Impacts of Clearcut Logging on the Fish and Wildlife Resources of Southeast Alaska

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INTRODUCTION

Logging, as currently practiced and planned in southeast Alaska, has the potential to significantly and permanently alter large amounts of wildlife habitat. Wildlife species which are adapted to use existing habitat may decline and associated recreational and subsistence uses may be substantially reduced.

Clearcut logging, with no post-logging treatment, is generally the primary type of silvicultural system in southeast Alaska. The Forest Service is currently interpreting the Alaska National Interest Lands Conservation Act (ANILCA) as a mandate to offer for harvest 450 MMbf of timber yearly, which will result in the scheduling of an average of 158,000 acres of old growth for timber harvest during this decade alone. Once cut, stands will be managed on a multiple-entry rotation schedule of 80-125 years. Thus, old-growth stands on federal lands will be permanently converted to second-growth stands. While second-growth trees will reach maturity prior to subsequent harvest, many of the forest stand characteristics which develop in older stands will not recur. The major long-term impacts of this harvest schedule on wildlife species and numbers will depend on how the habitat characteristics will be altered through forest management relative to the species' habitat requirements. Significant timber harvests are also occurring on state and privately-owned lands.

Human activities associated with logging can also have both significant short-term and long-term effects on wildlife populations. Roads will be built in roadless areas, camps and facilities will be established, and accessibility to wildlife populations will increase dramatically. Harvest rates and human encounters with animals which are sensitive to human disturbance, such as mountain goat, brown bear and wolf, will increase.

The habitat requirements of many wildlife species in southeast Alaska are not well known. However, evidence is mounting that a number of species present in southeast Alaska are dependent on old-growth, spruce-hemlock forest for their survival. Extensive research has been conducted on the Sitka black-tailed deer (Odocoileus hemionus sitkensis) in southeast Alaska and other areas of its range. Certain types of old-growth stands provide critical winter habitat for the animals during severe winters and largely determine carrying capacity. Research in southeast Alaska has also documented the importance of old-growth forests to mountain goats (Oreamnus americanus), black and brown bears (Ursus americanus and U. arctos, respectively), moose (Alces alces), several furbearer species, cavity-nesting forest birds, bald eagles (Haliaeetus leucocephalus), Vancouver Canada geese (Branta canadensis fulva), and blue grouse (Dendragapus obscurus). Concern is growing over the rate at which old-growth forest is being converted into second growth and the likely impacts on wildlife populations.

GENERAL RELATIONSHIP OF WILDLIFE TO THEIR HABITAT

Wildlife habitat requirements can be generalized as food, water, cover, and special requirements such as those needed for breeding or denning areas, or migratory routes. Cover is essential for prey animals (e.g. deer), providing areas to hide from predators (e.g. wolves) or for a more sheltered environment from winds and deep snowfall. Food, breeding, and denning areas are extremely variable requirements, ranging from the needs of a tree cavity-nesting, insect-eating bird to that of a black bear that dens and gives birth in a hollow tree, then forages throughout the forest from spring through fall.

To determine how many animals a specific land area can support requires the determination of habitat requirements for each species and the interactions of the different species. The number of animals of a single species that can be supported is ultimately limited by whichever of its habitat requirements is in lowest supply, unless predation or disease has a severe impact on the population levels. This limiting factor will be different for different species. For example, deer numbers may be limited by the amount of nutritious, abundant food present while woodpecker numbers may be limited by the number of suitable nesting cavities present. Numbers of predators, such as wolves, may be indirectly limited by the same factors which limit the numbers of their prey species. The effects of a limiting factor can vary as well. Deer and wolves that cannot get enough food die of starvation and/or fail to reproduce; woodpeckers fail to nest and reproduce or move to another area where they search for unoccupied nesting holes. Over time, animal population numbers fluctuate as animals are born and die, but the amount and quality of habitat ultimately determines the upper limit of animals that can be supported by a given area. As habitat is altered, this upper limit, or carrying capacity, is also altered.

Although it is not always possible to determine the exact habitat requirements of all species, one general rule of ecology is that more species can be supported by a habitat with a diversity of conditions than one that is more homogeneous. Habitat diversity provides a variety of conditions which can meet the requirements of many wildlife species.

One primary type of diversity is structural diversity. Layers of vegetation contribute to structural diversity. In the forest, trees provide vertical structural diversity. A stand of trees can significantly modify the climate within the stand by intercepting snow and serving to break the force of winds. The trees provide a number of niches for animals that live or breed in tree cavities, feed on bark and leaves, den in dead, hollow logs, or use the tree foliage as cover for hiding from danger. Plants growing on the ground and litter fall from the trees add to diversity, providing more abundant and varied winter foods for browsing and grazing animals than may be available in open areas that have deep snow accumulations. Shrubs add another layer of structural diversity, providing different food sources, nesting habitat, and better cover. The structural complexity of an area may satisfy a diversity of habitat requirements. A second important type of diversity is provided by the spatial distribution of different habitat types referred to as "patch diversity." Areas with different plants or structural diversity in close proximity can support animals that require more than one habitat type to meet all its survival needs. The pattern of habitat interspersion is a key consideration of habitat diversity, however the productivity of each habitat type must also be considered.

DESCRIPTION OF OLD-GROWTH FORESTS AND SERAL STAGES FOLLOWING CLEARCUTTING

OLD-GROWTH FORESTS

The term "old growth" refers to uneven-aged forests that have developed without major disturbance over a period of centuries. Old growth is an ecological concept related to composition, structure, and function of a forest stand that has reached its climax stage (Franklin et al. 1981).

Sitka spruce (Picea sitchensis) and western hemlock (Tsuga heterophylla) dominate the old-growth forest overstory in southeast Alaska. On some less productive sites, mountain hemlock (Tsuga mertensiana), western red cedar (Thuja plicata), and/or Alaska cedar (Chamaecyparis nootkatensis) may also exist as associate species. The understory of old growth is composed of shade tolerant conifer seedlings, saplings, and small trees in a wide range of size classes, plus diverse shrub, fern, herb, bryophyte, and lichen species (Alaback 1982). Many wildlife species find their optimum habitat either year-round or seasonally in old-growth forest.

An evaluation of the structural components of old-growth provides considerable insight into why it is preferred habitat of many species. Structurally, old-growth forests are characterized by the presence of large (greater than 3 foot diameter) trees, snags, and fallen logs on land and in streams; an uneven-size and aged forest stand composition; well-developed, multi-storied canopies with large diameter limbs and large overstory crown radii; diverse, and often patchy, shrub and herb understory; and snags, fallen logs, and dying standing trees in a variety of stages of decomposition (Franklin et al. 1981, Schoen et al. 1981, Alaback 1982). No other stage of forest succession provides these characteristics.

The functional qualities of old-growth forests have been summarized by the Society of American Foresters Task Force on Scheduling the Harvest of Old-Growth Timber (SAF 1984). The standing crop of wood fiber in climax forests remains stable or increases slowly over centuries with net primary production offsetting mortalities. The proportion of shade tolerant species may increase with time, and in southeast Alaska, spruce may comprise less than one tree/acre in some old-growth stands (Alaback 1982). Erosion and nutrient losses are lower in old-growth forests than other successional stages; water quality in streams associated with old growth is typically high. Old-growth forests are generally prolific conifer seed producers. Old growth, with its multi-layered canopy, allows enough light to reach the forest floor so that understory production is high, while intercepting sufficient snow to make that forage available to herbivores (e.g. deer) in winter (Wallmo and Schoen 1980). In addition, forage quality of blueberry (Vaccinnium spp.) and bunchberry (Cornus canadensis (important foods for herbivores) is higher in old growth than in clearcut stands (Billings and Wheeler 1979, Rose 1982, Schoen and Kirchhoff 1983).

The final element of old-growth forests relates to time. It takes 150 to 250 years before even-age stands begin to develop more diverse canopy structure and heterogenous understory (Alaback 1982). Considerably more time is required to develop an uneven-aged forest composition, diverse snag production, and large accumulations of large diameter woody debris in various stages of decomposition. Three hundred or more years may be required to create old growth on productive sites and slower growing sites will take even longer. Old growth, for practical purposes, is a nonrenewable resource under rotations of up to 150 to 250 years in length.

Once the climax successional stage of the spruce-hemlock stands is reached, the forest remains in an old-growth condition until a major disturbance such as windthrow, fire, landslide, or cutting destroys the standing forest. The frequency of such natural occurrences is relatively low in southeast Alaska, as the high ratio of old growth to young forest indicates. Old growth is a stable, albeit dynamic habitat that can persist for centuries. Mortality occurs among individual trees or small clumps within the stand, thus perpetuating patches of "young growth." This renewal process is an inherent feature of old growth and allows early successional species, such as Sitka spruce, Pacific elderberry (Sambucus racemosa), and trailing black currant (Ribes laxiflorum) to persist in varied abundance in old-growth stands and perpetuates uneven-aged forests with high vertical and horizontal structural diversity.

Commercial old-growth forests in southeast Alaska differ widely in appearance and in structural and functional qualities. The net inventory volume (merchantable wood biomass) of commercial old growth, for example, ranges from 8,000 to over 100,000 board feet per acre depending on site productivity and stand history. In general, however, stands having in excess of 30,000 board feet per acre are considered high volume and commercially important, and make up a relatively small percentage (13%) of the commercial forest-land base in the Tongass National Forest (Smith et al. 1983). High-volume stands typically occur at lower elevations in well-drained, U-shaped valley bottoms or near tidewater. They are characterized by larger trees, a higher proportion of spruce, and a more open understroy than low-volume stands. Different types of old growth, by virtue of their unique structural and functional characteristics, can be viewed as ecologically distinct habitats.

EARLY SUCCESSIONAL CLEARCUTS

The pattern of forest succession on the Tongass National Forest has been documented by Harris and Farr (1979) and Alaback (1982). The removal of old-growth forests by clearcutting generally retains the understory vegetation, except where severe soil disturbance and landslides occur. In situations where timber utilization is relatively high, vascular plant production recovers within 3 years following logging, and shrub and herb production increases linearly until the stand reaches about 20 years of age. Reduced utilization standards which result in leaving large amounts of uneconomic timber and slash in clearcuts is likely to retard this recovery or result in different patterns of colonization. In situations where rapid recovery occurs, understory biomass peaks at about 5,000 lbs/acre 15 to 25 years after clearcutting and is generally at the highest level for any age of forest. Woody shrubs comprise the bulk of the understory production, but fern and forb growth may also be relatively high in some early successional clearcuts.

Tree regeneration following clearcutting is generally excellent (Ruth and Harris 1979), with canopy cover approaching 100% on productive forest soils 15 to 25 years after logging. On soils with lower conifer site indices, canopy closure may be delayed.

Within 10 years of canopy closure, understory biomass becomes essentially absent (Alaback 1982). Forb and fern losses are most rapid, with woody shrub biomass (e.g. blueberry species, Vaccinium spp.) persisting somewhat longer. Snags, unless specifically retained, are absent, as are any large diameter trees for future snags and tree cavities. Logging residue, including limb debris and large downed logs, is substantially higher than in undisturbed old growth.

Much of the understory in early clearcuts results from the substantial understory that existed in the old-growth forest before clearcutting. In contrast, understory succession following logging of second-growth forests lacking forbs, ferns, and deciduous shrubs will undoubtedly be significantly different. This aspect of forest succession has not been studied in southeast Alaska.

Clearcuts can also directly affect the stability of the adjoining forests. The loss of the forest trees over a large area results in a simultaneous decay of all the large root structures that aid in soil stabilization. On steep slopes (generally those over 75%), the breakdown of the roots triggers landslides (Burke 1983, Doug Swanston, per. comm.) which may destroy forests downslope and deposit large amounts of silt in streams. For example, 116 landslides occurred in the Maybeso Valley within 9 years of clearcutting compared to only 13 landslides in the 100 years prior to logging (Bishop and Stevens 1964).

Clearcutting exposes the surrounding forest to greater risks of blowdown (Ruth and Harris 1979). This increased risk has not been well quantified, but it is evident that hundreds or thousands of acres of old growth along the edges of clearcuts are damaged or lost each year to windstorms. The frequency and degree of windthrow is many times higher in old growth adjoining clearcuts than in forests removed from cutting areas. "Salvage sales," on public lands designed to utilize windthrown timber, often incorporate additional old growth to enhance the economics of the sale. The net result is an "unravelling" of the surrounding forest and clearcut sizes significantly larger than originally planned.

It should be noted that this early seral stage occurring immediately after clearcutting is temporary and of rather short duration relative to the harvest rotation commonly planned for areas of southeast Alaska.

POLE STANDS

By 25 to 35 years of age, the forest stand that has received no post-logging treatment has generally developed into a pole-sized stand. Trees are small, densely stocked, and of uniform size compared to old growth. Canopies lack depth and well developed, large-limbed crowns. However, canopy cover may exceed 90 percent due to the high stem density. Large diameter snags and snag replacement trees are absent, although large-diameter logs may persist for more than 70 years. The forest floor of pole stands is dominated by mosses with less than 100 lbs/acre standing biomass of shrubs and herbs (Alaback 1982). Mosses increase significantly in biomass for the next 110 to 130 years if the site is not disturbed (Alaback 1982). In some cases, ferns become the dominant vascular plant in the understory about 50 to 60 years after logging (Alaback 1982).

Conifers produce seeds in the pole stand, but the timing of seed re-establishment and abundance of seed production relative to old growth are poorly understood. Decaying wood is less abundant on the forest floor of older pole stands compared to old-growth (Alaback 1982).

One hundred and forty to 160 years after the clearcutting, an understory of deciduous shrubs, herbs, and conifer seedlings begin to re-establish (Alaback 1982). Uneven-aged forest composition, old-growth overstory structural features, and large diameter snags with denning cavities develop during the next century or two. The transition stage between a pole stand and old-growth occurs well beyond the typical timber harvest rotation of 100 years, currently planned for areas of southeast Alaska.

The poorly-developed understory and even-aged overstory in pole stands results in relatively low habitat diversity (Schoen et al. 1981). These stands may persist for 75% of the harvest rotation and are the least valuable of all seral stages to wildlife populations.

EFFECTS OF PRECOMMERCIAL THINNING ON FOREST SUCCESSION

Over the past 10 years, the Forest Service (FS) has developed an active precommercial thinning program to increase the rate of timber production following clearcutting. Thinning usually consists of sawing off conifers and deciduous trees, such as alder, below the lowest live limb, while leaving a dominant conifer standing at spacings ranging from 8' X 8' to 16' X 16'. Stands are treated at 8-to-30-years of age, although most thinning occurs between ages 10 and 20. It has been speculated that thinning may benefit wildlife use of early successional stands by prolonging the deciduous shrub, fern, and forb understory (Ruth and Harris 1979, Kessler 1982).

Alaback (1984) and Alaback and Tappeiner (1984) found that while understory production may be prolonged or promoted by thinning, the species benefiting most are often conifers or deciduous shrubs with little forage value to the desired wildlife species. Doerr (in press) presented understory measurements from a 26-year-old clearcut experimentally thinned at 20 years of age that indicated prolonged understory forage production.

Doerr and Sandburg (in prep.) examined a 34-year-old clearcut on Big Level Island that had been thinned at 16 years of age. This is believed to be the earliest thinned stand in the Tongass National Forest. Forage was abundant in the understory compared to unthinned stands which had little forage and deer use.

The most significant understory response to thinning is dense conifer regeneration, coupled with increased vertical limb growth of leave trees (Alaback and Tappeiner 1984, Doerr and Sandburg in prep.). Thus any increased deciduous browse or forb production would likely be short-lived, and both studies concluded that repeated thinnings would be necessary to maintain the understory -- an option which, at this time, has not been shown to be economically feasible. Furthermore, a two-layered conifer stand is considered undesirable for timber production (Ruth and Harris, 1979). In British Columbia, thinning regimes developed to enhance deer habitat conflict with thinning regimes to maximize timber production and economic returns (McDaniels Research Limited 1980).

Kessler (1982) and other biologists have observed high slash accumulations (often exceeding heights greater than 4 feet above the ground) which they felt restricted deer movements and use in clearcuts. Thinning slash had largely decomposed 18 years after treatment on Big Level Island, but may have affected deer use of the treated stands immediately after thinning (Doerr and Sandburg in prep.). Morrison and Gibbs (1984) documented increased summer use of areas following a controlled burn of slash in the Pavlof drainage. However, conditions suitable for controlled burns are relatively rare in southeast Alaska.

Alaback and Tappeiner (1984) have presented measurements that show that thinned clearcuts cannot mimic old-growth forests. Understory diversity, composition, production, and quality, as well as overstory canopy cover, height of dominant and subdominant trees, crown radius, and limb size and structure, differ markedly between thinned stands and old growth. Ability to intercept snow will usually decrease in thinned stands (Kessler 1982, Doerr and Sandburg in prep.) compared to unthinned stands.

In summary, the data suggest that thinned stands may temporarily prolong shrub forage, while decreasing snow interception capabilities, and will result in the development of a two-layered (two-age class) pole stand with low understory biomass.

TLMP scheduled precommercial thinning on the most productive forest sites and assumed that at least some thinned stands would be managed on a shortened rotation of about 80 years. This shortened rotation, together with potential for prolonged understory production, could increase the capability of the thinned stands to provide forage over a longer portion of the harvest rotation, but this forage would be available only in periods of no or little snow accumulation. Neither state nor private land managers have scheduled or employed precommercial thinning as a silvicultural technique in the southeast Alaska region.

EFFECTS OF COMMERCIAL THINNING ON FOREST SUCCESSION

Commercial thinning (CT) is not an established silvicultural practice in southeast Alaska. The FS recognized this fact during TLMP preparation and did not assume that it would occur in determining the allowable sale quantity because its widespread use had not been demonstrated (FS 1983). Any discussion of the potential for commercial thinning is speculative.

OTHER NATURAL FOREST TYPES

Although old growth is the predominant forest "type" in southeast Alaska, other forest types exist which are valuable for fish and wildlife habitat and timber production. Among these forests are spruce river terrace stands, some of which exist as a subclimax community subject to periodic natural disturbance from flooding. River terrace forests and braided floodplain forests may play significant roles in the ecology of the freshwater streams they border and stabilize and protect some of the most important spawning and rearing habitat of salmon, trout, and char. Eagle nests are common in river terrace forests along the larger mainland rivers. River terrace forests provide key moose winter range and routes for migration to calving areas and are important habitat for a wide variety of furbearers and nongame bird species.

Logging changes the character of these forest habitats, and can result in both short and long term effects to species that utilize or depend on them. Subclimax river terrace forest habitat probably cannot be regenerated by a clearcutting system and subsequent shortened rotation.

