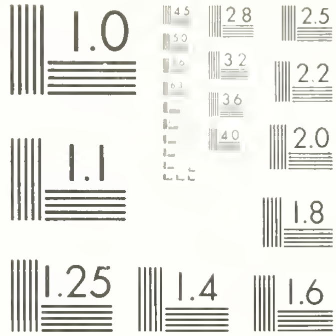


Figure 2—A National Bureau of Standards test chart (1963-A) used for determining overall microform system resolution.

Line-Scanning Test Conditions

To find out if a resolution of two lines/mm on the source map was readily attainable, given commercially available materials and copy procedures, we did a scanning test.

A precision planetary camera ordinarily used for engineering drawings was used to make 24X and 42X reductions. Several exposures were made to give a range of densities on standard (630 lines/mm) silver halide 35-mm microfilm. It is a customary business practice to protect the original negative by making an intermediate working copy, usually silver halide. We scanned not only the original but also a diazo microfiche copy to allow for a realistic loss of resolution caused by reproduction. High-speed scanners intended for digitizing type fonts, X-rays, and other large images record at coarse intervals; steps of 25 μm are typical. We used a PDS 1010 microdensitometer, which is slow but designed for steps as fine as 2 μm.

We scanned all of the target patterns on the NBS resolution chart at several square grid spacings. For 24X the readings were taken at 12, 10, 6, and 2 μm with equivalent apertures. For 42X the readings were 4, 3, and 2 μm with corresponding apertures.

One would expect individuals to disagree as to which target's lines are just barely separable under any given viewing conditions. The inherent variability of judging results can be reduced by making microscope comparisons or, as we preferred, by comparing density output from scanning microimages.

Line separation depends on the density level or "slice" selected. We grouped the 1024 possible density values into 64 categories. In coarse patterns the change from one density level to another was imperceptible. Once the threshold of separability was reached in finer patterns, results were quite sensitive to the density slice. At density level 12, the lines in the 2.2 target reduced 42X were completely separate. Increasing the grey level to 13 caused the lines to join in four places. We consider a resolution of 92 lines/mm as unattainable (*fig. 3*).

The condition of the scanning device used strongly affects line resolution. The PDS-1010 scanning microdensitometer we used recorded billions of densities over a 5-year period. The complex mechanism is subject to wear which is difficult to quantify. We found a directional bias in the scanning process, that is, horizontal lines separated before vertical ones. Scanning the same targets with a rented PDS 1010A microdensitometer verified the source of the problem to be mechanical—and not one due to the film. Continual machine maintenance, as well as inspection of test targets, is essential to assure high resolution capabilities.

Image Quality

The frequency distribution of densities provides ways of determining scanned image quality. One of these is the degree of concentration at the two modes (one representing lines, the other background). A high concentration of density values at the modes usually indicates sufficient separation.

Contrast ratios were computed from the modes for line and background densities. Commercial scans gave contrast ratios from 21:1 to 25:1 at 24X for silver halide and diazo images of the NBS test chart. A sample of 10 WRIS negatives of silver halide film had an average contrast ratio of 27 when scanned on the same machine. All these ratios are essentially "medium" and indicate sufficient leeway for selecting the density slice.

CONCLUSIONS

At great reductions and with density recordings at intervals of a few micrometers, either the film or the scanner become a limiting factor. Our experience suggests that the behavior of the scanning device is the most important factor. For example, before we overhauled our densitometer we could resolve about 40-50 lines/mm. With another, similar model, 90 lines/mm were resolvable.

Because map scanning is expensive, satisfactory results must be obtained with a high degree of certainty. We can barely resolve 0.01-inch (0.25-mm) map lines at 42X with commercial microfilm processing, a conditioned environment, and a finely adjusted microdensitometer. Since these conditions are difficult to maintain, we conclude that 24X is the maximum reduction onto microfiche recommended for production work. At this reduction, satisfactory results can be expected even with the second copy of the original negative and routine scanner maintenance.

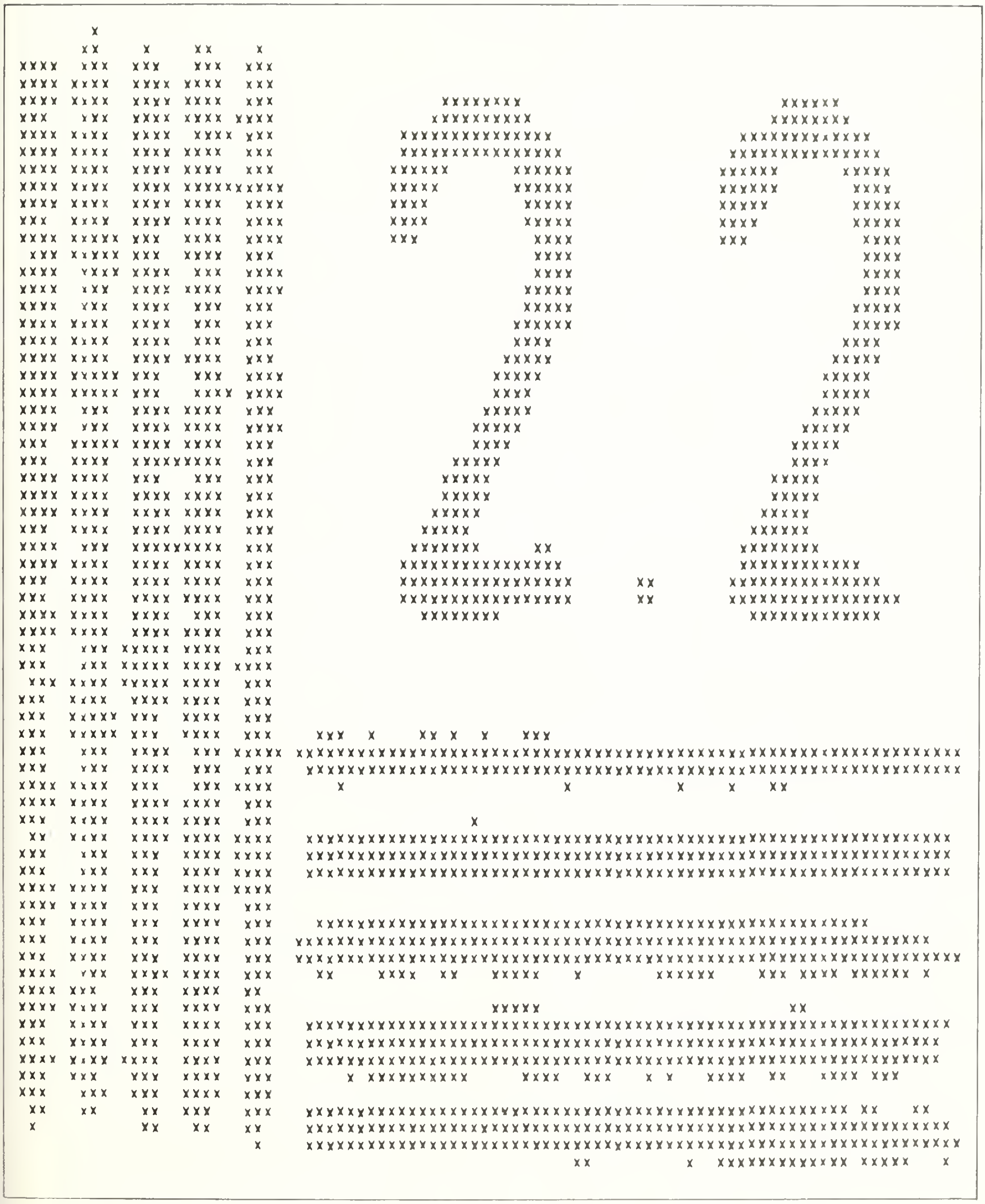


Figure 3—Separability is sensitive to the density slice. On the 2.2 target, at 42X, lines which were separate at density level 12 merge in four places at 13.

LITERATURE CITED

Altman, J. H.
1961. A simple camera for the measurement of photographic resolving power. Photo. Sci. and Engr. 5(1):17-20.

Amidon, Elliot L.
1974. Recording forest patterns from photographs and maps by computerized techniques. *In* Proceedings, monitoring forest environment through successive sampling. [Syracuse, N. Y., June 24-26, 1974.] State Univ. New York, Syracuse, p. 119-132.

Comptroller General of the U.S.
1974. Report to the Congress. Increased use of computer-output-microfilm by federal agencies could result in savings. Washington, D.C., 25 p.

Fouquet, Bernard H.
1963. The NBS Microcopy resolution test chart. *In* Proc. Annu. Meet. of the Natl. Microfilm Assoc., Washington, D.C., p. 67-81.

Goodwald, J. P.
1968. Storage and reproduction of mapping data. Natl. Microfilm Assoc. J. 1(3):82-84.

Gordon, Ronald F.
1971. Microfiche viewing equipment guide. Def. Doc. Cent., Alexandria, Va. Rep. DDC-TR-71-8, AD-734 400. 147 p.

Lynden, Frederick C.
1975. Replacement of hard copy by microforms. Microform Rev. 4(1):15-23.

National Microfilm Association
1973. Introduction to micrographics. Natl. Microfilm Assoc., Silver Springs, Md. 26 p.

National Microfilm Association.
1974. Fundamentals of computer output microfilm. Natl. Microfilm Assoc., Silver Springs, Md. 23 p.

Presidente, P. J. A., B. M. McCraw, and J. H. Lumsden.
1974. Pathologic features of experimentally induced *Fasciola hepatica* infection in white-tailed deer. Wildl. Dis. No. 63, 59 p., illus.

Rickman, Will W.
1973. Microfilming in color. *In* Color: theory and imaging systems. Raymond A. Eynard, ed. Soc. Photo. Sci. and Engr., Washington, D.C., p. 354-361.

Russell, Robert M., David A. Sharpnack, and Elliot L. Amidon.
1975. WRIS: a resource information system for wildland management. USDA Forest Serv. Res. Paper PSW-107, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Salmon, Stephen R.
1974. User resistance to microforms in the research library. Microform Res. 3(3):194-199.

U.S. Dep. of Commerce, Business and Defense Services Administration.
1969. Microforms a growth industry. U.S. Dep. Commerce, Washington, D.C. 18 p.

U.S. Dep. of Commerce, National Bureau of Standards.
1974. Standard reference materials. U.S. Dep. Commerce Spec. Publ. 260, Supplement. 14 p.

U.S. Dep. of the Interior Geological Survey.
1964. Topographic instructions, Part 5B, cartographic tables. U.S. Dep. Interior, Washington, D.C., 142 p.

Veaner, Allen B.
1971. The evaluation of micropublications, a handbook for librarians. Library Technol. Prog. Publ. 17, 59 p.

Williams, Bernard J. S.
1970. Miniaturised communications, a review of microforms. 190 p. Library Assoc., London, England.

The Forest Service of the U.S. Department of Agriculture

. . . Conducts forest and range research at more than 75 locations from Puerto Rico to Alaska and Hawaii.

. . . Participates with all State forestry agencies in cooperative programs to protect and improve the Nation's 395 million acres of State, local, and private forest lands.

. . . Manages and protects the 187-million-acre National Forest System for sustained yield of its many products and services.

The Pacific Southwest Forest and Range Experiment Station

represents the research branch of the Forest Service in California and Hawaii.

Amidon, Elliot L., and E. Joyce Dye.
1976. **Microcopying wildland maps for distribution and scanner digitizing.** USDA Forest Serv. Res. Paper PSW-114, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Images in graphic or printed form can be reduced in size by microcopying. Microform is a collective term for stored microimages. Conventional microform films include silver halide, nonsilver diazo, vesicular, and color. Criteria for selecting the proper format include map quadrangle size and reduction ratio. Among several competing types of microforms, only microfilm and microfiche were judged acceptable for application to wildland maps. Microimages can be digitized by automatic techniques. With careful planning, it is possible to digitize automatically forest map microimages for input to computerized mapping systems. Other benefits of microcopying include a reduction in the cost of handling and shipping the original documents, savings in space, and making archival copies more lasting.

Oxford: 91–(084.3):UDC 778.142
Retrieval Terms: wildland planning; maps; micrographics; computer mapping; digital techniques.

Amidon, Elliot L., and E. Joyce Dye.
1976. **Microcopying wildland maps for distribution and scanner digitizing.** USDA Forest Serv. Res. Paper PSW-114, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Images in graphic or printed form can be reduced in size by microcopying. Microform is a collective term for stored microimages. Conventional microform films include silver halide, nonsilver diazo, vesicular, and color. Criteria for selecting the proper format include map quadrangle size and reduction ratio. Among several competing types of microforms, only microfilm and microfiche were judged acceptable for application to wildland maps. Microimages can be digitized by automatic techniques. With careful planning, it is possible to digitize automatically forest map microimages for input to computerized mapping systems. Other benefits of microcopying include a reduction in the cost of handling and shipping the original documents, savings in space, and making archival copies more lasting.

Oxford: 91–(084.3):UDC 778.142
Retrieval Terms: wildland planning; maps; micrographics; computer mapping; digital techniques.

Amidon, Elliot L., and E. Joyce Dye.
1976. **Microcopying wildland maps for distribution and scanner digitizing.** USDA Forest Serv. Res. Paper PSW-114, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Images in graphic or printed form can be reduced in size by microcopying. Microform is a collective term for stored microimages. Conventional microform films include silver halide, nonsilver diazo, vesicular, and color. Criteria for selecting the proper format include map quadrangle size and reduction ratio. Among several competing types of microforms, only microfilm and microfiche were judged acceptable for application to wildland maps. Microimages can be digitized by automatic techniques. With careful planning, it is possible to digitize automatically forest map microimages for input to computerized mapping systems. Other benefits of microcopying include a reduction in the cost of handling and shipping the original documents, savings in space, and making archival copies more lasting.

Oxford: 91–(084.3):UDC 778.142
Retrieval Terms: wildland planning; maps; micrographics; computer mapping; digital techniques.

Amidon, Elliot L., and E. Joyce Dye.
1976. **Microcopying wildland maps for distribution and scanner digitizing.** USDA Forest Serv. Res. Paper PSW-114, 12 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Images in graphic or printed form can be reduced in size by microcopying. Microform is a collective term for stored microimages. Conventional microform films include silver halide, nonsilver diazo, vesicular, and color. Criteria for selecting the proper format include map quadrangle size and reduction ratio. Among several competing types of microforms, only microfilm and microfiche were judged acceptable for application to wildland maps. Microimages can be digitized by automatic techniques. With careful planning, it is possible to digitize automatically forest map microimages for input to computerized mapping systems. Other benefits of microcopying include a reduction in the cost of handling and shipping the original documents, savings in space, and making archival copies more lasting.

Oxford: 91–(084.3):UDC 778.142
Retrieval Terms: wildland planning; maps; micrographics; computer mapping; digital techniques.

PACIFIC SOUTHWEST
Forest and Range
Experiment Station

ST SERVICE
EPARTMENT OF AGRICULTURE
OX 245, BERKELEY, CALIFORNIA 94701

FOREST REGENERATION AND SEEDLING GROWTH
from five major cutting methods in north-central California

Philip M. McDonald

USDA FOREST SERVICE RESEARCH PAPER PSW-115/1976

CONTENTS

The Author

PHILIP M. McDONALD is doing research on silviculture of Sierra Nevada forest types, with headquarters at Redding, California. A native of Seattle, Washington, he holds bachelor's (Washington State University, 1960) and master's (Duke University, 1961) degrees in forestry.

Cover: Five types of harvest cuttings are illustrated. Top, *left to right:* clearcutting, seed-tree; bottom, *left to right:* shelterwood, group selection, single-tree selection.

SUMMARY

McDonald, Philip M.
1976. **Forest regeneration and seedling growth from five cutting methods in north central California.** USDA Forest Serv. Res. Paper PSW-115, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 187x465.6:221[–182.51 + 231.3]
Retrieval Terms: silvicultural systems; regeneration; height increment; site treatments; Challenge Experimental Forest; *Pinus ponderosa; Pseudotsuga menziesii; Pinus lambertiana; Libocedrus decurrens;* California.

One of the forester's most difficult jobs is to match a silvicultural regeneration cutting method to a given landscape. What he really needs to know is the amount and distribution of the various species of seedlings that are likely to ensue. He also needs some idea of how well each species will grow in that landscape. And he should have some knowledge of the competitive ability of the hardwood and shrub species that threaten his work.

On the Challenge Experimental Forest in north central California this knowledge is available for 9-year-old seedlings from five major silvicultural cutting methods. These are clearcutting, seed tree, shelterwood, group selection, and single-tree selection. All were applied in an area of similar and exceptionally high site quality.

Because bare ground quickly becomes revegetated, various slash disposal and site preparation techniques must be used to prepare the site and reduce competitive hardwood and shrub populations. For each cutting method, these techniques were: clearcut—broadcast burning; group selection—scarifying; shelterwood, seed tree, and single-tree selection—piling by bulldozer immediately after logging, piling just before seed fall, and top lop and branch scatter.

The conifer species evaluated were ponderosa pine, sugar pine, white fir, Douglas-fir, and incense-cedar. Hardwoods evaluated were California black oak, tanoak, and Pacific madrone. Competitive shrub species were whiteleaf manzanita and deerbrush.

Site preparation is just one of the techniques and modifications applied to the cutting methods to make them fit young-growth silviculture and to take advantage of the high site. For example, the traditional shelterwood method was modified from three to two stages to allow earlier establishment of regeneration. Another example is to apply improvement cutting guidelines and remove about 20 percent of the merchantable volume in the initial application of selection cutting. This procedure upgrades the growing stock and harvests would-be mortality.

Each cutting method creates a particular environment in terms of light, moisture, and other factors. A particular environment might favor survival and establishment of one species, but not others. It also might enhance a species survival but not its height growth. Nine years of data and analyses yield trends that provide insight to species potentials in comparative environments.

In the single-tree selection method, ponderosa pine was fairly well stocked, but its height growth was poorer than that of any other species under any cutting method. Opening up the stand just a little more, as in group selection, resulted in nearly twice as many ponderosa pine seedlings and a great improvement in their distribution. It also meant a doubling of the ponderosa pine seedling height growth. But height growth was still only one-third to one-sixth of that in the seed-tree, shelterwood, and clearcutting methods after 9 years.

In the environment created by shelterwood and seed-tree cutting, with slash disposal, ponderosa pine excelled. Stocking was 59 percent (milacre basis) and density was 3620 seedlings per acre (8941 per ha) in the shelterwood, and 61 percent stocked with 2100 seedlings (5187 per ha) in the seed-tree method.

Height growth, however, was held back by the overstory trees. Clearcutting created an environment in which ponderosa pine height growth excelled, but in which seedling density was fair and distribution somewhat clumpy.

