AN ABSTRACT OF THE THESIS OF

Karen L. Bruner for the degree of Master of Science in Forest Science presented on December 6, 1989.

Title: Effects of Beaver on Streams, Streamside Habitat, and Coho Salmon Fry Populations in Two Coastal Oregon Streams

Abstract approved: William McComb
William C. McComb
David E. Hibbs
David E. Hibbs

The effects of beaver (Castor canadensis) on stream morphology, riparian zones, and coho salmon (Oncorhynchus kisutch) fry in Cape and Cummins Creeks, Oregon, were examined using stream surveys, vegetation transects, and coho salmon fry counts in 1987. The basin around Cape Creek has been extensively logged since the late 1940's. Cummins Creek is surrounded by primarily old-growth forest.

Cape Creek had higher densities of coho fry ($P < 0.0004$) than Cummins Creek. Coho fry were two to ten times more numerous in pools ($P < 0.001$) than in glides or riffles, respectively.

The density of beaver dams in the autumn on the two streams was 1.2 and 1.1 dams/km on Cummins and Cape Creeks, respectively. By building dams, beaver added 7% and 14% more pool habitat in Cummins and Cape Creeks, respectively. This extra pool habitat was used by coho fry. Beaver ponds were larger than non-beaver ponds and thus contained more coho fry per pond. Densities of coho fry were, however, the same between beaver and non-beaver ponds.

Beaver preferred to cut salmonberry (*Rubus spectabilis*), alder (*Alnus rubra*), and vine maple (*Acer circinatum*) stems 2-9 cm in diameter for food and dam construction. Mean distance from the stream for foraging was 17.5 m (SDS=10.1). Beaver foraged up to 90 m from the stream bank along tributaries. The percentage of available stems (for salmonberry, alder, and vine maple) cut for the small size class (0.5-3 cm) decreased after 5 m from the stream, after 20 m for the medium size class (3-9 cm) and remained stable out to 30 m for the large size class (> 9 cm). Most cutting tended to be upstream of the dam site. The mean area affected by cutting around the dam site was 1944 sq. m (SD=921 sq. m).

Proximity to a logjam, tributary, or debris slide; midstory conifer cover; overstory conifer cover; and vine maple cover were factors that separated used beaver sites from unused random sites using stepwise discriminant analysis. Proximity to a logjam, tributary, or debris slide was positively associated with the discriminant function and accounted for 50% of the variability in the discriminant function. Vine maple cover was also positively associated with dam location in the discriminant function, while midstory and overstory conifer covers were negatively associated with the dam location.

Based on the results of this study, I believe beaver provide extra coho salmon rearing habitat, especially in late summer during reduced water flows. In heavily managed streams, beaver may be able to provide structure and stability in the stream at a much lower cost than stream rehabilitation projects.

Effects of Beaver on Streams, Streamside Habitat, and Coho Salmon Fry Populations in Two Coastal Oregon Streams

by

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INTRODUCTION

The beaver (Castor canadensis) is a keystone species (Paine 1966, 1969, 1974; Johnson 1984; Naiman et al. 1986), one which "affects ecosystem structure beyond its need for food and space" (Naiman and Melillo 1984). No other animal except man modifies its environment as much for its own benefit (Cook 1942; Grasse 1951). Forman and Godron (1986) characterized the beaver as an animal which plays an unusually significant role when present. In creating ponds for safety, food, and shelter, beaver change their ecosystems by modifying channel morphology, creating and maintaining wetlands, modifying nutrient recycling and decomposition, and modifying the riparian zone (Naiman et al. 1986).

LITERATURE REVIEW

HISTORY OF BEAVER AND ANADROMOUS FISH

Historically, beaver inhabited nearly every watershed in North America (Seton 1929). Mills (1913) estimated that there were 100 million beaver in North America at the beginning of the 17th century. Seton (1929) estimated there were 60-400 million, with an original density of 4 beaver per square km or 6 per linear stream km.

This wealth of fur was responsible for the majority of exploration of western North America (Cline 1974). Although the supply seemed inexhaustible, the trappers were diligent and thorough, and by the late 1800's, beaver were scarce (Jenkins and Busher 1979). In fact, when the Beaver State, Oregon, was admitted to the Union in 1859, it hardly deserved the name (Gregg 1948; Maser et al. 1981).

Beaver were protected in the late 1800's and the population soon recovered. By the 1920's, nuisance complaints were common over most of the U.S. (Bump 1941). Today, the current beaver population is estimated at 6-12 million (Naiman et al. 1988), far below the original population. In addition, since 1934, 195,000-260,000 sq. km of U.S. wetlands have been converted to dry land (Shaw and Fredine 1971). Much of this wetland was undoubtedly beaver habitat.

As beaver began to reoccupy former territory, biologists and fishermen worried about the effects of beaver dams and ponds on salmonids, not realizing the beaver were merely moving into areas they had occupied for centuries (Mills 1913). This rebound in the beaver population spawned numerous studies on the benefits and detriments of beaver on resources important to humans. One of the most extensively studied topics was the effect of beaver occupancy in trout streams. Numerous studies found beaver to have both positive and negative effects on trout, depending on the investigator and the study site. Whether beaver dams were detrimental or beneficial to the trout fishery seemed to depend on the type of stream. Beaver ponds were usually detrimental in slow moving streams and beneficial in cold, fast moving streams. The majority of these studies were in the eastern or midwestern U.S.

Increased water temperature, accumulation of silt in spawning areas, decreased dissolved oxygen in ponds, decrease in food organisms, and dams as barriers to migration for spawning have all been reported as detrimental of effects of beaver in trout streams (Salyer 1935a,b; Patterson 1950; Wilde et al. 1950; Reid 1951; Yeager and Hill 1954). In Wisconsin, Patterson found that mean water temperature was 5 degrees C higher at the outlet than at the inlet of beaver ponds. Reid (1951) reported an average increase of 7 degrees F from inlet to outlet of beaver ponds in New York. Both agreed that trout fishing was good immediately after the dam was built, but deteriorated within five years.

Stabilized water temperature, increased productivity in the pond, more pool habitat, increased area and volume of the stream, and increased cover have been reported as positive effects of beaver in trout streams (Rassmussen 1940; Tappe 1942; Grasse 1949; Grasse and Putnam 1950; Rutherford 1955, 1964; Huey and Wolfrum 1956; Gard 1961; Knudson 1962; Rabe 1970).

Tappe (1942) suggested that beaver dams may be instrumental in maintaining permanent trout populations in some small California streams that are nearly dry in late summer.

There has been much speculation on the interaction of beaver and salmon, but I have found only one study specifically dealing with this interaction. Sanner (1987) studied the effect of beaver on coho salmon (Oncorhynchus kisutch) in southeast Alaska. Her goal was to "understand beaver as a keystone species in altering stream channels and coho salmon habitat". She hypothesized that the formation of a beaver pond would influence the available habitat and cause fluctuations in coho populations during a 10-year cycle and that long-term occupation of the stream by beaver would provide more potential habitat for coho salmon in the long run (100 -1000 yrs). Although coho salmon may occupy a stream devoid of beaver, beaver will increase coho salmon habitat when present. She considered rearing and spawning habitat and concluded that the "cyclical succession pattern" created when beaver occupy and abandon stream reaches contributed to maintaining suitable coho habitat. During the portion of the cycle when beaver occupy the ponds, the ponds provided seasonal rearing habitat for coho fry. During the early post-abandonment stage, side channels, backwaters, and lateral scour pools developed in and below beaver ponds. Most of these areas were pool habitat, suitable for coho salmon. Sanner (1987) also concluded that beaver dams did not inhibit access to spawning grounds or limit spawning area in her study.

Coho salmon fry prefer pools over riffles or glides as rearing habitat (Lister and Genoe 1970; Nickelson et al. 1979; Bisson et al. 1982; Bryant 1983; Sedell et al. 1984; Bisson and Sedell 1984; Sanner 1987; Hankin and Reeves 1988). Streams with large woody debris have been reported to have more and larger pools than streams devoid of large woody debris (Bisson and Nielsen 1983; Sedell et al. 1985). Pools dammed by large woody debris were preferred by coho and large cutthroat trout (Salmo *clarki*) over other pool types (Bustard and Narver 1975; Everest and Meehan 1981).

Sanner (1987) and Naiman et al. (1986) reported that (1986) reported that beaver dams created stepped reservoirs, similar to the effect caused by debris jams. Sanner (1987) concluded that both reduced effective stream gradient, caused increased sedimentation and the formation of pool habitat, and decreased erosive effects of floods. There is also direct evidence that coho salmon fry prefer beaver ponds as rearing habitat (Everest and Sedell 1983; Everest et al. 1985). In Fish Creek, Oregon (a western Cascade stream), Everest et al. (1985) reported that beaver ponds were only 0.3% of the total habitat but were rearing 6% of the total coho salmon fry.

However, general sentiment has been that beaver are detrimental to salmonid populations. The dams have been seen as barriers to migration and have been torn out or blasted (Salyer 1935b; Bradt 1947; Patterson 1950; Reid 1952; Marston and Jong 1978, Marston and Deming 1979).

Although much is known about the general effect of beaver on rivers and streams (Rudemann and Schoonmaker 1938; Ives 1942; Hodkinson 1975; Naiman et al. 1982; Naiman et al. 1986), their usefulness in soil and water conservation (Finley 1937; Scheffer 1938), and the interaction between trout and beaver, very little research has been done in the Northwest, especially in the Coast

Range. Due to the Coast Range climate, forest types, forest management practices, and high gradient streams, the impacts of dam-building on coastal streams and their fish populations may be significantly different.

A combination of heavy winter rains and high gradient streams results in extreme variation in water flow during the year in coastal streams. In cold-winter areas, beaver dams are often improved, enlarged, and repaired from year to year in late summer or early autumn (Scheffer 1938; Gregg 1948). In contrast, beaver dams in coastal Oregon streams are often built on an annual basis, being washed out in heavy winter storms and rebuilt the next summer (Maser et al. 1981). These beaver usually live in bank burrows rather than in lodges (Maser et al. 1981), which would also be washed out during period of high water.

Streams and rivers of the Pacific Northwest have historically contained more large woody debris than streams in other regions of the country (Bisson et al. 1985). Anadromous fish populations are adapted to this environment by using the calm water around large woody debris as rearing habitat for young fish and as a refuge from winter floods. The swift changes caused by logging and stream cleaning affected their habitat. The ability of beaver to ameliorate these changes has not been fully explored.

HISTORY OF OREGON'S STREAMS

Oregon's coastal streams have changed greatly in the last 150 years (Morgan 1868; Sedell and Froggett 1984). Before settlement of the region, streams were choked with large woody debris, which made stream travel difficult to nearly impossible (Ogden 1961). These heavy concentrations of wood dispersed the force of the water, creating streams with numerous channels, marshes, scour pools, and quiet backwaters.

Early in the 20th century, streams were cleared and logjams removed to expedite timber harvest, farming, and transportation needs (Sedell et al. 1982). An extensive program of snagging, debris removal, splash damming, and sluicing was executed. Later, clear-cuts along streams eliminated the source of large wood in the stream. These practices have channelized many coastal streams (Gregory et al. 1985), eliminating many extra channels and pools which once buffered floods and provided fish habitat.

At approximately the same time, the beaver population was drastically reduced by trapping (Gregg 1948; Maser et al. 1981). This reduction served to further decrease the amount of pool and backwater habitat available for anadromous fish. This change in habitat probably contributed to the dramatic decline in the anadromous fish population in the last 60 years (Sedell and Luchessa 1982).

Sedell and Luchessa (1982) pointed out that old cannery records (Everman and Meek 1898) show the average annual run of coho salmon in the Siuslaw River between 1889 and 1896 was 218,750. In contrast, they report that the 1981 Oregon Department of Fish and Wildlife Coho Salmon Plan has an escapement goal of 200,000 -250,000 wild coho adults to all coastal Oregon streams after habitat enhancement projects. The Siuslaw River is only one of 30 major coastal Oregon streams and rivers.

HABITAT MODIFICATION

Instream modification

Modification of channel morphology and hydrology.

Beaver dams modify a stream by decreasing the effective channel bed gradient and creating a stair-step profile. This decreases the erosional power of the stream and changes riffle habitat to pool, backwater, or marsh habitat (Warren 1922; Scheffer 1938; Ives 1942). The lower gradient and slower flow increase the amount of sediment retained in the system (Apple 1985; Naiman et al. 1986).

Beaver dams dampen the runoff fluctuations and raise the water table of the area (Scheffer 1938; Apple 1985; Naiman et al. 1986). Sediment is held in the ponds, which eventually silt in and become meadows, and may remain for centuries (Ives 1942; Gregg 1948; Retzer 1956; Neff 1957). It has been said that we are now living off the income from the capital that beaver laid down centuries ago (J. Sedell quoted in Bergstrom 1985). In the high gradient streams of the Coast Range, most dams are washed out annually by high water. In some cases, no meadow is formed. In other areas, only a channel is opened in the dam and silt accumulates, widening the valley floor and producing wetlands.

Effect of stream modification on coho fry.

Few studies have been published on the effect of beaver dam-building activity on coho salmon. As noted previously, pools, side-channels, and backwaters are important types of rearing habitat for coho salmon (Lister and Genoe 1970; Bisson et al. 1982; Sedell et al. 1985; Bryant 1983). Sanner (1987) also found that coho salmon fry were more abundant in pools than other habitat types. At her study site, most of the available pool habitat was affected by beaver. Observations by divers showed that coho fry were using beaver dams, sticks, and food caches as hiding cover, and that the fry moved into the beaver ponds by November to overwinter. Coho fry were more abundant in habitat created by beaver than in other habitat.

Modification of the riparian zone.

Beaver are central place foragers (Jenkins 1975, 1980; McGinley and Witham 1985). This means that cutting activity is concentrated near their homesite rather than dispersed. Hardwoods are preferred over conifers (Denny 1952), so cutting by beaver may favor conifer growth.

Trees and shrubs that reproduce by sprouting may be changed from upright to shrubby form by beaver herbivory (Johnston and Naiman 1987). For example, willow (*Salix* spp.) was found to maintain high growth rates, increase in basal diameter, and become shrubby as the result of beaver herbivory (Kindschy 1985).

Beaver provide more light to the stream near the dam construction site, both by direct cutting and by flooding or waterlogging soils so that the trees and shrubs die (Naiman et al. 1988). Beaver ponds are more productive than other stream habitats and provide more useable food for fishes (Gard 1961; Meehan et al. 1977; Gregory et al. 1985). By opening up the canopy, beaver provide more light to the stream, stimulating autochthonous production. In addition, beaver add nitrogen and phosphorous to the stream. Concentrations of ammonia and orthophosphate were found to be doubled below beaver dams in coastal Oregon streams (Gregory et al. 1985). Francis et al. (1985) reported that nitrogen fixation increased 9 to 44 times when beaver dammed riffles and increased sediment storage. Naiman et al. (1988) found that plant available nitrogen was up to 4.3 times greater in anaerobic conditions, such as exist in beaver ponds, compared to aerobic conditions. This is significant because primary production is often limited by nutrient (nitrogen and phosphorous) availability in Pacific Northwest streams (Gregory 1980; Sollins et al. 1980; Gregory et al. 1985). This increased primary productivity leads to larger and more diverse invertebrate communities (Meehan et al. 1977) and more food for salmonids.

HABITAT CHOICE

The suitability of a site for habitation by beaver is affected by two main factors, food availability and topographic characteristics.

Food Availability

Beaver are "choosy generalist herbivores" (Jenkins 1975). They show clear preferences for certain plant species, yet eat substantial amounts of other species, including domestic crops such as soybeans when available

(Roberts and Arner 1984). The ability to survive and thrive on a wide variety of plant materials has allowed beaver a historic range that covered most of North America north of Mexico (Jenkins and Busher 1979). They inhabit lowlands and mountains, the forests and the plains; they inhabit streams, lakes, and other wetlands.

