AN ABSTRACT OF THE THESIS OF

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Title: The Influence of Geology and Timber Harvest on Channel Morphology and Salmonid Populations in Oregon Coast Range Streams

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Geology influences mainstem channel morphology in streams of about 1500 ha basin area in the Oregon Coast Range. Habitat availability and salmonid populations were surveyed in 3 km of main channel in each of five streams in basalt and five streams in sandstone. Differences in channel morphology were related to channel gradient (measured from topographic maps). Streams in basalt had a mean gradient of 2.5±0.6% (mean±95% confidence limits), compared to 1.2±0.5% for streams in sandstone with the same basin area. The streams in sandstone had greater mean frequency of pools (28 pools per kilometer) than the streams in basalt (18 pools per kilometer, Mann-Whitney *U* test, $p=0.016$). Mean frequency of glides (17 and 19 glides per kilometer) and riffles (26 and 23 riffles per kilometer) in streams in basalt and sandstone was not different (Mann-Whitney *U* test, $p>0.15$). However, riffles were almost twice as long in streams in basalt (14.6 m, geometric mean length) as in sandstone (7.7 m), and this difference in length was significant (Mann-Whitney *U* test, $p=0.008$).

Salmonid populations in streams in different rock types reflected the relative habitat availability. Streams in basalt were dominated by steelhead, resident rainbow trout, and cutthroat trout. In contrast, streams in sandstone were dominated by coho salmon. Age 0 coho salmon, and age 1 and older steelhead, resident rainbow trout, and cutthroat trout occupied pools more than glides or riffles. Age 0 steelhead and trout occupied pools, glides, and riffles about equally, except that

pools in sandstone and riffles in basalt were slightly avoided. Mean densities of salmonids in streams in sandstone were greater than those in basalt. Salmonid biomass in basalt and in sandstone, however, was similar because fish of the same species and age class were larger in streams in basalt than in sandstone, and there were also more age 1 and older fish in streams in basalt.

Timber harvest did not influence channel morphology significantly, except that the number of pools associated with large woody debris declined with increasing timber harvest. Streamflows in summer were generally much greater in basalt than in sandstone, though differences in rainfall influenced these streamflow differences. Coastal streams generally had higher flows than those further inland, but a stream in basalt had a higher base flow than streams in sandstone with similar summer climates. Timber harvest appeared to influence low flows in streams in sandstone. Apparent survival of age 0 trout was related to summer low flows in streams in sandstone, and these flows were inversely related to amount of timber harvest.

The Influence of Geology and Timber Harvest on Channel Morphology and Salmonid Populations in Oregon Coast Range Streams.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

LIST OF APPENDIX TABLES

Page

Page

The Influence of Geology and Timber Harvest on Channel Morphology and Salmonid Populations in Oregon Coast Range Streams

Chapter 1. Introduction

The ability to predict the response of watersheds and their salmonid populations to logging has become one of the more perplexing problems in fishery management. Although trends in habitat degradation resulting from clear-cut logging have been documented (e.g., Sullivan et al. 1987), there have been few unambiguous demonstrations of negative impacts on salmonid populations (Hicks et al. in press). There are a number of possible reasons for this.

First, the time between logging and evaluation of its impacts has usually been insufficient for manifestation of the full effects. There may have been no hydrologic event large enough to trigger widespread erosion in areas made prone to failure by roading or timber removal. Second, survival of the marine phase of anadromous species is dependent on ocean conditions (Nickelson 1986) and harvest rates. Fluctuating returns of adults mean that freshwater rearing habitat for juveniles may not be occupied to capacity when the number of spawners is small. Thus low abundance of juveniles in freshwater may reflect poor recruitment rather than limitations of stream habitat. Third, the freshwater environment is also subject to episodic natural disturbance, such as forest fire, mass wasting, debris torrents (Swanson et al. 1987), and drought. Imposed upon this background of changing ocean survival and natural fluctuations are the effects of timber harvest.

The effects of timber harvest on stream environments are dependent on the extent of clear-cut logging, forest roads (Rood 1984; Hogan 1986; Swanson et al. 1987), and the nature of buffer strips (Gregory et al. 1987). However, the response of the stream environment may be exacerbated by the geomorphic, climatic, and lithologic characterstics of the watershed. The unpredictable nature of the salmonid response may depend on a combination of variable forest practices and prevailing watershed characteristics (e.g., Burns 1972; Moring and Lantz 1974, 1975; Murphy and Hall 1981; Murphy et al. 1981; Hawkins et al. 1983; Bisson and Sedell 1984; Hartman and Scrivener in press).

The inconsistent effects of logging on salmonid populations are evident. Clear-cut logging to stream margins allows more incident radiation to reach a stream, which can increase primary productivity, variability of stream temperatures, and consequently salmonid growth rates (Beschta et al. 1987). However, the rate of input of large woody debris to streams will decline, often resulting in greatly simplified habitat (Swanson and Lienkaemper 1978; Lienkaemper and Swanson 1987; Bisson et al. 1987). Timber harvest has also been shown to influence stream hydrology (Harr and Krygier 1972; Harr et al. 1975). Logging can initially increase low flows, creating increased summer habitat, but can also increase the size of peak flows, which may reduce winter survival of salmonids.

