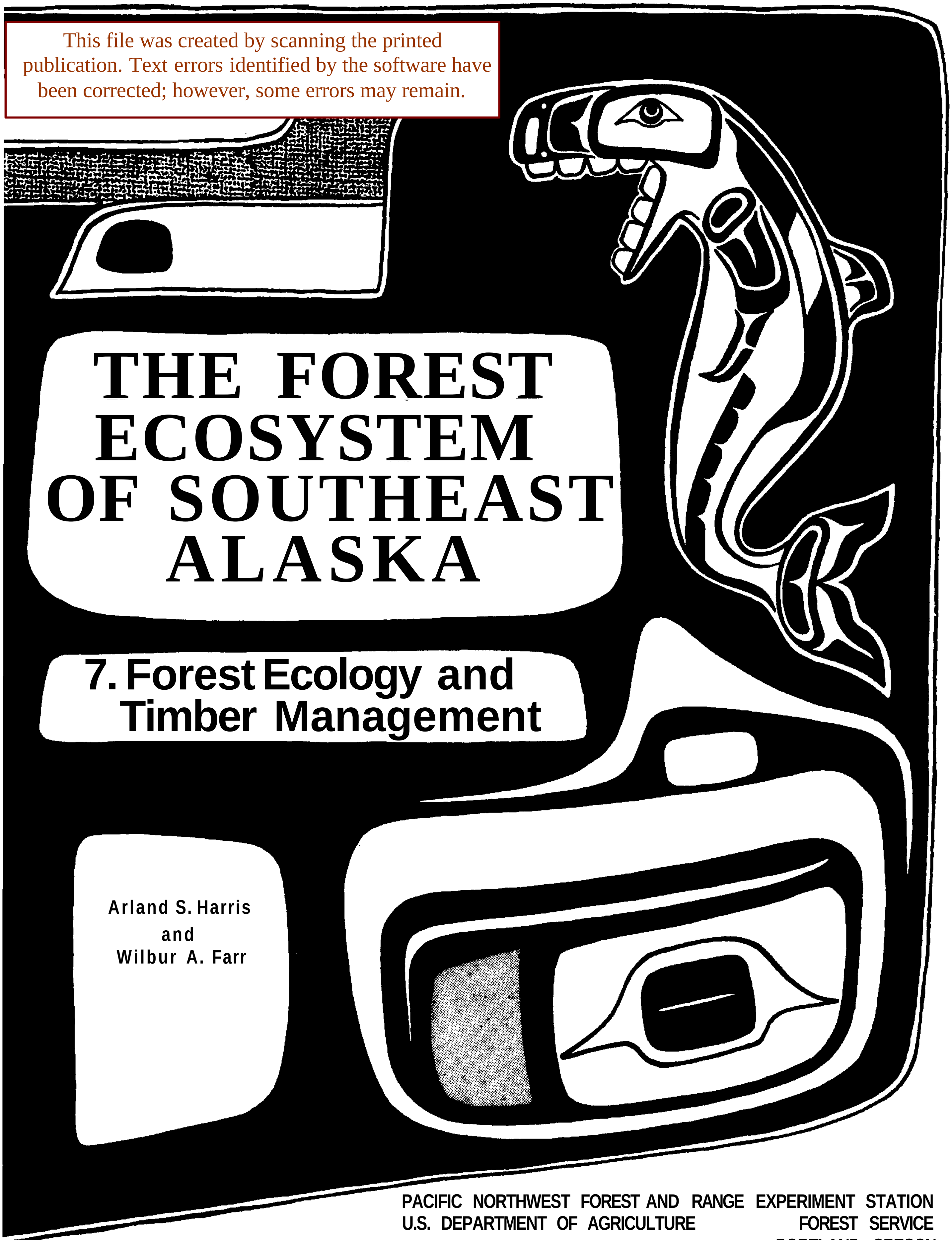
1974
USDA FOREST SERVICE GENERAL TECHNICAL REPORT PNW-25



THE FOREST ECOSYSTEM OF SOUTHEAST ALASKA

7. Forest Ecology and Timber Management

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ABSTRACT

Large-scale use of the timber resource of southeast Alaska began in 1953 after long efforts to establish a timber industry. Development and present status of the industry and present management of the timber resource are summarized, stressing the biological basis for timber management activities in southeast Alaska today, Ecological and silvicultural considerations related to timber harvest, reforestation, and stand development are discussed.

Published and unpublished information are brought together. Current management practices are discussed as a basis for a better understanding of how this information can be helpful in managing the timber resource and to point out where research is needed,

Keywords: Alaska, silvical characteristics, timber management planning, succession, timber, logging operations (general).

This **publication does not contain recommendations for use of pesticides** nor **does it imply that the uses discussed here have been registered. All uses *of* pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.**

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PREFACE

This is the seventh 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 infomation 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In this series of papers, we will summarize published and unpublished reports and data as well as the observations of resource scientists and managers developed over years of experience in southeast Alaska.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
2. Forest Insects
3. Fish Habitats
4. Wildlife Habitats
5. Soil Mass Movement
6. Forest Diseases

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INTRODUCTION

Southeast Alaska, the so-called Alaska Panhandle, is that portion of the State lying east of the 141st meridian--a coastal strip of land and numerous offshore islands some 540 miles long extending from Dixon Entrance in the south to Yakutat in the north. Although its 19 million acres of land area is just over 5 percent that of the entire State, southeast Alaska contains the major part of Alaska's timber resource.

From earliest times timber has been important to Alaska's residents. Today the timber resource is vital to Alaska's economy, and forest products from the area are marketed throughout the world.

In this report we will describe briefly the development of southeast Alaska's timber industry and then discuss the source of Alaska's timber resource, the forest ecosystem. As demands for goods and services increase, we must continue to improve our understanding of the forest ecosystem and develop better techniques for its management.

The objectives of this report are to bring together useful published and unpublished information concerning the forest ecosystem and timber management and to provide insight into needed research.

TIMBER USE IN SOUTHEAST ALASKA

ABORIGINAL USE

Before white men came, southeast Alaska was inhabited by Tlingit and Haida Indians. These Indians developed an advanced culture based on products from the sea and forest. They relied on the sea primarily for food and for travel between widely spaced villages and to the hunting and fishing grounds, but their mastery of the sea was made possible by material from the forests. They hewed large canoes up to 60 feet long, the best and largest made from western redcedar (scientific and common names are listed in the appendix). Smaller ones were often made from Sitka spruce or black cottonwood. Alaska-cedar provided paddles; cedar bark, the sails and lines.

Canoes were usually made in the winter. A hole was cut at the base of a large, standing tree on the windward side, and a fire was started at this point. The fire was kept burning until the tree toppled. Canoes were then hewed to shape with an adze with the help of fire.

Houses were log frames covered with hand-split cedar or spruce planks. A central fire pit was surrounded by a tiered wooden floor. Houses were clustered in villages where many families lived during the winter, and cedar totem poles in front of the houses kept alive the memory of important historical events or legends.

Trees furnished most of the household, personal, and ceremonial articles. Bentwood boxes in a variety of sizes were used for storage of food and equipment. Dishes and other utensils were carved from alder, spruce, or cedar, as were ceremonial masks, drums, and rattles. Bows, spears, fishhooks, and numerous other weapons or tools were of wood. Baskets and hats were woven from split roots of Sitka spruce, and cedar bark provided mats, clothing, ropes, and baskets. Firewood was always in demand for cooking, warming, and drying or smoking fish and meat. Gathering wood was the duty of men and boys who collected only enough fallen pieces for a day's supply. Even as late as 1879, a season's wood was not laid in and allowed to cure for later use (Krause 1956).

During the summers, families scattered about the countryside, each occupying summer camps at the mouths of family-owned salmon streams or at hunting camps, and villages were deserted. Summers were devoted to gathering and preserving the food needed for the next winter's use.

Before the white man came, the Indians made little change in the forest from their use of plants or timber. The total population was not large, their needs were small, and their technology was limited. The most marked changes in the forest were in the immediate vicinity of villages or camps where some clearing was done. Refuse was thrown out in the vicinity of houses; this added materially to the fertility of the soil (Lutz 1951). Even today the vegetation on long-abandoned village sites is markedly different from the surrounding forest--dominated by Sitka spruce and shrubs such as salmonberry, thimbleberry, and Pacific red elder, in sharp contrast to the surrounding forest.

With the widely dispersed population and varied uses of fire, one might expect that during the infrequent periods of dry weather, fires would occasionally escape to burn the forests. In the dry Alaskan interior, such man-caused wildfires were common, being set either accidentally or to clear the forest for hunting, improve game habitat, destroy insects, or for amusement or other reasons (Lutz 1959). Written documentation of large man-caused forest fires in southeast Alaska before the white man is lacking. However, it is possible that many of today's older even-aged stands originated after man-caused wildfires. Detailed study of the locations and age classes of these stands might form a pattern which would link their origin to man.

RUSSIAN OCCUPATION

The first demand for timber by white men came with Russian colonization. Under the direction of Alexander Baranof, a colony was founded at Yakutat in the 1790's. Logs were required for construction of a fort and dwellings, as well as for a continuing supply of firewood.

In 1799 the Russians attempted to establish a colony near the present site of Sitka. Logs were cut for building a fort, and lumber was sawed for building a boat. The venture was short lived, however, as in 1802 the fort was destroyed by Indians and a small vessel was burned while still on the ways.

The next year, Baranof ordered two boats to be built at Yakutat to be used in recapturing Sitka. In 1804 these two ships, the 100-ton *Yermak* and the 85-ton *Rostislaf* were completed and put in service (Bancroft 1886).

In 1804 Baranof led a punitive strike against the Sitkans, and a new post was established at the present site of Sitka. This time the colony was successful.

The colonists began logging immediately to supply logs and lumber for construction of a fort and magazine and for building a ship which was launched the following year, They built a foundry, the only one on the Northwest coast for many years. Stands of hemlock and spruce along Indian River were clearcut, and charcoal was produced there for the foundry. Charcoal mounds may still be seen in this area, now within the Sitka National Monument. Some of the earliest studies of tree growth in Alaska were done in the young stand which came in following this early clearcutting.[1]

The Sitka colony prospered, and new construction required a continuing supply of logs and lumber as well as a constant supply of firewood and charcoal. Shipbuilding was an important occupation and continued until 1867 when Russian holdings were transferred to the United States. During much of this period, no other shipbuilding facility existed on the Northwest coast. Alaska-cedar was favored for hull construction because of its durability; and selective logging for cedar took place along tidewater as far distant as Peril Straits, 60 miles away. Because of the demand for Alaska-cedar for ship construction and other uses, the Russians were reported later to have exhausted the accessible supply of cedar near Sitka.

At first, lumber for the growing colony was hewn or sawn by hand, but waterpowered sawmills soon appeared. The first Alaskan sawmill is thought to have been built at Redoubt Bay near Sitka in 1833, It was first operated by waterpower, then in the 1850's was converted to steampower, Lumber was sawn for export as well as for local use, and a cargo of lumber carried to Chile in 1839 by Captain Etolin was probably sawn at this mill (DeArmond 1946).

Sometime before 1853, a second sawmill was built at Sawmill Creek about 5 miles from Sitka, and a third at Sitka. About 3,000 board feet of lumber was produced daily by the Russian mills, for local use and export. Records show that lumber was exported to Chile, Macao, and Canton. Sawdust was used for packing ice cut at Swan Lake near Sitka for shipment to San Francisco during the California gold rush of the early 1850's.

Early Russian logging methods were primitive. Trees were cut with axe or saw, and logs were moved by jacks, levers, or pulleys. Most logging was done on a selective basis, and only high-quality trees of a size that could easily be handled were cut, except close to Sitka where several small areas were clearcut for firewood and charcoal.

EARLY AMERICAN USE OF TIMBER

Russian holdings in Alaska were sold to the United States in 1867, and the sawmill at Sitka became the property of the American-Russian Company. Interesting instructions from William Phillipson, who was in charge of the mill, included pay scales of \$1.75 per day for the sawer, \$1.25 per day for the machinist, and \$1 per day for all other hands, No more than \$3 per thousand board feet was to be paid for logs, and lumber prices were specified. As quoted by DeArmond (1946), 'The usual rates of lumber are \$20 a thousand all around but should the government or the Greek Orthodox Church require any, charge them \$30,

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[1]R. F. Taylor, An investigation of tree growth on the Sitka charcoal mounds. Report on file, Forestry Sciences Laboratory, Juneau, Alaska, 6 p., 1934.

they can stand it. You need not speak of the difference to anyone. Cedar lumber you will sell invariably for $35 a thousand, and for shingles charge $4 a thousand." This mill changed hands but remained in production into the early 1900's.

During the years after the Alaska purchase, civil government was virtually nonexistent in Alaska, and the many years of Government neglect are well documented (Bancroft 1886, Hulley 1953).

For 30 years after the transfer, standing timber could not be purchased from the Government; and anyone cutting timber was liable to suit. In his report of 1886 (p. 9), Governor A. P. Swinford wrote, "The manufacture of lumber would ere this have become an industry of considerable importance but for the fact that the Government Land Laws not having been extended over the territory, the title to timber lands cannot be secured, and operators are not permitted to export any part of their cuts to points outside the territory."

Timber cutting continued, however, and in 1887 five sawmills operated in southeast Alaska, Timber export was illegal, but some operators were willing to risk the consequences and were sometimes caught. In 1886 two vessels with cargoes aggregating between 3/4 and 1 million board feet of lumber were seized by U.S. authorities in San Francisco (Swinford 1886).

By 1889, 11 sawmills were operating in southeast Alaska, cutting lumber for domestic use despite occasional trouble over cutting rights, The pleas of Alaska's appointed governors apparently had some effect; and on May 14, 1898, Congress passed an act which provided for purchasing government timber on bid when sales were authorized and the timber had been examined and appraised. Unfortunately, the act set up no machinery for examining and appraising timber, and there were no local agents to handle the work. Operators continued to cut timber but were constantly faced with Government suits for timber depredations. Despite this, local demand for lumber needed in the fishing and mining industries increased. In 1900, 14 sawmills operated with a reported annual cut of 8.45 million board feet (DeArmond 1946).

Part of the slow growth of Alaska's timber industry was doubtless caused by little local and national demand for hemlock and spruce. There was virtually no demand for hemlock except for piling, and better quality Sitka spruce was easily available in the Puget Sound area in large quantities. The future of Alaska's forests for pulp production were recognized, but only as a distant possibility (Fernow 1902, 1910).

In 1902 Congress established the Alexander Archipelago Forest Reserve to include Chichagof, Kupreanof, Kuiu, Zarembo, and Prince of Wales Islands. The Tongass National Forest was established in 1907 and included land between Behm Canal and Portland Canal; this was later enlarged to include most of southeast Alaska. Forest officers were brought in, and timber sales were made comparatively easy. Most of the older mills continued to operate, and some new ones were established. Several mills operated near Juneau, and others operated at Wrangell, Sitka, Ketchikan, and at scattered locations elsewhere. Through the next decade, these and other mills continued to cut lumber for local use, but lumber was not exported.

During the First World War, high-quality Sitka spruce lumber suddenly came into demand for construction of military aircraft. Some timber was cut for this purpose near Howkan late in the war, but the operation was plagued with problems. Only a small amount of lumber was exported, and the operation was generally unsuccessful. Altogether during the decade from 1910 to 1920, some 4,000 sales of timber totaling 420 million board feet of sawtimber and piling were made on the National Forest lands in Alaska (Greeley 1920a).

DEVELOPMENT OF THE PRESENT TIMBER INDUSTRY

Soon after the First World War, the Forest Service began reconnaissance of the pulp timber resource and began efforts to attract the paper industry to southeast Alaska. Pulp operating units were laid out, inventories were made, and plans for the regional development of the pulp timber resources were developed (Smith 1921). Soon industry became interested and a sale was made. In 1920 the Alaska pulp and Paper Company was sold 100 million feet of timber on Admiralty Island and the adjacent mainland, and mill construction began at Port Snettisham near Juneau. This mill operated for about 2 years but was forced to close because costs proved too high to allow a profit.

During his years as Chief of the U.S. Forest Service, W. B. Greeley was active in promoting the use of Alaska's forests for production of pulp and paper (Greeley 1920a, 1920b, 1921). In 1921 he described the great potential for a paper industry in a magazine article for businessmen, noting that the Forest Service had already begun to locate pulp production units, each with a manufacturing site on salt water with waterpower available. Greeley defined his agencies' aims as follows, What we want in Alaska is a stable industry, manufacturing as much as the forests will grow under intelligent care and no more." Stressing a stable industry he added, "To insure stability, a thirty years' supply of timber should be procurable by the paper manufacturer as a basis for installing his plant. ... The Forest Service is prepared, upon request to cruise, appraise, and advertise for sale a thirty years' supply for the enterprise proposed." Greeley (1921) recognized that some provision should be made for a company to reserve additional timber when its initial supply was exhausted and that maximum limits should be imposed, "so that the consumer will be protected against the possibility of monopolistic combinations."

In 1923 six sawmills were sawing lumber in large quantities for local use and export. Logs for these mills came from large trees up to 225 feet tall and 8-foot diameter which grew in stands of pure spruce (Heintzleman 1923). Heintzleman, then Assistant District Forester with the Forest Service at Juneau, believed that the spruce lumber industry could not be expanded until extensive pulpwood logging operations were started and the many large, isolated spruce trees growing with the smaller pulp timber became economically accessible (fig. 1). He described the forests as being primarily suited for pulp and paper but recognized a large potential for sawtimber production as well.

Heintzleman (1928) continued efforts to promote a permanent timber industry in Alaska and published a descriptive account of the pulp-timber resource. He was concerned with establishing a stable economic base for the territory and, in writing on the subject in 1927, noted that agriculture formed

Figure 1.--Cruising timber in an old-growth stand containing high-quality Sitka spruce typical of that logged for sawtimber in former years on the Tongass. The Forest Service men shown in this 1930 photo are, left, J. M. Wycoff; right, B. F. Heintzleman. Mr. Heintzleman later became Governor of Alaska.

the basis for the permanent settlement and sustained prosperity of the West, but that agriculture was not an adequate base for settlement in southeast Alaska because of soil conditions and rough topography. Likewise, he wrote that the forests were unable to supply a sufficient quantity of wood to satisfy a lumber manufacturing industry of a size necessary to sustain a large population, and that the present mining and fishing industries were inadequate also. He recognized that the forests were well suited for supplying the raw materials for the manufacture of paper, and that such an industry could insure the future development of the area,

Heintzleman (1927) recognized that heavy plant investment was required and that a modem newsprint plant was so large that at least a 50-year supply of timber should be made available for its use at the start of operation to justify the heavy expenditures involved, He envisioned that with good management the forests of southeast Alaska could supply at least 1 million tons of newsprint each year in perpetuity, and that this industry could support directly or indirectly a population of **50,000** people and would guarantee the future economic stability of the region.

In 1926 legislation was enacted which gave the Department of Agriculture discretionary power over export of timber from the National Forests in Alaska. The Department's position was clarified in 1928 and remains generally in effect today in that primary manufacture of timber from National Forest lands in Alaska is required so as to insure the development of a stable year-round industry[2]

Interest developed on the part of the pulp industry, and two pulp sales were made in 1927. Substantial initial development work was done, but neither venture advanced to the point where mill construction was actually started. With the market collapse of 1929 and the depression that followed, plans were abandoned and both sales were cancelled by mutual consent in 1933. From then until the beginning of World War 11, there was only sporadic interest in pulp development (Bruce 1960).

During World War 11, Sitka spruce lumber again came into demand for military aircraft. In response the Alaska Spruce Log Program was set up in June of 1942 as an agency administered by the Forest Service. Nine camps were established with headquarters at Edna Bay on Kosciusko Island. The first raft of spruce logs reached Anacortes, Washington, in January of 1943 (Johnson 1943).

Heintzleman continued efforts to interest industry in locating in southeast Alaska; and in the 1940's, he probably canvassed every major pulp and paper manufacturer in the United States, mostly at his own expense.[3] He worked closely with Alaskan business interests and in 1947 pressed for passage of the Tongass Timber Act, which, when passed by Congress on August 8, 1947, settled for a time all Indian claims to lands not confirmed by patent, court decisions, or included within reservations. This act cleared the way for the long-term pulp sales, the basis for the present pulp industry (see footnote 3).

As efforts progressed toward development of a pulp industry, several sawmills continued to cut Sitka spruce and Alaska-cedar for local use and export, and one attempt was made to produce plywood. In 1953 a small plywood plant began production in Juneau. Sitka spruce plywood was produced and was well accepted. Large, high-quality logs were required, and some were rafted from as far away as Kosciusko Island, 220 miles by water. The mill had financial difficulties and shut down in 1955, then burned to the ground 4 years later without reopening.

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[2]Export of timber from the National Forests and certain other Federal lands in Alaska is restricted to products specified by the Federal Government under the Act of April 12, 1926 (44 Stat, 242; 16 U.S.C. 616). Under this Act and subsequent rulings, production of cants, planks, poles, piling, green veneer, pulp, and chips produced from mill waste constitutes primary manufacture of timber from National Forest lands. Cedar round logs that are considered surplus to the needs of domestic users and processors may be exported. The State of Alaska generally follows similar rules. Export restrictions do not apply to logs from private lands in Alaska. For more detailed information, see Austin (1969) and USDA Forest Service Export and Primary Manufacture Policy, National Forests of Alaska, Juneau, Alaska, 3 p., 1961.

[3]Robert K. Buchanan. The history, growth, use, and future development of the timber industry in southeastern Alaska. M.S. thesis, Pacific Coast Banking School, Western States Bankers Assoc., University of Washington, Seattle, 129 p., 1969.

PULP INDUSTRY ESTABLISHED

Efforts to establish a pulp industry were finally successful, and in 1948 preliminary award of a 50-year sale of 1.5 billion cubic feet (8.25 billion board feet, Scribner rule) of timber from an allotment on Prince of Wales and Revillagigedo Island went to the Ketchikan Pulp Company of Bellingham, Washington (fig. 2). Final terms of the sale contract were signed in July 1951.[4]

Figure 2.--Ketchikan Pulp Mill, Ward Cove, Alaska. One of two modern mills in southeast Alaska producing dissolving pulp for U.S. and foreign markets.

Construction of a pulpmill was completed at Ward Cove near Ketchikan in 1954. The mill was dedicated in July 1954 and culminated years of effort to bring pulp industry to Alaska. Among those present at the dedication were former Chief of the Forest Service, W. B. Greeley; former Regional Forester and then Governor of Alaska, B. F. Heintzleman; and Regional Forester Arthur W. Greeley. Their efforts had helped make this pulpmill possible. As Chief Forester R. E. McArdle put it, "It is the realization of a hope which the U.S. Forest Service has cherished for almost 50 years...." (Jones 1954).

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[4]Timber Sale Agreement, USDA Forest Service, File S., Sales, Region 10, Juneau, Alaska.

Japan became interested in Alaskan timber, and in 1952 a mission representing the Japanese government and the pulp and lumber industries studied technical questions of utilizing Alaskan timber. The U.S. State Department and Defense Department saw no objection to the Japanese plans, and the State Department recognized the economic benefits--"It has been apparent to the Department that the project, if developed, would materially assist the Japanese economy and at the same time be of real benefit in the economic development of a self-sustaining economy in the Territory of Alaska" (Anonymous 1953).

Within 3 years after opening of the pulpmill in Ketchikan, the Forest Service entered into three additional long-term agreements which provided for pulp development in Alaska (Bruce 1960).

In June 1954 the Forest Service made a preliminary award for a 50-year sale to Pacific Northern Timber Company of Wrangell for timber located in the vicinity of Petersburg and Wrangell. Terms of the contract called for building a sawmill by 1957 and a pulpmill by 1962 (Greeley 1954).

The sawmill was built at Wrangell, the first in Alaska designed for cutting hemlock. However, the company soon ran into difficulties and the mill closed. The sale was then taken by the Alaska Wood Products Company, now affiliated with Alaska Lumber and Pulp Company. Terms of the sale were modified several times, the mill was redesigned, and now the sale agreement is for a total of 693 million board feet of timber, with the only construction requirement being a sawmill.[5] The mill cuts western hemlock 4- by 4-inch timbers for the Japanese market.

In 1956 the Alaska Lumber and Pulp Company was awarded 50-year cutting rights to 5.25 billion board feet of timber located on Baranof and Chichagof Islands,[6] The company opened a high-alpha cellulose plant at Silver Bay near Sitka in 1959.

A third 50-year sale for timber on Admiralty Island and the mainland near Juneau and Yakutat was awarded to Georgia Pacific Company in 1955, but the company did not go through with its plans to build a mill. A new sale of 8.75 billion board feet of timber in approximately the same location was awarded to the St. Regis Company in 1965, the largest timber sale in Forest Service history (Lockhart 1966). The St. Regis Company later abandoned development plans, and in 1968 the sale was transferred to the U.S. Plywood-Champion Papers Co., Inc. (now Champion-International Corporation). In 1970 suit was filed by the Sierra Club and co-plaintiffs to stop the sale (Adasiak 1971, Miller 1971a), and the case is still in litigation.

To summarize the development of the present timber industry, use of the timber resource by the Indians and Russians was slight, and until near the turn of the century timber cutting was limited. With establishment of the Forest Reserves and administration by the U.S. Forest Service, continuing efforts were

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[5] Pacific Northern Timber Company, Contract No. A10fs-1283, dated 6/9/54, with modifications. On file, USDA Forest Service, Juneau, Alaska.

[6] Timber Sale Contract No. 12-11-010-1545, Alaska Lumber and Pulp Co., Inc., 1/25/56. On file, USDA Forest Service, Juneau, Alaska.

made to establish a sound economic base for Alaska through establishment of a permanent year-round pulp industry, The Forest Service directly supported and often led this effort because regional development was a generally unquestioned ideal and because as trained foresters, leaders of the Forest Service recognized that only through use of the timber resource could the forests be managed for maximum timber growth.

The need for multiple use of forest land was recognized by leaders of the Forest Service long before the concept became law, Timber production was recognized as the dominant use on land capable of producing good timber growth, but not to the exclusion of other uses. For example, the need to protect fish spawning streams was recognized. In addition a limited ban on timber cutting along steamer lanes to avoid esthetic damage was imposed. However, only recently have interests other than the timber industry been strong enough to attract national attention. Also, the demands for all forest resources have increased greatly. The general level of affluence has risen, and leisure time has increased to the point where many articulate people are now questioning previously accepted economic values. The result is that now the Forest Service is no longer in the position of trying to establish a timber industry but is increasingly acting as arbitrator between many factions which demand ever greater use of the forest resources.

THE TIMBER INDUSTRY TODAY

The timber resource in southeast Alaska supports an industry whose annual production is valued at about $103 million and which provides about 2,700 jobs for Alaska residents. Two dissolving pulpmills, one at Ketchikan and one at Sitka, consumed 300 million bd. ft. of timber from the Tongass National Forest in 1971 and produced 403,000 tons of high quality dissolving pulp (Alaska Division of Economic Enterprise 1972). Fifty-two percent of this dissolving pulp went to U.S. markets; 48 percent was exported to foreign countries, primarily Japan.[7]

In addition, in 1971, nine sawmills with a capacity of at least 5,000 bd. ft. per shift were in operation. Of these, four were band mills and five were circular mills. Five mills had a capacity of 100,000 to 200,000 bd. ft. per shift, and one sawed over 200,000 bd. ft. per shift. Six sawmills were equipped with barkers, and five had chippers for conversion of mill waste. Six mills had planers, and one had a dry kiln (Clapp 1972).

The principal products produced by these sawmills were export cants, squares, resaw cants, chips, and lumber. In 1971, production amounted to 217 million bd. ft., virtually all of which was exported. Several portable mills operated intermittently but only produced small amounts of lumber for local use, In addition, in 1971, over 5 million board feet of lumber was produced in southeast Alaska for domestic consumption.

In 1972, some 48 million board feet of logs were exported without primary manufacture, including 25 million board feet from private land and 23 million board feet of cedar[8] logs from the Tongass National Forest.[9] In 1972, export

[7]Data on file--USDA Forest Service, Region 10, Timber Management Division, Juneau, Alaska.

[8]The primary manufacture requirement does not now apply to cedar (see footnote 2).

[9]U.S. Exports - Dist. 31 (Anchorage), monthly printout of Form EM-563, U.S. Department of Commerce, Social & Economic Statistics.

of cedar logs from the Tongass nearly doubled from 13 million board feet reported in 1971, illustrating the volatility of the export market.

In 1971, 69 logging companies were cutting in southeast Alaska (Clapp 1972). Size ranged from small independent operations employing a few men to large pulp-company-owned operations with many woods workers--the largest being the Ketchikan Pulp Company camp at Thorne Bay on Prince of Wales Island, with a total population of 450 persons (Dupre 1972). This is the Nation's largest logging camp and the 12th largest settlement in southeast Alaska (fig. 3).

Figure 3.--Ketchikan Pulp Company's logging camp at Thorne Bay, Prince of Wales Island. This modern year-round community of 450 people is the largest logging camp in the United States.

VEGETATIVE SETTING

The forest of southeast Alaska is a segment of the temperate rain forest extending along the Pacific coast from northern California to Cook Inlet in Alaska (fig. 4). Viewed from a boat, the rugged mountains along the inside passage appear to be covered with unbroken conifer forests from the water to timberline (fig. 5). From the air, however, the forest zone is seen as a mosaic of forest stands of various densities, crown sizes, subtle colors, and natural and manmade openings.

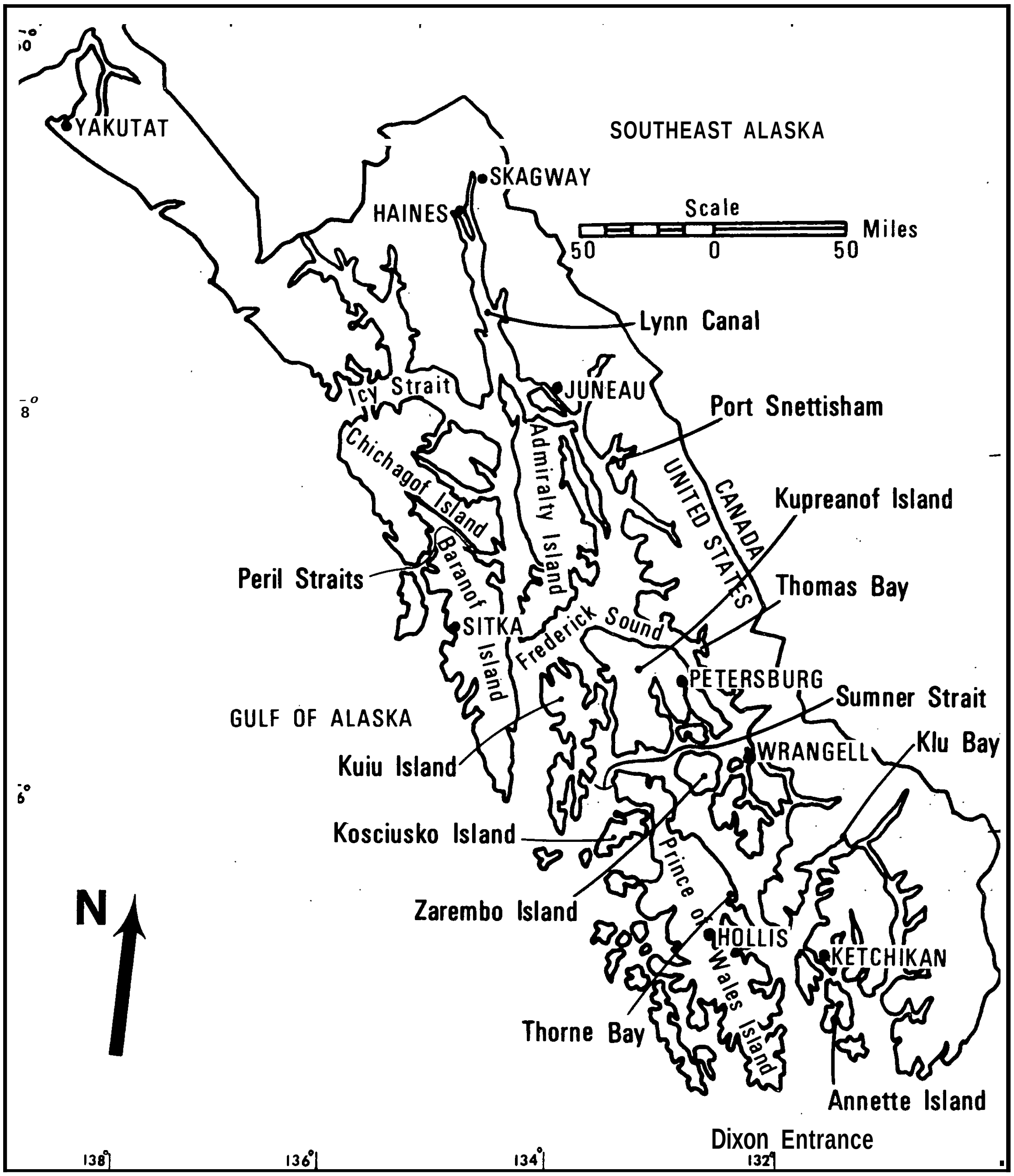

Figure 4.--Map of southeast Alaska.