Numerous studies on food selection by beaver have determined that beaver in the western U.S. and boreal forests generally prefer aspen (*Populus tremuloides*, *P. grandidentata*) (Aldous 1938; Bradt 1938; Denny 1952; Shadle 1954; Hall 1960; Brenner 1962; Northcott 1971), but will utilize many other species when aspen is not available. Denny (1952) ranked food choices from most to least preferred as aspen (*Populus tremuloides*), willow (*Salix* spp.), cottonwood (*P. balsamifera*), alder (*Alnus* spp.), maple (*Acer* spp.), and ash (*Fraxinus* spp.). During the summer, beaver seem to prefer herbaceous and aquatic vegetation rather than bark from woody species (Bradt 1938; Cox 1938; Cook 1943; Gregg 1948; Chabreck 1958; Brenner 1962; Brenner 1967; Aleksiuk 1970; Northcott 1971; Svendsen 1980; Jenkins 1981).

Studies on food consumption by beaver indicate that beaver consume 0.6-1.0 kg of woody material per day (Brenner 1962; Nixon and Ely 1969). Brenner (1962) estimated that 0.4 ha on his study site in Pennsylvania would support ten beavers for one year. The species at the site were mainly alder (Alnus spp.), red maple (Acer rubrum), and cherry (Prunus spp.). Bradt (1938) calculated that 0.4 ha of poplar (Populus spp.) trees would support 14 beavers for one year.

Beaver are well designed for water travel, but are rather clumsy on land. Therefore, most of their cutting for food and building materials occurs near the water. Nixon and Ely (1969) found most cutting within 90 m of the home lodge. Cox (1940) considered 45 m the maximum distance for beaver to cut trees. A cut tree 121 m from the shores of a lake was cited as unusual by Warren (1927). However, Bradt (1938) found poplar trees cut and dragged 200 m to a lake. Only one in five colonies studied by McDonald (1956) cut trees as far as 60 m from shore, and Hodgdon and Hunt (1953) thought that beavers seldom travel more than 30 m from water. Hall (1960) found that intensity of cutting decreased with distance from the water and confined his measurements of aspen availability to 30 m from the water edge, since 90% of the cutting was within this distance. Jenkins (1980) found that beaver cut trees of all sizes near the water, but select for small trees at sites further from the water. Obviously, the distance beaver will go for food is variable, and probably depends on factors such as available food supply, steepness of the banks, roughness of the terrain, size of trees cut, danger from predators, and perseverance of the particular beaver colony.

Geologic characteristics

Beaver are incredibly adaptable, but do not occupy every watershed in their range. Studies have been made to distinguish between characteristics which favor and limit beaver occupancy. In the Colorado Rockies, Retzer et al. (1956) determined that valley gradient, valley width, and rock type were important factors in determining beaver occupancy. Valleys with a 0-6% gradient were best for beaver, while valleys with a gradient of over 15% were almost entirely uninhabited by beaver. The limiting factors may be rapid streamflow and the greater erosive power, but the effects were well represented by stream gradient.

Stream reaches with a valley width greater than the channel width were found to be important for good beaver habitat (Retzer et al. 1956). The suitability for beaver improved as the valley widened, apparently without limit. Wide valleys allow floods to spread out, so they are less destructive to the habitat and dams. An inverse relationship was found between valley width and gradient, i.e., low gradient streams also tended to have wide valleys. Although not strongly stated, beavers tended to occupy streams on stable rock types rather than unstable types.

Streams in valleys with a grade of 0-6%, valley widths greater than channel widths, and on stable rock (glacial till, schist, or granite) were rated as excellent habitat for beaver (Retzer et al. 1956). In contrast, streams with a gradient greater than 15% and valley width the same as channel width were rated as unsuitable, no matter what the rock type.

Howard and Larson (1985) identified watershed size and stream width as positively associated with suitable sites for beaver in a Massachusetts study. Increasing stream gradient and well-drained soils were found to have a negative association.

Models

Several models have been proposed to determine sites most suitable for beaver. Howard and Larson (1985) developed two models which predicted colony site longevity and maximum colony density for small streams in mixed coniferous-deciduous forest habitat of central Massachusetts. Model development utilized principal components regression (PCR) and discriminant analysis (DA). Colony site longevity and density were predicted by watershed size, stream width, stream gradient, soil drainage, hardwood availability, and abandoned fields. The importance of physical and water characteristics is shown by the fact that all four were significant, while only two of the ten vegetation characteristics were significant.

An independent test of both predictive models showed a 75% success rate for the PCR model and a 80% success rate for the DA model in predicting one of the three habitat capability classes. The models were 90% and 95% successful, respectively, in predicting presence or absence of beaver. These models are useful in similar habitat and climate to that in which they were developed, according to Howard and Larson (1985). The same modeling approach could be used to develop site-specific models in other habitats.

Allen (1983) developed a general model for the U.S. Fish and Wildlife Service that can be used over the entire range of beaver in North America. In the introduction to the model, Allen discussed habitat needs (food, water, cover, reproduction) but considered only water and winter food in his model. He argued that cover and reproduction requirements are correlated with water requirements. He stated that beaver prefer herbaceous vegetation when it is available (also Boyce 1981), but assumed that woody vegetation is the limiting factor.

Allen's model is a hypothesis of species-habitat relationships, not proven cause and effect relationships. Allen (1983) predicted food and water availability from measurable variables--percent tree canopy closure, percent trees in the 2.5-15.2 cm dbh size class, percent shrub crown cover, average height of shrub canopy, species composition of woody vegetation, percent of lacustrine surface dominated by water lilies, percent stream gradient, and average water fluctuation on an annual basis. These variables were then combined in equations that indicate the Habitat Suitability Index (HSI). Zero is considered unsuitable, 1.0 or above is considered ideal habitat for beaver. Allen did not test this model.

An HSI model was developed specifically for the Missouri bottom-land hardwoods, using assumptions similar to the general HSI model (Urich et al. 1983). Characteristics include distance to permanent water, soil texture, slope of bank, species composition, number of important food plant species, tree size class, and distance to cropland.

Slough and Sadleir (1977) sampled beaver colony site density on lakes and streams in British Columbia. Multiple regression was used to relate beaver habitat factors to colony site density. A land capability classification was then developed for beaver on lakes and streams. A food variable, length of nonproductive brush and swamp shoreline was the most important factor, accounting for 40% of the variability of colonies per stream length. Stream gradient and stream width were the important physical characteristics in determining habitat suitability for beaver, accounting for 24% of the variability. Slough and Sadleir (1977) (p. 1327) stated that the stream survey was biased toward low gradient streams to obtain "adequate variability in other factors which determine habitat suitability" (e.g., the abundance of food species). Thus, the physical characteristics of the stream may have been more important in beaver habitat site selection than their model indicated. Their major recommendation for maintaining or enhancing beaver habitat is conservation of aspen (Populus tremuloides) stands.

Beier and Barrett (1987) used stepwise logistic regression to identify important factors in habitat use by beaver in the Truckee River Basin, California. They found that stream sections with high beaver use had flatter gradients, deeper and wider channels, gentler bank slope, less litter and fir (Abies spp.) cover than unused stream sections. Food availability did not contribute significantly to the model.

A model to predict beaver site establishment in Long Creek Basin in eastern Oregon was developed using 19 habitat characteristics and 14 characteristics of dam site and vegetation cut by beaver (McComb 1989, unpublished data). Discriminant analysis was used to select the best combination of habitat variables to predict beaver use at a site. Used sites were characterized by being wide, low gradient stream reaches. Their floodplains were wider and bank slope less than at unused sites. Used sites had more hardwood, forb, and grass cover than unused sites. Beaver avoided rocky banks.

Boyce (1974) found a positive correlation between beaver colony density and willow, poplar, total food biomass, and a vegetation diversity index. He hypothesized that since beaver exhibit seasonal variability in foraging strategies, they choose habitats with high vegetation diversity.

These studies indicate that in general, wide, low gradient streams with wide floodplains and an abundance of suitable woody food species (generally hardwoods) are favorable habitat features for beaver colonies.

OBJECTIVES

The goal of this study was to investigate the role of beaver as a keystone species in coastal streams in western Oregon. The specific objectives were:

(1) Assess the effects of beaver dam-building activity in modifying stream channel morphology and riparian vegetation.

Streams were surveyed in the spring to record area and volume of each habitat unit (pool, riffle, or glide). This survey was repeated in the fall after dam-building to detect changes in the stream habitat structure as a result of beaver activity. The effect on riparian vegetation was assessed by recording species and size classes selectively cut by beaver during the summer and by mapping used areas associated with beaver dams.

(2) Assess the effects of stream modification on coho salmon rearing habitat in these streams.

Counts of coho salmon fry were completed by divers in the spring and fall.

(3) Identify factors that characterize suitable habitat for beaver in coastal streams.

Geologic and vegetation characteristics were measured along transects at each beaver site and at random unused sites to identify important factors.

STUDY SITES

The following information on the two study streams is from Stream Assessment Surveys done by the Waldport Ranger District, Siuslaw National Forest, Oregon (Marston and Deming 1979; Marston and Jong 1978).

CUMMINS CREEK

Cummins Creek is a fourth order stream flowing directly into the Pacific Ocean (Figure 1). The mouth is located in T. 15S., R. 12W., Sec. 10. The watershed area is 2100 ha, not including Little Cummins Basin (a tributary that joins Cummins Creek just before it enters the Pacific Ocean). Cummins Creek has a trellis pattern (one main channel fed by small tributaries that intersect the main channel at approximately right angles). Stream length is 11 km, the average width in summer is 3 m, and the average gradient is 3%. The lower 0.4 km flows through Neptune State Park. The rest of the watershed is managed by the United States Forest Service as a Wilderness Area.

The watershed lies within the volcanic headlands of the Oregon Coast Range. The substrate is pillow basalt, breccias, and tuffs. The basin is judged to be moderately stable, although debris slides in undisturbed areas

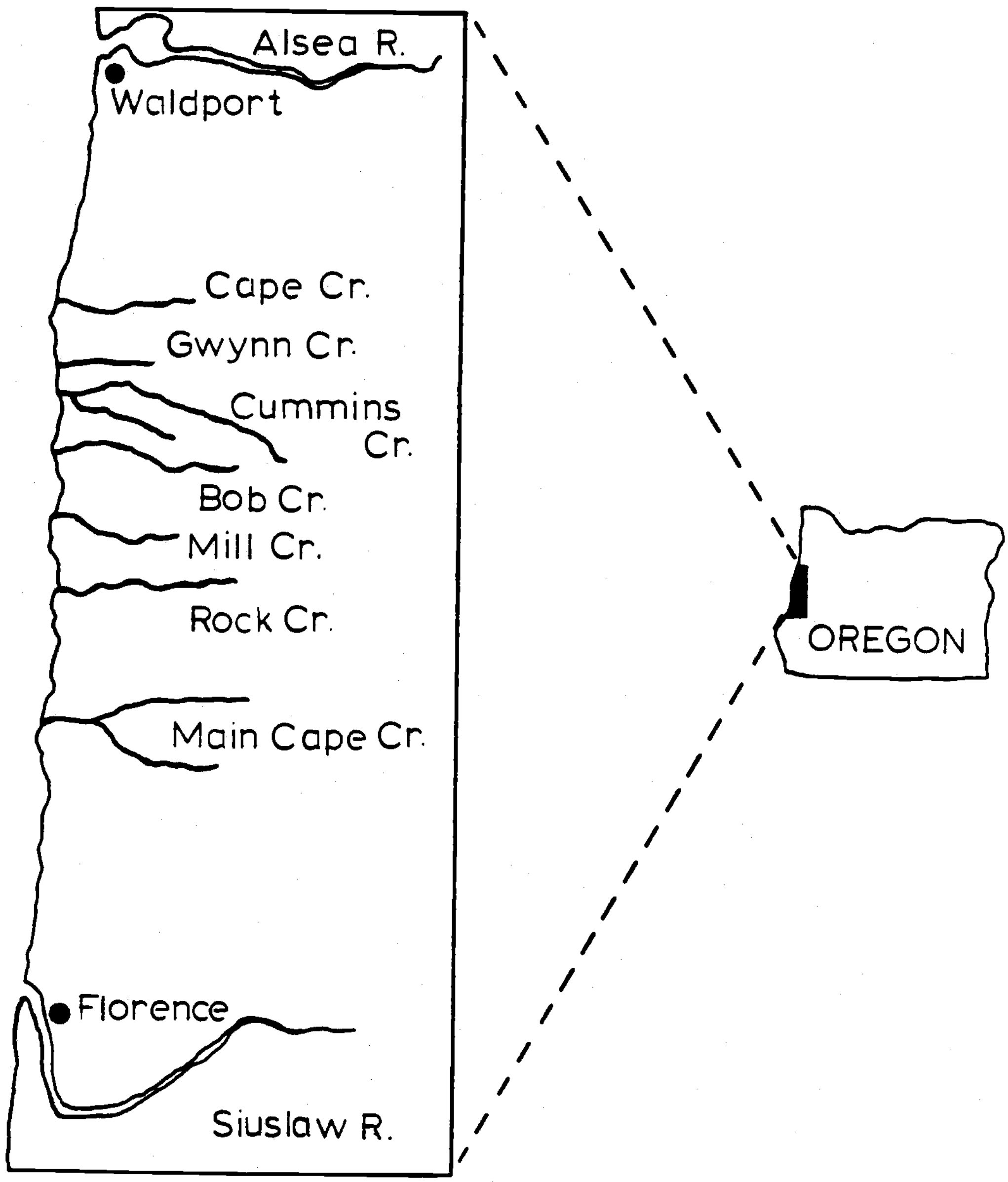

Figure 1. Location of study sites, Main Cape Creek, and Cummins Creek, Oregon.

do occur. The floodplain is wide and the stream is often braided. Gravel bars dominate the channel and are mainly controlled by large woody debris. There are several log jams and the upper reaches of the stream are controlled by log steps.

The vegetation consists of an overstory of red alder (Alnus rubra), Sitka spruce (Picea sitchensis), and Douglas-fir (Psuedotsuga menziesii). Western redcedar (Thuja plicata) and Western hemlock (Tsuga heterophylla) become more abundant in the upper reaches. Understory vegetation is mainly salal (Gaultheria shallon) and salmonberry (Rubus spectabilis).

Cummins Creek is mainly an old-growth watershed. However, there are small streamside clearcuts between 0.56-0.77 river km (1963), 2.2-2.6 river km (1955), and 4.2-5.1 river km (1966-67). The pool:riffle ratio is 5:5 overall. Discharge near the mouth was 0.28 cms in summer.

Spawning gravel, rearing habitat, and aquatic macroinvertebrate production were all judged excellent for juvenile salmonids by Marston and Deming (1979).

CAPE CREEK

Main Cape Creek is a fifth order stream (Strahler

1957) which flows into the Pacific Ocean (Marston and Jong 1978). Its mouth is located in T. 16S., R. 12W., Section 34 and its head is in T. 16S., R. 11W., Section 34 (Figure 1). The watershed area is 3292 ha and the stream is 15.3 km long. The average gradient of the stream is 3-4%. Cape Creek has a dendritic stream pattern, with three major tributaries.

The dominant feature of Cape Creek is its disturbance pattern. Over 70% of the watershed has been logged since 1948, usually without any buffer strips along streams. In addition, the lower 1.9 km of the stream were mined for gravel in the later 1950's.

The substrate of the watershed is similar to Cummins Creek (volcanic sediments, pillow lavas, breccias, and tuffs). However, the watershed is unstable and numerous debris slides are evident. The stream has long stretches devoid of large organic debris, punctuated by large debris jams. These jams are set up by mass wasting from hillside clearcuts and midslope roads, or from logging debris.

There is little opportunity for a steady addition of large organic debris to the stream--most of the streamside overstory vegetation is comparatively young alder, as a result of clearcuts. Sitka spruce, western red cedar, Douglas-fir, and western hemlock are also present. The understory is mainly salmonberry and thimbleberry

(*Rubus parviflorus*). Mature Douglas-fir dominates unmanaged units. The pool:riffle ratio is 2:8 overall and the discharge was 1.3 cms near the mouth in summer.

