AN ABSTRACT OF THE THESIS OF

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Title: Influence of Geomorphology and Land Use on Distribution and Abundance of Salmonids in a Coastal Oregon Basin

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The basin morphology of a fifth-order coastal Oregon stream was analyzed across a hierarchy of spatial scales which included segments, reaches, and channel units. These scales represent valley and channel characteristics based on functional processes of geomorphology and attempt to organize heterogeneity of stream habitat within a drainage network. Four segments were associated with major geologic influences on the landscape, and boundaries were selected by basin patterns of the valley corridor observed by indices of valley floor width. Segments provided a template for reach characteristics. Narrow valley segments had greater reach lengths of multiple channels, and densities of boulders than wide valley segments. Within wide valleys of alluvium, incision of the channel occurred in three reaches and had reduced multiple channel lengths and bedforms composed of bedrock. Reach boundaries were selected by major shifts in active channel width and condition of geomorphic surfaces along basin longitudinal profiles, and these boundaries coincided with changes in bedform gradient. Reach composition of channel unit types was associated with gradient; percent length of pools and glides was inversely related to gradient.

Basin patterns of salmonid distribution and abundance were examined at the different hierarchical scales. Juvenile chinook and coho salmon exhibited strong basin gradients of abundance within a upstream-downstream continuum. Juvenile chinook dominate the lower basin and juvenile coho dominate the upper basin, and the transition in abundances occurred between the two mid basin segments. From a basin perspective of reaches, salmonid abundances were not related to any specific valley landform. Abundances of trout (ages 0+ and 1+) were directly related to mainstem reach gradient. Trout occupied fast-water channel units among the mainstem reaches, while juvenile salmon were more variable in use of channel unit types. Salmonid densities per channel unit were 2 to 8 times greater in the tributary reaches than the mainstem reaches. In the tributaries, pools and glides were used extensively for habitat.

Salmonid abundances in the tributaries were associated with stream size and gradient. Densities of juvenile coho were greater in low-gradient tributaries, and densities of cutthroat trout (age 1+) and trout fry (age 0+) were greater in high-gradient and larger tributaries. Juvenile coho occupied streams with gradients less than 4%. In the tributaries, composition of channel unit types was important because salmonids used mostly pools and glide habitats, and percent length of pools and glides was associated with stream gradient.

Timber harvest in first- to third-order tributaries detrimentally affected cutthroat trout, where areal densities of trout were significantly lower in clearcut sites without buffers than in patch-cut sites with buffers and unharvested sites. Analysis of land-use effects on salmonid populations accounted for site differences in geomorphology. Tributaries contained both allopatric cutthroat trout populations and cutthroat trout populations sympatric with juvenile coho salmon. Sympatric sites exhibited greater significant differences in trout densities among land-use treatments than all sites combined, and allopatric sites were not different among treatments. CWD volumes significantly were lower in clearcut sites (1.6 $m^3/100\ m^2$) than unharvested sites (2.9 $m^3/100\ m^2$). Reexamining the Alsea Watershed Study (AWS) streams 23 years after logging demonstrated that detrimental effects were long term. In Needle Branch (the AWS clearcut watershed), older age classes of trout were substantially reduced in numbers after logging. Competitive interactions between juvenile coho salmon and cutthroat trout with a loss of CWD cover may contribute to the long-term decline in cutthroat trout abundance after logging.

Influence of Geomorphology and Land Use on Distribution and Abundance of Salmonids in a Coastal Oregon Basin

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INFLUENCE OF GEOMORPHOLOGY AND LAND USE ON DISTRIBUTION AND ABUNDANCE OF SALMONIDS IN A COASTAL OREGON BASIN

CHAPTER I: GENERAL INTRODUCTION

Watersheds are features of the landscape comprised of mosaics of landforms that have evolved over geologic time. Landform development is controlled by parent rock characteristics and climate. Valleys develop by hillslope and fluvial geomorphic processes. Forests in the Pacific Northwest are an integral part of landscape development. Rates of hillslope geomorphic processes are regulated, in part, by vegetation composition. Likewise, geomorphic processes influence composition of biota as ecologic disturbances. Landform structure, geomorphic processes, and biota interact to form heterogeneity in these forested ecosystems (Swanson et al. 1988, Gregory et al. in press).

Channel morphology characterizes stream habitat features which are shaped by hillslope and fluvial geomorphic processes. Complexity of channel morphology is an outcome of structural inputs into the stream (i.e., boulders from hillslopes, and coarse woody debris from fallen large trees). Rates of these structural inputs into the stream are determined by valley landform characteristics (Swanson et al. 1988). Structure in the stream influences arrangement of the bed material (substrates) by fluvial geomorphic processes (Grant et al. 1990). Channel morphology, boulders, coarse woody debris, and substrates are all determinants of stream habitat.

Morphology of valleys and streams can be described at various spatial scales that are associated with temporal scales of development (Frissell et al. 1986, Gregory et al. in press). The drainage network of a watershed is the broadest functional scale, and successively smaller scales are subdivided hierarchically. A watershed is the geomorphic and ecologic boundaries of a stream system (Warren 1979, Lotspeich 1980). In Chapter II, hierarchical patterns of basin morphology are analyzed for Drift Creek, a coastal Oregon stream. Dynamics of geomorphology function at different spatiotemporal scales that determine habitat formation, disturbance, and persistence (Gregory et al. 1990). A hierarchical geomorphic perspective provides a framework to better understand heterogeneity of habitat structure observed in stream systems.

Salmonid distribution and abundance are variable both spatially and temporally within a drainage network (Hall and Knight 1981). Salmonid life histories have evolved within the spatial variation of channel morphology and the temporal variation of geomorphic processes (Sullivan et al. 1987). Analysis of spatial organization of salmonids requires a functional view that recognizes the dynamics of geomorphology and stream habitat at different scales. Physical features of streams form a template that modifies biological patterns of aquatic ecosystems. In Chapter II, a hierarchical system of basin morphology served as a basis for interpreting patterns of stream habitat characteristics, and distribution and abundance of salmonids.

An understanding of geomorphology on the distribution and abundance of salmonids assists in interpretation of land-use effects on stream habitat quality. In the Pacific Northwest, timber harvest by clearcutting is the predominant land use. Timber harvest practices have been shown to affect stream habitat quality and salmonid populations (Moring 1975, Moring and Lantz 1975, Hicks et al. in press). Forestry and fishery interactions are complex, and management of these resources occurs over broad and diverse landscapes. A basin perspective to morphology and salmonid distribution and abundance is essential for evaluation of cumulative effects of land use within a watershed.

Effects of timber harvest on stream habitat and salmonid abundance are variable, and depend on stream size, gradient, and time after harvest (Murphy and Hall 1981). After logging, decreases in salmonid populations may result from increased siltation, increased stream temperature, reduced or degraded spawning gravels, and simplified channel morphology due to removal of coarse woody debris (Hicks et al. in press). Increases in salmonid population may result from greater aquatic productivity of autochthonous inputs (Gregory et al. 1987). In Chapter III, effects of timber harvest on stream habitat and salmonid abundance was investigated in Drift Creek tributaries that accounted for influences of geomorphology. Forest practices investigated were clearcutting without bufferstrips and clearcutting in patches with bufferstrips.

The Alsea Watershed Study (AWS) investigated effects of forest practices from 1959 to 1973 in three tributaries of the Drift Creek basin (Hall and Lantz 1969, Moring and Lantz 1975). The AWS streams provide an historical perspective to effects of timber harvest on salmonid populations in the Drift Creek basin. The AWS showed cutthroat trout to be detrimentally affected by clearcut logging without bufferstrips. A reexamination of the AWS streams allowed for a long-term investigation of timber harvest effects on salmonids 23 years after logging. These results are reported in Chapter IV.

Study Area

The Drift Creek basin is located in the central Coast Range of Oregon (Fig. 1). Drift Creek flows into the Alsea River estuary near the city of Waldport. Its length is approximately 45 km, and the drainage area is 180 km^2. Drift Creek is a fifth-order stream beginning at the confluence with Meadow Creek. Drift Creek is tidally influenced up to the junction with Lyndon Creek, approximately

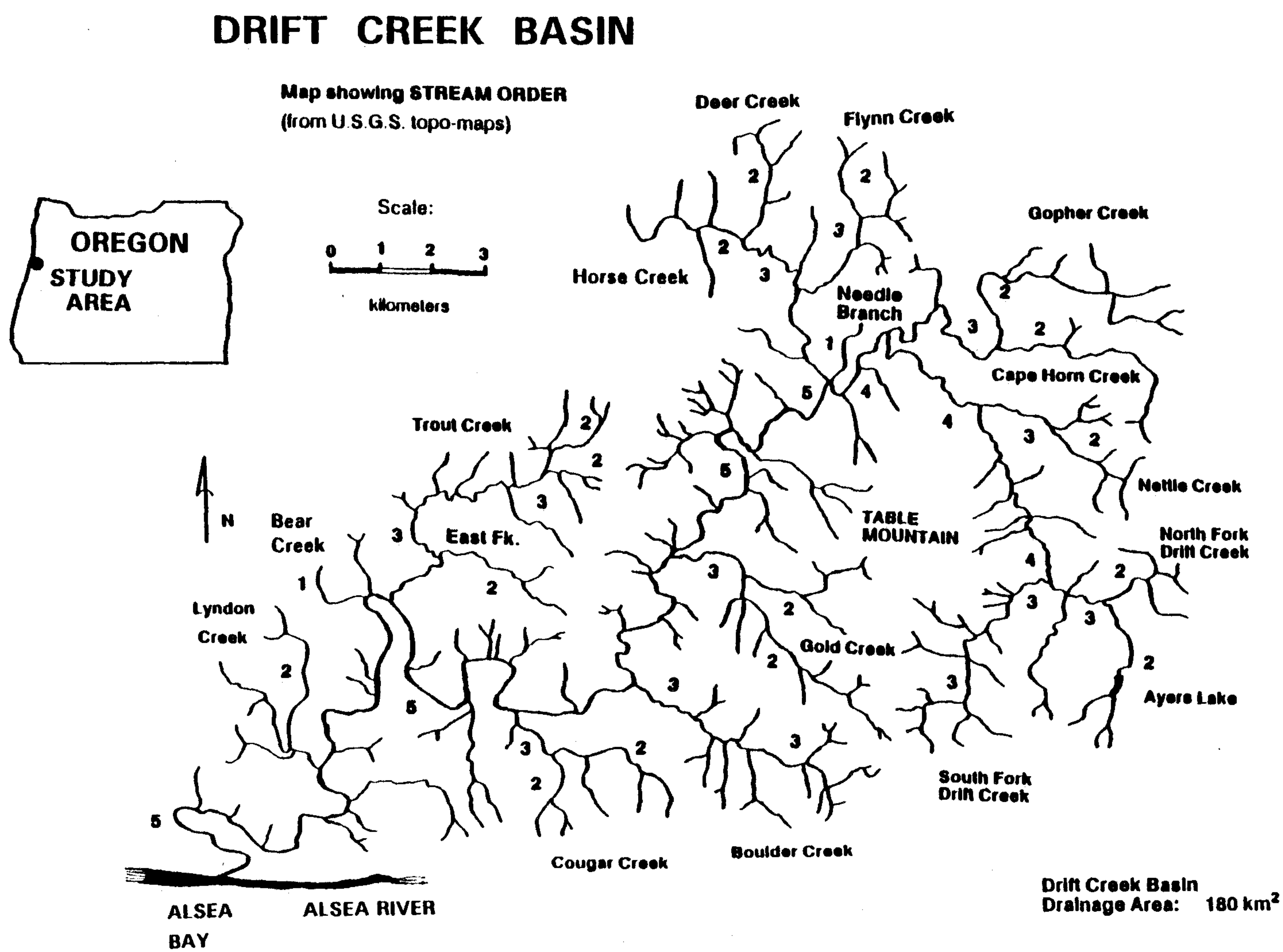


Figure 1. Location of the Drift Creek basin in Oregon; and map showing stream order.

5 km from the Alsea Bay. Watershed elevations range from sea level to 860-m on Table Mountain. The dendritic drainage pattern of the Drift Creek basin surrounds Table Mountain (Fig. 1). The basin lies completely in the Tyee Sandstone Formation (Snavely et al. 1976). Dikes and sills of igneous rock occur as thin intrusions in the Tyee sandstone throughout the basin. Table Mountain is an igneous sill composed of nepheline syenite.

The climate is maritime. The average annual precipitation is about 250 cm. Most of the precipitation occurs as rain from October through April. Mild air temperatures occur throughout the year.

The watershed was predominantly forested by 130- to 150-year-old stands of Douglas-fir (*Pseudotsuga menziesii*), intermixed with western hemlock (*Tsuga heterophylla*) and red alder (*Alnus rubra*). Riparian areas contain red alder, and lesser densities of western red cedar (*Thuja plicata*), and bigleaf maple (*Acer macrophyllum*). Much of the central Coast Range was burned during extensive wildfires around 1850 and 1870 (Juday 1977).

Drift Creek basin has a mixed management history of land use. Federal government ownership comprises 60% of the basin area, most of which is owned by the U.S. Forest Service. The basin contains two major unharvested areas: the Drift Creek Wilderness Area and the Flynn Creek Research Natural Area (Fig. 1). Most of federally managed lands have been clearcut, with use of streamside bufferstrips for the last two decades. Timber industry owns approximately 35% of the basin area located in mid, and upper portions of the watershed. Their lands are entirely clearcut without leaving bufferstrips, most of which were harvested between 1960 and 1975. Streams in the timber industry areas were salvaged for merchantable logs and were cleared for fish passage (Veldhuisen 1990).

General Basin Distribution of Salmonids

In the Drift Creek basin, anadromous salmonid communities include juvenile populations of spring and fall chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*), and winter steelhead (*Oncorhynchus mykiss*). Adult spring chinook were observed in the mainstem as far up as Gopher Creek during summer months. Anadromous/resident salmonids include the rainbow trout (*Oncorhynchus mykiss*) and coastal cutthroat trout (*Oncorhynchus clarki*). Non-salmonid species include the reticulate sculpin (*Cottus perplexus*) and longnosed dace (*Rhinichthys cataractae*).

General distributions of juvenile chinook and juvenile coho salmon for summer-rearing are illustrated in Figure 2. Juvenile steelhead trout/rainbow trout have a similar distribution to that of juvenile coho salmon. Cutthroat trout are found throughout the basin from the lower mainstem sections into first-order tributaries. Resident cutthroat trout are found above migration barriers.

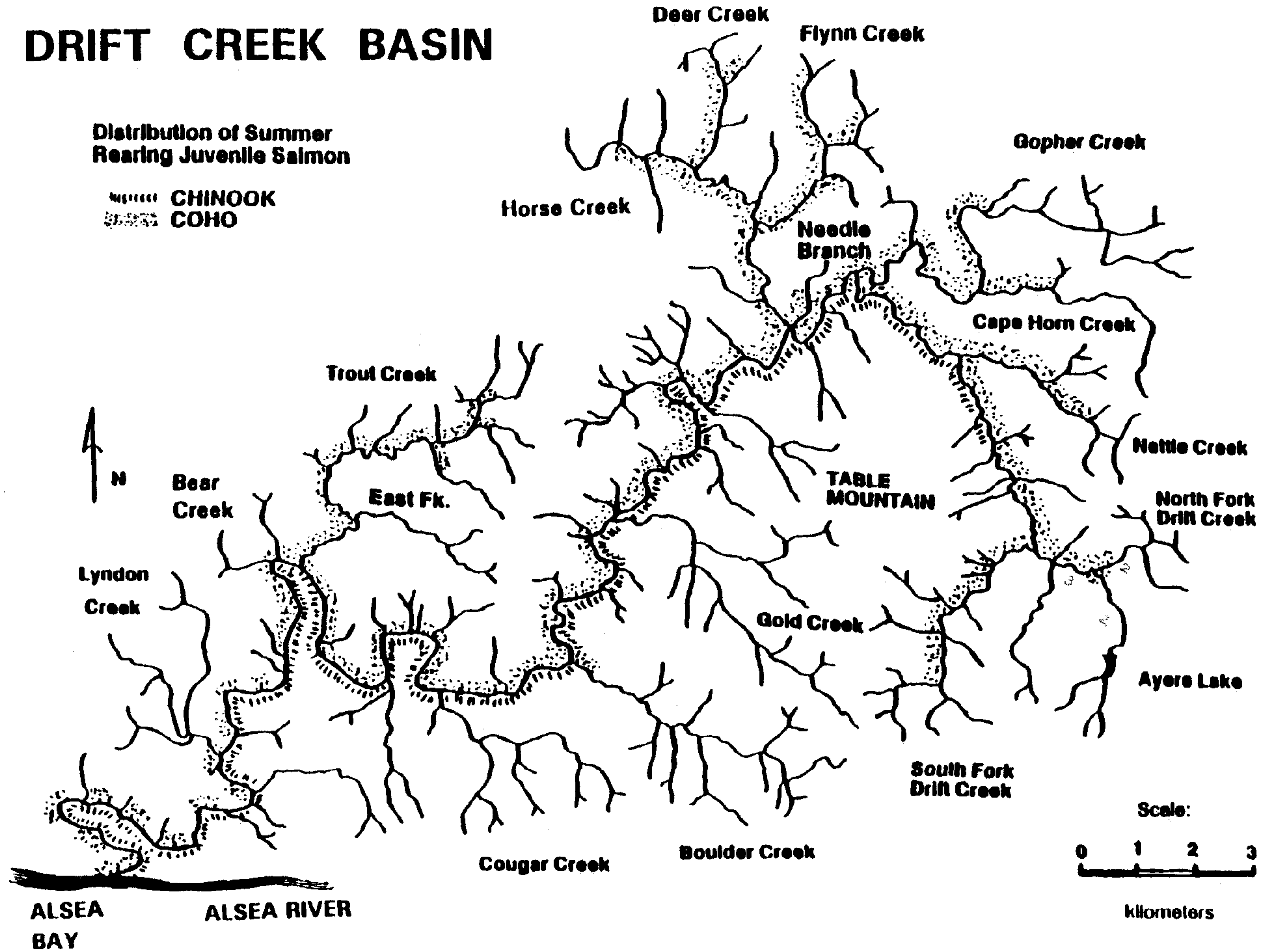


Figure 2. General distribution of summer-rearing juvenile salmon in the Drift Creek basin.

CHAPTER II: GEOMORPHOLOGY OF THE DRIFT CREEK BASIN, AND DISTRIBUTION AND ABUNDANCE OF SALMONIDS: A BASIN PERSPECTIVE

INTRODUCTION

Streams differ in morphology, and salmonid communities vary in composition and abundance within a watershed. Physical and biological characteristics of a stream change together as a continuum from headwaters to estuary (Vannote et al. 1980). Interactions between landscape features, riparian vegetation, and stream shift along this continuum. A drainage network can be examined as increments of the whole; each increment along the continuum has a functional relationship to its upstream and downstream increments. Scale of the increment largely determines the degree of variability observed in geomorphic parameters and salmonid and abundance, generally the smaller the scale, the greater the relative variability. Effects of scale are fundamental to understanding geomorphic processes and ecosystem relationships, in addition to interpreting disturbances from land-use practices.

Geomorphology of streams has been studied at various scales that range from pool-riffle sequences at a channel unit scale to landscape-valley relationships at a broad, watershed scale. Hydraulic geometry and sediment transport processes are important determinants of channel morphology (Leopold and Maddock 1953). Shape and longitudinal patterns of stream channels are determined by the simultaneous adjustment of discharge, sediment load, width, depth velocity, slope, and channel roughness (Leopold and Maddock 1953, Leopold and Wolman 1957). Sediment transport processes include erosion, deposition, and entrainment (Jackson and Beschta 1982, Ritter 1986, Whittaker 1987). In low-gradient streams, spatial patterns at the channel unit scale are recognized by pool-riffle sequences. Spacing and origin of pools and riffles are determined by sediment transport processes and bedform material. Bedrock outcrops and large instream material locally control channel morphology, and fluvial processes are involved in rhythmic formation of pool and riffles under all bedform conditions (Yang 1971, Keller and Melhorn 1978, Ashley et al. 1988). In high-gradient streams, deposition of large material from hillslopes, primarily large boulders and logs impose long-term imprints on channel morphology that often leads to development of step-pool profiles (Heede 1972, Keller and Swanson 1979, Richards 1982). Spatial patterns of channel units in high gradient streams (> 2% slope) are composed of pool-riffle-rapid sequences, and pool-cascade sequences (Grant et al. 1990).

Valley floor-stream channel relationships operate at a broader, reach scale. Magnitude and frequency of flood events provide a framework to understand valley and channel forming events in low-gradient streams (Wolman and Leopold 1957, Wolman and Miller 1960, Schumm 1973, Richards 1982, Ritter 1986). Overbank discharges onto a floodplain shape the valley floor, whereas bankfull discharges have the greatest potential to mold channel structure. Extreme flooding events can change longitudinal profiles, channel widths, and bed-material conditions (Lisle 1982, Coats et al. 1985). Valley floor landforms, and channel morphology have been linked to hillslope characteristics and geomorphic processes in high-gradient streams (Sullivan et al. 1985, Grant 1989, Hurley 1990). Constrained valley floors occur adjacent to landslides/earthflows, alluvial fans, exogenous bedrock (shifts in geologic stratigraphy resistant to erosion), or terminus of ridgelines. Constrained valley floors have a greater abundance of pool-cascade sequences of channel units, and unconstrained valley floors have more pool-riffles-rapids sequences of channel units (Grant et al. 1990). Characteristics of bedform material are related to channel unit morphology; fast-water units such as rapids and cascades contain more cobble and boulders.

Relationships between landscapes and valley landforms occur at broad scales that require a regional geologic analysis. Few studies have described these relationships. One study in north-coastal California by Kelsey (1988) related tectonic uplift to the formation of inner gorge landforms; basin geomorphic features (i.e., bedform parent material, sideslope gradients, and stream power) determined longitudinal location of inner gorges within the basin. An abrupt break in longitudinal profile from high-gradient to low-gradient stream (at approximately 2% slope) is a functional boundary at this scale.

Recognition of stream habitat as components of geomorphic features provides a functional view of salmonid ecology based on processes of geomorphology. This advocates a habitat-centered view of stream ecosystems which assumes that physical habitat determines the structure and dynamics of biological systems (Southwood 1977, Vannote et al. 1980). Habitat characteristics influence biological factors of behavior, food abundance, diet, and predation (Chapman 1966, Allen 1969, Chapman and Bjornn 1969, McFadden 1969, Mundie 1969, Hall and Knight 1981). Morphologic features of streams are functional components of habitat for the survival and productivity of salmonids (Beschta and Platts 1986). Several classification schemes based on various spatial scales of geomorphology have been developed to distinguish patterns in physical and biological systems that are highly variable (Platts 1974, Bisson et al. 1982, Lotspeich and Platts 1982, Rosgen 1985, Frissell and Liss 1986, McCullough 1988, Cupp 1989a). Spatial patterns in habitat use (as it relates to geomorphic scales) have been described mostly between pools and riffles and among microhabitat features within these channel units. Recent studies have begun to examine patterns of habitat use at broader scales of basin morphology.

Microhabitat features (i.e., substrate, current velocity, depths, and cover) provide boundaries for salmonids to partition pools and riffles. Within pools, cover and current velocity were found to account for at least 70% of the spatial variation in trout (age 1+) abundance during the summer in a Montana stream (Lewis 1969). In two Idaho streams, juvenile steelhead trout (*Oncorhynchus mykiss*) in sympatry with juvenile chinook (*Oncorhynchus tshawytscha*) were associated with rubble/boulder substrate (Everest and Chapman 1972). Abundance of cutthroat trout fry (*Oncorhynchus clarki*) was related to quality of lateral habitats (i.e., margins, backwaters, and side channels) in a Cascade Mountain stream (Moore and Gregory 1988). Microhabitat features describe channel complexity and are correlated to fish community diversity (Gorman and Karr 1978). In Pacific Northwest streams, much of channel complexity is due to large woody debris (Bisson et al. 1987).

Spatial patterns of salmonid habitat use between pools and riffles are the most distinct, and have been extensively researched in studies on habitat segregation through interspecific interactions. Sympatric populations of salmonids coexist through habitat segregation that result from interspecific behavioral aggression, innate habitat preference, size relationships from differences in emergence timing, and body morphology (Hartman 1965, Fraser 1969, Allee 1974, Glova 1978, Hearn 1987, Bisson et al. 1988). Juvenile coho salmon (*Oncorhynchus kisutch*) and steelhead trout coexisting in three British Columbia basins segregated at the channel unit scale, with juvenile coho primarily utilizing pools and trout (age 0+) mainly utilizing riffles during summer-rearing periods (Hartman 1965). Similar patterns of habitat use were observed between sympatric populations of juvenile coho salmon and cutthroat trout, in which juvenile coho occupy pools and cutthroat trout fry occupy riffles (Glova 1978). Juvenile chinook salmon and steelhead trout segregated at the channel unit scale as a result of size and timing of emergence; trout (age 0+) occupied shallower, faster-velocity riffle habitat, and juvenile chinook salmon occupied deeper, slower-velocity pool habitat (Everest and Chapman 1972). Habitat use at the channel unit scale between juvenile coho and chinook salmon was related to size differences from timing of emergence in British Columbia streams (Lister and Genoe 1970). Juvenile chinook were larger in size because of earlier emergence and were able to occupy channel units of higher velocity than juvenile coho. These two salmon species in an Oregon stream did not segregate by habitat when timing of emergence overlapped and fish sizes were similar (Stein et al. 1972). Allopatric populations of cutthroat trout occupied different habitat based on age class; older trout used pools and fry used fast-water habitat or margins of pools (Glova 1978, Moore and Gregory 1990).

Distribution and abundance of salmonids at broader spatial scales have been associated with valley floor characteristics and landform types. These habitat scales are not well defined; they vary from 100 meters to several kilometers, and differ in criteria used to distinguish boundaries. In an Oregon Cascades stream, abundance of resident cutthroat trout was greater in unconstrained valleys than in constrained valleys (valley floor width > 2 active channel widths); unconstrained reaches were composed of pool-riffle sequences lacking cascades (Moore and Gregory 1990). In five western Oregon streams, stream types classified by valley and channel characteristics were associated with species composition; general trends included: steelhead trout (age 1+) dominated high-gradient sections, and juvenile coho and trout (age 0+) dominated low-gradient sections (Reeves and Everest in press). Salmonid densities (by total and individual species/age classes) varied greatly between different stream types. In an Idaho drainage basin, salmonid distribution and abundance were associated with landform types, with most fish occurring in depositional U-shaped glacial troughs, and dissected mountain landforms with incised stream channels (Platts 1974). Geomorphic parameters used in this analysis included stream order, elevation, gradient, average widths, and average depths. Composition of salmonid species and total abundance of salmonids were greater in streams of larger stream order (Platts 1979). Juvenile chinook, rainbow trout (*Oncorhynchus mykiss*), and sculpins (*Cottus* ssp.) followed this trend, but cutthroat trout and Dolly Varden (*Salvelinus malma*) exhibited opposite patterns of distribution and abundance. Pattens of physical habitat and salmonid distribution and abundance were correlated by landform types in a large southwestern Washington drainage; abundances (linear and areal densities) of resident salmonids were greatest in low-elevation, low-gradient segments with alluvium (Cupp 1989b).

Salmonid distribution and abundance have been correlated with geomorphic parameters of watersheds. In southwestern British Columbia, distributions of juvenile steelhead trout and cutthroat trout differed between small and large basins (Hartman and Gill 1968). Juvenile steelhead trout occupied the larger basins (> 130 km^2), and cutthroat trout occupied the smaller basins (< 13 km^2). Where both species occupied the same watershed, cutthroat trout were found in small tributaries and headwaters, and juvenile steelhead were found in the mainstem. In Rocky Mountain streams, small, gently sloping watersheds contained the greatest abundances of trout (Lanka et al. 1987). Physiographic parameters for basins (i.e., latitude, size, gradient, elevation, and aspect) were associated with fish distributions in British Columbia (Harding 1982) and basin production of salmon in southeast Alaska (Swanston et al. 1977).

In this study, a hierarchical organization of basin morphology was used as a means to link basin patterns of stream habitat and salmonid distribution and abundance. A hierarchy of basin morphology has been described by the following scales: segment, reach, channel unit, and channel sub-unit, as shown in Figure 3 (Frissell et al. 1986, Gregory et al. in press). This hierarchical arrangement of spatial scales were based on temporal scales of geomorphic development (Table 1). Since the broader scales of basin geomorphology were not well defined, the task of this study was two-fold. Before patterns of salmonid habitat use could be examined at the different hierarchical scales, a pragmatic approach was needed to define boundaries of segments and reaches.

Table 1. Hierarchical scales and constraints on stability of channel features; adapted from Gregory et al. (in press).

Hierarchical Feature	Spatial Dimensions (channel widths)	Time Scale of Stability (years)	Constraint on Stability and Surface Boundary
Network	10^5+	10^6+	Watershed geology
Segment	$10^3 - 10^4$	$10^4 - 10^5$	Valley corridor geology
Reach	$10^2 - 10^3$	$10^3 - 10^4$	Valley floor and channel aggradation, and degradation
Channel unit	$10^0 - 10^1$	$10^1 - 10^2$	Channel hydraulics and roughness elements
Channel sub-unit	10^{-1}	10^0	Channel hydraulics, sheer stress, and roughness elements

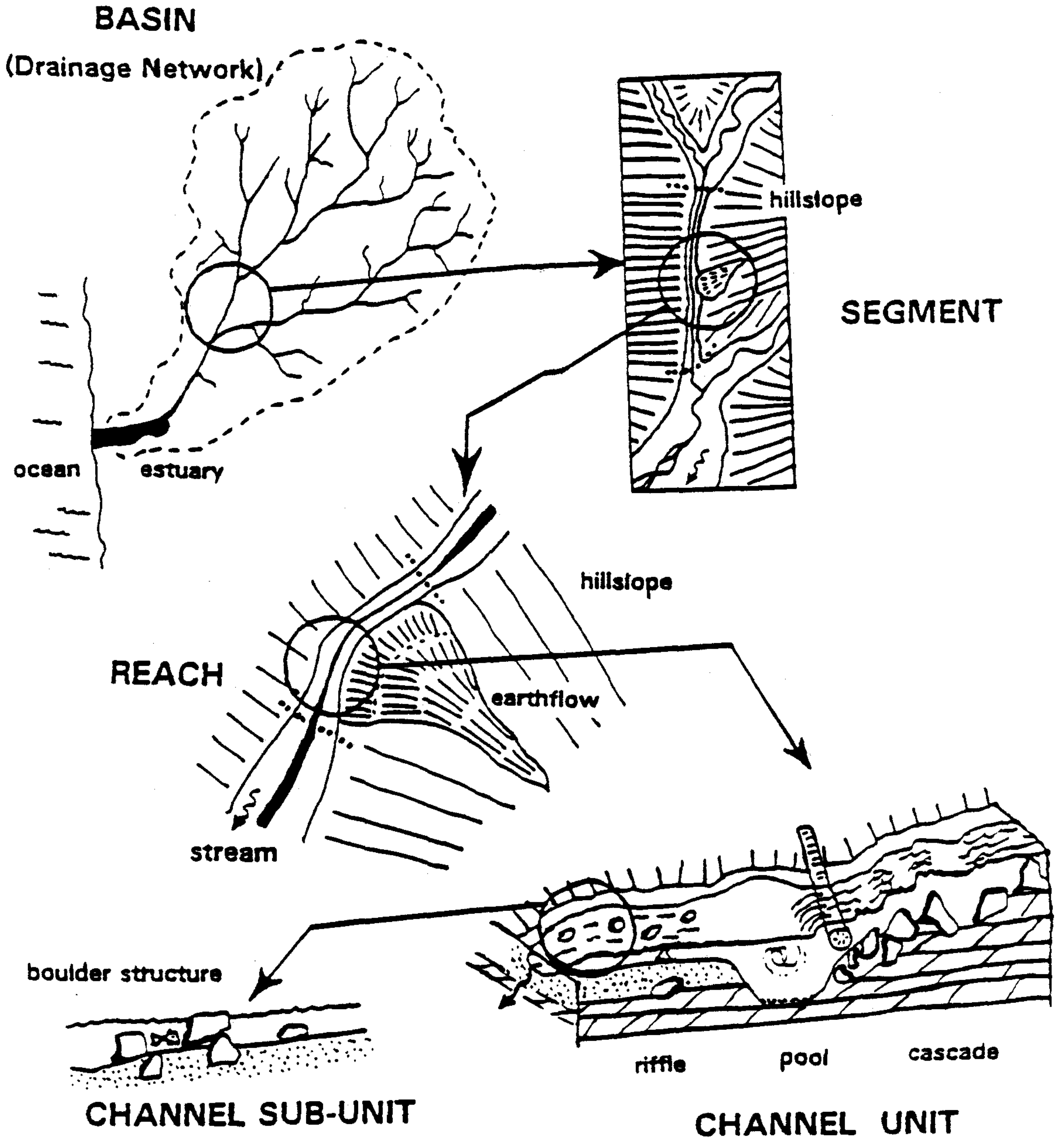


Figure 3. Hierarchical scales of basin morphology.

The objectives of this study were to 1) investigate geomorphic parameters that define segment and reach boundaries in the Drift Creek basin, 2) examine the physical characteristics of segments, reaches, and channel units, and 3) relate patterns of salmonid distribution and abundance (summer-rearing populations) to these hierarchical patterns of basin morphology. A basin perspective provided the opportunity to examine broad patterns of salmonid habitat use related to landscape features.

METHODS

Geomorphic features in the Drift Creek basin were hierarchically organized into segments, reaches, and channel units. Segment and reach boundary designations in the hierarchy of basin morphology were determined by quantitative measurement of geomorphic parameters. Physical characteristics of channel units were measured in field studies. The significance of tributary junctions on salmonid abundance were examined at the reach scale.

Surveys for geomorphic parameters and salmonid abundance were conducted in the Drift Creek basin during July 1988 and 1989. In 1988, the continuous basin survey extended to Bohannon Ranch Falls; and in 1989, the survey extended beyond Bohannon Ranch Falls on the mainstem to the anadromous fish limit in South Fork Drift Creek (Fig. 4). Comparison of geomorphology and patterns in salmonid distribution and abundance were based on 1989 field data because that survey extended continuously into the headwaters.

Map standard distances were defined to calibrate survey data between years and interpretative data from United States Geological Survey (USGS) topographic maps (Table A.1). Boundaries for map standard distances were chosen at major tributary junctions, the stream gauge, and Bohannon Ranch Falls. Distances were determined by digitizing lengths (an average of three measurements) from USGS topographic maps, 1:24000 scale.

Longitudinal profiles along Drift Creek and through South Fork Drift Creek were based on calibrated cumulative distances of stream, starting at the confluence of Lyndon Creek. Field surveys begin at a point on Drift Creek 6.52 km above Lyndon Creek and extend 32.2 km upstream to the headwaters of South Fork Drift Creek (Fig. 4).

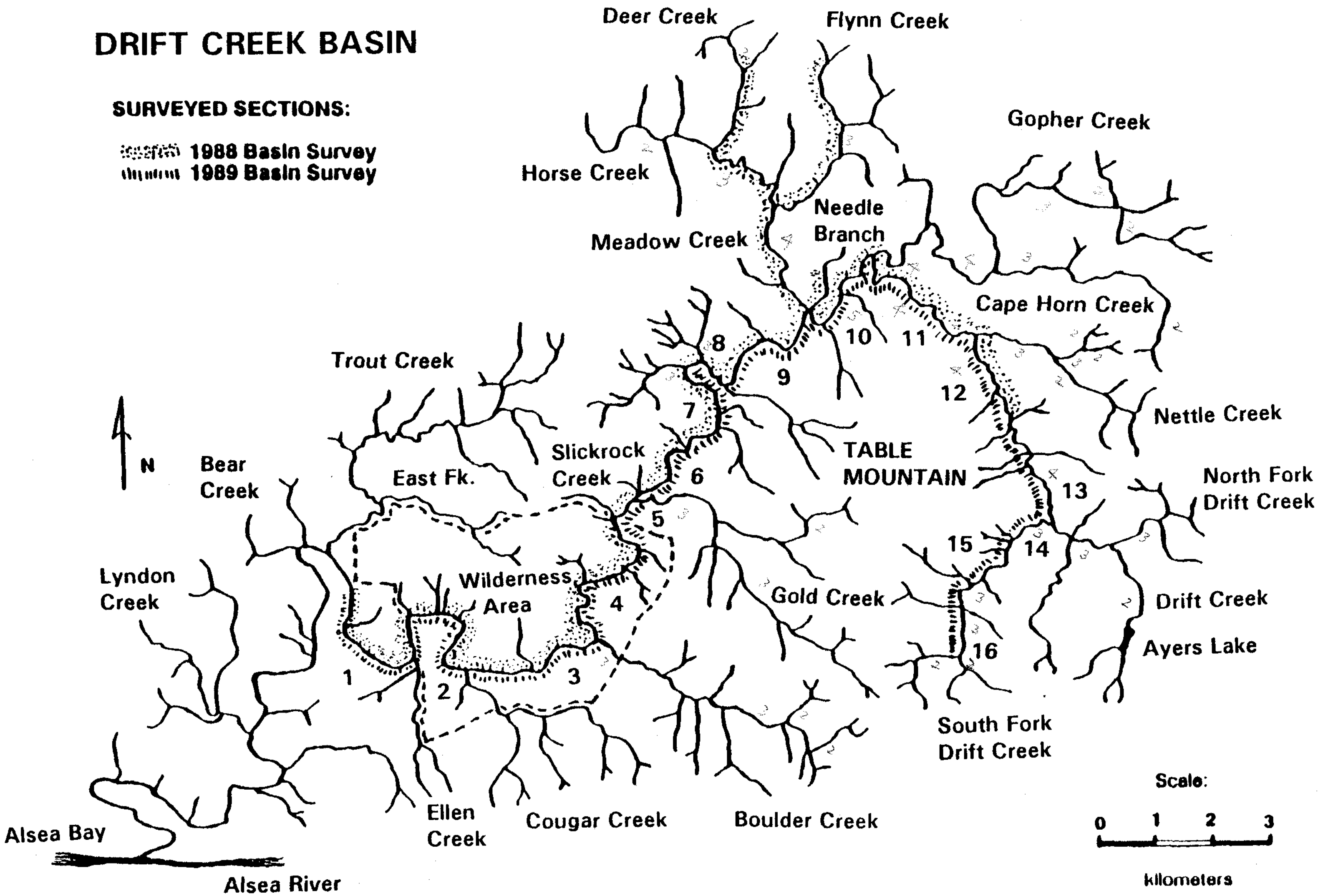


Figure 4. Drift Creek basin map showing extent of 1988 and 1989 surveys and reach designations.

Geomorphic Analysis

Segments

Segment boundaries were defined by use of valley floor width index (VFWI). Segment boundaries selected by the VFWI were associated with longitudinal stream profile, Hack stream-gradient analysis, and stream power index. Segments were also recognized by interpretation of the area's geologic map.

VFWI is the ratio of valley floor width to active channel width. Valley floor widths along mainstem Drift Creek and South Fork Drift Creek were located and measured from aerial photos (1:18000 scale, July 1988). Geomorphic surfaces were traced over USGS topographic maps, 1:24000 scale. This plan view map of geomorphic surfaces was digitized for valley floor width and stream distance from Lyndon Creek. Channel width was an average (over a 0.5-km distance) derived from 1989 field estimates.

Longitudinal stream profile was drawn from field surveys of gradient, measured at each channel unit in sequence. Gradient was measured by two methods: 1) measuring the rise with a hand level and stadia rod, and measuring distance with a rangefinder, and 2) estimating percent slope with a hand-held clinometer. Cumulative rise was computed at each channel unit boundary and standardized vertically to USGS topographic map elevations (1:24000 scale). In 1988, gradient was measured from the survey start in the lower basin to Bohannon Ranch Falls; in 1989, gradient was measured from Bohannon Ranch Falls to the anadromous fish limit in South Fork Drift Creek.

Hack stream-gradient analysis is a landscape analysis of stream profile (Hack 1973). A basin logarithmic plot of longitudinal stream profile that is perfectly concave will produce a simple straight line. Stream sections that are steep relative to the logarithmic curve will have higher Hack-index values. Hack stream-gradient indices were computed from the equation $k = (H_1 - H_2)/(\log_e L_2 - \log_e L_1)$ defined by Hack (1973). Elevations at each section boundary were reported as H_1 and H_2, where H_1 was the boundary farthest upstream. Distances from the headwaters at each section boundary were L_1 and L_2. Elevations and distances digitized from topographic maps were used in the analysis. Section boundaries were determined by contour intervals and tributary junctions.

Stream power indices link basin hydrology with pattern of drainage. Stream power per unit width (W) is defined in Ritter (1986) by the equation $W = p\ Q\ S/w$, where p is specific gravity of water, Q is discharge, S is percent slope for a given reach, and w is average active channel width (meters). Stream power indices (P) were computed by the equation $P = c\ S\ D/w$, where D is cumulative drainage area (km^2) at the end of a given reach, and c is a constant used as a multiplier. This equation for stream power index assumes a linear relationship between Q and D. For the same stream sections as in the Hack stream-gradient analysis, slopes and drainage areas were derived from USGS topographic maps, 1:24000 scale. Channel widths at section boundaries were an average (over a 0.5-km distance) derived from 1989 field estimates.

Reaches

Reach boundaries were defined by longitudinal stream profile, Hack stream-gradient index, stream power index, geomorphic surfaces, and active channel width. For descriptive purposes, other channel characteristics (multiple channels, large roughness elements, dominant substrate type, percent bedrock exposure by area, spawning gravels by area, and pool-forming elements) were summed for designated reaches.

Geomorphic surfaces included active floodplains and older terraces. Floodplains were operationally defined as geomorphic surfaces less than 1.5 m above the active channel, and terraces were defined as surfaces greater than 1.5 m above the active channel. Heights to geomorphic surfaces were estimated visually from left and right stream banks at each channel unit.

Multiple channels were reported by lengths and percent total flow of each channel (during the 1989 survey). In a reach with multiple channels, a secondary channel was the smaller channel that contained greater than 5% of the total stream flow. Channels that contains less than 5% of the total flow were categorized as side channels. In this geomorphic analysis, multiple channel lengths included lengths of both secondary channels and side channels.

Large roughness elements included boulders and coarse woody debris (CWD). Boulders in two categories were counted at each channel unit. The categories were small boulders, 0.5 - 2.0 m in diameter, and large boulders, greater than 2.0 m in diameter. Length and end diameters of each piece of CWD were estimated at each channel unit. Minimum size limits for each CWD piece were 2 m in length and 0.15 m in diameter. Four major zones of hydrologic influence were estimated each CWD piece by percent (Robison and Beschta 1990). Zone 1 was the area in the wetted (summer low-flow) channel, zone 2 was the area in the active channel at bankfull discharge, zone 3 was the area directly above the active channel, and zone 4 was the area adjacent to the active channel at bankfull discharge on either bank. Volumes were computed by assuming logs as cylinders. Volumes were expressed per channel length (which used map standard distances) and per channel area (from field data).

Dominant substrate type was recorded at each channel unit during the field surveys. Though more than one substrate type occurs in any channel unit, only the dominant type was recorded. Substrate categories included wood, clay, silt, sand, small gravel (2 - 10 mm), large gravel (10 - 100 mm), cobble (101 - 300 mm), boulder (> 300 mm), and bedrock.

Pool-forming element was recorded for each pool (channel unit type) during the 1989 survey. Forming agents included bedrock, boulders, large woody debris, root wads, stream curvature, and beaver dams. Where two or more elements interact to create a pool, only the dominant element acting during high-flow discharge was recorded.

Channel Units

During field surveys, channel units were classified in sequence and estimated for dimensions. Channel units were classified as either a pool, a glide, a riffle, a rapid, a cascade, a step, or a side channel. Physical and hydraulic characteristics of these channel units (except side channels) are described in Table 2. Physical measurements of length, width, mean depth were visually estimated for each unit (summer low-flow). Maximum depth was measured with a meter stick as the deepest point in the unit. In addition, active channel widths were visually estimated from high-flow bank markings (bankfull discharge).

Visual estimates of channel dimensions were calibrated with correction factors derived from a sub-set of direct channel measurements (Hankin and Reeves 1988). Measured channel units were randomly selected by a stratified sampling technique based on frequency of occurrence of each type within a defined section of stream (Hankin 1984). Frequencies used in 1988 and 1989 basin surveys are reported in Table A.2. Channel units were measured with a

Table 2. Channel unit descriptions based on physical and hydraulic characteristics at summer low-flow (from G. E. Grant, U.S. Forest Service, PNW Forest Research Laboratory, Corvallis).

CRITERIA	Pools	Glides	Riffles	Rapids	Cascades	Step
FLOW STRUCTURE	slow, tranquil	fast, tranquil	fast, turbulent	fast, turbulent, some hydraulic jumps	very fast, turbulent with many hydraulic jumps	similar to fast water units
SURFACE % IN SUPERCRITICAL FLOW	0 - 5	0 - 5	5 - 15	15 - 50	> 50	> 50
DEPTH OF FLOW	deep	slightly deep	shallow	shallow	deep and shallow	shallow
BED PARTICLES EXPOSED AT LOW FLOW	few, only largest	few, only largest	some	many	many	many
PARTICLES ARRANGED AS STEPS ?	no	no	no	yes	yes	some-times
CHANNEL UNIT LENGTH	> 1 channel width	> 1 channel width	> 1 channel width	> 1 channel width	> 1 channel width	< 1 channel width; represents break in profile

100-m fiberglass tape and a meter stick. Mean depths were computed from an average of 6 to 12 depth measurements, taken where sets of three measurements across the channel.

Salmonid Distribution and Abundance

Salmonid abundance estimates were made for juvenile chinook salmon, juvenile coho salmon, trout (age 0+), steelhead trout (age 1+), and cutthroat trout (age 1+). Trout (age 0+) included all trout below 80-mm fork length, which were either steelhead or cutthroat underyearlings. Steelhead trout (age 1+) included both juvenile steelhead and rainbow trout that were above 80-mm fork length. The trout (age 1+) group included all trout above 80-mm fork length (juvenile steelhead, rainbow trout, and cutthroat trout).

Sampling for salmonid abundance was stratified by channel unit type; a proportion of each type of channel unit was estimated for salmonid numbers (Hankin and Reeves 1988). In 1988 and 1989, numbers of salmonids were estimated by divers within designated channel units. Channel units to be dived were determined by frequencies of habitat types that were established prior to the surveys (Table A.2). In lower mainstem Drift Creek, four divers counted salmonids in parallel across the stream; as stream width decreased, fewer divers were used for fish estimates. Salmonid numbers were estimated only by diver counts and were not verified by electrofishing. This deviates from methods outlined in Hankin and Reeves (1988). Differences in snorkeling efficiency can occur between different size streams, habitat types, and salmonid species. This analysis assumed equal efficiency between the different stream sections, thus estimates of abundance were a relative measure between stream sections.

Salmonid Abundance by Hierarchical Scales

Patterns of salmonid distribution and abundance were examined at different hierarchical scales (basin, segments, reaches, and channel units). For basin patterns, continuous profiles were drawn for salmonid numbers, linear densities, and areal densities of channel units. For segments and reaches, estimates of abundance were computed from the stratified sample proportions by channel unit type. Computation techniques and statistical explanations to this estimation method are described in Hankin and Reeves (1988). Estimates for each segment and reach were converted to linear densities.

Habitat Electivity at Channel Units

Habitat electivity compares patterns of channel unit use by each species/age group with channel unit availability. Electivity of salmonids for channel unit type was computed using an algorithm developed by Ivlev (Lechowicz 1982). Electivity values were computed by $E_i = (r_i - p_i)/(r_i + p_i)$, where p_i was the percent channel unit composition for reach i and r_i was the percent fish composition for reach i. Electivity values of 0.00 indicated that fish were distributed in proportion to the channel units available; values of -1.00 indicated the species/age groups were not present.

Salmonid Abundance at Tributary Junctions

During the 1989 basin survey, channel units were intensively sampled for salmonids at major tributary junctions. All channel units within 100 m upstream and downstream of a tributary junction were dived for visual estimates. Salmonid areal densities (fish per m^2) were used in the upstream and downstream comparisons.

RESULTS

Geomorphic Analysis

Segments

In Drift Creek, longitudinal analysis of VFWI showed four distinct segments (Fig. 5). A wide valley in alluvium extending up to Cougar Creek was named the lower segment. A narrow valley with steep sideslopes extending from the Cougar Creek confluence to a point approximately 3 km above the Gold Creek confluence was named the mid-lower basin segment. A wide valley extending up to Bohannon Ranch Falls was named the mid-upper segment. The remaining headwaters of the basin (through South Fork Drift Creek) was named the upper segment. In this headwater stream, overall valley floor width was narrow (< 15 m) and VFWI were moderate and quite variable (Fig. 5). Segments with narrow valleys had steep sideslopes, and segments with wide valleys had moderate-gradient sideslopes as illustrated by valley cross-sections in Figure A.1.