Figure 5.--Forest and water dominate the view in southeast Alaska. A State ferry nearing Sitka.

Most of the forest is old growth undisturbed by man. Differences in external appearance are due to age, species, and vigor. Stands which have remained undisturbed for centuries have a ragged texture because they include trees of various ages, sizes, and conditions, with many dead tops and snags. Stands disturbed during the last century or two by windthrow, fire, landslides, or ,logging have a more uniform appearance because they contain trees of relatively uniform age and size, with fewer snags and defective trees.

Tree species composition varies by location, topography, drainage, soil type, and stand history. Based on number of trees of 1-inch diameter and larger on commercial forest land, species composition is western hemlock, 73 percent; Sitka spruce, 12 percent; western redcedar, 5 percent; Alaska-cedar, 5 percent; mountain hemlock and other softwoods, 4 percent; black cottonwood, red alder, and other hardwoods, 1 percent.[10] Species composition of trees on land classified as noncommercial forest land consists largely of hemlocks, cedars, and shore pine.

[10]Memo from Vernon J. LaBau, February 28, 1973, on file, Forestry Sciences Laboratory, Juneau, Alaska.

Southeast Alaska's forests contain fewer tree species than do the coastal forests of British Columbia and the Pacific Northwest, and species diversity decreases with increasing latitude. Nine conifer and 22 broadleaf species attain tree size. Of these, four species are sought for commercial harvest--western hemlock, Sitka spruce, western redcedar, and Alaska-cedar. Mountain hemlock is logged along with western hemlock when encountered in mixed stands. The wood is equal in all respects to western hemlock, and it is sometimes difficult to tell the two species apart, Pacific silver fir and subalpine fir occur in limited areas and may be cut, although neither species is sought for harvest. Pine is used locally for firewood and for Christmas trees but is seldom found in dense commercial stands. Black cottonwood has been harvested occasionally and tested for use as dissolving pulp but is not being harvested today. Red alder is used locally for firewood, carving, and smoking fish. Alders are capable of fixing atmospheric nitrogen and so are valuable in improving soil fertility.

The forests contain many shrub species--Viereck and Little (1972) recognized 72 species as the more important. Many of these shrubs are characteristic of the dry interior and appear in southeast Alaska only in the drier transition zones at the heads of Lynn Canal and Portland Canal. At present, berries are the only shrub products gathered commercially, and then only on a limited scale. Berries are also used extensively by local residents.

SILVICAL CHARACTERISTICS OF FOREST TREES

Tree species differ in their requirements for moisture, light, nutrients, heat, and growing space. Each species responds in a different way to its total environment. Physical factors such as climate, soil, light, and heat are all important in establishment and growth of trees as are biotic factors such as animals, insects, micro-organisms, and associated plants. Many of these are difficult to measure, and all interact in endless combinations so that exact description and quantification of requirements are impossible, Through years of observation and experimentation, a large body of knowledge has been built up on the general silvical characteristics of tree species. Much of this is subjective and expressed in comparative terms among associated tree species. None of the tree species native to southeast Alaska are unique to the area, and much knowledge of species gained elsewhere is applicable in Alaska, although size, age, plant associations, and shade tolerance differ with latitude. An excellent source of general information on silvics of trees throughout their ranges is "Silvics of Forest Trees of the United States" (Fowells 1965). A brief silvical description of the more important, tree species of southeast Alaska follows. All nine tree-size conifers are included; but of the broadleaf species, only black cottonwood and the alders have been included.

Western Hemlock

Western hemlock is found throughout southeast Alaska from sea level to timberline. It is the most abundant tree species and comprises 64 percent of the total growing stock volume (Hutchison 1967). Western hemlock occurs in dense stands in mixture with Sitka spruce, mountain hemlock, cedars, and other conifers. Tree associates and growth characteristics vary with latitude, soil type, topography, elevation, and stand history. Western hemlock is a major stand component on low-site organic soils and is found in stunted or decumbent form on muskegs. At high elevations, it is largely replaced by mountain hemlock but is often found at timberline. Best development and growth is on well-drained soils in valley bottoms and on lower slopes where it is an important commercial timber resource.

Mature trees usually range from 100 to 150 feet in height and from 2 to 4 feet in diameter, but trees 6 feet in diameter and 170 feet tall have been reported in Alaska. Age may exceed 1,100 years.

Western hemlock is a prolific seed producer with some seed produced most years and good seed crops at 5- to 8-year intervals (Harris 1969b). Seeds are light, averaging 297,000 per pound (USDA Forest Service 1948), and are carried long distances by wind (Harris 1967).

Seedlings come in readily on organic soils, undisturbed forest duff layers, and well-mixed organic and mineral soil seed beds. Rotten wood is an excellent seed bed beneath light shade but dries out too rapidly in the open to sustain seedling growth. Western hemlock is seldom found as a pioneer on recently exposed land or on soil lacking in organic material.

Western hemlock is considered to be very tolerant of shade, and, in comparison with its associates, is more tolerant than Sitka spruce and the cedars but less tolerant than the true firs. It will become established beneath stands of Sitka spruce or mixed hemlock-spruce and, if left undisturbed for 300 to 600 years, will gradually dominate the site. Western hemlock responds well to thinning, even at an advanced age; it is more adaptable to a variety of silvicultural systems than less shade-tolerant species. It becomes established readily under partially cut stands, but early growth is much slower in partial shade than in the open following clearcutting (Farr and Harris 1971). Seedling growth in deep shade is slow, and seedlings a foot tall beneath old-growth stands may be 20 years old.

Present use of western hemlock is primarily for dissolving pulp, but an increasing number of the better quality logs are being sawn into cants and lumber.

Sitka Spruce

Sitka spruce is the second most abundant timber species in southeast Alaska, making up 28 percent of the growing stock volume on commercial forest land (Hutchison 1967). It occurs throughout the area from sea level to timberline, occasionally in pure stands but more commonly in mixture with western hemlock, mountain hemlock, cedars, and shore pine. It is common along sea beaches, on or fringing tidal meadows, and as a pioneer species in mixture with alder, willow, and cottonwood.

Best growth occurs on well-drained bottom land and lower slopes, where Sitka spruce is an important commercial species. Mature trees are commonly from 3 to 5 feet in diameter and from 100 to 160 feet in height. Largest trees are over 10 feet in diameter and over 200 feet tall.

Sitka spruce is a prolific seed producer with some seed produced most years and good crops at 5- to 8-year intervals (Harris 1969b). Seed averages 210,000 per pound (USDA Forest Service 1948). Seeds have a large wing and are dispersed well by the wind (Harris 1967).

Sitka spruce is not as shade tolerant as western hemlock but more so than the cedars and lodgepole pine. It can become established beneath light shade but not to the degree of hemlock. It will come in beneath partially cut stands, although growth in the shade is extremely slow (Farr and Harris 1971).

Seedlings establish on mineral soil and organic seed beds readily and under light shade on moss, organic soils, and rotten wood, Rotten wood is a good seed bed under light shade, but dries out rapidly in the open, and usually will not sustain seedling growth. Stilt-rooted trees which became established on stumps or logs and lines of trees which geminated atop down logs attest to the suitability of rotten wood seed beds beneath shade. On mineral soil containing little organic material growth is slow because of the poor nutritional status of mineral soils, Sitka spruce is more likely to become established on mineral soil than is western hemlock. Excellent establishment and growth occur after clearcutting, especially on mixed organic-mineral soil seed beds.

Sitka spruce responds to thinning by increasing diameter growth, but height development is less well documented. In some cases severe shock after drastic thinning may reduce the rate of height growth. More information is needed on response of the species to thinning.

Most of the better grades of Sitka spruce logs are sawn into cants or slabbed for export, and some lumber is produced for local use. Lower grade logs are chipped for use in dissolving pulp.

Western Redcedar

Western redcedar is found only in the southern portion of southeast Alaska. Its northern range is rather sharply defined along the northern and western shores of Sumner Strait on Kupreanof and Kuiu Islands and extends to the vicinity of Petersburg on Mitkof Island (Andersen 1953). Temperatures during the growing season may largely determine the limits of its range (Gregory 1957b), but planted trees are capable of growing at least as far north as Juneau, 120 miles north of the species' known natural range,

At lower elevations, western redcedar occurs on poorly drained organic soils and on shallow soils over bedrock in nearly pure stands or in mixture with western and mountain hemlock, Sitka spruce, shore pine, and Alaska-cedar. On muskegs it often appears in stunted form. It is occasionally found on productive well-drained sites and in these situations makes its best growth. However, on good sites it has difficulty in competing with western hemlock and Sitka spruce and so is seldom found.

Studies indicate that within southeast Alaska western redcedar is less shade tolerant than hemlock or spruce, Seedlings are able to germinate and grow for a time beneath well-stocked old-growth stands but usually do not survive. Apparently the direct effect of light and its indirect effect through warming are necessary for survival (Gregory 1957b).

Western redcedar is a good seed producer. During a "medium" seed year, 36 pounds of seed per acre were produced by a cedar stand (James 1959). Information on frequency of seed crops is lacking, as is information on seed dispersal distances. Seeds average 414,000 per pound (USDA Forest Service 1948). Seeds are flat and equipped with two small wings and thus would appear to be more easily dispersed by wind than Alaska-cedar, less easily than the larger winged hemlock and spruce, Measurements of dispersal distance are lacking.

Seedlings become established in the open after clearcutting, fire, or other major disturbances. Seed bed requirements are not well known, but organic material and mixed mineral-organic soils appear suitable. Calcareous soils are highly suitable, and dense reproduction often comes in on disturbed soils in the vicinity of marble outcroppings.

Mature trees 4 feet or more in diameter are common and some are hown to reach 9.5 feet in diameter and 158 feet tall (Farr and LaBau 1971). Growth tends to be faster than that of Alaska-cedar but may be extremely slow on poor sites. Longevity is not known, but trees 800 years old have been reported. The wood is extremely durable, and dead trees and snags may remain standing for many years.

Many old-growth trees are of good quality timber but, in general, quality is lower than farther south. Until a few years ago, there was little demand for the species in Alaska. Stands with a high percentage of cedar were not logged, and cedars encountered on clearcut areas were felled but often left in the woods. Now, however, good quality western redcedar logs are second only to Alaska-cedar in value. Most production is exported to Japan in round log form or as rough cants. Some interest is being expressed in cedar pole production and is likely to increase. No attempt is being made at present to manage stands specifically for growth of western redcedar. More study should be devoted to proper management of this valuable species.

Alaska-cedar

Alaska-cedar has a scattered distribution throughout southeast Alaska, both on the mainland and on many of the islands, most notably on Chichagof and Baranof Islands. The species occurs in nearly pure stands but more often in scattered groups or individually in mixture with western and mountain hemlocks, Sitka spruce, shore pine, and western redcedar.

Best development is on thin organic soils over bedrock or occasionally on deep, well-drained soils. On the better sites it has difficulty competing successfully with western hemlock and Sitka spruce and so is seldom found there. It is a common component of "scrub" stands on organic soils and often occurs in stunted or shrublike form on muskegs.

Trees may reach 8-foot diameter and 120-foot height. Growth tends to be slower than for other conifers, even on good sites.

Alaska-cedar is a moderate seed producer with fair crops at irregular intervals. Cones require 2 years to mature. Seeds average 108,000 per pound and lack a prominent wing (USDA Forest Service 1948). Information on seed dispersal distance is lacking but distance is thought to be less than for most conifers.

Seed bed requirements are not known. Younger stands tend to be even aged, and numerous searches have failed to locate seedlings beneath old-growth conifer stands. This indicates that Alaska-cedar is less shade tolerant than western hemlock. Tolerance apparently decreases northward (Andersen 1959).

The wood is aromatic and highly resistant to decay. Until recently, there was little demand for Alaska-cedar from southeast Alaska, and trees felled during clearcutting operations were left in the woods. Now, however, logs command top prices and high-quality trees are sought for harvest. The wood is prized in Japan, where most of the Alaskan production is sent.

Little is known about the silviculture or management of Alaska-cedar, and no attempt is being made to manage the species. Although not a major commercial species, the wood is very valuable; more attention should be given to assuring its proper management in southeast Alaska.

Mountain Hemlock

Mountain hemlock occurs throughout southeast Alaska from sea level to timberline. At lower elevations, it is commonly found on the poorer sites on organic soils. It is a major component along with western hemlock, cedars, shore pine, and Sitka spruce on noncommercial forest land fringing muskegs and is often found on muskegs in stunted or prostrate form, Near timberline, mountain hemlock is a major component of forest stands along with Sitka spruce, and it is often found in prostrate or "krummholz" form on alpine meadows above timberline.

Growth tends to be slower than that of western hemlock, even on the better sites; and the species does not attain so large a stature. Occasionally it occurs on good sites along with western hemlock and Sitka spruce. Best development is on well-drained soils where trees 3.8 feet in diameter and 105 feet tall have been reported.

Mountain hemlock is equal in shade tolerance to western hemlock, and it reproduces beneath old-growth western hemlock-Sitka spruce stands. Organic soils and rotten wood are suitable seed beds under shade.

Little is known of its seeding habits, but reports indicate that it is a less prolific seeder than western hemlock, with crops at roughly the same intervals, Seed averages 114,000 per pound (USDA Forest Service 1948) or nearly three times heavier than western hemlock. Wing size is roughly the same as that of western hemlock, so dissemination distance is probably less.

Mountain hemlock is logged along with western hemlock and Sitka spruce when encountered in clearcutting operations, The wood is comparable to western hemlock, and no attempt is made to separate the two species. It is used for dissolving pulp; and because of its slow growth and higher density, it is reported to give higher pulp yields than western hemlock.

No attempt is being made to manage mountain hemlock. As logging proceeds onto poorer sites and higher elevations, mountain hemlock will become a more important timber resource.

Shore Pine and Lodgepole Pine

Pine is represented in southeast Alaska by two varieties, shore pine and lodgepole pine. Shore pine is well distributed on the islands and mainland to Cross Sound, with the exception of the area about the head of Lynn Canal, and in isolated locations along the outer coast from Cross Sound westward to the vicinity of Yakutat. Lodgepole pine is restricted to the vicinity of upper Lynn Canal. Estimates of the amount of pine available as a resource are lacking.

Shore pine is capable of growing on a wide variety of soil and drainage situations. Usually it is found on the poorer sites on organic soils in association with cedars, hemlocks, and Sitka spruce. It is commonly found as a small tree on muskegs, on thin soils over bedrock, and occasionally in even-aged stands with other species on good sites.

On poorer sites, shore pine is often limby and slow growing. It is less shade tolerant than the hemlocks, Sitka spruce, and the cedars, and usually will not become established beneath light shade. When seed is available, shore pine becomes established on good sites following disturbance such as fire or logging. Here it makes excellent growth for 30 to 40 years or until overtopped by other conifers and shaded out.

Lodgepole pine is limited to upper Lynn Canal where it has apparently migrated from the Yukon Territory. Near Haines and Skagway, it has become established in even-aged stands after fire. It occurs from sea level to about 1,500-foot elevation, where a transition to moister conditions makes fire a rare occurrence. Trees are generally of straighter form than shore pine, and branches tend to be smaller. Trees of both varieties may reach 2-foot diameter and 90-foot height, and ages of up to 400 years have been noted.

Both varieties of pine produce seed at irregular intervals, and little information on amount or quality of seed is available. Cones require 2 years to mature. Cones of shore pine open during dry periods in the fall and winter in which they mature. In contrast, a substantial proportion of cones of lodgepole pine are serotinous and may remain closed for many years after reaching maturity. Serotinous cones require heat to open, so seed from several successive cone crops may be stored on the trees. Cones open in the heat of a fire, and seed is released. Some seed may be destroyed, but much survives and is available for gemination immediately after the fire. This gives the variety a strong initial advantage over other conifers following fire and probably accounts for its presence around upper Lynn Canal where summers are relatively dry and fires more frequent.

Pine is not harvested commercially, and no attempt is made to manage the species as a commercial forest tree. It is often used for ornamental plantings and locally for firewood. It is a favorite Christmas tree because of its thick, dark green foliage, long needles, and because it retains needles longer than other local conifers.

True Firs

Two species of true firs--Pacific silver fir and subalpine fir--occur in southeast Alaska, both with very restricted ranges.

Pacific silver fir is found on the mainland from Portland Canal and Boca de Quadra south and at scattered locations on Revillagigedo Island, usually at low elevations. It is more shade tolerant than western hemlock and is capable of establishment and growth beneath hemlock-spruce stands. Best growth is on well-drained soils on lower slopes, where growth rate is comparable to that of western hemlock and Sitka spruce. Trees 4 feet in diameter and 150 feet tall have been reported. Longevity in Alaska is not known, but trees to 540 years old have been reported from Vancouver Island (Schmidt 1957).

Little information on seed production and seed beds of Pacific silver fir in Alaska is available. Seeds are heaviest of any Alaskan tree species, averaging 11,000 seeds per pound (USDA Forest Service 1948), and hence probably are less likely to be widely dispersed by wind than most other conifers.

Moss, organic soils, and rotten wood are suitable seed beds under shade. Mixed mineral-organic seed beds are probably best in the open.

Subalpine fir occurs on the mainland at the heads of Lynn Canal and Portland Canal. In the Taku River valley it has been observed at timberline at 3,900-foot elevation (Heusser 1954) and at lower elevations on alluvial soils along the river growing in mixture with Sitka spruce, willows, and black cottonwood, It has been reported from alpine areas on Prince of Wales Island (Harris 1965b),[11] and from Dall Island.[12] Numerous other alpine locations throughout southeast Alaska appear to be suitable for its occurrence, and further botanical exploration will doubtless disclose a wider range than is now known.

On well-drained soils, growth is good and trees 2.1 feet in diameter and 95 feet tall have been reported. Subalpine fir is comparable to Pacific silver fir in shade tolerance and able to become established beneath hemlock-spruce stands. At Skagway, it occurs in the understory of lodgepole pine stands which originated after wildfire.

Seed is smaller than that of Pacific silver fir, averaging 37,000 per pound (USDA Forest Service 1948). Seeding habits in Alaska are not well known, but good crops have been reported at irregular intervals.

The true firs are not commercially important because of their scarcity. Both species are logged when encountered in mixed stands during clearcutting operations, and logs are included with hemlock and spruce for pulp or sawtimber. No attempt is being made to manage the true firs, and little is known about their seed bed and nutritional requirements and growth rate.

Pacific Yew

Pacific yew is rare in southeast Alaska, restricted to the extreme southern portion. It occurs singly or in small groups at low elevations, on poor sites and organic soils, often in the beach fringe in the understory of mixed stands of western and mountain hemlocks, cedar, and Sitka spruce,

Growth is extremely slow, and little is known of its seeding habits or seed bed requirements. It is shade tolerant and apparently capable of reproduction beneath fairly dense conifer stands. Trees are known to reach 10 inches in diameter and 30 feet tall.

Pacific yew is used locally by natives for carving decorative halibut hooks. No thought is being given to its management.

Alders

Three species of alder occur in southeast Alaska. Two of these, red alder and Sitka alder, are found throughout the area, but thinleaf alder is restricted to the northern portion, from the vicinity of Juneau northward.

Sitka and thinleaf alder tend to be shrublike in form with multiple stems and rarely exceed 30 feet in height. In contrast, red alder usually has a

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[11] Dennis Randall Jaques. Reconnaissance botany of alpine ecosystems on Prince of Wales Island, southeast Alaska. M.S. thesis, Oregon State University, Corvallis, 133 p., illus., 1972.

[12] Personal communication, Ian J. Worley, University of Vermont, Burlington.

single well-defined stem and reaches heights of over 50 feet. In southeast Alaska. diameters of 2.8 feet and heights of 53 feet have been recorded.

Alder is commonly found along beaches and streams, on avalanche tracks and landslides, and as a pioneer with Sitka spruce, willows, and cottonwood on land recently exposed by glacial outwash, retreat, or land uplift. Alders are also common on roadsides, landings, and wherever soil has been highly disturbed by man. In successional stands, alder is usually shaded out after 40 to 50 years as it is overtopped by Sitka spruce. Red and thinleaf alder are seldom found above 1,000-foot elevation, but Sitka alder may grow above 3,000 feet.

Seeds of all three species are very light, averaging more than 600,000 per pound, and are spread great distances by the wind. Alder apparently requires a mineral soil seed bed and is intolerant of shade. Growth rate is rapid, often 6 to 12 inches during the first year, with annual height growth of over 5 feet during its maximum growing period.'

All three species of alder have the ability to directly fix atmospheric nitrogen from the air in the same manner as legumes and so are capable of becoming established on sterile mineral soil (Bond 1970). Because of this ability to fix nitrogen and from the abundant leaf fall which adds needed humus, alder is important in stabilizing and improving soils and otherwise improving the forest environment (Tarrant and Trappe 1971, Tarrant et al. 1969).

Red alder is used in Alaska for smoking fish and for carving but otherwise is not used commercially. The wood is excellent for pulp and furniture (Plank 1971), and red alder is the most important hardwood species in the Pacific Northwest with some 250 million board feet logged in 1970 (Lawton 1972).

Red alder is not being managed as a timber resource at the present time in southeast Alaska and is still considered a weed by forest managers. Efforts are being made to control the species in situations where it competes with Sitka spruce and other conifers. However, all three alders are recognized for their value in stabilizing and improving highly disturbed soils and, as such, may be useful in enhancing soil fertility and forest productivity. Studies are being made in Alaska to test use of alder in stabilizing and revegetating landslide tracks. More infomation is needed on growth and yield of red alder and its potential value as a commercial species and on the economics of management as a resource versus control as a weed.

Black Cottonwood

Black cottonwood is found primarily in the major river valleys and outwash plains on the southeast Alaska mainland, and in scattered locations on the islands. Major occurrences are in the Unuk, Chickamin, Stikine, and Taku River valleys, in many valleys in the vicinity of Lynn Canal, and on glacial outwash plains near Yakutat. It is found in island valleys in the vicinity of Sitka, but on island locations it is usually found only in the vicinity of present or former habitations where it may have been planted. It is the largest broadleaf tree in Alaska, commonly reaching 3-foot diameter and 100 foot height. The largest hown specimen, located near Klukwan, is 10.3-foot diameter and 101 feet tall.

Black cottonwood'is a prolific seed producer with good crops produced annually. The seed is extremely tiny and attached to a feathery wisp of cotton which allows it to be carried many miles by the wind. A moist mineral soil seed bed is required for establishment. The species is intolerant of shade and will not reproduce beneath closed stands. It occurs as a pioneer species along with willow, alder, and Sitka spruce on alluvial soil in river valley bottoms and on newly-exposed land following glacial retreat or outwash. It is seldom found on organic soils.

Black cottonwood has been logged along with Sitka spruce and western hemlock in clearcutting of primary stands, but it is not sought for harvest. The wood has been tested in Alaska for use as dissolving pulp, but at present there is no market for the species. The tree is often planted as an ornamental because of its fast growth and handsome form. However, the wood is brittle, and exposed trees are subject to wind damage,

THE FOREST AS A COMMUNITY

FOREST SUCCESSION

From the preceding pages, it is apparent that the tree species which make up the' forests of southeast Alaska differ in their environmental requirements for regeneration and growth; and in characteristics such as growth rate, stature, and longevity. When we consider that trees and other plants are living organisms with finite lifespans and that disruption of the forest occurs from time to time either by nature or man, we realize that the forest is a dynamic plant community, constantly undergoing change. The changes in development of a plant community over time are referred to as plant succession. These changes are not haphazard but follow generally predictable patterns.

The natural establishment and development of a plant community on a barren portion of the earth's surface is known as primary plant succession. The site can be rock or coarse gravels (xeric succession), water (hydric succession), or some condition between (mesic succession). Pioneer plants are established from spores or seeds as they become available and growing conditions permit. In the process of growing, plants may cause changes in their surroundings which tend to favor other species. These species in turn may produce changes that render the site inhospitable for themselves and more hospitable for other species. As species become disadvantaged, they tend to die out and are replaced by those more able to cope with current growing conditions. This change and development of the plant community is continuous; and if no change in climate or outside disturbance occurs, it proceeds to a final or climax plant community which is controlled by site conditions and climate. When the dominant plants are trees, we think in terms of primary forest succession.

Secondary forest succession refers to the changes in a forest community that take place following disruption of an existing forest community rather than after exposure of new land. The distinction blurs, however, in cases where an existing forest is completely destroyed and all vegetation and soil organic matter are removed or deeply buried. For example, disruption is so severe after glacial advance and retreat that primary succession again follows (Cooper 1923a).

Primary Forest Succession

In southeast Alaska, the widespread and rapid retreat of glaciers during the last 200 years has provided unmatched opportunities for the study of primary succession. The first studies of primary succession were made in 1879 when the naturalist, John Muir, first visited Glacier Bay (Muir 1895, 1915). Fernow (1902) also described forest succession at Glacier Bay; Manson (190.3) described forest advance following retreat of Mendenhall Glacier; and in 1916 Cooper established permanent quadrats at Glacier Bay to study plant development (Cooper 1923c, 1956). Cooper's work continued over many years, and we owe much of our howledge of primary succession to him (Cooper 1923b, 1923c, 1924, 1931a, 1931b, 1937, 1939a, 1939b). To this work, Lawrence[13] (1950, 1958) and Lawrence and Hulbert (1950) have added knowledge of soil development accompanying primary succession, especially on the important role of alder in providing nitrogen for plant nutrition. This work on soil and plant development has been augmented by other investigators (Crocker and Major 1955; Crocker and Dickson 1957; Chandler 1942a, 1942b; Decker 1966; Ugolini 1966, 1968).

Primary succession in southeast Alaska usually begins when land is laid bare following glacial retreat, uplift from the sea, or landslides, The most prevalent substrates are glacial outwash, moraine or till, river alluvium, and rock. Water too is a point of beginning; eutrophication with conversion of ponds or lakes to bogs or muskegs is well documented (Dachnowski-Stokes 1941, Heusser 1960). However, the emphasis here will be on succession from a land beginning.

Primary plant succession begins with the appearance of willows, fireweed, horsetail, and mosses. Added to these may be mountain avens or alder which are especially important as soil builders because of their ability to fix nitrogen directly from the air. This pioneering vegetation may become established almost immediately after ice retreat, or several years may elapse before the pioneers appear. Scattered cottonwood and Sitka spruce may come in with the first wave of plant invaders or may not appear for some time. The time lag between exposure of new land and the establishment of vegetation and the species composition of the pioneers varies, depending on the nature of the surface exposed, rate of ice recession, available seed source, and other factors (fig. 6).

For ease of understanding, the continuous changes in the developing plant community may be thought of as separate stages. Cooper (192%) identified three distinct stages based on the character of the dominant plant or tree species present--pioneer, willow-alder, and forest stages. Decker (1966) further refined this description by recognizing eight distinct successional stages of subclimax vegetation, and plant diversity over time has been studied (Reiners et al. 1971). Because of local variation within the successional pattern, only a general description of this complex and continuous process will be given here, with Cooper's three stages of forest succession serving as points of reference.

The pioneer stage is a community of small plants such as lichens, mosses, perennial herbs, small shrubs, and young trees such as willow, alder, cottonwood, Sitka spruce, and occasional lodgepole pine and western hemlock. The second stage is a willow-alder community featuring willow, alder, cottonwood, and spruce as dominant plant species with many species of small plants in the understory. The third stage is the conifer forest community dominated by Sitka

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[13]Donald B. Lawrence. Development of vegetation and soil on deglaciated terrain of southeastern Alaska with special reference to the accumulation of nitrogen. Final report, project NR 160-183, University of Minnesota, College of Science, Literature, and the Arts, Minneapolis, 39 p., illus., 1953. (Report on file, Forestry Sciences Laboratory, Juneau.)

Figure 6.--Sitka alder, willows, and black cottonwood are among the most conspicuous plants in the early stages of primary succession following glacial retreat in southeast Alaska. Conifer seedlings occur under broadleaf trees and shrubs. (Mendenhall Glacier, Alaska)

spruce with some cottonwood, western hemlock, and occasional pine, and with a varied understory of shrubs such as salmonberry, blueberry, huckleberry, rusty menziesia, and devilsclub over a dense moss carpet.

Investigators have not been uniform in their interpretation of what constitutes climatic climax vegetation in southeast Alaska. Taylor (1932b) described the climatic climax vegetation as old-growth, uneven-aged forests. Heusser (1960) referred to vegetation below timberline as consisting primarily of the climatic climax Pacific coastal forest, interspersed with muskeg areas. Several investigators (Zach 1950, Rigg 1937, Cooper 1957) have speculated that bogs or muskegs as described by Dachnowski-Stokes (1941) may be expanding and encroaching into forest land, thus indicating continuing succession from forest to muskeg. Each has cited convincing examples of the gradual deterioration of site as forest stands increase in age. Lawrence (1958) agreed with this theory and concluded that bog or muskeg rather than forest is the climax vegetation type in coastal Alaska, advancing theories on how paludification or change from forest to bog might come about.

Investigation of soil morphology by Stephens et al. (1970) showed that muskegs are much less extensive now than they were some time after major Pleistocene deglaciation, and that muskeg may not be the climax vegetative type in southeast Alaska.

Recent ecological investigation by Neiland (1971) suggests a complex picture of the final stages of plant succession. This involves a continuous shifting of habitat patterns and species occurrence with tendencies for (1) better drainage, forest development, and raised bog humification, and (2) poorer drainage, bog development, and raised-bog growth. The vegetation at any particular time and place is pictured as depending on the combination of climate, surface physical features, and time lag of changes in vegetation and soil brought about by climatic fluctuations.

In view of the well-documented, long-term climatic changes occurring in southeast Alaska (Heusser 1960, Lawrence 1950, Goldthwait 1966), the pure concept of a climatic climax vegetation may be of only academic interest. The forest manager who is concerned with maintaining or improving the productivity of forest land is more immediately concerned with varying degrees of subclimax forest as exemplified by young, even-aged stands and older, uneven-aged "climax" forest stands of western hemlock and Sitka spruce (Godman 1952). This will be discussed in more detail under secondary forest succession, and reforestation.

Secondary Forest Succession

Secondary forest succession usually begins after the sudden destruction of a subclimax or climax stand of old-growth western hemlock and Sitka spruce (Taylor 1932b). Destruction of the forest stand may occur naturally as a result of blowdown, fire, landslide, flood, tidal wave, or from man's activities such as logging or land clearing. When disruption occurs, the first plant community to follow reflects the severity of disruption of the vegetation and disturbance to the soil. Usually not all plants are destroyed--roots, shoots, or entire plants may remain alive; and viable seeds are left in the ground or are located on undisturbed areas nearby where they can be easily carried onto the site. Soil may be disturbed, but its organic component is usually not removed entirely.

In general, secondary succession after forest disruption by clearcutting, blowdown, or fire consists of a shrub stage of short duration in which blueberry, huckleberry, rusty menziesia, devilsclub, Pacific red elder, salmonberry, currant, and other species are the dominant vegetation (fig. 7). Sitka spruce and western hemlock seedlings become established at almost the same time; but because of their slow early growth, these conifers are at first inconspicuous. Within 8 to 10 years after logging, western hemlock and Sitka spruce overtop the shrub layer and will develop into an even-aged stand. The stand may remain even-aged for up to 300 years before gradually changing to an uneven-aged condition. Conifer stands resulting from secondary succession are more uniform in age, denser, and tend to have a higher percentage of hemlock than stands resulting from primary succession (Taylor 1929). Species composition, growth rate, and timber yield of even-aged stands have been described in detail (Taylor 1934a). Because of the important role of even-aged stands for timber production, we will devote considerable attention to them in the section on even-aged stands.

The more the soil is initially disturbed and the more organic matter removed, the better conditions become for plants typical of earlier successional

Figure 7.--Salmonberry, thimbleberry, and ferns are prominent members of the plant community during early secondary plant succession on this study plot 6 years after logging in Maybeso valley, Alaska. Western hemlock and Sitka spruce seedlings are beginning to gain dominance.

stages; and plant communities tend to revert back in successional status toward the willow-alder stage. Seed source is important in determining the composition of the first plant community. When Sitka alder or red alder seed is available, alder may be among the first species to become established and may dominate the site for 40 years OF more. Sitka spruce usually becomes established with the alder; but because of its slower growth, the spruce is soon overtopped. Alder grows rapidly at first, gradually slowing in growth, and, after 30 to 40 years, is overtaken in height by spruce. Sprouting is also important; and brush species such as salmonberry, huckleberry, and others which were present under the previous stand may proliferate after removal of the overstory. Western hemlock usually lags behind spruce after heavy soil disturbance because hemlock does not readily become established on a mineral seed bed, With accumulating forest litter, the more shade-tolerant hemlock becomes established in the understory and, with time, becomes an increasingly important member of the forest comity.

