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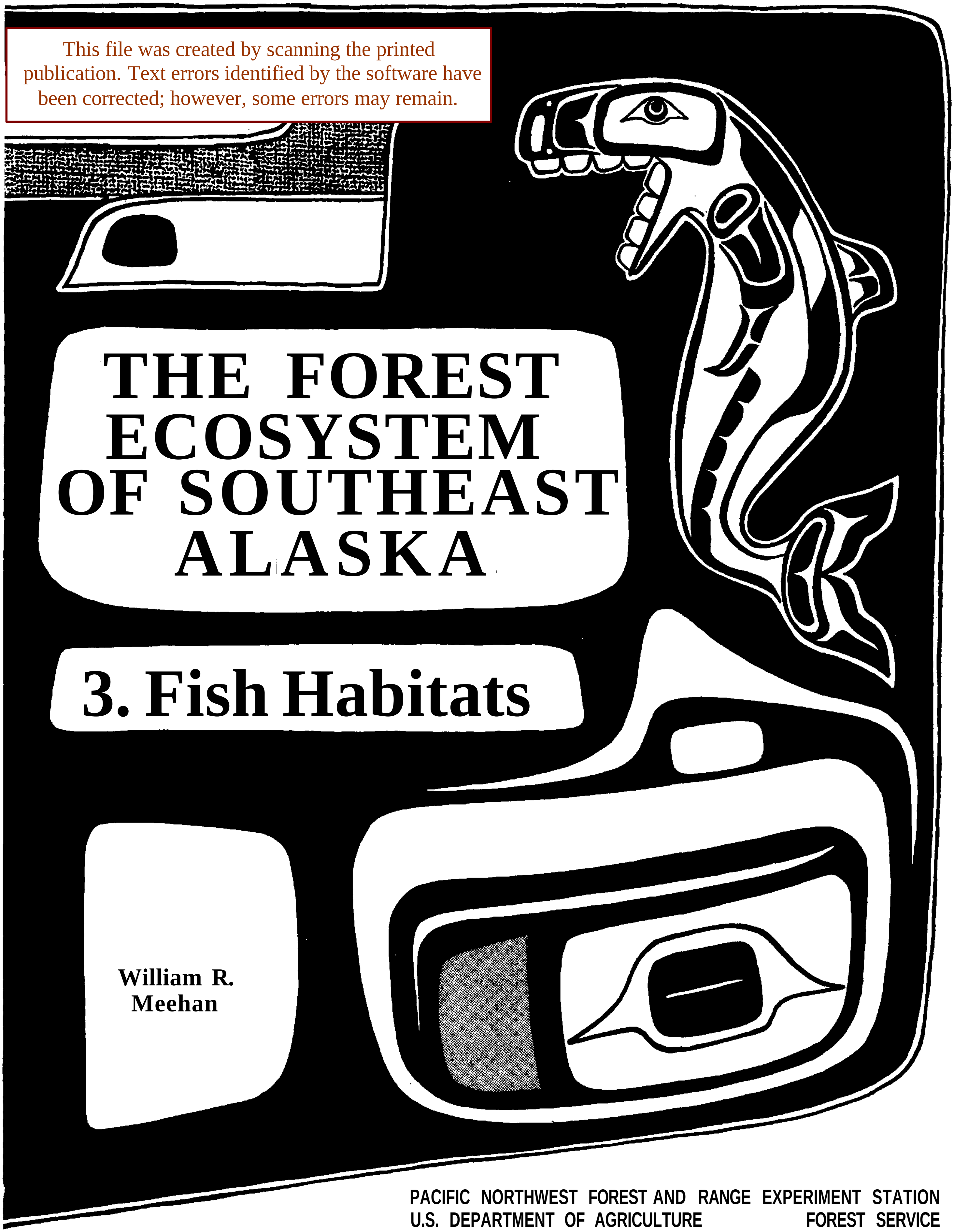

THE FOREST ECOSYSTEM OF SOUTHEAST ALASKA

3. Fish Habitats

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ABSTRACT

The effects of logging and associated activities on fish habitat in southeastern Alaska are discussed, and fish habitat research applicable to southeast Alaska is summarized. Requirements of salmonids for suitable spawning and rearing areas are presented. Factors associated with timber harvest which may influence these habitats are discussed in detail; e.g., sediment, stream temperature, streamflow, logging debris, and chemicals. Recommendations for further research are made.

Keywords: Fish, habitats, research, logging effects.

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PREFACE

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

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

In this series of papers, we will summarize published and unpublished reports and data as well as the observations of resource scientists and managers developed over years of experience in southeast Alaska.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

Previous publications in this series include:

1. The Setting
2. Forest Insects

Robert E. Buckman

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CONTENTS

Page

INTRODUCTION 1

SEDIMENT 4

WATER TEMPERATURE 9

STREAMFLOW 12

DISSOLVED OXYGEN AND OTHER WATER CHEMISTRY FACTORS 13

LOGGING DEBRIS AND LOG JAMS 14

FOREST CHEMICALS 15

ESTUARINE HABITAT 17

HABITAT IMPROVEMENT. EFFECTIVENESS/COST 18

DISCUSSION AND SUMMARY 20

RESEARCHNEEDS 23

LITERATURE CITED 25

REFERENCES 30

INTRODUCTION

The fisheries resource of southeast Alaska (fig. 1) is dependent largely upon the streams and lakes within the National Forests. These waters are the habitat for several species of salmonid fishes, which contribute materially to the livelihood of everyone engaged in or affected by the commercial fisheries. This is a direct and visible contribution to the economy of the region. These same streams and lakes also are prime habitat for the sport fishes--both anadromous and resident species.[1]

The more important species utilizing the freshwater environment in southeast Alaska are:

Pink (humpback) salmon, *Oncorhynchus gorbuscha* (Walbaum)
Chum (dog) salmon, *O. keta* (Walbaum)
Sockeye (red) salmon, *O. nerka* (Walbaum)
Chinook (king) salmon, *O. tshawytscha* (Walbaum)
Coho (silver) salmon, *O. kisutch* (Walbaum)
Rainbow and steelhead[2] trout, *Salmo gairdneri* Richardson
Cutthroat trout, *S. clarki* Richardson
Dolly Varden, *Salvelinus malma* (Walbaum)

The spawning habitats of the various species of salmon and trout, both anadromous and resident, are basically similar. They must consist of suitable gravel spawning beds and a continuous supply of high quality water, and be protected from physical damage as well as damage to the biological community.

Pink and chum salmon utilize the freshwater habitat only for spawning and subsequent egg incubation. Spawning takes place in late summer and early fall, eggs hatch generally from late November through early January, and the resultant fry emerge from the streambed gravels from late March through early May and most immediately migrate to the sea. Some fry, chums in particular, remain in the stream for a short time. For the most part, however, the feeding and growing portion of their life cycle takes place in the ocean. After 1-1/2 to 3-1/2 years, they return to the streams of their origin to spawn and die.

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[1]An anadromous fish is one which spends part of its life in the ocean and returns to fresh water to spawn. A resident fish is one which remains in fresh water for its entire life. Some species, e.g., rainbow trout, have both anadromous and resident populations.

