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Growth of Historical Sitka Spruce Plantations at Unalaska Bay, Alaska

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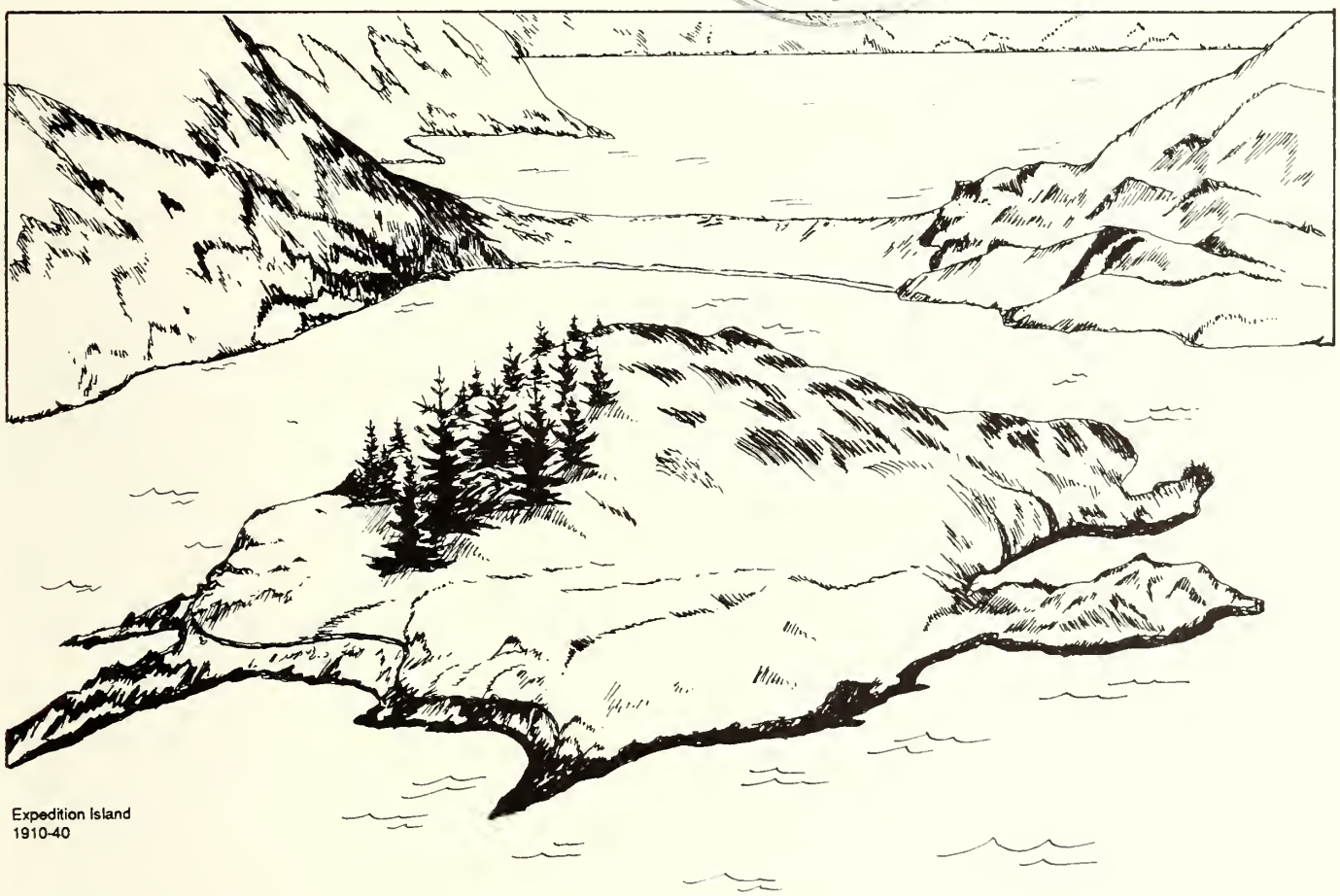

Expedition Island
1910-40

Authors

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Abstract

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Sitka spruce (*Picea sitchensis* (Bong.) Carr.) grew an estimated 37 cubic feet of stemwood per acre per year (2.6 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) in remnant World War II plantations on Amaknak Island and 38 cubic feet of stemwood per acre per year (2.7 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) in an early 19th century grove on Expedition Island, 520 miles (837 km) southwest of natural tree limits in Alaska. Trees in fairly dense plots on Amaknak Island averaged 7 inches (18 cm) in diameter at breast height (d.b.h.) and 21 feet (6.5 m) tall on sheltered sites. The largest trees in the Expedition Island grove were 21.5 inches (54.6 cm) in d.b.h. and 55 feet (16.8 m) tall.

Growth and quality of Sitka spruce on productive sites near Unalaska Bay should be adequate for subsistence wood production, amenity of barren landscapes around homes and villages, soil enhancement, wind breaks, and wildlife habitat. Small outplantings of Sitka spruce and other species on sheltered sites from sea level to 820 feet (250 m) in elevation are recommended to determine tree limits, superior seed sources, wood yield, and forest association with native flora and fauna and to refine afforestation methods.

Keywords: Sitka spruce (*Picea sitchensis* (Bong.) Carr.), tree limits, provenance, growth and yield, historical plantations, Unalaska Bay, Alaska.

Contents

Introduction

The Aleutian Islands extend 1,100 miles (1770 km) in a southwest arc from the Alaska Peninsula to the Commander Islands of East Asia and separate the Bering Sea from the North Pacific Ocean. The most striking feature of the Aleutian Islands is the treeless landscape. Absence of forests was an obstacle to colonization of the region during the 18th and 19th centuries. The nearest forests were more than 500 nautical miles (926 km) northeast of the Aleutian Islands and wood was needed for firewood,[1] construction of houses and other buildings, and repair of ships. Driftwood was substituted for timber in building construction and other uses. Early 19th century Russian settlers transplanted Sitka spruce (*Picea sitchensis* (Bong.) Carr.) from southeast Alaska or Kodiak Island to Unalaska and neighboring islands (fig. 1). Success of the plantations[2] attracted the attention of visiting botanists, and many additional attempts were made to establish trees in the Aleutian Islands during the 19th and 20th centuries. Thousands of seedlings from Kodiak, southeast Alaska, and the contiguous 48 States were transplanted during World War II to reduce the monotony of the landscape, beautify dwellings, and control erosion of disturbed soils (Bruce and Court 1945). Sitka spruce was the most successful species, and many seedlings transplanted during the 19th century and World War II survived on sheltered sites in Unalaska Bay. Trees transplanted during the early 19th century produced natural regeneration on disturbed sites after World War II. A dense 19th century grove on Expedition Island and several small World War II plantations on Amaknak Island provided an opportunity to measure tree size and growth. The measurements were used to estimate the growth and yield of fully stocked plantations on productive sites in Unalaska Bay.