The cumulative effects on salmonids of the changes brought about by logging are not well shown by short-term studies. Long-term, basin-scale, population-level studies are most appropriate to investigate cumulative effects, and very few of these have been done. Classic studies are those of the Alsea Watershed (Moring and Lantz 1975; Hall et al. 1987) and Carnation Creek (Hartman and Scrivener in press). However, as both of these studies involved only small watersheds, extrapolation of the results to larger watersheds may not be possible. Also, despite the considerable periods of study both before and after logging, it is probable that even these studies did not span a long enough time period to detect cumulative effects (Hall et al. 1987; Holtby 1988; Hicks et al. in press). Identification of the sources of variability is a crucial part of studies of the response of salmonids to logging.

Underlying rock type is one aspect of variability of streams that has a strong influence on channel morphology (e.g., Hack 1957, 1973; Keller and Tally 1979). Changes in channel morphology in response to logging have been shown to affect salmonid distribution (e.g., Bisson and Sedell 1984; Tripp and Poulin 1986b; Hogan and Church 1988). However, the association of such changes with underlying rock type has not often been investigated. Geomorphic variables have been used to explain salmonid abundance with some success (Ziemer 1973; Platts 1974; Heller et al. 1983; Lanka et al. 1987), but are useful only in the region of the studies.

Development of Hypotheses and Objectives

I visually inspected channel morphology of 38 streams and rivers in 16 watersheds in the Oregon Coast Range from the Wilson River in the north to the Elk River in the south. These streams occur in a range of bedrock types, including sandstone, dike and flow basalts, schists, and gneisses. I observed similarities in channel morphology among streams in similar rock types, and consistent differences among streams in different rock types. This cursory comparison of streams supported the conclusions of Hack (1957, 1973) and others that rock type is a major factor influencing channel morphology. Thus it seemed reasonable to develop hypotheses considering the influence of rock type on the response of channel morphology and salmonid populations to timber harvest. Sandstone and basalt are two rock types with different hardness and structure that are widespread in the Oregon Coast Range, and thus streams in these rock types were compared.

Hypotheses and Objectives. The following hypotheses were developed:

1) Channel morphology will differ in basalt and sandstone rock types, reflecting the hard, jointed nature of basalt, and the softer, layered but less jointed nature of sandstone.
2) Differences in channel morphology in basalt and sandstone will be reflected in salmonid populations.
3) Streams will have wider channels, reduced amount of pool habitat, and increased amount of riffle habitat in proportion to the area of the basin logged.

4) Channel morphology and salmonid populations will show less response to timber harvest in basalt than in sandstone because of the larger and harder substrate in basalt.

The objectives of the study developed from these hypotheses were:

1) To determine the response of channel morphology to timber harvest by comparison of streams in basalt and sandstone rock types.
2) To determine channel unit characteristics, such as gradient, width, depth, substrate size, habitat complexity, and frequency of different channel units, in stream segments flowing through basalt and sandstone.
3) To determine the extent to which the abundance of stream salmonids is associated with channel morphology and amount of timber harvest in basalt and sandstone in the Oregon Coast Range.
4) To determine a set of criteria that can be used to classify channel units.

Chapter 2. Influence of Geology and Timber Harvest on Channel Morphology and Hydrology

Abstract

Streamflows in early October 1987, at the end of a drought, were much greater in basalt (44-90 l/s) than in sandstone (0-5 l/s). Though rainfall influenced these differences, a stream in basalt had a higher base flow than streams in similar summer climates in sandstone. Timber harvest appeared to influence low flows in streams in sandstone. Low flows in late summer 1988, in three streams closely grouped and flowing on sandstone bedrock, were inversely related to the area of each watershed logged.

Bedrock type influenced channel morphology in 3 km segments of ten streams draining basins of about 1500 ha each in the Oregon Coast Range. Five streams in sandstone had greater mean frequency of pools (28 pools/km) than five streams in basalt (18 pools/km, Mann-Whitney *U* test, $p=0.016$). Mean frequency of glides (17 and 19 glides/km) and riffles (26 and 23 riffles/km) in streams in basalt and sandstone was not different (Mann-Whitney *U* test, $p>0.15$). However, riffles were almost twice as long in streams in basalt (13.3 m, geometric mean length) as in sandstone (7.2 m), and this difference in length was significant (Mann-Whitney *U* test, $p=0.008$). Differences in channel morphology were related to channel gradient measured from topographic maps. Streams in basalt had a mean gradient of $2.5\pm0.6\%$, compared to $1.2\pm0.5\%$ for streams in sandstone. Mean depths of pools measured at similar streamflows (between 26 and 135 l/s) in basalt and sandstone were similar (0.35 and 0.32 m respectively). In contrast, glides were significantly deeper in basalt (mean 0.19 m) than in sandstone (mean 0.15 m), as were riffles (means 0.15 m and 0.09 m respectively). Timber harvest did not influence channel morphology significantly, except that number of pools associated with large woody debris declined with increasing timber harvest.