CLIMATE

The study sites are within the *Picea sitchensis* Zone (Franklin and Dyrness 1973). The mean minimum temperature in January is 0-2.5 degrees C; the mean maximum temperature in July is 20-25 degrees C. The zone receives 200-300 cm of precipitation yearly, most of which falls as rain from October through May.

METHODS

RESEARCH METHODS

Field work began in April, 1987. The two streams, Cummins Creek and Cape Creek were surveyed from mouth to the upper extent of coho salmon use in the stream (7-8 kilometers). Each habitat unit of the stream was classified as a pool, riffle, or glide, and average length, width and depth for each unit was estimated visually. One in ten units was measured to provide a correction factor for visual estimates.

Definitions of habitat units are as follows (Bisson et al. 1982):

pool - an area that is scoured out during times of high water flow

riffle - an area where deposition occurs during high water flow

glide - an area where neither deposition nor scouring occurs during high water flow.

Metal flashers on streamside trees were already in place on Cummins Creek, at 0.1-km intervals. A tape measure was used to put in flashers in Cape Creek, also at 0.1-km intervals. These markers made accurate record-keeping possible.

Visual estimates were also made of the species and d.b.h. of trees and shrubs within the riparian zone as this survey was conducted. This provided a simple vegetation map along each stream.

Only one dam was in place in the spring survey, but areas of beaver activity were identified by bank slides and feeding sticks in the water, and recorded by distance. In the fall, streams were surveyed in the same way to determine the effect of beaver dam-building activity on the pool area of the streams. Coho salmon fry were counted by divers by the method described in Hankin and Reeves (1988). Fall counts were made in Cummins Creek. Spring and fall counts were made in Cape Creek.

During the summer, the beaver's effect on the riparian zone was studied. Transects were established at used and unused sites, one on each side of the stream (see Figure 2). Used sites were active dam sites; unused sites were chosen using a random numbers table, but sites within 100 m of present or previous beaver use were disqualified. Transects were approximately perpendicular to the stream. On used sites, they were placed in areas of obvious beaver activity, one on each side of the stream. If no areas of concentrated use were obvious, as evidenced by foraging activity, slides, and paths, transects were placed at the dam. Transects were usually 30 m long. Exceptions occurred when a road was closer than

Sampling Transects for Woody Vegetation at Beaver Sites

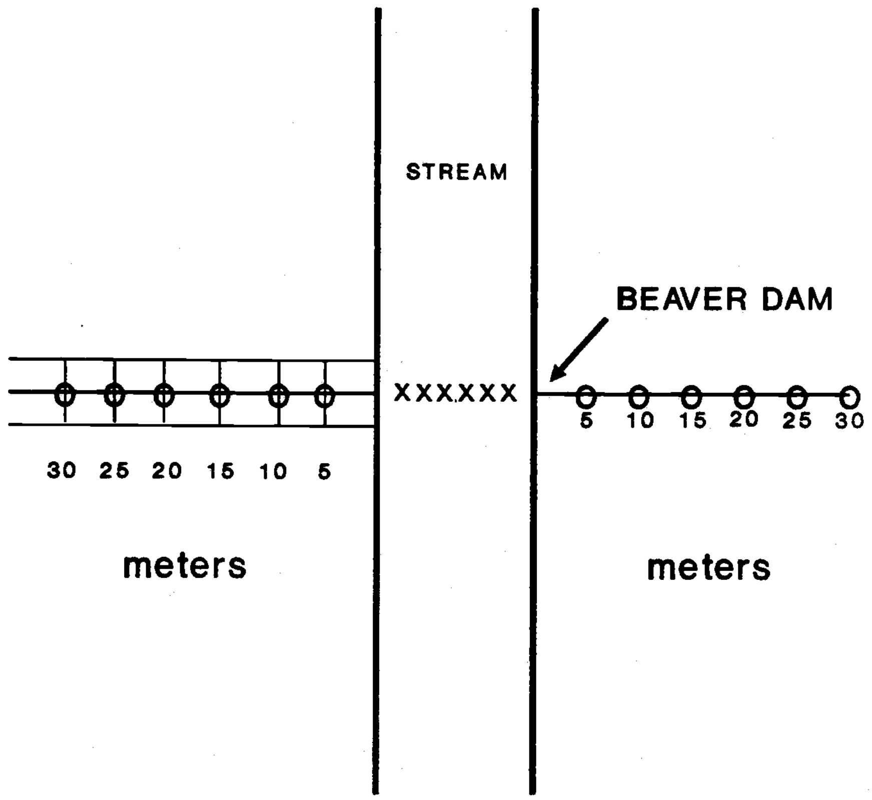

Figure 2. Schematic drawing of sampling transects. Circles indicate 1 meter radius plots. The 2 meter wide band used to record stems over 4 cm in diameter is shown on the left. Transects were routinely sampled to 30 meters.

30 m to the stream, in which case the transect went only to the road. In rare cases, where cutting activity occurred beyond 30 m (usually along a tributary), the transects were extended to the edge of activity. On unused sites, transects were perpendicular to the stream and 30 m long.

Along the transects, circular 1-m radius plots were established at 5-m intervals. Within these circular plots at used sites, all woody vegetation was recorded. Stems were tallied by species, size classes of stem diameter at ground level (shrubs--1/2-1 cm, 1-2 cm, 2-4 cm, >4 cm; trees--1/2-3 cm, 3-6 cm, 6-9 cm, >9 cm), beaver-cut (previous years or current year) or not cut. Larger trees (dbh > 4cm at base) were counted along the transect in a band 2 m wide and recorded in 5 m sub-units.

Percent cover of understory (0.5-2 m), midstory (2-10 m), and overstory (>10 m) by species was recorded at both used and unused sites. Cover was estimated visually at each plot. The recording of cover was to facilitate comparisons between used and unused sites. Since stems were not cut at unused sites, cover was the only vegetation characteristic recorded at the random unused sites. This allowed easy comparison of the vegetation on used and unused sites.

The bank slope between plots on the transect was recorded using a clinometer. This gave a profile of the stream bank, as well as general steepness of the sides.

In August and September, beaver sites were mapped by pacing and visual estimation to determine the extent and location of beaver cutting sites in relation to the dams. Paths, cut areas, and any large cut trees were recorded.

METHODS OF ANALYSIS

Students' *t*-test was used to compare number of coho fry between streams and between beaver and non-beaver ponds. Scheffe's range test (Steel and Torrie 1980) was used to compare cover by species and total cover between used and random transects. Scheffe's test is a multiple comparison test that allows all possible contrasts to be tested for significance. As a consequence of testing all possible contrasts, the test is conservative and the power may be low (Steel and Torrie 1980). Number of fry per stream and densities were calculated from counted habitat units.

Food preferences were determined using the Selection Index (Ivlev 1961). The formula for the Selection Index is:

$$SI = \frac{(\%\ \text{frequency in diet} - \%\ \text{frequency available})}{(\%\ \text{frequency in diet} + \%\ \text{frequency available})}$$

SI values range from -1 to +1.

Stepwise discriminant analysis was used to select a subset of variables important to selection of dam sites by beaver. A non-parametric discriminant analysis procedure (NEIGHBOR) was then used to classify observation using the nearest-neighbor method (SAS Institute, Inc., 1986).

The statistical package used was SAS (SAS Institute, Inc., 1986).

RESULTS AND DISCUSSION

BEAVER ABUNDANCE

There were no beaver dams on Cummins Creek in the spring survey and only one on Cape Creek. The fall survey showed 8 dams (1.2 dams/km) on Cummins Creek and 8 dams (1.1 dams/km) on Cape Creek. This frequency of dams is low in comparison with that found by Naiman et al. (1986) in Quebec, Canada. They found 8.6-16.0 dams/km, with an average of 10.6 dams/km. However, colonies per km may not be as low as this suggests. There was usually one dam per colony, with an occasional colony building two or three dams, in contrast to colonies known to build 20 or more dams per colony (Warren 1922). This low number of dams per colony is probably because most colonies have to rebuild dams each summer (Maser et al. 1981).

There was ample evidence of transient beaver use along both streams before dams were constructed (occasional light cutting of small woody stems along the stream bank). This may have been the result of two-year-olds searching for suitable building sites after leaving their birth site or unpaired older beaver (Seton 1929). There was also evidence of previous beaver use, especially along Cummins Creek. At one previously used site in upper Cummins Creek, beaver had felled several large (80-90 cm) big-leaf maples (*Acer macrophyllum*).

Dam construction began in late June. Most of the construction was done in July and August, although new dams were being started even in September.

COHO FRY HABITAT AND ABUNDANCE

Change in Pool Habitat from spring to fall

The volume of the streams decreased substantially from high water in the spring survey to low water in the fall survey. Therefore, a relative measure (percent volume) of the stream in each habitat type was used to compare spring and fall surveys.

The percent volume of the streams in nonbeaver pools remained fairly constant from the spring to the fall survey (Figure 3). However, beaver-influenced pools added 7% and 14% more pool habitat in Cummins and Cape Creeks, respectively. Thus, beaver ponds were 12% of the total pool volume in the fall on Cummins Creek and 22% of the total pool volume in the fall on Cape Creek. This is not to say that beaver increased the percentage of pool volume by 12 or 22%, because some beaver dams only enlarged present pools. However, some dams were built so as to create pool habitat from riffle and/or glide habi-

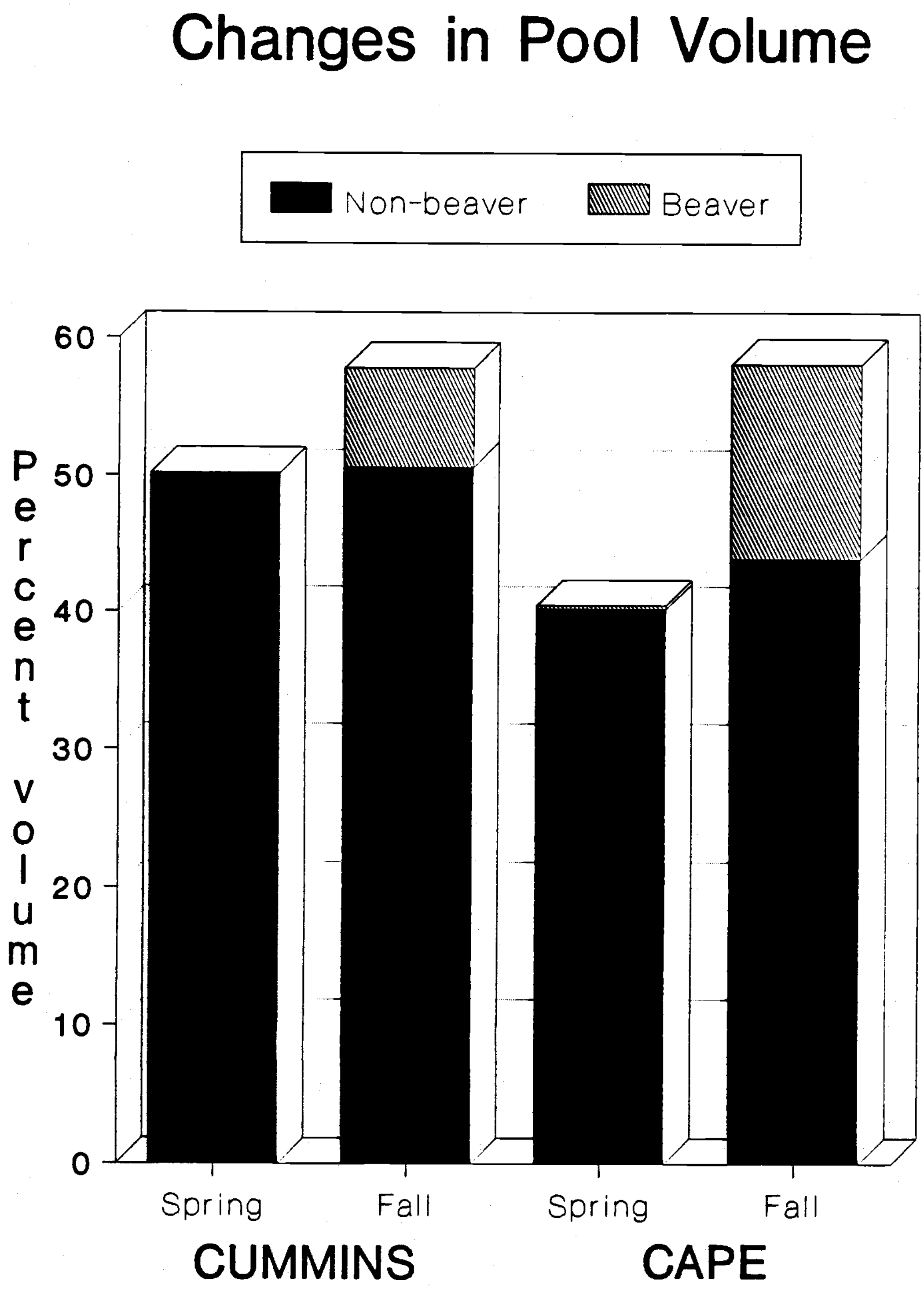

Figure 3. Changes in percentage of the stream volume in pool habitat in Cummins and Cape Creeks, 1987. No beaver ponds were present in Cummins Creek at the spring survey, and only one small beaver pond in Cape Creek.

tat and those dams that increased the size of existing pools usually did so at the expense of riffle or glide habitat. Therefore, the construction of beaver dams had a considerable effect on the amount of pool habitat available in the fall in these two streams.

Comparison of coho fry in beaver and non-beaver ponds

The coho fry used the extra habitat created by beaver in these streams. The mean number of coho fry in beaver ponds was three times the mean number of coho fry in non-beaver ponds although the variance was too high for this to be statistically significant (Table 1 and Figure 4).

Density of coho fry by area and volume was similar between beaver and non-beaver ponds. This indicates that fry were not selecting beaver ponds, but were using the increased pool habitat. It also indicates that beaver ponds on the average are larger than pools formed by other means (Figures 5 and 6). Analysis of beaver vs. nonbeaver ponds shows that beaver ponds on the average are 3-4 times larger than nonbeaver ponds and have a larger range.

There was also qualitative evidence that coho fry in beaver ponds in the two study creeks were larger than fry

Table 1. Comparison of coho fry in beaver and non-beaver ponds, by pool, density per area, and density per volume. Values are given for Cape and Cummins Creeks combined, Fall 1987.