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[1] Wood was needed for fuel to supplement whale and seal oil. Tree seed of unknown species was sent to Grigorii G. Potorochin, manager of The Russian-American Company on Kodiak by Chief Manager of the Russian-American Company, Captain-Lieutenant Cavalier Leontii A. Hagemeister of Novo-Arkhangel'sk (Sitka, Alaska) in 1818 with instructions to "please send the enclosed seeds to Unalaska. The trees grow quickly and in two years can serve as firewood. Order the manager to plant some of them immediately" (Pierce 1984). This planting would have been mentioned by Father Veniaminov (1840) if it had been successful. Fischer (1841) recommended afforestation of *Populus* spp. for "obtaining fuel sooner." The wood was known to be inferior to "much slower growing tree species . . . for other household uses." Fuel became an increasing problem in native villages that abandoned "sod barabara" homes for Euro-American style frame houses (McMillan, Neville J., community worker for the U.S. Department of the Interior, Office of Indian Affairs, Field Service, Noatak, Alaska, in a letter to Charles G. Burdick, assistant director, Alaska Civilian Conservation Corps, Juneau, Alaska, February 6, 1938. 2 p.). Frame houses were above the ground and difficult to heat. Transition to Euro-American housing styles began in 1805 with orders from Nikolai P. Rezanov of the Russian-American Company (Veniaminov 1984).

[2] Although the first transplanted seedlings grew slowly, survival was apparently high until late in the 19th century. Ivan Veniaminov (1984), the first priest at Unalaska, observed in 1834 that the most vigorous trees planted on Amaknak Island in about 1805 were taller than 7 feet (2 m) and were 18 inches (46 cm) in circumference at their base after 29 years. Upward growth was observable at about 22 years, however, and increased dramatically between 24 and 29 years of age.

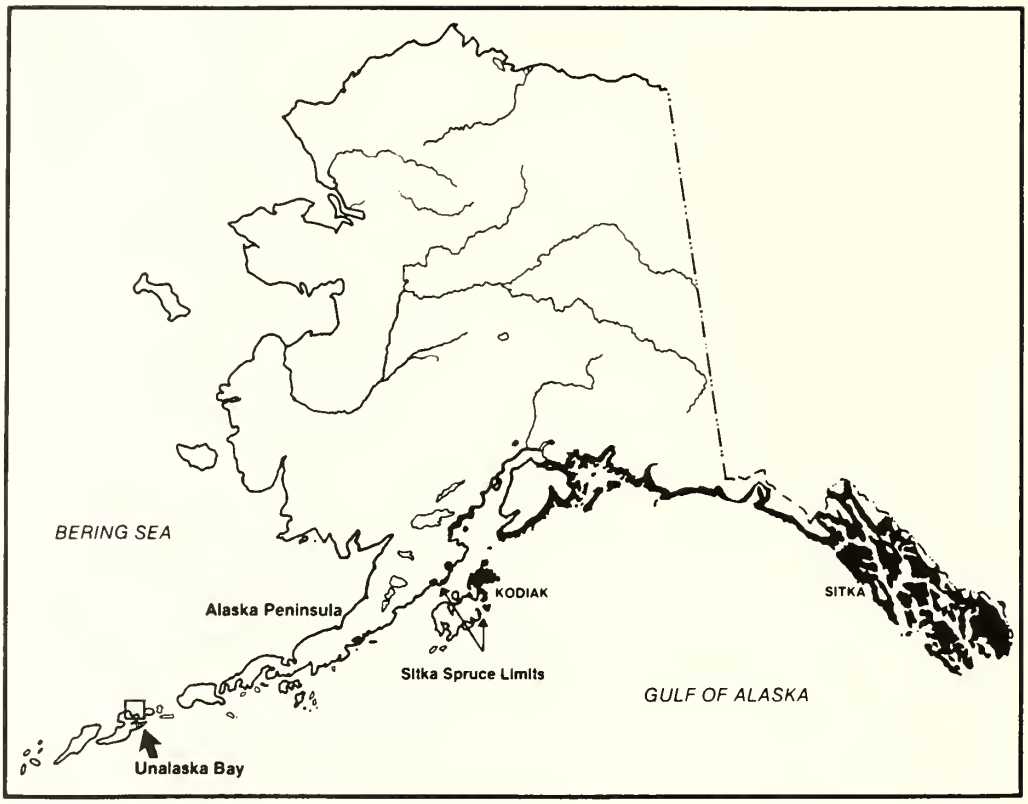

Figure 1—Unalaska Bay and the natural range of Sitka spruce in Alaska.

Description of the Study Areas

Three fairly dense plots of Sitka spruce at about 50 feet (15 m) above mean sea level (m.s.l.) on Amaknak Island and a small grove of Sitka spruce at about 20 feet (6 m) above m.s.l. on Expedition Island were selected for the study (fig. 2). Amaknak and Expedition Islands provide shelter for Iliuliuk Harbor at latitude 53°53′ N. and longitude 166°33′ W. in Unalaska Bay, which is 520 miles (837 km) southwest of natural Sitka spruce limits on the Alaska Peninsula (fig. 1).

The climate of Unalaska Bay is cold maritime. Seasonal temperatures have a small range; long periods of wind, drizzling rain, and fog are common. Mean annual temperature from 1917 to 1941 at Dutch Harbor on Amaknak Island was 40.4 °F (4.7 °C) (U.S. Weather Bureau 1917-41). Mean January and July temperatures were, respectively, 31.9 and 51.3 °F (-0.1 and 10.7 °C) during this period. Temperature extremes were 5 and 80 °F (-15 and 27 °C). The four warmest months (June to September) averaged 50 °F (10 °C), and the frost-free growing season (> 32 °F or 0 °C) varied from about 120 to 190 days between early May and November. The growing season averaged 160 days and accumulated 1,351 growing degree-days above 41 °F (750 growing degree-days above 5 °C) annually from 1930 to 1934 (Farr and Hard 1987). Annual precipitation averaged 58 inches (1470 mm) and was greatest in fall and winter during the 25 years of record. Frequency and velocity of prevailing wind in Unalaska Bay have not been recorded by the U.S. Weather Bureau.