Whatever the early history of conifer'stands, there is a general successional tendency toward more hemlock at the expense of spruce until a climax condition prevails, Once this climax forest develops, it tends to remain essentially unchanged as long as individual trees die and are replaced by new trees. Given enough time, such a forest is indistinguishable from one previously described as resulting from primary succession.

As even-aged stands gradually change to all-aged climax stands, they decline in growth and vigor. This decline is related to increasing average tree age and to changing conditions on the forest floor largely brought about by the forest stand itself. With continued shading, temperature of the forest floor is reduced. Biological activity decreases, organic decomposition slows, thus reducing the supply of available nutrients, and a deep organic mat and moss layer develops (Lawrence 1958). With decreased biological activity in the soil, less nitrogen is available for tree growth; and the tree's nutritional status is lowered. As stands continue in a climax condition, their growth and vigor remain nearly constant but at a level below that of the even-aged stand they replaced.

Removal of the forest cover allows the sun's warmth to reach the forest floor and soil temperature is increased (Gregory 1956). This rejuvenates the site by increasing the availability of nutrients, More light reaches the forest floor, and seed bed conditions which are conducive for seedling establishment and growth are created.

The method by which a forest stand is removed has an effect on tree regeneration and on future stand growth, A study of tree growth in relation to seed bed history showed that even-aged stands of western hemlock-Sitka spruce grew at a faster rate when they originated after wildfire or logging than after blowdown (Stephens et al. 1969). After forest removal by wildfire or logging, soil temperatures increase, with a subsequent increase in available nutrients. In contrast, following blowdown, the dense cover of down stems and branches tends to shade the soil surface so that soil temperature remains lower, resulting in a relatively lower rate of organic matter decomposition and nutrient release. The importance of soil temperature has implications for the forest manager in the selection of the silvicultural system to be used in final timber crop removal and the treatment of logging debris, When the rate of growth of the renewed stand is an important consideration, complete forest removal with a minim of logging debris left onsite is indicated. Large amounts of logging slash or debris left after clearcutting may be detrimental to future growth of a new forest stand.

Forest Succession and Soil Development

As vegetation proceeds through various stages of succession, soils also undergo development, and no discussion of forest succession would be complete without reference to accompanying changes in the soil. Several studies have been made in southeast Alaska which clearly demonstrate the interdependence of soils and vegetation.

Beginning with the nearly sterile glacial till, soil genesis proceeds rapidly as vegetation develops. Changes in soil are strongly correlated with vegetation and tend to involve primarily the soil's organic phase. Changes in the.soil's physical, chemical, or mineralogical character were not readily apparent in studies by Crocker and Dickson (1957), although Chandler (1942b) noted a progressive increase in both silt and clay content with age. Stephens (1969) concluded that even in mature soils of the region, alumino-silicate clays either do not form or are leached out of the profiles in the cool, wet climate and that organic matter is the source of almost all the cation exchange capacity of even certain mature soils. Organic matter then is especially important as the medium of nutrient transfer from the soil to plants.

During the first 35 to 50 years of successional development, soil becomes more acidic, organic carbon and nitrogen accumulate rapidly, and bulk density decreases. Buildup of nitrogen is especially great during the alder stages, when mean annual accumulation rates of 55 pounds per acre have been observed (Crocker and Major 1955). With elimination of the alder and the subsequent transition to conifers, nitrogen accumulates at a reduced rate. However, total annual organic matter added through litter fall may not change markedly from one successional stage to the next, although there may be differences in accumulation from year to year (Hurd 1971).

Decomposition rate is slow in the cool, moist climate of southeast Alaska, and organic matter builds up rapidly. Gregory (1960) found that during the first 125 years after the substrate was laid bare by landslide, the soil organic layer under spruce-hemlock stands accumulated at an annual rate of 383 pounds per acre and that during the period from 125 to 300 years, an additional 1,121 pounds per acre accumulated annually. By the time a mature hemlock-spruce stand had developed (300 plus years), some 235,418 pounds per acre of surface organic material had accumulated to an average depth of 6.20 inches. This is in general agreement with Chandler's (1942a) data which showed a total organic matter accumulation of 455,704 pounds per acre in the 5-inch surface organic layer and upper 8 inches of the mineral soil in 250 years after glacial retreat.

As organic material decomposes, it gradually works down into the mineral soil layers by water movement and by soil fauna activity, and a podzol profile develops. Chandler (1942a) stated that about 1,000 years were required to develop a mature podzol in southeast Alaska. Crocker and Dickson (1957) found little evidence that anything approaching a typical podzol resulted from soil formation on glacial moraines in the region and favored Kellogg and Nygard's (1951) opinion that such soils should be regarded as weak podzols. Ugolini (1966), however, described podzol formation at soil age 150-250. Taylor (1934b), Stevens (1963), and Stephens (1969) noted that mature mineral soils under timber were well-developed podzols. Cation exchange capacity and water retention in these soils have been shown to be dependent on organic matter and iron rather than clay (Stephens 1969, Holty and Heilman 1971).

As forest management experience increases, it is becoming apparent that "youthful" soils, as exemplified by glacial outwash, recently glaciated or uplifted areas, and alluvial soils, all of which support forest stands undergoing primary succession, present problems in regeneration and growth after forest stands are harvested. This is in sharp contrast to more mature upland soils where natural regeneration tends to become well established soon after logging. Youthful soils are commonly found adjacent to streams and rivers and on glacial outwash sites on the mainland. The most significant area of glacial outwash is located in the vicinity of Yakutat.

Nutrient exchange in these youthful soils is confined almost entirely to the soil organic layers, and hence any removal of organic material will adversely affect regeneration and growth of trees because of the reduced nutritional status of the soil. Other changes such as increases in soil bulk density and in water-holding capacity may also adversely affect tree regeneration and growth. The time required for a soil to develop beyond this "youthful" stage is not known. Soil development, especially regarding the soil organic component and its relationship to tree growth, is an important topic for further study.

DESTRUCTIVE AGENTS

Aging and death of trees are natural processes that pave the way for renewal and continuation of forests. As individual trees die, they make room for others and their remains are incorporated into the soil to provide nutrients for future generations. In nature, living (biotic) and nonliving (abiotic) destructive agents alter the natural aging and death processes of trees and stands.

Biotic agents include disease organisms, insects, nematodes, plant parasites, birds, and mammals, including man. Abiotic agents include wind, fire, landslides, floods, tidal waves, earthquakes, and others. A single agent or a combination may be responsible for a tree's death.

Destructive agents become a problem to man when they interfere with his uses of the forest. When forests are managed for timber production, fish and wildlife habitat, recreation, watershed protection, amenities, or other uses, great economic or social loss may result from the natural process of forest destruction.

The pattern of death of trees in a stand determines to a large extent the character of the succeeding forest. For example, when all trees in a stand are blown down, killed by fire, removed by landslides, or clearcut by man, even-aged stands follow. When individual trees die, as often happens from attack by insects or disease, or in selection cuttings, all-aged stands tend to develop. In climax stands, trees decline in vigor as the natural aging process occurs, and the ultimate cause of death may be difficult or impossible to determine.

Some destructive agents are more important in all-aged climax stands and, others are more important in even-aged stands. The relative importance of each may change with stand age. Disease is perhaps the least spectacular in visual damage but accounts for much economic loss through destruction of valuable timber. In some cases such as in fluting of hemlock, the damaging agent is unknown. Fluting, although it apparently does not kill trees, renders some stands of hemlock unfit for sawtimber production.

Silvicultural techniques used to manage stands, such as thinning and fertilization, may tend to reduce or increase the susceptibility of trees and stands to damage by various destructive agents. The forest manager should be cautious in the application of management practices. He should be alert to possibilities for potential damage and ready to adjust management techniques as experience dictates. A brief account of some of the more important damaging agents, their potential effects, and experience to date follows.

Insects

Of the thousands of insect species that live in our forests, most are harmless or even beneficial. Many species feed on dead organic material and thus hasten breakdown and release of essential nutrients for new plant growth. Others provide food for fish, wildlife, and birds. Many species are parasites or predators which help to regulate population levels of destructive insects.

Western hemlock and Sitka spruce have few insect enemies in southeast Alaska, and hemlock is more susceptible to attack than spruce. Two defoliating insects, the black-headed budworn and the hemlock sawfly, rank one and two as our most destructive forest insects (Hard 1967). Periodically they cause widespread defoliation, particularly to western hemlock, their favorite host. Known budworm outbreaks occurred in the years 1917-21, 1948-55, and 1958-65. Millions of acres of forest land were defoliated during these outbreaks. In some stands which suffered from heavy or repeated attack, much of the hemlock overstory was badly damaged or killed. Sitka spruce was also attacked, particularly when budworm population levels were high. Total growth and volume losses resulting from these defoliator outbreaks are unknown; but to people living in the area at the time, it appeared serious. In the ensuing years, most trees recovered, and today past losses are not readily evident.

Except for an occasional attack by defoliators, Sitka spruce has few insect enemies. The Sitka spruce beetle occurs at endemic levels in old-growth stands but rarely reaches epidemic proportions. The largest recorded outbreak of the Sitka spruce beetle took place in high-site spruce stands on Kosciusko Island in the years just before 1946. During the outbreak, 35-1/2 million board feet of spruce was killed over 6,400 acres.[14]

It appears that the cool, moist climate that typifies this region is important in limiting the buildup of insect populations (Hard 1974b). For example, the rate of development of the black-headed budworm in Alaska is related to temperature,[15] [16] and budworm population trends in British Columbia and coastal Alaska are related to weather (Silver 1960, 1963; Schmiege 1966; Hard 1974a). Other factors also appear to be important, including the buildup of

[14] R. L. Furniss and Ivan H. Jones, A second report concerning the bark beetle outbreak on Kosciusko Island. Report on file, Forestry Sciences Laboratory, Juneau, 7 p., 1946.

[15] 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.

[16] 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.

parasitic insects (Torgersen 1968, 1969, 1970) and microbial disease organisms such as viruses (Torgersen and Baker 1967) and fungi.[17]

Recently, insect epidemics have been short enough to preclude the need for control measures involving aerial or ground applications of insecticides. If future experience follows that of the past, the best procedure may be to depend on natural processes to keep insect populations in balance; but short periods of high activity should be expected. For these periods, management planning should be flexible enough to minimize resource losses by salvage of as much of the killed material as possible.

At present we have few insect problems compared with other areas within the western hemlock-Sitka spruce type. Two very destructive forest insects, the spruce budworm and the western hemlock looper, have done little damage in southeast Alaska. A small outbreak of the spruce budworm on Sitka spruce near Haines between 1948 and 1950 (Downing 1957) and a 400-acre outbreak of the hemlock looper on Sitka spruce along the Bradfield River near Wrangell in 1965 and 1966 (Torgersen and Baker 1967) are the only outbreaks of these species recorded in Alaska. A third insect, the Sitka spruce weevil, has not been found in Alaska. Reasons for the absence or low populations of these species are unknown, but climate is suspect. As more forest land comes under intensive management and stand structure changes from predominantly old growth to that of young, even-aged stands, these and perhaps other insects could become more damaging. This has happened in British Columbia (Silver 1962).

Each year the Forest Service conducts an intensive insect survey throughout southeast Alaska. Results of these surveys are published yearly in the U.S. Department of Agriculture's publication, "Forest Insect and Disease Conditions in the United States." Over the years, information .obtained from these surveys will be of value in projecting population trends and for pinpointing insect problem areas. In addition there is a need for surveys to quantify the damage. Except for damage surveys[18] [19] [20] during the budworm outbreak of the 1950's, there is little information available on the actual damage by the different species of insects. Such information is needed to evaluate the relative importance of insect problems in Alaska and for cost-benefit analyses of various control alternatives.

Disease

Losses from tree diseases are high principally because of the old-growth structure of our forests, About 32 percent of the gross board-foot volume in old-growth stands is estimated to be unusable as sawtimber.[21] Current problems in young-growth stands are minor in comparison.

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[17]W. F. McCambridge. Studies of the biology, habits, and control of the black-headed budworm in Alaska, season of 1953. (Mimeogr.) USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon, 25 p., illus., 1954.

[18]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, Oregon, 8 p., illus., 1953.

[19]See footnote 17.

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

[21]Forest Survey statistics on file at Forestry Sciences Laboratory, Juneau, Alaska.

Defect varies greatly within and between species. Sitka spruce averages considerably lower in defect than does hemlock. The cedars are most defective. About 9 percent of the total gross volume of spruce in old-growth stands is cull. Western hemlock and the cedars average about 22 and 52 percent.

As trees mature and their vigor declines, they become more subject to disease. Conifers less than 100 years old have little decay. After 100 years, the probability of a tree having rot increases rapidly. By 200 years, 65 percent of the cedar, 50 percent of the hemlock, and 20 percent of the spruce contain some rot (Kimmey 1956).

Although many diseases exist in our forests, only a few tree diseases cause significant damage. Foliage diseases and various stains and molds are of little importance. Stem diseases and rots, however, are of concern. Decay caused by heart and root-rotting fungi is probably the greatest single cause of volume loss in old-growth stands (Laurent 1974).

Western dwarf-mistletoe is the most important stem disease.[22] Western hemlock in parts of southeast Alaska and British Columbia is severely parasitized by this organism; damage is only slight in Washington and Oregon where hemlock reaches its optimum development (Boyce 1961). Sitka spruce is rarely infected (Laurent 1966). Although dwarf-mistletoe produces some of its own food, its nutrients are obtained from its host. This reduces vigor, growth, and quality of hemlock. Dead tissue caused by the organism provides entrance points for decay and stain-producing fungi. Spread of the organism, however, is slow because mistletoe cannot forcefully eject seed beyond about 40 feet and usually 15 feet or less (Boyce 1961).

Mistletoe can best be controlled as the mature stands are harvested. Clearcutting and the removal of all infected residuals effectively control its spread (Shea 1966). In young stands, mistletoe is not a serious problem except where infected trees are left after logging.[23] Periodic thinning and removal of infected stems may control the spread of mistletoe in young stands. The actual amount of growth that would be lost if mistletoe went unchecked in young stands is not known for Alaska, and only limited information is available on the damage caused by this organism elsewhere (Smith 1969). Possibly, for rotations of up to 100 years there would be little growth loss in dense, fast growing stands. Economic analyses of costs and benefits of control should be conducted before expensive control programs are set up.

In the past few years a stem disease, identified as *Sirococcus strobilinus*, has been noted in stands of young-growth hemlock (Funk 1972). This disease causes dieback of the tip and lateral branches. Some trees have been killed. The potential for damage is not known. Research is needed to evaluate the organism in Alaska.

Many species of fungi are responsible for decay in living spruce, hemlock, and cedar. Two generalized groups are recognized, white rots and brown rots.

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[22] Keith R. Shea and James L. Stewart. An examination of the dwarf-mistletoe situation in western hemlock forests of southeast Alaska. Special report, USDA Forest Service, Juneau, Alaska, 15 p., 1970.

[23] Douglas R. Miller. An extensive forest disease survey of second-growth stands in southeast Alaska. Report on file at USDA Forest Service, Alaska Region, Juneau, Alaska, 1971.

The white rots are caused by fungi that decompose all components of the wood; the brown rots, by fungi that attack the cellulose, leaving the lignin more or less unaffected (Boyce 1961). The brown rots account for 84 percent of the decay in Sitka spruce. The white rots account for 68 percent of the decay in western hemlock and 98 percent in western redcedar. *Fomes pinicola*, a brown rot fungus, causes 74 percent of the decay in Sitka spruce and 22 percent in western hemlock. In western hemlock the white rot fungi *Armillaria mellea* and *Fomes annosus* account for 20 and 22 percent of the decay, The white rot fungi *Poria albipellucida* and *P. weirii* account for 46 and 41 percent of the decay in western redcedar (Kimmey 1956).

Over the years as old-growth stands are converted to young growth, losses from disease will decline, and potential of sites for producing wood products will be more fully realized. An extensive forest disease survey of young, well-stocked stands (see footnote 23) found them to be in generally good health, with little rot, We anticipate, however, that problems may arise when intensive management comes to the coastal forests. One potential problem is that exposed stumps and wounds left after thinning could lead to the development of *F. annosus* infection centers (Driver and Wood 1968). This fungus is commonly found in old-growth stands. About 22 percent of the decay volume of western hemlock in old-growth stands is attributed to this fungus (Kimmey 1956).

The thin bark and shallow roots of hemlock and spruce make them particularly susceptible to logging injury, so thinning will cause some damage to the stand. Studies by Buckland et al. (1949), Foster and Foster (1951), Wright and Isaac (1956), Shea (1960, 1961), and Wallis et al. (1971) have shown that bark and root scarring can lead to serious decay. The need for cooperative research on the mensurational, pathological, and economic aspects of thinning is evident.

Fire

Fire has not played an important role in the management of our coastal forests. Summers are generally moist and cool, with dry periods lasting a week or 10 days followed by several days of precipitation. Dry periods of 2 weeks or more with above normal temperatures occur every few years; but during recent dry summers, there have been few large fires. During the summers of 1958, 1968, and 1971, some sections of southeast Alaska experienced extended dry periods; but total area burned in each of the 3 years was only 1,465, 137, and 71 acres.[24] All but two of the 70 fires during these years were man-caused.

Although we know little of the past fire history of our coastal forests, we could learn much from detailed studies of even-aged stands. However, fire appears to have played a more significant role in present stand structure than is generally recognized. Although most of our forests are uneven aged, there are extensive areas of even-aged stands that apparently owe their origin to fire. Origin of older even-aged stands is often difficult to determine because charcoal is soon hidden by the rapid buildup of organic matter on the forest floor.

Studies farther south in British Columbia and in the Pacific Northwest suggest that conditions occasionally develop which trigger disastrous forest fires (Morris 1934; Schmidt 1960, 1970). There is ample evidence that extensive

[24] Annual fire report for Region 10 on file at Region 10, USDA Forest Service, Juneau, Alaska.

fires burned all along the north Pacific coast long before white men first entered the region. These fires were caused by activities of the natives and perhaps by lightning strikes. Lightning is more common farther south than in southeast Alaska, and within southeast Alaska the probability of lightning decreases to the north. Even during very dry summers, lightning-caused fires are rare.

Morris (1934) has provided a good summary of recorded fire history for western Washington and western Oregon from the early 1800's up to the Tillamook fire of 1933, and Schmidt (1970) has studied the history of presettlement fires on Vancouver Island. From Schmidt's history we know that major fires occurred on Vancouver Island about 150, 230, 310, 360, 410, 560, 760, and 870 years ago. The fires of 310 and 410 years ago probably covered 2 million acres on the island, plus extensive areas on the British Columbia mainland and in the Pacific Northwest. We have observed that extensive fires occurred in southeast Alaska about 150 to 170, 240, and 310 years ago. It seems likely that extreme fire years occurred about the same time here as farther south, Since 1900, few fires have been over 100 acres in size in southeast Alaska. The three largest were the 15,000-acre Karta Bay fire, the 5,000-acre Skowl Arm fire, both of which occurred in the early 1900's, and the 2,000-acre Cleveland Peninsula fire of 1938. In recent years only three fires have exceeded 100 acres in size. Two occurred in the dry summer of 1958, the other in 1968. Two of the fires were caused by logging--the 745-acre Klu Bay fire in 1958 and the 110-acre Sitkoh Lake fire in 1968. The third fire occurred on Annette Island in 1958. It burned over 650 acres.

Our current fire problem is due to activities of man. Permanent residents, transients, sportsmen, contractors, and others are all responsible (Noste 1969). As more use is made of our forests, we can expect greater risks of fire. Disastrous fire years will no doubt occur in the future as they have in the past.

Wind

Wind damage is common in the coastal forests. Every year storm winds take their toll in uprooted and broken trees all along the Pacific coast. Most of the damage goes unnoticed, but every few years a disastrous storm levels extensive forested areas. Oregon and Washington have a recorded history of wind damage dating back to the turn of the century, with the Columbus Day (October 12) storm of 1962 being the most severe. The Columbus Day storm blew down an estimated 11.2 billion board feet of timber in the States of Washington and Oregon (Orr 1963). A number of earlier storms in Washington and Oregon also resulted in large losses (Boyce 1929, Ruth and Yoder 1953, Orr 1963).

We know little about past storm damage in southeast Alaska although there is much physical evidence. Each fall several storms pass through the area accompanied by high winds. Because of past storms, small patches of even-aged western hemlock and Sitka spruce dot the landscape.

Like the Columbus Day storm that hit Washington and Oregon, the most destructive windstorm on record for southeast Alaska also occurred on a holiday. About 9:00 a.m. Thanksgiving Day 1968, a cold front that was accompanying a deep low pressure area in the Pacific moved onshore at Prince of Wales Island. This northwest-southeast-oriented front moved quickly northward through southeast

Alaska with hurricane force winds generally peaking just northeast of the front.[25] By 3:00 p.m. the storm passed through Skagway and had left in its wake about 1 billion board feet of timber in concentrated blowdown, plus an undetermined amount of scattered blowdown (fig. 8). Winds up to 100 miles per hour were recorded (U.S. Department of Commerce 1968).

Figure 8.--Wind may damage more than trees. Windthrown trees were removed from Kook Creek, Chichagof Island, after the 1968 Thanksgiving Day storm to allow passage of salmon. The watershed was unlogged.

The National Weather Service has estimated the frequency of such a storm as once in 8 years (see footnote 25). The forests of southeast Alaska are rarely damaged to the extent they were from this particular storm; however, windthrow loss from recurring storms is common. For example, Forest Survey data indicate that about 27 percent of annual timber losses is due to windthrow.[26]

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[25] Personal communication with Mr. Francis W. Poole, former meteorologist in charge, National Weather Service office, Juneau, Alaska.

[26] Data on file, Forestry Sciences Laboratory, Juneau, Alaska,

No known physical evidence exists that suggests past storms were as destructive as the 1968 storm although an intensive survey might prove otherwise. A study of existing even-aged stands could provide valuable insights of stand origin and periodicity of disasters,

Much interest in windthrow has developed in recent years, due partly to damage caused by many recent storms, but also to increased logging activity with accompanying windthrow losses along cutting boundaries. There is no ready solution for eliminating windthrow along cutting boundaries, but steps can be taken to minimize losses.[27] The shallow-rooted character of western hemlock and Sitka spruce, frequent fall storms, abundant rainfall, shallow soils, complex topographic features, cyclonic wind patterns, and other factors are no doubt important. With projected increases in logging activities and exposure of more clearcut boundaries, timber losses from windthrow will increase in the future. Also, as the size of clearcuts is reduced and cutting units are shaped to more closely resemble natural forest openings, the length of cutting boundaries in relation to timber removed and losses due to windthrow may increase accordingly.

Other regions in the Western United States have similar windthrow problems, and studies have been conducted to evaluate where windthrow occurs in relation to the location of cutting boundaries (Ruth and Yoder 1953, Gratkowski 1956, Alexander and Buell 1955, Alexander 1964, Steinbrenner and Gessel 1956). Results from these studies generally agree. It seems apparent from the general howledge of the forest that windthrow problems here are similar to those elsewhere. Recommendations have been developed and are being followed in locating cutting boundaries to provide wind-protected edges (see footnote 27). However, we need to evaluate these guidelines to determine if additional steps would further reduce windthrow losses associated with timber harvest.

Because western hemlock and Sitka spruce generally have shallow roots in southeast Alaska, they depend on mutual support for wind resistance. When stands are opened, particularly those growing on shallow or wet soils, they become more susceptible to windthrow. Wind firmness is slowly developed by the trees growing along cutting boundaries; but depending on tree age and vigor, this may take many years. Ideally, logging should be scheduled so that an operator can remain in an area for several years. This allows time for cutting boundaries to stabilize; and should blowdown occur, there is a better chance that it can be salvaged.

Most windthrow goes unsalvaged because logging is more expensive and dangerous in windthrown timber and windthrown patches tend to be widely scattered and difficult to reach. However, if windthrown timber is not salvaged, site productivity will probably be lower for the next rotation than it would be if the site were cleared (Stephens et al. 1969). Also, there will be little spruce in the next stand, particularly if abundant advanced hemlock regeneration is already established. Opportunity for intensive management in the next rotation will be lost because of the tangle of debris left on the ground, and raw material will be wasted. If the downed timber is not salvaged, other standing timber will be cut in its place to meet cutting goals.

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[27] Recommendations for locating cutting boundaries are given in section 433.2--3 of Forest Service Handbook 2409.22R10, "Timber sale preparation and appraisal handbook," USDA Forest Service, Juneau, Alaska.

Fluting

Flutes or vertical grooves are common in the main stems of hemlock in southeast Alaska. Some stands contain more damaged stems than others. Fluting is particularly noticeable in some even-aged stands (fig. 9). The agent or mechanism that triggers development of flutes is not hown although an apparently similar problem has received some attention in Britain (Day 1958, 1964). Day (1964) suggested that development of flutes may be due to problems of water transport and supply within the stem as influenced by the condition of the root system and the demand made by the crown.

Figure 9.--Western hemlock in this even-aged stand at Point White, Kupreanof Island, is extremely fluted. Sitka spruce is not affected. Fluting decreases pulp yield and can make trees unsuitable for sawtimber.

Seriously fluted stands occupy the range of sites in southeast Alaska. Some second-growth stands are so badly affected that the hemlock component is of no merchantable value for sawtimber (Alaska Forest Research Center 1957, p. 24-25). Spruce apparently is not affected.

Fluting of hemlock appears to be more of a problem in southeast Alaska than farther south. Although pulpmills can more readily separate the bark from wood in the pulping process than was the case a few years ago, the process is more costly and there is less cubic-foot volume for a given size log.

Intensive management of our second-growth stands could be greatly influenced by howledge of what factor or factors cause fluting of hemlock. Soil, stand density, root disease, frost, or genetics might be responsible. A complete assessment of the problem is needed.

Landslides

Landslide tracks are common throughout southeast Alaska. More than 3,800 large-scale debris avalanches and flows have been counted on aerial photographs of the Tongass Forest.[28]

The downslope movement of large masses of earth material known as "mass wasting" (Swanston 1969) is due to a combination of factors which characterize the region: oversteepened slopes; abundant rainfall; youthful, shallow, coarse-.textured soils with relatively high permeability; and minimal surface runoff. Slides, generally triggered during heavy spring or fall rains, originate on very steep forested slopes. Slope angles range from 30" to 60°. Damage is often extensive, especially with debris flows, as the downslope movement of material often removes all vegetation and soil material in its path. Regrowth may take years as development of new soil is a slow process and sloughing of material may continue in the slide track. Man-caused landslides may also be objectionable from an esthetic standpoint. Mechanics of the landslide process, although complex, can be described quantitatively[29] (Swanston 1970).

Mass erosion was not considered a serious forest management problem in southeast Alaska before large-scale clearcutting began in the mid-1950's. Nothing could be done about landslides in the natural environment, and there was no experience to demonstrate what might happen after extensive logging. It was not until the heavy rains of October 1961 that the problem became evident. Mass soil movement began in the Maybeso valley, at Neets Bay, and at Gedney Pass, on steep clearcut slopes that had been logged 4 to 6 years before (Bishop and Stevens 1964) (fig. 10). Since then, considerable attention has been focused on investigations on landslide distribution, process of movement, and factors affecting occurrence (Bishop and Stevens 1964; Swanston 1967a, 1967b, 1969, 1970, 1971; also see footnote 29).

Vegetative cover plays an important role in helping to stabilize steep mountain slopes. When this cover is disturbed by activities of nature or man, the probability of mass movement of soil increases. The angle of internal friction for soils commonly found on slopes in southeast Alaska varies from about 34" to 46" depending on soil density and weight of overlying material (Swanston 1967a). Slope stability, however, is also conditioned by other factors such as the anchoring effect of root systems, cohesion provided by organic colloids, bedrock structure, and moisture content.

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[28]Landslide occurrence in coastal Alaska. Study No. 1604.12; data on file, Forestry Sciences Laboratory, Juneau, Alaska.

[29]D. N. Swanston. Slope stability problems associated with timber harvesting in mountainous regions of the Western United States. Paper presented at the Symposium on Forest Operations in Mountainous Regions, Krasnodar, USSR, 1971.

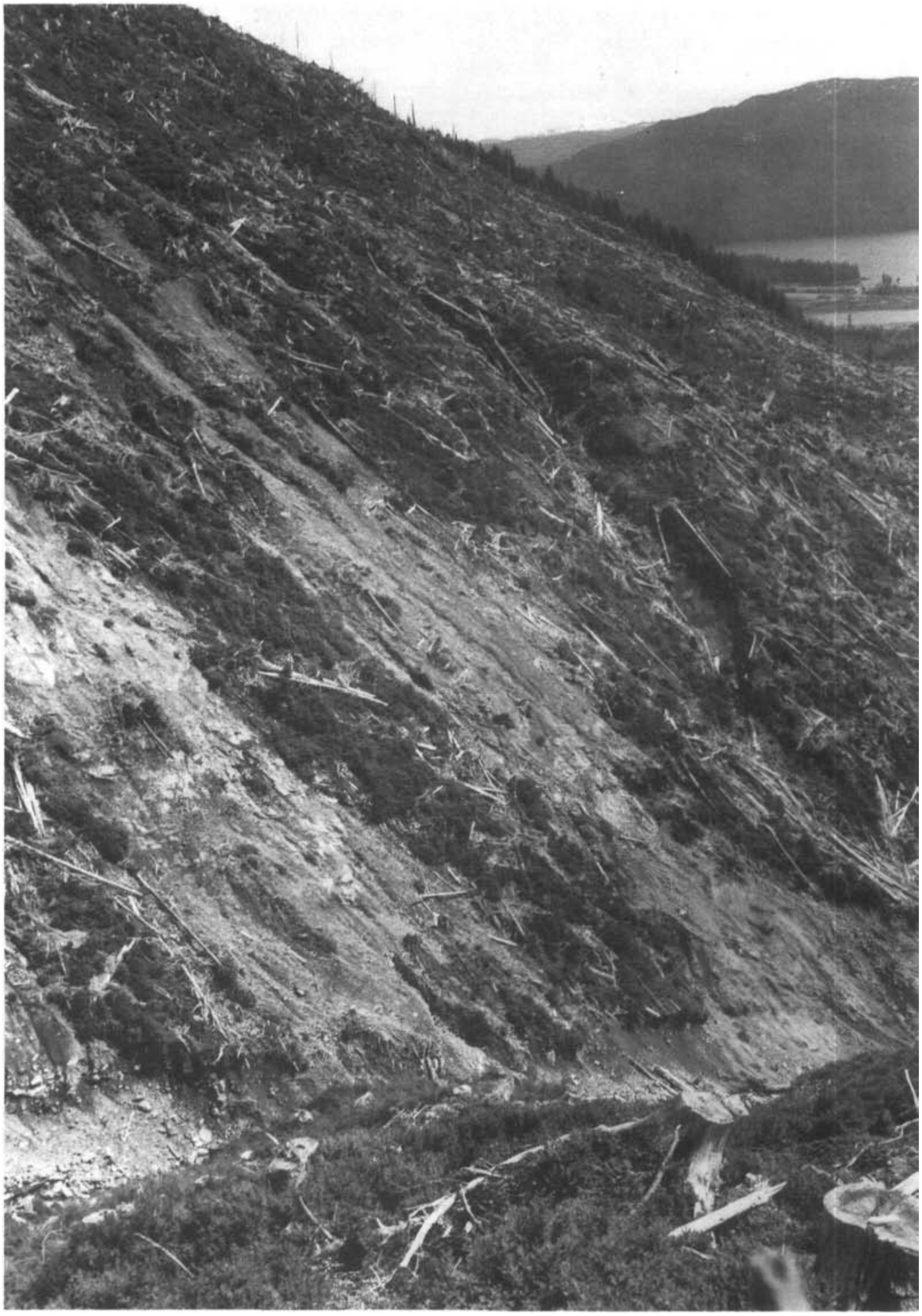

Figure 10.--Frequency of landslides may increase following logging. Maybeso valley near Hollis, Alaska.

Swanston (1969) recommended that probably the most practical and direct management policy would be to avoid logging in areas of maximum slide susceptibility; that is, slopes of approximately 34° or more. Slopes with gradients equal to or greater than this are highly susceptible to sliding, particularly if greatly disturbed, The Forest Service's present policy is to avoid road construction or logging on unstable soil areas until methods that do not damage the particular soil involved can be developed, Timber on slopes greater than 37° is excluded from the regulated cut.[30]

There are alternatives to high-lead systems for logging steep slopes; skyline, balloon, and helicopter logging are possibilities that would greatly reduce site disturbance. Whether avoiding soil disturbance will eliminate the problem remains to be demonstrated, however. Tree root systems may be extremely important in maintaining slope stability. If trees are the major holding force on steep slopes, then 'clearcutting of these areas by any method would most certainly still result in significant landslide activity. Still other possibilities might be to use the selection method on oversteepened slopes or some form of the shelterwood method (Hawley and Smith 1954). Use of either the selection or shelterwood method on steep slopes would be too costly now, but it might be feasible to consider them given a more favorable economic climate or relaxation of the primary manufacturing requirement for material extracted from such areas. Of perhaps equal importance is the lack of technology for logging old growth other than by clearcutting. Research is needed to evaluate various alternatives for management of forests growing on steep slopes, and the costs and benefits of various management practices should be quantified. To know that slopes greater than some critical angle are apt to slide is not enough--probabilities of sliding and total damage that may result are questions that must be answered.

