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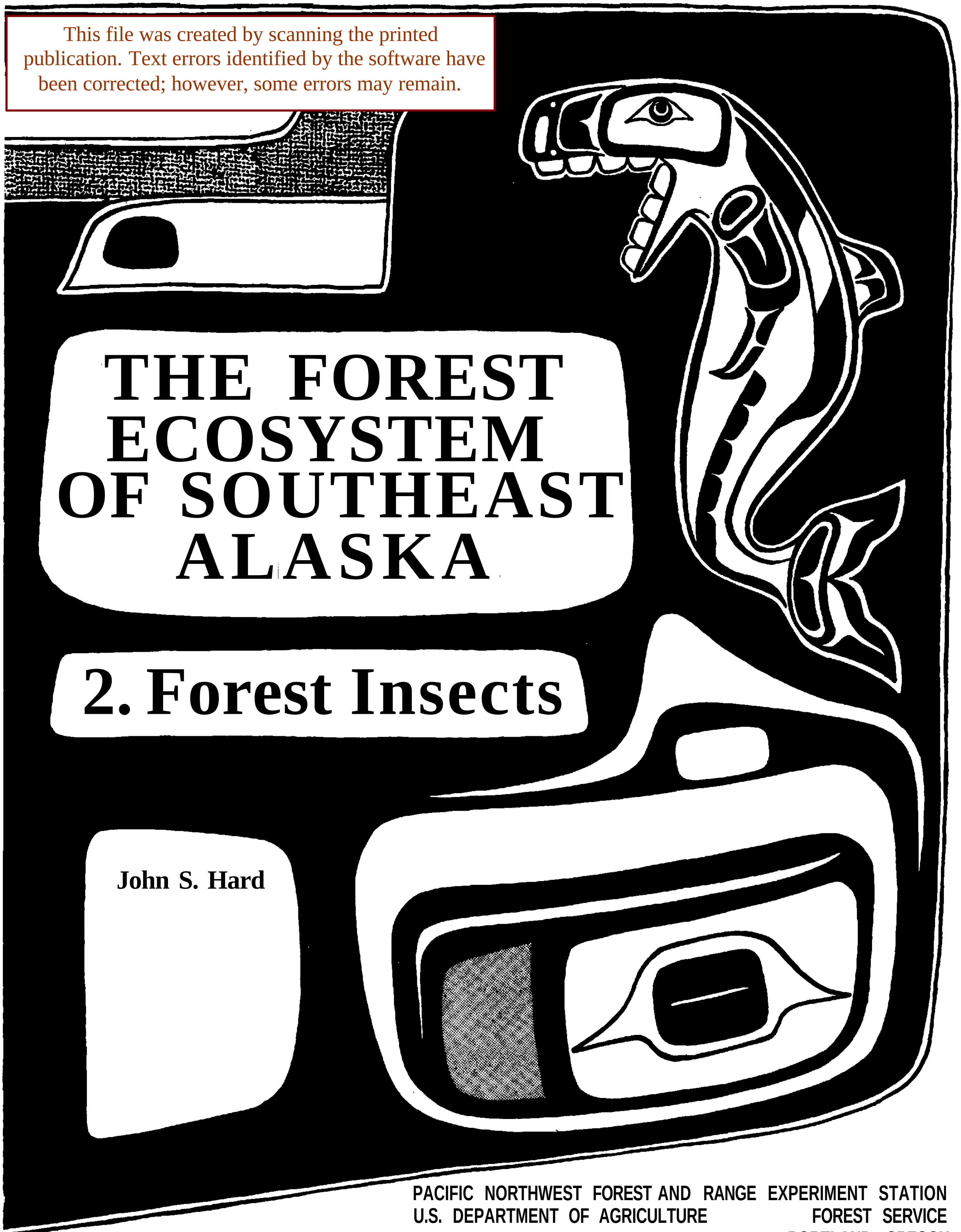

THE FOREST ECOSYSTEM OF SOUTHEAST ALASKA

2. Forest Insects

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ABSTRACT

Southeast Alaska's remaining virgin forests have few insect pests. The black-headed budworm and the hemlock sawfly, both western hemlock defoliators, are the most important species. They kill some trees, kill tops in others, and cause growth loss, but stands survive their attacks. Extensive conversion of virgin stands to second growth may result in an increase in pest problems as it has in similar areas such as coastal British Columbia. Widespread use of insecticides to control major outbreaks is not practical because of risk of contaminating salmon-spawning and trout-rearing streams; but insecticide use may be justified in local, high value areas. Weather, diseases, and parasites control outbreaks naturally. Damage-prone stands should be identified and harvested before insect attack or salvage-logged following outbreaks. Ideally, second-growth stands should be managed for resistance to insect pests.

Keywords: Insects, natural control (insects), southeast Alaska, research.

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PREFACE

This is the second in a series of publications summarizing knowledge about the forest resources of southeast Alaska.

Our intent in presenting the information in these publications is to provide managers and users of southeast Alaska's forest resources with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we will summarize published and unpublished reports and data as well as the observations of resource scientists and managers developed over years of experience in southeast Alaska. These compilations will be valuable in planning future research on forest management in southeast Alaska. The extensive lists of references will serve as a bibliography on forest resources and their utilization for this part of the United States.

Previous publications in this series include:

1. The Setting.

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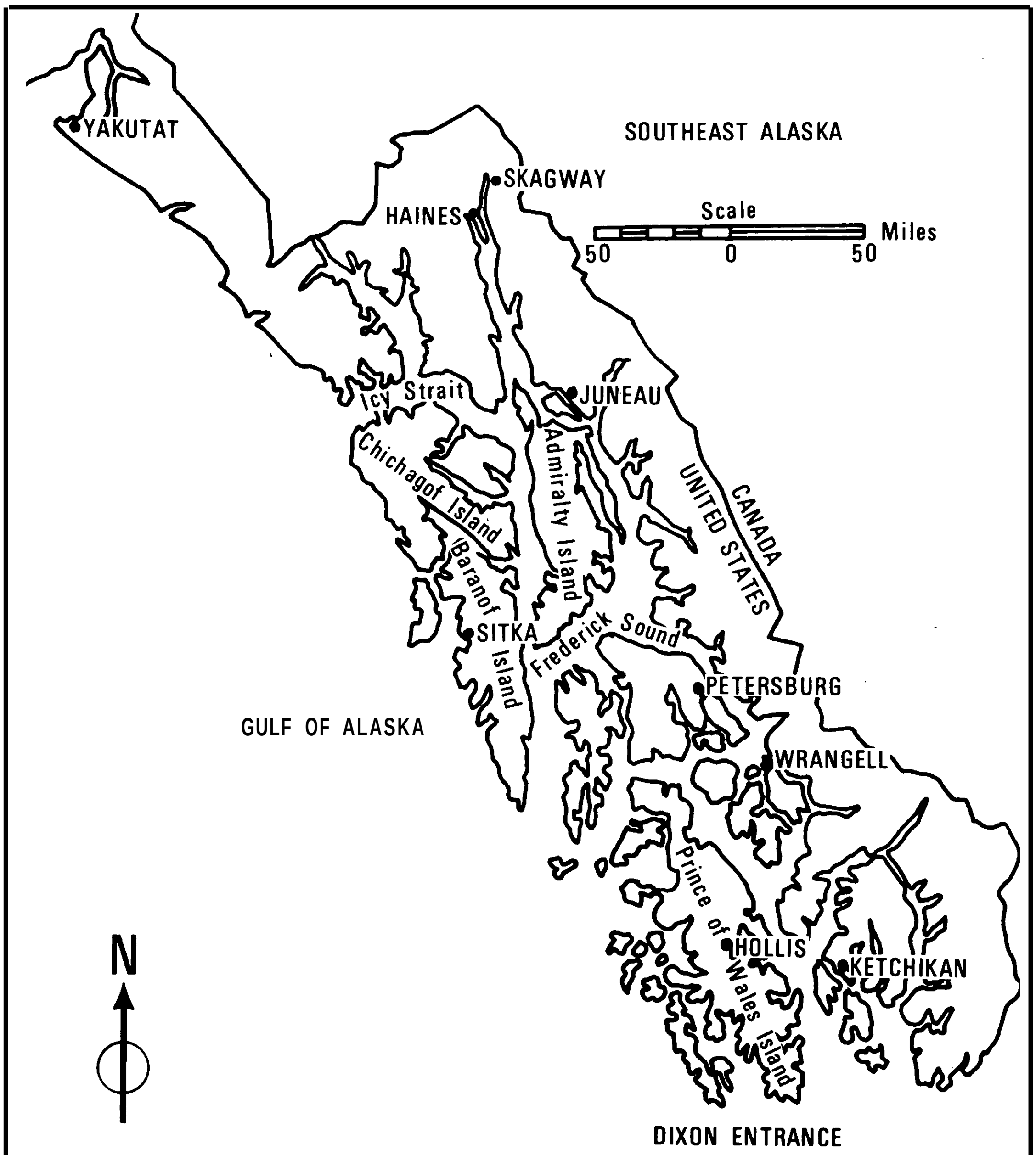