OTHER POTENTIAL HABITAT MANAGEMENT TECHNIQUES

The FS has experimented with other techniques to mitigate alteration of natural wildlife habitats, but, to date, none has been successful that would be feasible for application on a broad scale. The Society of American Foresters recently completed a review of the state-of-the-art with regard to creating stands with old-growth characteristics and managing second-growth stands to maintain or enhance desirable stand characteristics. The report (SAF 1984) concluded:

Old growth is a complex ecosystem, and lack of information makes the risk of failure high. In view of the time required, errors could be very costly. At least until substantial research can be completed, the best way to manage for old growth is to conserve an adequate supply of present stands and leave them alone.

For the same reasons, it is not clear that second-growth stands can be managed to enhance their old-growth characteristics. Thus, if old-growth stands are to be part of a managed forest, the management must begin with existing stands. Then the quantity to be retained must be considered in planning timber harvests.

IMPACTS OF TIMBER HARVESTING ON SPECIFIC WILDLIFE SPECIES

DEER

The Sitka black-tailed deer reaches the northern limits of its natural range in southeast Alaska. The species is indigenous to the mainland and most islands, however they are absent or in low numbers on some of the smaller islands of the Alexander Archipelago. They are the most frequently sought after game animal in the region, and provide an important dependable food supply for recreational and subsistence hunters. Due to the importance of deer to residents of the region, considerable research on the impacts of logging on deer has been conducted since 1979 when ANILCA passed.

Deer populations have historically fluctuated in response to winter weather conditions, quality of range, and predation rates. In addition, large-scale logging results in a major alteration of habitat. Concern is growing that logging will significantly and permanently reduce deer numbers throughout the region as old-growth forests are converted to second-growth forests (Wallmo and Schoen 1980, Rose 1982, Schoen et al. 1984, 1985; Hanley et al. 1985, Territorial Sportsmen 1985). Under certain combinations of natural conditions, local deer populations may be reduced to levels so low that they will not be able to recover.

A major symposium on Sitka black-tailed deer was held in Juneau in 1978. Existing knowledge on the impacts of logging on deer was presented which documented the basis for concern for the future of southeast Alaska deer populations. At that time, the following facts were known:

1. Intensive timber harvest of the coastal forests of Vancouver Island, the area most similar to southeast Alaska in terms of forest community and climate, had resulted in deer population declines of 50-75% (Hebert 1979).

2. Winter conditions, specifically the depth and persistence of snow cover in combination with the pattern of cold temperatures, were the major factor affecting deer populations (Olson 1979).

3. Snow depths during winter were much higher in clearcuts than in adjacent uncut areas due to the interception of snow by trees (Merriam 1971, Jones 1975, Weger 1977, Schoen and Wallmo 1979).

4. Preliminary results of a deer forage study indicated that green forage was important nutritionally to overwintering deer (Schoen and Wallmo 1979). The most nutritious forage was most abundant and available under old-growth stands with mature canopies (Billings and Wheeler 1979).

5. In a study on Admiralty Island, deer winter distribution was correlated with the availability of one preferred plant species, Vaccinium, which was in turn influenced strongly by snow depth. Preferred range areas were at elevations of 200-700 feet in stands of moderately high timber volume (Barrett 1979).

6. A large percentage of commercial forest lands (CFL) with valuable and accessible timber was also valued as deer winter habitat (Harris and Farr 1979).

7. The successional pattern following clearcut logging in southeast Alaska had been described as 20 years of understory production followed by 180 years with little herbaceous or shrub understory under a closed canopy followed by an opening of the canopy and understory development (Robuck 1975 in Schoen and Wallmo 1979).

8. Preliminary results of a deer habitat use study indicated that deer used regrowth stands during summer only 1/5 as much as they used old growth stands. Regrowth stands less than 15-40 years old had dense shrub growth and logging slash accumulations that precluded deer movement and use. Deer use of clearcuts decreased in stands 4-147 years old (Schoen and Wallmo 1979).

9. Wolf predation appeared to be having a significant impact on deer populations, whereas hunting mortality appeared to be having little overall effect (Olson 1979).

In summary, by 1979, a conflict between deer winter range requirements and clearcutting was well-documented. An additional future potential conflict based on the inability of regrowth stands to sustain summer food production for deer had already been identified. Finally, a complicating natural factor, wolf predation, was recognized as an important component of the management situation.

The results of subsequent research by the Alaska Department of Fish adn Game (ADFG) and FS have caused what was of concern in 1979 to become a significant wildlife habitat management issue in coastal forests in Alaska in 1985.

In 1979, the Alaska Chapter of the Wildlife Society (TWS) adopted a position statement concerning forest practices in Alaska (TWS 1979). It recommended 1) that research be conducted to provide information on the ecological relationships of wildlife to old-growth forests and of the effects of clearcutting on wildlife, and 2) that to provide for maintenance of optimal deer winter habitat, and to ensure survival of deer during severe winters, substantial portions of high-volume commercial forest land should never be clearcut. In 1980, the Alaska Joint Boards of Fisheries and Game passed a resolution (#80-8-JB) that recommended revision of TLMP to provide more protection for fish and wildlife habitat and to reflect then-recent research findings, additional research and incorporation of results into planning, cessation of harvest of timber stands of more than 50,000 board feet per acre, and harvest of other timber volume classes in proportion to their occurrence. In 1982, the Northwest Section of the TWS passed a resolution recommending funding of research on old-growth forests while research was being conducted to provide management guidelines (TWS 1982). In the same year, the Alaska Chapter of the Society of American Foresters passed a resolution recommending that a technical committee be established to review the timber harvest-deer habitat issue with existing commitments for timber in land management plans to be maintained in the interim (SAF 1982).

The outgrowth of this last resolution was the appointment by the Governor and the Regional Forester, of a Technical Committee to look into the timber-wildlife habitat situation in southeast Alaska. Members included the State Forester, the Forest Service's Deputy Regional Forester, the Deputy Director of the Alaska Department of Fish and Game's Habitat Division, and representatives of Sealaska Corporation, SAF, and TWS.

The Technical Committee focused its attention on the deer-logging issue and offered its findings and recommendations in its 1983 report (Smith et al. 1983) entitled, "Deer and Timber Management in Southeast Alaska - Issues and Recommendations." The Technical Committee made twenty-one recommendations dealing with deer and forest ecology, economic considerations, and professionalism.

A second symposium on wildlife relationships in old-growth forests was held in Juneau in April, 1982. Further research findings were presented and the implications for forest management of deer habitat summarized by several wildlife biologists. The published symposium papers were not available for review during preparation of this report, but have recently been published (Meehan et al. 1984).

In 1984, a task force appointed by the Governor of Alaska to determine how to improve the economic outlook for the timber industry endorsed the recommendations of the Technical Committee appointed by the Governor and Regional Forester(ATTF 1984).

In 1985, the Alaska Chapter of the Wildlife Society (1985) adopted a position statement concerning old-growth forest management in Alaska. Noting the strong evidence that cutting old growth adversely affects black-tailed deer populations, the Alaska Chapter of TWS recommendations included: (1) management of the Tongass National Forest should comply with the National Forest Management Act, (2) the FS and the Alaska Department of Fish and Game should develop an educational program to inform the public about the long-term consequences for wildlife and fish resulting from harvesting old-growth forest, (3) the disproportionate harvest of high-volume, old-growth timber classes should cease, and (4) specific old-growth stands with exceptional fish and wildlife values should be identified and managed to protect those values, including the management option of no harvest.

Research conducted by the Alaska Department of Fish and Game after 1979 has fulfilled many of the recommendations of the Technical Committee. That Sitka black-tailed deer make highest use of forest stands in areas that have not been cutover has been confirmed. Use of pellet-group transect counts and radio-tracking of collared deer have documented that old-growth stands with well developed canopies are preferred winter habitat (Schoen et al. 1985). Optimum deer winter range under moderate to severe conditions have been described through discriminant factor analysis as high-volume, old-growth stands on productive, well-drained sites with irregularly spaced trees and a well-developed understory consisting of preferred deer winter foods, i.e. bunchberry (Cornus canadensis), blueberry (Vaccinium spp.), and five-leaved bramble (Rubus pedatus), or fern-leaved goldthread (Coptis aspleniifolia) (Schoen et al. 1982, Rose 1982). Greater dispersal of deer was observed in a milder winter when deer made more use of low-volume timber stands (Schoen and Kirchhoff 1983). In all winters, however, and in areas of both northern and southern southeast Alaska, deer preferred old-growth habitats and avoided clearcuts and regrowth stands (0-147 years) and upper forest areas where deep snow accumulations occurred (Wallmo and Schoen 1980, Schoen et al. 1982, Rose 1982). These findings concerning the relationship of forest stand types in terms of timber volume class and logging history to deer winter range have significant implications for appropriate management of timber harvest that protects this critical component of deer habitat.

Research on food habits and quantity and quality of available winter forage has also confirmed the importance of old-growth stands with large irregularly spaced trees, well developed canopies, and well developed understories with abundant deer forage (Schoen et al. 1985, Kirchhoff and Schoen 1985, Hanley and McKendrick 1985). Schoen and Kirchhoff (1984) documented that the nutritional value of bunchberry was highest in high-volume, old-growth forest stands, intermediate in low volume old-growth stands, and lowest in clearcuts. Other researchers (Billings and Wheeler 1979, Van Horne 1982, Rose 1982) documented the high nutritional value of a variety of plants in old-growth understory. Lichen litterfall emerged as an important food source for deer in old-growth stands in areas similar to southeast Alaska (Rochelle 1980).

More information has been gained on home range patterns and seasonal distribution, as well. A radio-tracking study (Schoen and Kirchhoff 1985) documented that a portion of a deer population in a watershed reside at higher elevations during all seasons. Resident deer have overlapping summer and winter ranges while those of migratory deer are distinct and average up to 8 km apart. Home ranges are relatively small in size (averaging 79 ha) and individual deer display strong fidelity to seasonal home ranges, rarely dispersing from one watershed to another watershed. Deer move downward from higher elevations as snow accumulates, and may eventually be driven into the coastal forest fringe under severe conditions. Winter use can also range inward from the coast up to 9 km (Schoen and Kirchhoff 1985). Thus, the concept of critical deer winter range has been expanded to include inland forest stands, as well as beach fringe stands. When deer habitat is restricted to coastal beach fringe areas, heavy losses during severe winter conditions are more likely than if inland winter habitat also exists. These findings are also significant ones to consider in long-term management of critical deer winter range.

Kirchhoff et al. (1983) investigated whether deer made preferential use of the "edge" areas of clear-cuts adjacent to mature stand and found that they did not. Clear-cuts emerged as areas which received extremely low winter deer use and could serve as a barrier to deer movements from beach fringe to inland habitats at higher elevations during winter (Schoen and Kirchhoff 1985).

Research results on the successional pattern following clear-cut logging, including the response to thinning, were reviewed in the previous section. The results indicate that understory vegetation is essentially eliminated during forest succession for approximately 75% of a 100-year rotation. These cut-over stands are characterized by extremely low deer use (Wallmo and Schoen 1980, Rose 1982). Alaback (1984), Alaback and Tappenier (1984), and Doerr and Sandburg (in prep) concluded that precommercial thinning may temporarily prolong understory productivity in young (pre-canopy closure) stands, but that any prolonging of deciduous browse or forb production will be short-lived. Thinning also promotes a two-layered conifer stand.

Logging slash has been shown to be an effective barrier to deer movement in areas other than southeast Alaska (Lyon and Jensen 1980). Parker et al. (1984) calculated the high energetic costs of movement through logging slash and deep snow. Kessler (1982) and Morrison and Gibbs (1983) have observed high slash accumulations (often exceeding heights greater than 4 feet above the ground) which they felt obviously restricted deer movements and use in clearcuts. Gibbs and Morrison (1984) studied the effects of prescribed burning to reduce slash. They concluded that deer use was higher in burned areas because large accumulations of small slash had been removed. More recently, FS biologists have experimented with clearing trails through slash accumulations. Thinning slash had largely decomposed 18 years after treatment of a clearcut on Big Level I, but may have affected deer use of the treated stands immediately after thinning (Doerr and Sandburg in prep.). Gibbs and Morrison (1984) cautioned, however, that an increase in carrying capacity of summer range could not alter carrying capacity of winter habitat, often the limiting factor for deer populations.

A study of wolf predation on deer in southeast Alaska was initiated by ADFG with some FS funding in 1984. In 1982, Van Ballenberghe and Hanley (1985) reviewed deer-wolf studies in other areas and modeled deer-wolf relationships in southeast Alaska. They concluded that logging of old-growth forests could initiate deer population declines by lowering the carrying capacity of the environment for deer, and that wolves could accelerate the rate of decline and keep deer numbers at extremely low densities. They summarized the implications of both the successional pattern of the forest and of deer predation as follows:

> The closed-canopy, second-growth stage (age 25 or 30 years to rotation) is a virtual desert in terms of forage for deer. Deep accumulation of snow in the young (25-30 yrs) clearcuts buries forage and makes it unavailable to deer. . . Thus, in regions of southeast Alaska where snow accumulates to an important degree in winter, the conversion of old-growth forest to managed, even-aged forest is expected to result in substantial declines in deer population levels.
>
> We visualize the long-term effects of removing old-growth timber on deer in Alaska as ultimately acting to reduce the rate of increase of deer. In the absence of wolf predation and hunting, deer populations subject to extensive logging would be expected to decline; the rate of decline would be greatly accelerated if predation and hunting were intensive. Deer would then remain at low densities unless wolf numbers were reduced.

Schoen et al. (1985) modeled existing knowledge about the impacts of the scheduled harvest in the Tongass National Forest throughout the first 100-year rotation on the deer populations of southeast Alaska. Of 461 VCUs analyzed, 340 VCUs will have less than 50% of current deer populations and 100 VCUs will have less than 25% of current deer populations at the end of the rotation.

MOUNTAIN GOAT

Mountain goat populations in southeast Alaska occur on most major ridge complexes of the mainland and have been introduced successfully to Baranof Island. They were also recently transplanted to Revillagigedo Island near the city of Ketchikan. Population and habitat use studies have been conducted near Juneau (Schoen 1978, Fox 1979 a, b, c; 1982, Schoen et al. 1980, Schoen and Kirchhoff 1982), Haines (Hundertmark et al. 1983), and Ketchikan (Smith 1982, 1983a, 1983b, 1985), and in areas outside of southeast Alaska with similar habitat conditions.

Mountain goats are considered specialists, with a very narrow range of habitat characteristics that meet their life history requirements. Seasonal ranges are distinctive, but steep, broken terrain is a predominant feature of all goat habitat with the possible exception of some travel corridors (Smith 1985, Fox et al. in prep.). Although mountain goats are generally thought of as living in areas well above treeline, use of forested habitat has been found to occur throughout the year (Schoen 1978; Fox 1978, 1979a,b,c, 1980; Schoen et al. 1980; Fox et al. 1982; Schoen and Kirchhoff 1982; Smith 1982, 1983a, 1985; Hundertmark et al. 1983; Fox et al. in prep.). Summer use of forests is limited and considered a response to wet, windy weather when lower elevation, sheltered areas are used (Fox 1978) or for heat and/or insect relief habitat during hot weather (Smith pers. comm.). Use of forested habitat during winter may be extensive and appears to be most influenced by the availability of food resources (Fox 1983).

In the southern portion of the region where wet, heavy snow covers all alpine terrain for 5 to 6 months each year, goats were found to winter almost exclusively on forested slopes and commercial size timber was found to be a significant factor in predicting the location of goats during winter (Smith 1985). Near Juneau, where colder temperatures and high winds combined to clear ridgetops of snow and expose forage, some goats used areas above treeline for much of the winter while others wintered as low as a few hundred feet above sea level (Schoen and Kirchhoff 1982). Hundertmark et al. (1983) did not find any use of forested habitat by goats near Haines, possibly because of mild winter conditions or a lack of steep forested terrain within the study area, but others (Schnabel pers. comm. and Smith unpub. data) have observed goats wintering below treeline in this vicinity. Thus in areas with significant snowfall, timbered habitat may be critical winter range for goats as it is for deer.

The steep, broken habitats used by goats are often not suitable areas for logging given present technology. However, clearcutting has already removed timber from known wintering sites in Alaska near Icy Bay (Smith and Reynolds 1977), Haines (Hundertmark et al. 1983), and Baranof Island (L. Johnson, pers. comm.) and in areas of Washington (Reed 1983). The proximity of cutting units to goat range must be carefully evaluated. Schoen and Kirchhoff (1982) and Smith (1983b) have developed techniques to accurately identify areas of goat habitat. Wintering areas at low elevations or on southerly exposures are particularly critical wintering sites.

Hundertmark et al. (1983) recommended deferring timber harvest adjacent to a goat range in the Haines area to avoid long-term impacts. Schoen and Kirchhoff (1982) and Hundertmark et al. (1983) recommended leaving a windfirm buffer strip of timber not less than 800 m. wide around goat concentration areas. More specifically, Fox et al. (in prep.) recommend a 400 m. wide buffer strip to escape terrain, but also recommended that these postulated areas of habitat use be verified with more detailed information particularly in forested wintering areas. As harvest methods change (e.g. helicopter logging and multi-span high-lead systems), more significant conflicts could develop.

Large clearcuts in areas outside of goat wintering areas could create barriers to movement between patches of escape terrain within the winter ranges of individual goats during periods of deep snow or pose barriers to dispersal to "islands" of preferred goat habitat (Schoen and Kirchhoff 1982). Fox et al. (in prep.) recommend that travel corridors be identified and maintained between important wintering sites and summer range. They also recommend that forested travel corridors between wintering sites be kept intact.

Human activity involving noise and vehicle traffic has been documented as disturbing goat behavior and potentially interfering with reproductive behavior through separation of nannies and kids. Such disturbance can increase susceptibility of kids to predation (Foster and Rahs 1983). Abandonment of summer range and increased mortality, associated with disturbance stress, has occurred in response to camps and other activity within 2 km of goat habitat. (Foster and Rahs 1983). In Montana, goats left an area during timber harvest operations that occurred near, but not, within goat habitat, then returned some time after the disturbance ceased (Chadwick 1973).

Road access is a major long-term impact that can cause disturbance, displacement, and overharvest of goat populations. Female goats displayed high fidelity to home range, and roading has resulted in elimination of use of high-quality, preferred range by nannies for many years (Chadwick 1983). Roads can bisect goat movement corridors between seasonal habitat use areas, effectively eliminating traditional habitat use. These impacts have been documented in areas other than Alaska (Brandborg 1955, Chadwick 1973, Rideout 1974, Herbert and Turnbull 1977, Kuck 1977). Phelps et al. (1983) described the history of mountain goat management in the Kootenay Region of British Columbia. They concluded that goat populations declined as a result of progressive exploitation and decimation of previously unhunted herds as new industrial roads expanded. Foster (1977) also attributed a large decline in goat populations in British Columbia to increased hunter access that followed the creation of new road systems in formerly undeveloped areas.