UNDERSTANDING THE FOREST ECOSYSTEM

A great deal is known about forest ecology in southeast Alaska; the requirements of major tree species--their development as members of the forest community and the natural succession of these communities--and the natural agents that bring abut changes in the forest. This information has been gathered over the years from observation and experimentation. In fact, much pioneering in the field of ecology has been done by foresters. This information is used to guide present forest management activities.

Today many land management decisions reach far beyond the relatively narrow confines of maximizing production of goods from forest lands; actions originating on forest land affect adjacent lands, streams, estuaries, and the air itself.

The need is growing to understand and quantify the relationships between primary production, consumption, and decomposition within the forest ecosystem. Such factors as primary production, energy transfer, nutrient cycling, and water movement through and beyond forest stands are all vital processes which bear'on improved forest management practices. Pioneering research efforts are now underway in the Pacific Northwest to better understand coniferous forest ecosystems; for example, the recent work of the U.S. International Biome Program (Franklin et al. 1972). Much future ecological research in southeast Alaska will follow the patterns now being developed in similar forest types to the south. Such research will provide the understanding needed for future management of the forests of southeast Alaska.

[30]Forest Service Manual R-10 Supplement 126, Title 2400--Timber Management, November 1972.

CHARACTERISTICS OF COMMERCIAL TIMBER STANDS

In the following sections we will consider timber management, limiting discussion to forest stands which occur on the more productive sites--more specifically, on what is now considered to be commercial forest land.

Commercial forest land is defined as land capable of growing stands containing 8,000 board feet (International 1/4-inch rule) of timber per acre, and available for timber production (Hutchison 1967). This land is at least 10 percent stocked with conifers or hardwoods of sufficient size and quality to make them attractive for commercial harvest now or in the foreseeable future. Muskegs with scattered trees, land surrounding muskegs with low-volume, open stands, and alpine stands above the continuous tree line are not considered to be commercial forest land. Detailed statistics on area and volume of commercial forest land and on the extent of the timber resource and economic considerations are available (Hutchison 1967).

Forests of commercial quality include stands of various ages, conditions, and species composition--the gamut of primary and secondary successional stages, from seedling stands to the advanced all-aged forest community dominated by western hemlock, commonly considered to be southeast Alaska's climatic climax vegetation (Taylor 1932b, Heusser 1960). Species composition on commercial forest land is variable depending on soil, stand history, and latitude. Attempts now being made to classify forest environments based on characteristics of the soil show that soil drainage and depth are well correlated with vegetation and site productivity, the latter increasing with better soil drainage and greater soil depth.[31]

STAND SPECIES COMPOSITION

For the convenience of timber managers, five major forest types have been classified by predominant tree species; hemlock, Sitka spruce, hemlock-spruce, cedar, and coastal hardwoods (Hutchison 1967).

Hemlock.--This type includes stands in which western hemlock comprises 50 percent or more of the gross volume.[32] Common associates are Sitka spruce, western redcedar, Alaska-cedar, mountain hemlock, and, rarely, true firs. All-aged stands far advanced in successional development and commonly considered to be the typical forest climax vegetation are included. These stands occur on a variety of sites. Stands of mountain hemlock are included in this type, often with Sitka spruce, Alaska-cedar, or western redcedar as associated species. Even-aged stands of nearly pure western hemlock may become established after windthrow or logging where soil disturbance is light, where advanced hemlock regeneration is abundant, or where the seed source is primarily hemlock.

Sitka spruce.--This type includes stands in which Sitka spruce accounts for 50 percent or more of the gross volume. Stands of pure spruce occur on well-drained sites following glacial recession, land uplift, landslides, stream cutting, or other severe soil disturbances. Such stands are in an early

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[31]F. R. Stephens, C. R. Gass, R. F. Billings, and D. E. Paulson. Soils and associated ecosystems of the Tongass. USDA Forest Service Alaska Region, draft report, June 1969.

[32]Gross stand volume was used to characterize stand species composition and the initial inventory. Stocking in terms of basal area is being used for the reinventory.

successional stage and may or may not have passed through an alder stage. Hemlock is often found in the understory, and the successional trend is toward more hemlock.

Hemlock-spruce.--This type includes stands in which Sitka spruce comprises 30 to 49 percent of the gross volume and hemlock is predominant. Stands are often advanced in age and essentially two storied, with large residual spruce dominant in the overstory and an all-aged understory of hemlock and occasional spruce. Hemlock-spruce stands become established as even-aged stands after logging, fire, or blowdown where soil disturbance is moderate.

Cedar.--The cedar type includes either western redcedar or Alaska-cedar as the predominant species (over 50 percent of gross volume). Stands of western redcedar are limited to the southern portion of southeast Alaska, Alaska-cedar extends throughout the area. The two species of cedar often occur together where their ranges overlap. Other associates are mountain hemlock, western hemlock, and, less commonly, Sitka spruce. The type usually occurs on organic soils or soils shallow to bedrock.

Coastal hardwoods.--This type includes stands in which broadleaf tree species predominate. Black cottonwood and willow stands occur chiefly along the larger mainland river valleys and along the Yakutat coastal strip. Red alder or Sitka alder are also found in the major river valleys and on avalanche and landslide tracks. Western paper birch and aspen stands occur rarely at the head of Lynn Canal.

Hardwood stands become established following glacial recession, land uplift, alluvial deposition, fire, or extreme soil disturbance by man and represent early successional stages of forest vegetation. Usually they contain an understory of more shade-tolerant conifers which gradually overtop the hardwoods and eventually dominate the stands.

OLD-GROWTH STANDS

For inventory purposes, forest stands on commercial forest land have been arbitrarily classified by age and tree size (Hutchison 1967). Old-growth stands are defined as those having the majority of timber volume in trees more than 150 years of age. Such stands contain a minimum net volume of 8,000 board feet (International 1/4-inch rule) per acre in trees 11.0 inches in diameter and larger in the case of conifers, and 4,000 board feet per acre in the case of hardwoods. Old-growth sawtimber stands occupy 87 percent (4.2 million acres) of the total commercial forest land area of southeast Alaska (Hutchison 1967).

Old-growth stands vary widely in structure and species composition. Most of the timber volume is in trees 21- to 30-inch diameter, but more than one-third is in trees over 30-inch diameter, On a board-foot basis 61 percent of the volume is western hemlock, 33 percent Sitka spruce, and 6 percent cedar and other species (Hutchison 1967).

The decadent condition of old-growth stands in southeast Alaska has often been emphasized, the assumption being that mortality is balancing growth in climax stands. However, not all stands classified as old growth are decadent. Included within this class are older, even-aged stands that are still thrifty and adding volume.

All-aged stands contain a wide range of tree sizes, from seedlings and saplings to occasional trees over 8 feet in diameter and 200 feet tall. Live trees decay increasingly with age, and stands far advanced in age may be very defective (Kimmey 1956). Stands with over 40 percent of their wood volume unusable for sawtimber are not uncommon. In extreme cases, climax stands may be declining in total usable wood volume, with paludification of the site and a tendency toward successional conversion to muskeg (Lawrence 1958).

Even-aged, old-growth stands range in age from 150 to over 300 years. They are in a preclimax successional status, contain little defect, higher than average percentages of Sitka spruce, and are adding net growth (fig. 11).

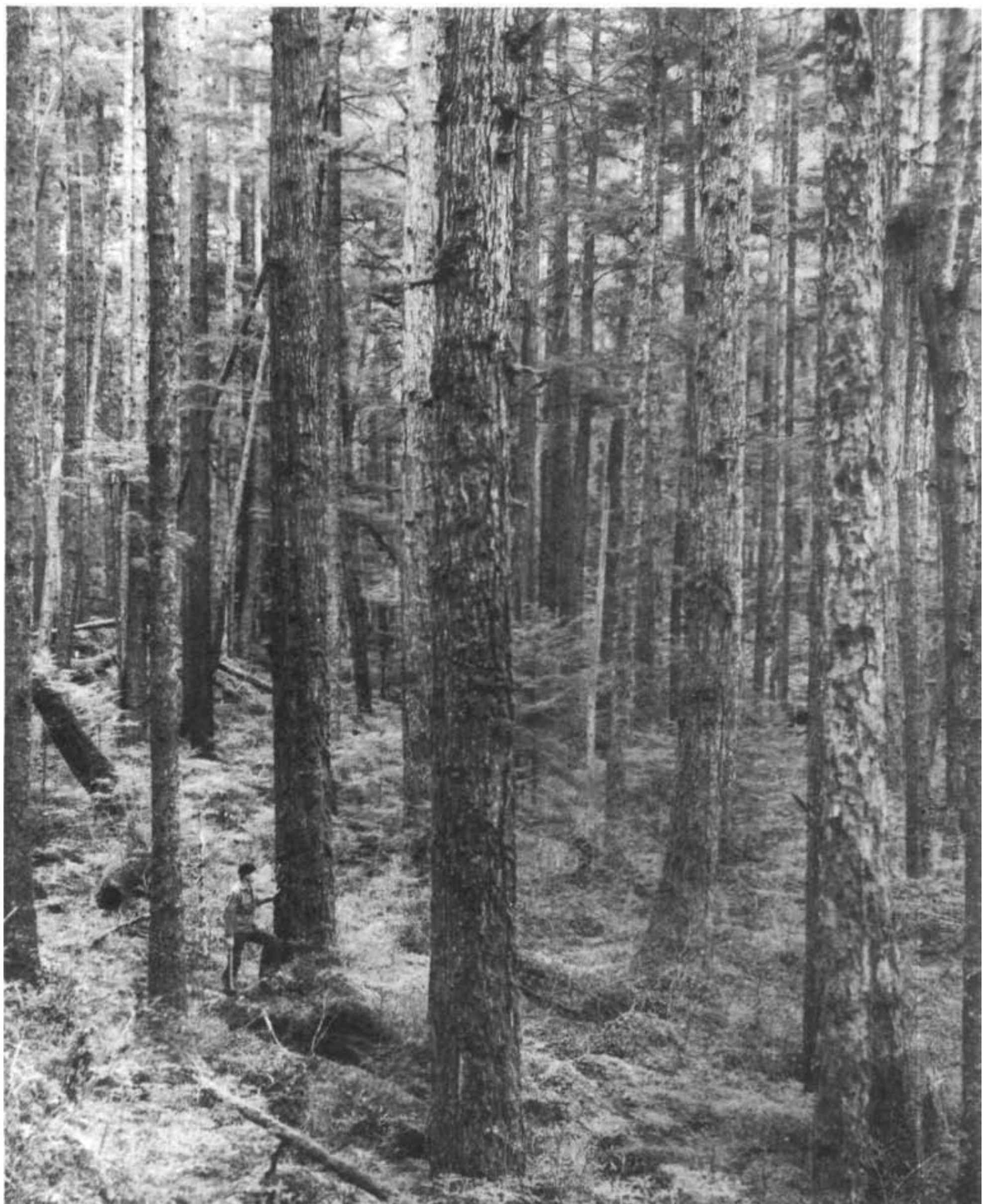

Figure 11.--This 160-year-old even-aged stand on Tuxekan Island is making better growth and contains far less defective timber than older uneven-aged stands on a similar site. Even-aged stands such as this contain prime sawtimber.

These even-aged stands have resulted from natural events, such as windthrow, fire, and landslides--natural destructive factors which tend to keep the forest in an overall, healthy preclimax condition.

Windthrow and landslides are comon. Extensive fires have not occurred in recent decades, but apparently in the past large areas have burned over. For example, extensive 160- to ZOO-year-old stands, apparently of fire origin, are found on the north and west sides of Prince of Wales Island.

Detailed information on the character, extent, or location of stands by various stand condition classes within the old-growth classification is lacking, but efforts are being made to classify them in terms of vigor and potential risk (see footnote 30).[33]

FUTURE PRODUCTIVITY OF SITES OCCUPIED BY OLD-GROWTH STANDS

Productivity of sites now occupied by even-aged stands may be predicted from existing yield tables (Taylor 1934a, Barnes 1962). However, as pointed out by Taylor (1933) and Godman (1952), potential productivity of sites now occupied by all-aged stands cannot be determined from examination of the present stand.

Taylor (1933) worked on the problem of site evaluation from 1931 to 1933, concluding that potential productivity of a site occupied by a climax stand could not be readily predicted from information then available.

Godman (1952) recognized three general condition classes within commercial timber stands; sawtimber, even-aged second growth, and climax or pulp timber, with the climax comprising about 75 percent of the total area. He classified climax forest stands in terms of height, relating stand height to species composition, tree diameter, spacing, and gross and net wood volumes. Although providing insight into stand conditions, the system gave little indication of basic site potential and has not been used for management purposes.

Soil scientists have studied the problem of estimating site productivity of lands now occupied by climax stands (Stephens et al 1968; also see footnote 31). Their work in even-aged stands has shown that site productivity can be related to soil characteristics. It is now possible to use these relationships to estimate potential productivity of lands presently occupied by old growth.. Because of their work, soils information is now being gathered in connection with Forest Survey work to provide estimates of land area by site class.

Average site index of commercial forest land is currently based on plot data from even-aged stands.[34] Recent forest inventory information suggests that these calculated averages are fairly accurate.

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[33]Manual of field instruction for Forest Survey, coastal Alaska, on file Forestry Sciences Laboratory, Juneau, Alaska, p. 90, 92, 1970.

[34]Timber Management Plans for the Juneau, Sitka, Yakutat, Petersburg-Wrangell, and Ketchikan-Craig Working Circles. USDA Forest Service, Juneau, Alaska.

YOUNG-GROWTH STANDS

Young-growth stands are those less than 150 years of age. These are essentially even-aged stands that originated following blowdown, fires, landslides, or logging. Young stands undergoing primary succession are also included in this classification.

METHODS OF TIMBER CUTTING (SILVICULTURAL SYSTEMS)

Before examining cutting practices in southeast Alaska we will describe what is meant by "silvicultural systems" and how they are related to management objectives. Silviculture may be defined as the culture of trees and stands. Silviculture developed both as an art and science in Europe and the Orient over several hundred years as need arose to manage forests for the benefit of people. Benefits have traditionally included useful wood products, water, game, forage, recreation, and amenities. Regardless of management goals, perpetuation of the forest is a primary concern.

Silvicultural systems are classified according to the cutting methods used to obtain regeneration of a forest. The system selected depends on (1) the silvical characteristics of the trees involved such as their requirements for light, water, nutrients, and growing space; (2) biotic and abiotic characteristics of the environment that affect regeneration and growth; (3) management objectives for the stand or forest in question; and (4) economic considerations.

Silvicultural systems applicable to conifer stands are called high-forest systems, and regeneration obtained by various cutting methods may be thought of as concentrated or diffuse. Concentrated regeneration implies the establishment at one time of numerous evenly distributed seedlings such as occurs when even-aged management is practiced. Clearcutting, seed-tree cutting, and shelterwood cutting are silvicultural systems which result in concentrated regeneration and the development of even-aged stands. Diffuse regeneration implies the establishment of few, widely scattered seedlings at one time, such as occurs when uneven-aged management is practiced. Selection cutting or group selection are silvicultural systems which result in diffuse regeneration and the development of all-aged stands.

There are many variations of shelterwood systems, all having to do with the pattern and timing of tree removal. These grade imperceptibly toward systems of group selection and individual tree selection, and endless and usually fruitless debate is possible over where, along the scale between shelterwood and group selection, some variant system might be best classified. We will consider only the four major silvicultural systems here.

CLEARCUTTING SYSTEM

Clearcutting is a silvicultural system in which trees are cleared from an area at one time, Usually all merchantable trees over a specified diameter limit are cut and removed; unmerchantable trees may be felled but not removed. Reforestation may be natural--from residual seedlings that survive logging, from seedlings that sprout from seed blown onsite from adjacent stands, or from cones left on logging slash. Reforestation may be artificial as from planted seedlings or from seeding from air or ground. In either case regeneration tends to be concentrated, and even-aged stands result. In many ways clearcutting duplicates natural processes of forest renewal such as blowdown, landslide, fire, or epidemic, in which all trees of a stand are destroyed, with the difference that wood is removed from the site and used.

Patch logging or patch cutting is a modification of the clearcutting system in which patches of timber are logged as single units, separated until reforestation is secured. This method is used to assure adequate natural seed dispersal from adjacent stands and to reduce the extent of continuous areas of slash which may increase the hazard of fire or insects. Clearcutting and patch cutting have been used almost exclusively in southeast Alaska.

The distinction between clearcutting and patch cutting involves size and purpose. The size distinction is arbitrary. One definition of patch cutting involves areas of from 40 to 200 acres (Ford-Robertson 1971). The purposes may include optimum dispersal of seed, reduced hazards from fire or insect pests, or improved wildlife habitat. A more important distinction is that between clearcutting and such systems as shelterwood and group selection, for this distinction involves biological considerations. As pointed out by Baker (1934):

> It is customary to cease regarding [a cutting area] as a clear cutting when the area becomes so small that the surrounding trees exercise a distinct protective or competitive effect over the area. To define this point precisely is impossible. It illustrates the shadowy line that separates all silvicultural systems.

The term clearcutting will be used here to denote an area of any size from which all trees over 11-inch diameter have been felled, and large enough that the surrounding stand does not materially influence the bulk of the cutover area.

SEED-TREE SYSTEM

The seed-tree cutting system is a silvicultural system in which the mature forest is removed in one cut, except that a small number of seed-bearing trees are left singly or in small groups to provide seed for natural restocking of the area. The seed-tree system results in concentrated regeneration and even-aged stands. The seed-tree system is considered impractical in southeast Alaska because of the danger of wind damage to seed trees and unnecessary because seed dispersal from adjacent uncut stands is usually adequate.

SHELTERWOOD SYSTEM

The shelterwood system is designed to retain part of the mature stand to provide seed and shelter for regeneration. The overstory stand is removed in two or more successive cuttings. There are many variations of the system depending on the pattern and scheduling of stand removal. Shelterwood cutting prepares the way for establishment of seedlings, with a final cut to release them once they are established. The method results in concentrated regeneration and essentially even-aged stands. Shelterwood cutting requires more extensive road systems than does clearcutting, and periodic entries into the stand are required. Shelterwood cutting has not been done in Alaska although there are situations where it may prove useful in reaching management objectives.

SELECTION SYSTEM

The selection cutting system is an uneven-aged silvicultural system in which individual trees are selected and removed here and there from a large area, annually or periodically. The resulting forest has no beginning or end in time. Theoretically, the selection system requires removal of some trees each year as individuals mature. In practice, individual trees or small groups of trees may be removed periodically as economics and other considerations dictate. If groups of trees are removed, the system is properly described as a group-selection system. In any case, an extensive road system must be maintained for access, and continual tending of the stand is necessary.

The selection system resembles the natural process of forest renewal where individual trees die and are replaced by seedlings in the understory. It differs from this natural process in that useful wood products are removed from the site, and an effort is made to upgrade the quality and vigor of the stand rather than relying on chance. Selection cutting may be used to advantage in special situations in southeast Alaska as we will point out later.

In popular writing, the term "selective cutting" is often used interchangeably with "selection cutting," although this usage is incorrect. Selective cutting is synonymous with exploitation cutting or high-grading of a forest where the overriding goal is greatest immediate gain. Trees to be cut are selected on the basis of their value, with only trees of suitable quality, size, or species removed. Little thought is given to silvicultural requirements of the species involved or to the future condition of the stand.

In contrast, selection cutting refers to the method used with'the selection system; the goal is to improve the forest, with removal of usable timber a secondary though important concern. Tree selection stresses removal of diseased or poorly formed trees or of trees of inferior species, before the removal of healthy, mature trees. If the initial stand condition is poor, it may be many years before trees of high quality can be removed. At first this may seem to be a rather fine distinction between terms. However, it serves to point out the fact that perpetuation of the forest is the basis of silviculture.

CLEARCUTTING IN SOUTHEAST ALASKA

HISTORICAL PERSPECTIVE

Clearcutting is the silvicultural system used exclusively in southeast Alaska. Its use dates back to Russian times and, except for the high-grading of selected trees along the shores from the 1800's until the 1940's, virtually all large-scale timber cutting has been clearcutting.

Clearcutting developed as a system in the Douglas-fir forests of Oregon and Washington with the introduction of large cable logging machinery which could operate most efficiently and economically when stands were clearcut. At first little attention was paid to regeneration of a new stand after clearcutting, but technical observations on the reproductive habits of Douglas-fir, the principal commercial species in the Pacific Northwest, began as early as 1899. These studies showed that Douglas-fir was intolerant of shade and would reproduce well only in the open (Isaac 1943).

Regeneration was often inadequate because of seed bed conditions or lack of a seed source, but the need for complete removal of the old stand was apparent. Clearcutting provided the happy combination of an economical method of logging and the open conditions required for seedling establishment,

Mechanized logging was brought to Alaska in the early 1900's by men from the Pacific Northwest. These men brought the equipment and methods they understood and that had been proven around Puget Sound, With little modification they were found to be suitable for use in Alaska as well. Clearcutting was first limited to stands of high-quality Sitka spruce sawtimber or even-aged hemlock suitable for piling. Such stands were scarce and the market for logs was limited, so selective logging close to tidewater was continued.[35]

In the Pacific Northwest, clearcutting was accepted as necessary to assure regeneration of Douglas-fir, and in Alaska it was considered necessary to obtain regeneration of Sitka spruce, In anticipation of future pulp logging, a study of regeneration following clearcutting in Alaska began in 1924 under the direction of B. F. Heintzleman and continued into the early 1930's. This work was begun by forest examiner, J. M. Walley, and was later carried on by R. F. Taylor. Taylor's work clearly showed the desirability of clearcutting for establishment and growth of the future stand because of the site improvement and excellent reproduction which followed.

Experience with similar forest types in the Pacific Northwest reinforced the belief that clearcutting was a valid system for logging old-growth stands containing valuable shade-intolerant species.

During the economic depression of the 1930's, clearcutting stands was uneconomical because of the lack of market for low-quality trees. Forest economists then advocated selective cutting of large, high-quality trees which could be milled at a profit (Brandstrom 1933, Kirkland and Brandstrom 1936). They assumed that western hemlock and other shade-tolerant species would fill in the spaces left after the Douglas-fir or Sitka spruce were removed, and that the remainder of the stand would continue to grow, thus maintaining a thrifty, all-aged stand, The method was adopted, and for the next decade selective logging was the rule.

Foresters, however, became aware that selective logging as it was practiced did not produce the anticipated thrifty stands, A study by Isaac (1956) showed that growth of residual trees was disappointing. Growth of both residual Douglas-fir and Sitka spruce declined after logging, although western hemlock, cedar, and Pacific silver fir showed an increase in growth. Windthrow caused the greatest losses in the residual stand, and felling and skidding of logs by tractor caused injury to more than a third of the residual trees. A study by Wright and Isaac (1956) showed that 63 percent of logging scars contained decay.

Early experience with clearcutting in southeast Alaska was favorable, climax hemlock-spruce stands were known to be generally overmature, and results of selective cutting in the Pacific Northwest were disappointing. Thus clearcutting was the logical silvicultural system to be used when pulp logging began in Alaska in 1953 (Andersen 1954, 1956).

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[35] R. R. Robinson. Logging practices in Alaska. Manuscript on file, Forestry Sciences Laboratory, Juneau, Alaska, 49 p., April 26, 1938.

EXPERIENCE WITH CLEARCUTTING SINCE 1953

Since 1953, timber stands on some 250,000 acres of forest land in southeast Alaska have been clearcut, and clearcutting is continuing on the Tongass National Forest at the rate of 18,000 acres annually. Size of contiguous clearcut areas ranges from a few acres to well over 2,000. In general, natural reforestation has been good on these cutover areas although problems are apparent in specific situations as will be discussed later in the section on reforestation.

At the start of pulp logging in 1953, concern over clearcutting centered primarily on regeneration and the effects of clearcutting on salmon spawning habitat. Studies since then indicate that salmon spawning habitat need not be damaged if clearcutting is properly done (Meehan et al. 1969).

Since the early 1960's, public concern over esthetics and amenities of the National Forests has also been growing. At the same time, with inauguration of a State ferry system, southeast Alaska has become more accessible to people of average means, and tourism is an important, fast-growing industry now ranking fourth in Alaska, behind mining and petroleum, fisheries, and forest products.[36] The result has been increasing public concern over management of the Tongass National Forest with clearcutting a focal point. Because of this we will examine the rationale behind the continued use of clearcutting as a silvicultural system in southeast Alaska and some alternatives.

BASIS FOR CONTINUED CLEARCUTTING

Development of a stable year-round timber industry in southeast Alaska has been considered a desirable goal for over 50 years. This goal has been realized with the sale of over 23 billion board feet of National Forest timber and subsequent construction of two large pulpmills and several sawmills. Use of the timber resource is consistent with Forest Service objectives for managing the Tongass National Forest. These objectives include harvesting of timber in line with sustained yield management of all resources, and generally improving the health and vigor of the forests.[37]

Clearcutting appears to be the silvicultural system that most nearly meets these objectives from both biological and economic points of view, There are many biological reasons for clearcutting:

1. Most old-growth stands in southeast Alaska are in climax or near-climax successional condition. They are generally defective (Kimmey 1956), and lower in vigor than younger stands (Andersen 1954, Godman 1952, Taylor 1933). Forest improvement through clearcutting of old growth followed by regeneration of a new stand appears more feasible than attempts to improve existing old-growth stands by using selection systems. Even the older even-aged stands are generally beyond the age where partial removal of the stand would improve the growth of the remaining stand. Farther south, the shelterwood system is sometimes used in even-aged hemlock-spruce stands where serious brush competition develops when stands are clearcut (Ruth 1967, Williamson 1966). Except on alluvial streamside terraces, brush competition does not appear to be a serious problem in southeast Alaska. On most upland sites, conifers compete successfully with shrubs and within a few years overtop them (Harris 1967).

[36] Data on file, Alaska Department of Economic Development, Juneau, Alaska,

[37] Title 2400--Timber Management. USDA Forest Service Manual, R-10.

2. Clearcutting allows more solar radiation to reach the forest floor, thus raising soil temperature and hastening biological decomposition of the thick organic mat. A study on the Maybeso Experimental Forest associated with clearcutting showed an average seasonal increase in soil temperature of about 6" F at a 3-inch depth. Increases up to 5° F extended to a 24-inch depth (Gregory 1956). Large quantities of plant nutrients are tied up in the organic matter, and these are made available to plants only through decomposition, a process that is temperature dependent (Wiant 1967). The warming associated with clearcutting has been shown to increase soil biological activity, thereby increasing the concentration of nitrate nitrogen and other ions. If no vegetation is present to take up these nutrients, they may be leached from the soil (Likens et al. 1970). Measurements of ions in streamwaters have not been made to determine changes following clearcutting in southeast Alaska, so the relative amounts of nutrients leached from the ecosystem and taken up by plants are not hown. However, observations indicate that growth and vigor of shrubs and conifer seedlings increase greatly after clearcutting and that clearcutting has the effect of rejuvenating an apparently deteriorating site (Taylor 1933). Forest productivity increases more after complete stand removal by fire or logging than from stand destruction by wind (Stephens et al. 1969).

3. Windthrow is a serious problem which increases when stands are opened up by partial cutting (Isaac 1956, Ruth and Yoder 1953, Wright et al. 1947). Clearcutting disturbs less area for a given amount of timber removed than does partial cutting. Large cuttings expose less timber edge per unit area of cutover land, and there is greater flexibility provided for selecting more windfirm cutting boundaries. For example, some progressive strip cutting has been used in spruce-hemlock stands in the Pacific Northwest to reduce blowdown along cutting boundaries (Ruth and Yoder 1953, Ruth 1965).

4. Clearcutting, including removal of infected seedlings, is the most effective means known for eliminating dwarf mistletoe. Many old-growth stands contain western hemlock trees heavily infected with dwarf mistletoe, a parasite known to reduce growth and vigor of trees (Smith 1969). Clearcutting and removal of infected residual trees reduce the chance for infestation of the future stand. The problem of reinfestation from trees around the perimeter of cutting units is minimized by cutting large areas (Shea 1966, Buckland and Marples 1952).

5. Clearcutting generally assures a higher percentage of Sitka spruce regeneration, a desirable timber species that is less shade-tolerant than hemlock. In addition to its economic importance, spruce adds diversity to stands and helps promote stand development (Taylor 1929). The increase in nitrate nitrogen associated with warming of the soil and the consequent increase in organic decomposition have been shown to favor establishment of Sitka spruce (Taylor 1934b). When stands are opened by partial cutting, western hemlock predominates in the understory and seedling growth is much slower than in the open (Farr and Harris 1971). In short, clearcutting results in more light and more available nutrients, thus promoting regeneration of Sitka spruce.

6. Clearcutting requires less road construction than other silvicultural systems for removal of a given amount of timber. This is desirable as roads are expensive and tend to be major sources of sediment. For example, studies in California showed that conversion of 0.6 percent of a watershed into low-standard roads increased sediment by 24 percent (Wallis and Anderson 1965). Roadbuilding also stands out as the most damaging activity responsible for mass movement of soil on steep slopes (see footnote 29).

7. Both western hemlock and Sitka spruce tend to be shallow rooted in Alaska. Roots are easily damaged by compaction and by heavy equipment. This was a serious problem with equipment available a few years ago (Ruth 1965). With the rapid development of new logging systems, this problem now largely involves cost rather than availability of alternate logging systems.

8. Western hemlock and Sitka spruce have thin bark and are subject to logging damage and subsequent wound infection. A study in the Pacific Northwest showed that approximately half the trees injured in logging became infected with wood-rotting fungi in from 5 to 32 years, with decay losses amounting to over 40 percent of the gross increment after logging (Wright et al. 1947).

Clearcutting is also used for economic reasons. The silvicultural system selected must be efficient. With the relatively low value of Alaskan timber and the high costs of logging, transport, and manufacture, clearcutting is probably the only system efficient enough for large-scale timber harvesting unless subsidies are granted.

There are also disadvantages to the use of clearcutting in southeast Alaska. Most have to do with values other than timber; for example, where esthetics, recreation, or wildlife considerations require the continued presence of a mature forest stand. Much of the esthetic difficulty comes from the size, shape, or placement of cutting units rather than from the practice of clearcutting as such, and efforts are being made to alleviate the problem. For example, the size of clearcut blocks is being reduced, In the past, contiguous clearcut areas have exceeded 2,000 acres. Now, under a policy which went into effect on the Tongass National Forest in 1972 (see footnote 37), cutting units of over 100 acres require 'approval by the Forest Supervisor, and clearcutting units in excess of 160 acres can be made only in special circumstances and require written justification by the Forest Supervisor. The timing of cutting adjacent units has not been specified and is still under study. In addition to reduced size of clearcutting units, particular attention is being given to appearance of forested areas along routes of public access. Principles of landscape architecture are being applied to fit cutting units less conspicuously into the natural environment. Size, shape, and distribution of cutting units are key elements in this process.[38]

The application of such techniques should greatly mitigate some undesirable esthetic consequences of clearcutting, .although probably not without cost. Logging costs are expected to increase because of additional roadbuilding and less efficient yarding, and windthrow along cutting edges is likely to increase because more cutting units are required. The irregular shapes of cutting units may also result in greater windthrow along edges because some trees may be more exposed to wind. As yet experience has been insufficient to warrant more, than speculation regarding potential problems associated with forest landscaping.

ALTERNATIVE SILVICULTURAL SYSTEMS

From the standpoint of 'timber management alone, clearcutting is a biologically sound system for use in southeast Alaska and is now the only practical system that can meet present contract commitments and future demands

[38] FSM 2309.21R10, Landscape Management Handbook. USDA Forest Service, Region 10, April 1970.

for National Forest timber. However, clearcutting may be incompatible with some management objectives. Efforts are now underway to identify situations and specific locations where alternative systems are required.

Clearcutting is obviously incompatible with a management goal of maintaining and improving forest stands in campgrounds and recreation areas. Through selection cutting, diseased and defective trees in such areas can be removed in a way that will improve access and lessen hazards to those using the area.

Maintenance of roadside stands is another situation where alternate silvicultural systems may be appropriate. Selection cutting to gradually open the stand may be useful along roadways to improve the view. When roadside stands are designed to screen areas behind them, shelterwood cutting may be appropriate. With this form of even-aged management, an overstory could be maintained while encouraging regeneration of conifers beneath it, followed by overstory removal when regeneration is tall enough to provide an effective screen.