The more tolerant conifers (sugar pine, Douglas-fir, white fir) responded much differently to the different environments of the various cutting methods. Seedling stocking and density were best in the selection methods (850 seedlings per acre [2100 per ha] and 40 percent stocking). The shelterwood environment approaches the limit—in terms of light, heat, and moisture—in which seedlings of these species will become established. Plainly, the seed-tree and clearcut environments do not favor the more tolerant conifers. Early seedling height growth, however, became better as the intensity of cutting increased from single-tree selection to shelterwood. Thus the shelterwood environment favored height growth but not establishment of tolerant conifers.

Hardwood regeneration consisted of seedlings and sprouts. Each had a different competitive potential. In general, sprouts were fierce competitors, with rapid growth rates and low mortality. Hardwood seedlings, although prolific, suffered from poor distribution, high mortality, and slower growth rates. The stocking and density of hardwood seedlings and sprouts tended to be high in all cutting methods. Density values varied from 746 to 2937 seedlings per acre (1843 to 7254 per ha), stocking from 24 to 63 percent. Where site preparation was intensive, as in group selection and clearcutting, fewer hardwoods were present.

In all methods, hardwoods were taller than conifer seedlings. But only in the single-tree selection method are hardwoods likely to both outnumber and outgrow conifers in the years to come.

Shrub seedlings also were numerous and well distributed in all cutting methods, except single-tree selection, where the shady environment was not beneficial. Shrub seedlings are most abundant in the clearcuts where they are threatening the conifers and making their distribution more clumpy. They also are overtopping nearly half of the Douglas-fir seedlings, some of the white firs, and a few ponderosa pines. Because broadcast burning stimulates thousands of dormant shrub seeds stored in the surface soil, it is not recommended as a slash disposal technique in conjunction with clearcutting.

This study suggests that each cutting method has unique merits; the forest manager can capitalize on these merits. And he can select from a variety of techniques for site preparation and guides for stand manipulation. He can, therefore, select the combination of methods, techniques, and guides that come closest to meeting his specific management objectives.

The forest manager's repertory contains many cutting methods, slash disposal operations, re-eneration alternatives, and stand manipulation uides. These techniques, applied alone or in com-ination, enable him to practice sound resource ıanagement in an atmosphere of increasing and often onflicting production, environmental, and social emands. But before he can apply any of these echniques, he needs to know how the individual pecies in his forest respond to them. He also must be horoughly familiar with the invader and pioneer species that can weaken or even ruin his best silvicultural prescriptions.

This paper reports a comparison of five valuable conifer species, three hardwood species, and two abundant and highly competitive shrub species within five different cutting methods in the same area on a site of similar growth potential. Seedling stocking, density, and height growth were compared after a 9-year period. Results indicate striking differences among species and cutting methods, and have strong ecological and silvicultural implications.

STUDY SITE AND METHODS

This study was done at the Challenge Experi-ıental Forest, in north central California. Here, site uality is extremely high. Soils often are more than 00 feet (30 m) deep, and mean annual temperature s 55°F (13°C), and annual precipitation averages 68 nches (1680 mm). These conditions insure that egetation is both abundant and fast-growing. Indeed, he dominant species, ponderosa pine (*Pinus pon-erosa* Laws.), will average 140 feet (43 m) in height 1 100 years (Arvanitis and others 1964). Trees 170 eet (52 m) tall at the same age are not unusual.

Other tree species on the Experimental Forest, and he 1.5 million acres (600,000 ha) it represents, are Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), ugar pine (*Pinus lambertiana* Dougl.), white fir *Abies concolor* [Gord. & Glend.] Lindl.), and in-ense-cedar (*Libocedrus decurrens* Torr.). Hard-voods, principally California black oak (*Quercus elloggii* Newb.), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and Pacific madrone *Arbutus menziesii* Pursh), are scattered throughout ıs individual trees, clumps, or groves (*fig. 1*). Al-ogether, trees larger than 3.5 inches (8.9 cm) in liameter at breast height (d.b.h.) number 248 per acre (613 per ha) (*table 1*) and contain about 270 ft² (62 m²) of basal area.

Whiteleaf manzanita (*Arctostaphylos viscida* Parry) and deerbrush (*Ceanothus integerrimus* H. & A.) tend to be abundant on the Experimental Forest. Seeds from these shrubs in the duff and surface soil beneath an old-growth sugar pine-white fir forest in central California numbered about 165,000 per acre (410,180 per ha) (Quick 1956). This number probably is conservative for these species in the elevational range of the Experimental Forest. Even after the most drastic site preparation measures, hardwoods sprout. These sprouts, plus frequent and heavy hardwood seed crops, add to the revegetational potential. Conifer seed crops also are frequent and heavy, contributing significantly to revegetation.

Five cutting methods were used in this study: single-tree selection, group selection, shelterwood, seed tree, and clearcutting. Each was applied on three to six compartments having similar topography, soil, and drainage. The total area treated by each method ranged from 18 to 88 acres (44 to 217 ha).

Each cutting method was modified to better fit young-growth silviculture, to take advantage of the

Figure 1—This 90-year-old uncut stand on the Challenge Experimental Forest, north central California, typically has mostly ponderosa pines in the overstory, with hardwoods, incense-cedar and Douglas-fir beneath them.

Table 1—*Stand table before regeneration cuttings, Challenge Experimental Forest, California*

Species	Trees per acre when diameters (inches) were:						
	3.5-8.0	8.1-12.0	12.1-16.0	16.1-20.0	20.1-30.0	30.1+	Total
Conifers:							
Douglas-fir	27	13	7	3	4	2	56
Ponderosa pine	2	4	7	7	17	6	43
Sugar pine	1	0	1	0	1	1	4
White fir	6	2	1	1	1	0	11
Incense-cedar	47	12	4	1	1	0	65
Total	83(205)[1]	31(77)	20(49)	12(30)	24(59)	9(22)	179(442)
Hardwoods:							
California black oak	11	3	2	1	1	1	19
Tanoak	13	5	2	1	0	0	21
Pacific madrone	22	6	1	0	0	0	29
Total	46(114)	14(35)	5(12)	2(5)	1(2)	1(2)	69(170)
Total	129(319)	45(112)	25(61)	14(35)	25(61)	10(24)	248(612)

[1] Value in parenthesis indicates number of trees per hectare.

igh site, and to enhance regeneration. The many nall trees and the high slash volumes that follow ogging (Sundahl 1966) require that some form of ash disposal and site preparation be undertaken fter harvesting by each regeneration cutting method.

Basic tenets of the single-tree and group selection ethods are frequent cutting and light cuts. Biologi-ally mature and defective trees are constantly re-ioved, and new volume is concentrated on the finest idividual stems. In each selection method, cuttings ere initial applications. As a marked degree of stand nprovement was needed, diseased, damaged, rooked, and over-crowded trees were removed--a orthwhile practice when beginning selection cutting young-growth stands.

In the single-tree selection method, about 20 ercent of the merchantable volume was removed. arge concentrations of slash were piled by a bull-ozer and burned in the winter. Otherwise, slash was ypped and scattered. Only a small amount of mineral oil was available, occuring largely where the turning ction of the logging tractor mounded the soil, or at ie few locations where the slash was piled and urned.

The group selection method created openings 30, 0, and 90 feet (9, 18, and 27 m) in diameter. The ze of these openings simulated the removal of everal small or large trees (McDonald 1966). Each pening was scarified by a bulldozer to provide a iineral-soil seedbed.

The shelterwood cutting, by design, provided some iade for the sugar pine, white fir, and Douglas-fir eedlings that were anticipated. Therefore, the 12 esidual trees per acre (30 per ha) were large, full rowned, and thrifty. All other merchantable trees hose above 12 inches d.b.h. [30 cm]) were removed a single operation, making this a two-stage shelter-ood. This variation of the shelterwood method ermits much quicker establishment of regeneration -a desirable goal for windfirm species on high sites. qual areas on each compartment had slash bull-ozer-piled immediately after logging, bulldozer-piled ist before a good seed crop, and top lopped with ranch scattering. Many smaller saplings and poles, nd most of the hardwoods, were eliminated by these reatments. Overstory shelterwood trees were present uring the entire study.

The seed-tree method consisted of leaving four to ight vigorous seed-producing trees per acre (10 to 20 er ha) for the entire study. Numerous old cones at he base of a tree constituted a major selection riterion for seed trees (Sundahl 1971). Site prepara-ion was similar to that of the shelterwood cut.

All merchantable trees were harvested in each clearcut compartment. Hardwoods and unmerchant-able conifers were flattened by a bulldozer in the spring and broadcast burned about a year later. About 98 percent of the surface area in each broad-cast-burned compartment was disturbed--13 percent by fire alone, 46 percent by logging alone, and 39 percent by fire and logging combined (Neal 1975). Hand seeding by cyclone seeders with about 2 pounds (2.2 kg) per acre of conifer seed followed. Ponderosa pine, Douglas-fir, and white fir were seeded both alone and in mixture with sugar pine. Portions of the compartments also were treated by a tractor dragging several sections of heavy railroad iron. This treatment helped cover the seeds (Hall 1967) and reduced rodent depredations.

Sampling in all cutting methods followed a ran-dom start-systematic procedure. In some instances, sample plots were located along line transects and in others, along radii. Circular milacre plots 44 ft^2 (4 m^2) in area, were examined for all but the group selection method where one-fourth milacre plots were installed. Seedling stocking and density values were converted, however, to the milacre basis.

In this study, density quantifies the number of seedlings per acre, and stocking is indexed by the percentage of milacre plots having one or more seedlings. In this context, stocking percentage de-notes the degree of uniformity with which seedlings of each species are distributed throughout the sam-pling area. High percents usually indicate rather even distribution; low percents indicate either few seed-lings or a clumpy distribution.

Sampling intensity in general was proportional to number and size of compartments in each cutting method. It ranged from a total of 90 milacre plots in the single-tree selection method to 653 plots in the clearcuttings. Regeneration was surveyed at annual and other intervals.

Seedling stocking and density were recorded for all conifers and hardwoods. Shrub seedlings (deerbrush and whiteleaf manzanita combined) were evaluated only by stocking percent except in the clearcut compartments, where density also was recorded. Seedlings were surveyed initially when they were about 2 months old. Each was marked and studied individually. Seedlings from numerous other seed crops became established, but exerted little influence, and were not considered.

In 1960, major seed crops for ponderosa pine, white fir, and incense-cedar were produced as well as fair crops of sugar pine and Douglas-fir. Seedlings from these seed crops were studied in the single-tree selection, shelterwood, and seed-tree methods. The group selection method was installed in 1963 and benefited from a major seed crop of ponderosa pine, sugar pine, white fir, and Douglas-fir in 1964. In the clearcuttings, seedlings of these four species originated from artificial seeding in 1965. In all cutting methods, seeds from at least four different conifer species fell or were distributed. Because overstory composition was heavily weighted toward ponderosa pine, natural seedfall was also. In all methods, seed fell or was distributed 1 or 2 years after cutting. In addition, seedlings in all methods benefited from an equal number of years with good weather, and suffered through at least one of below-average precipitation.

Conifer seedlings examined in this study were 9 years old. The age of most hardwood seedlings could not be determined accurately because many died back to the root crown after disturbance, but resprouted. Thus, above-ground hardwood ages ranged from 4 to 13 years. Most brush seeds germinated immediately after cutting or site preparation.

Seedling heights were measured after the ninth growing season. Where several seedlings of a species of this age grew on a single plot, heights of the three tallest were measured to represent the species on that plot.

Values for seedling stocking, density, and height were analyzed for each compartment, and examined closely for trends. As data for all compartments within a given cutting method were quite similar, they were combined. Stocking, density, and height values then were calculated for each cutting method.

Large differences in compartment numbers and sizes, and differing sampling patterns and intensities precluded statistical analysis. Nevertheless, species relationships are expressed strongly within and between cutting methods.

RESULTS

Within Each Cutting Method

After 9 years, pronounced differences in seedling stocking, density, and height of the various species were apparent. Hardwoods, ponderosa pine, and white fir were better stocked and most dense in the single-tree selection method (*table 2*). The same species performed well in the group selection method, although ponderosa pine led all species in stocking and density. The shelterwood and seed-tree cutting methods favored ponderosa pine, hardwoods and shrubs, as did clearcutting. Shrub species were notably prolific in the clearcut compartments, and their density exceeded 6500 seedlings per acre (16,000 per ha).

Table 2–*Stocking and density of 9-year-old seedlings, by species and cutting methods, Challenge Experimental Forest, California*

	Single-tree selection		Group selection		Shelterwood		Seed tree		Clearcut	
	Stocking (pct.)	Density (seedlings/ acre)	Stocking (pct.)	Density (seedlings/ acre)	Stocking (pct.)	Density (seedlings/ acre)	Stocking (pct.)	Density (seedlings/ acre)	Stocking (pct.)	Density (seedlings/ acre)
Ponderosa pine	23	860	44	1500	59	3620	61	2100	42	1115
Sugar pine	10	111	10	185	8	240	4	75	5	51
Douglas-fir	11	308	6	134	4	80	5	174	4	157
White fir	22	400	22	565	7	192	5	66	4	166
Incense-cedar	4	44	1	16	8	470	5	67	–	–
Hardwoods	52	1330	31	807	53	2225	63	2937	24	746
Shrubs	10	–	43	–	41	–	40	–	51	6523

The arrangement of species based on seedling eight growth presented a much different picture. In ne single-tree selection cutting, hardwoods and hrubs grew tallest. Next in order of decreasing verage height were white fir, sugar pine, incense-edar, and Douglas-fir (*table 3*). Height growth of onderosa pine rated poorest among all species (*fig.* ?).

Species behavior in the group selection method vas quite similar, although Douglas-fir outgrew ncense-cedar and equalled white fir and sugar pine. 'onderosa pine and incense-cedar ranked poorest.

In the shelterwood cutting, conifer species were tarting to catch up to hardwoods and shrubs. Of the onifers, white fir and ponderosa pine grew best, with ugar pine a close third. Even incense-cedar grew well vhere this method was applied.

In the seed-tree cutting, ponderosa pine outgrew ther conifers. Hardwoods also performed well. And n the clearcuttings height growth of ponderosa pine ccelerated faster than that of other conifer species *ig. 3*). Shrub height growth also was rapid, and that f the hardwoods, more so.

Figure 3—A 9-year-old ponderosa pine seedling in a clearcutting has grown to be about 6 feet (1.8 m) tall.

Figure 2—Nine-year-old seedlings in the single-tree selection cutting method. Compare vigor and height of the two ponderosa pine seedlings in the left foreground to that of the sugar pine and white fir.

Table 3—*Height (feet) of 9-year-old seedlings, by species and cutting methods, Challenge Experimental Forest, California*

Cutting methods	Ponderosa pine	Sugar pine	Douglas-fir	White fir	Incense-cedar	Hardwoods	Shrubs
Single-tree selection	.5	1.0	.7	1.4	.9	2.4	2.1
Group selection	1.0	1.5	1.5	1.5	.9	2.4	2.9
Shelterwood	2.7	2.6	2.1	2.9	1.9	2.9	3.1
Seed tree	3.7	3.4	3.1	3.7	2.7	4.3	3.7
Clearcut	6.2	5.5	4.2	4.0	–	12.6	7.8

Between Cutting Methods

Differences between cutting methods are illustrated best by species comparisons. Ponderosa pine stocking and density increased as the intensity of the cutting method increased from single-tree selection to shelterwood. Seedling stocking was best (about 60 percent) in the seed-tree and shelterwood methods, while seedling density peaked under the shelterwood regime at 3620 seedlings per acre (8941 per ha). In the clearcuttings, stocking and density of ponderosa pine seedlings were lower than that of the group selection, shelterwood, and seed-tree methods.

In all cutting methods, ponderosa pine seedling stocking and density outranked that of the more shade-tolerant conifers. Douglas-fir, sugar pine, and especially white fir became established best in the cool, shady habitat provided by selection cutting. Stocking of white fir reached 22 percent and density 565 seedlings per acre (1396 per ha) in the group selection method. Incense-cedar regenerated poorly in all cutting methods.

Hardwood stocking and density were high in all cutting methods. Lower densities and stocking percentages were found in the group selection and clearcut methods, probably because site preparation was more complete in them. The small openings created in group selection were scraped free of hardwoods, and hardwood clumps were uprooted purposely in the clearcuttings. In the other cutting methods, and particularly where slash was lopped and scattered, few hardwoods were eliminated. In fact, they were enhanced. Many small misshapen hardwoods died back to the root crown. Sprouts then burst forth, fueled by sprout vigor (McDonald 1969a).

The percentage of plots stocked by shrubs ranged from 10 to 51, and was lowest in the single-tree selection cut and highest in the clearcuttings.

On the basis of seedling height, species comparisons among cutting methods showed a definite pattern. Without exception, height of every species, whether conifer, hardwood, or shrub, increased as the intensity of the cutting method increased.

DISCUSSION

Each of the five classical silvicultural cutting methods creates a specific environment in terms of light, moisture, soil surface temperatures, and other factors. Seedlings of each species also have specific, but different environmental tolerances. One would think an ideal species-cutting method combination would result for each species within the range of cutting methods studied.

This was so for most species. Ponderosa pine is a good example. In the single-tree selection cut, not enough bare mineral soil was provided. Seeds germinated readily in the duff and litter, but seedling roots seldom penetrated the organic debris on the soil surface fast enough to stay ahead of the rapidly advancing soil drying front in late spring. Consequently, 30 to 40 percent of the ponderosa pine seedlings died during the first growing season. Those that survived lacked thrift and vigor, probably because of inadequate moisture and light. Indeed, many seedlings were only 0.2 feet (6 cm) tall after six growing seasons. Soon, competition from the better adapted, more tolerant species will increase, and light levels will decrease even further. High ponderosa pine seedling mortality will continue, and even if another cutting cycle is applied, most of these seedlings will die.

This same process applies to the group selection method. In the 30- and 60-foot (9- and 18-m) openings, ponderosa pine seedlings closely resemble their puny counterparts in the single-tree selection cut. Only in the center of the 90-foot (27-m) openings have ponderosa pine seedlings become vigorous and robust. But how long this will continue is a moot point.

The shelterwood and seed-tree cutting methods, along with the site-preparation and slash-disposal techniques applied, enhanced the establishment of ponderosa pine. Seed fall was prolific, mineral soil was plentiful, and moisture and light were adequate. The shelterwood and seed trees existed however, at the expense of the seedlings, and seedling height growth was decreased beneath their crowns. If seedling density and distribution meet acceptable standards under this method, seed trees should be removed when seedlings are 2 years old (Mc Donald 1969b).