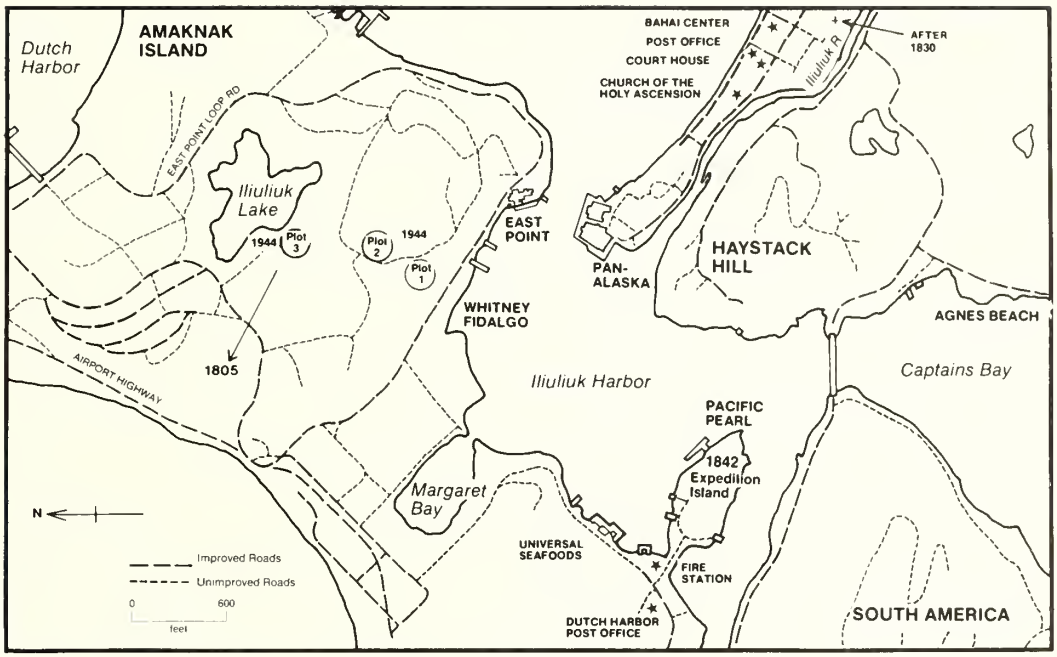

Figure 2—Location of Sitka spruce plantations on Expedition and Amaknak Islands, Unalaska Bay, Alaska.

Winter is warmer and summer is cooler at Dutch Harbor than at the limit of Sitka spruce forests on Kodiak Island. Mean annual temperature for the 38 years before 1940 at Kodiak was 40.7 °F (4.8 °C) (U.S. Weather Bureau 1940). Mean January and July temperatures were 30.0 °F (-1.1 °C) and 54.3 °F (12.4 °C) (U.S. Weather Bureau 1940). Mean annual precipitation was 62 inches (1577 mm) during this period. The growing season at Kodiak averages about 155 days and has 285 more growing degree-days F (150 growing degree-days C) than the growing season at Dutch Harbor.

Native vegetation at the planting sites was mainly meadow associations of grasses, sedges, and herbs as described by Tatewaki and Kobayashi (1934). The flora at plot 1 were dominated by lyme grass (*Elymus* sp.). Soils were volcanic in origin, finely textured, rich in organic matter, and sufficiently deep for rapid tree growth.

Trees in plots 1 and 2 on Amaknak Island were planted in a small draw and appeared partially sheltered from strong winds (fig. 3). The crowns of several trees in plot 1 had not closed, and the plot was quite open. Plot 2 was quite dense. Plot 3 was on a bench above Iliuliuk Lake and was protected by a ridge to the southwest. This plot contained six wide-crown trees with dense foliage. Trees on Expedition Island were planted on a south aspect near the crest of a low ridge bisecting the island (fig. 4).

Figure 3—Plot 1 as viewed from the east on June 1, 1987. The trees were probably transplanted as seedlings from the understory of Sitka spruce forests on Afognak or Kodiak Island in 1944. Foliage produced in 1985 and 1986 was consumed by a bud moth, *Zeiraphera* sp.

Figure 4—A 1910 view of Expedition Island and the early 19th century grove of Sitka spruce from Haystack Hill, Unalaska Island. Photo courtesy of Alaska and Polar Regions Department, University of Alaska Fairbanks, Archives #78-4-106, Boaz Collection.

Trees measured on Amaknak Island were planted during World War II and were estimated to be 43 years old.[3] Source of the trees is unknown, but they most likely were wild stock from Kodiak or southeast Alaska. Trees on Expedition Island were planted after 1840. The source and planting date are unknown. The trees were probably planted as seed or transplanted as seedlings from the understories of forests at either Sitka or Kodiak. Age of the grove was estimated to be 145 years at the end of 1986.[4]

Methods

Boundaries of the three plots on Amaknak Island and the grove on Expedition Island were measured to the nearest foot (0.3 m) on June 1 and 2, 1987. Plot boundaries on Amaknak Island were determined by the edge of the tree crowns. Boundaries of the Expedition Island grove extended about 10 feet (3 m) under the crowns of trees on the south side and about the same distance outside the tree crowns on the north side. The location of each tree was plotted on field maps (fig. 5). Area of each plot and the Expedition Island grove was estimated from a grid overlay of the field maps.

Trees were measured to 0.1 cm in diameter at breast height (d.b.h.) (4.5 feet or 1.37 m). Tree heights were measured to 0.5 feet (15 cm) with a Relascope (trees 1-21, Expedition Island) and Haga altimeter percentage scales at a horizontal distance of 50 feet.[5]

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[3] The U.S. Army Headquarters for the defense of Alaska under command of Lieutenant General Simon B. Buckner, Jr. ordered World War II commanders at military posts in the Aleutian Islands and at Cold Bay on the Alaska Peninsula to plant trees in small groups during autumn 1944. Instructions were prepared for lifting wild seedlings from Alaska forests, balling the roots, and watering the stock during shipment to prevent desiccation. The seedlings were to be planted at an average spacing of 4 feet (1.2 m) on sites with wind protection, productive soils, and favorable exposure to light. It is not known if the orders were carried out, or if the trees that date from World War II in Unalaska Bay were planted before autumn 1944. Locating and lifting wild seedlings were costly, and plans were made in 1944 for growing 125,000, 2-2 seedlings annually in a nursery at Kodiak.

[4] The earliest likely planting date on Expedition Island is 1842. Father Veniaminov requested instructions for introducing trees to Unalaska from O.B. Fischer (1841), a "member of the Society for the Encouragement of Forestry." The priest did this while in St. Petersburg, Russia, from 1839 to 1841. In September 1841, Father Veniaminov, now Bishop Innokentii of the Russian Church, returned to Sitka, Alaska, from St. Petersburg and visited Unalaska for about 6 weeks starting on May 27, 1842. The evidence we have for this planting date is circumstantial but may be confirmed when Veniaminov's letters to family and friends are translated. The close spacing and the several multiple-stemmed trees with apparent stump grafts indicate that the Expedition Island grove may have been planted with seed in cleared 1- by 1-archine (71.1-cm) spots at 2-archine spacing as prescribed by Fischer (1841). (*Archine* [also *arshin*] is a Russian unit of linear measure equivalent to 28 inches.)

[5] The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.