Figure **1.--Map of** *southeast Alaska east* **of** *the 141st* **meridian.**

The harsh reality of the situation is that we must live with pests--be they insects, mites, snails, worms, fungi, bacteria, viruses, epiphytic plants, allergens, or weeds. Rarely do we eradicate them; the best we can do is to coexist with them. We and they are part of a giant ecosystem, and man is merely trying to shift the balance of power so he can exist in reasonable comfort and security. It is necessary for us to be sufficiently objective to understand this ecosystem in which the role of man is defined as a competitive force, albeit a bit more intellectual and far-sighted than his competitors. (McNew 1972, p. 119.)

INTRODUCTION

The resource manager concerned with forest protection must examine southeast Alaska (fig. 1) in the light of its unique character. Compared with coniferous forests at lower latitudes, biotic diversity is limited for several reasons. Geologically, this region has only recently been freed from glaciation and has a maritime climate with relatively mild winters and cool, moist summers. It is separated from the rest of the North American Continent on the north and east by a range of continually snowclad coastal mountains which acts as a climatic and physical barrier to reinvasion of flora and fauna. Beyond the coastal range, life is adapted to a continental climate with extremely long, cold winters and hot, dry summers. Therefore, the main avenue for reinvasion by plant and animal species adapted to a maritime climate is from coastal British Columbia immediately to the southeast.

The climate of southeast Alaska is more rigorous, however, than that of coastal British Columbia, and there are indications that weather during the growing season may be a limiting factor in the growth and distribution of some species (Andersen 1955). For example, climate apparently limits the northward distribution of western redcedar, *Thuja plicata* Donn (Andersen 1953), which occurs naturally only in the southern half of southeast Alaska. Pacific silver fir, *Abies amabilis* (Dougl.) Forbes, Pacific yew, *Taxus brevifolia* Nutt., swordfern, *Polystichum munitum* (Kaulf.) Presl, and salal, *Gaultheria shallon* Pursh, all reach the northern extremities of their ranges in southern southeast Alaska (Hultén 1968). Mean site index, a ratio of tree height over age which diminishes from south to north in southeast Alaska (Andersen 1953), is apparently related to temperature during the growing season.

The hemlock sawfly, *Neodiprion tsugae* Midd., has not been positively identified north of southeast Alaska, although its primary host, western hemlock, *Tsuga heterophylla* Raf. (Sarg.), occurs as far north as the Kenai Peninsula. The Sitka spruce weevil, *Pissodes sitchensis* Hopk., a major pest of Sitka spruce, *Picea sitchensis* (Bong.) Carr., in the Pacific Northwest and British Columbia has not been found north of coastal British Columbia (Wright 1970), although its host occurs around the Gulf of Alaska to Kodiak Island. The black-headed budworm, *Acleris gloverana* (Wals.), formerly referred to as *A. variana* (Fern.), (Powell 1962), becomes epidemic sporadically in southeast Alaska (Schmiege and Crosby 1970), and the acreage of defoliated forest varies directly with regional temperature during the adult and larval periods.[1/] The western hemlock looper, *Lambdina fiscellaria Zugubrosa* (Hulst.), found only in the southern part of southeast Alaska, occurs primarily south of 56 degrees latitude in British Columbia (Jardine 1969). This may be due to the distribution of its primary host, western hemlock, in British Columbia (Fowells 1965).

Fewer species of insects are considered pests on southeast Alaska's trees (Hard 1967) than those considered pests on the same tree species farther south (Keen 1952). Also, the major insect species that occur in southeast Alaska in addition to forests farther south are parasitized by fewer insect species in Alaska (Torgersen 1968, 1970). The hown parasite fauna of southeast Alaska is composed primarily of hymenopterous species. Few parasitic dipterous species are represented, although flies that breed in aquatic habitats are abundant.

In the relatively simple Alaskan ecosystem, such species as the black-headed budworm often become more widespread when released by periods of favorable weather than they do in the conterminous Pacific Northwest States. This is probably due in part to the scarcity of regulatory feedback loops between tree species, pest species, and parasite and predator species that interact to govern the stability of the system. Simple ecosystems, those having relatively few species of flora and fauna with few energy pathways leading from the primary producers to the ultimate consumers, are usually unstable ecosystems (Odum 1959, Wilson and Bossert 1971). In contrast, diverse systems are more stable, and serious pest outbreaks occur infrequently (Southwood 1972).

There are no records of forest insect outbreaks in southeast Alaska before 1917. Since that time a number of epidemics have been documented, but insect control measures have never been taken for economic reasons. Within much of the remaining virgin forests, insect damage may continue to

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[1/] John S. Hard. Black-headed budworm (Lepidoptera: Tortricidae) population fluctuations in coastal Alaska in relation to temperature during adult and larval periods. Unpublished report, Forestry Sciences Laboratory, Juneau, Alaska, 1972.

fall within the limits of acceptable loss. A more complete understanding of the virgin forest ecosystem may show that the "pest" insect species are actually beneficial, since virgin forests have been evolving for thousands of years with insects an integral part.

Some effects of feeding by insects are opening of the forest canopy to allow greater light penetration to understory vegetation, alteration of species composition of both woody and herbaceous plants, and changes in the composition of litter. These and many other effects of insect feeding may result in greater total forest productivity through increased nutrient availability (Rafes 1970).

As more virgin forest is converted to intensively managed second-growth forest,. insect damage may reach economically unacceptable levels because of increased competition between insects and man and because insects innocuous in virgin forests may suddenly become pests in altered forest habitats as they have in British Columbia (Silver 1962) and other areas.

> *Actually, pest status appears to originate in four ways: by the entry of species into previously uncolonized regions; by changes in the characteristics of species that did not previously compete or otherwise interact directly with man; by changes in man's activities or habits, which make him sensitive to the existence of species to which he was previously indifferent; and by increases in the abundance of species whose interactions with man were previously negligible because of the low numbers in which they occurred. Such increases happen for one of three reasons, i.e. a lasting increase in the supply of a limiting resource, a lasting decrease in the frequency or severity of repressive interactions that previously prevented the species from exploiting fully the resources of their environments, and the simultaneous occurrence of both of these changes.* (Clark et al. 1967, p. 183.)

Insect suppression may become necessary in second-growth forests because logging will convert large areas of relatively unstable all-aged virgin forests to even less diverse, more unstable even-aged forests (Mitchell 1970).

> *The complex ecosystems of natural areas are generally more stable than ecosystems that have been drastically altered by man, since the latter may achieve stability only at the cost of large energy supplements.* (Moir 1972.)

Essentially, then, the conversion of Alaska's virgin forests to managed forests appears to be a step toward greater instability and a resultant increase in insect-caused damage, as has happened elsewhere (Graham 1956). Therefore, the relationships between insect and tree populations must be understood in order to develop biologically and economically sound forest management practices. The following biological information on major forest insect species, although incomplete, contributes to an understanding of the insect-tree relationship.

