THE BALSAM WOOLLY ADELGID AND SPRUCE-FIR FORESTS

NATIONAL PARK SERVICE
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THE BALSAM WOOLLY ADELGID

AND

SPRUCE-FIR FORESTS

A Summary of Pertinent Information for the

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1. SIGNIFICANCE OF THE BALSAM WOOLLY ADELGID IN THE SOUTHERN APPALACHIANS

The balsam woolly adelgid (*Adelges piceae*) is an exotic insect that attacks most species of true fir in North America. It was introduced from Europe at the turn of the century, and since then it has become established by a separate introduction in New England and eastern Canada, in the Southern Appalachians, and in the Pacific Northwest. In the Southern Appalachians, it has caused extensive mortality among Fraser fir (*Abies fraseri*).

Fraser Fir is the only fir endemic to this region, and damage has been such that the very existence of this species is threatened. It represents an irreplaceable genetic entity and is an integral part of one of the more unique ecosystems found in this region--the Southern Appalachian spruce-fir forest. These forests are famous for their disjunct nature and endemism of plant species contained in them. The disappearance of Fraser fir would foreseeably affect the whole system in unknown ways.

In addition to being an invaluable scientific resource, this forest provides recreation opportunities and enjoyment for millions of visitors every year, as well as economic revenue to all those in the area who provide goods and services for them.

The presently available balsam woolly adelgid (formerly called the balsam woolly aphid) control methods are not suitable for large scale application, and it is conceivable that the current trend of destruction could continue to the point of total extinction of Fraser fir.

In the following pages, effort has been made to express the complexity of this issue in simple terms, yet without omitting any details relevant to the understanding of the whole issue.

2. THE SOUTHERN APPALACHIAN SPRUCE-FIR FOREST

2.1 Physical Description

The climate of the Southern Appalachian spruce-fir forest is characterized by high winds, cool summers and cold winters. Precipitation and humidity are high throughout the year. The growing season (the time in a year between the last frost and the first one) is short and the soils are thin and acidic (McCracken et al. 1962; Stephens 1969). All these factors combine to allow only the presence of certain species well-suited for this environment.

The Southern Appalachian spruce-fir forests are dominated by red spruce (*Picea rubens*) and Fraser fir. Associated canopy species include yellow birch (*Betula lutea*), fire cherry (*Prunus pensylvanica*), and American mountain-ash (*Sorbus americana*). Fraser fir is the only true fir occurring in this region and it is also limited to this region alone.

In the Southern Appalachians, Fraser fir density increases with elevation so that most mountain tops above 6200 feet in this region are covered exclusively by Fraser fir (Whittaker 1956). In mixed stands at about 5800, Fraser fir seedlings are about five times more numerous than red spruce seedlings (Oosting and Billings 1951).

There are also other differences between the two species. Red spruce attains a greater size (maximum height 120 feet, maximum diameter 40 inches vs. maximum height of Fraser fir 75 feet, maximum diameter 30 inches). Red spruce grow slower but live longer (up to 400 years as opposed to 150). Fraser fir has a higher seedling-to-mature-tree ratio and is a very prolific seed producer. Both red spruce and Fraser fir are quite shade tolerant and respond well to release. The roots of Fraser fir are deeper and grow more rapidly, enabling it to survive in soils where the upper inch or so has been dried by sun and wind. Consequently, Fraser fir is important as a pioneer species--reproducing fast and occupying openings.

Some typical plants of boreal forests throughout North America find their southern limit in the Southern Appalachian mountains (Peter White, personal communication):

Prunus pensylvanica	-	Fire cherry
Sorbus americana	-	American mountain-ash
Acer spicatum	-	Mountain maple
Sambucus pubens	-	Red-berried elder
Viburnum alnifolium	-	Hobblebush
Rubus canadensis	-	Smooth blackberry
Circaea alpina	-	Smaller enchanter's-nightshade
Clintona borealis	-	Bluebead lily
Oxalis montana	-	Wood sorrell

Other species are found in spruce-fir forests in northern regions and in the Southern Appalachians but are missing in the intermediate regions. Oosting and Billings (1951) reported an unusually high proportion of species common to both spruce-fir forests of the Southern Appalachians and of the White Mountains in New Hampshire. Likewise, Hoffman (1964) reported that 36 families of plants, 78 genera, and 109 species and varieties were common to the boreal forests of Canada, Alaska, and the Great Smoky Mountains (Boner 1979; page 15).

Among the most extreme of these disjuncts are (Peter White, personal communication):

Gentiana linearis	–	Linear-leaved gentian
Betula cordifolia	–	Heart-leaved paper birch
Lonicera canadensis	–	Canadian honeysuckle
Milium effusum	–	Wild millet
Thelypteris phegopteris	–	Northern beech fern

There are a few species which are endemic to the Southern Appalachians (Peter White, personal communication):

Abies fraseri	–	Fraser fir
Rhododendron catawbiense	–	Catawba rhododendron
Diervilla sessilifolia	–	Sessile-leaved bush-honeysuckle
Chelone lyonii	–	Pink turtlehead
Solidago glomerata	–	Skunk goldenrod

There are three plant species limited to the spruce-fir zone in the Great Smoky Mountains National Park alone. These are:

Cacalia rugelia	–	Rugel's ragwort
Glyceria nubigena	–	Smoky Mountain mannagrass
Calamagrostis cainii	–	Cain's reed-bent grass

To illustrate the geographical diversity of plants and the great number of northern species represented in the Southern Appalachians the concept of a "trip to Labrador" has arisen. Traveling from the lowlands of the Southern Appalachians to the mountain tops is the same, climatically and floristically, as taking a trip 1000 miles north, all the way to Labrador.

2.2 Distribution

The spruce-fir forests or boreal forests are widely distributed throughout North America (See Figure 1). In the far north it is the first type of forest encountered as one moves south from the treeless tundra. (The term "boreal" means of or pertaining to the north (Random House Dictionary)). In the mountains of New England it is found at increasing altitudes, where it is the last forest type found prior to the tree line. In the Southern Appalachians it is found above elevations of 4,500 feet, and this region represents the southernmost limit of its range.