Introduction

Channel gradient and substrate size have been shown to be related to geology (Hack 1957, 1973; Brush 1961; Miller 1958). Proportions and sizes of different types of channel units (pools, glides, and riffles) are also dependent on gradient and size of bed material (Miller 1958; Brush 1961; Dolling 1968). Large woody debris has been shown to influence local channel gradient and routing of sediment and water in streams on the Pacific Coast of North America (Keller and Swanson 1979; Lisle 1986; Sullivan et al. 1987). Timber harvest activities influence origins of large woody debris and its rate of entry into streams. The role of wood in channel morphology depends partly on its size compared to stream width (Swanson et al. 1976; Swanson and Lienkaemper 1978; Bilby and Ward in press). The purpose of this study is to compare the effects of timber harvest on channel morphology and hydrology in streams in basalt and sandstone rock types in the Oregon Coast Range.

Physical Description of Study Sites

Criteria for Site Selection.

Four stream segments in basalt and four stream segments in sandstone were selected for this study in 1987. Forests in the study basins ranged from largely unharvested to heavily harvested, and all stream segments were accessible to anadromous salmonids. Equal basin or sub-basin areas were chosen to give similar hydrologic conditions. The upper limit of basin size was the largest basin that could be found in a largely unharvested state, which was about 1500 ha. Where stream segments in basins larger than 1500 ha were used for comparison, the downstream end of the surveyed segment was positioned so that 1500 ha drained to the stream at this point.

Largely unharvested basins were defined as having 15% or less of their area harvested. Heavily harvested basins had 70% or more of their area harvested in the last 60 years. Moderately harvested basins fell between these criteria. Basins in basalt included Bob Creek (largely unharvested), Rock and upper Tenmile Creeks (moderately harvested), and Cape Creek (heavily harvested), and were located in the Cape Perpetua region of the Oregon Coast Range (Figure 2.1). Basins in sandstone included Franklin Creek (largely unharvested), Halfway and Paradise Creeks (moderately harvested), and Big Creek (heavily harvested), and were located in the upper Smith and lower Umpqua River basins near Elkton.

A shortcoming of these groupings was that the sandstone basins were all 25 to 50 km inland, and flowed into larger rivers (96,600 ha (Smith River) to 1,196,000 ha (Umpqua River) basin area). In contrast, study streams in basalt were all within 15 km of the coast, and flowed into streams of 5,702 ha basin area or less, or flowed directly to the sea without substantial estuaries. To investigate the effect of climate and varying basin area, a further stream in each rock type was added in 1988 to represent a coastal sandstone stream (North Fork Beaver Creek), and an inland stream in basalt flowing into a larger river (North Fork Wilson River). North Fork Beaver Creek flows into a basin of total area 9,850 ha, and North Fork Wilson River flows into a basin of total area of 51,500 ha. Latitudes and longitudes of the upstream and downstream ends of the surveyed stream segments are given in Appendix 2.1.

Watershed and Segment Characteristics

Geology. Bob, Rock, Tenmile, and Cape Creeks flow through porphorytic basalt and pyroclastic rocks of the Toledo Formation. North Fork Wilson River flows through an area of aphanitic to porphorytic basalt, breccia, and tuffs of the Tillamook Formation (Wells and Peck 1961). Franklin, Halfway, Paradise, and Big Creeks flow through rhythmically-bedded feldspathic and micaceous sandstone of the Tyee and Fluornoy Formations (Wells and Peck 1961). The study segment of North Fork Beaver Creek also flows through Tyee Formation sandstone. Sandstones are generally softer and more easily eroded, but less jointed and porous than the basalts and related volcanic rocks.