MAJOR SPECIES

BLACK-HEADED BUDWORM

The most important insect species in southeast Alaska forests is the black-headed budworm. This species prefers hemlock but defoliates spruce also. Phenology of the budworm is more closely synchronized with western hemlock than with Sitka spruce, whose buds burst earlier than hemlock, suggesting greater survival of young larvae on hemlock (Schmiege and Hard 1966b), since young larvae typically feed singly within the buds (Werner 1969). In addition, the budworm prefers hemlock for oviposition (Schmiege and Hard 1966b). Although the budworm concentrates its feeding on hemlock buds and current year's needles, egg production of females appears to be unaffected if nearly mature larvae are forced to complete development on previous years' needles (Schmiege 1965).

The budworm is also a major pest in the nearby coastal forests of British Columbia where damage to second-growth hemlock is of special concern (Prebble and Graham 1945a, Fiddick 1972). Frequently, a succession of budworm outbreaks begins in the Olympic Peninsula or southern British Columbia and progresses north to the Queen Charlotte Islands, southeast Alaska, and Prince William Sound[2/] (Prebble and Graham 1945a; Downing 1957, 1961). This phenomenon could be interpreted as the result of dispersal by moths from heavily defoliated stands since they have strong flight capabilities.[3/] Also, fall storms that occur during the budworm's flight period in September often come from the southeast which could partially account for the progression of outbreaks up the coast.

[2/] H. B. Leech. The hemlock tip-moth *(Peronea variana* Fernald) in British Columbia. B.S. thesis, University of British Columbia, Vancouver, 70 p., illus., 1933.

[3/] W. F. McCambridge. The black-headed budworm survey on the Tongass National Forest, Alaska, season of 1952. Unpublished report, USDA Bureau of Entomology and Plant Quarantine, Portland, Oreg., 11 p., illus., 1952.

A more likely explanation is that there are resident low-level populations capable of building up in place throughout southeast Alaska and in the forests of Prince William Sound to the north. Another possible explanation is that budworm populations throughout coastal British Columbia and southeast Alaska begin to increase simultaneously; but populations in the northern part of the region require more time to reach epidemic proportions because of the characteristically cooler temperatures there. Analysis of budworm populations in eastern Canada revealed a direct relationship between population trend and sum of degree-days (Miller 1966). Budworm population trends in coastal British Columbia and Alaska also are related to weather (Silver 1960, 1963; Schmiege 1966b), and rate of budworm development in Alaska is related to cumulative temperature.[4/][5/]

The earliest recorded defoliator outbreak in Alaska tentatively attributed to the budworm occurred between 1917 and 1921 (Downing 1957). The second outbreak, which resulted in some defoliation on nearly every forested acre in southeast Alaska, with greatest defoliation on well-drained slopes and in second-growth hemlock, occurred between 1948 and 1955 (McCambridge 1956). As a result of this outbreak appraisals of damage were made in three separate areas.

The first appraisal was made from the air on selected areas in the southern half of southeast Alaska in 1953,[6/] the peak year of the outbreak. Most damaged areas occurred on north- and east-facing slopes at elevations between 450 and 900 feet (see footnote 4). Only hemlock stands that contained 50 percent or more of their stems with some degree of top kill were mapped. A *gross* volume of 105 million board feet of hemlock on 6,600 acres had 50 percent or more dead crown length. The area with less than 50 percent dead crown length covered nearly 12,000 acres and contained a total hemlock volume of 180 million board feet. This report was a conservative appraisal because mortality as a result of heavy defoliation is often delayed (Kinghorn 1954), and weakened trees may deteriorate further from fungus infection (Johnson et al. 1970).

4/ W. F. McCambridge. Studies of the biology and control of the black-headed budworm in Alaska. Progress Report, Alaska Forest Research Center, Juneau, Alaska, 11 p., illus., 1955.

5/ William E. Rose. The development of the black-headed budworm, *Acleris variana* (Fernald) in response to environmental factors. M.S. thesis, University of Massachusetts, Amherst, 51 p., illus., 1962.

6/ F. T. Hutchison. An aerial appraisal of black-headed budworm damage on selected areas of the Tongass National Forest. Special report, Forest Insect Laboratory, Portland, Oreg., 8 p., illus., 1953.

The second appraisal[7] was made of mature stands on Admiralty Island in 1956, the year following collapse of the budworm outbreak in Alaska. The stands in this area were severely damaged by repeated defoliation. The appraisal showed that net volume loss averaged 7,300 board feet per acre and that the budworm showed no preference for either overstory or understory trees. An earlier examination (see footnote 4) of 121 budworm-damaged areas in the Admiralty Lakes area showed that they were most numerous at elevations between 450 and 900 feet and on north- and west-facing slopes. Also, the damaged areas were confined to mature stands containing over 50 percent western hemlock by volume.

A third appraisal (McCambridge 1956) was made near Juneau of second-growth hemlock and spruce stands that had experienced a single year of heavy defoliation. The hemlock stand, which was densely stocked, had top-kill in 25 percent of all hemlock trees, but top-kill in 85 percent of the dominant crown class trees and 52 percent of the codominant crown class trees. The spruce stand, which was much less densely stocked, had top-kill in 74 percent of all spruce trees, but top-kill in 93 percent of the dominant crown class trees and 86 percent of the codominant crown class trees. However, the top-kill in spruce was confined primarily to current year's shoot growth, whereas in hemlock top-kill extended into previous years' shoot growth.

The most recent occurrence of significant budworm defoliation in southeast Alaska occurred between 1962 and 1964 (Crosby 1965), but the outbreak collapsed in 1965 (Crosby 1966). Since then, budworm populations have remained at endemic levels and no damage has been reported. However, budworm populations reached outbreak status in 1970 on the Olympic Peninsula of Washington (Pettinger and Dolph 1971) and on Vancouver Island in British Columbia (Wood and Koot 1972) and are increasing in the Prince Rupert District of British Columbia (Andrews and Erickson 1972, Fiddick 1972). A sharp increase in budworm populations in Alaska can be expected soon. Samples taken of budworm larvae in 1971 and budworm eggs and larvae in 1972 and 1973 show that budworm populations are already increasing in southeast Alaska near Ketchikan.

HEMLOCK SAWFLY

The second most important forest insect in southeast Alaska is the hemlock sawfly (Middleton 1933, Hard and Schmiege 1968, Schmiege 1970). Its primary host is western hemlock, but other conifer species may be fed upon if they are overtopped by defoliated hemlock. Damage is often

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[7] G. L. Downing. Western hemlock damage caused by the black-headed budworm, appraisal survey Thayer Lake, Admiralty Island, Alaska. Unpublished report, USDA Forest Service, Alaska Forest Research Center, 7 p., 1957.

greatest in large hemlocks of all-aged stands.[8] Unlike the budworm, this species feeds primarily on previous years' needles, and the larvae feed in clusters. Nearly mature larvae forced to complete development in the laboratory on an unnatural diet of current year's needles experienced a disproportionate increase in female mortality and reduced egg production in survivors (Hard 1971a). In the field, heavily defoliated hemlock trees produce less fecund and proportionately fewer females than do lightly defoliated trees, indicating a feedback mechanism between host and insect that keeps the sawfly from reaching the damaging proportions characteristic of the black-headed budworm. A study of the sawfly in British Columbia showed a similar relationship between population density, sex ratio, and egg production.[9]

Hemlock stands in British Columbia that appeared most prone to sawfly outbreaks had a heavy undergrowth of salal (see footnote 9). This broad-leaved evergreen species occurs in Alaska as far north as Sitka (Hultén 1968, Viereck and Little 1972) and is abundant on Prince of Wales Island. The sawfly has been more active in southern southeast Alaska than in the northern half, and local outbreaks persist longer in the south. Areas on Prince of Wales Island that have a history of repeated sawfly outbreaks often have salal as a major component of the ground vegetation. In addition, a study of the abundance of sawflies by stand composition and site index in British Columbia showed that sawflies were most abundant on the intermediate sites of an open stand containing 60 percent western hemlock and 40 percent western redcedar, which resembles some infested stands in Alaska. The areas in British Columbia with the next most abundant sawfly populations were on the intermediate sites of a closed,, pure hemlock stand with salal and swordfern as the most abundant ground cover species (see footnote 9).