*Anadromous rainbow trout are commonly called steelhead trout when they enter or return from the sea,

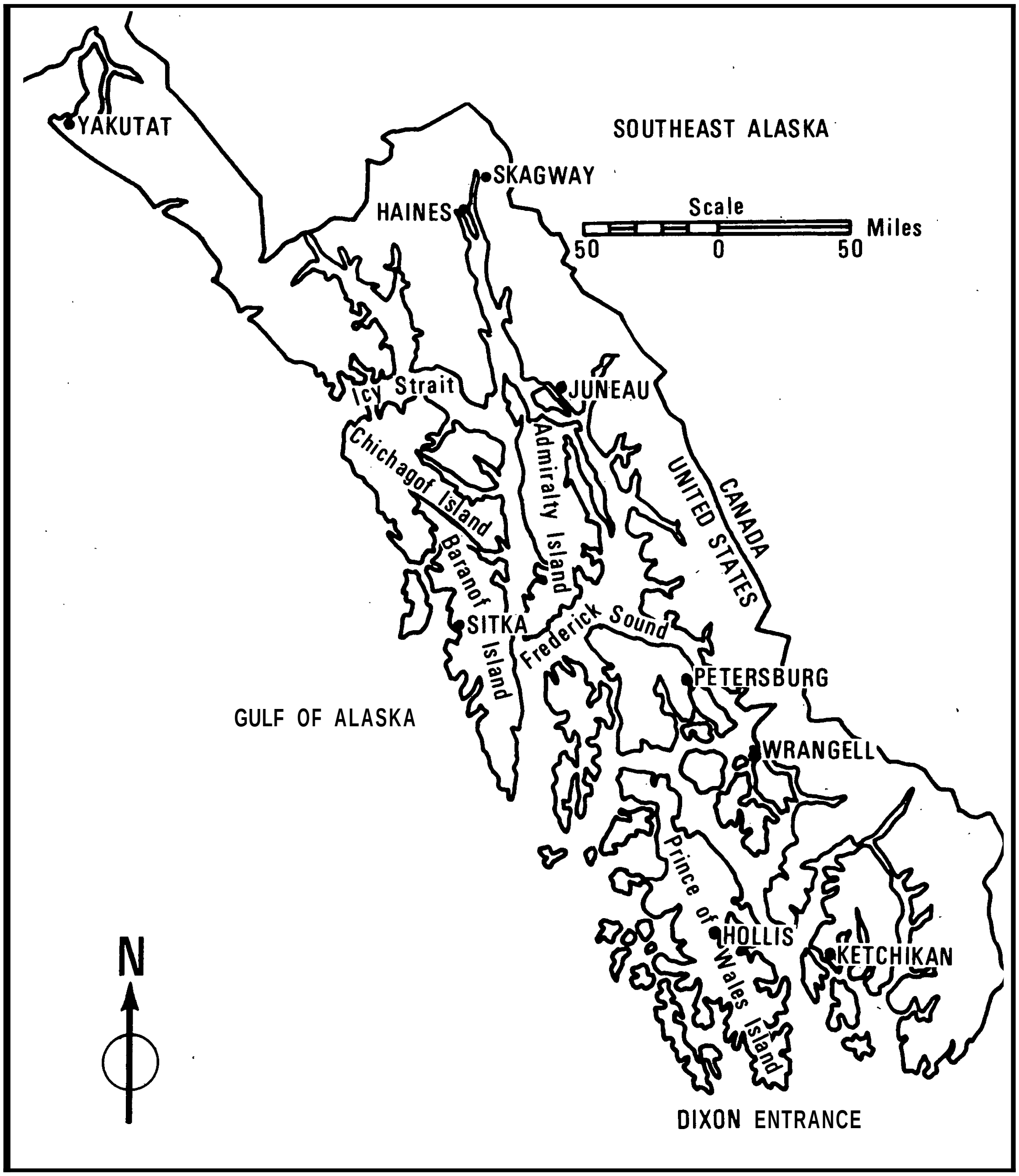

Figure 1.--Map of southeast Alaska east of the 141st meridian.

The sockeye salmon generally requires a lake system for its early rearing, Adults usually spawn in lake inlet streams; the emerging fry drop down to the lake where they spend one or more summers and then migrate seaward in the spring of their second or third year of life. After one or more growing seasons in the ocean (two or three is typical), they return to spawn and die.

Chinook and coho salmon also utilize fresh water as rearing habitat. Chinooks generally favor larger river systems such as the Chilkat, Taku, Stikine, and Unuk Rivers of southeast Alaska. Coho salmon have a much wider range of suitable habitat and will rear in large or small streams, lakes, beaver ponds, sloughs, etc. (fig. 2). Both chinook and coho juveniles spend one or more summers in fresh water before migrating to sea where they remain for 1 or more years before they return to spawn and die.

Figure 2.--Small tributary streams and side channels ***are*** *important rearing areas* for *young coho salmon, trout, and Dolly Varden.*

Rainbow and cutthroat trout and Dolly Varden char have both anadromous and resident populations. The factor which controls whether a fish will migrate to sea during its life or remain entirely a fresh-water form (assuming both have equal access to the ocean) is apparently genetic.

Rainbow (steelhead) and cutthroat trout spawn in the spring of the year, and the Dolly Varden is a fall spawner. The life cycles of the anadromous forms of these species, although similar to those of the salmon, differ primarily in that trout and char do not die after spawning. In addition, the Dolly Varden has a somewhat more complex life history, e.g., some forms rear in systems other than the one of their origin, some forms are anadromous, and some are entirely freshwater residents (Armstrong 1965).

Sedimentation and water temperature are the most important habitat factors affecting the freshwater phases of salmon production, although other nondensity-dependent factors such as stability of streambeds and waterflow are also significant. Many of the studies on which this conclusion is based were concerned mainly with pink and chum salmon, species which use fresh water for spawning and incubating eggs but not for rearing young. These have been the main commercial species in southeast Alaska. Other species of salmon and other fishes are increasing in both commercial and recreational importance. The young of these other fishes may live in fresh water for many months, which adds additional factors such as food, cover, and high-quality water the year-around, to the important habitat considerations. Density-dependent factors such as competition for spawning or nursery areas, which place an upper limit on carrying capacity, may be more important than habitat considerations in many cases.

The importance of these factors varies from stream to stream and also according to the environmental requirements of individual fish species. Biologists recognize that evaluation of the importance of these factors may change, and new factors (water chemistry, for example) may prove to be significant as fish environmental requirements are better understood.

SEDIMENT

Sediment in streams is a consequence of natural geologic processes and of certain disturbances due to man's activities. Southeast Alaska is a geologically youthful topography in which mass wasting and valley and stream system development are in particularly active stages. These natural processes create sediment. Steep ground and large amounts of rainfall make the land sensitive to such activities as road construction and log yarding. Ameliorating influences include soils of high permeability and conditions that favor rapid revegetation of disturbed soil.

High mortality of pink salmon has been associated with high stream stages, which cause shifting gravels. Shifting gravels can displace eggs from their protective gravel cover, exposing them to predators, dessication, etc. Shifting gravels can also physically damage eggs and alevins (preemergent fry) or cause deep burial due to gravel redeposition. High stream stages also move debris, such as logging slash and logs, or stumps and trees excavated from streambanks, which in turn cause gravel excavation and redeposition.

Sampling of streambed gravels shows that gravel composition may include particles from silts and fine sands through large boulders and shapes that range from angular to nearly spherical. These combinations have specific responses, in terms of stability, to stream energy, and should also affect suitability of the habitat for fish.