The four segments were associated with geologic features in Drift Creek basin (Fig. 6). Principal Cenzoic events for the Oregon Coast Range are summarized in Table A.3. The lower segment was influenced by the Pleistocene period rising and lowering of the ocean. A Pleistocene river terrace, located just below the confluence of Cougar Creek, provided evidence that marine influences extended up to and possibly beyond the Cougar Creek confluence (Fig. 6). Wide valley deposits of alluvium were located in this lower segment. The mid-lower segment resembled an inner gorge as defined by Kelsey (1988), a landscape feature often created by bedrock uplift and downcutting through a relatively competent, homogeneous parent rock. This segment lies within an

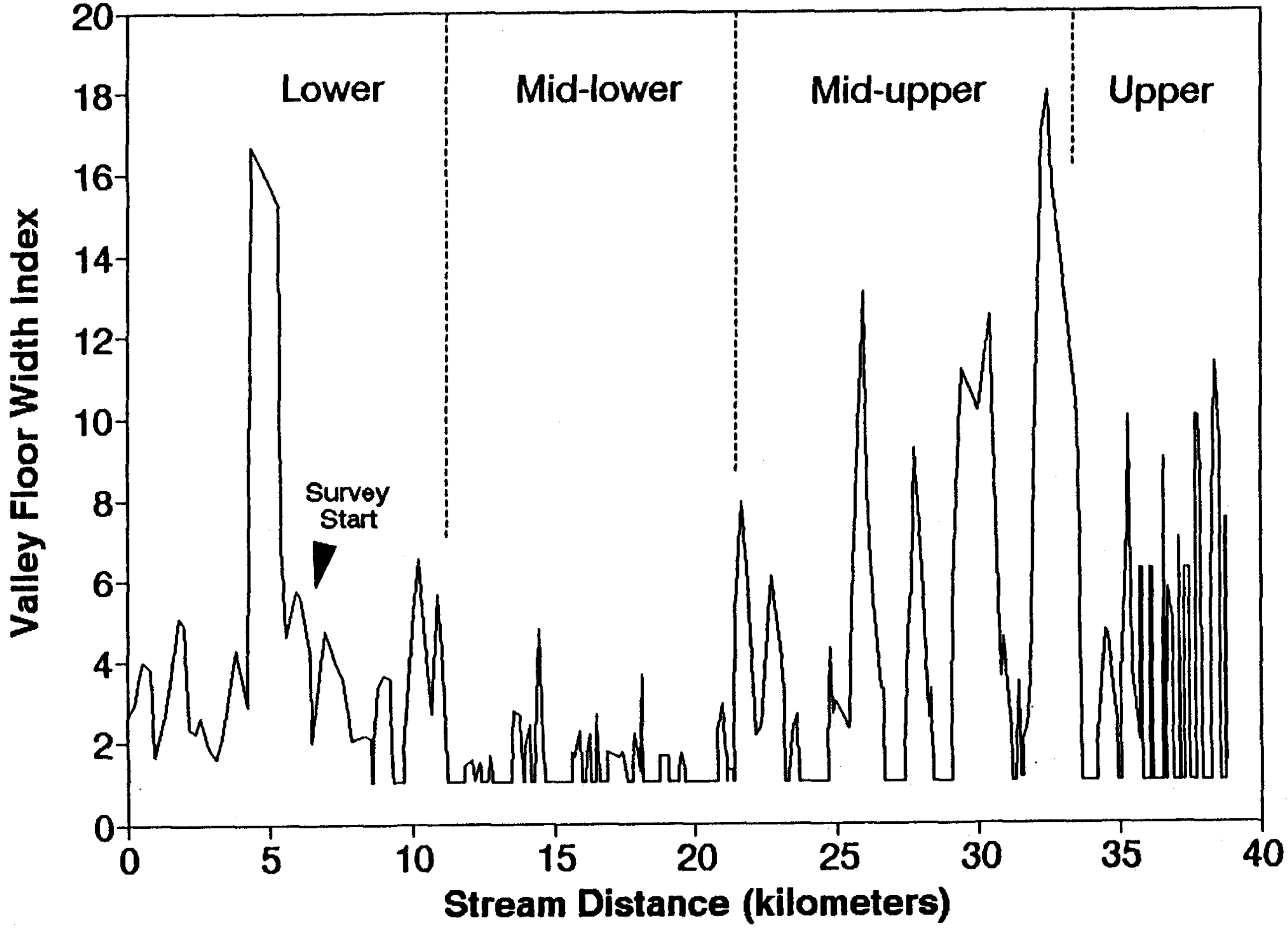


Figure 5. Longitudinal profile of valley floor width indices (VFWI) along Drift Creek. Field surveys start at 6.53 km upstream from the confluence of Lyndon Creek.

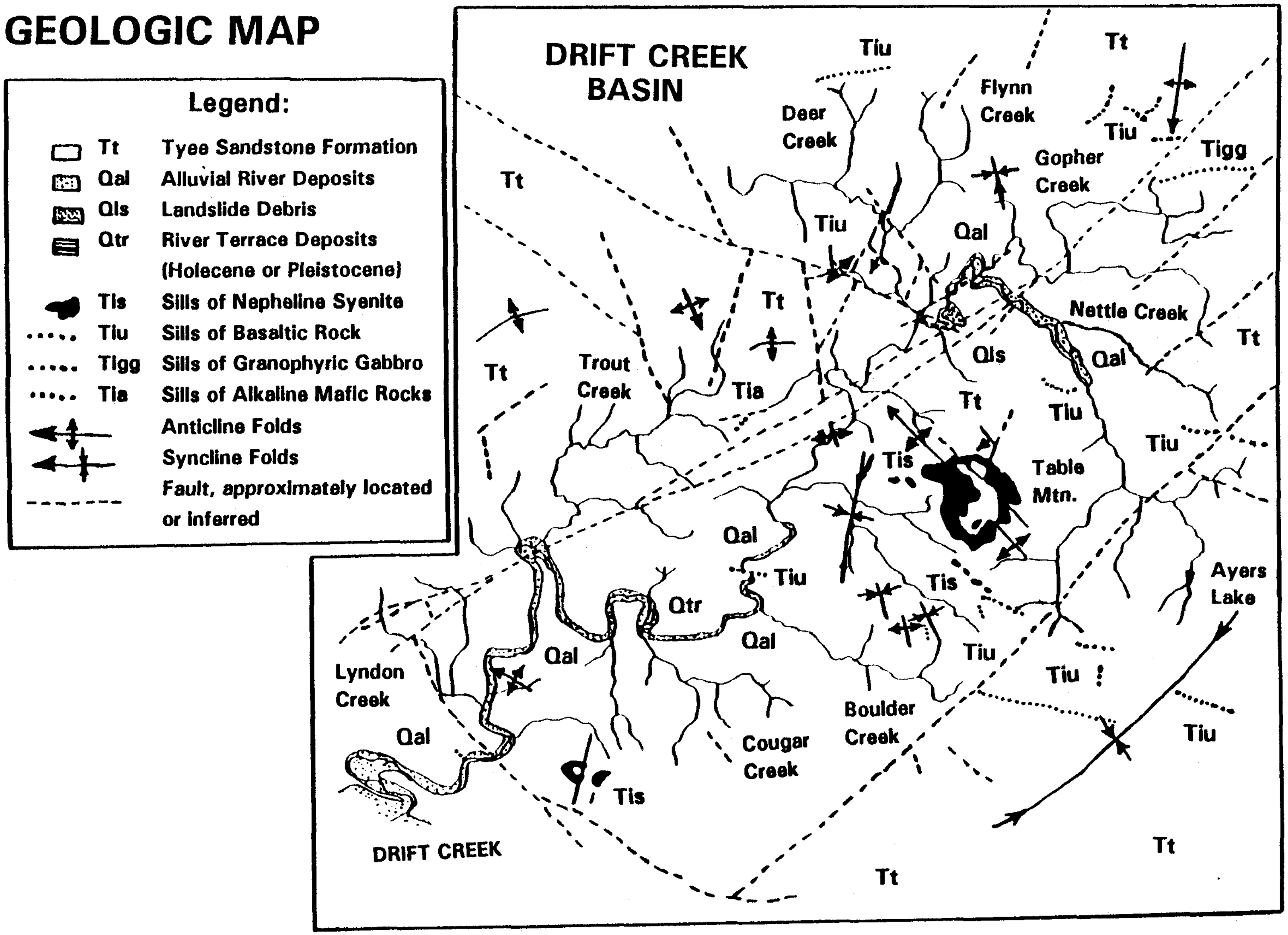


Figure 6. Geologic map of Drift Creek basin (based on map by Snavely et al. 1976).

area of competent bedrock as indicated by the lack of faulting (Fig. 6). Snavely et al. (1976) shows alluvial deposits extending up to Slickrock Creek within the mid-lower segment; but these deposits were not evident from field observations.

A change in lesser bedrock competence occurred at the boundary between the mid-lower and mid-upper segments. The mid-upper segment was observed as highly faulted (Fig. 6). The most complex faulting occurred near the junction of Meadow Creek with Drift Creek. Between Table Mountain tributary and Meadow Creek, the left valley had a gradual sideslope gradient corresponding to a large block fault in the sandstone (Figs. 6 and A.1). Within the mid-upper segment, a major landslide (Holocene age) along Drift Creek was located just above the confluence of Meadow Creek (Fig. 6). This major landslide dammed Drift Creek for a period of time, thus extensively deposited alluvium to create a wide valley floor that extends to Bohannon Ranch Falls. The falls marked the upper boundary to the mid-upper segment. The upper segment occupied the steep, uppermost headwaters portion of the basin, that lies in an area of competent bedrock (not highly faulted).

Delineation of segment boundaries in a landscape analysis required Hack stream-gradient or stream power indices to interpret longitudinal stream profile. A longitudinal stream profile of Drift Creek showed three major slope breaks, two of which were associated with segment boundaries (Fig. 7); the two major slope breaks occurred at Cougar Creek confluence and Bohannon Ranch Falls. Hack stream-gradient and stream power indices identified a higher gradient section of stream between Cougar and Gold Creeks (Figs. 8 and 9). The mid-lower segment mostly lied in this section of stream, which had valley characteristics of a gorge. The upper segment showed high variability in Hack stream-gradient indices and had higher stream power indices than compared to downstream

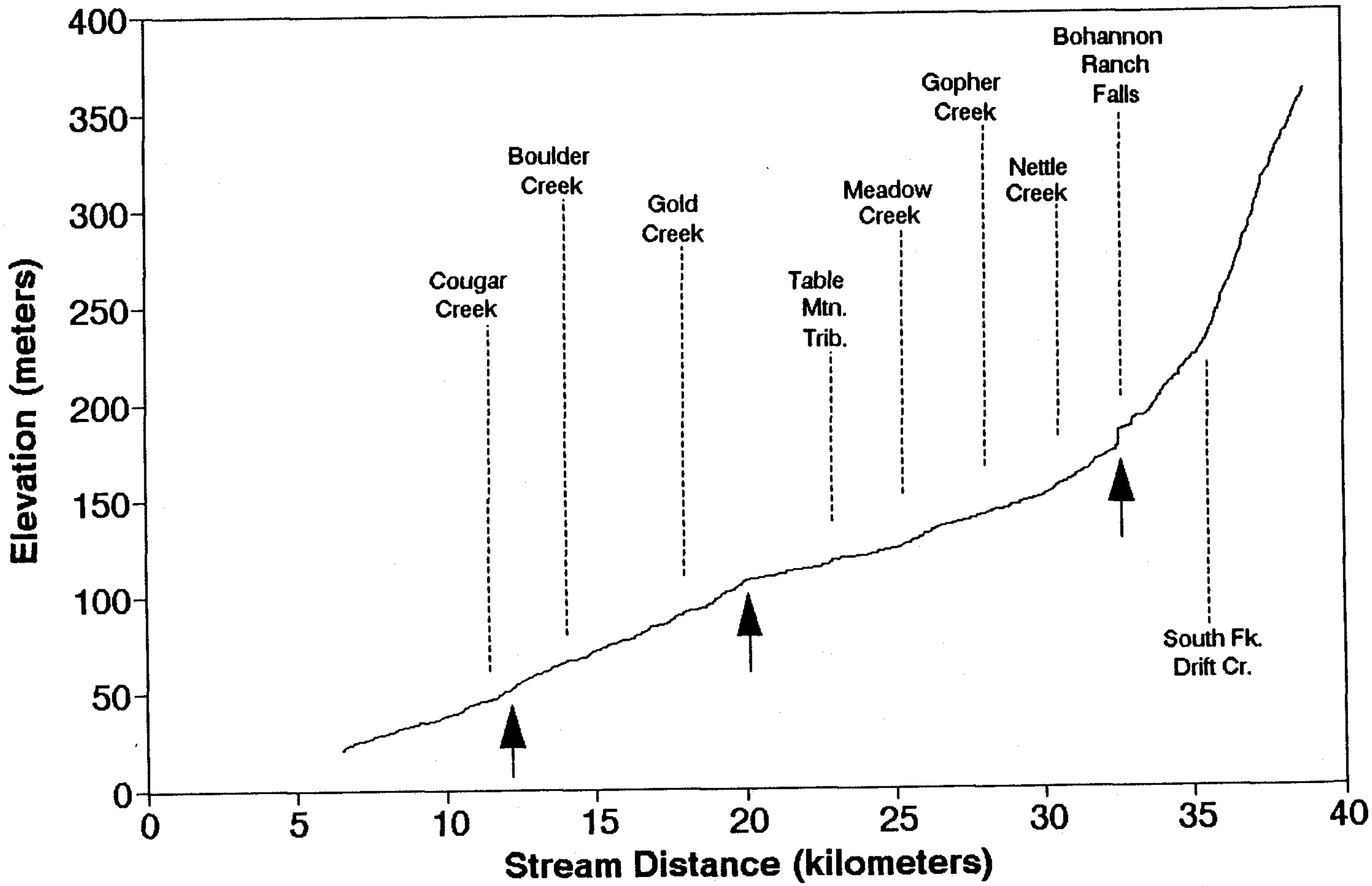


Figure 7. Longitudinal stream profile of Drift Creek; arrows indicate major slope breaks.

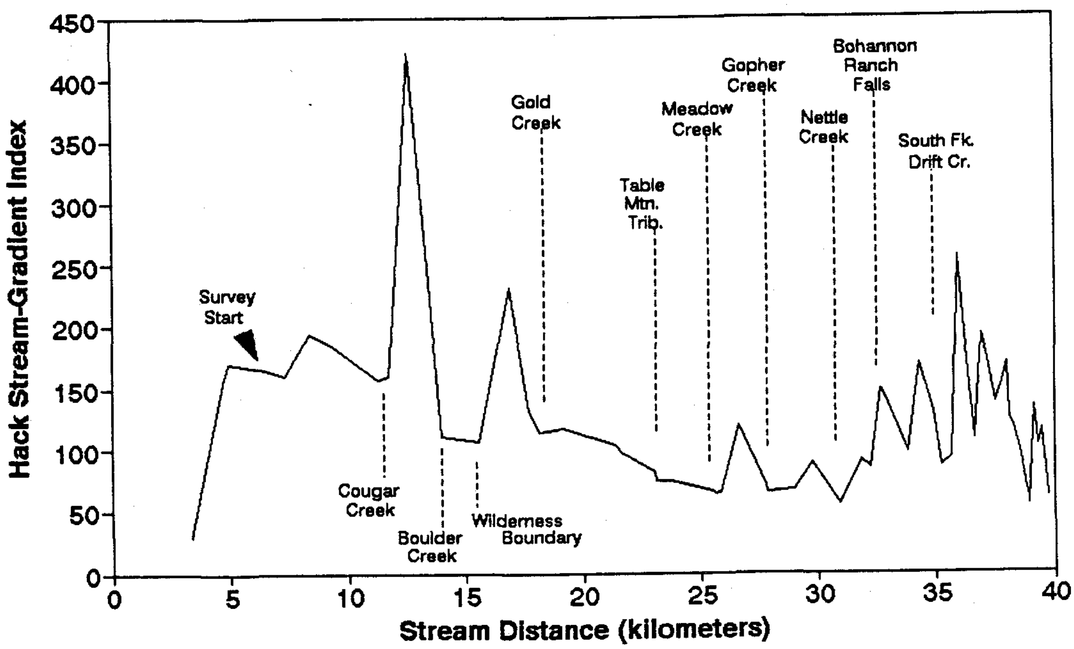


Figure 8. Longitudinal profile of Hack stream-gradient indices along Drift Creek.

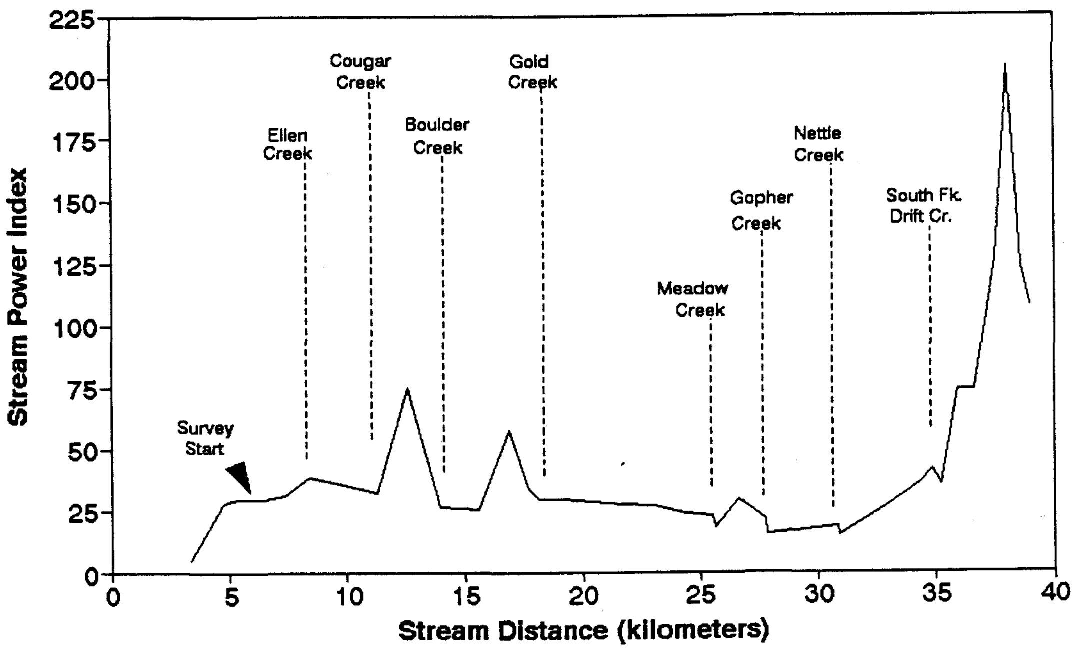


Figure 9. Longitudinal profile of stream power indices along Drift Creek.

segments.

Reaches

Reaches were distinguished by longitudinal stream profile, Hack stream-gradient indices, stream power indices, geomorphic surfaces, and active channel width (Table 1). Sixteen reaches were demarcated using various combinations of these geomorphic parameters (Table 3). Distinct breaks by all geomorphic parameters rarely occurred together. Active channel width appeared to identify reach boundaries more often. Boundary locations are reported in Table 4.

A longitudinal stream profile of Drift Creek basin delineated major shifts in gradient (Fig. 7). Major slope breaks along the mainstem occurred at: Cougar Creek, 1.7 kilometers above the Gold Creek confluence (Fish Camp), and Bohannon Ranch Falls. These major slope breaks, along with several other slope breaks were observed by shifts in Hack stream-gradient and stream power indices (Figs. 7 and 8). Reach boundaries selected by use of Hack stream-gradient and stream power indices coincided with shifts in geomorphic surface conditions and/or active channel widths (Table 3).

Gradients for the individual sixteen reaches reflected the shifts observed in longitudinal stream profile of the basin (Table 5). Higher gradient reaches in the mid-lower segment occurred from Cougar Creek to Fish Camp, with slopes ranging from 0.5% to 0.9%. Upstream of Fish Camp, gradient reduced to 0.3% and remained low in gradient to Meadow Creek (reaches 7, 8, and 9). Upstream of Meadow Creek, overall gradient was 0.6%; and after Nettle Creek, overall gradient was greater than 1%. Above Bohannon Ranch Falls, the gradient approached 2%. The three South Fork Drift Creek reaches (14, 15, and 16) had

Table 3. Basis for reach boundary designations along Drift Creek.

Reach Break	Reach Upper Boundary	Longitudinal Stream Profile	Gradient: Reach Summmary	Hack stream-gradient indices	Stream Power Indices	Geomorphic Surface Heights	Active Channel Widths
1 - 2	Ellen Creek			X		X	X
2 - 3	Cougar Creek	X	X	X	X	X	X
3 - 4	Boulder Creek			X	X		
4 - 5	Wilderness Boundary		X	X		X	X
5 - 6	Gold Creek			X	X	X	X
6 - 7	Fish Camp	X	X				
7 - 8	Stream Gauge					X	X
8 - 9	Table Mtn. Tributary			X		X	X
9 - 10	Meadow Creek		X	X	X		X
10 - 11	Gopher Creek			X	X	X	X
11 - 12	Nettle Creek		X	X	X	X	X
12 - 13	Bohannon Ranch Falls	X	X	X			X
13 - 14	South Fk. Drift Creek		X		X		X
14 - 15	South Fk. Drift Creek				X	X	X
15 - 16	South Fk. Drift Creek		X			X	X

Table 4. Segment and reach descriptions and their map standard stream lengths are in meters. Cumulative stream lengths begin at Lyndon Creek, 6520 meters below the survey start.

Segment	Reach Number	Reach Length	Reach Upper Boundary	Map Standard Cumulative Stream Length
			Survey Start	6520
Lower	1	1850	Ellen Creek	8370
Lower	2	2922	Cougar Creek	11292
Mid-lower	3	2702	Boulder Creek	13994
Mid-lower	4	1946	Wilderness Boundary	15940
Mid-lower	5	2353	Gold Creek	18293
Mid-lower	6	1724	Fish Camp	20017
Mid-lower	7	1399	Stream Gauge	21416
Mid-upper	8	1718	Table Mtn. Tributary	23134
Mid-upper	9	2407	Meadow Creek	25541
Mid-upper	10	2237	Gopher Creek	27777
Mid-upper	11	3045	Nettle Creek	30822
Mid-upper	12	1624	Bohannon Ranch Falls	32446
Upper	13	2818	South Fk. Drift Creek	35264
Upper	14	1503	South Fk. Drift Creek	36767
Upper	15	1330	South Fk. Drift Creek	38097
Upper	16	681	South Fk. Drift Creek Survey End (1989)	38778

Table 5. Stream channel characteristics by Drift Creek reaches.

Reach Upper Boundary	Reach Number	Percent Gradient	Avg. Active Channel Width (meters)	*Average A.C./Wetted Width Ratio	Secondary Channel (% by channel)	Channel Bedrock (% by area)
Ellen Creek	1	0.61	30.8	1.56	8.7	54.1
Cougar Creek	2	0.49	25.6	1.42	4.4	56.0
Boulder Creek	3	0.76	28.4	1.71	20.9	48.2
Wilderness Boundary	4	0.52	27.5	1.82	17.2	55.1
Gold Creek	5	0.65	24.3	2.04	17.8	20.5
Fish Camp	6	0.88	22.1	1.51	11.4	24.5
Stream Gauge	7	0.32	19.5	1.34	2.3	8.2
Table Mtn. Tributary	8	0.37	17.3	1.44	13.8	17.0
Meadow Creek	9	0.33	16.9	1.37	2.4	9.2
Gopher Creek	10	0.60	13.0	1.17	9.7	43.2
Nettle Creek	11	0.60	15.8	1.55	8.1	40.0
Bohannon Ranch Falls	12	1.01	13.6	1.55	2.3	39.0
South Fk. Drift Creek	13	1.82	12.7	1.72	5.5	32.3
South Fk. Drift Creek	14	3.96	10.6	2.59	24.3	7.2
South Fk. Drift Creek	15	3.99	5.3	2.16	12.0	0.8
South Fk. Drift Creek	16	3.20	4.0	2.14	10.7	0.0

* Average for the segment of the active channel width divided by the wetted channel width at each channel unit. The active channel width is the width at bankfull discharge, and wetted channel width is the width at summer low flow.

slopes greater than 3%.

Geomorphic surfaces (terraces and floodplains) were used to delineate reach boundaries by shifts in minimum heights of continuous surfaces (Table 6 and Fig. A.2). Ten of the sixteen reaches showed major shifts in conditions of geomorphic surfaces (Table 3). Characteristics and origin of geomorphic surfaces depended on the segment. Wide valley floors in the lower and mid-upper segments were composed primarily of alluvium. Incision of the channel occurred in three reaches (2, 10, and 12) within these alluvial valleys and formed high terraces. Reaches with incised channels had lower ratios of active channel to wetted (summer flow) channel widths compared to all other reaches; the incised channel of reach 10 had the lowest ratio of 1.17 (Table 5). Reach 11, located in a wide alluvial valley was the only reach in Drift Creek that had an unconstrained channel with floodplain development to any extent.

Abrupt shifts in active channel widths longitudinally demarcated most reaches (Table 3). These shifts in channel width coincided with shifts in geomorphic surface conditions that were longitudinally extensive (Figs. 10 and A.2). Reductions of active channel width occurred when the channel incised in alluvial deposits of wide valleys (Fig. 10). Also, widths reduced sharply when the channel was constrained by hillslopes. Two sub-reaches were constrained by valley walls in reaches 5 and 11 that were less than 600 m in length along the mainstem (Fig. 10). These sub-reaches were not broken out as reaches because of method limitations, reaches less than 600 m did not contain enough measured channel units to calibrate visual estimates.

Most multiple channels were high-flow (winter) secondary channels in Drift Creek. Multiple channels occurred to a greater extent (> 10% by length) in reaches within the mid-lower segment and in reach 14 of South Fork Drift Creek

Table 6. Characteristics of geomorphic surfaces along Drift Creek.

Reach Upper Boundary	Reach Number	Longitudinal Extent [1]	Left-Bank Minimum Heights [2]	Left-Bank Lateral Extent [3]	Right-Bank Minimum Heights [2]	Right-Bank Lateral Extent [3]	Incised Channel
Ellen Creek	1	C	1.5 - 3.0	L	1.5 - 2.0	L	
Cougar Creek	2	C	1.5 - 2.5	L	1.0 - 2.0	L	X
Boulder Creek	3	D	0.3 - 2.0	S	0.3 - 2.0	S	
Wilderness Boundary	4	D	0.3 - 1.5	S	0.5 - 1.0	S	
Gold Creek	5	D	0.0 - 1.0	S	0.2 - 1.0	S	
Fish Camp	6	C	1.5 - 3.0	S	1.5 - 3.0	S	
Stream Gauge	7	C	1.5 - 3.0	S	1.5 - 3.0	S	
Table Mtn. Tributary	8	D	0.5 - 1.5	S	0.0 - 1.0	L	
Meadow Creek	9	C	1.0 - 2.5	S	1.0 - 2.5	S	
Gopher Creek	10	C	1.0 - 2.5	L	1.0 - 2.5	S	X
Nettle Creek	11	D	0.0 - 1.0	L	0.2 - 1.0	L	
Bohannon Ranch Falls	12	C	0.5 - 3.0	L	0.5 - 2.0	S	X
South Fk. Drift Creek	13	C	0.5 - 2.0	S	0.5 - 1.5	S	
South Fk. Drift Creek	14	D	0.2 - 1.5	S	0.5 - 1.5	S	
South Fk. Drift Creek	15	D	0.5 - 1.5	S	0.3 - 1.0	S	
South Fk. Drift Creek	16	D	0.2 - 1.5	S	0.2 - 1.0	S	

1 Longitudinal extent of geomorphic surfaces: continuous over extent of reach (C), and discontinuous over extent of reach (D) as observed from field data.

2 Minimum heights are a range interpreted visually from a longitudinal profile (Fig. A.2) for the left and right banks. Heights are in meters.

3 Lateral extent of geomorphic surfaces: short, extends less than one active channel width from bank (S), and long, extends greater than one active channel width from bank (L) as observed from field data.

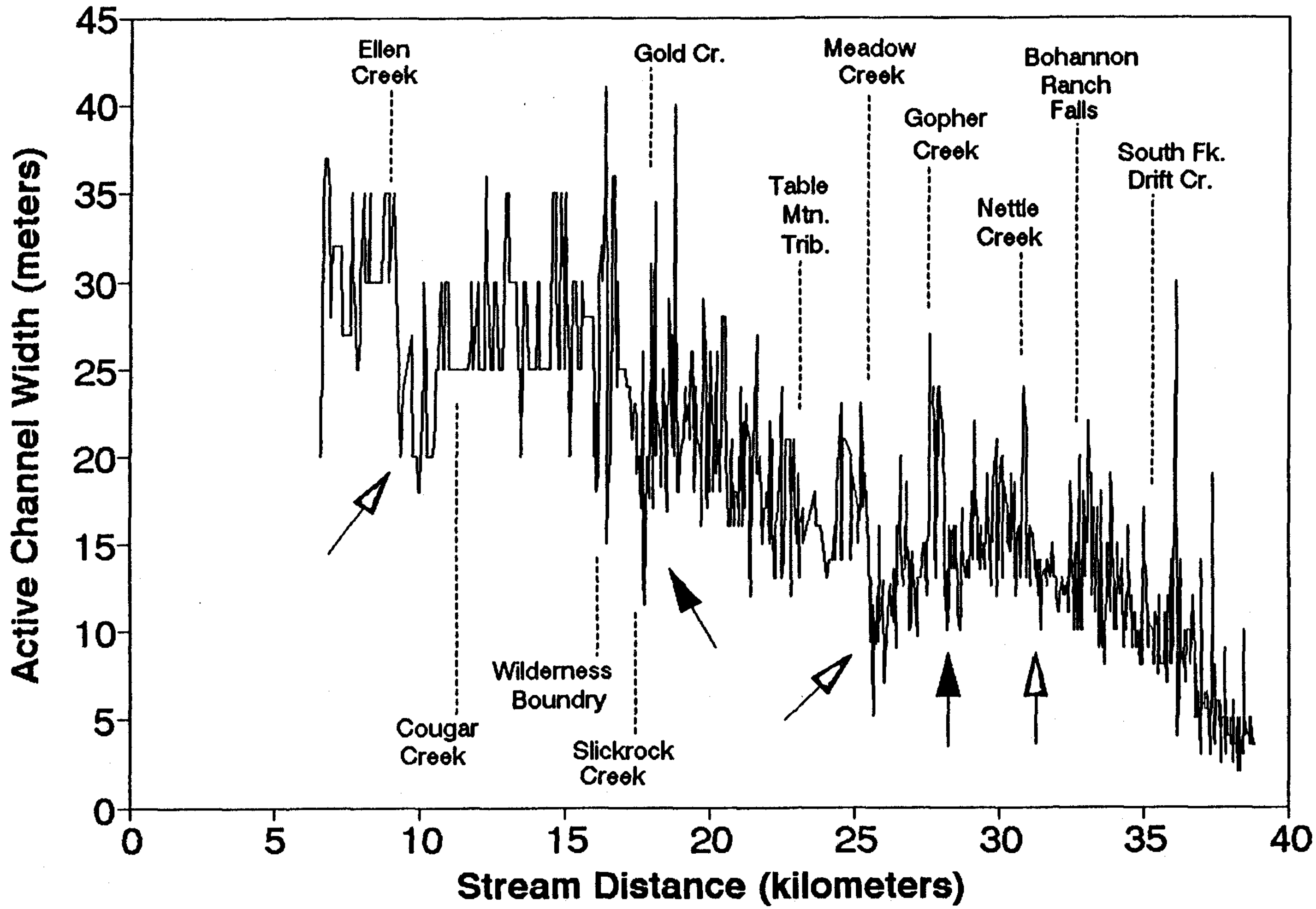


Figure 10. Longitudinal profile of active channel widths along Drift Creek. Solid arrows indicate locations of hillslope-constrained sub-reaches, and open arrows indicate locations of incised reaches.

(Table 5). Mainstem reaches in the mid-lower segment had low VFWI values, high overall gradients, high stream power indices, and steep sideslopes.

Large roughness elements (boulders and CWD) were more abundant in headwater reaches of South Fork Drift Creek (Tables 7 and 8). Downstream of Gopher Creek in mainstem Drift Creek, reaches 1, 2, 9, and 10 occurred in alluvial valleys or were bounded by moderate gradient hillslopes; these reaches had lower numbers of small boulders (< 350/km). Boulders occurred to a greater extent (> 450/km) in reaches within the mid-lower segment and South Fork Drift Creek where sideslopes are steep (Table 7 and Fig. A.1). In reach 5,

Table 7. Boulder densities by Drift Creek reaches (1989), reported in numbers per kilometer (using map standard distances).

Reach Upper Boundary	Reach Number	Small Boulders	Large Boulders
Ellen Creek	1	297	24
Cougar Creek	2	276	9
Boulder Creek	3	460	7
Wilderness Boundary	4	597	5
Gold Creek	5	1578	60
Fish Camp	6	728	46
Stream Gauge	7	662	33
Table Mtn. Tributary	8	453	17
Meadow Creek	9	293	6
Gopher Creek	10	301	5
Nettle Creek	11	690	22
Bohannon Ranch Falls	12	973	13
South Fk. Drift Creek	13	276	10
South Fk. Drift Creek	14	451	23
South Fk. Drift Creek	15	1056	24
South Fk. Drift Creek	16	740	28

Table 8. Coarse woody debris in Drift Creek reaches, expressed in volumes by channel length and area. Total volume included CWD estimates from all four hydrologic influence zones.

Reach Number	Total Volume (m^3) per 100 m	Zones 1 & 2 Volume (m^3) per 100 m^2	Zone 1 Volume (m^3) per 100 m^2	Zone 2 Volume (m^3) per 100 m^2
1	16.9	0.43	0.04	0.39
2	12.2	0.27	0.06	0.21
3	15.8	0.33	0.05	0.28
4	15.4	0.26	0.02	0.24
5	16.5	0.61	0.12	0.49
6	8.7	0.19	0.03	0.16
7	13.0	0.31	0.04	0.27
8	4.3	0.17	0.02	0.15
9	10.2	0.31	0.10	0.21
10	6.5	0.28	0.04	0.24
11	19.0	0.63	0.09	0.54
12	23.8	0.59	0.07	0.52
13	20.5	0.42	0.09	0.33
14	55.0	1.32	0.11	1.21
15	77.5	0.81	0.21	0.60
16	144.2	8.70	1.28	7.42

Reaches 1-14, & 16 estimates are from database files by Veldhuisen (1990). Reaches 1-12, and 16 were estimated in 1988, and reaches 13-15 were estimated in 1989.

high numbers of boulders were delivered into the channel by Slickrock Creek as a result of an old debris flow. A hillslope-constrained sub-reach located just downstream of Slickrock Creek enhanced the storage of boulders within this reach.

In mainstem Drift Creek reaches (1 - 13), total volumes of CWD ranged from 4.3 to 23.8 $m^3/100$ m (Table 8). In lower Drift Creek, CWD volumes were not substantially different in wilderness area reaches (2 - 4) compared to immediate upstream and downstream reaches. South Fork Drift Creek reaches (14 - 16) contained substantially greater volumes of total CWD which ranged from 55.0 to 144.2 $m^3/100$ m compared to mainstem reaches. Within South Fork Drift Creek, CWD volumes decreased longitudinally from headwaters to downstream reaches. Reaches 15 and 16 occurred in unharvested, mature conifer forest. Interpretation of CWD data was difficult due to land-use and was discussed by Veldhuisen (1990).

In mainstem Drift Creek reaches, bedrock was the dominant channel bedform ranging from 22% to 56% by length (Table 9). Reaches 8 and 9, two low-gradient reaches contained dominant substrates of gravel, cobble, and boulders; bedrock was less than 22% by length. In mainstem reaches, percentages of exposed bedrock of the channel (as measured by percent area) ranged from 24.5 to 56.0, except for lesser percentages in the low-gradient reaches 7 - 9 (Table 5). In the mainstem reaches, the primary pool-forming element was bedrock (Table 10). Gravels occurred in greatest amounts in reaches 2, 5 - 7, 9, 13 - 16 and were over 13% by length as the dominant reach substrate (Table 9). Spawning gravels were greatest by percent area (> 2.8%) in South Fork Drift Creek reaches 15 and 16 compared to all other reaches (Table 11). In the mainstem Drift Creek, reach 2 had the most spawning gravel (1.25%). Other mainstem Drift Creek reaches with spawning gravels greater than 0.3% occurred in reaches 1, 5, 6, and 9.

Stream-bed characteristics changed between mainstem Drift Creek and South Fork Drift Creek (tributary reaches 14, 15, and 16). In South Fork Drift Creek, gravel, cobble, and boulders were the dominant bed material (Table 9). This shift in bed material was reflected also by pool-forming elements, changing from bedrock to CWD and boulders (Table 10). In the sixteen reaches, percent

Table 9. Dominant substrate types by percent channel unit length for each reach in Drift Creek.

Reach Number	Wood	Clay	Silt	Sand	Small Gravel	Large Gravel	Cobble	Boulder	Bedrock
1	0.0	0.0	0.0	0.0	0.0	8.2	33.9	3.6	54.3
2	0.0	0.0	0.0	0.0	0.0	28.1	8.4	9.8	53.7
3	0.0	0.0	0.0	0.0	0.0	3.4	4.4	38.9	53.3
4	0.0	0.0	1.4	0.0	0.0	0.1	3.9	41.4	53.1
5	0.0	0.0	0.0	0.0	2.6	11.1	19.4	45.1	21.8
6	0.0	0.0	0.0	0.0	6.6	14.1	34.5	22.6	22.2
7	0.0	0.0	0.0	0.0	5.6	8.8	23.4	31.0	31.3
8	0.0	0.0	0.0	0.0	0.0	2.6	47.5	32.8	17.1
9	0.0	0.0	0.0	0.0	0.0	31.5	59.8	4.8	3.8
10	0.0	0.0	6.0	0.0	0.0	7.5	15.4	26.3	44.7
11	0.0	0.0	0.6	0.8	0.0	6.2	6.5	29.9	55.9
12	0.0	0.0	4.3	0.0	2.7	0.0	5.8	37.9	49.4
13	0.0	0.0	0.0	0.0	0.0	13.8	49.7	7.2	29.4
14	0.3	0.0	0.0	0.0	0.0	16.3	66.3	11.6	5.5
15	1.4	0.0	1.3	0.0	0.5	14.0	27.9	54.4	0.4
16	0.0	0.0	0.0	0.6	0.0	25.7	72.5	1.2	0.0

Table 10. Pool-forming elements in Drift Creek, values are by reach percentage of total pools (1989 survey).

		POOL-FORMING ELEMENT					
Reach Number	Total No. of Pools	Bedrock	Boulder	Large Wood	Root Wad	Stream Curvature	Beaver Dam
1	13	77	15	0	0	8	0
2	12	92	8	0	0	0	0
3	18	94	6	0	0	0	0
4	13	54	38	8	0	0	0
5	22	36	55	9	0	0	0
6	19	32	42	0	5	21	0
7	13	38	38	15	0	9	0
8	17	35	23	12	0	29	0
9	10	0	40	20	0	40	0
10	19	95	5	0	0	0	0
11	41	57	12	20	2	7	2
12	20	85	0	15	0	0	0
13	27	74	4	7	7	4	4
14	22	8	19	37	9	27	0
15	39	3	51	38	5	3	0
16	27	0	34	66	0	0	0

Table 11. Spawning gravel estimates in Drift Creek reaches (1989 survey).

Reach Upper Boundary	Reach Number	Total Spawning Gravel (m^2)	Spawning Gravel (% by area)
Ellen Creek	1	126	0.32
Cougar Creek	2	742	1.25
Boulder Creek	3	70	0.15
Wilderness Boundary	4	28	0.08
Gold Creek	5	121	0.34
Fish Camp	6	204	0.76
Stream Gauge	7	94	0.23
Table Mtn. Tributary	8	0	0.00
Meadow Creek	9	111	0.34
Gopher Creek	10	14	0.05
Nettle Creek	11	39	0.11
Bohannon Ranch Falls	12	21	0.14
South Fk. Drift Creek	13	12	0.05
South Fk. Drift Creek	14	12	0.15
South Fk. Drift Creek	15	124	2.84
South Fk. Drift Creek	16	71	4.68

areas of bedrock were inversely correlated with CWD volumes ($p = 0.028$, $r = -0.55$).

Channel Units

Channel unit composition was influenced by overall reach-scale gradient (Fig. 11). For the sixteen reaches, percentages of pools and glides were positively correlated with gradients ($p < 0.001$, $r^2 = 0.70$). Also, percents of pools were positively correlated with gradient ($p = 0.003$, $r^2 = 0.49$). In mainstem Drift Creek, pools and glides comprised approximately 60% of channel units by length, except for low-gradient reaches 7 - 9 that comprised approximately 80% (Fig. 12, Tables A.4 - A.6). In reaches 13 - 16 of the upper

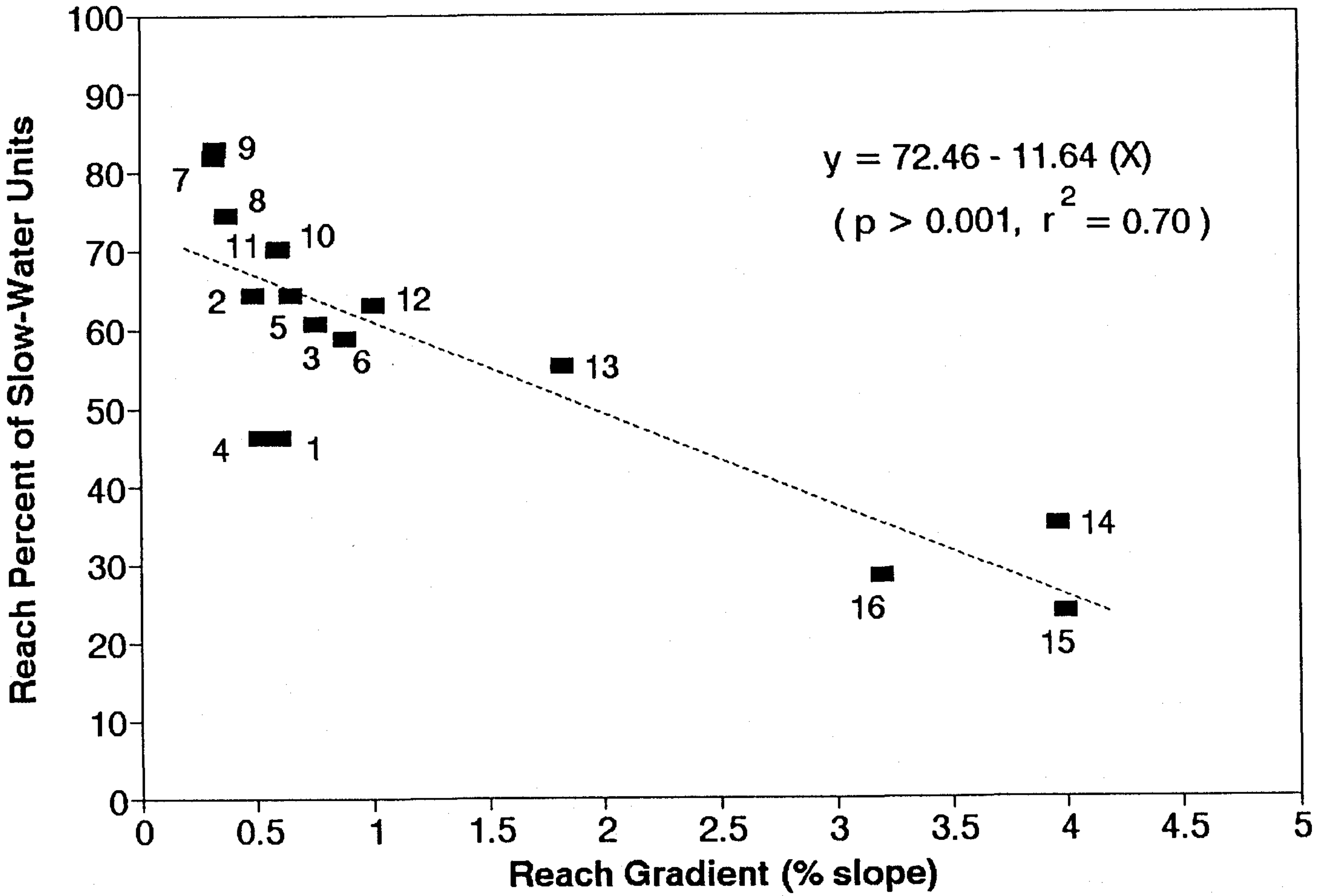


Figure 11. Percent composition of slow-water channel units versus reach gradient for Drift Creek reaches.

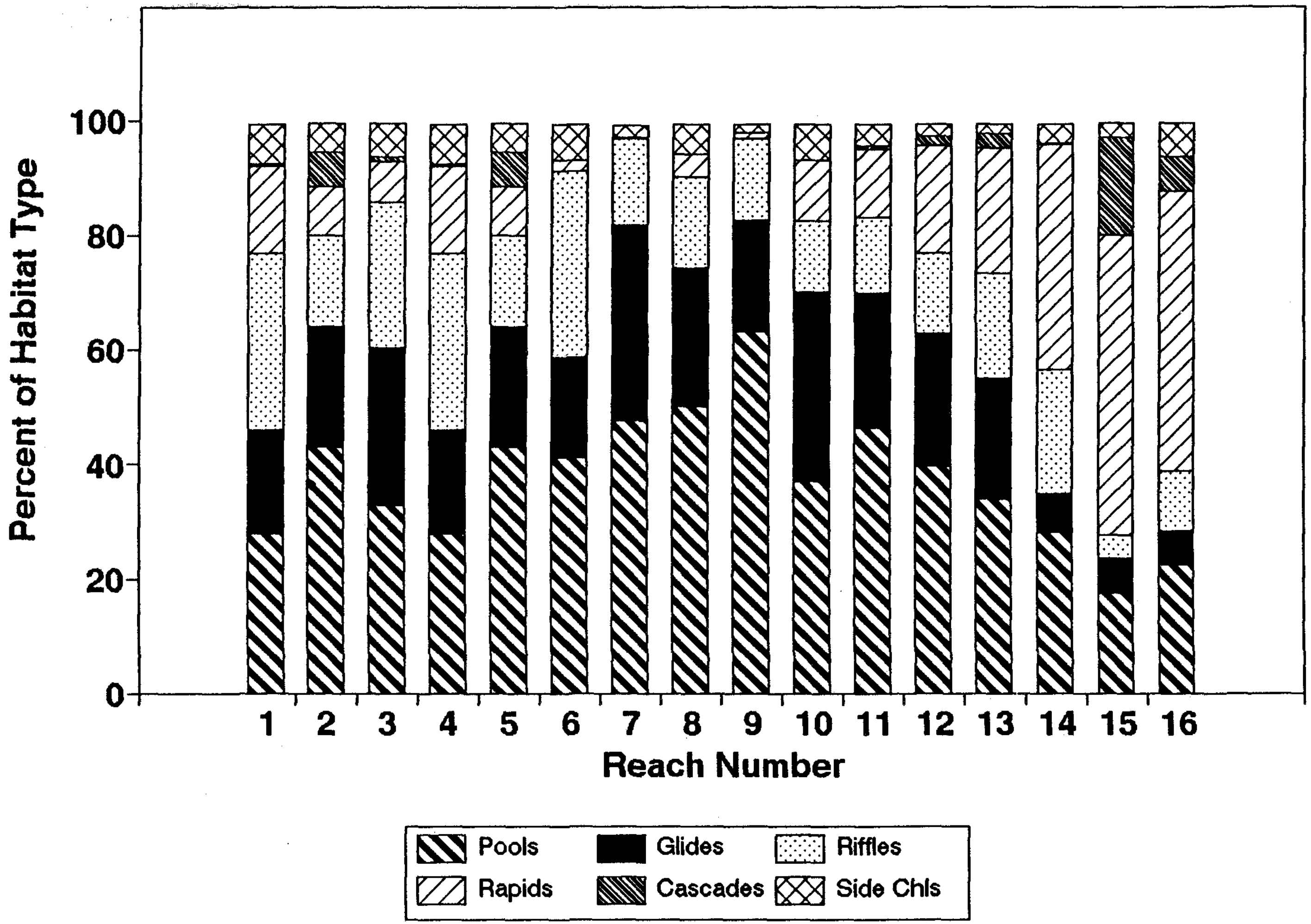


Figure 12. Percent composition of channel unit types for Drift Creek reaches.

basin, fast-water units (i.e., riffles rapids, and cascades) comprised a greater percentage (> 40%) of channel unit types. Gradients in these reaches were greater than 1.8%. Cascades were dominant bedform features in upper reaches of South Fork Drift Creek (Fig. 12).

Salmonid Distribution and Abundance

Basin

Basin patterns in distribution and abundance of salmonids (summer-rearing) can be viewed as a continuum from headwaters to lower mainstem Drift Creek (Figs. 13a - 17a). Juvenile chinook occupied the lower portion of the basin, and did not occur above Bohannon Ranch Falls (Fig. 13a). Juvenile coho occupied the upper portion of the basin to a greater extent (Fig. 14a). Trout (age 0+) and steelhead trout (age 1+) were variable in basin distribution and abundance (Figs. 15a and 16a). Cutthroat trout (age 1+) were equally distributed in the basin as shown by numbers per channel unit (Fig. 17a).

Basin patterns of salmonid distribution were similar between summers (1988 and 1989), but abundances between years differed (Figs. 13 - 17). Juvenile chinook and coho salmon were more abundant in 1989 than in 1988. Trout (age 0+) were more abundant in 1988 than in 1989. Cutthroat trout (age 1+) and steelhead trout (age 1+) numbers were approximately equal between years.

The basin transition in abundances between juvenile chinook and coho salmon occurred at approximately the same location for 1988 and 1989 (Fig. 18). The transition was illustrated by areas encompassing maximum salmonid abundances within channel units along a basin profile. This transition along Drift Creek occurred just downstream of the major slope break at Fish Camp,

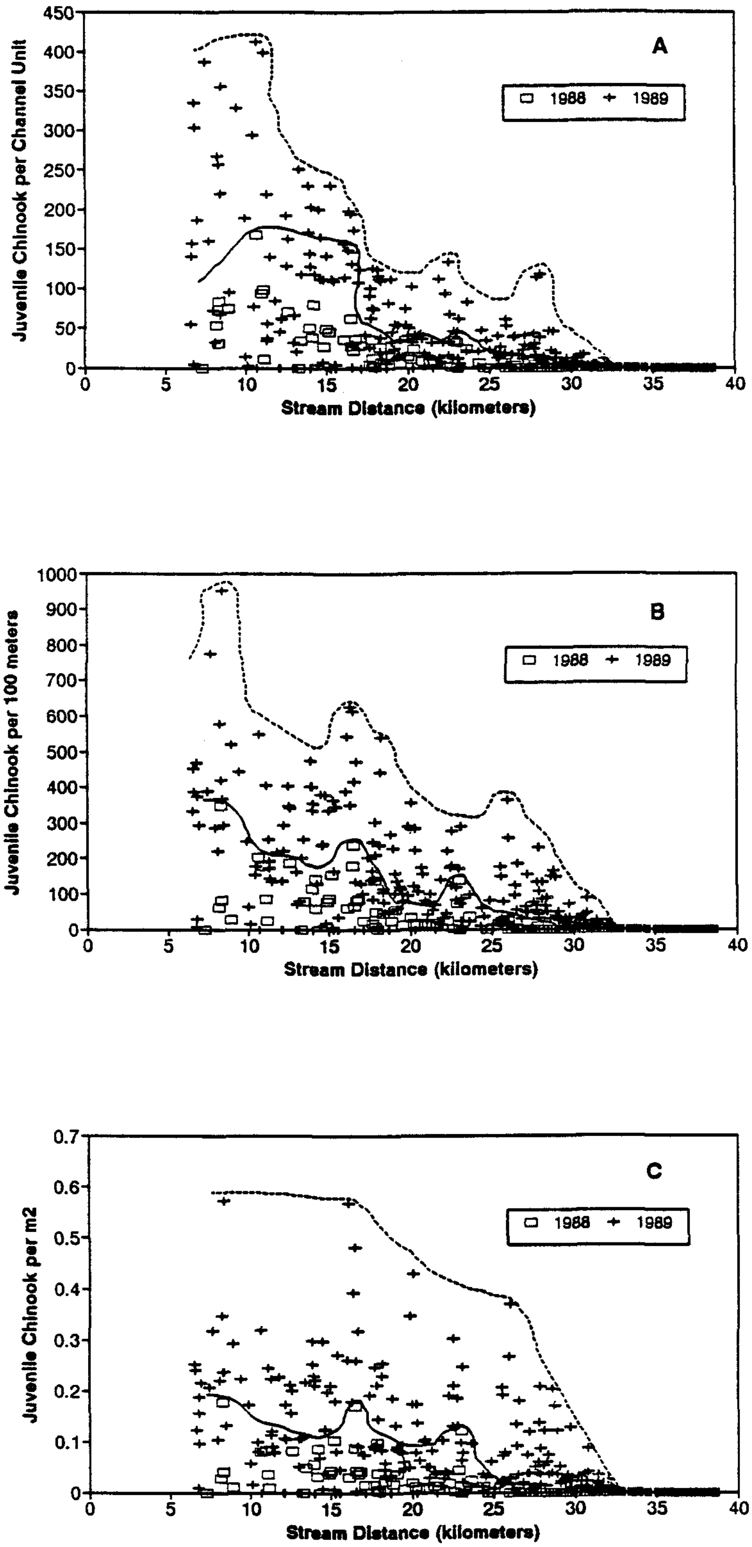


Figure 13. Longitudinal profiles of abundance of juvenile chinook salmon by (A) numbers per channel unit, (B) linear densities per channel unit, and (C) areal densities per channel unit. Lines indicate range of maximum abundances.