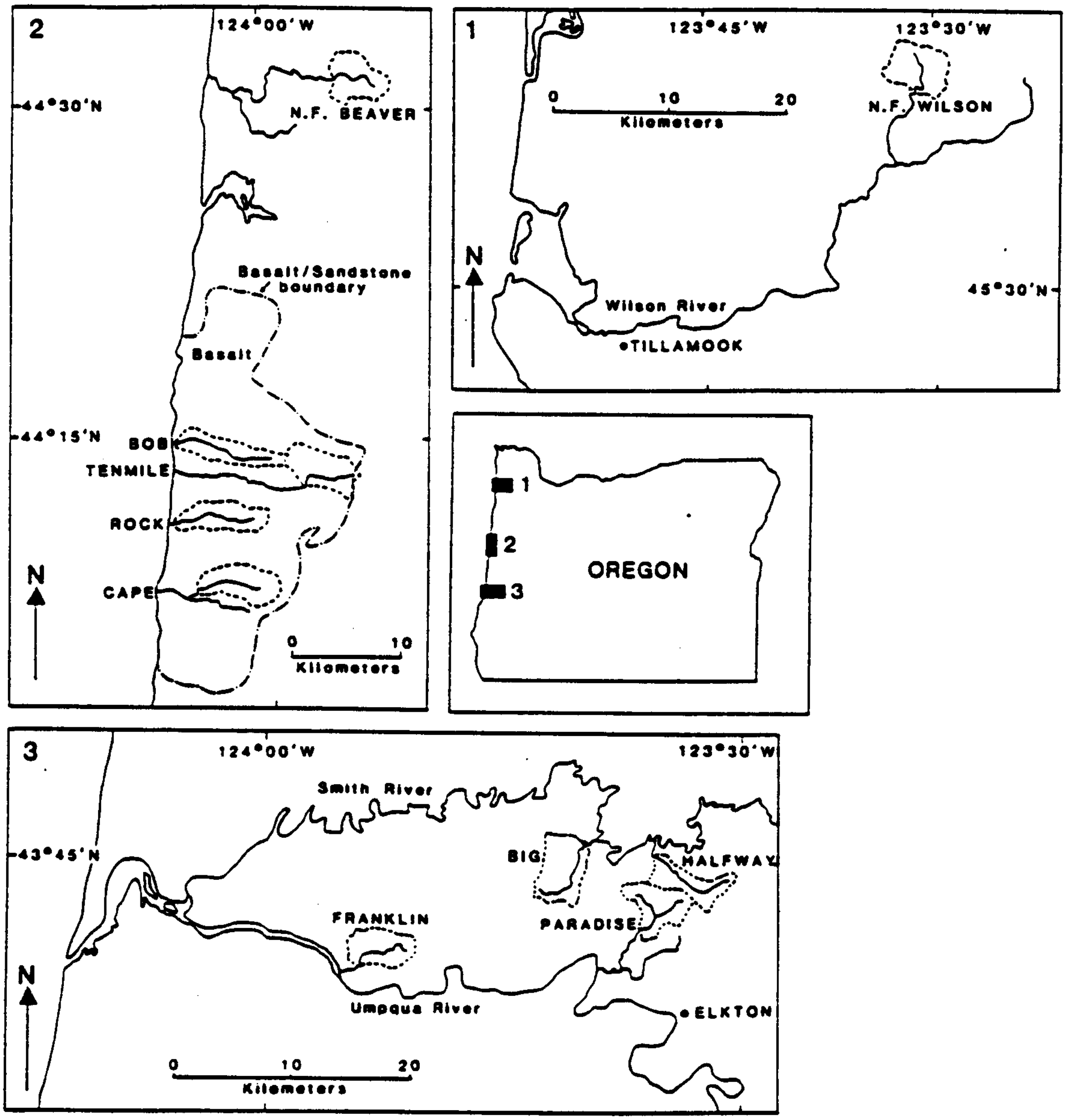

Figure 2.1. Location of study sites in the Oregon Coast Range.

Stream channel gradients are related to rock type. Channel gradient was measured from 1:24,000 maps as the difference in elevation between contour intervals immediately upstream and downstream of the surveyed segment divided by length of channel between them. Channel gradient of the segments in basalt is steeper (2.5±0.6%, mean±95% confidence interval) than segments in sandstone (1.2±0.5%, Table 2.1). Slopes are uniform throughout individual study segments except for Tenmile Creek. The channel gradient of the segment above Wildcat Creek, a major tributary of Tenmile, has a slope of 4.1%, compared to 1.8% for the segment below (Figure 2.2). The elevation of upstream and downstream ends of the surveyed segments, interpolated between adjacent contour intervals, ranged between 4 and 415 m above sea level.

Climate and hydrology. The study sites fall within the Humid Temperate Domain (Bailey 1983). Seasonal distribution of precipitation is very uneven, which is well-documented in western Oregon and western Washington (Harr 1983). Only 4.1-8.3% of total annual rainfall occurs in July-September (Table 2.2). Very little of the annual precipitation falls as snow. However, precipitation is not uniform over all study streams. Normal annual precipitation recorded at nearby weather stations ranged from 1385 mm at Elkton to 2378 mm at Tidewater (Table 2.2). The distribution and small number of rain gauges in relation to the study streams makes interpretation of the effects of distance from the coast and altitude difficult, however. Streams are listed next to the closest weather station, but precipitation and temperature data may not accurately reflect conditions in the watershed because of basin relief and distance from the station. Isohyetal maps, which take relief into account in prediction of normal precipitation, show that N.F. Wilson may receive as much as 3048 mm annually (Table 2.2). However, the accuracy of these maps is not certain for areas as small as the 1500 ha basins used in this study. The upper limits of annual precipitation for Bob, Rock, Tenmile, and Cape Creeks are especially uncertain. For example, another estimate of average annual precipitation for the Rock Creek basin is 3400 mm (Dietrich and Dunne 1978). Precipitation in calendar year 1987 was unusually low.