The sawfly often becomes epidemic in the same areas and at the same time as the budworm, which suggests that populations of both species may be released by a common environmental factor (Downing 1961). When both species feed together on the same tree, which often happens, the tree may be completely defoliated (Schmiege 1970). Competition for food between the species is probably more detrimental to the sawfly for several reasons. Sawflies hatch later than budworms, become established later, and complete development later. In case of a local food shortage within a tree or between adjacent trees, sawfly larvae must walk to a more favorable feeding site, whereas budworm larvae can spin webs and drop to a more favorable feeding site. The budworm apparently can complete development on previous years' needles, but the sawfly cannot complete development on current

[8] R. F. Taylor. Insect infestation, report for field season of 1932. Unpublished report, USDA Forest Service, Juneau, Alaska, 11 p., illus., 1932.

[9] George Stuart Brown. Some factors influencing the populations of the hemlock sawfly, *Neodiprion tsugae* Midd. M.S. thesis, University of British Columbia, Vancouver, 57 p., illus., 1951.

year's needles without detrimental effects. Also, sawfly adults in Alaskan populations do not appear to have the strong flight capabilities of the budworm which enables budworm moths to disperse readily from defoliated to undefoliated areas. This could be due to colder temperatures during the adult sawfly period, since peak emergence usually occurs in early October.

Additional differences between the sawfly and the budworm may account for the latter's reputation as the more destructive species. Females in a healthy sawfly population have a mean fecundity of 72 eggs (Hopping and Leech 1936, Hard and Schmiege 1968), but females in a healthy budworm population have a mean fecundity of at least 87 eggs (Schmiege 1965). In the laboratory, a single sawfly larva consumes approximately 80 hemlock needles (Hard and Schmiege 1968), but a single budworm larva destroys approximately two buds, each capable of producing over 50 needles, and consumes or destroys an additional 60 needles (Werner 1969).

Another major difference between the two species is that during outbreaks sawfly infestations occurred commonly in local areas on south to northwest aspects (see footnote 8) (Hard 1971b), but budworm damage was much more widespread and occurred commonly on west, north, and east aspects (see footnote 4). Whether this is an inherent difference between the two species or whether other factors such as climate in southeast Alaska are more favorable to buildup of budworm populations is unknown. When all of the hown differences between the sawfly and the budworm are considered, it appears that the sawfly is more closely in harmony with its primary host, western hemlock, than is the budworm.

OTHER DEFOLIATORS OF POTENTIAL IMPORTANCE

Four additional moth species of potential importance to southeast Alaska's forests are a spruce budworm, *Choristoneura* sp., probably *orae* Free. but formerly referred to as *fwniferana* (Clem.) (Freeman 1967), the western hemlock looper, *L. fiscellaria Zugubrosa*, the saddleback looper, *Ectropis crepuscularia* Schiff., and the green-striped forest looper, *Melanolophia imitata* Wlk.

A small spruce budworm outbreak occurred on Sitka spruce near Haines between 1948 and 1950 but apparently resulted in no permanent damage (Downing 1957). No other outbreak of this species in southeast Alaska has been recorded.

In 1965 and 1966 a local hemlock looper outbreak occurred about 50 miles southeast of Wrangell.[10/] Approximately 400 acres of vigorous Sitka spruce were heavily defoliated (Torgersen and Baker 1967). This is the only outbreak of the hemlock looper ever recorded in Alaska, but the looper is very destructive in coastal forests of British Columbia and the Pacific Northwest (Keen 1952) where outbreaks have occurred repeatedly, particularly on mature, open-grown hemlock in valley bottoms (Kinghorn 1954, Jardine 1969).

Both the saddleback looper and the green-striped forest looper occur commonly in southeast Alaska; but to date, only the saddleback looper has reached outbreak status. It, with the hemlock sawfly, caused moderate to severe defoliation and some mortality of western hemlock on 200 acres near Ketchikan in 1969 (Crosby and Curtis 1971). Both loopers attack a wide range of tree and shrub species (Sugden 1964), but western hemlock is a preferred host.

The saddleback looper caused heavy tree mortality on over 10,000 acres of forest near Kitimat, British Columbia, in 1960 and 1961 (Ruth and Silver 1966) but had not been considered a serious pest before this (Morris 1970).

The green-striped forest looper was not regarded as a serious forest pest either until 1960, when it defoliated approximately 23,000 acres of forest on the west coast of Vancouver Island (Silver et al. 1962). In 1963 and 1964 an outbreak extended over 100,000 acres on Graham Island in the Queen Charlotte Islands of British Columbia, but the population declined apparently due to unfavorable weather during the larval period in 1964 (Fiddick et al. 1965).

The spruce aphid, *Neomyzaphis abietina* (Wlkr.), is a sapsucking insect whose feeding defoliates and often kills Sitka spruce in the Pacific Northwest (Keen 1952) and coastal British Columbia (Holms and Ruth 1968). This species caused some Sitka spruce mortality near Sitka in 1969 and 1970, but the outbreak has subsided.

The spruce aphid can reproduce throughout the year, so a mild winter may release aphid populations and a harsh winter may aid in causing a population to collapse (Wilson 1948, Bevan 1966, Holms and Ruth 1968, Parry 1969). In British Columbia this species is considered a pest of ornamental trees and nurseries. In Alaska it may become a pest in local areas if released by favorable winter weather, but natural control factors such as parasites, starvation (Hussey 1952), and harsh winter weather can be expected to bring aphid populations under control before widespread damage occurs.

[10/] J. W. Quimby. The use of frass drop in predicting defoliation caused by the western hemlock looper *(Lambdina fiscellaria lugubrosa* (Hulst)) in southeast Alaska. M.F. thesis, University of Michigan, Ann Arbor, 52 p., illus., 1967.

Occasionally, hardwoods are defoliated by the cottonwood leaf beetle, *Chrysomela scripta* F. In 1971 and 1972 the striped alder sawfly, *Hemichroa crocea* (Fourcroy), infested young alder stands near Juneau. Elsewhere both species produce more than one generation per year (Baker 1972) but appear to produce only one in southeast Alaska. Hardwood species can survive repeated defoliation; therefore mortality due to these species is negligible, but growth is reduced.

SPRUCE BEETLE

The most important bark beetle in terms of reported damage in southeast Alaska is the spruce beetle, *Dendroctonus rufipennis* Kby., formerly called *Dendroctonus obesus* (Mann.). This species is a major pest of spruce in coastal Oregon and Washington (Keen 1952) and the most destructive pest of spruce in British Columbia (Grant and Cottrell 1968, Collis and Harris 1970).

Between 1941 and 1946, this species killed over 35 million board feet of Sitka spruce on a 6,400-acre tract on the west side of Kosciusko Island.[11/] This particular stand was one of the last of high-quality, mature Sitka spruce in southeast Alaska, The infested area was on humpy terrain with shallow, well-drained soil over limestone. The stand was composed of approximately two-thirds spruce and one-third hemlock, with much of the spruce over 400 years in age and 4 feet in diameter. This overmature stand was ripe for attack by the spruce beetle, and a number of additional factors could have contributed to the outbreak. Extensive windthrow occurred on the west side of Kosciusko Island before the outbreak, and during World War II logging took place at Edna Bay within 5 miles of the outbreak area. It is possible that beetles multiplied in down timber or slash and moved to the live trees, Another possibility is that weather conditions became favorable for beetle population increase, since rate of brood development increases with temperature (Collis and Harris 1970). Weather records for the immediate area are not available, but an examination of weather data for Sitka, approximately 100 miles northwest, revealed that the summers of 1939-42 were warmer than normal and those of 1939-41, drier than normal. Since both areas occur on the west coast of southeast Alaska where climate is relatively uniform, it is reasonable to assume that conditions probably were similar and that weather released the beetle population.