The Southern Appalachian spruce-fir forests have much in common with the Northern Appalachian forests to which they were geographically connected during the Pleistocene era (Oosting and Billings 1951). During that era (when the climate was cooler than it is today) spruce-fir forests advanced to lower elevations and, hence, covered a greater area. Disjunction probably took place after the climate warmed and the spruce-fir forests migrated to higher elevations.

Fig. 1. Distributions of Abies spp. and the balsam woolly adelgid in North America.

(from Greenbank 1970)

During the xerothermic period following the Wisconsin glaciation (or hypsithermal about 5000 years ago when the climate was warmer than it is today) the spruce-fir receded to higher altitudes and possibly disappeared from some peaks altogether. As the climate cooled, these peaks lacked the seed source essential to establish new populations of spruce-fir (Whittaker 1956). This may account for the fact that not all elevations in the Southern Appalachians above 4,500 feet have Fraser fir.

2.3 Human Impact to the Spruce-Fir Forests

Historically, man has been the greatest threat to the spruce-fir forests in the Southern Appalachians. Before the arrival of the white settlers, these forests and the red spruce forests of West Virginia and Pennsylvania covered around 800,000 hectares (2,000,000 acres). Clearing for agriculture and minor logging left 300,000 hectares (750,000 acres) by 1860. Subsequent exploitation further reduced the spruce-fir to about 71,400 hectares (176,400 acres) (Hopkins 1899 as seen in SARRMC 1980).

The demise of this forest during the last hundred years has come mainly as a result of careless logging activities. During the beginning of the 20th century, spruce and fir were extensively harvested for lumber and pulp, leaving only a few inaccessible forests at higher elevations untouched (most of which are located within the Great Smoky Mountains National Park). Slash would often catch on fire, destroying the remaining vegetation as well as seeds accumulated on the ground. These fires were often followed by extensive erosion. Whereas unburned logged stands had a good chance of regenerating and achieving a species composition similar to the original one, burnt areas developed into heath and scrub wood with little or no fir--a condition which may take from 200 to 1000 years for recovery (i.e., to return to a composition similar to the original one) (Saunders 1979).

Presently most of the remaining spruce-fir areas are under federal or state ownership (See Figure 2 for the distribution of spruce-fir in the Southern Appalachians). More than half of this area (19,750 hectares or 48,800 acres) is located within the Great Smoky Mountains National Park (See Figure 3 for distribution of spruce-fir in the Great Smoky Mountains National Park). The rest of the area is divided between the Black Mountains in North Carolina with 3,000 hectares (7,500 acres); the Balsam and the Plott Balsam Mountains of the Pisgah National Forest and the Blue Ridge Parkway; Roan Mountain (shared between the Pisgah and Cherokee National Forests and private ownership); Mount Rogers Recreation Area in Virginia; and Grandfather Mountain, under private ownership.

3. THREATS TO THE SPRUCE-FIR FOREST

There are several threats to the spruce fir forests in addition to the balsam woolly adelgid.

3.1 Human Disturbances

Because of the fact that most of the remaining spruce-fir forests are used for recreation purposes, a range of human disturbances such