Clearcutting followed by artificial seeding presents paradox. While the quantity of light, moisture, and nineral soil are nearly optimal for ponderosa pine, eedling distribution tends to be somewhat clumpy. his phenomenon probably results from a number of ictors: less seed than with natural seeding, hotter oil surface temperatures, especially on south and outhwest exposures, and influence of competitive egetation. Even with a near-complete burn, as this as, pioneer species like bracken (*Pteridium aquinum* [L.] Kuhn), poison oak (*Rhus diversiloba* T. & .), and mountain misery (*Chamaebatia foliolosa* enth.) resprout quickly after burning. Numerous tems surge upward from characteristically dense and xtensive root systems. Broadcast burning stimulates housands of manzanita and deerbrush seeds in the urface soil. Together, they compete vigorously with ine seedlings. In addition, those hardwoods that are ot eliminated by dozing and burning quickly sprout. Vith competition of this magnitude, a clumpy distriution is not surprising.

An ideal species-cutting method combination for he more tolerant conifer species is not as apparent as or ponderosa pine. Individually, the more tolerant onifer species were less numerous than ponderosa ine, and also produced higher proportions of unound seed, particularly young-growth white fir and Douglas-fir (McDonald 1973). Individually, a stocking alue of 22 percent for white fir in the single-tree and roup selection methods is quite good. Collectively, a alue of about 40 percent and a density of about 850 eedlings per acre (2100 per ha) for the more tolerant onifers also is good. This corresponds to a 6- by -foot (1.8- by 2.1-m) spacing if seedlings are well istributed. The environmental regime of mineral soil, elatively cool soil surface temperatures, and short ntervals of overhead light favor the more tolerant onifers. Mortality has been low. Their height growth ate has been increasing. Thus white fir, sugar pine, nd Douglas-fir should become the dominant conifer pecies in the selection cutting methods. These speies are better adapted to this environment than the umerically superior, but slower growing ponderosa ine.

For more tolerant conifers, the shelterwood cut ulfills a transitional role between selection and other utting methods. Although ponderosa pine stocking nd density are high, white fir grows faster than onderosa pine, and sugar pine grows almost as fast as t. Apparently, the amount of shelter provided aids he more tolerant conifer height growth, but not stablishment. Conversely, it favors ponderosa pine and hardwood establishment, but not height growth.

In the more intensive seed-tree and clearcutting methods, the more tolerant conifers fall victim to the higher ambient and soil surface temperatures. These cutting methods plainly do not favor the more tolerant conifers.

In all cutting methods, hardwoods are taller than conifer seedlings, but whether or not they will remain so is questionable. Preliminary analysis of hardwood sprouts, growing beneath fairly dense stands and in full sunlight, suggests that Pacific madrone and California black oak sprouts have a reduced height growth rate in shade. Tanoak sprout growth was less affected by shade. Also, the relatively poor 9-year height growth of the more tolerant conifer seedlings is the result of very little above-ground growth during the first 3 or 4 years. Now, some of these seedlings, especially white fir, are beginning to accelerate in height growth. Nevertheless, tanoak and Pacific madrone sprouts and seedlings will outnumber conifers in the new community brought about by single-tree selection cutting.

With group selection cutting and scarification, the more tolerant conifers probably will accelerate ahead of all hardwoods except the few tanoak sprouts. All conifers but incense-cedar should outgrow hardwoods in the shelterwood and seed-tree methods. In the clearcuttings, hardwood sprouts are outgrowing conifers, but fortunately there are less of them.

While stocking and height growth of shrubs are high in general, they are not expected to be a major factor in any cutting method, except possibly clearcutting. Here, most of the pines and some of the more tolerant conifers will dominate. At present, 47 percent of the Douglas-firs, 11 percent of the white firs, and 2 percent of the ponderosa pines in the clearcuttings are overtopped by shrubs. These conifer seedlings are smaller, more slender, and less vigorous than their free-to-grow brethren. On high sites, such as this, the trend is toward shorter intervals between harvests. These smaller trees will not reflect the true potential of the site in, for example, 40 years. In an economic sense, they constitute a loss.

Evaluation of a cutting method depends on more than seedling stocking and density. Seedling height growth is particularly helpful. The number, distribution, and growth of shrub and hardwood species also should be known. The differential ability of each species to dominate in a specific habitat having certain parameters of light, moisture, and vegetative competition also must be considered when comparing cutting methods.

LITERATURE CITED

Arvanitis, L. G., J. Lindquist, and M. Palley.
1964. **Site index curves for even-aged young-growth ponderosa pine of the westside Sierra Nevada.** Calif. For. and Forest Prod. 35, 8 p.

Hall, Dale O.
1967. **Broadcast seeding ponderosa pine on the Challenge Experimental Forest.** USDA Forest Serv. Res. Note PSW-144, 4 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

McDonald, Philip M.
1966. **Seed fall and regeneration from a group selection cut–first year results.** USDA Forest Serv. Res. Note PSW-113, 6 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

McDonald, Philip M.
1969a. **Silvical characteristics of California black oak (*Quercus kelloggii* Newb.).** USDA Forest Serv. Res. Paper PSW-53, 20 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

McDonald, Philip M.
1969b. **Ponderosa pine seed-tree removal reduces stocking only slightly.** J. Forestry 67:226-228.

McDonald, Philip M.
1973. **Cutting a young-growth, mixed-conifer stand to California Forest Practice Act Standards.** USDA Forest Serv. Res. Paper PSW-89, 16 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Neal, Robert L., Jr.
1975. **Early results of ponderosa pine seeding trials in westside Sierra Nevada clearcuts.** USDA Forest Serv. Res. Note PSW-305, 8 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Quick, Clarence R.
1956. **Viable seeds from the duff and soil of sugar pine forests.** Forest Sci. 2:36-42.

Sundahl, William E.
1966. **Slash and litter weight after clearcut logging in two young-growth timber stands.** USDA Forest Serv. Res. Note PSW-124, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Sundahl, William E.
1971. **Seed fall from young-growth ponderosa pine.** J. Forestry. 69:790-792.

GPO 689-987/5376

1976. **Forest regeneration and seedling growth from five cutting methods in north central California**. USDA Forest Serv. Res. Paper PSW-115, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Regeneration of five species of conifers, three of hardwoods, and two of shrubs was evaluated for five different cutting methods in terms of seedling stocking, density, and height growth on a high site at the Challenge Experimental Forest, in north central California. For ponderosa pine, seed-tree and shelterwood methods produced the highest stocking and density. Selection cutting methods were best for survival and establishment of sugar pine, white fir, and Douglas-fir. For all species (conifer, shrub, and hardwood), seedling height growth increased as the intensity of cutting method increased from single-tree selection to clearcutting. High stocking and height values characterized the shrubs and hardwoods for most cutting methods. Shrubs were particularly dense after clearcutting and broadcast burning, and could be a major factor in establishing adequate regeneration of rapid growth potential in this method.

Oxford: 187x465.6:221[–182.51 + 231.3]
Retrieval Terms: silvicultural systems; regeneration; height increment; site tretments; Challenge Experimental Forest; *Pinus ponderosa; Pseudotsuga menziesii; Pinus lambertiana; Libocedrus decurrens;* California.

1976. **Forest regeneration and seedling growth from five cutting methods in north central California**. USDA Forest Serv. Res. Paper PSW-115, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Regeneration of five species of conifers, three of hardwoods, and two of shrubs was evaluated for five different cutting methods in terms of seedling stocking, density, and height growth on a high site at the Challenge Experimental Forest, in north central California. For ponderosa pine, seed-tree and shelterwood methods produced the highest stocking and density. Selection cutting methods were best for survival and establishment of sugar pine, white fir, and Douglas-fir. For all species (conifer, shrub, and hardwood), seedling height growth increased as the intensity of cutting method increased from single-tree selection to clearcutting. High stocking and height values characterized the shrubs and hardwoods for most cutting methods. Shrubs were particularly dense after clearcutting and broadcast burning, and could be a major factor in establishing adequate regeneration of rapid growth potential in this method.

Oxford: 187x465.6:221[–182.51 + 231.3]
Retrieval Terms: silvicultural systems; regeneration; height increment; site treatments; Challenge Experimental Forest; *Pinus ponderosa; Pseudotsuga menziesii; Pinus lambertiana; Libocedrus decurrens;* California.

McDonald, Philip M.

1976. **Forest regeneration and seedling growth from five cutting methods in north central California.** USDA Forest Serv. Res. Paper PSW-115, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Regeneration of five species of conifers, three of hardwoods, and two of shrubs was evaluated for five different cutting methods in terms of seedling stocking, density, and height growth on a high site at the Challenge Experimental Forest, in north central California. For ponderosa pine, seed-tree and shelterwood methods produced the highest stocking and density. Selection cutting methods were best for survival and establishment of sugar pine, white fir, and Douglas-fir. For all species (conifer, shrub, and hardwood), seedling height growth increased as the intensity of cutting method increased from single-tree selection to clearcutting. High stocking and height values characterized the shrubs and hardwoods for most cutting methods. Shrubs were particularly dense after clearcutting and broadcast burning, and could be a major factor in establishing adequate regeneration of rapid growth potential in this method.

Oxford: 187x465.6:221[–182.51 + 231.3]
Retrieval Terms: silvicultural systems; regeneration; height increment; site treatments; Challenge Experimental Forest; *Pinus ponderosa; Pseudotsuga menziesii; Pinus lambertiana; Libocedrus decurrens;* California.

McDonald, Philip M.

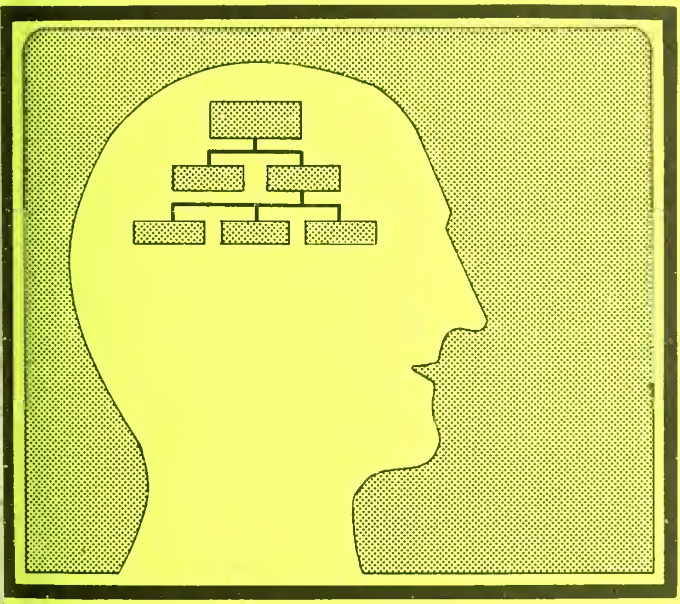
1976. **Forest regeneration and seedling growth from five cutting methods in north central California.** USDA Forest Serv. Res. Paper PSW-115, 10 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Regeneration of five species of conifers, three of hardwoods, and two of shrubs was evaluated for five different cutting methods in terms of seedling stocking, density, and height growth on a high site at the Challenge Experimental Forest, in north central California. For ponderosa pine, seed-tree and shelterwood methods produced the highest stocking and density. Selection cutting methods were best for survival and establishment of sugar pine, white fir, and Douglas-fir. For all species (conifer, shrub, and hardwood), seedling height growth increased as the intensity of cutting method increased from single-tree selection to clearcutting. High stocking and height values characterized the shrubs and hardwoods for most cutting methods. Shrubs were particularly dense after clearcutting and broadcast burning, and could be a major factor in establishing adequate regeneration of rapid growth potential in this method.

Oxford: 187x465.6:221[–182.51 + 231.3]
Retrieval Terms: silvicultural systems; regeneration; height increment; site treatments; Challenge Experimental Forest; *Pinus ponderosa; Pseudotsuga menziesii; Pinus lambertiana; Libocedrus decurrens;* California.

PACIFIC SOUTHWEST
Forest and Range
Experiment Station

EST SERVICE
DEPARTMENT OF AGRICULTURE
BOX 245, BERKELEY, CALIFORNIA 94701



ORGANIZATIONAL FACTORS IN FIRE PREVENTION: roles, obstacles, and recommendations

John R. Christiansen William S. Folkman W. Keith Warner Michael L. Woolcott

USDA FOREST SERVICE RESEARCH PAPER PSW-116/1976

CONTENTS

The Authors

JOHN R. CHRISTIANSEN is Professor of Sociology, Brigham Young University, Provo, Utah, Department of Sociology. He earned bachelor's (1949) and master's (1952) degrees at Utah State University, and a doctorate (1955) in sociology at the University of Wisconsin. **WILLIAM S. FOLKMAN** is a research sociologist with the Station's Wildfire Prevention Research Unit, headquartered in Berkeley, Calif. He holds a bachelor's degree (1940) in agriculture from Utah State Agricultural College, a master's degree in sociology (1949) from the University of Utah, and a doctorate in rural sociology (1952) from Cornell University. **W. KEITH WARNER** is also Professor of Sociology, Brigham Young University. He holds bachelor's (1954) and master's degrees (1959) from Utah State University, and a doctorate (1960) in rural sociology from Cornell University. **MICHAEL I. WOOLCOTT** is a sociology graduate of the University of Colorado (bachelor's degree, 1969) and Colorado State University (master's degree, 1972), and is currently a graduate assistant at Brigham Young University.

SUMMARY

Christiansen, John R., William S. Folkman, W. Keith Warner, and Michael L. Woolcott.

1976. **Organizational factors in fire prevention: roles, obstacles, and recommendations.** USDA Forest Serv. Res. Paper PSW-116, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 432.1(792):903

Retrieval Terms: fire prevention; program evaluation; personnel development; role congruence; organizational obstacles.

Personnel on three National Forests of the U.S. Forest Service's Intermountain Region were interviewed to determine incongruities between their perceived and actual roles in fire prevention.

The three forests were the Fish Lake, Uinta, and Wasatch. In general, a "moderate" degree of congruence was found between proportion of time spent on fire prevention activities and the importance assigned to those activities by the respondents. Field personnel assigned the greatest importance to fire prevention duties, while personnel from the Forest Supervisor's office assigned the least importance to such duties. Respondents from District headquarters were intermediate in the importance they assigned to fire prevention duties in relation to their other tasks. Little congruence was found between time spent on fire prevention and being rewarded with advancement by the organization. District field personnel were most inclined to believe that fire prevention success contributes to advancement, while the Forest level personnel reported such success bore little relationship to advancement.

Three-fourths of the respondents said most of their job know-how came from day-to-day experience; few reported job training sessions or formal training. This situation suggests that the Forest Service regards fire prevention as relatively low level, nontechnical work which, in the main, can be picked up on the job.

The criteria by which fire prevention success is judged was found to be confused. Respondents' reports of how their success was judged frequently differed from their supervisors' reports of how they judged success.

Obstacles to effective fire prevention work were lack of time and manpower (56 percent), lack of money for operational expenses (41 percent), problems in law enforcement (36 percent), and not enough training in latest techniques and programs (30 percent). Lack of money was most apparent to Forest Supervisors' office and District headquarters respondents, while District field personnel felt most keenly problems in law enforcement. District headquarters personnel were most aware of training needs.

The findings from the analysis of interviews with respondents were reported back to them in meetings on the Forests. The response was quite unanimous that the analysis fairly interpreted their feelings. Suggestions were solicited as to how best to resolve the problems revealed.

In addition to more money, suggestions for improvement included more training, more emphasis on fire prevention at higher levels of the organization, and more news media coverage.

The types of information needed to make fire prevention more successful centered about more effective evaluation procedures for fire prevention programs in general and for specific prevention techniques or activities. Other suggested needs include improved transmission of new fire prevention ideas, sources of money for fire prevention, and knowledge about the greatest fire risks.

On the basis of this study the following recommendations for improving fire prevention performance are offered:

1. Develop better methods of determining the degree of success in fire prevention efforts.
2. Improve methods for enabling personnel to achieve greater advancement in the Forest Service organization through successful fire prevention work.
3. Develop fire prevention technology further—especially the social technology.
4. Provide more or better training, or both, for personnel who have fire prevention responsibilities.
5. Place and sustain greater emphasis on fire prevention work at all levels of the Forest Service organization.

In many organizations, including the U.S. Forest Service, some of the most relevant information about how well the work is going, problems being encountered, and potentially helpful changes is available from individuals directly involved in the functioning of the organization. Many people having responsibility for various aspects of the work have just such information, but, for various reasons, it fails to be conveyed to the decisionmakers.

This paper reports a study of three factors related to fire prevention: role congruency in fire prevention activities, social and organizational obstacles, and how fire prevention performance might be improved. Interviews, written questionnaires, and "feedback" techniques were used to obtain responses from persons working directly in fire prevention on three National Forests in Utah.

In this report, the terms "role" and "role congruence" are used as shorthand expressions for technical sociological concepts or ideas. Simply stated, "role" refers to the tasks performed by a person; "role congruence," to the degree of correspondence between the two elements of role, for example, between what the person thinks he should do ideally and what he actually does.

This focus on roles and other organizational matters differs from many previous fire prevention studies which concentrated on the forest users. In such previous studies, the concern was with the public who used the forests: who they were, what kinds of activities they engaged in, what kinds of activities result in man-caused fires, and the like (Brown and Davis 1973). In this exploration, as in a few others, the focus is on another side of fire prevention problems: the people in the Forest Service itself and the organizational situations within which they work (Sarapata and Folkman 1970).

PROCEDURE

Employees from various parts of the U.S. Forest Service's Intermountain Region who had responsibilities for fire prevention were contacted in formulating the study problem, developing the research approach, and gathering data.

In an attempt to broaden the base of the study and make generalizations somewhat more possible, a multimethod, multiphase approach was utilized. In delineating the study problem and selecting suitable research techniques, nonstructured interviews were conducted with persons from the Intermountain Regional Office, and from the Intermountain Forest and Range Experiment Station. These initial interviews proved to be most useful in facilitating the construction and pretesting for the general interview schedule. Further discussion and pretesting was done with personnel from the Toiyabe and Manti-LaSal National Forests.

After the initial interviews, data for the study itself were obtained from 63 persons having fire prevention responsibilities on the Fish Lake, Uinta, and Wasatch National Forests during June and July 1974. This group represents all persons having such responsibilities at the Forest and District headquarters level and a sample of District field personnel. The generalizations made in this present report are primarily based on the data collected in these interviews. The respondents were classified for study purposes into three groups, depending on their fire prevention role:

Group	*Number* (n=63)	*Composition*
Forest	8	Supervisor, staff officer
District headquarters	27	District ranger, fire control officer
District (field)	28	Fire patrolman, seasonal employee

In addition to the interviews, questionnaire and "feedback" sessions elicited further information from respondents. These sessions were held on the Manti-LaSal, Fish Lake, Uinta, and Wasatch National Forests, and were used to help interpret the meaning and implications of the interviews.