BROWN/GRIZZLY BEAR

Historically the brown/grizzly bear (Ursus arctos) was widely distributed in North America from central Mexico to northern Canada and Alaska and from the Mississippi to the Pacific Coast (Hall and Kelson 1959). The distribution of this species, today, is greatly reduced from its former range with brown/grizzly populations restricted to northwestern Canada, Alaska, and a few scattered wilderness enclaves in Montana, Idaho, and Wyoming. Alaska has the last major population of brown/grizzly bears in the United States. Human-induced mortality, disturbance, and habitat alteration have been identified as prime factors in the decline of grizzly bear populations.

Brown/grizzly bears, commonly referred to as brown bears within the region, are indigenous to southeast Alaska where they occur on the mainland and islands north of Frederick Sound. Studies of habitat use and the impacts of timber harvest are in progress in southeast Alaska, but impacts have been documented in other areas of the bears' range.

In the northern Rockies, timber management has affected wildlife habitat more than any other activity (Zager and Jonkel 1983). In British Columbia, Russell (1974) indicated that coastal brown bear populations were incompatible with intensive forestry. Smith (1978) suggested that other factors, in addition to habitat alteration, may be contributing to declines in brown bear populations in this area. Archibald (1981) suggested that development in coastal mainland forests in British Columbia appears to result in declining brown bear populations.

Brown bears, in general, are opportunistic omnivores and able to utilize a variety of food sources. Food does not appear to be a limiting factor for brown bear populations in southeast Alaska. Work done on feeding habits has identified seasonally important food sources that include sedge/carex meadows, berry-producing areas, and anadromous fish streams (Russell 1974, Smith 1978, Lloyd 1979, and Johnson 1980). Berry-producing areas are important and seasonally vital to brown bears. The consumption of berries is critical during the late-summer, fall weight gain period. Salmon runs constitute a critical seasonal component of most brown bears' annual food intake (Johnson 1980).

Recent studies of brown bears radio-collared on Admiralty and Chichagof Islands have documented high use of old-growth forest habitats during all seasons (Schoen and Beier 1983, 1985; Schoen et al. in press) and consumption of salmonberries, devils club berries, and currants as major foods during summer (T. McCarthy unpub. data). Riparian old-growth stands receive high use during the salmon runs. Many den sites have been located in old-growth stands, with several excavated under the base of large-diameter, old-growth trees (J. Schoen and V. Beier unpub. data). Clearcuts are used, but use is relatively low compared with old growth; bears do not appear to prefer these areas during any season (Schoen and Beier 1985). Research is continuing to assess the effects of forestry practices on brown bears in southeast Alaska.

Potential impacts to southeast brown bear populations include both alteration of habitat or habitat use and human-induced mortality. Studies in Montana documented that the initial removal of the forest canopy removes hiding cover for bears which is an important habitat component even in the absence of predators or man (Black et al. 1976). Understory food plants, e.g. berry-producing shrubs are damaged or destroyed (Mealey et al. 1977). Opening the forest canopy can result in high berry production during early regrowth stages which were potentially beneficial to bear populations. Extensive clearcuts result in an initial flush of berries, with an eventual decline as the forest canopy closes (Mealey et al. 1977). This decline in berry crops could be detrimental to brown bear populations, as it is with black bears. Because of the importance of salmon as a seasonal food source, protecting the integrity of salmon streams and their productivity is also important for maintaining bear populations.

Research in other areas indicates that bear use of clearcuts is not based on food availability alone. Russell (1979) documented avoidance of clearcuts and other open areas by hunted bear populations in British Columbia. Logging slash in clearcuts can impede bear movements (Smith 1978) and clearcuts and roads can serve as barriers to movement (Elgmork 1976, Zager et al. 1983). Where slash is not treated in Montana, food production for bears is lower than that in mature forests (Zager et al. 1983). Timber leave strips can play an important role in meeting short-term cover requirements by bears feeding on salmon. Lloyd (1979) described mechanisms that have developed so that bears do not meet and fight, which results in injuries and deaths. Leave strips may thus serve as critical visual screens for bears aggregating on rivers to feed on salmon runs (Archibald 1983). Zager and Jonkel (1983) recommended that timbered strips be left around feeding sites such as wet meadows and as stringers for travel routes along riparian zones and snow chutes, and between cutting units.

Roads and camps can reduce habitat carrying capacity through disturbance to bears and a resultant loss of portions of their former range. In southeast Alaska, some former logging camps on federal land have become permanent communities through state land selections and subsequent transfer into private ownership. An interconnected road and ferry system will greatly increase recreational and administrative use of currently remote areas. In British Columbia, hunted bear populations avoid clear-cuts and other open areas and require forest cover for movement (Russell 1974). In Montana, bears used only the portions of logged units furthest from primary roads and only within 50-75 m. of cover (Zager 1980). In Norway, the density of forest roads has been found to be negatively correlated with bear densities over a 25-year period (Elgmork 1976, 1978). Bears often avoid roadside habitat along the Denali National Park road as well (Tracy 1977). Zager et al. (1983) concluded that cutting unit location in relation to open roads and the availability and proximity of escape cover were important factors in determining bear use. Thus, size and shape of cutting units can have an indirect effect on bear use because they determine the proximity of cover.

Human-induced bear mortality tends to increase when an area is developed for timber harvest. Accessibility to the area is increased through the construction of docking facilities and roads into a formerly unroaded area. Human use of the area inevitably increases unless access is restricted. Current Forest Service policy in southeast Alaska encourages public and administrative use of primary road systems, and silvicultural management and multiple entry logging requires that roads be maintained and re-used. Human-induced mortality results from legal and illegal hunter kills and killing of "problem" or nuisance bears. Such "bear problems" are often due to accumulations of human garbage, which, when improperly disposed, becomes an attractant to the opportunistically-feeding bears. Road access is a quantum change that generally leads to a much higher human-caused bear mortality rate.

Road access may initially increase hunter success and hunting mortality because it provides hunters access to previously unexploited populations. Archibald (1983) described the resultant management problem well in reference to British Columbia coastal bear populations:

> Forestry access roads provide legal hunters with the capability to hunt unexploited populations. Man-bear conflicts associated with logging or recreational activities in these watersheds often

develop. Poaching is a problem: illegal hunters have access to seasonal concentrations of coastal grizzlies in areas where enforcement staff is minimal due to high costs of patrolling and insufficient enforcement staff.

Additional mortality results when bear-human conflicts increase. Grizzly bears avoid traditional use areas where active logging is occurring (Mace and Jonkel 1980). However, they are attracted to camps or other human facilities by food or garbage. Artificial food sources result in changes to natural movement patterns (Mundy and Flook 1973) and the resulting conflicts are well documented from situations in national parks (Cole 1972, Herrerro 1976), pipeline construction camps (Douglass et al. 1980), outfitter guide camps (Hoak et al. 1983), and logging camps (Archibald 1983). Conflicts are generally resolved through destruction of the bear because of the difficulty of discouraging bear visits and the costs and ineffectiveness of relocating bears which either return or cause problems in new areas. Johnson (1980) estimated that bears killed in defense of life and property around logging camps in southeast Alaska could make up as much as 10% of the reported kill.

Jonkel (1977) concluded that extensive, uncontrolled road construction and access invariably leads to increased human activity and eventually increased human/grizzly conflicts. Human/grizzly impacts nearly always result in adverse actions to grizzlies and in many situations have led directly to extirpation of the grizzly from the ecosystem. Craighead (1977) also suggested that human-induced mortality associated with logging was one of the major contributions to grizzly declines.

Ruediger and Mealey (1978) summarized potential adverse impacts on grizzly bears from human development : 1) easy access for humans into grizzly habitat, 2) conversion of travel corridors for grizzlies into developments and areas where grizzlies are not tolerated, and 3) increased human use of adjacent backcountry which can lead to competition for space, legal and illegal hunting, settlement, increased camping and picnicking, and potential increases in the amount of garbage and other unnatural foods. They also developed guidelines for coordinating timber harvesting in grizzly bear habitat in Montana. They recommended road management as the most effective management tool to reduce the long-term negative impacts of roading on grizzlies during presale activities. Road management would include: restricting road and management activities during periods of high bear use, closing roads after work is completed, planning sales to avoid repeated entries over short periods, maintaining large areas of good quality "security" bear habitat as roadless areas, closing roads adjacent to active sale areas, and maintaining one-mile buffer zones between areas where road access is permitted and grizzly habitat. Zager and Jonkel (1983) also recommended minimizing new roads in occupied bear habitat to provide isolation and route roads only in sites with little bear food away from feeding and travel sites. These practices likely conflict with objectives for laying out economical timber sales in drainages in southeast Alaska with high brown bear populations.

In summary, road construction and increased human access are likely to increase human disturbance and human-induced mortality on brown bears. The old-growth habitat which receives the bulk of observed bear use will be significantly reduced. Protection of salmon stream productivity and sedge/grass meadows can maintain two seasonally-important food sources, and berry crop productivity may initially increase following opening of the canopy. However, research to date indicates that brown bears do not appear to be attracted to clearcuts and in fact, prefer old-growth forest habitats. Following canopy closure, berry and herbaceous forage production will be eliminated, removing this important food source. Thus, it is likely that conversion of old growth to clearcuts and second-growth succession will result in a decrease in carrying capacity for brown bears. Quantification of this relationship, however, remains unknown at this time.

Based on the above evidence, brown bear population declines will likely result from the altered pattern of hunter access, increased bear-human conflicts, and alteration of preferred habitat. If land use impacts in the region are similar in severity as they have been on other portions of the bear's range, the species may be vulnerable to local or regional reductions to the level of threatened or endangered status.

BLACK BEAR

As with brown bear, little work has been done regarding black bears and their habitat in southeast Alaska. The large-scale removal of cover and increased access by roads can render bears more visible and vulnerable to hunting. Increased harvest of black bears has resulted from improved access brought about by logging roads in southern southeast Alaska (ADFG 1981).

Erickson et al. (1982) observed a preference by black bears for young clearcuts (to 25 years) on Mitkof Island. Bears fed on the first green plants in south facing clearcuts during spring and on berries in late summer and early fall. However, the proximity of cover is also an important factor in determining bear use of available food supplies (Lindzey and Meslow 1977).

Canopy closure after 15-25 years and the resultant long-term poorly-developed ground cover will significantly reduce food supplies for bears in regrowth areas (Erickson et al. 1982). Food shortages can, in fact, limit black bear populations (Jonkel and Cowan 1971). The availability of den sites may be reduced in second-growth forests. Black bears studied on Mitkof Island denned in hollow logs left in clearcuts, the bases of diseased boles of hollow living hemlock trees, or in rotten stumps of hemlock trees. All den sites were the product of large-diameter, old-growth trees. Above-ground denning in trees appears to be an adaptation to the conditions of shallow, wet soils which were not suitable for excavating dens (Erickson et al. 1982, Hanson 1982, Hanson and Doerr 1982). These researchers noted that although hollow logs may be left in clearcuts, these will eventually decay and provide only temporary denning habitat. Second-growth stands, managed on a 100-year rotation will likely not provide a source of den trees of sufficient size to provide large cavities. The researchers also noted that a long time period is necessary for the development of heart-rot, other diseases or weather damage that result in hollow cavities accessible to bears. Silvicultural practices aimed at timber production will result in removal of diseased trees that would eventually develop into suitable denning sites.

Researchers have reported the importance of suitable denning habitat for pregnant female black bears in Washington (Polker and Hartwell 1973, Lindzey and Meslow 1976) and in Alaska (Miller and McAllister 1982). Erickson et al. (1982) noted indications of an apparent low rate of reproduction in the bears of Mitkof Island after 20 years of intensive logging and urged that an in-depth study of the population characteristics of these bears be undertaken.

Emigration may also result from habitat changes following logging. Lindzey et al. (in press) documented emigration of black bears as a result of aggression and poor reproductive success as the quality of habitat and food abundance deteriorated following logging on an island off the Washington coast.

MOOSE

In southeast Alaska, moose populations are generally associated with large, mainland river systems that provide suitable forage. Because this type of habitat is generally limited in distribution in Southeast, moose populations are relatively small and typically isolated. Work by Doerr (1983, 1985), Hundertmark et al. (1983) and Craighead et al. (1984) characterized moose populations in Thomas Bay, the Chilkat River, and the Stikine River drainage, respectively.

These studies have all indicated that certain coniferous forest stands are an essential component of moose winter range. The type and structure of these forests vary between the areas studied and include old-growth hemlock-spruce forests, spruce river terrace forests with riparian or blueberry browse, spruce-cottonwood forests, and upland lodgepole pine forests with mixed hardwoods. In addition, moose use old-growth, river terrace, and other unlogged forests to a considerable degree throughout the year. These forests may be important for calving areas (K. Hundertmark, pers. comm.) and as thermal cover from the summer sun (Hundertmark et al. 1983). In the Yakutat area, "stringers" of riparian spruce are used in early spring as migratory corridors when deep snow persists on the ground (B. Dinneford, pers. comm.).

In areas where riparian or other high-quality browse is limited, young clearcuts with high understory production may provide important foraging areas for moose during spring, fall, and winter periods with low snowfall (Doerr 1983, 1985). If adequate winter range is retained, the presence of high-forage regrowth areas may promote a temporary increase in moose numbers.

At Thomas Bay, clearcuts up to 30 years of age were selected over old-growth forests during spring, fall, and mild winters (Doerr 1983). During deep snow conditions, browse in clearcuts was unavailable and moose selected spruce river-terrace forests, riparian shrub stands with preferred browse, and old-growth forests. In late winter with deep snow accumulations, tracks in the Yakutat area documented high use of old-growth stands for browsing and/or resting and avoidance of open areas (B. Dinneford, pers. comm.)

As with deer, forest succession will limit the period of time moose will utilize clearcuts. As clearcuts mature, young conifers begin to dominate and forage is lost. The reduced quantity of browse will undoubtedly result in a lower carrying capacity and perhaps severe declines in moose populations (Doerr 1985). In situations where riparian habitat is limited initially (e.g. Thomas Bay), moose populations may be reduced below "huntable" levels as clearcuts become dominated by conifer regrowth.

Habitat management concerns for moose are specific to each area of southeast Alaska. However, studies to date strongly indicate that forested winter range is necessary for severe winter conditions and suggest that clearcutting certain forest habitats is detrimental to moose. Hundertmark et al. (1983) recommended that existing forests within and surrounding high density feeding, breeding, and movement areas be retained from timber harvest in the Chilkat Valley. Doerr (1985) recommended that all the limited river terrace forests and some of the high-volume (30+ MBF/acre) old-growth forest at Thomas Bay be permanently excluded from harvest to provide for the winter needs of moose.

Doerr (in press) addressed the need to maintain a mixture of forested winter range and clearcuts with high forage production in order to sustain moose populations at Thomas Bay. He recommended sustaining equal acres of forested winter range and regrowth with high forage production. Suitable moose habitat could be maintained by a combination of reducing the rotation length; retaining high-volume, old-growth and river-terrace forest winter range by avoiding timber harvest in these areas; clearcutting low volume (non-winter range) coniferous forests; and precommercial thinning. He developed a model to address long-term habitat needs of moose at Thomas Bay.Assuming that high forage production could be maintained for 30 years with precommercial thinning and assuming a 100-year harvest rotation, 46% of the CFL in moose range could be maintained over the rotation as moose habitat with acreage split equally between retained winter range and high-forage regrowth. Under a 60-year harvest rotation, 67% of the CFL could be maintained as moose habitat under the above conditions.

For clearcut rotations of 60 and 100 years, the model required that 33 and 23%, respectively, of the CFL, would be permanently retained as moose range and predicted that 33 and 54 percent, respectively, of the CFL would always be in second growth pole stands with little forage production or value as moose habitat. The amount of retention to be allocated for moose winter range in the model is considerably greater than that provided under TLMP. The results of the model are specific to Thomas Bay, an area with very limited riparian shrub habitat, and indicate that the key factors in maintaining moose habitat are 1) the amount of winter range retained for the entire rotation, 2) the degree to which the FS schedules the harvest equally over the rotation, and 3) the degree of implemention of shortened rotations and thinning to increase the percentage of time a clearcut provides forage.

In the more typical moose habitat of southeast Alaska where riparian forage is naturally abundant, the preservation of the existing natural habitat may likely be the optimal habitat management strategy for these moose populations (Hundertmark et al. 1983, Craighead et al. 1984).

Roading, whether prior to logging or concurrent, also affects moose populations indirectly. Where access for hunting is already adequate due to the presence of landing strips, existing roads, rivers or other water access, increased road access may result in crowded hunting conditions and overhunting. Hundertmark et al. (1983) recommended that roading and logging developments around Haines avoid restricted migration corridors between high density concentration areas and that restrictions be placed on use of roads in moose concentration areas to reduce potential harassment and poaching losses.

Where river or other inland access is largely limited, the construction of logging roads may promote increased moose hunting opportunities, such as at Thomas Bay. The increased intensity of hunting at Thomas Bay, however, has required ADF&G to closely monitor the harvest. Restrictions on motorized access, season closures, harvest quotas, emergency closures restricting the harvest, and registration permit hunts have all been implemented to prevent overharvesting of moose. Recent research in Yakutat indicates that while hunter use may shift to a road system, hunter success declines rapidly (D. Mills unpub. data).

WOLF

Wolves are found along the mainland coast of southeast Alaska and on the islands south of Frederick Sound. They are not presently found on Admiralty, Baranof or Chichagof Islands. Little work has been done to document habitat or predator-prey relationships of wolves in southeast Alaska.

Wolf population dynamics depend on the population dynamics of prey species. Black-tailed deer are a primary food source for wolves in southeast Alaska; moose, goats, salmon, and beaver are also important food sources (Merriam 1964, Smith unpub. data). The effects of logging on the carrying capacity of habitat of prey species thus directly affects the carrying capacity of an area for wolves.

Some research has been conducted within the region to determine predator-prey relationships of wolves. Wolves were introduced to Coronation Island as part of an "experiment" to evaluate wolf-deer relationships (Merriam 1964). Within a few years following introduction of wolves to the island, deer were virtually eliminated. Subsequently, the wolves fed on marine carrion, then on each other, and finally disappeared from the island. Recently the deer population has re-established and increased on the island. Although this study lacked a "control" and the small size of the island (approximately 70 km^2) prevented eventual stability of a predator-prey system, the rapid decline of deer following wolf introductions indicates the potential effects of wolves on an insular deer herd.