Under southeast Alaska conditions, the detailed knowledge of quantitative relationships that is needed for accurately evaluating both natural fish habitats and the potentials for habitat improvement and management is generally lacking. However, over the past 50 years, basic concepts concerning mechanics of streamflow and the effects of various stream parameters (depth, gradient, velocity, bedload, channel configuration) on sediment transport and deposition have been developed (Gilbert 1914, Rubey 1938, Kalinske 1947, Brooks 1958, Colby 1961). Recently, attempts have been made to apply these concepts to an analysis of the effects of transported sediments on survival of salmon eggs and alevins (Cooper 1965, Gangmark and Bakkala 1960, [3]). The results of these studies indicate an inverse relationship between stream sedimentation and salmon egg survival.

The principles relating stream parameters to sediment transport and deposition were developed from observations and measurements of streams in watersheds much older geomorphologically than those common to southeast Alaska. The gradients and velocities were much lower, the flows more constant, and the sediment load finer than in Alaskan streams. Consequently, although the basic concepts of stream mechanics and sediment transport remain the same for all streams, quantitative results obtained in these other areas cannot be applied directly to conditions in southeast Alaska.

Sediment, which directly or indirectly affects fish populations, occurs in two forms. The first is "suspended," i.e., as part of the free-flowing, above-streambed water of a stream. In this form it causes the turbid or murky appearance of the water. Suspended sediment has been shown to be harmful to fish if the concentrations of sediment are high and persistent. Cordone and Kelley (1961) have extensively reviewed the literature relating sediment to fish habitat and populations, and most studies have shown similar results. In high concentrations over prolonged periods, silt may accumulate on the gill filaments and actually inhibit the ability of the gills to aerate the

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[3] B. W. Johnson, M. E. Miller, and C. H. Ellis. Egg survival experiments on the north fork of the Stillaguamish River. Unpublished progress report, Washington Department of Fish & Game, 1952.

blood, eventually causing death by anoxemia and carbon dioxide retention. However, sediment concentrations necessary for this direct mortality are generally so high (some studies state lethal concentrations between 20,000 and 100,000 parts per million) that fish populations will be affected in some other way long before these concentrations are reached. Although we can evaluate the lethal concentrations of sediments of different composition, very little is known about the insidious effects on growth and condition of fish.

Another consideration is esthetic and recreational values. Fishermen will not have as high'a degree of angling success in turbid waters, since salmon and trout are primarily sight feeders (Phillips 1971). Phillips also suggests that salmon and trout production may be decreased in turbid streams where less desirable species such as squawfish and suckers, which are more tolerant of turbidity, can compete more effectively with the sight-feeding salmonids. Murky water is generally unappealing esthetically, and this factor can impair the recreational value of an otherwise high quality fishing stream.

The second form in which sediment occurs in the stream is "deposited," i.e., as particles which have settled out of suspension and have been deposited on and among the streambed gravels, on aquatic vegetation, etc. Again the effects here take many forms and Cordone and Kelley (1961) have summarized the literature in this area. Some later studies have essentially confirmed their conclusions (e.g., Hall and Lantz 1969, Meehan et al. 1969, McNeil 1966, Cooper 1965, Vaux 1962, 1968, Sheridan 1962, Bums 1972, [4]). The main effect of sedimentation on spawning habitat is the decreased rate of flow of oxygen-bearing waters within the gravels where eggs and alevins are incubating. In addition, sediment may actually act as a physical barrier to the emergence of fry up through the gravel (Hall and Lantz 1969, see footnote 4, [5]). A third effect of deposited or bedload sediment is reduction of habitat used by aquatic insects (Wagner 1959); a reduction of insects in turn may cause a reduction in growth rate and condition of rearing fishes. It is possible that biomass of aquatic insects might not be reduced appreciably, but species composition would be changed. The forms which are intolerant of large amounts of sediments, such as caddis flies (Trichoptera), stoneflies (Plecoptera), and mayflies (Ephemeroptera), would probably be replaced by the forms which live in mud and silt, e.g., midge larvae (Chironomidae). The latter forms, however, would not be as available to fish as the nonburrowing forms (Phillips 1971).

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[4] K Victor Koski. The survival of coho salmon (*Oncorhynchus kisutch)* from egg deposition to emergence in three Oregon coastal streams. M.S. thesis, Oregon State University, Corvallis, 84 p., illus., 1966,

[5] R. W. Phillips, R. L. Lantz, and E. W. Claire. The entrapment effect of 1-3 mm sand on emergent survival of coho salmon and steelhead trout fry. Manuscript being prepared.

Various studies throughout the western United States and Canada have demonstrated how bedload sediment can affect fish production. Cooper (1965) stated that reduction in survival of sockeye salmon eggs and alevins "is in proportion to the reduction of flow of water through the gravel, which in turn varies with the concentration of sediment and the sediment particle sizes." The finer the sediment particles were, for a given sediment concentration, the greater was the reduction in permeability (ability of water to flow through a gravel bed). When permeability is reduced, so is the supply of oxygen to incubating eggs and fry; likewise, waste metabolites (primarily CO_2 and ammonia nitrogen) are not removed at a sufficient rate (Alderdice and Wickett 1958). Alderdice, Wickett, and Brett (1958) stated that chum salmon eggs required from about 1 mg./l. dissolved oxygen during early stages to over 7 mg./l. just prior to hatching; however, their low figure was based on a theoretical extension of a curve on which the lowest observation relating minimum dissolved oxygen to age was about 4 mg./l. In summarizing much of this work, Cordone and Kelley (1961) concluded that sedimentation was one of the most important factors limiting salmonid reproduction in streams.

Limited research in this field in southeast Alaska has essentially confirmed results of studies done elsewhere. In a study of several streams in southeast Alaska, McNeil and Ahnell (1964) showed that streams with more sediment had lower permeability and lower pink salmon escapements. Although clearcutting did result in some increase in suspended sediment concentrations, Meehan et al. (1969) were unable to show a decrease in salmon production in two streams in southeast Alaska. An unfortunate occurrence was that regulations caused the fish traps in Alaska to be removed during the latter part of the study period, at the time when any decrease in salmon populations resulting from logging would have been detectable. Increased escapements due to trap removal would have masked any minor reduction in salmon production as a result of clearcutting. Sheridan and McNeil (1968) likewise observed a temporary increase in fine sediments in spawning gravels immediately following logging in two southeast Alaska watersheds. The amount of fine sediments 5 years after logging began was not significantly greater than prelogging levels. They also noted increases in pink salmon spawners and alevins which were probably due to abolition of fish traps during the study.

Sediment production is a characteristic of the watershed. Sediments can be removed from streambed gravels by redd[6] construction (McNeil and Ahnell 1964), by shifting gravels during high stream stages, and by cleaning devices and other artificial disturbances. The artificial cleaning of streambed sections, however, may also reduce stream-bottom fauna populations which are a major source of food for rearing fishes, at least for a short period of time (Meehan 1971).

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[6]Nest dug by spawning fish in which the eggs are deposited.

The discussion of sediment has so far been concerned only with inorganic sediment. Organic sediment is also a possible factor contributing to degradation of fish habitat including water quality. Bark in particular can create a significant oxygen demand as it decomposes, and it also can produce excessive amounts of slime bacteria which then may suffocate incubating eggs and alevins (Hall, and Lantz 1969, Burns 1972). Organic debris on the gravel surface can also decrease the exchange of water between the surface and the deeper gravel areas.

In southeast Alaska, most of the limited research on the effects of logging on fish has been done with pink and chum salmon populations, the most valuable commercial species. However, as recreational demands in the region increase, more effort must be devoted to those species which spend all or part of their lives feeding and growing in fresh water (fig. 3). These species include chinook, coho, and sockeye salmon; rainbow (steelhead) and cutthroat trout; and Dolly Varden.

