Volume 26 Study D-I

STATE OF ALASKA

Bill Sheffield, Governor

Annual Performance Report for

ECOLOGY OF REARING FISH; A REVIEW REPORT ON SOUTHEAST ALASKA FINDINGS

by

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Volume 26 Study D-I

RESEARCH PROJECT SEGMENT

State: Alaska Name: Sport Fish Investigations of Alaska

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Cooperator: Steven T. Elliott

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ABSTRACT

A 1985 review of research findings from the Pacific Northwest on the environmental requirements of salmonids and the effects of timber harvest on salmonids is referenced to southeast Alaska. Taken together, research strongly suggests that timber harvest in Southeast may increase sedimentation rates (reducing the egg-fry survival of salmonids) and that changes in watershed temperature regimes may have both positive and negative effects on non-rearing and rearing juveniles. Canopy removal increases primary productivity and, where nutrients are high, the number of age-0 fry can increase. Changes in stream flow, stability of stream habitat structures, and recruitment of woody debris necessary for habitat formation may eventually reduce rearing-salmonid carrying capacity by as much as 50% over the long term. The magnitude of the effects varies among species, with time, and with the severity of the perturbations. Buffer zones are superior to other strategies in preserving stream productivity; methods are compared and discussed. Long-term studies should be developed to examine temperature and sedimentation phenomena as observed in other studies and determine to what extent southeast Alaska stocks are affected.

KEYWORDS

Clearcut logging, sedimentation, temperature, streamflow, habitat, primary production, growth, winter survival, coho salmon, *Oncorhynchus kisutch* (Walbaum), Dolly Varden, *Salvelinus malma* (Walbaum), pink

salmon, *Oncorhynchus gorbusha* (Walbaum), cutthroat trout, *Salmo clarki* Richardson.

BACKGROUND

Since its inception in 1970, the Land-Use Project of the Sport Fish Division has investigated many aspects of development and documented its impact on rearing salmonids and their habitat. The project has completed research on the effects of debris removal on juvenile Dolly Varden, has participated in forest plan development, and has been active in providing data for prescriptive guidelines to reduce the impact of timber harvest on stream habitat. In cooperation with the National Marine Fisheries Service, Northwest and Alaska Fisheries Center Auke Bay Laboratory, and the Pacific Northwest Forest and Range Experiment Station, Forestry Sciences Laboratory, the project initiated studies of salmonid standing crop in streams clear-cut logged in the 1960's. These studies and those of coworkers suggested that clear-cut logging may exert its greatest influence during the winter. Consequently, the project began cooperative studies of the effects of logging on winter survival in 1983 and will complete those studies in July 1986.

In 1985, a literature review of pertinent research was conducted to summarize and reference findings on the effects of logging in southeast Alaska and to provide a clearer direction for current and future research. That review is the subject of the following report.

Table 1 lists the common name, scientific name, and abbreviation of each fish species mentioned in this report.

RECOMMENDATIONS

Research

1) Research on rearing salmonid life history in relation to logging is near completion. However, it would be advisable to investigate the winter survival parameters in the Haines area, where winter conditions are thought to be the most severe.

2) Studies should be developed to determine if the phenomena related to the temperature increases observed at Carnation Creek are occurring in southeast Alaska.

3) Studies should be developed to examine the changes in stream morphometry after logging and how it affects egg-fry survival and the carrying capacity of rearing juveniles.

4) Studies should be developed to determine the longevity and recruitment rate of woody debris in disturbed and undisturbed streams.

Management

Development of guidelines for stream habitat or riparian zone management will require the close cooperation of timber resource agencies; therefore, they are beyond the scope of this document.

OBJECTIVES

1) To document the history of the Land Use Project from 1971 to 1984, its objectives, findings, and recommendations.

2) To analyze data and publish the results collected from 1982 to 1984 on the survival of juvenile salmonids and their habitat requirements in logged and unlogged streams.

3) To prepare and present reports for the public, fishery and land managers, and the scientific community.

INTRODUCTION

This report summarizes results of research conducted in the Pacific Northwest on biological requirements and the effects of timber harvest on the various life stages of salmonids with particular reference to southeast Alaska. Its purpose is to analyze findings, locate regional data gaps, identify potential problem areas, and recommend research to investigate those problems. Additionally, it is hoped that the document will find use by timber and fishery managers as an aid to guideline development and by decision makers and the public in making more informed decisions regarding the effects of timber harvest.

Readers will find citations throughout this review of studies that are not complete and still in the analysis stage. The author cautions readers that results from these papers are preliminary and may be subject to change as data are more fully developed and subjected to peer review. Also, many results have been drawn by necessity from controlled laboratory experiments or from data on species not common in Southeast. Consequently, readers should be aware that these findings may not always apply in full to field conditions where environmental or biotic conditions are highly variable.

The following documents were found to be invaluable in formulating this report and were relied on throughout and are recommended for further reading:

Chamberlin, T. W. 1982. Timber harvest. In W. R. Meehan, ed. Influence of forest and rangeland management on anadromous fish habitat in western North America. USDA Forest Service Gen. Tech. Rep. PNW-136. Pac. NW For. Ran. Exp. Sta., Portland, Oregon. 30 pp.

Hartman, G. F., ed. Proceedings of the Carnation Creek workshop; A ten year review. Feb. 24-26, 1982. Malaspina College, Nanaimo, British Columbia.

Meehan, W. R., T. R. Merrell, Jr. and T. A. Hanley, eds. 1984. Proceedings of a symposium on fish and wildlife relationships in old-growth forests, Juneau, Alaska, 12-15 April 1982.

Moring, J. R. 1975. The Alsea watershed study: Effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Parts I, II, III. Fishery Research Report Number 9, Oregon Department of Fish and Wildlife, Federal Aid in Fish Restoration, Project AFS-58, Final Report.

Murphy, M. L. and K V. Koski. 1985. Links between habitat, juvenile salmonids, and effects of logging in Southeast Alaska. Can. J. Fish. Aquat. Sci. (in press).

Resier, D. W. and T. C. Bjornn. 1979. Habitat requirements of anadromous salmonids. In W. R. Meehan, ed. Influence of forest and rangeland management on anadromous fish habitat in western North America. USDA Forest Service Gen. Tech. Rep. PNW-96. Pac. NW For. Ran. Exp. Sta., Portland, Oregon. 54 pp.

FINDINGS

Streamflow

Many workers have demonstrated increases in streamflow following clear-cut logging (Rowe, 1963; Rothacher, 1965, 1970, 1971; Berndt and Swank, 1970; Meehan et al., 1969). Clear-cutting eliminates a substantial amount of vegetation which would otherwise intercept rain and snow and allow it to be reevaporated, and fewer tree roots reduce the amount of water that would otherwise be transpired. The combined effects of these factors are higher soil water content (and hence groundwater levels) and runoff in clear-cut areas than under forest cover (Chamberlin, 1982). Expressed as changes in annual runoff, streamflow has been shown to increase by 20-40% relative to pre-logging values (Chamberlin, 1982).

Some investigators feel that the magnitude of peak flows also increases after logging. Gilleran (1968), Harper (1969), Hsieh (1970), and Harr et al. (1975) report that logging-road construction had a pronounced influence on peak flows in the Alsea watershed; when roads exceeded 12% of the watershed area, peak flows increased significantly. These flows increased further in the fall after 72% of the watershed had been logged (Moring, 1975a). Moring (1975b) concluded that annual flows increased significantly after clear-cutting, and that the excess flow was generally expelled from the system during high winter flows in December and January.

Catastrophic flows are disputed by others. Some evidence suggests that increased runoff from evapotranspiration and interception loss alone does not increase high flows sufficiently to be of concern (Megahan, 1979 in Chamberlin, 1982). Much greater flow increases may be caused by synchronization of snowmelt and rain-on-snow events. Though no direct data demonstrate that these have caused destructive peak flows (Harr, 1980), there is "considerable circumstantial evidence that harvesting in coastal British Columbia may have contributed to deteriorating aquatic habitats in a region where rain-on-snow events are common" (Chamberlin, 1982). The similarities between British Columbia and southeast Alaska climates suggest that investigation of these hydrologic factors would be a fruitful area of research in Southeast.

The effects on streamflow discussed above apply to recently logged watersheds; there may be long-term effects with considerably different characteristics. In rapidly growing second-growth stands (greater than 20 years old) water requirements for vegetative growth may be greater than in either forested or newly clear-cut watersheds. The result could be lower soil water content, less runoff to streams, and lowered minimum flows (Berndt and Swank, 1970; Myren and Ellis, in press). Thus, the most significant effects on salmonids may occur in the long term when forests begin to return rather than immediately after logging.

Streamflow Effects on Adult Salmonids:

Migration of adults can be hampered by too low a streamflow and resulting shallow water. Thompson (1972) established passage criteria for various salmonids based on maximum depth and velocity (see Reiser and Bjornn, 1979). Stream discharges that will provide suitable depths and velocities for adult passage can be determined for the criteria and techniques described by Thompson (1972). Baxter (1961) reports that salmon require 30-50% of the average annual flow for access through lower and middle reaches of a stream and up to 70% in headwater areas.

High streamflow can frequently exceed the swimming capability of migrating salmonids; adults seek shelter in pools or in undercut bank areas and resume migration when flows decrease. The high peak flows that are thought to occur after logging could affect the migration of fall spawning fish in southeast Alaska, though it is generally thought that species such as coho can negotiate most flow levels. Drought conditions, on the other hand, can strand pink and chum salmon in pools as the water level drops, where they often die from anoxic conditions (Murphy, in press).

Spawning and Incubation:

Flow levels regulate the amount of spawning area available; as flows increase, more spawning area is made available to fish but the velocity effects make many areas unsuitable for spawning. At very high flows, losses outweigh the gains and the spawning capacity of the stream decreases (Reiser and Bjornn, 1979). When fish spawn in gravels that are later exposed by receding water levels, eggs can survive dessication and dewatering for up to 5 weeks (Reiser and White, 1983).

Incubation and Development:

Hartman et al. (1982) reported that winter water temperature increased after clear-cutting of Carnation Creek, British Columbia. They concluded that higher temperatures resulted from changes in general climatic conditions enhanced by clear-cutting, as there was a strong correlation between higher air temperatures and water temperature. (The influence of increased solar incidence [Meehan, 1970] may be linked to these changes.) Higher air temperatures after logging were also found by Edgerton and McConnel (1976); radiation exchange in forests with unbroken canopies occurs at the crown tops and the dense canopy prevents penetration by sun and wind (Geiger, 1965). For southeast Alaska, Elliott (unpublished data) found that winter water temperatures in small clear-cut streams were higher than in small forested streams although the amount of muskeg drainage and aspect of the watersheds (Sheridan and Bloom, 1975) may have been important factors in regulating winter temperatures.

Warmer water during winter appears to accelerate the development rate of coho embryos (and may similarly affect pink and chum embryos), shifting the time of emergence to earlier in the spring (Hartman et al., 1982)--a time when floods are more common. Early emergent fry can be swept out to sea, resulting in rapid reduction in fry populations and possible underutilization of stream habitat afterwards (Scrivener and Andersen, 1984). These same factors could cause chum salmon fry to emerge earlier than normal (Hartman and Holtby, 1982) and enter estuaries prior to spring plankton blooms which form their first source of food in the marine environment. Early marine survival may thus be affected.