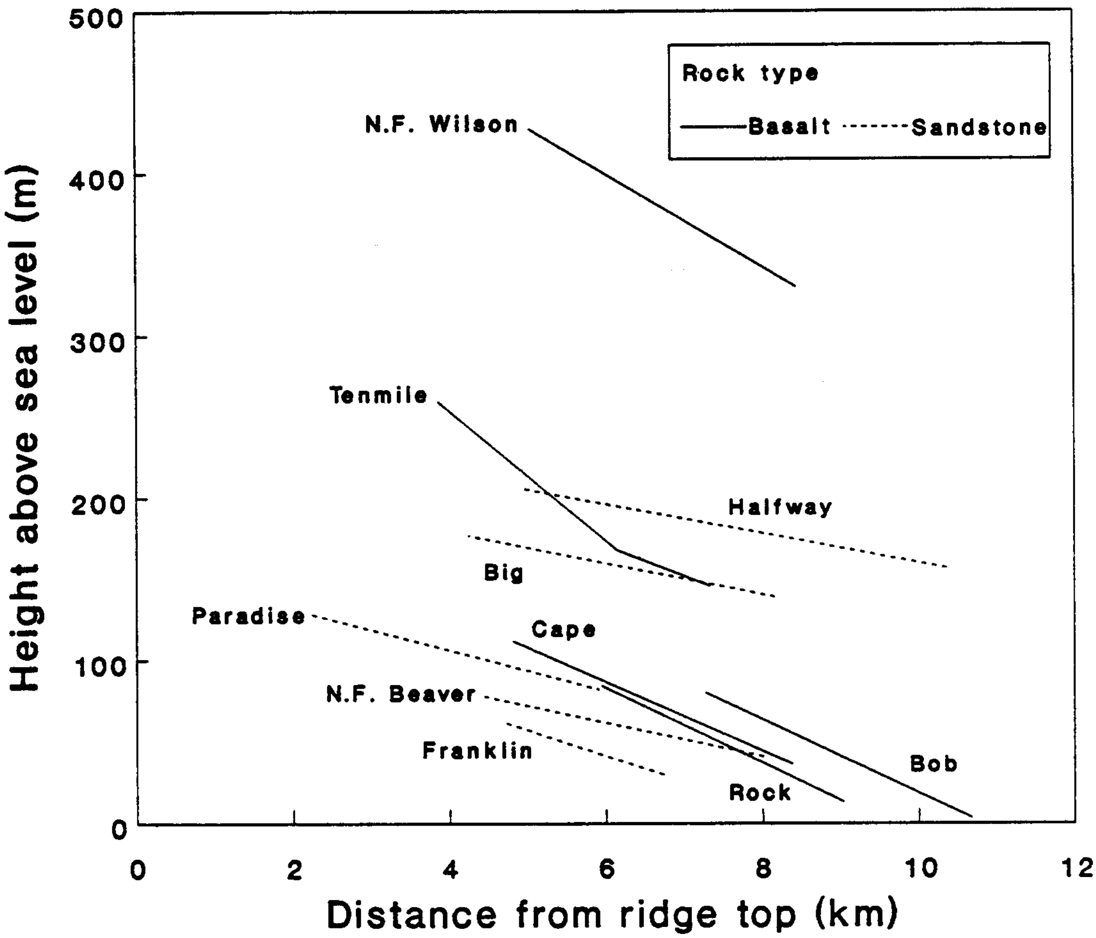

Figure 2.2. Profile of stream channel in surveyed segments of ten Oregon Coast Range streams.

Table 2.1. Physical attributes of study sites in ten Oregon Coast Range streams.

Rock type	Stream name	Basin area (ha) start of survey	Basin area (ha) gauge point	Length surveyed (m)	Timber harvest (% of basin upstream of gauge point)	Dates of timber harvest	Height above sea level[a] (m) down-stream	Height above sea level[a] (m) up-stream	Channel slope (%)
Basalt	Bob	1613	1613	2834	5	1950-1960	4	67	2.1
	Rock	1559	1559	2805	6[d]	1930-1962	21	82	2.4
	Tenmile	1705	1705	3059	32	1959-1986	150	251	3.2
	Cape	1670	1670	3242	78	1946-1986	41	107	2.1
	N.F. Wilson	1839	1407	2808	100	1933-1951[b]	335	415	3.0
Mean±95% confidence interval									2.5±0.6
Sandstone	Franklin	1448	1448	2580	15	1963-1972	27	73	1.8
	Halfway	1914	1514	3327	47	1950-1988	159	191	1.0
	N.F. Beaver	1571	1523	2587	49	1957-1987	43	70	1.0
	Paradise	2011	1617	2710	59	1950-1988	62	105	1.5
	Big	1614	1570	2669	100	1951-1966[c]	142	165	0.9
Mean±95% confidence interval									1.2±0.5

[a] interpolated from nearest contour intervals
[b] burned in Tillamook Burn in successive wildfires, and then salvage logged (Oregon State Forestry Department 1980, in McCullough (1987), p53)
[c] burned in successive wildfires, and then salvage logged
[d] unknown but limited amount of timber harvest occurred in riparian zone before Forest Service ownership

Annual totals were 11-21% below normal, except for the central coast site (Newport), which had 8% above normal (Table 2.2). Summer (July-September) totals were also well below normal (17-61% less), but the most remarkable difference was in October, when monthly totals were 92-98% below normal. Precipitation in November was 28-56% below normal, but was 16% below normal to 34% above normal in December. Winter 1987-88 was mild, and spring 1988 was also mild, though wetter than average. Summer and fall 1988 did not have the prolonged dry conditions of

Table 2.2. Precipitation and air temperatures near study streams in the Oregon Coast Range (from National Oceanic and Atmospheric Administration 1987).