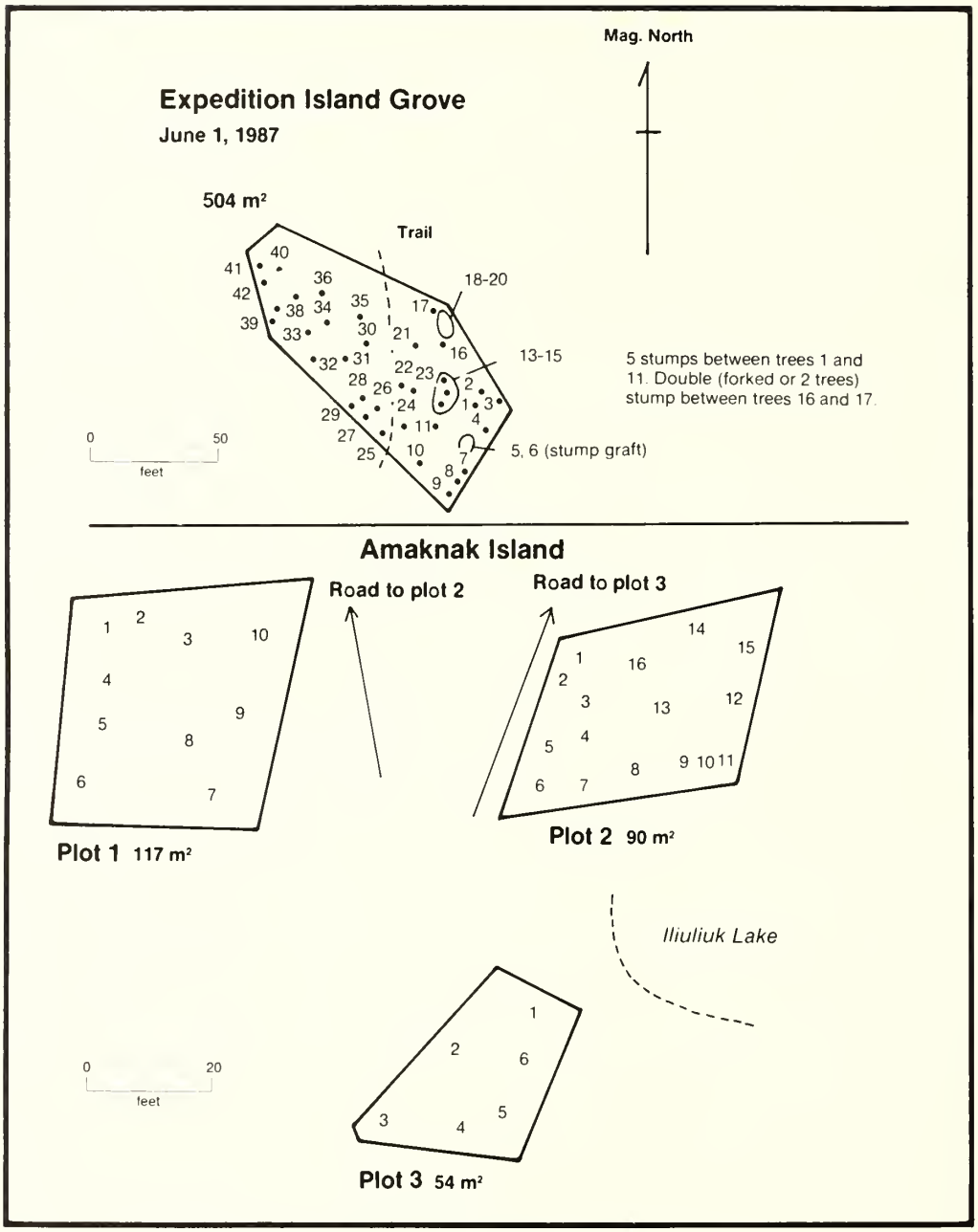

Figure 5—Distribution of trees in the Expedition Island grove and in the Amaknak Island plots on June 1-2, 1987.

Basal area (cross-section area of the stem at d.b.h.), stem volume outside bark, and wood volume inside bark were estimated from d.b.h. and height measurements for each tree. Volumes were estimated by using the geometric formula for a cone:

$V = 1/12\ \pi\ D^2H$,

where, V = volume in cubic centimeters, D = stem diameter at ground level in centimeters, and H = stem (tree) height in centimeters.

Diameter of each tree at ground level was extrapolated from d.b.h. and tree height. Double bark thickness was estimated as follows:

D.b.h. (cm)	Double bark thickness (cm)
<10	0.5
10.1-25	1.0
25.1-40	1.5
40.1-55	2.0

Estimated double bark thickness and corresponding bark volume agreed closely with bark thickness and percentage of bark volumes reported for Sitka spruce in 2-inch (5-cm) d.b.h. classes from 4 to 20 inches (10 to 50 cm) (Hamilton 1975). Bark volumes range from 12 to 22 percent of total stem volume for most species (Bell and others 1984), but Sitka spruce has thin bark. Basal area and wood volume were reported by unit area.

Results

Trees in the Expedition Island grove averaged 12.9 inches (33 cm) d.b.h. and 40 feet (12.1 m) tall. Basal area averaged 148 square inches (957 cm^2) per tree (table 1; table 6, appendix). The largest tree was 21.5 inches (54.6 cm) d.b.h. and had 52 cubic feet (1.5 m^3) stem volume, including bark, and 49 cubic feet (1.4 m^3) wood volume. The tallest tree was 55 feet (16.8 m). The grove consisted of 42 trees with a basal area of 43.2 square feet on 0.125 acre (4.0 m^2 on 0.05 ha). Stocking averaged 337 trees and 347 square feet basal area per acre (833 trees and 80 m^2 basal area per ha).

The grove contained an estimated 685 cubic feet (18 m^3) stemwood volume. Estimated bark volume was 8.75 percent of total stem volume. Stems grew at an estimated rate of 41.5 cubic feet per acre per year (2.9 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) (table 2). Estimated growth of stem wood was 38 cubic feet per acre per year (2.7 $m^3 \cdot ha^{-1} \cdot yr^{-1}$).

Trees in plots on Amaknak Island averaged 7 inches (18 cm) d.b.h. and 21 feet (6.5 m) tall. The largest tree was in plot 1. It measured 12 inches (31 cm) d.b.h. and 29 feet (8.8 m) tall (table 3, appendix). Stocking ranged from 346 (plot 1) to 720 (plot 2) trees per acre (855 to 1,777 trees per ha). Basal area ranged from 136 (plot 3) to 175 (plot 2) square feet per acre (31 to 40 m^2/ha) (table 1).