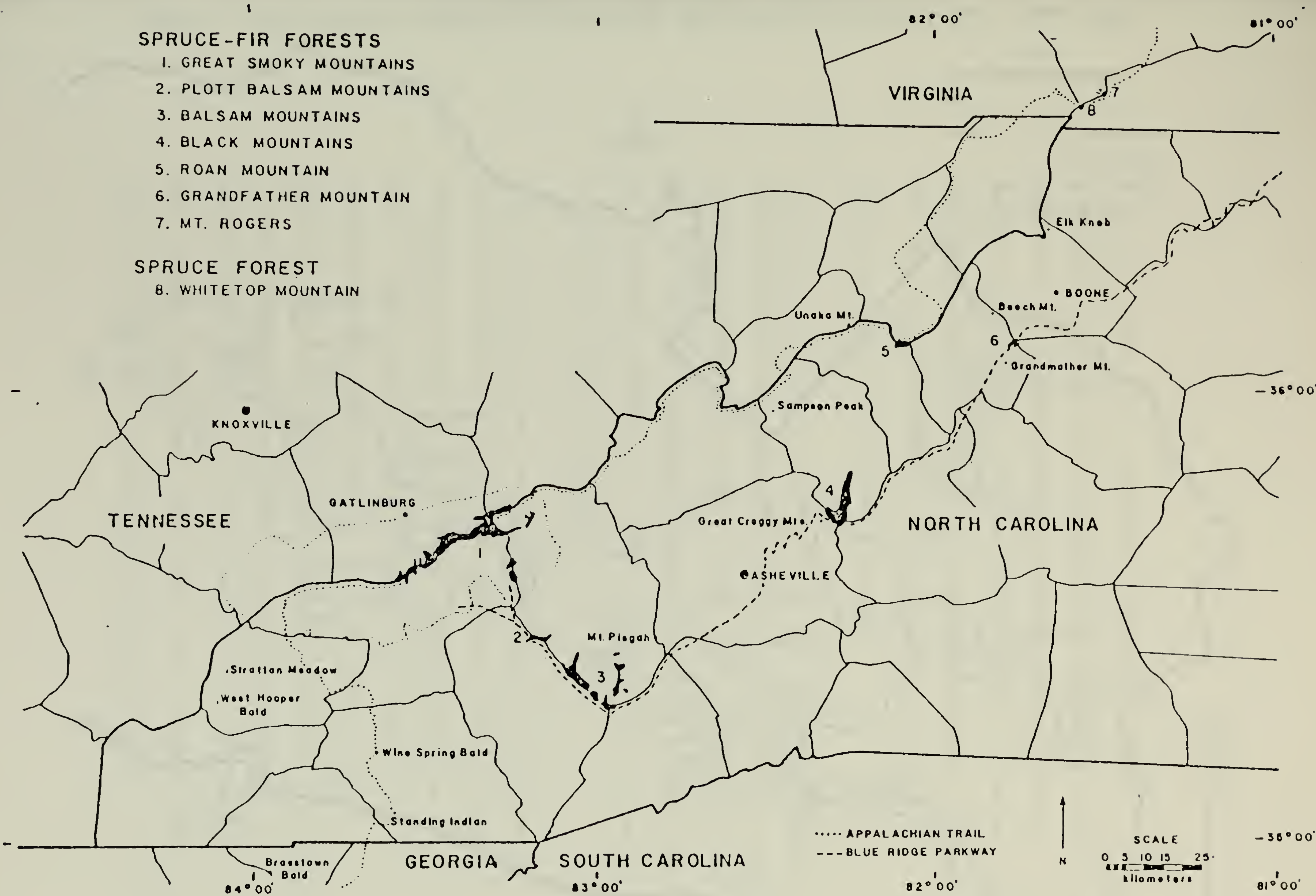

Figure 2. Spruce - Fir Distribution in the Southern Appalachians (Saunders 1979)

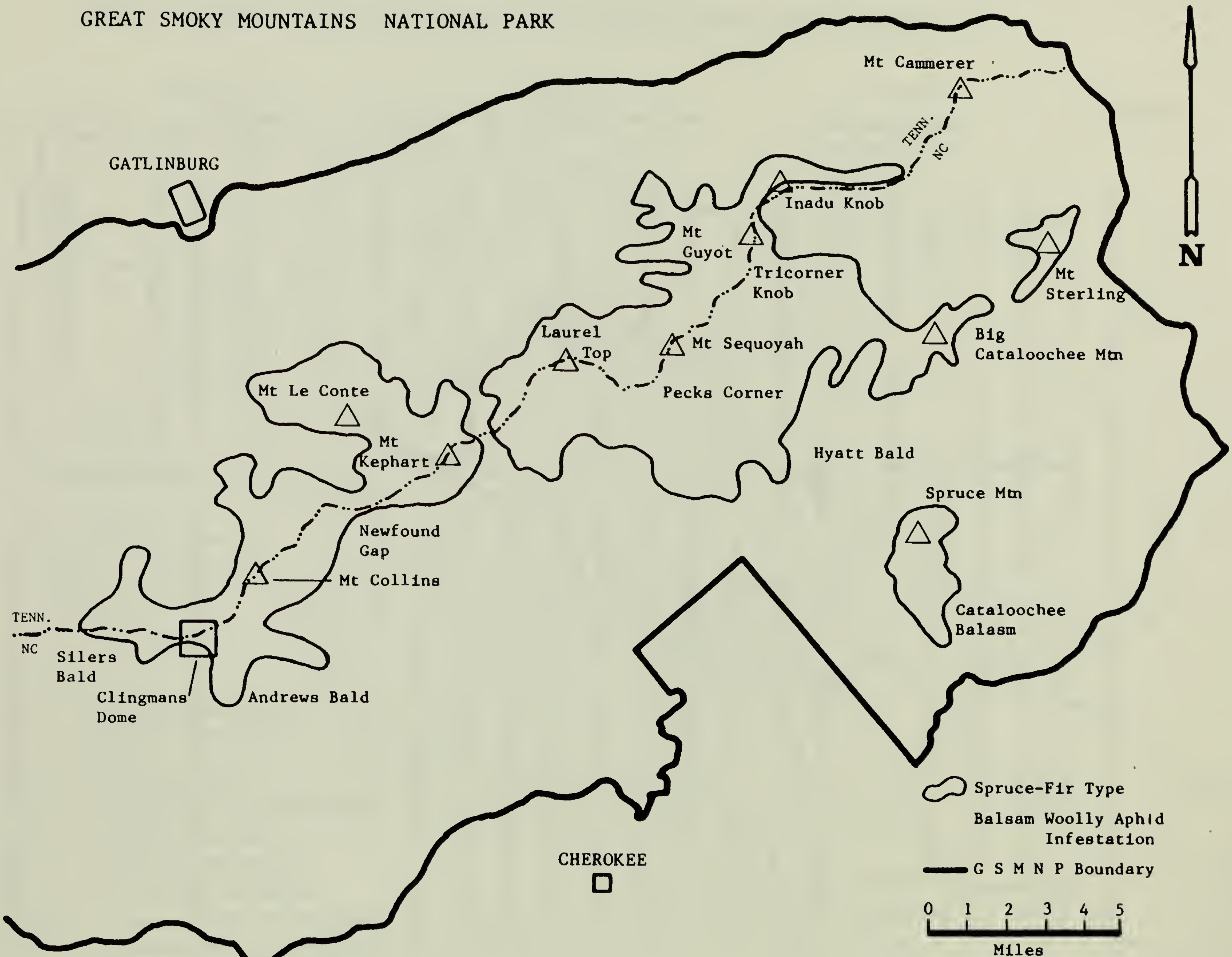

Figure 3: Distribution of spruce-fir in the Great Smoky Mountains National Park (Eagar 1978)

as trails, picnic areas, campsite and overnight shelters are unavoidable. Common to all of these disturbances is the complete destruction of vegetation within the immediate area. Normally, however, the alteration of species composition does not extend beyond the disturbance itself. On the periphery there is an area about 5 to 10 meters wide where the transition to undisturbed vegetation takes place (Saunders 1979).

Erosion may also become a problem in the case of trails; therefore, proper design and maintenance are important. Windthrow is a natural phenomenon leading to a community similar to the humanly disturbed one. Recreational disturbances, overnight shelters in particular, may increase the incidence of windthrow by providing a new surface for the wind to attack (Saunders 1979).