	Beaver Ponds (n=14)		Non-beaver Ponds (n=45)		P
	Avg	(SD)	Avg	(SD)	
Coho/Pool	108.43	(179.68)	35.62	(56.76)	0.16
Coho/m2	0.34	(0.38)	0.26	(0.38)	0.49
Coho/m3	0.95	(0.75)	0.71	(1.02)	0.43

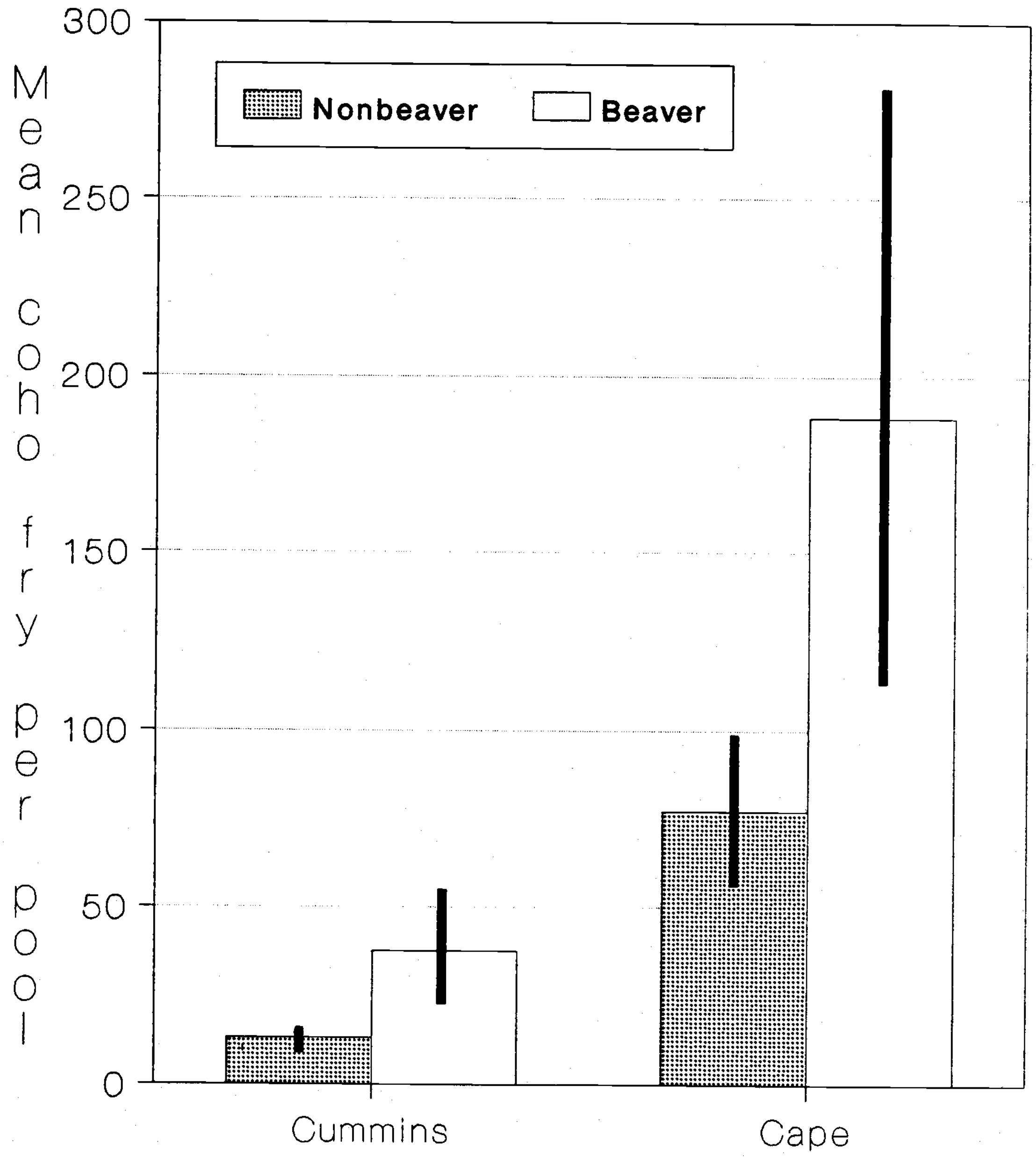

Figure 4. Average number of coho fry per pool in beaver and non-beaver pools, Cummins and Cape Creek, Fall, 1987. Standard error bars are shown.

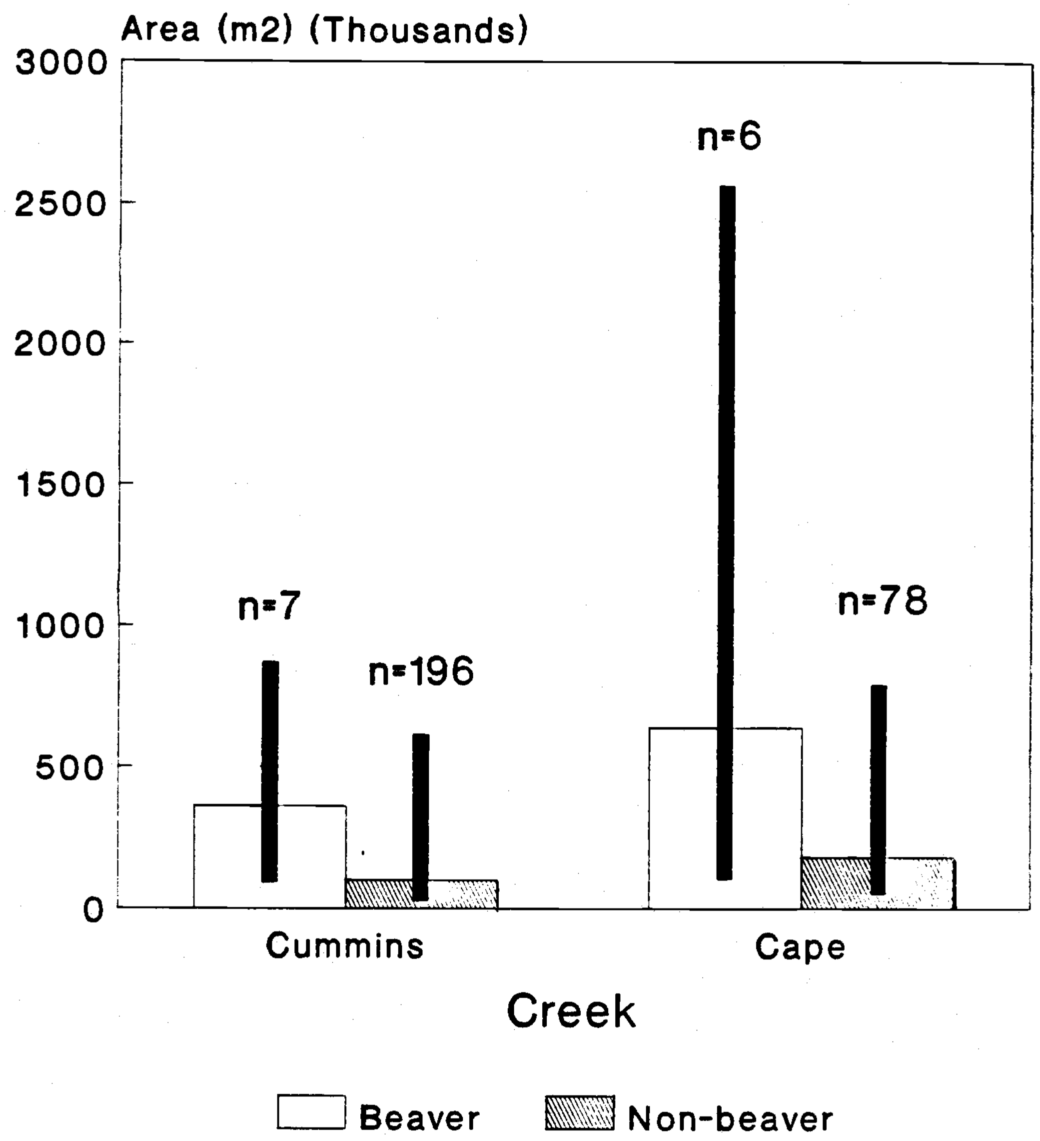

Figure 5. Mean area and ranges for beaver and non-beaver ponds, Cummins and Cape Creek, Fall, 1987. Beaver ponds, on the average, are 3-4 times larger than pools formed by other factors.

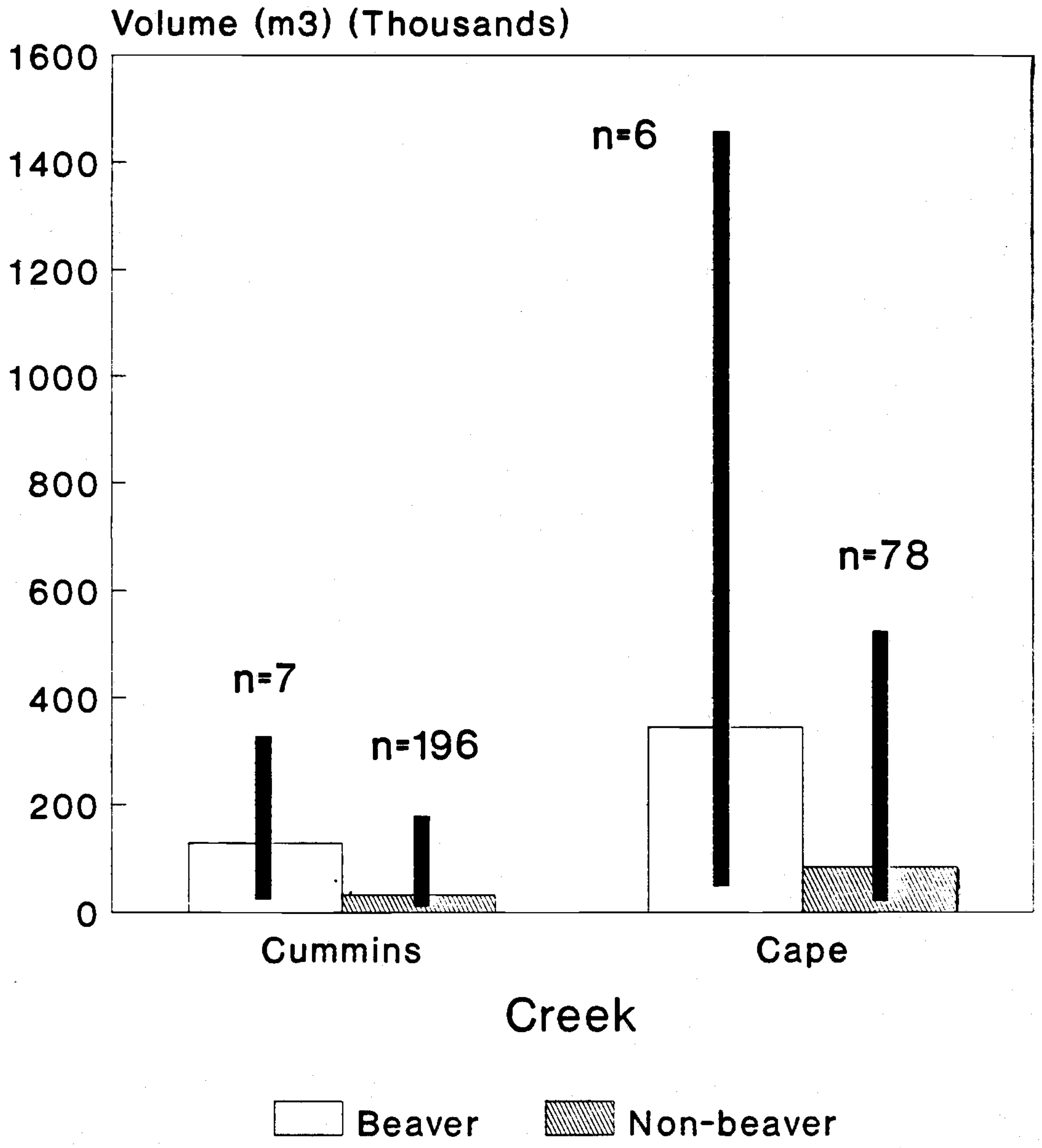

Figure 6. Mean volume and ranges for beaver and non-beaver ponds, Cummins and Cape Creek, Fall, 1987. Beaver ponds, on the average, are 3-4 times larger than pools formed by other factors.

in non-beaver pools. Fish were counted but not weighed, so this statement is supported only by observations of the diver. This observation is substantiated from the literature. Research in Fish Creek (Oregon) found that coho fry in a beaver pond had a weight gain three times that found in the main channel (Sedell in Bergstrom 1985). Gard (1961) found higher trout biomass in beaver ponds than in other reaches of the stream, though densities were similar.

Other studies have shown higher densities of coho fry in beaver ponds (Sanner 1987). Everest et al. (1985) reported that in Fish Creek, Oregon, beaver ponds were only 0.3% of the total stream habitat but were raising 6% of the coho fry. This extreme affinity of coho fry for beaver ponds is a result of the structure of the stream. Fish Creek is a steep, high-velocity stream and beaver ponds provide most of the quiet water in the stream. Phillips (1987) found 8-15 times more fish in beaver ponds compared with the main channel, and 10 times more coho in beaver ponds compared with gabion modified sites.

The use of beaver ponds by coho salmon (Figures 7 and 8) shows a tendency for high numbers of coho to be associated with beaver ponds or pools resulting from large woody debris. However, the distribution of coho fry was quite different between the two streams. In Cape Creek, the coho fry were mainly in the lower reaches of

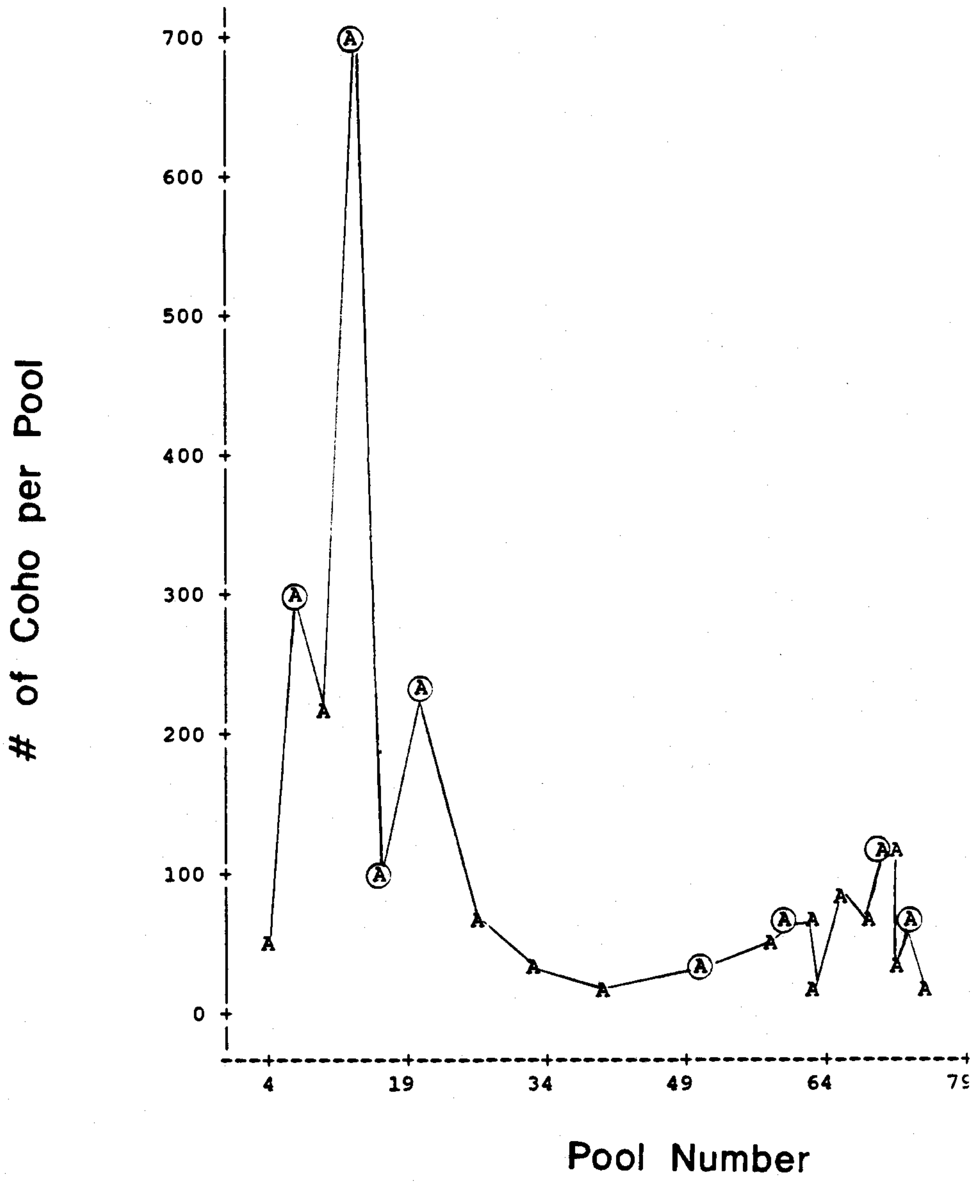

Figure 7. Number of coho fry per pool versus pool number in Cape Creek, Fall, 1987. The X-axis is not necessarily linear; pools are numbered consecutively from the mouth to the upper end of the survey. Pools with beaver activity are denoted by circles.