Streamside alluvial terrace sites often support mature or overmature stands with high timber values. Recreation values may also be high because of travel and fishing along the streams. These sites are important rearing and spawning areas for salmon and trout, especially where braided stream channels occur or where the area is laced with small tributary streams. Conifer regeneration may be slow because of unfavorable seed bed conditions and extreme vegetative competition from alder, salmonberry, currant, devilsclub, and other plants. For these areas management objectives must be carefully determined. Either a selection system or shelterwood system might be appropriate for optimum protection and use of all resources.

Many shorelines and other areas located along travel routes and near population centers have such high esthetic values that clearcutting, even when carefully designed and executed, may be unacceptable. Here the forest manager may wish to maintain and improve the stand with no apparent alteration, but still allow removal of some timber that otherwise would be lost through mortality. In that case it may be possible to develop thrifty all-aged stands through selection cutting and allow some timber production. If the manager wished to maintain a stand but was less concerned with changes in texture and height of the stand, even-aged management through use of shelterwood cutting might be appropriate and would allow greater utilization of the timber resource.

Are such alternatives to clearcutting biologically sound and are they practical? Experience is lacking on both counts. Old-growth stands are variable in species composition, age structure, and vigor. On the average, over 30 percent of the volume in old-growth stands is defective, and this figure would be far higher in the case of truly decadent stands. In these stands, improvement through selection cutting might be impossible, and emphasis on stand improvement might necessarily be confined to regeneration. For old-growth stands still in an even-aged condition, selection cutting might be appropriate although criteria for selecting trees for removal have not been developed. Observations on regeneration beneath old-growth stands suggest that natural regeneration under selection cutting would occur but consist mostly of slow growing hemlock. Limited experience with partial cutting in even-aged stands (Farr and Harris 1971) suggests that regeneration under shelterwood cutting would also be adequate, though growth would be slow, and that hemlock would be favored. In either case if mistletoe were present in the overstory, seedlings would likely become infested and stand vigor would decline. Many unanswered questions remain regarding continued vigor of the overstory stand and its increased susceptibility to wind damage.

Great care will be required in removing trees to avoid soil compaction and wounding of roots and boles. Wounds serve as points of entry for disease organisms (Wright and Isaac 1956). Logging methods must also be economical or subsidies must be provided. Despite these apparent difficulties, alternatives to clearcutting of old-growth stands must be developed that will be suitable for use in attaining management objectives; additional research is needed.

There may also be situations where the most appropriate course of action will be to leave certain stands alone, relying on nature and chance to maintain the stand in accordance with natural succession. This alternative too should be recognized as a valid form of resource management.

LOGGING AND LOG HANDLING

DEVELOPMENT

Before the 1940's some selective logging of large spruce was done by hand. When possible, trees were cut close to tidewater, preferably on steep ground so they could be more easily skidded out of the woods, Logs were often moved to tidewater with logging jacks. Where deep water lay close offshore, boats were often used to yard logs to the water. A cable was carried ashore by hand and fastened to the log, and the boat faced away from shore. With a short run to the end of the cable's slack, a heavy boat could send large logs crashing out of the woods and into the water.

Steampower was also used in logging early in the century, and the equipment used had surprising capabilities. Steam yarders could carry 2,000 feet of 1-1/8-inch mainline cable, and with the mainline doubled, could reach out 4,000 feet for logs (Anonymous 1915). By the early 1920's steam logging had largely replaced hand logging. Most cutting units were adjacent to tidewater, yarding was done by steam donkeys mounted on rafts equipped with high A-frames to give deflection, and logs were yarded directly into the water. This technique worked well for selective logging of spruce along shorelines as well as for the occasional small clearcuts in unusually good stands of spruce and hemlock. To reach farther back from the beach, donkeys were mounted on log skids so the machines could winch themselves overland. A suitable tree was topped and rigged for a spar, and logs within a radius of 800 to 1,000 feet were yarded into a central landing, then ground-skidded or swung by cable to an A-frame on tidewater. Truck roads for hauling logs overland were not used because roadbuilding equipment was not available and trucks then available were inadequate. Railroads were not used for logging in Alaska,

Trucks came into use to a limited extent for hauling logs beginning in 1938. The first logging road was built of fore-and-aft poles and planks at Coning Inlet on Long Island (see footnote *35)* (fig. 12). During World War 11, trucks were used at the Alaska Spruce Log Program operation on Kosciusko Island, on roads built with bulldozers. Virtually no hauling of logs by truck was done after this until 1953 when large-scale pulp cutting was begun at Hollis on Prince of Wales Island.

Timber falling and bucking was done by two-man teams using crosscut saws until about 1940, when some electric and gasoline-powered chain saws came into use. Gasoline-powered chain saws came into general use after World War 11.

Figure 12.--The first truck logging operation in southeast Alaska at Coning Inlet, Long Island. Logs were hauled to tidewater over a planked road. This view was taken in 1941 (compare with figure 15).

PRESENT LOGGING METHODS AND TRENDS

Logging methods are determined largely by economics and the silvical requirements of the tree species desired in the new stand. Logging is a key process in forest management today because it represents the one time when large-scale manipulation or treatment of the soil and seed bed are not only economically possible but unavoidable. The effects of logging practices on the character of the new stand will be apparent for the next rotation period.

cutting

Timber is usually cut by a single faller using a gasoline-powered chain saw. Trees are felled, limbed, and bucked into logs. Tops are left intact. A skilled faller may fall, limb, and buck 50,000 board feet of timber per day. When possible, trees are felled parallel to the direction in which they will be yarded. On steep slopes, trees are felled along the contour to avoid excessive breakage and so they will stay in place.

Present contracts call for maximum stump height equal to stump diameter. However, when encouraged to do so, a skilled faller will often cut lower stumps than required, thus reducing waste and helping to avoid breakage of timber and damage to equipment. Low stumps also help avoid unnecessary soil disturbance caused when logs hang up on stumps during cable logging.

Present logging contracts require that all trees 12 inches in diameter and larger at breast height be cut, including snags over 15 feet tall. The desirability of requiring snags to be felled is debatable. Snags may appear unsightly to some people. They may interfere with future management activities, spread wildfire, or damage the regenerated stand when they finally fall. Snags may also interfere with yarding of logs and endanger logging crews. On the other hand, snags provide homes for insectivorous birds, appear picturesque to some people, and are expensive to cut. Additional research is needed to determine the desirability of falling snags.

Trees less than 12 inches in diameter need not be felled, but many are knocked down when logs are yarded. Of those remaining, up to 49 percent may die within 5 years (Embry 1964). Some of these produce seed which can help to restock the cutting unit, but in most cases seed from this source is unnecessary. Residual western hemlock poles are often infested with dwarf mistletoe and can infect trees in the new stand.

Yarding

Today most logging is done some distance inland, and logs are yarded to landings along a road system for transport to tidewater. In 1970, 95 percent of volume was logged using various yarding systems combined with truck hauling of logs to tidewater. Only 5 percent was done by A-frame operations yarding logs directly into the water or combined cold deck-A-frame swings to tidewater. This is a drastic change from the past when A-frame operations accounted for the bulk of logging. The current trend toward less use of A-frames on beach fronts is continuing, as suitable stands adjacent to tidewater are becoming scarce and because of the awareness that beach-front logging to tidewater is esthetically damaging and may destroy valuable habitat used by deer, eagles, and other wildlife.

In 1971, 77 percent of yarding was done by conventional high-lead systems, 13 percent by various short-line cable systems, 4 percent by long-line cable systems, 2 percent by tractors or rubber-tired skidders, and 4 percent by A-frame.[39] High-lead yarding systems have undergone improvements in recent years, primarily involving increased mobility. Portable spars or towers that can be moved quickly are now in common use (fig. 13). However, basic principles of high-lead logging have not changed since pulp logging began in Alaska.

Most yarding is done downhill because access is usually from the valley bottoms and roadbuilding on steep slopes is difficult and costly. In downhill yarding, it is often difficult to maintain proper cable deflection and there is a greater tendency for logs to hang up on stumps and rock outcrops and for stumps to be uprooted. This results in more timber breakage, greater site disturbance, and greater equipment breakage than would be the case if uphill yarding were possible. Lower stumps help to reduce the problem.

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[39]Data on file--USDA Forest Service, Timber Management Division, Juneau, Alaska.

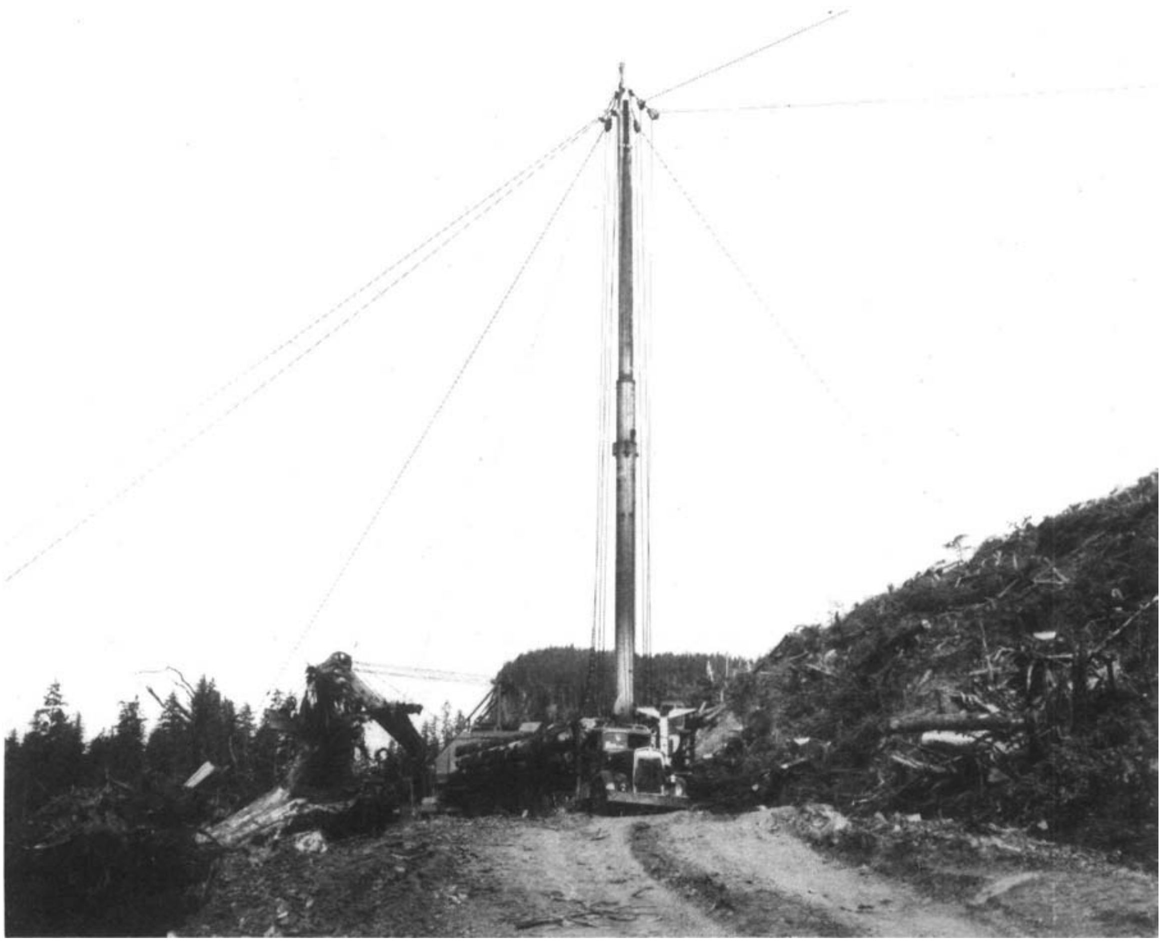

Figure 13.--A high-lead logging operation on the Tongass National Forest using a portable steel spar.

Tractor yarding has been confined to valley bottoms and other relatively flat ground. Tractor yarding is especially damaging to the soil organic layer because of the churning of treads or tires and the dragging of logs. This disturbance is a major cause of severe alder competition on valley bottom sites. If done in winter on frozen ground, although less soil disturbance is likely, often there is still damage to the site.

Tractor yarding nearly always has been combined with truck hauling. Rubber-tired skidders have been used for swinging logs to tidewater; but because a relatively good road is required for their use and logs are abraded by dragging, truck hauling has proved superior. The trend has been away from tractor logging because of its proven damage to the site. It is now used rarely on the Tongass National Forest, unless damage would be negligible.

Balloon logging was introduced in Alaska in 1971 and represents a major innovation in yarding systems (Sieber 1972). By providing lift, the balloon eliminates many problems caused by lack of cable deflection inherent in conventional cable systems. Reach is extended greatly, and logs are lifted rather than dragged over the ground. The need for roads is reduced, and more timber can be reached. Soil disturbance and compaction are far less than that caused by other yarding systems (Dyrness 1972), and sediment produced by roadbuilding is greatly reduced, Disadvantages include difficulty of operating on windy days, high initial investment costs, and reduced access for future management. Experience in operation will determine the system's economic practicability. Additional research is needed to determine the character of reforestation on the lightly disturbed seed beds resulting from balloon logging.

Log Transport and Storage

Coastal Alaska lacks a continuous road network for transportation of logs from woods to mill. Because much of the commercial forest land is located on islands, log rafting, usually in conjunction with truck hauling, is used almost exclusively for transporting logs.

The old-growth timber being logged in southeast Alaska varies greatly in size, and the logging and log transportation system which has evolved is necessarily designed to handle the largest logs--some over 8 feet in diameter and 40 feet long. The usual method of logging involves cable logging systems with large portable spars, floating A-frames, or large tractors and wheeled skidders. The steep and broken topography contributes to timber breakage and to difficulty in removing logs, and the outsize equipment now in use is often unsuitable for handling smaller logs and broken pieces.

On large timber sales, logs are typically yarded to landings along a road system, loaded onto trucks, and hauled to a log dump on saltwater. There loads are strapped into bundles and placed in the water where they are gathered into rafts and moored for storage or towed to the mills, At the mill, bundles are either broken apart and individual logs brought ashore, or bundles are removed from the water and logs are processed on the mill deck. When logs are dumped into the water, bark and fiber are dislodged and may contaminate the local dump site. Logs, bundles, or entire rafts are occasionally lost in storms and constitute a menace to navigation. Some logs sink to the bottom when bundles are broken. Rafting also limits the type of material that may be transported. Short logs, irregular pieces, and chunks cannot be contained.

Rafting is known to result in the release of quantities of bark fibers and extractives into navigable waters. The quantity and effects of these pollutants are not known although studies have shown that considerable material may accumulate in the immediate vicinity of dump sites except in areas where strong tidal currents are found (Pacific Northwest Pollution Control Council 1971).

Logs stored in saltwater may be attacked by marine borers. This damage can be reduced by mooring rafts in intertidal zones of bays and estuaries in fresh water or where low tide leaves them out of water. Such storage may severely damage crabs, mollusks, and other bottom fauna and may adversely affect migrating fish and waterfowl. To overcome some of these problems, the large pulp companies have greatly improved log handling and storage facilities in recent years and continue to improve their facilities at the mills and larger woods operations. For example, logs are now sorted and stored on land at the Ketchikan Pulp Company's large pulp logging operation at Thorne Bay (Anonymous 1971).

Preliminary evaluation of the physical and biological effects of log dumping and rafting on marine fauna indicates considerable damage to the marine environment in the immediate vicinity of dumping and storage sites, but this damage does not appear to extend far. The time required to return to normal conditions is not known (Pease 1974).[40]

Logs are barged on a limited scale in southeast Alaska where long distances and open water are involved (Anonymous 1972). This helps to eliminate some problems associated with rafting, Barging is widely used in British Columbia. However, barging may require more elaborate on-shore log handling and loading facilities, thereby increasing esthetic damage to the waterfront. If not designed specifically to eliminate bark discharge , barging systems may result in more bark in the water than rafting because of increased handling of logs.

More research is needed to determine environmental effects of transporting logs and to determine the economic and legal implications of rafting and barging logs. Information is also needed on the environmental and economic consequences of rafting versus barging to guide selection of log transporting systems in the future.

FOREST RESIDUE

The term "forest residue" refers to the unused portion of trees--organic material for which there is no market--left behind after logging, material that will bring no profit after the expense of removal, and merchantable logs that were missed in logging. The term is synonymous with "logging slash" (fig. 14). Residues contain cellulose, lignin, ash-forming minerals, and extractives. But they are often of the wrong species, size, or shape to fit the current harvesting or utilization system or they may be in various stages of decay. Residue consists of sound or rotten logs, dead snags, live cull trees, trees too small to harvest economically, and the unused parts of merchantable trees such as stumps, roots, tops, bark, branches, leaves, and cones. Understory brush species are included, especially if they have been hocked to the ground during the logging operation.

The volume and arrangement of forest residues vary widely depending on the age and size of the timber that was harvested, its volume and percent of defect, the volume in undersize trees and unwanted species,, the logging method used, and the utilization standards in effect.

Forest residues are an integral part of the forest ecosystem and constitute a portion of the ecosystem's nutrient capital. They are "residues" only in a utilitarian sense and, if accessible to view, constitute an esthetic problem of primary importance immediately after logging. The problem lessens as residues decay and are incorporated into the soil, as tree seedlings, shrubs, and grass grow and hide them from view, or as the canopy of a thinned stand closes.

Forest residues are of great concern to people who view, use, or manage the forest. Residues may present an unsightly tangle of limbs, tops, and cull

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[40] Robert J. Ellis. Report on a study of effects of log rafting and dumping on marine fauna in southeast Alaska, June 6-9, 1970. Manuscript report NR-F No. 87, National Marine Fisheries Service, Auke Bay Biological Laboratory, Auke Bay, Alaska, April 1971.

Figure 14.--Forest residue is a prominent feature after clearcutting of old-growth stands on the Tongass National Forest. This area at Thomas Bay, Alaska, was clearcut in 1972.

logs. They may dry out in the sun and become a fire hazard. They can be a breeding area for insects and disease. Large woody residues such as logs and stumps impede access to forests and may continue to hamper management activities throughout a rotation period.

On the other hand, light slash may be beneficial. Light shading by slash can improve seedling establishment during abnormally hot, dry summers. Well-decayed piles of logging slash may also provide good seed beds on alluvial soils subject to periodic flooding. In some cases light slash may also help to reduce surface erosion. On balance, some reduction in residue, especially of large material, would appear desirable.

The most obvious and certainly among the most lasting components of forest residues are the unused stem portions of trees--unwanted or defective logs, stumps, undersize trees, defective snags, and portions of tops with attached branches. Controlled burning has been used to reduce logging slash in the Pacific Northwest where summers are dry and the danger of wildfire is great.

However, with the generally cool, moist summers in southeast Alaska, slash burning is considered unnecessary, and often undesirable because of possible damage to the soil organic component and the difficulty of controlling burns. Better utilization not only would reduce the mount of residue but also would provide additional usable raw material. Several unanswered questions are: How may utilization be improved? If more organic material is removed from the site through better utilization, will future site productivity be lowered through loss of nutrients in the additional material removed? How serious a threat is fire? Should fire be used to reduce slash accumulations? Answers to these questions will require considerable research.

HOW MUCH RESIDUE?

Studies describing forest residues in Alaska have dealt exclusively with the felled stems of trees. No direct measurements of stumps, roots, branches, leaves, or understory vegetation have been made. However, knowing the volumes of residue resulting from the woody stems of trees gives an indication of the minimum amount of fiber available.

This residue is of two types. The first is sound merchantable wood left after logging that is within the size and quality specifications of the timber sale contract. This is material which the purchaser has agreed to buy and the seller has agreed to sell. The amount left on the ground after logging reflects the degree to which utilization standards of the timber sale contract have been met. Under current practices on National Forest land, the purchaser pays for logs that are scaled at mill yards or in rafts. After they are logged, cutting units are examined by Forest Service sale administrators to see whether utilization standards have been met. If, in the administrator's judgment, the standards have been met, the operator has no further obligation on the area. If logs are left behind, the operator can be required to pay for them or to remove them from the area. Studies show how closely timber operators are meeting the utilization standards set forth in the sale contract but do not indicate the total volume of wood fiber left after logging.

The second type of residue left from the woody portions of trees includes the sound wood fiber beyond present utilization standards which experience has shown could be converted into useful products if economic and marketing conditions warranted. This includes sound wood down to a 4-inch top diameter and 4 feet in length, and chunks and irregular pieces at least 52 inches long. A 1971 study[41] of 19 areas averaging 35,000 board feet (Scribner) net volume per acre showed that this chippable volume left after logging averaged 1,329 cubic feet per acre, a volume equivalent to about 20 percent of the net cubic-foot volume.

UTILIZATION STANDARDS CHANGE

Timber utilization has continued to improve since pulp logging began, and the amount of residues left in the woods after logging has continued to decrease. Until pulpmills became established in 1953, only Sitka spruce sawtimber and hemlock suitable for piling was merchantable. In some cases, high-quality trees were selectively cut. When clearcutting was practiced, defective and low-quality trees or logs were either used to fire steam donkeys or left in the woods. This

[41] Personal communication with Richard L. Davis, U.S. Forest Service Region 10, Juneau, Alaska.

waste was offset to some degree because only the best stands were clearcut, usually even-aged stands containing a minimum of unusable wood. Even so, large amounts of residues were left in the woods.

When pulp logging began in 1953, a demand arose for what before was considered unusable material. The better quality uneven-aged and near-climax stands began to be logged, and lower quality logs were removed. Cedars remained unused for the most part through the 1950's and, when encountered, were felled but left in the woods. Today the cedars command the highest round-log value of any Alaskan species and are sometimes sought for harvest. A ready market exists for cedar logs in Japan, and export restriction on round logs does not apply to cedars as local demand for cedar is considered slight.

Utilization standards are continuing to improve. Minimum top diameter is now set at 6 inches, and a recent study (see footnote 41) showed that only 5.9 percent of the merchantable volume as defined by today's standards was left in the woods.

STAND CONDITIONS AFFECT RESIDUE

Economics largely dictates which stands industry prefers to log. Mature, even-aged stands are naturally preferred to the more decadent, uneven-aged stands because they contain more volume, a higher percentage of spruce, less defective wood, and trees of more uniform size. Truly decadent climax stands are least preferred. Many stands now being logged are generally overmature, defective, and contain a wide range of tree sizes, from seedlings and saplings to occasional trees over 8 feet in diameter and 200 feet in height. Standing dead trees and snags are common, especially in uneven-aged stands approaching climax conditions, and much of their wood volume is unusable for, sawtimber.

Forest residue will likely increase as logging shifts more to poorer quality climax stands unless offset by improved technology and economic conditions. Less residue is expected when even-aged stands are harvested during the next rotation because these stands will be made up of smaller, more uniform-sized trees with far less defect.

FOREST OWNERSHIP IS IMPORTANT

Until December 1971, over 99 percent of the commercial forest land in southeast Alaska was in Federal or State ownership. Under the Alaska Native Claims Settlement Act, current estimates are that about 500,000 acres of National Forest land could change ownership. On public lands the land management agency has the responsibility of designating where and when timber is sold, the method of logging to be used, and the utilization standards required. These decisions are made in response to demands for timber, current economics and technology, and the need for reforestation and environmental protection. Logging practices are supervised and rules enforced by professional foresters. On private lands there are no restrictions controlling utilization standards or forest practices except that water quality must not be impaired. Terms of sales are agreed upon between buyer and seller, and logging often proceeds with no supervision to protect environmental quality, or to minimize the amount of residue left behind.

LOGGING AND TRANSPORTATION AFFECT RESIDUE

Logging and log transportation systems in use are designed to handle the largest logs. This affects the amount of residue because the outsize equipment for handling the largest logs is unsuitable for handling smaller logs and broken pieces. In addition, rafting limits the type of material that may be transported because short logs, irregular pieces, and chunks cannot be contained. Chipping of residue at the logging site and transport of chips by barge might offer one solution. The techniques and economics of such chipping have not been developed. Until woods residue can be economically moved to the mill, better utilization seems unlikely.

MARKETS MAKE A DIFFERENCE

Over the years, the timber industry has improved utilization through development of manufacturing and marketing techniques that make possible the use of lower quality material, but finding a market for forest residues in southeast Alaska presents a serious problem. Current markets for Alaskan timber must be viewed in terms of primary manufacture restrictions which apply on Federal and State lands. Timber from private lands is exempt from these restrictions but provides little of the timber that is cut. As now defined, the primary manufacture rule requires the conversion of timber to pulp, lumber, or cants within Alaska, except where there is no local market for a particular species of timber, With this restriction, and the high cost of establishing additional mills in Alaska, markets for logs consist of two dissolving pulpmills and 12 sawmills. This limited market reflects the marginal timber economy in Alaska which historically has been plagued with high labor and transportation costs. Considering the limited capacity and abundance of timber, there is little competition among buyers or incentive to develop uses for low-quality wood fiber.

In the Pacific Northwest and British Columbia, timber operators have been encouraged to improve utilization through more stringent logging requirements. For example, clean logging has been used to encourage better utilization. Clean logging requires that all material over a certain size be yarded to landings, the assumption being that once the investment in yarding has been made, the operator may find it to his financial advantage to haul the material to market. Such requirements may accomplish little in southeast Alaska because of transportation and marketing problems.

For environmental reasons, pressures may mount to lower the amount of residues left after logging. This will add to the supply of pulpable material. Ironically, environmental concern over pollution may also reduce chances of establishing pulpmills designed to utilize this low-quality material.

The timber industry will doubtless continue to develop methods to harvest and transport more residue as economic conditions allow, especially with public encouragement to do so. Meanwhile, low-quality but sound and potentially useful material is being left in the woods, more forest land is being cut over than need be to supply current markets, and unsightly residues cover cutover land. A thorough evaluation of economic and marketing problems is needed as a start toward reducing forest residues in southeast Alaska. The problem is formidable, and only imaginative and well-funded research can do the job.

EVEN-AGED STANDS

ORIGIN AND DISTRIBUTION

The forests of southeast Alaska are still much in the condition they were before white men arrived. Large scale cutting did not begin until 1953; before that, cutting was on a small scale with scattered clearcuts adjacent to saltwater. These older cutovers are now covered with even-aged stands of hemlock and spruce.

Because of little cutting and only occasional losses to fire, wind, and landslides, the extent of young even-aged stands is limited. Acreage of young growth by origin is not known, but less than 20 percent of the commercial forest land is covered by forests less than 150 years of age. About 250,000 acres is cutover land dating from the present to the early Russian cuttings of over 100 years ago. Clearcutting currently adds about 15,000-18,000 acres annually. This figure is expected to increase in the next few years as stands with lower volumes per acre are harvested and logging methods are improved. In the decades ahead, general stand structure will change from uneven-aged stands to a diverse pattern of even-aged stands.

Most forested areas disturbed by man or nature are quick to revegetate. In addition to the older cuttings, there are many examples of abandoned cannery and village sites that have reverted back to forest. From a distance, there is little evidence that man was there except for a few rotted pilings along the beach, a pile of rusted-out tin from the cannery, stumps, or an abandoned cemetery. Areas disturbed by wind or fire are also quick to revegetate. Landslide tracks are slower to revegetate.

Throughout the region there are many even-aged stands older than 150 years. Just how much area is covered by such stands is unknown as these areas are classified as old growth along with the more typical uneven-aged old-growth stands. There is ample evidence, however, that past windstorms and fires destroyed forests over wide areas--such as those stands aged 150 years on Mitkof Island, 170 years on the west coast of Prince of Wales and nearby islands, 310 years on Chichagof Island, and 420 years on Revillagigedo Island. Many of these areas have been or are presently being logged for their high timber volumes.

REFORESTATION

Prompt and adequate reforestation is important to forest managers. After clearcutting, the forest cover must be reestablished promptly to restore the landscape's natural beauty, to minimize erosion, and to assure a sustained yield of timber from productive forest land.

Natural regeneration is relied on to restock cutover lands in southeast Alaska. Natural regeneration is preferable to planting or seeding because chance for success is usually excellent and no initial investment is required. Except for limited testing, no planting or seeding is being done.

Studies of natural regeneration following clearcutting began in 1924 under the direction of B. Frank Heintzleman, then Assistant District Forester. Regeneration studies continued until 1934, carried on first by J. M. Walley and later by R. F. Taylor.[42] Work was confined to areas where high-quality, even-aged stands had been clearcut for spruce lumber and hemlock piling. The largest units included a 265-acre cutting at George Inlet, a 300-acre cutting at Mud Bay near Ketchikan, and a 300-acre cutting at Whitewater Bay on Admiralty Island. Taylor concluded that clearcutting was a desirable silvicultural system for use in the cool, moist climate of southeast Alaska and that, on the sites then being cut, regeneration in most cases would naturally follow clearcutting within 10 years (Taylor 1930-31). His interest in regeneration led to detailed studies of the relationship between soil nitrogen and seedling establishment, of Sitka spruce (Taylor 1934b, 1935).

[42] Data from early regeneration studies are included in a series of office reports by J. M. Walley and R. F. Taylor dated 1924-34. On file, Forestry Sciences Laboratory, Juneau, Alaska.

No further studies of regeneration were done until 1948, when the Alaska Forest Research Center was established. With the beginning of large-scale pulp logging in 1953, suitable areas became available for studies of natural regeneration after extensive clearcutting. Studies were resumed to test the validity of Taylor's early conclusions and to extend his results to areas supporting lower quality stands of the type which in the future would be logged for pulp timber. Much of the more recent investigations of reforestation has been done on the Maybeso Experimental Forest near Hollis.

Experience gained over nearly half a century of clearcutting in southeast Alaska, 20 years of which have involved large-scale pulp logging, has shown that except for certain situations, regeneration is not a serious problem on the Tongass. We shall examine here several factors involved in reforestation and experience to date and then discuss some problem situations.

Immediately after clearcutting, the units appear desolate and devoid of life from a distance, but close examination will show that some plant life remains. Trees, shrubs, and herbaceous plants begin to reestablish themselves or invade the site and within a few years vegetation is abundant. Bunchberry, blueberry, huckleberry, rusty menziesia, salmonberry, elder, currant, and ferns, that may have been present beneath the old stand, begin to gain in vigor. Devilsclub again appears on the wetter areas, Twisted stalk and other herbaceous plants begin to appear, and the ground cover of feather mosses which formerly thrived on the shaded forest floor breaks down and is replaced by hair mosses. Species composition depends largely on soil conditions (Taylor 1930).

Both hemlock and spruce seedlings grow slowly during their early years, and the period required for a cutting unit to "green up" with conifers may take 10 years. During this time, the initial raw look of a clearcut area softens and from a distance appears less harsh. During the summer months, the cutting units appear quite green. Logging residues, such as twigs, leaves, and small branches, deteriorate and fall to the ground; and the unsightly limbs and debris are covered, first by brush then by conifers.

Seed Supply and Distribution

Both western hemlock and Sitka spruce are prolific seed producers, Seeds of both species are small, with large wings in relation to their weight, and are blown great distances, Seed is dispersed in the fall and winter, usually beginning with the first dry weather in September or October (Harris 1969b). Cones open and close in response to weather conditions, opening when dry and reclosing when wet. Strong winds are a regular occurrence in the fall, and seed may be blown great distances. On a mile-square cutting unit, the amount of seed dispersed from surrounding uncut stands diminished with distance from seed source; but the pattern of seedling establishment indicated that enough seed was available throughout the cutting unit to provide adequate restocking. Eight years after the unit was logged, 83 percent of 4-milacre plots were stocked with at least one seedling, and stand density averaged 5,012 stems per acre (Harris 1967). This high level of restocking was typical of natural regeneration on many cutting units in southeast Alaska. Regeneration surveys, made between 1957 and 1962 on 218 cutting units from 1 to 14 years after logging, showed that stocking averaged 80 percent. Less than 0.5 percent of this area was below the 40-percent stocking level considered adequate,[43]

[43]Region 10 stocking standards, based on the percentage of stocked, 4-milacre plots are: desired stocking, 70 percent or more; satisfactory stocking, 40-69 percent; poor or unsatisfactory stocking, 10-39 percent; nonstocked, less than 10 percent.

Small mammals are hown to destroy large amounts of tree seed and to damage conifer seedlings in many areas but have not proven to be a problem in southeast Alaska. Species distribution varies by locale (Klein 1965). Those present in Maybeso valley include the white-footed muse, vole, shrew, and flying squirrel (James 1956, McGregor 1958). Biannual censuses during a 9-year period showed that although population levels fluctuated, white-footed mice were more abundant on cutover land, and voles and shrews were more abundant on timbered land. Seed losses attributable to small mammals are not known nor is the extent of damage to seedlings, although some seedlings were observed to have been clipped. Regeneration proved to be adequate on cutover land despite the presence of small mammals (Harris 1968).