These disturbances present an additional threat to the spruce-fir zone in that they facilitate the introduction of exotic species. The removal of cover and the available sunlight provide an opportunity for exotics to gain a stronghold. Horses are an important vector for the introduction of new species (mainly grasses), since horse owners are required to provide their own feed for their horses. Horses also have the greatest effect in destroying the cover and compacting the soil. So far, however, exotics seem to be limited to trails and other disturbances and are unable to compete with natural species (Saunders 1979).

3.2 Acid Rain

The extent of damage caused by acid precipitation in the Southern Appalachian spruce-fir forests have not been determined. Rainfall in the spruce-fir zone is about twice as much as that at low elevations. In addition to rainfall, spruce-fir forests receive about an additional 50% moisture input from cloud and fog condensation (Douglas Holland, personal communication). In some cases, fog and cloud moisture will contain four times as many dissolved hydrogen ions (a measure of acidity) as the total rainfall at low elevations. This is because of the greater surface-to-volume ratio of fog participles, which enables them to take up more sulphur dioxide (SO_2) and nitrous oxide (NO_x) particles (the causes of acid rain) (Douglas Holland, personal communication). It follows, then, that spruce-fir forests may receive as much as 10 times the amount of acid precipitation (or, more specifically, hydrogen ion input) as lower elevations (2x for rain + 2 x 4x for acid in fog and clouds).

Research in the White Mountains of Vermont (Siccama et al. 1982) has shown a 50 percent reduction in red spruce basal area during the period from 1964 to 1979. Many of the remaining trees in these stands show signs of stress and are in poor condition. The authors discuss the possible role of acid precipitation as well as other factors in this decline but stop short of identifying a causal agent.

Many questions remain unanswered concerning the effect acid precipitation has on the total Southern Appalachian spruce-fir system, such as: What effect does acid precipitation have on an already acidic soil with very little buffering capacity, and what are the effects of the decreased pH?

In the Great Smoky Mountains National Park an acid rain monitoring program has been going on since 1978, and research on the specific effects of acid precipitation at higher elevations is under way.

4. HISTORY AND DISTRIBUTION OF THE BALSAM WOOLLY ADELGID

The balsam woolly adelgid was first discovered in Maine in 1908 (Kotinsky, 1916). The probable means of introduction seems to have been imported nursery stock from Europe. In 1916, it was discovered on Mount Monadnock in New Hampshire and, in 1929, it was reported in Nova Scotia (Balch, 1952). In the Northeast, it is presently distributed throughout southern Maine, New Hampshire, Vermont and northwestern Massachusetts. In Canada, it has become established throughout Nova Scotia, Prince Edward Island and southern New Brunswick (Schooley and Bryant, 1978). Its host in the Northeast is balsam fir, and damage has occasionally been severe (Balch 1952).

A separate introduction brought the adelgid to the western United States where it was discovered in 1928 (Annand, 1928). The balsam woolly adelgid is now present in Oregon, Washington, and southern British Columbia. Throughout North America, the balsam woolly adelgid has not extended more than 100 miles from each coast except for the infestations in the Southern Appalachians (Greenbank, 1970).

The balsam woolly adelgid was discovered in 1957 on Mount Mitchell, the highest peak in the Southern Appalachians (Speers, 1958). Judging from the damage present at the time, introduction of the insect must have occurred around the late 1930s. How the insect was introduced is not known. A possibility is the extensive reforestation programs which included European silver fir that were taking place on Mount Mitchell at that time (C. Eagar, personal communication). In 1962, the balsam woolly adelgid was discovered on Roan Mountain to the north of Mount Mitchell. In 1963, it was discovered on Mount Sterling, the easternmost peak in the Great Smoky Mountains National Park, and it was not until 1972 that adelgids were discovered on Clingmans Dome (Hay et al. 1978), the limit of the Fraser fir's extension to the west. By that time it was thought that the balsam woolly adelgid had colonized the entire Southern Appalachian spruce-fir zone to some extent, except the stands on Mount Rogers in Virginia. Monitoring efforts by the U.S. Forest Service in 1979 detected two small infestations on Mount Rogers. Subsequent work revealed that the adelgid had been present since 1962, however, mortality and damage to Fraser fir on Mount Rogers is considerably less than in other Southern Appalachian areas (Johnston 1980). The reasons for this apparent tolerance are still not fully understood.

5. THE WOOLLY ADELGID LIFE HISTORY

The balsam woolly adelgid belongs to the insect order Homoptera, family Phylloxeridae and sub-family Adelginae.

The Adelginae are characterized by a very complex life cycle involving alternation between sexual and asexual reproduction and also between hosts (Balch 1952). In Europe _Adelges_ _piceae_ is a relatively harmless pest on its host, European silver fir (_Abies alba_). In its new environment in America however, it found favorable conditions and caused extensive damage to its host, particularly in the Southern Appalachians. It has no natural predators or parasites and is very resistant to extreme environmental conditions. It is capable of surviving eight days without feeding and has a tremendous reproductive potential.

The lethal low temperature for the adelgid is -35° C for the overwintering generation and 0° C for all other stages. High ambient temperatures will not have an adverse effect on the adelgid; on the contrary, they may increase the rate of development (Greenbank 1970).

Desiccation may occur as a result of high bark temperatures and low humidity. Protection against desiccation is afforded by the wool (actually a waxy secretion) and the insects habit of settling predominantly under branches, in cracks and in lenticels (small opening on the bark of Fraser fir). Rain may mat the wool and subsequently lead to desiccation. It may also wash away the adelgids (Balch 1952). In summary, climatic factors have very little effect in reducing the total population; in fact, the mild conditions prevalent in the Southern Appalachians have a beneficial influence on the adelgid.

Population control is exerted mainly by the carrying capacity of the host. The number of adelgid will increase as long as the host is able to provide food for all individuals (Balch 1952). Once the tree is unable to do this, populations will start declining and eventually die out. By that time, however, the tree will have incurred such damage that it will usually die.