11/ R. L. Furniss and Ivan H. Jones. A second report concerning the bark beetle outbreak on Kosciusko Island. Unpublished report, USDA Forest Service, Portland, Oreg., 9 p., illus., 1946.

In 1956 an appraisal was made of a much smaller spruce beetle outbreak confined to a north-facing slope where western hemlock predominated on Dall Island.[12/] Approximately 1-1/2 million board feet of mature Sitka spruce died on 200 acres over several years, but the outbreak apparently subsided in 1957 (Downing 1957).

Stands in southeast Alaska where mature Sitka spruce occurs as a major component are often confined to primary succession zones such as along rivers and beaches. The most extensive mature spruce stands occur near Yakutat. However, there remain no extensive overmature stands comparable to the one that was decimated by the spruce beetle on Kosciusko Island. Susceptibility of existing spruce stands to attack by the spruce beetle probably depends on weather conditions favorable to the beetle, availability of spruce slash or blowdown in a condition suitable for beetle brood production, or stands of low vigor trees weakened by flooding, defoliation, or prolonged drought.

CEDAR BARK BEETLE

A cedar bark beetle, *Phloeosinus squamosus* Blkm., infests both western redcedar and Alaska-cedar, *Chamaecyparis nootkatensis* (D. Don) Spach., in southeast Alaska. Downing (1960) surveyed a cedar bark beetle outbreak extending over several thousand acres of scrub cedar on Kuiu and Kupreanof Islands and killing thousands of cedar trees in the larger diameter classes.

Because cedar is rot resistant, many of the beetle-killed trees are still standing, and large areas of whitened cedar snags are visible from the air. Causes of this outbreak are unknown, and since cedar has until only recently been considered of limited value, compared with hemlock and spruce, no attempt has been made to study the cedar-beetle relationship.

Much of the dead cedar throughout southeast Alaska occupies poorly drained slopes and muskegs and may have died from a variety of causes over a prolonged period. The durability of cedar wood accounts for a seemingly larger amount of mortality compared with that of hemlock and spruce. Since the latter two species deteriorate rapidly after death, aerial observation reveals recent mortality, whereas observation of dead cedar reveals cumulative mortality over a much longer period.

[12/] George L. Downing. Sitka spruce beetle, South Tongass National Forest, Port Bazan, Dall Island, Alaska. Unpublished report, USDA Forest Service, Alaska Forest Research Center, 2 p., 1956.

AMBROSIA BEETLE

The ambrosia beetle, *Trypodendron lineatum* (Oliv.), is not destructive to living trees, but its reproductive behavior damages softwood logs. Adults bore into logs during late spring and early summer, lay eggs, and inoculate the mines with a symbiotic fungus which serves as larval food. Damage is not structural because the mines are very small in diameter. However, the introduced fungus causes a blue-to-black staining of wood cells surrounding the mines, decreasing log value, especially if it is to be converted to lumber or veneer (McBride 1950, McBride and Kinghorn 1960). Fortunately, most of the damage is confined to sapwood, but it may extend into the heartwood depending on tree species (Prebble and Graham 1957).

Ambrosia beetle damage cannot be eliminated economically because beetle populations breed in stumps, slash, and fallen trees; but it can be reduced substantially by maximum utilization of breeding material to reduce population buildup and through log handling practices. Logs from trees felled between late summer and midwinter are much more attractive to ambrosia beetles than those from trees felled between late winter and midsummer (Dyer and Chapman 1965). Therefore, if logs from autumn-felled trees are stored in water before the beetle attack period, which occurs normally in June, damage will be reduced. The exposed portions of floating logs may be damaged (Richmond and Radcliffe 1961), but there is little chance for population buildup in log rafts because brood survival is low in water-soaked logs (Dyer and Chapman 1962). However, salt water log storage creates a marine borer hazard (see section on shipworm). If logs are stored on land at the log dump or mill, damage by ambrosia beetles can be reduced substantially by keeping the logs soaked with a continuous fine water mist (Richmond and Nijholt 1972). Sprinkling also reduces log deterioration caused by checking and fungi (Lane and Scheffer 1960, Roff and Dobie 1968).

OTHER BEETLES OF POTENTIAL IMPORTANCE

The Sitka spruce weevil, mentioned earlier, is a potential pest of spruce in southeast Alaska. This insect kills the leaders of young spruce, which results in reduced height growth, a deformed stem, and poorer log grade of the host tree (Wright 1970). It occurs in coastal British Columbia, but has not been found in the Queen Charlotte Islands. Although adults in Washington are active and feed on host stems and laterals in winter, temperatures in the Queen Charlotte Islands and southeast Alaska may be too low to permit establishment of the weevil. The lower host stem temperature threshold for weevil mating is approximately 65° F. and for egg-laying, approximately 75° F. (Gara et al. 1971), both relatively high temperatures for southeast Alaska. On Vancouver Island (Harris et al. 1968) and in Oregon (Wright and Baisinger 1956), intensity of attack by the weevil was highest on young spruce in valley bottoms and lowest in areas close to tidewater.

Another weevil species, *Steremnius carinatus* (Boh.), that girdles and kills conifer seedlings in coastal British Columbia (Condrashoff and Kinghorn 1963), occurs in southeast Alaska. This species breeds in stumps and roots, and the adults feed on the bark of conifer seedlings and on ground vegetation (Koot 1972). Apparently the weevil has caused extensive damage only in areas in coastal British Columbia where forests were clearcut, burned, and planted within a 2- or 3-year period. Adult weevils that emerged from stumps killed many conifer seedlings, the only food available (Lejeune 1962).

In southeast Alaska, clearcut areas normally regenerate naturally and much ground vegetation is present with conifer seedlings. Thus, this weevil is unlikely to become more than a temporary and local problem.

SHIPWORM

The shipworm, *Bankia setacea* Tryon, is not an insect but a mollusk, destructive to rafted logs and untreated piling in British Columbia and Alaska. This marine borer, incorrectly called *Teredo* but closely related, is especially destructive in booming grounds and log storage areas because of population buildup in sunken logs and subsequent mining in fresh logs. Chemicals will protect logs from attack, but such treatment is a potential contamination hazard.

Shipworm damage can be eliminated or substantially reduced by (1) transporting logs by barge and storing them on land, (2) removing sunken logs from log storage areas, (3) minimizing the period when logs are stored in salt water, or (4) storing logs in fresh water since salinities of six or fewer parts per thousand are lethal to *Bankia* (Bramhall 1966). There are few bodies of fresh water suitable for log storage in Alaska, and storage at river mouths provides limited protection (Trussel et al. 1956). Perhaps fresh water impoundments deep enough for storage of floating logs could be constructed on the ocean surface. This would also protect the logs from ambrosia beetles.

NATURAL CONTROL FACTORS

Pest insect populations fluctuate from endemic levels where no noticeable damage occurs to epidemic levels where damage becomes prevalent. Little is known about the causes of epidemics, but favorable weather is apparently an important factor in the release of insect populations near the extremities of their ranges (Watt 1968). Much more is known about natural factors involved in collapses of pest epidemics: (1) parasitic insects, (2) predators such as spiders, birds, and small mammals, (3) microbial disease organisms such as viruses, fungi, and bacteria, (4) starvation, and (5) adverse weather. Parasites, predators, disease organisms, and starvation kill proportionately more insect hosts as the hosts become more abundant, whereas adverse weather usually affects insects independent of their abundance. Near the extremities of an organism's natural range, adverse weather is usually a more important mortality factor than are biological agents (Watt 1968). Weather may also regulate the effectiveness of the biological mortality agents because parasite and predator activity and growth of pathogenic organisms are controlled by such factors as temperature and humidity.

Little is hown of the effects of predation on forest insect populations in southeast Alaska. Small mammals such as mice, voles, and shrews are suspected of causing minimum pest mortality, compared with spiders and birds, except to insect species such as some loopers that pupate on the ground. Much more is hown about the parasitic insects than any other pest mortality factor, but viruses and fungi appear to be the most important biological agents contributing to the collapse of forest pest epidemics in southeast Alaska.