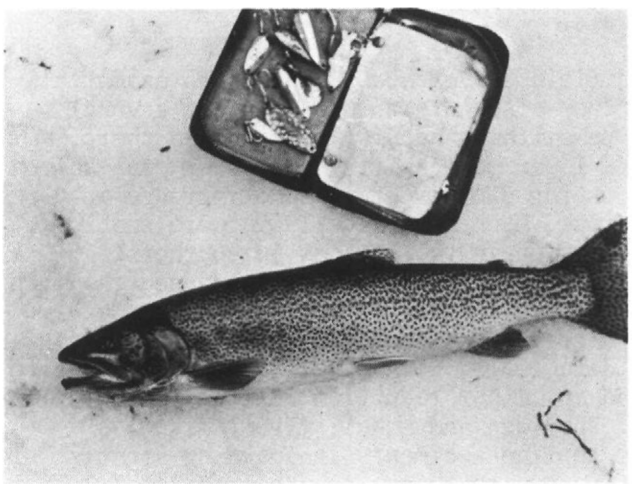

Figure 3.--Cutthroat trout, one of southeast Alaska's important sport fishes.

Most of what we have already discussed regarding the spawning habitat applies to the resident fish populations as well as the strictly anadromous forms. However, we must also be concerned with the rearing habitat of these resident fishes.

The two most important sediment effects on rearing areas are increased oxygen demand by decaying organic sediment and reduction of habitat for preferred aquatic insects. Combinations of factors, such as increased biological oxygen demand and wanner temperatures, are more serious than either of the two conditions separately. Since most organic sediment which finds its way into stream channels can be prevented by careful logging practices (minimizing soil disturbance, falling and yarding away from streams, etc.), there is not much need to expand our discussion at this point.

WATER TEMPERATURE

The principal source of heat which raises water temperatures is direct solar radiation (Brown 1969). When shade-producing streamside vegetation is removed, water temperatures may be increased several degrees. It is often possible to predict the magnitude of this response. The amount of temperature increase depends on such conditions as volume of streamflow, ground water influences, length of stream exposed to solar radiation, and general climatic conditions. Confounding conditions are entry of surface and ground waters. The most drastic changes occur in small streams; many of these small streams contribute significantly to the production of salmon and trout (Lantz 1971b, Brown and Krygier 1967).

Several recent studies have demonstrated how streamside vegetation directly controls water temperature. Brown and Krygier (1970) could not detect any increases in stream temperature as a result of patchcutting a watershed in the Alsea River basin in Oregon, where buffer strips remained to provide shade for the stream. In an adjacent watershed which was clearcut and later burned, mean monthly maximum temperatures were increased by 8° C. (14° F.), and the annual maximum was increased by 16" C. (29" F.) during the first year after treatment. Both annual maximum temperatures and mean monthly maximum temperatures decreased as shade-producing riparian vegetation returned.

Levno and Rothacher (1967) reported that mean monthly maximum temperature increased as much as 7" C. (12° F.) during midsummer in an Oregon stream which was exposed to direct sunlight as it flowed through a small clearcut. In a second stream in which logging debris created some shade, an increase in mean monthly maximum temperature of only 2" C. (4" F.) occurred during the same period.

Burns (1972) reported that protection of riparian vegetation along one California stream prevented temperatures from increasing after logging. In a second stream, maximum temperature increased 11.1" C. (20° F.) during road construction which removed the streamside canopy.

From the summer temperature standpoint, the type of vegetation which creates the shade is probably not important. Brown and Brazier (1972) felt that shrubs were more effective than conifers in providing summer shade. In the winter, deciduous plants will lose their effectiveness after the leaves drop.

In southeast Alaska, effects of shade removal on stream temperatures are consistent with these studies. Meehan et al. (1969) observed a maximum increase in stream temperature of 5" C. (9" F.) in midsummer after clearcutting, although mean monthly maxima increased only 2" C. (4" F.). Meehan (1970) demonstrated how temperatures increase as streams flow through unshaded reaches; shading from streamside vegetation reduces heating of the water and helps to maintain cool stream temperatures. An ameliorating influence in southeast Alaska is the abundance of cloudy weather which reduces the amount of solar energy reaching the streams.

Winter temperature changes resulting from removal of insulating riparian vegetation is another area in which we lack definitive information. Sheridan (1961) discussed how ice and snow cover has an insulating effect during "closed" winters. However, during "open" winters with little snow cover but with cold temperatures, lack of insulation by vegetation might be important. In southeast Alaska, where sustained periods of well-below-freezing temperatures are common, a slight lowering of water temperature in winter due to back radiation might be more critical than summer increases.

As with sediment and most other factors influencing fish habitat, water temperature must be considered with respect to both spawning and rearing habitat. In some instances a given reach of stream may serve in both capacities, but often emerging fry will seek areas for rearing which are different from the spawning beds. Coho salmon and Dolly Varden, for example, often utilize slow-moving or even still waters (fig. 4). These may be in the form of small tributaries, sloughs,

Figure 4.--Traps are used to evaluate production of juvenile salmonids in small tributary streams.

beaver ponds, or just side meanders of the main stream, The effects of water temperature may be quite different in these different types of habitat. For example, pink and chum salmon utilize fresh water only for spawning and subsequent incubation of eggs and alevins. Although some minor feeding may occur immediately following emergence, feeding and growth are generally considered to take place in the marine environment. In this situation, water temperature plays its main role in regulating the duration and timing of incubation, hatching, and emigration from the freshwater system. A given total number of temperature units[7] is required (from the time of egg deposition and fertilization) for the eggs to hatch. If this development is accelerated by even a very minor temperature increase (2° or 3° F.) due to removal of streamside vegetation, fry may emerge considerably earlier than they normally would in that stream. Downstream migration to the sea might be impeded at that time or conditions for growth and survival in the ocean might be unfavorable at that time of year (Martin 1958). These are considerations that have largely been overlooked until now.

In some situations where water temperatures were warm to begin with, an increase in temperature could contribute to decreased dissolved oxygen supplies and might promote the growth of slime bacteria or fungi which could cause excessive mortality to incubating eggs.

In rearing areas, water temperature changes may affect habitat in different ways. Food organisms such as aquatic insects and other invertebrates may respond to temperature changes in terms of species composition as well as biomass. In some cases this might be favorable. Cold streams, shaded by dense forest canopies, may not be optimum trout habitat (White and Brynildson 1967). Thinning the riparian canopy would allow more solar energy to reach the stream, raising water temperature a few degrees and possibly increasing production of algae and aquatic insects. Bums (1972) reported that in two California streams salmonid biomass increased after areas were carefully logged. This type of treatment must be done cautiously, particularly in streams which are fairly warm to begin with,to avoid increase of nutrients to the point that oxygen deficiencies and generally stagnant conditions are created (i.e., eutrophication). In most cases, a maximum temperature of about 15.6" C. (60' F.) should not be exceeded. Another factor that should be considered in this type of manipulation is that a cold stream may have its greatest value in controlling higher water temperatures in downstream areas.

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[7]A temperature unit (TU) is defined as 1 degree of temperature (Fahrenheit) above freezing for 24 hours; e.g., at 34° F. constant temperature, eggs accumulate 2 TU's per day.