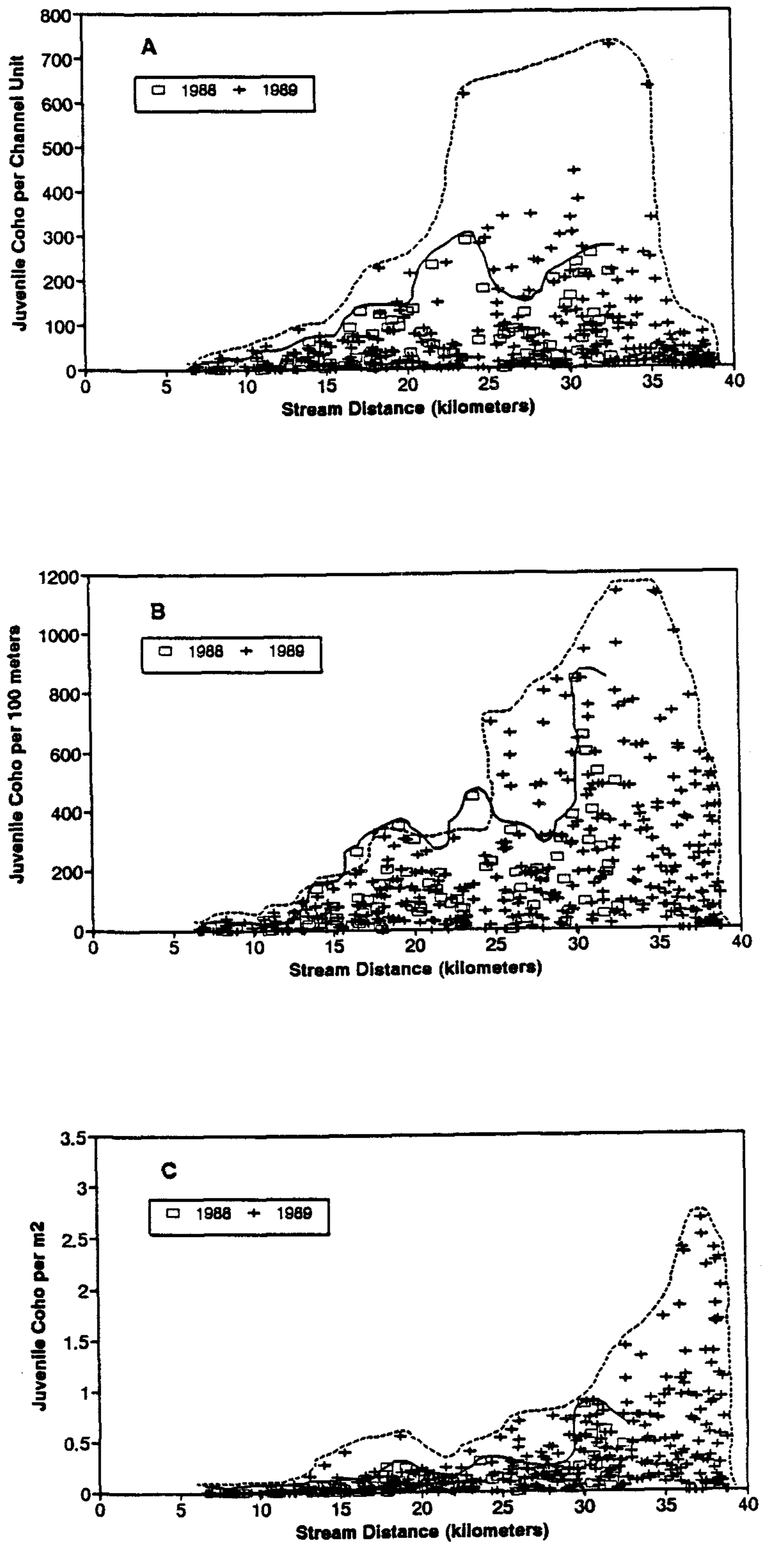


Figure 14. Longitudinal profiles of abundance of juvenile coho salmon by (A) numbers per channel unit, (B) linear densities per channel unit, and (C) areal densities per channel unit. Lines indicate range of maximum abundances.

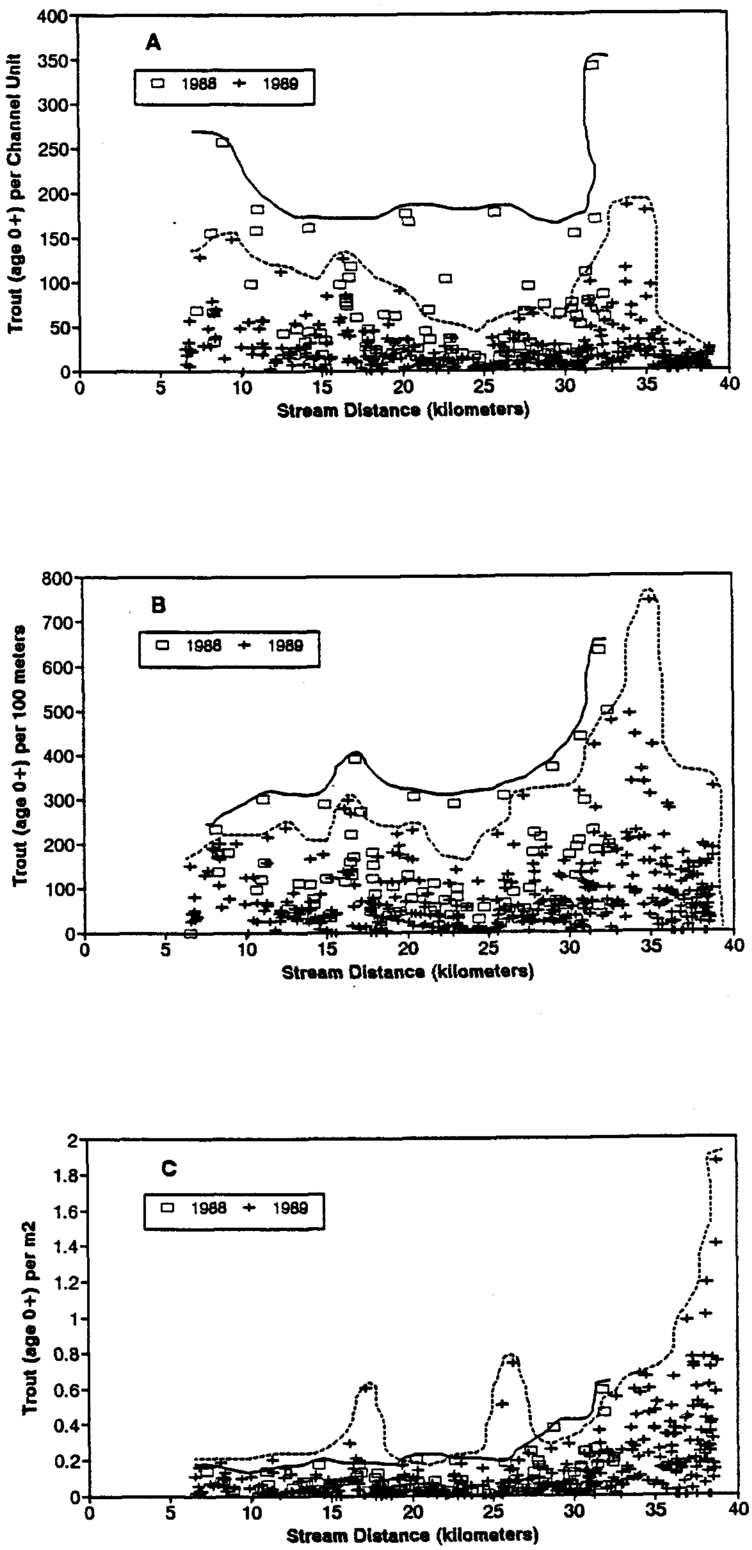
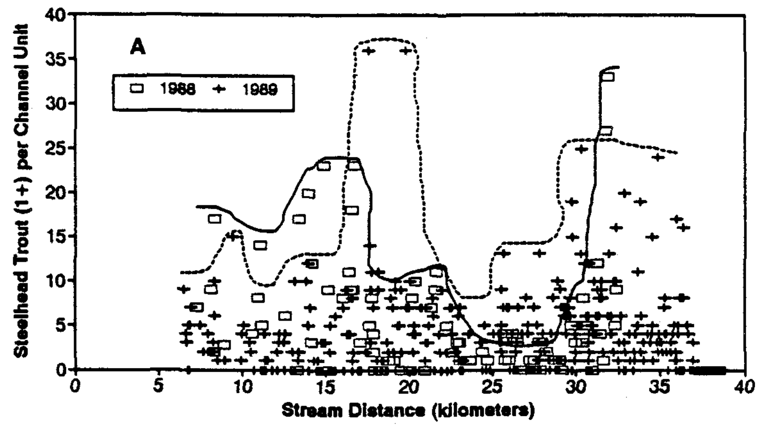
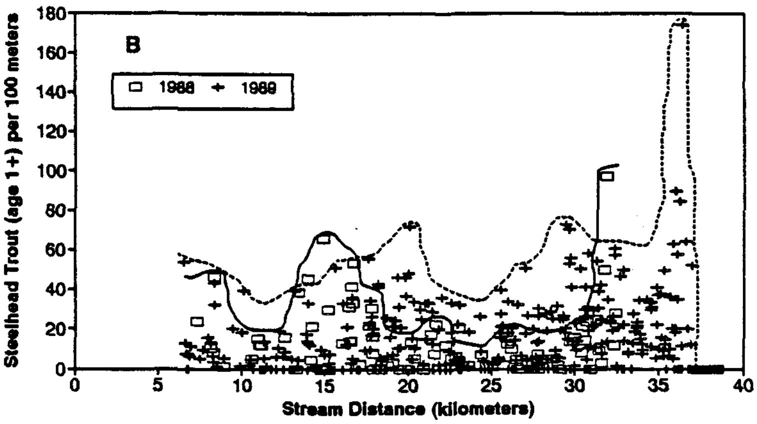


Figure 15. Longitudinal profiles of abundance of trout fry (age 0+) by (A) numbers per channel unit, (B) linear densities per channel unit, and (C) areal densities per channel unit. Lines indicate range of maximum abundances.





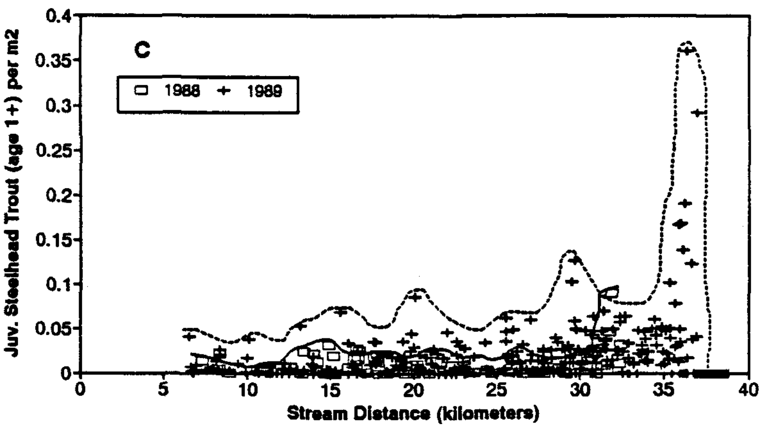


Figure 16. Longitudinal profiles of abundance of steelhead trout (age 1+) by (A) numbers per channel unit, (B) linear densities per channel unit, and (C) areal densities per channel unit. Lines indicate range of maximum abundances.

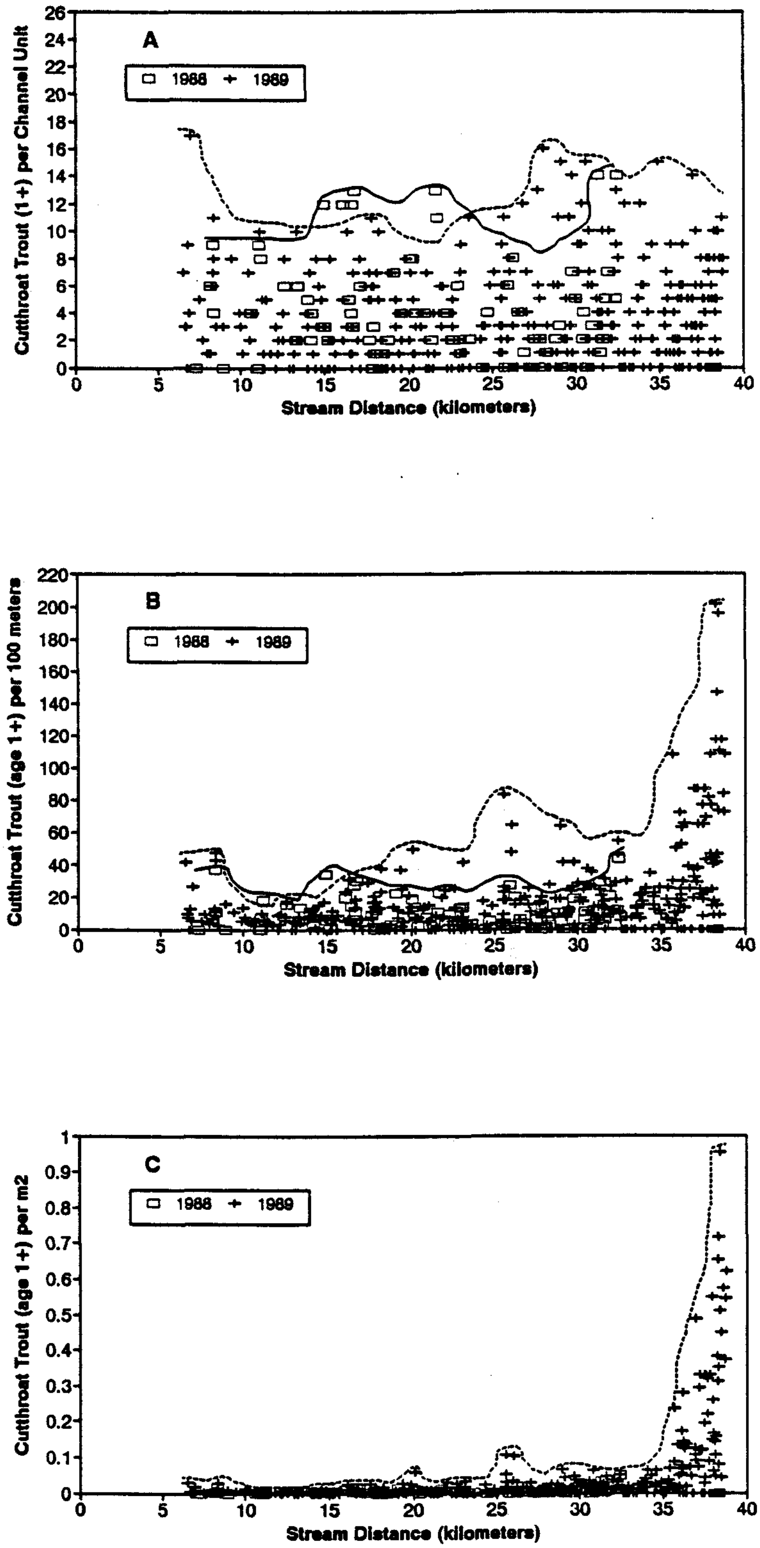


Figure 17. Longitudinal profiles of abundance of cutthroat trout (age 1+) by (A) numbers per channel unit, (B) linear densities per channel unit, and (C) areal densities per channel unit. Lines indicate range of maximum abundances.

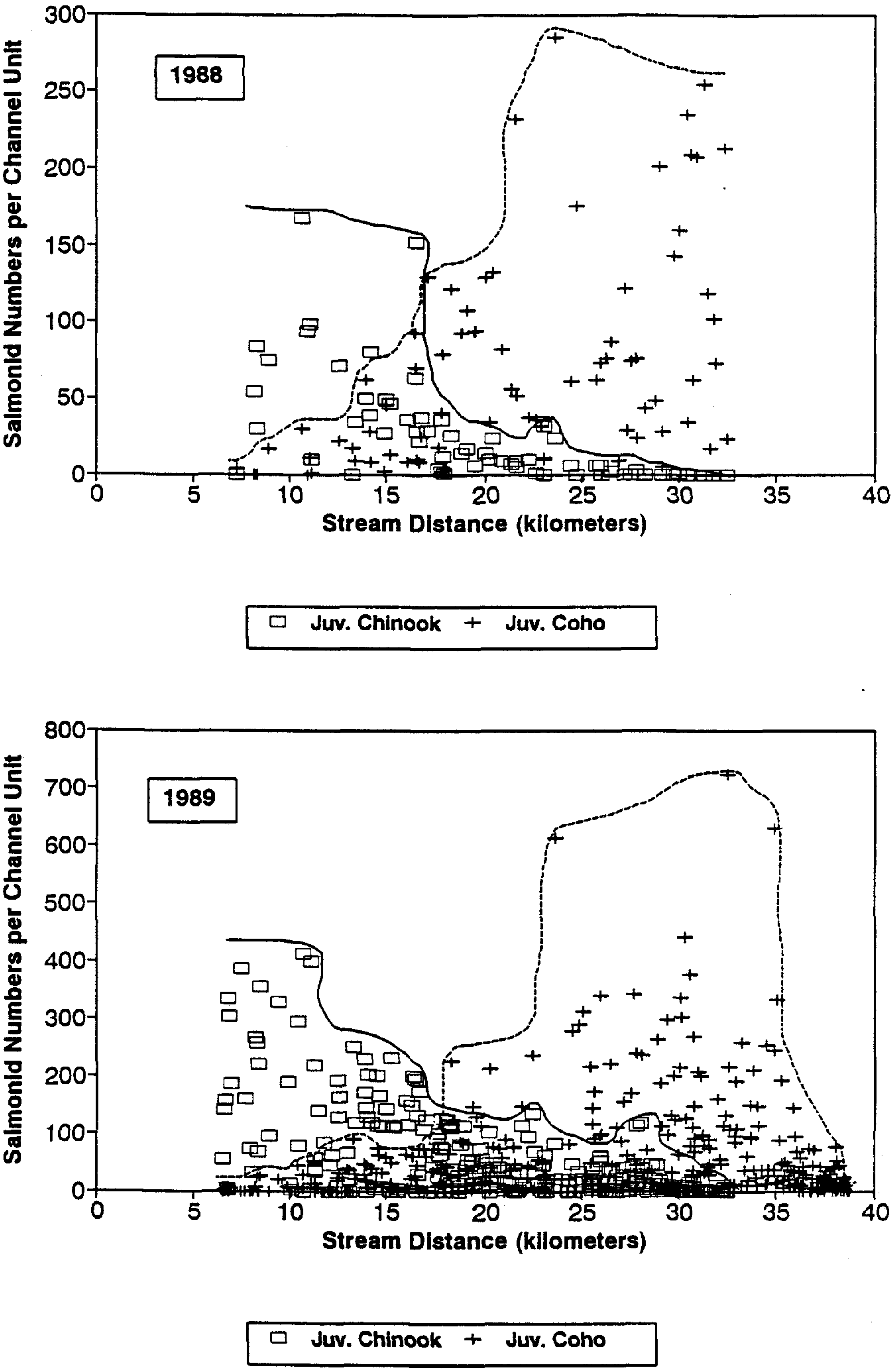


Figure 18. Basin transition in abundances (fish numbers per channel unit) of juvenile chinook and coho salmon.

approximately 16 to 20 km from the Lyndon Creek confluence. In 1989, juvenile coho abundances within channel units showed a peak at Bohannon Ranch Falls, the anadromous limit for juvenile chinook salmon.

Abundances of salmonids differed within the Drift Creek basin whether longitudinal patterns represented numbers, linear densities, or areal densities per channel unit (Figs. 13 - 17). Salmonid linear and areal densities increased abruptly in South Fork Drift Creek, a third-order tributary, due to decreased size of channel units. This effect of channel unit size was most pronounced with cutthroat trout (age 1+), for which numbers per channel unit were uniform throughout the basin (Fig. 17a), but densities in the tributary increased abruptly (Figs. 17b and c). This effect of channel unit size was least pronounced with juvenile chinook, because their range did not extent into South Fork Drift Creek (Fig. 13). Linear and areal densities of juvenile coho, trout (age 0+), and steelhead trout (age 1+) increased in the upper portion of the basin due to greater numbers per channel unit and the reduced size of channel units.

<u>Segments</u>

Salmonid abundances in segments reflected basin patterns of fish numbers per channel unit (Fig. 19). Juvenile chinook salmon dominated the lower segment. Juvenile coho salmon dominated the mid-upper and upper segments. The basin shift in dominant abundance between juvenile chinook and coho salmon occurred between the mid-lower and mid-upper segments (located on Drift Creek 21 km from Lyndon Creek). Trout (ages 0+ and 1+) generally occupied all segments equally for summer-rearing. In 1988, trout (age 0+) occupied the mid-upper segment slightly greater than other segments.

Composition and total abundance of salmonids differed between 1988

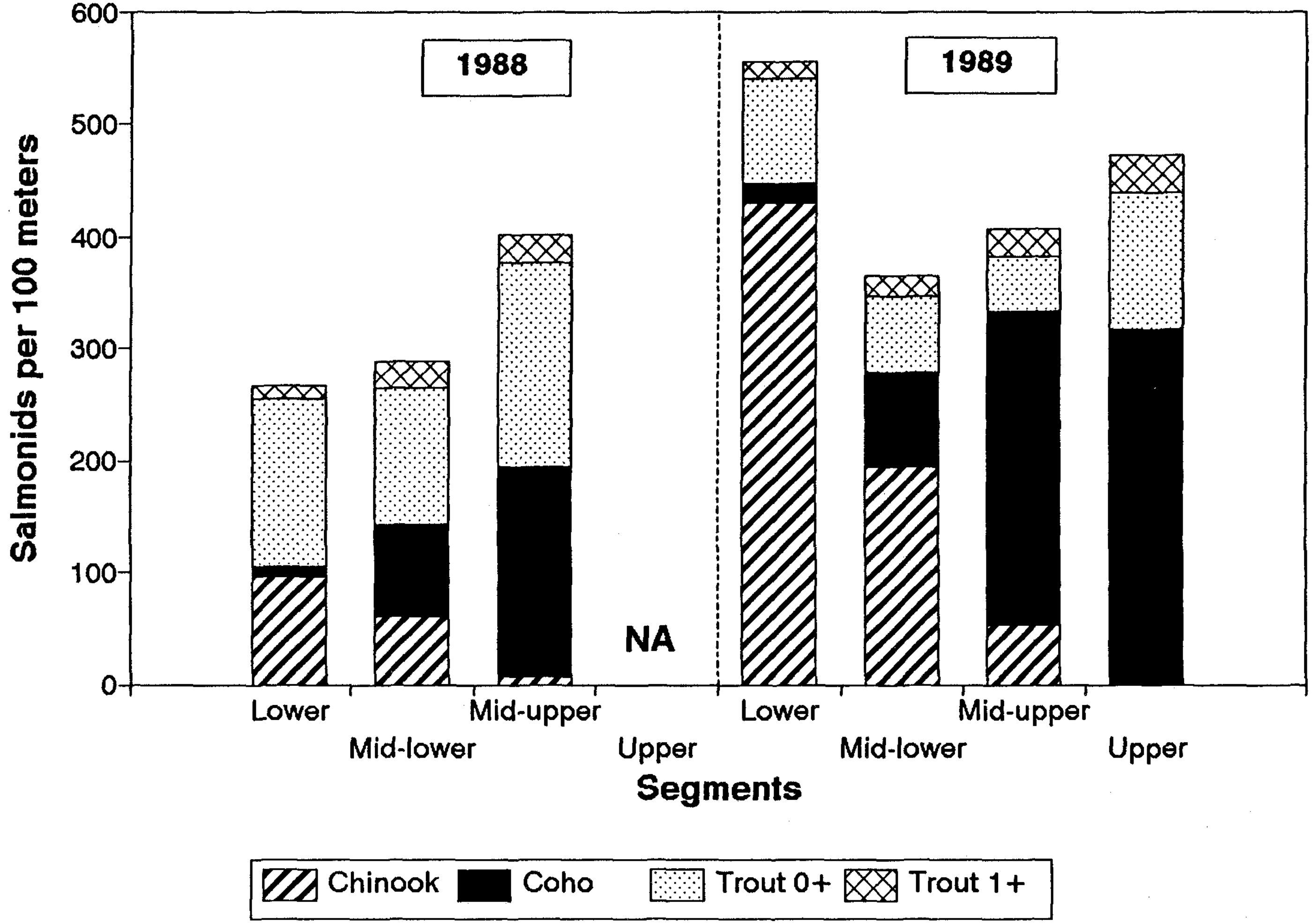


Figure 19. Segment estimates of salmonid abundances in Drift Creek for 1988 and 1989.

and 1989 for the same segments (Fig. 19). Juvenile chinook were more abundant in 1989 than 1988 throughout the basin, particularly the lower segment. Juvenile coho salmon were more abundant in the mid-upper segment in 1989 than 1988 but were similar between summers in lower and mid-lower segments (Table A.7). The lower segment differed more in total abundance between summers than all other segments. In all segments, trout fry (age 0+) were more abundant in 1988 than 1989. Abundances of trout (age 1+) were similar between summers for all segments and were much lower than all other salmonids.

Reaches

Total salmonid abundances for the sixteen reaches were more variable in basin patterns compared to abundances in the four segments (Fig. 20). This effect of scale was observed in Figures 13a - 17a, for which salmonid numbers at the channel unit scale along a basin profile were more variable than numbers at reaches. Total abundances of salmonids were compared between segments and reaches in 1989 only; frequency of dived channel units for 1988 did not allow for a comparison.

Salmonid abundances in reaches reflected basin patterns (Fig. 21). Juvenile chinook salmon occupied lower basin reaches in greater abundance. Juvenile coho salmon occupied upper basin reaches in greater abundance. Trout (ages 0+ and 1+) occupied all reaches with equal abundance, except abundances were slightly less in mid-basin reaches 7 to 11.

Juvenile chinook salmon were found in greatest abundance in the downstream-most reach (Fig. 21). Juvenile chinook abundances declined for consecutive reaches upstream of their anadromous limit at Bohannon Ranch

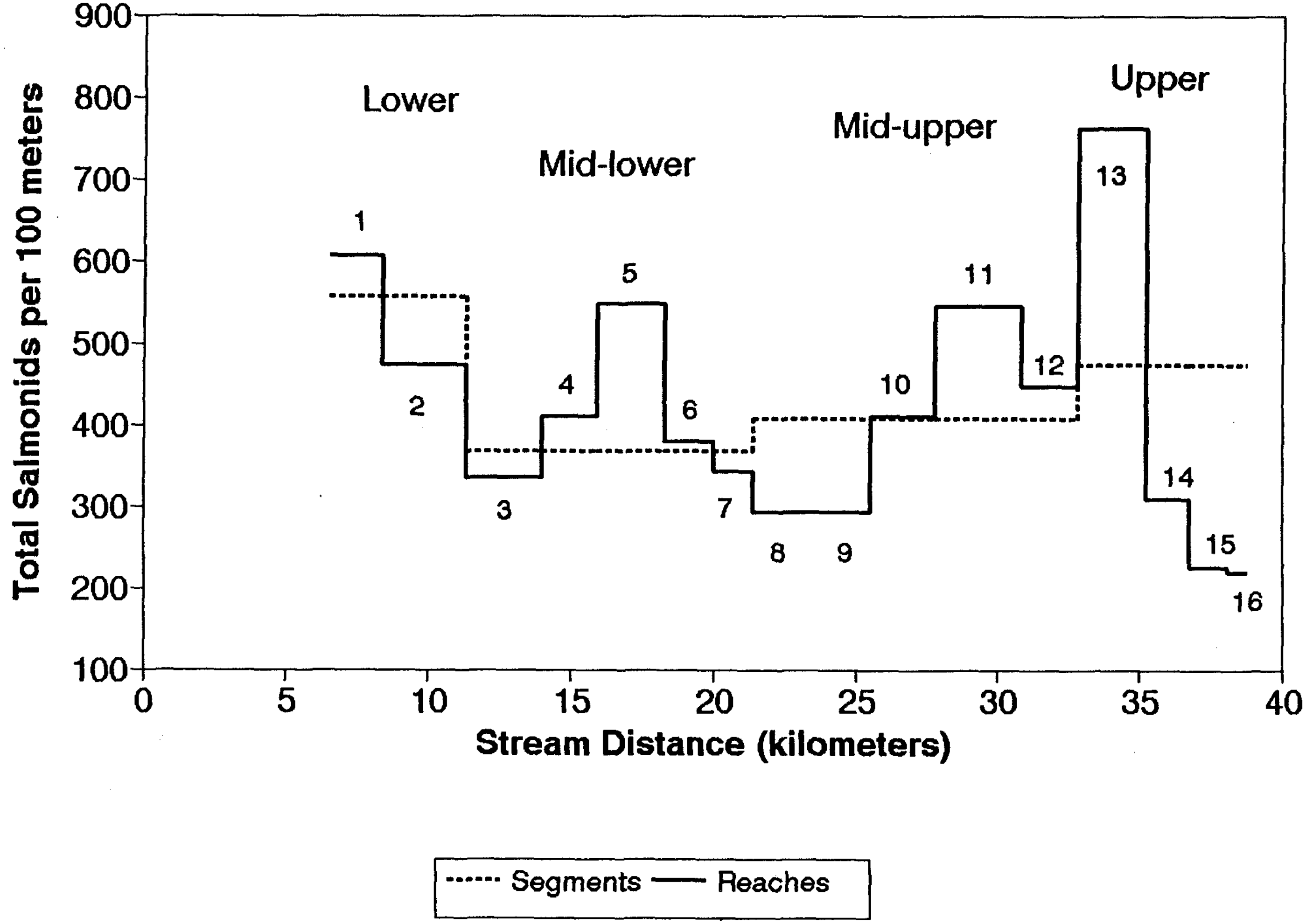


Figure 20. Segment and reach estimates of total salmonid abundance in Drift Creek for 1989.

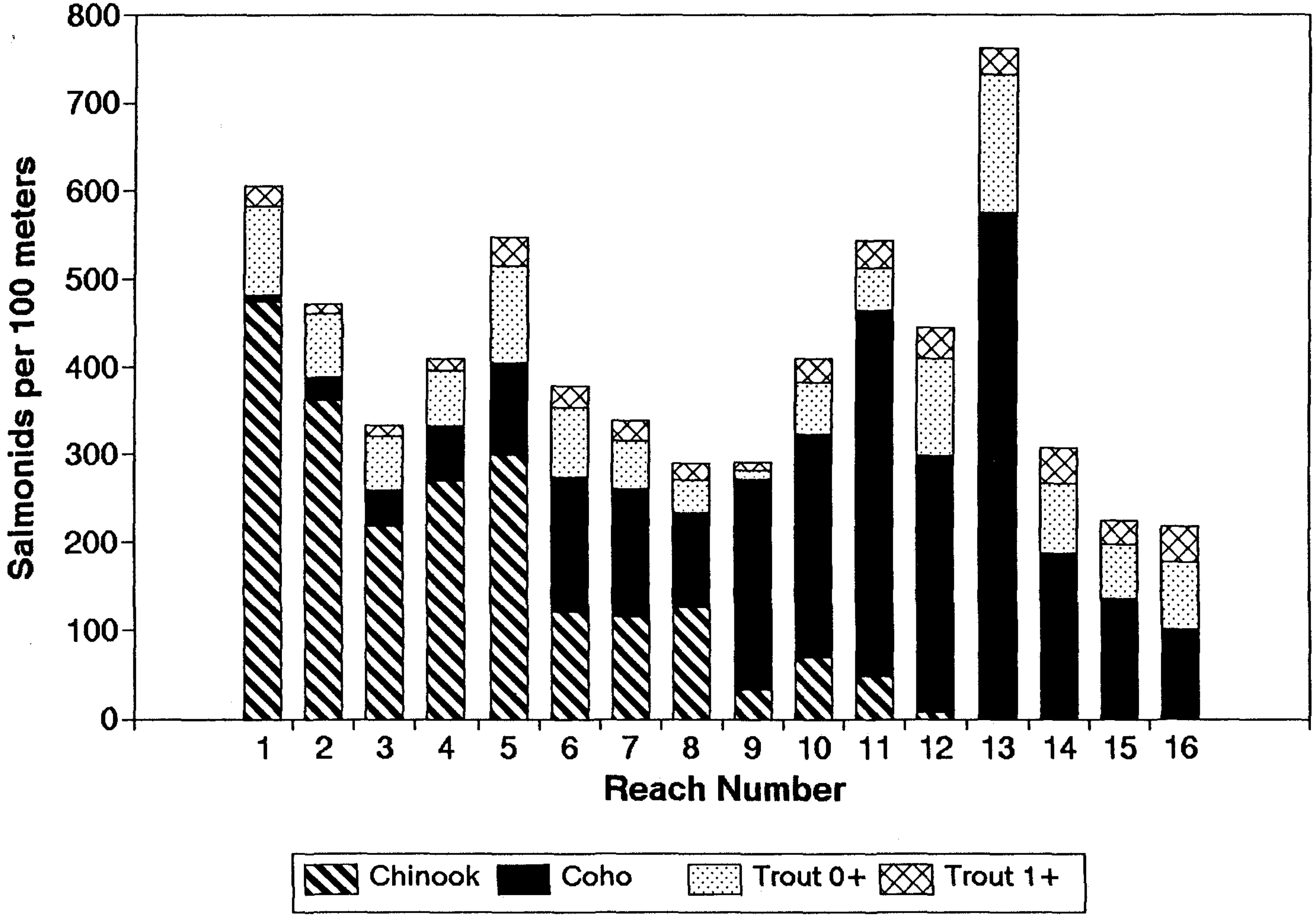


Figure 21. Reach estimates of salmonid abundances in Drift Creek for 1989.

Falls (reach 12). Abundance decreased abruptly between reaches 5 and 6. Another sharp decline in abundance occurred between Table Mountain tributary and Meadow Creek (reaches 8 and 9). Reach 9, a low-gradient reach had a greater percentage (by length) of slow-water channel units (Fig. 12).

The basin transition in abundance between juvenile chinook and coho salmon occurred among reaches 6 - 8 (Fig. 21). Abundances of juvenile chinook and coho were equal among reaches 6 - 8 for 1989. Juvenile chinook were more abundant below reach 6, and juvenile coho were more abundant above reach 8. This transition in abundances occurred near the major slope break at Fish Camp and the low-gradient reach 9 (below Table Mountain tributary).

Juvenile coho salmon were most abundant among reaches 9 - 13, compared to all other basin reaches (Fig. 21). These upper basin reaches occurred where several large tributaries enter the mainstem of Drift Creek, including Meadow-Horse Creek, Gopher Creek, Nettle Creek, and South Fork Drift Creek. Reach 13 was located in a canyon with moderate gradient sideslopes immediately upstream of Bohannon Ranch Falls, and begins the fourth-order mainstem from the confluence of Drift Creek and South Fork Drift Creek. Reach 13 had the greatest abundances compared to all other reaches. Juvenile coho salmon were more abundant in reach 11 (between Gopher and Nettle Creeks) compared to reaches 10 and 12. Reach 11 was located mostly in an alluvial valley of unconstrained channel, whereas reaches 10 and 12 were incised channels.

In reaches (1 - 13) of mainstem Drift Creek, trout (ages 0+ and 1+) were more abundant in higher gradient reaches. Reach gradient strongly correlated with trout (age 0+) abundance ($p < 0.001$, $r = 0.83$), and weakly correlated with trout (age 1+) abundance (p = 0.107, r = 0.47). Reaches 8 and 9 (between the stream gauge and Meadow Creek) had the lowest abundance of trout (ages 0+ and 1+). These reaches were the lowest gradient reaches (0.3-0.4% slope) of mainstem Drift Creek (Fig. 21, Table 5, Table A.7). Reach 13, the highest gradient reach (1.82% slope) of mainstem Drift Creek had the highest abundances of trout (ages 0+ and 1+). Reach correlation between trout abundance and gradient did not incorporate the tributary reaches because of additive influences of stream size. Abundances of trout (ages 0+ and 1+) in tributary reaches (14 - 16) were similar to abundances in higher gradient reaches of Drift Creek mainstem.

Tributary Junctions

At major tributary junctions for 1989, salmonid densities between 100-m upstream and downstream sections of Drift Creek were not significantly different (p > 0.1). Salmonid areal densities examined at major tributary junctions included juvenile chinook, juvenile coho, trout (age 0+), trout (age 1+), and total salmonids (Table 12). A Wilcoxon signed-rank test was used to test upstream and downstream areal densities of salmonids as paired samples.

Channel Units

Salmonid use of channel units differed as by percent of total numbers for the basin, where juvenile salmon occupied slow-water units more than trout (ages 0+ and 1+) (Fig. 22). Patterns of salmonid occupancy of different channel units were examined within reaches by average numbers of salmonids per unit type (Figs. 23 - 26, Table A.8) and electivity (Table 13). Since reaches differed in composition of channel unit types, electivity allowed for a relative

Table 12. Salmonid areal densities at major tributary juctions for upstream (ups) and downstream (dws) positions in the Drift Creek mainstem (1989 survey).

		SALMONID DENSITIES (Fish / m^2)				
Tributary Juction	Junction Position	Total Fish	Chinook Juveniles	Coho Juveniles	Trout (age 0+)	Trout (age 1+)
Ellen Creek	dws	5.95	4.30	0.00	1.12	0.52
	ups	1.69	1.32	0.01	0.26	0.02
Cougar Creek	dws	1.94	1.22	0.26	0.43	0.29
	ups	1.40	0.88	0.11	0.38	0.41
Boulder Creek	dws	3.52	2.45	0.35	0.53	0.18
	ups	2.61	2.23	0.06	0.18	0.15
Slickrock Creek	dws	2.21	1.06	0.52	0.33	0.30
	ups	2.62	1.45	0.49	0.42	0.26
Gold Creek	dws	3.18	1.51	1.11	0.37	0.19
	ups	1.55	0.43	0.95	0.16	0.02
Table Mtn. Tributary	dws	1.84	0.93	0.35	0.35	0.19
	ups	1.03	0.13	0.83	0.04	0.03
Meadow Creek	dws	2.90	0.35	2.17	0.22	0.15
	ups	3.71	0.38	2.18	0.65	0.51
Gopher Creek	dws	3.12	0.87	1.34	0.76	0.16
	ups	4.52	1.23	2.59	0.46	0.24
Nettle Creek	dws	6.84	0.33	5.58	0.47	0.46
	ups	5.46	0.32	3.85	0.85	0.45

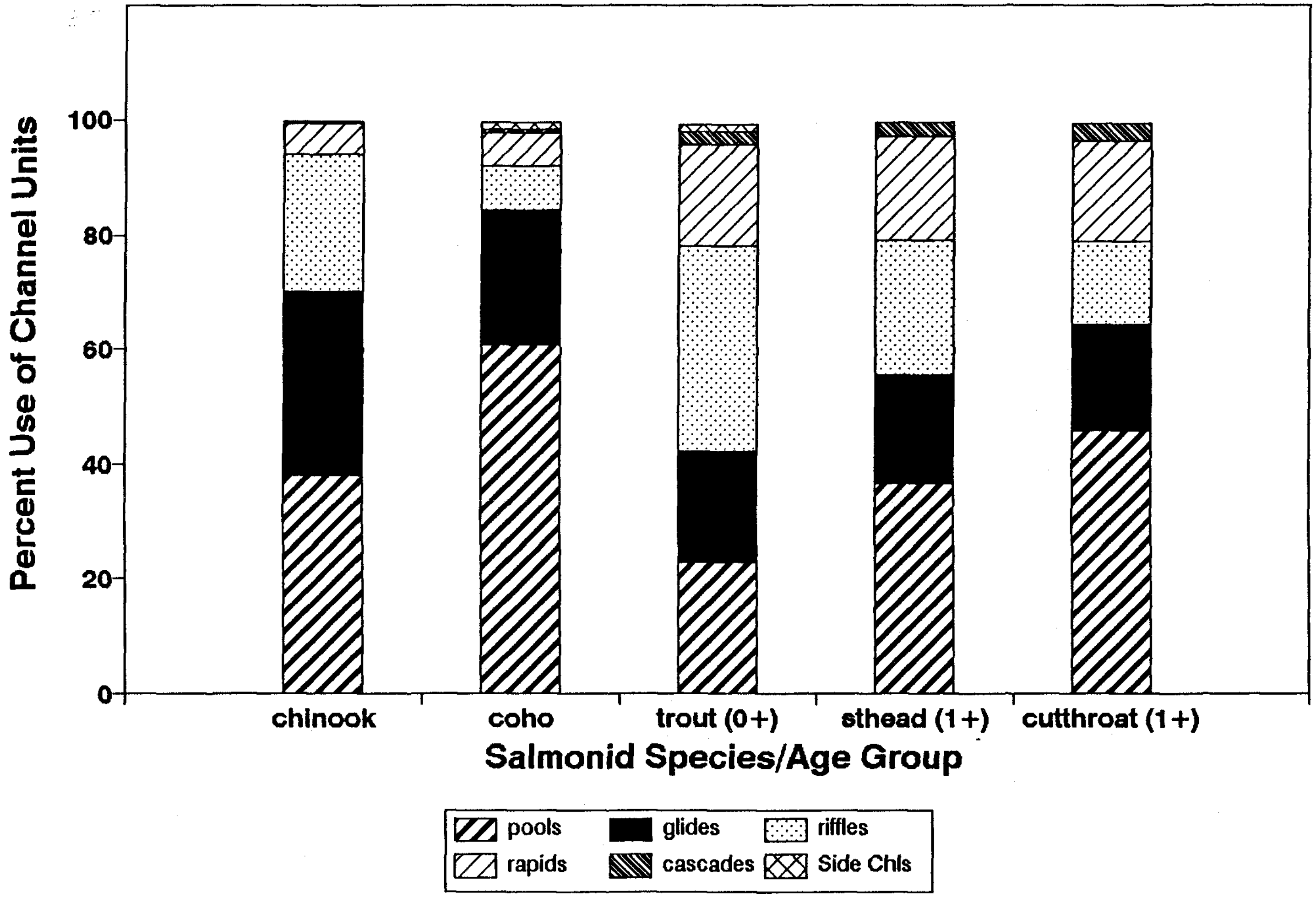


Figure 22. Summary of channel unit use by salmonids in Drift Creek as percent of total numbers per channel unit type (1989 survey).

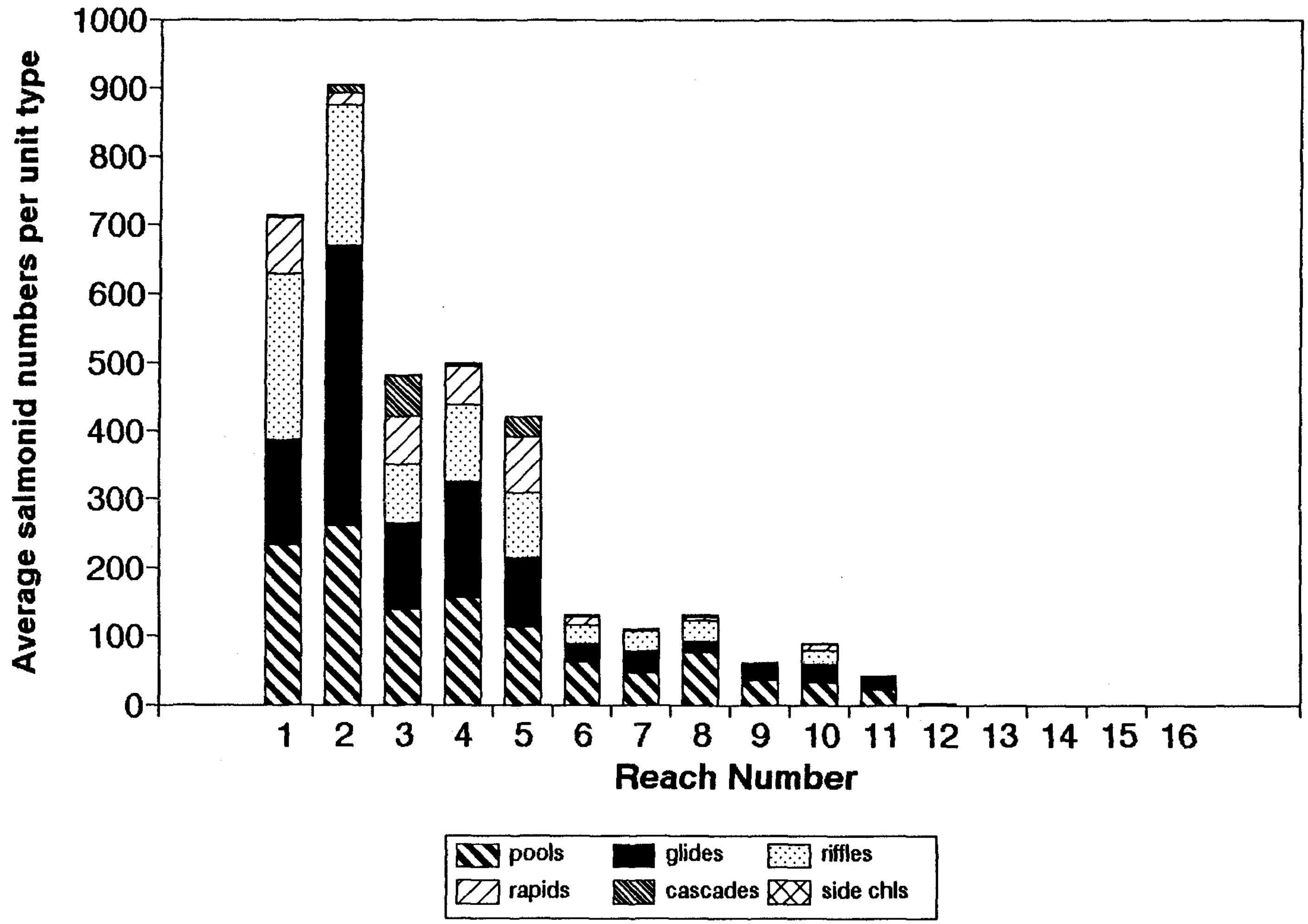


Figure 23. Average numbers of juvenile chinook salmon by channel unit type for the Drift Creek reaches (1989 survey).

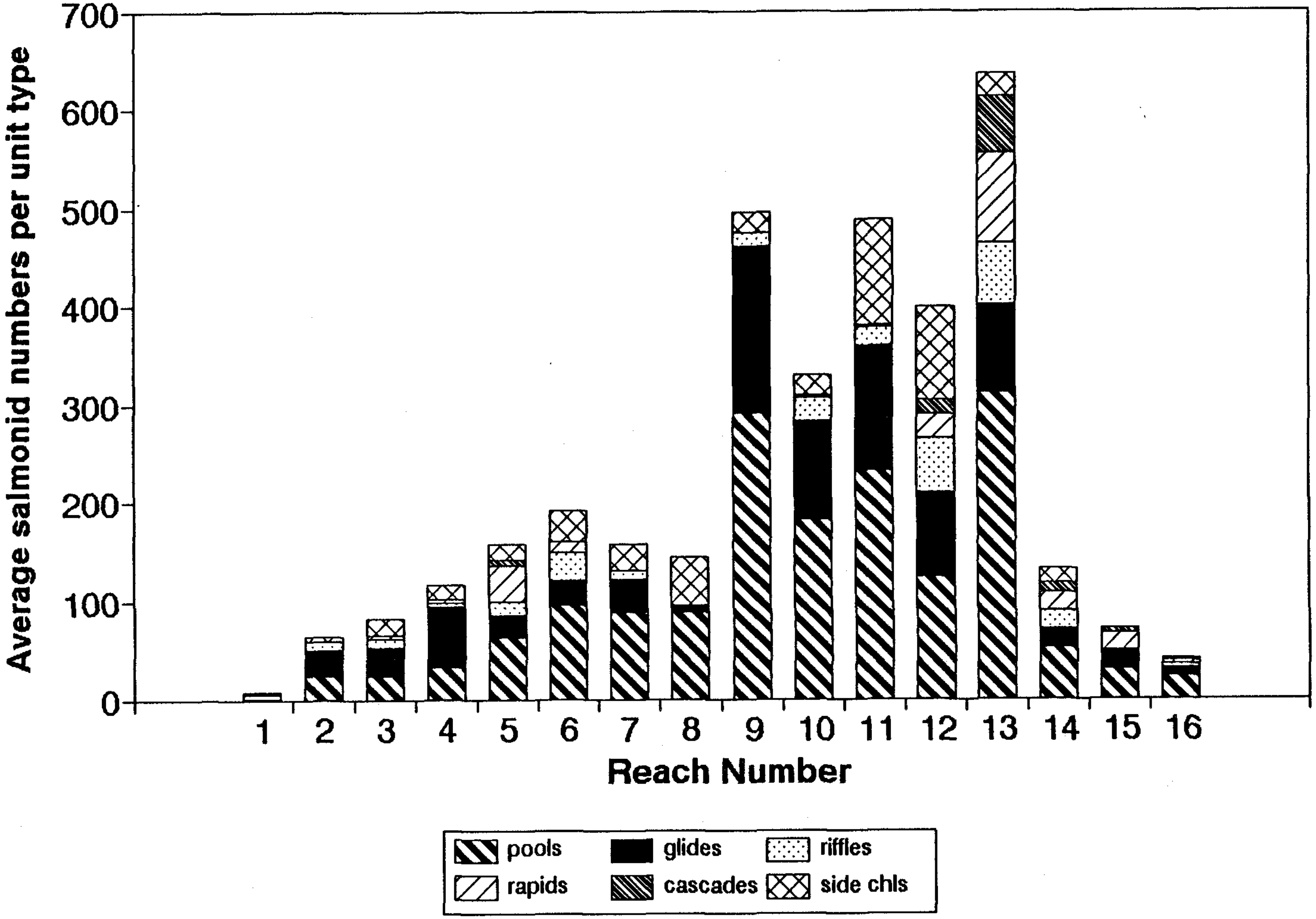


Figure 24. Average numbers of juvenile coho salmon by channel unit type for the Drift Creek reaches (1989 survey).