The parasite complex of the black-headed budworm in southeast Alaska is composed of at least 16 species that attack budworm eggs, larvae, and pupae. This contrasts sharply with a total of 48 species that attack the budworm in coastal British Columbia (Torgersen 1970). Budworm populations in Alaska are also infected by an unidentified virus and a fungus, *Empusa grylli* (Fres.) Nowak.[13/] A polyhedral virus was considered to be the most important natural control factor involved in the collapse of the budworm outbreak in coastal British Columbia in the 1940's (Prebble and Graham 1945b, Graham 1954). Although associations do exist between budworm population fluctuations and weather in coastal British Columbia and southeast Alaska, the only quantitative measure of budworm mortality attributed to effects of weather was an average egg loss of 30 percent during three winters in the early 1960's (Schmiege 1966a).

The parasite complex of the hemlock sawfly in southeast Alaska is composed of at least nine species, and most of them attack prepupal sawfly larvae within cocoons (Torgersen 1968, 1969). In Oregon, the sawfly parasite complex consists of at least 20 species and most attack host larvae in cocoons (Furniss and Dowden 1941). Studies in Holland show that larval sawfly predation by birds and parasitism by wasps are low compared with attacks on moth larvae. This is apparently due to evolved sawfly behavior mechanisms whereby visual stimuli in the form of moving enemies elicit larval responses, such as rearing, stretching, jerking, or regurgitation of a droplet of fluid, which startle or repel the potential attacker. The effect is greater if several larvae or an entire feeding colony respond simultaneously (Prop 1960). Hemlock sawfly larvae respond

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13/ W. F. McCambridge. Studies of the biology, habits, and control of the black-headed budworm in Alaska, season of 1953. Unpublished report, USDA Forest Service, Pacific Northwest Forest & Range Experiment Station, Portland, Oreg., 25 p., illus., 1954.

in nearly identical ways to threat, which may partially account for the very low incidence of larval parasitism, No viruses have been isolated from Alaska sawfly populations, but apparently a virus has caused sawfly mortality in coastal British Columbia (see footnote 9).

The most important pathogen of the hemlock sawfly in Alaska is a fungus, *Entomophthora sphaerosperma* (Fres.), which infects larvae. Recent studies showed this fungus was much less prevalent in sawfly populations in 1971 than in 1969 and 1970. However, the summer of 1971 was comparatively dry, and many fungi require moist conditions for growth. In a study made in 1945, an unidentified fungus was considered to be the most effective natural control agent of the sawfly on Vancouver Island.[14/]

No attempts have been made to correlate sawfly population fluctuations with weather. The only quantitative measure of weather-induced loss was 34-percent mortality of sawfly eggs during the overwintering stage in hemlock needles in 1964-65 (Schmiege 1966a). The amount of overwintering mortality apparently varies among years according to weather conditions. The winter of 1971-72 in southeast Alaska was characterized by extremely prolonged cold weather and little rain. As a result, much of the western hemlock near Juneau showed signs of "winter burn" or moisture stress and many needles dried and fell off. Therefore, egg mortality of both budworms and sawflies may have been significantly higher than average during the winter of 1971-72 due to loss of egg-bearing needles.

An appraisal of natural mortality factors of the hemlock looper outbreak near Wrangell showed the parasite complex for the looper to consist of at least eight species (Torgersen 1971). This compares with a complex of at least 12 parasite species that attack the looper in the Pacific Northwest[15/] and British Columbia (Hopping 1934). The most important mortality factor of the looper in southeast Alaska was a polyhedral virus which caused the population to collapse during the late larval stage in 1966 (Torgersen and Baker 1967).

Hemlock looper outbreaks in British Columbia appear to be related to unusually dry weather in September, when looper moths normally mate and lay eggs[16/] (Thomson 1952), Analysis of precipitation records for Wrangell,

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14/ G. R. Wyatt and P. H. D. Parizeau. Studies on the hemlock sawfly, *Neodiprion tsugae* Midd. at Quatsino Sound, B.C., in 1945. Report of Forest Insects Investigations, Victoria, B.C., 8 p., 1946.

15/ V. M. Carolin. Studies on western hemlock looper in southwest Washington in 1962. Unpublished progress report, USDA Forest Service, Pacific Northwest Forest & Range Experiment Station, Portland, Oreg., 26 p., illus., 1964.

16/ M. G. Thomson. Studies of factors affecting reproduction in the western hemlock looper, *Lambdina fiscellaria lugubrosa* (Hulst) (Lepidoptera: Geometridae). Canada Department of Agriculture, Science Services, Forest Biology Division, Interim Report 1955-4, Forest Biology Laboratory, Victoria, B.C., 41 p., 1956.

the weather station nearest the Alaskan looper infestation, showed that for the period 1950-71, September precipitation was lowest for 2 consecutive years, 1964 and 1965. In 1964, September precipitation was only 54 percent of normal; and in 1965, only 21 percent of normal. Conditions were apparently favorable for mating and oviposition then since most defoliation occurred in 1965 and 1966.

SUGGESTED ALTERNATIVES FOR PEST MANAGEMENT

The foregoing history of forest insect activity in southeast Alaska's forests during the last half century indicates that insect outbreaks have occurred infrequently relative to coniferous forests at lower latitudes, have affected vast areas, and that few insect species are involved. This situation has existed for thousands of years, and the existing virgin forests are, in part, a result of it since forests respond to all environmental influences. Therefore, a description of southeast Alaska's virgin forests as decadent is a relative tern. They are decadent only in terms of production of wood fiber harvestable for man's use as compared to what might be produced under even-aged management.

From the ecological viewpoint, the virgin forests are a healthy ecosystem composed of many plant and animal organisms as well as trees, and the system is capable of restoring itself after catastrophic disturbances such as insect outbreaks. Such disturbances, although detrimental to individual trees, may be beneficial to the complex virgin forest ecosystem. This is analogous to the situation concerning beneficial effects of fire in northern coniferous forests (Heinselman 1971) and the folly of attempting to control all wildfire. The recent indiscriminate control of fire, in areas where uncontrolled fire was a common occurrence, has allowed fuels to increase to a point where a runaway fire might actually destroy the fire-resistant overstory of mature trees (Prasil 1971). The lesson here is that it may not always be wise to attempt to control a factor that is an integral part of a natural system. Therefore, perhaps the best alternative to outright control of insect outbreaks in most of southeast Alaska's remaining virgin forests is to let the outbreaks run their course and accept the fact that trees will die, but establish a flexible harvesting policy that allows for salvage of timber in areas suitable for conversion to high production even-aged management. Insect suppression may be justified in high quality, old-growth stands that cannot be salvage-logged immediately due to such factors as inaccessibility or administrative delays, or recreation areas and town sites where scenic values are high.

The philosophy for pest management or control in managed even-aged forests differs because of competition between man and pests for the same high value resource. Even in these forests insect outbreaks may occur infrequently, but if the frequency of occurrence remains comparable to what has happened before, several major outbreaks can be expected to occur in a 100-year period, the planned rotation age at which managed second-growth stands will be harvested. In addition, new pest problems will probably arise from management-induced changes in habitat, as has happened in British Columbia (Silver 1962) and other areas (Mitchell 1970).

Although use of chemical insecticides may be justified in the management of southeast Alaska's forests, the decision to use them should be made very carefully for the following reasons. (1) The streams within Alaska's forests produce another high value resource, salmon. Application of chemical insecticides regardless of caution will probably contaminate some streams and, unless the chemical has a low vertebrate toxicity, may have some direct effect on fish. (2) Unless the chemical used is toxic only to the pest species, many beneficial insects, including parasites, predators, and aquatic insects, may be destroyed. (3) The immediate cost of insecticide application will be compounded because the initial cost must be prorated for the years remaining until the stand is ready for harvest. (4) Insecticidal treatment is merely a stopgap measure and does not reduce susceptibility of the stand to reattack. Instead, such treatment may result in a subsequent increase in the pest population. Most insecticides do not have persistent insecticidal effects, and survivors of the treatment are relieved of constraints such as intraspecific competition (watt 1968). However, naturally occurring insecticides such as the pyrethrins or their synthetic substitutes, the pyrethroids, may have potential for use in Alaska, because they are highly toxic to the black-headed budworm and the hemlock sawfly and risk of environmental contamination is low.