Lowered water temperatures during winter may also result from loss of plant cover in northern areas, causing reductions in the rate of egg development and losses due to icing (Chamberlin, 1982). The effects of low water temperature on egg development and survival have been well documented by Reiser and Bjornn (1979). Patric (1967) reported that in the Juneau area soils froze to greater depths and earlier in the fall in clear-cuts (heat loss is greatest) compared to forested soils. Freezing rate also appears to be related to snow depth. By January, snow accumulation at both sites apparently served as insulation and maximum frost depth was about 15 inches in both clear-cut and forested soils. Kirchhoff and Schoen (1984) report that snow depths in forest openings far exceeded depths found under the forest canopy. Increased snow depth could be beneficial in clear-cuts and preserve some of the heat stored during the summer. Gard (1963) showed that stream temperatures under 41 inches of snow ranged from 32 to 32.5°F while air temperature above the snow ranged from -15 to 48°F. During the coldest period, he found that stream water 19 inches under the snow was 44°F warmer than the air above.

When snow cover is absent, low air and water temperature can cause mortality of incubating eggs and fry by the formation of frazil or anchor ice which reduces gravel permeability and water interchange. Anchor ice can freeze to the gravel and, upon thawing, can remove large blocks of gravel, destroying redds in the process (Reiser and Bjornn, 1979).

Increased peak flows could increase the rate of egg and alevin mortality. Rapid fluctuations disturb redds, and crush and dislodge eggs. Gangmark and Broad (1956) attributed complete mortality of planted chinook eggs to floods that occurred during planting. Deleterious effects of floods have also been reported by Neave (1953), Gangmark and Bakkala (1960), and Sheridan and McNeil (1968). Seegrist and Gard (1972) reported that winter floods decimated the eggs of brook trout and, because of reduced competition from brook trout young, spring-spawning rainbow fry increased in the years following. Spring floods, conversely, destroyed rainbow trout eggs, thereby enhancing the survival of brook trout. Flood-related changes in species composition endured for several years after the flood events.

McNeil and Ahnell (1964) found the apparent velocity of water moving through substrate materials to be one of the most critical parameters in egg survival. Since apparent velocity is related to the head pressure on the water and the permeability of the gravel, increased streamflow (and hence water depth) could have the beneficial effect of increased apparent velocity (Wickett, 1954).

Effects of Streamflow on Juveniles:

Streamflow is related to the amount of cover available, which is related to the standing crop of juvenile salmonids (Kraft, 1968; 1972; Weshe, 1973; 1974; Nickelson and Reisenbichler, 1977; Murphy and Koski, in press; Heifetz et al., in press). Generally, the amount of habitat and standing crop increases with increasing streamflow, but then begins to decrease (probably in third-and fourth-order streams). In very large streams the relationship becomes negative, with fish confined to a narrow band along each shore or near midstream structures such as large organic debris (LOD) jams or eddies (personal observation). The relationship between streamflow and habitat may be responsible for the strong correlation between adult coho salmon abundance (catch) and streamflow observed by Smoker (1953) in Washington.

Bachman (1984) reported that brook trout choose foraging sites based on their size and the water velocity. Rimmer and Paim (1984) showed similar relationships for Atlantic salmon juveniles; larger fish selected higher-velocity habitat than did age-0 fry.

Increases in flow after clear-cutting may limit the amount of usable habitat for juveniles, and increased water depth may not necessarily make other habitat available; habitat located in off-channel areas is usually of poorer quality (personal observation) than LOD habitat accumulated and incorporated into stream channels.

The most significant effects of streamflow are the effects of freshets on juvenile abundance. Hartman et al. (1982) and Scrivener and Andersen (1984) showed that if coho fry emerge earlier than normal, their numbers can be rapidly reduced by spring floods. The same may also apply to pink and chum salmon fry. Fall freshets can reduce presmolt populations and when cover is lost during timber harvest (Tschaplinski and Hartman, 1983) or removed through stream clearance (Elliott, in press).

Table 1. List of common names, scientific names, and abbreviations.

Common Name	Scientific Name and Author	Abbrev.
Atlantic salmon	*Salmo salar* Linnaeus	AS
Brook trout	*Salvelinus fontinalis* (Mitchill)	BT
Brown trout	*Salmo trutta* Linnaeus	BR
Chinook salmon	*Oncorhynchus tshawytscha* (Walbaum)	KS
Chum salmon	*Oncorhynchus keta* (Walbaum)	CS
Coho salmon	*Oncorhynchus kisutch* (Walbaum)	SS
Cutthroat trout	*Salmo clarki* Richardson	CT
Dolly Varden char	*Salvelinus malma* (Walbaum)	DV
Pink salmon	*Oncorhynchus gorbuscha* (Walbaum)	PS
Rainbow (Steelhead) trout	*Salmo gairdneri* Richardson	RB

Temperature

Salmonids are cold-water-adapted fish that prefer a relatively narrow range of temperature. Optimum temperatures vary among the species and range from 10°C to 13.5°C, and lethal temperatures range from 23°C to 26°C (Reiser and Bjornn, 1979). The timber canopy provides shade during the summer months and its removal increases the summer water temperature in direct proportion to the amount of increased sunlight on the water. Smaller streams, because of their lower water velocity, discharge, and volume, heat quicker and have greater increases in water temperature than larger streams (Chamberlin, 1982). Meehan et al. (1969) and Meehan (1970) showed that temperatures of streams in southeastern Alaska increased after logging but did not reach levels that were lethal to salmonids.

Effects of Temperature on Migrating Adults:

Adult salmonids can successfully migrate upstream in water with temperatures ranging from 3°C to 20°C (see Table 1 in Reiser and Bjornn, 1979); water warmer than this can stop migration. Meehan et al. (1969) reported that water temperature in a logged stream in Southeast reached or exceeded 20°C for 65 hours during only 1 year in a study lasting 14 years. However, Sheridan (1962) showed that the timing of pink salmon runs was associated with stream temperature and Hartman and Holtby (1982) found that warmer water may inhibit coho adults from entering streams. Changes in the timing of adult migration and spawning time could influence the development time of incubating eggs and alevins.

High stream temperature after logging has been cited by fishery managers as a major factor in mortality of adult pink and chum salmon. The Department of Fish and Game has compiled a list of 43 streams that had pink salmon mortalities associated with elevated water temperatures and low flows in 1977. Murphy (in press) observed mortality of pink salmon at Porcupine Creek in 1981. He found that adults were stranded in intertidal pools when low flows coincided with neap tides. High temperatures contributed to but were not the major cause of mortality; stream temperature diminished oxygen in the pools by lowering the saturation point to 8.8 mg/l at 19°C and increasing the oxygen demand of fish. Since the observed temperature was within the range of tolerance of salmonids, he concluded that low flows and suffocation, not thermal shock, caused the mortality.

Spawning:

Successful spawning can occur in water with temperatures ranging from 2.2 to 20°C. A sudden drop in temperature may cause all spawning activity to cease, resulting in lowered redd building and reduced production (Reiser and Bjornn, 1979). Optimum spawning temperatures for pink and chum salmon are 7.2-12.8°C; coho salmon, 4.4-9.4°C; and cutthroat trout 6.1-17.2°C (Reiser and Bjornn, 1979). Increased water temperature reported by Meehan et al. (1969) after logging frequently exceeded the optimum for pink and chum salmon.

Effects of Temperature on Rearing Salmonids:

Hartman et al. (1982) showed that water was warmer during winters after clear-cutting, causing early emergence of coho fry and, in turn, decreased density of juveniles during the summer. However, after logging, those fish that escaped flooding enjoyed a longer growing season and were larger by the end of their first year. Since an increase in size tended to increase the probability of overwinter survival (Hartman et al., 1984), changes in temperature regimes can influence the production of smolt (Scrivener and Andersen, 1984). Hartman et al. (1982) summarized the situation as follows:

> the conditions of higher stream temperature regimes, associated primarily with climatic conditions, and enhanced by clear-cutting, may be advantageous to overwintering presmolts. Smolts have increased in number from a range of 1,750-2,474 before logging to a range of 3,511-4,619 after that period. However, these same conditions which are positive to smolt production cause early emergence of fry, and result in early freshet-related movement of fish which may be of negative value to them. An optimum balance between the conditions of advantage to smolts and to those of fry is of importance in the watershed processes.

In southeast Alaska, Murphy and Koski (in press) and Elliott (unpublished) have found that densities and size of juvenile coho salmon and Dolly Varden are greater in some logged streams than forested streams. Murphy and Koski (in press) showed that increased fry density was related to elevated levels of primary and secondary productivity caused by increased amounts of solar radiation and warmer water (Meehan, 1970), and larger size may be attributable to a longer growing season.

During long periods of cloudless days, overheating of some streams could occur (Sheridan and Bloom, 1975). Although temperatures may not exceed lethal levels, sublethal temperatures can affect the density and growth rate of juveniles. Salmonids cease growth at 20.3°C because increased metabolic activity consumes energy to drive high metabolic rates and little remains for growth. Growth of chinook parr increases as temperature increases from 10 to 15.7°C but then decreases with increasing temperature (Burrows in Reiser and Bjornn, 1979). Baldwin (1956) reported that the growth rate of brook trout increased as temperature increased from 9.1 to 13.1°C, then began to decrease after temperatures exceeded 17.1°C. At 17.1°C, brook trout ceased feeding and at 21.2°C they ate only 0.85% of their body weight in prey per day.

Temperature may also regulate the density of salmonids. Hahn (1977) reported twice as many steelhead fry in stream channels at 13.5°C than in a channel at 18.5°C and that fry density at 8.5°C was double that at 13.5°C. Since stream temperatures frequently exceed these levels, more so in logged than forested areas, it can be concluded that interference with feeding and growth and effects on density occur more often in logged streams than in forested streams.

Sedimentation

This section is not intended to be a comprehensive review of the effects of sedimentation on stream biota. It provides highlights of the effects of sedimentation on salmonids drawn from key papers. Comprehensive reviews of the effects of sedimentation can be found in Cordone and Kelly (1961), Hall and McKay (1983), Koski and Walter (1977), and Reiser and Bjornn (1979).

Adult Migration and Behavior:

Adult migration can be affected by turbid water conditions. Migrating king salmon avoided turbid water in preference for the clear water of a relatively small tributary stream (Smith, 1940). Bell (in Reiser and Bjornn, 1979) cited a study in which salmonids would not move in streams where a landslide had caused sediment concentrations to exceed 4,000 mg/l. Adult trout ceased feeding and moved closer to cover when turbidity exceeded 35 mg/l (Bachman, 1958).

Spawning:

Spawning Pacific salmon prefer gravel sizes from 1.3 to 10.2 cm in diameter, steelhead and cutthroat trout prefer 0.6- to 10.2-cm gravel (Reiser and Bjornn, 1979), and anadromous Dolly Varden generally select 0.6- to 5.0-cm gravel (Blackett, 1968). Gravel size at each redd site is related to the body size of the fish; larger fish tend to select larger gravel. Fish frequently select the tails of pools for spawning. These areas are characterized by sediment-free gravel with high permeability and intragravel flows.

Incubation and Emergence:

Sediment has two major effects on incubating eggs and alevins: 1) reduction of the intragravel flow and delivery of oxygen, and 2) entombment of emergent alevins.