For the most part, this discussion about stream temperature has been concerned with direct effects on mortality or survival of fishes. A less dramatic, but nonetheless important, consideration is the effect of temperature on such factors as growth, condition, and behavior of fish. Fish utilize food best at lower water temperatures (Averett 1969, Lantz 1971a). The reason for this is that food energy is available for growth only after other functions have been satisfied. At wanner temperatures, metabolic rates increase, which uses more energy. Hence, given an equal amount of food, more energy will be available for growth at lower water temperatures. At the same time, however, maximum growth rate occurs at higher temperatures (assuming lack of food is not a limiting factor), even though food conversion is less efficient. Other factors enter into this energy utilization structure, but this one example will serve to show the complex of stream temperature factors. Another consideration is that at lower temperatures fish are more active and, from a recreational standpoint, might be more desirable than if they were taken from wanner waters in which they might be more sluggish and poorer fighters.

In summary of stream temperatures, with our present knowledge we should attempt to maintain shade cover on most streams. The smaller the stream, the more critical is this shade since the influence of solar energy will be more pronounced.

STREAMFLOW

Streamflow is regulated primarily by seasonal precipitation patterns and influenced greatly by evapotranspiration, normal streamflow regime of a given watershed, condition of the soil, and saturation level of groundwater aquifers.

In general, research has shown that after clearcut logging (1) streamflow increases (especially when burning follows removal of logs), (2) minimum streamflow during dry summers is significantly increased, and (3) assuming that soil compaction to the point that soil infiltration capabilities are decreased has not occurred, major peak (flood) flows are apparently not greatly increased (Rothacher 1971). Normal variations in streamflow due to climatic conditions are in most cases greater than variations produced by vegetation removal. In areas where precipitation patterns vary greatly, the effects of evapotranspiration may be difficult to detect (Rothacher 1971).

In southeast Alaska the generally very wet climate may cause streamflow increases after clearcutting to be very difficult to observe. Meehan et al. (1969) were unable to detect differences on two watersheds of Prince of Wales Island.

The effects of increased streamflows on fish populations could be harmful or beneficial, depending on their time of occurrence. Increased flow during periods of naturally high water might cause mortality of eggs and alevins from gravel bed movement and might also flush aquatic insect populations. On the beneficial side, increased flow during normally low flow periods could enlarge the available living space and increase the carrying capacity of the stream for rearing fish. The increased flow at this time of year would also tend to lessen water temperature increases resulting from removal of streamside vegetation. Increased streamflow might also minimize oxygen privation and freezing in spawning beds,

In southeast Alaska, change in streamflow resulting from timber harvest is probably not as significant a problem as it is in other areas.

DISSOLVED OXYGEN AND. OTHER WATER CHEMISTRY FACTORS

In any consideration of water chemistry in relation to fish habitat and fish populations, D.O. (dissolved oxygen) surfaces as the most important constituent. We have already discussed some of the effects of dissolved oxygen'on fish; however, this factor is sufficiently important to warrant further consideration.

Dissolved oxygen is important in surface waters and in intragravel waters. Oxygen is utilized by the developing eggs in relation to size and stage of development. More oxygen is required as the egg develops, with the maximum requirement just before hatching (Alderdice et al. 1958, Phillips 1971). In general, the greater the concentration of oxygen, the better the growth and survival of eggs and alevins, with highest survival at the saturation level of about 11 mg./1. (Shumway et al. 1964, Silver et al. 1963, Phillips and Campbell 1962).

After hatching of the fry and emergence from the gravel, dissolved oxygen is important in maintaining the "fitness" of young salmonids living in the stream. Feeding activity and growth (and consequently survival) are generally better in waters with higher dissolved oxygen concentrations (Narver 1971).

After felling of streamside timber along Needle Branch (a tributary of Drift Creek in Oregon's Alsea River watershed), reduction in D.O. was first noted in the intragravel water (Hall and Lantz 1969). A layer of debris on the gravel surface, combined with ponding of surface water, caused a reduction in the rate of interchange between surface and intragravel waters. This reduction, plus the oxygen demand from decomposition of logging debris, caused a rapid decline of oxygen in the intragravel water. An oxygen deficiency was noted in surface waters soon afterward.

Other chemical considerations are often directly associated with D.O. Increase in carbon dioxide, ammonia, and other metabolic waste products of developing eggs and alevins are often found along with low D.O. levels. This is usually the result of reduced flow of water within the gravel beds, because oxygen is not adequately replenished and metabolites are not satisfactorily removed. In most cases when D.O. is adequate, these other factors are not cause for concern. In extreme cases, such as a small, slow-moving stream choked with great quantities of fine logging debris, anaerobic bacteria could possibly cause the production and release of hydrogen sulfide gas which could be a serious cause of mortality to young salmonids (Narver 1971). However, other problems (e.g., dissolved oxygen reduction) would probably be evident before this kind of situation would arise, and would be of overriding importance relative to the survival of salmonids.

LOGGING DEBRIS AND LOG JAMS

Logging debris is considered here as the leaves, branches, bark, tops, and other nonmerchantable material resulting from logging operations which finds its way into the stream channel. It may cause oxygen deficiencies in several ways, such as (1) creating an oxygen demand as it decomposes, (2) forming a barrier on the gravel surface which reduces the interchange of surface and intragravel waters, (3) impounding waters which normally would flow over riffles and be oxygenated, (4) producing slime bacteria which smother developing eggs, and (5) contributing to temperature increases as a result of reduced water velocity through unshaded reaches of stream. Narver (1971) has summarized the literature in this area, and most studies have confirmed the foregoing points.

Aside from creating oxygen deficiencies, fine logging debris can cause changes in the habitat of aquatic insects and hence affect fish populations. Accumulated debris can likewise fill in the interstices of gravel and rock areas, effectively reducing the living space of some insects and an important type of cover for small juvenile fishes, and decreasing the survival-to-emergence of alevins if the accumulation takes place during egg incubation.

The most obvious effect of log jams is to block fish passage to upstream spawning and rearing areas, Large jams also have a significant bearing on streambed topography, gravel stability, sediment deposits, and streamflow (Helmers 1966).

Thus far we have considered factors which are primarily harmful to fish populations. In some ways logging debris and jams may serve beneficial roles. Streambed movement associated with log jams may serve a useful purpose by accelerating the flushing of fine sediments from the gravel (Meehan et al. 1969, Helmers 1966); however, the effects of sediment flushing on downstream areas, including the estuaries, must not be overlooked. Dense accumulations of large debris across the stream channel can provide shade to lessen the impact of solar energy on water temperature. In otherwise fast-flowing streams, some impounding could provide rearing areas for trout and coho salmon. Feeding and escape cover might also be a function of relatively stable debris jams.

Uphill felling of timber has been suggested as a means of keeping logs and debris out of streams (Burwell 1971). This method was considered for old-growth timber in steep V-notch drainages in the Pacific Northwest, where reduced breakage made it economically advantageous. In southeast Alaska, most of the larger timbered drainages have glacier-formed, U-shaped valleys. In the latter situation, it should be easier to keep logging debris out of the stream channel in the first place.