Dispersal is passive, depending predominantly on wind currents, and occurs only during the egg and crawler stages. Surface winds can carry adelgids 300 feet, and vertical air currents could conceivably transport adelgids for several miles (Balch 1952).

5.1 Life Cycle

The life cycle of the balsam woolly adelgid consists of an egg stage, three larval instars, and the adult. The following description of the balsam woolly adelgid's life cycle is based on observations by Balch (1952) as summarized by Hay et al. (1978).

> Eggs laid by the stationary adult are attached to the host bark by a silken thread. Initially light amber colored, the eggs become orange brown as the embryo develops. After about 12 days young larvae emerge, leaving the empty shell behind. This is the first instar, and the only stage capable of movement. These mobile larvae or crawlers as they are also known, are light purple with a flattened oval body between .35

millimeter and .47 millimeter long. They have three pairs of fully functional legs and are capable of crawling up to 30 meters in search of a suitable feeding site. (It is unlikely that they would crawl from one tree to another.) After inserting its stylet (a slender thread-like mouth part used for feeding) into the host bark, the insect turns dark purple black with a fringe of white waxy threads and the legs and antennae begin to atrophy. The insects remain stationary during the following three larval molts. A dormant period of variable length will follow. This is the stage that the insects overwinter and are known as hiemosistens, while the summer generation are known as aestivosistens. The hiemosistens begins to feed when the sap rises in the spring, while the aestivosistens are dormant for three to eight weeks.

The second instar develops after the first molt. It has a longer (.45 millimeter to .55 millimeter) and broader body than the first instar, with long, curling, waxy threads.

After a second molt, the third instar develops. This one is similar to the second, except that it is .60 millimeter to .86 millimeter long. The adults develop after the third molt and are .70 millimeter to 1.0 millimeter long, hemispherically shaped and covered with long, curling, waxy threads of "wool".

The number of generations in a year depends mainly on the climate. The warmer the climate, the more generations will be produced. In maritime Canada and New England, two generations are the rule. (Balch, 1952). Due to the wide range of elevations in the Pacific Northwest, the number of generations range from two at high altitudes, three in the intermediate altitudes, to four at lower altitudes where climatic conditions are optional (Mitchell, et al. 1961).

In the Southern Appalachians, there is a similar variation in the number of generations but two are the general rule.

5.2 Reproduction

The balsam woolly adelgid reproduces by parthogenesis; that is, without mating or fertilization. The entire population consists of females, all capable of producing eggs. Oviposition begins three days after the final molt and may continue for up to five weeks. The adult will die soon after completing this process. An adult of the hiemosistens (overwintering) generation will produce around 100 eggs (although figures of more than 200 have been recorded). The adult of the less fecund aestivosistens generation generally lays around 50 eggs (Balch 1952). Using two generations per year and a survival rate of 60%, 1800 adelgids can be produced from a single individual in one year.

6. BALSAM WOOLLY ADELGID EFFECT ON FIR TREES

6.1 Types of Attacks

Balsam woolly adelgid attacks can be classified in two categories; crown infestations and stem infestations (Balch, 1952). The type of infestation will depend mainly on the host species. Balsam fir, for example, usually suffers from the crown infestation while Fraser fir suffers predominantly stem attacks; however, both species can suffer either kind of attack. Stem infestations tend to be more severe than crown infestations because they can affect the entire tree; crown infestations affect parts immediate to the attack site, and the tree may recover even after a heavy infestation (Balch, 1952).

6.2 Physical Changes in Infested Trees

Very obvious changes take place in the tree after it has become infested by the balsam woolly adelgid. When the crown is attacked, a symptom called gouting occurs. This will be most obvious near or at the top of the tree. Balch (1952; p. 47) reported that for balsam fir the branchlets are thickened and irregularly twisted, often turned downward at the ends. The stem may taper rapidly towards the top. The tip of the crown is often flattened or bent, sometimes umbrella-shaped and, in typical cases, dead.

Stem infestations are recognizable by very small white splotches of "wool" along the bole. The crown of Fraser fir will undergo a series of changes after the tree is attacked by the balsam woolly adelgid. The speed of these changes seems to reflect the severity of the attack and/or the lack of host resistance (Hay et al., 1978) as well as the available water in the soil (Chris Eagar, personal communication). While healthy trees are blue green, upon attack they will fade into yellow green, then bright rusty red, and finally dead brown (Hay et al., 1978). These changes will occur if conditions are dry, and death can occur in as short as two years time. If there is abundant soil moisture during the growing season, death will be slower and will be preceded by a gradual loss of needles without noticeable color changes until only a gray skeleton remains (Chris Eagar, personal communication).

Death may take from two to seven years (Amman 1962) and results from the disruption in the transport of water and minerals from the roots to the rest of the tree. Lack of water in the soil will aggravate this condition and therefore cause faster death.

6.3 Feeding and Microscopic Changes

The following account of balsam woolly adelgid feeding activity is based mainly on descriptions by Balch (1952). Other sources are indicated when appropriate.

After the adelgid has found a suitable feeding site, the newly hatched larvae inserts its stylet intercellularly through the periderm into the cortical parenchyma (see Figure 4). Feeding does not start until the insect has gone through a resting stage. Swelling of the insect body and a clear drop of honeydew at the anus indicates that feeding has started. Feeding only takes place in the parenchyma cells. A substance within the insect's saliva will diffuse into the cells surrounding the stylet. This causes these cells to increase tremendously in size (around 6 to 7 times the normal size). There is also a thickening of the cell wall and an enlargement of the nucleus (see Figure 5).