Fine sediments reduce gravel permeability, thereby lowering the apparent velocity of water flowing through the gravel and reducing both the delivery of oxygen to the eggs and the removal of metabolic wastes. Permeability is high (apparent velocity: 24,000 cm/hr) where sand and silt (0.883 mm), make up less than 5% of the volume of the bottom material, and relatively low (apparent velocity: <1,300 cm/hr) where fine sediment makes up more than 15% of the bottom material (McNeil and Ahnell, 1964).

Reduction in gravel permeability due to presence of fine sediment will reduce both the interchange of surface and intragravel water and the apparent velocity of the intragravel water (Gangmark and Bakkala, 1960; Wickett, 1962; Cooper, 1965). Diminished oxygen supply to developing embryos can have the following effects: Sac fry from embryos incubated in low and intermediate oxygen concentrations were smaller and weaker than sac fry reared at higher concentrations and thus may not survive as well as larger fry (Silver et al., 1963). Reduced oxygen concentration

leads to smaller newly hatched fry and a lengthened incubation period (Shumway et al., 1964). Low oxygen concentration in the early stages of development may delay hatching, increase the incidence of anomalies, or both. Low oxygen levels in the later stages of development may stimulate premature hatching (Alderdice et al., 1958).

Coble (1961) found a positive correlation between steelhead embryo survival and intragravel oxygen content. Phillips and Campbell (1961) reported similar findings for coho salmon and steelhead; they concluded that intragravel oxygen concentration must average 8 mg/l for high survival of coho salmon and steelhead embryos. "Generally, concentrations at or near saturation with temporary reductions no lower than 5.0 mg/l are recommended for anadromous salmonids" (Reiser and Bjornn, 1979).

Substrate Composition:

Successful fry emergence is hindered by excessive amounts of sand and silt in the gravel. Even though fry can hatch and develop, survival will be poor if they cannot emerge. Koski (1966) found redds where eggs had developed normally but were unable to emerge because of sediment.

Phillips et al. (1975) found an inverse relation between the quantity of fine sediment and fry emergence. Bjornn (1969) and McCuddin (1977) demonstrated that survival and emergence of chinook salmon and steelhead embryos were reduced where sediments smaller than 6.4 mm made up 20-25% or more of the substrate. Tappel and Bjornn (1983) showed that the survival of chinook and steelhead embryos was related to the percentage of sediment smaller than 9.5 mm and the percentage smaller than 0.85 mm, respectively. Gravel mixtures with high percentages of fines also produced slightly smaller steelhead fry, possibly a function of egressability; smaller fry were able to emerge more easily from sedimented gravel than larger fry.

Effects of Sediment on Rearing Fish:

Sigler et al. (1983) showed that juvenile steelhead and coho salmon grew slower in prolonged turbid conditions and had a greater rate of emigration from turbid stream sections than did fish held in clear-water sections. Noggle (1978; cited in Sigler et al.) found that larger coho did not emigrate, but had a strong tendency to stay in their initial territory when exposed to short periods of turbidity. Larger fish may have a stronger affinity for their territories and less tendency to emigrate. Berg (1982) demonstrated that during short pulses of suspended sedimentation juvenile coho social patterns were disturbed, forms of aggression changed, activity increased, and feeding ability decreased. Crouse et al., (1981) demonstrated that increased sedimentation suppressed production (tissue elaboration) in juvenile coho salmon. Carrying capacity for juveniles can also be reduced by sedimentation. Bjornn et al., 1977 found that abundance of juvenile chinook salmon in pools declined in almost direct proportion to the amount of pool area lost to deposited sediment.

Sediment Contribution from Timber Harvest:

Sediment is introduced into streams as a result of timber harvest in four main ways: 1) harvesting techniques, mass slope failure, and landslide; 2) landslides caused by road building, and erosion of road beds and gravel pits; 3) disturbance of stream banks and stream channels; 4) construction of bridge and culvert crossings.

Surface erosion from yarding and felling is highly correlated with timber harvest technique and design (Rienhart et al., 1963), with larger clear-cuts producing the most sediment. Tree removal from steep slopes reduces slope stability and may accelerate the rate of mass soil movement and landslides (Swanston, 1974). Anderson (1971) found that recently logged areas and logging roads had a significant effect on sediment discharge. Fredriksen (1970) reported an increase after road building in peak sediment concentrations to 250 times those recorded in natural watersheds. Brown and Krygier (1971) found that sediment production doubled after road construction in one watershed and tripled in another after logging and burning. Burns (1970) found that sedimentation was greatest during road construction and after destruction of stream banks.

Sedimentation in Southeast Alaska:

Mass wasting is a common natural event in southeast Alaska, where over 3,800 large-scale landslides have occurred within the last 150 years (Swanston, 1974). Logging can trigger landslides by destabilizing soils; Bishop and Stevens (1964) noted a four-fold increase in the rate of landslides in Maybeso Creek following logging. Many sedimentation events are directly attributed to human activity. Road building in Bear Creek, Mitkof Island, caused two major slides in 1976. In Kisutchia Creek, Baranof Island, flood waters diverted into a gravel pit resulted in sedimentation of intertidal spawning areas (Art Schmidt, personal communication). Logging on unstable soils on Kruzof Island caused a number of small landslides on cut slopes along roads (personal observation).

Koski and Walter (1977) also cite the following observations:

- turbidity on a tributary of Twelve Mile Creek, Prince of Wales Island, reached 3,200 ppm in 1 day during gravel removal operations.

- bridge construction across Bonnie Creek, Prince of Wales Island, increased sediment from 0.49 lb/8 hr to 1,048 lb/8 hr.

- an 8.5% increase in sediment followed logging of Rodman Creek, Baranof Island.

Low-level introductions of sediment are poorly documented in Southeast and, with the exception of observations of bank destruction by Reed and Elliott (1972), have not been quantified. Most low-level sources result from bank destruction, bank and channel instability after removing

streamside trees, and channel modification by disturbance or accumulation of debris (Scrivener and Brownlee, 1981; Bryant, 1983; Culp and Davies, 1983; Tschaplinski and Hartman, 1983).

Logging Sediment and Fish Mortality:

Studies in Southeast on the effects of sediment on salmon have focused on sediment particles 0.833 mm in diameter or smaller as those most likely to reduce gravel permeability. A significant percentage increase in this size range following logging was noted in the Harris River by Sheridan and McNeil (1968) and in 108 Creek by Novak (1975). However, these results were inconclusive regarding the effects on salmonid abundance because of variation in adult escapement (Pella and Myren, 1974; Sheridan, 1982). Benda (1983) showed that there was an increase of 11.5% in sediment particles less than 4.0 mm in diameter and a significantly lower mean survival of pink salmon alevins after a landslide caused by road construction in the Blossom River.

Holtby and Hartman (1982) summarized the effects of logging sedimentation on salmonids in Carnation Creek:

> very significantly, streamside logging has led to gradual but accelerating changes in stream morphometry. Sedimentation and bedload movement associated with bank erosion and channelization have resulted from streambank logging practices and debris transport caused by logging activity. Such habitat degradation is implicated in already declining egg to fry survival.

These findings have been corroborated in part by Bryant (1980) at Maybeso Creek on Prince of Wales Island.

Cedarholm et al. (1981) reported that cumulative sedimentation from logging roads significantly reduced the survival of coho embryos in the Clearwater River, Washington. Both Cedarholm et al. (1981) and McNeil (1980) recommended increased escapement to compensate for decreased production where egg survival is being impaired. A significant reduction in the survival of chum salmon and coho salmon embryos in Carnation Creek, British Columbia, occurred after fines were deposited in the top strata of gravel spawning beds (Scrivener and Brownlee, 1981). They also show that fine sediment is removed from gravels during freshets when the source of sediment is arrested and that fines less than 0.297 mm did not persist in the gravel for more than 1 year.

Most destructive sedimentation in Southeast appears to be caused by catastrophic events attributable to human error, poor planning and layout, poor construction methods, and violation of best practices. However, evidence from Carnation Creek suggests that sedimentation from bank destruction and destabilization of debris may be a greater and more long-term source of mortality of salmonid embryos. Though most sediment is flushed from the system within 1 year, there is concern that sedimentation and bedload movement associated with bank erosion and channelization is increasing (Holtby and Hartman, 1982). If similar

processes are occurring in southeast Alaska, they have not been detected due to a lack of research.

Water Quality

Dissolved Oxygen:

Adult Migration. Reduced dissolved oxygen concentration can adversely affect the swimming performance of migrating salmonids (Reiser and Bjornn, 1979). Low oxygen can also cause avoidance reactions or cause migration to stop (Whitmore et al., 1960). Oxygen levels recommended for spawning fish include levels at the 80% saturation level and temporary absolute levels no lower than 5.0 mg/l.

Large-scale mortality of spawning pink salmon has frequently been observed in logged and forested streams in Southeast (Novak, 1975; Murphy, in press). Mortality is primarily due to low oxygen levels when drought conditions decrease discharge and elevate stream temperature (reducing the oxygen saturation point) and strand fish in pools where there is poor aeration. The decomposition of salmon carcasses may also contribute to the reduction in oxygen.

Since clear-cutting increases stream temperature (thereby decreasing the saturation point), it is possible that logging may exacerbate adult mortality during drought conditions. Additionally, rapidly growing second growth may reduce streamflow relative to pre-logging levels (Berndt and Swank, 1970). Since approximately 50 years are required before second growth reaches a height sufficient to shade stream channels, the combination of high temperatures and decreased streamflow may increase the frequency of mortality incidents during periods of low precipitation. Although clear-cutting may be related to adult die-offs in Southeast, current observations (Novak, 1975) are not conclusive; managers should be prepared with adequate study designs to examine these effects in detail when the next event occurs.

Incubation and Development. The range of concentrations of dissolved oxygen critical to the survival and development of salmonid embryos is narrow (Lindroth, 1942; Hayes et al., 1951; Wickett, 1954; Alderdice et al., 1958). Laboratory tests with coho, chum, and chinook salmon, and steelhead eggs indicate the following relationships: sac fry from embryos incubated at low and intermediate oxygen concentrations are smaller and weaker than sac fry reared at higher concentrations (Silver et al., 1963); reduced oxygen levels lead to smaller newly hatched fry and a longer incubation period (Shumway et al., 1964); low oxygen levels in the early stages of development may delay hatching or increase the incidence of abnormal embryos (Alderdice et al., 1958).

Oxygen delivery to salmonid embryos can be reduced when sediments clog gravels and reduce the intragravel water flow (McNeil and Ahnell, 1964). Furthermore, heavy accumulations of fine particulate debris from logging slash increase the biological oxygen demand and decrease the intragravel oxygen concentration (Hall and Lantz, 1969; Berry, 1974; Ponce, 1974).

Effects on Juveniles. The concentration of dissolved oxygen in streams is important to rearing salmonids. Hermann et al. (1962) showed that growth rate, food consumption, and efficiency of food utilization of juvenile coho salmon all decline when oxygen is less than 6 mg/l. Juvenile chinook will avoid water with concentrations of 1.4-4.5 mg/l in the summer, but will react less to low concentrations in the fall when temperatures are lower (Whitmore et al., 1960). The swimming speed of rainbow trout is impaired by reduced oxygen levels in the water (Jones, 1971).

Heavy accumulation of fresh slash can impound streams and, during sunny weather, water temperatures can increase, thereby lowering the oxygen saturation point. Fresh green slash contains water-soluble leachates that when dissolved by the water are attacked by stream microorganisms. Under these conditions biological oxygen demand may reduce the amount of oxygen below the tolerance levels of juveniles. Reduction of dissolved oxygen as a result of these factors has not been documented in the field in Southeast, but low oxygen from decomposing slash was a major cause of salmonid mortality after logging of Needle Branch Creek, Oregon (Moring, 1975b).