RESULTS

Limitations

The number of respondents is large enough and sufficiently representative to provide useful information about role and other organizational issues relating to fire prevention work on the Fish Lake, Uinta, and Wasatch National Forests. It is not large enough in numbers or scope, however, to represent the entire region, much less other forests or regions in the country. But the responses from Forest Service respondents who are familiar with the situations on other forests suggest that the conclusions probably do have wider generality.

Another limitation concerns the method of defining the abstract concept "role congruency" in terms of simple, observable behavior (*table 1*). This method assumes that for complete congruency most time will be spent on activities which are ranked as being most important. It is possible that some tasks ranked "important" might require less time than others to be completed satisfactorily. Consequently, the expectation of achieving a linear-type relationship between time spent on tasks and the importance of these tasks for fire prevention might be unrealistic.

It is possible that other limitations exist in the study which may affect the validity of the generalization. However, if any exist which would modify the conclusions to an appreciable degree, they remain unrecognized.

Role Congruence

How well is the fire prevention program working? Does the Forest Service, as one of many organizations responsible for fire management, give primary emphasis to fire prevention? One way to examine that question is to inquire how the personnel are carrying out their expected assignments. In this study, the approach centered on the idea of congruence: Is there a congruence or correspondence between what the people think they ought to be doing and what they are actually doing? And are these assigned responsibilities compatible with the organizational context within which they are to be performed?

Congruence Between Perceived Effectiveness of Fire Prevention Duties, and Time Spent—Fire prevention duties and the perceptions of the relative effectiveness of those duties by Forest Service personnel were ranked in 12 categories (*table 1*). Most respondents indicated that contacting people who used the National Forests in patrol areas was the most effective means that the Forest Service employees could use to prevent fires. Conversely, routine activities were considered to be least effective. The fire prevention duties having the four highest rankings all involve personal contacts with people.

Responses concerning the proportion of the time spent during May through October 1973 on each of

Table 1—*Averaged rankings of fire prevention duties concerning perceived effectiveness in preventing fires, and time spent on each*[1]

Fire Prevention Duties	Rank of perceived effectiveness in Fire Prevention[2]	Rank of time spent on each duty[3]
User contacts—contact areas	1	1
User contacts—campgrounds	2	2
Public contacts—organizations	3	7
Public contact-homes	4	4
Implementing prevention plan	5	3
Supervising prevention program	6	5
Training fire prevention crews	7	8
Purchasing and maintaining equipment	8	10
Writing fire prevention plan	9	6
Enforcing laws	10	12
Maintaining signs and posters	11	9
Contacting mass media representatives	12	11

[1]"1" has the highest ranking and "12" has the lowest ranking.
[2]Rank based on percentage of respondents who ranked the duty "1".
[3]Rank based on average percentage of time spent on each duty.
Spearman Rank-Order Correlation Coefficient (Rho) = .85.

the fire prevention duties in which respondents had been involved were ranked (*table 1*). One measure of role congruency is the ranking of perceived effectiveness of their tasks, and time spent. The rankings show considerable congruence.

The two duties rated most effective in preventing fires—contacting users in patrol areas and campgrounds—are likewise those on which most fire prevention time is spent. However, contact with the public through organizations such as civic clubs, schools, churches, and scout troops—rated as third most effective in prevention—ranks seventh in the amount of time spent on it. Many respondents mentioned that they would like to have more time to spend in such contacts. One other activity—writing a fire prevention plan—appeared to be relatively incongruent. That is, more time seems to be spent on it than its effectiveness in prevention fires would justify.

We also explored the amount of congruence by computing gamma measures of association between perceived effectiveness and time spent. This was done separately for each of the three groups: Forest, District staff, and District field. The results showed a general pattern of moderate congruence, though with some exceptions. In this analysis, the greatest congruence appeared to be in the duties connected with supervising the program, contacting users in campgrounds, and purchase and maintenance of equipment.

Congruence Between Time Spent on Fire Prevention, and Importance of Fire Prevention—A second way to examine role congruence is to explore the relationship between the proportion of a person's total time spent on fire prevention duties, and the importance he attaches to those duties as compared with his other responsibilities.

We found a "moderate" degree of congruence (Cramer's V = 0.41) (Loether and McTavish 1974) between the proportion of total time spent on fire prevention activities and the importance assigned to those activities as compared with all other duties listed by each person (*table 2*).

This relationship held for each separate group: Forest, District headquarters, and District field staff.

More detailed analysis of this relationship shows, however, that the greatest proportion of time spent on fire prevention tends to be among those in the District field group, with less time spent on fire prevention among the personnel in the District headquarters group, and least among those in the Forest group. Persons in the Forest group less often regard fire prevention work as more important than their other assigned duties, whereas, the personnel in the District headquarters group stand between the Forest group and the District field group in the importance they assign to fire prevention duties in relation to their other tasks. These findings, coupled with a finding (to be detailed later in this report) that Forest Service employees at all levels have considerable autonomy in their priorities and expenditures, suggest that fire prevention efforts may indeed be *relatively* unimportant to the Forest Service generally.

Congruence Between Time Spent and Organizational Advancement—A different kind of congruence is that which concerns the correspondence between role performance and being rewarded by the organization. If the organization, in fact, views particular programs and tasks as important, it almost certainly will reward in their careers those individuals who successfully work on those programs and tasks. Moreover, individuals will be inclined to spend their time on work which is important, and hence rewarded.

Respondents were asked to indicate just how much they think advancement in the Forest Service depended upon success in fire prevention activities. Over-all, fire prevention work was rated by relatively few respondents as being important for their advancement. One-third of the respondents gave it the two lowest marks on a six-point scale. Two-thirds of all respondents gave it a "low" rating for advancement opportunities (*fig. 1*). When responses of the three groups are compared, it is evident that the Forest group believes that their advancement is least dependent upon fire prevention success. The District field group is relatively high in its belief that fire prevention success contributes to advancement, whereas, the District head-

Table 2—*Distribution of respondents according to perceptions of the importance of fire prevention, and time that they spent on fire prevention*

Importance of fire prevention	Percent of time spent on fire prevention			
	0–20	21–40	41+	total[1]
"Very Important"	3	5	9	17
"Moderately Important"	16	5	1	22
"Unimportant"	20	1	0	21
Total	39	11	10	60

Chi-square = 19.9; d.f. = 4; p = .001; Cramer's V = 0.41.
[1]Excludes three "No responses."

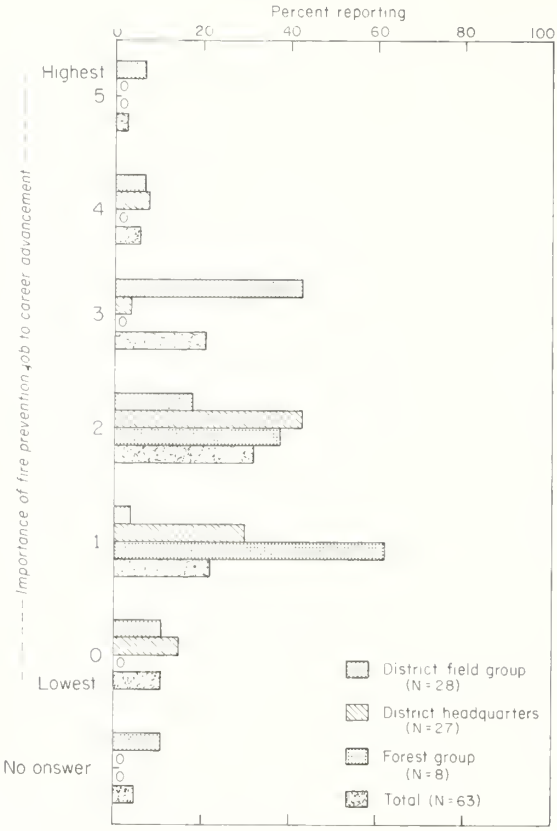


Figure 1—Quality of one's fire prevention work is seen as having little bearing on career advancement.

quarters group's responses tend to be between those of the other groups.

There is a low to moderate relationship (Cramer's V = 0.39) between the amount of time respondents report spending on fire prevention, and the importance they think this kind of work has for advancement (*table 3*). Those respondents who rated fire prevention activities "high" tended to spend relatively more of their time on such activities. This tendency is not strong, however. It is obvious, therefore, that substantial congruence is lacking between perceived importance of success in fire prevention on advancement, and proportion of time spent on such activities. This lack of congruence probably results from three major conditions: (a) fire prevention success is not highly valued—despite rhetoric to the contrary; (b) demands for fire suppression success are so great that fire prevention activities are restricted; and (c) lack of adequate measures of fire prevention activities are restricted; and (c) lack of adequate measures of fire prevention success is such that despite moderate values being placed upon prevention, activities connected with it are not rewarded because they have not been demonstrated to be effective.

Factors Determining Advancement in the Forest Service—Having replied that success in fire prevention activities was not strongly related to advancement in the Forest Service, respondents were then asked to indicate what factors were important for advancement.

Ability was mentioned by 82 percent of all respondents as being most important for advancement (*fig. 2*). Knowledge (68 percent) and recognition in the field (58 percent) were also mentioned by a majority of the respondents. Somewhat fewer persons (48 percent) responded that the performance rating profile was important whereas 47 percent said the number of job openings, 33 percent—friends and personal relations, and 28 percent—seniority. Being from a Forest Service family and the ability to work with others were mentioned by 13 and 6 percent, respectively.

Comparing responses of the three groups shows some differences in responses. Forest group responses emphasized knowledge in advancement. However, the District headquarters group's responses focused on ability. The District field group considered ability and knowledge as most important in advancement, but placed considerable importance on recognition in the field and on the Performance Rating Profile as well.

When these factors for advancement are compared with the ratings of the importance fire prevention success has on advancement it is possible to gain some additional insight about what seems to count for organizational advancement. It appears that if recognition in the field is ranked high in importance, there is somewhat less tendency to think fire prevention success counts heavily. The same general tendency appears for those who cite

Table 3—*Distribution of respondents according to ratings of the extent that advancement depends on success in fire prevention activities*[1] *and time spent on fire prevention*

Rating of extent that advancement depends upon fire prevention success	Percent of time spent on fire prevention				
	0-9	10-19	20-29	30+	total
High (4-5)	0	3	0	3	6
Medium (2-3)	8	6	11	6	31
Low (0-1)	10	6	0	5	21
Total	18	15	11	14	58

Chi-square = 17.4; d.f. = 6; p = .01; Cramer's V = 0.39.
[1]Excludes five "No responses."

friends or personal relations as important bases for advancement.

On the other hand, those who rated both knowledge and seniority as important also tended, a little more often, to assign some importance to fire prevention success as helpful for advancement.

By considering the foregoing, it is helpful to note that considerable differences exist among the three groups studied when they were asked specifically about the importance of fire prevention activities relative to advancement. The farther respondents were removed from the field, the less importance they placed on fire prevention.

This finding suggests that advancement and rewards for effective fire prevention activities diminish as persons rise on the Forest Service career ladder. It also suggests reasons why attention to fire prevention practices, policies, and measurements appear to be lacking relative to other Forest Service activities. First, the people in positions most capable of changing fire prevention procedures and emphasis are least inclined to do so. Second, most talented and able persons in the Forest Service tended to achieve high positions through outstanding performance in activities other than fire prevention.

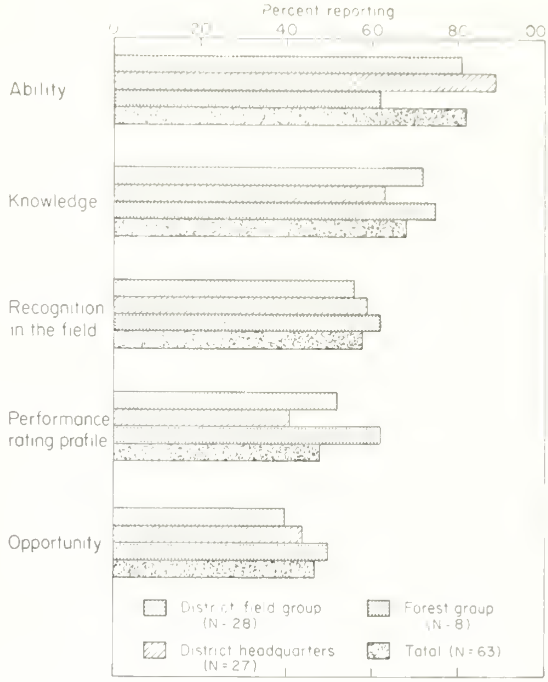


Figure 2—Recognized ability and knowledge are seen as most important for advancement of field personnel, knowledge and opportunity for Forest level personnel.

Development of Technology and Roles—One consideration that may underlie the effective performance of fire prevention roles, and the success of fire prevention programs, is the extent to which the technology of fire prevention work is developed and reflected in the duties assigned personnel. For instance, if the technology is highly developed, routinized, and standardized, then finding the same specific duties assigned to the same roles everywhere could be expected. Thus, details on what tasks were to be done and when each was to be done would be specified.

To inquire about this, respondents were asked a very general question about the freedom they had in deciding (a) what they do and (b) when they do the specific parts of their work. In each case, two-thirds reported "great freedom." A comparison of responses among groups revealed that District staff personnel had somewhat more freedom in decisions than those in the other groups, but generally the responses were similar.

A second indicator of the development, standardization, and specification of roles is the total number of duties into which a person's fire prevention responsibilities are divided. Simply counting the number of those duties shows a wide variation in the number of duties reported. About one-third of all respondents had one or two fire prevention duties. Another third had three duties, and the rest had five or six fire prevention duties.

A third indicator is how people learn their fire prevention job. Do they learn it in the course of day-to-day experience, in some kind of job training sessions, in formal schooling, or in some other way? Three-fourths of the respondents said their greatest job know-how came from day-to-day experience. Another 13 percent reported some combination of on-the-job experience, formal training in school, or training sessions (*fig. 3*).

A comparison of responses among the groups showed the two District groups to be quite similar. In both of these groups, most respondents stated that they learned most about their jobs from day-to-day experiences. The Forest group were evenly divided in their emphasis on day-to-day experience learning, and combinations of learning sources.

This suggests that the Forest Service does not regard fire prevention work as so technical that much more than job experience is necessary to learn it; or possibly that a person learns things in other training that is applicable to fire prevention.

How Fire Prevention Success is Judged— Related to the development of technology and roles,

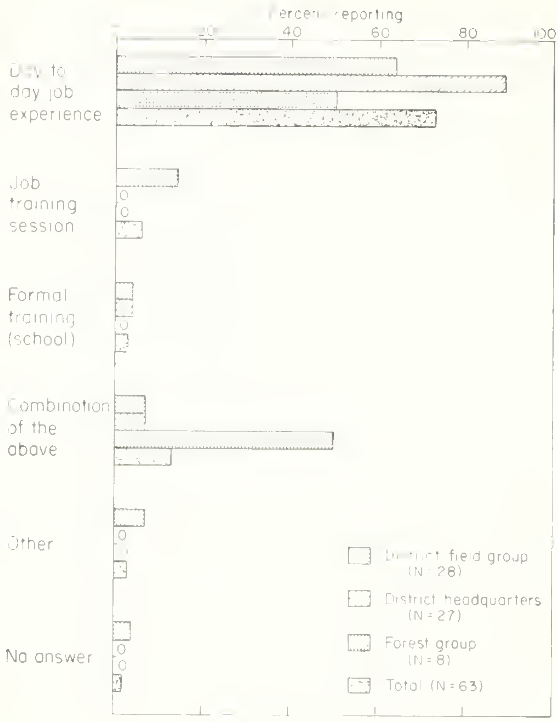


Figure 3—Day to day job experience is the most frequently reported way personnel learn their fire prevention duties.

and to perceived bases for advancement in the organization, is the important issue of how fire prevention success is judged. It appears that the criteria and methods for judging success are not yet sufficiently developed. As a consequence, it is difficult for either the organization or the individual to judge the success of an individual's efforts or even those of the organizational program.

Forest level personnel were asked, "How do people in the Regional Office judge the degree of success your Forest has in fire prevention work?" Then they were asked, "How do people in the Forest Supervisor's office judge the degree of success of each District?" Similarly, district rangers and fire control officers were asked how the Forest people judged success and how they, themselves, assessed the success of their fire prevention people in the District. Finally, the other personnel in the District were asked, "How does your supervisor judge the degree of success you have in your fire prevention work?"

All but one of the eight forest-level respondents indicated that the "number of man-caused fires" was the principal criterion used by regional personnel in judging fire prevention success. On the other hand, they indicated they used two criteria in judging the fire prevention success of districts on their forests. These two criteria were: (1) number of man-caused fires occurring in the district, and (2) reduction in the number of fires relative to previous years. The first criterion for judging the fire prevention success of districts was used by five of the eight forest-level respondents, and the second criterion was used by four forest-level respondents.

Nearly two-thirds (63 percent) of the District headquarters respondents maintained that the "number of man-caused fires" was a criterion used by Forest level personnel to judge their district's fire prevention success. As seen above, this is the criterion Forest level personnel say they use. However, two other criteria appeared to be incorrectly considered by some District headquarters respondents to be used by forest level personnel in judging fire prevention success. The first of these criteria, "making and carrying out fire prevention plans," was mentioned by 22 percent of District headquarters respondents; and 19 percent of them mentioned "public relations." "Public relations" includes those activities in which members of groups or institutions are contacted to promote fire prevention. For example, contacts with Boy Scout groups, civic clubs, and schools would be included, together with efforts made with the news media on a local level. Additionally, about two-fifths of District headquarters respondents revealed that they are uncertain about criteria used by forest personnel to judge their district's fire prevention success.

In responding to the question of how they judge fire prevention success in their district, District headquarters personnel gave answers which were categorized into several criteria. The two criteria used by the largest percentage of respondents were: (1) Number of man-caused fires, and (2) public relations activities, both of which were mentioned by 44 percent of these respondents. Other criteria mentioned included: completing assigned duties (33 percent), analysis of reports and inspections (21 percent), area conditions, control (15 percent), and reduction in fires (15 percent).

District field respondents' perception of the criteria by which their fire prevention success was judged were more congruent with criteria reported being used by their supervisors than was that of District headquarters respondents with their supervisors. Again, the two criteria mentioned by most respondents were: number of man-caused fires and public relations activities, both reported by 39 percent of the respondents. Other criteria mentioned were: completing assigned duties (25 percent), analysis of reports and inspections (21 percent), and number and quality of personal contacts (21 percent). Eighteen percent of the District Field respondents reported that they were uncertain how their success was judged.

The responses generally indicate some incongruity in the criteria and their implementation. The number of man-caused fires is the most frequently mentioned criterion of success, but even that criterion is not mentioned by most respondents. It is evident that people assigned to fire prevention do not clearly understand how their success is judged by their supervisors, and that their supervisors have difficulty in making such judgments.