Stream	Isohyetal bounds of watershed (mm)	Weather station	Precipitation (mm) annual normal	annual 1987	1987 Jul-Sep	1987 Oct	1987 Nov	summer[d]/annual (%)
Wilson[a]	2540-3048	Nehalem 9 NE	-[e]	2247 (-)[f]	106 (-)	12 (-)	250 (-)	-
		Tillamook 1 W	2309	1826 (-21)	99 (-44)	16 (-92)	149 (-53)	7.7
Bob Rock Cape Beaver	2286-2540[b]	Newport	1553	1677 (+8)	92 (-29)	3 (-98)	114 (-56)	8.3
Tenmile	2286-2540[b]	Tidewater	2378	1967 (-17)	104 (-17)	13 (-92)	209 (-36)	5.3
Franklin	2032-2286[c]	Gardiner 1 N	1940	1722 (-11)	41 (-61)	6 (-95)	193 (-28)	5.3
Halfway Paradise Big	1524-1778[c] 1524-1778[c] 1778-2032[c]	Elkton 3 SW	1385	1136 (-18)	42 (-25)	4 (-96)	127 (-34)	4.1

[a] Nehalem station is closer, but has no previous record
[b] from U.S. Department of Agriculture (1964)
[c] from Froehlich et al. (1982)
[d] normal precipitation from July-September as a proportion of normal total annual precipitation
[e] missing data
[f] percent departure from normal

October and November 1987, but flows in the study streams in sandstone were almost as low as in 1987. Monthly mean air temperatures from July to September in 1987 were within -1.2 to +1.0°C of normal, and coastal sites (12.9-15.4°C) were cooler than inland sites (16.7-20.7°C, National Oceanic and Atmospheric Administration 1987).

<u>Vegetation</u>. The study sites fall within the Pacific Forest Province of Bailey (1983). Bob, Rock, Cape, and North Fork Beaver Creek are in the Sitka spruce, cedar, hemlock Forest Section of this Division. Tree species present are Sitka spruce, western hemlock,

western red cedar, Douglas-fir, and grand fir (Franklin and Dyrness 1973). Study segments of Tenmile, Franklin, Halfway, Paradise, and Big Creeks and North Fork Wilson River are in the Cedar, hemlock, Douglas-fir Forest Section (Bailey 1983). Tree species present are Douglas-fir, western hemlock, and western red cedar (Franklin and Dyrness 1973). These differences in natural vegetation caused variation in riparian zone composition among study streams.

Differences in the area of each watershed logged or burned (Table 2.1) also caused differences in riparian zone composition among streams. The riparian vegetation on Bob Creek was dominated by large Sitka spruce, Douglas-fir, and western red cedar, with minor amounts of red alder, reflecting the undisturbed nature of the watershed. The riparian zone of Rock Creek was dominated by red alder and young Douglas-fir, despite no recorded timber harvest since the land came into Forest Service ownership the early 1960's. Cut stumps of large conifers and scraps of cable in the stream attested to previous logging activity; presumably some large conifers were removed from the readily accessible riparian flats before records of logging were kept. Sitka spruce and bigleaf maple also occurred in the riparian zone of Rock Creek. The riparian vegetation of Tenmile and Cape Creeks was dominated by red alder with some bigleaf maple, reflecting the timber harvest activities. The upper 300 m of the Tenmile Creek survey segment was bordered by forest of undisturbed Douglas-fir and western red cedar. The riparian zone of North Fork Wilson River did not shade the stream extensively, and was composed of willow, red alder, and young Douglas-fir.

Among basins in sandstone, Franklin Creek had the least disturbed riparian zone. The riparian vegetation was dominated by large (50-80 cm diameter at breast height (dbh)) bigleaf maple, with vine maple in places. Salmonberry and western red cedar were also common. Red alder, Douglas-fir, elderberry, and stink currant were minor components of the riparian vegetation. On Halfway Creek the riparian zone was dominated by red alder that overhung the channel in many places. Large Douglas-fir bordered the stream in unharvested sections. The riparian zone of the lower two-thirds of the study segment in Paradise Creek was also dominated by alders overhanging the channel. However, forest adjacent to the upper third of the study segment was unharvested, and the riparian vegetation was largely Douglas-fir, bigleaf maple, and vine maple. The riparian zone of Big Creek was dominated by 15-25 cm dbh alders that formed a canopy over much of the channel. Douglas-fir was a minor component of vegetation in the riparian zone.

The proportion of basin area above the downstream end of the study sites affected by timber harvest or salvage logging following fire ranged from about 5 to 100% (Table 2.1). In general, where some undisturbed forest was present in a basin, it was in the upper part. In my study, fire followed by salvage logging has been treated as equivalent to normal timber harvest practices. Fire disturbs larger areas than is usual with normal timber harvest, but road construction for timber removal occurs in both, and fire is a usual treatment following normal timber harvest. Therefore the hydrologic responses due to normal timber harvest and due to fire followed by salvage logging are very similar. Timber harvest or other widespread disturbance in the study basins occurred up to nearly 60 years before the end of the study. Therefore substantial vegetative regrowth occurred following timber harvest prior to this study even in the heavily impacted basins. Recent clear-cut logging (up to 1986) took place in Tenmile, Cape, Halfway, Paradise, and North Fork Beaver Creeks.

Large woody debris was removed from many streams in the Oregon Coast Range because of its intrinsic worth as timber, to allow water transport of logs, and to improve fish passage. Roads run parallel to parts of the survey segments in Tenmile, Cape, Halfway, Paradise, Big, and North Fork Beaver Creeks, and North Fork Wilson River. Large woody debris was probably removed from some or all of these streams, but the extent of removal is unknown.