Nutrients:

Nutrient concentrations may increase after logging (Bormann and Likens, 1970), but usually by moderate amounts and for short periods of time (Chamberlin, 1982). Nutrients released after clear-cutting are taken up rapidly by soil and stream microorganisms (Fredriksen, 1971). Short-term increases in nitrates have been documented after clear-cutting in some west coast streams, but without deleterious effects (Chamberlin, 1982). However, where streams are limited in nutrients, such as phosphate, major algal blooms can occur after minor increases in the nutrient.

Since drainages in Southeast are generally nutrient poor (Schmidt, 1979), logging may increase primary production if temperature and flow conditions permit. Increased nutrients may be linked with solar radiation in causing the higher primary and secondary production observed by Murphy and Koski (in press) in logged streams of southeast Alaska.

Leachates:

Logging slash may contribute leachates that are potentially toxic to salmonids. Buchanan et al. (1976) found that extracts from spruce and hemlock bark were toxic to pink salmon fry at 56 mg/l (96-hr LC50) and Peters et al. (1976) reported that leachates from western red cedar (*Thuga plicata*) were toxic to juvenile coho salmon at 0.33 mg/l for foliage terpenes and 2.7 mg/l for tropolones.

Effects on the Rearing Environment

Logging Slash and Debris Deposition:

Clear-cutting to or across small streams frequently deposits large quantities of woody debris (such as limbs, boles, and non-merchantable timber) into the streams. Logging debris is generally smaller and accumulates more densely than naturally occurring debris. Studies by Bryant (1983) on Prince of Wales Island show that accumulation of logging debris can be as much as seven times the amount of debris occuring in undisturbed streams.

Hall and Baker (1975) summarized beneficial and adverse effects of organic debris on fish habitats. Most adverse effects arise from water quality impacts. Accumulations of debris were found to increase biological oxygen demand (BOD), and several investigators measured decreases of instream and intragravel oxygen which resulted from heavy accumulations of fine organic material (Hall and Lantz, 1969; Berry, 1974; Ponce, 1974). This material may also contribute potentially toxic leachates (Buchanan et al., 1976). Peters et al. (1976) reported that water-soluble leachates of western red cedar were toxic to juvenile coho salmon at 0.33 mg/l for foliage terpenes and 2.7 mg/l for tropolones. Neither BOD problems nor toxic concentrations from debris deposition have been documented in southeast Alaska.

Under certain conditions debris can form barriers to migrating adults and must be removed (Merell, 1951). When log jams create falls, migration can be blocked (Narver, 1971), but in most situations the stream will undermine or be diverted around log jams, thereby providing access (personal observation). In large streams of sufficient discharge, small materials (such as branches) are floated and washed downstream, but in smaller streams (1-5 in width), materials such as slash, branches, timber, and small pieces of fractured wood may interlock to form barriers to adults (though seldom to juveniles). Elliott (in press) found that removal of such material greatly improved access for spawning pink salmon and also provided new spawning gravels for fish.

Removal of logging residue from streams is a common practice and has been conducted on many streams in Southeast, but with no evaluation of its effects on fish or other biota. Both Cardinal (1980) and Dolloff (1983) found that juvenile Dolly Varden char and coho salmon were highly associated with logging debris and that densities in littered streams were similar to densities in pristine streams. Furthermore, Cardinal (1980) predicted that removal of logging debris would have a detrimental effect on the abundance of rearing salmonids. Elliott (in press) found that removal of logging debris caused an 80% reduction in the abundance of juvenile Dolly Varden and a temporary reduction in benthos numbers, and may have caused a long-term destabilization of the char population. Bryant (1983) summarized these and other findings and developed concise guidelines for conditions under which debris is to be removed, goals of debris removal, and procedures for removal.

Changes in the Physical Structure of the Habitat:

Stream habitat provides for two important functions that are directly related to a stream's salmonid carrying capacity: fish can reside in low

velocity "pockets," from which they venture out to forage; and seek refuge in concealed areas when disturbed (Bachman, 1984). Habitat requirements change with age, size (Bachman, 1982; 1984), and season; during the fall, declining water temperatures reduce metabolic activity and swimming performance (Brett, 1964), and habitat may be selected based on its ability to shelter fish from floods (Bustard and Narver, 1975a). Winter habitat may be the most critical factor in determining the annual abundance of juveniles during their freshwater phase, as considerable evidence shows that in the absence of suitable winter cover, populations can be greatly reduced by floods (Mason, 1976; Tschaplinski and Hartman, 1983). In Southeast coastal streams, habitat for juveniles is formed by the hydraulic action of water plunging over or moving around large organic debris (LOD), such as logs or root boles. The cutting action of the stream scours out pools and provides quiet areas free from strong current velocities. About 70% of the stream habitat structures that are used by juveniles are formed by the influence of LOD (Murphy and Koski, in press; Elliott, unpublished), making it the single most important feature characterizing rearing salmonid habitat.

Timber harvest affects summer and winter habitat in several ways: mechanical removal of LOD and destruction of undercut banks, overcleaning by stream clearance crews, and the growth of streamside vegetation. Cross-stream yarding dislodges and destabilizes in-stream debris, often moving it to near-shore areas. Yarding of logs parallel to or up stream channels is particularly destructive. Removal of logging residue, even by experienced crews, frequently overcleans streams and much natural debris is removed in the process (Murphy and Koski, in press). This, however, appears to be site specific as Elliott (unpublished) found no significant difference in the amount of debris in logged and forested streams of the northern Tongass Forest.

Cutting and yarding operations collapse undercut banks, eliminating valuable cover for juveniles. Both Murphy and Koski (in press) and Elliott (unpublished) have found undercut bank habitat to be twice as infrequent after logging. Tschaplinski and Hartman (1983) observed that streamside logging destabilized undercuts contributing to their collapse during freshets and resulting in decreased coho abundance.

Removal of the forest canopy stimulates profuse growth of streamside vegetation. Although vegetation can form valuable cover for juveniles, especially when it overhangs pools or other quiet areas, it is not universally important as cover in all locations. Overhanging vegetation, especially when in flower, attracts numerous terrestrial insects (personal observation) which contribute to the diet of juveniles and supplement their food supply (Meehan et al., 1977).

Channel Morphology:

Because logging debris is more densely concentrated (up to seven times) than most natural accumulations, it can severely constrict flows. In large streams this results in rapid streambed and streambank cutting and destabilization of all woody material (Bryant, 1983). When logging

debris enters a stream, it is loose and floats easily. Thus, it will move in channels during floods and dislodge more stable accumulations, release sediment, and increase channel instability. Large concentrations of unstable material can have adverse effects on channel morphology and the general suitability of streams for salmonid spawning and rearing. As organic material and sediment shift along the stream, gravel bars are formed, erosion occurs around piles of large organic debris, and channels become unstable. Heavy loading of debris in streams of more than 10% gradient can cause debris torrents that scour out entire channels and deposit massive jams downstream.

Additional effects of large woody debris on stream channel morphology were discussed by Swanson et al. (1977) and Bryant (1980) for Southeast streams. These effects include long-term changes in sediment storage, direction of flow, and heterogeneity of stream channels.

Light Levels:

Stockner and Shortreed (1975) found that low levels of algal production in forested streams were related to the poor light conditions found under the dense timber canopies. Sunlight penetration increases after clear-cutting to the edge of streambanks and, either independently or coupled with elevated nutrients and temperature, has been shown to increase the primary productivity of small streams (Bormann and Likens, 1970; Hansmann and Phinney, 1973; Murphy and Koski, in press). Weber (1981) found more benthos in southeast Alaska clear-cuts, and Murphy and Koski (in press) reported a strong correlation between increased algal production in clear-cuts and elevated levels of aquatic benthos production and concluded that these factors were responsible for increased abundance of age-0 coho fry in logged streams that had high nutrient levels.

Increased Fry Production Examined:

As seen in the section on "Light Levels," periphyton growth in many streams is light limited and removal of the canopy increases sunlight penetration, increases autotrophy, and may lead to greater benthos production and significantly greater abundance of age-0 coho fry if nutrients are high. There is less response to these factors where nutrients are low (Murphy and Koski, in press). These findings corroborate the conclusions of McFadden (1969) and the observations of Mason and Chapman (1965) and Hunt (1969) that density of juveniles may be food limited and that juveniles frequently respond to increases in food supply with an increase in rearing density (Dill et al., 1981). Not only are fry more numerous, but they are slightly larger in size (Elliott, unpublished; Murphy and Elliott, unpublished data). Increased size is thought to be a response to longer growing seasons (Hartman et al., 1982; Scrivener and Andersen, 1984) rather than increased food supply.

These recent findings have been seized and promoted by some as evidence that logging is beneficial to the production of salmonids. However, these phenomena are confined to specific areas (Murphy and Koski, in

press) and there is no conclusive evidence that "enrichment" of streams after logging improves stock abundance.

Fry populations in pristine settings are extremely ephemeral and can rapidly decrease during their first year in fresh water (Chapman, 1965; Crone and Bond, 1976). As the fry grow, demands for food and space increase and populations adjust by decreasing their density, usually through emigration of the least fit individuals (Chapman, 1966). However, when food is abundant relative to fry recruitment, space requirements decrease (McFadden, 1969; Mason, 1976) and permit higher densities of fry, a condition that has been observed by Murphy and Hall (1981) in Oregon clear-cuts and Murphy and Koski (in press) in southeast Alaska (Prince of Wales Island) clear-cuts. Experiments by Mason (1976) demonstrated that supplemental feeding of fry increased the number and biomass of coho fry by 6-7 times that found in natural streams. However, he showed that the increased number of coho did not survive the winter and emigrated (during fall-winter floods) due to the lack of suitable winter cover required to support the population at elevated levels. Mason (1976) concluded that "a 6-7 fold increase in potential smolt yield induced by a supplemental feeding strategy during the summer was nullified by the natural carrying capacity of the stream over winter." This is further supported by findings that habitat used during the summer which can support large numbers of fish is not necessarily beneficial during the winter. Bustard and Narver (1975a) show that behavior of juvenile coho salmon changes at the onset of fall and that they move deeper in pools and to recesses provided by LOD. The amount and quality of LOD is probably the most critical factor in determining the suitability of winter habitat; Heifetz et al. (in press) showed that habitat with LOD was used extensively by wintering coho and steelhead, but the same type of habitat without LOD was not used. Thus, the above findings strongly suggest that winter habitat is limited to stream structures with specific characteristics and that smolt yield is directly related to the amount and quality of these structures. Furthermore, though clear-cutting may produce an abundance of fry during the summer, there is no evidence that increased fish density will contribute to smolt yield above levels dictated by the carrying capacity of winter habitat.

Effects on Winter Survival:

Winter survival of rearing salmonids is thought to be most regulated by three environmental factors: 1) fall and winter freshets, 2) quality of winter habitat, and 3) temperature.

Tschaplinski and Hartman (1983) reported that fall and winter freshets can greatly reduce the abundance of juvenile coho salmon. The timing of freshets may also influence survival. Elliott (in press) found that freshets in October not only had little effect on the density of juvenile Dolly Varden, but often resulted in immigration from mainstream sources. Freshets of similar magnitude in November and December, when the water temperature was lower, were destructive and reduced fish abundance.