This lack of clear criteria for judging fire prevention success has a number of important implications. First, the possibility exists that an individual might perform his role well and not get much credit for it because of the difficulty in knowing what "good performance" is. Second, a person may not do his job well, but could receive credit for success. This situation could diminish the status of prevention programs or the emphasis given them at various levels of the organization.

Social and Organizational Obstacles

The second major objective of this study was to explore some of the social and organizational problems or obstacles to fire prevention work. What things may be hindering this program?

To answer this question, respondents were asked to assign a rank order of importance to a list of possible problems. They were then asked to add any other problems to the list that they thought ought to be included and rank the importance of any such additions.

Just over half (56 percent) of all respondents at all organizational levels studied gave their first or second place rankings to problems of lack of time and manpower. Two-fifths (41 percent) cited lack of money for operational expenses as most important (ranked first or second), and nearly the same proportion (36 percent) gave the first and second ranks to problems of law enforcement. Nearly a third (30 percent) gave high ranking to problems of "not enough training in the latest techniques and programs" (*fig. 4*).

The two problems ranked as most important by the largest proportion of all respondents may be translated directly into money. Time, manpower, and operating expenses all have the common de-

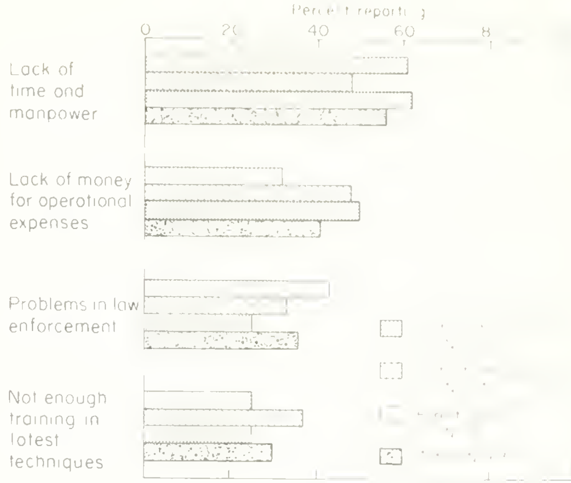


Figure 4—There is considerable agreement that money-related factors are the major hinderances to effective fire prevention work.

nominator of funds available for them. But it appears likely that important problems would not be automatically taken care of by increased funding. Funds are a perennial problem, but getting more funds is not always a panacea. Thus, problems of law enforcement and of getting "more training in the latest programs and techniques" (mentioned quite frequently by the two district groups) are not matters of budget allocation only. When this information is put together with other data on the lack of fire prevention technology, it gives some basis for possible improvements.

Providing more money for manpower, time, and operating expenses can help. But the questions remain: What is the effect of law enforcement on number of fire starts? What are the most effective methods of law enforcement in different situations? Which methods of contacting or "educating" the public really make a difference or make the most difference? What are the relative advantages of contacting forest users at their homes or businesses or through mass media, versus contacting them as they use the forests? Developing further the technology involved, training the personnel in the latest techniques, and reconsidering how the organizational structure facilitates and supports fire prevention work—these steps in response to problems involve more than money.

Proposals for Improvement

The third aim of this study was to look for some possible improvements that might be made in the fire prevention work.

From their various perspectives within the organization, personnel intimately involved in fire prevention activities on a day-to-day basis have an excellent platform from which to assess success and failures, strengths and weaknesses of policies and practices in operation. For this reason, impressions were solicited from the fire prevention personnel studied.

Discrepancies between perceived and actual roles and social-organizational obstacles in fire prevention identified from our analysis of the previous interviews were reported back in meetings with the fire prevention personnel on the Forests. The respondents concurred that the analysis correctly interpreted their feelings.

Possible Improvements—The respondents were asked what they felt could be done to make their fire prevention activities more successful. More specifically, what could be done at the District level? What could be done at the forest, regional, and national levels?

By grouping the responses into categories, we found that the possible improvements for the district level cited most often were funds for manpower, more training, and more public education. Just under one-third of the respondents mentioned each of these items.

Somewhat fewer people at the district level mentioned coordination improvements, and funds for supplies.

For the forest level, more law enforcement and more news media coverage were mentioned by about a quarter of the respondents. Fewer mentioned more communication (14 percent), more emphasis on fire prevention (14 percent), and more consistency (11 percent).

What might be done at the national level? One-third of the respondents mentioned more news media coverage. The next most frequently mentioned suggestion (21 percent) was more emphasis on fire prevention. Then about a tenth mentioned more coordination, more money, more training, and more emphasis on fire and fuel management.

Looking across the entire pattern of responses, money was most frequently mentioned. Beyond that, there were some other needs: more training, more emphasis on fire prevention, and more news media coverage, each of which appear in three of the four levels (*table 4*).

One possible interpretation of these findings is that fire prevention does not receive as much "standing" or "status" in the organization as might be helpful. If it had more status, there might be more attention to developing the fire prevention technology, more technical development of the training aspects, more communication about this part of the work of the over-all organization and more news media recognition, and the like.

Brown and Davis (1973, p. *263*) claim that "all fire control organizations, forest, rural or urban, give primary emphasis in carrying out their jobs to preventing as many fires as possible." In a sense that may be true but it sounds a little more like rhetoric than reality. No doubt the fire prevention work of the Forest Service is conducted with care and much is done to foster that effort. But the findings of this study do not lead us to conclude that "primary emphasis" is given to fire prevention work. And our respondents seem to be saying that indeed one way to improve the work is to really give greater emphasis to fire prevention activities, and to do this at all levels of the Forest Service organization, especially at higher levels.

More Useful Information about Improving Fire Prevention Work—Finally the respondents were asked: What would be the most useful information

Table 4—*Responses to the question: What could be done to make fire prevention duties more successful?*

At the District Level		At the Forest Level		At the Regional Level		At the National Level	
Category	*Pct.*[1]	Category	*Pct.*[1]	Category	*Pct.*[1]	Category	*Pct.*[1]
Funds for manpower	32	More law enforcement	26	More news media	22	More news media	32
More training	30	More news media	26	More emphasis on fire prevention	18	More emphasis on fire prevention	21
More public education	30	More communication	14	More communication	16	More coordination	11
Coordination	16	More emphasis on fire prevention	14	More money, equipment	10	More money	11
Funds for supplies	13	More consistency	11	More consistent program	10	More training	10
				More training	10	More emphasis on fire and fuel management	10

[1]Percentage add to more than 100 because of multiple responses (N = 63).

about how to make fire prevention work more successful? Most responses to this question concerned a need for determining the effectiveness of various fire prevention activities. Just over one-third of the respondents wanted information about determining the effectiveness of fire prevention activities generally. The second most frequent response (mentioned by just over one-fourth of the sample) had to do with learning new ideas of preventing fires. The third item in terms of frequency dealt with a specific fire prevention activity: "How effective is public relations?" (*fig. 5*).

These and other responses indicated an openness to new ideas and better ways of doing things, and the possibility that the organization might make a worthwhile investment in responding to questions of that kind and, further, in taking steps to insure workable answers are conveyed to personnel doing fire prevention work.

Such responses suggest that one need consists of developing proven fire prevention technology and policy. Particularly needed are procedures and policies for contacting and dealing with all kinds of forest users. Moreover, the means of implementing these procedures and policies into on-going procedures and organizational structures of the Forest Service is needed. Obviously, these kinds of improvements go beyond trying to motivate personnel to do their jobs better. They are examples of activities that might profit from changes that are not simply consequences of faulty individual role performances.

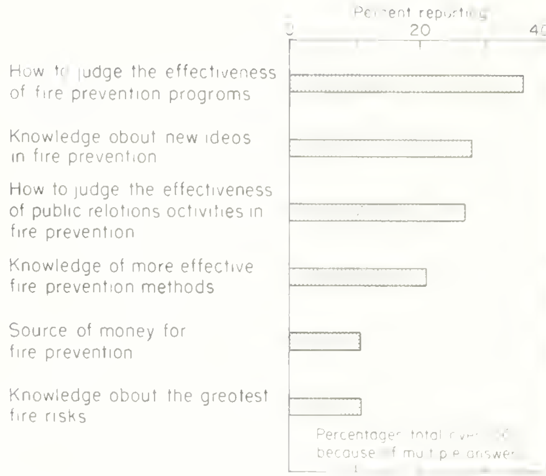


Figure 5—Developing a workable means for judging fire prevention effectiveness is considered the most pressing need to make fire prevention more successful.

RECOMMENDATIONS

It appears that a number of worthwhile improvements of individual role performance could be accomplished by certain modifications of organizational policies, procedures, or programs, rather than the usual emphasis on how to get better work performance out of individual personnel. This does not mean that individual role performance is beyond improvement. No doubt much could be done there. But it does suggest that a careful examination of the organizational context within which individuals do their work could be most profitable.

What are some of the specific things that might be done? The foregoing information from the respondents has suggested several.

Determination of Success in Fire Prevention—There is a good deal of variation and some lack of clarity in how people think success in fire prevention is judged. In other words, the criteria and methods for judging success are apparently not clear and completely agreed upon.

"How to judge effectiveness of fire prevention work generally" and the "effectiveness of public relations efforts" as one specific example, were among the few items of "needed information" most often cited by respondents (*fig. 5*).

The implications of findings like these lead us to the first recommendation:

- Develop better methods of determining the degree of success in fire prevention efforts.

If supervisors cannot tell whether efforts are having the desired effect or whether one person's performance is more successful than another's, then there is no equitable way to reward success more than lack of success. And, if administrators cannot judge with reasonable accuracy which programs or activities are successful, or the general degree of success, then they have no precise way of deciding whether resources invested in these programs are better put to alternative uses. Similarly, if individuals cannot tell which things work better than others, they have no sound basis for improving their individual performance.

There may be no way to make extremely precise "measurements" of success in fire prevention, but considerable improvement might be made. The question, then, is what improvement could be made.

Development of Advancement Potential Based on Fire Prevention Work—Success in fire prevention activities does not appear strongly related to career advancement in the Forest Service (*figs. 1, 2; table 3*). The farther removed from the field the respondents are, the less importance they tended to place on success in fire prevention work as a basis for advancement in the organization.

This has a number of serious implications for any major efforts to improve fire prevention work. Consequently, the second recommendation addresses this issue:

• Improve methods for enabling personnel to achieve greater advancement in the Forest Service organization through successful fire prevention work.

If fire prevention work is a "dead-end street," or if it is an avenue that is not productive for long-term career advancement opportunities, then some powerful constraints may be operating against successful fire prevention programs. On the other hand, one way of motivating continuing productivity in individual roles is to make it routinely possible or even probable for persons to "get ahead" in the organization by their work in fire prevention roles and programs. One specific aspect of this recommendation includes the communicating of clear instructions about expectations regarding fire prevention duties up and down the organization ladder.

Development of the Social Technology of Fire Prevention—Fire prevention roles in general are not highly standardized, as indicated by the substantial freedom reported regarding what the personnel do, and when they do it. Moreover, the technology is apparently not considered highly technical and complex, as indicated by the response that most of the work is learned by day-to-day job experience rather than expert training (*fig 3*). Of course, some aspects of the jobs could be both standardized and technically complex, but these could not be mastered by on-the-job experience.

The respondents report some of the "hindrances" to be problems of social technology, problems like law enforcement, getting sufficient training on the latest techniques and programs, and others (*fig. 4*). Recommendations for improvement (*table 4*), include suggestions for more training, as well as for some other changes that involve "social technology," such as public education.

Additionally, the bases on which the respondents judge, and think they are judged in their success, give important place to "public relations activities." This is a social program of work, the technology for which is part of fire prevention activity. And there is a need for more information about effective ideas and methods about social aspects of fire prevention work (*fig. 5*).

Therefore our next recommendation:

• Develop fire prevention technology further—especially the social technology.

Development of More and Better Training for Fire Prevention—As we have mentioned, the data show that most of the work is learned through on-the-job experience (*fig. 3*). And one of the major hindrances reported was "not enough training in the latest techniques and programs " (*fig. 4*).

The respondents' suggestions for improvement (*table 4*) and the kinds of information about new ideas and more effective methods that are reported needed, (*fig. 5*) join with the implications of the previous recommendations in leading to our next suggestion:

• Provide more or better training, or both, for personnel who have fire prevention responsibilities.

Although some of the duties in fire prevention work are simple and routine, many are complex. Many call for actions that are unclear, unspecified, and difficult to implement. Some can be done simply with perhaps a little success, where much success requires complicated and more skilled approaches.

Development of Greater Emphasis on Fire Prevention Work—One of the important ways to emphasize fire prevention work at all levels of the Forest Service organization would be to enhance the opportunities for career advancement based on success in fire prevention work. Yet this emphasis apparently is not the case—especially higher up the organization ladder (*figs. 1, 2; table 3*).

Many other ways to emphasize the place of fire prevention work are available. Without trying to enumerate these, we note that "greater emphasis on fire prevention work at the Forest, Regional, and National levels" was among the suggestions for improvement made by the most respondents. In addition to rather direct suggestions of this kind, the calls for more public education, more news media coverage, more communication, and the like (*table 4*) also support the interpretation that "greater emphasis at all levels of the Forest Service on fire prevention work" could help improve the success of that work.

- Place and sustain greater emphasis on fire prevention work at all levels of the Forest Service organization.

By more or different communication through the news media, by internal communication in the Forest Service organization, by advancement opportunities, by budgetary allocations, and other means, it appears desirable to increase the emphasis on fire prevention work and its importance in the over-all program of work in the Forest Service. This emphasis would include more attention on a continuing basis at higher levels of the organization to this work and its place in the total program.

Subsequent to the completion of this study, a report dealing with some of the same concerns as the study was prepared by the National Wildlife Prevention Analysis Task Force (*May 1975*). This inter-agency Task Force was directed by the Chief of the Forest Service to analyze wildfire prevention problems and programs throughout the United States. In several key points, the analysis and recommendations of this Task Force and our own findings and interpretations in this study are remarkably complementary. This is particularly true in the recognition of the need for increased emphasis on wildfire prevention and on the necessity for developing effective fire prevention evaluation procedures and techniques.

LITERATURE CITED

Brown, Arthur A., and Kenneth P. Davis.
1973. **Forest fire: control and use.** 2nd ed. 686 p. McGraw-Hill Book Co., New York.

Loether, Herman J., and Donald G. McTavish.
1974. **Descriptive statistics for sociologists: an introduction.** 388 p. Allyn and Bacon, Inc., Boston.

Sarapata, Adam, and William S. Folkman.
1970. **Fire prevention in the California division of forestry . . . personnel practices.** USDA Forest Serv. Res. Pap. PSW-65, 10 p., Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

The National Wildfire Prevention Analysis Task Force.
1975. **Wildfire prevention analysis: problems and programs.** Washington, D.C., May 1975. 28 p.

Christiansen, John R., William S. Folkman, W. Keith Warner, and Michael L. Woolcott.

1976. **Organizational factors in fire prevention: roles, obstacles, and recommendations.** USDA Forest Serv. Res. Paper PSW-116, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn, Berkeley, Calif.

Problems being encounterd in implementing fire prevention programs were explored by studying the organization for fire prevention at the Fish Lake, Uinta, and Wasatch National Forests in Utah. The study focused on role congruency in fire prevention activities and on the social and organizational obstacles to effective programs. The problems identified included lack of consistency and lack of adequate measures in determining success in fire prevention performance; limited career advancement potential based on fire prevention work; need for improvement in fire prevention technology—particularly social technology; and need for more emphasis on fire prevention at all levels of the U.S. Forest Service. Recommendations for improving fire prevention performance are included.

Oxford: 432.1(792):903
Retrieval Terms: fire prevention; program evaluation; personnel development; role congruence; organizational obstacles.

Christiansen, John R., William S. Folkman, W. Keith Warner, and Michael L. Woolcott.

1976. **Organizational factors in fire prevention: roles, obstacles, and recommendations.** USDA Forest Serv. Res. Paper PSW-116, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn, Berkeley, Calif.

Problems being encountered in implementing fire prevention programs were explored by studying the organization for fire prevention at the Fish Lake, Uinta, and Wasatch National Forests in Utah. The study focused on role congruency in fire prevention activities and on the social and organizational obstacles to effective programs. The problems identified included lack of consistency and lack of adequate measures in determining success in fire prevention performance; limited career advancement potential based on fire prevention work; need for improvement in fire prevention technology—particularly social technology; and need for more emphasis on fire prevention at all levels of the U.S. Forest Service. Recommendations for improving fire prevention performance are included.

Oxford: 432.1(792):903
Retrieval Terms: fire prevention; program evaluation; personnel development; role congruence; organizational obstacles.

Christiansen, John R., William S. Folkman, W. Keith Warner, and Michael L. Woolcott.

1976. **Organizational factors in fire prevention: roles, obstacles, and recommendations.** USDA Forest Serv. Res. Paper PSW-116, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Problems being encountered in implementing fire prevention programs were explored by studying the organization for fire prevention at the Fish Lake, Uinta, and Wasatch National Forests in Utah. The study focused on role congruency in fire prevention activities and on the social and organizational obstacles to effective programs. The problems identified included lack of consistency and lack of adequate measures in determining success in fire prevention performance; limited career advancement potential based on fire prevention work; need for improvement in fire prevention technology—particularly social technology; and need for more emphasis on fire prevention at all levels of the U.S. Forest Service. Recommendations for improving fire prevention performance are included.

Oxford: 432.1(792):903
Retrieval Terms: fire prevention; program evaluation; personnel development; role congruence; organizational obstacles.

Christiansen, John R., William S. Folkman, W. Keith Warner, and Michael L. Woolcott.

1976. **Organizational factors in fire prevention: roles, obstacles, and recommendations.** USDA Forest Serv. Res. Paper PSW-116, 13 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Problems being encountered in implementing fire prevention programs were explored by studying the organization for fire prevention at the Fish Lake, Uinta, and Wasatch National Forests in Utah. The study focused on role congruency in fire prevention activities and on the social and organizational obstacles to effective programs. The problems identified included lack of consistency and lack of adequate measures in determining success in fire prevention performance; limited career advancement potential based on fire prevention work; need for improvement in fire prevention technology—particularly social technology; and need for more emphasis on fire prevention at all levels of the U.S. Forest Service. Recommendations for improving fire prevention performance are included.

Oxford: 432.1(792):903
Retrieval Terms: fire prevention; program evaluation; personnel development; role congruence; organizational obstacles.

PACIFIC SOUTHWEST
Forest and Range
Experiment Station

T SERVICE
PARTMENT OF AGRICULTURE
OX 245, BERKELEY, CALIFORNIA 94701

SHELTERWOOD CUTTING IN A YOUNG-GROWTH, MIXED-CONIFER STAND IN NORTH CENTRAL CALIFORNIA

Philip M. McDonald

USDA FOREST SERVICE RESEARCH PAPER PSW-117 /1976

CONTENTS

The Author

PHILIP M. McDONALD is doing research on silviculture of Sierra Nevada forest types, with headquarters at Redding, California. A native of Seattle, Washington, he holds bachelor's (Washington State University, 1960) and master's (Duke University, 1961) degrees in forestry.