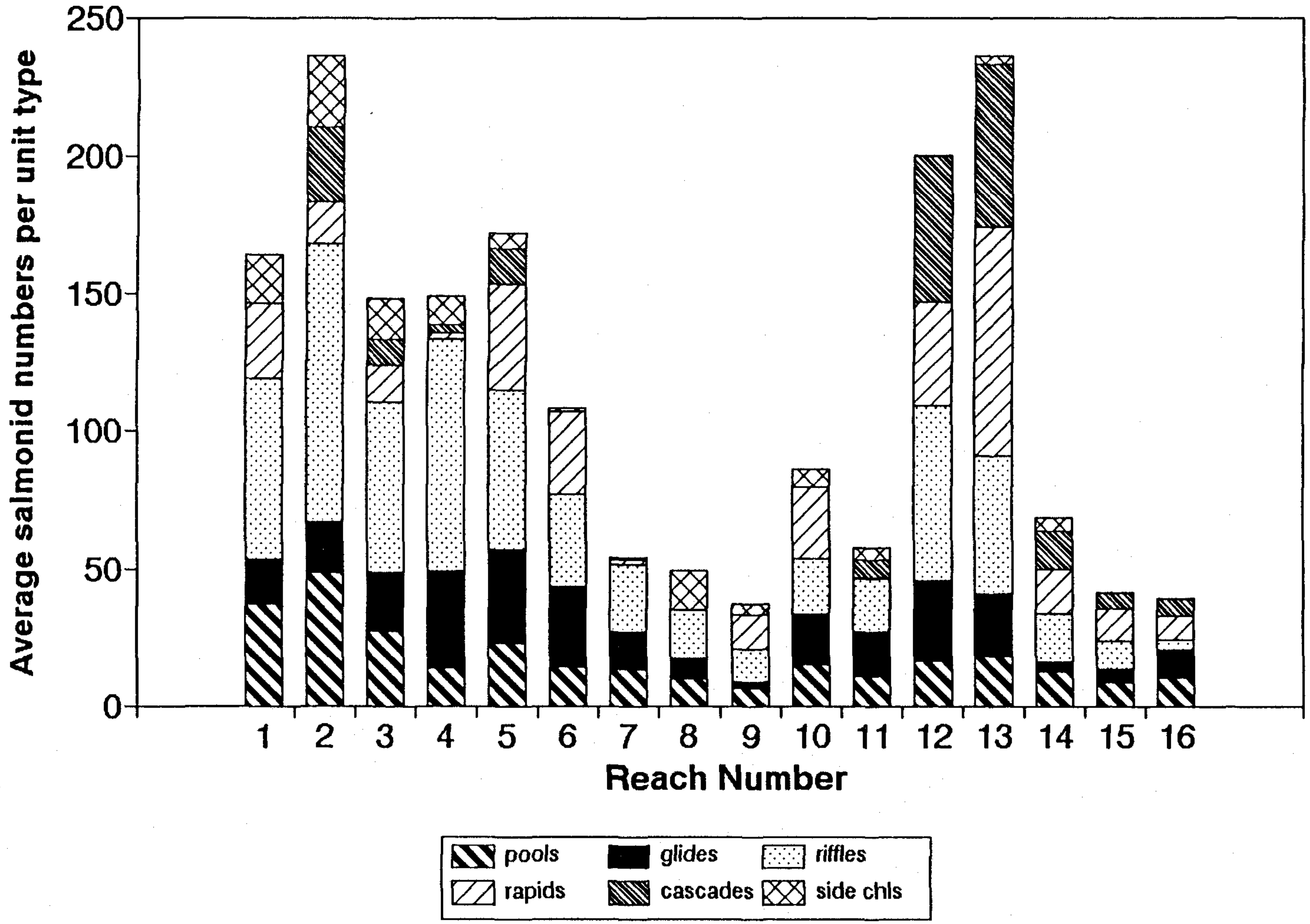


Figure 25. Average numbers of trout fry (age 0+) by channel unit type for the Drift Creek reaches (1989 survey).

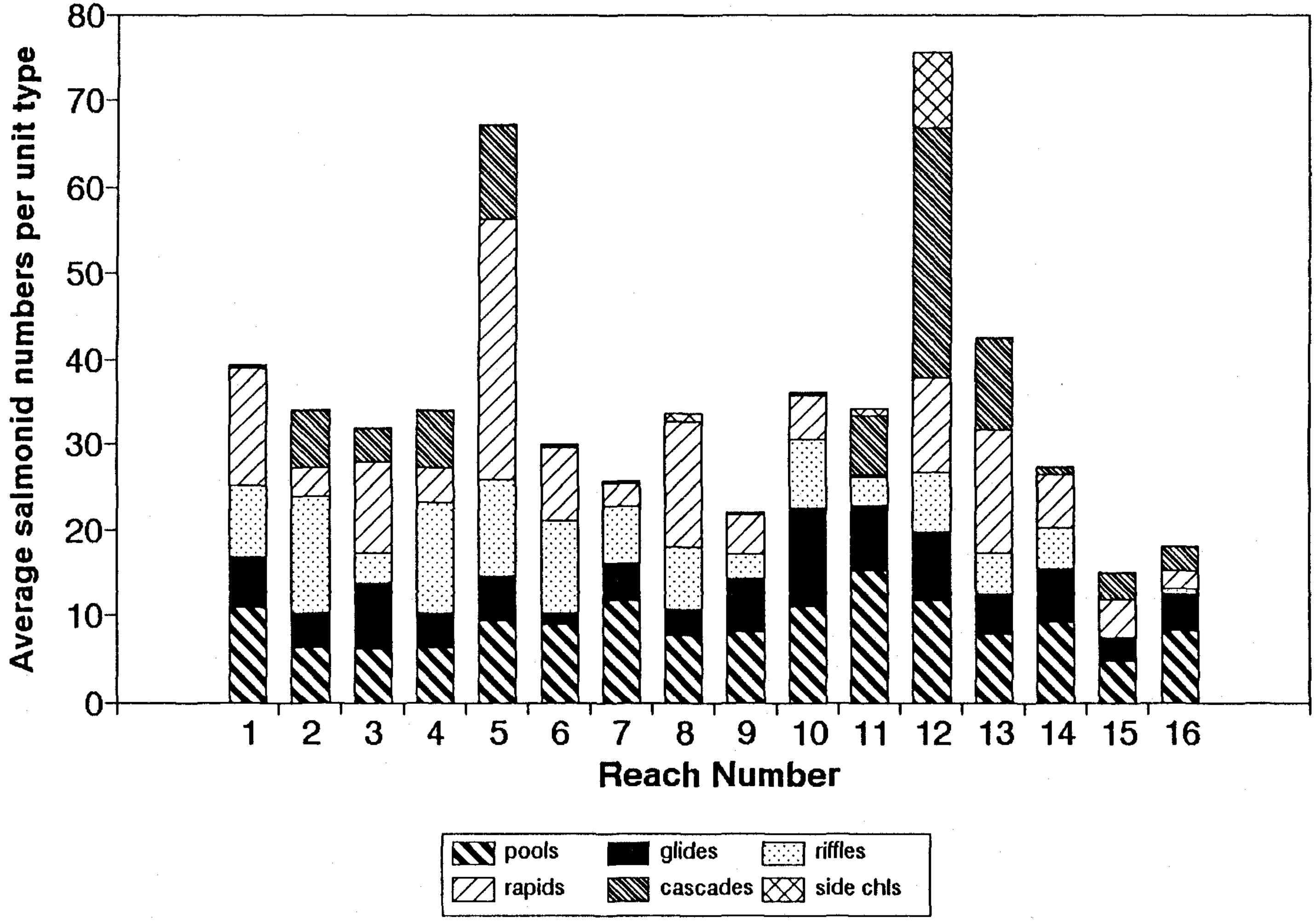


Figure 26. Average numbers of trout (age 1+) by channel unit type for the Drift Creek reaches (1989 survey).

Table 13. Electivity of salmonids for channel unit type for Drift Creek reaches (1989). Values: (+) indicate greater use and (-) indicate less use. Blanks indicate channel unit type not present in reach.

JUVENILE CHINOOK SALMON

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	+0.07	+0.08	+0.04	-0.13	-1.00	-0.85
2	-0.20	+0.36	+0.17	-0.63	-0.59	-1.00
3	-0.07	-0.03	-0.17	+0.34	+0.86	-1.00
4	+0.05	+0.30	-0.16	-0.16	+0.22	-0.84
5	-0.24	+0.07	+0.17	+0.39	+0.07	-0.97
6	+0.06	+0.08	-0.22	+0.68		-1.00
7	-0.07	-0.07	+0.28	+0.45		-1.00
8	+0.06	-0.28	+0.20	+0.17		-1.00
9	-0.08	+0.26	-0.13	+0.02		-1.00
10	-0.04	-0.02	+0.28	+0.02		-0.87
11	+0.03	+0.26	-0.45	-0.92	+0.68	-1.00
12	+0.06	-0.05	0.00	+0.03	-1.00	-1.00
TOTAL	-0.37	+0.96	+0.01	+0.28	-0.76	-11.5

JUVENILE COHO SALMON

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	-0.19	-1.00	+0.24	-0.14	-1.00	+0.47
2	-0.11	+0.31	+0.06	-1.00	-1.00	+0.17
3	-0.10	+0.11	-0.41	-0.02	-1.00	+0.56
4	+0.00	+0.48	-0.77	-0.61	-1.00	+0.30
5	-0.05	-0.16	-0.28	+0.45	-0.24	+0.33
6	+0.09	-0.15	-0.38	+0.50		+0.45
7	+0.06	-0.22	-0.34	-1.00		+0.76
8	-0.08	-0.69	-0.66	-1.00		+0.72
9	-0.04	+0.27	-0.61	-1.00		+0.49
10	+0.19	-0.04	-0.28	-0.76		-0.01

Table 13 continued.....

Juvenile Coho Salmon

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
11	+0.01	+0.05	-0.54	-0.95	-0.24	+0.70
12	-0.13	-0.04	-0.01	-0.50	+0.40	+0.83
13	+0.18	-0.20	-0.31	-0.20	+0.54	+0.35
14	+0.15	+0.38	-0.25	-0.46	+0.93	+0.53
15	+0.40	+0.59	-0.11	-0.38	-0.38	-0.59
16	+0.38	+0.57	-0.14	-0.65	-0.04	-0.27
TOTAL	+0.93	+0.26	-4.78	-7.74	-3.02	+5.80

TROUT (age 0+)

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	-0.11	-0.28	+0.12	+0.05	-1.00	+0.24
2	-0.35	-0.45	+0.46	-0.14	+0.30	+0.37
3	-0.29	-0.30	+0.23	+0.12	+0.74	+0.27
4	-0.51	+0.13	+0.29	-0.80	+0.60	+0.04
5	-0.53	-0.03	+0.35	+0.44	+0.10	-0.19
6	-0.52	+0.21	-0.03	+0.85		-0.75
7	-0.32	-0.15	+0.50	+0.78		-1.00
8	-0.45	-0.23	+0.40	-1.00		+0.68
9	-0.57	-0.48	+0.38	+0.92		+0.76
10	-0.36	-0.22	+0.30	+0.46		+0.11
11	-0.44	+0.09	+0.43	-0.79	+0.87	+0.33
12	-0.66	-0.23	+0.38	0.00	+0.88	-1.00
13	-0.63	-0.37	+0.07	+0.23	+0.80	-0.11
14	-0.24	-0.05	+0.07	-0.24	+0.97	+0.35
15	+0.07	+0.32	+0.71	-0.28	-0.11	-1.00
16	+0.06	+0.63	-0.10	-0.39	+0.48	-1.00
TOTAL	-5.86	-1.41	+4.57	+0.21	+4.64	-1.92

Table 13 continued.....

STEELHEAD TROUT (age 1+)

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	+0.01	-0.04	-0.21	+0.38	-1.00	-1.00
2	-0.75	-1.00	+0.53	+0.35	+0.60	-1.00
3	-0.47	-0.10	-0.49	+0.71	+0.88	-1.00
4	-0.41	-0.32	+0.01	-0.23	+0.97	-1.00
5	-0.64	-0.52	-0.02	+0.71	+0.49	-1.00
6	-0.18	-0.43	+0.12	+0.83		-1.00
7	-0.09	-0.35	+0.29	+0.92		-1.00
8	-0.47	-0.51	+0.18	+0.84		-0.33
9	-0.28	-0.09	+0.11	+0.91		-1.00
10	-0.11	-0.11	+0.41	+0.11		-1.00
11	-0.04	+0.14	-0.04	-0.73	+0.75	+0.20
12	-0.44	-0.27	-0.08	-0.12	+0.91	+0.60
13	-0.37	-0.42	-0.15	+0.23	+0.82	-1.00
14	+0.14	+0.55	-0.27	-0.33	+0.93	-1.00
15	+0.55	+0.72	-1.00	-1.00	-1.00	-1.00
TOTAL	-3.54	-2.75	-0.61	+3.55	+4.35	-11.54

CUTTHROAT TROUT (age 1+)

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	-0.01	-0.15	-0.18	+0.42	-1.00	-1.00
2	-0.18	+0.03	+0.28	-0.51	+0.47	-1.00
3	-0.05	-0.03	-0.24	+0.49	+0.77	-1.00
4	-0.07	-0.15	+0.16	-0.06	+0.83	-1.00
5	-0.31	-0.37	+0.10	+0.60	+0.37	-1.00
6	-0.11	-1.00	-0.16	+0.90		-1.00
7	+0.11	-0.28	+0.18	-1.00		-1.00
8	-0.28	-0.38	+0.09	+0.80		-0.25
9	-0.26	+0.32	-0.27	+0.84		-1.00

Table 13 continued.....

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
			Cutthroat Trout (age 1+)			
10	-0.08	+0.06	+0.03	+0.23		-1.00
11	-0.01	-0.29	-0.33	-0.92	+0.95	-1.00
12	-0.44	-0.53	-0.45	-0.13	+0.92	+0.75
13	-0.20	-0.16	-0.40	+0.17	+0.79	-1.00
14	+0.02	+0.54	+0.02	-0.22	-1.00	-1.00
15	+0.27	+0.49	-1.00	-0.29	+0.12	-1.00
16	+0.34	+0.59	-0.59	-0.60	+0.45	-1.00
TOTAL	-1.25	-1.32	-2.76	+0.72	+3.67	-13.50

comparison of salmonid use of channel units by unit availability.

Juvenile chinook salmon used a broad range of channel unit types from pools to cascades, and did not change proportionally between basin reaches (Fig. 23). By total numbers in the basin, 93.4% of juvenile chinook occupied pools, glides, and riffles (Fig. 22). By basin reaches, glides, riffles, and rapids were used to a greater extent than their relative availability (Table 13). Side channels were occupied rarely; they were used in reaches 1, 4, 5, and 10 with less than 5 fish per unit (Table A.8). For cascades, juvenile chinook showed a variable occupancy with electivity values ranging from 0.86 to -1.00.

Juvenile coho salmon predominantly used pools and glides as shown by average numbers per unit (Fig. 24). By total numbers in the basin, 84.5% of juvenile coho occupied pools and glides (Fig. 22). By basin reaches, pools, glides, and side channels were used to a greater extent than their relative availability (Table 13). Thus in Drift Creek, juvenile coho generally occupied slow-water units. Two other exceptions where fast-water units were occupied to a greater extent than unit availability occurred in reaches 1 - 2 with riffles and 5 - 6 with rapids (Table 13). Pools were least used in lower basin reaches 1 - 5, and most used in South Fork Drift Creek reaches 15 - 16. In South Fork Drift Creek reaches 15 - 16, side channels were not as strongly occupied compared to downstream reaches (Table 13). Reach 13, the reach with highest densities of juvenile coho used a broader range of channel units (Fig. 24). Cascades in reaches 12 - 14 had electivity values from 0.40 to 0.93.

Trout (age 0+) primarily occupied fast-water units, where 76.2% by total numbers in the basin occurred in riffles, rapids, and cascades (Fig. 22). These fast-water units were used to a greater extent as to channel unit availability (Table 13). In reaches 7 - 9, average numbers of trout (age 0+) per channel unit declined compared to all other reaches (Fig. 25). These reaches were low-gradient reaches that contained 80% slow-water units. In South Fork Drift Creek (reaches 15 - 16), trout age 0+ showed a greater use of pools as compared to downstream reaches (Table 13). Riffles and rapids were shallow (means ranged from 0.09 to 0.18-m) in these reaches compared to downstream (Table A.9). Use of side channels were variable throughout the basin reaches (Table 13). By total numbers in the basin, 1.3% of trout (age 0+) occupied side channels (Fig. 22).

Steelhead and cutthroat trout (age 1+) were similar in basin use of channel units by percent total numbers (Fig. 22) and electivity (Table 13). Approximately 60% by total numbers of trout (age 1+) used pools and glides (Fig. 22). By basin reaches, riffles, rapids, and cascades were used to a greater extent than their relative availability (Table 13). Pools and glides were used to a greater extent proportionally in the South Fork Drift Creek reaches (14 - 16) than downstream reaches (Table 13). Riffles and rapids were shallow in these reaches compared to downstream (Table A.9). Among basin reaches, average numbers of trout (age 1+) were constant for slow-water units at approximately 5 - 10 per unit, while they were variable for fast-water units at approximately 15 - 50 per unit (Fig. 26). Reach 12 was unusually high in use of side channels (electivity equals 0.60). In most reaches, side channels were used rarely as shown by electivity values between -1.00 and 0.20 (Fig. 26, Table 13).

DISCUSSION

Geomorphology

Drift Creek is a coastal Oregon stream that lies in a mountainous, conifer-forested landscape. It drains an 180 km^2 watershed which flows to the Alsea Bay (Fig. 4). The landscape of the central Oregon Coast Range began to carve into the present-day drainage patterns about 2 - 5 million years ago through the Tyee sandstone around competent igneous sills (Table A.3). About 1 - 2 million years ago regional faulting and mass movements shifted large blocks of sandstone. The Drift Creek drainage surrounds Table Mountain, an igneous sill, and portions of Drift creek has weathered massive faulting (Snavely et al. 1976). Major geologic events have left imprints on the landscape of the Drift Creek watershed. A watershed is composed of a network of valley landforms that extend from headwaters to estuary (Gregory et al. 1990). Valley landforms provide a template for channel characteristics (Sullivan et al. 1987, Grant et al. 1990). Spatiotemporal scales of channel features have been organized hierarchically that relate development and persistence of valley landforms and channels (Frissell et al. 1986, Gregory et al. in press). Segments, reaches, and channel units were the geomorphic scales examined in this Drift Creek study.

Segments distinguish pattern between landscape and valley corridor characteristics that have evolved over geologic time in the range of 10^4 - 10^5 years (Table 1). In Drift Creek, four segments were associated with major geologic features of the landscape. The lower segment lies a wide alluvial valley developed by the Pleistocene rising and lowering of the ocean. The mid-lower segment is a canyon where Drift Creek flows through competent sandstone bedrock. The mid-upper segment contains a wide valley shaped by regional faulting of the sandstone. Faulting in this area may be a result of softer beds of sandstone containing more siltstone, or beds being less thick than non-faulted areas downstream (Fred Swanson, U.S. Forest Service, PNW Forest Research Laboratory, pers. comm.). In this segment, earth-flows and landslides formed geomorphic surfaces that are longitudinally extensive. A major landslide (Holocene age) from the Table Mountain sideslope located just above the Meadow Creek confluence created a wide valley floor of thick alluvium extending up to Bohannon Ranch Falls. The upper segment and tributaries are geologically younger, and have steep hillslopes that are prone to landslides.

Segment boundaries were identified by a basin longitudinal profile of VFWI, and were associated with changes in valley sideslope gradients (Figs. 5 and A.1). The mid-lower and upper segments had narrow valleys with steep sideslopes. The lower and mid-upper segments had wide valleys with moderate gradient sideslopes. Narrow valleys were more variable in VFWI than wide valleys. VFWI of the upper segment were most variable reflecting the younger geology.

In the Drift Creek basin, associations between lateral characteristics of segments (by VFWI) and longitudinal stream profile were revealed by Hack stream-gradient and stream power analyses. Hack stream-gradient and stream power indices were greater in segments with steep valley sideslopes (canyons) and lower in segments with moderate valley sideslopes. Shifts in these index values did not coincide exactly at segment boundaries, as demarcated by shifts in VFWI), but general patterns were observed longitudinally in the basin. In a northern California coast basin, stream power identified the basin position of an inner gorge (canyon) landform (Kelsey 1988). The distinction between low-gradient and high-gradient streams occurs at approximately 2% slope (Grant et al. 1990). In Drift Creek, this occurred at the boundary between the mid-upper and upper segments at Bohannon Ranch Falls.

Valley characteristics of segments provide a template for reach-scale geomorphic processes, as recognized in Drift Creek basin by certain patterns in channel structure. Multiple channel occurred more often in reaches located in the mid-lower and upper segments, where there are narrow valleys with steep hillslopes. These segments of narrow valleys had greater densities of large roughness elements. CWD and boulders influence channel morphology, particularly in the formation of pools (Heede 1972, Keller and Swanson 1979, Andrus et al. 1988) In Drift Creek, boulders occurred in high numbers among reaches of the mid-lower and upper segments (> 450/km) compared to other reaches (< 350/km). Boulders were a dominant pool-forming element in most reaches of the mid-lower and upper segments where boulders accounted for 32% of the 6 possible elements compared to 13% in the lower and mid-upper segments. The upper segment had greater volumes of CWD in contrast to all other segments. In the tributary reaches of South Fork, CWD volumes were greater by 50 - 80% compared to all downstream reaches, and CWD was the dominant pool-forming element.

Reaches incorporate patterns of valleys and channels influenced by interaction of hillslope geomorphic processes and fluvial sorting of sediments within the channel. These processes create landform features that persist for 10^3 - 10^4 years (Table 1). Valley floor landforms, hillslope gradients, stream-bed gradient, and tributary junctions determine channel characteristics of reaches. Valley floor landforms and sideslope gradients influence the input rate of material from the hillslopes to channels (Swanson et al. 1987). A wide valley floor buffers the active channel from hillslope material inputs. Input rates of hillslope material into the active channel are potentially higher in reaches with steep sideslopes. Stream bed gradient influences the aggradation and degradation of channels and the formation of channel and valley floor (Leopold and Maddock 1953, Wolman and Leopold 1957, Wolman and Miller 1960). Tributary junctions are potential locations for the deposition of coarse sediments and woody debris from high flows and debris torrents.

Reach boundaries were identified primarily by changes in active channel width and condition of geomorphic surfaces longitudinally along Drift Creek. These changes coincided with shifts in channel bedform gradient. Basin patterns of Hack-stream gradient and stream power indices reflected these longitudinal changes in channel gradient. Tributary junctions have been used to delineate segment boundaries because they represent a position that has persisted over geologic time (Frissell et al. 1986). This may be true, but reach-scale geomorphic processes that shape the present-day channel in low-gradient mainstem areas occur between major tributary junctions. In mainstem Drift Creek, major tributary junctions marked changes in active channel width and conditions of geomorphic surface. Channels that were either hillslope-constrained or incised were delineated by basin patterns of reduced channel widths.

Reaches of low-gradient and high-gradient streams differ in the relative degree that channels are influenced by hillslope or fluvial geomorphic processes. In both low- and high-gradient reaches, interactions between hillslope and channel geomorphic processes are critical determinants of valley development, but fluvial mechanisms are of greater importance in downstream portions of the drainage network (Sullivan et al. 1987). In high-gradient streams of the Oregon Cascades, reach-scale definitions of constrained and unconstrained channels have relied on the VFWI, where VFWI < 2 defined constrained channels and VFWI > 2 defined unconstrained channels (Grant et al. 1990). In a high-gradient stream of the Oregon Cascades, greater channel complexity of margins, backwaters, and side channels occurred in unconstrained channels with VFWI > 2 (Moore and Gregory 1990). In low-gradient mainstem reaches of Drift Creek, incised channels can not be delineated by these VFWI definitions. Incision of the channel occurred when the valley floor was composed of thick alluvium. Incised channels were constrained by high terraces, even though their geomorphic setting occurred in wide valley floors. From an ecological perspective, incised channels are constrained because they represent simplified channels with less diverse stream habitat than a more complex channel that can migrate position laterally along a valley floor. In Drift Creek, multiple channels were less abundant in reaches with incised channels (an average of 5.5% by reach length) than all other reaches (an average of 11.9% by reach length). Channel incision results from degradation in a bedload-starved reach of stream (Richards 1982). In the incised channels of Drift Creek, the dominant pool-forming element was bedrock, forming 85 - 95 % of the pools in these reaches.

In the Drift Creek reaches, channel structure (e.g., sediment composition, boulder density, and CWD volume) exhibits high variability among landform types of hillslope-constrained, incised, unconstrained in a narrow valley, and unconstrained in wide floodplains. Gravel abundances lacked consistent patterns among the Drift Creek reaches with landform types. Low-gradient reaches (7 - 9) had areas of spawning gravel that ranged from 0 - 111 m^2. Some reaches had more gravels as a dominant substrate type (> 13% by length) than others, and several physical factors may account for the higher amounts of gravels in these reaches. In reaches 2, 5 - 7, and 9, geomorphic surfaces provided a stored source of material. Abundant boulders in reaches 5 - 7 may have enhanced retention of gravels. In-channel CWD was more abundant in reaches 14 - 16, thus providing greater retention. CWD is effective in retaining sediment in smaller tributary streams (Bilby and Ward 1988). In Drift Creek, the highest percent (by area) of spawning gravels (> 2%) occurred in the upper two tributary reaches of South Fork. Variability in boulder densities depend on local hillslope conditions that determine rates of inputs. An old debris torrent near the confluence of Slickrock Creek contributed high numbers of boulders (1578/km for reach 5). In mainstem reaches, channels were primarily composed of bedrock and boulders, lacking abundant accumulations of CWD. Variability of CWD volumes in the mainstem Drift Creek may be an artifact of land-use influences. Veldhuisen (1990) suggested that low volumes of CWD in Drift Creek compared to other basins may be a result of salvage operations after timber harvest.

In Drift Creek, channel unit morphology was linked to reach-scale bedform gradient. Percent length of slow-water units was inversely correlated to reach gradient, thus pools and glides comprised greater proportion of channel length in low-gradient reaches. Channel unit types differ significantly by bedslope (Grant et al. 1990). Thus, it appears the cumulative percentage of each unit type sums to the total reach gradient. In five Oregon drainages, stream reaches classified by gradient-based criteria in Rosgen (1985) were similar in composition of channel unit types (Reeves and Everest in press). From a basin perspective, overall composition of channel unit types appears to be strongly influenced by bedform gradient. Occurrence of fast-water units, primarily cascades, commonly reflects constraint by adjacent hillslopes in narrow valleys.

Salmonid Distribution and Abundance

Specific landscape features within watersheds influence distribution and composition of aquatic biota (Swanson et al. 1988, Gregory et al. in press). In Drift Creek, Alsea River Bay and Table Mountain are dominant landscape features. The lower 5 km of Drift Creek is tidally influenced (below the confluence with Lyndon Creek) before flowing into the Alsea River Bay. Life history and distributional patterns of fall chinook in a south-Oregon coastal drainage showed significant use of the estuary and lower mainstem for juvenile summer-rearing (Riemers 1971, Stein et al. 1972). The extent Drift Creek's estuary affects summer-rearing patterns of juvenile chinook is not known, but juvenile chinook were of greatest abundance in the lowest (surveyed) basin reach. Juvenile spring and fall chinook occupied the fourth- to fifth-order mainstem during mid-summer below Bohannon Ranch Falls (Fig. 2). Juvenile coho salmon and steelhead trout occupied the mainstem and tributaries with less than 4% gradients. Table Mountain is composed of igneous sill. Tributaries that drain Table Mountain are steep and contain only cutthroat trout.

In Drift Creek, basin patterns of salmonid distribution and abundance were observed by longitudinal profiles of abundances at segment, reach, and channel unit scales. General patterns include: juvenile chinook salmon were more abundant in the lower basin, juvenile coho salmon were more abundant in the upper basin, trout (age 0+) were slightly more abundant in the upper basin, and juvenile steelhead trout (age 1+) and cutthroat trout (age 1+) were distributed throughout the study area. Juvenile chinook and coho salmon had strong basin gradients of abundance along an upstream-downstream continuum, whereas trout (age 1+) exhibited no major patterns. The basin transition where dominance changed between juvenile chinook and coho occurred near the boundary of the mid-lower and mid-upper segments (approximately 16 - 20 km upstream from the Lyndon Creek confluence.

Segments provide a valuable context for examining salmonid distribution and abundance because this geomorphic scale reflects long-term geologic processes and pattern. Juvenile chinook and coho salmon partition the Drift Creek basin near a segment boundary and in proximity of a major basin slope-break. Life history patterns at a basin scale may have evolved by interactions between salmonids and past segment-scale geomorphic settings. The stock concept implies genetic and homing characteristics of anadromous salmonids are derived from the long-term interaction of species and local "basin" environment (MacLean and Evans 1981).

In Drift Creek, salmonid use of channel units within the basin differed between the upper segment (and tributaries) and lower mainstem segments, linear and areal densities per channel unit were 2 to 8 times greater in the upper segment. Discrete shifts in salmonid densities occurred at the boundary between the mid-upper and upper segments, and particularly at the confluence of South Fork Drift Creek with Drift Creek which forms a fourth-order stream. These shifts in densities were most pronounced for cutthroat trout (age 1+), and excluded juvenile chinook because their anadromous limit occurred at Bohannon Ranch Falls, the boundary between the upper-most segments. This shift in salmonid densities coincided with a shift in reduced size of channel units, and with a change in habitat electivity to greater use of pools and glides. From a basin perspective, there appears to be greater "packing" of juvenile coho and trout (ages 0+ and 1+) in channel units, mostly of pools and glides in the upper segment and tributaries.

Waterfalls, debris dams from landslides, and high-gradient reaches can be barriers to anadromous fish migrations and influence basin patterns of salmonid distribution and abundance. The effectiveness of these landforms to limit upstream migration depends on seasonal hydrology. In Drift Creek, the mid-lower segment has characteristics of a gorge and contains a few long cascade channel units; its overall gradient ranges from 0.5 to 0.9%. This inner gorge potentially limits upstream migration of adult salmonids during low-flow conditions. Bohannon Ranch Falls, a distinctive landform in Drift Creek, occurs between the mid-upper and upper segments marking the upper range of juvenile chinook. Above the falls, Drift Creek is greater than 1.8% gradient. The 20-ft high falls has a fish ladder; but prior to construction of the ladder, it may had been a migration barrier. Migration of juvenile coho in upper basin tributaries were limited by debris dams from landslides and streams gradients greater than 4%. Timber harvest induced landslides that block coho migration occurred in North Fork Drift Creek, upper Drift Creek, and upper Trout Creek. Resident cutthroat trout were found above all these migration barriers.

Abundances of all salmonids were not associated with reach summaries of boulder densities, CWD volumes, pool-forming elements, multiple channel lengths, spawning gravels, and dominant substrate types. The only pattern of salmonid abundance observed among the Drift Creek reaches was a correlation of trout with gradient; abundances of trout (ages 0+ and 1+) were greater in higher gradient reaches of the mainstem. In the low-gradient reaches (7 - 9) of 0.32 - 0.37% slope, trout were least abundant compared to all other Drift Creek reaches. Habitat electivity by trout (ages 0+ and 1+) showed greater use of fast-water units as to their reach availability. In Drift Creek, percent length of slow-water channel units was inversely correlated with reach gradient. Thus, trout tend to occupy fast-water units, and fast-water units were more abundant (by percent length) in higher gradient reaches. In Rocky Mountain streams, trout standing stock was inversely correlated with gradient (Lanka et al. 1987).

The pronounced basin gradients of abundance of juvenile chinook and coho along an upstream-downstream continuum may override habitat influences (i.e., channel structural elements and morphology) on reach patterns of abundance. Juvenile chinook and coho salmon were not associated with reach gradient. Lack of pattern at the reach scale for salmon species compared to trout species may be a result of their life history differences. Chinook and coho parr mostly occupy freshwater for one year, however trout occupy freshwater for 1 - 5 years, and portions of their populations are residents. Differential migration of juvenile chinook and coho within a local population after emergence and during the spring may influence basin patterns of distribution and abundance. Downstream migrants prior to smolting can travel extensive distances in a basin and compose a large portion of local populations (Chapman 1961, Chapman 1966, Riemers 1971, Au 1972, Stein et al. 1972, Lindsay 1975).

Along mainstem Drift Creek reaches, composition of channel unit types was more important in determining trout distribution and abundance than amounts of channel structural elements. This illustrates an effect of scale on patterns of salmonid abundance. Trout were not correlated to boulder densities in stream reaches. Within channel units, juvenile trout utilized areas next to boulders more than other stream locations. This spatial association between trout and boulders was also observed in streams in Idaho (Everest and

Chapman 1972). A basin correlation by reach summaries of boulder densities assumes a linear relationship. The relationship may not be linear, but rather asymptotic. Boulder densities may influence salmonid abundance up to a threshold and then have no additional effect.

Reaches are a useful scale to examine salmonid productivity because composition of channel unit types were correlated with reach gradient. Composition of channel unit types affects salmonid productivity by feeding efficiency (Mundie 1969), density-dependent mechanisms of food and space (Chapman 1966, Allen 1969), and interspecific and intraspecific interactions that segregate juveniles by channel unit type (Hearn 1987). Reaches provide a context to evaluate habitat use differences by channel unit availability (through electivity). In Drift Creek, juvenile coho tended to use pools and glides, trout (age 0+ and 1+) used fast-water units, and juvenile chinook used all units. Juvenile chinook and coho salmon were more variable in channel unit use than the trout as observed by electivity. Juvenile coho occurred in greatest abundance in reaches (12 - 14); juvenile coho use of cascades were greater in these reaches compared to all other Drift Creek reaches. Total abundances of salmonids were lower in low-gradient reaches (7 - 9) than adjacent upstream and downstream reaches. These reaches comprised greater than 75% slow-water units by length, and pools were long up to 400 m. Salmonid linear and areal densities in tributary reaches were much greater than in mainstem reaches. In the tributaries reaches, frequency of channel units were greater, and juvenile coho and cutthroat trout (age 1+) both occurred primarily in pools because riffles were too shallow.

In the Drift Creek mainstem, salmonid abundances at tributary junctions were not significantly different between upstream and downstream 100-m sections. Downstream sections were hypothesized to have greater salmonid abundances than upstream sections because they are potential sites for greater in-channel complexity from tributary contributions of large roughness elements. At each tributary junction, upstream and downstream sections were different in composition of channel unit types, which likely contributed to the lack of pattern since salmonids exhibit strong patterns of habitat use by channel unit types. Complexity of channel structure was not examined in detail by the experimental design, thus interpretation of results is limited.

A basin perspective was important in the interpretation of patterns of salmonid distribution and abundance at various scales within a drainage network. Though the hierarchy of basin morphology was able to identify some patterns of physical characteristics between spatial scales, variability in abundance of channel structural elements was still high, especially among reaches. This variability in channel characteristics reflects heterogeneity in the landscape. Salmon and trout species exhibited different patterns among the spatial scales. Juvenile coho salmon occupied pools to a greater extent, but their abundance was dependent on basin position. Both juvenile chinook and coho salmon exhibited sharp gradients in patterns of abundance within the basin. Trout (ages 0+ and 1+) occupied fast-water channel units to a greater extent along the mainstem, and their abundance was associated with reach gradient. Salmonid abundances were not related to any specific reach landform from a basin perspective (i.e., unconstrained valley, alluvial valley with unconstrained channel or with incised channel). Basin location and composition of channel unit types were the principal determinants for basin patterns of salmonid distribution and abundance in Drift Creek.

CHAPTER III: LAND-USE INFLUENCES ON STREAM HABITAT AND SALMONID ABUNDANCE IN THE DRIFT CREEK TRIBUTARIES

INTRODUCTION

Many studies have examined effects of forest practices on stream habitat and salmonid populations with varied results. Stream habitat as characterized by channel morphology has been shown to be altered after clearcut logging, but this is not always the case. After timber harvest, morphological changes to the stream are a result of accelerated sediment production and routing through streams by debris flows, stream bank erosion, and removal of in-channel woody debris (Swanson et al. 1987). Rates of these geomorphic processes are, in part, determined by valley landform type (Grant et al. 1990). Population responses of salmonids to logging are complex; both decreases and increases in densities and biomass have been observed during summer rearing periods (Table 14). Population responses to physical changes of habitat are species-specific.

Channel morphology frequently is altered after clearcut logging. In the mainstem of Carnation Creek, channels straightened, stream banks eroded, and channel cross-sectional areas decreased in two of three clearcut logged sites (Hartman et al. 1987). In southwest Washington streams, frequency of pools and riffles was lower after stream clearance of woody debris in clearcut sections than in undisturbed, old-growth sites (Bisson and Sedell 1984). In addition, pool volumes decreased, and riffle volumes increased in clearcut stream sections.

Some studies have shown channel morphology not to be altered after timber harvest. In the Alsea Watershed Study (AWS), parameters of channel morphology (pool/riffle ratio, mean depth, mean width, and percent spawning gravel by area) were not significantly different before and after clearcut logging (Moring 1975). In ten streams of the Oregon Coast Range, parameters of

Table 14. Past studies of timber harvest effects on salmonid populations (summer-rearing). Results of intensive before and after study designs are simplified to increase (I), decrease (D), or no change (NC) after logging; and results of post-treatment study designs are simplified to logged sites were greater than (G), less than (L), or not different than (ND) unharvested sites.

Intensive Before and After Study Designs

Study Name	Study Location	Species and Measurement	Result in logged stream	References
Alsea Watershed Study	Central Oregon Coast Range	coho density coho biomass cutthroat density cutthroat biomass	**NC** **NC** **D** **D**	Hall and Lantz (1969); Moring and Lantz (1975)
Carnation Creek Study	Carnation Creek, B.C.	coho density cutthroat density steelhead density	**I** **NC** **D**	Hartman et al. (1987)

Post-treatment Study Designs

Study Design	Study Location	Species and Measurement	Result in logged stream	References
Paired stream sections; intensive post-treatment design	Jump Creek, Vancouver Island, B.C.	trout (all ages) includes rainbow cutthroat density biomass	 **L** **L**	Narver (1972)

Table 14 continued.....

Study Design	Study Location	Species and Measurement	Result in logged stream	References
Paired stream sections; intensive post-treatment design	Wolf Creek, Vancouver Island, B.C.	coho density (in tributary)	**L**	Narver (1972)
		coho density (in mainstem)	**ND**	
		trout (age 0+) density (in tributary)	**G**	
		trout (age 0+) density (in mainstem)	**G**	
		trout (age 1+) density (in tributary)	**ND**	
		trout (age 1+) density (in mainstem)	**G**	
Extensive before and after treatment design; ten stream sections 152-m in length	Oregon Coast Range	coho density	**D & I**	Moring and Lantz (1974)
		coho biomass	**D & I**	
		cutthroat density	**D**	
		cutthroat biomass	**D**	
		steelhead (age 0+) density	**I**	
		steelhead (age 0+) biomass	**I**	
Intensive post-treatment design; one paired site	Cascade Mountains, Oregon	cutthroat density	**G**	Aho (1977)
		cutthroat biomass	**G**	
Extensive post-treatment design; nine paired stream sections	McKenzie River basin; Cascade Mtns., Oregon	trout biomass	**G**	Murphy and Hall (1981)

Table 14 continued.....

Study Design	Study Location	Species and Measurement	Result in logged stream	References
Extensive post-treatment design; paired stream sections	Oregon central Coast Range, and Cascade Range	salmonid density salmonid biomass	G G	Hawkins et al. (1983)
Extensive post-treatment design; nine paired and seven unpaired stream sites	Washington Coast Range and Cascade Range	salmonid density salmonid biomass coho * cutthroat trout * trout age 0+ * * % of total salmonid density	G G L L G	Bisson and Sedell (1984)
Extensive post-treatment design; ten streams with varying degrees of watershed harvest in two different geologies (sandstone and basalt)	Central Coast Range of Oregon	coho density cutthroat trout density steelhead (age 1+) density trout (age 0+) density	ND ND ND ND	Hicks (1990)

channel morphology were not significantly correlated to area of watershed harvested, except that the number of pools associated with coarse woody debris (CWD) declined with greater timber harvest (Hicks 1990).

Decreases in salmonid abundance and biomass after logging may be a result of physical degradation and instability of stream habitat. Juvenile coho salmon (*Oncorhynchus kisutch*) avoid turbid reaches (Bisson and Bilby 1982), and increased suspended sediment loads have chronic effects on densities and growth of juvenile steelhead trout (*Oncorhynchus mykiss*) and coho salmon (Sigler et al. 1984). Fine sediments in the substrate may be detrimental to egg-to-fry survival of salmonids (Everest et al. 1987). Removal of CWD from the stream channel can reduce available spawning gravels and instream cover (Bisson et al. 1987). Since salmonids (by species or age) partition habitat by channel unit morphology, a physical change in habitat structure may shift species/age composition (Allee 1974, Glova 1978, Bisson and Sedell 1984). After an initial shift in physical habitat, competitive interactions between sympatric populations may further modify community structure for the long term. Long-term declines in cutthroat trout (*Oncorhynchus clarki*) abundance and biomass have occurred in Needle Branch, the clearcut logged site in the AWS (Hall et al. 1987).

Increases in salmonid abundance and biomass after logging may be due to a greater food base as a result of more light energy reaching the stream from the open canopy (Gregory et al. 1987). Logged stream sections have greater amounts of nutrients and annual primary production that contribute to greater aquatic productivity than in forested stream sections (Gregory 1980). In western Oregon, abundances of aquatic invertebrates were greater in streams with open canopies than in forests (Hawkins et al. 1983). Feeding efficiency of cutthroat trout was enhanced under full light conditions than shaded light (Wilzbach and Hall 1985, Wilzbach et al. 1986). Food abundance appears to be more important than cover in determining densities of allopatric cutthroat trout (Wilzbach 1985).

The Drift Creek basin provides an opportunity to examine land-use effects on stream habitat and salmonid abundance within a historical context of the AWS. The AWS investigated three tributary streams of the Drift Creek basin from 1959 to 1973, representing three treatments - unharvested, clearcut in patches with bufferstrips, and clearcut without bufferstrips (Hall and Lantz 1969, Moring and Lantz 1975). An overview of the AWS results can be found in Chapter IV. The AWS was an intensive before-and-after treatment design, that lacks replication of treatments (Hall et al. 1978). The AWS streams and other Drift Creek tributaries serve as treatment replications for a post-treatment study design.

The objectives of this study were to compare geomorphic characteristics of stream habitat and salmonid abundance among three land-use treatments to investigate for effects of timber harvest. Specifically, the objectives were to: 1) investigate potential land-use effects on physical characteristics of stream habitat, 2) examine influences of physical stream characteristics on salmonid abundance, and 3) test for land-use effects on salmonid abundance. In tributaries of Drift Creek, comparisons were made among three treatments: unharvested (the control), clearcut patches with bufferstrips, and clearcut without bufferstrips, replicating the treatment design of the AWS. Treatment replications allowed for an analysis of variability of treatment response, and reexamining the AWS streams provided a long-term perspective.

METHODS

Study Design

In the Drift Creek tributaries, stream sections were identified by their adjacent land-use treatment (i.e., unharvested, clearcut logged with bufferstrips, and clearcut logged without bufferstrips) to expand the number of treatment blocks similar to the AWS streams. Duplicating the AWS design within the Drift Creek basin was difficult because most watersheds were not managed uniformly. Complete watersheds with one uniform treatment of land use were not always found; thus, the study design was based on stream sections with an adjacent uniform treatment of land use. Even this design limited the possible number of sites and led to selection of sites with different geomorphic settings and drainage areas. Tributary sites were chosen in first- to third- order streams (USGS classification) which set an upper limit for drainage area at 11 km^2.

Twenty-one stream sections were selected within the treatment designs (Fig. 27). Sites were identified by aerial photo interpretation before field surveys began. Of the timber harvested sites, logging occurred 5 to 25 years prior to this study's field surveys. Stream sites were surveyed for habitat physical features and salmonid abundances in the summers of 1988 and 1989; only five sites were surveyed in both years. Land-use treatments for specific sites are described in Table 15, and their exact locations (by latitude and longitude) are in Table A.10. Lengths of study sections ranged from 360 m to 2930 m (Table 16).

Basin Analysis

Drainage area above the site's lower boundary and overall site gradient was determined from USGS topographic maps (1:24000 scale). Basin areas,

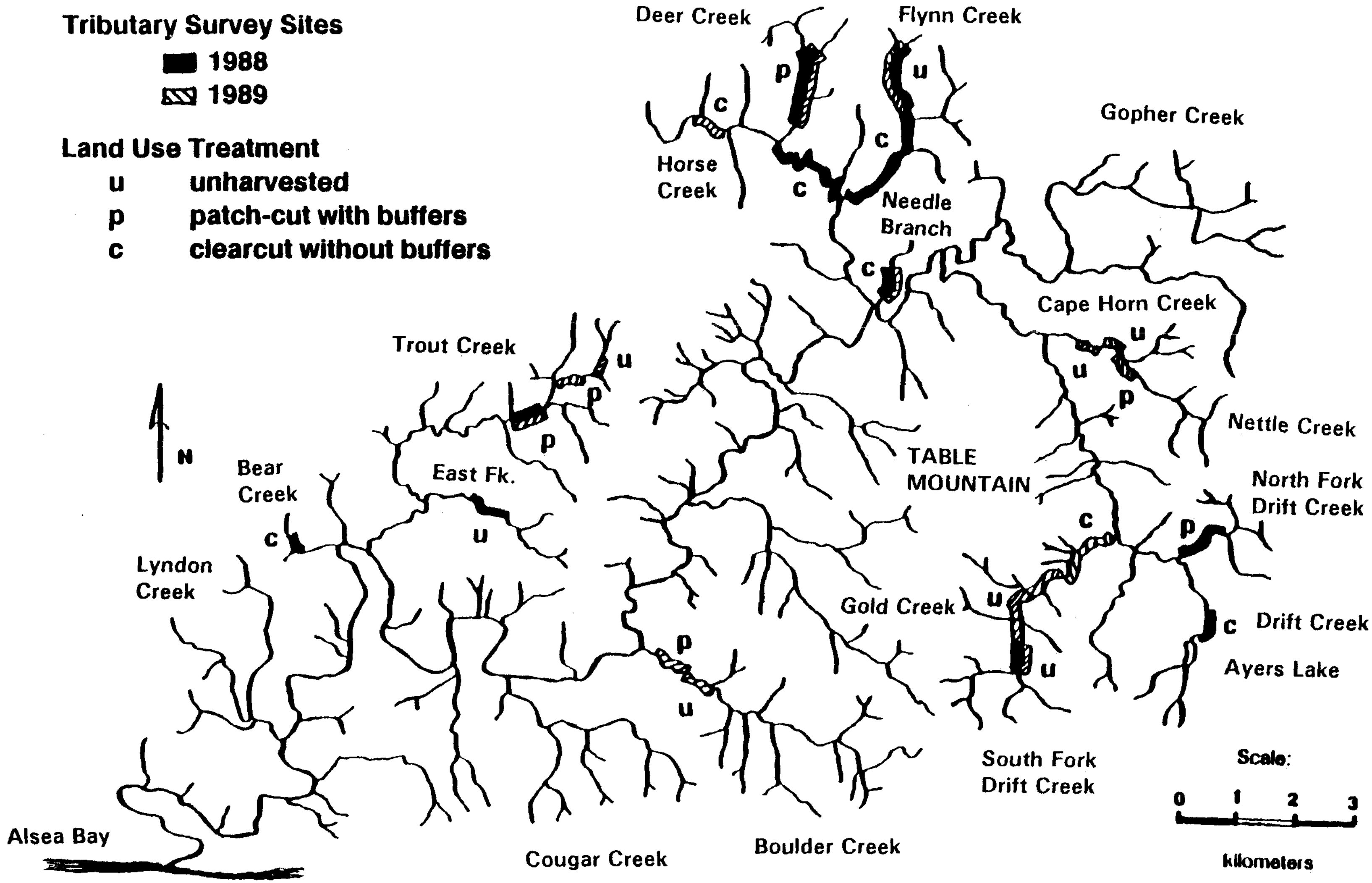


Figure 27. Location map showing Drift Creek tributary sites by land-use treatment and year surveyed.

Table 15. Study site descriptions of Drift Creek tributaries by land-use treatment and basin location.

Tribuary Name	Site Number	Year(s) Surveyed	Land-Use Treatment [1]	Basin Location [2]	Dominant Riparian Veg. [3]	Upstream Land-Use Treatment [1]
Flynn Creek	1	1988, 89	U	M	M	U
Lower Nettle Creek	2	1989	U	M	C	U, P, & C
Mid Nettle Creek	3	1989	U	M	M	P & C
Upper So. Fk. Drift Cr.	4	1988, 89	U	U	C	U
Mid South Fk. Drift Cr.	5	1989	U	U	M	U
East Fork Trout Creek	6	1988	U	L	B & C	U
Upper Trout Creek	7	1989	U	L	C	U & C
Upper Boulder Creek	8	1989	U	L	M	U
Deer Creek	9	1988, 89	P	M	M	P & C
Upper Nettle Creek	10	1989	P	M	H	P & C
North Fork Drift Creek	11	1988	P	U	M	C
Lower Trout Creek	12	1988, 89	P	L	H	U, P, & C
Mid Trout Creek	13	1989	P	L	H	U, P, & C
Lower Boulder Creek	14	1989	P	L	M	U
Needle Branch	15	1988, 89	C	M	A	C
Lower Flynn Creek	16	1988	C	M	B & H	U
Lower Horse Creek	17	1988	C	M	B & H	P & C
Upper Horse Creek	18	1989	C	M	A	C
Upper Drift Creek	19	1988	C	U	A	C
Lower So. Fk. Drift Cr.	20	1989	C	U	B & A	U
Bear Creek	21	1988	C	L	A	C

1 Land-use treatments: unharvested (U), patch-cut with bufferstrips (P), and clearcut without bufferstrips (C).

2 Basin locations: upper basin (U), mid basin (M), and lower basin (L).

3 Dominant riparian vegetation recoreded during field surveys: brush (B), alder (A), hardwoods mix (H), conifer-hardwood mix (M), and conifer (C).