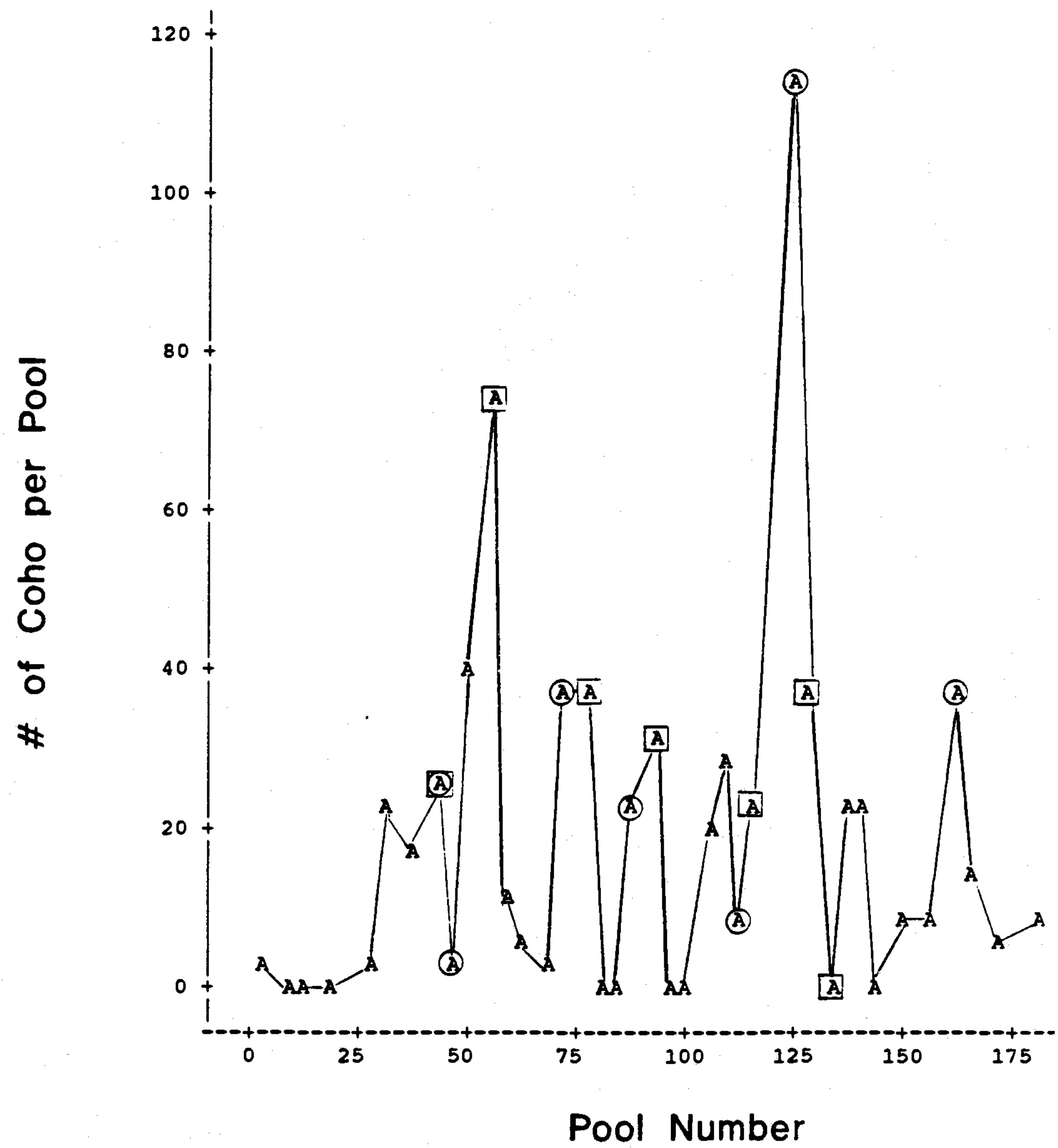

Figure 8. Number of coho fry per pool versus pool number in Cummins Creek, Fall, 1987. The X-axis is not necessarily linear; pools are numbered consecutively from the mouth to the upper end of the survey. Pools with beaver activity are denoted by circles; pools influenced by large woody debris are denoted by squares.

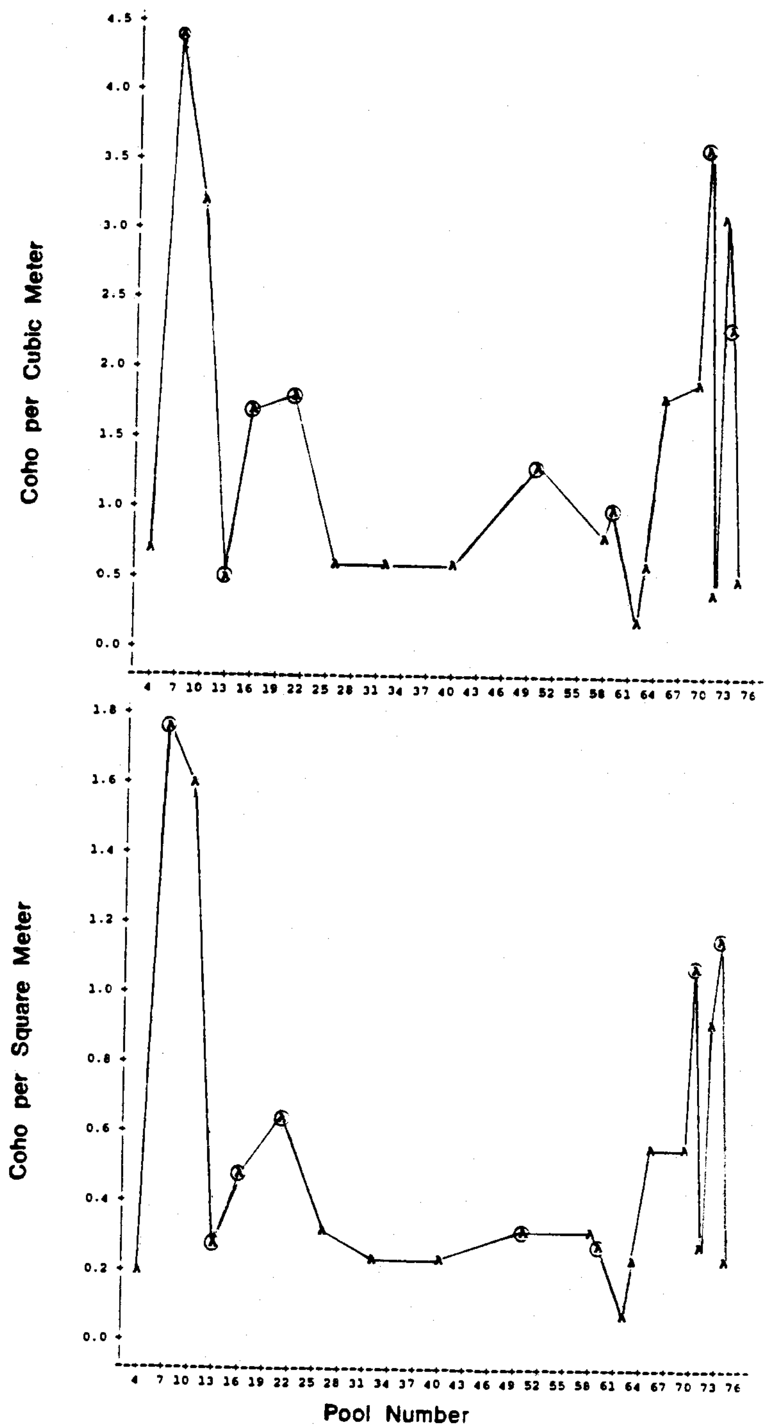

Figure 9. Density of coho fry in pools verses pool number in Cape Creek, Fall, 1987. The X-axis is not necessarily linear; pools are numbered consecutively from the mouth to the upper end of the survey. Pools with beaver activity are denoted by circles.

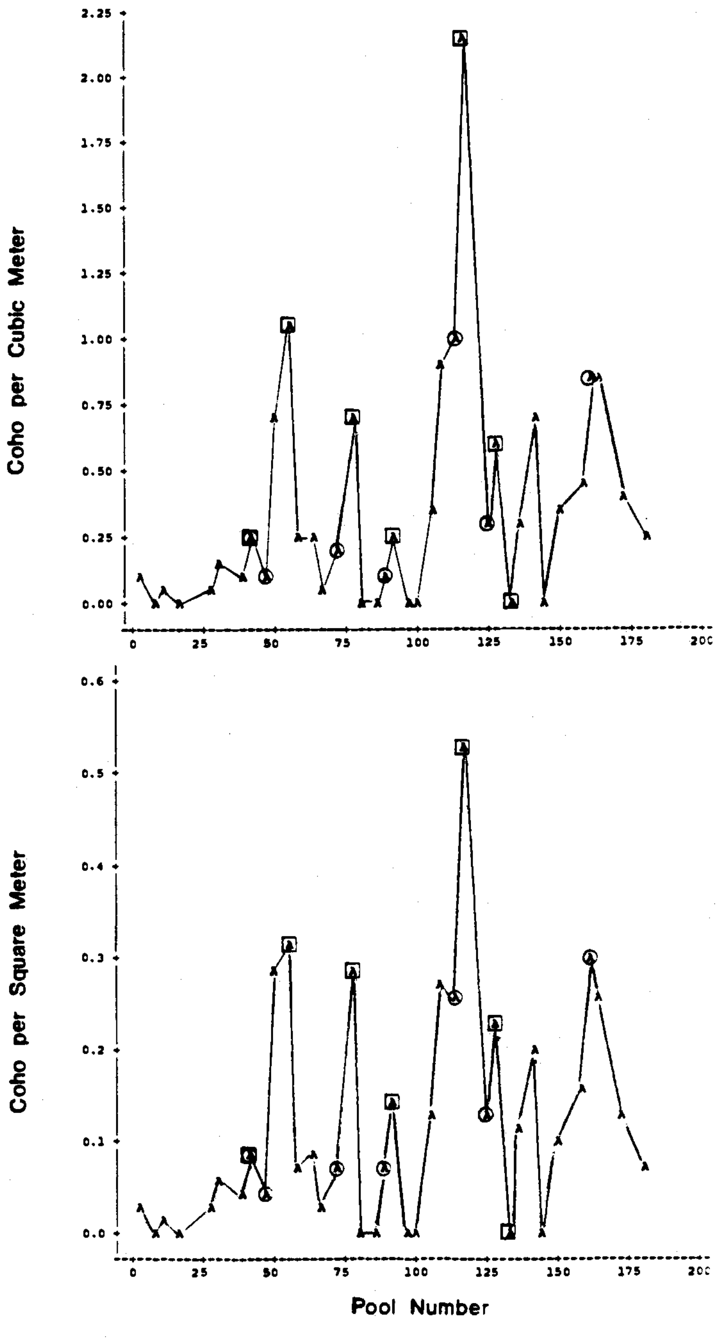

Figure 10. Density of coho fry in pools verses pool number in Cummins Creek, Fall, 1987. The X-axis is not necessarily linear; pools are numbered consecutively from the mouth to the upper end of the survey. Pools with beaver activity are denoted by circles; pools influenced by large woody debris are denoted by squares.

the stream (Figures 7 and 9). The middle reach was almost barren; numbers increase slightly in the upper reaches. Cape Creek has been heavily influenced by road-building and clearcutting and lacks structural complexity. This is especially evident in the steep-sided canal-like middle reach. This reach is highly constrained, mainly bedrock, has little coarse woody debris or beaver dams, and is primarily riffle habitat. The existing pools tended to be small, have fast water, and lack cover. The lower reach is unconstrained and has numerous large pools formed by coarse woody debris, rocks, and beaver dams. The upper reach has not been influenced by roads and has less clearcutting. Although pools were small in this upper reach, beaver activity was frequent and most pools contained large woody debris. Density of coho fry was greater in the lower and upper reaches than in the middle reach.

The distribution of coho salmon fry in Cummins Creek was much more even than in Cape Creek (Figures 8 and 10). High numbers of coho fry tended to be associated with beaver ponds or pools caused by large woody debris. While beaver ponds were larger and often had more coho fry per pool, ponds formed by large woody debris often had high densities of fry. It is also interesting to note that six of the seven beaver ponds were near or in pools formed by large woody debris.

Cummins Creek has not been heavily affected by timber harvest. The stream has many pools formed both by large woody debris and by beaver dams, as well as many side channels and braids on the wide floodplain.

No preference or avoidance of clear-cut areas by beaver was detectable in this study. Beaver dams occurred with similar frequencies in both clear-cut and old-growth forests.

Comparisons of Coho fry abundance between Cummins and Cape Creek

The total estimated number of coho fry in Cape Creek was much higher than in Cummins Creek (8767 vs. 3437). Coho fry per pond and per area and volume show that Cape Creek also had a higher density of coho fry (Table 2 and Figure 4).

A partial explanation is the larger pool size in Cape Creek (Figure 11), but density was still higher in Cape Creek. There may be several explanations for this difference in density. First, Cape Creek is a larger stream: longer (15.3 km vs. 11.0 km), larger watershed (3292 ha vs. 2100 ha), and has over four times the discharge (1.3 cms vs. 0.28 cms at summer flow).

The bedrock of both streams is basalt, and they have similar gradients. Cummins Creek is a trellis pattern

Table 2. Coho fry per pool in Cape and Cummins Creek, 1987.

	Cummins (n=38) Avg (SD)	Cape (n=21) Avg (SD)	P
Coho/m2	0.11(0.12)	0.57(0.48)	0.0004
Coho/m3	0.36(0.44)	1.50(1.21)	0.0004
Coho/pool	18 (23.1)	115 (153)	0.0089

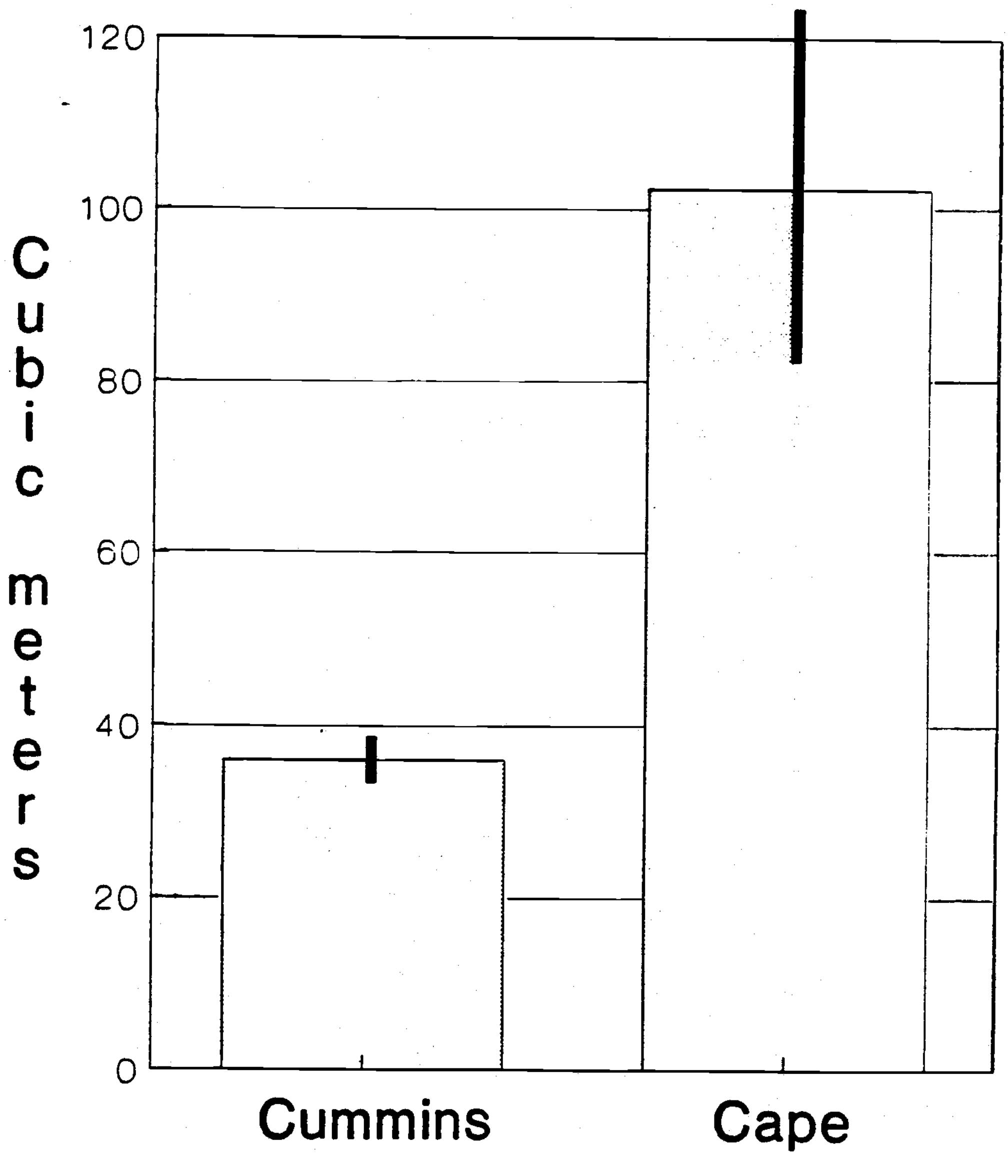

Figure 11. Average pool volume for Cape and Cummins Creeks, Fall, 1987. Standard error bars are shown.

stream, while Cape Creek has a dendritic pattern. This size and pattern difference is a possible explanation for different densities in the two streams. Au (1971) reported that coho fry disperse downstream for three to seven nights after they emerge from the redd. After this time, most become established. Fry that do not obtain sufficient food and space requirements continue to disperse downstream. If Cape Creek has more tributaries as a result of its size and dendritic pattern, this dispersal would concentrate fry in the main stem to a greater degree than in Cummins Creek. However, this explanation assumes that Cape Creek has proportionally more area in tributaries than Cummins, and that habitat in the mainstem of Cape Creek for coho fry is not already saturated. A more probable explanation is productivity differences in the streams.