The salivary substances secreted by the adelgid during feeding even affects the distant xylem. Cell division is stimulated in the cambium and there is a production of tracheids with thickened, irregularly shaped cell walls and dark hard brittle cellulose. This is known as a "rotholz" or "redwood" because of its reddish color, and it closely resembles compression wood (the wood on the underside of a branch that is compressed by the weight of that branch). The

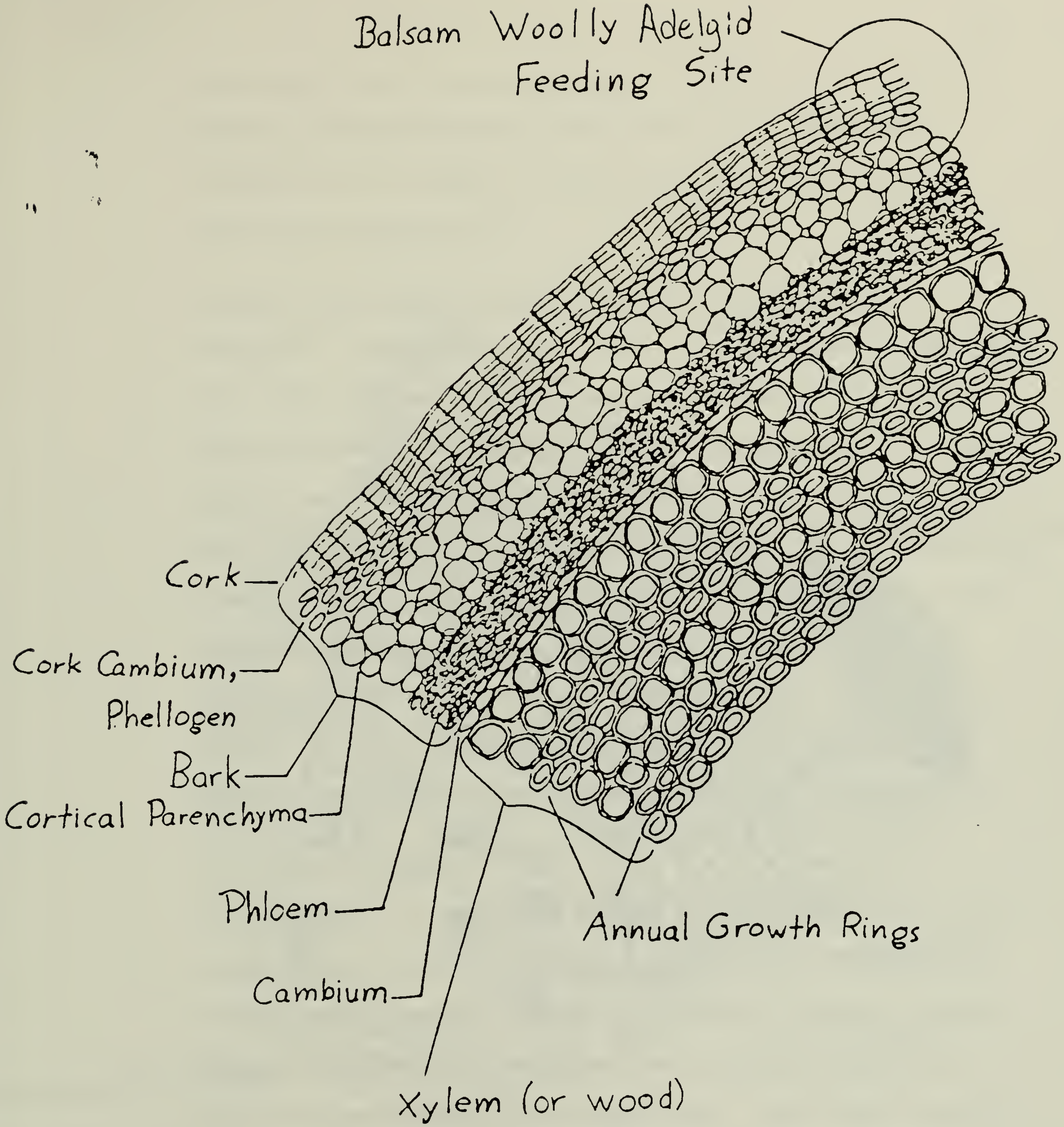

Figure 4: Schematic cross section of a Fraser fir stem showing the principal structures and balsam woolly adelgid feeding site.