Methods

Determination of Physical Characteristics of Study Segments

Streamflows. Streamflows were estimated by measuring water velocity with a magnetic inductance current velocity sensor at 0.6 of depth at 10 points. These points were equally spaced across a transect that was perpendicular to the streamflow. Streamflow was estimated from these measurements by the method of Buchanan and Somers (1969). Streamflow was first measured in this study in early October 1987. In 1988 flows were measured between 14 April and 31 October to follow flow recessions and to compare base flows. To measure flows, gauging sites were selected near the downstream end of each survey segment. These sites were at the downstream end of pools or in glides in areas of steady, non-turbulent flow, and were as free as possible from the influence of bed roughness. Gauging sites were entirely on bedrock (Paradise, Big, and North Fork Beaver Creeks), or had bedrock in part of the gauged cross-section (Rock and Cape Creeks), where possible. It was not possible to measure streamflows on bedrock in other streams, but bedrock outcrops in the streambed nearby indicated that bedrock was close to the streambed at gauge sites in North Fork Wilson River and in Bob, Tenmile, and Halfway Creeks. Franklin Creek, however, presented a particular problem. Because of the considerable amount of alluvial gravel near the gauge site it was not possible to measure flows close to bedrock, and by late summer in both 1987 and 1988 the stream was intermittent in many places.

Channel Morphology. Channel units of various types, that is, pools, glides, and riffles, were used as the primary sampling unit. Channel units were identified on the basis of water surface slope and depth (Table 2.3) after the system adopted by Bisson et al. (1982). Debris scour pools were substituted for plunge pools of Bisson et al. (1982) in the classification used in my study, because this addition broadens the type of pools associated with large woody debris. Pools clearly scoured by woody debris were placed in this category even

Table 2.3. Channel units into which streams were visually classified (after Bisson et al. 1982).

Primary channel unit types	Secondary channel unit types	Criteria	
		water surface slope (%)	maximum depth (m)
1. Pool	1. lateral scour pool (LSP) 2. trench pool (TP) 3. debris scour pool (DSP) 4. boulder scour pool (BSP) 5. backwater pool (BP) 6. beaver-dammed pool (BDP)	<0.5	≥0.40
2. Glide	no secondary divisions (G)	≥0.5, <1.5	<0.40
3. Riffle	1. low gradient riffle (LGR) 2. low gradient cascade riffle (LGCR) 3. rapid riffle (RR) 4. cascade riffle (CR)	≥1.5, <4.0 ≥1.5, <4.0 ≥4.0 ≥4.0	<0.30 ≥0.30 <0.30 ≥0.30
4. Side channel	no secondary divisions (SC)		

though in some instances the debris was suspended above the water surface at the time of the survey. I created an additional riffle type (low gradient cascade riffles) parallel to cascade riffles and rapid riffles to distinguish deep and shallow low gradient riffles. Low gradient cascade riffles were deeper than low gradient riffles, and usually had transverse ribs of cobbles, boulders, or bedrock that were not present in low gradient riffles.

Physical characteristics of every channel unit were assessed in an upstream direction in about 3 km of each stream segement. Surveys were conducted between 11 July and 23 September in 1987, and between 24 June and 14 September in 1988 (Appendix 2.2). In 1988, streams in sandstone were surveyed before those in basalt to compare channel morphology in the two rock types at similar streamflows. Channel morphology, habitat complexity, substrate size, and abundance of large woody debris were assessed in streams in basalt and sandstone rock types, stratified by channel units, with methods adapted from Duff and Cooper (1978), Beschta (1978), and Hankin and Reeves (1988).

Length of each channel unit was measured with a hip chain. Hip-chain measurements were compared to distances of 50 and 100 m measured with a fiberglass tape. A correction factor, $\hat{Q}$, of 1.0093 was calculated from the sum of 28 tape-measured distances divided by the sum of hip-chain measured distances (equation (3), Hankin and Reeves 1988, p836). Accuracy of hip-chain measurements was not determined for individual streams, but the estimated variance, $\hat{V}(\hat{M})$, equalled 28 m for a 3000 m length of channel with 250 channel units (equation (4), Hankin and Reeves 1988, p836).

Widths of average water surface and active channel were estimated for each unit by pacing a width visually judged to be equal to the mean. Paced distances were periodically compared to distances measured using a hip chain to determine the accuracy of paced measurments. A $\hat{Q}$ of 1.029 was calculated from the sum of 66 measured distances divided by the sum of the paced distances (equation (3), Hankin and Reeves 1988, p836).

Mean depths of glides and riffles were estimated by visually choosing a representative transect, often the same one used to estimate mean width, and by measuring depths at three equally spaced points with a graduated wading stick. For glides and riffles these depths were summed and divided by three. For pools a variation of this technique was used to estimate mean depth. Three depths were measured on a transect as above, except that the transect was selected so that it spanned the deepest part of the pool. The three depths were then summed, and divided by a denominator ranging from 3.0 to 4.0, the value of which was decided by the symmetry of the pool. If the pool was short and the cross-section U-shaped, then a denominator close to 4.0 was chosen. If the pool was long and the transect chosen deep compared to the rest of the pool, a smaller denominator was selected. Denominators normally ranged between 3.2 and 3.7. This method is a modification of a technique originally used by Anadromous Fish Habitat Research staff (pers. comm., F.H. Everest, U.S. Forest Service Research Laboratory, Corvallis, Oregon). Maximum depths were measured with the same wading stick, or a collapsible pocket rod for deep pools (>1.2 m maximum depth), after severals trials to find the deepest part of the pool.