Productivity is influenced by stand age and size of the stream. Cummins Creek is mainly surrounded by old-growth forest, while the forests around Cape Creek have been clear-cut extensively since the late 1940's (Marston and Jong 1978), often to the stream edge. Cape Creek is a much larger stream than Cummins Creek. Therefore, the channel is wider, is more open, and receives more direct sunlight, resulting in greater autochthonous production (Hall 1972; Naiman and Sedell 1980; Gregory 1980). The openness of Cape Creek has been increased by its timber harvest history. This increase in productivity may more than compensate for the loss of habitat caused by the loss of woody debris. Many studies have found greater numbers and larger biomass of fish in open reaches of logged streams than in forested reaches (Iwanaga 1971; Aho 1977; Murphy and Hall 1981; Murphy et al. 1981; Tschaplinski and Hartman 1983). In addition, well lighted streams increase the efficiency of prey capture for visual predators such as salmon (Wilzbach et al. 1986). While food availability and space requirements are important factors for summer populations, cover becomes more important in winter with high water flow. Koski et al. (1984) studied coho salmon populations in clear-cut, buffered, and old-growth streams in southeastern Alaska. Due to blowdown, the buffered stream had the highest concentration of large woody debris. The clear-cut stream was cleaned and had the lowest concentration of large woody debris. Koski reported that coho fry were significantly more numerous in clear-cut and buffered streams than in old-growth streams, but the density of coho parr (1-year-olds) was highest in the buffered streams, intermediate in the old-growth, and lowest in the clear-cut streams. Thus, the streams receiving more solar insolation were more productive, but winter survival was greatest in streams with cover and refuge from fast water provided by the large woody debris. Winter counts were not made in Cummins and Cape Creek, so it is not known which stream has better winter survival of coho fry.

Despite the differences in coho fry densities between the two streams, it is not advisable to base conclusions or decisions on just one year's data. Everest and Sedell (1984) found that natural variability in fish populations can exceed 100% between years in Pacific Northwest streams. Other researchers have found similar natural variation in natural fish populations (Larkin 1974; White 1975; Hall and Knight 1981; Hall 1984). For small streams, the catch of a single trawler can affect the abundance of anadromous fish for one to several years. This variation makes it difficult to evaluate fish production in the streams without several years of data.

Distribution of coho salmon fry in the streams.

In this study, there were two to ten times more coho salmon fry in pools than in glides or riffles, respectively (P=0.001). Coho salmon fry are typically found in pools rather than riffles or glides (Bisson et al. 1982; Sedell et al. 1984).

Beaver dams create pool habitat with many of the same attributes as that formed by large woody debris jams (Naiman et al. 1986), and may increase the complexity of debris jams by building dams in the jam. Coho rearing habitat is strongly tied to the presence of large woody debris (Bisson and Nielsen 1983; Sedell et al. 1984). Sedell et al. (1984) reported that coho salmon fry were more abundant in complex woody debris jams than in habitat formed by a single large down tree.

Conclusion

In conclusion, beaver are increasing suitable habitat for coho salmon fry. The fry are not concentrating at higher densities in beaver ponds, but are using the increased habitat in proportion to its availability. On the average, beaver ponds are larger than other ponds or pools and therefore have more coho fry.

The presence of beaver in coastal Oregon streams seems to have a positive effect on fish populations rather than the negative effects that have been reported in the midwestern U.S. The coastal streams are steeper (and faster) and generally colder. The frequency of dams in these coastal streams is low because most are washed out in winter floods. The slight warming that may occur with the opening of the canopy and with water being held in ponds may increase productivity of salmonids in these cold-water streams. The coho fry are especially benefitted by the slower water in beaver ponds leading to a lower energy output to maintain their position in the stream and probably by increased food production.

HABITAT

Herbivory

The two most abundant woody species in this study were salmonberry and alder (Table 3), constituting 61 and 27% of the total stems sampled, respectively (Figure 12). The only other species showing positive indices for usage was vine maple. Beaver were highly selective for vine maple (*Acer circinatum*) , with a SI of 0.47 and 0.32 for the two upper size classes (Figure 13). This was shown by a virtual elimination of vine maple where it occurred near a dam site. However, vine maple only constituted approximately 1% of the available stems in the survey. Therefore, although beaver showed positive selection for vine maple, it was not a large part of the stems cut in this study.

Beaver selected salmonberry stems greater than 2 cm in diameter. The smallest size class (1/2-1 cm) was selected against, and the next class (1-2 cm) showed no selection. Beaver showed selection for the two middle size classes of alder (3-6 and 6-9 cm). Alder over 9 cm in diameter showed positive selection, but had a lower SI

Table 3. Woody stems cut by beaver by species and size class in Cape and Cummins Creek, 1987.

Species	Size class (cm)	# Cut	# Available	SI
Salmonberry	0.5-1	107	596	-0.32
Salmonberry	1-2	82	228	0.01
Salmonberry	2-4	58	74	0.39
Salmonberry	>4	30	41	0.36
Alder	0.5-3	63	190	-0.04
Alder	3-6	78	87	0.43
Alder	6-9	32	40	0.39
Alder	>9	62	95	0.29
Vine Maple	0.5-3	1	7	-0.43
Vine Maple	3-6	12	12	0.47
Vine Maple	6-9	15	22	0.32
Thimbleberry	0.5-1	0	40	-1.00
Thimbleberry	1-2	3	12	-0.23
Elderberry#	0.5-1	1	15	-0.67
Elderberry	1-2	1	13	-0.62
Elderberry	2-4	0	14	-1.00
Other*	0.5-1	2	24	-0.69
Other*	1-2	0	7	-1.00
Other*	2-4	0	4	-1.00
Other*	>4	0	9	-1.00

#(Sambucus spp.)

*Includes spruce, hemlock, Douglas-fir, big-leaf maple, Vaccinium spp., salal.

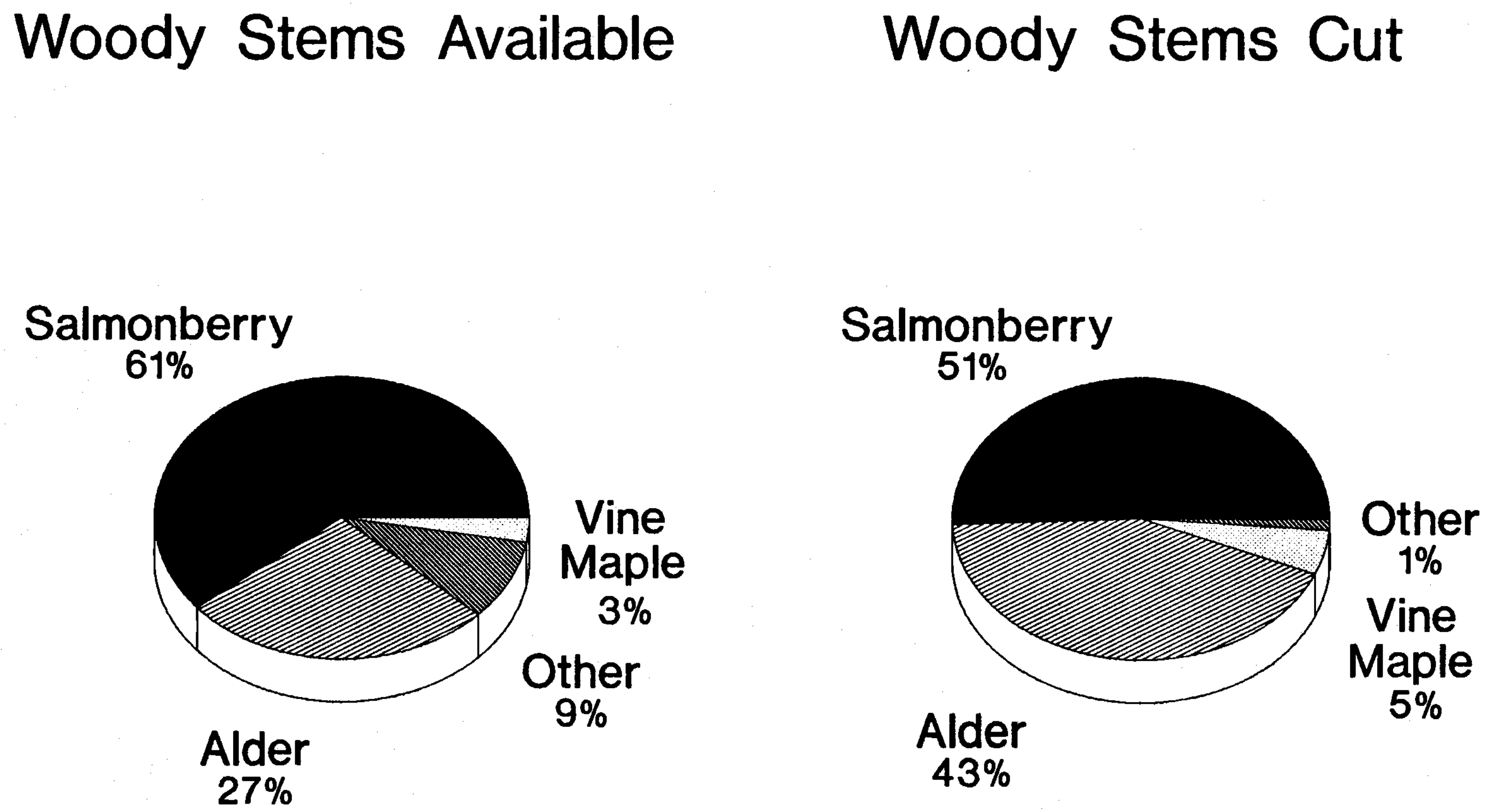

Figure 12. Comparison of percentages of woody stems available to beaver with percentages of those woody stems that were cut by beaver. "Other" included spruce, hemlock, Douglas fir, Vaccinium spp., salal, Salix spp., big-leaf maple, elderberry, and thimbleberry.

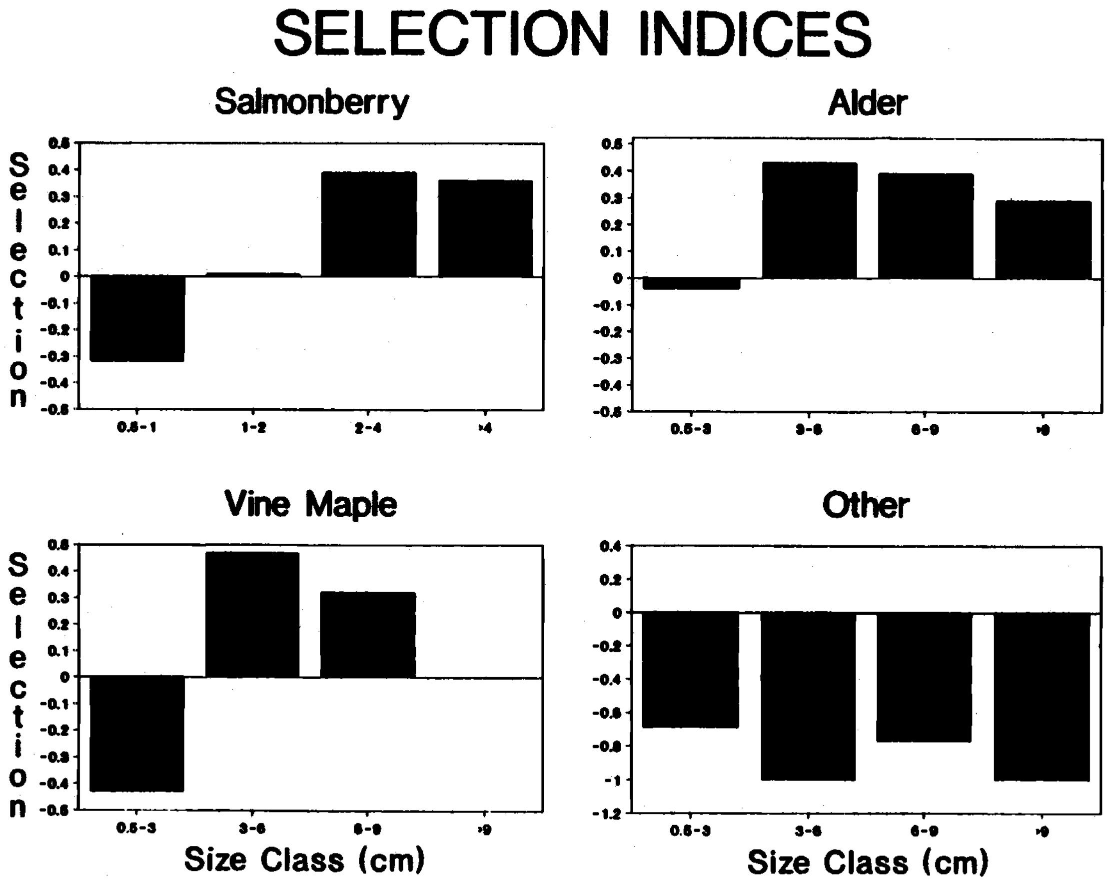

Figure 13. Selection indices for salmonberry, alder, vine maple, and "other" species selected by beaver. "Other" included spruce, hemlock, Douglas fir, Vaccinium spp., salal, Salix spp., big-leaf maple, elderberry, and thimbleberry. Negative values indicate avoidance, positive values indicate preference for a species.

than size classes 3-6 cm and 6-9 cm.

A portion of the alder stems were not used for food (the bark was left on), but were used only for dam construction. This distorts the use of the selection indices to show food preferences. Other species were also occasionally cut without being debarked, but this was not as common as in alder. The selection indices show species beaver cut, not necessarily what they ate.

Among all species, the smaller size classes were not selected, but were still an important part of the stems selected by the beaver. The smaller size classes are by far the most numerous (87% of the salmonberry was in the two smaller size classes, 46% of the alder was 1/2-3 cm), and make up a large portion of the number of cut stems (Table 3). Many of the small salmonberry stems were sprouts that started following cutting of the older stems by beaver.