A decrease in stream temperature during fall and winter reduces swimming speed (Brett, 1964). In fall, juvenile coho salmon and steelhead trout move deeper into pools and into close association with woody debris (Bustard and Narver, 1975a), a behavioral change that may be a strategy to seek lower-velocity environments and thereby reduce population loss during freshets. Tschaplinski and Hartman (1983) found that where bank habitat and woody debris were lost as a result of streambank logging, there was a reduction in juvenile coho abundance.

Juvenile coho salmon appear to prefer specific types of winter habitat. During the summer months, abundance of coho is highly correlated with the volume of pools in the stream (Nickelson and Hafele, 1978), but as fall progresses they are found only in pools with woody debris (Heifetz et al., in press). Bustard and Narver (1975b) demonstrated that when coho were given the choice between winter habitat with and without woody debris, they chose areas with debris cover. In larger streams, root systems of downed trees may be the only habitat available in midchannel areas and they are used extensively; large numbers of juvenile coho have been observed crowding among roots of overturned trees during fall months (A. Schmidt, Alaska Department of Fish and Game, personal communication).

Management of stream habitat by manipulating or providing debris must take into account these specific preferences. Introduction of logs that through hydraulic action of the stream will provide pools, may not satisfy the "crevice behavior" so frequently observed in coho. Instead, strategies should provide relatively dense interlocking material, located at frequent intervals in the stream channel; many small pools with abundant debris may be of greater benefit than a few large pools formed by introduced logs.

Movement of Fish into Refuge Habitat:

Juveniles frequently move into off-channel areas during fall months and remain there throughout the winter. Since many of these areas are relatively low-velocity environments, this may be a strategy to escape fall and winter freshets. Skeesick (1970) found that juvenile coho move into tributaries to escape mainstream flooding. In larger rivers, the number of fish immigrating to ponds can be considerable (Cedarholm and Scarlett, 1982; Peterson, 1982). At Starrigavan Creek (near Sitka, Alaska), approximately 300-400 juvenile Dolly Varden immigrated into each tributary during fall with the onset of freshets (Elliott and Reed, 1974; Dinneford and Elliott, 1975) and recovery of marked fish indicated that movement of fish was confined to about 30% of the juvenile coho and Dolly Varden populations. In small streams, such as headwater areas or streams that have high-quality wintering areas, fall movement is even less. Only 16% of the coho populations at Kake Bake Creek moved into off-channel refuge habitat (where indigenous fish had winter survival rates exceeding 90%) and fish in tributaries less than 1 m in width remained throughout the winter in those locations and undertook no movement.

The foregoing suggests a relationship between the amount of movement,

use of refuge habitat, and size of the origin stream. Larger streams have greater discharge and encourage movement, while very small streams have relatively low discharge and allow maximum retention rates of indigenous fish. Furthermore, with the exception of upstream-moving juveniles, this suggests that most movement is not volitional, but instead represents displacement during freshets.

Construction of refuge habitat, such as ponds or opening up access to existing ponds, has been suggested as a management strategy to improve winter survival of juveniles. The above suggests that refuge habitat is more likely to be utilized if it is confluent to larger streams where fish seek relief from winter floods. Providing access to refuge habitat confluent to small streams or tributaries would probably not benefit fish living in an area where conditions are benign; however, fish that colonize refuge habitat during the summer should enjoy high survival rates during the winter, regardless of location.

Salvage Logging in Large Rivers; A Special Case:

Salvage logging of downed trees has been practiced intermittently from 1972 to 1984 on the Chickamin and Unuk Rivers of southeast Alaska. Newly introduced trees are cut above the root bole during spring low water periods and allowed to float downstream with rising streamflow during the summer. The logs ground out on the tide flats where they are collected.

Salvage loggers generally select the largest (most commercially valuable) trees, usually greater than 2 feet in diameter at the butt, and seldom harvest smaller trees. Woody debris in these rivers, especially larger material, provides significant midstream and off-channel habitat for juvenile chinook and coho salmon, and salvage logging, as presently practiced, may seriously reduce the carrying capacity of these rivers.

Salvage loggers selectively remove the largest trees, which are more permanent features of the river's habitat. Large trees are not easily moved by high streamflow; smaller trees are more easily floated and are quickly swept downstream. As in small streams, hydraulic action around grounded trees either in single or aggregate form scours pools and provides low-velocity environments that form the only habitat available for juveniles. In other areas of the river, streamflow is too great for successful rearing.

It has been argued that root boles from cut trees can provide adequate cover for juveniles. However, observers have found that root boles are too small to remain within the channel during higher streamflow and are more mobile; because of their mobility they seldom remain long enough to form pool habitat.

In past years, salvage loggers have removed 100-120 trees from each river annually. This is probably a harvest level far in excess of the natural recruitment rate. Between March 1984 and March 1985, only three new trees were added to the Unuk River (Paul Kissner, pers. comm.).

Land managers have estimated that the annual recruitment rate for the Unuk River is approximately 500 trees. This estimate, made on poor data, is too high; at that annual recruitment rate there would be few trees remaining in either the Chickamin or Unuk River valleys.

Salvage logging, as currently practiced, may be the most destructive form of timber harvest in southeast Alaska; it is not logging per se, but the removal of fish habitat. Continued removal of the logs from the Chickamin and Unuk Rivers will have the obvious and predictable effect of reducing the carrying capacity for juvenile chinook and coho salmon (if it has not done so already) and will impair the freshwater success of those stocks.

Allochthonous Energy Sources:

In forested streams, where there is little sunlight, energy enters aquatic communities through allochthonous litter fall in the form of leaves, twigs, needles, etc. and provides a source of carbon, nitrogen, and other nutrients. Organic particulates are consumed by aquatic organisms, which in turn are consumed by juvenile salmonids as food. This process occurs to a greater degree in headwater sections of streams where light penetration is poor, but in downstream sections of a stream, where the canopy permits greater amounts of light, stream communities utilize a mixture of autotrophic and heterotrophic energy pathways. Energy is accumulated via photosynthetic processes and by gathering fine particulate detritus transported downstream from headwater sections.

Clear-cutting induces a functional shift in the sense of the Stream Continuum Concept (Vannote et al., 1980) by changing the ecological function of upstream sections to that which is more representative of downstream sections. This shift of function in an upstream direction occurs without the benefit of upstream carbon input and could affect the diversity of aquatic communities and their functions. It is not known how these effects will impact fish communities, but it is presumed that function will return to normal when the second-growth forests develop along the stream margins.

Instream Woody Debris: Long-Term Aspects

Woody debris from forest sources is a critical feature of stream habitat in coastal Alaska and provides foraging and refuge sites for juveniles during summer and protection against floods during winter. LOD forms up to 70% of the habitat used by juveniles. Long-term changes may occur in the quality and quantity of LOD and LOD-formed habitat after clear-cutting.

Natural stream processes, such as mechanical abrasion, biological activity, and especially floods, gradually reduce and transport woody debris downstream. In forested streams, the downstream transport and replacement from the forest through windthrow, etc. is a continuous cycle and debris-formed habitat remains at relatively constant levels over time. But where streams have been clear-cut, the source of debris is eliminated and stream processes, uninterrupted, will continue to remove debris but do so without replacement.

Swanson and Lienkaemper (1978), using data from old forest fires, estimated that debris gradually disappears from streams and after 110 years instream debris is 50% of its former levels. Second-growth forests begin to contribute debris at about 110 years and debris loading is estimated to return to natural levels by 150+ years after source removal. Sedell and Triska (1977) report that debris accumulation in streams is even slower. They found that accumulation of debris is asymptotic and requires about 450 years to recover to natural levels in streams where all native material was removed.

The rate at which stream processes remove debris is unknown. Decay and removal rates in fresh water appear to be very slow because of low biological activity. Even on land, where decay rates are more rapid, downed logs can last from 100 to 200 years and large logs can last for over 450 years. In streams, the rate of removal probably depends on stream discharge; material may be very persistent in small streams but temporary in large streams and rivers.

Rearing salmonids are strongly associated with LOD and LOD-formed habitat. This relationship permits the calculation of the density of juveniles per volume of LOD with fair accuracy. Assuming a maximum of 50% loss of LOD in the first 110 years after clear-cutting, equations developed by Elliott (unpublished data) predict a loss of about 30% carrying capacity for juvenile coho salmon during the summer. Since juveniles are even more strongly associated with LOD during winter (Heifetz et al., in press), the total loss in annual carrying capacity could be as high as 50%.

Streamside logging at Carnation Creek has led to gradual and accelerating changes in stream morphometry caused by bank erosion and channelization due to the cutting of streamside trees and from debris transport caused by general logging techniques. These factors may cause continued degradation of habitat quality which will eventually compromise overwinter survival (Holtby and Hartman, 1982) and may undercut increases in summer production (Mason, 1976).

If left to themselves after clear-cutting, streams may, in time, gradually repair themselves. However, by 110-150 years after the first cutting, the forest will again be ready for harvest. This will occur at a time when instream debris may not have recovered sufficiently to support optimum densities of juveniles. The result of this scenario is a gradual and perhaps permanent debilitation of stream habitat and a decrease in the yield of salmonid smolt.

Buffer Zones:

Buffer zones have long been advocated as a management strategy to preserve the character of stream environments during and after logging. Buffers provide shade, which as seen in the preceding, prevents increases in water temperature during summer months. Streamside canopy is also thought, in some cases, to moderate winter low-temperature extremes, although the mechanisms are poorly understood and existing data inconclusive. Buffer zones prevent sedimentation by preserving and

maintaining streambanks, thereby preventing the destruction or alteration of stream benthos communities (Newbold et al., 1980; Culp and Davies, 1983) and reducing sediment-related mortality of incubating salmon eggs and alevins (Scrivener and Brownlee, 1982; Holtby and Hartman, 1982).

Finally, buffer zones can provide overhead cover for rearing juveniles, provide energy via allochthonous detritus, provide food through terrestrial insect contribution, and most importantly, provide a source of large woody debris needed to stabilize streambanks and provide in-stream habitat structures (Meehan et al., 1977) for summer and winter rearing.

Murphy and Koski (in press) showed that buffer zones in Southeast had the highest density of juvenile coho salmon during summer and winter compared to forested and clear-cut streams. They concluded that buffer zones provide increased light penetration, promoting primary and secondary productivity, while maintaining habitat quality at optimum levels.

Management strategies such as felling timber into streams to provide long-term volumes of debris for habitat formation have been suggested by managers. However, research and observations suggest that this material may be of limited use to juveniles and may become unstable during freshets. These techniques are utilized in Oregon and Washington, but have not always been successful. Continued research on appropriate types of debris and debris loading would be beneficial before the concepts are applied in the field.

A comparison of these two strategies will show that buffer zones are not only inexpensive relative to active management, but are certainly more effective in protecting the stream environment. They are almost a panacea. Unfortunately, they are frequently subject to wind damage. Even so, mass entry of windthrown trees into streams is not necessarily a problem, as windthrown tangles of debris provide excellent wintering habitat, albeit temporary in larger channels.

No investigation has been conducted in Southeast to establish design indices for buffer zones. Considering the value of this management technique, research on buffer zones would be a fruitful area of research.