SUMMARY

McDonald, Philip M.
1976. **Shelterwood cutting in a young-growth, mixed-conifer stand in north central California.** USDA Forest Serv. Res. Paper PSW-117, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Oxford: 231:187x466(794):221.23
Retrieval Terms: shelterwood methods; natural regeneration; slash disposal; site preparation; Challenge Experimental Forest; young-growth forestry; mixed-conifer stands.

In 1958, a mixed-conifer stand on a high site was logged to two-stage shelterwood specifications. The primary goal was to test the applicability of a modified shelterwood method to a young-growth stand. Changes in species composition and stand structure, seedfall, regeneration, and growth of the residual stand were evaluated.

Because slash volumes are high and aggressive hardwood and brush populations build up quickly after logging, combination slash disposal and site preparation techniques must be applied. Treatments compared were piling by bulldozer immediately after logging, piling just before seedfall from a heavy cone crop, and top-lop and branch-scatter.

Cutting removed 68 percent of the stand basal area and 70 percent of the merchantable volume. Most of the remaining volume was in the 12 trees per acre (30 per ha) that constituted the shelterwood.

These trees produced seed abundantly during the 5-year period after logging. In fact, fifteen conifer and two hardwood seed crops were produced, and four out of five conifer species generated at least one moderately heavy seed crop. Cone counts proved valuable in assessing the number of trees with cones and the number of cones per tree, but were poor quantifiers of sound seed. Seed trap catches gave more accurate results, indicating a total seed production of 134,000 sound seed per acre (330,980 per ha) during a 3-year period. In general, young-growth trees, even on this high site, produced high percentages of unsound seed.

Regeneration was exceptional on the prepared ground beneath the shelterwood. After 50 months, about 3700 ponderosa pine seedlings per acre (9139 per ha), and 600 shade-tolerant conifer seedlings (1482 per ha) were established. Corresponding stocking values were 62 percent for ponderosa pine and 19 percent for the tolerant conifers. An additional 320 26-month-old tolerant conifer seedlings per acre (790 per ha) also were present.

Seedlings survived better when slash was piled just before seedfall than when it was piled immediately after logging, or when branches were lopped and scattered.

Hardwood seedlings and sprouts also were abundant, numbering about 3000 per acre (7410 per ha), but the seedlings were poorly distributed and rather slow growing. Sprouts were the most serious competitors of the conifer seedlings, especially of the more tolerant conifers.

In general, the species composition of the new stand regenerated by this shelterwood application closely resembled that of the stand before logging.

Seedfall and regeneration were compared to a control block. Nine times more seeds were produced in the shelterwood, more seeds were sound, more sound seeds germinated, more seedlings resulted, a lower proportion of the seedlings died, and the seedlings were better distributed throughout the area.

Basal area growth of individual trees in 5 years exceeded that of the control for nearly all conifer and hardwood species and diameter classes. In the shelterwood, sugar pine responded best to cutting, and its basal area growth rate was twice that of ponderosa pine and Douglas-fir.

Increased amounts of seed and seedlings, plus accelerated growth rates of residual trees, are gains in productivity that the landowner may realize from applying the shelterwood method to young-growth stands. Because reforestation is accomplished by natural regeneration rather than by expensive nursery stock, the shelterwood cutting method is attractive to a wide range of forest landowners, including those having small acreage and limited capital.

Nearly 30 years ago Hawley (1946) noted that the shelterwood cutting method was particularly applicable to young-growth conifer stands. Yet in the Western United States, this method has been only sparingly applied. A 70-year-old western hemlock stand was cut in three stages in western Washington (Herman 1962), and a Douglas-fir stand under 90 years of age was logged by a modified shelterwood cutting in Oregon. In the latter study, the overstory trees were removed by several partial cuttings over a 30-year period (Starker 1970).

Because of its wide silvicultural application, the shelterwood method now is being used much more frequently, by a more diverse audience, and with a broader spectrum of objectives. Shearer (1971) noted that the shelterwood method provided a high output of both commodities and amenities: timber, wildlife and livestock forage, water, and esthetics. Indeed, Rickard and others (1967) found that the method opened up the stand, thus improving visual penetration and scenic enjoyment.

The shelterwood method is particularly useful as an alternative to clearcutting. It is a gentler method; the land is never without trees and their presence lessens the harshness of the environment. The habitat provided is midway between the open sunlit clearcut and that of the dense shady uncut forest.

Owners of small parcels of timberland also can benefit from the shelterwood method. Large increases in productivity can be realized, and by means of natural seedfall and natural regeneration, a new tree crop can be established without high capital outlays for nursery stock and planting crews.

The shelterwood method can be applied in many environments and for such diverse silvicultural objectives as protecting regeneration, establishing difficult-to-regenerate species, conversion to more desirable species, and natural regeneration of large areas.

For propagating species whose regeneration requires protection from adverse environmental factors such as high temperatures, frosts, or strong sunlight, the shelterwood method is without peer. It has been used to protect hybrid spruce in Canada from frost damage (Day 1970); black and white spruce, balsam fir, and northern white cedar from frost in mixed-conifer swamps in Michigan's Upper Peninsula (Benzie 1963); Scots pine and Norway spruce from frost in Sweden and other Scandinavian countries (Hagner 1962); and white pine from excessive soil surface temperatures and improper amounts of light in the Northeastern United States (Hawley and Clapp 1942; Smith 1951).

A well-applied shelterwood cutting is ideal for regenerating an infrequent seed producer and a difficult-to-plant species such as longleaf pine. It produces enough shade to inhibit brush, grass, and other competitive vegetation until enough seed crops have occurred to provide adequate regeneration (Croker 1969).

The shelterwood method also is used for converting to a more desirable species, like spruce, in the spruce-aspen stands of Manitoba (Lees 1964), and in the hardwood-spruce stands of the Northeastern United States (Westveld 1938). Sometimes a different mixture of species is desired. In northeastern Washington, shelterwood cutting favors western larch and Douglas-fir over lodgepole pine and western white pine (Pacific Logger & Lumberman 1971).

In addition to protection and conversion, the shelterwood method is applicable where evenly distributed natural regeneration is desired over large areas, as in the spruce-beech-fir forests of southern Germany and nearby countries (Spurr 1956), and in the western larch forests of Montana and northern Idaho (Roe 1955).

At the Challenge Experimental Forest in north central California,[1] early research goals were to evaluate shelterwood and other cutting methods in terms of species composition, seedfall, regeneration, and growth of residual trees. Information on these components, for the various cutting methods, is sorely needed for young-growth stands. By comparing cut stands to a control, this research also encouraged investigation of an increasingly important concern of silviculture—cutting-caused vegetative succession, not just on the ground or into the overstory, but into each stand stratum. Further, the comparison permitted quantification of the gain in productivity for seed crops, seeds, seedlings, and growth resulting from shelterwood cutting.

This study embraces the principles of protection

[1] U.S. Forest Service research at the Challenge Experimental Forest is conducted in cooperation with the Soper-Wheeler Company, Strawberry Valley, California.

and conversion: protection for shade-tolerant conifer seedlings and advance reproduction from strong sunlight and high temperatures, and conversion in the sense of reversing normal plant succession and converting the vegetation to an earlier serial stage. This report documents results from a two-stage shelterwood cutting on the Challenge Experimental Forest, as observed about 5 years after logging. Three slash disposal treatments as well as species composition, stand structure, seedfall, regeneration, and growth of the residual stand were evaluated. The cutting was found to maintain the character of the stand before logging and to increase productivity of the cut blocks as compared to the uncut control.

METHODS

Site and Stand Characteristics

Research on the Challenge Experimental Forest is applicable to about 1.5 million acres (600,000 ha) of highly productive timberland along the lower west slopes of the Sierra Nevada. An important attribute of the Experimental Forest is its high site. The dominant species, ponderosa pine (*Pinus ponderosa* Laws.) averages 140 feet (43 m) in height in 100 years (Arvanitis and others 1964). Deep soil, warm temperatures, and an average annual precipitation of 68 inches (1680 mm) lead to rapid site occupancy by vegetation. With time, this vegetation has resulted in conifer and hardwood stands (*fig. 1*).

In stand volume, ponderosa pine is the dominant species, followed by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) with lesser amounts of sugar pine (*Pinus lambertiana* Dougl.), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), and incense-cedar (*Libocedrus decurrens* Torr.). Hardwoods, principally California black oak (*Quercus kelloggii* Newb.), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and Pacific madrone (*Arbutus menziesii* Pursh), are scattered throughout as individual trees, clumps, or groves. They often form extremely dense stands.

Four 6-acre (2.4-ha) rectangular compartments with generally eastern exposure and slopes of 15 percent or less were selected for the shelterwood study. Each compartment supported a stand of conifers and hardwoods of about 248 stems per acre (613 per ha) 3.5 inches (8.9 cm) or more in diameter at breast height (d.b.h.). Basal area was about 270 ft^2 per acre (62 m^2/ha). Stand volume of trees larger than 12 inches (30 cm) in diameter averaged slightly under 54,000 board feet per acre Scribner rule (308 m^3/ha).

Figure 1—This 90-year-old mixed-conifer stand is typical of the Challenge Experimental Forest, Yuba County, California, in 1958.

Cutting Plan, Logging, and Slash Disposal

In the summer of 1958, each compartment was cut to form a modified shelterwood. Shelterwood cutting in young-growth, windfirm stands on high sites can differ considerably from cutting in old-growth stands, 200 or more years in age. First, because much quicker establishment of regeneration often is a management goal, the classical shelterwood stages of "preparatory" and "seed" can be combined. The combined operation plus the removal stage form a two-stage shelterwood. Second, not only must enough trees remain to provide the desired level of protection to advance reproduction or new seedlings, but also the trees left must produce seed. Seed production cannot be as readily assumed as in old-growth stands. Some trees in young-growth stands are physiologically incapable of producing cones even though they are full crowned and appear thrifty. Thus, after considering the number of trees to leave evenly spaced over each acre, the silviculturist should further consider leaving trees that show evidence of past cone production.

To form the desired two-stage shelterwood, 12 large, vigorous, full-crowned trees were evenly spaced throughout each compartment. All other trees larger than 12 inches d.b.h. were harvested. Trees with cones on the ground below were chosen as leave trees whenever possible. Conifers other than ponderosa pine were desired, but because this species predominated, it constituted about 60 percent of the shelterwood. After logging, Douglas-fir, white fir, and sugar pine advance reproduction, small poles, and large poles remained in the understory, both as individual trees and in thickets. Because they could be expected to prosper in the shelterwood environment, they were retained.

Flexibility was the rule in logging, and landings were quickly and cheaply constructed near the compartments at appropriate locations. Timber fallers cut all unmarked conifers and were careful not to injure designated shelterwood trees. Skidding was done by 113-drawbar horsepower, dozer-equipped tractors (D-7 and TD-20). Loading also was done with a large tractor equipped with a hydraulic fork. Other than in the small landings, soil compaction appeared to be negligible.

Slash volumes tend to be heavy in young-growth stands on high sites–Sundahl (1966) found slash volumes to range from 88 to 110 tons per acre (80 to 100 metric tons per ha). Also, over one-third of the total stand density was less desirable pole- and sapling-sized incense-cedar and Pacific madrone. Therefore, a combined slash disposal and site preparation treatment was advisable.

To ascertain the effectiveness of the regeneration medium provided, three widely differing intensities of site-preparation-slash-disposal were installed on equal acreages in each compartment. These were:

1. Pile with bulldozer immediately after logging. Burn piles later.
2. Delay piling until late summer of an obviously good seed year. Burn piles later.
3. Lop and hand scatter.

In the dozer-piled operations, many hardwoods and small incense-cedars were eliminated deliberately. Few were removed in the lop-and-scatter treatment. In the process of piling, much mineral soil was bared; little was bared, and that only by logging, in the lop and scatter treatment. Delaying slash disposal until just before seedfall provided a fresh, friable seedbed.

Within each 6-acre compartment a 4-acre (1.6-ha) rectangular cut block was delineated. An adjacent compartment of similar size, with similar terrain and timber stand structure, was used as a control. Here, about 20 percent of the volume in trees over 12 inches d.b.h. was removed in a light improvement cut in 1958. Slash was piled and burned on about 15 percent of this compartment. Within it, a 4-acre "control block" was defined for measurement.

After the light cutting and slash disposal, the control block contained almost the same number of trees (252 per acre or 622 per ha) as the average cut block before logging (269 trees per acre or 664 per ha). A statistical comparison of the control block after logging and the cut blocks before logging, based on species and 4-inch (10-cm) diameter classes, showed no significant differences between cut blocks and control ($p = 0.05$).

Data Gathering and Analysis

Within each 4-acre cut block, every tree larger than 3.5 inches d.b.h. was tagged to facilitate remeasurement. Trees smaller than 3.5 inches in diameter were not tallied until they reached this diameter. Then they were recorded separately as ingrowth. Trees were measured before logging in 1958, after logging in 1959, and after five full growing seasons (1963). Tree mortality was recorded annually. In the 4-acre control block, all trees above 3.5 inches d.b.h. also were tagged and recorded.

Stand Structure

Stand tables by species and 4-inch diameter classes were prepared for each cut block and for the control block as of 1958 and 1963, and analyzed statistically for differences between blocks.

Seedfall

Seedfall data were gathered annually for the first 5 years after cutting (1958-62). Cone counts and seeds caught in traps quantified seedfall.

Cone counts—All cones produced in the shelterwood cut blocks and control, except cones of incense-cedar, were counted each year using 7 x 35 binoculars. The number of cones observed was increased by a factor of 1.5 for ponderosa pine and white fir (Fowells and Schubert 1956) and by 1.6 for Douglas-fir. Cones of Douglas-fir are difficult to count because they are small, clustered, and often blend with the surrounding foliage. Because the count was taken during the short ripening period when cones are yellowish and counting is easiest, I chose a factor of 1.6 instead of 2 as used by Garman (1951). All sugar pine cones were seen readily.

Dissection of Douglas-fir cones revealed about 50 fully developed (sound) seeds in each. Ponderosa pine cones contain about 70 sound seeds per cone, white fir about 185, and sugar pine about 215 (Fowells and Schubert 1956).

Seed traps—In 1960, 18 seed traps, 1 foot square, were systematically arranged (random start) in each shelterwood block and the control block. This sampling intensity was tested for the seed crops produced in 1960, 1961, and 1962, and reflected the true proportion of sound seed ($p = 0.05$). The traps were emptied annually in winter and cleaned and checked in late summer.

Regeneration

For sampling, 30 circular milacre plots (each containing 4 m^2) for each shelterwood block and for the control block were arranged along three transects whose points of origin were randomly located. Each transect traversed a given slash disposal treatment in each block and consisted of 10 milacre plots. Every plot was visited in the spring, and all seedlings, both coniferous and hardwood, were recorded. At the first measurement in 1959 only those plants less than 4.5 feet (1.4 m) tall rated as "seedlings." Each clump of hardwood sprouts was recorded as one plant even though the individual sprouts per clump often were numerous. All new seedlings were marked to denote species and year of origin.

The effect of slash disposal treatment was tested by analysis of variance using transformed (arc-sine) stocking percentages. Separate analyses of variance tested initial (2-month-old) seedling stocking and established (26-month-old) seedling stocking for both ponderosa pine and the combined tolerant conifers. Significant differences were examined further by Tukey's test (Hamilton 1965).

Basal Area Growth

Growth increment (accretion) for the 5-year period 1959 through 1963 included the basal area growth added to all living trees greater than 3.5 inches d.b.h., and the growth added to trees that died during the measurement period. Basal area growth rates per tree for each shelterwood block were combined and averaged to form a composite block value when no significant differences between blocks were found.

RESULTS

After logging and slash disposal, a change in stand structure in the cut blocks was evident. And after 5 years, beneficial effects in productivity from cutting were noticeable in seedfall, amount of regeneration, and growth of the residual stand.

Stand Structure and Species Composition

Because statistical analyses of the stand tables for 1958 and 1963 showed no significant differences ($p = 0.05$) among cut blocks for species, data for all cut blocks were combined (*table 1*). Five years after cutting, however, stand structure had changed considerably. In the 3.5- to 20-inch (51-cm) diameter classes, the average cut block contained one-seventh the number of ponderosa pines in the control block, one-half of the incense-cedars, and one-sixth of the hardwoods. In the diameter classes above 20 inches d.b.h., the cut block contained one-third of the number of ponderosa pines in the control.

The reduction of trees in the cut blocks was accounted for as follows:

	Trees lost per acre (ha)
Cause of reduction:	
Cutting	57 (141)
Site preparation-slash disposal	131 (324)
Natural mortality	5 (12)
Total	193 (477)

Changes in basal area and stand volume were similar in magnitude. They indicate the intensity of this cutting method and the cultural practices that were applied. Stand basal area was reduced 68 percent to 88 ft^2/acre (20 m^2/ha). More than half the reduction occurred in the size classes above 20 inches. Volume decreased by 70 percent or 38,000 board feet per acre (217 m^3/ha). Nearly all of the remaining volume (16,000 fbm per acre or 91 m^3/ha) was in shelterwood trees.

Changes in the species composition of various stand strata varied widely (*table 2*). Relatively minor changes were realized in the small tree size class (trees 3.5 to 12 inches d.b.h.), where the proportion of Douglas-fir and sugar pine increased at the expense of incense-cedar and the hardwoods. In the medium tree size class (trees 12.1 to 20 inches d.b.h.) a major change resulted. Ponderosa pine was reduced by 30 percent whereas most of the other species gained. Only slight changes appeared in the large tree size class; sugar pine gained proportionally and Douglas-fir lost.

Natural mortality from 1958 to 1963 was evaluated for all species in the three size classes. In the smallest category an average of five trees per acre were lost: two of incense-cedar, and one each of Douglas-fir, white fir, and ponderosa pine. Windsnap was the leading cause of mortality, with delayed death from logging damage and unknown causes equally important in second place. Mortality from insects ranked next. None of the medium-sized trees died, because nearly all trees of this size were removed in logging or slash disposal. Only three large ponderosa pines in the entire shelterwood overstory of 192 trees were lost—the sole agent being the western pine beetle (*Dendroctonus brevicomis* Lec.). Virtually no hardwoods died. The overall effect of natural mortality on stand structure and species composition was small.

Natural mortality in the control differed markedly from that in the shelterwood blocks. Nearly twice as many trees per acre died; all three tree size classes were affected, and cause of death as related to species generally differed. In the small trees, the average per acre was one ponderosa pine killed by insects and six hardwoods killed by suppression. The western pine beetle also killed one medium-sized ponderosa pine and one large ponderosa pine per acre.