Stemwood volumes averaged 1,610 cubic feet per acre (113 m^3/ha) for all plots (table 2). Estimated bark volume ranged from 10.1 percent of total stem volume for plot 1 to 10.9 percent for plot 2. Stems grew at an average rate of 42 cubic feet per acre per year (2.9 $m^3 \cdot ha^{-1} \cdot yr^{-1}$), of which an estimated 37 cubic feet (2.6 m^3) was wood.

Table 1—Characteristics of Sitka spruce plots on Amaknak and Expedition Islands, Alaska, 1987

Location and plot number	Number of trees	Area		Trees per unit area		Average diameter		Average height		Basal area	
		ft^2	m^2	*acre*	*ha*	*in*	*cm*	*ft*	*m*	ft^2/*acre*	m/ha^2
Amaknak Island:											
1	10	1,259	117	346	855	8.6	21.9	23.8	7.3	157	36
2	16	967	90	720	1,777	6.5	16.5	21.1	6.4	175	40
3	6	583	54	447	1,111	6.1	15.5	18.0	5.5	136	31
Expedition Island grove	42	5,425	504	337	833	13.0	32.9	39.8	12.1	347	80

Table 2—Estimated age, volume, and mean annual growth per unit area of well-stocked Sitka spruce plots on Amaknak and Expedition Islands, Alaska, 1987

Location and plot number	Estimated age	Estimated volume				Estimated growth			
		Outside bark		Inside bark		Outside bark		Inside bark	
		ft^3/*acre*	m^3/*ha*	ft^3/*acre*	m^3/*ha*	$ft^3 \cdot acre^{-1} \cdot yr^{-1}$	$m^3 \cdot ha^{-1} \cdot yr^{-1}$	$ft^3 \cdot acre^{-1} \cdot yr^{-1}$	$m^3 \cdot ha^{-1} \cdot yr^{-1}$
Amaknak Island:									
1	43	1,896	133	1,704	119	44.1	3.1	39.6	2.8
2	43	2,060	144	1,826	128	47.9	3.3	42.5	3.0
3	43	1,440	101	1,299	91	33.5	2.3	30.2	2.1
Mean		1,799	126	1,610	113	41.8	2.9	37.4	2.6
Standard deviation		321	22	276	19	7.5	0.5	6.4	0.5
Expedition Island grove	145	6,023	422	5,500	385	41.5	2.9	37.9	2.7

Discussion

The results show that survival and wood production of Sitka spruce on sheltered sites in Unalaska Bay are adequate for subsistence purposes[6] (fig. 6). Tree quality and growth may be marginal, however, for commercial use by Alaska's economic standards. Commercial forests in Alaska must grow at least 20 cubic feet of industrial wood per acre annually (1.4 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) (Hutchison 1967). Growth exceeded commercial standards, but stem form and large branches may reduce quality and recovery of manufactured products.

Growth and yield of Sitka spruce forests on marginal habitats have not been studied in Alaska. Forty-year-old stands of Sitka spruce and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) in southeast Alaska grow 69 cubic feet of stemwood per acre per year (4.8 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) on sites with an index class of 70 feet (21 m) in height in 100 years (Taylor 1934). Growth of 40-year-old stands (as extrapolated from Taylor's data for site index classes from 70 to 40 feet [21 to 12 m]) decreased from 11 to 9 cubic feet per acre per year (0.8 to 0.6 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) and was 39 cubic feet per acre per year (2.7 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) for site index 40. Maximum growth for natural Sitka spruce and western hemlock stands on sites with an index of 70 was achieved at 75 years and was 75 cubic feet per acre per year (5.2 $m^3 \cdot ha^{-1} \cdot yr^{-1}$).

[6] Subsistence, as defined in Title 8, Section 803, of the 1980 Alaska National Interest Lands Conservation Act, "is the customary and traditional uses by rural Alaska residents of wild renewable resources for direct personal or family consumption, as food, shelter, fuel, clothing, tools, or transportation...for barter or sharing for personal or family consumption and for customary trade."

Figure 6—Interior view of the early 19th century Expedition Island grove on June 8, 1985. Quality and wood volume of most trees are satisfactory for subsistence use. Photo courtesy of Frank Lockyear, ReTree International, Wilsonville, Oregon.

On severe sites, trees benefit from mutual shelter afforded by close spacing and large plantations (Low 1987). Trees were planted in small groups on Amaknak Island, and potential growth per unit area of extensive well-stocked Sitka spruce plantations may be underestimated. Trees in the interior of plots 1 and 2 averaged 34 and 47 percent more volume, respectively, than trees on the plot boundaries. Shelter from near neighbors was absent on one or more sides of the border trees of plots 1 and 2 and of all trees in plot 3. On mild sites, growth per unit area as estimated from small plantations may be inflated, however. Use of tree crowns as boundaries may underestimate the area occupied by roots and the benefits of full sunlight. Border trees of the Expedition Island grove averaged 12.8 percent more stemwood than the interior trees. When 10 feet (1,830 ft^2 [170 m^2]) were added to the southern boundaries of the grove to compensate for favorable edge effects, basal area and estimated growth per unit area were reduced by 25 percent. Growth of stemwood on Expedition Island may be as much as 9.5 cubic feet per acre (0.7 m^3/ha) less than estimated in table 2.

Estimated growth of Sitka spruce in Unalaska Bay was comparable to that of spruce in Iceland, where growth rates of 25-year-old plantations range from 7 to 28 cubic feet per acre per year (0.5-2.0 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) (Bloendal and others 1986). Iceland is actively developing forests of introduced conifers to replace nearly 7.4 million acres (3.0 million ha) of native downy birch (*Betula pubescens* Ehrh.) woodlands destroyed by centuries of overharvest and sheep grazing. About 840,000 acres (340,000 ha) under 820 feet (250 m) above m.s.l., or 3 percent of the total land area of Iceland, is suitable for wood production. An additional 1.4 million acres (580 000 ha) could be reforested for soil protection and recreation. The climate and soils of Iceland and Unalaska are similar. Mean January, July, and annual temperatures at Reykjavik in southwest Iceland are, respectively, 31, 52, and 41 °F (-0.5, 11, and 5 °C) (Magnusson and Bjoernsson 1978). Average temperatures are about 1.8 °F (1 °C) colder at Akureyri in northern Iceland. Mean annual precipitation ranges from 15 to 78 inches (400 to 2000 mm). On the most productive sites, 30- to 45-year-old Siberian larch (*Larix sibirica* Ledeb.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud.) plantations are growing from 42 to 100 cubic feet per acre per year (3-7 $m^3 \cdot ha^{-1} \cdot yr^{-1}$). Pure stands under short rotations may produce more wood than Sitka spruce on cold dry sites in Iceland and the Aleutian Islands.