Thus, the most important woody species for beaver on these two streams were salmonberry and alder in the 2-9 cm size class. A small number of large (20-70 cm) alder were cut along the streams. This was especially evident at the one large impoundment on lower Cape Creek, where 11-12 large alders (15-70 cm DBH) were cut in late summer. These large trees provided a great amount of food, but most of it was inaccessible, suspended above the ground. Once large trees were down, only the smaller twigs and stems within reach were used. Sometimes the trunk was partially debarked. Also, felling large trees requires large amounts of energy so they may not be as energy efficient to harvest as smaller stems (Jenkins 1975).

In other environments, willow is a preferred food (Denny 1952). In Alaska, willow was used for forage and construction while available alder was unused (Sanner 1987). There was little willow on my study area. The only willow found had been repeatedly cropped by beaver, causing it to be very bushy. Aspen, the preferred food of beaver where available, did not occur on my study area.

Sites with riparian alder and willow provide a stable habitat because of their ability to resprout, especially if cut young (Novakowski 1967). Alder is a tough, fast-growing species. It sprouts rapidly and within two to three years, some alder species are a useable size for beaver (Northcott 1971). Northcott estimates that beaver can cut 20-40% of the current year's growth without endangering the supply. DeBell and Turpin (1989) found that alder (age 4-10 years) stumps cut in May, August, and September had a higher resprouting rate than stumps cut in June and July. They also reported that 4-year-old trees had a higher survival rate than 6- to 10-year-old trees. Four-year-old alder trees growing in a riparian zone are approximately 10 cm at the base (Berntsen 1961). Since beaver selected alder in the 2 to 9-cm size class and cut mainly in late July through September, they were optimizing the resprouting potential of the alder they cut.

Salmonberry resprouts easily, even when older stems are cut (Ruth 1970, Tappeiner et al. in prep.). It is possible that beaver help to perpetuate salmonberry on a riparian site because it resprouts more easily than other species.

In total, these data indicate that beaver were selecting not only for certain plant species, but for certain size classes. Jenkins (1975) found that beaver cut indiscriminately with respect to size class near the edge of the water, but become more selective as the distance from the water increased. Beaver chose medium stems at large distance from the stream. The beaver in my study selected for stems 2-9 cm in diameter, perhaps indication that these are the most energy-efficient sizes for the beaver (Jenkins 1975).

Chronology of plant species utilization

A change in cutting habits was observed through the summer. Large amounts of salmonberry were cut early in the spring (March-April) and the bark eaten. Large drifts of debarked salmonberry stems were observed in the streams. This tapered off in June. In May and June, beaver were probably eating large amounts of herbaceous material(Svendsen 1980; Jenkins 1981). The evidence of this was clipped vegetation along the ponds and some vegetation floating in the ponds. Only light cutting of woody material was evident until July, when beaver began constructing dams in earnest. Alder was cut in July through October and used in dams. Some stems had the bark eaten while others were cut specifically for the dam, with the bark left on. No observations were made from late November through the winter.

Effect of distance from stream on foraging activity

The mean distance of foraging along all transects was 17.5 meters (SD=10.1). The heaviest foraging was within 20 m of the stream and 90% within 30 m of the stream. Exceptions to this occurred when beaver foraged up to 90 m along tributaries. Since most of these tributaries were almost dry by the time beaver were actively foraging along them, it is questionable whether they should be classed as streams. There was not enough water to transport the branches or to swim in. Perhaps the bare rocks made transportation of woody stems easier. The riparian areas of these small tributaries contained a large amount of suitable forage, especially salmonberry and alder.

Average number of uncut, new cut (cut during current year), and old cut (cut during previous years) stems were summarized by distance from the stream (Figure 14, 15) For all size classes, abundance of stems decreased at 25 to 30 meters from the stream edge (Figure 14). This distance corresponded to the average floodplain width, and the beginning of the upland forest. Small stems were cut in proportion to availability up to 5 meters from the stream edge (Figure 14). At greater distances, availability was greater than the stems cut. Old and new cut stems showed the same pattern. This may be because salmonberry and alder sprout quickly, and thus this size class is not easily depleted. The SI scores for the small size classes were negative, indicating an avoidance of this size class in relation to availability. The percent of available stems cut dropped to approximately 20% at 10 meters from the stream and less than 5% at 20 meters from the stream (Figure 15). Thus, small stems were cut near the stream, but may not have been energy efficient at greater distances or beaver get all they need within these distances.

The pattern for medium stems in Figure 14 is

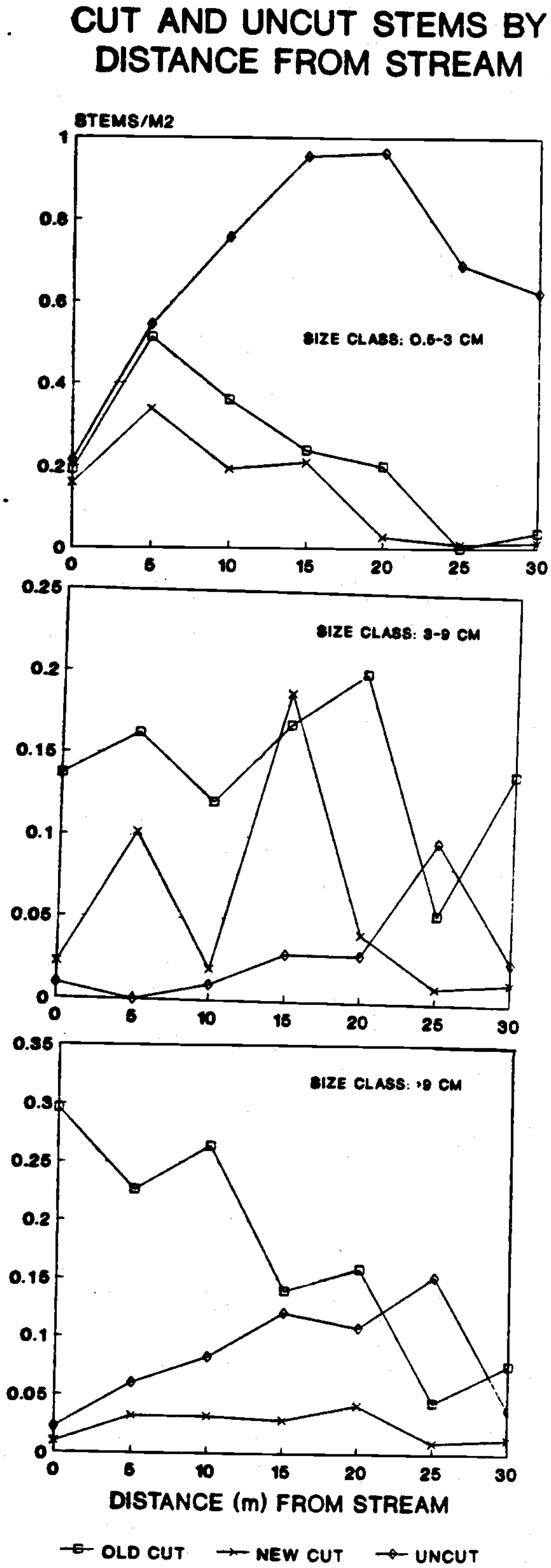

Figure 14. Old cut, new cut, and uncut stems for preferred species (salmonberry, alder, and vine maple) per square meter by distance from the stream, Cummins and Cape Creeks, Summer, 1987.

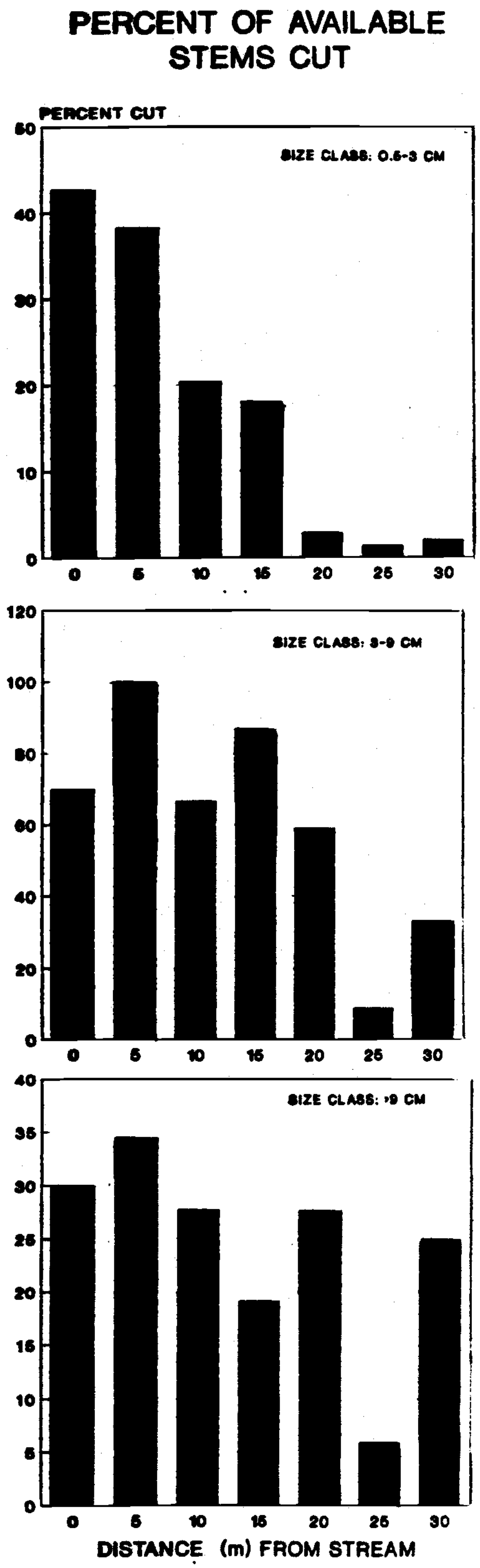

Figure 15. Percent of available stems for preferred species (salmonberry, alder, and vine maple) cut by beaver during the current season by distance from the stream, Cummins and Cape Creek, 1987.

erratic. Up to 20 meters from the stream, the majority of the stems in this size class were cut (see also Figure 15). At 5 meters from the stream, all medium stems were cut. This corresponds to the SI analysis, which showed beaver prefer stems in the 2-9 cm size class.

For the large size class (>9 cm), there are many more old cut stems than new cut stems. There are two possible explanations. First, stumps from cut stems in this size class persist longer than stumps of the smaller size classes. Therefore, the old cuts in this size class may encompass more years than the two smaller size classes. Second, cutting was still occurring after surveys were done in the summer. By observation, beaver were cutting more large stems later in the season. The distribution of cut stems by distance from the stream for the current year was more even than the distribution for the two smaller size classes (Figure 15). The percent of available stems cut for the small size class decreased after 5 meters, after 20 meters for the medium size class, but remained fairly stable out to 30 meters for the large size class.

Beaver foraged from 0-7 meters vertically, occasionally going much higher along tributaries. The mean height above stream level of foraging was 2.1 meters (2.5 SD).

Foraging tended to be intensive and patchy. Once beaver established good paths and slides into the stream, they tended to exploit that area, rather than use other seemingly suitable areas. This supports the observation by other researchers (McGinley and Whitham 1985; Jenkins 1975,1980) that beaver are central place foragers and that most feeding is confined to the riparian area near the pond. Steepness did not seem to be a major factor, since extensive beaver cutting was evident on a slopes up to 45 degrees. Stems on these steep slopes would be easy to drag back to the stream.

Most cutting tended to be upstream of the dam site, although cutting occurred downstream of the dam site in a few cases. Boyce (1974) also reported that beaver traveled further upstream than downstream to obtain forage materials, and attributed this to energy expenditure to get materials back to the site. The average area affected by beaver cutting around a dam site was 1944 m2, (SD=921). This is smaller by a factor of 6 than that found by Johnston and Naiman (1987) in Minnesota. They measured two ponds and found that approximately 12,900 m2 were affected by browsing at each pond. This may reflect a higher number of beaver living in these colonies, longer occupancy at the site, a less productive food source, or other factors.

Comparison of vegetative and geologic factors at used and random sites.

The mean sideslope (along a 30-m transect perpendicular from the stream) was significantly different ($P=0.89$ using Students t-test) between used and unused sites on Cape Creek, with used sites having a lower slope (10.5%, SD=2.8) than unused sites (24.8%, SD=6.7). The slope of used and unused sites on Cummins was not significantly different, with mean sideslopes almost identical (9.2% and 8.3%, respectively). This difference may be largely a consequence of the geomorphology of the two streams. The sideslope of the used sites is similar for both Cape and Cummins Creeks, approximately 10 degrees. Sideslopes for unused sites on Cape were much steeper, around 25 degrees. Cummins Creek has a wider flood plain, so neither used or unused areas are very steep.

Johnston and Naiman (1987) found that on level sites, beaver tended to concentrate browsing in defined patches with a well-worn system of paths, while on steep-banked sites, browsing was more random. They hypothesized this difference in forage patterns was related to the differences in beaver's vulnerability to predation related to topography. Steep-sided banks allow beaver quick access to deep water and safety, so they can browse randomly. In contrast, on level sites, beaver have to travel further to reach the safety of deep water. On these sites, browsing is restricted to patches which are connected to the pond by good paths or canals. The browsing at dam sites in my study had a tendency to be random on steep sites and concentrated on level sites, but the relationship was not strong.

Overstory cover was divided among alder, hemlock, Douglas-fir, and spruce cover (Table 4). Using Scheffe's multiple-comparison procedure, none of the overstory variables were significantly different between used and unused sites at the $P < 0.05$ level. However, it is interesting to note that percent alder cover and total cover on unused sites in Cape Creek was greater than on used sites on Cape Creek or any sites on Cummins Creek. This reflects Cape Creek's timber harvest history--it has been extensively clear-cut and much of the riparian vegetation is dense red alder. The fact that alder cover and total cover on used sites were not significantly different between streams suggests that (1) beaver choose more open areas for damsites, (2) beaver reduce the alder cover while inhabiting an area, or (3) a combination of the two.

Midstory cover is shown in Table 5. Although none of the variables were significant ($P < 0.05$) using Scheffe's multiple-comparison procedure, some trends may

Table 4. Comparison of mean overstory cover by species on beaver and non-beaver sites in Cummins and Cape Creeks, 1987.

Variable	Cummins Beaver (n=14) Avg(SD)	Cummins Non-beaver (n=6) Avg(SD)	Cape Beaver (n=14) Avg(SD)	Cape Non-beaver (n=6) Avg(SD)	Prob > F*
Alder	23.1(29.9)	20.5(21.1)	35.4(19.0)	54.9(3.5)	0.192
D. fir	2.9(4.2)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.115
Hemlock	11.4(14.4)	15.6(17.4)	4.4(7.7)	13.2(17.1)	0.478
Spruce	12.7(17.4)	5.0(4.9)	1.1(3.3)	1.9(3.3)	0.189
Total	49.9(43.6)	41.1(7.0)	40.0(23.5)	70.0(12.7)	0.470

*Scheffe's multiple comparison procedure was used.

Table 5. Comparison of mean midstory cover by species on beaver and non-beaver sites in Cummins and Cape Creek, 1987.

Variable	Cummins		Cape		Prob>F*
	Beaver (n=14) Avg(SD)	Non-beaver (n=6) Avg(SD)	Beaver (n=14) Avg(SD)	Non-beaver (n=6) Avg(SD)	
Alder	9.2(5.5)	17.1(15.6)	4.4(7.7)	0.0(0.0)	0.084
Elderberry	4.0(3.1)	5.2(7.1)	4.3(9.4)	4.5(3.3)	0.997
Hemlock	4.2(5.8)	2.1(3.6)	0.9(2.1)	7.5(8.4)	0.199
Salmonberry	0.0(0.0)	0.0(0.0)	0.0(0.0)	1.7(2.9)	0.120
Vine Maple	7.0(9.6)	2.9(5.1)	5.3(9.4)	0.0(0.0)	0.690
Other**	24.3(11.1)	29.9(15.1)	13.7(17.5)	12.8(7.3)	0.306
Total cover	48.7(22.1)	57.2(36.9)	28.6(35.9)	26.5(18.1)	0.427

**Includes: Douglas-fir, spruce, western redcedar, <u>Vaccinium</u> spp.

*Scheffe's multiple comparison procedure was used.

be biologically significant. Salmonberry was absent on used sites. Any midstory salmonberry would be in the larger size classes (2-4 and >4 cm). Since these classes were selected for by beaver, the lack of midstory salmonberry at used sites can be attributed to beaver cutting.