Small mammals play a useful role in forest ecology. Their insectivorous nature, large numbers, and year-round activity make them more useful than birds in controlling some insect pests. They help to improve penetration of air and water into the forest floor by working in the duff layer, and serve as food for carnivores. Evidence to date shows no need to control small mammal populations on cutover land.

Seedling Establishment and Growth

Most old-growth stands contain conifer seedlings and saplings in the understory. Hemlock, being more shade tolerant, tends to be more abundant than other conifers. Growth is often very slow, with annual height growth of an inch or less being common. Trees 2 feet tall may be over 20 years old., When stands are cut, many of these small seedlings escape logging and respond almost immediately to the increased light and warmth by increasing growth, so that for the first few years after clearcutting, advanced hemlock seedlings constitute the dominant stand component.

Many advanced seedlings die within a few years and are replaced by seedlings from windblown seed. Many of these are spruce, and there is a tendency for the percentage of spruce to increase during the stand's early years. Studies on the Maybeso Experimental Forest at Hollis generally characterize this early regeneration period. For example, the year after logging, over 4,000 residual conifer seedlings per acre, 72 percent of which were hemlock, were present on the mile-square clearcutting. These were supplemented over the next 8 years by conifer seedlings from seed blown in from surrounding uncut timber stands. During the 8 years, many residual seedlings died and were replaced by sprouts from windblown seed.

Species composition varies with soil and site conditions. Both hemlock and spruce germinate on a wide variety of seed beds, but survival may be low. Spruce survives and grows best on moist, well-drained sites where the soil organic layer and mineral soil have been well mixed. Spruce also becomes established readily on organic seed beds on decayed logs or stumps and grows well when roots reach an adequate source of nutrients. On mineral soil low in organic matter, .it may survive but is usually chlorotic and slow growing. Hemlock germinates well on almost any seed bed, but highly disturbed soils low in organic matter are unsuitable for survival and growth.

The nutritional status of forest soils is important in determining species occurrence. Taylor (1935) found that spruce seedlings are more abundant on seed beds with a higher percentage of nitrate nitrogen. In incubation tests of seed bed material, an increase in percentage of Sitka spruce was associated with accumulation of nitrate nitrogen up to 50 p/m, and nitrification varied significantly with the character of typical seed beds. Mulls of salmonberry, alder, elderberry, and devilsclub were, in decreasing order, capable of greatest nitrification and highest percentages of spruce. Hemlock was more abundant on seed beds where oxidation of ammonia to nitrates could not occur. Seed bed material which contained from 20 to 60 p/m of ammonia after incubation tended to support hemlock but not spruce. These seed bed types included, in decreasing order of nitrifying ability, spruce duff, willow-poplar mull, hemlock-*Vaccinium* duff, hemlock duff, and rotten wood.

Open conditions favor Sitka spruce, and a gradual change in species composition occurs. At Hollis 8 years after logging, a new stand contained 4,300 seedlings per acre; 53-percent hemlock, 41-percent spruce, and 6-percent cedar. Variations occur because of differences in site and seed source, but this species composition is typical of young second-growth stands on the Tongass.

The trend toward more spruce at the expense of hemlock may continue, but little information is available. Taylor (1934a) found that even-aged stands **usually** contained from 10 to 75 percent spruce by basal area depending on soil type and stand age. He estimated that, on the average, the volume of spruce in even-aged stands after a rotation period of 75 to 100 years was abut 50 percent.

At Hollis 8 years after logging, dominant hemlock seedlings averaged 5 feet in height with a maximum of 11 feet; dominant spruce, 2 feet with a maximum of 5 feet; and dominant cedar, 2 feet with a maximum of 3 feet. Hemlock seedlings tended to be larger because many were advanced seedlings which were released after clearcutting.

Tops, large branches, and logs have deteriorated little, however, and this heavy debris together with dense patches of seedlings continues to make foot travel through cutover areas difficult. During the green-up period, cutting units provide summer browse for deer, a "movable feast" that diminishes as the conifer stands close and browse species are shaded out.

From 15 to 20 years after logging, crown closure begins to take place (fig. 15). Fifteen years after clearcutting, sapling stands on the better sites at Maybeso valley contained dominant trees ranging to over 30 feet in height. Dominant hemlock averaged 24 feet in height; dominant spruce, 15 feet. The initial advantage of hemlock residuals remained much in evidence. Height growth of both species at 15 years of age was nearly identical, averaging 2.2 feet per year.

Experience with reforestation and stand development following **pulp** logging extends only to 20 years. Beyond this, normal yield tables for even-aged stands (Taylor 1934a) can be used to predict future stand development.

Alluvial Stream-Terrace Sites

Prompt and adequate restocking is the rule on most sites on the Tongass, but experience has shown that some regeneration problems exist. Perhaps the most serious situation is on stream-terrace sites that have soils of the Tonowek or Tuxekan series (Harris 1967). These soils are well-drained, loamy soils derived from alluvium (Gass et al. 1967). Old-growth stands on these moist sites contain high percentages of Sitka spruce, and trees are often large.

Figure 15.--Twenty-five years after logging at Coning Inlet, Long Island (compare with figure 12).

Some of the best spruce are found on these sites, and timber values are high. Competition from shrubs and red alder usually occurs along streams and sloughs; salmonberry, devilsclub, currant, thimbleberry, Pacific red elder, ferns, and a variety of forbs and grasses are comon in the understory of conifer stands. After logging, regeneration is often sparse on these sites, and alder and shrubs may proliferate and capture the site (fig. 16).

Sitka spruce and western hemlock seedlings usually become established on raised microsites, alongside stumps, or atop decayed logs or debris in much the same pattern as the original stand but can remain suppressed beneath dense alder stands for 40 years before finally overtopping the alder and shading it out. Salmonberry is a more serious competitor, and conifers may have difficulty becoming established beneath dense patches.

Valley-bottom sites are sensitive from a fisheries and recreational standpoint. Pink and chum salmon often spawn in the streams, and coho salmon and trout spawn and rear in the streams and in small braided channels. Streamsides are important habitat for brown or black bear which feed on salmon during late summer and fall. Access to valleys is often near the streams; and hunting, fishing, and other recreational opportunities are high.

Figure 16.--Conifer regeneration is often sparse on streamside alluvial sites, and alder may capture the site (Eliza Harbor, Admiralty Island).

Problems with alluvial sites are more prevalent on the mainland and the more northerly islands where alluvial terraces are broader in relation to valley width. Planting of Sitka spruce with spot-treatment of competing brush and alder is now being planned where needed, and cutting in critical areas is being deferred until better management techniques can be developed, A great deal of thought should be given to future management of valley-bottom areas.

Alder Competition on Upland Sites

Alder is not uniformly distributed in southeast Alaska but is often found along beaches or streams, on landslide tracks, or in small openings. The species may offer severe competition to conifers. Dense thickets of red alder or Sitka alder often become established immediately after logging when a seed source is present and mineral soil is exposed. Alder may dominate the site for 40 years or more until overtopped by spruce. Competition from alder is considered a serious problem by some foresters, and attempts have been made to release suppressed conifers by aerial application of selective defoliating herbicides. Chemical control of alder is not necessarily effective in releasing conifers because removal of alder may release salmonberry or grass beneath it and promote more serious vegetative competition than before. In addition, chemicals may be dangerous to fish or other organisms (Sears and Meehan 1971).

Falling or poisoning alder seed trees may help to reduce the problem. For example, ammate was used to poison alder seed trees in Maybeso valley (Andersen 1955a). This treatment apparently reduced alder establishment but failed to completely eliminate the seed source. Some alder became established on disturbed ground; within 5 years, young trees were producing seed. An unforeseen side effect of poisoning streamside alder was that as trees decomposed, stems and branches fell into the stream, adding considerably to stream debris.

The presence of alder on cutover upland sites is often a symptom of excessive soil disturbance (fig. 17). More effort should be directed toward eliminating the cause rather than attempting to eradicate alder. Tractor logging is especially destructive to the soil organic layer and, for this reason, is being eliminated. High-lead logging, especially on frozen ground, causes less soil disturbance; and Wyssen logging has been shown to cause less soil disturbance than high-lead logging (Weisgerber 1963). Balloon logging has also been shown to cause less soil disturbance than high-lead logging. Skyline systems or balloon logging may largely eliminate the problem of alder competition on upland sites. Whether such light disturbance will result in adequate spruce establishment is not known and should be investigated.

Landslides

An additional reforestation problem is found on unstable soils on steep slopes. Landslides and debris flows may seriously retard regeneration on steep slopes by removing the soil mantle down to glacial till or rock and by covering high-site land on lower slopes and valley bottoms with debris and rubble. Slides are common throughout southeast Alaska, but their frequency is greatly increased after logging (Bishop and Stevens 1964, Swanston 1971). On the mile-square cutting unit in Maybeso valley, 11 percent of regeneration plots were disturbed by slides, 8 percent being eroded to bedrock or glacial till and 3 percent covered by debris (Harris 1967).

Usually the lower parts of slides quickly revegetate, pass through a red alder successional stage, and eventually support excellent stands of spruce. Alder contributes to the buildup of nutrients in mineral soil and, from this standpoint, may be beneficial to the future spruce crop. For example, net annual accumulation of 700 pounds of organic carbon and 55 pounds of nitrogen per acre per year has been measured under a 50-year-old alder stand which originated on the bare mineral soil of a glacial moraine (Crocker and Major 1955). However, the time required to pass through the alder successional stage will add many years to the rotation period of the future merchantable stand.

Interest is now being shown in use of alder to stabilize and revegetate landslide tracks and other areas of great soil disturbance. The beneficial effects of alder in improving the forest ecosystem are well documented (Tarrant and Trappe 1971). Where a conifer stand is ultimately desired, Sitka alder might prove to be superior to red alder as a nurse crop because its shorter stature should reduce the time required for overtopping by spruce. Red alder might be superior on more accessible sites where the possibility of selectively logging merchantable alder at maturity might exist, leaving the spruce component for future harvest.

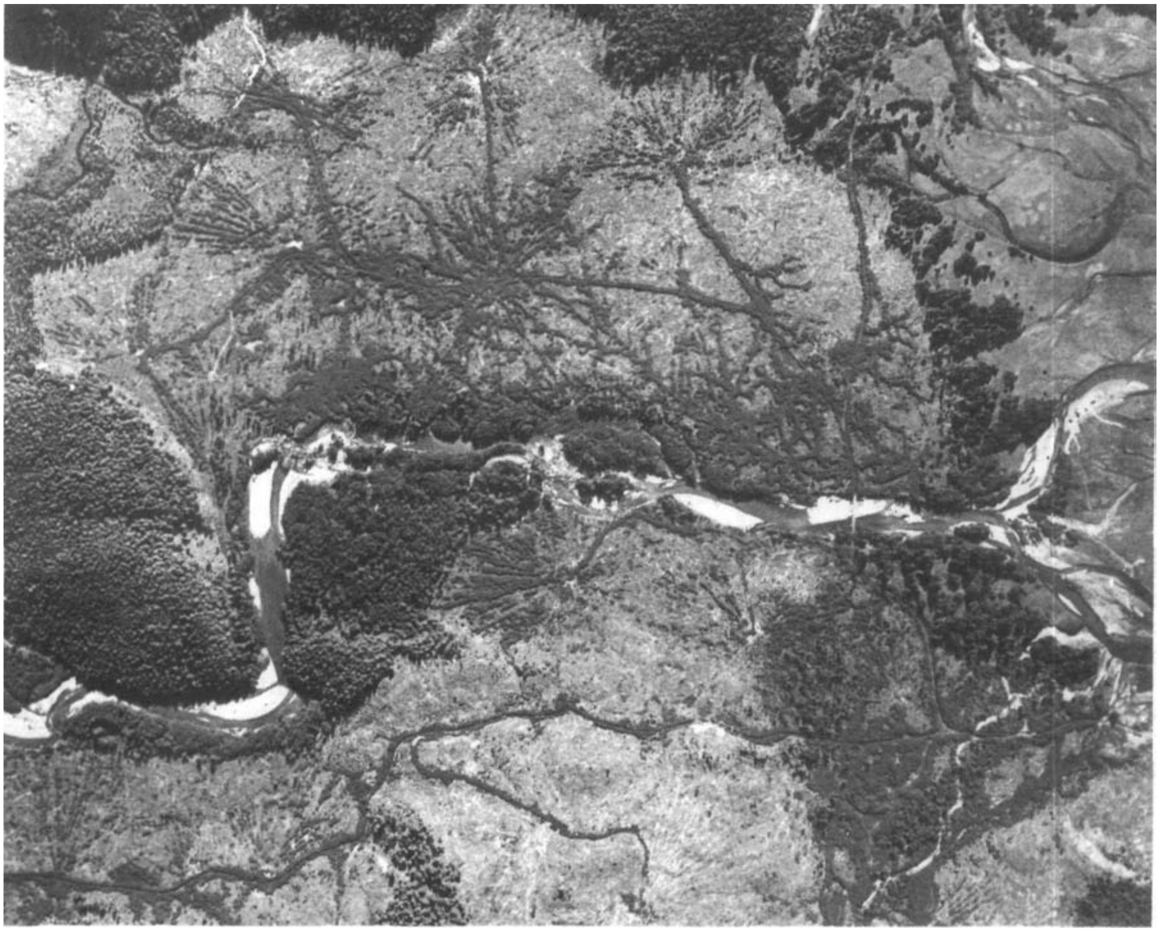

Figure 17.--Alder invasion often follows excessive soil disturbance. The pattern of logging is apparent from alder establishment seen in this aerial view 10 years after clearcutting (Katlian Bay, Alaska).

Overdense Stands

Stocking on many upland sites tends to be overdense, typically averaging 4,000 stems per acre, often with patches of 20,000 stems per acre or more. Such dense stands show no signs of stagnation, and dominance is soon expressed by individuals. Although such stands thin naturally, production of usable wood would be hastened if stocking were less dense. Because of the high cost of precommercial thinning by hand, other methods of achieving wider and more uniform initial spacing should be developed. These might include use of fire or selective chemicals, mechanical thinning with tractors or other equipment, or planting of superior stock.

Light burning of logging slash followed by aerial seeding has resulted in a reduction of stems per acre, a more uniform distribution of seedlings, and an increase in the percentage of spruce 8 years after treatment (Harris 1966a). The long-term effect of burning on site productivity is not well understood, but there are indications that light burning may be beneficial. Stephens et al. (1969) found no significant difference in site index between stands which originated after wildfire or logging, but stands resulting from these origins grew at a faster rate than stands originating from blowdown of a previous stand. However, a severe burn which removes most of the surface organic material could seriously reduce site potential.

Slash burning might be used to improve the appearance of cutover land by removing unsightly slash and debris, as well as improving accessibility for recreation and future stand management. Slash burning should not be done on steep slopes because of the possibility of creating unstable soil conditions or destroying shallow organic soil.

Because of the usual wet conditions in southeast Alaska, only a few days each summer may be dry enough to allow burning of slash. During these periods, fire in slash is difficult to control, although it tends to go out or is more easily controlled when it reaches the cool, moist conditions under surrounding timber.[44]

Although fire appears to be a promising silvicultural tool for controlling initial stocking and species composition, much more experience and information on its behavior and effects will be needed before fire can be used with reliability. The effect of fire on air quality has been documented in detail (Hall 1972) and would be an important consideration which might prohibit its widespread use in southeast Alaska. As more intensive management is practiced, additional research on the use of fire and other means of reducing the density of stocking will be required.

Seeding and Planting

Natural restocking is usually adequate to meet present management objectives, but there are situations when seeding or planting may be necessary. Examples include, when a natural source of seed for a desired tree species is lacking or when the manager wishes to introduce special seed, establish plant cover on eroding soil, or reduce the time required for natural reforestation.

Techniques for aerial seeding of conifers by helicopter have been adapted for use in southeast Alaska,[45] and tests have shown that aerial seeding can increase stocking of conifers on cutover land (Harris 1965a). Tests are now being made to determine the effectiveness of seeding with alder on unstable soils following landslides.

Planting of conifers has been done only experimentally, using wildings of hemlock and spruce. Planting will become more important as more intensive forestry is practiced. Planting may be necessary when natural regeneration fails to produce a new stand within 5 years after logging (USDA Forest Service 1972). Streamside alluvial soils, highly disturbed soils, or landslide tracks are specific situations when planting may be needed. Red or Sitka alder might be especially useful when site rehabilitation is important. Much experience with alder species has been gained abroad which might prove useful here. More experience and research on revegetation of disturbed soils are needed.

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[44] R. C. McGregor. Observations of the Kina Cove burn. Office report on file, Forestry Sciences Laboratory, Juneau, Alaska, March 15, 1957.

[45] A. S. Harris and E. A. Crozer. Helicopter seeding technique used at Katlian Bay and Nakwasina Sound, 1960. Office report on file, Forestry Sciences Laboratory, Juneau, Alaska.

STAND DEVELOPMENT

Initial rate of height growth of hemlock and spruce is slow for the first few years after germination but then steadily increases to age 10 to 15 years. Growth then remains nearly uniform until age 30 to 40 years, and after that slowly declines. It is during the period of most rapid growth, as competition increases, that cultural treatment can be used most effectively to influence stand development.

With favorable seed bed conditions, such as are commonly found on upland sites in southeast Alaska, dense regeneration is generally assured. Seedling density of 5,000 to 10,000 per acre is common, and stands are almost too dense to walk through after the first few years. Because of such dense stocking, competition affects early development of the stand. Crown closure usually takes place within the first 20 years, and competition for growing space, light, and nutrients is intense.

Stocking varies with stand composition. Pure or nearly pure stands of hemlock tend to be most dense and pure stands of spruce most open. A mixture of the two species provides the highest yields (Taylor 1934a).

Tree mortality increases with crown competition, and the number of trees per acre drops off rapidly early in the life of the stand. At the same time, live crown length is reduced from nearly 100 percent of a tree's height to about 30 percent. This in turn reduces photosynthetic efficiency and slows diameter growth.

In young stands, hemlock and spruce have slightly different patterns of height growth but, for practical purposes, height growth can be considered the same. Taylor (1934a) found that the greatest error involved in averaging dominant heights of the two species is only about 1-1/2 feet. Recent stem analyses of hemlock and spruce have confirmed that height development of the two species in even-aged stands is similar.[46]

Dominant spruce are usually larger in diameter than dominant hemlock because of faster radial growth of spruce and differences in mortality rates. Mortality rates are higher for spruce, so there are fewer small spruce than hemlock (Godman 1949). At 100 years, a typical even-aged stand will contain twice as many hemlock as spruce trees; but because the spruce will be larger, half the stand volume will be in spruce (Taylor 1934a).

There is no evidence that even-aged hemlock-spruce stands in Alaska stagnate--that is, cease their height growth because of severe competition. However, most stands are greatly overstocked. Because of high stand density, individual tree growth is slowed but natural mortality rates are high, and there is generally good expression of dominance. During a rotation, these dense stands accrue considerable volume, Meyer (1937) noted that western hemlock produces as much or more wood per acre than any other tree species in the Pacific Northwest (fig. 18).

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[46]Wilbur A. Farr. Site index curves for western hemlock and Sitka spruce in southeast Alaska. Study plan on file, Forestry Sciences Laboratory, Juneau, Alaska, 1968.

Figure 18.--Forty-one years after clearcutting, this stand at Virgin Bay, Alaska, contained 1,176 trees, or 298 square feet of basal area per acre.

High volumes are produced at no expense to the land manager. At 100 years of age a typical unmanaged stand contains about 12,000 cubic feet of wood per acre in trees averaging 12 inches in diameter at breast height. Crown canopy is still closed at this age, and little sunlight reaches the ground. Advanced regeneration is sparse. Over time, openings slowly develop in the canopy, and the more shade-tolerant hemlock becomes established. Stand deterioration slowly takes place, and volume declines. After a few hundred years, an uneven-aged climax stand evolves in which hemlock comprises about 75 percent of the stand volume. Most of the forests of southeast Alaska are presently in this climax condition, with volumes at levels far below those of stands that formerly occupied the sites.

TIMBER YIELDS FROM EVEN-AGED STANDS

Yield estimates have been compiled for many species in the form of yield tables since about 1900 in the United States, and for a considerably longer time in Europe. Until recently most tables were normal or two-variable yield tables, based on site index[47] and age. Density was held constant by the selection of sample plots from well-stocked, even-aged stands. With only the two independent variables, site index and age, the yield tables could be conveniently constructed by graphical methods. Although useful, normal yield tables generally have serious limitations--for most species they do not represent average stocking conditions nor do they show desirable stand conditions (Spurr 1952, p. 260-262). However, for many species they continue to be used for lack of better guides.

Normal yield tables for even-aged stands of hemlock and spruce in southeast Alaska (Taylor 1934a) have been very useful over the past few decades and will doubtlessly continue to be used because most second-growth stands are normally stocked and in many areas will remain untended over the next rotation. New guides, however, will be needed for stands under intensive management.

Yield studies began in southeast Alaska in 1925 and led to the development of the normal yield tables (Taylor 1934a). Taylor's yield estimates, derived from graphical analysis, were based on the variables site index and age. The site index curves were proportional curves developed using anamorphic techniques (Bruce '1926). About the same time that Taylor's yield tables were published, Walter Meyer began to compile yield data for hemlock and spruce from the entire north Pacific coast. For his yield tables Meyer (1937) used 300 of Taylor's plots from southeast Alaska, 64 plots from British Columbia, and 294 plots from Washington and Oregon. Meyer's proportional site-index curves did not differ appreciably from those prepared by Taylor.

Meyer recognized that species composition and geographical location had an effect on site index and yields. He provided supplementary tables for correcting yields but considered the effect of site index to be minor. Barnes (1962) later pointed to other discrepancies in the expected yields and site indexes and showed that many yield variables differ with latitude. For example, stands of the same age and site in Alaska tend to have more trees per acre, a smaller average diameter, shorter average height, and less timber volume than stands in Oregon and Washington.

Site productivity declines with increasing latitude. Yield tables by Taylor (1934a), Meyer (1937), and Barnes (1962) indicate that site index averages about 156 in Oregon and Washington, 126 in British Columbia, and 106 in southeast Alaska. Within southeast Alaska, site index averages 109 in the Ketchikan-Craig area and 104 for the Sitka and Juneau area. Average site index for the Yakutat area is about 83.

Recently, stem analysis techniques have been used to check the validity of existing proportional site-index curves for hemlock-spruce in southeast Alaska (see footnote 46). This work suggests that height growth trends differ somewhat from those shown in the existing site curves, with differences greater for low sites than for high sites. Comparison of these preliminary curves for hemlock with Wiley's provisional site index curves for western hemlock[48] in the Pacific Northwest--both based on an index age of 50 years--suggests that height growth trends for stands in Alaska and in the Pacific Northwest are nearly identical

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[47] Site index is a measure of the relative productivity of a site. Here it is based on the average height of dominant and codominant trees at a total stand age of 100 years.

[48] Kenneth N. Wiley. Site index tables for western hemlock. Weyerhaeuser Timber Co., Centralia, Wash., 17 p., mimeogr., 1970.

for the first 50 years. After age 50, height growth of dominants tends to drop off slightly in Alaska so that, by age 100, dominant hemlock and spruce will be 2 to 4 feet shorter in Alaska than on similar sites in the Pacific Northwest. This apparent 2- to 4-foot difference is of little practical importance for management purposes. Although these general regional curves depict average height growth trends for different sites, considerable variation in the basic data is not accounted for.

The general shape of the site-index curves apparently differs by soil series. Sufficient data are not yet available to develop and test separate sets of curves for each major soil series in southeast Alaska, but there are indications that at some future time separate sets of curves will be needed.

Following completion of new site-index curves for spruce and hemlock, there will be a need to reanalyze Taylor's basic data, and if indicated, revise the yield tables.

INTENSIVE FORESTRY

Intensive forestry refers to the practice of forestry to produce a high level of volume and quality of timber per unit of area through the application of the best available techniques of silviculture and management (Ford-Robertson 1971).

To maximize the values of timber produced per unit of area, stands must be carefully tended throughout their rotation. Periodic thinning, pruning, and fertilization may be required and mortality or anticipated mortality salvaged to. maximize yields (fig. 19). To reduce the length of the rotation cutover areas might be planted with conifers instead of relying on natural regeneration; and during the early stages of stand development, competing vegetation might be controlled. To carry out intensive forestry successfully, the forest manager must have a good howledge of species' requirements for growth, their pattern of growth in stands, and guides for estimating anticipated response to various types of treatment. For the foreseeable future, most areas will not be intensively managed because of the costs involved.

Priority for selecting areas for intensive forestry should be based on productivity, topography, accessibility, and demand for resources other than timber. Once suitable areas have been selected, priorities for treatment can be established through benefit/cost analysis.

If possible, selected areas should be treated within 10 to 20 years after clearcutting to reduce initial overstocking before competition becomes too severe. Except for special situations, natural regeneration following clearcutting is usually too abundant. Evidence from yield studies by Meyer (1937) and Barnes (1962) suggests that average stand density also increases with latitude. This is probably because of wetter and cooler summers and the consequent higher seedling survival rates in Alaska than in the Pacific Northwest. For example, total number of growing-degree days (threshold 41° F) in southeast Alaska is only half the total for coastal Oregon.[49] Barnes (1962) found that for the same site and age, hemlock-spruce stands in Alaska have more stems per acre, a smaller average diameter, and less volume than stands in the Pacific Northwest. Some degree of stocking control, therefore, would seem to be a desirable management objective.

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[49] Data on file, Forestry Sciences Laboratory, Juneau, Alaska,

Figure 19.--A dense stand of Sitka spruce and western hemlock 39 years after clearcutting. Yield of usable wood from such stands could be increased by periodic thinning.

Thinning

Little research on thinning has been conducted in the hemlock-spruce type although the type appears to have great management potential. Silvicultural research has lagged mainly because of low market value for hemlock and spruce. Wiley (1968) found published results from only four studies on thinning of western hemlock in British Columbia and the Pacific Northwest. All, however, reported substantial growth increases following thinning.

Low market value of timber and an abundance of old growth are principal reasons for lack of second-growth management in southeast Alaska, Large-scale clearcutting began only 20 years ago, and today only about two-thirds of the regulated cut is being harvested annually. Over 80 percent of the forests are overmature. Management conditions could change quickly and unpredictably, however; on one hand there could be increased demand for the timber resource, and on the other hand, public insistence that large portions of the Tongass National Forest be set aside for other uses.

Few published studies show growth potential of hemlock and spruce under intensive management although several new studies are underway or being planned in the Pacific Northwest and British Columbia. Theoretical basal-area growth rates for thinned stands of western hemlock using nonlinear methods outlined by Turnbull (1963) and Pienaar (1965) were recently prepared by Hoyer.[50] Bradley et al. (1966) prepared managed-stand yield tables for many species in Britain, including western hemlock and Sitka spruce. Their work can be used as provisional guides for southeast Alaska.

When intensive culture of some even-aged stands becomes economical, the density of initial stocking may dictate. the kind and amount of stand improvement work necessary. Experience has shown that precomercial thinning in dense hemlock-spruce stands is expensive in this region.[51] [52] Some research, therefore, should be directed toward finding ways to limit initial stocking.

Since much of the volume lost through periodic mortality would be recovered if stands were managed more intensively, gross yield is a closer approximation of the stand's potential productivity than is net yield. Gross yield tables that predict net yield plus mortality give estimates of total wood production but are available for only a few species. For most species, data from managed stands will not be available for some time. In the interim, useful *gross* yield tables could be developed from temporary plot data by procedures similar to those developed by Dahms (1964) or Curtis (1967).

Gross yields for hemlock-spruce stands are not known; however, some insight into probable values might be gained by comparing gross and net yields of species where this information is available. Dahms (1964) developed gross and net yield tables for lodgepole pine for the pumice soil areas of central and south-central Oregon. He found gross mean annual increment to be 44 to 66 percent higher than net mean annual increment, depending upon site. For Douglas-fir, gross cubic-foot yields are estimated to be 46 to 60 percent higher than net yields (Curtis 1967). Bruce's (1969) comparison of managed-stand yield data for Douglas-fir in Europe with *gross* and net yields for unmanaged stands in the United States suggests that the gross yield estimates by Curtis are reasonable estimates of yields from managed stands.

Our best estimate of average site for western hemlock and Sitka spruce in southeast Alaska growing on operable areas is about site index 110 (based on index age 100 years).[53] Height development of site index 110 is approximately equivalent to the yield class 160 in the British managed-stand yield tables for western hemlock (Bradley, et al. 1966). For example, mean annual increment for yield class 160 converted to cubic-foot measure amounts to about 200 cubic feet per acre per year.

Maximum net mean annual increment for site 110 in southeast Alaska is 131 cubic feet (Taylor 1934a). Adjusting this value upward 50 percent to account for expected mortality during the rotation gives an estimated *gross* mean annual

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[50] Personal communication, Gerald E. Hoyer, Department Natural Resources, State of Washington.

[51] Robert C. Smith. Administrative study. Level Island precomercial thinning study. USDA Forest Service, North Tongass National Forest, Petersburg Ranger District, Petersburg, Alaska, 17 **p.,** mimeogr., 1965.

[52] Russell Weisinger. Administrative study. Sea Otter Sound precomercial thinning. USDA Forest Service, South Tongass National Forest, Craig, Alaska, 19 **p., mimeogr.,** 1965.

[53] Reinventory information on file at Forestry Sciences Laboratory, Juneau, Alaska.

increment of 196 cubic feet per acre per year, a value approximating the British value. This admittedly crude comparison gives some idea of the average productive potential of managed even-aged stands in southeast Alaska. There are, of course, many unanswered questions about size of material removed in periodic thinnings, the amount that could be economically utilized, costs of precomercial thinnings, species mix, and tree quality, to mention a few.

Advantages and Disadvantages of Thinning

Evidence from long-term European studies indicates that maximum yields are obtained fromlightly thinned, well-stocked stands where anticipated mortality is salvaged (Assmann 1970). Redistribution of growth through heavy thinning allows for larger size trees and greater return on investments but generally does not increase gross yield unless moisture, nutrients, soil temperature, or other limiting factors are influenced by the thinning.

Short-term studies, which showed an increase in radial growth and mean annual increment after heavy thinning, led early researchers to believe that usable stand volumes would be increased over a rotation. However, long-term studies have shown that repeated thinnings, begun at an early age, usually resulted in a reduction of mean annual increment of about 5 percent (Assmann 1970). This reduction was due to periodic thinning which temporarily reduced stocking to levels below optimum.

There are a number of potential disadvantages to thinning. Tree specific gravity of softwoods is reduced, lower branches become coarser, and natural pruning is delayed. In the case of Sitka spruce, opening of the stand encourages the development of epicormic branches on the lower bole (Farr and Harris 1971). There is not enough evidence to show how serious this problem will be in managed stands of hemlock and spruce.

Hemlock and spruce have thin bark and shallow roots. These characteristics make them particularly susceptible to logging injury from thinning and may lead to serious decay (Buckland et al. 1949; Foster and Foster 1951; Wright and Isaac 1956; Shea 1960, 1961; Wallis et al. 1971). Shallow-rooted trees in well-stocked stands depend upon their neighbors for support; if initial thinnings are delayed until late in the life of the stand, considerable wind damage may result. Windfirmness is generally improved if stands are thinned at an early age.

With a favorable economic environment, the advantages of thinning outweigh the disadvantages. Early and heavy thinnings produce larger diameter trees in a shorter period of time so that greater economic returns are realized. Investment in growing stock is also reduced. Heavy thinning is usually justified provided there are markets for the thinnings and compound interest is used to evaluate timber growing alternatives.

Unless stands are thinned, considerable volume is lost to mortality over a rotation. Intensive management may greatly increase volume production as much of this mortality would be utilized. Present long-range management plans anticipate that thinnings will contribute to the cut in the latter part of the present rotation, Pressure to produce more wood products from Federal land will no doubt lead to more intensive management of the timber resource.

Thinning Experience in Southeastern Alaska

Thinning experience in the hemlock-spruce forests of southeast Alaska is limited, and past thinnings generally have not been heavy enough to sufficiently benefit individual tree development, The first known thinning in southeast Alaska was done in 1929 by R. F. Taylor, who thinned a small plot in a dense 30-year-old stand of hemlock and spruce near Juneau (Taylor 1949). Seventy-seven percent of the trees were removed, and basal area was reduced from 216 square feet to 110. Taylor found that after 20 years the unthinned and thinned plots appeared almost identical.

Although it is true that nature can thin dense stands with no apparent stagnation, it also appears that nature's stocking standards may be higher than desirable if timber production is a major goal. Taylor's plots had two to three times the normal number of trees per acre at age 30 and nearly the normal number at age 50, Normal stocking is about 1,800 trees per acre at age 50 for this particular site, an average spacing of less than 6 by 6 feet (Taylor 1934a). In contrast, the British yield tables for managed stands of western hemlock call for less than half this number of trees per acre for the same average diameter (Bradley et al. 1966).