Table 1—*Stand table for composite shelterwood block before logging in 1958 and five years later, Challenge Experimental Forest, California*

Species	Trees per acre by diameter class (inches)[1]													
	3.5 to 8.0		8.1 to 12.0		12.1 to 16.0		16.1 to 20.0		20.1 to 30.0		30.1+		All classes	
	1958	1963	1958	1963	1958	1963	1958	1963	1958	1963	1958	1963	1958	1963
Conifers:														
Douglas-fir	29	8	17	10	8	2	3	0	4	1	3	1	64	22
Ponderosa pine	2	0	6	2	10	1	7	0	15	4	5	3	45	10
Sugar pine	1	0	1	1	1	0	1	0	1	1	1	1	6	3
White fir	6	2	3	1	1	0	1	0	1	1	0	0	12	4
Incense-cedar	52	11	12	5	3	1	1	0	1	0	0	0	69	17
All conifers	90	21	39	19	23	4	13	0	22	7	9	5	196	56
Hardwoods:														
California black oak	6	2	3	1	2	1	1	0	1	1	1	0	14	5
Tanoak	10	2	4	1	2	1	1	1	1	0	0	0	18	5
Pacific madrone	31	6	9	4	1	0	0	0	0	0	0	0	41	10
All hardwoods	47	10	16	6	5	2	2	1	2	1	1	0	73	20
All species	137	31	55	25	28	6	15	1	24	8	10	5	269	76

[1] Data include ingrowth into 1963 diameter classes.

Table 2–*Species composition by tree-size classes in shelterwood blocks before logging and 5 years later, Challenge Experimental Forest, California*

Size class and species	Before logging	After 5 years	Change
	Percent		
3.5 to 12 inches d.b.h.:			
Ponderosa pine	4	4	0
Sugar pine	1	3	+2
Douglas-fir	24	30	+6
White fir	5	6	+1
Incense-cedar	33	29	–4
Hardwoods	33	28	–5
12.1 to 20 inches d.b.h.:			
Ponderosa pine	41	11	–30
Sugar pine	3	5	+2
Douglas-fir	26	30	+4
White fir	5	3	–2
Incense-cedar	9	16	+7
Hardwoods	16	35	+19
20+ inches d.b.h.:			
Ponderosa pine	58	59	+1
Sugar pine	8	16	+8
Douglas-fir	19	12	–7
White fir	5	4	–1
Incense-cedar	3	0	–3
Hardwoods	7	9	+2

In the cut blocks, the most abundant ingrowth species were hardwoods, particularly tanoak and Pacific madrone. They constituted 41 percent of the new trees. Next was Douglas-fir (36 percent), followed by incense-cedar (14 percent), white fir (7 percent), sugar pine (1 percent), and ponderosa pine (1 percent). Altogether, ingrowth in the cut blocks averaged 6 trees per acre over the 5-year period.

In the control block, ingrowth averaged 16 trees per acre (40 per ha) of the same species, similarly ranked, as in the cut blocks.

Seedfall

Ponderosa pine produced a few cones in 1958 and a bumper seed crop in 1960. Douglas-fir bore cones in 1958, 1960, 1961, and 1962. Sugar pine yielded cones in 1960 and 1962. White fir produced a light cone crop in 1958, 1960, and 1962, and incense-cedar bore cones in 1960 and 1962. California black oak produced a bumper seed crop in 1958; Pacific madrone did the same in 1960. Tanoak yielded a few acorns nearly every year of the study.

The 1960 seed year was remarkable both for the amount of cones produced and for the number of species that bore them. Even small trees produced cones. The ponderosa pine crop was outstanding. Trees over 20 inches in diameter produced from 8 to 540 cones per tree, averaging 325. Trees 12 to 20 inches d.b.h. averaged 78 cones per tree in the range of 40 to 117, and trees smaller than 12 inches d.b.h. produced about 15 cones per tree in the range of 6 to 24.

Douglas-fir also produced a bountiful cone crop in 1960. Trees over 20 inches in diameter yielded an average of 987 cones per tree in a range of 2 to 3634. Trees 12 to 20 inches d.b.h. bore an average of 63 cones per tree in the range of 21 to 120, and trees less than 12 inches in diameter averaged 60 cones per tree in the range of 1 to 240.

Douglas-fir produced cones on smaller trees than did other species. For example, the smallest fruitful Douglas-fir was 3.6 inches (9 cm) in diameter and produced 21 cones. The smallest productive ponderosa pine was 11.2 inches (28 cm) d.b.h. and yielded 6 cones. This and the tendency to bear frequent light- to medium-cone crops is characteristic of Douglas-fir on the Experimental Forest.

Most cone production was from larger trees. For example, the proportion of the total crop produced by trees 20 inches d.b.h. and larger was as follows:

	Percent
Year and species:	
1958	
Ponderosa pine	100
1960	
Pondersoa pine	97
Sugar pine	100
Douglas-fir	80
White fir	100
1961	
Douglas-fir	67
1962	
Douglas-fir	84
White fir	100

Not only did trees in the largest diameter class contribute most to the total cone crop, but they also had the highest proportion of fruitful trees. This was true in both shelterwood and control blocks. In the shelterwood, however, a higher proportion of trees in nearly all diameter classes bore cones than in comparable classes in the control block:

Year, species, and diameter class (inches):	*Percent of trees which bore cones*	
	Shelterwood	*Control*
1960		
Ponderosa pine		
Under 12	19	14
12 to 20	77	52
Over 20	90	51
Douglas-fir		
Under 12	28	0
12 to 20	29	77
Over 20	95	88
1961		
Douglas-fir		
Under 12	3	1
12 to 20	11	6
Over 20	32	0
1962		
Douglas-fir		
Under 12	9	0
12 to 20	46	10
Over 20	86	75

The trend of higher cone production in the shelterwood cuttings, as opposed to the control, was even more manifest in terms of estimated seed from the cones:

Year and species:	*Estimated sound seed per acre*	
	Shelterwood	*Control*
1958		
Ponderosa pine	1,540	2,730
Douglas-fir	29,000	11,200
White fir	7,215	0
1959		
Ponderosa pine	350	0
1960		
Ponderosa pine	144,970	113,750
Sugar pine	35,905	645
Douglas-fir	95,550	83,100
White fir	5,920	555
1961		
Douglas-fir	2,100	2,000
1962		
Ponderosa pine	840	210
Sugar pine	1,398	0
Douglas-fir	31,200	21,000
White fir	9,250	93

The supremacy of seed production in shelterwood blocks over that in the control block is even better demonstrated for estimates of seed production from seed traps:

Year and species:	*Estimated sound seed per acre*	
	Shelterwood	*Control*
1960		
Ponderosa pine	110,110	12,100
Sugar pine	8,470	0
Douglas-fir	1,815	2,420
White fir	1,815	0
Incense-cedar	3,630	0
1962		
Douglas-fir	1,815	0
Incense-cedar	6,050	0
Total	133,705 (330,251 per ha)	14,520 (35,864 per ha)

Regeneration

The sampling plan encouraged year-by-year observation of the survival of individual seedlings. Mortality trends also were readily definable. Because new seedlings were 1 to 2 months old at the time of the yearly survey, most viable seeds had germinated, and seedling mortality generally was still low. Thus seedling abundance was at or near maximum at each survey.

Regeneration was evaluated by number of seedlings per acre and stocking percentage (percent of milacre plots having one or more seedlings). In this context, stocking percentage is a measure of how well the seedlings are distributed throughout the sampling area. High stocking percentages indicate good distribution; low percentages indicate either few seedlings or a clumpy distribution. Results were evaluated for individual species when possible, or for tolerant conifers (Douglas-fir, white fir, sugar pine, and incense-cedar as a group), hardwoods, and ponderosa pine.

The seed-to-seedling ratio often reflects the biological agents and environmental conditions that affect germination and early seedling survival. In this shelterwood cut, the ratio for ponderosa pine was 13:1—that is, for every 13 sound seeds that fell in the fall of 1960, one ponderosa pine seedling was tallied in the spring of 1961. In another study at the Challenge Experimental Forest where seedbeds were mostly bare mineral soil, and rodents were not controlled, 14 sound seeds produced one ponderosa pine seedling (McDonald 1966). Fowells and Schubert (1956) rated the seed-to-seedling ratio at 40:1 for ponderosa pine on seedbeds having a medium-to-heavy cover of vegetation, litter, or logging debris, and several hundred to one with no seedbed preparation or rodent control measures. Therefore, in the present shelterwood cutting, the ratio of ponderosa pine seed to seedlings was low.

Seed-to-seedling ratios for other seed crops during 1960 or as noted were:

Sugar pine	39:1
White fir	17:1
Douglas-fir	10:1
Douglas-fir (1962)	10:1
Incense-cedar	8:1
Incense-cedar (1962)	11:1

Initial ponderosa pine stocking was almost the same for all three slash disposal methods and no significant differences prevailed. Two years later, however, ponderosa pine seedling stocking was significantly worse ($p = 0.05$) where the lop-and-scatter method was employed. Delayed piling was best, but results did not differ significantly from those of the pile-after-logging treatment.

Initial stocking of tolerant conifer seedlings, 2 months old, was best for the delayed slash disposal treatment, and differed significantly ($p = 0.05$) from that of the after-logging treatment, but not significantly from stocking in the lop-and-scatter treatment. These relationships were found to be consistent for 26-month-old seedlings as well.

The effect of slash disposal treatment on hardwood regeneration also was examined. Numerous hardwood seedlings became established where the slash had been piled, but sprouts excelled where the slash was lopped and scattered.

Mineral soil seedbeds favor ponderosa pine (Curtis and Lynch 1957; Fowells and Stark 1965) more than other species. Ponderosa pine seeds readily germinate and large numbers of seedlings result, but many soon die from drought and overcrowding. On high sites, some seedlings quickly become dominant and suppress others (*fig. 2*). High mortality of young seedlings is part of the natural thinning process and is not deleterious; 3700 5-year-old seedlings per acre or 9139 per ha (*fig. 3*) are more than enough to satisfy the most ambitious management goals. In fact, seedling mortality in this instance may be considered beneficial as seedling numbers are reduced greatly without impairing distribution.

Early survival of tolerant conifer seedlings decreased less sharply than that of ponderosa pine, and after 5 years numbered 600 per acre (1482 per ha) (*fig. 3*). Survival for the second wave of seedlings was less than for the first, probably because vegetative competition had increased greatly. Of the tolerant conifers, survival of sugar pine and incense-cedar was best, white fir was intermediate, and Douglas-fir was poor.

Reproduction of California black oak, tanoak, and Pacific madrone is usually a combination of sprouts and seedlings. Logging and slash disposal eliminated

Figure 2—Some of these 3-year-old ponderosa pine seedlings on a mineral soil seedbed are already expressing dominance.

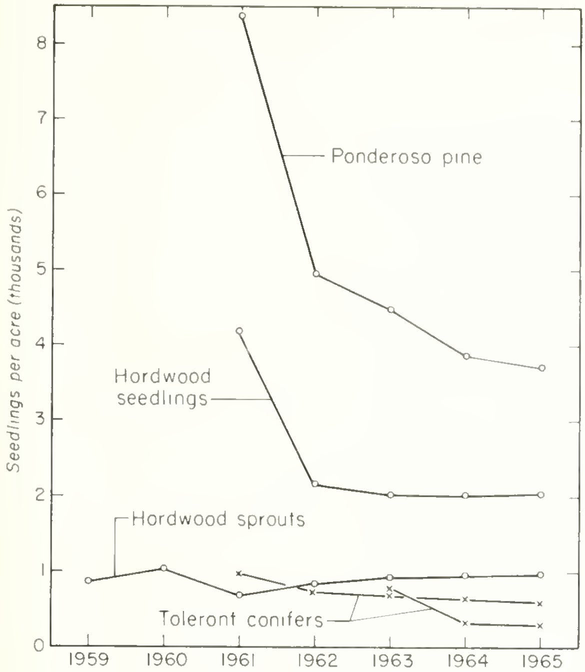


Figure 3—Variation between species is evident in seedling survival patterns for the composite shelterwood block.

many small hardwood trees, saplings, and seedlings. Others were broken off at ground line or severely damaged. These promptly sprouted from root crowns. Other small seedlings died back to the root crown after logging because of shock from increased sunlight. Most of these also sprouted. Together the sprouts numbered about 1000 per acre (2470 per ha; *fig. 3*).

Hardwood seedlings of one species or another became established nearly every year. The bumper seed crops of Pacific madrone and California black oak, plus the near-annual yield of tanoak acorns, resulted in many seedlings. Distribution of these seedlings was clumpy, ranging from as many as 70 per milacre plot to none. On some plots they decreased rapidly. When hardwood seedlings numbered 20 or more per milacre, the intense competition drastically reduced their numbers (*fig. 3*). On plots containing only 1 to 5 seedlings, almost none died. Altogether, hardwood seedlings averaged about 2000 per acre (4940 per ha) after 5 years and were second only to ponderosa pine.

Relative to the control, seedling establishment and survival favored the shelterwood cutting, both for number of seedlings and seedling distribution, as shown in the data for 1963 (1960 seed crop):

	Milacre stocking, (percent)		*Seedlings per acre*	
	Shelterwood	*Control*	*Shelterwood*	*Control*
Species:				
Ponderosa pine	76	10	4495	250
Sugar pine	8	0	120	0
Douglas-fir	3	3	25	60
White fir	7	0	85	0
Incense-cedar	11	0	500	0
Hardwoods	44	23	2025	560

Growth of Residual Stand

An important consideration in any partial cutting method is the growth of the residual trees. In this operation the 12 shelterwood trees per acre were ideally situated to maximize growth. The site is high, and they were the most vigorous trees in the stand—tall, full-crowned, and thrifty. They possessed the photosynthetic area necessary to respond quickly to their new environment. Cutting removed virtually all competition and allowed them almost unlimited growing space with increased available water, nutrients, and sunlight. The 63 trees per acre (156 per ha) in the small- and medium-size classes probably benefited from the cut, but not to the extent of the larger trees. First, their distribution was clumpy, as thickets of them were deliberately avoided by the bulldozer. Second, they needed time to develop and respond to their new environment.

Understory basal area growth generally was distributed according to the abundance of each species, as indicated in the stand table (*table 1*). Douglas-fir contributed most to total accretion, showing twice the growth of incense-cedar, the next largest contributor. Pacific madrone, which ranked third in abundance, also was third in growth. Ponderosa pine contributed less than any other conifer or hardwood in the understory. In the large tree size class, however, ponderosa pine was most abundant and contributed most to basal area growth. Sugar pine and Douglas-fir ranked second and third in abundance and held the same rank in their contribution to total accretion.

Ranking of growth rates over all diameter classes showed sugar pine best, followed by ponderosa pine and Douglas-fir, white fir, California black oak, and tanoak. Pacific madrone and incense-cedar grew slowest (*table 3*).

Ranking of growth rates over all diameter classes in the control indicated Douglas-fir best, followed by ponderosa pine, incense-cedar, and hardwoods, with sugar pine and white fir too few to be tested.

Table 3—*Comparative basal area growth rates in composite shelterwood (S) and control (C) blocks, by species and diameter classes, 1959-63, Challenge Experimental Forest, California*

Species	Tree growth[1] by diameter class (inches)											
	3.5 to 8.0		8.1 to 12.0		12.1 to 16.0		16.1 to 20.0		20.1 to 30.0		30.1+	
	S	C	S	C	S	C	S	C	S	C	S	C
	Square feet per tree											
Conifers:												
Ponderosa pine	–	0.01	0.04	0.02	0.11	0.07	–	0.17	0.46	0.27	0.58	0.42
Sugar pine	–	–	.17	–	–	–	–	–	.74	–	1.15	.92
Douglas-fir	0.06	.03	.12	.08	.17	.16	–	.26	.40	.45	.58	.60
White fir	.04	.03	.09	.12	–	–	–	–	.38	.42	–	–
Incense-cedar	.02	.01	.08	.04	.11	.06	–	.12	–	–	–	–
All conifers	.04	.02	.10	.06	.16	.11	–	.18	.49	.29	.64	.46
Hardwoods:												
California black oak	.03	.02	.07	.04	.11	.09	–	.08	.32	.10	–	–
Tanoak	.06	.03	.09	.07	.10	.07	.11	.11	–	–	–	–
Pacific madrone	.05	.02	.08	.06	.06	.05	–	.05	–	–	–	–
All hardwoods	.04	.02	.08	.06	.09	.07	.11	.08	.32	.10	–	–
All species	.04	.02	.09	.06	.13	.09	.11	.16	.45	.29	.64	.46

[1] Dash indicates no trees present.

Analysis of variance showed significant differences ($p = 0.05$) in the overall growth rate between the composite cut block and control. Individual ponderosa pines, incense-cedars, and hardwoods in the cut blocks outgrew their counterparts in the control in nearly all diameter classes. Notably, Douglas-fir grew at about the same rate in both the shelterwood cut and control and thus was relatively insensitive to release, at least during the study period.

In the composite shelterwood block, accretion during the study period amounted to 4.60 ft^2 of basal area per acre for trees 3.5 to 20.0 inches in diameter. In the control, it was 10.43 ft^2/acre for trees of similar size. Obviously, trees in the cut blocks grew faster than trees in the control, as the control contained 3½ times as many trees (63 against 220 per acre). And trees over 20.0 inches in diameter outgrew their counterparts in the control (13 trees per acre and 5.52 ft^2 of basal area per acre in the cut against 23 trees and 7.32 ft^2/acre in the control).

In heavy partial cuts such as this shelterwood cutting, leave trees are subjected to a sudden and drastic "opening up" of the stand, and an increased risk of mortality from sun, wind, and insects. Trees that die after logging seldom are salvaged before the shelterwood is removed, and the entire basal area of each is lost. Increment accruing between the time of initial measurement and the tree's death also is lost.

In the cut area, nearly 2.45 ft^2 of basal area per acre was lost to natural causes, half in the small- and half in the medium-sized tree classes. About 5.76 ft^2 were lost in the control. Accretion on trees that died in the cut and control amounted to 0.03- and 0.1-ft^2 per acre, respectively, during the 1959-63 period.

When a tree becomes ingrowth, its initial basal area plus any growth from time of entry to end of the measurement period are recorded. Accretion on ingrowth into the 3.5- to 8-inch diameter class in the control was over twice that of the cut blocks (1.35 ft^2/acre against 0.55 ft^2/acre), which is logical, as there were 2½ times as many ingrowth trees in the control.