Forests in drier climates are manipulated silviculturally to increase their resistance to fire. It is possible that Alaska's second-growth forests could be managed for resistance to insects. How this can be done is not known, but as we learn more about the requirements and limiting factors of potentially destructive pests the chances are increased of developing silvicultural control measures.

Clearcutting is the currently used form of timber harvesting in the region and is an accepted silvicultural technique for assuring good hemlock and spruce reestablishment on cutover lands. Generally, spruce is more abundant in the second-growth stands than in the virgin stands (Taylor 1932). This may be advantageous because most of the known pest insect species in southeast Alaska prefer western hemlock; also spruce can apparently withstand a greater degree of defoliation.

Many of the young second-growth stands are so densely stocked that they are almost devoid of ground vegetation. Thinning these stands to reduce tree competition would have the additional benefit of increasing light penetration through the canopy to allow establishment of ground vegetation. Since many insect parasite species feed during the adult stage on flower pollen and fruit of woody and herbaceous plants, thinning would tend to maintain these beneficial forms within the second-growth stands and would increase biological diversity. Also, wider leave strips between clearcuts, and more clearcuts smaller than the current average size, would probably provide greater effectiveness of natural controls such as some parasite and bird species that normally occur on the edges of old-growth forests, but range out in search of hosts or food. Smaller clearcuts on a staggered harvesting schedule would also reduce area of single-aged contiguous "monoculture" suitable for buildup of pest populations.

Allowing alder to remain in some second-growth stands despite its inhibitory effect on early growth of spruce and hemlock regeneration may be justified for several reasons. Alder improves the stand by fixing nitrogen in the soil and by inhibiting growth of some tree pathogens in the soil (Tarrant and Trappe 1971). An increase in available nitrogen may reduce conifer.susceptibility to defoliation by insects; nitrogen fertilization in Europe has had similar results (Francke-Grosmann 1963). Retaining alder would also increase stand diversity which is less desirable for insect buildup.

Perhaps entomologists should be involved with other specialists in determining what areas could be safely converted to even-aged management and how timber sales should be laid out in order to create insect-resistant, second-growth stands. Pest problems *that* arise due to management practices, as they have in other areas (Graham 1956, Lejeune 1962), could be averted or minimized.

Another way in which pest problems might be reduced would be to import parasites and predators that do not now occur in southeast Alaska. This is an extremely complex problem that requires much study for several reasons. For example, parasites that attack pests such as the black-headed budworm and the hemlock sawfly in the Pacific Northwest and British Columbia but not in Alaska probably cannot be successfully introduced; otherwise, they would probably now occur in Alaska.

Parasites that occupy similar habitats in areas with climate, fauna, and flora comparable to southeast Alaska should be considered for introduction. The spruce-fir forests of northern Japan are a potential source. The black-headed budworm parasite complex in the Maritime Provinces of eastern Canada (Miller 1966) should also be considered as a source. Such species would have to be tested intensively prior to introduction to assure that (1) they could successfully parasitize Alaskan pest species, (2) Alaska's climate was amenable to their survival, (3) the flora of Alaska was suitable for needs such as supplementary feeding for adults and, most important, (4) the introduced parasites would not compete with native species to the point that their combined effect on the pest population would be less than before introduction. In any case, the decision to introduce exotic species to an area should not be made without careful analysis (Tomes 1972).

Apparently, some niches exist in southeast Alaska that could be filled by introduced parasite species. Hemlock sawfly eggs and free-feeding larvae are almost completely free of parasite attack (Torgersen 1968, 1969), and only one species is hown to parasitize black-headed budworm eggs in the west (Torgersen 1970). Ideally, an introduced species should be capable of successfully parasitizing several host species in order to maintain a viable population that could exert immediate control on a different host that suddenly increased in numbers. One of the major parasites of the sawfly and the budworm which also parasitizes the hemlock looper is *Itoplectis quadricingulatus* (Prov.). Its effectiveness against any host may be partially contingent on maintenance of a population on an alternate host in the same or nearby areas.

Parasites and predators generally cannot cause a pest epidemic to collapse before significant damage has been done, because their response to increase in host numbers is usually delayed, especially if they have only one generation per year. They are important pest regulators, however, and forests should be managed to maximize their effect.

Probably a more effective way to reduce pest populations to tolerable levels is through the manipulation of naturally occurring disease organisms because they are virulent, do not normally compete detrimentally with parasites and predators, and do not cause environmental contamination (Cameron 1971). Unlike chemical insecticides whose virulence may be reduced by evolution of resistant insect strains, these biological insecticides (or pathogens) are also capable of evolving in response to evolved resistance in their insect hosts.

In drier areas, the best candidates for such use are viruses and bacteria because they are more amenable to manipulation than are the fungi. However, in the cool, moist forests of southeast Alaska the pathogenic fungi might show more promise. In British Columbia, encouraging experimental results have occurred through manipulation of the fungus, *Cordyceps*, in controlling the green-striped forest looper.[17] Another important reason for considering fungi is that they can be cultured easily on artificial media (Tanada 1967). Development of such materials to the operational stage requires much experimentation, testing under laboratory and field conditions, and approval by the Federal Environmental Protection Agency before they can be used. This is a lengthy, expensive process but should be considered. Viruses and fungi that occur naturally in black-headed budworm and hemlock sawfly populations are potential candidates for manipulation in southeast Alaska.

In the past 20 years, a biological insecticide in the form of a bacterium, *Bacillus thuringiensis* Berliner, has been cultured and sold commercially under the name of Thuricide.[18] This material has little or no toxic effect on most parasites and predators. It kills plant-feeding moth larvae both by infecting and killing the insect directly and by producing a substance toxic to insects.

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[17] Personal communication with Roy Shepherd, Research Entomologist, Victoria, B.C.

[18] Mention of products by name is for the information and convenience of the reader and does not constitute an official endorsement or approval of any product by the U.S. Department of Agriculture to the exclusion of others which may be suitable.

A commercial formulation of the bacterium and toxin was tested experimentally against the black-headed budworm in Alaska with some success (Schmiege and Hard 1966a). In this very limited laboratory test performed at field temperatures and humidities and using several concentrations of Thuricide on dipped foliage, the highest mortality to budworm larvae was 81 percent. The experiment was terminated after 120 hours of larval exposure to this material on hemlock foliage; but, if the test had been run longer, mortality might have been higher due to delayed effects of actual bacterial infection.

Use of *B. thuringiensis* to control the spruce budworm in Canada has been unsuccessful because susceptibility of budworms is dependent on larval age, physiological condition, and environmental temperature. Recent studies show that addition of an enzyme, chitinase, to the bacterial formulation increased the infectivity rate of the bacterium to budworm larvae and increased efficiency of the bacterium at lower temperatures (Smirnoff 1972, Smirnoff et al. 1972). Chitinase is an enzyme produced naturally by insect-killing fungi that enables fungal spores to penetrate the layer of chitin in the insect integument or gut. Until recently, it was produced commercially in small quantities by culturing certain bacteria and fungi and was very expensive. Now the enzyme can be extracted cheaply in large quantities from viscera of slaughtered domestic fowl (Smirnoff 1972). This discovery may result in a more extended use of *B. thuringiensis* as a biological insecticide. Since the bacterium does not become permanently established in a pest population, it has the disadvantage of expense in repeated application, However, it does not contaminate the environment whereas use of a chemical insecticide could.