CONCLUSIONS

Throughout the preceding text, findings from different studies would suggest that considerable contradiction or inconsistency occurs in their results. Inconsistency, however, appears to be a perception; all of these phenomena are well documented with well-supported conclusions and, as such, illustrate the wide variation in biotic response that can be expected to occur from such a complex and varied set of factors that is typical of logging effects. Furthermore, that some factors have not caused an observed effect on Southeast salmonids does not imply that these impacts are absent.

Studies outside the region have documented that logging does indeed affect salmonid populations; thus, there is a high probability that stocks in Alaska are similarly affected. The inability to detect logging effects in southeast Alaska may simply be due to a lack of adequate research. Inadequate research is defined as either the complete absence of research, lack of sophistication needed to detect complex effects, poor statistical design, or programs that are too short term to detect effects related to extremes in climatic conditions.

Findings on the major effects of logging with reference to Southeast are itemized below:

Streamflow:

1) Streamflow generally increases after logging. Variation in streamflow between watersheds after logging appears to be due to the amount of area harvested and the amount of roads.

   - Increased streamflow may increase the amount of rearing area and increase the production of rearing salmonids.

   - Increased streamflow may increase bank erosion and sedimentation causing lower egg-fry survival.

   - Increased flow may exacerbate sedimentation by shifting already destabilized woody debris.

2) Second growth may cause a reduction in streamflow relative to pre-logging flow regimes.

   - Decreased flow could reduce rearing-salmonid carrying capacity by reducing rearing area.

   - Decreased flow could result in warmer water, though this may be offset by improved shading.

   - Decreased flow may increase the frequency of adult "die-offs" during midsummer drought conditions.

Temperature:

Temperature increases in proportion to the amount of streamside canopy removal. Temperature should revert to normal regimes when second-growth canopy develops to a height capable of shading the stream.

Increased temperature can persist through the winter and shorten the development time of incubating salmon eggs and alevins, causing earlier emergence. Early-emerging pink and chum salmon fry may enter the estuary prior to spring blooms of marine plankton and experience a food shortage. Early-emerging coho and other rearing species enter streams at a time when floods are more common and may be swept downstream and lost to the system, causing reduced rearing density. Elevated primary productivity and longer growing season results in higher growth rates

and larger fish. Larger fish have greater summer and winter survival rates, yielding more smolts of larger size, which increases adult return. These effects are short-lived; second growth should reduce temperatures to pre-logging levels 15-20 years after cutting.

The timing of pink salmon runs is correlated with stream temperature. Changes in watershed temperature could inhibit upstream migration of adult pink, chum, and coho salmon.

Sedimentation:

Sedimentation can increase over natural levels as a result of catastrophic incidences attributable to human error, poor planning, or improper design and layout. Chronic sedimentation can occur as a result of increased streamflow and accelerated erosion, bank destruction, destabilization of midstream woody debris, destabilization or loss of debris that anchors stream banks, and the death of tree roots that support or strengthen stream banks.

- Sedimentation decreases egg-fry survival of salmonids.

- Intense pulses of sediment affect rearing salmonid behavior and decrease feeding and growth rate.

- Sedimentation can reduce rearing area by filling pools.

- Sedimentation can reduce benthos diversity and abundance.

- If sources of sedimentation are arrested, most fines are flushed from the system during freshets and are usually removed within 1 year.

- Streamside logging leads to gradual, but accelerating, changes in stream morphology with increasing rates of sedimentation and bedload movement and has been implicated in declining egg-fry survival at Carnation Creek.

Light Levels and Nutrients:

Solar penetration increases with timber canopy removal and, in conjunction with increased temperature and nutrients, leads to increased primary production, benthos production, and (where nutrients are abundant) density of coho fry during summer.

Changes in stream productivity are presumed to be, in part, responsible for higher growth rates and earlier smolt age of juvenile coho salmon. Increased production in some studies has been nullified by the winter carrying capacity, which is regulated by the amount of winter habitat.

Stream Habitat Structures:

In coastal forest streams, habitat is formed by the influence of streambank conifers and the introduction and incorporation of large woody debris. Woody debris and the low-velocity conditions it creates are essential for optimum rearing production.

Logging can overload streams with introduced debris. In large streams, debris is transported downstream where it can dislodge natural accumulations and cause channel modification and sedimentation. Debris in large streams generally does not create barriers to upstream migrants; streams scour passages under or around large jams.

In small streams, debris remains in place. Fresh green material can potentially cause a decrease in dissolved oxygen and its leachates can create conditions toxic to fish. Slash in small streams is dense and interlocked and can create barriers to upstream migrant adults.

Dense logging debris loses most of its leachates after 1 year and does not constitute a water quality problem thereafter. Dense accumulations do not inhibit rearing-salmonid production; in some cases, production may actually be increased by providing greater amounts of cover.

Over-zealous clearance of logging slash often removes natural as well as introduced material. Removal of too much debris deprives juveniles of cover and populations can be seriously reduced during fall freshets. Populations remain unstable for years afterward until stream habitat is rehabilitated.

Loss or destabilization of midstream woody debris, disturbance of debris that anchors stream banks, or death of tree roots that support bank structures can reduce the amount of high-quality rearing habitat. This reduces summer and winter carrying capacity and may affect smolt yield. Losses in smolt yield resulting from habitat degradation may nullify increases in summer productivity or, in conjunction with severe winters, may cause a net loss of smolt relative to pre-logging levels.

Long-term effects on habitat quality may result from stream destabilization as observed in Carnation Creek and from lack of recruitment of woody debris upon removal of streamside timber. Data suggest a 30-50% decrease in carrying capacity occurs 80 years after initial cutting of streamside conifers.

LITERATURE CITED

Alderdice, D. F., W. P. Wickett and J. R. Brett. 1958. Some effects of temporary exposure to low dissolved oxygen levels on Pacific salmon eggs. J. Fish. Res. Board Can. 15(2):229-250.

Anderson, H. W. 1971. Relative contribution of sediment from source areas and transport processes. Pages 55-63 in J. T. Krygier and J. D. Hall, eds. Proceedings of a symposium; forest land uses and stream environment. Oregon State University, Corvallis.

Bachman, R. A. 1982. A growth model for drift feeding salmonids: a selective pressure for migration. Pages 128-135 in E. L. Brannon and E. O. Salo, eds. Proceedings of salmon and trout migratory behavior symposium. University of Washington, Seattle.

Bachman, R. A. 1984. Foraging behavior of free-ranging wild and hatchery brown trout in a stream. Trans. Amer. Fish. Soc. 113:1-32.

Bachman, R. W. 1958. The ecology of four north Idaho trout streams with reference to the influence of forest road construction. M.S. thesis, University of Idaho, Moscow. 97 pp.

Baldwin, N. S. 1956. Food consumption and growth of brook trout at different temperatures. Trans. Amer. Fish. Soc. 86:323-328.

Baxter, G. 1961. River utilization and the preservation of migratory fish life. Proc. Instit. Civ. Eng. 18:225-244.

Berg, L. 1982. The effect of exposure to short-term pulses of suspended sedimentation on the behavior of juvenile salmonids. Pages 177-197 in G. F. Hartman, ed. Proceedings of the Carnation Creek workshop; a ten year review. February 24-26, 1982. Malaspina College, Nanaimo, British Columbia.

Benda, R. S. 1983. Slope failure, fine sediments, and pre-emergent alevin/egg pumping at U.S. Borax Quartz Hill mining development project. American Fisheries Society Annual Meeting, Alaska Chapter, Nov. 14, 1983, Soldotna, Alaska.

Berndt, H. W. and G. W. Swank. 1970. Forest land use and streamflow in Central Oregon. USDA Forest Service Res. Pap. PNW-93. Pac. NW For. and Ran. Exp. Sta., Portland, Oregon. 15 pp.

Berry, J. D. 1974. Modeling the impact of logging debris on the dissolved oxygen balance of small mountain streams. Master's thesis, Oregon State University, Corvallis.

Bishop, D. M. and M. E. Stevens. 1964. Landslides on logged areas in Southeast Alaska. U.S.D.A. Forest Service Res. Pap. NOR-1. Northern Forest Experiment Station, Juneau, Alaska. 18 pp.

Bjornn, T. C. 1969. Embryo survival and emergence studies. Idaho Fish and Game Dept. Federal Aid in Fish and Wildlife Restoration, Proj. F-49-R-7, Job No. 5. 11 pp.

Bjornn, T. C., M. A. Brusven, M. P. Molnau, J. H. Milligan, R. A. Klamt, E. Chacho and C. Schaye. 1977. Transport of granitic sediment in streams and its effects on insects and fish. For. Wildlife and Range Exp. Sta., Completion Rep., Water Resources Res. Inst. Proj. B-036-IDA, University of Idaho, Moscow, Idaho. 43 pp.

Blackett, R. F. 1968. Spawning behavior, fecundity, and early life history of anadromous Dolly Varden, *Salvelinus malma* (Walbaum), in Southeastern Alaska. Alaska Department of Fish and Game, Research Report No. 6, Juneau, Alaska. 85 pp.

Bormann, F. H. and G. E. Likens. 1970. The nutrient cycles of a watershed. Scientific American 223:92-100.

Brett, J. R. 1964. The respiratory metabolism and swimming performance of young sockeye salmon. J. Fish. Res. Board. Can. 21:1183-1226.

Brown, G. W. and J. T. Krygier. 1971. Clear-cut logging and sediment production in the Oregon Coast Range. Water Resources Res. 7:1189-1198.

Bryant, M. D. 1980. Evolution of large, organic debris after timber harvest: Maybeso Creek 1949-1978. USDA Forest Service Gen. Tech. Rep. PNW-10., Pac. NW Forest and Range Exp. Sta., Portland, Oregon.

Bryant, M. D. 1983. The role and management of woody debris in west coast salmonid nursery streams. N. Amer. J. Fish. Man. 3:322-330.

Buchanan, D. V., P. S. Tate and J. R. Moring. 1976. Acute toxicities of spruce and hemlock extracts to some estuarine organisms in southeastern Alaska. J. Fish. Res. Board Can. 33:1188-1192.

Burns, J. W. 1970. Spawning bed sedimentation studies in northern California streams. Calif. Fish and Game 56:253-270.

Bustard, D. R. and D. W. Narver. 1975a. Aspects of the winter ecology of juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Salmo gairdneri*). J. Fish. Res. Board Can. 32:667-680.

Bustard, D. R. and D. W. Narver. 1975b. Preferences of juvenile coho salmon (*Oncorhynchus kisutch*) and cutthroat trout (*Salmo clarki*) relative to simulated alteration of winter habitat. J. Fish. Res. Board Can. 32:681-687.

Cardinal, P. J. 1980. Habitat and juvenile salmonid populations in streams in logged and unlogged areas of southeastern Alaska. M.S. thesis, Montana State University, Bozeman. 115 pp.

Cedarholm, C. J. and W. J. Scarlett. 1982. Seasonal immigration of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. Pages 98-110 in E. L. Brannon and E. O. Salo, eds. Proceedings of a symposium; salmon and trout migratory behavior. University of Washington, Seattle.

Cedarholm, C. J., L. M. Reid, and E. O. Salo. 1981. Cumulative effects of logging road sediment on salmonid populations in the Clearwater River, Jefferson County, Washington. Pages 38-74 in Salmon spawning gravel: a renewable resource in the Pacific Northwest? Water Research Center, Pullman, Washington, Rep. No. 39.