VanBallenberghe and Hanley (1985) synthesized the limited existing knowledge of wolf predation into a conceptual model applicable to the old-growth forest ecosystem of southeast Alaska. Their model inter-relates various deer productivity and mortality rates, kill rate for wolves, and influence of hunter harvest on deer recruitment. It then calculated wolf:deer ratios required to maintain equilibrium of both populations. Using this approach, these authors concluded that wolves are capable of limiting deer populations. They suggested that in view of the detrimental effects of logging and hunter harvest on deer productivity, wolves would be an additive factor in depressing deer populations. Biologists studying deer-wolf relationships on Vancouver Island (Hebert 1981, Hebert et al. 1982, Scott and Shackelton 1980 and Jones and Mason 1983) have clearly documented the role of wolves in reducing and limiting deer in ecosystems similar to these in southern southeast Alaska where timber harvest has reduced deer winter ranges.

Retention of "islands" of high-quality winter habitat can be expected to concentrate deer during severe winters and increase the efficiency of wolf predation (Harestad 1979, Hebert et al. 1982). The implications of reduction of deer habitat carrying capacity through logging coupled with the demonstrated capability of wolves to reduce deer populations below the capacity determined by habitat and winter conditions may severely limit management options. Jones and Mason (1983) concluded that meeting population objectives for deer would require maintaining winter ranges, regulating hunting, and managing predators if habitat capabilities were to be realized. Van Ballenberghe and Hanley (in press) also concluded that wolf control would be necessary to maintain deer populations at the carrying capacity of the habitat. To reduce the necessity for wolf control, which is strongly objectionable to a large segment of the Alaskan and national public, critical winter habitat will have to be retained in sufficient quantity to maintain deer populations at levels that can sustain both a desired human harvest and an unmanaged wolf population.

Management of the wolf is of special concern due to the unique status of Alaska as one of two states where the species is not endangered and one of the few areas of the wolf's former broad range where it is still abundant.

FURBEARERS

Marten, beaver, mink, and land otter are four furbearer species commonly trapped in the region. Wolves are also trapped where they occur in the region, but are discussed in the preceding section.

Muskrats, wolverines, and lynx are also available in some areas. Logging may affect furbearers through habitat alteration, reduction of prey species following reduced understory food production and habitat diversity in second-growth stands, impeded travel through slash, and increased mortality through increased trapper access.

Marten

Marten are present on the mainland and were introduced to Prince of Wales, Baranof, and Chichagof Islands and are abundant on Admiralty Island. They are present on most of the other islands in southeast Alaska, but absent from some.

Specific habitat requirements of marten in southeast Alaska are not known. Johnson (1981) has reviewed the literature on habitat use and the effects of logging on marten in other areas. The following is excerpted from his review. Elsewhere, within their range it has been reported that marten are creatures of mature forests (Seton 1929, Marshall 1951, deVos 1952, Lensink 1953, Hawley 1955, Francis and Stephenson 1972, Koehler et al. 1975, Clark and Campbell 1977, Koehler and Hornocker 1977, Mech and Rogers 1977, and Soutiere 1978). The marten is considered to find optimum habitat in old-growth Douglas fir forests in western Oregon and Washington (Meslow et al. 1981).

Researchers in other areas have found that alteration of the pristine forest can have significant impact on marten populations. Marshall (1951) in Idaho, deVos (1952) in eastern Canada, and Mech and Rogers (1977) in Minnesota reconstructed the decline of marten populations following settlement with its attendent forms of land alteration, especially clearing, logging, and fire. Marshall (1946) reported little marten sign in winter in areas devoid of tree cover. In Canada deVos (1952) noted that marten were less abundant in second growth stands than in mature forests. Lockie (1964) traced a similar decline in the related pine marten (M. martes) in Scotland. In response to a 1976 survey, nine states and one Canadian province reported marten as extirpated from their jurisdictions. The reason for extirpation was given as habitat destruction (Deems and Pursley 1978). Soutiere (1978) also documented marten numbers in clearcut areas to be one-third those in undisturbed forests in Maine. Major (1979) also described lower population levels following clearcutting.

Several workers have documented changes in small mammal populations which provide the main food source for marten (Martell and Radvanyi 1977), particularly reductions in red-backed vole populations (Tevis 1956, Gashwiler 1970, Hoovan 1973, Sims and Buckner 1973, Clark and Campbell 1977).

The habitat requirements that are likely to be adversely affected by clearcut logging include canopy cover, high prey populations, and tree cavities for denning. Koehler et al. (1975) in Idaho showed that marten prefer stands older than 100 years and that such a stand must have a canopy cover greater than 30 percent. Those authors also reported that marten will cross but not hunt in openings less than 300 feet in width during winter. They noted that marten were not observed to have crossed openings greater than 300 feet and that marten do not use "dog hair thickets" because of minimal small rodent populations. Soutiere (1978) observed marten tracks in openings as wide as 200 m. Habitat requirements in summer seem to be less rigid than in winter (Grinnell et al. 1937, Marshall 1946). Clark and Campbell (1977) in Wyoming reported that marten do not utilize harvested areas at least within one year following harvest. These authors further noted that in winter, marten foraging was confined to dense, mature stands of coniferous forests. Koehler et al. (1975) and Steventon (1979) observed that in winter females are more reluctant to enter clearcut areas than are males.

No study of the food habits of marten in southeast Alaska has been conducted, however in other areas, microtine rodents, especially red-backed voles, are the primary prey of marten (Cowan and Mackay 1950, Remington 1950, Newby 1951, Lensink 1953, Hawley 1955, Lensink et al. 1955, Quick 1956, Lockie 1961, Murie 1961, Weckwerth and Hawley 1962, Clark and Campbell 1977, Koehler and Hornocker 1977). Red squirrels and deer mice do not appear to be preferred food items for marten, according to these and other studies, but tree squirrels, berries, and arthropods may be seasonally important. The winter use of witches broom (mistletoe infection) areas has also been reported, possible to provide feeding opportunities on flying squirrels which nest in the witches broom (R. Mowry, pers. comm.).

Marten rest, give birth, and rear their young in dens. The few natal dens that have been found have been in rocky banks, hollow trees, woodpecker or squirrel holes, boulders, or hollow logs. As noted under the discussion of cavity-nesting bird habitat, second-growth forests managed on a 80-100 year rotation would have few excavated holes or hollow trees and logs for den sites. Reduction in denning sites would also contribute to reduced carrying capacity for marten.

Road access is likely to increase trapping pressure on marten. In areas where road systems are available to the trapper, marten may be reduced below levels which make it profitable for trappers to trap. Traditionally, marten trapping has been accomplished by boat, working the beach fringe. As trapping removed animals from the beach fringe, other animals moved in from the "reservoir" of animals in upland areas. As "reserve" areas are roaded and trapped, marten populations and trapping success will decline over a relatively large area.

Beaver

Beaver are abundant in major mainland river drainages or other areas with extensive freshwater marsh areas and deciduous woodlands. They are also present on islands of the Alexander Archipelago with suitable habitat.

The only study of beaver in southeast Alaska has been conducted in the Petersburg area. Beaver dens, lodges, and food caches were observed along deep, slow-moving streams and sloughs bordered by *Sphagnum* moss mats surrounded by sedge-alder or hemlock communities, along deep slow-moving streams with clay banks, and in lakes with *Sphagnum* moss mats with steep banks for denning. Swift, shallow streams with sandy or rocky bottoms, areas of tidal influence with fluctuating water levels, and salt marsh meadows did not appear to provide suitable habitat. Beaver food caches contained stems from a variety of shrubs and hemlock (Curatolo et al. 1981). Beavers use conifers extensively for food and for lodge and dam construction in portions of their range in southeast Alaska (J. Doerr pers. obs.).

Beaver ponds and streams deepened by beaver activity serve as important habitat for furbearers such as muskrat (Boyce et al. 1981), mink, otter, and wolves. They also provide rearing habitat for certain fish species, including coho salmon (Bryant 1984), cutthroat trout, Dolly Varden char, and steelhead; and waterfowl habitat for nesting, rearing, molting, and migrational habitat (J. Doerr pers. obs.). Emergent aquatic plant in beaver ponds provide foraging areas for moose (B. Dinneford, pers. obs.). Snags bordering wetlands and often resulting from flooding by beaver dams are valuable habitat for snag-dependent wildlife (J. Doerr pers. obs.).

Roads, facilities, and cutting units which include beaver ponds may encroach and alter this habitat through fill, equipment movement through the pond, sedimentation, or slash deposition. The maintenance of a riparian buffer zone around beaver ponds and stream habitats can benefit beaver as food sources, and serve as a filter for sediment from erosion following logging and soil disturbance and thus provides a natural mitigation measure for other fish and wildlife species.

Mink

Mink populations are distributed primarily along the coastal fringe of the region, but are also abundant in riparian habitat along streams. Harbo (1958) documented high use of intertidal invertebrates as a food source, and mink movements along beaches and in wooded cover parallel to the beach. He described den sites in rock crevices, rock piles, and in cavities under tree roots. Natal dens were located within spruce cover in close proximity to intertidal feeding areas.

Johnson (1985) recently completed a study on the use of coastal habitat by mink on Prince of Wales Island in southeast Alaska. He found that mink use was concentrated within 10 m of the shrub-tree border of the shoreline and only occurred inland for crossing of points or peninsulas. His data indicated that mink use was highest in residual beach fringe and old-growth low-volume timber; higher in old-growth (high-volume, low-volume, and residual stands) than in second growth; and lowest in clearcuts and virtually nonexistent in muskegs and along streams. He concluded that beach-fringe timber was used for travel, denning, feeding on captured prey, and escape cover. He recommended that buffer strips of timber which would withstand windthrow (at least 60 m inland from the shoreline) be maintained. If beach-fringe timber was to be clearcut, he recommended that 1) the shoreline length of the clearcut be as short as possible, preferably less than the smallest average range of mink (.8 km), and 2) clearcutting beach-fringe timber should be avoided on islet points, on convex, and reef shorelines; along short intertidal zones (less than

40 m from 0- m to +6 m lines), and along intertidal areas with high amounts of bedrock and boulder cover.

Land otter

Land otters occur throughout the region. Recent studies in southeast Alaska (Larson 1983, Woolington 1984) documented an avoidance of clearcuts for travel routes, burrows, and natal dens. Woolington (1984) suggested that logging would result in temporary removal of shrub cover needed by otters, slash deposition that would impede their travel, mechanical destruction of den sites and burrows under stump mounds and rotting stumps, road encroachment through their habitat, disturbance during the breeding period, and loss of natal den sites in riparian forest stands along stream courses. He recommended that logging be avoided adjacent to watercourses during the breeding season from early May to late summer.

Based on these recent studies (Larson 1983, Woolington 1984), clearcut logging along beaches and stream courses will alter preferred otter habitat for travel, forage, cover, burrows, and natal dens. Conversion of old-growth forests to second-growth forests could remove important breeding and burrowing habitat. Loss of suitable habitat for reproduction can have a significant adverse impact on otter populations.

Both Larson (1983) and Woolington (1984) recommended retaining a fringe of timber along the beach to meet otter habitat requirements. Larson (1983) recommended a minimum width of 60 m, while Woolington (1984) recommended a minimum of 50-75 m, with larger leave strips where windthrow was likely. The latter author also recommended that no roads be located adjacent to steep, rocky shorelines and along watercourses to protect natal den sites.

SMALL MAMMALS

Studies on small mammals are very limited in southeast Alaska, but information on general habitat requirements of the species present strongly indicate that clearcutting can have long-term impacts on populations of certain species.

Forb and shrub understory production in the forest is necessary for abundant populations of certain rodent species. Van Horne (1981, 1982) demonstrated that both longtail voles (*Microtus longicaudus*) and deer mice (*Peromyscus maniculatus*) prefer sites with high understory production.

Small mammals which depend on forbs and shrubs during summer may benefit from the initial high shrub production in clearcuts. However, the results of field studies have been contradictory for the deer mice. Harris (1968) reported consistently lower population levels of deer mice in clearcuts on Prince of Wales Island compared to nearby forested areas during the first 10 years following cutting; whereas Van Horne (1981) documented a slight increase in deer mice populations in clearcuts continuing until the stage of maximum shrub production prior to canopy closure. Deer mouse populations appeared to decrease with canopy closure and understory loss in pole stands and likely remain low until an understory is reestablished as the stands develop into old growth (Van Horne 1981).

Van Horne (1982) also conducted population studies on longtail voles, a species that primarily occupies forest edges or shrubby areas. She concluded that the species appeared to find optimum habitat in young, 7-to-10-year-old clearcuts, and attributed this preference to the availability of low cover in the form of shrubs and logs and open areas with high production of preferred herbs and berries. She found that forb production declined 10 to 25 years after logging, resulting in declines in vole carrying capacity and abundance. She predicted that 30-to-150-year-old pole stands would be entirely devoid of long-tailed voles and that such stands would act as barriers to dispersal of voles between suitable habitat patches.

Other herbivorous small mammals, i.e. other mouse species and voles, also require understory forest production to maintain their populations. Because clearcutting on a 100-year rotation results in a pole stand with a low-diversity understory for approximately 70% of the harvest rotation, overall small mammal diversity and production will likely decline significantly in areas where extensive clearcutting occurs.

In addition to the reduction of understory food supplies, some small mammal species depend on cone seeds for food and/or require tree cavities. Removal of the tree canopy will eliminate denning and feeding areas for red squirrels (Tamiasciurus hudsonicus) and flying squirrels (Glaucomys sabrinus). Red squirrels, a common small mammal throughout much of southeast Alaska, depends on seed production from conifers to survive (Wolff and Zasada 1975). Field observations indicate that clearcutting essentially eliminates red squirrel habitat in southeast Alaska, as has been documented in other coniferous biomes (J. Doerr, pers. obs.). This impact persists until cone production is reestablished in second-growth stands which should occur within 20-30 years for western hemlock trees and within 20-40 years for Sitka spruce (FS 1965).

The northern flying squirrel is a species that merits habitat management concern. Meslow et al. (1981) described the species as one that finds optimum habitat for breeding or foraging in old-growth Douglas fir forests. Harris (1984) described a particular ecological role in energy transfer that flying squirrels fill in these forest ecosystems through their consumption of arboreal lichens during winter. The squirrels also feed on ectomycorryhisal fungi, e.g. truffles, and dig up and spread the below-ground spores of the fungi to other areas where they perform an essential role of fixing nitrogen for the roots of many conifers. Thus, truffle-feeding small mammals play a positive role in forest regrowth following logging or disturbance (Maser et al. 1978).

Although no work has been done on the habitat requirements of the flying squirrel in southeast Alaska, research has been conducted in interior Alaska. Mowrey and Zasada (1984) found that flying squirrels fed on truffles, mushrooms, and other fungi, berries, insects, and carrion when available, but depended primarily on cached fungi and arboreal lichens during winter. They preferred spruce trees over hardwood trees because of the rough bark that permitted clinging both after gliding to the tree and by young squirrels during rearing in den trees. Large diameter, tall trees also afforded a better landing surface; spruce trees provided year-round cover. Trees were used for denning, both to rear young and for thermal cover and protection from wind and rain. During the coldest weather, all squirrels denned in white spruce trees infected by mistletoe that produced clumps of abnormal growth of branches or "witches broom." In warm or wet weather, they use tree cavities excavated by woodpeckers, thus utilizing the same old-growth stands preferred by woodpeckers for nesting. Mowrey and Zasada (1984) observed a maximum home range size of 31 ha, a maximum distance between den trees equal to 470 m., and as many as 13 different den trees used over the year within the home range.

Mowrey (1982) concluded that old coniferous forest stands with den trees containing "witches broom," woodpecker cavities, and natural cavities for nesting were essential habitat. Mowrey and Zasada (1984) recommended timber leave strips between clearcuts in excess of 30 m. in width for use as travel corridors from tree to tree. They also noted that the size and number of forest openings a squirrel had to cross were an important consideration and recommended that openings generally not be more than 20 m. across and that openings wider than 30 m. should contain scattered trees, especially tall spruce.

These data suggest that in the southeast region, early regrowth clearcuts would lack trees for denning and landing sites and that second-growth forests with poor arboreal lichen development could reduce winter carrying capacity for flying squirrels when conditions are most severe through reduced food supplies, feeding areas, and den trees. Second-growth management for timber production will eliminate diseased trees that provide cold weather nests. Stands managed on a 100-year rotation will be harvested before they develop sufficient heart-rot to permit cavity excavation by woodpeckers.

Decreases in small mammal populations as a result of clearcutting will affect those mammal and bird species that depend upon these species as a prey base, including owls, hawks, marten and weasels.

A final concern for small mammals is the potential for the elimination on a localized or regional basis of old-growth dependent species. Basic biology questions such as habitat needs, species distribution, and even proper taxonomic classification surround many of the small mammal species that inhabit the Tongass. This unique archipelago limits interisland dispersal by small mammals, thus increasing the chances for local extinction.

A number of small mammal species have extremely limited known distributions in southeast Alaska. These include the meadow jumping mouse, Zapus hudsonius, water shrews, Sorex palustris and S. arcticus, and the endemic species Coronation Island vole Microtus coronarius, and Sitka deer mouse, Peromyscus sitkensis, (MacDonald and Pengilly 1979). A unique subspecies, the Prince of Wales flying squirrel (Glaucomys sabrinus grisifrons) may be old-growth dependent and has recently been proposed to "Category 2" of the federal Candidate Species List for endangered and threatened vertebrates.

BIRDS

The Tongass National Forest provides migratory and breeding habitat for numerous bird species as well as important winter habitat for resident birds. Of approximately 100 species observed on the mainland during a species and habitat inventory (Gibson and MacDonald 1975), and some 80 species observed in the Alexander Archipelago (Gibson 1976), 18 and 14, respectively, were resident species. The surveys reported that the mainland area had 170 known breeders and 19 other possible breeders, while the Archipelago had 43 breeders and 19 probable breeders. Survey work and research on the effects of timber harvest on birds have focussed on breeding birds during the spring and summer season. More recently, Hughes (in prep.) conducted winter surveys and enumerated 20 species within old-growth forest plots on Admiralty Island. Research has also recently been concluded on winter habitat requirements of bald eagles (Hansen et al. 1984).

Breeding Habitat Studies

Several studies in the southeast Alaska region have been conducted on the effects of logging on breeding bird populations (Noble 1978, Kessler 1979, Reid et al. 1980). Studies have also been conducted on breeding requirements of bald eagles (Hodges and Robards 1981), marbled murrelets (Quinlan and Hughes in prep.), and two resident birds, the blue grouse (Doerr et al. in press), and the Vancouver Canada goose (Lebeda and Ratti 1983).