Table 16. Geomorphic characteristics and lengths for Drift Creek tributary sites by land-use treatment.

Tribuary Name	Site Number	Land Use Treatment [1]	Percent Gradient	Drainage Area (km^2)	Stream Order	Geomorphic Valley Type [2]	Site Length (m)
Flynn Creek	1	U	3.7	2.0	2	C	1611
Lower Nettle Creek	2	U	1.0	5.6	2	A	381
Mid Nettle Creek	3	U	1.3	5.2	2	A	358
Upper So. Fk. Drift Cr.	4	U	3.5	3.7	3	C	772
Mid South Fk. Drift Cr.	5	U	4.6	7.7	3	C	1410
East Fork Trout Creek	6	U	7.3	2.6	2	C	671
Upper Trout Creek	7	U	4.4	2.0	2	C	252
Upper Boulder Creek	8	U	5.9	9.9	3	C	547
Deer Creek	9	P	2.1	3.1	2	A & C	2471
Upper Nettle Creek	10	P	2.2	4.9	2	C	566
North Fork Drift Creek	11	P	4.7	2.8	2	C	1033
Lower Trout Creek	12	P	2.8	6.4	3	C	754
Mid Trout Creek	13	P	3.9	2.6	2	C	511
Lower Boulder Creek	14	P	4.4	11.0	3	C	291
Needle Branch	15	C	2.6	0.9	1	A	993
Lower Flynn Creek	16	C	0.7	6.1	3	A	2929
Lower Horse Creek	17	C	0.7	10.4	3	A	2886
Upper Horse Creek	18	C	3.2	1.9	1	C	706
Upper Drift Creek	19	C	4.6	3.5	3	C	914
Lower So. Fk. Drift Cr.	20	C	3.0	9.2	3	C	1594
Bear Creek	21	C	5.7	0.8	1	C	496

1 Land use treatments: unharvested (U), patch-cut with bufferstrips (P), and clearcut without bufferstrips (C).

2 Geomorphic valley types: wide alluvial valley (A), and narrow canyon valley (C) as qualitatively observed from field surveys.

and stream longitudinal distances were measured with a digitizer. Elevation differences for each site were determined by interpolation of contour lines (40-ft intervals) across the stream. Overall gradients were computed by converting all distances and elevations to similar units and dividing elevations by distances. Basin geomorphic characteristics are described in Table 16.

Stream Habitat Measurements

Channel Unit Characteristics

Stream surveys in 1988 and 1989 classified channel units continuously within tributary sections. Channel units were classified as either pool, glide, riffle, cascade, step, or side channel (Table 2). Stream habitat for channel unit types are described in Bisson et al. (1982) and Platts et al. (1983).

Physical dimensions of channel units were estimated by a visual estimation technique and calibrated by direct measurement (Hankin and Reeves 1988). Physical characteristics of stream habitat estimated included channel unit (wetted) length, width, mean depth, and maximum depth. In addition, active channel width at bankfull discharge was visually estimated by observing high-flow markings. Estimates of mean depth were calibrated by an average of six to twelve meter stick measurements, taken in sets of three across a channel unit transect. Maximum depth was the deepest point within a channel unit. In this survey technique, estimates were calibrated by measuring a subsample of the channel units with a 100-m fiberglass tape and meter stick. The frequency of measured channel units by type were as follows: pools - 1/3, glides - 1/4, riffles - 1/4, rapids - 1/4, cascades - 1/2, and side channels - 1/2.

Substrate and Spawning Gravels

Dominant substrate type was recorded at each channel unit during the field surveys. Substrate type categories included the following: wood, clay, silt, sand, small gravel (2-10 mm), large gravel (10-100 mm), cobble (101-300 mm), boulder (> 300 mm), and bedrock. For this analysis, amounts of clay, silt, and sand were categorized together as fine sediment (< 2 mm).

Area of spawning gravel was visually estimated within each channel unit designation. Spawning gravels were substrates in the size range of 10 - 80 mm. For each site, percent spawning gravel was computed by dividing the site total area of spawning gravel by total active channel area.

Coarse Woody Debris

Length and end diameters of each piece of CWD were estimated at each channel unit. Minimum size limits were 2 m in length and 0.15 m in diameter. CWD volumes were computed from these estimates assuming logs as cylindrical shapes. Percent of the log in four major zones of influence was estimated for each piece (Robison and Beschta 1990). Zone 1 was the area in the wetted (summer low-flow) channel. Zone 2 was the area in the active channel at bankfull discharge. Zone 3 was the area directly above zone 2. Zone 4 was the area adjacent to the active channel at bankfull discharge on either bank. Details on collection of CWD field data are described in Veldhuisen (1990).

Salmonid Abundance Estimates

Populations of juvenile coho salmon, trout fry (age 0+), steelhead trout (age 1+), and cutthroat trout (age 1+) were estimated by diver observations.

Trout fry (age 0+) included all trout below 80-mm fork length, which were either steelhead or cutthroat underyearlings. Steelhead trout (age 1+) included juvenile steelhead and resident rainbow trout. The trout (age 1+) group included all trout above 80-mm fork length.

Salmonid abundance was estimated by diver counts within designated channel units. Estimates of salmonid numbers were not verified by electrofishing. Population estimates were a relative measure of abundance, and it was assumed that efficiency of observation was constant between different stream sections.

A subsample of all channel units, stratified by unit type, was dived to estimate salmonid numbers. Frequencies of dived channel units used in the survey were as follow: pools - 1/3, glides - 1/4, riffles - 1/4, rapids - 1/4, cascades - 1/2, and side channels - 1/2. The proportion of total units to dived units for each habitat type was used to compute abundances. Details of computation techniques and statistical explanations for this sampling method are described in Hankin and Reeves (1988).

Habitat Use by Salmonids

Patterns in salmonid habitat use by channel unit types were examined by electivity analysis. Channel unit composition (derived from lengths in Table A.11) was related to average number of fish per channel unit type (Table A.12) at each tributary site. Electivity values for channel unit (habitat) type by each salmonid species or age group were computed using the algorithm by Ivlev in Lechowicz (1982), $E_i = (r_i - p_i)/(r_i + p_i)$. The percent habitat composition for section i is p_i, and percent salmonid composition (by averages for each channel unit type) for section i is r_i.

Statistical Analysis

Statistical analyses included single-factor analysis of variance (ANOVA) and regression models. Land-use effects on salmonid abundance by treatment blocks were tested by ANOVA. Regression models were used to: 1) associate physical stream parameters with each other, 2) associate salmonid abundance with physical stream parameters, and 3) test significance of land-use effects on physical stream parameters and salmonid abundance. Physical stream parameters were expressed as site averages or totals. All regressions models investigated, significant or not, are shown in the result tables.

Regression models with significant correlations between physical stream parameters, and between physical stream parameters and salmonid abundances were used to test effects of land use. A land-use variable was added to these models as allocated codes (Neter and Wasserman 1974). Coded variables were a set of integers (1, 2, and 3). Land-use effects were evaluated by the coded variable p-value.

Regression models were used because of geomorphic differences between sites, and the multitude of physical variables to be tested. Statistical analysis of land-use effects on salmonid abundance incorporated adjustments for differences in geomorphic setting by regression models with coded variables. This statistical approach has its limitations since it forces a relationship between land-use treatments. It assumes that effects of clearcut in patches with buffers is intermediary to unharvested areas and effects of clearcut without buffers.

Treatment sites were assumed to be independent from one another and to have equal variance, normality was tested by use of normal probability plots (STATGRAPHICS software). Five sites were surveyed in both summers, 1988 and 1989. Correlations of physical parameters used only the 1989 data for these five sites. Regression models with salmonid abundance used both 1988 and 1989 data due to the high annual variance associated with salmonid population estimates; this assumed treatment and survey year as an independent response to land-use effects.

RESULTS

Physical Stream Habitat and Land-Use Effects

Channel Unit Composition

Composition of channel unit types differed among sites overall among treatment groups (Fig. 28 and Table A.11). Channel unit composition (percent by length) was significantly related to gradient (Table 17). Percent pools and percent pools and glides combined were inversely related with gradient.

Differences in channel unit composition could not be attributed to land-use effects, because of treatment group differences (Table 18). Percent length of pools was significantly greater in clearcut sites than in patch-cut and unharvested sites. Thus, percent length of pools could not be used in a multiple regression test of inference because of covariance associated with land-use treatment.

Widths and Depths

Active channel width was significantly related to drainage area, increasing with greater drainage area (Table 17). Active channel width was not significantly related to gradient. Likewise, gradient and drainage area of sites were not related to each other. Active and wetted channel widths for each tributary site are reported in Table A.13. Differences in active channel width could not be attributed to land-use effects (Table 18). Regression analysis accounted for stream size by use of drainage area. In the Drift Creek tributaries, stream channels were not widened in logged streams.

Depth measurements were associated with both active channel width and drainage area (Tables 17). Overall mean depths, and maximum depths

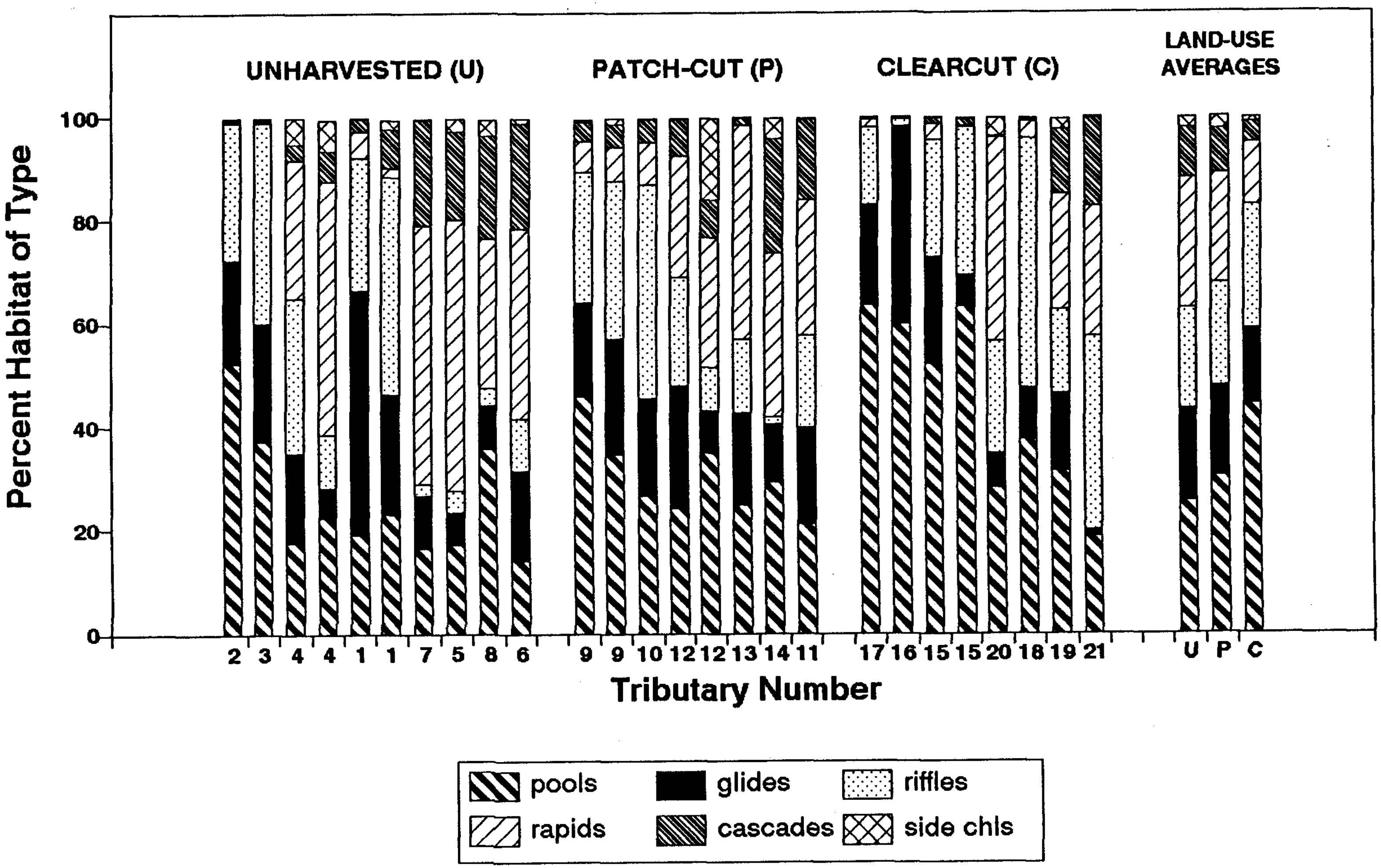


Figure 28. Composition of channel unit types in Drift Creek tributary sites by land-use treatment; sites are ordered by increasing gradient within treatment groups.

Table 17. Correlations between parameters of geomorpholgy and physical stream habitat in the Drift Creek tributaries based on regression analyses. Significance levels are less than 0.10 and 0.05.

Dependent Variable	Independent Variable	Model p-value	significance	& model slope	r^2
gradient	drainage area	0.390		-	0.00
ac width	drainage area	0.001	**	+	0.61
ac width	gradient	0.740		-	0.00
% pools	gradient	0.001	**	-	0.51
% pools+glides	gradient	0.001	**	-	0.60
ome depth	ac width	0.014	**	+	0.25
ome depth	drainage area	0.001	**	+	0.69
ome depth	gradient	0.635		-	0.00
omx depth	ac width	0.004	**	+	0.35
omx depth	drainage area	0.001	**	+	0.59
omx depth	gradient	0.098	*	-	0.09
pme depth	drainage area	0.001	**	+	0.45
pme depth	gradient	0.670		+	0.00
pmx depth	drainage area	0.001	**	+	0.49
pmx depth	gradient	0.205		-	0.03
pool area	gradient	0.060	*	-	0.13
pool area	drainage area	0.021	**	+	0.21
pool volume	gradient	0.134		-	0.07
pool volume	drainage area	0.015	**	+	0.24
spawn % area	gradient	0.118		-	0.13
spawn % area	drainage area	0.246		-	0.02
spawn % area	% pools	0.288		+	0.01
spawn % area	% glides	0.078	*	+	0.12
spawn % area	% riffles	0.109		+	0.09
spawn % area	% pools + glides	0.099	*	+	0.10
spawn % area	% glides + riffles	0.044	**	+	0.16
spawn % area	% pools, glides, riffles	0.039	**	+	0.17
% gravel	% pools	0.009	**	+	0.27
% gravel	% pools + glides	0.013	**	+	0.25
% gravel	% pools, glides, riffles	0.001	**	+	0.47
% gravel	% riffles	0.019	**	+	0.22
% gravel	% riffles + glides	0.009	**	+	0.27
% gravel	gradient	0.008	**	-	0.28
% fine sediment	gradient	0.107		-	0.09
spawn % area	cwd z1	0.625		+	0.00
spawn % area	cwd z1 + z2	0.881		+	0.00
spawn % area	cwd total volume	0.343		-	0.00
spawn % area	cwd pieces	0.301		-	0.01

Table 17 continued.....

Dependent Variable	Independent Variable (s)	Model p-value	significance & model slope		r^2
% gravel	cwd z1 + z2	0.917		-	0.00
% pools	cwd z1 + z2	0.121		-	0.08
% pools + glides	cwd z1 + z2	0.107		-	0.09
% pools	cwd z1 + z2 / % boulder	0.057	*		0.27
pme depth	cwd z1 + z2	0.545		+	0.00
pmx depth	cwd z1 + z2	0.406		-	0.00

<u>Variable Descriptions</u>:

gradient	overall stream gradient
drainage area	drainage area above site's lower boundary
segment type	geomorphic segemnt type classification
ac width	active channel width
% pools	channel unit type, percent by length
% glides	" " " " " "
% riffles	" " " " " "
% pools + glides	" " " " " "
% glides + riffles	" " " " " "
% pools, glides, riffles	" " " " " "
ome depth	site average for overall mean depths
omx depth	site average for overall maximum depths
pme depth	site average for pool's mean depths
pmx depth	site average for pool's maximum depths
pool area	pool surface area average for site
pool volume	pool volume average for site
spawn % area	spawning gravels, percent by channel area
% gravel	percent dominant substrate type, small & large gravel
% fine sediment	percent dominant substrate type, fine sediment
% boulder	percent dominant substrate type, boulders
cwd total volume	coarse woody debris, total volume per stream length
cwd pieces	coarse woody debris, pieces per stream length
cwd z1	coarse woody debris, volume in zone 1 per stream area
cwd z1 + z2	coarse woody debris, volume in zones 1 & 2 per area

Table 18. Effects of land use on physical stream habitat in the Drift Creek tributaries based on regression analysis, including covariance analysis for treatments with parameters of geomorphology and physical stream habitat. Significance levels are less than 0.10 and 0.05.

Part a: Regression models with land use as a coded variable.

Dependent Variable	Independent Variables	Land-Use p-value	significance
% pools	gradient/landuse	0.082	*
% pools + glides	gradient/landuse	0.357	
ac width	drainage area/landuse	0.499	
ome depth	ac width/landuse	0.691	
ome depth	drainage area/landuse	0.797	
omx depth	ac width/landuse	0.383	
omx depth	drainage area/landuse	0.054	*
omx depth	gradient/landuse	0.444	
pme depth	drainage area/landuse	0.269	
pmx depth	drainage area/landuse	0.026	**
pool area	drainage area/landuse	0.005	**
pool volume	drainage area/landuse	0.002	**
spawn % area	gradient/landuse	0.505	
spawn % area	drainage area/landuse	0.670	
% gravel	gradient/landuse	0.911	
% gravel	% pools, glides, riffles/landuse	0.372	
% gravel	% riffles	0.911	
% fine sediment	gradient/landuse	0.324	
% gravel	cwd z1 + z2 /landuse	0.618	
% pools	cwd z1 + z2 /landuse	0.110	

Part b: Regression analysis examining for covariance of parameters of geomorphology and physical stream habitat with land-use treatments.

Dependent Variable	Independent Variable	Land-Use p-value	significance
gradient	landuse	0.271	
drainage area	landuse	0.931	
ac width	landuse	0.649	
spawn % area	landuse	0.712	
cwd z1 + z2	landuse	0.113	

Table 18 continued.....

Dependent Variable	Independent Variable	Land Use p-value	significance
% pools	landuse	0.042	**
% pools + glides	landuse	0.146	
% pools, glides, riffles	landuse	0.104	
ome depth	landuse	0.942	
omx depth	landuse	0.262	
pme depth	landuse	0.453	
pmx depth	landuse	0.145	
pool area	landuse	0.018	**
pool volume	landuse	0.011	**

<u>Variable Descriptions</u>:

landuse	land use treatment classification (coded variable)
gradient	overall stream gradient
drainage area	drainage area above site's lower boundary
ac width	active channel width
% pools	channel unit type, percent by length
% riffles	" " " " " "
% pools + glides	" " " " " "
% pools, glides, riffles	" " " " " "
ome depth	site average for overall mean depths
omx depth	site average for overall maximum depths
pme depth	site average for pool's mean depths
pmx depth	site average for pool's maximum depths
pool area	pool surface area average for site
pool volume	pool volume average for site
spawn % area	spawning gravels, percent by channel area
% gravel	percent dominant substrate type, small & large gravel
% fine sediment	percent dominant substrate type, fine sediment
cwd z1 + z2	coarse woody debris, volume in zones 1 & 2 per stream channel area

(averages of all channel units) were related to active channel width and drainage area. Area, volume, mean depths, and maximum depths of pools during summer low-flow were related to drainage area. Overall maximum depths and areas of pools (summer low-flow) were also associated with gradient, but maximum depths of pools were not (Table 17). These associations with gradient largely reflected stream size or basin position. Site averages for depth measurements are reported in Table A.14.

Maximum depths of the sites and of pools were related to land-use treatment, as analyzed by regression models with drainage area and land use as independent variables (Table 18). Clearcut sites were deeper than unharvested sites. Pool area and volume were significantly different among land-use treatments, but these two variables could not be used in a multiple regression test of inference because of covariance associated with land-use treatment (Table 18).

Substrate and Spawning Gravel

Substrate characteristics were associated with gradient and composition of channel unit types (percent by length) (Tables 17). Percent fine sediment was inversely associated with gradient. Percent gravel included the combined categories of small and large gravels (as measured by dominant substrate type). Percent gravel was associated with gradient and composition of channel types. Percent gravel was most associated with percent pools, glides, riffles combined, than other combinations of these channel units. Larger substrates, such as cobbles and boulders, occurred in rapid and cascade channel unit types. Site summaries of substrate characteristics and spawning gravel are reported in Table A.15.

Percent of the channel containing suitable spawning gravel was associated with composition of channel unit types and weakly associated with site gradient (Tables 17). Spawning gravel was related to various combinations of percent pools, glides, and riffles. Percent spawning gravel by area was most associated with pools, glides and riffles combined (percent by length), which indicated these channel unit types were localized areas of gravel deposition.

Spawning gravel (percent by area) did not significantly differ among land-use treatments (Table 18). Also, percent gravel and percent fine sediment were not significantly different among land-use treatments. Regression models used gradient and land use as independent variables.

Coarse Woody Debris

Volumes of CWD in active channels were not associated with channel unit composition (percent length of pools, and pools and glides), mean and maximum depths of pools, percent spawning gravels, or percent gravel by dominant substrate type (Table 17). Volumes of CWD in active channels were inversely associated with percent pools and percent boulders in a multiple regression. In this regression model, percent boulders was the significant independent variable ($p = 0.0697$). CWD volumes and densities are summarized in Table A.16.

Average volumes of CWD in active channels for clearcut were less than for unharvested sites (Fig. 29). Average CWD volumes were 1.6 m^3 per 100 m^2 area (s.d. = 1.3) in clearcuts and 2.9 m^3 per 100 m^2 area (s.d. = 1.4) in unharvested sites. These two treatment groups were significantly different ($p = 0.10$) as indicated by ANOVA. Volumes of CWD in active channels were weakly associated (by regression) with all three land-use treatments where unharvested

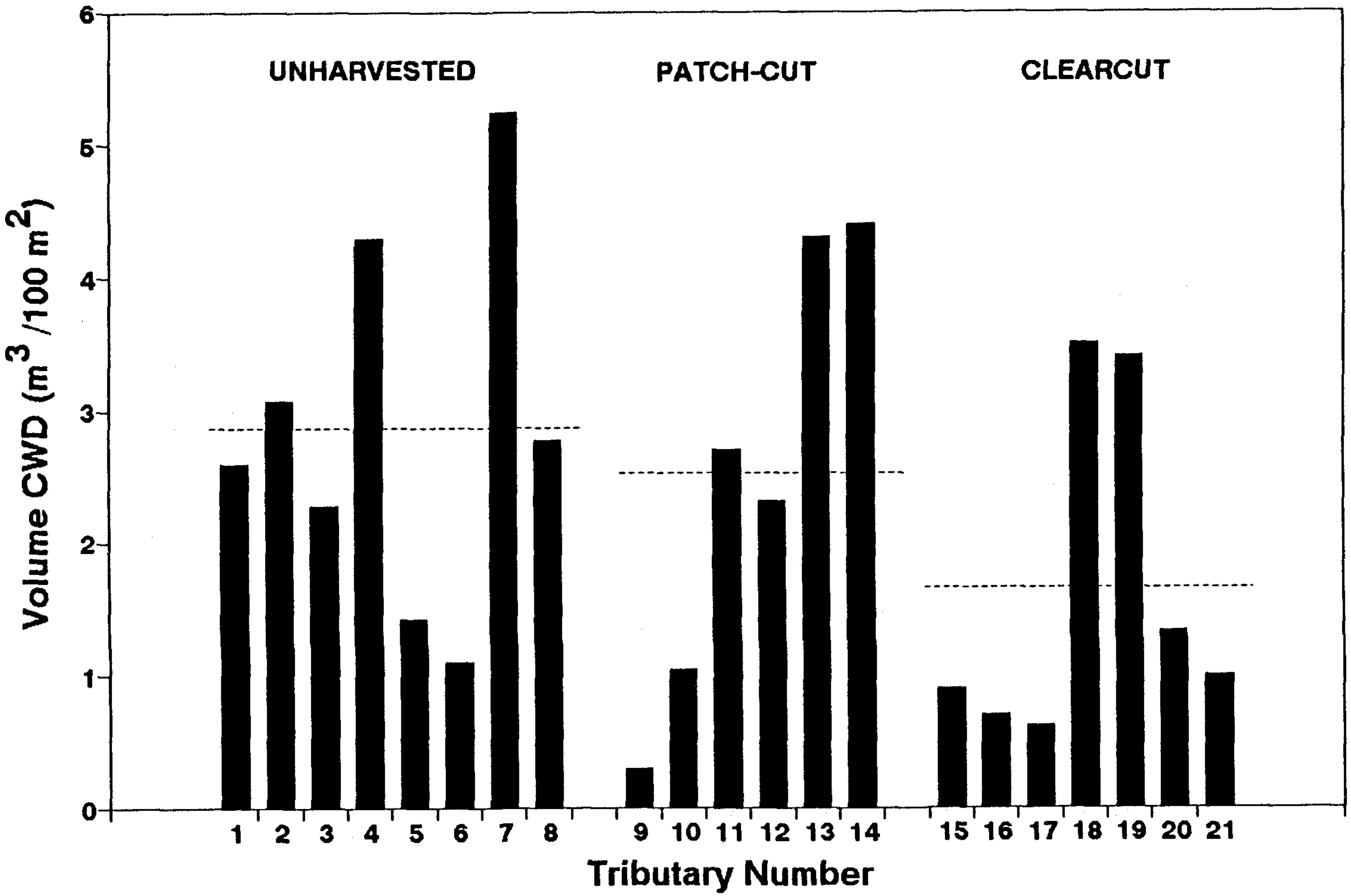


Figure 29. Volumes of coarse woody debris in the active channel ($m^3/100m^2$) for Drift Creek tributary sites. Dashed lines indicate averages of CWD volumes by land-use treatments.

sites had a greater abundance of in-channel large wood (Table 18). Effects of land use on stream CWD in the Drift Creek tributaries were investigated also by Veldhuisen (1990).

Salmonid Abundance

Relationships With Physical Habitat

Salmonid densities in the Drift Creek tributaries were significantly related to stream gradient (Fig. 30). Trout (age 0+) and cutthroat trout densities were directly associated with stream gradients, and juvenile coho densities were inversely associated with gradients (Table 19). Trout (age 0+) and cutthroat trout densities were inversely related to percent length of pools, and pools and glides, whereas juvenile coho densities were related directly. Salmonid densities (both linear and areal) for each tributary and year are reported in Table A.17.

Trout (age 0+) and cutthroat trout densities were directly associated with drainage areas, but juvenile coho densities were not (Table 19). This relationship with drainage area indicated that stream size was a major determinant of trout abundance, with greater densities in larger streams. Cutthroat trout densities were highly correlated with stream gradient and drainage area in a multiple regression model (Table 19). Thus, cutthroat densities were influenced by channel unit composition (by gradient) and stream size (by drainage area). Cutthroat trout densities were directly associated also with overall mean depth (Table 19).

Cutthroat trout (linear densities) and juvenile coho (areal densities) were associated with percent by area of spawning gravels (Table 19). Interpretation of these results was difficult because salmonid densities may not be directly related to spawning gravels, but rather to the types of channel units in which

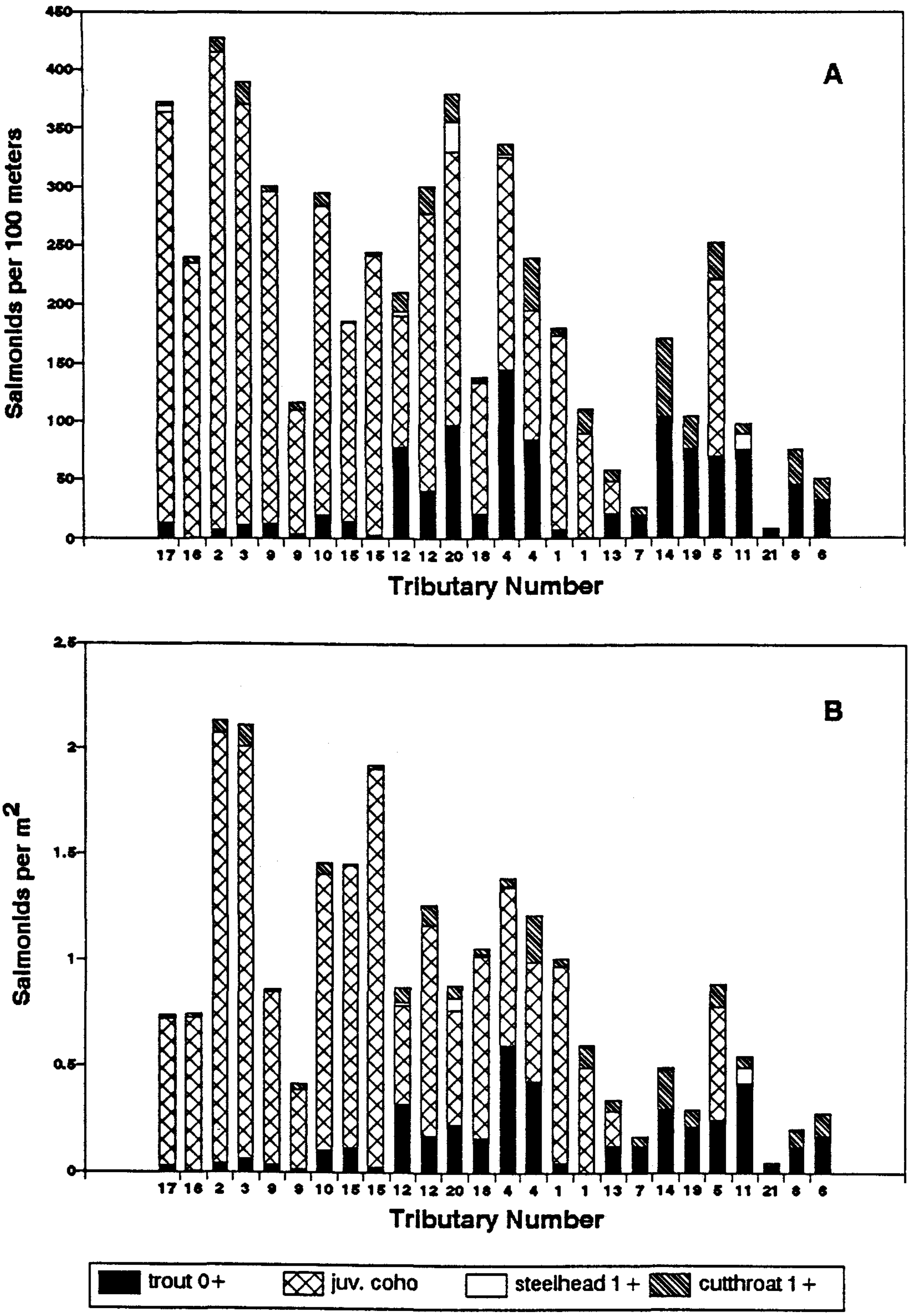


Figure 30. Salmonid abundances for Drift Creek tributary sites ordered by increasing gradient; (A) linear densities of salmonids, and (B) areal densities of salmonids.

Table 19. Correlations between parameters of physical stream habitat and salmonid densities in the Drift Creek tributaries based on regression analysis. Significance levels are less than 0.10 and 0.05.

Dependent Variable	Independent Variable(s)	Model p-value	significance & model slope		r^2
l fish	gradient	0.001	**	-	0.52
l trout 0	gradient	0.118		+	0.06
l coho	gradient	0.001	**	-	0.70
l cutt	gradient	0.115		+	0.06
a fish	gradient	0.001	**	-	0.36
a trout 0	gradient	0.097	*	+	0.07
a coho	gradient	0.001	**	-	0.46
a cutt	gradient	0.134		+	0.05
l fish	drainage area	0.029	**	+	0.18
l trout 0	drainage area	0.048	**	+	0.12
l coho	drainage area	0.301		+	0.01
l cutt	drainage area	0.003	**	+	0.29
a fish	drainage area	0.838		-	0.02
a trout 0	drainage area	0.477		+	0.00
a coho	drainage area	0.600		-	0.00
a cutt	drainage area	0.108		+	0.07
l cutt	gradient/drainage area	0.001	**		0.44
a cutt	gradient/drainage area	0.048	**		0.17
l fish	% pools	0.020	**	+	0.21
l trout 0	% pools	0.023	**	-	0.20
l coho	% pools	0.001	**	+	0.38
l cutt	% pools	0.123		-	0.09
a fish	% pools	0.030	**	+	0.18
a trout 0	% pools	0.008	**	-	0.26
a coho	% pools	0.003	**	+	0.32
a cutt	% pools	0.041	**	-	0.16
l fish	% pools + glides	0.036	**	+	0.17
l trout 0	% pools + glides	0.007	**	-	0.27
l coho	% pools + glides	0.001	**	+	0.38
l cutt	% pools + glides	0.039	**	-	0.17
a fish	% pools + glides	0.045	**	+	0.16
a trout 0	% pools + glides	0.005	**	-	0.29
a coho	% pools + glides	0.004	**	+	0.30
a cutt	% pools + glides	0.020	**	-	0.20
l fish	ome depth	0.211		+	0.03
l trout 0	ome depth	0.091	*	+	0.08
l coho	ome depth	0.743		+	0.00
l cutt	ome depth	0.003	**	+	0.29
a fish	ome depth	0.529		-	0.00
a trout 0	ome depth	0.453		+	0.00
a coho	ome depth	0.351		-	0.00
a cutt	ome depth	0.082	*	+	0.08

Table 19 continued.....

Dependent Variable	Independent Variable(s)	Model p-value	significance & model slope		r^2
l fish	spawn % area	0.577		+	0.00
l trout 0	spawn % area	0.468		-	0.00
l coho	spawn % area	0.312		+	0.00
l cutt	spawn % area	0.093	*	-	0.08
a fish	spawn % area	0.054	*	+	0.12
a trout 0	spawn % area	0.918		+	0.00
a coho	spawn % area	0.059	*	+	0.11
a cutt	spawn % area	0.200		-	0.03
l fish	cwd z1	0.384		-	0.00
l trout 0	cwd z1	0.345		+	0.00
l coho	cwd z1	0.209		-	0.03
l cutt	cwd z1	0.182		+	0.03
a fish	cwd z1	0.772		-	0.00
a trout 0	cwd z1	0.241		+	0.02
a coho	cwd z1	0.501		-	0.00
a cutt	cwd z1	0.118		+	0.06
l fish	cwd z1 + z2	0.276		-	0.01
l trout 0	cwd z1 + z2	0.020	**	+	0.17
l coho	cwd z1 + z2	0.042	**	-	0.13
l cutt	cwd z1 + z2	0.035	**	+	0.14
a fish	cwd z1 + z2	0.646		-	0.00
a trout 0	cwd z1 + z2	0.006	**	+	0.24
a coho	cwd z1 + z2	0.201		-	0.03
a cutt	cwd z1 + z2	0.013	**	+	0.20
l cutt	gradient/drainage area/ cwd z1 + z2	0.001	**		0.58
a cutt	gradient/drainage area/ cwd z1 + z2	0.011	**		0.39
l cutt	gradient/drainage area/ ome depth/cwd z1 + z2	0.001	**		0.59
a cutt	gradient/drainage area/ ome depth/cwd z1 + z2	0.028	**		0.39
l coho	gradient/ome depth cwd z1 + z2	0.001	**		0.70
a coho	gradient/ome depth cwd z1 + z2	0.001	**		0.55
l trout 0	ome depth/cwd z1 + z2	0.018	**		0.30
a trout 0	ome depth/cwd z1 + z2	0.021	**		0.29

Table 19 continued.....

Variable Descriptions:

gradient	overall stream gradient
drainage area	drainage area above site's lower boundary
% pools	channel unit ype, percent by length
% pools + glides	channel unit ype, percent by length
ome depth	site average for overall mean depths
spawn % area	spawning gravels, percent by channel area
cwd z1	coarse woody debris, volume in zone 1 per stream area
cwd z1 + z2	coarse woody debris, volume in zones 1 & 2 per area
l fish	sum total of all salmonids, lineal densities
a fish	sum total of all salmonids, areal densities
l trout 0	trout age 0+, lineal densities
a trout 0	trout age 0+, areal densities
l coho	juvenile coho salmon, lineal densities
a coho	juvenile coho salmon, areal densities
l cutt	cutthroat trout (age 1+), lineal densities
a cutt	cutthroat trout (age 1+), areal densities

gravels accumulate (i.e., pools, glides, riffles).

Areal densities of trout (age 0+) and cutthroat trout were associated with CWD volumes in active channels, but juvenile coho salmon were not (Table 19). Linear densities of all salmonids species/age groups were associated with CWD in active channels. Areal densities and linear densities were not associated with CWD volumes in wetted areas of summer low-flow channels. CWD volumes in the wetted area of summer low-flow channel (zones 1) reflected available in-stream cover for salmonids, and CWD volumes in the active channel (zones 1 and 2) reflected available in-stream and overstream cover. Multiple regression models with CWD, and other geomorphic parameters (i.e., gradient, drainage area, mean depths) as independent variables developed significant relationships with salmonid densities (Table 19).

Habitat Use of Channel Units

Pools and glides were the dominant channel unit types occupied by all salmonids in the Drift Creek tributaries (Table 20). Riffles were occupied by trout fry (age 0+). Riffles and rapids become shallow during summer low-flow, limiting their use by salmonids. Side channels were not occupied by salmonids in large numbers, because they were generally too shallow.

Electivity values of trout (age 1+) in pool habitat were significantly related to average area, volume, mean depth, and maximum depth of pools ($p < 0.08$). Electivity values of trout fry (age 0+) and juvenile coho in pool habitat did not associate with these average pool characteristics. This indicated that habitat use of trout (age 1+) was dependent on pool size, which was directly related to overall stream size.

Land-Use Effects

Land-use effects on salmonid abundance were significant only for areal densities of cutthroat trout (Table 21). Land-use effects on linear and areal densities of juvenile coho and trout fry (age 0+) and linear densities of cutthroat trout were not significant. Salmonid densities observed for different land-use treatments are illustrated in Figure 31. With this regression analysis, similar patterns were observed; only areal densities of cutthroat trout showed a significant difference among land-use treatments (Table 22). Regression models used gradient and drainage area as independent variables to adjust for site differences in geomorphic setting. Low areal densities of cutthroat trout were

Table 20. Habitat electivity for salmonids in the Drift Creek tributaries. Sign indicates greater use (+), or less use (-). A blank row indicates salmonid not present in that tributary, and a blank space indicates habitat type absent. For tributary numbers repeated, data presented first is for 1988 and second is for 1989.

JUVENILE COHO SALMON

Trib. No.	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	+0.46	-0.05	-0.69	-1.00	-1.00	
1	+0.31	-0.02	-0.80	0.70	0.42	-1.00
2	-0.03	+0.41	-0.84			
3	+0.09	+0.40	-0.90			
4	+0.42	+0.42	-0.96	-1.00	+0.47	+0.03
4	+0.38	+0.57	-0.14	-0.65	-0.04	-0.27
5	+0.40	+0.59	-0.11	-0.38	-0.38	-0.59
6						
7						
8						
9	+0.03	-0.17	-0.52	-1.00	+0.38	+0.96
9	-0.34	-0.36	-0.64	+0.31	+0.80	+0.83
10	+0.33	+0.00	-0.84	-1.00	+0.68	
11						
12	+0.31	+0.23	-0.16	-0.96	-1.00	
12	-0.14	-0.30	-0.01	-0.91	-0.34	+0.54
13						
14						
15	+0.15	+0.08	-0.92	-1.00	+0.49	
15	-0.34	+0.80	-0.89	+0.91	-1.00	+0.77
16	+0.06	-0.10	-0.33	-1.00		
17	+0.02	+0.09	-0.20	-0.55		
18	+0.34	+0.40	-1.00	-1.00		
19						
20	+0.15	+0.38	-0.25	-0.46	+0.93	+0.53
21						

Table 20 continued.....

TROUT (age 0+)

Trib. No.	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	+0.38	-0.29	+0.10	-1.00	-1.00	
1						
2	-0.82	+0.27	+0.37			
3	-0.61	-1.00	+0.39			
4	-0.33	+0.06	-0.22	-0.72	+0.63	+0.74
4	+0.06	+0.63	-0.10	-0.39	+0.48	-1.00
5	+0.07	+0.32	+0.71	-0.28	-0.11	-1.00
6	+0.03	-0.05	+0.62	-0.21	-0.73	-1.00
7	-0.53	+0.41	+0.88	-0.64	+0.10	
8	-0.25	+0.54	+0.64	-0.14	-0.25	-1.00
9	+0.04	-0.40	-0.09	+0.56	-1.00	-1.00
9	-0.37	-0.09	-0.13	+0.64	+0.39	-1.00
10	-0.31	-0.09	-0.31	-1.00	+0.82	
11	+0.13	+0.09	-0.07	-0.18	+0.01	
12	-0.48	-0.14	+0.37	-0.24	+0.29	
12	-0.71	-0.28	-0.18	-0.28	+0.22	+0.57
13	-0.32	+0.57	+0.20	-1.00	-1.00	
14	+0.06	+0.44	+0.39	-0.16	-0.30	-1.00
15	-0.13	+0.18	+0.14	-1.00	-1.00	
15	-0.62	-1.00	-0.72	-1.00	+0.97	-1.00
16	-1.00	+0.45	-1.00	-1.00		
17	-0.71	-0.55	+0.45	+0.92		
18	+0.22	+0.51	-0.67	-1.00		
19	-0.58	+0.54	+0.20	-0.32	-0.42	-1.00
20	-0.24	-0.05	+0.07	-0.24	+0.97	+0.35
21	+0.60	-1.00	-0.50	-0.34	-1.00	

Table 20 continued.....

TROUT (age 1+)

Trib. No.	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	+0.62	-0.45	-1.00	-1.00	-1.00	
1	+0.26	-0.30	-0.65	+0.80	+0.50	-1.00
2	+0.31	-1.00	-1.00			
3	+0.46	-1.00	-1.00			
4	+0.35	+0.43	-0.21	-1.00	-1.00	-1.00
4	+0.34	+0.59	-0.59	-0.60	+0.45	-1.00
5	+0.28	+0.50	-1.00	-0.30	+0.11	-1.00
6	+0.48	-0.68	+0.46	-0.10	-1.00	-1.00
7	+0.72	-1.00	-1.00	-1.00	-1.00	
8	+0.20	+0.06	-1.00	-0.38	+0.09	-1.00
9	-0.22	+0.17	-1.00	-1.00	+0.83	-1.00
9	-0.27	-0.83	-1.00	-0.12	+0.88	-1.00
10	+0.54	-0.22	-1.00	-1.00	-1.00	
11	+0.34	-0.42	-1.00	-0.43	+0.43	
12	+0.28	-0.16	-0.25	-0.48	+0.44	
12	-0.41	+0.17	-0.64	-0.15	+0.46	+0.35
13	+0.52	-0.31	-0.08	-1.00	-1.00	
14	-0.19	+0.06	+0.56	+0.02	+0.15	-1.00
15	+0.32	-1.00	-1.00	-1.00	-1.00	
15	+0.23	-1.00	-1.00	-1.00	-1.00	-1.00
16	+0.25	-1.00	-1.00	-1.00		
17	-0.09	+0.26	-0.03	-1.00		
18	+0.46	-1.00	-1.00	-1.00		
19	+0.07	+0.42	-0.46	-0.87	+0.21	-1.00
20	+0.09	+0.54	-0.11	-0.28	+0.87	-1.00
21	+0.19	-1.00	-1.00	-1.00	+0.61	

Table 21. Effects of land use on salmonids in the Drift Creek tributaries based on analysis of variance (ANOVA).

LINEAL DENSITIES:

Salmonid	p-value	significance
Juvenile Coho Salmon	0.841	
Trout (age 0+)	0.708	
Cutthroat Trout (age 1+)	0.260	

AREAL DENSITIES:

Salmonid	p-value	significance
Juvenile Coho Salmon	0.717	
Trout (age 0+)	0.435	
Cutthroat Trout (age 1+)	0.037	**

associated with low volumes of CWD in the active channel of clearcut sites.

Regression of electivity values of trout (age 1+) in pool habitat against mean depth of pools and land-use treatments indicated a weak inverse association among land-use treatments ($p = 0.109$). Thus, trout (age 1+) occupied pools to a lesser extent than their availability in streams of clearcut sites. This same regression model with electivity values of trout fry (age 0+) and juvenile coho in pool habitat and land use did not show a significant association among land-use treatments.

Cutthroat trout densities were significantly lower in clearcut sites than in patch-cut and unharvested sites where juvenile coho co-occur (Table 22). These sympatric sites showed a greater significant difference between cutthroat trout densities among land-use treatments than when all sites were combined. Of allopatric sites, cutthroat trout densities were not significantly different among land-use treatments, but the low number of allopatric sites had high statistical variance. Cutthroat densities for sympatric sites and allopatric sites, and all sites combined are illustrated in Figures 32 and 33.

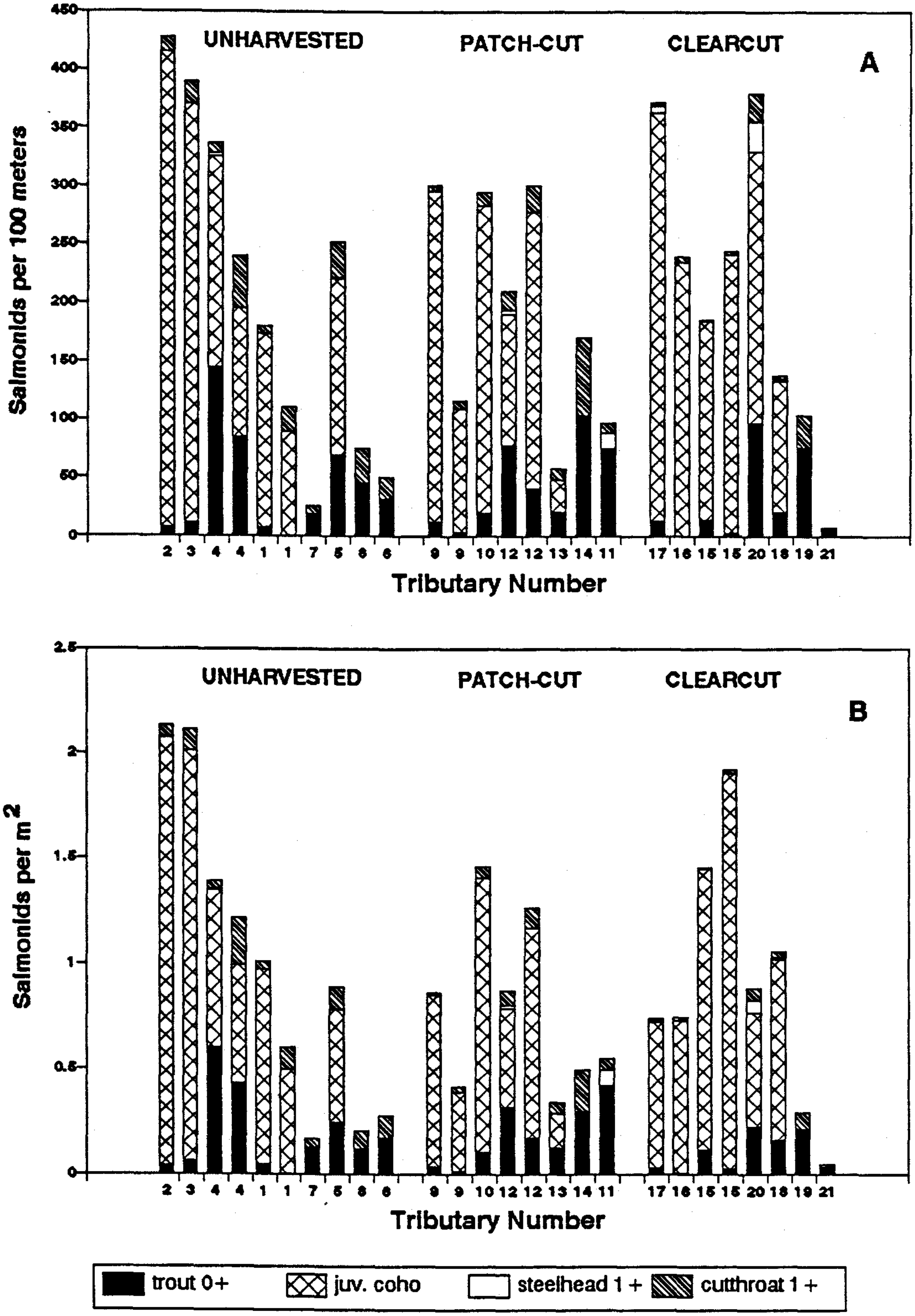


Figure 31. Salmonid abundances for Drift Creek tributary sites by land-use treatment; (A) linear densities of salmonids, and (B) areal densities of salmonids.

Table 22. Effects of land use on salmonid abundance in the Drift Creek tributaries based regression analysis. Regression models used coded variables for land-use treatments. Significance levels are less than 0.10 and 0.05.