Chamberlin, T. W. 1982. Timber harvest. in W. R. Meehan, ed. Influence of forest and rangeland management on anadromous fish habitat in western North America. USDA Forest Service Gen. Tech. Rep. PNW-136. Pac. NW For. Ran. Exp. Sta., Portland, Oregon. 30 pp.

Chapman, D. W. 1965. Net production of juvenile coho salmon in three Oregon streams. Trans. Amer. Fish. Soc. 94:40-52.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Amer. Nat. 100:345-357.

Coble, D. W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Trans. Amer. Fish. Soc. 90:469-474.

Cooper, A. C. 1965. The effects of transported stream sediments on the survival of sockeye and pink salmon eggs and alevins. International Pacific Salmon and Fish Commission Bull. 18. 71 p.

Cordone, A. J. and D. W. Kelly. 1961. The influences of inorganic sediment on the aquatic life of streams. Calif. Fish and Game 47(2):189-228.

Crone, R. A. and C. E. Bond. 1976. Life history of coho salmon, *Oncorhynchus kisutch*, in Sashin Creek, southeast Alaska. Fishery Bulletin 74:897-923.

Crouse, M. R., C. A. Callahan, K. W. Malueg and S. E. Dominquez. 1981. Effects of fine sediments on growth of juvenile coho salmon in laboratory streams. Trans. Amer. Fish. Soc. 110:281-286.

Culp, J. M. and R. W. Davies. 1983. An assessment of the effects of streambank clear-cutting on macroinvertebrate communities in a managed watershed. Can. Tech. Rep. Aquat. Sci. 1208. 115 p.

Dill, L. M., R. C. Ydenberg and A. H. G. Fraser. 1981. Food abundance and territory size in juvenile coho salmon (*Oncorhynchus kisutch*). Can. J. Zool. 59:1801-1809.

Dinneford, W. B. and S. T. Elliott. 1975. Ecology of rearing fish. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1974-1975, Project F-9-7, 16 (D-I):1-46.

Dolloff, C. A. 1983. The relationship of wood debris to juvenile salmonid production and microhabitat selection in small southeast Alaska streams. Ph.D. dissertation. Montana State University Bozeman.

Edgerton P. J. and B. R. McConnel. 1976. Diurnal temperatures of logged and unlogged mixed conifer stands on elk summer range. USDA Forest Service Res. Note PNW-277. Pac. NW For. Ran. Exp. Sta. Portland, Oregon. 6 pp.

Elliott, S. T. in press. Reduction of a Dolly Varden population and macrobenthos after removal of logging debris. Trans. Amer. Fish. Soc.

Elliott, S. T. and R. D. Reed. 1974. Ecology of rearing fish. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Report of Progress, 1973-1974, Project F-9-6, 15(D-I):9-43.

Fredriksen, R. L. 1970. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small Oregon watersheds. USDA Forest Service Gen. Tech. Rep. PNW-104. Pac. NW For. Ran. Exp. Sta., Portland, Oregon.

Fredriksen, R. L. 1971. Comparative chemical water quality - natural and disturbed streams following logging and slash burning. Pages 125-137 in J. T. Krygier and J. D. Hall, eds. Proceedings of a Symposium; forest land uses and stream environment. Oregon State University, Corvallis.

Gangmark, H. A. and R. D. Broad. 1956. Further observations on stream survival of king salmon. Calif. Fish and Game 42:37-49.

Gangmark, H. A. and R. G. Bakkala. 1960. A comparative study of stable and unstable spawning areas for incubating king salmon at Mill Creek. Calif. Fish and Game 46:151-164.

Gard, R. 1963. Insulation of a sierra stream by snow cover. Ecology 44:194-197.

Geiger, R. 1965. The climate near the ground. Harvard University Press, Cambridge, Mass. Pages 316-321.

Gibbons, D. R. and E. O. Salo. 1973. An annotated bibliography of the effects of logging on fish of the western United States and Canada. USDA Forest Service Gen. Tech. Rep. PNW-10, Pac. NW For. Ran. Exp. Sta., Portland, Oregon. 145 pp.

Gilleran, D. J. 1968. Rapid calibration of coastal streams to detect effects of road building. Master's thesis, Oregon State University, Corvallis. 51 pp.

Hahn, P. J. K. 1977. Effects of fluctuating and constant temperature on behavior of steelhead trout (*Salmo gairdneri*). Ph.D. dissertation, University of Idaho, Moscow.

Hall, J. D. and C. O. Baker. 1975. Biological impacts of organic debris in Pacific Northwest streams. In Workshop on logging debris in streams. Oregon State University, Corvallis. 13 pp.

Hall, J. D. and R. L. Lantz. 1969. Effects of logging on habitat of coho salmon and cutthroat trout in coastal streams. Pages 355- 375 in T. G. Northcote, ed. Symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver.

Hall, J. E. and D. O. McKay. 1983. The effects of sedimentation on salmonids and macroinvertebrates - a literature review. Alaska Department of Fish and Game, Habitat Division, Anchorage, Alaska.

Hansmann, E. W. and H. K. Phinney. 1973. Effects of logging on periphyton in coastal streams of Oregon. Ecology 54:194-199.

Harper, W. C. 1969. Changes in storm hydrographs due to clear-cut logging of coastal watersheds. Master's thesis, Oregon State University, Corvallis, Oregon. 116 pp.

Harr, R. D. 1980. Effects of timber harvest on streamflow in the rain-dominated portion of the Pacific Northwest. In Proceedings, workshop on scheduling timber harvest for hydrologic concerns, 27-29 November 1979, Portland, Oregon. 45 pp.

Harr, R. D., W. C. Harper, J. T. Krygier and F. S. Hsieh. 1975. Changes in storm hydrographs after road building and clear-cutting in the Oregon Coast Range. Water Resources Res. 11:436-444.

Hartman, G. F., B. C. Andersen and J. C. Scrivener. 1982. Seaward movement of coho salmon (*Oncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal stream in British Columbia. Can. J. Fish. Aquat. Sci. 39:588-597.

Hartman, G. F. and L. B. Holtby. 1982. An overview of some biophysical determinants of fish production and fish population responses to logging in Carnation Creek, British Columbia. Pages 348-374 in G. F. Hartman, G. F. ed. Proceedings of the Carnation Creek workshop; a ten year review. February 24-26, 1982. Malaspina College, Nanaimo, British Columbia.

Hayes, F. R., I. R. Wilmot and D. A. Livingstone. 1951. The oxygen consumption of the salmon egg in relation to development and activity. J. Exp. Zool. 116:337-395.

Heifetz, J., M. L. Murphy and K V. Koski. in press. Effects of logging on winter habitat of juvenile salmonids in Alaskan streams. N. Amer. J. Fish. Man. 6.

Hermann, R. B., C. E. Warren and P. Doudoroff. 1962. Influence of oxygen concentrations on the growth of juvenile coho salmon. Trans. Amer. Fish. Soc. 91:153-167.

Holtby, L. B. and G. F. Hartman. 1982. The population dynamics of coho salmon (*Oncorhynchus kisutch*) in a west coast rain forest stream subjected to logging. Pages 308-348 in G. F. Hartman, ed. Proceedings of the Carnation Creek workshop; a ten year review. February 24-26, 1982. Malaspina College, Nanaimo, British Columbia.

Hsieh, F. S. 1970. Storm runoff response from road building and logging on small watersheds in the Oregon Coast Range. Master's thesis, Oregon State University, Corvallis. 147 pp.

Hunt, R. L. 1969. Effects of habitat alteration on production, standing crops, and yield of brook trout in Lawrence Creek, Wisconsin. Pages 281-312 in T. G. Northcote, ed. Symposium on salmon and trout in streams. H. R. Macmillan Lectures in Fisheries. University of British Columbia, Vancouver.

Jones, D. R. 1971. The effect of hypoxia and anemia on the swimming performance of rainbow trout (*Salmo gairdneri*). J. Exp. Biol. 55:541-551.

Kirchhoff, M. D. and J. W. Schoen. 1984. Seasonal distribution and habitat use by Sitka black-tailed deer in southeast Alaska. Alaska Department of Fish and Game, Federal Aid in Wildlife Restoration, Progress Report W-22-, Job 2.R, 1983-1984. 20 pp.

Koski, K V. 1966. 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 pp.

Koski, K V. and R. A. Walter. 1977. Forest practices in relation to management of Alaskan coastal zone resources: a review with management and guideline recommendations. Unpublished report. U.S. Department of Commerce, NOAA, National Marine Fisheries Service, Northwest and Alaska Fisheries Center Auke Bay Laboratory, Auke Bay, Alaska. 189 pp.

Kraft, M. E. 1968. The effects of controlled dewatering on a trout stream. M.S. thesis, Montana State University, Bozeman. 31 pp.

Kraft, M. E. 1972. Effects of controlled flow reduction on a trout stream. J. Fish. Res. Board. Can. 29:1405-1411.

Lindroth, A. 1942. Sauerstoffverbrauch der fische. I. Verschiendene entwicklungsund altersstadien vom lachs und hecht. Z. Vergl. Physiol. 29:583-594.

Mason, J. C. 1976. Response of underling coho salmon to supplemental feeding in a natural stream. J. Wildl. Man. 40:775-788.

Mason, J. C. and D. W. Chapman. 1965. Significance of early emergence, environmental rearing capacity, and behavioral ecology of juvenile coho salmon in stream channels. J. Fish. Res. Board Can. 22:173-190.

McCuddin, M. E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. Master's thesis, University of Idaho, Moscow. 30 pp.

McFadden, J. T. 1969. Dynamics and regulation of salmonid populations in streams. Pages 313-329 in T. G. Northcote, ed. Proceedings of a symposium on salmon and trout in streams. H. R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver.

McNeil, W. J. 1980. Vulnerability of pink salmon populations in streams. Pages 147-151 in W. J. McNeil and D. C. Himsworth, eds. Salmon ecosystems of the north Pacific. Oregon State University Press, Corvallis.

McNeil, W. J. and W. H. Ahnell. 1964. Success of pink salmon spawning relative to size of spawning bed materials. U.S. Fish and Wildlife Service Spec. Sci. Rep. Fish. 469. 15 pp.

Meehan, W. R. 1970. Some effects of shade cover on stream temperatures in southeast Alaska. USDA Forest Service Res. Note PNW-113. Pac. NW. For. Ran. Exp. Sta., Portland, Oregon.

Meehan, W. R., F. J. Swanson and J. R. Sedell. 1977. Influence of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. Pages 137-145 in R. R. Johnson, tech. coord. Importance, preservation and management of riparian habitat: Proceedings of a symposium, 1977, Tucson, Arizona. USDA Forest Service, Gen. Tech. Rep. RM-43. Rocky Mountain Forest and Range Exp. Sta., Fort Collins, Colo.

Meehan, W. R., W. A. Farr, D. M. Bishop and J. H. Patric. 1969. Some effects of clear-cutting on salmon habitat of two southeast Alaska streams. USDA Forest Service Res. Pap. PNW-82. Pac. NW Forest and Range Exp. Sta., Portland, Oregon. 45 pp.

Merrell, T. R. 1951. Stream improvement as conducted in Oregon on the Clatskanie River and tributaries. Fish Commission of Oregon Briefs 3:41-47.

Moring, J. R. 1975a. The Alsea watershed study: effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part II--Changes in environmental conditions. Oreg. Dept. Fish and Wildl., Fish. Res. Rep. 9. 39pp.