Table 1 summarizes the results of studies conducted in the region and in the Pacific Northwest on the effects of clearcutting on some bird species which breed in the region. Noble (1978) conducted preliminary surveys of breeding birds in logged and unlogged Sitka spruce, western hemlock forests on Prince of Wales Island, Alaska during June and July of 1977. He reported that golden-crowned kinglets (Regulus satrapa), ruby-crowned kinglets (Regulus calendula), and red-breasted sapsuckers (Sphyrapicus ruber) are drastically reduced or eliminated when old growth is removed whereas other species reached higher densities in small clearcuts and regrowth areas than in old growth because of their preference for early successional stages or nesting in shrubs. Noble further speculated that other species known to require old growth, but not occurring in his limited old-growth study plots (i.e., three-toed woodpecker (Picoides tridactylus), hairy woodpecker (Picoides villosus), downy woodpecker (Picoides pubescens), sharp-shinned hawk (Accipiter striatus), red-tailed hawk (Buteo jamaicensis), blue grouse (Dendragapus obscurus), pine grosbeak (Pinicola enucleator), pine siskin (Carduelis pinus), red crossbill (Loxia curvirostra), yellow-rumped warbler (Dendroica coronata), chestnut-backed chickadee (Parus rufescens), and brown creeper (Certhia americana) would also be

Table 1. Reported response of bird species breeding in southeast Alaska to clearcutting.

I. Species that will increase following clearcutting of oldgrowth:	
Orange-crowned warbler	(Noble 1978, Kessler 1979)
Wilson's warbler	(Noble 1978)
Dark-eyed junco	(Noble 1978, Kessler 1979, Mannan and Meslow 1980)
Fox sparrow	(Noble 1978, Kessler 1979, Reid et al. 1980)
Hermit thrush	(Noble 1978, Kessler 1979)
Winter wren	(Kessler 1979)
Steller's jay	(Kessler 1979)
Swainson's thrush	(Kessler 1979)
Ruby-crowned kinglet	(Kessler 1979, Mannan and Meslow 1980)
American robin	(Kessler 1979)
Song sparrow	(Kessler 1979)
II. Species that will decrease following clearcutting of old growth:	
Ruby-crowned kinglet	(Noble 1978)
Chestnut-backed chickadee	(Noble 1978, Kessler 1979)
Golden-crowned kinglet	(Noble 1978, Kessler 1979)
Townsend's warbler	(Kessler 1979)
Varied thrush	(Kessler 1979)
Western flycatcher	(Kessler 1979)
Yellow-bellied sapsucker	(Kessler 1979)
Red-breasted sapsucker*	(Noble 1978)
Hairy woodpecker	(Kessler 1979)

*This species was listed by the author in the publication as the yellow-bellied sapsucker, however the common name was subsequently changed by the American Ornithologists Union (1982).

substantially reduced or eliminated as old-growth habitat is eliminated.

Kessler (1979) working on Kosciusko Island, (near Ketchikan, Alaska) added Townsend's warbler (Dendroica townsendi), chestnut-backed chickadee, varied thrush (Ixoreus naevius), western flycatcher (Empidonax difficilis), and hairy woodpecker, to Noble's list of known bird species whose populations would be decreased by clearcutting. Kessler (1979) also reiterated a concern for other old-growth dependent species which might be present on her study plots but which remained unrecorded due to low densities or nocturnal habits. Her partial listing of these species includes northern goshawk (Accipiter gentillis), western screech-owl (Otus kennicottii), great horned owl (Bubo virginianus), great gray owl (Strix nebulosa), northern hawk-owl (Surnia ulula), boreal owl (Aegolius funereus), northern saw-whet owl (Aegolius acadicus), boreal chickadee (Parus hudsonicus), red-breasted nuthatch (Sitta canadensis), and brown creeper.

Reid et al. (1980) censussed breeding bird populations in clearcuts, old growth, and scrub forest in the Pavlof drainage. Lowest total bird densities were found in recent (two-year-old) clear-cuts and highest densities in scrub (non-commercial stands) forest. The study provided additional habitat use information for the eight bird species that bred in successional stands but not in old-growth commercial stands in the studies by Noble (1978) and Kessler (1979). Four species (Steller's jay, tree swallow, American robin, and rufous hummingbird) utilized scrub forests for breeding and two species (Swainson's thrush, song sparrow) nested in old-growth forests but at densities low enough to be missed by earlier census plots. They concluded that clearcutting might benefit fox sparrow populations.

In summary, all breeding bird studies have concluded that fox sparrows will likely benefit from clearcutting. Noble (1978) and Kessler (1979) both concluded the orange-crowned warbler, dark-eyed junco, and hermit thrush would also benefit, while Reid et al. (1980) observed that these species also bred abundantly in non-commercial scrub forests. The breeding bird surveys and consideration of requirements for characteristics of old-growth forests concluded that a number of bird species would likely be adversely affected by clearcutting. The species most commonly described as requiring old-growth forests included hawks (sharp-shinned and red-tailed hawks, northern goshawk, and American kestrel), owls (boreal owl, western screech-owl, northern hawk-owl, northern saw-whet owl), woodpeckers (downy and three-toed woodpeckers), blue grouse, boreal chickadee, brown creeper, and red-breasted nuthatch. A number of other species have been described as potentially benefitting from or being adversely affected by clearcutting.

Noble (1978) recommended retention of old-growth tracts within areas to be logged with a minimum site of 400 acres. He also recommended that such tracts be no more than one mile from any similar tract and that old-growth corridors be left to connect the tracts.

Winter Habitat Studies

Hughes (in prep.) censussed bird species resident in old-growth forest stands on Admiralty Island during winter (Table 2). He further described old-growth habitat use during winter by five species of cavity and snag-nesting birds (hairy woodpecker, three-toed woodpecker, red-breasted sapsucker, chestnut-backed chickadee, and brown creeper) by timber volume classes (Table 2). Winter food can be the limiting factor for resident bird populations (Haapanen 1965, Fretwell 1972), and for resident, hole-nesting birds in particular (McClelland 1977).

Hughes (in prep.) found that brown creepers and hairy woodpeckers were most numerous in high-volume stands (greater than 40,000 MMbf/acre) while three-toed woodpeckers were most numerous in high and medium-volume stands (25,000-40,000 MMbf/acre) and red-breasted sapsuckers and chestnut-backed chickadees were most numerous in low-volume stands (less than 25,000 MMbf/acre) during winter. He concluded that harvesting high-volume, old-growth stands would impact hairy woodpecker populations more severely than harvesting low or medium-volume stands. He also concluded that timber harvesting in old-growth stands would probably have the greatest impact on snags with cavities used as winter roosts by chestnut-backed chickadees. He noted that the high densities of chickadees might reflect a seasonal habitat shift with birds moving into southeast Alaska from areas with more continental, colder climates.

He recommended that winter habitat be maintained as well as breeding habitat through retention of undisturbed old-growth tracts.

Bird Use of Snags and Tree Cavities

Recent research in southeast Alaska (Hughes in prep.) has focussed on the impacts of timber harvesting on bird species that utilize snags, particularly those that depend upon the presence of standing dead trees or older, decaying trees with heartrot or other diseases that make them suitable for excavation of cavities for nest sites or winter roosts. Noble and Harrington (1978) described 25 bird species in southeastern Alaska that are cavity-dependent or cavity-users. Birds such as the hairy woodpecker, three-toed woodpecker, and red-breasted sapsucker, are primary hole nesters, i.e. they excavate their own nest. They depend upon tree characteristics that permit excavation. Other bird species, including the chestnut-backed chickadee and brown creeper, are secondary hole nesters, and usually do not excavate their own nests. Instead, they depend upon the presence of natural cavities or cavities excavated by primary hole nesters. Four of the five hole-nesters mentioned above are winter residents of southeast Alaska, while the red-breasted sapsucker is an early migrant.

Birds in southeast Alaska have also been observed using snags for song perches, by territorial males during breeding season, for perches and courtship display areas for band-tailed pigeons, and as foraging perches for sharp-shinned hawks and goshawks (Gibson and MacDonald 1975, Gibson 1976). Snags may also be used as drumming sites by woodpeckers or for insect "hawking" or hunting (Hughes, pers. comm.). Cavities are used as roosts by birds that overwinter in the forests (Hughes in prep.).

In areas other than southeast Alaska, the importance of snags and trees that provide for cavity excavation and re-use is well-documented. Raphael and White (1984) recently cited 20 studies that document the regular use of snags by wildlife for nesting, feeding, shelter, communication, and resting. Studies have also focussed on adverse impacts of timber harvests that resulted in snag removal. The findings of Raphael and White (1984) in the Sierra Nevada complemented findings from other studies in Finland (Haapanen 1965), Sweden (Nilsson 1979), and Arizona (Balda 1975, Scott 1979) that removal of snags resulted in 32% to 52% fewer cavity-nesting birds than in adjacent areas with snags. Raphael and White (1984) determined that populations of cavity-nesting birds were proportional to snag density and that larger trees were preferred. Cavity nesting birds exhibited a strong preference for large snags for cavity excavation on Admiralty Island (Hughes in prep.). Snags were also preferred as foraging areas by several species. Mannan and Meslow (1984) compared populations of breeding birds and the structure and composition of managed and old-growth forests in northeastern Oregon and concluded that the abundance of snags in old growth was responsible for the relatively high numbers of hole-nesting birds. Large trees were indirectly important to hole-nesting birds as a source of large snags.

Timber harvest can result in loss of snags suitable for use by cavity-nesters in two ways: (1) through removal of snags during logging or associated human activities and (2) through shortened rotations which result in no recruitment of "new" old, large snags in areas managed intensively for timber production (Conner 1978). The first type of loss could be minimized by retaining snags during timber harvest. In Alaska, however, the majority of snags are removed to meet human safety requirements.

Improved public access by logging roads results in additional utilization of snags for firewood. Silvicultural practices, including thinning and improvement cuttings, often selectively remove diseased trees that would develop into snags suitable for cavity-excavation (Evans and Conner 1979).

The problem of snag recruitment is a more long-term impact. Hughes (in prep.) census of snags in old-growth forest stands resulted in the identification of key characteristics of snags of commercial tree species which had bird cavities. Bird cavities were most often located in large-diameter, broken-top western hemlock snags with heartrot and with more than 80% of the bark remaining. Intensive forest management practices necessary to achieve rotations of 80-125 years will result in removal of defective trees before these characteristics can develop.

Hughes (in prep.) made the following management recommendations concerning snag management:

Table 2. Winter use of old-growth forest habitat (Hughes in prep.)

I. Bird species resident in old-growth forest in southeast Alaska

Bald eagle
Northern pygmy-owl
Blue grouse
Common raven
Steller's jay
Black-billed magpie
*Hairy woodpecker
*Red-breasted sapsucker
*Three-toed woodpecker
*Brown creeper
*Chestnut-backed chickadee
American robin
Varied thrush
American dipper
Winter wren
Pine siskin
Dark-eyed junco
Golden-crowned kinglet
Red crossbill
White-winged crossbill

*Species requiring tree cavities or snags for nesting or roosting.

(1) Specific guidelines should be adopted for each cutting unit to maintain a diversity of habitats for hole-nesting birds.

(2) The forest planning process specified in the National Forest Management Act of 1976 should be completed for the Tongass National Forest to select representative management indicator species for cavity-nesting wildlife and determine desired population levels.

(3) Until the planning process is completed, managers should attempt to retain all snags within cutting units, in patches, where possible, to survive intensive timber management practices and potential windthrow. Snag patches should be left connected to cutting unit borders rather than isolated within cutting units.

(4) A program to provide a sustained supply of snags is essential. Second-growth management techniques, such as girdling live residual trees, leaving snags, and identifying defective trees with heartrot or fungi to be left throughout the rotation should be implemented.

(5) Firewood cutting areas should be designated by the Forest Service to insure that snags left standing for wildlife are not removed by the public.

(6) Patches of undisturbed old-growth forests should be retained to meet all habitat needs of cavity-nesters, including winter habitat for resident species. Retention areas of at least 160 ha have been recommended by Noble (1978) for breeding birds.

Bald Eagle

Southeast Alaska supports the highest density of breeding bald eagles, estimated at more than 7,000 breeding birds (King et al. 1972, Hodges et al. 1979), and the largest breeding population in North America (Conant et al. 1979). This important resource has been the subject of nest surveys since 1969. Productivity surveys of a core area of 90 nests along 52 miles of coastline have been conducted since 1972. However, some areas of the coastline remain unsurveyed. By 1981, 3850 nests had been located.

Based on the survey of these approximately 4,000 nests, Hodges and Robards (1982) concluded that eagles utilize large, primarily live old-growth trees near the waterfront to support their nests. Exposed coasts, prominent points, and islets are preferred foraging areas. Few nests are located beyond 200 m (220 yd) inland of the saltwater coastline. Eagles also nest in large cottonwood trees along river bottomlands of large mainland river systems and occasionally along the major freshwater streams and lakes of the largest islands. Ground nests are rare. Nests are usually located in trees with bushy, live, broken, and deformed tops. Over the ten-year period 1969-79, the highest nesting activity occurred in nests in heavy old-growth stands and on islets with limited or sparse amounts of timber. Based on average nest tree characteristics, typical nest trees are approximately 400 years old.

Bald eagle nest trees are an important component of eagle habitat. The Bald Eagle Act of 1940 prohibits disturbance or harassment of bald eagles. Known bald eagle nests are protected from timber harvest by state and federal regulations. A Memorandum of Understanding (MOU) between the U.S. Forest Service (USFS) and U.S. Fish and Wildlife Service (USFWS) requires that areas be surveyed for nests and that an undisturbed wildlife habitat zone 330 feet or more in radius be established around each eagle nest tree. Encroachments within the buffer zone are permitted by the USFWS on a case-by-case basis. During the period 1969-1983, 126 variance requests were received by the USFWS for activities in the Tongass National Forest. Fifty-two variances were issued before the impact to the buffer had occurred; 3 were issued following the impacts; 42 requests were denied; 14 nests were found after construction; and 15 variances had insufficient records to determine the circumstances. Forty-one percent of the variance requests occurred during the 1979-1982 period (M. Jacobsen, unpub. data).

Hodges (1982) evaluated the 100-meter protective zone for bald eagle nests in southeast Alaska and concluded that the zone was inadequate for providing nesting and perching habitat indefinitely in the face of adjacent sustained yield clearcut logging practices. He surveyed 89 nests where logging activity had occurred within 1.6 km of the nests, 77 nests 1.6 km or more away from the same logging activities, and 60 additional nests at least 10 km away from any logging activity. Sample sizes were too small to detect a significant difference in nest activity rate as a function of distance from logging development, however he concluded that logging development did not result in a substantial decline of nesting activity. During the five-year period of study, nest destruction rates from natural causes was highest when development activity was within 45 m of the nest trees; and blowdown of nest trees was 20 times more common than when logging activity was further than that distance from the edge of clearcuts. Many protective buffer zones were lost either as a result of human development or as a result of blowdown. He concluded that clearcuts adjacent to protective buffer zones would result in substantial loss of the forested zone within five years and a higher potential for loss of nest trees through blowdown. He recommended that only carefully planned access corridors and selective logging be practiced in shoreline fringe forests and that blowdown be anticipated and cautiously removed along pre-planned routes to minimize disruption of beachfront habitats.

During winter, bald eagles are distributed fairly evenly where food is available along the unfrozen coastline, however large concentrations occur on the Chilkat River near Haines and in response to large eulachon runs during late winter and early spring on specific river systems within the region. Conifers are used extensively for communal roosting during mid- to late fall and winter (Hansen et al. 1984). Wintering populations are significant, with up to 3000-3600 eagles in the Haines area (Hansen et al. 1984) and an estimated 5000-7000 birds in northern southeast Alaska in March - 3000 more than in March during the breeding season (Hodges and Conant 1980). Concentrations of eagles on the Stikine River during eulachon runs reached a peak of 1500 in 1979 (Hughes 1980a).

Perch and roost trees are also an important habitat requirement for bald eagles. Perching and roosting are strategies that help conserve energy output during periods of food shortage and energy stress through reduction of stressful weather conditions and minimizing activity (Hansen et al. 1984).

The USFS-USFWS MOU also requires that a tree, or cluster of trees, if necessary to improve wind-firmness, be preserved in forested areas as feeding and perch trees in each hundred yards of beachfront. No similar provision currently exists for state, municipal, or private lands. Removal of existing or potential perch and feeding trees will remove habitat that provides thermal cover (Stalmaster 1981) and lowered risks of predation and injury (Hansen et al. 1984). Hodges et al. (1982) found that areas without old-growth trees were used less than their proportion of availability for perching.

Timber harvest within winter concentration areas could remove roosting trees which serve the same purposes as perching trees, but are more critical to overwinter survival during periods of severe winter weather. The important Chilkat River Valley winter concentration area and feeding grounds was placed in a protective State Bald Eagle Preserve status in 1982. Other wintering concentration areas and concentrations to exploit seasonally abundant food sources like eulachon are poorly documented so no protective measures have been developed.

Timber harvest could impact bald eagle populations indirectly if adverse impacts occurred to their food sources, especially specific salmon and eulachon runs (Hansen et al. 1984). Food is described by Hansen et al. (1984) as controlling both survival and reproduction. Breeding birds require food in close proximity to their nests during the six-month breeding period and it is likely that only a portion of the breeding habitat offers a stable food supply throughout the period in any given year. Measures which maintain the productivity of salmon and eulachon runs also benefit the eagle population.

A similar problem exists for eagle nest, perch, and roost trees as that for snags; conversion of the large acreages of the forest to second-growth forests on 100-year rotations is likely to significantly reduce the recruitment of trees with the characteristics associated with eagle use as existing nest and roost trees eventually die. The result would be a long-term loss of carrying capacity.

Hansen and Hodges (1985) have recently reported that a large portion of the Southeast eagle population are non-breeding birds, with sub-adults, and unsuccessful breeders comprising 30-89% of the population surveyed in May and June during four different years. Use of available nests ranged from 25 to 49%. The trend in these two population parameters has been toward an increase in the proportion of non-breeders and a decrease in use of available nests. They advanced two hypotheses for the trends: (1) that low breeding rates are normal where food resources are ephemeral so that more individuals survive than can reproduce and (2) that recent environmental disturbance has seriously reduced the breeding rate. They urged that efforts be made to determine the cause of this low breeding rate and also urged that measurement of reproductive success be expanded to include monitoring the status of other population segments to determine long-term population trends. They recommended that managers would be prudent to consider the requirements of sub-adults and non-breeding adults in an eagle population with an excess of non-breeders.

Osprey

Ospreys are one of the few raptors for which habitat information is available in Southeast. Hughes (1980b) identified four active nesting territories including 8 nest sites in the Stikine Area of the Tongass National Forest. All nest trees were located in the spruce-hemlock forests and all nests were at the top of large-diameter trees or snags. Other areas have apparently not been surveyed for osprey nests.

Hughes (1980b) observed mortality of two nestlings one year as a result of behavioral responses by the breeding pair to disturbance created by equipment noise associated with timber cutting and road construction. He concluded the adults were preoccupied with nest defense and were unable to provide adequate food and brooding. Working in northern California, Levenson and Koplin (1984) observed a decline in the average percent of occupied nests producing fledglings and the average number of young fledged per occupied nest with increasing logging activity that commenced after ospreys began nesting. They concluded that logging initiated after nesting commenced had a significant negative impact on productivity of osprey populations. Hughes (1980b) recommended additional surveys for osprey nests, horizontal and vertical buffers around nest sites, monitoring of impacts, and a possible need for restrictions on potential disturbances during the breeding period. Levenson and Koplin (1984) recommended minimizing human activity near nesting ospreys, no initiation of activity after nesting had commenced, and designing logging operations to minimize disruption by delaying operations until the young have fledged.