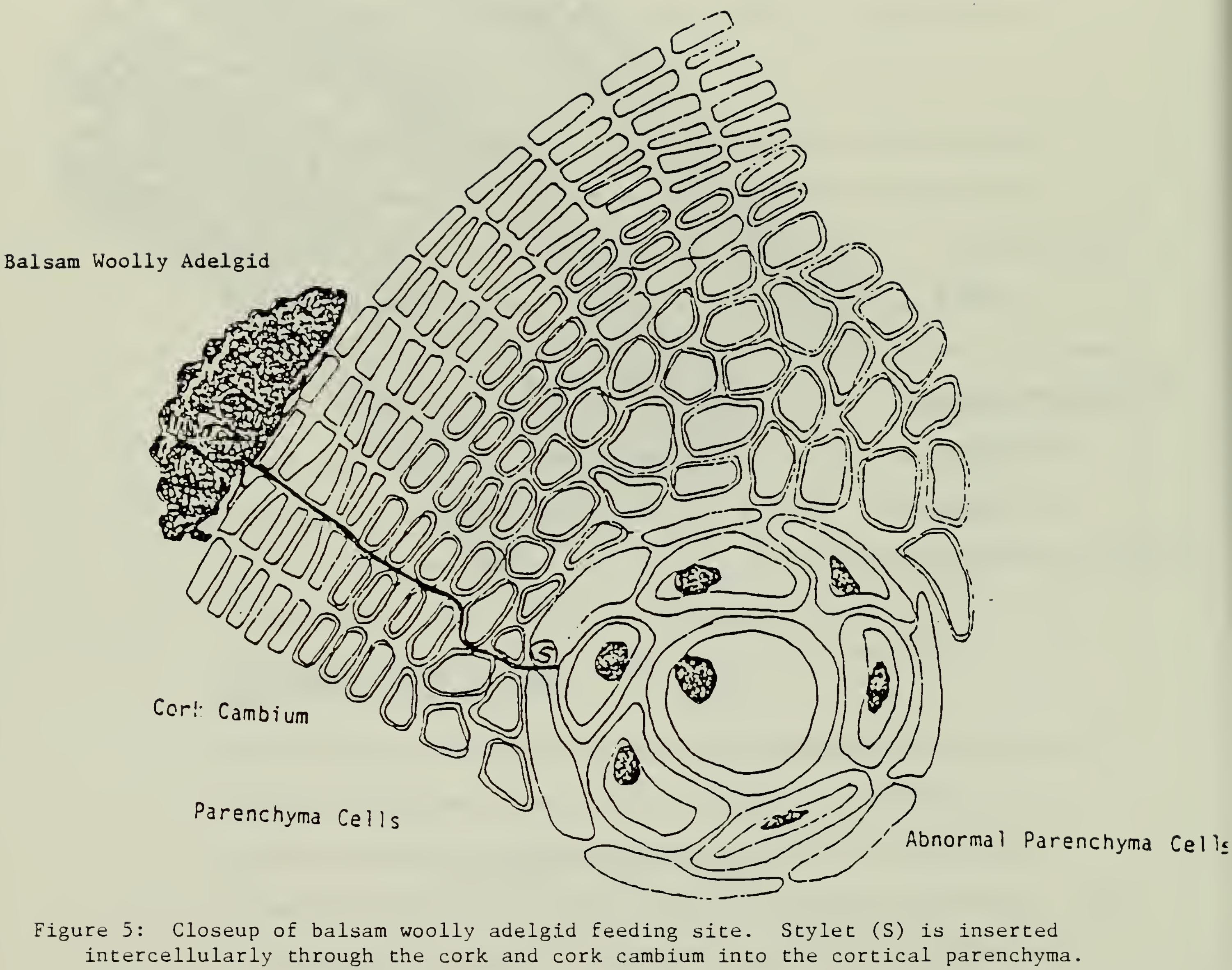

Figure 5: Closeup of balsam woolly adelgid feeding site. Stylet (S) is inserted intercellularly through the cork and cork cambium into the cortical parenchyma. Abnormal cells develop around tip of stylet.

membranes of the bordered pit pairs in the xylem, the microscopic openings through which water and nutrients pass, will become encrusted and the passage of fluids will be severely impeded (Puritch and Johnson 1971).

The exact active constituents of the saliva have not been determined. Indoleacetic acid (IAA), a growth hormone, is suspected to be one of the main compounds involved in altering the host's cellular structure (Chris Eagar, personal communication). It is thought that IAA may facilitate the flow of nutrients towards the feeding site, thereby providing more nourishment for the adelgid and causing adjacent cells to grow. Several facts support this theory: Diameter growth increases at the time of infestation; adelgids prefer to settle in groups on the stem (Hay et al., 1978)--the combined action of many individuals would be more effective than that of a single one. Also, adelgid survival may increase as the bark is changed by feeding (Balch 1952).

Death of Fraser fir apparently results from the impediment of flow through the bordered pit pairs of the xylem vessels (Chris Eager, personal communication). The rate of mortality increases during drought conditions. Infested trees seem also more susceptible to Armillaria root rot (Hudak and Wells, 1974). This fungus destroys the cambium and phloem of the roots and root collar and is an additional cause of mortality. Damaged and weakened trees are also more vulnerable to windthrow and top breakage. Fedde (1973) observed that the cumulative stress from a balsam woolly adelgid attack also reduces the seed crop but, given the short time it takes for adelgids to kill a tree, this should have little effect on the total Fraser fir population dynamics.

Whereas in normal spruce-fir stands the threat of fire is minimal, the accumulation of dead trees in an infested stand creates large amounts of fuel. A fire would not only destroy surviving trees but it would also reduce the potential for regeneration. The organic matter would burn, exposing the mineral soil and providing a seedbed more suitable for yellow birch, fire cherry, and mountain ash, and less suitable for Fraser fir. Also, accumulated Fraser seeds in the soil which normally remain viable for around five years would be destroyed.

6.4 Factors Affecting Host Suitability

Not all Fraser fir are equally affected by the balsam woolly adelgid. Similarly, infestations in different stands do not always follow the same patterns.

Young vigorous trees less than 20 years of age rarely have large adelgid populations, and tree mortality at this stage is not frequent (Chris Eager, personal communication). It appears that adelgids require modifications of the tight, smooth gray bark characteristic of young vigorously growing Fraser fir trees. These modifications are splitting of the bark and formation of lenticels, a process that generally occurs after the tree is 15 to 20 years old. Stress from competition will cause these modifications at an earlier age and thus make the tree more vulnerable to attack (Hay and Eager, 1981).

Large trees, on the other hand, hold the largest adelgid populations. In addition to their bark characteristics and potential to support the largest number of adelgids, they present a tall profile and therefore are able to intercept airborne adelgids more readily (Hay et al., 1978).

The development of infestations in the Great Smoky Mountains National Park suggests that adelgids first established themselves along the northern hardwood/spruce-fir ecotone (the boundary between northern hardwood and spruce-fir) and then gradually began to invade higher elevations (Eager 1978). The high winds at high altitudes probably do not allow airborne adelgids to be deposited on mountain tops. Instead, the insects tend to settle out in the eddies on the leeward side. Gentle thermal currents then favor gradual dispersal from low elevations towards the summit. Also, the mixed uneven-aged stands at lower altitudes are much more likely to catch adelgids suspended in the air than the smaller, pure fir stands on the tops of mountains.

7. REGENERATION OF INFESTED STANDS

Because of the relatively recent history of balsam woolly adelgid infestations in the Southern Appalachians, the changes taking place in community structure after the death of Fraser fir are not yet fully understood. Boner (1979) studied the species composition in spruce-fir forests with different degrees of infestations in the Great Smoky Mountains National Park and the Black Mountains. These are some of his observations: (1) Red spruce is favored by the release and their crowns expand to cover a greater area in the canopy. (2) There is an increase in other tree species associated with the spruce-fir forests; in particular, yellow birch and mountain ash. (3) In the understory there was an increase in the density of thornless blackberry, red raspberry and Fraser fir; however, the densities of mountain cranberry and hobblebush decreased. (4) Ground coverage of mosses and ferns decreased. (5) Subsapling densities increased with time after death of the overstory and Fraser fir proved to be the most abundant understory species. All factors considered, Fraser fir reproduction seems abundant although the future of these young stands is still uncertain.