Sitka spruce grows faster in the Falkland Islands (South Atlantic Ocean) than in Unalaska Bay and Iceland. Trees in a 58-year-old plantation of mixed Sitka and Yeddo spruce (*Picea jezoensis* (Sieb. & Zucc.) Carr.) on a productive site on the north coast of West Falkland Island averaged 8.3 inches (21 cm) in d.b.h. and 50 feet (15.5 m) tall (Low 1986). Stocking averaged 1,255 stems and 475 square feet (44 m^2) of basal area per acre (3,100 stems and 109 m^2 of basal area/ha). The tallest tree was 55 feet (17 m), and trees on the edge of the plantation exceeded 24 inches (60 cm) in d.b.h. Climatic data are unavailable for West Falkland Island, but winters are warmer and summers are cooler at Stanley, East Falkland Island, than in Unalaska Bay and Iceland. Temperatures at Stanley for the four warmest months (December-March) average 47 °F (8.4 °C) (U.S. Weather Bureau 1980) and are about 3 °F (1.7 °C) colder than the four warmest months at Dutch Harbor, Alaska. February, the warmest month, averages only 48 °F (9 °C). The barren landscape, constant wind, and angle of sun in the Falkland Islands (lat. 51° to 52°30" S.) are similar to conditions in the Aleutian Islands (lat. 51°30" to 55° N.).

Sitka spruce on Amaknak and Expedition Islands have survived since the early 19th century and may become naturalized if the trees and their offspring are not disturbed. Natural regeneration from at least two seed crops between 1950 and 1970 is well established on exposed soils near the Expedition Island grove[7] (fig. 7). The energy requirements for production of viable Sitka spruce seed have not been studied, but 670 to 700 growing degree-days (°C) are needed for pollination, fertilization, and 75-percent embryo growth of white spruce (*Picea glauca* (Moench) Voss) seed in interior Alaska (Zasada 1988), and 625 growing degree-days (°C) are needed for germination after pollination[8] (Zasada 1973). Scotch pine (*Pinus sylvestris* L.) requires about 950 growing degree-days (°C) for seed maturation in northern Finland (Sarvas 1968).

The grove on Expedition Island was crowded (table 1), and mortality has increased in recent years. The grove contained 59 trees before 1944, 47 living of 53 total trees in 1958, and 44 living trees in 1977. The surviving trees averaged 11.3 inches (29 cm) in d.b.h. in 1958, 12.5 inches (32 cm) in d.b.h. and 39 feet (11.9 m) tall in 1977,[9] and 12.9 inches (33 cm) in d.b.h. and 39.8 feet (12.1 m) tall in this survey. Heat and smoke emitted from a nearby cannery caused tree vigor to decline rapidly and mortality to increase sharply from 1984 to 1986. Only 29 of 42 trees were living in 1987 (table 6, appendix).

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[7] Rear Admiral Harley D. Nygren, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, "noticed, for the first time, a prolific growth of young seedlings" on a visit to the Expedition Island grove in 1958 (letter to Dr. A.E. Helmers, director, Institute of Northern Forestry, Juneau, Alaska, 1970). Seedlings were not observed on visits in 1948 and 1953. Von Johnson, forester, Bureau of Land Management, Anchorage, Alaska, reported "numerous seedlings averaging 5" high" from the 1805 outplanting on Amaknak Island in 1958 but failed to report the seedlings on Expedition Island. A cross section through the root collar (epicotyl) of a seedling sampled in 1986 showed that it germinated in 1969. It probably germinated from a seed produced in 1968.

[8] White spruce in interior Alaska require 120 to 150 growing degree-days for pollen maturation, flowering, and pollination; about 625 growing degree-days for germination after pollination; and about 200 growing degree-days to complete the maturation process after seed is capable of germination. Thus, 900 to 950 growing degree-days may be necessary for maximum seed vigor of cold-climate species.

[9] Report by Von J. Johnson to Area Fire Control Officer, Bureau of Land Management, Anchorage, Alaska, October 27, 1958. 3 p. Field notes by Richard W. Tindall, Tindall Enterprises, Forestry Consultants, Anchorage, AK 99504. April 26, 1977. 1 p.

Figure 7—Natural regeneration in the foreground of the early 19th century Expedition Island grove on May 21, 1986. The regeneration is 15 to 35 years old. The grove and its offspring sustained injury from heat and smoke in the exhaust of a nearby cannery.

Defoliation may have reduced vigor and growth of trees sampled on Amaknak Island. Larvae of a bud moth, *Zeiraphera* sp. (USDA, Forest Service 1983) completely defoliated shoots of many trees in 1985 and 1986. Persistence of the epidemic suggests that climate and provenance of Sitka spruce favor the insect (fig. 3). Although the trees grew slowly (tables 3-5, appendix), tree form was not always characteristic of Sitka spruce on Kodiak Island (fig. 8). Populations on Kodiak Island are at the species limit for southwest Alaska and appear genetically uniform. Phenotypes are short, stocky, and broad-crowned. Height growth of Sitka spruce populations from Kodiak Island is inferior to that of other populations from Alaska in nursery[10] and field trials (Benedikz 1982). Heavy infections of ectomycorrhizal fungi were found on rootlets sampled near plot 1 and from plot 2 on June 2, 1987.[11] Mycorrhizal associations may benefit Sitka spruce in these cold soils.

Recommendations

Forest development is of major interest to land managers in southwest Alaska. Trees are planted to protect dwellings and gardens from wind, prevent soil erosion, enhance soil development, produce wood, and relieve the barren landscape around homes and villages. Large afforestation projects similar to those planned during World War II (see footnote 3) are impractical if such things as site variation, adapted species and provenances, site preparation requirements, and planting stock standards are not known. Several outplantings of 1 to 5 acres each (0.5-2.0 ha) are therefore recommended to determine tree growth and survival at a wide range of productive sites from sea level to altitudinal tree limits. Altitudinal tree limit is the upper limit of tree growth-form and is estimated to be about 820 feet (250 m) above m.s.l. on Unalaska Island. Altitudinal tree limits lie between the upper limit of closed-crown stands at "the forest limit" and a zone of shrubby (krummholz) growth-form at "the species limit." This definition is described for northern (arctic) tree limits by Hustich

[10] Alden, John; Loopstra, Elaine. 1988. Establishment of trees and shrubs on Naval Air Station, Adak Island, Alaska-1987. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 39 p. Progress report. On file with: Institute of Northern Forestry, 308 Tanana Drive, Fairbanks, AK 99775-5500.

[11] Personal communication, Dr. Paul Hennon, Forest Pathologist, USDA Forest Service, Forestry Sciences Laboratory, P.O. Box 20909, Juneau, AK 99802.