Each accumulation of debris in a stream (whether natural or man-caused) should be treated as an individual case, based upon the various potential effects of removing it or leaving it in place. With our present knowledge of the effects of debris accumulations, we can say that our first concern is to keep logging debris out of the stream channel. Next, debris should be removed with the least possible disturbance to the streambed and the banks. This precludes the use of heavy machinery in the stream and probably means removal by hand. Fine debris can be considered harmful to the aquatic ecosystem in all cases. Logs, either in jams or individually, should be considered from several aspects before they are removed. If spawning area is the factor limiting fish production in a given stream, the material should probably be removed; if nursery or rearing habitat is the limiting factor, some impoundment by log jams which do not restrict passage of fish may be desirable. The various effects of debris on streamflow, dissolved oxygen, water temperature, sediment, fish food supplies, quantity and quality of spawning and rearing areas, and perhaps even recreational and esthetic values must all be heeded before a decision is made to remove or to leave debris.

FOREST CHEMICALS

Modern land use treatment practices utilize a large number of chemicals including herbicides, insecticides, and fertilizers. Norris and Moore (1971) and Thut and Haydu (1971) have summarized the literature concerned with the entry and fate of forest chemicals in streams and their effect on aquatic life. Their conclusions are that most forest chemicals have minimum pollution potential. It should be stressed that the behavior of each chemical and formulation and the effects on aquatic life must be known before widespread application.

In southeast Alaska, widespread use of forest chemicals has not occurred, although a few relatively minor treatments take place each year. Most of these are local applications of insecticides in the vicinity of campgrounds or of herbicides along roads and airfields to control brush. Applied by hand, they are no problem to aquatic habitat since the chemicals can be applied directly to target organisms and kept away from water surfaces. Care must be taken after spraying not to clean equipment in and flush excess chemicals into the streams and standing waters.

In the last few years there have been a small number of larger operations in which chemicals were applied aerially. The two commonly used chemicals in southeast Alaska have been the herbicide 2,4-D and urea fertilizer. In the aerial application of these chemicals, areas of several hundred acres have usually been treated.

Large-scale application of insecticides for control of forest insects is not now practiced in southeast Alaska. However, between 1961 and 1964, the effectsonfish and aquatic insects of an aerial application of DDT (0.28 kg./ha. or 1/4-1b./acre) to control black-headed budworm were studied in four streams on Prince of Wales Island (Reed 1966). Although fish mortality was not demonstrated, this study did show a drastic reduction in populations of aquatic insects for a year after treatment and a resultant decrease in growth and condition of trout for 2 years after treatment. Although this type of treatment might not have significant influences on pink and chum salmon, the rearing species (coho, chinook, and sockeye salmon, cutthroat and rainbow trout, and Dolly Varden) could be seriously affected by reduced food (fig. 5).

Figure 5.--*Quantity* and species composition of streambed *fauna* **being** *sampled* **here provide** *a* **means** of *evaluating* **stream productivity.**

At the present time, 2,4-D is the only herbicide used extensively in southeast Alaska for the control of undesirable plants. In 1968, the U.S. Forest Service treated with 2,4-D approximately 400 acres of cutover land on the Nakwasina River watershed on Baranof Island to inhibit the growth of broad-leaved plants. The effects of this treatment on water quality and aquatic life were reported by Sears and Meehan (1971). No immediate mortality to salmonid fishes or aquatic insects was attributable to the spray, and samples of water and fish had concentrations of 2,4-D well below the level generally considered lethal to aquatic organisms. This study dramatically pointed out the lack of howledge of the properties and effects of 2,4-D and resulted in a rigorous testing of the acute toxicity to salmonid fishes of several formulations of. the chemical.[8] Of the esters tested, the butyl ester and the propylene glycol butyl ether ester were much more toxic to salmonids than the isooctyl ester. Since the esters are all equally effective in controlling the undesirable plants, the isooctyl ester should be used for aerial applications where there is any possibility of the chemical falling directly on surface waters.

The small amount of forest fertilization in southeast Alaska has been with urea fertilizer. This fertilizer generally contains 46 to 47 percent nitrogen and is applied at the rate of 400 pounds (200 pounds of nitrogen) per acre. Studies done elsewhere (summarized by Norris and Moore 1971) have shown that ammonia nitrogen is the most toxic product of urea fertilizer to aquatic organisms, but that lethal concentrations have never been approached in the field. A recent study in Alaska[9] showed similar results, with an initial increase in ammonia which lasted for only a short time. Nitrate concentration in water samples showed a slight increase after fertilization but was probably not enough to stimulate a significant increase in stream productivity.

ESTUARINE HABITAT

The absence of roads and the distances between sale areas and processing mills in southeast Alaska have resulted in the extensive use of salt water for storage and transportation of logs. Wood-boring organisms, such as teredos, are inhabitants of these marine waters, so logs are generally stored in shallow bays which drain dry at low tide. Protection from strong winds is another factor in storing logs in estuarine coves.

During the log dumping and rafting processes, bark is knocked off the logs and sinks to the bottom, often in large quantities. This

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[8] W. R. Meehan, L. A. Norris, and H. S. Sears. Toxicity of various formulations of 2,4-D to salmonid fishes in southeast Alaska. Journal of the Fisheries Research Board of Canada, in press.

[9] William R. Meehan, Frederick B. Lotspeich, and Ernst W. Mueller. Effects of forest fertilization on two southeast Alaska streams. Manuscript being prepared.

accumulation can greatly increase oxygen demand, resulting in reduced populations of marine benthic organisms, and also smother the bottom so thoroughly that repopulation by benthic forms is prevented (Pacific Northwest Pollution Control Council 1971).

Observations at several dump sites in southeast Alaska showed that significant accumulations of organic debris may persist for long periods of time (Ellis 1970). Marine animals, including crabs and clams, were very scarce in some areas. In general, the impact of these log facilities depends on several conditions including the type and age of the facility and the characteristics of the water (depth, influence of tidal currents, etc.).

Water storage of logs also results in a release of soluble organic compounds (leachates) which further increases the oxygen demand in the storage area. Length of storage, species of logs stored, and various estuarine conditions all influence the effects on marine communities (Schaumburg 1970).

Much remains to be learned about the effects of water-based log handling in southeast Alaska. The economic as well as biological considerations involved in rafting and towing versus barging, for example, need to be determined. In general, any method which reduces the amount of bark and other log debris which accumulates on the bottom should be considered.

HABITAT IMPROVEMENT, EFFECTIVENESS/COST[10]

Streams and lakes in Alaska provide excellent opportunities to enhance habitat, to increase production of salmon, and to attach a dollar value to the improvement. Although the salmon resource may be recovering very slowly from low levels, increased production would help both the fisherman and the industry.

At the present time both the Alaska Department of Fish and Game and the U.S. Forest Service are engaged in stream improvement programs. These include such activities as: (1) debris and log jam removal, (2) construction of fish ladders or steeppasses over barrier falls, (3) construction of spawning channels, (4) removal of beaver dams, (5) removal of blowdown, and (6) gravel cleaning. The Forest Service has been instrumental in development of a machine for removing sediment from streambed gravels. The "riffle sifter" is a self-powered amphibious vehicle which stirs up the gravel, sucks out the fine sediments and sprays them onto the streambanks. Although this machine shows promise,

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[10] Much of this section is excerpted from "Benefit/Cost Aspects of Salmon Habitat Improvement in the Alaska Region," by W. L. Sheridan, USDA Forest Service, Region 10, February 1969, 47 p.

basic mechanical problems require redesign. In conjunction with the gravel cleaning operation, a study in southeast Alaska showed that aquatic insect populations were reduced as a result of treatment, but that biomass returned to precleaning levels within a year (Meehan 1971).

During project inventory and planning by the Forest Service, it became apparent that a method was needed whereby the dollar value of a potential improvement could be established. This would permit establishment of priorities and a basis for requesting funds to accomplish a realistic, planned, habitat-improvement program over a period of time. Such a method was developed, using the effectiveness/cost analysis approach. The effectiveness/cost analyses are equally applicable to both commercial and sport fisheries.