8. BALSAM WOOLLY ADELGID CONTROL METHODS

8.1 Manipulation of Fraser fir Communities and Establishment of Seed Orchards

The main purpose behind the manipulation of fir communities would be to achieve dense young stands of uniform height and vigorous growth in the hope that they would reach reproductive age before adelgid attack. This could be accomplished by removing the overstory after the seedlings had rooted in the mineral soil (to avoid desiccation from exposure of the soil and the sun). Thinning out stands before seed-bearing stage and leaving those trees that promise the highest seed yield would also increase the rate of reproduction (Hay et al. 1978; Hay and Eagar 1981).

The establishment of Fraser fir seed orchards outside the range of the balsam woolly adelgid (e.g., Michigan's Upper Peninsula or northern Minnesota) has been suggested as a possible means of ensuring a seed supply for the future and preserving the species if it were to disappear from the Southern Appalachians (SARRMC 1980).

8.2 Biological Control

Biological control involves the introduction of parasites, diseases or predators to which a particular pest will be vulnerable.

Fusarium larvorum is a fungus pathogen first observed growing on balsam woolly adelgids in Mount Mitchell. It can attack all stages of the balsam woolly adelgid and cause mortality, but not all adelgids are equally vulnerable to it and it requires the presence of other insects for dispersal. It is therefore not effective as a control mechanism (G. Fedde, unpublished paper as cited in Johnson 1980).

Because of its exotic character the balsam woolly adelgid is not the natural prey of any North American predator. Several insects native to the Southern Appalachians have been observed feeding on it but none exerts an appreciable effect on the total population (Amman 1970). During the late 1950s and early 1960s, seven different insect species were introduced on Mount Mitchell for control of the balsam woolly adelgid. Only two seem to have established themselves: Laricobius erichsonii, a small, dark brown beetle, and the small, yellow ladybird beetle, Aphidecta obliterata. The latter is found mostly in the crown of trees and, although preliminary results with L. erichsonii were promising, it is not the answer to the adelgid control question (Amman and Speers 1964). The reasons for the failure of all these introductions seems to be:

(1) The lack of specificity on the part of the predator (i.e., it feeds on other insects besides A. piceae),

(2) Inability of the insect to find the adelgids,

(3) Inability of the insect to adapt to the new environment,

(4) The high reproductive capacity of the adelgid, and

(5) The rapid death of the host (Fraser fir).

8.3 Chemical Control

There are a number of chemical insecticides effective against the balsam woolly adelgid (e.g., Baygon, Diazinon, Dursban, Permethrin, and Chlorphrifos). Until recently Lindane was the only pesticide registered for this application. It was used extensively during the 1960's despite evidence that it persisted in the soil (Jackson et al. 1974). At present Lindane has been placed on the Environmental Protection Agency's Rebuttable Presumption Against Registration list, due to its harmful environmental effects.

A promising alternative seems to be the use of fatty acids (Puritch 1975) and their salts (basically the same as soaps) which have the necessary solubility for spray application. Fatty acids occur naturally in plant and animal tissues and are readily biodegradable.

They are harmless to wildlife and their phytotoxicity is limited to the fact that they may remove some of the cuticle on leaf surfaces.

Application of fatty acids is only feasible on a small scale. In order to be effective the stem has to be soaked completely and each stem has to be done individually. Aerial application is not possible because the crown is in the way. A water source is necessary to dilute the insecticide to the desired concentration and gasoline powered high pressure pumps are necessary in order to reach the higher portions of the stem.

9. CONTROL AND POLICY IN THE GREAT SMOKY MOUNTAINS NATIONAL PARK

Given the limited number of presently available balsam woolly adelgid control methods, there are few restrictions involving their use. Policy regarding balsam woolly adelgid control and management of affected areas has not been established completely in the Great Smoky Mountains National Park. When the adelgid was first detected on Mount Sterling in 1963, attempts were made to control it by cutting down all the trees in the infested area, which was 600 meters long by 150 meters wide. However, ground checks the following year showed 16 hectares around the original area were infested (Ciesla, et al. 1965, in Johnson 1980). The cutting program was dropped after it proved ineffective and the balsam woolly adelgid continued expanding its range. The U.S. Forest Service limited itself to monitoring the advance of the pest by aerial surveys using infrared photographs and ground checks. By

1978, the balsam woolly adelgid was present through the entire spruce-fir distribution in the Park (Eagar 1978).

In May of 1982, a meeting took place attended by the Park Superintendent, Uplands Field Research Laboratory staff involved in balsam woolly adelgid research, and Park Resources Management staff. The status of the adelgid in the Park and currently available control methods were discussed. The decision was made to start a biannual pesticide spraying program at Clingmans Dome using insecticidal soap. The site was chosen because of heavy visitor use, accessibility, and the availability of a suitable water source. The high percentage of fir in the area was an additional factor; it was feared that if all the Fraser fir were to perish under adelgid attack, the aesthetic impact on the total scenery would be far more detrimental than to a mixed stand. Protection to this limited number of Fraser fir will provide future seed sources as well as preservation of genetic diversity. The two spraying operations were to take place in July and September.

These particular dates were chosen in order to coincide with the maximum number of adult adelgids and the least number of eggs, on which the soap is less effective. Approximately nine acres were sprayed, concentrating on hotspots in trees highly visible to the public, such as the area adjoining the parking area, the area behind and adjacent to the restrooms, and along the paved trail. In spite of the limited size of the area involved, this control program was the largest one to date using insecticidal soap against balsam woolly adelgids.

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