(1979) and Payette (1983). Altitude tree limits are more precisely described in Norway: a "tree line" is where scattered trees are less than 8.2 feet (2.5 m) tall, and the "timber line" is where at least 5 trees per acre (12 trees per ha) are not less than 9.8 feet tall (3 m) (Braathe 1977). Mean temperature of the four warmest months at timberline for Norway spruce (*Picea abies* (L.) Karst.) in southeast Norway (lat. 60° N.) is 48.7 °F (9.3 °C). Mean temperature of the four warmest months near forest limits of Sitka spruce on Kodiak Island (lat. 57°48′ N.) is 52.2 °F (11.2 °C).

Promising genotypes of adapted species and provenances from future trials and the historical plantations could be propagated in an arboretum for breeding to improve the growth and yield of future generations. Arboretums preserve adapted germplasm, educate, provide amenity of barren landscapes, afford comparisons among species and provenances at the same site, and reveal forest and native flora-fauna relations. Arboretums should be established at sheltered sites with productive soils and roads for easy access. An arboretum west of Iliuliuk Lake on Amaknak Island could include trees in plot 3, additional Sitka spruce planted during World War II, and 1985 outplantings of several other potential species.

Relative wind severity and suitability of sites for small plantations and arboretums can be assessed with standard tatter flags (Lines and Howell 1963, McAdam 1980, Savill 1974). The rate of flag tatter depends on exposure (wind, distance to the sea, rain, elevation, and so forth) and is related to tree growth. Extensive site preparation and disturbance of the tundra before planting is not recommended. Soils formed from recent volcanic ash lack clay and erode rapidly when exposed to wind and water. In addition, soils freeze and thaw continuously in winter climates with diurnal temperatures that fluctuate around 32 °F (0 °C). Surface vegetation and organic matter insulate underlying soils and prevent the freezing and thawing action from lifting recently planted seedlings. Afforestation attempts at Adak Island, Alaska, demonstrated that frost heaving of seedlings planted in exposed soils is a major cause of plantation failure.[12]

One-year-old planting stock of boreal species is small and usually fails from competition with native vegetation on unprepared sites. Planting stock for unprepared sites in southwest Alaska must be vigorous, 18 to 24 inches (45 to 60 cm) tall and physiologically preconditioned for a subarctic maritime climate. Seedlings started in a greenhouse should be transplanted to a sheltered bed at Unalaska or preconditioned in a regulated environment for 2-3 years before outplanting. Seedlings planted at a spacing of 5 feet (1.5 m) or less on exposed sites benefit from mutual shelter as they grow older. Harsh microsites with trees that fail to survive should be replanted immediately to maintain fully stocked plantations. Our data from plots on Amaknak Island indicate that basal areas of 150 to 200 square feet per acre (35 to 46 m^2/ha) may be optimum for yield of Sitka spruce on sheltered sites. Individual trees may grow faster and larger with less basal area on productive sites, however. Trees on exposed sites may benefit from the additional shelter of 200 to 400 square feet of basal area per acre (46 to 92 m^2/ha). Field trials are needed to determine stocking levels for maximum growth and yield of Sitka spruce.

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[12] Alden, John; Loopstra, Elaine. 1986. Establishment of trees and shrubs on Naval Air Station, Adak Island, Alaska-1985-1986. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 20 p. plus appendix. Progress report. On file with: Institute of Northern Forestry, 308 Tanana Drive, Fairbanks, AK 99775-5500.

Conclusions

Sitka spruce is capable of long survival and natural regeneration on productive sites in Unalaska Bay, Alaska. Trees planted during the early 19th century have produced natural regeneration and may become naturalized. Sitka spruce can be grown for amenity of barren landscapes, wind protection, soil stabilization and enhancement, wildlife habitat, and wood production. Small outplantings are recommended at a wide range of sheltered sites to determine planting stock requirements, best species and provenances, stocking, growth rates, and altitudinal tree limits.

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Appendix

Individual tree measurements, stocking, and area of the Expedition Island grove and Amaknak Island plots.

Table 3—Number, diameter at breast height, basal area, height, and volume of the trees in the grove on Expedition Island[a]

Tree number	D.b.h. outside bark	Basal area outside bark	Height[b]		Estimated volume		Remarks
					Outside bark	Inside bark	
	cm	*cm²*	*ft*	*m*	*m³*	*m³*	
1	54.6	2,341	52	15.8	1.4822	1.3756	Upturned branch to 54 ft
2	30.0	707	47.5	14.5	.4162	.3756	Dead
3	42.7	1,432	51.5	15.7	.8994	.8171	Dead
4	43.4	1,479	53	16.2	.9511	.8654	
5	31.2	765	39	11.9	.3870	.3507	Stump graft
6	36.6	1,052	51.5	15.7	.6608	.6078	Epicormic branches-poor form
7	47.8	1,795	50	15.2	1.1006	1.0104	Large limbs on south side
8	35.1	968	44	13.4	.5366	.4917	
9	35.1	968	32.5	9.9	.4303	.3943	Measured to upturned branch—abnormal bole
10	43.9	1,514	37	11.3	.7372	.6716	Upturned branch to 40 ft
11	36.3	1,035	55	16.8	.6858	.6303	
12	22.4	394	43	13.1	.2147	.1960	Dying
13	15.7	194	38.5	11.7	.0971	.0851	Dead
14	22.1	384	47	14.3	.2240	.2042	Forked at 10 ft
15	19.8	308	43.5	13.2	.1693	.1526	
16	27.2	581	38	11.6	.2886	.2576	Dead
17	33.8	897	42	12.8	.4802	.4385	Dead
18	32.8	845	35	10.7	.3955	.3602	Dead—multiple forks
19	33.8	897	39.5	12.0	.4585	.4187	Dead
20	32.5	829	14.5	4.4	.2567	.2335	Dead (broken top)
21	37.6	1,110	51	15.5	.6919	.6203	
22	21.1	350	41	12.5	.1837	.1667	Dying
23	22.9	411	48	14.6	.2445	.2236	Dead
24	33.8	897	42	12.8	.4805	.4385	Upturned branch to 49 ft
25	22	380	25	7.6	.1435	.1308	Dead top—multiple forks
26	30.5	731	40	12.2	.3769	.3407	
27	40	1,257	30	9.1	.5299	.4909	Upturned branches to 33 ft
28	25.5	511	45	13.7	.2882	.2553	
29	51.5	2,083	50	15.2	1.2776	1.1803	
30	32	1,310	46.5	14.2	.7072	.6396	Multiple tops and stems from base
	21.5[c]		39[c]	11.9[c]			Dead
	13.5[c]		28[c]	8.5[c]			Dead
31	50.5	2,003	47	14.3	1.1694	1.0786	
32	34	908	31	9.4	.3912	.3574	
33	33	855	46	14.0	.4910	.4474	
34	27.5	594	38	11.6	.2950	.2637	Dead—forked top
35	22.5	744	32	9.8	.2366	.2156	Dead—forked at d.b.h.
	21[c]		22[c]	6.7[c]			Dead—double top
36	27.5	594	27	8.2	.2345	.2096	Dead—double top
37	27	988	41	12.5	.4170	.3707	Forked at d.b.h.
	23[c]		31[c]	9.4[c]			Dead
38	33	855	37.5	11.4	.4207	.3833	
39	20.5	599	17[c]	5.2[c]	.1953	.1758	Multiple stems below d.b.h.
	18.5[c]		19.5	5.9			May be 2-tree graft
40	43	1,452	39	11.9	.7351	.6683	Multiple top above d.b.h.
41	48	1,810	30	9.1	.7631	.7008	
42	21.5	363	14	4.3	.1120	.1018	Dead
Mean	32.9	957	39.8	12.1	.5061	.4618	

[a] Dimensions of Expedition Island grove. Area: 5,422.2 feet² (504 m²). Trees/acre: 337 (833/ha). Mean spacing: 11.4 feet (3.5 m).