Marbled Murrelet

Marbled murrelets are seabirds which breed throughout the region and are known to utilize forested habitat for nesting (Quinlan and Hughes in prep.). The department initiated a research project in 1983 to characterize their breeding habitat requirements. Only one nest has been located to date, due to the difficulty of installing radio transmitters on the small birds and tracking them. The nest was located in an area similar to that described as typical for murrelet tree nests by Binford et al. (1975); a large decadent tree, with an open crown structure to allow easy access to feeding areas, and moss-covered limbs large enough to support and camoflauge a nest. The forest stand containing the nest tree was inaccessible for logging, however. Quinlan and Hughes (in prep.) speculate that use of moss-covered limbs for nests may restrict murrelet tree nesting to old-growth forest habitats.

Blue Grouse

Doerr et al. (in press) surveyed breeding male blue grouse on Kuiu Island, Mitkof Island and at Thomas Bay in southeast Alaska. Densities of territorial males averaged 7.2 birds/100 ha in old-growth forests vs. .16/100 ha in clearcuts. Singing males were found in large, live trees and more than 15 m above the ground. Birds located in clearcuts were in live, residual trees, either in individual trees or in clumps of residuals. Their observations suggest that old-growth forests are heavily used and clearcuts largely avoided for breeding habitat. In contrast to studies in areas other than southeast Alaska that have emphasized the importance of open habitats as preferred breeding areas, they found no evidence that territory selection was a function of distance to openings. They recommended that leaving trees greater than 15 cm diameter at breast height (dbh) and more than 80 m from the forest edge might increase breeding use of clearcuts, but emphasized the lack of information concerning habitat needs of blue grouse and relationships between forest succession and seasonal habitat use.

Vancouver Canada Goose

Over 90% of the estimated world population of Vancouver Canada geese (a largely nonmigratory subspecies) occurs in southeast Alaska (Bellrose 1976). This goose nests and rears its broods in forested habitats, a unique phenomenon among waterfowl. Nests have been observed on tree snags and tree-nesting is likely. Trees are used for perching, as well. Forest habitats are used as escape cover by breeding adults and broods and may function as the equivalent of large bodies of water used by other waterfowl to escape from terrestrial predators. Brood-rearing areas and nesting sites are typified by heavy understory vegetation, abundant food sources, and surface water sources. Heavy use is made of one timber stand type with commercial volumes of timber (Lebeda and Ratti 1984). Conversion of these stands to managed second-growth will likely lower the carrying capacity of this habitat for goose production.

Birds - Final Considerations

Research completed to date indicates that several bird species are likely to be adversely impacted by logging, secondary succession, and intensive management of second-growth stands. Timber management will eventually reduce the supply of large, old live trees and large snags. A few species may benefit from early successional stages. While snags can be selectively retained to prolong their useful life in second growth, researchers in the Pacific Northwest have recommended old-growth stand retention as the best overall management strategy (Bull 1978, Raphael and White 1984, Mannan and Meslow 1984). Old-growth stand retention will also maintain habitat for species requiring the characteristics of large, old trees as well as those requiring large snags for breeding, feeding, and winter habitat. Table 3 summarizes the other reported bird species which may fit this category for which research is lacking.

Devising a habitat management strategy for birds is a complex undertaking due to the diversity of species currently present and their corresponding diversity of habitat requirements. Habitat management is of lowest priority for those species that are abundant throughout a variety of habitats and on those habitats that are not commercial forest lands. The selection of Forest Service Management Indicator Species, as required by the National Forest Management Act, and development of monitoring strategies should seek to ensure that the full complement of bird species is maintained. To do so, the process should focus on species most vulnerable to logging impacts, despite the difficulties of monitoring species present in low numbers or difficult to detect.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

1) The review of documented impacts from clearcut logging and of research conducted to date in southeast Alaska have documented two likely general patterns of response to clearcutting and post-logging succession in the region:

   a) a loss of habitat carrying capacity in second-growth timber stands for Sitka black-tailed deer, land otter, brown bear, mountain goat, and several bird species, and possibly for marten. Breeding bird studies indicate the following species of birds will be adversely impacted by clearcut logging and resultant succession: yellow-bellied sapsucker, red-breasted sapsucker, golden-crowned kinglet, hairy woodpecker, western flycatcher, varied thrush, Townsend's warbler, chestnut-backed chickadee, blue grouse, osprey, and the Vancouver Canada goose. Concern also exists for removal of old-growth winter habitat for cavity-nesting resident bird species, the brown creeper, hairy woodpecker, three-toed woodpecker, and chestnut-backed chickadee; and of breeding bird habitat for an early migrant cavity-nester, the red-breasted sapsucker.

   For wildlife species which are adversely affected throughout post-logging succession or by the long-term loss of old-growth forest characteristics, avoiding timber harvest in optimum habitat is the appropriate management strategy. The management goal should be to identify and maximize the amount of optimum habitat to be retained, for example, retention of low elevation (1000 feet and below), high-volume old-growth timber stands which are relatively rare in occurrence in southeast Alaska and which comprise critical deer winter range; and

   b) a short-term benefit during the early clearcut stage of succession (3 to 15-25 years) due to increased abundant forb and shrub production in combination with a loss of winter habitat carrying capacity during periods of deep snow accumulation. The wildlife species that appear to exhibit this response pattern include black bear, moose, long-tailed vole, wolf (indirectly from deer population responses), and a number of migratory breeding bird species that nest and/or feed in understory vegetation. Due to loss of the understory, the benefits of this stage are absent in the pole stand stage of succession which occurs for approximately 75% of the rotation. The carrying capacity of the pole stand is low to non-existent for these species.

   For wildlife species that are beneficially affected during early clearcut stages of succession but which require winter habitat with relatively shallow snow depths, long-term scheduling of timber harvest to maximize the availability of

Table 3. Bird species identified as requiring characteristics of old growth for which research in southeast Alaska is lacking

Downy woodpecker	(Noble 1978, Hughes in prep.)
Sharp-shinned hawk	(Noble 1978)
Red-tailed hawk	(Noble 1978)
Northern goshawk	(Kessler 1979, Meslow et al. 1981)
American kestrel	(Noble and Harrington 1978)
Western screech-owl	(Noble and Harrington 1978, Hughes in prep.)
Northern hawk-owl	(Noble and Harrington 1978, Kessler 1979, Hughes in prep.)
Boreal owl	(Kessler 1979, Hughes in prep.)
Northern saw-whet owl	(Noble and Harrington 1978, Kessler 1979, Hughes in prep.)
Great horned owl	(Kessler 1979)
Great gray owl	(Kessler 1979)
Northern pygmy-owl	(Noble and Harrington 1978)
Blue grouse	(Noble 1978, Doerr et al. in press)
Pine grosbeak	(Noble 1978, Meslow et al. 1981)
Pine siskin	(Noble 1978)
Red crossbill	(Noble 1978)
Boreal chickadee	(Kessler 1979, Hughes in prep.)
Yellow-rumped warbler	(Noble 1978)
Red-breasted nuthatch	(Noble and Harrington 1978, Kessler 1979, Hughes in prep.)
Vaux's swift	(Noble and Harrington 1978, Meslow et al. 1981, Mannan and Meslow 1984)
Northern flicker	(Noble and Harrington 1978)
Common goldeneye	(Noble and Harrington 1978)

both types of habitat through time is the appropriate habitat management strategy. The goal of habitat management should be to ensure an optimum mix of old-growth and early-clearcut-stage forest stands that will be distributed in time and space in a manner that is appropriate to the species' typical movement patterns.

2) Other patterns of response include a loss of carrying capacity until well into the pole stand stage (when spruce cone production resumes for red squirrels), avoidable losses through maintenance of riparian buffer strips (beaver), short-term responses dependent on suitable snag retention in clearcuts followed by a long-term loss of carrying capacity, through lack of suitable snag recruitment (flying squirrels, cavity-nesting birds), and a long-term loss of carrying capacity through lack of old-growth nest tree recruitment (bald eagle).

   Land managers should develop and implement policies to retain riparian habitat and to manage stands for retention and recruitment of large-diameter snags.

3) Adverse impacts of increased human access have also been documented, and have been particularly severe for mountain goats and the brown/grizzly bear leading to severe population declines in other portions of their range. Black bears, deer, moose, and furbearers will also be subject to the potential for local over-harvests, displacement, and harassment from increased human activity.

   One objective of timber sale planning should be to minimize the effects of roading and increased human activity on vulnerable wildlife species. Guidelines and mitigative measures, including no roading in wildlife concentration areas as identified by the Alaska Department of Fish and Game, should be developed and implemented. Roading of areas in advance of timber sales, and particularly when no timber harvest activity is scheduled within five or ten-year planning horizons, should not occur.

4) Timber harvest activity can affect wildlife habitat through disturbance of habitats adjacent to forest stands. Most notably, adverse impacts to beaver pond habitat through roading or hydrological changes will also adversely affect several fish species, muskrats, and waterfowl, and should be avoided during timber sale planning.

5) Research should be conducted to further delineate wildlife habitat requirements and responses to second-growth timber management. Research from other geographic areas should be relied upon for habitat management direction only when its applicability and relevancy to habitat conditions in southeast Alaska can be clearly demonstrated.

6) Adverse impacts on habitats adjacent to cutting units and other indirect adverse impacts to wildlife should be minimized through long-range planning and on-the-ground monitoring.

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PART II

The Impacts of Clearcut Logging on the Fisheries Resources of Southeast Alaska

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INTRODUCTION

Land and water system processes that shape the character of the aquatic environment are complex and dynamic. The activities of man can affect these processes in ways that result in environmental changes that go beyond natural effects or result in impacts that otherwise would not have taken place.

Salmonid fishes have definite freshwater habitat requirements. Considerable data have been collected that indicate timber harvesting and associated road construction activities alter many habitat variables critical to salmonid fishes. Certain of these impacts singularly or collectively produce short and long term effects on salmonid populations and their users. However, in Alaska, long-term effects of logging on fish populations are still not completely understood because logging and related research are relatively new to the region.

Research on the habitat requirements of juvenile salmonids and the effects of logging on rearing ecology is on-going in the region. A more detailed literature review on this aspect of logging effects will be contained in a 1985 Alaska Department of Fish and Game Federal Aid in Fish Restoration and Anadromous Fish Studies Annual Report (Elliott, in press).

IMPORTANT AQUATIC HABITAT VARIABLES FOR FISH PRODUCTION

STREAMFLOW AND HYDROLOGICAL DYNAMICS

Streamflow is defined as "the amount of water flowing in a channel per unit time," and is only meaningful in regards to fish habitat when it is correlated with water velocity, depth, the amount of channel covered, and how the flow, at a particular time, compares to what is considered normal for the channel (Chamberlain, 1982).

Streamflow can be a barrier to fish movement when the depth is too shallow or velocity is too high (Thompson, 1972). Obviously, when there is no escape from depths too shallow to maintain adequate oxygen and moisture for a fish, death results. Drought conditions can strand adult pink and chum salmon in pools in southeast Alaska as the water level drops, where they often die from anoxic conditions (Murphy in press).

Streamflow requirements by fish vary by life history stage. Optimum streamflows for spawning in given channels are those that will maximize the availability of suitable areas during the spawning season. If flows are so low that suitable spawning gravel is dewatered, eggs will not be deposited in these areas and potential productivity will not be realized from these areas. However, Reiser and White (1983) have documented high survival of king salmon eggs which were deposited but dewatered during the winter. As flow increases, there is a level past which velocity may be so high that eggs deposited in the gravel are washed away, also resulting in lost potential production (Reiser and Bjornn, 1979).

The streamflow requirements for salmonid egg incubations have not been determined because it is difficult to measure flows through the intragravel environment. However, it is generally assumed that to assure successful incubation of salmonid embryos, enough surface flow should be present to permit emergence of fry out of the gravel and velocities no greater than that which would scour gravel from redds ("nests" where eggs have been deposited). Rapid water fluctuations and increased peak flows can result in direct mortality of salmon eggs (Gangmark and Broad 1956) and trout eggs (Seegrist and Gard 1972).

Recommendations concerning the required streamflows for salmonid rearing have usually been based indirectly on the relationships of habitat components such as food or cover as they are affected by streamflows rather than directly to productivity in terms of numbers or biomass of fish (Reiser and Bjornn, 1979). The density of juvenile anadromous salmonids may be regulated by the abundance of food in some streams (Chapman, 1966). Streamflow is related to the amount of cover available, which is related to the standing crop of juvenile salmon (Murphy et al. 1985; Heifetz, in press).

The most significant effects of streamflow are the effects of freshets on juvenile abundance. Hartman et al. (1982) and Scrivener and Anderson (1984) showed that if coho fry emerge earlier than normal, their numbers are rapidly reduced by spring floods.

Some researchers believe that water velocity is the most important parameter in determining the distribution of aquatic invertebrates, one of the primary food sources for fish, in streams (Scott, 1958; Allen, 1959). The relationship between water depth and aquatic invertebrate production is not well understood. In one study, mayflies, stoneflies, and caddisflies were found in depths less than 0.3 meters (Kimble and Wesche, 1975). Hooper (1973) reported that areas of highest invertebrate production most often occur in streams at depths between 0.15 and 0.9 meters if substrates and velocities are suitable.

Water depths are important because juvenile salmonids have requirements for space in streams which vary with species, age, and time of year and are likely related to the abundance of food (Chapman, 1966). The standing crop of coho salmon has been shown to be directly related to pool volume (Nickelson and Hafele, 1978) and a similar relationship has been shown for chinook salmon in small streams (Bjornn et al., 1977).

Streamflow is an important site-specific variable, but it is only one aspect of the hydrologic cycle of a watershed that is affected by timber harvesting. Streamflow can be considered an output in an overall watershed balance equation:

$$\text{Inputs} - \text{Losses} \pm \text{Storage} = \text{Output},$$

where inputs include amounts of rain, snow, and fog drip; losses include amounts of evaporation from water, ground, and foliage, transpiration from plants, and deep seepage to ground water tables; storage may be in amounts of water in surface depressions, the soil, in channels, or as snowpacks; and, as mentioned above, the amount of stream runoff is the output. The equation expresses the relationship between the amounts of water in each component at any given time, but not with the rates of movement of water over time, which can also be affected by land use practices.

WATER QUALITY

The principal water quality parameters important for the quality of salmonid fish habitat that may be affected by land use activities are temperature, dissolved oxygen content, sediment levels, and organic matter content (Chamberlain, 1982).

Temperature: Salmonid fishes are cold water organisms, and have definite thermal requirements for physiological functioning. Water temperature affects growth rate, swimming ability, functional behaviors like catching and using food, and resistance to disease. Water temperature also affects the availability of dissolved oxygen in water, because more oxygen stays in solution at lower temperatures. Table 1 lists preferred, optimum, and upper lethal temperatures (degrees Celsius) of selected salmonid fishes and illustrates that salmonids generally prefer rather narrow ranges of temperature.

Researchers have found that sub-lethal high temperatures result in cessation of growth and feeding and lower fry densities. Salmonids cease growth at 20.3 C because metabolic activity increases instead at the expense of growth. Growth rates of chinook parr increase as temperature increases from 10.0 C to 15.7 C; growth rates then decrease with increasing temperature (Burrows in Reiser and Bjornn 1979). A similar relation for brook trout has been shown. Growth rate increases as temperature increases from 9.1 to 13.1 C and there is a decrease in growth rate after temperature exceeds 17.1 C. At 17.1 C, brook trout cease feeding and at 21.2 C eat only 0.85% of their body weight per day (Baldwin 1956).

Successful incubation of salmonid eggs occurs within a range of upper and lower lethal temperatures as well. Combs and Burrows (1957) and Combs (1965) showed that pink and chinook salmon eggs can tolerate long periods of low temperature and remain viable as long as the temperature during initial deposition and early embryogenesis is above 6.0 C. Extremely cold air and water can cause mortality on incubating eggs and alevins (yolk sac fry) by the formation of frazil ice or anchor ice that reduces water exchange in the gravel (Neave, 1953; McNeil, 1966; Reiser and Bjornn, 1979).

Water temperatures also affect adult and juvenile fish. Water temperature affects upstream migration of adult anadromous salmonids (Reiser and Bjornn, 1979). Sheridan (1962) showed that the timing of pink salmon runs was associated with temperature and Hartmen and Holtby (1982) found that warmer waters may inhibit coho adults from

Table 1. Preferred, optimum and lethal temperature ranges of selected fish species in degrees Celsius (from Reiser and Bjornn 1978)

SPECIES	PREFERRED TEMP. RANGE	OPTIMUM TEMP.	UPPER LETHAL TEMP.
Chinook	7.3 - 14.6	12.2	25.2
Coho	11.8 - 14.6	---	25.8
Chum	11.2 - 14.6	13.5	25.8
Pink	5.6 - 14.6	10.1	25.8
Sockeye	11.2 - 14.6	---	24.6
Steelhead	7.3 - 14.6	10.1	24.1
Cutthroat	9.5 - 12.9	---	23.0

entering streams. Abnormal stream temperatures can facilitate disease outbreaks and accelerate or retard ripening for spawning.

Water temperature also appears to regulate the density of salmonids. Hahn (1977) found 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. Stream temperatures in Southeast Alaska frequently exceed these levels during the months of July and August.

Dissolved Oxygen Concentration: Survival and development of salmonid eggs and embryos occurs within a critical range of dissolved oxygen concentrations (Lindroth, 1942; Hayes et al., 1951; Wickett, 1954; Alderdice et al., 1958). Laboratory tests with coho, chum, and chinook salmon, and steelhead trout eggs indicate the following relationships: sac fry from embryos incubated in low and intermediate oxygen concentrations are smaller and weaker than sac fry reared at higher concentrations (Silver et al., 1963); reduced oxygen concentrations lead to smaller newly hatched fry and a lengthened incubation period (Shumway et al., 1964); and low oxygen concentrations in the earliest stages of development can delay hatching or increase the incidence of abnormal embryos (Alderdice et al., 1958).

Dissolved oxygen concentrations in streams are important to rearing salmonids. Generally, stream water is at or near saturation levels for oxygen, however, the warmer the water, the less dissolved oxygen the water can contain at saturation. Herrmann et al. (1962) showed that growth rate, food consumption rate, and the efficiency of food utilization of juvenile coho salmon all decline when oxygen is less than 6 mg/L. Also, juvenile chinook salmon avoid water with oxygen concentrations near 1.5 to 4.5 mg/L in the summer, but show weaker avoidance reactions to low levels 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). Low dissolved oxygen concentrations can adversely affect the swimming performance of migrating salmonids (Reiser and Bjornn, 1979). Low dissolved 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.