Economics will dictate the need for control of pest populations in the second-growth forests of southeast Alaska, but the means used will be largely determined by existing techniques and acceptability of side effects. Although a number of alternative approaches varying in effectiveness and cost have been presented, probably the least expensive approach in the long run, environmentally as well as monetarily, is to anticipate potential pest problems and attempt to forestall them through cultural manipulations of the forest and natural control factors. This will not completely eliminate the need for expensive pest control practices such as the application of insecticides, but it will reduce the need for them.

SUMMARY

Relatively few insect species are destructive to the forests of southeast Alaska, and weather during the growing season appears to be a major limiting factor in their activity. Two defoliators, the black-headed budworm and the hemlock sawfly, have caused the most damage in the past, primarily to forests south of Frederick Sound. However, much of the virgin forest in southeast Alaska is all-aged and defoliator outbreaks that resulted in extensive top-kill and complete tree mortality have not, to our knowledge, destroyed entire stands.

Insects and their host trees have been evolving together for thousands of years, with each responding to changes in the other. Thus, it is quite possible that the insects, though destructive to individual trees, are actually beneficial to the virgin forest ecosystem. Insects are obviously partly responsible for the present structure of southeast Alaska's virgin forests. Therefore, it is important to understand that they are not intruders but a natural and perhaps necessary component of the system.

As more virgin forest is harvested and converted to managed stands, what are now potential insect pests may become actual pests for a variety of reasons, but primarily because of increased competition with the forest manager for a resource in which he is investing time and money and expects maximum return.

Pest problems have intensified in nearby coastal British Columbia as more forest land has been placed under management; similar problems can arise in southeast Alaska for the same reason. Potential pest problems could be averted in some cases through silvicultural practices. However, since many of the requirements and limiting factors of the potential pest species are as yet unknown, effective silvicultural practices cannot always be prescribed. Thus, the alternative may be direct pest suppression methods.

Alternative approaches such as insecticide application, parasite introduction, and manipulation of microbial disease organisms will not be operationally feasible until more research has been completed. Of the three alternatives, insecticides may be most attractive to the manager because their operational use could be developed most rapidly. However, use of certain insecticides could be disadvantageous, on both a short- and long-term basis, because it could be detrimental to the salmon resource in southeast Alaska, and it would be a stopgap measure that does not reduce stand susceptibility to attack. The pyrethrins and the biological insecticide, *Bacillus thuringiensis*, are prime candidates for further testing against major defoliators if the insecticide alternative is given top priority because they are potent, have low vertebrate toxicity, and risk of environmental contamination is low.

The forest manager's current, most realistic approach to insect pest management in virgin stands based on biological and economic considerations may be to do nothing to suppress widespread outbreaks. He should allow them to run their course but establish a flexible harvesting policy that allows for salvage of good quality timber in damaged areas and conversion of nonproductive old growth to more productive even-aged stands.

The manager's primary approach to insect control in intensively managed stands should be prevention, assisted by suppression. Prevention, which consists largely of stand manipulation to maximize effects of natural insect mortality factors, will usually eliminate need for insect suppression. However, suppression, which usually involves use of insecticides, may be required in areas with high commercial or esthetic values where failure to control could result in heavy losses.

OUTLINE OF FOREST INSECT RESEARCH NEEDS

1. TREE PESTS
   - A. Continue population studies to determine and quantify key mortality factors.
   - B. Develop additional sampling techniques.
   - C. Develop techniques to determine actual forest losses caused by insects.
   - D. Identify silvicultural techniques that inhibit growth of pest insect populations.
   - E. Test safe insecticides and naturally occurring pathogens against laboratory and field populations of potentially destructive insect species.

2. AQUATIC INSECTS
   - A. Determine taxonomy and life histories.
   - B. Determine relative importance of various species and stages of development as a source of food for trout and juvenile coho salmon.
   - C. Determine and quantify physical factors that limit aquatic insect populations.
   - D. Determine effects of various forest management practices on the limiting factors and subsequent effect on aquatic insects.
   - E. Develop sampling techniques to measure effects of insecticidal treatment of stands on aquatic insects.

3. SOIL INSECTS
   - A. Determine taxonomy and life histories.
   - B. Determine importance regarding conversion of slash and litter to soil.
   - C. Determine and quantify physical factors that limit soil insect populations.
   - D. Determine effects of various forest management practices on soil insects.

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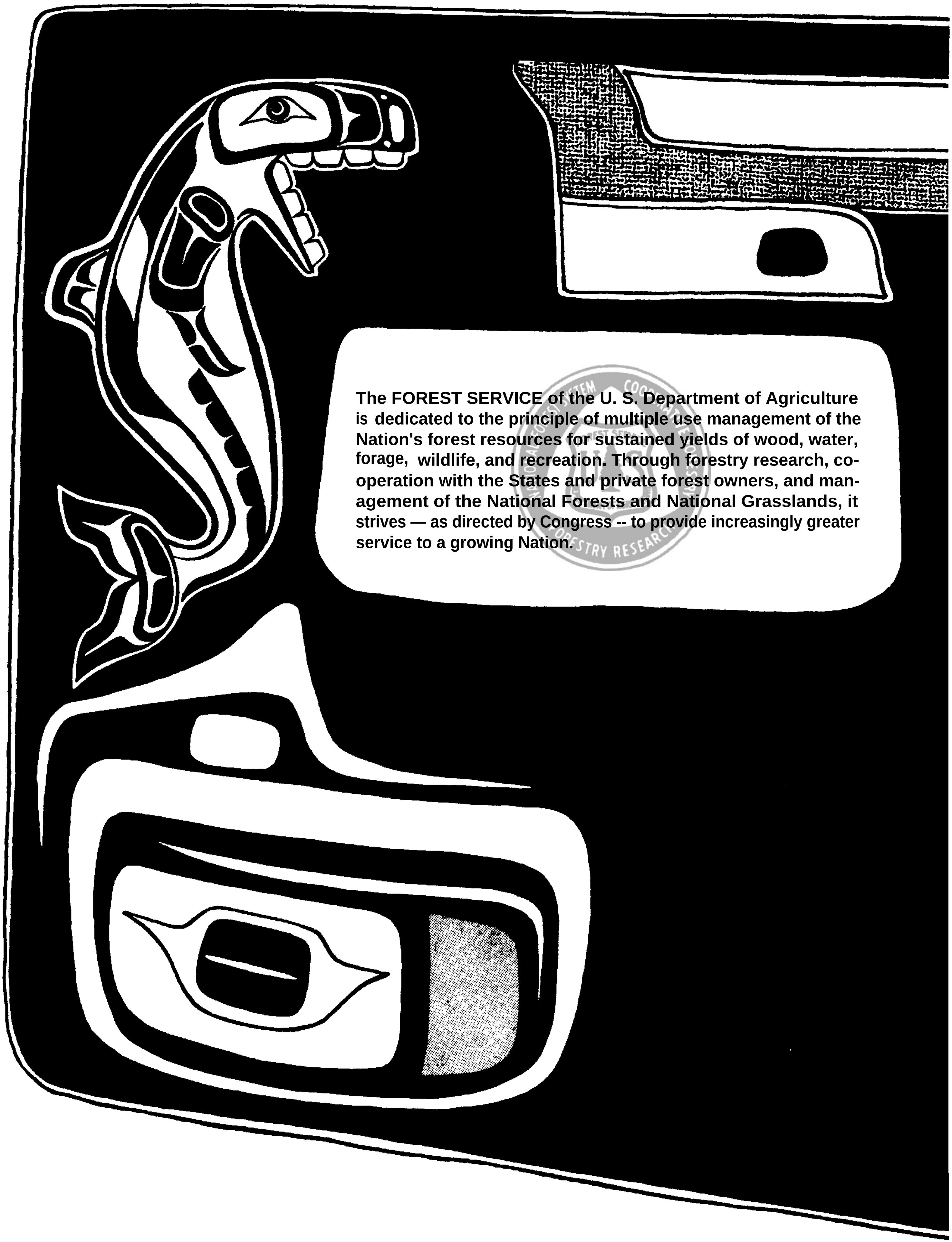

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