There were no additional thinnings until 1950, when plots were installed in a 96-year-old stand at Karta Bay (Godman 1951, Farr and Harris 1971). In 1951, plots were also established in a 38-year-old stand at Skowl *Arm* (Harris 1966b). Both areas are located on the east side of Prince of Wales Island. The objectives of these studies were to determine how much volume could be removed during a thinning and the time required to remove it and also to study the effects of cutting on stand.growth.

Results from thinning the rotation-aged stand at Karta Bay indicated that considerable volume could be removed from even-aged stands without reducing future stand growth. Opening the stand stimulated epicormic branching on spruce and the understory became well stocked with regeneration, mostly hemlock (Farr and Harris 1971). Thinning resulted in increased rate of diameter growth of selected crop trees, but annual diameter growth after thinning was no greater than 0.12 inch. From the standpoint of fiber production, it would be better to clearcut such stands at or before this age and regenerate a new stand rather than to thin in an attempt to increase growth of selected crop trees, If sustained production of quality sawtimber is an objective, crop trees might be held for future sawtimber harvest. From an economic standpoint, there would have to be a considerable value differential for grade to justify holding such stands for quality sawtimber,

During the 1960's, a number of cleaning, pruning, and thinning projects were completed on the Tongass Forest. They were principally concerned with methods and costs of treatment and not with response to treatment. Both chemical and mechanical thinning treatments were applied, but combinations were not tested. Equipment preference varied among individuals and type of stand being treated. Pruning shears were found to be effective in a 10-year-old stand at Sea Otter Sound where dominant spruce averaged 2 inches in diameter; hemlock,1 inch.[54] Treatment cost averaged $98 per acre. A similar project on Kosciusko Island[55] cost $79 per acre.

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[54] From Timber Management Plans for the Ketchikan-Craig, Sitka, Juneau, and Yakutat Working Circles, USDA Forest Service, Juneau, Alaska.

[55] Data on file, USDA Forest Service, Juneau, Alaska.

Thinning in older stands is considerably more expensive. A thinning in a 17-year-old stand at Level Island to 12- by 12-foot and 16- by 16-foot spacing cost $417 per acre (see footnote 51). Because of stand density, mechanical thinning of older stands leaves a heavy accumulation of slash that hinders access for a considerable time, and could pose a fire hazard in dry seasons.

In 1963 a 65-year-old stand on Kosciusko Island was chemically thinned by use of ammate crystals and 2,4,5-T in diesel fuel at an average cost per tree of about $0.20. Single-hack girdling with an application of 2,4,5-T was preferred. Significant quantities of ammate were lost when used in the rain, and girdling of large fluted trees was difficult.

Elsewhere, opinions vary on best methods for precommercial thinning of hemlock and spruce. Schroedel (1971) reported that the Washington Department of Natural Resources uses both chemicals and chainsaws in their precommercial thinning work, Chainsaws are used in stands averaging less than 2-1/2 inches in diameter when branches reach the ground and there are 2,000 or more stems per acre to be removed. Chemicals are used most efficiently in larger diameter stands where fewer stems are to be removed. The Weyerhaeuser Company (Hansen 1971) at one time thinned mostly with chemicals but now has switched almost entirely to powersaws. One consideration for the change was the field crew's exposure to organic arsenicals (Tarrant and Allard 1972). Other considerations were that quality suffered as it was difficult for field crews to remain oriented in dense stands and for supervisors to determine if thinning standards were being met. Studies to evaluate the effects of arsenicals on human health, animals, and the environment concluded that "Evidence now available indicates the key to safe use of organic arsenical herbicides is carefully controlled handling and application to minimize exposure of man and animals" (Norris 1971).

Limited experience to date indicates that western hemlock and Sitka spruce respond quickly to increased growing space but costs of providing this growing space are high. Research should be directed toward finding new and less expensive ways of limiting initial stocking, Response information is also needed before reliable benefit-cost analyses can be made to evaluate alternatives of intensive timber management, Possibilities also exist for using forest fertilization to improve site potential and growth of dense stands, especially those growing on poor sites. When left untreated, such stands produce little if any merchantable wood during their rotation. Environmental concern will play a large part in determining how and where thinning will be done in the future, particularly in connection with the use of chemicals, and in the development of road systems required if stands are to be managed intensively.

Forest Fertilization

The use of fertilizers in agriculture is a centuries-old practice, but its use on forested areas is relatively new. Only in the past 10 years has forest fertilization been conducted on an operational basis in most areas in the world (Groman 1972). For example, forest fertilization in the Pacific Northwest began on a small scale in 1963. By 1970, some 100,000 acres were being fertilized annually with prospects that 200,000 acres or more will be fertilized annually within the next 5 to 10 years (Moore [n.d.]).

The fact that most forest soils lack sufficient concentrations of usable nutrients for optimum tree growth is well documented, but optimum nutrient levels are not well known. The forest fertilization problem is complex, not only for economic reasons but because it is difficult to predict the degree of response following an increase in nutrient supply (Leyton 1958, Waring and Youngberg 1972). After 20 years of research, the most general statement that can be made for the Douglas-fir type, for example, is that overall average response is expected to be about a 30-percent increase in cubic-foot volume over a 5- to 7-year period after an application of 150 to 300 pounds of nitrogen per acre (Strand and Miller 1969). So far, for Douglas-fir there is no clear relationship between nutrient response and site quality (Crossin et al. 1966, Heilman 1971), but there is evidence that some combination of thinning and fertilization may give the best results (Heilman 1971, Miller 1971b).

Nutrient Requirements of Western Hemlock and Sitka Spruce

Little is hown about the nutrient requirements of western hemlock and Sitka spruce in this country; but in the United Kingdom, considerable research has been conducted since about 1945, particularly for Sitka spruce nursery stock, because of problems that arose during the large afforestation program in England, Wales, and Scotland. An excellent summary of nutritional research carried out in forest nurseries between 1945 and 1962 by the Rothamstad Experimental Station and the Research Branch of the Forestry Commission is contained in Forestry Commission Bulletin 37 (Benzian 1965). Research on nursery practices is still active in 'the United Kingdom, and studies are underway to evaluate nutritional requirements of established-plantations.

Nitrogen.--Available nitrogen is the nutrient most universally found to be in short supply in forest soils. Nitrogen deficiency is recognized in conifers by an abnormally pale green color of the foliage. This is especially noticeable in seedlings (Benzian 1965).

The soils of southeast Alaska are deficient in available nitrogen (Stephens et al. 1968). Apparently this deficiency not only affects tree growth but may also affect regeneration of Sitka spruce. For example, Taylor (1935) found a positive correlation between percent of spruce regeneration and release rate of available nitrogen.

Chemical analysis of foliage collected during the dormant season has been used most to assess the nutrient balance of trees. Sampling variation is less during dormancy than during the growing season (Lavender 1970, Waring and Youngberg 1972), and difference in nutrient levels are greatest between deficient and healthy plants (Goodall and Gregory 1947, Morrison 1970). However, the use of dormant-season foliage has been criticized because it may be a less sensitive indicator of a plant's nutrient status than foliage obtained during periods of rapid growth (Waring and Youngberg 1972, Smith et al. 1970).

Limited fall sampling of both hemlock and spruce in southeast Alaska indicates that foliar nitrogen levels for both species average about 1.3 percent on the better sites and 0.9 percent on poor sites.[56] In the United Kingdom, foliar nitrogen of spruce averages 1.6 percent on the better sites and 1.1 on poor sites (Binns et al. 1970).

Nitrogen levels in forest stands are considerably lower than the optimum levels suggested from laboratory experiments, which for Sitka spruce range from

[56] Data on file, Forestry Sciences Laboratory, Juneau, Alaska.

1.5 to 2.4 percent[57] (Leyton 1958, Parker 1962, van den Driessche 1969). No suggested values are available for western hemlock.

Implications are that the forest stands of southeast Alaska should generally benefit from additional supplies of available nitrogen. The amount, chemical form, and frequency of application required for optimum growth under various soil and stand conditions and the costs and benefits of fertilization are unknown. However, both western hemlock and Sitka spruce have responded to nitrogen fertilization in nurseries (Winjum and Cummings 1961, Benzian 1965), plantations (Smith et al. 1968, Austin and Strand 1960), and in the natural forest stands of southeast Alaska.[58]

Other nutrients.--Critical and optimum levels for nutrients other than nitrogen are not well known. Interpretation of available published research (Leyton 1958, van den Driessche 1969; also see footnote 57) suggests that for Sitka spruce approximate critical and optimum values for phosphorus are 0.14 and 0.25 percent and for potassium, 0.7 and 1.2 percent. Critical levels for calcium and magnesium are about 0.25 and 0.07 percent, respectively. Comparative values for western hemlock are not available. If these values are close to the optimum values for forest stands, then there is the strong possibility that the soils of southeast Alaska are deficient in other nutrients as well as nitrogen. However, so far no relationship has been found between site index and extractable phosphorus, potassium, calcium, or magnesium (Stephens et al. 1968). Considerable research would be required to evaluate the effects of added nutrients on stand growth.

Experience in Southeast Alaska

The late F. R. Stephens carried out a number of administrative studies of forest fertilization in southeast Alaska in the later 1960's as regional soil scientist for the U.S. Forest Service. His background from the Pacific Northwest plus general knowledge of the soils and climate of the region, and limited chemical analysis of the foliage of western hemlock and Sitka spruce convinced him that the forests of the region would benefit from an added supply of available nitrogen. In 1967 Stephens installed fertilizer plots at Thomas Bay, near Petersburg; at Lemon Creek, near Juneau; and on Afognak Island. Early results showed significant growth increases from added nitrogen (Johnson 1970).

Encouraging results from the small plot trials led the Forest Service to undertake forest fertilization on a larger scale (Bowkett 1969). The first large-scale project took place in May 1969 at Thomas Bay near Petersburg (fig. 20). About 1,500 acres of 5- to 10-year-old hemlock and spruce regeneration in scattered cuttings were fertilized with urea prills (46-percent nitrogen by weight), at the rate of 400 pounds of urea per acre. Cost per acre was about $40, higher than the $22 to $28 per acre average for the Pacific Northwest (Heilman 1971).

[57]Hsieng-Fang Chen. Growth and mineral uptake of Sitka spruce (*Picea sitchensis*) in solution cultures. Master's thesis, University of Washington, Seattle, 69 p., illus., 1955.

[58]Data on file, USDA Forest Service, Region 10, Juneau, Alaska.

Figure 20.--Loading urea fertilizer for aerial application by helicopter, Thomas Bay, Alaska.

Yearly measurements showed no detectable increase in rate of height growth the first season, but from 1970 through 1973, Sitka spruce on the fertilized plots grew about 20 percent faster than those on unfertilized plots.[59] The effect on hemlock could not be determined because the hemlock was seriously damaged by the fungus *Sirococcus strobilinus* (Funk 1972). Fertilization does not appear to have increased susceptibility of hemlock to attack by this fungus--both treated and untreated areas were equally infected,

In a study of deer browse in this area, growth of early blueberry was 6.1 percent greater on the fertilized than on the unfertilized area the first season after treatment. Protein content averaged 8.56 percent on the fertilized area and 7.04 percent on the unfertilized area (Merriam 1971).

In 1970, another 1,500 acres of 5- to 10-year-old hemlock and spruce regeneration were fertilized near Falls Creek on Mitkof Island at a rate of 400 pounds of urea per acre. The Falls Creek area was selected for its high sites and closeness to Petersburg where crew accommodations and heavy equipment were readily available. Objectives of the project were to speed up the rate of

[59]Data on file, Forestry Sciences Laboratory, Juneau, Alaska.

stand growth, to shorten the rotation period, and to reduce the time necessary for the cutover areas to regain a pleasing appearance, Information on tree growth is not available from the treated areas, but water samples were taken to evaluate the effect of nitrogen fertilization on water quality and bottom fauna.[60] Despite somewhat higher concentrations in the treated streams, no statistically significant increase in bottom fauna or periphyton was noted.

Two other fertilization projects have been completed since 1970. In 1971, 1,500 acres of 6- to 10-year-old hemlock and spruce regeneration were fertilized at Thorne Bay on Prince of Wales Island; and in 1972, 930 acres of 15-year-old regeneration were fertilized near Cape Pole on Kosciusko Island. Growth plots have been installed on Kosciusko Island as part of an administrative study to measure growth response after fertilization.

Fertilization is often thought of as a possible substitute for thinning (Crossin et al. 1966, Gessel 1968). However, fertilization does not accomplish the same objectives that thinning does. In effect, fertilization raises the site index, trees grow faster, competition within the stand increases, and the rate of tree mortality increases. The increase in mortality, however, is insignificant when compared with the number of stems removed in periodic thinnings, The result of fertilization may be a faster growing overstocked stand. Some combination of thinning and fertilization will no doubt provide the maximum usable volumes per unit of area (Heilman 1971, Miller 1971b).

The forests of southeast Alaska have great potential for timber growth, especially those on the more productive sites, most of which are located in the southern part of the Tongass National Forest. Timber production from these areas could be increased considerably through periodic thinnings and fertilization. In the future, advancements in technology and demands for timber will warrant intensive timber management. In the meantime, there is a need to develop intensive management guides for the hemlock-spruce forests.

MANAGEMENT PROBLEMS AND RESEARCH

For over 50 years, considerable effort was given to developing the timber resource of southeast Alaska so that the forests could be managed and a stable economy developed, Although attention was directed to the protection of other resources, there was little public pressure on the forests for other uses. Beginning in the late 1960's and continuing today, the "environmental revolution" has dramatically changed the management picture.

Probably the single most important problem facing the National Forest System in southeast Alaska is resource planning. To reconcile the many demands for resources from forest land requires that those demands be quantified, that the land be classified according to the uses for which it is suited, and that land be allocated to best reconcile conflicting demands. This is now being done on the Tongass National Forest through the use of planning teams. Public involvement is encouraged.

Land use planning requires extensive information on the productive capacity and capability of lands to supply resources, including both commodities and those less tangible but equally important resources such as recreation and

[60] William R. Meehan, Frederick B. Lotspeich, and Ernst W. Mueller. Effects of forest fertilization on two southeast Alaska streams. (In preparation for publication, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.)

amenities. Conversely, the effect of various resource uses on the land must be known. Both demand and supply of resources vary with time; and to be effective, an allocation system *must* be flexible enough not only to adapt to rapid changes but also to anticipate them, Significant contributions that research might make to resource planning include information on the productive potential of various lands for timber, fish and wildlife habitat, recreation, and the effects that management policy would have on these resources. Probable demands might be anticipated through economic, marketing, and recreational research.

In the preceding pages, we have attempted to tell something about forest ecology and the history and present status of timber management in southeast Alaska. Throughout there are noted specific problems and questions which need additional attention.

Timber is only one of several valuable resources in southeast Alaska. The fishery is also extremely important, and many people depend on it for their livelihood. Recreation and tourism is a growing industry based on the scenic grandeur, fish and game populations, and uniqueness of the area. Mining will become more important in the future.

Many problems associated with forest management are related directly to forest ecology. To solve these will require a deeper understanding of the dynamics of the forest ecosystem including primary production, energy transfers, decomposition, and nutrient cycling. The forest environment includes not only trees and other plants but animals, soil, water, and air, Thus, silvicultural treatments affect not only a forest stand but adjacent land, water, and the air itself. A basic understanding of the interrelationships between many variables is needed to insure continuing productivity of the ecosystem.

REFERENCES

Anonymous
1915. Logging in Alaska. Timberman 16(4): 48, illus,

______ 1953. State department's views on Alaska, the Japanese plan. Pulp & Pap. 27(11): 54, 56.

______ 1971. Ketchikan pulp Co. adds dry land sorting. West. Conserv. J. 28(5): 48-49, illus.

______ 1972. Barges transport logs in Alaska. West. Conserv. J. 29(4): 44, illus.

Adasiak, Allan
1971. The Tongass sale lawsuit blow by blow. Alaska Constr. & Oil 12(1): 40, 42-43, 45-46, 48, 50, illus.

Alaska Division of Economic Enterprise
1972. Alaska statistical review. 198 p., illus. Alaska Dep. Econ. Dev., Div. Econ. Enterp., Juneau.

Alaska Forest Research Center
1957. Biennial report for 1956-1957. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 9, 39 p., illus.

Alexander, Robert R.
1964. Minimizing windfall around clear cuttings in spruce-fir forests. For. Sci. 10(2): 130-142, illus.

______ and Jesse H. Buell
1955. Determining the direction of destructive winds in a Rocky Mountain timber stand. J. For. 53(1): 19-23, illus.

Andersen, H. E.
1953. Range of western redcedar (*Thuja plicata*) in Alaska. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 22, 2 p., illus.

______ 1955a. Alder control on cutover areas. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 25, 1 p.

______ 1955b. Climate in southeast Alaska in relation to tree growth. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 3, 5 p., illus.

______ 1956. Clearcutting as a silvicultural system in converting old forests to new in southeast Alaska. Soc. Am. For. Proc. 1955: 59-61, illus.

Andersen, Harold E.
1954. Clearcutting as a silvicultural system in southeast Alaska. 5th Alaska Sci. Conf. Proc., p. 1-4.

______ 1959. Silvical characteristics of Alaska-cedar (*Chamaecyparis nootkatensis*). USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 11, 10 p., illus.

Anderson, J. P.
1959. Flora of Alaska and adjacent parts of Canada. 543 p., illus. Ames: Iowa State Univ. Press.

Andrews, Clarence L.
1934. Russian shipbuilding in the American colonies. Wash. Hist. Q. 25: 3-10.

Assmann, Ernst
1970. The principles of forest yield study. Translated by Sabine H. Gardiner. 506 p., illus. Oxford, New York [etc.]: Pergamon Press.

Austin, John W.
1969. Log export restrictions of the Western States and British Columbia. USDA For. Serv. Res. Pap. PNW-91, 13 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Austin, R. C., and R. F. Strand
1960. The use of slowly soluble fertilizers in forest planting in the Pacific Northwest, J. For. 58(8): 619-627, illus.

Baker, Frederick S.
1934. Theory and practice of silviculture. 502 p., illus. New York: McGraw-Hill Book Co.

Bancroft, Hubert Howe
1886. History of Alaska, 1730-1885. 775 p., illus. San Francisco: The Hist. Co. Publ. (Reprinted 1960, New York: Antiq. Press.)

Barnes, George H.
1962. Yield of even-aged stands of western hemlock. U.S. Dep. Agric. Tech. Bull. 1273, 52 p., illus.

Benzian, Blanche
1965. Experiments on nutrition problems in forest nurseries. Vol. 1. G. B. For. Comm. Bull. 37, 251 p., illus.

Binns, W. O., J. M. MacKenzie, and J. E. Everard
1970. Analysis of soils and foliage. Rep. For. Res. For. Corn. London 1969/70: 78-80.

Bishop, Daniel M., and Mervin E. Stevens
1964. Landslides on logged areas in southeast Alaska. USDA For. Serv. North. For. Exp. Stn. Res. Pap. NOR-1, 18 p., illus.

Bond, G.
1970. Fixation of nitrogen in non-legumes with *Alnus*-type root nodules. *In* E. A. Kirby (ed.), Nitrogen nutrition of the plant, p. 1-8. Agric. Chem. Symp. Leeds 2. Leeds: The Waverly Press.

Bowkett, Gerald
1969. Fertilization project underway. Alaska Constr. & Oil 10(6): 56-57, 59, illus.

Boyce, J. S.
1929. Deterioration of wind-thrown timber on the Olympic Peninsula, Wash. U.S. Dep. Agric. Tech, Bull. 104, 28 p., illus.

Boyce, John Shaw
1961. Forest pathology. Ed. 3, 572 p., illus. New York: McGraw-Hill Book Co.

Bradley, R. T., J. M. Christie, and D. R. Johnston
1966. Forest management tables. G. B. For. Corn. Booklet 16, 218 p., illus.

Brandstrom, Axel J. F.
1933. Analysis of logging costs and operating methods in the Douglas fir region. 117 p., illus. Wash., D.C.: Charles Lathrop Pack For. Found,

Bruce, David
1969. Potential production in thinned Douglas-fir plantations. USDA For. Serv. Res. Pap. PNW-87, 22 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Bruce, Donald
1926. A method of preparing timber-yield tables. J. Agric. Res. 32(6): 543-557, illus.

Bruce, Mason B.
1960. National Forests in Alaska. J. For. 58(6): 437-442, illus.

Buckland, D. C., R. E. Foster, and V. J. Nordin
1949. Studies in forest pathology. VII. Decay in western hemlock and fir in the Franklin River area, British Columbia. Can. J. Res. C, 27: 312-331, illus.

——— and E. G. Marples
1952. Management of western hemlock infested with dwarf mistletoe. B. C. Lumberman 36(5): 50-51, 136, 138, 140, illus.

Byers, Archie M.
1960. The timber industry and industrial forestry in Alaska. J. For. 58(6): 474-477.

Chandler, Robert F., Jr.
1942a. Some observations of soils and vegetation in Canada, southern Alaska, and Mexico. Chron. Bot. 7(6): 271-272.

——— 1942b. The time required for podzol profile formation as evidenced by the Mendenhall glacial deposits near Juneau, Alaska. Soil Sci. Soc. Am, Proc. 7: 454-459, illus.

Clapp, Verner W.
1972. Alaska's forest products industry. A directory of loggers, sawmills and other primary and secondary forest products industries in the State of Alaska. USDA For. Serv., Alaska Reg., 34 p., illus.

Cooper, William S.
1931a. The layering habit in Sitka spruce and the two western hemlocks. Bot. Gaz. 91: 441-451, illus.

——— 1931b. A third expedition to Glacier Bay, Alaska, Ecology 12(1): 61-95, illus.

——— 1937, The problem of Glacier Bay, Alaska. A study of glacier variations. Geogr. Rev. 27(1): 37-62, illus.

——— 1939a. Additions to the flora of the Glacier Bay National Monument, Alaska, 1935-36. Torrey Bot. Club Bull. 66: 453-456.

——— 1939b. A fourth expedition to Glacier Bay, Alaska. Ecology 20(2): 130-155, illus.

______ 1956. A contribution to the history of the Glacier Bay National Monument. 36 p. Dep. Bot., Univ. Minn., St. Paul.

______ 1957. Vegetation of the Northwest-American Province. Pac. Sci. Congr. Proc. 8(4): 133-138.

Cooper, William Skinner
1923a. The recent ecological history of Glacier Bay, Alaska: I. The interglacial forests of Glacier Bay. Ecology 4(2): 93-128, illus.

______ 1923b. The recent ecological history of Glacier Bay, Alaska: 11. The present vegetation cycle. Ecology 4(3): 223-246, illus.

______ 1923c. The recent ecological history of Glacier Bay, Alaska: 111. Permanent quadrats at Glacier Bay: An initial report upon a long-period study. Ecology 4(4): 355-365, illus.

______ 1924. The forests of Glacier Bay--present, past, and yet unborn. J. For. 22(1): 16-23, illus.

Crocker, Robert L., and B. A. Dickson
1957. Soil development of the recessional moraines of the Herbert and Mendenhall Glaciers, south-eastern Alaska. J. Ecol. 45(1): 169-185, illus.

______ and Jack Major
1955. Soil development in relation to vegetation and surface age at Glacier Bay, Alaska. J. Ecol. 43(2): 427-448, illus.

Crossin, E. C., J. A. Marlow, and G. L. Ainscough
1966. A progress report on forest nutrition studies on Vancouver Island. For. Chron. 42(3): 265-284, illus.

Curtis, Robert O.
1967. A method of estimation of gross yield of Douglas-fir. For. Sci. Monogr. 13, 24 p., illus.

Dachnowski-Stokes, A. P.
1941. Peat resources in Alaska. U.S. Dep. Agric. Tech. Bull. 769, 84 p., illus.

Dahms, Walter G.
1964. Gross and net yield tables for lodgepole pine. USDA For. Serv. Res. Pap. PNW-8, 14 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg,

Darr, David R.
1972. Production, prices, employment, and trade in Northwest forest industries, fourth quarter 1971. USDA For. Serv. Pac. Northwest For, & Range Exp. Stn., 55 p., illus. Portland, Oreg.

Daubenmire, Rexford
1953. Notes on the vegetation of forested regions of the far northern Rockies and Alaska. Northwest Sci. 27(4): 125-138.

Day, W. R.
1958. Studies in 30- to 35-year-old, even-aged, spruce stands with reference to the development of fluting, bark necrosis, and variations in crown density. Rep. Imp. For. Inst. Oxford 1957/1958: 13-15.

——— 1964. The development of flutes or hollows on main stems of trees and its relation to bark splitting and strip necrosis. Forestry 37(2): 145-160, illus.

DeArmond, Bob
1946. Early Alaskan sawmills. Ketchikan Daily News 18(1775): 5; 18(1777): 4; 18(1779): 4.

Decker, Henry F.
1966. Plants. *In* Soil development and ecologic succession in a deglaciated area of Muir Inlet, southeast Alaska, p. 73-95, illus. Inst. Polar Stud. Rep. 20, Part 4. Ohio State Univ., Columbus.

Downing, G. L.
1957. The recent history of destructive forest insect activity in Alaska. USDA For. Serv. Alaska For. Res. Cent. For. Insect Surv. Rep. 1, 4 p.

Driessche, R. van den
1969. Tissue nutrient concentrations of Douglas fir and Sitka spruce. B. C. For. Serv. Res. Note 47, 42 p., illus.

Driver, Charles H., and R. E. Wood
1968. Occurrence of *Fomes annosus* in intensively managed young-growth western hemlock stands. Plant Dis. Rep. 52(5): 370-372, illus.

Dupre, Normand
1972. Nation's largest logging camp is in Alaska. West. Conserv. J. 29(4): 46-47, 51, illus.

Dyrness, C. T.
1972. Soil surface conditions following balloon logging. USDA For. Serv. Res. Note PNW-182, 7 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Embry, Robert S.
1964. What happens to nonmerchantable trees left after clearcutting? North. For. Exp. Stn. USDA For. Serv. Res. Note NOR-7, 3 p.

Farr, Wilbur A.
1973. Specific gravity of western hemlock and Sitka spruce in southeast Alaska. Wood Sci. 6(1): 9-13, illus.

______ and A. S. Harris
1971. Partial cutting of western hemlock and Sitka spruce in southeast Alaska. USDA For. Serv. Res. Pap. PNW-124, 10 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

______ and Vernon J. LaBau
1971. Volume tables and equations for old-growth western redcedar and Alaska-cedar in southeast Alaska. USDA For. Serv. Res. Note PNW-167, 18 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Fernow, B. E.
1902. The forests of Alaska. For, & Irrig. 8(2): 66-70, illus.

______ 1910. Forests of Alaska In History, geography, resources, p. 235-256, illus. Harriman Alaska Ser., Vol. 2. Smithson. Inst, Publ. 1991.

Ford-Robertson, F. C. (Ed,)
1971, Terminology of forest science, technology practice and products. 349 p., illus. Soc. Am. For., Wash., D. C.

Foster, R. E., and A. T. Foster
1951. 'Studies in forest pathology. VIII. Decay of western hemlock on the Queen Charlotte Islands, British Columbia. Can. J. Bot. 29: 479-521, illus.

Fowells, H. A. (Compiler)
1965. Silvics of forest trees of the United States. U.S. Dep. Agric. Agric. Handb. 271, 762 p., illus.

Franklin, Jerry F., L. J. Dempster, and Richard H. Waring (Eds.)
1972. Proceedings--research on coniferous forest ecosystems--a symposium. USDA For, Serv. Pac. Northwest For. & Range Exp. Stn., 322 p., illus. Portland, Oreg.

Funk, A.
1972. *Sirococcus* shoot-blight of western hemlock in British Columbia and Alaska. Plant Dis. Rep. 56(8): 645-647, illus.

Gass, Charles R., Richard F. Billings, Freeman R. Stephens, and Mervin E. Stevens
1967. Soil management report for the Hollis area. USDA For, Serv. Alaska Reg., 118 p., illus.

Gessel, S. P.
1968. Progress and needs in tree nutrition research in the Northwest. In Forest fertilization theory and practice, p. 216-225, TVA, Muscle Shoals, Ala,

Godman, R. M.
1949. What kind of trees make the best growth in southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 2, 1 p.

________ 1951. Thinning second-growth hemlock-spruce for pulpwood. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 7, 1 p.

________ 1952. A classification of the climax forests of southeastern Alaska. J. For. 50(6): 435-438.

________ 1953. Seed dispersal in southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 16, 2 p.

________ and R. A, Gregory
1953. Physical soil characteristics related to site quality in climax stands of southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Tech, Note 17, 1 p.

Goldthwait, R. P.
1966. Evidence from Alaskan glaciers of major climatic changes. *In* Royal Meterological Society Proceedings International Symposium on World Climate from 8000 to 0 B.C., p. 40-53, illus, Inst. Polar Stud. Contrib. 94, Ohio State Univ., Columbus.

Goldthwait, Richard P.
1963. Dating the little ice age in Glacier Bay, Alaska. Rep. Int. Geol. Congr., 21st Sess., Norden, 1960, Part 27: 37-46, illus.

Goodall, D. W., and F. G. Gregory
1947. Chemical composition of plants as an index of their nutritional status. Tech. Commun. Bur, Hortic. Plant. Crops No. 17, 167 p. East Malling.

Gratkowski, H. J.
1956. Windthrow around staggered settings in old-growth Douglas-fir. For. Sci. 2(1): 60-74, illus.

Greeley, A. W.
1954, Alaska's acres at work...at last. Am. For. 60(10): 8-11, 52, illus.

Greeley, W. B.
1920a. Alaskan forests offer solution to pulp and paper shortage. Paper (June 2): 17-18, illus.

________ 1920b. Utilization of the forests of Alaska. Science [N.S. 52(1341)]: 244.

________ 1921. Paper from American trees. Nation's Bus. 9(3): 39-40.

Gregory, R. A.
1956. The effect of clearcutting and soil disturbance on temperatures near the soil surface in southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 7, 22 p., illus.

———— 1957a. 1956 cone crop report for Alaska tree species. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 35, 2 p., illus.

———— 1957b. Some silvicultural characteristics of western redcedar in southeast Alaska. Ecology 38(4): 646-649, illus.

———— 1958. 1957 cone crop report for Alaska tree species. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 41, 2 p., illus.

———— 1959. 1958 cone crop report for Alaska tree species. USDA For. Serv. Alaska For. Res. Cent, Tech. Note 44, 2 p., illus.

Gregory, Robert A.
1960. The development of forest soil organic layers in relation to time in southeast Alaska, USDA For, Serv, Alaska For. Res. Cent. Tech, Note 47, 3 p., illus.

Groman, William A.
1972. Forest fertilization. (A state-of-the-art review and description of environmental effects.) Natl. Environ. Res. Cent. EPA-R2-72-016, 57 p., illus. U.S. Environ. Prot. Agency, Corvallis, Oreg.

Haley, David
1966. The economics of forest fertilization. For. Chron. 42(4): 390-394.

Hall, J. Alfred
1972. Forest fuels, prescribed fire, and air quality. USDA For. Serv. Pac. Northwest For. & Range Exp. Stn., 44 p.

Hansen, Robert A.
1971. Precommercial thinning--Weyerhaeuser style. *In* David M. Baumgartner (ed.), Proceedings, precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 103-105. Wash. State Univ., Pullman,

Hard, J. S.
1967. Identification of destructive Alaska forest insects. USDA For. Serv. Pac. Northwest For. & Range Exp. Stn., 19 p., illus.

Hard, John S.
1974a. Budworm in coastal Alaska. J. For. 72: 26-31, illus.

———— 1974b. The forest ecosystem of southeast Alaska. 2. Forest insects. USDA For. Serv. Gen. Tech. Rep. PNW-13, 32 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Harris, A. S.
1960. 1959 cone crop report for Alaska tree species. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 50, 2 p., illus.

——— 1962. Cone crops in coastal Alaska - 1960 and 1961. USDA For. Serv. Alaska For. Res. Cent Tech. Note 53, 4 p., illus.

Aerial seeding Sitka spruce and western hemlock on a cutover area in southeast Alaska. North. For. Exp. Stn. USDA For. Serv. Res. Note NOR-10, 6 p., illus.

——— 1966a. Effects of slash burning on conifer regeneration in southeast Alaska. North For. Exp. Stn. USDA For. Serv. Res. Note NOR-18, 6 p., illus.

——— 1966b. A test of pruning Sitka spruce in Alaska. North. For. Exp. Stn. USDA For. Sew, Res. Note NOR-13, 3 p., illus.

——— 1967. Natural reforestation on a mile-square clearcut in southeast Alaska. USDA For. Serv. Res. Pap. PNW-52, 16 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

— 1968. Small mammals and natural reforestation in southeast Alaska. USDA For. Serv. Res. Note PNW-75, 7 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

——— 1969a. Alaska-cedar. A bibliography with abstracts. USDA For. Serv. Res. Pap. PNW-73, 47 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

19 — 69b. Ripening and dispersal of a bumper western hemlock-Sitka spruce seed crop in southeast Alaska. USDA For. Serv. Res. Note PNW-105, 11 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

——— 1971. Experience with Douglas-fir in southeast Alaska. Northwest Sci. 45(2): 87-93, illus.