Average vine maple cover was more abundant on used sites than unused sites. Much of the vine maple was cut by beaver after the vegetation transects had been completed. Even though most of the vine maple was not cut until after transects were completed, the SI (Table 3) still showed selection for vine maple.

Although beaver have a large impact on understory vegetation, especially salmonberry, no significant differences were detected. This is largely because the stream vegetation is highly variable from site to site (Table 6).

HABITAT SUITABILITY FACTORS

Important factors for beaver habitat suitability

Several existing habitat suitability models were tested to determine their appropriateness in coastal Oregon streams (Table 7). These models are described in the literature review. None of the models exhibited good

Table 6. Comparison of mean understory cover by species on beaver and non-beaver sites in Cummins and Cape Creeks, 1987.

Variable	Cummins Beaver (n=14) Avg(SD)	Cummins Non-beaver (n=6) Avg(SD)	Cape Beaver (n=14) Avg(SD)	Cape Non-beaver (n=6) Avg(SD)	Prob>F*
Alder	2.7(6.0)	2.8(3.5)	3.7(9.1)	0.0(0.0)	0.902
Elderberry	2.0(4.1)	3.9(5.4)	2.7(3.9)	0.0(0.0)	0.660
Hemlock	0.0(0.0)	1.0(1.7)	0.0(0.0)	0.0(0.0)	0.120
Salmonberry	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.0(0.0)	0.000
Vaccimium spp.	3.7(5.4)	0.3(0.5)	0.0(0.0)	1.0(0.4)	0.133
Thimbleberry	0.0(0.0)	2.6(4.5)	1.8(3.4)	0.7(0.6)	0.578
Other**	14.5(8.3)	22.8(6.7)	14.3(8.0)	12.2(3.6)	0.249
Total cover	22.9(15.7)	33.4(7.2)	22.4(17.6)	13.9(4.5)	0.443

**Includes Douglas-fir, spruce, salal.

*Scheffe's multiple comparison procedure used.

Table 7. Existing habitat suitability models tested with data from Cape and Cummins Creeks, 1987.

Location	Beaver (n=14) Mean score (SD)	Nonbeaver (n=6) Mean score (SD)
Missouri HSI (Urich et al. 1983)	26.4 (7.7)	25.1 (4.1)
California (Beier and Barrett 1987)	1.4 (0.85)	1.5 (0.81)
Eastern OR (McComb, unpublished)	-0.6 (1.2)	-0.7 (1.0)
Massachusetts (Howard and Larson 1985)	1.5 (0.51)	1.4 (0.13)
General HSI (Allen 1983)	1.6 (0.46)	1.5 (0.34)

definition between beaver used and unused sites. As expected, mean scores for beaver sites and non-beaver sites were similar. Beaver are generalists, with a historic range in North America from the Yukon to northern Mexico (Jenkins and Busher 1975). Models developed for one environment might not be expected to work well in another environment.

Since existing models were not appropriate for these streams, stepwise discriminant analysis was used on the raw data to identify important factors for beaver habitat in coastal Oregon streams by comparing used and unused sites. Variables included were overstory hardwood cover, overstory conifer cover, midstory alder cover, midstory salmonberry cover, midstory vine maple cover, other midstory cover, understory salmonberry cover, understory alder cover, other understory cover, bank slope, and proximity to a logjam, tributary, or debris slide.

A formal model is not presented. The analysis is descriptive in nature to identify combinations of factors important to selection of dam sites by beaver. Model development was not feasible because of small sample sizes and lack of independent validation. The data from one year on two streams is very useful but not enough to produce a general model.

The most important factor was the proximity to a logjam, tributary, or debris slide. When this variable was included in the stepwise discriminant analysis function, it explained 52% of the variation in the model. Beavers often used existing structures in the stream as a starting point for a dam. Dams were begun on top of large logs in the stream, or in or above logjams. Those dams built above logjams have the advantage of the slower water above the jam. Dams were also typically built on side channels, and in the main channel near a tributary or major debris slide. Dams built on side channels are usually small, but may flood a large area. Since most dams wash out during the winter storms on the coastal streams, beaver dams on side channels seemed the most enduring (personal observation). Dams built near a tributary have the advantage of a larger food supply (in the riparian zone of the tributary) as well as the physical factor of the tributary-stream junction. The stream was usually wider at the junction, leading to reduced water levels and velocity. Beaver dam-building above or in debris slides had the advantage of a larger food supply, and the beneficial effect of slower water.

The importance of this physical variable (proximity to a logjam, tributary, or debris slide) also agrees with other studies and models (Slough and Sadlier 1977; Howard and Larson 1985; Beier and Barrett 1987) that report that physiographic factors have more effect on damsite selection than vegetation characteristics.

The three other variables included were midstory conifer cover, midstory vine maple cover, and overstory conifer cover. Together, they accounted for only 23% of the variability beyond the 50% accounted for by proximity to a logjam.

Vine maple was not abundant along the streams, representing only 3% of the stems tallied. However, it was used extensively, as evidenced by its virtual elimination by beaver where it was available. Overstory and midstory conifer cover negatively affected suitability for a beaver dam site.

Since the proximity to a logjam essentially controlled the discriminant analysis, the procedure was carried out again excluding this factor. Midstory vine maple cover, midstory conifer cover, and overstory conifer cover were again selected as the best combination of variables to explain selection of dam sites. Overstory and midstory conifer cover were negatively associated with the discriminant axis scores, while midstory vine maple cover had a positive association. Midstory conifer cover accounted for 50% of the variation in the model, with overstory conifer cover and midstory vine maple cover each accounting for an additional 10%.

Although salmonberry seemed to be an important food item, it was not selected by stepwise discriminant analysis. Salmonberry was abundant along both streams, did not seem to be a limiting factor, and therefore was not a distinguishing factor.

Projected Beaver Populations in Cape and Cummins Creeks

A discriminant function was developed from the factors identified as important to suitable beaver habitat by discriminant analysis. When the logjam factor was included, the model placed 20 of the 20 (100%) sites in the correct groups.

The high correct classification rate would suggest that the beaver are habitat limited, because none of the random sites were classified as a used site. However, because the sample size was small, it is possible that unused sites suitable for beaver habitation were not sampled. Therefore, I do not feel justified in concluding from the discriminant function that all suitable beaver sites are being used.

Trapping records are kept only by county (personal communication, Oregon Department of Fisheries and Wildlife), so it was impossible to tell if beaver were being affected by trapping in these two streams.

My conclusion from observing the study streams and 8 other coastal streams of comparable size is that beaver are mainly constrained by high water during the rainy season in these steep stream systems. Food availability in general does not seem to be a limiting factor. The presence of a suitable physical site for dam-building may be more limiting.

Beaver dams occurred with approximately the same frequency (1 dam per kilometer) in both Cape Creek and Cummins Creek, indicating no preference for old-growth or clear-cut streams by the beaver. Food availability was greater in Cape Creek and along Cummins Creek where clearcutting had occurred. Although food availability may have been a limiting factor on some abandoned sites in Cummins Creek, it was generally not limiting. This may be due, in part, to the generally unconstrained character of Cummins Creek. There was an abundance of small alder and salmonberry growing on the floodplain. Much of the alder was approximately 20 years old and was undoubtedly started after the 1964 Christmas flood (Oregonian 1964). The greater presence of large woody debris in Cummins Creek may have provided more suitable physical sites for beaver dam construction. One dam and two side channel dams occurred in the small clear-cut on Cummins Creek, but this frequency was not greater than dams occurring on the rest of the stream.

SUMMARY OF BEAVER EFFECTS

On Cape and Cummins Creek, beaver increased the amount of pool habitat available for coho salmon fry in late summer and fall when water is normally low. Densities were the same in nonbeaver ponds and beaver ponds, but because beaver ponds were larger, they supported a disproportionate share of the fry. Without this extra habitat, coho fry would be more crowded, some would be pushed into less favorable habitat (glides and riffles), or some might be pushed out into the ocean. This increase in the amount of pool habitat would seem to raise the number of fry able to be reared in these streams in the summer.

Besides pools, side-channels, tributaries and inundated floodplains are a favorable habitat for coho fry (Bisson et al. 1982; Peterson 1982; Sedell et al. 1985). Since beaver ponds raise the level of the stream, they may provide access to side channels as the water level decreases during the summer, and prevent fry from becoming stranded in sidechannel ponds.

Over 90% of the dams were destroyed by high water during the winter. However, the entire dam may not be breached, leaving calm areas above the dam edges as a refuge to the developing fry during winter floods. The side channels, canals, and dens developed at a beaver site may be important winter habitat for coho fry. Floodplain development may also be important to winter survival of fry. During high water, these floodplains are innundated and the edges provide quiet water during the floods (Peterson 1982).

Beaver were found to modify the riparian zone at the dam site. They selectively ate salmonberry and alder in the 2-9 cm diameter range. Vine maple and willow were also preferentially cut, although neither was abundant enough to be important to the beaver at these sites.

Physical factors were important in determining where dam sites were located. Usually dams were associated with a logjam, tributary, or debris slide, all of which provided favorable building sites. Vine maple cover was positively associated with choice of dam sites, while conifer cover was negatively associated. Beaver populations in these streams were probably limited by high water flow in winter.

In addition to the local effects beaver have on pond size, coho fry numbers, and the riparian zone, they also affect the stream on the watershed and landscape level. Low order streams (1-5) are usually characterized by narrow, shaded channels, receive much of their energy input from the surrounding forest and, when in the natural state, have large amounts of coarse woody debris (Naiman et al. 1986). When beaver are present, open patches averaging 1944 m2 (921 SD) along the stream were created by browsing and flooding. This allowed more light to reach the water and more primary production to occurr. In addition to the coarse woody debris, beaver add finer woody debris and digested materials (Naiman et al. 1986). The water table is raised and the area of wetland and anaerobic soils increases. When dams are built in the same area for a number of years, the flood-plain is extended because of the accumulation of silt. These changes increase the intrariparian diversity along the low-order streams, and modify the invertebrate community in the streams (Naiman et al. 1986), the fish distribution in the stream, the riparian vegetation structure, and habitat for other vertebrates.

MANAGEMENT IMPLICATIONS

The quiet water of pool and sidechannel habitat is the preferred habitat of coho fry (Lister and Genoe 1970; Nickelson et al. 1979; Bisson et al. 1982; Bryant 1983; Sedell et al. 1984; Bisson and Sedell 1984; Sanner 1987; Hankin and Reeves 1988). This type of habitat is created and enhanced by large woody debris, beaver dam-building, and at times by stream improvement projects (gabions, introduced boulders and large woody debris, excavated pools, flow deflectors, and floating log covers) (Bisson et al. 1985).

Streams that have been clear-cut, especially those without a buffer strip, lose their source of large woody debris to the stream channel for more than a century (Gregory et al. 1985). In addition, the composition of the streamside vegetation may shift from primarily coniferous material to deciduous material, which decays at a much faster rate (Gregory et al. 1985) and therefore has a shorter residence time in the stream. When the large woody debris in the stream decays and breaks up, there will be none to replace it for many years. If the stream has been cleaned at harvest time, the habitat formed by the large woody debris is lost even sooner.

Stream enhancement projects have been instituted in some anadromous fish streams in the Pacific Northwest

(Bisson et al. 1985). While these projects have demonstrated the ability of enhancement structures to increase spawning or rearing habitat, and so increase salmonid production, they have also shown that stream enhancement can be quite expensive. Costs for placing an individual boulder ranged from $22 to $35. Average cost for an individual gabion was estimated at $1200. Installing gabions in tributaries of the Coos River, Oregon, to retain spawning gravel cost $225,000 in 1981. These costs exclude engineering design and road costs (Bisson et al. 1985). These projects may cost more than the cost incurred by foregoing timber harvest in the riparian zone.

On streambanks that have been extensively harvested and cleaned, beaver provide a low-cost, ecologically sound method of increasing coho rearing habitat. While beaver dams are not structurally the same as large woody debris, they can provide some of the same benefits to coho fry: increased pool area in the stream, slower water, increased productivity in pools, increased hydraulic diversity, and possibly refuge during high water.

Current ecosystem theory predicts that streams have low resistance to disturbance relative to oceans, lakes, and forests (Webster et al. 1975; O'Neill et al. 1979 cited in Naiman et al. 1986). This means that streams are easily moved from their reference state by disturbance, but recover quickly. One reason for this low resistance to disturbance is the lack of a stable biomass and nutrient pool to buffer the system against change. Naiman et al. (1986) suggested that beaver ponds act as large, stable biomass and nutrient pools, and that streams inhabited by beaver are more resistant to disturbance. They also suggested that beaver help a stream return quickly to the reference point by rebuilding dams and collecting sediment. This is supported by the findings of O'Neill et al. (1979), that streams with greater diversity were more resistant to change.

The maintenance of a buffer strip along anadromous fish streams is essential for providing long-term input of large woody debris to the stream (Sedell et al. 1984; Bisson et al. 1985; Gregory et al. 1985). To maximize habitat for beaver, these buffer strips should provide both large woody debris to the stream and open areas for food. The large woody debris often creates suitable sites for dam construction. Most streams have abundant woody species available as food for beaver on the floodplain. In areas where the streamside vegetation consists exclusively of conifers, small openings could be made to provide food species. This may not be necessary as blowdown in the buffer strip often opens up patches.

The concern has been expressed that undisturbed buffer strips and managed buffer strips (with cutting of merchantable trees allowed) will succeed to shrub communities as a result of increased side and overhead light, and that these shrub communities will prevent tree regeneration (Hibbs 1987). Hibbs offers two alternatives to buffer strips, both of which have strengths and weaknesses.

The first alternative is no entry into the riparian zone or zone of influence. This alternative has the advantage of maintaining stream shading, future inputs of woody debris, and sediment filtering. The obvious disadvantage is the loss of highly valuable merchantable timber in this larger zone of influence.

The second alternative is clearcutting and planting, with modifications appropriate to the sensitivity of water and soil resources in riparian zones. This alternative allows more rapid regeneration of the forest and reduces the chance of perpetuating a shrub community along the stream (Hibbs 1987). The disadvantages include temporary loss of streamside shading and future woody debris input, increased sediments entering the stream, and loss of cover for other wildlife.

If we are to manage for both fish and timber, a possible compromise would be alternating patches of set-aside areas and replanted areas, with selected trees in clear-cut areas left to minimize increases in stream temperature (Pope and Lafferty 1987; Lafferty 1987).

This compromise would continue to provide large woody debris and shade to the stream for fish production, as well as allow some merchantable timber to be taken from the highly productive riparian zone. Along heavily shaded streams, these openings may increase primary production and food for salmon, hopefully without raising stream temperatures detrimentally. In addition, they would provide structural and food resources for beaver dam-building and maintenance. Maintaining a beaver population in the streams would further increase the amount of pool habitat (i.e. rearing habitat) in the stream. Openings should be small and would likely be the most beneficial in the middle and upper reaches of the stream, where the stream is heavily shaded.

Where beaver occur in these streams, they should be considered an integral part of the watershed. Surveys done in this study indicate that beaver are not overpopulated in these streams. In light of the beneficial effects of beaver on coho salmon rearing habitat, where the goal is to enhance coho salmon production, I would suggest that these streams be closed to trapping of beaver or the trapping severely limited. Both counties in which these streams occur are open to beaver trapping (personal communication, Oregon Department of Fisheries and Wildlife), but the extent of beaver trapping in these streams is not known. Where land management objectives are to maximize profit, limited beaver trapping could be allowed to supplement income derived from fish and timber production.

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