Developing such a method was not easy for two reasons. First, there is apparently some confusion among economists regarding the economics of sport and commercial fisheries. Second, and this factor exerts an even more profound influence on results, is the difference in the *quality* of spawning and rearing areas in different lake and stream systems. Since much is unknown of the influence of this quality, and only crude methods have been developed by which to measure it, potential benefits must at present be calculated on the basis of *quantity* of spawning and rearing areas and *average* survival rates presented in results of research carried on in the past 20 plus years.

This effectiveness/cost analysis has distinct advantages in that it enables priorities to be set so that alternatives can be chosen. There are limitations, however, some of which are as follows:

1. Costs are estimated as closely as possible. If actual costs exceed estimated costs, the actual effectiveness/cost ratio is decreased; if actual costs are less than estimated costs, the actual effectiveness/cost ratio will be increased.

2. Yields are calculated on the basis of average survival rates and normal production from an "average" environment. Until practical methods are developed to evaluate the quality of spawning and rearing areas, production must be based on quantity. Obviously the quality of different spawning and rearing areas can vary considerably. In some instances, this means that by using average production figures, actual production will exceed the estimated production, and in other cases actual production may fall well below the estimated figure. Production of salmon also depends to a large extent upon climatic factors--rainfall, temperature, and others.

3. Dollar values are used in the effectiveness/cost analysis. Changes in costs of construction and in the price of fish will affect the effectiveness/cost ratios.

We will gain a better understanding of these limitations as more projects are completed and evaluated. It may be necessary to change some of the constants used in calculating yield as more information is obtained.

The economic desirability of a fish habitat improvement project can be measured by the amount of yield the project will give beyond that already established for the environment as it existed prior to modification. Needed for different types of improvement are: (1) project cost, (2) maintenance cost, (3) increased yield by year, and (4) an effectiveness/cost ratio adjusted by discounting.

Yield is given in dollar value of the fish at the price-to-fishermen level. By multiplying the value to the fisherman by 2.5, a rough wholesale (case-pack) value can be obtained. The further values are carried, however, the more complex they become. For example, wholesale and retail values should include all the costs incurred in catching, processing, and marketing, and these costs are difficult to come by.

Estimating effectiveness/cost ratios has been programed by the Fisheries Research Institute, University of Washington, Seattle, Wash. 98105.

DISCUSSION AND SUMMARY

Fish and timber are the two most important natural resources in southeast Alaska at the present time (fig. 6). Salmonids (Pacific salmon', trout, and char) often spend most of their freshwater life in

Figure 6.--Important fish and timber resources frequently share the same valley, as here on Prince of Wales Island.

streams that flow through forested watersheds. In the glacier-formed, U-shaped valleys common in southeast Alaska, much of the best timber is found in the valley bottoms in close association with salmon and trout streams. This makes timber harvesting a more difficult problem, because timber harvesting can affect streams.

Two major freshwater habitat types are important to salmonids, i.e., spawning areas and nursery or rearing areas. In some cases a reach of stream may serve as both spawning and rearing habitat, but more often rearing areas are located some distance away from the major spawning riffles. Pink and chum salmon utilize spawning habitat; but after fry emerge from the gravel beds, they migrate to sea almost immediately, so that freshwater rearing areas are not significant factors in their life cycle. On the other hand, the remaining salmon species (coho, chinook, and sockeye), the trouts (rainbow and cutthroat), and the char (Dolly Varden) spend from a few months to 3 or 4 years in fresh water before migrating to sea; in some cases they spend their entire life in fresh water. To these species the rearing areas are often more important than spawning habitat (although both can be critical), since the amount and quality of "living room" is generally the factor which limits their production.

The primary function of spawning gravels is to provide an environment suitable for the development of the eggs and alevins up to the time of hatching and emergence. The rearing areas must provide conditions suitable for the growth and survival of the young fish. Because of these different requirements, the two habitat types may be quite dissimilar. The spawning environment must (1) contain sufficient quantities of suitable gravel, (2) provide sufficient surface and intragravel water flow to assure adequate flow of oxygen to and removal of metabolic wastes from the developing embryos, (3) maintain temperatures which assure proper rate of development and time of emergence of the eggs and fry, and (4) be free of sediment in quantities which would inhibit development of embryos and emergence of fry. The rearing environment must provide the food, living space, cover, and water quality necessary for good growth and survival of fish populations. The spawning reaches are generally characterized by series of riffles and pools, where the flowing surface water can be oxygenated, and where bottom contours favor the interchange of surface and intragravel waters. The rearing habitat is often slow-moving water, rich in plant and invertebrate animal life, and ranges from small streams and tributaries through sloughs and side channels of major streams and rivers to ponds and lakes of varying size.

Consideration for fish habitat in southeast Alaska during timber harvesting was in the past often directed only toward the larger spawning streams. Today, the great importance of the smaller rearing areas is being more fully recognized, and these areas are now beginning to receive the attention which they warrant. Small streams are generally more dramatically affected by changes than are larger streams and rivers.

Sediment (both suspended and deposited), water temperature, dissolved oxygen, streamflow, and debris are the factors associated with logging practices which can affect the habitat of anadromous and resident fish populations. These factors often are interrelated, and the total cumulative effects may be greater than the sum of their individual effects. For example, if streamside shade is removed from a reach of stream, water temperature will be increased. If logging debris accumulates in this reach, dissolved oxygen levels may be reduced. If sediment is introduced, intragravel water flow and the interchange, between surface and subsurface waters may be inhibited. Each of these factors might cause a reduction in salmon egg survival if it was the only factor involved. However, if all three conditions were to occur simultaneously, still greater effects could be produced. Increased water temperature would increase the oxygen demand produced by the decomposing debris, thereby further decreasing the dissolved oxygen content of the water. The sediment would decrease the interchange and flow of water through the gravel, further limiting the amount of oxygen reaching the embryos and also inhibiting removal of waste products produced by the embryos and the decomposing debris. The total effect on the developing eggs of this combination of conditions could be much more disastrous than the sum of their individual influences.

Sediment and fine logging debris (bark, leaves, twigs) are not compatible with high quality fish habitat. There is an inverse relationship between the accumulation of these materials and salmonid production. This consequence must be considered when timber sales are laid out and during logging (e.g., road location, falling, and yarding away from streams).

Water temperature is controlled by the amount of solar energy reaching the stream. Such factors as surface area of stream, amount of streamflow, groundwater, and tributary influences may ameliorate the effects, but shade is of greatest importance. *As* shade cover is removed, summer water temperatures will rise. Within limits, temperature increases in small streams as a result of removing streamside vegetation can be predicted. In some situations a slight warming of stream water might enhance fish production, but the cumulative downstream effects of temperature increases in upstream tributaries must be considered.

Log jams and large debris may limit fish production in one stream; in another stream this material could be beneficial.

Streamflow should increase as a result of clearcutting. In southeast Alaska there is no evidence that this is a major factor in causing increased storm flows. The climate and high infiltration rates of the soil probably account for the inability to observe streamflow increases.

Many of the factors which have been discussed in this report are difficult to measure because often natural variation can be greater than the variation caused by man. For example, if severe storms occur during the measurement period, small changes in suspended sediment concentration or streamflow as a result of roadbuilding or logging might go undetected. Natural variations in stream temperature are also a potential problem in identifying temperature changes resulting from man's activities.