[b] Height of stem (bole). Upturned branches excluded from volume and height measurements.

[c] Values of the smallest stems were excluded from the means.

Table 4—Number, diameter at breast height, basal area, height, and volume of the trees in plot 1 on Amaknak Island[a]

Tree number	D.b.h. outside bark	Basal area outside bark	Height		Estimated volume: Outside bark	Estimated volume: Inside bark	Remarks[b]
	cm	*cm²*	*ft*	*m*	*m³*	*m³*	
1	19.4	296	21	6.4	0.1021	0.0918	
2	14	154	21	6.4	.0532	.0458	
3	25.5	511	25	7.6	.1928	.1708	
4	19.8	308	25	7.6	.1163	.1048	
5	31.1	760	29	8.8	.3135	.2840	
6	23.7	441	28.5	8.7	.1801	.1652	
7	24.8	483	16.5	5.0	.1530	.1409	
8	19.3	395	27.5	8.4	.1429	.1296	Forked at 2 ft
	11.4[c]		24.5[c]	7.5[c]			
9	25.3	503	25	7.6	.1898	.1680	
10	15.8	363	19.5	5.9	.1076	.0941	Forked at 2 ft
	14.6[c]		20.5[c]	6.2[c]			
Mean	21.9	421	23.8	7.3	.1551	.1395	

[a] Dimensions of plot 1. Area: 1,258.6 feet2 (117 m^2). Trees/acre: 346 (855 ha). Mean spacing: 11.2 feet (3.4 m).

[b] Most trees were defoliated by *Zeiraphera* sp. in 1986.

[c] Value of the smallest stem was excluded from the plot means.

Table 5—Number, diameter at breast height, basal area, height, and volume of the trees in plot 2 on Amaknak Island[a]

Tree number	D.b.h. outside bark	Basal area outside bark	Height		Estimated volume: Outside bark	Estimated volume: Inside bark
	cm	*cm²*	*ft*	*m*	*m³*	*m³*
1	6.8	36	14	4.3	0.0112	0.0096
2	16.5	214	19.5	5.9	.0715	.0631
3	19.8	308	25.5	7.8	.1176	.1060
4	20.8	340	25	7.6	.1283	.1162
5	11	95	17	5.2	.0303	.0251
6	17	227	18	5.5	.0737	.0653
7	13.5	143	16.5	5.0	.0453	.0389
8	20.9	343	25.5	7.8	.1310	.1188
9	16.9	224	23	7.0	.0810	.0717
10	17.9	252	22.5	6.8	.0898	.0801
11	16.2	206	19	5.6	.0683	.0601
12	18.5	269	25.5	7.8	.1026	.0918
13	16.5	214	23.5	7.2	.0782	.0689
14	20.6	333	21	6.4	.1151	.1042
15	11.8	109	17	5.2	.0349	.0292
16	19.8	308	25.5	7.8	.1176	.1060
Mean	16.5	226	21.1	6.4	.0810	.0722

[a] Dimensions of plot 2. Area: 967.2 feet2 (90 m2). Trees/acres: 720 (1,777/ha). Mean spacing: 7.8 feet (2.4 m)

Table 6—Number, diameter at breast height, basal area, height, and volume of the trees in plot 3 on Amaknak Island[a]

Tree number	D.b.h. outside bark	Basal area outside bar	Height		Estimated volume		Remarks
					Outside bark	Inside bark	
	cm	*cm²*	*ft*	*m*	*m³*	*m³*	
1	24.8	483	21	6.4	0.1668	0.1537	
2	19.7	305	17.5	5.3	.0981	.0884	
3	10.8	234	14	4.3	.0587	.0501	Forked at 2.5 ft
	9.5[b]		14[b]	4.3[b]			
	9.5[b]		14[b]	4.3[b]			
4	19.6	302	19	5.8	.0999	.0900	
5	13.4	141	15.5	4.7	.0441	.0377	
6	17.1	230	21.5	6.6	.0802	.0711	
Mean	15.5	282	18	5.5	.0912	.0818	

[a] Dimensions of plot 3. Area: 582.8 feet² (54 m²). Tree/acre: 447 (111 ha). Mean spacing: 9.9 feet (3 m).

[b] Values of the smallest stems were excluded from the plot means.

Alden, J.; Bruce, D. 1989. Growth of historical Sitka spruce plantations at Unalaska Bay, Alaska. Gen. Tech. Rep. PNW-GTR-236. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Experiment Station. 18 p.

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) grew an estimated 37 cubic feet of stemwood per acre per year (2.6 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) in remnant World War II plantations on Amaknak Island and 38 cubic feet of stemwood per acre per year (2.7 $m^3 \cdot ha^{-1} \cdot yr^{-1}$) in an early 19th century grove on Expedition Island, 520 miles (837 km) southwest of natural tree limits in Alaska. Trees in fairly dense plots on Amaknak Island averaged 7 inches (18 cm) in diameter at breast height (d.b.h.) and 21 feet (6.5 m) tall on sheltered sites. The largest trees in the Expedition Island grove were 21.5 inches (54.6 cm) in d.b.h. and 55 feet (16.8m) tall.

Growth and quality of Sitka spruce on productive sites near Unalaska Bay should be adequate for subsistence wood production, amenity of barren landscapes around homes and villages, soil enhancement, wind breaks, and wildlife habitat. Small outplantings of Sitka spruce and other species on sheltered sites from sea level to 820 feet (250 m) in elevation are recommended to determine tree limits, superior seed sources, wood yield, and forest association with native flora and fauna and to refine afforestation methods.

Keywords: Sitka spruce (*Picea sitchensis* (Bong.) Carr.), tree limits, provenance, growth and yield, historical plantations, Unalaska Bay, Alaska.

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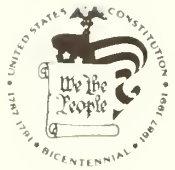

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