Dependent Variable	Independent Variables	Land-Use p-value	significance
l fish	gradient/landuse	0.150	
l trout 0	gradient/landuse	0.774	
l coho	gradient/landuse	0.141	
l cutt	gradient/landuse	0.247	
a fish	gradient/landuse	0.110	
a trout 0	gradient/landuse	0.466	
a coho	gradient/landuse	0.232	
a cutt	gradient/landuse	0.025	**
l trout 0	drainage area/landuse	0.510	
l coho	drainage area/landuse	0.739	
l cutt	drainage area/landuse	0.089	*
a trout 0	drainage area/landuse	0.280	
a coho	drainage area/landuse	0.975	
a cutt	drainage area/landuse	0.009	**
l cutt	drainage area/gradient/landuse	0.229	
a cutt	drainage area/gradient/landuse	0.025	**
l cutt patric 1	drainage area/landuse	0.317	
l cutt patric 2	drainage area/landuse	0.013	**
a cutt patric 1	drainage area/landuse	0.885	
a cutt patric 2	drainage area/landuse	0.007	**
a cutt	cwd z1 + z2/landuse	0.074	*
l cutt	cwd z1 + z2/landuse	0.452	

Variable Descriptions:

landuse	land-use treatment classification (coded variable)
gradient	overall stream gradient
drainage area	drainage area above site's lower boundary
cwd z1 + z2	coarse woody debris, volume in zones 1 & 2 per stream area
l fish	sum total of all salmonids, lineal densities
a fish	sum total of all salmonids, areal densities
l trout 0	trout age 0+, lineal densities
a trout 0	trout age 0+, areal densities
l coho	juvenile coho salmon, lineal densities
a coho	juvenile coho salmon, areal densities
l cutt	cutthroat trout (age 1+), lineal densities
a cutt	cutthroat trout (age 1+), areal densities
l cutt patric 1	allopatric cutthroat trout (age 1+), lineal densities
a cutt patric 1	allopatric cutthroat trout (age 1+), areal densities
l cutt patric 2	sympatric cutthroat trout (age 1+), lineal densities
a cutt patric 2	sympatric cutthroat trout (age 1+), areal densities

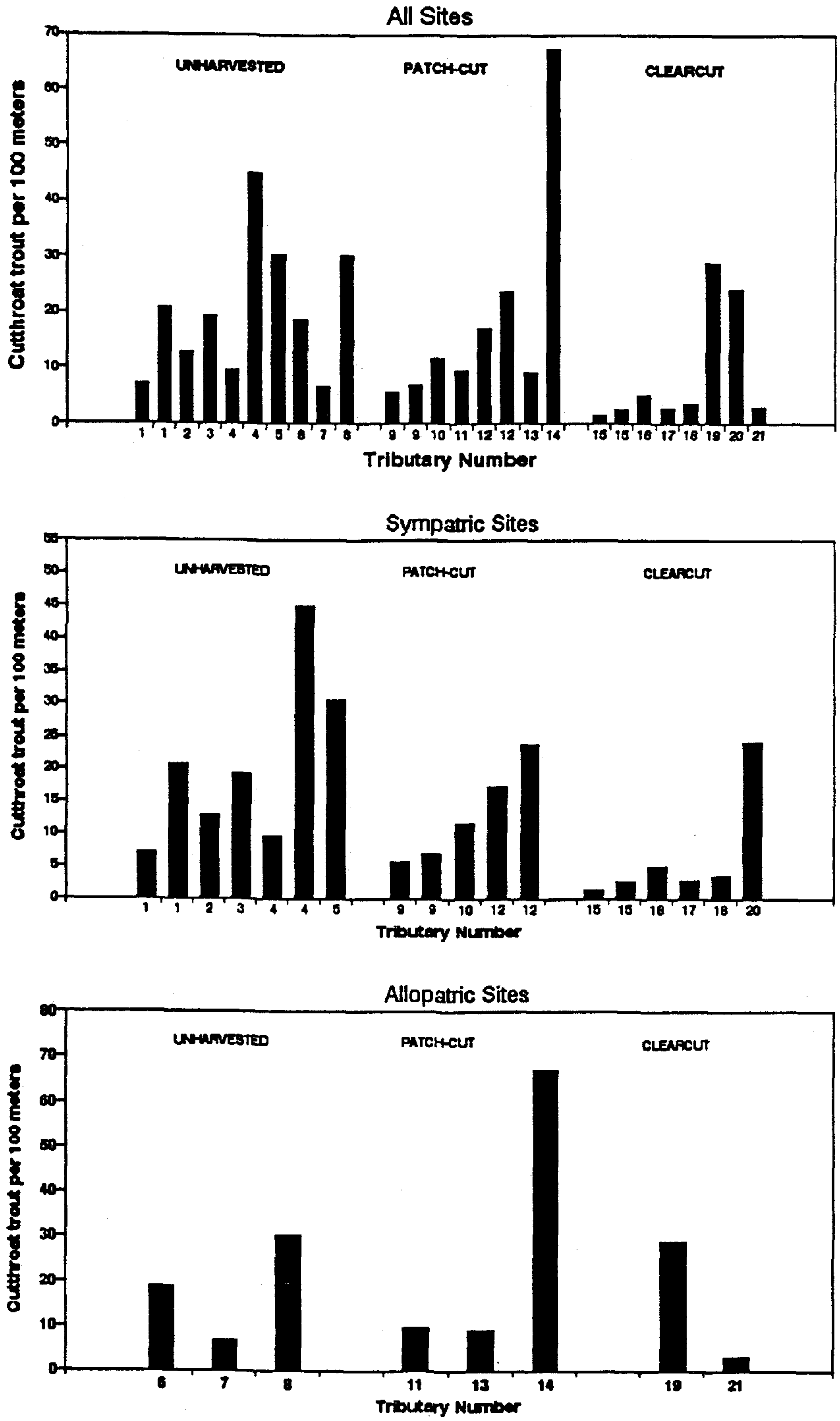


Figure 32. Linear densities of cutthroat trout by land-use treatment for sympatric and allopatric sites and all sites combined.

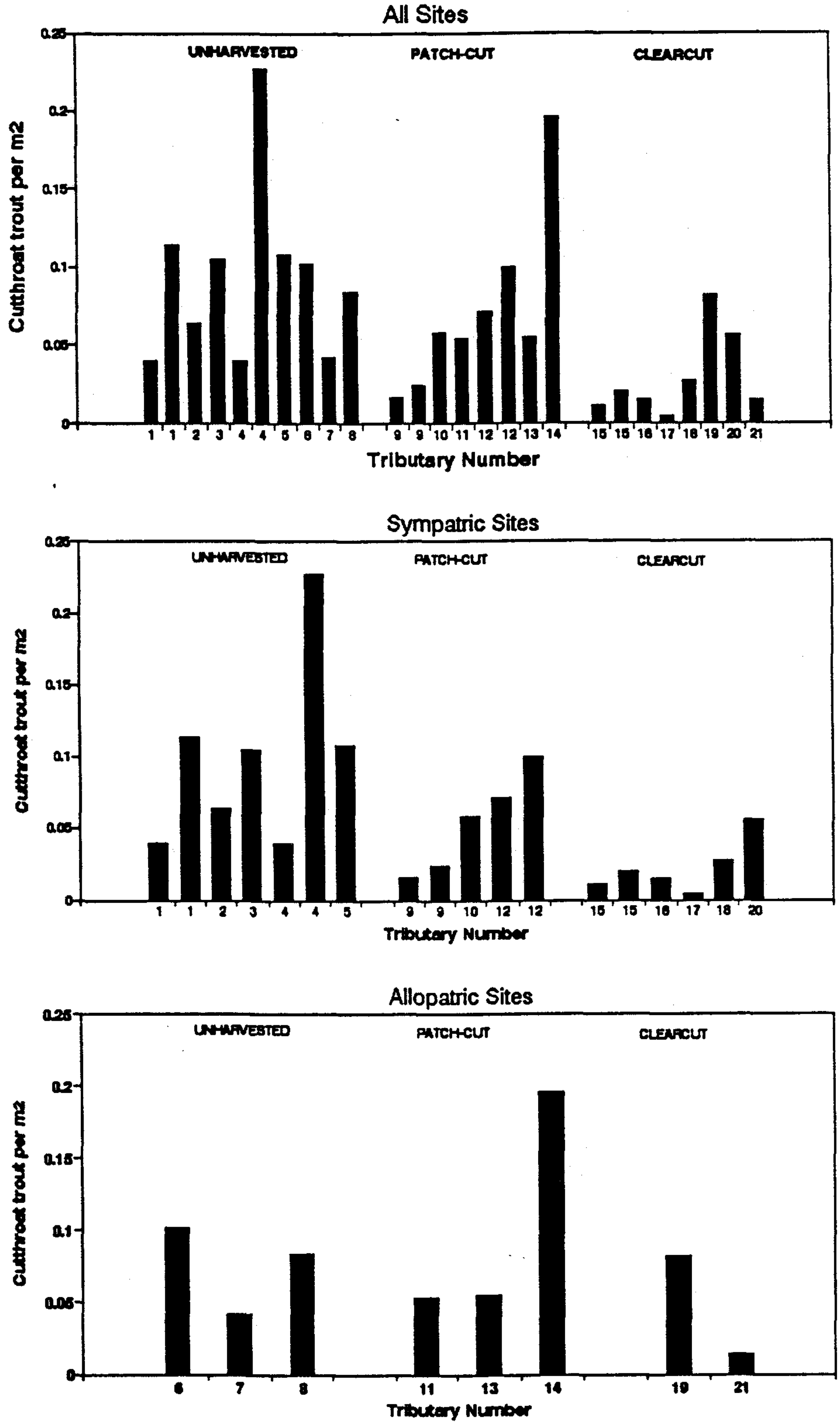


Figure 33. Areal densities of cutthroat trout by land-use treatment for sympatric and allopatric sites and all sites combined.

DISCUSSION

Stream habitat quality and salmonid abundance were influenced by past forest practices of clearcut logging without buffers in tributaries of the Drift Creek basin. Compared to unharvested and patch-cut sites, clearcut sites had lower volumes of CWD in the active channel, and lower densities of cutthroat trout. Also, clearcut sites had deeper maximum depths of channel averages and pool averages. Morphological differences of channel depths among land-use treatments may be a result of geomorphic setting rather than a direct response to timber harvest. Geomorphic setting (i.e., valley landform type, and stream size and gradient) influences stream habitat characteristics and salmonid abundance, thus, are key to understanding possible effects of land use.

Basin locations of sites influence physical habitat characteristics of the stream channel, primarily in terms of gradient and stream size. In the Drift Creek tributaries, composition of channel units was related to reach gradient; lower gradient reaches had more pools and glides (percent by length). Lower gradient reaches generally occurred in wide alluvial valleys (Table 16). Active channel widths, a measure of stream size were directly related to drainage areas, and they were directly related to reach mean and maximum depths and pool mean and maximum depths (summer low-flow). Active channel widths and mean channel depths were related to gradients. Maximum depths of overall site averages were inversely related to gradient.

The deeper maximum depths in clearcut sites than in patch-cut or unharvested sites were likely due to the greater portion of low-gradient reaches surveyed for that treatment group. Site gradients were not significantly different among land-use treatments, but treatment averages of gradient in logged streams (i.e., clearcut - 2.9% and patch-cut - 3.4%) were lower than the unharvested average of 4.0%. Percent pools were significantly longer in clearcut sites as a result of the lower gradients (Fig. 28). In the clearcut sites, 3 out of 7 sites occurred in alluvial valleys. Influences of land use on channel unit depths were complicated by the greater percent length of pools in clearcut sites than in other treatment sites. Because overall maximum depths of sites were related also to gradient, this response, in part, may be due to the long deep pools found in alluvial valley channels. In addition, beaver ponds were more commonly found in the clearcut sites deepening the overall maximum depth of sites. In the clearcut sites, 4 out of 7 sites had beaver ponds, whereas unharvested sites had no intact ponds.

In this study, the physical habitat characteristics of the stream channel: composition of channel units, active channel width, and spawning gravels were not significantly different among land-use treatments, which is consistent with the AWS findings. In the AWS, no differences in channel morphology occurred after logging in patch-cut and clearcut sites (Moring 1975). Another study with similar results examined ten coastal Oregon streams, where no differences in channel morphology were associated with effects of timber harvest, and channel morphology was related to reach gradient (Hicks 1990).

In the Drift Creek tributaries, cutthroat trout were detrimentally affected by clearcutting without buffers. Cutthroat trout densities were significantly lower in clearcut sites than in patch-cut and unharvested sites. Juvenile coho salmon and trout (age 0+) densities were not different among the three treatments. These results are consistent with the AWS findings (Moring and Lantz 1975). Other studies have shown cutthroat trout populations to increase or stay the same after logging (Table 14). The varied responses of salmonid populations to timber harvest, especially cutthroat trout populations, are the results of a complex set of interacting physical and biological factors (Hicks et al. in press). Land-use effects on physical stream habitat and salmonid populations depend on stream size, gradient, and time after harvest (Murphy and Hall 1981). Influences of physical characteristics of stream habitat on salmonid abundance are important in the interpretation of land-use effects.

Salmonid abundances have been related to stream size (through drainage area or stream order) and gradient (Platts 1979, Lanka et al. 1987, Cupp 1989b). Upstream-downstream gradients in salmonid abundance have been observed in other studies. For example, Aho (1977) observed a downstream clearcut site had greater densities of cutthroat trout compared to a upstream site. In the Drift Creek tributaries, densities of all salmonid species (or age groups) were related to gradient. Densities of juvenile coho salmon were greater in lower gradient sites, whereas densities of cutthroat trout and trout (age 0+) were greater in higher gradient sites. Densities of cutthroat trout and trout (age 0+) were greater in larger streams as observed by drainage area, active channel width, and mean depths. Densities of cutthroat trout were strongly related to both gradient and drainage area (in a multiple regression model).

In the Drift Creek tributaries, cutthroat trout and juvenile coho primarily occupied pools and glides, and trout (age 0+) occupied pools, glides and riffles as distinguished by habitat electivity. Rapids and cascades were used less extensively, and trout fry were the most common salmonid in such habitats. Similar patterns of channel unit (habitat) use were observed with these salmonids (Glova 1978, Bisson et al. 1982, Bisson et al. 1988, Hicks 1990). During the summer, riffles and rapids become shallow and potentially limit their use by salmonids. Body form of trout fry (age 0+) may be better adapted for shallow riffle habitat (Bisson et al. 1988). Dominant use of pools and glides by salmonids illustrate the importance of these channel units in determining abundances in reaches of varying gradients.

In the Drift Creek tributaries, areal densities of trout (age 0+) and cutthroat trout were directly associated with volumes of CWD in the active channel, whereas juvenile coho salmon were not. Salmonid densities were not associated with volumes of CWD in the wetted, low-flow channel. Abundance of CWD was associated with pool channel units in tributary size streams (Andrus et al. 1988, Bilby and Ward 1989). Since pools were used predominantly by salmonids in the summer, this illustrates the importance of CWD as fish cover, particularly for trout. In a western Washington stream, steelhead trout (age 1+) and cutthroat trout (age 1+) abundances in pools were correlated with CWD cover, whereas juvenile coho densities were not (Grette 1985). In southwest Alaska, juvenile coho salmon were not directly correlated with CWD accumulations, but were consistently lower when CWD was absent (Bryant 1985). In a coastal Oregon stream, cutthroat trout were observed to use cover more than juvenile coho (Lowry 1964).

In the Drift Creek tributaries, CWD volumes in the active channel were lower in clearcut sites without buffers than in patch-cut and unharvested sites. Low cutthroat abundance found in clearcut sites may be attributed to less available cover. Cover above or adjacent to the channel was important to trout as protection from avian predation, and can influence trout abundance (Lewis 1969, Wesche et al. 1985). In a northwest Washington stream, declines in resident cutthroat trout populations during the first winter after logging were associated with habitat instability resulting from removal of CWD cover in the active channel (Lestelle 1978).

In the Drift Creek tributaries, cutthroat trout in sympatry with juvenile coho salmon exhibited greater differences in abundance among land-use treatments than when all sites were combined. Allopatric cutthroat populations were not significantly different among land-use treatments, but this may be attributed to the low number of these sites surveyed. This result may indicate that cutthroat trout are affected by interspecific interactions with juvenile coho (the dominant species by numbers). In a laboratory stream, juvenile coho salmon and cutthroat trout compete for food resources as observed by high rates of aggression, especially under high population densities, whereas allopatric populations of cutthroat trout lacked competition for food resources as observed by reduced aggression rates (Glova 1986). CWD cover may play a vital role in aiding cutthroat trout to compete for food resources with juvenile coho salmon.

Food and cover relationships may influence feeding efficiency of sympatric cutthroat trout, especially under circumstances of high abundances of juvenile coho salmon. Abundance and channel sub-unit distribution of allopatric cutthroat trout were associated with food abundance superseding the importance of cover, especially when food resources were low (Wilzbach 1985). If food is limited by low cover for sympatric populations of cutthroat trout with juvenile coho, populations of juvenile coho would increase after logging, and cutthroat trout would decrease, while allopatric populations of cutthroat trout would increase. A few studies suggest this relationship is possible, but no one study has been reported testing these multiple factors. In the Oregon Cascades, allopatric populations of cutthroat trout have been shown to be greater in streams after logging (Aho 1977, Murphy and Hall 1981). In the Carnation Creek Study, juvenile coho abundance has been shown to increase after logging, along with a shift to greater numbers of age 1+ smolts (Hartman et al. 1987). In the AWS clearcut site, juvenile coho numbers were substantially greater the first year following logging; after the first year, juvenile coho numbers declined in the clearcut and unharvested sites (Moring and Lantz 1975).

Cutthroat trout populations appear to be more susceptible to effects of timber harvest, and the varied responses to timber harvest may be attributed to trade-offs between food and cover that are associated with species composition and stream habitat quality. Valley landform types, stream size, and gradient influence physical characteristics of stream habitat and salmonid abundance (species specific), and complicate the interpretation of land-use effects. This study did show cutthroat trout populations in sympatry with juvenile coho salmon to have lower densities on average in clearcut sites than in patch-cut and unharvested sites. Assuming that this difference in cutthroat trout abundance was facilitated by changes in habitat quality, this study indicated it was a result of lower CWD volumes in the active channel. Differences in channel morphology could not be detected among the land-use treatments. Loss of channel complexity by lower CWD volumes may yield a multitude of responses on the salmonid community, one of which is a shift in partitioning food resources between populations of cutthroat trout and juvenile coho. Others include shifts in predation rates, and lower overwinter survival from lack of CWD during high stream flows. The varied responses by numerous studies illustrate the complexity of the problem. Many environmental factors interact to determine salmonid abundance at any given time.

CHAPTER IV. AN ALSEA WATERSHED STUDY COMPARISON: A TEMPORAL PERSPECTIVE IN THE DRIFT CREEK BASIN ON THE EFFECTS OF LAND USE

INTRODUCTION

The Alsea Watershed Study (AWS) is one of the few long-term watershed studies to document effects of timber harvest practices on stream habitat quality and salmonid populations (Hall et al. 1987). Forestry and fisheries interactions are complex and some relationships can only be observed by long-term investigations (Hicks et al. in press). A temporal perspective provides an important context for evaluating responses of salmonid populations to land-use practices across ranges of natural variation. Examining the AWS streams at present allows for an investigation of long-term effects of timber harvest on habitat quality and salmonid populations. Over the past three decades the Drift Creek basin has been extensively harvested for commercial timber. The AWS provides a historical record for responses of salmonid populations to forest practices in the Drift Creek basin tributaries.

An Overview of the Alsea Watershed Study

The AWS was a 15-year project initiated in 1958 to examine timber harvest impacts on habitat quality and fish populations (Hall and Lantz 1969, Moring and Lantz 1975, Hall et al. 1987). Three small coastal streams were selected in the upper drainage of Drift Creek (Fig. 34). Before timber harvest, these watersheds were primarily forested with mature Douglas-fir. Needle Branch, a 75-ha watershed, was completely clearcut logged leaving no bufferstrip. Deer Creek, a 304-ha watershed, was clearcut logged in three patches, each consisting of about 25-ha with conifer bufferstrips left along the stream. Flynn Creek, a 200-ha watershed, was not logged and was the study

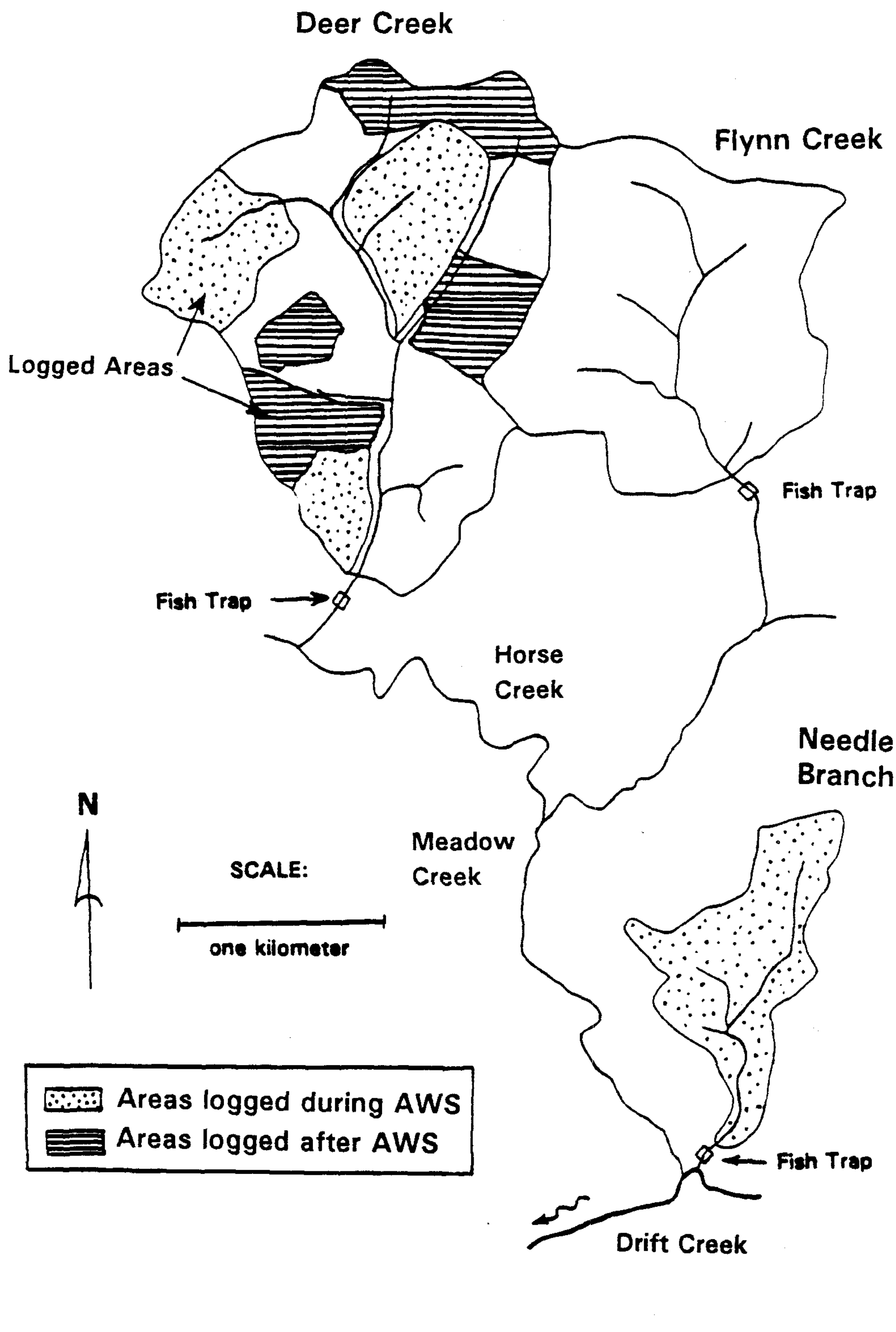


Figure 34. Location map of Alsea Watershed Study streams.

control.

These three streams were studied seven years prior to timber harvest to establish the natural annual variation in environmental factors and salmonid populations. Fish traps for both upstream and downstream migrations were constructed on each stream to monitor the anadromous populations. Habitat quality and salmonid population studies began in 1959. Road construction took place in 1965, and the sites were logged in 1966. These streams were monitored for another seven years after timber harvest to examine impacts.

Salmonid communities in these study streams are dominated by two species, juvenile coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Oncorhynchus clarki*). During the AWS, steelhead trout (*Oncorhynchus mykiss*) was observed in small numbers in Deer Creek only (Moring and Lantz 1975). Adult strays of chinook salmon (*Oncorhynchus tshawytscha*) were observed on a rare occurrence in the upstream trap in Deer Creek; most returned downstream never spawning. Common non-salmonid species include the reticulate sculpin (*Cottus perplexus*) and the western brook lamprey (*Lampetra richardsoni*).

The AWS showed several short-term (1-2 years) detrimental effects on habitat quality in Needle Branch (the clearcut watershed): increased maximum temperatures, increased maximum diurnal fluctuations, decreased surface and intragravel dissolved oxygen, and increased suspended sediments (Hall and Lantz 1969). Deer Creek (the patch-cut watershed) showed only a slight increase in suspended solids following road construction. Of the physical stream parameters measured (i.e., percent pool, percent riffle average width, and average depth), no discernible effects could be assessed as a result of timber harvest (Moring 1975). Habitat quality changes during the AWS are described in Moring (1975).

The AWS showed juvenile coho salmon to be fairly resilient to adverse environmental changes following clearcut logging (Hall and Lantz 1969, Moring and Lantz 1975). Juvenile coho (summer-rearing) populations and coho smolt numbers declined slightly after logging in all watersheds, though the decline was greatest in the forested control watershed. Juvenile coho biomass was greater in the two logged watersheds, and was less in the control watershed on average in the post-logging period. Juvenile coho salmon populations and coho smolt numbers were quite variable under natural conditions (Moring and Lantz 1975).

Numbers of early migrating coho fry (standardized by the number of spawning females in each stream for that brood year) leaving Needle Branch (the clearcut watershed) declined in the post-logging period (Hall et al. 1987). Average numbers of migrating coho fry for the pre- and post-logging periods remained approximately the same in the patch-cut and unharvested watersheds. This provides evidence of a decrease in coho survival-to-emergence in Needle Branch, most likely due to the increased sedimentation of fines and lower intragravel dissolved oxygen (Hall et al. 1987).

Cutthroat trout appear to be susceptible to habitat quality changes caused by clearcut logging with no bufferstrips (Moring and Lantz 1975). In Needle Branch, cutthroat trout abundance and biomass substantially declined in the post-logging period (as observed by late summer estimates). Also, cutthroat trout migrated downstream earlier for the two years following clearcut logging compared to the pre-logging period. In Flynn Creek and Deer Creek, cutthroat trout abundances and biomass were greater in the post-logging period than in the pre-logging period. In Needle Branch, cutthroat abundance remained low compared to pre-logging abundances even ten years after logging (Hall et al. 1987).

The Alsea Watershed Study Comparison

Broad fluctuations in juvenile coho salmon and cutthroat trout populations demonstrate the value of long-term investigations. Intensive watershed designs, like the AWS design, make it possible to assess land-use impacts in the context of natural variation (Hall et al. 1978, Hall and Knight 1981). Intensive (before-after) watershed designs lack replication, thus limit applicability of their results to streams of different geomorphic settings. An extensive (post-treatment) design incorporating additional blocks of sites can test applicability of results from intensive before-after designs (see Chapter III).

This study investigated long-term shifts in habitat quality, and salmonid (late summer) densities and biomass in the AWS streams 23 years after logging and 16 years since the completion of the AWS. Logging has continued in the Deer Creek watershed since the AWS (Fig. 34). This AWS comparison also examined present salmonid populations within the context of historic natural variation. Ranges of natural variation in salmonid abundance for the AWS streams provided a basis to evaluate timber harvest practices in other Drift Creek tributaries of comparable size.

METHODS

Stream Habitat Measurements

Alsea Watershed Study

In the original AWS, stream habitat measurements were recorded at 7.6-m (25-ft) intervals during summer low-flow. Depth was measured as the average of depth at three equally spaced points across the stream. Total lengths of pool and riffle habitat were measured along the stream center line. Area of spawning gravels were estimated during the survey and reported as percent of the total stream area. Details of the AWS methods are described in Moring (1975).

The 1988-1989 Study Design

In 1988 and 1989, physical habitat and spawning gravel were measured at each channel unit in sequence by a visual estimation method (Hankin and Reeves 1988). Channel units were classified as either pool, glide, riffle, rapid, cascade, step, or side channel. Physical habitat measurements included wetted (summer low-flow) channel unit length, width, and mean depth. Active channel widths at bankfull discharge were visually estimated by observing high-flow markings. Mean depths were computed from an average of six to twelve measurements, where sets of three were taken across a channel unit transect with meter stick. Spawning gravel was visually estimated by area in the active channel.

In the visual estimation technique (Hankin and Reeves 1988), a subsample of channel units was measured with a 100-m fiberglass tape and a meter stick. The frequency of measured units used for each channel unit type was as follows: pools - 1/3, glides - 1/4, riffles - 1/4, rapids - 1/4, cascades -

1/2, and side channels - 1/2. In each stream, measured units were used to derive correction factors to calibrate all visual unit measurements.

Salmonid Population and Biomass Estimates

Alsea Watershed Study

Salmonid populations were enumerated from mark-recapture data and biomass was estimated by multiplying population estimates by average weights of marked fish (Moring and Lantz 1975). Population numbers for juvenile coho reflected estimates on August 15th as interpolated from annual curves of standing crop. Juvenile coho biomass reflected estimates for September as interpolated from annual biomass curves. Cutthroat trout numbers and biomass reflected estimates for September (Knight 1980). Methods employed during the AWS for salmonid population and biomass estimates are described in Moring and Lantz (1975) and are summarized in Table A.18.

Study areas were determined in each stream above the fish traps. The standard study lengths were: Flynn Creek - 1311 m, Deer Creek - 2073 m, and Needle Branch - 869 m. Salmonid population and biomass estimates reported in Moring and Lantz (1975) were calibrated to these standard lengths.

The 1988-1989 Study Design

In 1988 and 1989, salmonid populations were estimated by the removal (multiple pass) method as described by Armour et al. (1983). A backpack electro-shocker was used to capture fish. Population estimates made by the removal method are similar to estimates made by the mark-recapture method when at least one hour is allowed between electrofishing passes (Peterson and Cederholm 1984). This suggests that a reasonable comparison can be made between population estimates of both methods. In this study, more than 2-3 hours elapsed between electrofishing passes at all sites to measure and weigh fish.

Within each study stream, electrofishing sites were selected in morphologically different sections to stratify the sampling by reach scale characteristics. This method assumed that reach morphology influences the spatial distribution of salmonids in these small streams. Reach types included constrained (valley floor width < 2 active channel widths) and unconstrained (valley floor width > 2 active channel widths). Positions of electrofishing sites were randomly selected within each reach type. Stream lengths for each reach type and locations of electrofishing sites are reported in Table 23. Population estimates, 95% upper confidence limits for each site, and electrofishing site lengths are reported in Table A.19.

Salmonid population and biomass estimates for the entire study stream were computed using the stratified sampling by reach type (Table A.20). Populations for each stream reach were estimated by multiplying the corresponding site estimate by a ratio of reach length to electrofishing site length. Reach estimates were summed to obtain estimates for the entire study stream. Biomass (g/m^2) was estimated for each site by multiplying the population estimate by average fish weight and dividing by the total site area. Biomass estimates were then weighted using the stream length proportion in each reach type.

In a second method, population numbers and biomass were computed by averaging site estimates equally to obtain estimates for the entire study length. Populations for each stream's standard length were estimated by multiplying the summed site estimates by a ratio of total stream length to

Table 23. Alsea Watershed Study stream lengths as reported in Moring and Lantz (1975). Lengths shown are used to weight electrofishing sites for estimations of salmonid numbers and biomass.

Stream and Features	AWS Reported Distance (m)	Stream Length (m)	Reach Type [1]	1988 Site Location [2]	1989 Site Location [2]
FLYNN CREEK Total study length: 1311 meters					
fish trap	-305				
		305	U		Site 1
USGS weir	0				
		305	U	Site 1	Site 2
canyon	305				
		244	C	Site 2	Site 3
canyon end	549				
		457	U	Site 3	Site 4
survey end	1006				
DEER CREEK Total study length: 2073 meters					
fish trap	-152				
		152	U		
USGS weir	0				
		152	U		Site 1
canyon	152				
		275	C	Site 1	Site 2
canyon end	427				
		1006	U	Sites 2 - 3	Sites 3 - 4
stream fork	1433				
		487	U		Site 5
survey end	1920				
NEEDLE BRANCH Total study length: 869 meters					
fish trap	-61				
USGS weir	0				
	89	271	U		Site 1
	331	242	U		Site 2
	574	233	U		Site 3
	776	133	C		Site 4
1st waterfalls	808				

1 Unconstrained (U) reaches have a valley floor width > 2 active channel width, constrained (C) reaches have a valley floor width < 2 active channel widths.

2 Electrofishing sites for 1988 and 1989 are located within the described reach.

summed electrofishing site lengths. Biomass (g/m^2) for each stream was the average of all individual site estimates. Differences between the stratified procedure and averaging procedure were small (Table A.20). Estimates from the stratified procedure were used in comparisons with the AWS estimates.

Population estimates from this study and the AWS were converted to linear and areal densities. Linear densities were obtained by use of the standard study lengths (Table 23). Areal densities were based on the following total stream areas: Flynn Creek - 2491 m^2, Deer Creek - 6012 m^2, and Needle Branch - 1130 m^2. Total areas for each stream were calculated by standard study length (Table 23) and average stream width (Table 24).

Abundances of cutthroat trout by age class were estimated by the stratified procedure. Age class groups were separated by a site length-frequency analysis, grouping trout into 5-mm size intervals and assigning them to age groups by a visual inspection of peaks and troughs. Length ranges for each cutthroat age class (0, 1, 2, and 3+) are reported in Table A.21, and these age group separations compared to ranges reported by Sumner (1962) and Lowry (1964), whose studies included scale analysis. For each site, numbers for each age group were computed by multiplying the site proportion of total population estimate to number caught. The stratified procedure (as described above) was used to obtain an overall abundance estimate of cutthroat trout by age classes for each stream (Table A.21).

Needle Branch was not electrofished in 1988 because of drought conditions in the Oregon Coast Range. In mid-September, approximately 65% of the channel length was dry from the fish trap to the first falls. Electrofishing in the remaining shallow wetted areas (pools) would have stressed the fish remaining in the isolated sections.

Table 24. Stream habitat measurements (in meters), percent pools are by stream length, and spawning gravel estimates (as percent of total stream area). Data from years 1959-1972 are from Moring (1975).

FLYNN CREEK

Year	Percent Pools	Pool/Riffle Ratio [1]	Average Width	Average Depth	Percent Area of Spawning Gravel
1959	51.8	1.08	-	0.10	25.5
1960	59.2	1.45	-	0.13	18.4
1961	58.8	1.43	-	0.13	19.2
1962	46.6	0.87	1.9	0.09	-
1972	53.6	1.16	2.0	0.10	17.9
1988	54.6	1.20	1.8	0.10	11.9
1989	38.8	0.63	1.8	0.09	-

DEER CREEK

Year	Percent Pools	Pool/Riffle Ratio [1]	Average Width	Average Depth	Percent Area of Spawning Gravel
1959	60.5	1.53	-	0.10	32.4
1960	60.5	1.53	-	0.10	32.4
1961	59.2	1.45	-	0.10	32.7
1962	44.6	0.81	2.6	0.14	-
1972	54.1	1.18	2.3	0.14	20.0
1988	58.1	1.39	3.7	0.17	5.8
1989	40.3	0.67	3.0	0.12	15.9

NEEDLE BRANCH

Year	Percent Pools	Pool/Riffle Ratio [1]	Average Width	Average Depth	Percent Area of Spawning Gravel
1959	52.5	1.11	1.2	0.06	41.6
1960	67.1	2.04	-	0.07	35.2
1961	64.5	1.82	-	0.07	37.0
1962	54.5	1.20	1.4	0.07	-
1968	54.5	1.20	1.3	0.09	30.9
1971	59.2	1.45	1.3	0.09	-
1972	67.0	2.03	1.1	0.09	35.0
1988	68.3	2.15	1.3	0.10	13.6
1989	67.7	2.10	1.3	0.14	6.5

1 Pools (by length) in ratio include field recorded pools, glides between two riffles, and half of glides between a pool and a riffle. Riffles (by length) in ratio include field recorded cascades, rapids, riffles, and half of glides between a pool and a riffle.

RESULTS

Stream Habitat Measurements

Stream habitat data for 1988 and 1989 show little change from original AWS data, except average width in Deer Creek and spawning gravels in all streams (Table 24). In Deer Creek, the average width was estimated to be approximately one meter greater than that estimated during the AWS. Percent spawning gravel (by area) in 1988 and 1989 compared to the AWS was substantially lower in all streams (i.e., Flynn Creek 41%, Deer Creek 63%, and Needle Branch 72%). Physical habitat parameters (i.e., percent pool, percent riffle, average width, and average depth) for all streams were not altered during the AWS to any discernable degree (Moring 1975).

Salmonid Population and Biomass Estimates

Differences in abundance of juvenile coho salmon before and after logging could not be attributed to timber harvest (Fig. 35). In all AWS streams, the post-logging period exhibited fewer juvenile coho numbers than the pre-logging period (Moring and Lantz 1975). In Flynn Creek (the unharvested watershed), juvenile coho populations in late summer were quite variable between years, with areal densities (fish per m^2) ranging from 0.10 to 1.97 (Table 25). Areal densities of juvenile coho for 1988 and 1989 were similar to the overall average of 1.00 coho per m^2 (s.d. = 0.51). In Deer Creek (the patch-cut watershed), areal densities for juvenile coho in 1988 and 1989 were within the range reported by the AWS, 0.61 - 1.78 coho per m^2, but were lower than the AWS pre- and post-logging averages (Table 25). In Needle Branch (the clearcut watershed), the 1989 estimate of 2.60 juvenile coho per m^2 was substantially

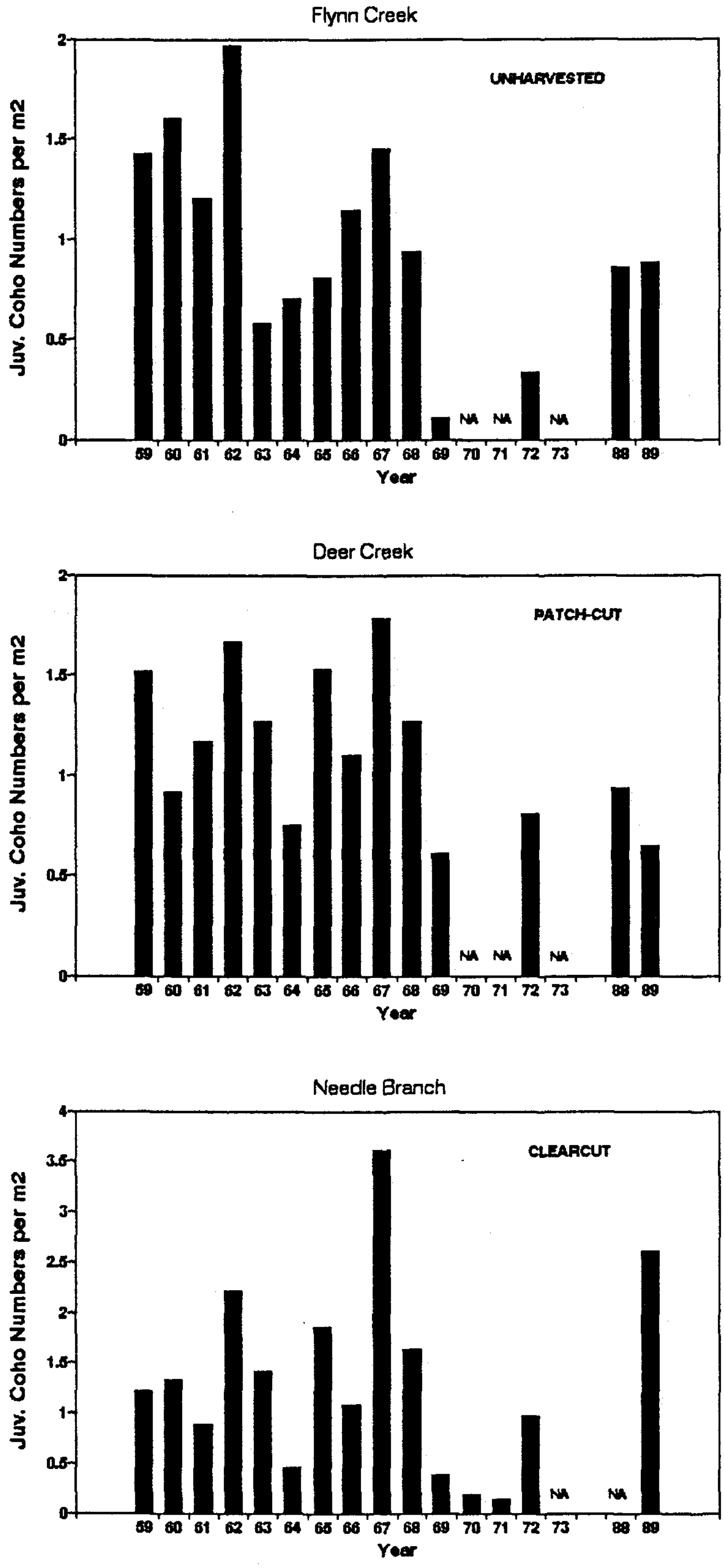


Figure 35. Areal densities of juvenile coho salmon for the Alsea Watershed Study streams.

Table 25. Late summer population estimates for juvenile coho salmon and cutthroat trout. The 1959-1973 data are from Moring and Lantz (1975). The 1976 data are from Hall et al. (1987). Post-logging average includes the AWS years 1966-1973. No estimate is indicated by n.e.

AREAL DENSITIES (Salmonids per m^2)

	JUVENILE COHO SALMON			CUTTHROAT TROUT		
Year	Flynn Creek	Deer Creek	Needle Branch	Flynn Creek	Deer Creek	Needle Branch
1959	1.43	1.51	1.22	n.e.	n.e.	n.e.
1960	1.61	0.91	1.33	n.e.	n.e.	n.e.
1961	1.20	1.16	0.88	n.e.	n.e.	n.e.
1962	1.97	1.66	2.21	0.26	0.15	0.20
1963	0.58	1.26	1.42	0.21	0.14	0.32
1964	0.70	0.75	0.46	0.23	0.12	0.24
1965	0.80	1.53	1.86	0.20	0.12	0.18
1966	1.14	1.10	1.08	0.25	0.14	0.06
1967	1.45	1.78	3.61	0.29	0.14	0.07
1968	0.93	1.26	1.64	0.32	0.12	0.08
1969	0.10	0.61	0.38	0.38	0.23	0.16
1970	n.e.	n.e.	0.18	0.33	0.22	0.05
1971	n.e.	n.e.	0.14	0.35	0.20	0.09
1972	0.34	0.80	0.98	0.30	0.16	0.06
1973	n.e.	n.e.	n.e.	0.22	n.e.	0.05
1976	n.e.	n.e.	n.e.	0.22	n.e.	0.11
1988	0.86	0.94	n.e.	0.32	0.06	n.e.
1989	0.88	0.64	2.60	0.27	0.11	0.11
AVERAGES						
Pre-logging	1.19 (0.52)	1.26 (0.34)	1.34 (0.58)	0.22 (0.02)	0.13 (0.01)	0.23 (0.06)
Post-logging	0.79 (0.56)	1.11 (0.45)	1.14 (1.21)	0.30 (0.05)	0.17 (0.05)	0.08 (0.03)
Overall	1.00 (0.51)			0.28 (0.05)		

Table 25 continued.....

LINEAL DENSITIES (Salmonids per 100 meters)

	JUVENILE COHO SALMON			CUTTHROAT TROUT		
Year	Flynn Creek	Deer Creek	Needle Branch	Flynn Creek	Deer Creek	Needle Branch
1959	2.71	4.39	1.59	n.e.	n.e.	n.e.
1960	3.05	2.65	1.73	n.e.	n.e.	n.e.
1961	2.29	3.38	1.15	n.e.	n.e.	n.e.
1962	3.74	4.82	2.88	0.49	0.43	0.26
1963	1.11	3.67	1.84	0.40	0.39	0.42
1964	1.33	2.17	0.60	0.43	0.35	0.31
1965	1.53	4.44	2.42	0.38	0.36	0.23
1966	2.17	3.18	1.41	0.47	0.40	0.07
1967	2.75	5.16	4.69	0.55	0.41	0.09
1968	1.77	3.67	2.13	0.61	0.33	0.10
1969	0.20	1.78	0.50	0.71	0.66	0.21
1970	n.e.	n.e.	0.24	0.64	0.65	0.07
1971	n.e.	n.e.	0.18	0.66	0.58	0.12
1972	0.64	2.33	1.27	0.58	0.47	0.08
1973	n.e.	n.e.	n.e.	0.42	n.e.	0.06
1976	n.e.	n.e.	n.e.	0.42	n.e.	0.15
1988	1.62	2.72	n.e.	0.60	0.17	n.e.
1989	1.67	1.87	3.38	0.50	0.32	0.15
AVERAGES						
Pre-logging	2.51 (0.98)	3.65 (0.98)	1.74 (0.76)	0.43 (0.05)	0.38 (0.04)	0.31 (0.08)
Post-logging	1.51 (1.06)	3.22 (1.31)	1.49 (1.58)	0.58 (0.10)	0.50 (0.13)	0.10 (0.05)
Overall	1.90 (0.96)			0.52 (0.11)		

greater than AWS pre- and post-logging averages by 93% and 128% (Table 25).

Differences in biomass of juvenile coho salmon could not be attributed to timber harvest treatments (Fig. 36). In the AWS, juvenile coho biomass was reported lower in the post-logging period than the pre-logging period for Flynn Creek (the unharvested watershed), and higher for Deer Creek and Needle Branch (Table 26). In Flynn Creek, biomass estimates for 1988 and 1989 were similar to the overall average of 2.2 g/m^2 (s.d. = 0.8). In Deer Creek, the biomass estimates for 1988 and 1989 were low as compared with the AWS range of 2.4 - 6.8 g/m^2 (Table 26). In Needle Branch, the 1989 biomass estimate of 5.2 g/m^2 was substantially greater than the AWS pre- and post-logging averages.

Cutthroat trout in Needle Branch were detrimentally affected by clearcut logging without bufferstrips during the AWS (Moring and Lantz 1975), and long-term effects were indicated by recent data (Figs. 37 and 38). In Flynn Creek, areal densities and biomass for cutthroat trout in 1988 and 1989 were within the annual range reported by the AWS, 0.20 - 0.38 cutthroat per m^2 and 2.7 - 5.8 g/m^2, respectively (Tables 25 and 26). Overall averages of areal densities and biomass in Flynn Creek were 0.28 cutthroat per m^2 (s.d. = 0.05) and 3.7 g/m^2 (s.d. = 0.8), which were similar to the 1988 and 1989 estimates. In Deer Creek, areal densities and biomass for 1988 were the lowest estimates in all years surveyed, and for 1989 they were lower than pre- and post-logging averages (Tables 25 and 26). Cutthroat trout population in Deer Creek have declined since the AWS as suggested by the recent data. In Needle Branch, cutthroat areal density for 1989 was below the AWS pre-logging average by 50%, but was greater than the post-logging average (Table 25). Biomass for Needle Branch in 1989 was below that of AWS pre-logging and post-logging averages (Table 26).

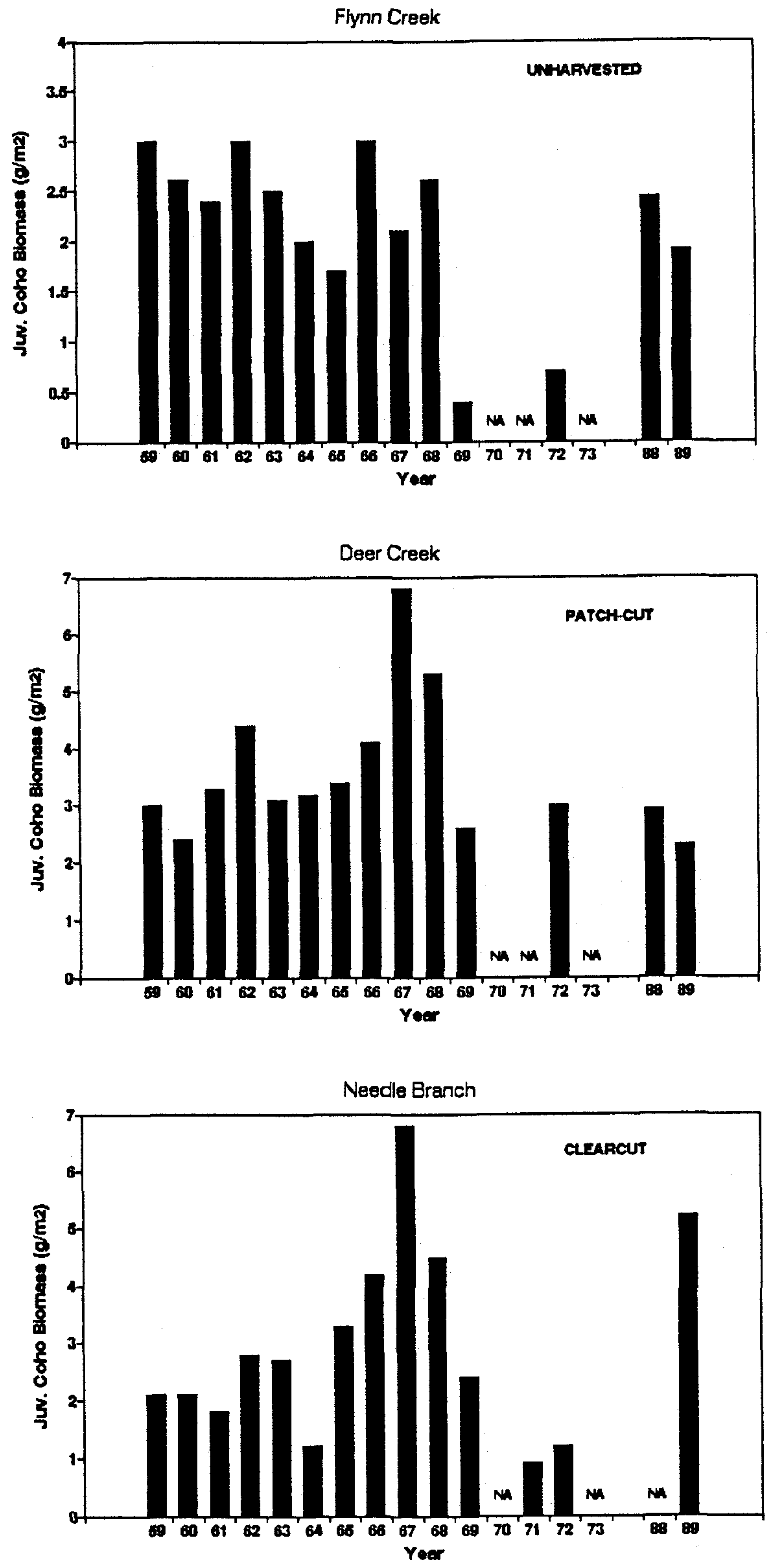


Figure 36. Biomass (g/m^2) of juvenile coho salmon for the Alsea Watershed Study streams.

Table 26. Mean September biomass estimates (g/m^2) for juvenile coho salmon and cutthroat trout. For coho the 1959-1972 data are from Moring and Lantz (1975). For cutthroat trout the 1962-1973 data are from Knight (1980). Post-logging average includes the AWS years 1966-1973. No estimate is indicated by n.e.