Sediment Load: Suspended and deposited fine sediment can adversely affect salmonid habitat if present in excessive amounts. Streams with silt loads averaging less than 25 mg/L of suspended sediment can be expected to support good freshwater fisheries (Reiser and Bjornn, 1979), assuming that other environmental elements to be suitable. On the other hand, high levels of suspended solids may abrade and clog fish gills, reduce rates of feeding, and cause fish to avoid some areas (Trautman, 1933; Pautzke, 1938; Smith, 1939; Kemp, 1949; Wallen, 1951; Cooper, 1956; Bachman, 1958; Cordone and Kelley, 1961).

Suspended sediment directly affects rearing salmonids. Long term exposure of coho salmon and steelhead to suspended sediment (11-14 days at 23-84 NTU's) results in lower growth rates and greater emigration from test channels (Sigler et al. 1984). Observations of trout in the wild indicate that fish cease feeding at 35 mg/L suspended sediment (Bachman 1958) or reduce their feeding rate (Bachman 1984). Decrease in feeding rates may be responsible for low growth rates of salmonids, as observed by Sigler et al. (1984). Suspended sediment can fill in the interstices of, or completely cover, stream gravels, and where gravels are used as cover by juveniles, suitable foraging sites and refuge sites may be lost. The rate of production in coho can be reduced (Crouse et al. 1981) or emigration of steelhead and chinook can result (Bjornn et al. 1977).

Deposited sediment can change the composition of spawning substrates and reduce permeability to oxygen. McNeil and Ahnell (1964) determined that highly productive spawning streams have gravels with high permeability. Permeability is high when bottom materials have less than 5% sands and silts and is low when fine sediments make up more than 15% of the bottom material. Successful fry emergence is impaired as well by excessive amounts of sand and silt in the gravel. Koski (1966) examined redds where eggs had developed normally but the hatched fry were unable to emerge because of sediment. Phillips et al. (1975) found an inverse relation between quantity of fine sediments and fry emergence.

<u>NUTRIENT CYCLING</u>: Information regarding nutrient cycling in aquatic habitats is limited and even more limited concerning the relationships of nutrient cycling to fish production.

<u>PHYSICAL HABITAT FEATURES</u>

<u>Stream banks</u>: Stream bank areas provide lower water velocities compared to main stream currents. Undercut banks, overhanging root complexes, vegetation, and stable debris provide shade and protection from predators. Root networks contribute to stream bank stability and minimize bank erosion during high water flows (Chamberlain, 1982).

<u>Riparian Vegetation</u>: Plants living adjacent to streams, as mentioned above, help maintain stream bank integrity, which in turn provides continued shelter for rearing and spawning anadromous salmonids. Riparian vegetation also directly provides overhead cover and protection for fish. Certain anadromous salmonids, like chinook salmon and steelhead trout enter freshwater months before they spawn, and cover is essential for fish waiting to spawn (Reiser and Bjornn, 1979). Nearness of cover to spawning areas may be a factor in the selection of spawning sites by some species (Johnson et al., 1966; Reiser and Wesche, 1977).

Cover is extremely important to rearing salmonids, the life stage most vulnerable to predation by other fish, birds and mammals. Riparian vegetation is used by most salmonids as overhead cover (Newman, 1956; Wickham, 1967; Butler and Hawthorne, 1968; Baldes and Vincent, 1969;

Bjornn, 1969; Chapman and Bjornn, 1969; Lewis, 1969). Streamside vegetation also provides shade which is important in maintaining cool water, as discussed earlier. This factor appears to be important not just in temperate zones but in southeast Alaska as well (Meehan, 1970).

The presence of streamside vegetation enhances food supplies in the stream. Plant detritus (dead matter) that falls into streams from streamside vegetation may be an important source of food to aquatic invertebrates, which in turn are sources of food for fish. Terrestrial insects and other invertebrates that fall into streams from nearby plants also are eaten by fish. In southeast Alaska, rearing anadromous salmonids feed heavily on invertebrates that either fall from riparian vegetation, or else live in the streams but obtain energy from riparian plant detritus (Schmidt and Robards, 1974; Schmidt, 1975; Schmidt, 1976).

Finally, large plants like spruce, hemlock, and cottonwood provide sources of large organic debris (LOD) when they fall into streams, after death, when currents cut banks and undermine these large trees, or when they are blowndown during storms. These downed trees, which have a stream life yet to be accurately determined, create water velocity barriers, plunge pools, and provide cover for rearing and spawning anadromous salmonids. LOD appears to have a significant role in the evolution and maintenance of stream habitat diversity.

Barriers: Permanent blocks to fish movements, like large waterfalls, have always been a significant factor in shaping the distribution of anadromous salmonids in a stream system. Man has often attempted to open up new habitat for anadromous fish by devising ways to get fish above previously insurmountable barriers. Other natural barriers to upstream migrants may include excessive water velocities, debris jams, low water flows, excessive water temperatures, and pollution. All of these are of a more temporary nature, with the possible exception of large debris jams, and all can be the result of the activities of man.

SHORT-TERM EFFECTS ON FISH HABITAT

The activities of road construction, movement of logging equipment, felling and yarding of trees, and transportation of logs result in direct impacts to fish habitat which cease when the activities cease or which are relatively short-term. The major categories of impacts are changes in water quality parameters and changes in the physical structure of the habitat. By their nature, streams possess a natural capacity to restore disturbed portions to natural functioning, for example, flood flows will re-distribute sediment that has settled. The forest industry and forest managers have also developed logging practices, termed "best management practices" which help to minimize the extent or duration of short-term impacts during periods of human activity.

The extent and duration of impacts are directly related, in particular, to management of the riparian area adjacent to the stream.

This riparian area, or streamside zone, is comprised of vegetation in the extended floodplain of the stream which is influenced by its proximity to the stream and the stream's flooding characteristics. The natural streamside zone contributes to maintenance of fish habitat in several ways, thus activities related to timber harvesting which occur in this zone can affect these natural functions.

CHANGES IN WATER QUALITY

Temperature

The removal of streamside vegetation during timber harvest activities increases solar radiation to the stream and results in warmer water during the summer, especially in small streams (Greene, 1950; Chapman, 1962; Reinhart et al., 1963; Brown and Krygier, 1967, 1970; Levno and Rothacher, 1967; Gray and Edington, 1969; Meehan et al., 1969; Meehan, 1970; Brown et al., 1971; Narver, 1972; Tyler and Gibbons, 1973; Moring and Lantz, 1974). As water warms, its capacity for containing dissolved oxygen is diminished, which in turn can lead to salmon mortality from hypoxia. The magnitude of temperature change depends on the amount of timber harvested adjacent to a stream (Meehan et al., 1969; Brown and Krygier, 1970) and is a temporary effect until streamside vegetation regrows.

One of the most detailed studies on the effects of logging on a watershed has been the 15-year Alsea Watershed Study in coastal Oregon (Moring, 1975). Three small headwater tributaries were studied. One stream served as a control and remained unlogged, another watershed was completely clearcut, and a third was partially clearcut with buffer strips left along the stream. Water temperature ranges and maximums increased in the completely cut watershed and monthly average temperatures increased over pre-logging averages by 12.7 C in June, 11.8 C in July, and 9.3 C in August. Water temperatures in the completely cut watershed exceeded the pre-logging maximum fluctuation (4.4 C) 28% of the days in 1966 and 82% of the days in 1967. At no time during or after logging were these maximum fluctuations exceeded in the buffered or control creeks.

In southeast Alaska, Meehan et al. (1969) found that maximum temperature in logged streams exceeded those of unlogged control streams by about 5 C, but that temperatures did not reach levels lethal to juvenile salmonids. The increased water temperatures frequently exceeded the optimum for pink and chum salmon documented by Reiser and Bjornn (1979).

High summer air temperature has, however, been associated with adult salmon mortality. The Alaska Department of Fish and Game compiled a list of 43 streams that had mortality of pink and chum salmon in 1977 associated with high water temperature and low flow. The largest clearcut in Alaska is located within the watershed of Staney Creek. In 1979 15,000 pink salmon died there before spawning, a result of warm water and low oxygen. In an effort to help cool Staney Creek, the FS planted cottonwood trees along the stream to provide shade.

Murphy (1985) concluded that mortality of adult salmon in another instance, was primarily due to low water and suffocation, rather than warm water and thermal shock. Fish were stranded in pools when the water level became low during lowtide and that they then depleted the oxygen in the water. High temperatures could also have been an exacerbating factor, however, because warmer water contains less oxygen at saturation than cooler water.

Removal of riparian vegetation in northern areas may result in lower stream temperatures during winter, increasing the chances for frazil and anchor ice formation (Chamberlain, 1982).

Research at Carnation Creek, British Columbia showed that logging of coastal watersheds can cause a shift in temperature regimes that results in a complex chain of physical and biological effects. Winter water temperatures were warmer after logging, resulting in accelerated development rates of incubating salmonid eggs and alevins. This caused emergent coho fry to leave the gravel earlier than normal, and at a time when spring freshets are common. Consequently, many fry were swept to sea causing some sections of the stream to be underpopulated. The resulting low density population grew faster and fish were larger by fall. Larger fish tended to have better winter survival and greater potential to smolt at an earlier age. This resulted in a positive effect by increasing the number of smolt leaving the stream and by presumably increasing the adult return (Hartman et al. 1982).

The implications of these processes are unclear for southeast Alaska. As described in a following section, other research shows that regardless of increased summer growth, the number of potential smolt is regulated by the amount of winter habitat (Mason 1976) and by the severity of the winter climate (Murphy and Elliott, unpub. data) thus causing a neutral effect after logging. Other research suggests that rapid growth would stimulate some fish to leave the stream in the fall rather than during the spring, or chum fry to enter estuaries prior to the spring phytoplankton blooms that are their major food (Hartman and Holtby 1982). Fall and early smolt have poor marine survival and thus do not contribute to the fishery and can result in a negative effect by decreasing the number of returning adults.

Thus, in streams that have been logged, extended periods of high temperature will occur which may affect feeding, growth rates, and the density of juvenile salmonids. Additional research is needed concerning the effects of increased winter temperatures. Lower winter temperatures could result in winter mortality in the gravel, while higher winter temberatures could result in early emergence and vulnerability to flooding. It is presumed that temperature regimes return to normal levels after regrowth of vegetation occurs in the watershed. Some streams however, are considered particularly "temperature-sensitive" and prone to temperature extremes. The USFS has developed criteria to define this stream type. Special measures are needed to maintain their normal temperature regime.

Dissolved Oxygen Concentration

Logging can affect dissolved oxygen concentrations when organic debris, logging slash, or fine sediments enter streams and accumulate on and in streambeds. This accumulation reduces concentrations of dissolved oxygen in intergravel spaces and places a higher biological oxygen demand on available supplies. Research indicates that excessive logging debris in streams can reduce stream velocity and exchange of intergravel water. Fine sediments can also clog surface gravels and restrict intergravel flow enough to lower dissolved oxygen concentrations. This latter type of flow restriction is more often associated with road construction and land slides (Chamberlain, 1982).

Increases in stream temperatures can exacerbate adult mortality during drought conditions. Additionally, rapidly growing, second-growth forests with higher water demands may reduce streamflows relative to pre-logging levels. Combinations of high temperatures and decreased stream flows may occur more frequently until vegetation regrows to shade the stream, which can be 50 years.

The Alsea Watershed Study investigated the effects of logging on dissolved oxygen concentrations in streams. Clearcutting a tributary stream leaving no buffer strips resulted in sharp declines in surface dissolved oxygen levels during the summer of logging when debris was in the stream bed. After debris was removed and winter rains came, surface levels of dissolved oxygen returned to pre-logging levels (Moring, 1975). The study also showed a dramatic decrease in intragravel dissolved oxygen during the winter after logging, which could lower successful incubation rates for salmonid eggs.

Sediment Load

There are four main ways in which sediment is introduced into streams as a result of timber harvest: (1) harvesting techniques which cause mass slope failure, and landslides; (2) landslides caused by road building, erosion of roadbeds and gravel pits; (3) streambank and stream channel disturbance, and (4) construction of bridge and culvert crossings.

Clearcutting practices, construction of logging roads, and resultant landslides have caused sediment to wash into salmon streams in this region and elsewhere (Sheridan and McNeil, 1968; Novak, 1975; Cordone and Kelly, 1961). Studies conducted in southeast Alaska on the effects of sedimentation on salmon, have focused on sediment particles with diameters of 0.833 mm or smaller as those most likely reducing gravel permeability. A significant percentage increase in this size range of sediment was noted in the Harris River by Sheridan and McNeil (1968) and in 108 Creek by Novak (1975) following logging. However, results from these early studies were inconclusive regarding effects on salmon numbers because of the variation in escapement management (Pella and Myren 1974; Sheridan 1982).

Suspended sediment in streams is increased from accelerated surface erosion or slope mass movements, both of which may result from timber harvest and road construction activities. The Alsea Study showed significant increases in suspended sediments from 293.8 to 451.0 metric tons per year in Deer Creek (the watershed with patch clearcuts and buffer strips) following road construction and from 39.5 to 120.6 metric tons per year (205.0% increase) in Needle Branch (the watershed completely clearcut). Sediment discharge increased by only 0.1% in Flynn Creek (control creek) during the same time period.

Sediment deposition can alter or destroy stream benthic communities which comprise fish food sources (Newbold et al., 1980; Culp and Davies, 1983). Sedimentation can also cause mortality of incubating salmon eggs and alevins. Cederholm et al. (1981) showed that cumulative sedimentation from logging roads significantly reduces the survival of coho salmon eggs and alevins (sac fry in the gravel) (Clearwater, Washington). Where egg survival is being impaired both Cederholm (1981) and McNeil (1980) recommend increased escapement to offset the effect of lowered production. The Carnation Creek study on Vancouver Island, B.C. concluded that a significant reduction in the survival of chum and coho from egg to emergent fry occurred due to fines settling in the top strata of gravel spawning beds after logging commenced (Scrivener and Brownlee, 1981, Holtby and Hartman, 1982). Results of the Carnation Creek study also indicated that large freshet flows flushed fines out of the gravels when the source of sediment had been arrested. However, fines less than 0.297 mm persisted in the gravel for more than a year.

Sedimentation as a result of road construction or development of rock and gravel sources have been documented in southeast Alaska, and landslides have been triggered by these activities. Benda (1983) showed that during road construction there was an 11.5% increase in sediment particles less than 4.0 mm diameter and a significantly lowered mean survival of pink salmon alevin resulting from a 2,300 m rock and overburden slide into a tributary of the Blossom River in southeast Alaska. Often, the rock source for a road is located above a stream on an adjacent mountain slope. In many cases fine powdered rock from the pit enters the stream via overland washing and becomes a chronic point-source of sedimentation (Edgington 1976). Debris avalanches are natural events in the relative young soils of southeast Alaska and the conditions that trigger such mass wasting are fairly well understood (Swanston 1970). However, road building under mountain slopes and rainfall conditions conducive to avalanching caused two major land slides on Bear Creek (Mitkof Island) in 1976. These slides covered a total of 7 and 13 acres, dammed the stream and cost in excess of $29,000 to rehabilitate (Edgington and Larson, 1977).

Mass wasting of slopes is a common natural event in southeast Alaska. Logging can trigger landslides by destabilizing soils. Neither the frequency of occurrence nor the extent of damage resulting from landslides or road building is reported or monitored in a standardized fashion by the USFS. Several slides that were a result of logging activities have, however, been observed by Alaska Department of Fish and Game staff. Bishop and Stevens (1984) noted a four-fold increase in the rate of landslides in Maybeso Creek valley following logging. A reporting mechanism should be activated to track the sources and extent of land disturbances that may affect salmon streams.

Logging in and through a stream can also result in massive siltation. The USFS documented a logging contract violation that almost completely eliminated the odd year pink salmon cycle into Bayhead Creek, Freshwater Bay, in 1964. The Alaska Department of Fish and Game noted virtually no return of adults in 1965 and 1967 to Bayhead Creek, whereas, in 1966 and 1968 (the even year cycle) several thousand spawners returned to the creek. A similar contract violation occurred in Saginaw Creek, Saginaw Bay, in 1965.

Most short-term severe sedimentation events such as landslides or road failure are caused by human error, poor layout design, or from activities in violation of standard practices. Evidence from Carnation Creek studies in British Columbia 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 stream in one year, there is concern that sedimentation and bedload movement associated with bank erosion and channelization may be increasing (Holtby and Hartman 1982).

Introduction of sediment into streams is an inevitable consequence of many logging activities, but best management practices can minimize the duration or amount. Activities can also be timed to avoid sensitive periods for fish or take advantage of the stream's capacity for flushing the sediments from spawning gravels.

Research on the impacts of sedimentation on fish is on-going in the region. Sheridan (1982) has recommended an assessment of numbers of spawners, egg deposition, number of pre-emergent fry, sediment levels in the gravels in selected portions of the stream, and evaluation of the effects of climatic variability on embryo survival to assess the impact of logging.

Current methods of sampling gravel use the single or triple freeze core technique (Everest et al. 1981) which was developed to reduce sample size variation. The U.S. Forest Service Forestry Sciences Laboratory in Juneau has studies in progress designed to measure seasonal changes in gravel substrate of pink salmon spawning streams and to further understand the relationship of fine sediment and emergence of fry. An instrument is also in the final stages of testing by the laboratory that will be able to measure intergravel water flow. This instrument will greatly enhance the efficiency of the study of survival of fry in the gravel by providing measurements of the most important single physical parameter of the gravel environment (Meehan 1984). The understanding of stream sedimentation dynamics in salmon streams is increasing, but is not at a level that "trade-off" discussions in fish-forest management can be discussed. In the meantime, Sheridan et al. (1984) recommends that stringent guidelines governing logging practices can minimize the addition of sediments into streams.

Logging Slash and Debris Deposition

Clearcutting to or across small streams frequently deposits large quantities of woody debris such as limbs, boles, and non-merchantable timber. Logging debris is generally smaller and accumulations more dense than naturally occurring debris. Bryant (1983) showed that, on Prince of Wales Island, logging can produce as much as seven times the amount of debris occurring in unlogged streams.

Hall and Baker (1975) summarized beneficial and adverse effects of deposits of organic debris on fish habitats. Most adverse effects arise from water quality impacts such as increased biological oxygen demand (BOD), decreased instream and intragravel oxygen (Hall and Lantz 1969; Berry 1974; Ponce 1974), and toxic leachates (Buchanan et al. 1976). Water-soluble leachates of the western red cedar (Thuga plicata) which is logged in some portions of the region have been shown to be toxic to juvenile coho salmon at 0.33 mg/L for foliage terpenes and 2.7 mg/L for tropolones (Peters et al. 1976). However, neither BOD problems nor toxic leachate concentrations resulting from timber harvest activities have been documented in southeast Alaska.