——— and Robert H. Ruth
1970. Sitka spruce--a bibliography with abstracts. USDA For. Serv. Res. Pap. PNW-105, 251 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Harris, Arland S.
1965b. Subalpine fir on Harris Ridge near Hollis, Prince of Wales Island, Alaska. Northwest Sci. 39(4): 123-128, illus.

Hawley, Ralph C., and David M. Smith
1954. The practice of silviculture. Ed. 6, 525 p., illus. New York: John Wiley & Sons, Inc.

Heilman, Paul
1971. Effects of fertilization on Douglas-fir in southwestern Washington. Wash. Agric. Exp. Stn. Circ. 535, 23 p., illus.

Heintzleman, B. F.
1923. The standing timber resources of Alaska. West Coast Lumberman 44(518): 102-103, 108, illus.

——— 1927. The forests of Alaska as a basis for permanent development. Alaska Mag. 1(4): 169-174, illus.

——— 1928. Pulp-timber resources of southeastern Alaska. U.S. Dep. Agric. Misc. Publ. 41, 35 p., illus.

Heintzleman, B. Frank
1949. Forests of Alaska. U.S. Dep. Agric. Yearb. 1949: 361-372, illus.

Heusser, C. J.
1954. Alpine fir at Taku Glacier, Alaska with notes on its postglacial migration to the Territory. Torrey Bot. Club Bull, 81(1): 83-86, illus.

Heusser, Calvin J.
1960. Late-Pleistocene environments of north Pacific North 'America. Am. Geogr. Soc. Spec. Publ. 35, 308 p., illus.

Holty, Joseph G., and Paul E. Heilman
1971. Molecular sieve fractionation of organic matter in a podzol from southeastern Alaska. Soil Sci. 112(5): 351-356, illus.

Hulley, Clarence C.
1953. Alaska 1741-1953. 406 p., illus. Portland, Oreg.: Binfords and Mort.

Hultén, Eric
1968. Flora of Alaska and neighboring territories. A manual of the vascular plants. 1008 p., illus. Stanford, Calif.: Stanford Univ. Press.

Hurd, Richard M.
1971. Annual tree-litter production by successional forest stands, Juneau, Alaska. Ecology 52(5): 881-884, illus.

Hutchison, O. Keith
1967. Alaska's forest resource. USDA For. Serv. Resour. Bull. PNW-19, 74 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Isaac, Leo A.
1943. Reproductive habits of Douglas-fir. 107 p., illus. Wash., D.C.: Charles Lathrop Pack For. Found.

——— 1956. Place of partial cutting in old-growth stands of the Douglas-fir region. USDA For. Serv. Pac. Northwest For. & Range Exp. Stn. Res. Pap. 16, 48 p., illus. Portland, Oreg.

James, G. A.
1956. The rodent problem on cutover areas in southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 31, 2 p.

——— 1959. Seed production in a scrub stand. USDA For. Serv. Alaska For. Res. Cent. Tech. Note 43, 3 p.

James, George A., and Robert A. Gregory
1959. Natural stocking of a mile-square clear cutting in southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 12, 9 p., illus.

Johnson, Herman M.
1943. Recovery of aero quality lumber from Alaska spruce logs. Timberman 44(7): 56-57, 64.

Johnson, W. Howard
1970. How to grow a giant tree. Alaska Constr. & Oil 11(1): 76-77, illus.

Jones, Nard
1954. Ketchikans "catch"--the new pulp mill. Am. For. 60(10): 12-13, 38, illus.

Kellogg, Charles E., and Iver J. Nygard
1951. Exploratory study of the principal soil groups of Alaska. U.S. Dep. Agric. Monogr. 7, 138 p., illus.

Kimmey, James W.
1956. Cull factors for Sitka spruce, western hemlock and western redcedar in southeast Alaska. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 6, 31 p., illus.

Kirkland, Burt P., and Axel J. F. Brandstrom
1936. Selective timber management in the Douglas fir region. 122 p., illus. Wash., D.C.: Charles Lathrop Pack For. Found.

Klein, David R.
1965. Postglacial distribution patterns of mammals in the southern coastal regions of Alaska. Arctic 18(1): 7-20, illus.

Krause, Aurel
1956. The Tlingit Indians: Results of a trip to the northwest coast of America and the Bering Straits. Translated by Erna Gunther. 310 p., illus. Seattle: Univ. Wash. Press.

Laurent, T. H.
1966. Dwarfmistletoe on Sitka spruce--a new host record. Plant Dis. Rep. 50(12): 921.

Laurent, Thomas H.
1974. The forest ecosystem of southeast Alaska. 6. Forest diseases. USDA For. Serv. Gen. Tech. Rep. PNW-23, 30 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Lavender, Denis P.
1970. Foliar analysis and how it is used. A review. Oreg. State Univ. Sch. For. Res. Note 52, 8 p., illus.

Lawrence, Donald B.
1950. Glacier fluctuation for six centuries in southeastern Alaska and its relation to solar activity. Geogr. Rev. 40(2): 191-223, illus.

——— 1958. Glaciers and vegetation in southeastern Alaska. Am. Sci. 46(2): 89-122, illus.

——— and Lloyd Hulbert
1950. Growth stimulation of adjacent plants by lupine and alder on recent glacier deposits in southeastern Alaska. Ecol. Soc. Am. Bull. 31: 58.

Lawton, Donald M.
1972. Alder challenges established hardwoods. Woodworking & Furniture Dig. 74(2): 28-30, illus.

Leyton, Leonard
1958. The relationship between the growth and mineral nutrition of conifers, *In* Kenneth V. Thimann, William B. Critchfield, and Martin H. Zimmerman (eds.), The physiology of forest trees, p. 323-345, illus. New York: The Ronald Press Co.

Likens, Gene E., F. Herbert Bormann, Noye M. Johnson, and others
1970. Effects of forest cutting and herbicide treatment on nutrient budgets in the Hubbard Brook watershed-ecosystem. Ecol. Monogr. 40(1): 23-47, illus.

Lockhart, R. E.
1966. Alaska sized timber sale. J. For. 64(2): 83-86, illus.

Lutz, H. J.
1930. Observations on the invasion of newly formed glacial moraines by trees. Ecology 11(3): 562-567, illus.

——— 1951. The concentration of certain chemical elements in the soils of Alaskan archaeological sites. Am. J. Sci. 249: 925-928.

Lutz, Harold J.
1959. Aboriginal man and white man as historical causes of fires in the boreal forest, with particular reference to Alaska. Yale Univ. Sch. For. Bull. 65, 49 p.

McGregor, R. C.
1958. Small mammal studies on a southeast Alaska cutover area. USDA For. Serv. Alaska For. Res. Cent. Stn. Pap. 8, 9 p., illus.

Manson, Marsden
1903. Forest advance over glaciated areas in Alaska and British Columbia. For. Q. 1(3): 94-96, illus.

Matthews, R. G.
1971. Container seedling production: a provisional manual. Can. For. Serv. Pac. For. Res. Cent. Inform. Rep. BC-X-58, 48 p., illus.

Meehan, W. R., W. A. Farr, D. M. Bishop, and J. H. Patric
1969. Some effects of clearcutting on salmon habitat of two southeast Alaska streams. USDA For. Serv. Res. Pap. PNW-82, 45 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Meehan, William R.
1974a. The forest ecosystem of southeast Alaska. 3. Fish habitats. USDA For. Serv. Gen. Tech. Rep. PNW-15, 41 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

______ 1974b. The forest ecosystem of southeast Alaska. 4. Wildlife habitats. USDA For. Serv. Gen. Tech. Rep. PNW-16, 32 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Merriam, Harry R.
1971. Response of *Vacciniwn ovalifolium* to fertilization. Final report. Alaska Dep. Fish & Game, Fed. Aid Wildl. Restoration Proj. W-12-7-2, Job 2.3R, 7 p., illus.

Meyer, Walter H.
1937. Yield of even-aged stands of Sitka spruce and western hemlock. U.S. Dep. Agric. Tech. Bull. 544, 86 p., illus.

Miller, Mike
1971a. The fight for...the trees in the Tongass. Am. For. 77(7): 16-19, illus.

Miller, Richard E.
1971b. The future of precommercial thinning. *In* David M. Baungartner (ed.), Proceedings, precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 105-106. Wash. State Univ., Pullman.

Moore, Duane G.
[n.d.] Fertilization and water quality. West. Refor. Coord. Corn. Proc. 1971: 28-31.

Morris, William G.
1934. Forest fires in western Oregon and western Washington. Oreg. Hist. Q. 35: 313-339.

Morrison, Ian George
1970. Foliar nitrogen range and variability in a second growth Douglas-fir forest and its relationship to certain stand and tree characteristics. 268 p., illus. Ph.D. thesis, Univ. Wash., Seattle.

Muir, John
1895. Discovery of Glacier Bay. Century Mag. N.S. **28: 234-247,** illus.

———— 1915. Travels in Alaska. **327** p., illus. Boston and New York: Houghton Mifflin Co.

Neiland, Bonita J.
1971. The forest-bog complex of southeast Alaska. Veg., Acta geobot. Separatum **22(1-3): 1-64**, illus.

Norris, Logan A.
1971. Studies of the safety of organic arsenical herbicides as precommercial thinning agents: a progress report. In David M. Baumgartner (ed.), Proceedings, precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. **63-74.** Wash. State Univ., Pullman,

Noste, Nonan V.
1969. Analysis and summary of forest fires in coastal Alaska. USDA For. Serv. Inst. North. For. Pac. Northwest For, & Range Exp. Stn., **12** p., illus.

Orr, P. W.
1963. Windthrown timber survey in the Pacific Northwest, **1962.** USDA For. Serv. Pac. Northwest Reg., I&DC Branch, **22** p., illus.

Pacific Northwest Pollution Control Council
1971. Log storage and rafting in public waters. A task force report. 56 p. Seattle, Wash.

Parker, R. E.
1962. Factors limiting tree growth on peat soils. An investigation into the nutrient status of two peatland plantations. Irish For. **19(1)**: **60-81**, illus.

Patric, J. H., and D. N. Swanston
1968. Hydrology of a slide-prone glacial till soil in southeast Alaska. J. For. **66(1)**: **62-66**, illus.

Pease, Bruce C.
1974. Effects of log dumping and rafting on the marine environment of southeast Alaska. USDA For. Serv. Gen. Tech. Rep. **PNW-22**, 58 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Pienaar, Leon Visser
1965. Quantitative theory **of** forest growth. **176** p., illus. Ph.D. thesis, Univ. Wash., Seattle.

Plank, Marlin E.
1971. Red alder (*Alnus mbra* Bong.). (Rev.) U.S. Dep. Agric. Am. Woods **FS-215**, **7** p., illus.

Reiners, William A., Ian A. Worley, and Donald B. Lawrence
1971. Plant diversity in a chronosequence at Glacier Bay, Alaska. Ecology **52**(1): **55-69**, illus.

Rigg, George B.
1917. Forest succession and rate of growth in sphagnum bogs. J. For. 15: 726-739, illus.

——— 1937. Some raised bogs of southeastern Alaska with notes on flat bogs and muskegs. *Am.* J. Bot. 24: 194-198.

Riggs, George B.
1925. Some sphagnum bogs of the north Pacific coast of America. Ecology 6(3): 260-278, illus.

Rudolph, Emanuel D.
1966. Ecological succession: a summary. *In* Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaska, p. 163-167. Inst. Polar Stud. Rep. 20, Part 9. Ohio State Univ., Columbus.

Ruth, Robert H.
1965. Silviculture of the coastal Sitka spruce-western hemlock type. Soc. Am. For. Proc. 1964: 32-36, illus.

——— and Ray A. Yoder
1953. Reducing wind damage in the forests of the Oregon Coast Range. USDA For. Serv. Pac. Northwest For. & Range Exp. Stn. Res. Pap. 7, 30 p., illus. Portland, Oreg.

Ruth, Robert Harvey
1967. Differential effect of solar radiation on seedling establishment under a forest stand. 176 p. Ph.D. thesis, Oreg. State Univ., Corvallis.

Schmidt, R. L.
1957. The silvics and plant geography of the genus *Abies* in the coastal forests of British Columbia. B. C. For. Serv. Tech. Publ. T-46, 31 p., illus.

——— 1960. Factors controlling the distribution of Douglas-fir in coastal British Columbia. Q. J. For. 54(2): 156-160, illus.

——— 1970. A history of pre-settlement fires on Vancouver Island as determined from Douglas-fir ages. *In* Tree ring analysis with special reference to northwest America, p. 107-108. Univ. B. C. Fac. For. Bull. 7.

Schmiege, Donald C.
1966. The relation of weather to two population declines of the black-headed budworm, *Acleris variana* (Fernald) (Lepidoptera: Tortricidae), in coastal Alaska. Can. Entomol. 98(10): 1045-1050, illus.

Schroedel, Thomas E.
1971. Application of economic and biological yield data in precommercial thinning. *In* David M. Baumgartner (ed.), Proceedings, precommercial thinning of coastal and intermountain forests in the Pacific Northwest, p. 83-95. Wash. State Univ., Pullman.

Sears, Howard S., and William R. Meehan
1971. Residues in fish, wildlife, and estuaries. Short-term effects of 2,4-D on aquatic organisms in the Nakwasina River watershed, southeastern Alaska. Pestic. Monit. J. 5(2): 213-217, illus.

Shea, Keith R.
1960. Deterioration--a pathological aspect of second-growth management in the Pacific Northwest. Weyerhaeuser Co. For. Res. Note 28, 16 p., illus.

——— 1961. Deterioration resulting from logging injury in Douglas-fir and western hemlock. Weyerhaeuser Co. For. Res. Note 36, 5 p.

——— 1966. Dwarfmistletoe of coastal western hemlock: principles and practices for control. Weyerhaeuser Co. For. Pap. 9, 14 p., illus.

Sieber, Otto
1972. An update on Alaska's balloon-logging experiment. Alaska Constr. & Oil 13(10): 42, 46, 48, illus.

Silver, G. T.
1960. The relation of weather to population trends of the black-headed budworm *Acleris variana* (Fern.) (Lepidoptera: Tortricidae). Can. Entomol. 92(6): 401-410.

——— 1962. A review of insects affecting regeneration and plantations in British Columbia. Can. Dep. For. For. Entomol. Pathol. Branch. Bi-mon. Prog. Rep. 18(6): 1-2.

——— 1963. A further note on the relation of weather to population trends of the black-headed budworm, *Acleris variana* (Fern.) (Lepidoptera: Tortricidae). Can. Entomol. 95(1): 58-61.

Smith, Clinton G.
1921. Regional development of pulpwood resources of the Tongass National Forest, Alaska. U.S. Dep. Agric. Bull. 950, 39 p., illus.

Smith, DeWilton C.
1965. Planning a timber harvest in Alaska. J. For. 63(5): 341-343, illus.

Smith, J. Harry G., John Walters, and Antal Kozak
1968. Influences of fertilizers on cone production and growth of young Douglas fir, western hemlock, and western red cedar on the U. B. C. research forest. Univ. B. C. Fac. For. Bull. 5, 58 p., illus.

Smith, R. B.
1969. Assessing dwarf mistletoe on western hemlock. For. Sci. 15(3): 277-285, illus.

Smith, W. H., G. L. Switzer, and L. E. Nelson
1970. Development of the shoot system of young loblolly pine: 1. Apical growth and nitrogen concentration. For. Sci. 16(4): 483-490, illus.

Sprague, Roderick, and Donald B. Lawrence
1959. The fungi on deglaciated Alaskan terrain of known age. I. Mendenhall Glacier area. Wash. State Univ. Res. Stud. 27(3): 110-128, illus.

________ and Donald B. Lawrence
1959. The fungi on deglaciated Alaskan terrain of known age. II. Herbert Glacier area. Wash. State Univ. Res. Stud. 27(4): 214-229, illus.

________ and Donald B. Lawrence
1960. The fungi on deglaciated Alaskan terrain of known age. III. Glacier Bay area. Wash. State Univ. Res. Stud. 28(1): 1-20, illus.

Spurr, Stephen H.
1952. Forest inventory. 476 p., illus. New York: Ronald Press Co.

Steinbrenner, E. C., and S. P. Gessel
1956. Windthrow along cutlines in relation to physiography on the McDonald tree farm. Weyerhaeuser Timber Co. For. Res. Note 15, 19 p., illus.

Stephens, F. R.
1969. Source of cation exchange capacity and water retention in southeast Alaskan spodosols. Soil Sci. 108(6): 429-431.

________, C. R. Gass, and R. F. Billings
1968. Soils and site index in southeast Alaska. Report number two of the soil-site index administrative study. USDA For. Serv., Alaska Reg., 17 p., illus,

________, C. R. Gass, and R. F. Billings
1969. Seedbed history affects tree growth in southeast Alaska. For. Sci. 15(3): 296-298, illus.

________, C. R. Gass, and R. F. Billings
1970. The muskegs of southeast Alaska and their diminished extent. Northwest Sci. 44(2): 123-130, illus.

Stevens, M. E.
1963. Podzol development on a moraine near Juneau, Alaska. Soil Sci. Proc. 27(3): 357-358, illus.

____
1965. Relation of vegetation to some soils in southeastern Alaska. *In* Chester T. Youngberg (ed.), Forest-soil relationships in North America, p. 177-188, illus. 2d North Am. For. Soils Conf.

Strand, Robert F., and Richard E. Miller
1969. Douglas-fir growth can be increased report from Pacific Northwest shows. For. Ind. 96(11): 29-31.

Swanston, D. N.
1971. Principal mass movement processes influenced by logging, road building, and fire. Proceedings of a symposium, Forest land uses and stream environment, October 19-21, 1970, p. 29-40, illus, Oreg. State Univ., Corvallis.

Swanston, Douglas N.
1967a. Debris avalanching in thin soils derived from bedrock. USDA For. Serv, Res. Note PNW-64, 7 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

______ 1967b. Soil-water piezometry in a southeast Alaska landslide area. USDA For. Serv. Res. Note PNW-68, 17 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

______ 1969. Mass wasting in coastal Alaska. USDA For, Serv. Res. Pap. PNW-83, 15 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

______ 1970. Mechanics of debris avalanching in shallow till soils of southeast Alaska. USDA For. Serv. Res. Pap. PNW-103, 17 p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Swinford, A. P.
1886. Report of the Governor of Alaska for the fiscal year 1886. p. 937-987, illus. Wash., D.C.: Gov. Print. Off.

Tarrant, Robert F., and Jack Allard
1972. Arsenic levels in urine of forest workers applying silvicides. Arch. Environ. Health 24: 277-280.

______, K. C. Lu, W. B. Bollen, and J. F. ,Franklin
1969. Nitrogen enrichment of two forest ecosystems by red alder. USDA For. Serv. Res. Pap. PNW-76, 8 p. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

______ and James M. Trappe
1971. The role of Alnus in improving the forest environment. Plant & Soil Spec. Vol., p. 335-348.

Taylor, R. F.
1929, The role of Sitka spruce in the development of second growth in southeastern Alaska, J. For. 27(5): 532-534.

______ 1931. Two extremes of forest soils in southeastern Alaska. For. Work. 7(6): 10-11.

——— 1932a. Plant indicators in southeastern Alaska. J. For, 30(6): 746,

——— 1933. Site prediction in virgin forests of southeastern Alaska, J. For. 31(1): 14-18,

——— 1934a. Yield of second-growth western hemlock-Sitka spruce stands in southeastern Alaska, U.S. Dep. Agric, Tech. Bull. 412, 30 p., illus.

——— 1949. First results of thinning in Alaska. USDA For. Serv. Alaska For. Res, Cent. Tech. Note 3, 1 p.

——— and R. M. Godman
——— 1950. Increment and mortality in southeast Alaska's second-growth stands. J. For, 48(8): 329-331, illus,

Taylor, Ray F.
1930-31. Indicator vegetation on cutover lands of southeastern Alaska. Univ. Wash, For. Club, Q. 9(1): 21-27.

Taylor, Raymond F.
1932b. The successional trend and its relation to second-growth forests in southeastern Alaska. Ecology 13(4): 381-391, illus.

——— 1956. Alaska. *In* Stephen Haden-Guest, John N. Wright, and Eileen M. Teclaff (eds.), World geography of forest resources, p. 115-125, illus. Am. Geogr. Soc. Spec, Publ. 33,

——— and Elbert L. Little, Jr.
——— 1950. Pocket guide to Alaska trees. U.S. Dep. Agric. Handb. 5, 63 p., illus.

Taylor, Raymond Frank
1934b. Available nitrogen as a factor influencing the occurrence of Sitka spruce and western hemlock seedlings in the .forestsof southeastern Alaska, 143 p., illus. Ph.D. thesis, Yale Univ., New Haven, Conn.

——— 1935. Available nitrogen as a factor influencing the occurrence of Sitka spruce and western hemlock seedlings in the forests of southeastern Alaska. Ecology 16(4): 580-602, illus.

Torgersen, Torolf R.
1968. Parasites of the hemlock sawfly, *Neodiprion tsugae*, in coastal Alaska. Ann. Entomol. Soc. Am. 61(5): 1155-1158, illus.

——— 1969. Hymenopterous parasites of the hemlock sawfly, *Neodiprion tsugae* Middleton, in southeast Alaska, with a key to larval remains. J. Entomol. Soc. B. C. **66(August): 53-62**, illus.

——— 1970. Parasites of the black-headed budworm, *Acleris gloverana* (Lepidoptera: Tortricidae), in southeast Alaska. Can, Entomol. **102**(10): **1294-1299**, illus.

——— and Bruce H. Baker
1967. The occurrence of the hemlock looper (*Lambdina fiscellaria* (Guenée)) (Lepidoptera: Geometridae) in southeast Alaska, with notes on its biology. USDA For. Serv. Res. Note **PNW-61**, **6** p., illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Turnbull, K. J.
1963. Population dynamics in mixed forest stands. A system of mathematical models of mixed stand growth and structure. **187** p., illus. Ph.D. thesis, Univ. Wash., Seattle.

U.S. Department of Commerce
1968. Storm data. Environ. Sci. Serv. Adm. 10(11): **150.**

USDA Forest Service
1948. Woody-plant seed manual. U.S. Dep. Agric. Misc. Publ. **654**, **416 p.**, illus.

——— 1972 National Forests in a quality environment--action plan. **51** p. Wash., D.C.

Ugolini, F. C.
1968. Soil development and alder invasion in a recently deglaciated area of Glacier Bay, Alaska. *In* J. M. Trappe et al. (eds.), Biology of alder. Northwest Sci. Assoc. Fortieth Annu. Meet. Symp. Proc. **1967**: **115-140**, illus. Pac. Northwest For. & Range Exp. Stn., Portland, Oreg.

Ugolini, Fiorenzo C.
1966. Soils. *In* Soil development and ecological succession in a deglaciated area of Muir Inlet, southeast Alaska, p. **29-72**, illus. Inst. Polar Stud. Rep. 20, Part 3. Ohio State Univ., Columbus.

Viereck, Leslie A., and Elbert L. Little, Jr.
1972. Alaska trees and shrubs. U.S. Dep. Agric. Agric. Handb. **410**, 265 **p.**, illus.

Wallis, James R., and Henry W. Anderson
1965. An application of multivariate analysis to sediment network design. *In* Symposium, Design of hydrological networks, p. **357-378**, illus. Int. Assoc. Sci. Hydrol. Publ. **67.**

Wallis, G. W., G. Reynolds, and H. M. Craig
1971. Decay associated with logging scars on immature western hemlock in coastal British Columbia. Can. For. Serv. Inform. Rep. BC-X-54, 9 p., illus.

Walters, John
1963. An annotated bibliography of western hemlock. *Tsuga heterophylla* (Raf.) Sarg. 86 p., Fac. For. Univ. B. C., Vancouver.

Waring, R. H., and C. T. Youngberg
1972. Evaluating forest sites for potential growth response of trees to fertilizer. Northwest Sci. 46(1): 67-75, illus.

Weisgerber, John F.
1963. Soil and cover conditions after Wyssen skyline and high-lead logging. 13th Annu. Alaska Sci. Conf. Proc., p. 88-90.

Wiant, Harry V., Jr.
1967. Influence of temperature on the rate of soil respiration. J. For. 65(7): 489-490, illus.

Wiley, Kenneth N.
1968. Thinning of western hemlock: a literature review. Weyerhaeuser For. Pap. 12, 12 p., illus.

Williamson, Richard L.
1966. Shelterwood harvesting: tool for the woods manager. Pulp & Pap. 40(1): 26-28, illus.

Winjum, Jack K., and W. H. Cummings
1961. Effects of N, P, and K fertilizers on nursery-grown trees and shrubs common to Douglas-fir forests. Weyerhaeuser Co. For. Res. Note 43, 12 p., illus.

Wright, Ernest, and Leo A. Isaac
1956. Decay following logging injury to western hemlock, Sitka spruce and true firs. U.S. Dep. Agric. Tech. Bull. 1148, 34 p., illus.

_______, Arthur S. Rhoads, and Leo A. Isaac
1947. Decay losses following logging injury in partially cut stands of western hemlock and Sitka spruce. Timberman 48(10): 52, 54, 72, 74, 76, illus.

Zach, Lawrence W.
1950. A northern climax, forest or muskeg? Ecology 31(2): 304-306, illus.

APPENDIX

COMMON AND SCIENTIFIC NAMES

PLANTS

Alder, red, *Alnus rubra* Bong.
Alder, Sitka, *Alnus sinuata* (Reg.) Rydb.
Alder, thinleaf, *Alnus tenuifolia* Nutt.
Aspen, quaking, *Populus tremuloides* Michx.
Blueberry, Alaska, *Vacciniwn alaskaense* Howell
Blueberry, early, *Vacciniwn ovalifolium* Sm.
Bunchberry, *Cornus canadensis* L.
Cedar, Alaska-, *Chamaecyparis nootkatensis* (D. Don) Spach
Redcedar, western, *Thuja plicata* Donn
Cottonwood, black, *Populus trichocarpa* Torr. & Gray
Currant, northern black, *Ribes hudsonianum* Richards,
Currant, stink, *Ribes bracteosum* Dougl.
Currant; trailing black, *Ribes laxiflorum* Pursh
Deer cabbage, *Fauria crista-galli* (Menzies) Makino
Devilsclub, *Oplopanax horridus* (Sm.) Miq.
Dwarf mistletoe, hemlock, *Arceuthobium tsugense* (Rosend.) G. N. Jones
Elder, Pacific red, *Sambucus callicarpa* Greene
Fern, POLYPODIACEAE
Fir, Pacific silver, *Abies amabilis* (Dougl.) Forbes
Fir, subalpine, *Abies lasiocarpa* (Hook.) Nutt.
Hemlock, mountain, *Tsuga mertensiana* (Bong.) Carr.
Hemlock, western, *Tsuga heterophylla* (Raf.) Sarg.
Horsetail, *Equisetum* sp.
Huckleberry, red, *Vacciniwn parvifolium* Sm.
Menziesia, rusty, *Menziesia ferruginea* Sm.
Mountain-avens, *Dryas* sp.
Paper birch, western, *Betula papyrifera* var. *commutata* (Reg.) Fern.
Pine, lodgepole, *Pinus contorta* var. *latifolia* Engelm.
Pine, shore, *Pinus contorta* Dougl. var. *contorta*
Salmonberry, *Rubus spectabilis* Pursh
Sedge, *Carex* sp.
Skunk cabbage, *Lysichiton americanum* Hult. & St. John
sphagnum, *Sphagnum* sp.
Spruce, Sitka, *Picea sitchensis* (Bong.) Carr.
Thimbleberry, western, *Rubus parviflorus* Nutt.
Twisted stalk, *Streptopus amplexifolius* (L.) DC.
Willow, *Salix* sp.
Yew, Pacific, *Taxus brevifolia* Nutt.

INSECTS

Budworm, black-headed, *Acleris gloverana* (Walsingham)
Budworm, spruce, *Choristoneura fumiferana* (Clemens)
Beetle, Sitka spruce, *Dendroctonus obesus* (Mannerheim)
Looper, western hemlock, *Lambdina fiscellaria lugubrosa* (Hulst)
Sawfly, hemlock, *Neodiprion tsugae* Middleton
Weevil, Sitka spruce, *Pissodes sitchensis* Hopkins

FUNGI

Red belt fungus, *Fomes pinicola* (Sw,) Cke,
Honey fungus, *Armillaria mellea* Vahl ex Fr.
Fomes root fungus, *Fomes annosus* (Fr.) Cke.
Poria albipellucida Baxt.-P.
Poria weirii (Murr.) Murr.
Sirococcus strobilinus

MAMMALS

Shrew, dusky, *Sorex obscurus longicauda* (Merriam)
Squirrel, flying, *Glaucomys sabrinus zapheus* (Osgood)
Vole, *Microtus longicaudus littoralis* (Swarth)
White-footed muse, *Peromyscus maniculatus hylaeus* (Osgood)

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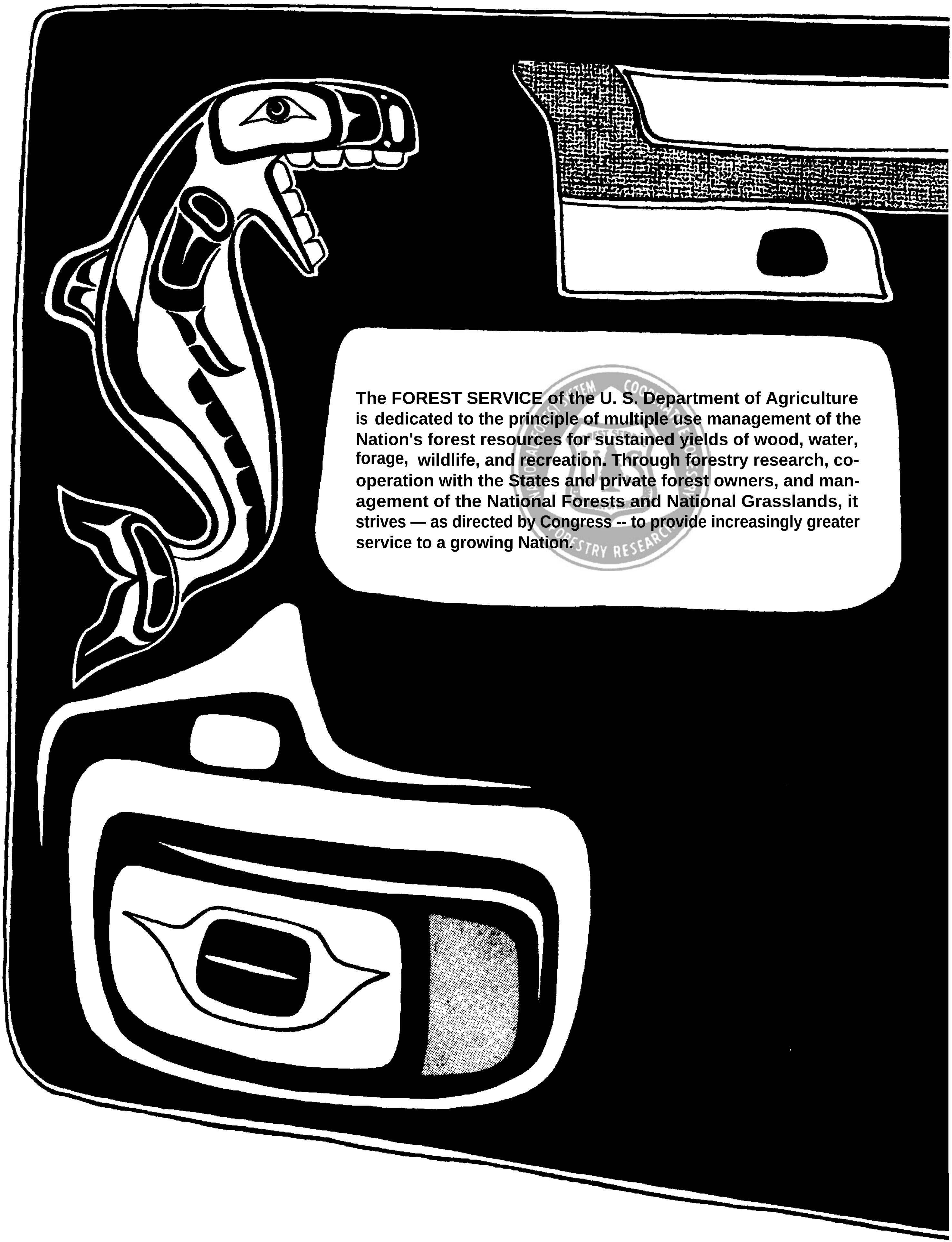

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