	JUVENILE COHO SALMON			CUTTHROAT TROUT		
Year	Flynn Creek	Deer Creek	Needle Branch	Flynn Creek	Deer Creek	Needle Branch
1959	3.0	3.0	2.1	n.e.	n.e.	n.e.
1960	2.6	2.4	2.1	n.e.	n.e.	n.e.
1961	2.4	3.3	1.8	n.e.	n.e.	n.e.
1962	3.0	4.4	2.8	5.8	5.1	3.9
1963	2.5	3.1	2.7	3.5	2.9	3.4
1964	2.0	3.2	1.2	4.0	1.9	3.2
1965	1.7	3.4	3.3	2.7	2.9	3.0
1966	3.0	4.1	4.2	2.7	2.1	1.1
1967	2.1	6.8	6.8	4.3	3.3	0.7
1968	2.6	5.3	4.5	2.7	2.2	1.6
1969	0.4	2.6	2.4	3.7	2.8	1.5
1970	n.e.	n.e.	n.e.	4.0	3.8	1.1
1971	n.e.	n.e.	0.9	4.3	4.2	1.3
1972	0.7	3.0	1.2	4.1	4.0	1.4
1973	n.e.	n.e.	n.e.	3.8	n.e.	1.5
1988	2.4	2.9	n.e.	3.2	1.1	n.e.
1989	1.9	2.3	5.2	3.4	2.7	1.0
AVERAGES						
Pre-logging	2.5 (0.5)	3.3 (0.6)	2.3 (0.7)	4.0 (1.3)	3.2 (1.3)	3.4 (0.4)
Post-logging	1.8 (1.2)	4.4 (1.7)	3.3 (2.6)	3.7 (0.6)	3.2 (0.9)	1.3 (0.3)
Overall	2.2 (0.8)			3.7 (0.8)		

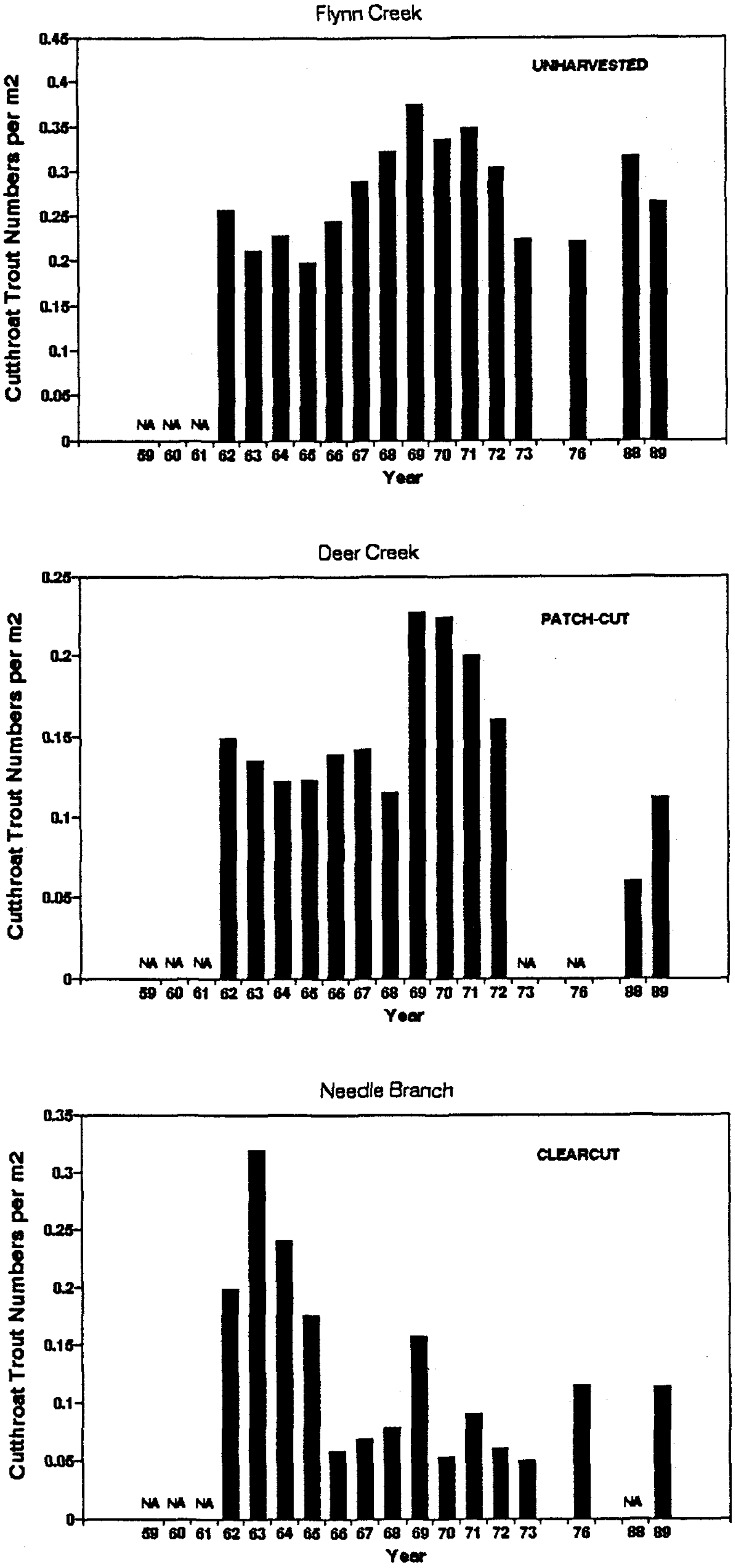


Figure 37. Areal densities of cutthroat trout for the Alsea Watershed Study streams.

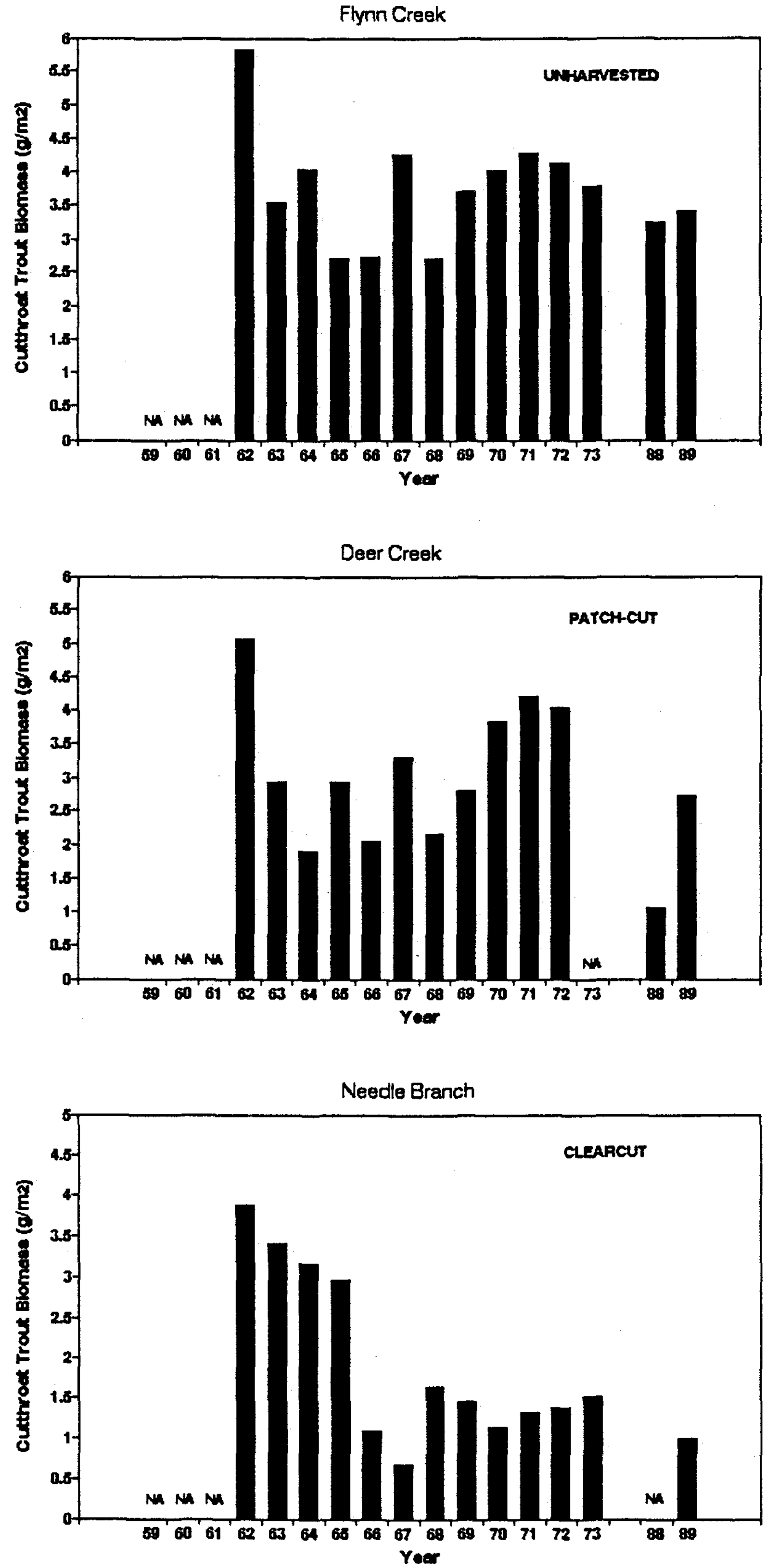


Figure 38. Biomass (g/m^2) of cutthroat trout for the Alsea Watershed Study streams.

DISCUSSION

Physical characteristics of the AWS streams have changed little in the past three decades. At a channel unit scale, changes in habitat structure were not detectable. Microhabitat structures, such as cover from undercut banks, boulders, and coarse woody debris (CWD), were not measured during the AWS, thus can not be compared to recent data. Estimates of spawning gravel for 1988 and 1989 were lower than estimates in the AWS, but reductions occurred in all AWS streams, including Flynn Creek, the mature forest watershed. Needle Branch (the clearcut watershed) experienced the greatest reduction in spawning gravel, and Flynn Creek (the unharvested watershed) experienced the least. Differences between study methods for characterizing spawning gravels may be responsible.

Flynn Creek, the mature forested (unharvested) watershed, provided an opportunity to generate a long-term, temporal framework for natural variation of salmonid populations in the upper Drift Creek drainage. Populations of juvenile coho and cutthroat trout were quite variable annually in these small AWS streams (Figs. 35 and 37). In Flynn Creek, the overall coefficient of variation is 50% for juvenile coho and 20% for cutthroat trout based on linear densities. In late summer, annual densities for juvenile coho changed by an order of magnitude (Table 25). These broad annual ranges for coho densities were observed also in pre-logging data from Deer Creek and Needle Branch, exhibiting coefficients of variation of 27% and 43%, respectively. Cutthroat densities from pre-logging years in Deer Creek and Needle Branch exhibit coefficients of variation of 10% and 27%, respectively. In general, juvenile coho densities were more variable than cutthroat trout densities. Comparing natural variation between estimates of biomass and densities, biomass fluctuated less than densities (Figs. 35 - 38).

Tributary size influenced the degree of annual variance in salmonid populations. In Needle Branch, the smallest stream had the greatest annual variation of population densities, and the lowest (linear) densities of salmonids compared to the two larger AWS streams. Likewise, coefficients of variation for juvenile coho and cutthroat trout were lowest in the largest stream. Average linear densities were greater in these two larger streams.

Knowledge of natural ranges of salmonid densities aids in the evaluation in long-term population shifts. Large annual fluctuations in trout populations have been observed in other studies, thus long-term data are essential for adequate evaluation of land-use effects (Hall and Knight 1981, Platts and Nelson 1988). In this study, inferences based on population and biomass estimates must be interpreted cautiously because different methods were used between years (Table A.18). Estimates include a sampling variance though no confidence limits are shown in the tables and figures. Confidence limits derived by different equations of each method's population estimators would not be comparable.

Juvenile coho showed no long-term shifts in densities or biomass beyond the range of natural variation as a result of timber harvest. In the AWS, juvenile coho were not detrimentally affected by timber harvest (Moring and Lantz 1975). In all AWS streams, juvenile coho densities and biomass exhibited greater variability in the post-logging period than in the pre-logging period. In 1989, coho density and biomass in Needle Branch were high compared to the AWS years, but did not surpass the 1967 estimate. The greater variability of juvenile coho abundance makes interpretation of land-use impacts difficult.

Cutthroat trout showed long-term detrimental effects from clearcutting without bufferstrips. In Needle Branch, the density and biomass for 1989 were as low as the AWS post-logging estimates. Cutthroat numbers and biomass significantly declined in Needle Branch after logging (Moring and Lantz 1975). In other coastal Oregon streams, an extensive (before-after) study found cutthroat numbers to decline after logging in streams with no bufferstrips (Moring and Lantz 1974). In the Cascade Mountains, another study (extensive post-treatment design) found cutthroat trout abundance greater in a logged section of stream compared to an unlogged section (Aho 1977). Studies on trout populations in the Coast Range and Cascade Mountains have shown varied responses to clearcut logging (Murphy and Hall 1981).

Cutthroat trout density and biomass in Deer Creek for 1988 and 1989 has declined from the AWS period. With only two years of data, it was difficult to distinguish whether this recent observation was the result of a long-term trend or a consequence of a different estimation method. Since Flynn Creek (the unharvested watershed) did not change in densities or biomass for 1988 and 1989, the data provided additional evidence that cutthroat populations have declined in Deer Creek. Further investigation is warranted because timber harvest has continued in the Deer Creek watershed since the AWS. The AWS treatment in Deer Creek logged approximately 25% of that watershed. As of 1988, 50% of the Deer Creek watershed has been logged (Fig. 34). Most of the recent logging occurred in the upper areas of the watershed and included removal of half the bufferstrip in the east fork tributary of Deer Creek.

Cutthroat trout are dependent on the small first-second order streams for spawning during winter flows (Lowry 1964). Life histories of coastal cutthroat trout are complex; anadromous, potamodromous, and resident forms may all inhabit one stream (Trotter 1989). Beginning in November, there is an upstream migration in a basin to spawn that includes sea-run trout and mature residents (Sumner 1962, Lowry 1965, Giger 1972). This upstream migration into tributaries to spawn continues through February (Sumner 1962, Lowry 1965). Fry emerge in the spring and rear in these small tributaries (DeWitt 1954, Sumner 1962, Lowry 1964). During summer as the stream flows drop, the young-of-the-year move down into larger-order streams (Lowry 1964). In the spring, trout one-year-olds move from their natal streams to downstream basin reaches (Sumner 1962, Lowry 1965). Many older trout, including ocean-destined trout, move further downstream in a basin (Sumner 1962, Giger 1972). This gradual seasonal downstream shifting of non-smolting cutthroat trout from headwaters to the lower basin is unique to this species' life history pattern, which can include two to five years of freshwater residence before migrating to sea (Giger 1972).

Migration patterns of coastal cutthroat trout emphasize the importance of small headwater streams for reproduction capability of these trout in the basin as a whole. The AWS streams provide summer-rearing habitat for cutthroat trout that may eventually smolt and also support older age classes of resident cutthroat. Downstream migrants of cutthroat trout in Flynn Creek and Deer Creek were primarily two-years-old fish; and one-year-old fish comprised the majority of migrants in Needle Branch, which is the smaller stream (Lowry 1965). From a basin perspective, disturbances in headwater tributaries may potentially alter cutthroat distribution and age class structure in lower tributary/mainstem areas. Such changes may result from increased emigration or reduced migration of a particular age class.

In Needle Branch during the summer-rearing period, the decline in cutthroat trout abundance following logging appears to be accompanied with a shift in age-class structure (Fig. 39). In a pre-logging year 1962, all streams showed a dominant age class of one-year-old trout. In 1989, one-year-old trout continue to dominate in Flynn Creek and Deer Creek, but not in Needle Branch. In 1989, young-of-the-year in Needle Branch were found in greater numbers than older age classes. Trout fry (age 0+) were found only within a 55-m reach below the first falls. In lower reaches of Needle Branch, few 1+ and 2+ trout were captured, and these occurred in deep pools having some CWD cover or an undercut bank.

In Needle Branch, decline in older age class trout following logging may represent a loss of residents from the cutthroat trout population because estimates of trout were for the late-summer period. After logging, outmigration of cutthroat trout occurred earlier than in pre-logging years and was correlated to higher stream temperatures (Moring and Lantz 1975). Downstream migrants of cutthroat trout increased three years following logging (1967-1969), and after 1969, annual outmigration declined to lower levels than pre-logging values (Fig. 40). Cutthroat migration from Needle Branch may have resulted from higher stream temperatures or loss of CWD cover, or both. Low numbers of outmigrants observed in the late AWS years may represent remnants of an anadromous population. An anadromous population of cutthroat would have a better ability to recover from a short-term disturbance (i.e., high stream temperatures) than a resident population because a portion of the population would be absent during the disturbance. The extent to which anadromous and resident population interbreed is not well known; it appears residents do not contribute to anadromous populations in headwater streams (Michael 1983).

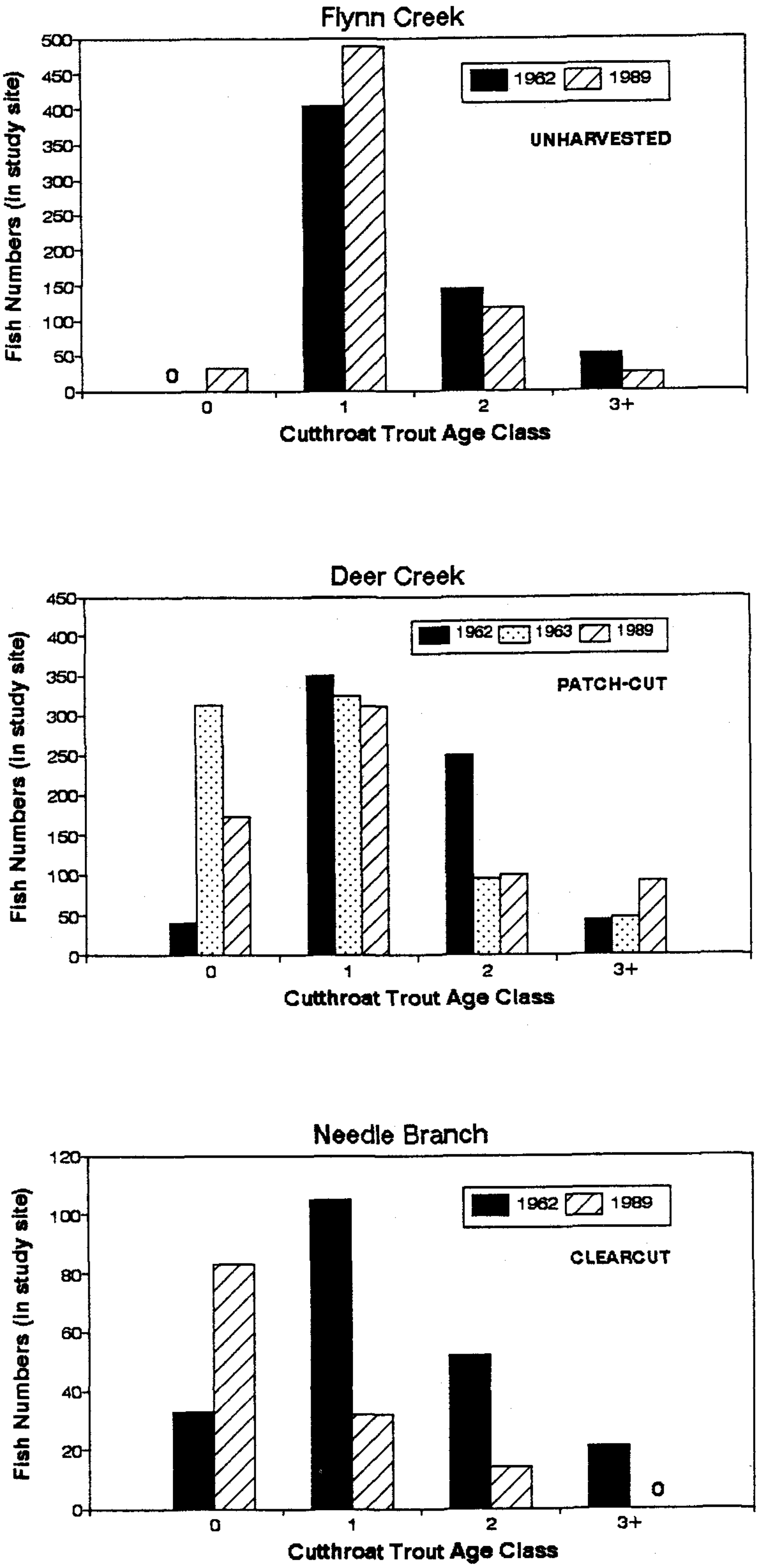


Figure 39. Age class structure of cutthroat trout in 1962, 1963 (pre-logging years from Lowry 1964), and 1989 (a post-logging year) in the Alsea Watershed Study streams.

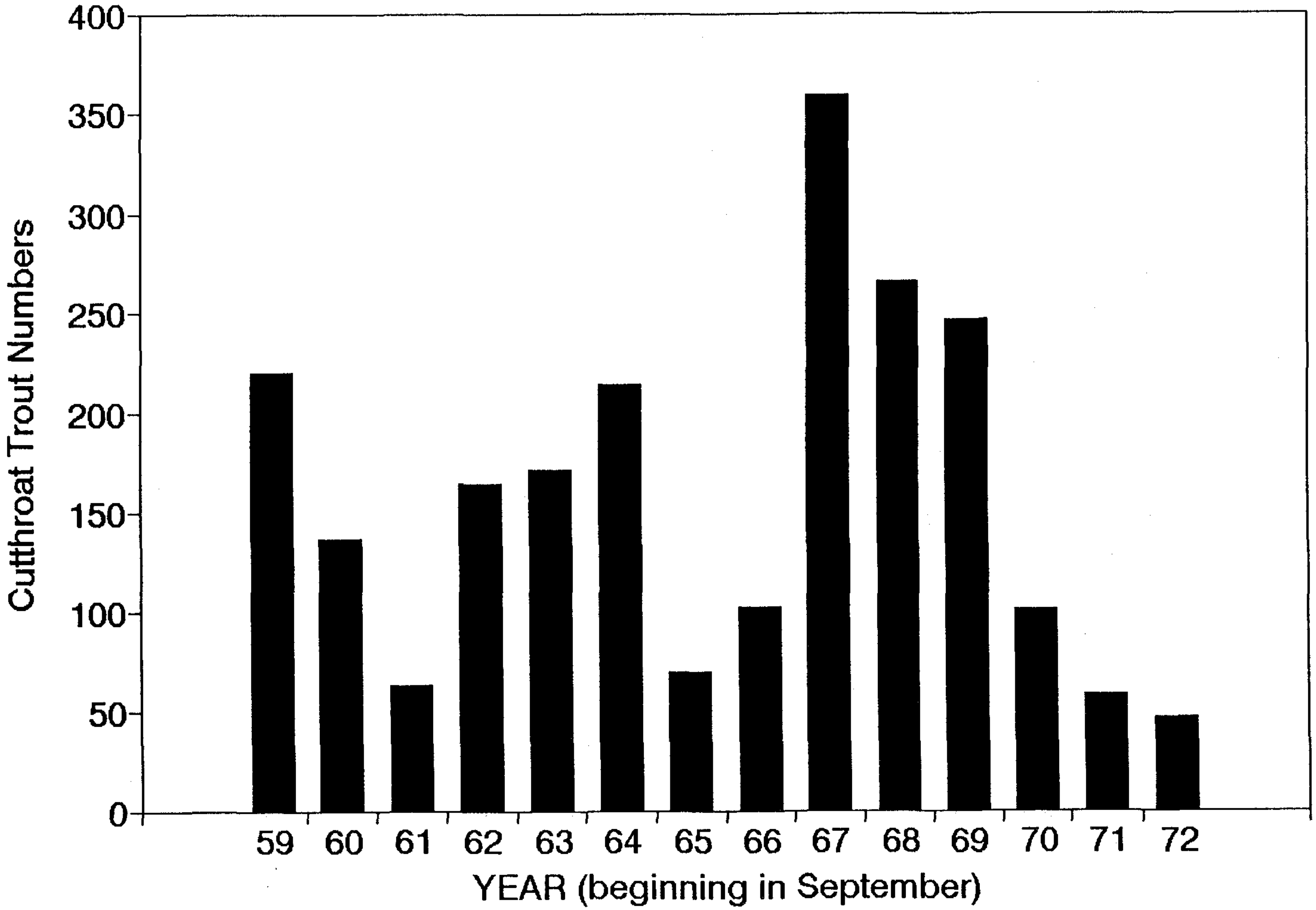


Figure 40. Downstream migration of cutthroat trout in Needle Branch from trap data (1959-1973) of the Alsea Watershed Study; numbers reported in Moring and Lantz (1975).

The cutthroat trout population of Needle Branch has not recovered over the long-term. This may be in response to a lack of CWD cover and morphologic characteristics of stream habitat (unchanged) that favor the juvenile coho population. Needle Branch is morphologically distinct from the other AWS streams. Needle Branch is a small, first-order stream with a gradient of 1.4%. The stream often flows subsurface through riffle habitat in the late summer, leaving only pool habitat (Moring 1975). Pool habitat is favorable for juvenile coho (Glova 1986, Glova 1987, Bisson et al. 1988). In Deer Creek and Flynn Creek, juvenile coho densities were greater in lower gradient reaches compared to high-gradient (canyon) reaches (Chapman 1961, Au 1972). Cutthroat trout fry in Deer Creek reared in the early summer above the anadromous coho limit (Lowry 1964). In Needle Branch, a migration barrier is located at the top end of the study section (900 m upstream from Drift Creek). This migration barrier does not allow migrating cutthroat trout to spawn above where coho spawn, and forces trout fry (age 0+) to summer rear with juvenile coho. Juvenile coho are more aggressive than cutthroat trout fry, thus dominate pool habitat for food resources (Glova 1986). Under these conditions, the morphology of Needle branch appears to favor juvenile coho over cutthroat trout during the summer suggesting there may be competitive interactions between the salmonids.

Competitive interactions between juvenile coho and cutthroat trout for food and space may prevent the reestablishment of a cutthroat population structure similar to that in the pre-logging period. An attempt was made to examine competitive interactions at a annual population level during the summer-rearing period with the AWS data. For each AWS stream, annual linear densities for both juvenile coho and cutthroat were divided by their pre-logging average. The annual linear densities were standardized by average pre-logging densities to lessen stream size influences on density estimates. These standardized values for juvenile coho and cutthroat trout by year are plotted against each other in Figure 41. Correlation analysis with all data, except the Needle Branch post-logging data revealed a weak correlation between salmonids ($r = -0.31$, $p = 0.12$), whereas the Needle Branch post-logging data resulted in no relationship between the salmonids ($p > 0.10$). This suggests a lack of competitive interaction between the salmonids after logging, or that competitive interactions can not be represented by this approach. Populations may be too variable from other environmental factors to show a response by abundance at one point in time (late-summer). This analysis illustrates the difference between salmonid population densities of Needle Branch post-logging data and all other AWS data, highlighting the decline of cutthroat trout after clearcut logging.

Revisiting the AWS streams illustrated that there are long-term, detrimental effects on cutthroat trout population in the clearcut watershed. The long-term decline in trout density and biomass was associated with a decline in older age-classes that likely represents the resident proportion of the cutthroat population. The initial sharp decline in cutthroat trout populations as observed in Needle Branch may be due to elevated stream temperatures 2 - 3 years after clearcut logging. In the Carnation Creek Study, temperature changes as a result of riparian cover removal influenced trout abundance and shifted life history patterns of salmonids (Hartman 1987, Hartman et al. 1987). The long-term effects may reflect degraded habitat from loss of instream CWD cover, influencing the ability of cutthroat trout to compete for food over the juvenile coho salmon. This assumes that CWD cover has been loss from the stream-cleaning operations during the AWS, since CWD data are not available. Juvenile

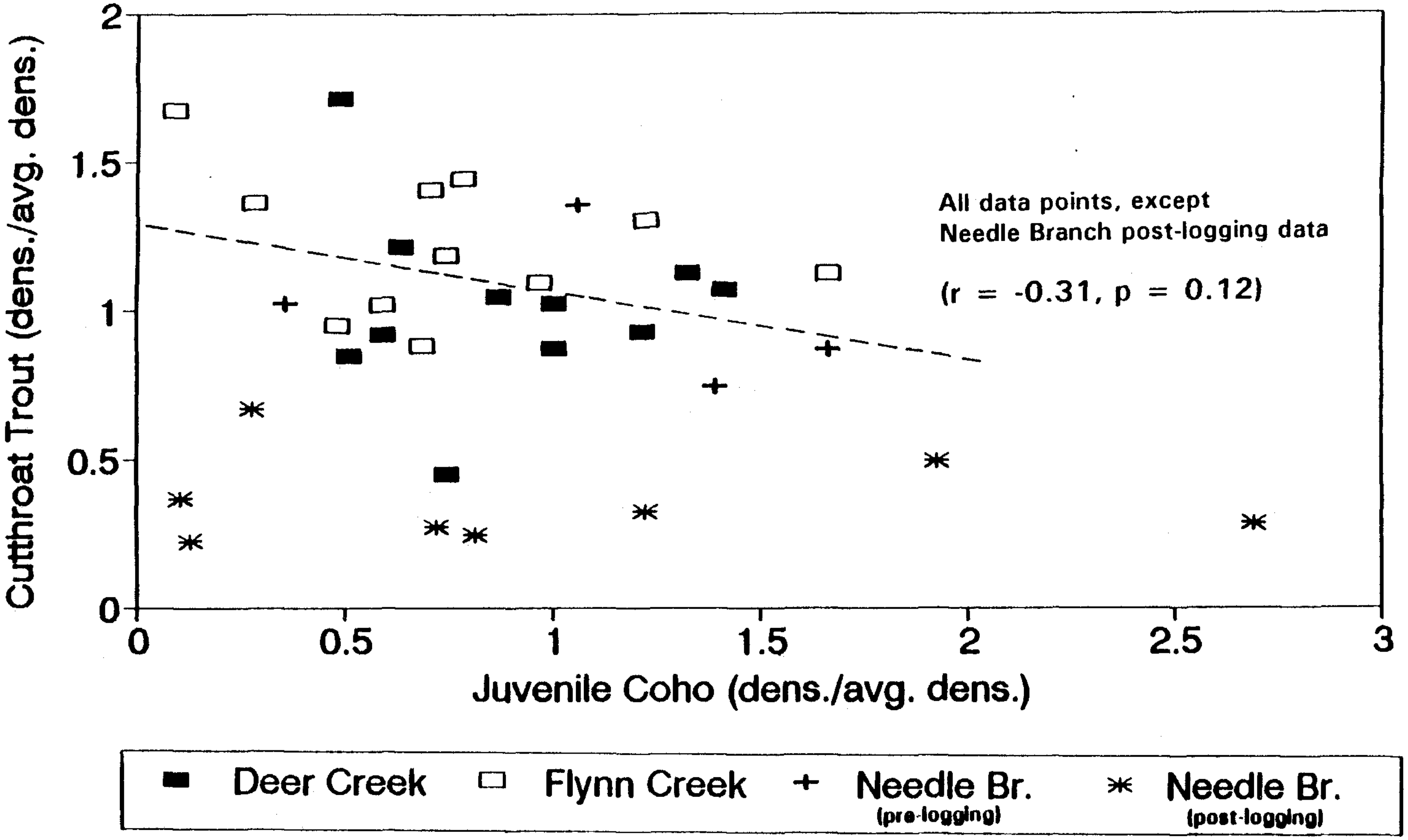


Figure 41. Interactions between juvenile coho salmon and cutthroat trout as observed by annual relative abundances in the Alsea Watershed Study streams.

coho salmon exhibit no significant changes in response to the AWS logging treatments. Further studies are needed to examine food-cover relationships with sympatric populations of cutthroat trout and juvenile coho salmon.

CHAPTER V: SUMMARY

The Drift Creek study of basin geomorphology illustrated that landscape heterogeneity within a watershed could be organized hierarchically to exhibit certain patterns in valley landform and channel characteristics. Segments with narrow valleys had greater lengths of multiple channels and densities of boulders than segments with wide valleys. In the upper headwaters, the narrow valley segment contained more volumes of coarse woody debris (CWD) in the active channel than all other segments, and the greatest CWD volumes (by 50 - 80%) occurred in the two upper-most reaches of South Fork Drift Creek (unharvested, mature conifer forest). Within wide valleys of alluvium, incision of the channel occurred in three reaches. Reaches of incised channels had reduced multiple channel lengths and a channel composed primarily of bedrock. Composition of channel unit types was associated with reach gradient, in which percent length of pools and glides was inversely related to gradient. Within Drift Creek basin, composition of channel unit types was influenced by bedform gradient, and occurrence of fast-water units, primarily cascades reflected constraint by adjacent hillslopes in narrow valleys. Channel structures as characterized by sediment composition, boulder densities, and CWD volumes were highly variable along a continuum of basin reaches and could not be associated with reach landform features. Local hillslope conditions exhibit broad ranges in rates of geomorphic processes, and fluvial processes shift in competence to move bedload along a continuum from headwaters to estuary.

Basin patterns of salmonid distribution and abundance in Drift Creek revealed limited associations with geomorphic structure, but did illustrate the importance of basin position and habitat composition of channel unit types. Juvenile chinook and coho salmon exhibited strong basin gradients of abundance along an upstream-downstream continuum. Juvenile chinook occupied the lower basin in greater abundance and juvenile coho occupied the upper basin in greater abundance, and transition in abundance occurred between two mid basin segments. Juvenile coho abundances were greater in mainstem reaches of the upper basin where major tributaries join Drift Creek. The reach with greatest abundance of juvenile coho occurred below the confluence of South Fork Drift Creek which forms the fourth-order mainstem of Drift Creek. Basin patterns of juvenile coho distribution and abundance are reflected in coho's life history where tributaries are natal areas and a large proportion of local populations emigrate downstream. Thus, basin position in relation to headwater drainage densities may be important in determining juvenile coho abundance during summer rearing. Salmonid abundances were not related to any specific valley landform from a basin perspective of reaches. Abundances of trout (ages 0+ and 1+) were directly associated with reach gradient. Because trout were specific in habitat occupancy of fast-water channel units and that fast-water units were directly correlated with mainstem reach gradients, it is assumed trout distribution and abundance in the mainstem reflected composition of channel unit types. Salmonid abundances were not related to channel characteristics of sediment composition, boulder densities, and CWD volumes among mainstem reaches. Functional relationships between microhabitat features and salmonid abundance change along a basin continuum, thus precluding a linear analysis by basin reaches.

Basin surveys have limitations in explaining spatial variation of stream habitat features and salmonid distribution and abundance. Within a basin, the mainstem has no replications, and tributaries provide pseudo-replications for interpreting associations among geomorphic settings, channel habitat parameters, and salmonid abundances. A basin analysis relating measurements of habitat quality to salmonid abundance may be more applicable for trout species than for salmon species since trout (ages 0+ and 1+) were related to reach gradient in the Drift Creek mainstem. This Drift Creek basin survey provided summer-rearing patterns only. A complete representation of channel characteristics within a basin and their function in modifying salmonid distributional patterns requires a seasonal temporal perspective.

Salmonid densities and habitat use differed between mainstem and tributary reaches of Drift Creek. Salmonid densities per channel unit were two to eight times greater in the tributaries, where pools and glides became extensively used for habitat. Cutthroat trout densities changed more than the other salmonids. Habitat use of channel units among salmonids was more variable in the mainstem where microhabitat features in fast-water units were more suitable for use than in tributaries. Riffles and rapids in the tributaries became too shallow for use in the summer. In the tributaries, salmonid densities were strongly influenced by stream size and gradient. Juvenile coho densities were more in low-gradient streams, and trout (ages 0+ and 1+) were more in high-gradient and larger streams. In the mainstem, only trout were directly related to reach gradient. In the tributaries, abundances of trout (ages 0+ and 1+) were associated with volumes of CWD, but not in the mainstem.

In the Drift Creek tributaries, cutthroat trout were less abundant in clearcut sites without buffers than in patch-cut sites with buffers and unharvested sites. This result was similar to the Alsea Watershed Study (AWS) findings. In this study sympatric populations of cutthroat trout with juvenile coho salmon were significantly lower in densities for the clearcut sites compared to the other land-use treatments. Allopatric populations of cutthroat trout did not *show any difference among harvested and unharvested sites.* Reexamination of the AWS streams demonstrated that detrimental effects were long term, and population structure was altered in which older age trout declined more. Of the habitat parameters investigated, CWD was the only measure of habitat quality that was significantly lower in clearcut sites compared to patch-cut and unharvested sites. CWD may provide important cover for cutthroat trout and affect their feeding efficiency in the presence of juvenile coho. In clearcut watersheds, the initial decline in cutthroat trout abundance may be a result of elevated stream temperatures from an open riparian canopy. Competitive interactions between juvenile coho salmon and cutthroat trout with a loss of CWD cover may contribute to the long-term decline in cutthroat abundance after logging.

A basin perspective of geomorphology and salmonid distribution and abundance allows resource mangers to assess risks of land-use activities on basin populations, rather than a sections of stream. This is especially important in coastal Oregon basins because most salmonids are anadromous. Understanding landscape influences on salmonid populations allows for prediction of basin distributions, and abundance in the case with trout. Cutthroat trout may be useful indicators to effects of timber harvest, particularly because influences of geomorphic setting on abundance can be accounted for by reach gradient. Forest practices on federal and state lands leave buffers on third-order streams, but cutthroat trout spawn and rear in first-order streams of the Oregon Coast Range. Protection of riparian zones in smaller order streams may be required for cutthroat trout. The integrity of salmonid populations depends on the entire drainage.

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APPENDIX

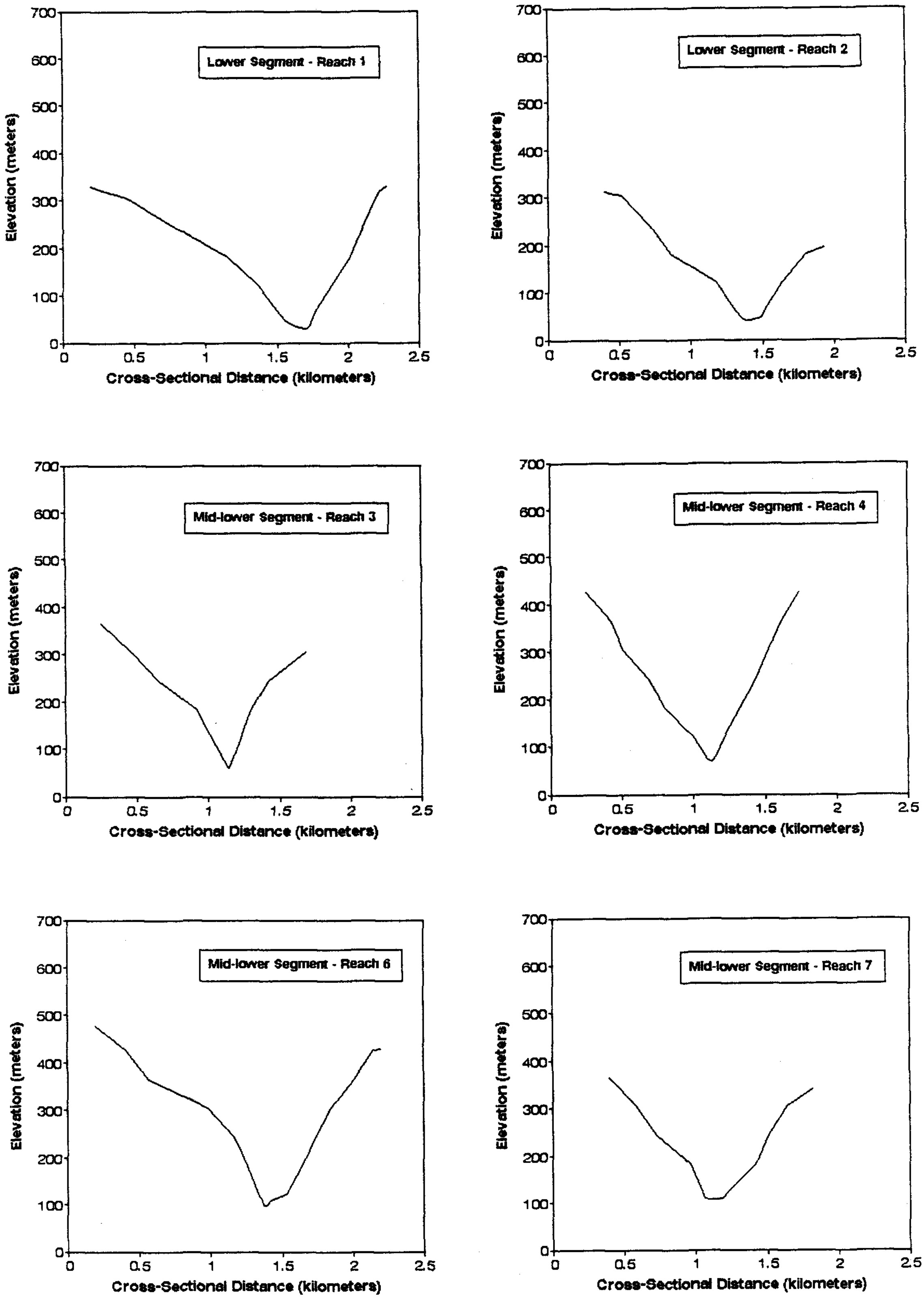

Figure A.1. Valley cross-sections in Drift Creek.

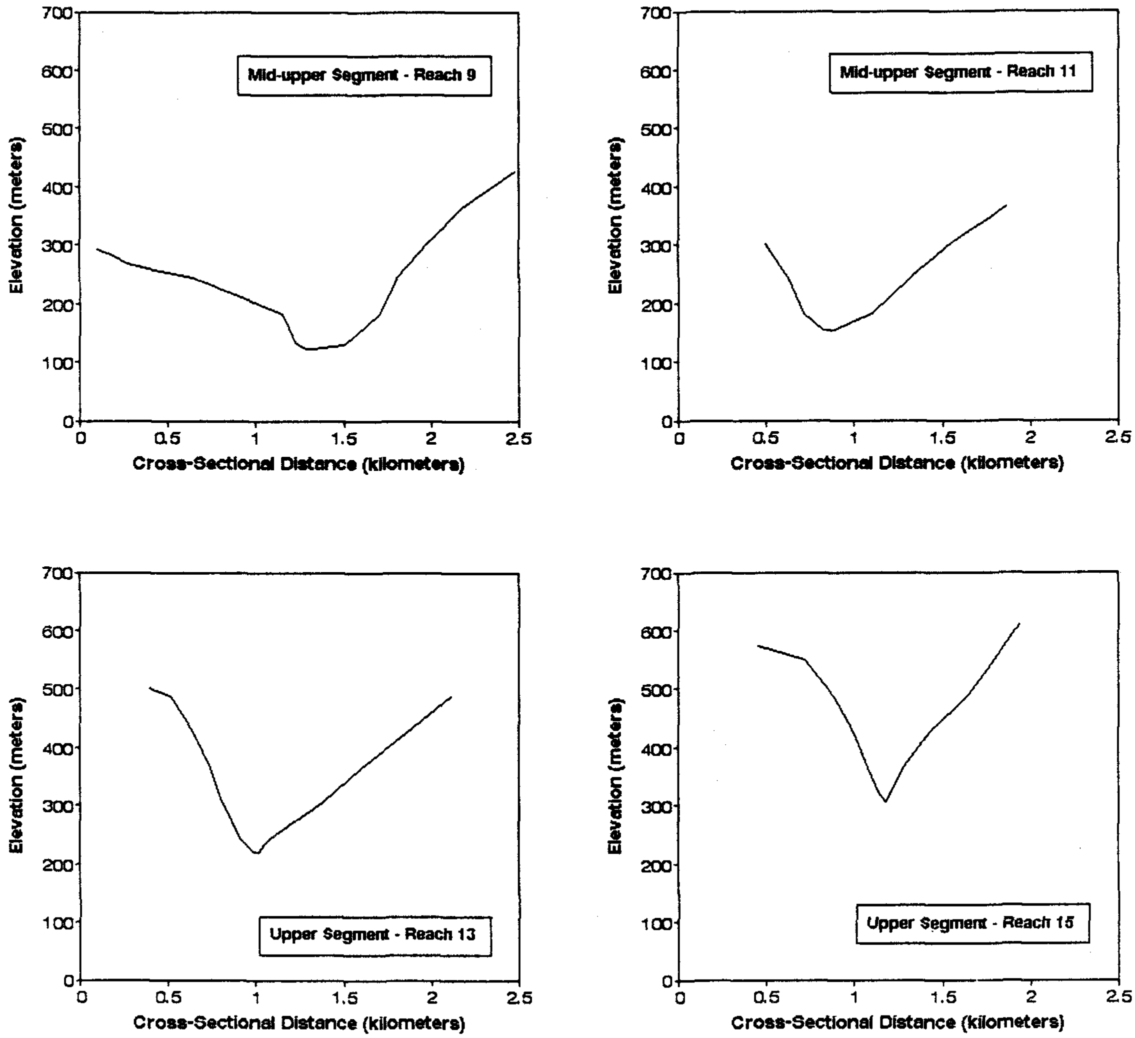

Figure A.1. Valley cross-sections in Drift Creek.

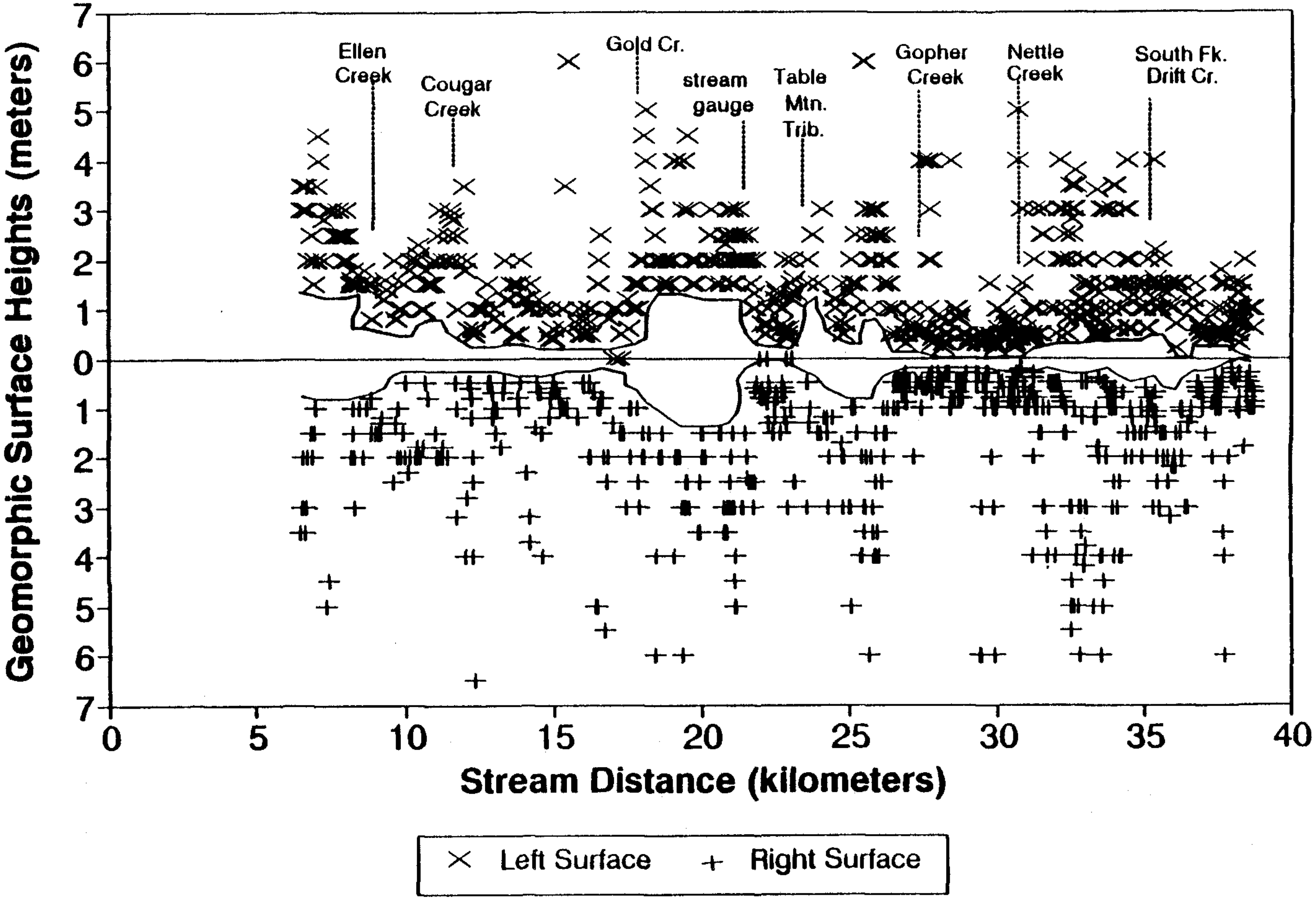

Figure A.2. Longitudinal profile of geomorphic surface heights along Drift Creek. Above zero are heights of geomorphic surfaces on the left bank (looking upstream), and below zero are heights on the right bank. Zero indicates no geomorphic surface exists

Table A.1. Map standard distances for Drift Creek used to calibrate all longitudinal data of geomorphic, stream habitat, and fish abundance.

Section Description	Cumulative Stream Distance (meters)	Section Length (meters)
Lyndon Creek	0	
		4851
Bear Creek	4851	
		489
Trout Creek	5349	
		1711
Survey Start	6520	
		1853
Ellen Creek	8373	
		2919
Cougar Creek	11292	
		2702
Boulder Creek	13994	
		3719
Slickrock Creek	17713	
		580
Gold Creek	18293	
		3120
Stream Gauge	21413	
		1721
Table Mtn. Tributary	23134	
		2406
Meadow Creek	25540	
		2237
Gopher Creek	27777	
		3045
Nettle Creek	30822	
		1625
Bohannon Ranch Falls	32447	
		2817
South Fork Drift Creek	35264	
		3514
South Fork Drift Creek 1989 survey end at "major forks"	38778	

Table A.2. Frequencies for channel unit (habitat) measurements and diver counts used in the Hankin and Reeves (1988) method.