In summary, man's activities in a watershed can affect fish habitat. These activities (logging, road construction, etc.) can be compatible with the production of salmonid fishes if adequate consideration is given to the aquatic environment during both planning and operational stages. Protection of our fish-producing waters in conjunction with land use treatments is a responsibility which our land managers must never overlook. Fishery biologists must help determine the type of protection necessary for each stream system, and foresters must plan timber harvest in that system to assure that the necessary protection is afforded.

RESEARCH NEEDS

Much is known about the effects of man's activities on fish habitat. Using our present knowledge, we can fairly well predict how various treatments of a watershed will affect the streams within that watershed. We know, for example, that poor road layout and construction methods and improper log yarding can cause sediment in streams. We know that removal of shade-producing vegetation from the streambanks will raise the water temperatures during the summer months. We can assume that clearcutting in a watershed will result in increased streamflow. We know that accumulations of fine logging debris in a stream can cause reduced levels of dissolved oxygen.

However, we need to know more than just the ways in which these changes to the stream may be brought about. We must be better able to define the changes to the aquatic habitat which result from man's activities. We also need to know just what effects these changes will have on fish populations. For example, it is not enough to know that stream temperature will be increased when streamside vegetation is removed. We must be able to determine precisely what these changes will be under different conditions, such as amount and kind of shade cover which will remain along the stream. And we must know how these various changes will affect the fish and their food supplies. One of our biggest needs for future research is to define the response of the aquatic ecosystem to stream changes resulting from land treatment practices.

In the area of sedimentation, one of the most important questions to be answered is, *How much sediment can salmonid populations tolerate?*

This type of information is necessary before alternatives can be selected and a decision made regarding treatment within a watershed.

The same question needs answering with regard to water temperature. *How much temperature change can salmonid fishes tolerate without a Zoss in production?* Leave, or buffer, strips along streams need much more study before the ramifications of their presence or removal can be clearly understood. The type of riparian vegetation which can produce the shade necessary for maintaining suitable water temperatures should be determined, as well as the rate at which it can be established along a watercourse. The effects on water temperature of various cutting patterns should be determined.

The merits of removing or maintaining debris jams in various situations need to be explored in considerable detail in southeast Alaska. *How do debris accumulations affect spawning areas, and how do they influence fish production in rearing areas? When can strategically placed materia2 improve the habitat for salmonid fishes?*

When forest chemicals are used, we must be certain that we know the immediate effects on the aquatic ecosystem. In many cases this is already hown, and in others it can be ascertained easily, However, much more research is necessary before the chronic effects of these chemicals on our aquatic resources will be filly understood. Also, we should know how materials associated with' forest chemicals (e.g., carriers and surfactants) react in the aquatic environment. Laboratory bioassay studies are important, but it is also necessary to evaluate these chemicals in the field.

Habitat improvement programs, in both treated and untreated watersheds, are one way in which salmonid production can be maintained or increased. However, some streams may be inherently capable of greater fish production than others. This potential productive capacity is probably controlled by natural factors. A research program to identify the watershed factors which influence fish production is a necessary prerequisite to effective stream improvement operations. It would be wiser to expend money and effort in systems which were capable of substantially greater production than to do so in systems which could never be good producers. This may have the highest priority in southeast Alaska fish habitat'research.

All the points discussed here are steps necessary in developing guidelines for the land manager to use in making decisions with regard to watershed use. The ultimate goal of research in this field is to provide the resource manager with a howledge of the consequences of various land uses with respect to fish habitat and a system for making alternative decisions to obtain the best possible balance of resource values. A modeling and systems analysis approach to achieving this goal should be thoroughly explored.

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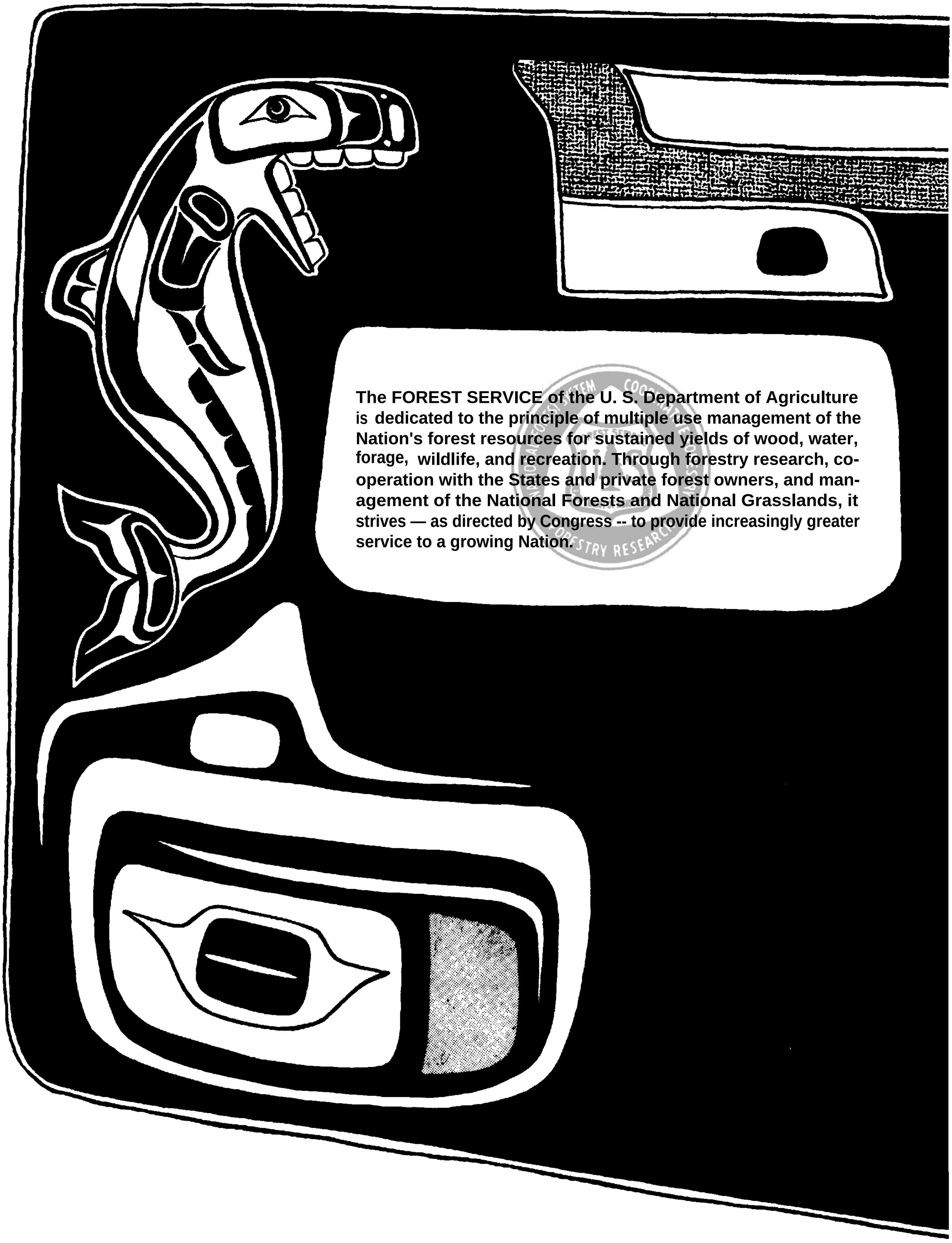

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