Debris jams, whether natural or caused by human activities, can prevent or delay upstream migration (Merell, 1951; Narver, 1971). One study showed a 75% decrease in spawning salmon in a stream because of debris blockage (Chapman, 1962). Elliott (in press) also found that removal of logging debris improved access for adult pink salmon and provided new spawning habitat. However, it is important to note that large organic debris (LOD) can be an important habitat feature beneficial to fish. Reiser and Bjornn (1979) recommended that all debris jams should be evaluated before they are removed.

Removal of logging residue from streams can also have impacts on fish habitat. Removal is a common practice and has been conducted on many streams in southeast Alaska, but with no evaluation of its effects on fish or other biota. On the other hand, Cardinal (1980) and Dolloff (1983) found that juvenile Dolly Varden char and coho salmon are both highly associated with logging debris, and that densities in littered streams are similar to that of both species in pristine streams. Furthermore, Cardinal (1980) predicted that removal of logging debris would have a detrimental effect on abundance of rearing salmonids. Elliott (unpublished) found that removal of logging debris caused an 80% reduction in the abundance of juvenile Dolly Varden, a temporary reduction in benthos numbers, and speculated that it might result in 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, the goals of debris removal, and procedures for debris removal.

The impacts of debris deposition and removal on physical habitat structure is discussed in the next section of the report.

CHANGES IN THE PHYSICAL STRUCTURE OF THE HABITAT

Juvenile Fish Habitat

Two important stream habitat functions are directly related to the carrying capacity, or maximum density of stream dwelling salmonid fishes in a stream: 1) the stream must include foraging habitat where fish can reside in low-velocity water "pockets" from which they venture out to perform various life functions and 2) the stream must include refuge habitat where fish can seek concealment when disturbed, e.g. undercut banks (Bachman 1984). Habitat requirements change with age, size, and season (Bachman 1982; 1984).

The habitat required by adult salmon during their brief spawning period is much more limited than habitat required by rearing juvenile salmon and resident salmon and trout.

Declining water temperatures during the fall reduce metabolic activity and swimming performance (Brett 1964), and habitat may be selected that provides shelter for fish from floods (Bustard and Narver 1975a and b). Winter habitat is considered by many researchers to be the most critical factor in determining the annual abundance of juveniles during their freshwater life, for in the absence of suitable winter cover, populations can be greatly reduced by floods (Tschaplinski and Hartman 1983; Mason 1976).

In southeast Alaska coastal streams, optimum 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 the velocity of the main current. 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: 1) LOD can be removed mechanically, 2) undercut banks can be broken down, 3) streams can be "overcleaned" of LOD if logging debris is removed, and 4) the growth of streamside vegetation can be enhanced. Stream banks, more than any other habitat component, are susceptible to direct affects from logging activity. Felling trees across streams, yarding trees through or across streams, operating heavy machinery adjacent to streams, and removing vegetation which has roots that strengthen stream bank soil structure, all can potentially drastically affect the integrity of stream banks. Water table increases in riparian zones also weaken stream bank structure (Chamberlain, 1982). Cross-stream yarding can dislodge and destabilize 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 debris, even by experienced crews, frequently results in overcleaning of LOD from streams with much natural debris being removed in the process (Murphy and Koski in press). These adverse impacts, however, appear to be limited to site-specific and localized situations. Elliott (unpublished) found no significant difference in the amount of debris in a sample of logged and forested streams in the northern Tongass forest.

Cutting and yarding operations can collapse undercut banks, eliminating valuable cover for juveniles, if equipment operates adjacent to the banks or drags logs across them. Murphy and Koski (in press) and Elliott (unpublished) have found undercut bank habitat to be reduced by 50% following logging. Streamside logging can also destabilize undercuts, which contributes to their collapse during freshets and resultant reduction in coho abundance (Tschaplinski and Hartman 1983).

Removal of the forest canopy can have a positive effect on fish habitat through stimulation of profuse growth of streamside vegetation. Vegetation can form valuable cover for juveniles, especially when it overhangs pools or other quiet areas, although it is not universally important as cover in all locations. Overhanging vegetation, especially when in flower, is important in attracting numerous terrestrial insects which contribute to the food supply of juvenile fish (Meehan et al. 1977).

The effects of logging on coho salmon productivity and proper streamside zone management is an area of active research in the region. Earlier researchers documented that low levels of algal production in forested streams was related to the poor light conditions found under the dense timber canopies (Stockner and Shortreed 1975). Primary productivity of small streams has been shown to increase after clearcutting to the edge of stream banks, primarily due to improved sunlight penetration. Increases in nutrients and temperature are other factors thay may also contribute to increased primary productivity (Bormann and Likens 1970; Hansmann and Phinney 1973; Murphy and Koski in press). Additionally, in one study area, Murphy and Koski (in press) found a strong correlation between increased algal production in clearcuts and elevated levels of aquatic benthos production. They concluded that these factors are responsible for the increased abundance of age 0 coho fry in logged streams, relative to coho fry abundance in forested streams. These findings corroborate the conclusions of others and the observations that the density of juveniles may be limited by food supplies and that juveniles frequently respond to increases in food supply with an increase in rearing density (McFadden 1969; Mason and Chapman 1965; Hunt 1969). Not only are fry more numerous but they appear to be slightly larger in size (Elliott unpublished). Increased size is thought to be a response to longer growing seasons rather than increased food supply (Tschaplinski and Hartman 1983; Scrivener and Andersen 1984). Murphy and Koski's most recent data analysis (unpub.) has correlated this fry response with a specific geographic area of the region with a characteristic limestone bedrock geology. Thus, the response is variable, but the factors responsible for variability are just beginning to be understood.

Under some conditions, larger fry can result in better survival, more smolts, and presumably higher adult salmon returns (Hartment et al. 1982), however winter habitat is considered the limiting factor in many southeast streams, so that larger fry and larger fry populations may not result in higher productivity and salmon harvests. Fry populations in pristine settings can be extremely ephemeral, sometimes rapidly decreasing in number during their first year in fresh water (Chapman 1965; Crone and Bond 1976). As they 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) permitting higher densities of fry, a condition that has been observed in Oregon clearcuts (Murphy and Hall 1981) and in some southeast Alaska clearcuts (Murphy and Koski in press). Experiments by Mason (1976) demonstrated that supplemental feedings of fry increase 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 do not survive the winter and emigrate (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 conclusion 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. The behavior of juvenile coho salmon changes at the onset of fall and they move deeper in pools and to recesses provided by LOD (Bustard and Narver 1975a).

As noted earlier, 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 is used extensively by wintering coho and steelhead but the same types of habitat without LOD are 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 of winter habitat. Furthermore, though clearcutting may produce an abundance of fry during the summer in some streams, there is evidence that these fish may not survive and contribute to smolt yield over and above that dictated by winter habitat.

Channel Morphology

Because logging debris is more densely concentrated (up to seven times) than most natural accumulations, it can severely constrict flows. The results may be rapid stream bed and stream bank 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.

Research at Carnation Creek, British Columbia, also demonstrated that logging to or across streams can destabilize channels and streambanks, increasing erosion, sedimentation, and bedload shift (Holtby and Hartman, 1982). These logging impacts have been implicated in declining egg-fry survival of salmonids at Carnation Creek. Stream destabilization after logging has been documented at Harris River (Bryant, 1980) and elsewhere in southeast Alaska. Consequently, it is reasonable to assume that decreased egg-fry survival as a result of streamside logging may be occurring in Alaska as well. Research is needed to determine the extent and severity of these effects.

LONG TERM EFFECTS ON FISH HABITAT

STREAMFLOW AND HYDROLOGICAL DYNAMICS

Timber harvesting usually does not alter the total amount of rain or snow falling on a watershed basin (Troendle, 1980), except where foliage intercepts significant quantities of fog (Harr, 1980). This exception has not been shown to be an important part of the water cycle in southeast Alaska.

Removal of the forest canopy does, however, result in dramatic changes in the distribution of water and snow on the ground through changes in the amounts intercepted or evaporated by foliage, the rates of snow melt or evaporation from snow, the amounts that can be stored in the soil or transpired from the soil by vegetation, and the physical structure of the soil, which determines the rate and routes of water movement to stream channels (Chamberlain, 1982).

Clearcut areas alter wind patterns, resulting in more snow being trapped in them. Winds can often be more intense in forest openings, which will also augment snow melt. Because the soil in forest openings is wetter and nearer its saturation level, meltwater comes out faster, which can result in earlier and higher peak flows (Swanson and Hillman, 1977; Gary, 1979; Troendle, 1980). Whether or not increased flows from a specific logged area actually cause a change in the runoff for an entire basin depends on the distribution of openings in the basin, their aspect, elevation, and distance from stream channels.

Removal of trees from a forest area eliminates countless leaves and stems that would have intercepted, stored, and reevaporated rain and snow. The death of tree roots also reduces the amount of water that can be transpired from the soil and removed from runoff. Other effects of timber harvest related to hydrological cycling can include an increase in ground water levels and content of water in soils which also weakens soil strength and leads to increased rates of slope mass movements after timber harvesting (O'Loughlin, 1972; Swanston, 1974). The amound of roading in a watershed can also affect peak streamflows by increasing the rate of runoff and decreasing soil storage capacity (Gilleran, 1968; Harper, 1969; Hsieh, 1970; Harr et al., 1975).

The net effect of timber harvesting on streamflows has been shown to be increased flows immediately after clearcut logging (Rowe, 1963; Rothacher, 1965, 1970, 1971; Berndt and Swank, 1970; Meehan et al., 1969), with streams of low discharge being affected more than larger streams (Riggs, 1965).

The effects on streamflow patterns in southeast Alaska that will result from the replacement of old-growth forests with second-growth forests are not known. In rapidly growing second-growth forests stands (greater than 20 years old) water requirements for vegetative growth may be greater than in either forested or newly clearcut watersheds. Lower soil water content, less runoff to streams, and lowered minimum flows have been documented through limited studies in second-growth forests in regions other than southeast Alaska (Berndt and Swank 1970, Myren and Ellis, 1984). Thus, the most significant effects on salmonids may occur in the long-term when forests begin to return rather than immediately following logging.

BARRIERS TO FISH PASSAGE

One of the greatest impacts to anadromous fish from activities associated with timber harvest is the improper placement of culverts where logging roads cross streams. If improperly placed, road culverts can restrict upstream access for fish by the creation of outfall barriers (waterfalls), excessive water velocities through the culvert, insufficient water in the culvert, the lack of resting pools below the culvert, or any combination of the above conditions (Yee and Roelofs, 1980). In addition to improper culvert placement, logging debris from hillsides can, over time, collect at the heads of culverts, causing fish blocks (Chamberlain, 1982).

NUTRIENT CYCLING

Dramatic increases in levels of nitrate, phosphate, and organic carbon have been documented in streams after nearby logging and slash burning, however, there is no evidence that this affects fish deleteriously. However, if nutrient enrichment results in algal blooms, algae could clog gravel interstices which could be detrimental to fish production (Chamberlain, 1982).

In forested streams where there is little sunlight, energy enters aquatic communities from leaves, twigs, needles, etc., which also provide sources of carbon, nitrogen, and other nutrients. Organic particulates are consumed by aquatic invertebrates, which in turn are consumed by juvenile salmonids. This process (the heterotrophic energy pathway) occurs to a greater degree in headwater sections of streams where light penetration is poor. In downstream sections of streams, where the canopy is more divided, permitting more light to reach the water, stream communities utilize a mixture of autotrophic and heterotrophic energy pathways. In other words, energy is accumulated via photosynthetic (light-fixing) processes and from organisms extracting energy from fine particulate detritus transported downstream from headwater sections.

Clearcutting shifts the energetic character of headwater sections to that which is more representative of downstream sections. This shift, however, occurs without the benefit of upstream carbon input and could, therefore, affect the diversity of aquatic communities and their functions. It is not known how these effects will impact fish communities, but, presumably, community function will gradually revert to conditions similar to pre-logging conditions after 40 to 60 years, when the second-growth forest develops into a pole stand along the stream margins.

PHYSICAL HABITAT STRUCTURE-RECRUITMENT OF INSTREAM WOODY DEBRIS

As described under short-term impacts, woody debris from forest sources is a critical feature of stream habitat in coastal Alaska, providing foraging and refuge sites for juveniles during summer and protection against floods during winter. Long-term changes may occur in the quality and quantity of LOD and LOD-formed habitat after clearcutting. 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 clearcutting occurs adjacent to streams, the source of debris is eliminated and stream processes, uninterrupted, will continue to remove debris but will do so without any replacement occurring. Using data from old forest fires, Swanson and Lienkaemper (1978) estimated that debris gradually disappears from streams, and that after 110 years, instream debris is reduced to 50% of 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) suggest an even slower rate of debris accumulation in streams. 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 100-200 years and large logs have been found that have been on the ground for more than 450 years (Franklin et al. 1981). The rate of removal in streams is probably dependent on stream size as material may be very persistent in small channels but more temporary in large channels.

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 loss of 50% of LOD in the first 110 years after clearcutting, equations developed by Elliott (unpublished) predict a loss of about 30% carrying capacity for juvenile coho 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 clearcutting, streams will in time gradually repair themselves. However, by 110-150 years after the first cutting, the forest will again be harvested. 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 STRIPS

Buffer strips of undistrubed streamside vegetation have long been advocated by fishery managers as a technique to preserve fish habitat during and after logging. Buffers provide shade preventing increased water temperature during the summer months (Brazier and Brown 1973, Meehan 1970). Streamside canopy is also thought to moderate winter low temperatures although the mechanisms involved are poorly understood and existing data inconclusive. Buffer strips prevent sedimentation by preserving and maintaining streambanks and filtering run-off to streams. Finally buffer strips provide overhead cover for rearing juveniles, provide energy via allocthonous detritus, provide food through terrestrial insect contribution (Meehan et al. 1977), and most importantly, provide a source of large woody debris needed to stabilize channels and provide instream habitat structures for summer and winter rearing (Grette 1985, Heifetz 1985, Lammel 1972).

Buffer strips are an integral part of streamside management strategies in British Columbia (Moore 1977) and in Washington (Gillick and Scott 1975). Buffer strips, however, are not widely used in southeast Alaska, primarily because of their susceptibility to blow-down during storms. However, Murphy et al. (in press) demonstrated that blow-down within buffer strips often forms beneficial winter habitat and juvenile coho densities can be greater in these areas compared to other reaches of stream. If the potential for blow-down is high, buffer strips can be thinned or designed to resist winds (Moore 1977, Steinblums et al. 1984).

Where buffer strips are impractical due to potential wind-throw, other methods of habitat management are possible. These include the addition of large woody debris to anchor stream channels and to provide habitat for juveniles. Management of stream habitat by manipulating debris must take into account the specific habitat preferences of juveniles, particularly for winter habitat. Debris management has had mixed success in Oregon and Washington; introduced structures often wash out during freshets and some are ineffective in forming habitat. Debris management projects are also planned for southeast Alaska. These projects, however, suffer from inadequate experimental design and the lack of long-term evaluation of effects of introduced debris on stream channels and fish populations. Research is needed to assist land and fish managers in designing criteria and standards for debris management over a wide spectrum of stream and channel types and in respect to the varied requirements of different salmonid species.

CONCLUSIONS

We reviewed recent scientific investigations being conducted in southeast Alaska on the effects of logging on fish. Although there are areas of needed additional research, a significant body of knowledge has been developed. The following is a summary of the more pertinent findings.

Stream Flow:

1) Streamflow generally increases after logging. Variations in streamflow between watersheds after logging appear to be due to the amount of area harvested and the amount of roads. Potential effects of increased streamflows include:

   -- An increase in the amount of rearing area and an increase in the production of rearing salmonids.

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

   -- Exacerbation of sedimentation by shifting of destabilized woody debris.

2) Conversion to second-growth forests may cause a reduction in streamflow relative to pre-logging flow regimes, however the applicability of limited studies to southeast Alaska is not known. Potential effects of decreased flows include:

   -- A reduction in rearing salmonid carrying capacity by a reduction in rearing area.

   -- Warmer water temperatures, although this may be offset by improved shading.

   -- An increase in the frequency of adult "die-offs" during mid-summer drought conditions.

Temperature:

1) 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.

2) 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 can have greater summer and winter survival rates, in some streams, yielding more smolts of a larger size, which increases adult return. These effects are short-lived, however as 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:

1) Sedimentation can increase over natural levels as a result of catastrophic incidents attributable to human error, poor planning, or improper design and layout. Streamside logging leads to gradual, but accelerating, changes in stream morphology with increasing rates of sedimentation and bedload movement. Chronic sedimentation can occur as a result of increased streamflow and accelerated erosion, bank destruction, destabilization of mid-stream woody debris, destabilization or loss of debris that anchors streambanks, and the death of tree roots that support or strengthen streambanks. Potential effects of sedimentation include:

   -- A decrease in egg-fry survival of salmonids.

   -- Intense pulses of sediment affecting rearing salmonid behavior and decreasing feeding and growth rate.

   -- A reduction of benthos diversity and abundance, thus changes in fish food supplies.

   -- A reduction in pool habitat and habitat carrying capacity.

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

Light Levels and Nutrients:

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

2) Changes in stream productivity are presumed to be, in part, responsible for higher growth rates and earlier smolt age of juvenile coho. 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:

1) 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.

2) 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 since streams scour passages under or around large jams.

3) 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.

4) Dense logging debris loses most of its leachates after one 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.

5) Overly 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.

6) Loss or destabilization of mid-stream woody debris, disturbance of debris that anchors streambanks, 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.

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

8) Stream protection and mitigation techniques should be applied during logging as the key to preserving the productive capacity of streams over the short and long term. The two most promising techniques are buffer strips and debris management but design criteria for these techniques need to be determined through applied research before maximum benefit can be gained from their use. Design criteria should address:

a) Buffer strip design and the number and type of trees that should be left in buffer strips to prevent severe windthrow and to maintain the benefits to salmonids.

b) The application of techniques for managing large woody debris in streams that have been clearcut logged to streambanks.

9) Additional research should be conducted to:

a) Determine if changes in winter temperature regimes occur in southeast Alaska as a result of timber harvest and how winter temperature changes affect salmonid stocks.

b) Determine the extent and severity of streamside destabilization caused by logging and how salmonid stocks are affected. Research should be conducted in three phases: (1) survey watersheds to document the number of streams affected; (2) determine if decreased egg-fry survival is occurring in the affected streams; (3) develop techniques for rehabilitating affected streams.

c) Correlate intergravel water flows to fry survival.

10) Stringent guidelines should be implemented to minimize the addition of sediment to streams from logging-related activities.

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