1988 FREQUENCY for HABITAT MEASUREMENTS

Stream Section Description	pool	glide	riffle	rapid	cascade	side channel
all sections	1/8	1/8	1/12	1/8	1/4	1/2

1989 FREQUENCY for HABITAT MEASUREMENTS

Stream Section Description	pool	glide	riffle	rapid	cascade	side channel
survey start						
	1/9	1/15	1/8	1/9	all	all
Slickrock Creek						
	1/9	1/8	1/6	1/3	all	all
Meadow Creek						
	1/15	1/8	1/10	1/6	all	all
South Fk.Drift Creek						

1988 FREQUENCY for FISH SAMPLING

Stream Section Description	pool	glide	riffle	rapid	cascade	side channel
all sections	1/4	1/8	1/12	1/6	1/2	all

Table A.2. continued.....

1989 FREQUENCY for FISH SAMPLING

Stream Section Description	pool	glide	riffle	rapid	cascade	side channel
survey start						
	1/3	1/5	1/4	1/3	all	all
Cougar Creek						
	1/3	1/5	1/4	1/4	1/3	all
Slickrock Creek						
	1/3	1/4	1/3	1/3	all	all
stream gauge						
	1/3	1/4	1/4	1/2	all	all
Meadow Creek						
	1/4	1/4	1/5	1/3	all	all
Gopher Creek						
	1/3	1/4	1/5	1/2	all	all
Bohannon Ranch Falls						
	1/4	1/4	1/4	1/2	all	all
South Fk. Drift Creek						

Table A.3. Cenozoic geologic history for the Oregon Coast Range (Baldwin 1981).

AGE in millions of years	EPOCH	DESCRIPTION of GEOLOGIC EVENTS
50 - 65	**PALEOCENE to early EOCENE**	The Coast Range was covered by a large, partially enclosed ocean basin of sedimentation called a geosyncline. The southern edge of this geosyncline was at the Klamath Mountains, and the eastern edge was a chain of volcanic peaks (presently the Cascade Range). From these volcanic peaks came large amounts of submarine flows, breccias, and tuffaceous sediments which interfingered the geosyncline sediments. In the early Eocene volcanism was particularly active.
40 - 50	**mid EOCENE**	By the middle Eocene volcanism ceased temporally. An uplift in the Klamath Mountains produced an influx of sand into the geosyncline. Sedimentation and turbidity currents in the geosyncline formed rhythmically bedded layers consisting mostly of medium-grained sandstone, that graded upward into fine-grained sandstone and siltstone near each layer top.
30 - 40	**late EOCENE to early OLIGOCENE**	Volcanism in the Cascade Range resumed, but it was not as extensive as in the early Eocene. Sedimentation and sinking continued in the geosyncline.
20 - 30	**OLIGOCENE to early MIOCENE**	The Coast Range started to uplift with land taking form. This uplift is believed to be caused by the crustal margin of the Pacific tectonic plate being shoved under the North American plate. The geosyncline receded remaining only in the north part of the Coast Range.
5 - 20	**MIOCENE**	The land continued to uplift, and there was widespread intrusions of volcanic sills and dikes into the upper sandstone formations. This volcanic activity produced some gabbroic sills as much as 300 meters thick.

Table A.3 continued.....

AGE in millions of years	EPOCH	DESCRIPTION of GEOLOGIC EVENTS
2 - 5	**PLIOCENE**	The geosyncline completely withdrew with the ocean lapping against the outer margin of the Coast Range. Uplift continued as the older Cenozoic sandstone formations began to weather. The Coast Range rivers carved through the sandstone and the landscape acqiured it's present day drainage patterns. Prominent volcanic intrusive sills and dikes were exposed by the carving rivers, and today they are the high elevation central Coast Range peaks.
1 - 2	**Early PLEISTOCENE**	The ocean relative margin to the land was to a point several hundred feet above the present sea level. High precipitation facilitated numerous landslides in the narrow valleys carved by the rivers. Uplift of the land continued which caused faulting, and folding of the sandstone formations. Where the sandstone beds were soft from rainfall saturation folding occurred continuously and slowly as waves of viscous material producing synclines and anticlines. Faulting and catastrophic mass movements shifted large blocks of sandstone.
0.011 - 1	**PLEISTOCENE**	During the Ice Age, continental glaciation stored water on land and the sea level dropped several hundred feet below the present sea level. Uplift of the land continued as did faulting and folding of the landscape.
0 - 0.011	**HOLOCENE**	Deglaciation meltwater filled the ocean to a level higher than it's present level. Uplifting of the land continues to the present day.

Table A.4. Summary of channel unit numbers in Drift Creek for segments (1988 and 1989) and reaches (1989). Data not available indicated by n.a..

Segments 1988	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Lower	12	22	14	10	1	3
Mid-Lower	56	58	28	35	9	3
Mid-Upper	109	63	58	29	2	6
Upper	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Segments 1989	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Lower	25	21	36	14	2	3
Mid-Lower	83	77	71	27	7	18
Mid-Upper	110	95	65	56	3	11
Upper	144	67	64	107	27	11
Reaches 1989	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	13	9	15	7	0	2
2	12	12	11	7	2	1
3	16	20	12	7	1	6
4	13	11	7	9	1	4
5	22	18	18	7	5	5
6	19	11	22	3	0	2
7	13	17	12	1	0	1
8	17	18	12	4	0	2
9	12	13	9	3	0	1
10	19	20	15	15	0	5
11	41	28	21	22	2	2
12	21	16	8	12	1	1
13	33	33	27	20	4	2
14	45	14	26	28	1	3
15	39	13	4	35	18	3
16	27	7	7	24	4	3

Table A.5. Summary of channel unit lengths in Drift Creek for segments (1988 and 1989) and reaches (1989). Lengths are in meters, and n.a. indicates data not available.

Segments 1988	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Lower	991.9	2404.3	1183.3	424.7	29.4	109.9
Mid-Lower	3057.5	3216.6	1981.8	1507.8	374.1	224.7
Mid-Upper	5220.2	3047.3	1988.6	769.6	40.0	263.4
Upper	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Segments 1989	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Lower	1900.2	1060.9	1338.6	448.5	84.3	124.7
Mid-Lower	4090.6	2563.4	2651.6	840.4	204.4	605.3
Mid-Upper	5520.7	2894.1	1609.7	1082.5	55.8	450.3
Upper	1955.6	894.7	1087.1	2583.4	397.9	206.1
Reaches 1989	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	743.5	338.3	558.2	246.5	0.0	85.4
2	1156.8	722.7	780.4	202.0	84.3	39.2
3	927.1	791.0	721.6	202.3	28.6	166.3
4	648.0	425.7	722.2	354.7	11.6	157.8
5	1157.1	575.7	429.5	234.5	156.1	137.2
6	731.9	319.0	579.1	40.0	0.0	114.3
7	626.5	452.0	199.2	9.0	0.0	29.8
8	899.8	442.0	287.3	75.9	0.0	96.2
9	1537.6	478.8	354.2	35.4	0.0	134.5
10	866.8	784.5	291.6	257.1	0.0	152.7
11	1566.0	803.2	446.3	404.6	28.1	129.8
12	650.5	385.7	230.4	309.6	27.8	37.0
13	983.3	618.7	531.4	637.5	77.8	53.8
14	528.7	128.0	408.8	743.4	4.9	65.4
15	269.3	99.8	64.6	818.8	267.0	40.4
16	174.3	48.3	82.3	383.8	48.3	46.6

Table A.6. Summary of channel unit areas in Drift Creek for segments (1988 and 1989) and reaches (1989). Areas are in m^2 and n.a. indicates data not available.

Segments 1988	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Lower	20394	55158	26716	9008	492	591
Mid-Lower	55549	58219	38648	27410	7202	1073
Mid-Upper	66200	38990	25702	8208	345	1597
Upper	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Segments 1989	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Lower	36038	21230	29734	8240	933	1003
Mid-Lower	64817	39396	40880	11481	3322	2857
Mid-Upper	70225	32268	17801	9855	529	1457
Upper	11075	5571	5990	11186	1885	227
Reaches 1989	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	14600	7381	11594	4460	0	612
2	21437	13849	18140	3780	933	391
3	16593	13449	12297	2784	607	900
4	10442	6309	11887	5379	87	941
5	16845	8004	4954	2683	2628	431
6	11964	4806	8888	513	0	452
7	8973	6828	2855	123	0	133
8	11659	4592	3513	675	0	327
9	21821	5978	4297	317	0	76
10	12061	9239	3206	2409	0	423
11	18104	8876	4472	3935	277	463
12	6580	3583	2314	2519	252	168
13	7691	4835	4056	4586	950	81
14	2315	421	1637	3417	28	60
15	695	235	142	2425	812	30
16	375	79	155	758	94	56

Table A.7. Salmonid abundance estimates in Drift Creek for segments (July 1988 and 1989) and reaches (July 1989). Lengths and cumulative stream distances at boundaries are in meters. Data not available indicated by n.a.

SEGMENTS

JULY 1988

Segment Information			Salmonids per 100 meters				
segment	* lower boundary	* segment length	juvenile chinook	juvenile coho	trout (age 0)	steelhead (age 1+)	cutthroat (age 1+)
Lower	6520	5258	95	11	150	8	5
Mid-Lower	11292	10582	60	84	122	15	9
Mid-Upper	21408	11495	7	189	183	18	8
Upper	32447	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

JULY 1989

Segment Information			Salmonids per 100 meters				
segment	* lower boundary	* segment length	juvenile chinook	juvenile coho	trout (age 0)	steelhead (age 1+)	cutthroat (age 1+)
Lower	6520	5003	429	20	93	7	9
Mid-Lower	11292	11185	194	86	68	12	8
Mid-Upper	21408	11756	53	281	49	14	11
Upper	32447	7290	0	318	121	14	21

Table A.7. continued.....

REACHES

JULY 1989

Reach Information			Salmonids per 100 meters				
reach	* lower boundary	* reach length	juvenile chinook	juvenile coho	trout (age 0)	steelhead (age 1+)	cutthroat (age 1+)
1	6520	1828	475	8	101	11	13
2	8730	2887	362	27	73	5	6
3	11292	2916	218	43	62	7	6
4	13994	1946	269	65	63	5	9
5	15940	2284	298	107	111	20	13
6	18293	1803	120	156	79	19	6
7	20017	1305	116	147	55	16	8
8	21416	1603	126	110	36	10	10
9	23134	2460	32	240	11	4	5
10	25540	2361	70	255	59	14	13
11	27777	3421	47	418	49	19	13
12	30822	1658	7	293	111	23	14
13	32447	2968	0	576	156	18	12
14	35264	1958	0	189	79	21	20
15	36767	1569	0	137	62	1	27
16	38097	795	0	102	77	0	41

* Lower boundary is the cumulative map-standard distance along Drift Creek from the Lyndon Creek confluence. Segment and reach lengths are estimated field distances and used for the fish estimates, thus segment and reach lengths do not exactly correspond to lower boundary distance differences.

Table A.8. Average number of fish per channel unit type for Drift Creek reaches (1989). Reach lengths are in Table A.5.

JUVENILE CHINOOK SALMON

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	233.0	157.0	242.6	85.8	0.0	4.0
2	258.7	412.0	203.5	18.0	14.0	0.0
3	138.0	127.0	87.7	70.3	63.0	0.0
4	156.7	172.0	113.0	56.5	4.0	3.0
5	112.1	104.3	95.5	83.5	30.0	0.3
6	62.0	28.5	28.3	16.0		0.0
7	46.0	32.8	29.7	2.0		0.0
8	75.4	18.3	31.8	8.0		0.0
9	35.4	22.0	7.2	1.0		0.0
10	31.1	29.8	20.5	10.6		0.4
11	22.8	18.6	2.3	0.2	2.0	0.0
12	3.1	1.5	1.0	1.4	0.0	0.0

JUVENILE COHO SALMON

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	2.5	0.0	6.6	1.5	0.0	2.5
2	24.0	28.0	12.5	0.0	0.0	5.0
3	23.6	30.6	9.3	6.0	0.0	18.2
4	33.5	62.5	5.0	4.5	0.0	15.3
5	62.2	25.0	14.5	36.5	6.0	16.3
6	95.3	25.5	28.5	13.0		32.5
7	87.6	35.8	12.0	0.0		27.0
8	87.9	6.8	4.8	0.0		49.0
9	290.4	172.0	17.4	0.0		21.0
10	181.7	102.0	23.2	5.0		21.2
11	232.5	128.4	19.3	1.4	2.5	108.5

Table A.8. continued.....

Juvenile Coho Salmon

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
12	123.9	87.0	55.3	25.3	16.0	96.0
13	311.9	90.2	62.1	92.9	57.0	24.5
14	52.1	20.7	17.6	19.9	10.0	15.5
15	29.9	18.7	2.5	17.7	5.8	0.5
16	21.9	10.0	3.5	4.5	2.5	1.5

TROUT (age 0+)

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	37.3	17.0	65.6	28.0	0.0	18.5
2	48.7	19.0	101.5	15.5	27.0	26.0
3	27.0	22.4	61.3	13.7	10.0	15.2
4	13.5	36.0	84.0	2.5	3.0	11.0
5	22.8	34.8	57.8	39.0	13.0	6.0
6	14.1	30.0	33.4	31.0		0.0
7	13.4	14.0	24.7	3.0		0.0
8	9.7	7.8	19.0	0.0		14.5
9	6.6	2.7	12.2	13.0		4.0
10	15.3	18.8	20.3	26.0		7.0
11	10.7	16.8	19.4	0.8	7.0	4.5
12	16.3	29.5	63.3	38.1	54.0	0.0
13	18.1	23.4	49.9	83.9	58.5	3.5
14	12.0	4.3	17.6	16.7	14.0	5.0
15	8.4	5.3	10.5	12.4	5.8	0.0
16	10.1	11.0	3.5	8.8	7.0	0.0

Table A.8. continued.....

STEELHEAD TROUT (age 1+)

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	5.5	3.0	3.6	6.0	0.0	0.0
2	1.0	0.0	8.5	3.0	4.0	0.0
3	2.3	4.4	1.7	8.0	3.0	0.0
4	1.8	1.5	5.0	1.5	6.0	0.0
5	4.2	3.0	6.8	22.5	8.0	0.0
6	6.0	1.5	8.8	5.0		0.0
7	7.2	3.0	5.0	3.0		0.0
8	3.4	1.5	4.3	9.0		0.5
9	3.6	1.7	1.8	3.0		0.0
10	5.7	5.1	5.8	2.6		0.0
11	7.5	5.5	2.1	0.3	1.0	1.0
12	6.9	6.0	5.3	6.6	16.0	4.0
13	4.1	2.3	3.6	9.2	7.3	0.0
14	5.4	3.3	1.8	2.9	1.0	0.0
15	0.3	0.2	0.0	0.0	0.0	0.0

CUTTHROAT TROUT (age 1+)

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
1	6.0	3.0	4.8	8.3	0.0	0.0
2	5.3	4.0	5.0	0.5	3.0	0.0
3	3.9	3.4	2.0	2.7	1.0	0.0
4	4.5	2.5	8.0	2.5	1.0	0.0
5	5.2	2.3	4.5	8.0	3.0	0.0
6	3.0	0.0	2.1	4.0		0.0

Table A.8. continued.....

Cutthroat Trout (age 1+)

Reach	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
7	4.6	1.5	1.7	0.0		0.0
8	4.4	1.7	3.0	6.0		0.5
9	4.6	4.7	1.0	2.0		0.0
10	5.4	6.5	2.3	3.0		0.0
11	7.8	2.3	1.1	0.1	6.0	0.0
12	4.9	2.3	1.7	4.6	13.0	5.0
13	3.8	2.6	1.3	5.1	3.8	0.0
14	3.8	3.0	3.0	3.3	0.0	0.0
15	4.6	2.8	0.0	4.4	3.3	0.0
16	8.3	4.3	0.5	2.3	3.0	0.0

Table A.9. Averages of mean and maximum depths for channel unit types in Drift Creek (1989 survey). Depths are in meters and n.a. indicates data not available.

MEAN DEPTHS

Reach	Pool	Glide	Riffle	Rapid	Cascade
1	0.46	0.21	0.17	0.26	
2	0.42	0.23	0.17	0.24	0.28
3	0.57	0.31	0.23	0.28	0.29
4	0.58	0.31	0.29	0.30	0.26
5	0.63	0.25	0.19	0.17	0.29
6	0.58	0.33	0.20	0.22	
7	0.56	0.34	0.20	0.11	
8	0.64	0.33	0.21	0.22	
9	0.52	0.30	0.18	0.22	
10	0.59	0.31	0.19	0.25	
11	0.50	0.26	0.16	0.21	0.30
12	0.39	0.27	0.16	0.23	0.23
13	0.51	0.28	0.14	0.19	0.31
14	0.34	0.17	0.09	0.11	0.28
15	0.30	0.26	0.12	0.18	0.22
16	0.29	0.19	0.10	0.12	0.20

MAXIMUM DEPTHS

Reach	Pool	Glide	Riffle	Rapid	Cascade
1	1.01	n.a.	n.a.	n.a.	
2	1.27	n.a.	n.a.	n.a.	n.a.
3	1.34	0.70	0.86	0.42	1.20
4	1.27	n.a.	0.90	1.08	0.45
5	1.48	0.38	0.39	0.42	0.78
6	1.27	0.57	0.42	0.45	
7	1.18	0.64	0.38	0.22	
8	1.31	1.13	0.39	0.40	
9	1.13	0.59	0.33	0.34	
10	1.21	0.59	0.32	0.43	
11	1.01	0.49	0.27	0.38	0.76
12	0.92	0.48	0.28	0.45	0.45
13	1.11	0.57	0.26	0.40	0.93
14	0.68	0.31	0.21	0.27	0.51
15	0.54	0.37	0.18	0.31	0.41
16	0.48	0.25	0.16	0.23	0.34

Table A.10. Boundary locations for land-use treatment sites in the Drift Creek tributaries.

Site Name and Year Surveyed	Site Number	Site Position	Latitude	Longitude
UNHARVESTED				
Flynn Creek 1988 & 1989	1	begin	44° 32' 20"	123° 51' 04"
		end	44° 32' 54"	123° 51' 13"
Lower Nettle Creek 1989	2	begin	44° 30' 21"	123° 48' 50"
		end	44° 30' 17"	123° 48' 29"
Mid Nettle Creek 1989	3	begin	44° 30' 17"	123° 48' 29"
		end	44° 30' 16"	123° 48' 16"
Upper So. Fk. Drift Cr. 1988 & 1989	4	begin	44° 27' 35"	123° 49' 19"
		end	44° 27' 14"	123° 49' 22"
Mid So. Fk. Drift Cr. 1989	5	begin	44° 28' 13"	123° 48' 48"
		end	44° 27' 35"	123° 49' 19"
East Fork Trout Creek 1988	6	begin	44° 28' 33"	123° 56' 33"
		end	44° 28' 25"	123° 56' 16"
Upper Trout Creek 1989	7	begin	44° 29' 43"	123° 54' 53"
		end	44° 29' 47"	123° 54' 42"
Upper Boulder Creek 1989	8	begin	44° 27' 02"	123° 53' 42"
		end	44° 26' 56"	123° 53' 20"
PATCH-CUT WITH BUFFERSTRIPS				
Deer Creek 1988 & 1989	9	begin	44° 32' 07"	123° 52' 37"
		endRF	44° 32' 53"	123° 52' 24"
		endLF	44° 32' 49"	123° 52' 13"
Upper Nettle Creek 1989	10	begin	44° 30' 16"	123° 48' 16"
		end	44° 30' 03"	123° 47' 58"
North Fork Drift Creek 1988	11	begin	44° 28' 23"	123° 47' 21"
		end	44° 28' 36"	123° 46' 44"
Lower Trout Creek 1988 & 1989	12	begin	44° 29' 20"	123° 55' 58"
		end	44° 29' 27"	123° 55' 34"
Mid Trout Creek 1989	13	begin	44° 29' 35"	123° 55' 28"
		end	44° 29' 45"	123° 55' 04"
Lower Boulder Creek 1989	14	begin	44° 27' 08"	123° 53' 54"
		end	44° 27' 02"	123° 53' 42"

Table A.10 continued.....

Site Name and Year Surveyed	Site Number	Site Position	Latitude	Longitude
CLEARCUT WITHOUT BUFFERSTRIPS				
Needle Branch 1988 & 1989	15	begin	44° 30' 33"	123° 51' 20"
		end	44° 30' 55"	123° 51' 12"
Lower Flynn Creek 1988	16	begin	44° 31' 22"	123° 51' 56"
		end	44° 32' 07"	123° 50' 59"
Lower Horse Creek 1988	17	begin	44° 31' 41"	123° 51' 54"
		end	44° 31' 59"	123° 52' 47"
Upper Horse Creek 1989	18	begin	44° 32' 05"	123° 53' 27"
		end	44° 32' 13"	123° 53' 47"
Upper Drift Creek 1988	19	begin	44° 28' 10"	123° 47' 10"
		end	44° 27' 47"	123° 46' 56"
Lower So. Fk. Drift Cr. 1989	20	begin	44° 28' 34"	123° 48' 08"
		end	44° 28' 13"	123° 48' 48"
Bear Creek 1988	21	begin	44° 27' 56"	123° 58' 44"
		end	44° 28' 04"	123° 58' 33"

Table A.11. Summary of channel unit lengths (m) for land-use treatment sites in the Drift Creek tributaries.

Name of Tributary	Year of Survey	Trib. No.	Pool	Glide	Riffle	Rapid	Cascade	Side Channel	Total
Flynn Creek	88	1	301.8	749.0	404.2	80.3	44.7	0.0	1580
Flynn Creek	89	1	376.5	381.9	689.7	30.8	125.7	29.9	1635
Lower Nettle Creek	89	2	207.6	81.2	108.7	0.0	0.0	0.0	398
Mid Nettle Creek	89	3	135.0	84.6	144.1	0.0	0.0	0.0	364
Upper South Fk. Drift Cr.	88	4	149.4	150.6	257.6	230.3	25.0	43.6	857
Upper South Fk. Drift Cr.	89	4	174.3	48.3	82.3	383.8	48.3	46.5	783
Mid South Fk. Drift Cr.	89	5	269.3	99.8	64.6	818.8	267.0	40.4	1560
East Fork Trout Creek	88	6	93.1	188.2	65.7	245.4	137.5	6.0	666
Upper Trout Creek	89	7	41.4	26.5	5.5	125.9	51.4	0.0	251
Upper Boulder Creek	89	8	200.6	48.1	20.1	163.3	113.5	17.2	563
Deer Creek	88	9	1103.8	443.2	608.4	141.5	97.5	9.9	2404
Deer Creek	89	9	849.1	557.8	746.1	170.5	112.2	23.7	2459
Upper Nettle Creek	89	10	149.6	108.4	234.7	45.5	26.6	0.0	565
North Forth Drift Creek	88	11	215.9	194.0	184.7	270.4	161.5	0.0	1027
Lower Trout Creek	88	12	182.1	180.6	157.6	177.3	55.5	0.0	753
Lower Trout Creek	89	12	318.6	78.7	75.9	233.3	67.1	144.2	918
Mid Trout Creek	89	13	133.0	98.9	77.1	224.7	8.4	0.0	542
Lower Boulder Creek	89	14	135.1	52.5	5.6	146.8	102.7	17.9	461
Needle Branch	88	15	513.6	204.9	223.6	32.7	12.5	0.0	987
Needle Branch	89	15	624.8	64.0	282.2	3.2	13.6	3.4	991
Lower Flynn Creek	88	16	1734.4	1112.2	50.9	6.6	0.0	0.0	2904
Lower Horse Creek	88	17	1814.7	560.4	430.9	56.2	0.0	0.0	2862
Upper Horse Creek	89	18	269.6	74.3	348.2	28.8	0.0	0.0	721
Upper Drift Creek	88	19	292.0	138.7	154.1	206.3	118.3	19.8	929
Lower South Fk. Drift Cr.	89	20	528.7	128.0	408.8	743.4	4.9	65.4	1879
Bear Creek	88	21	112.7	7.4	226.5	151.9	104.6	0.0	603

Table A.12. Average number of fish per channel unit type for land-use treatment sites in the Drift Creek tributaries.

JUVENILE COHO SALMON

Name of Tributary	Year of Survey	Trib. No.	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Flynn Creek	88	1	19.7	16.3	1.8	0.0	0.0	0.0
Flynn Creek	89	1	20.6	10.5	2.2	5.0	8.8	0.0
Lower Nettle Creek	89	2	63.6	62.7	3.0	0.0	0.0	0.0
Mid Nettle Creek	89	3	52.8	64.5	2.5	0.0	0.0	0.0
Upper South Fk. Drift Cr.	88	4	31.8	31.7	0.5	0.0	6.0	4.0
Upper South Fk. Drift Cr.	89	4	52.2	20.7	17.6	19.9	10.0	15.5
Mid South Fk. Drift Cr.	89	5	29.9	18.7	2.5	17.7	5.8	0.5
East Fork Trout Creek	88	6	0.0	0.0	0.0	0.0	0.0	0.0
Upper Trout Creek	89	7	0.0	0.0	0.0	0.0	0.0	0.0
Upper Boulder Creek	89	8	0.0	0.0	0.0	0.0	0.0	0.0
Deer Creek	88	9	64.7	17.4	10.5	0.0	12.0	28.0
Deer Creek	89	9	21.6	13.8	8.7	17.0	54.0	13.0
Upper Nettle Creek	89	10	59.6	21.8	4.3	0.0	28.5	0.0
North Forth Drift Creek	88	11	0.0	0.0	0.0	0.0	0.0	0.0
Lower Trout Creek	88	12	18.3	15.0	6.0	0.2	0.0	0.0
Lower Trout Creek	89	12	51.0	9.0	15.7	2.3	7.0	108.0
Mid Trout Creek	89	13	0.0	0.0	0.0	0.0	0.0	0.0
Lower Boulder Creek	89	14	0.0	0.0	0.0	0.0	0.0	0.0
Needle Branch	88	15	18.9	6.5	0.3	0.0	1.0	0.0
Needle Branch	89	15	23.7	45.0	1.3	5.0	0.0	2.0
Lower Flynn Creek	88	16	54.1	24.9	0.7	0.0	0.0	0.0
Lower Horse Creek	88	17	114.6	41.2	17.7	1.0	0.0	0.0
Upper Horse Creek	89	18	17.3	5.4	0.0	0.0	0.0	0.0
Upper Drift Creek	88	19	0.0	0.0	0.0	0.0	0.0	0.0
Lower South Fk. Drift Cr.	89	20	52.2	20.7	17.6	19.9	10.0	15.5
Bear Creek	88	21	0.0	0.0	0.0	0.0	0.0	0.0

Table A.12 continued.....

TROUT (AGE 0)

Name of Tributary	Year of Survey	Trib. No.	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Flynn Creek	88	1	0.8	0.5	0.6	0.0	0.0	0.0
Flynn Creek	89	1	0.0	0.0	0.0	0.0	0.0	0.0
Lower Nettle Creek	89	2	0.1	1.0	1.7	0.0	0.0	0.0
Mid Nettle Creek	89	3	0.2	0.0	2.0	0.0	0.0	0.0
Upper South Fk. Drift Cr.	88	4	6.1	13.8	13.3	3.0	9.0	24.0
Upper South Fk. Drift Cr.	89	4	10.1	11.0	3.5	8.8	7.0	0.0
Mid South Fk. Drift Cr.	89	5	8.4	5.3	10.5	12.4	5.8	0.0
East Fork Trout Creek	88	6	2.3	2.5	6.5	3.8	0.5	0.0
Upper Trout Creek	89	7	0.6	3.0	4.0	1.3	3.0	0.0
Upper Boulder Creek	89	8	5.2	7.0	4.0	5.3	3.0	0.0
Deer Creek	88	9	2.4	0.4	1.0	1.0	0.0	0.0
Deer Creek	89	9	0.5	0.6	0.8	1.0	0.3	0.0
Upper Nettle Creek	89	10	1.4	1.7	2.3	0.0	5.0	0.0
North Forth Drift Creek	88	11	8.2	6.8	4.7	5.4	4.8	0.0
Lower Trout Creek	88	12	3.1	6.8	17.0	5.3	5.0	0.0
Lower Trout Creek	89	12	3.0	2.5	3.0	7.5	6.0	30.0
Mid Trout Creek	89	13	0.9	4.6	1.5	0.0	0.0	0.0
Lower Boulder Creek	89	14	12.0	10.5	1.0	8.3	4.3	0.0
Needle Branch	88	15	1.0	0.8	0.8	0.0	0.0	0.0
Needle Branch	89	15	0.9	0.0	0.3	0.0	5.0	0.0
Lower Flynn Creek	88	16	0.0	0.3	0.0	0.0	0.0	0.0
Lower Horse Creek	88	17	1.5	0.8	5.3	6.0	0.0	0.0
Upper Horse Creek	89	18	2.6	1.4	0.4	0.0	0.0	0.0
Upper Drift Creek	88	19	4.0	24.0	12.0	5.5	2.5	0.0
Lower South Fk. Drift Cr.	89	20	12.0	4.3	17.6	16.7	14.0	5.0
Bear Creek	88	21	2.0	0.0	0.3	0.3	0.0	0.0

Table A.12 continued.....

TROUT (AGE 1+)

Name of Tributary	Year of Survey	Trib. No.	Pool	Glide	Riffle	Rapid	Cascade	Side Channel
Flynn Creek	88	1	1.7	0.4	0.0	0.0	0.0	0.0
Flynn Creek	89	1	4.7	1.5	1.1	2.0	2.8	0.0
Lower Nettle Creek	89	2	2.7	0.0	0.0	0.0	0.0	0.0
Mid Nettle Creek	89	3	4.6	0.0	0.0	0.0	0.0	0.0
Upper South Fk. Drift Cr.	88	4	1.2	1.5	0.7	0.0	0.0	0.0
Upper South Fk. Drift Cr.	89	4	8.3	4.3	0.5	2.3	3.0	0.0
Mid South Fk. Drift Cr.	89	5	4.9	3.0	0.0	4.4	3.3	0.0
East Fork Trout Creek	88	6	3.0	0.3	2.0	2.3	0.0	0.0
Upper Trout Creek	89	7	1.4	0.0	0.0	0.0	0.0	0.0
Upper Boulder Creek	89	8	5.4	1.0	0.0	1.3	2.5	0.0
Deer Creek	88	9	1.0	0.9	0.0	0.0	1.5	0.0
Deer Creek	89	9	1.8	0.2	0.0	0.5	6.7	0.0
Upper Nettle Creek	89	10	3.6	0.5	0.0	0.0	0.0	0.0
North Forth Drift Creek	88	11	4.1	0.8	0.0	1.0	3.8	0.0
Lower Trout Creek	88	12	3.4	1.4	1.0	0.7	1.5	0.0
Lower Trout Creek	89	12	4.2	3.5	1.0	3.5	3.7	6.0
Mid Trout Creek	89	13	1.6	0.2	0.3	0.0	0.0	0.0
Lower Boulder Creek	89	14	4.6	3.0	1.0	7.7	7.0	0.0
Needle Branch	88	15	0.2	0.0	0.0	0.0	0.0	0.0
Needle Branch	89	15	0.3	0.0	0.0	0.0	0.0	0.0
Lower Flynn Creek	88	16	1.7	0.0	0.0	0.0	0.0	0.0
Lower Horse Creek	88	17	1.0	0.3	0.0	0.0	0.0	0.0
Upper Horse Creek	89	18	1.0	0.0	0.0	0.0	0.0	0.0
Upper Drift Creek	88	19	6.0	6.0	1.0	0.3	3.3	0.0
Lower South Fk. Drift Cr.	89	20	9.2	6.3	4.8	6.2	1.0	0.0
Bear Creek	88	21	0.4	0.0	0.0	0.0	1.0	0.0

Table A.13. Averages for active channel widths and wetted channel (summer low-flow) widths in Drift Creek tributaries by land-use treatment. Data not available indicated by n.a.

Tributary Name	Survey Year	Trib. No.	Active Channel Width (meters)	Wetted Channel Width (meters)
Flynn Creek	88	1	2.75	1.79
Flynn Creek	89	1	4.17	1.82
Lower Nettle Creek	89	2	4.74	2.01
Mid Nettle Creek	89	3	4.18	1.84
Upper SF Drift Creek	88	4	n.a.	2.42
Upper SF Drift Creek	89	4	4.04	1.98
Mid SF Drift Creek	89	5	5.59	2.84
East Fk. Trout Creek	88	6	4.39	1.85
Upper Trout Creek	89	7	2.78	1.59
Upper Boulder Creek	89	8	6.75	3.63
Deer Creek	88	9	n.a.	3.49
Deer Creek	89	9	4.10	2.79
Upper Nettle Creek	89	10	3.11	2.02
North Fk. Drift Creek	88	11	5.47	1.78
Lower Trout Creek	88	12	5.98	2.42
Lower Trout Creek	89	13	4.99	2.38
Mid Trout Creek	89	14	3.53	1.67
Lower Boulder Creek	89	15	5.55	3.44
Needle Branch	88	15	3.34	1.28
Needle Branch	89	15	1.66	1.27
Lower Flynn Creek	88	16	4.03	3.23
Lower Horse Creek	88	17	9.29	5.04
Upper Horse Creek	89	18	2.31	1.31
Upper Drift Creek	88	19	n.a.	3.52
Lower SF Drift Creek	89	20	10.37	4.31
Bear Creek	88	21	3.28	1.96

Table A.14. Averages for overall mean and maximum depths, pool areas, and pool volumes in the Drift Creek tributaries. For tributaries that were surveyed twice, data presented first is for 1988 and second is for 1989.

Tributary Number	Overall Mean Depth (m)	Overall Maximum Depth (m)	Pool Mean Depth (m)	Pool Maximum Depth (m)	Pool Area (m2)	Pool Volume (m3)
1	0.10	0.21	0.20	0.42	16.3	3.4
1	0.10	0.22	0.16	0.35	20.6	3.5
2	0.20	0.37	0.29	0.56	26.4	7.9
3	0.16	0.31	0.26	0.57	21.1	5.8
4	0.13	0.26	0.26	0.49	16.3	4.6
4	0.17	0.29	0.28	0.48	13.9	3.9
5	0.22	0.40	0.30	0.53	17.8	5.4
6	0.16	0.25	0.25	0.42	8.6	2.3
7	0.15	0.27	0.24	0.44	6.3	1.5
8	0.25	0.49	0.37	0.73	31.3	12.2
9	0.16	0.53	0.25	0.86	65.0	19.1
9	0.11	0.45	0.19	0.71	45.2	9.7
10	0.13	0.25	0.23	0.45	22.8	5.5
11	0.16	0.28	0.26	0.47	12.9	3.3
12	0.21	0.34	0.34	0.56	19.3	6.7
12	0.21	0.37	0.27	0.55	32.8	9.2
13	0.14	0.25	0.24	0.45	12.1	3.2
14	0.29	0.59	0.39	0.84	34.7	13.4
15	0.10	0.22	0.14	0.30	10.2	1.4
15	0.13	0.23	0.18	0.31	10.6	1.9
16	0.26	0.65	0.36	0.89	67.9	25.7
17	0.25	0.75	0.31	0.96	156.1	48.6
18	0.12	0.21	0.22	0.37	9.6	2.1
19	0.21	0.45	0.39	0.81	66.0	29.7
20	0.18	0.41	0.33	0.69	51.4	17.8
21	0.10	0.21	0.28	0.53	46.3	14.6

Table A.15. Spawning gravels as total area (m^2) and percent of active channel, and dominant substrate type expressed as percent by length in the Drift Creek tributaries. For tributaries surveyed twice, the 1989 are reported only. Data not available indicated by n.a.

	SPAWNING GRAVEL		DOMINANT SUBSTRATE TYPES						
Tributary Number	Total Spawning Gravel	Percent Spawning Gravel	Wood	Fine Sediment	Small Gravel	Large Gravel	Cobble	Boulder	Bedrock
1	34	1.2	0.0	23.9	28.0	16.8	16.0	9.2	6.0
2	112	14.6	0.1	28.8	15.8	55.3	0.0	0.0	0.0
3	84	12.8	0.0	18.1	5.6	63.2	13.1	0.0	0.0
4	71	5.0	0.0	0.6	0.0	25.7	72.5	1.2	0.0
5	124	3.1	1.3	1.4	0.5	14.0	28.2	54.1	0.4
6	39	3.1	1.0	23.0	9.3	4.7	40.7	21.1	0.5
7	16	4.0	0.3	0.0	6.6	26.5	46.2	18.4	2.0
8	49	2.5	0.2	5.0	0.0	17.2	28.1	49.5	0.0
9	1191	17.4	0.9	20.2	3.0	52.4	23.3	0.2	0.0
10	16	1.4	0.0	1.9	3.0	7.9	52.1	2.9	32.3
11	235	12.8	0.3	3.0	14.0	24.1	15.4	43.1	0.0
12	28	1.6	1.2	25.0	1.9	14.5	38.0	18.4	1.1
13	35	4.1	0.8	17.7	6.8	28.2	44.9	0.0	1.4
14	39	3.9	0.0	4.3	0.0	17.7	36.9	41.1	0.0
15	78	6.2	0.3	35.3	16.3	38.7	2.1	0.0	7.3
16	n.a.	n.a.	2.1	74.9	22.0	0.5	0.2	0.2	0.0
17	250	1.7	7.5	9.3	66.7	11.6	2.9	2.0	0.0
18	139	15.0	0.0	12.4	15.1	58.9	13.6	0.0	0.0
19	81	2.5	0.4	19.2	3.7	24.5	24.7	24.8	2.7
20	12	0.2	0.3	0.0	0.0	16.3	66.3	11.6	5.5
21	13	1.3	1.8	22.6	17.0	7.8	28.5	15.1	7.2

Table A.16. Volumes and densities of coarse woody debris in the Drift Creek tributaries by land-use treatments.

Tributary Number	Density: Numbers per 100 m	Total Volume (m^3) per 100 m	* Zones 1 & 2 Volume (m^3) per 100 m^2	* Zone 1 Volume (m^3) per 100 m^2	* Zone 2 Volume (m^3) per 100 m^2
1	22	27	2.6	0.7	1.9
2	26	18	3.1	1.4	1.7
3	9	9	2.3	0.6	1.7
4	30	107	4.3	0.9	3.4
5	41	73	1.4	0.4	1.0
6	20	33	1.1	0.2	0.9
7	45	74	5.2	1.2	4.0
8	78	164	2.8	1.0	1.8
9	11	7	0.3	0.1	0.2
10	14	9	1.0	0.3	0.7
11	62	105	2.7	0.6	2.1
12	36	56	2.3	0.6	1.7
13	67	67	4.3	1.5	2.8
14	59	40	4.4	0.9	3.5
15	15	12	0.9	0.2	0.7
16	8	5	0.7	0.3	0.4
17	10	8	0.6	0.4	0.2
18	14	13	3.5	0.9	2.6
19	47	39	3.4	1.1	2.3
20	44	54	1.3	0.1	1.2
21	15	23	1.0	0.3	0.7

Tributaries 1, 4, 6, 9, 11, 12, 15-17, and 19-21 are from Veldhuisen (1990). Total volume included CWD estimates from bankfull areas in, above, and adjacent the channel. * Zone 1 is wetted (summer low-flow channel) and zone 2 is bankfull channel.

Table A.17. Salmonid linear and areal densities in the Drift Creek tributaries for land-use treatment sites, total stream length (meters) and total wetted surface area (m^2).

			SALMONID LINEAL DENSITIES (Fish per 100 meters)					
Name of Tributary	Year of Survey	Trib. No.	Stream Length	Surface Area	Juvenile Coho	Trout Age 0	Steelhead Trout 1+	Cutthroat Trout 1+
Flynn Creek	88	1	1595.1	2855.2	166.8	7.8	0.0	7.1
Flynn Creek	89	1	1626.8	2960.8	90.0	0.0	0.0	20.8
Lower Nettle Creek	89	2	381.0	765.9	409.2	7.9	0.0	12.9
Mid Nettle Creek	89	3	357.7	658.1	360.4	10.9	0.0	19.3
Upper South Fk. Drift Cr.	88	4	821.6	1988.3	181.6	144.5	3.0	9.6
Upper South Fk. Drift Cr.	89	4	722.2	1430.0	111.9	84.9	0.0	45.0
Mid South Fk. Drift Cr.	89	5	1410.1	4004.8	152.2	69.5	0.9	30.6
East Fork Trout Creek	88	6	670.9	1241.1	0.0	33.2	0.0	18.8
Upper Trout Creek	89	7	251.9	400.6	0.0	20.6	0.0	6.8
Upper Boulder Creek	89	8	547.1	1986.0	0.0	47.0	0.0	30.3
Deer Creek	88	9	2482.2	8663.0	285.0	11.9	0.0	5.6
Deer Creek	89	9	2459.3	6861.6	106.9	3.7	0.0	6.8
Upper Nettle Creek	89	10	566.2	1143.7	264.8	20.0	0.0	11.7
North Forth Drift Creek	88	11	1033.4	1839.5	0.0	76.1	13.9	9.7
Lower Trout Creek	88	12	747.4	1808.8	113.1	78.0	3.6	17.3
Lower Trout Creek	89	12	761.0	1811.1	237.5	40.7	0.0	23.8
Mid Trout Creek	89	13	510.5	852.5	0.0	20.8	0.0	9.2
Lower Boulder Creek	89	14	291.0	1001.0	0.0	105.2	0.0	67.4
Needle Branch	88	15	995.1	1273.8	171.1	14.3	0.0	1.4
Needle Branch	89	15	990.6	1258.1	240.2	2.5	0.0	2.5
Lower Flynn Creek	88	16	2929.3	9461.5	235.3	0.6	0.4	5.0
Lower Horse Creek	88	17	2886.2	14546.5	351.6	13.3	6.2	2.7
Upper Horse Creek	89	18	706.4	925.4	112.5	21.0	2.4	3.5
Upper Drift Creek	88	19	913.5	3215.5	0.0	76.3	1.2	29.0
Lower South Fk. Drift Cr.	89	20	1593.53	6868.1	232.6	97.6	26.2	24.2
Bear Creek	88	21	496.0	972.1	0.0	7.5	0.0	3.0

Table A.17 continued.....

Name of Tributary	Year of Survey	Trib. No.	Stream Length	Surface Area	Juvenile Coho	Trout Age 0	Steelhead Trout 1+	Cutthroat Trout 1+
					SALMONID AREAL DENSITIES (*Fish per 100 m^2*)			
Flynn Creek	88	1	1595.1	2855.2	93.2	4.3	0.0	4.0
Flynn Creek	89	1	1626.8	2960.8	49.4	0.0	0.0	11.4
Lower Nettle Creek	89	2	381.0	765.9	204.0	3.9	0.0	6.4
Mid Nettle Creek	89	3	357.7	658.1	195.9	5.9	0.0	10.5
Upper South Fk. Drift Cr.	88	4	821.6	1988.3	75.0	59.7	1.3	4.0
Upper South Fk. Drift Cr.	89	4	722.2	1430.0	56.5	42.9	0.0	22.7
Mid South Fk. Drift Cr.	89	5	1410.1	4004.8	53.6	24.5	0.3	10.8
East Fork Trout Creek	88	6	670.9	1241.1	0.0	18.0	0.0	10.2
Upper Trout Creek	89	7	251.9	400.6	0.0	13.0	0.0	4.2
Upper Boulder Creek	89	8	547.1	1986.0	0.0	12.9	0.0	8.4
Deer Creek	88	9	2482.2	8663.0	81.7	3.4	0.0	1.6
Deer Creek	89	9	2459.3	6861.6	38.3	1.3	0.0	2.4
Upper Nettle Creek	89	10	566.2	1143.7	131.1	9.9	0.0	5.8
North Forth Drift Creek	88	11	1033.4	1839.5	0.0	42.7	7.8	5.4
Lower Trout Creek	88	12	747.4	1808.8	46.7	32.2	1.5	7.1
Lower Trout Creek	89	12	761.0	1811.1	99.8	17.1	0.0	10.0
Mid Trout Creek	89	13	510.5	852.5	0.0	12.4	0.0	5.5
Lower Boulder Creek	89	14	291.0	1001.0	0.0	30.6	0.0	19.6
Needle Branch	88	15	995.1	1273.8	134.1	11.1	0.0	1.1
Needle Branch	89	15	990.6	1258.1	189.1	2.0	0.0	2.0
Lower Flynn Creek	88	16	2929.3	9461.5	72.8	0.2	0.1	1.5
Lower Horse Creek	88	17	2886.2	14546.5	69.8	2.6	1.2	0.5
Upper Horse Creek	89	18	706.4	925.4	85.9	16.0	1.8	2.7
Upper Drift Creek	88	19	913.5	3215.5	0.0	21.7	0.3	8.2
Lower South Fk. Drift Cr.	89	20	1593.53	6868.1	54.0	22.6	6.1	5.6
Bear Creek	88	21	496.0	972.1	0.0	3.8	0.0	1.5

Table A.18. Alsea Watershed Study (AWS) methods for population and biomass estimates as reported by Moring and Lantz (1975).

Juvenile Coho Salmon

1. **1959-1962:** The mark-recapture technique was employed; capture for marking was done by use of seines and backpack electrofishing gear, and recapture occurred at the fish trap. During capture for marking length and weight data were collected for biomass estimates. Petersen population estimates were computed by Ricker's method, using the modification by Bailey. Population curves from Chapman (1965) were interpolated to reflect the population on August 15th. Monthly biomass data from Chapman (1965) were interpolated for mean September values.

2. **1963-1968:** Au (1972) provided population estimates using the same method as years 1959 through 1962 interpolating yearly population curves to reflect the population on August 15th. Au (1972) weight data was converted to biomass (g/m^2) using surface records provided by Lowry (1964), and the monthly estimates were interpolated for mean September values.

3. **1969:** Oregon State Game Commission (OSGC) made population and biomass estimates from 1000-foot study sections. Petersen estimates were computed from the mark-recapture data. Mark and recapture were both done by use of backpack electrofishing gear.

4. **1970-1972:** Population estimates by OSGC are from the AWS standard study sections. Petersen estimates were computed from the mark-recapture data. Biomass estimates were made from OSGC specified biomass areas, and these areas are defined on page 9 in Moring and Lantz (1975).

Cutthroat Trout

1. **1962-1963:** Population and biomass estimates are from Lowry (1964). A point census, mark-recapture procedure was used for the AWS standard study section. Petersen's method was used for the population estimates. Monthly population and biomass estimates were interpolated for mean September values.

2. **1964-1973:** Population and biomass estimates were done by OSGC using a single census mark-recapture procedure for the AWS standard study section in the late summer. Petersen's method was used for the population estimates. Biomass estimates were made from OSGC specified biomass areas, except in 1969 biomass was estimated from 1000-foot study sites for all streams.

Table A.19. Results from electrofishing sites in the AWS streams, including distances (*) used to expand population estimates to equal the AWS estimates, and site physical data.

STREAM and YEAR	juvenile coho salmon			cutthroat trout			electrofishing site measurments		* Pop. est. distance
	^ N	upper 95% CI	avg. wt. (g)	^ N	upper 95% CI	avg. wt. (g)	site length (m)	average width (m)	stream length (m)
FLYNN 1988									
Site 1	187	221	2.91	66	84	12.70	100	2.87	610
Site 2	100	110	2.66	60	74	9.32	100	1.58	244
Site 3	163	185	2.76	52	54	8.53	100	1.27	457
DEER 1988									
Site 1	169	224	3.83	18	56	12.96	100	2.31	579
Site 2	162	265	3.22	5	7	7.74	100	2.24	747
Site 3	462	565	3.29	29	58	28.70	100	4.20	747
FLYNN 1989									
Site 1	141	162	2.42	20	25	10.84	50	2.34	305
Site 2	94	117	2.05	25	85	10.46	50	2.87	305
Site 3	87	95	2.01	61	82	10.21	100	1.58	244
Site 4	59	74	2.18	26	29	12.74	50	1.27	457
DEER 1989									
Site 1	53	64	2.78	4	4	33.91	40	2.84	304
Site 2	100	120	2.68	11	19	10.62	50	2.40	275
Site 3	283	297	2.61	--	--	18.88	100	3.18	498
Site 4	168	188	3.18	30	34	20.26	100	2.24	498
Site 5	135	145	3.58	48	68	14.72	100	1.72	498
NEEDLE 1989									
Site 1	261	293	1.96	1	1	20.75	50	1.16	271
Site 2	182	198	1.66	1	1	15.30	45	1.28	242
Site 3	85	92	1.93	4	4	14.65	50	1.20	223
Site 4	67	83	1.52	42	48	4.26	55	0.88	133

Table A.20. Population and biomass estimates for AWS streams in 1988 and 1989. Estimates for the entire study lengths are from two different procedures (stratified and average), the procedures are explained below.

STREAM and YEAR	POPULATION ESTIMATES				BIOMASS ESTIMATES (g/m^2)			
	JUV. COHO SALMON		CUTTHROAT TROUT		JUV. COHO SALMON		CUTTHROAT TROUT	
	strat.	avg.	strat.	avg.	strat.	avg.	strat.	avg.
FLYNN 1988	2130	1967	787	778	2.43	2.37	3.24	3.32
DEER 1988	5637	5479	358	359	2.93	2.92	1.06	1.05
FLYNN 1989	2185	2212	661	665	1.91	1.85	3.41	3.21
DEER 1989	3871	3814	673	570	2.29	2.20	2.74	2.23
NEEDLE 1989	2936	2648	129	191	5.23	4.73	1.00	1.33

PROCEDURES:

1. **Stratified**: This procedure uses stream channel characteristics (at the reach scale) of constrained (valley floor width < 2 active channel widths) and unconstrained (valley floor width > 2 active channel widths) to stratify the electrofishing sites within each stream's study area. Proportions of reach length to electrofishing site length are used to weight the electrofishing site population and biomass estimates for each reach. Reach lengths can be found in Appendix II. The reach population and biomass estimates are summed to obtain estimates for each stream's entire study length (as reported by the AWS and show in Table 1).

2. **Average**: This procedure averages all electrofishing sites equally to obtain population and biomass estimates. Proportions of stream (AWS) study length to electrofishing sites summed length are used to estimate fish numbers for the entire study length.

Table A.21. Age class structure for cutthroat trout in the AWS streams. Trout numbers are population estimates for entire AWS sites in years 1962, 1963 (Deer Creek only), and 1989. Data for 1962 and 1963 are from Lowry (1964).

Year	Age Class	Flynn Creek	Deer Creek	Needle Branch
1962	0	0	40	33
	1	404	350	105
	2	145	250	52
	3+	52	44	21
1963	0		312	
	1		323	
	2		95	
	3+		46	
1989	0	32	172	83
	1	487	310	32
	2	117	99	14
	3+	25	92	0

AGE CLASS DIVISIONS (by fish fork length):

Age (yr)	Fish Length Range (mm)
0	< 75
1	76 - 125
2	126 - 155
3+	> 156