Net growth for all species, consisting of ingrowth plus accretion minus mortality, for the 5-year period was:

	Cut	*Control*
	ft²/acre	
Net growth:		
Accretion	+10.12	+17.75
Accretion on trees that died	+.03	+.09
Ingrowth	+.55	+1.35
Mortality	−2.45	−5.76
Accretion on trees that died	−.03	−.09
Net	8.22	13.34
	(1.9 m^2/ha)	(3.1 m^2/ha)

DISCUSSION AND CONCLUSIONS

The typical young-growth forest on sites of high quality often contains too many trees, growing too slowly. Also, it often contains a disproportionate number of small trees of less desirable species. In fact, 66 percent of the trees in the small tree size class on the Experimental Forest are hardwoods and incense-cedars. The Forest also contains the more desirable sugar pine, Douglas-fir, and white fir, which in this size class number 2, 46, and 9 per acre, respectively (5, 114, and 22 per ha). Although, in the shelterwood block, some of these desirable trees, particularly Douglas-fir, were older suppressed trees of low growth potential, many were younger and had a high potential for increased growth.

Logically, a forest manager would want to reduce the number of less valuable hardwoods and incense-cedars and proportionally increase the more valuable pines and firs. Because these desirable species serve as a potential interim monetary return after the shelterwood is removed and before the reproduction grows to maturity, the manager also wants to know what the species proportions will be after logging, and the potential for survival and growth.

To increase the numbers of these desirable species, then, and because it is expensive to remove and dispose of this size of tree, 24 sugar pine, white fir, and Douglas-fir per acre (59 per ha) remained after logging. They represented a slight proportional gain in relation to other species in this size class. Only two of these trees per acre (five per ha) died from natural causes in the next 5 years. Two incense-cedars and one ponderosa pine per acre also died. The combined loss was less than that gained from ingrowth.

The only other natural mortality was that of ponderosa pine in the overstory shelterwood, and this was minimal. Of a total of 192 overstory trees, only 3 were lost in 5 years. Therefore, if the landowner wants to retain his shelterwood for some time, losses from natural mortality need not keep him from doing so.

Overall, the effect of shelterwood cutting and slash disposal on stand structure and species composition was to eliminate the 14- to 20-inch d.b.h. conifer component of the stand. A secondary effect was to reduce greatly the number of trees in both the largest and smallest tree size classes while only slightly changing the species composition of either.

In the control block, both the ponderosa pine overstory and the hardwood and tolerant conifer understory remained essentially intact. In this environment, natural mortality was decidedly different. Different species died from different causes. Suppression was the primary cause of death to sun-loving California black oak and ponderosa pine.

Ingrowth is of special interest because it indicates the trend of species composition. Shade tolerant tanoak, Pacific madrone, Douglas-fir, incense-cedar, and white fir compose fully 98 percent of ingrowth. Ponderosa pine and sugar pine amount to only 2 percent. In the undisturbed control, the forest of the future will be much different from the present one. It will consist of increasing proportions of shade-loving conifers and hardwoods. But in the cut blocks, the new environment created by cutting assures that the future forest will closely resemble the present one.

The discrepancy between estimates of seed production, which were lower from traps than from cone counts, has several probable causes. Douglas-fir, for example, is capable of producing viable seed as early as age 20, and young trees frequently bear a few cones. In these young trees, many seeds reach full size but are undeveloped internally because of lack of pollen (Allen 1942). Roy (1960) noted that larger trees also produce many apparently fully developed, but empty seed, owing to lack of fertilization. Differences between trap and cone counts also are caused by insects, chiefly the cone moth larvae (*Barbara colfaxiana* [Kearf.]) and the gall midge (*Contarinia* spp.), which either destroy seeds or cause them to adhere to the cone scales.

The discrepancy between counts applies to a lesser extent for white fir (Keen 1958) and other species, and is well illustrated in this study by the 1961 Douglas-fir and 1962 white fir seed crops. Estimates of 2100 and 9250 sound seeds were made from the two cone counts, respectively, but no seeds appeared in seed traps nor were any seedlings counted in regeneration surveys. Sound seeds from seed trap catches obviously give the best estimate of conifer seed production.

Overall, the proportion of sound seed was low. Even on this high site with near-ideal growing conditions, the young-growth trees in the shelterwood blocks produced only 49 percent sound seed. Ponderosa pine was highest in percentage of sound seed, but even in a bumper year this was only 58 percent.

The comparison of sound seed in the cut blocks and control emphasized the reproductive potential of the shelterwood method, not only for quantity of seed, but also for the larger number of species that produced it. In 3 years (1960-62), seven of the nine seed crops yielded by various conifer species resulted in sound seed in the shelterwood cutting, whereas only two species (ponderosa pine and Douglas-fir in 1960) produced sound seed in the control (as estimated from seed traps). The sound seed ratio of shelterwood to control was 9.2:1.

The probability that cone and seed production were stimulated by the shelterwood cut (a phenomenon noted by Williamson [1973] for Douglas-fir in the Oregon Cascades) is important: trees that would otherwise produce medium or even light seed crops of the various species could suffice for establishing adequate regeneration on prepared ground. Also, the short interval between adequate seed crops increases the applicability of the shelterwood method.

Ultimately, the success of a cutting method depends on establishing enough well-distributed seedlings of the desired species to meet management goals. This result is usually assured by proper choice of cutting method, adequate preparatory steps before the regeneration phase, and a certain amount of good luck.

Seed-to-seedling ratios are a good index to the success or failure of establishing a new crop of trees. In this trial, seed-to-seedling ratios in the shelterwood ranged from 8:1 for incense-cedar to 39:1 for sugar pine, and relative to other studies, demonstrated high seed efficiency for all conifer species. Of course, the slash-disposal-site-preparation operations greatly influenced seedling survival. Other reasons for the high seed efficiencies could have been favorable weather and low deer mice (*Peromyscus maniculatus*) populations. During the critical months of February through May 1960, precipitation was 10.5 inches more than Challenge's 30-year average, and temperatures were below normal. A rodent survey in the spring of 1961 indicated only 1.5 mice per acre (3.7 per ha) in shelterwood and nearby compartments.

The slash - disposal-site - preparation treatments helped immeasurably to reduce slash, bare the soil, lessen vegetative competition, and disturb the habitat of seed-eating rodents. Where the piling was delayed until late summer, the just-loosened soil not only helped cover the seeds, but facilitated faster and deeper root penetration by seedlings.

The initial stocking in the delayed-piling treatment was best for tolerant conifers and hardwood seedlings, and later for ponderosa pines. Tolerant conifer stocking consistently was poorest for the pile-immediately-after-logging treatment. In blocks where slash was piled in 1958 and seed germinated in spring 1961, this delay, and perhaps the crusting or recompaction of the soil, apparently was deleterious to root penetration by the tolerant conifers. Lack of scarification in the lop-and-scatter treatment left hardwood rootstocks intact. This favored hardwood sprouts—not enough were eliminated. Under such a treatment, Douglas-fir, incense-cedar, and other conifer seedlings are likely to be overtopped by the burgeoning hardwood sprouts.

Of the three slash-disposal treatments tested, piling just before a major seedcrop is best if the maximum number of seedlings is desired. Lop-and-scatter treatment, however, is 10 to 15 times less expensive.

The environment in the shelterwood strikingly favored regeneration, except for Douglas-fir, which regenerated better in the dense shaded control block (the seed-to-seedling ratio in the control was 9:1). In contrast, the seed-to-seedling ratio for ponderosa pine in the control (28:1) was more than twice that of the shelterwood. Also, ponderosa pine seedling mortality was 96 percent higher in the control.

Survival is only half the regeneration story. The other half is seedling height growth. Hardwood seedlings grow slowly; sprouts have a much faster rate of height growth. In the shelterwood, sprouts and white fir seedlings are tallest, followed by ponderosa pine and sugar pine. With time, some of the slower-growing Douglas-fir and incense-cedar seedlings may fall behind, but because of their shade tolerance, they will persist and may even prosper.

Growth of the merchantable shelterwood types and their response after cutting is often of major interest because it can determine the number of trees that should be left in subsequent applications of the method. Without exception, the shelterwood trees were tall, full-crowned, and seemingly vigorous.

Nearly every species of most sizes responded to the shelterwood cut, and in basal area growth for the first 5 years after cutting, surpassed their counterparts in the control. Large Douglas-firs and white firs were exceptions, however, as they grew slightly better in the control. Of the larger shelterwood trees, sugar pine had the best basal area growth rate and responded more to cutting than any other species. Ponderosa pine rated next best, followed by Douglas-fir. As a whole, accretion was small, however, and was gained at the expense of the established seedlings. For this reason, and because small seedlings are least susceptible to logging damage, the shelterwood overstory should be removed early.

The shelterwood can be removed efficiently and with minor seedling losses. When 2 to 10 seed trees per acre (5 to 25 per ha) were removed carefully at Challenge, stocking of 29-month old seedlings fell by only 3.8 percent and density by 212 seedlings per acre (524 per ha; McDonald 1969a). Skidding production increased by 38 percent or 1247 board feet per hour over that in the original seedtree cutting (McDonald 1969b).

By 1965, revegetation of the shelterwood compartments was nearly complete and the forest of the future could be predicted. Ponderosa pine regeneration was abundant and well distributed; so were hardwood sprouts and seedlings. Throughout, an admixture of tolerant sugar pine, incense-cedar, white fir, and Douglas-fir seedlings stocked the ground. Also, residual saplings and poles, mostly Douglas-fir and incense-cedar, bolstered the tolerant conifer component of the stand.

The new timber stand will differ relatively little from the old. Ponderosa pine will be most abundant and again will dominate in the overstory. Tolerant conifers also will be present. A few hardwoods, especially California black oak, will reach into the overstory as well. Most hardwoods, however, will again be relegated to understory positions. Before the shelterwood cut, the forest was progressing toward the more tolerant mixed-conifer climax in which ponderosa pine is a lesser component (*table 1*). Ponderosa pine was not reproducing itself and the species composition of the stand was tending toward more and more tolerant conifers and hardwoods. Cutting interrupted this process, and allowed succession to begin anew with ponderosa pine. Thus the forest our children will enjoy will closely resemble that of our fathers.

LITERATURE CITED

Allen, George S.
1942. Parthenocarpy, parthenogenesis, and self-sterility of Douglas-fir. J. For. 40:642-644.

Arvanitis, L. G., J. Lindquist, and M. Palley.
1964. Site index curves for even-aged young-growth ponderosa pine of the westside Sierra Nevada. Calif. Forest Prod. 35, 8 p.

Benzie, J. W.
1963. Cutting methods in mixed-conifer swamps, Upper Michigan. USDA Forest Serv. Res. Paper LS-4, 24 p. Lake States Forest Exp. Stn., St. Paul, Minn.

Croker, Thomas C., Jr.
1969. Natural regeneration systems for longleaf pine. Forest Farmer 28(13):6-7, 16-18.

Curtis, J. D., and D. W. Lynch.
1957. Silvics of ponderosa pine. USDA Forest Serv. Misc. Publ. 12, 37 p., illus. Intermountain Forest and Range Exp. Stn., Ogden, Utah.

Day, R. J.
1970. Shelterwood felling in late successional stands in Alberta's Rocky Mountain subalpine forest. For. Chron. 46(5):380-386.

Fowells, H. A., and G. H. Schubert.
1956. Seed crops of forest trees in the pine region of California. U.S. Dep. Agric. Tech. Bull. 1150, 48 p., illus.

Fowells, H. A., and N. B. Stark.
1965. Natural regeneration in relation to environment in the mixed-conifer forest type of California. USDA Forest Serv. Res. Paper PSW-24, 14 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Garman, E. H.
1951. Seed production by conifers in the coastal region of British Columbia related to dissemination and regeneration. B.C. Forest Serv. Tech. Bull. 35, 47 p.

Hagner, Stig.
1962. Natural regeneration under shelterwood stands. An analysis of the method of regeneration, its potentialities and limitations in forest management in central northern Sweden. Medd. Skogsforskn. Inst. Stockholm 52(4):224-253.

Hamilton, Martin A.
1965. Multiple comparison procedures. USDA Forest Serv. Res. Note RM-44, 12 p. Rocky Mountain Forest and Range Exp. Stn., Fort Collins, Colo.

Hawley, R. C.
1946. The practice of silviculture. 5th ed. 354 p., illus. John Wiley and Sons, Inc., New York.

Hawley, R. C., and R. T. Clapp.
1942. Growing of white pine on the Yale Forest near Keene, New Hampshire. Yale Univ. Sch. For. Bull. 48, 44 p.

Herman, F. R.
1962. Shelterwood cutting to see if young-growth hemlock can be regenerated by series of successive cuttings. Pulp and Paper 36(12):61-63.

Keen, F. P.
1958. Cone and seed insects of western forest trees. U.S. Dep. Agric. Tech. Bull. 1169, 168 p., illus.

Lees, J. C.
1964. A test of harvest cutting methods in Alberta's spruce-aspen forest. Can. Dep. For. Publ. 1042, 19 p.

McDonald, Philip M.
1966. Seed fall and regeneration from a group selection cut–first year results. USDA Forest Serv. Res. Note PSW-113, 6 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

McDonald, Philip M.
1969a. Ponderosa pine seed-tree removal reduces stocking only slightly. J. For. 67(4):226-228.

McDonald, Philip M.
1969b. Harvesting costs and production rates for seed-tree removal in young-growth, mixed-conifer stands. J. For. 67(9):628-630.

Pacific Logger and Lumberman
1971. [Shelterwood cutting in a mixed-conifer stand in northeastern Washington.] Pacific Logger and Lumberman 19(6):8-9.

Rickard, W. M., Jay M. Hughes, and Carl A. Newport

1967. Economic evaluation and choice in old-growth Douglas-fir landscape management. USDA Forest Serv. Res. Paper PNW-49, 33 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

Roe, Arthur L.
1955. Cutting practices in Montana larch-Douglas-fir. Northwest Sci. 29:23-34.

Roy, Douglass F.
1960. Douglas-fir seed dispersal in northwestern California. USDA Forest Serv. Tech. Paper 49, 22 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Shearer, Raymond C.
1971. Silvicultural systems in western larch forests. J. For. 69:732-735.

Smith, D. N.
1951. The influence of seedbed conditions on the regeneration of eastern white pine. Conn. Agric. Exp. Stn. Bull. 545, 6 p.

Spurr, Stephen H.
1956. German silvicultural systems. Forest Sci. 2(1):75-78.

Starker, T. J.
1970. Douglas-fir shelterwood. J. For. 68:393.

Sundahl, William E.
1966. Slash and litter weight after clearcut logging in two young-growth timber stands. USDA Forest Serv. Res. Note PSW-124, 5 p. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Westveld, Marinus.
1938. Silvicultural treatment of spruce stands in northeastern United States. J. For. 36:944-950.

Williamson, R. L.
1973. Results of shelterwood harvesting of Douglas-fir in the Cascades of western Oregon. USDA Forest Serv. Res. Paper PNW-161, 13 p., illus. Pacific Northwest Forest and Range Exp. Stn., Portland, Oreg.

McDonald, Philip M.

1976. **Shelterwood cutting in a young-growth, mixed-conifer stand in north central California.** USDA Forest Serv. Res. Paper PSW-117, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A two-stage shelterwood cutting, at 12 trees per acre, with site preparation, enhanced seedfall, regeneration, and residual growth at the Challenge Experimental Forest, north central California. Shelterwood trees produced 9.2 times more seed than trees in the control. Ponderosa pine regeneration numbered about 3700 seedlings per acre (9139 per ha) and tolerant conifers 600 seedlings (1482 per ha) after 5 years. Hardwood seedlings and sprouts also were abundant. Basal area growth rates for all species in nearly all diameter classes were greater in the shelterwood than in the control. The shelterwood cutting method is recommended for use in young-growth, mixed-conifer stands.

Oxford: 231:187x466(794):221.23

Retrieval Terms: shelterwood systems; natural regeneration; slash disposal; site preparation; Challenge Experimental Forest; young-growth forestry; mixed conifer stands.

McDonald, Philip M.

1976. **Shelterwood cutting in a young-growth, mixed-conifer stand in north central California.** USDA Forest Serv. Res. Paper PSW-117, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A two-stage shelterwood cutting, at 12 trees per acre, with site preparation, enhanced seedfall, regeneration, and residual growth at the Challenge Experimental Forest, north central California. Shelterwood trees produced 9.2 times more seed than trees in the control. Ponderosa pine regeneration numbered about 3700 seedlings per acre (9139 per ha) and tolerant conifers 600 seedlings (1482 per ha) after 5 years. Hardwood seedlings and sprouts also were abundant. Basal area growth rates for all species in nearly all diameter classes were greater in the shelterwood than in the control. The shelterwood cutting method is recommended for use in young-growth, mixed-conifer stands.

Oxford: 231:187x466(794):221.23

Retrieval Terms: shelterwood systems; natural regeneration; slash disposal; site preparation; Challenge Experimental Forest; young-growth forestry; mixed conifer stands.

McDonald, Philip M.

1976. **Shelterwood cutting in a young-growth, mixed-conifer stand in north central California.** USDA Forest Serv. Res. Paper PSW-117, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A two-stage shelterwood cutting, at 12 trees per acre, with site preparation, enhanced seedfall, regeneration, and residual growth at the Challenge Experimental Forest, north central California. Shelterwood trees produced 9.2 times more seed than trees in the control. Ponderosa pine regeneration numbered about 3700 seedlings per acre (9139 per ha) and tolerant conifers 600 seedlings (1482 per ha) after 5 years. Hardwood seedlings and sprouts also were abundant. Basal area growth rates for all species in nearly all diameter classes were greater in the shelterwood than in the control. The shelterwood cutting method is recommended for use in young-growth, mixed-conifer stands.

Oxford: 231:187x466(794):221.23

Retrieval Terms: shelterwood systems; natural regeneration; slash disposal; site preparation; Challenge Experimental Forest; young-growth forestry; mixed conifer stands.

McDonald, Philip M.

1976. **Shelterwood cutting in a young-growth, mixed-conifer stand in north central California.** USDA Forest Serv. Res. Paper PSW-117, 16 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

A two-stage shelterwood cutting, at 12 trees per acre, with site preparation, enhanced seedfall, regeneration, and residual growth at the Challenge Experimental Forest, north central California. Shelterwood trees produced 9.2 times more seed than trees in the control. Ponderosa pine regeneration numbered about 3700 seedlings per acre (9139 per ha) and tolerant conifers 600 seedlings (1482 per ha) after 5 years. Hardwood seedlings and sprouts also were abundant. Basal area growth rates for all species in nearly all diameter classes were greater in the shelterwood than in the control. The shelterwood cutting method is recommended for use in young-growth, mixed-conifer stands.

Oxford: 231:187x466(794):221.23

Retrieval Terms: shelterwood systems; natural regeneration; slash disposal; site preparation; Challenge Experimental Forest; young-growth forestry; mixed conifer stands.

85