Moring, J. R. 1975b. The Alsea watershed study: effects of logging on the aquatic resources of three headwater streams of the Alsea River, Oregon. Part III-Discussion and recommendations. Oregon Dept. Fish and Wildl. Fish. Res. Rep. 9. 24 pp.

Murphy, M. L. in press. Fish kills of adult pink salmon and chum salmon in Southeast Alaska. N. Amer. J. Fish. Man.

Murphy, M. L. and J. D. Hall. 1981. Varied effects of clear-cut logging on predators and their habitat in small streams of the Cascade Mountains, Oregon. Can. J. Fish. Aquat. Sci. 38:137-145.

Murphy, M. L. and K V. Koski. in press. Links between habitat, juvenile salmonids, and the effects of logging in southeast Alaska. Can. J. Fish. Aquat. Sci.

Myren, R. T. and R. J. Ellis. in press. Evapotranspiration in forest succession and long-term effects upon fishery resources: a consideration for management of our old-growth forests. In Proceedings of a symposium on old-growth forest relationships. Amer. Instit. Fish. Res. Biologists, Juneau, Alaska.

Narver, D. W. 1971. Effects of logging on fish production. Pages 100-110 in J. T. Krygier and J. D. Hall, eds. Proceedings of Symposium on forest land uses and stream environment. Oregon State University, Corvallis.

Neave, F. 1953. Principles affecting the size of pink and chum salmon populations in British Columbia. J. Fish. Res. Board Can. 9(9):-450-490.

Newbold, J. D., D. C. Erman and K. B. Roby. 1980. Effects of logging on macroinvertebrates in streams with and without buffer strips. Can. J. Fish. Aquat. Sci. 37:1076-1085.

Nickelson, T. E. and R. E. Hafele. 1978. Streamflow requirements of salmonids. Oregon Dept. Fish and Wildl. Prog. Rep. AFS-62. Portland, Oregon. 25 pp.

Nickelson, T. and R. R. Reisenbichler. 1977. Streamflow requirements of salmonids. Oreg. Dept. Fish and Wildl. Prog. Rep. AFS-62. Portland, Oregon. 12 pp.

Noggle, C. C. 1978. Behavioral, physiological, and lethal effects of suspended sediment on juvenile salmonids. Master's thesis, University of Washington, Seattle.

Novak, P. 1975. Study of land use - salmon problems and planning in Southeast Alaska. Alaska Department of Fish and Game Technical Report, July 1, 1973 to June 30, 1974 (unpublished). 111 pp.

Patric, J. H. 1967. Frost depth in forest soils near Juneau, Alaska. USDA Forest Service Res. Note PNW-60. Pac. NW For. Ran. Exp. Sta., Portland, Oregon. 7 pp.

Pella, J. J. and R. T. Myren. 1974. Caveats concerning evaluation of effects of logging on salmon production in southeastern Alaska from biological information. Northwest Science 48:132-144.

Peters, G. B., M. J. Dawson, B. F. Hrutier and R. R. Whitney. 1976. Aqueous leachate from western red cedar: effects on some aquatic organisms. J. Fish. Res. Board Can. 33:2703-2709.

Peterson, N. P. 1982. Immigration of juvenile coho salmon (*Oncorhynchus kisutch*) into riverine ponds. Can. J. Fish. Aquat. Sci. 39:1308-1310.

Phillips, R. W. and J. H. Campbell. 1961. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in spawning beds. 14th Annual Report of the Pacific Marine Fisheries Commission, Portland, Oregon. p. 60-73.

Phillips, R. W., R. L. Lantz, E. W. Claire and J. R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Trans. Amer. Fish. Soc. 104(3):461-466.

Ponce, S. L. 1974. The biochemical oxygen demand of finely divided logging debris. Water Resources Res. 10:983-988.

Reed, R. D. and S. T. Elliott. 1972. Effects of logging on Dolly Varden. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Report of Progress, 1971-1972, Project F-9-4, 13(R-IV-B):1-62.

Reiser, D. W. and T. C. Bjornn. 1979. Habitat requirements of anadromous salmonids. In W. R. Meehan, ed. Influence of forest and rangeland management on anadromous fish habitat in western North America. USDA Forest Service Gen. Tech. Rep. PNW-96. Pac. NW Forest and Range Exp. Sta., Portland, Oregon. 54 pp.

Reiser, D. W. and R. G. White. 1983. Effects of complete redd dewatering on salmonid egg-hatching success and development of juveniles. Trans. Amer. Fish. Soc. 112:532-540.

Rienhart, K. G., A. R. Eschner and G. R. Trimble. 1963. Effect on streamflow of four forest practices in the mountains of West Virginia. USDA Forest Service Res. Pap. NE-1. Upper Darby, Pennsylvania. 79 pp.

Rimmer, D. M. and U. Paim. 1984. Changes in the selection of microhabitat by juvenile atlantic salmon (Salmo salos) at the summer-full transition in a small river. Con. J. Fish. Aquat. Sci. 41:469-475.

Rothacher, J. 1965. Streamflow from small watersheds on the western slope of the Cascade Range of Oregon. Water Resources Res. 1:125-134.

Rothacher, J. 1970. Increases in water yield following clear-cut logging in the Pacific Northwest. Water Resources Res. 6(2):653-658.

Rothacher, J. 1971. Regimes of streamflow and their modification by logging. Pages 40-54 in J. T. Krygier and J. D. Hall, eds. Forest land uses and stream environment. Oregon State University, Corvallis.

Rowe, P. B. 1963. Streamflow increases after removing woodland-riparian vegetation from a southern California watershed. J. Forestry 61(5):365-370.

Schmidt, A. E. 1979. Inventory and cataloging of sport fish waters in Southeast Alaska. Alaska Department of Fish and Game, Federal Aid in Fish Restoration Annual Report of Performance, 1978-1979, Project F-9-11, 20(G-I-R). 131 pp.

Scrivener, J. C. and B. C. Andersen. 1984. Logging impacts and some mechanisms that determine the size of spring and summer populations of coho salmon fry (*Oncorhynchus kisutch*) in Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 41:1097-1105.

Scrivener, J. C. and M. J. Brownlee. 1981. A preliminary analysis of Carnation Creek gravel quality data, 1973-1980. Pages 195-226 in Salmon spawning gravel: a renewable resource in the Pacific Northwest? Water Research Center, Pullman, Washington. Rep. No. 39.

Scrivener, J. C. and M. J. Brownlee. 1981. An analysis of Carnation Creek gravel-quality data, 1973-1981. Pages 154-176 in G.F. Hartman ed. Proceedings of the Carnation Creek workshop; a ten year review. February 24-26, 1982. Malaspina College, Nanaimo, British Columbia.

Sedell, J. R. and F. J. Triska. 1977. Biological consequences of large organic debris in northwest streams. In Logging debris II, Applications of stream cleanup. Oregon State University, Corvallis. 10 pp.

Seegrist, D. W. and R. Gard. 1972. Effects of floods on trout in Sagehen Creek, California. Trans. Amer. Fish. Soc. 101:478-482.

Sheridan, W. L. 1962. Relation of stream temperatures to timing of pink salmon escapements in southeast Alaska. Pages 87-102. in Symposium on pink salmon. H. R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver.

Sheridan, W. L. 1982. Pink salmon escapements in some logged and unlogged streams in Southeast Alaska. Unpublished manuscript. USDA Forest Service. 32 pp.

Sheridan, W. L. and A. M. Bloom. 1975. Effects of canopy removal on temperatures of some small streams in southeast Alaska. USDA Forest Service, Admin. Rep. Alaska Region, Juneau. 13 pp.

Sheridan, W. L. and W. J. McNeil. 1968. Some effects of logging on two streams in Alaska. J. For. 66:128-133.

Shumway, D. L., C. E. Warren and P. Duodoroff. 1964. Influence of oxygen concentration and water movement on the growth of steelhead trout and coho salmon embryos. Trans. Amer. Fish. Soc. 93:-342-356.

Sigler, J. W., T. C. Bjornn and F. H. Everest. 1984. Effects of chronic turbidity on density and growth of steelhead trout and coho salmon. Trans. Amer. Fish. Soc. 113:142-150.

Silver, S. T., C. E. Warren and P. Duodoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Amer. Fish. Soc. 92(4):327-343.

Skeesick, D. G. 1970. The fall immigration of juvenile coho salmon into a small tributary. Oregon Fish Commission Res. Rep. 2:1-6.

Smith, O. R. 1940. Placer silt and its relation to salmon and trout on the Pacific coast. Trans. Amer. Fish. Soc. 69:225-230.

Smoker, W. A. 1953. Streamflow and silver salmon production in western Washington. Wash. Dept. Fish. Res. Pop. 1:5-12.

Stockner, J. G. and K. R. Shortreed. 1975. Attached algal growth in Carnation Creek: a coastal rain forest stream on Vancouver Island, British Columbia. Fish. Mar. Serv. Dev. Tech. Rep. 558. 64 pp.

Swanson, F. J., J. R. Sedell and G. W. Lienkaemper. 1977. Studies of organic debris in several southeast Alaska streams. USDA Forest Service, Final Report, Grant PNW-48, Juneau, Final Report. 15 pp.

Swanson, F. J. and G. W. Lienkaemper. 1978. Physical consequences of large organic debris in Pacific Northwest streams. USDA Forest Service Gen. Tech. Rep. PNW-69 Pac. NW Forest and Range Exp. Sta., Portland, Oregon. 12 pp.

Swanston, D. M. 1974. Slope stability problems associated with timber harvesting in mountainous regions of the western United States. USDA Forest Service Gen. Tech. Rep. PNW-21, Pac. NW For. Ran. Exp. Sta., Portland, Oregon. 14 p.

Tappel, P. D. and T. C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. N. Amer. J. Fish. Man. 3:123-135.

Thompson, K. 1972. Determining stream flows for fish life. Pages 31-50 in Proceedings, Instream flow requirement workshop, Pac. Northwest River Basin Comm., Vancouver, Washington.

Tschaplinski, P. J. and G. F. Hartman. 1983. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) before and after logging in Carnation Creek, British Columbia, and some implications for overwinter survival. Can. J. Fish. Aquat. Sci. 40:452-461.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell and C. E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 40:452-461.

Weber, P. K. 1981. Comparisons of the lower trophic levels of small stream communities in forest and clear-cut sites, southeast Alaska. Ph.D. dissertation, University of Washington, Seattle. 228 pp.

Weshe, T. A. 1973. Parametric determination of minimum streamflow for trout. Wyoming Water Resources Ser. No. 37. Water Resources Instit., University of Wyoming, Laramie. 102 pp.

Weshe, T. A. 1974. Relationship of discharge reductions to available trout habitat for recommending suitable streamflows. Wyoming Water Resources Ser. No. 53. Water Resources Instit., University of Wyoming, Laramie. 71 pp.

Whitmore, C. M., C. E. Warren and P. Doudoroff. 1960. Avoidance reactions of salmonids and centrachid fishes to low oxygen concentrations. Trans. Amer. Fish. Soc. 89:17-26.

Wickett, W. P. 1954. The oxygen supply to salmon eggs in spawning beds. J. Fish. Res. Board Can. 11(6):933-953.

Wickett, W. P. 1962. Environmental variability and reproduction potentials of pink salmon in British Columbia. Pages 73-86 in N. J. Wilimovsky, ed. Symposium on pink salmon. H. R. MacMillan Lectures in Fisheries. University of British Columbia, Vancouver.

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