Estimates of mean depth, mean water surface width, mean active channel width, wetted area, and volume were compared with more accurate estimates from a subsample of 37 pools, 24 glides, and 30 riffles. Water surface and active channel width were estimated by pacing at each of five equally spaced transects perpendicular to the water flow in channel units of >6 m long. Depths were measured at five points equally spaced along each transect to give a total of 25 measurments for each channel unit. Mean depth and volume were calculated from these measurements weighted for water surface width. Channel units ≤6 m long that were used for verification were treated similarly, except that only three transects were used, giving a total of 15 depth measurements. Accurate estimates of mean depth, mean widths of water surface and active channel, and wetted area and volume were compared to estimates made by standard methods used on all channel units, and $\hat{Q}$ was calculated (Appendix 2.3). Correction factors were used by pooling estimates from all streams, then applying the combined $\hat{Q}$ to individual streams.

Slope of the water surface and bed of channel units was measured using a 5-x magnifying hand-held Abney level and a collapsible rod. Measurements were made in every fifth pool, fifth glide, tenth riffle, and tenth side channel. The maximum distance over which the Abney level could be readily used was 25-30 m. For channel units longer than this, consecutive placements of the rod and observer from downstream to upstream were summed to give total fall over total distance. The accuracy of slopes measured with the Abney level was compared to slopes of five channel units measured with a transit level mounted on a tripod. The correction factor, $\hat{Q}$, for gradients measured with the more accurate transit level compared to the Abney level was 1.000165. Thus gradients measured with the Abney level were very close to those measured with the transit level.

Substrate composition was estimated as the relative area covered by the dominant and subdominant substrate size classes in each channel unit. The classification system used for substrate size was based on a

$\log_2$ scale (Appendix 2.4). Fine gravel and very fine gravel were grouped because of the difficulty of visually distinguishing between these classes. Size classes smaller than very coarse sand were grouped as sand and silt. Size of individual substrate particles was measured as the length of the intermediate axis (Wolman 1954).

Abundance of large woody debris in the active channel of each channel unit was assessed as the number and size range of pieces. A rating scale that was logarithmic for debris volume was used to group pieces of large woody debris >0.1 m diameter and >2 m long into visual size classes (Appendix 2.5). Where one large piece spanned two or more channel units, it was allocated to the tally of wood in the unit in which it was presumed to have greater influence on either channel morphology or fish habitat.

Shading. Shading was estimated visually for each channel unit during summer when deciduous trees and shrubs were in full leaf. Account was taken of shading from valley walls and evergreen trees as well, but no attempt was made to separate the shade into valley wall, deciduous, and non-deciduous components. The accuracy of visual estimates of shade was determined by comparison with measurements made with a Solar Pathfinder (trademark) designed to measure availability of solar energy. Comparisons were made at 25 channel units in North Fork Beaver Creek on 26 September, and at 26 channel units in Bob Creek on 29 September 1989. The proportion of the total solar energy available at any site was summed for each month, and the percent available energy for April to September was regressed against eye-estimated shading. A linear equation

$$Y = 90.4 - 0.879X \quad \text{- equation (1)}$$

was calculated using least-squares regression, where Y=percent available solar energy, and X=visually estimated shading (r^2=0.71, n=49). A source of variability was error caused by inclusion of the entire sky gap in visual estimates of shading regardless of orientation, compared to the sunpath tracing that neglected any sky gap to the north because it did not fall on a sun path.

Dissolved Oxygen. Dissolved oxygen concentrations were measured 5-10 cm below the stream water surface and at the bottom with an oxygen meter. Accuracy of oxygen meter readings were determined by comparison with oxygen concentrations measured with the Winkler method (Wetzel and Likens 1979, p71-77). No correction of oxygen meter readings was required as Q was 1.008 (n=10) (Hankin and Reeves 1988, equation (3)).

The equation

$$Y = 100 * DO/(1/(0.0674 + (0.0021 * T)) \quad \text{- equation (2),}$$

derived from data in Wetzel and Likens (1979), was used to calculate percent saturation from dissolved oxygen and temperature. In this equation, Y=percent saturation, DO=dissolved oxygen concentration in g/m^3, and T=temperature in degrees Celsius.

Data Frequency Distribution

Frequency distributions of many data were positively skewed by infrequent large values. Log, inverse tangent, or square root transformations may be useful to produce a normal distribution from positively skewed data (Sokal and Rohlf 1981). Natural log transformation reduced the coefficient of variation (C.V., i.e., (S.D./mean) x 100, where S.D.=standard deviation) of lengths of all channel unit types combined from 107% before transformation to 31% after transformation (Appendix 2.6). The C.V. of lengths of individual channel unit types was reduced from 75-132% before transformation to 23-40% after (Appendix 2.6).

A chi-square test indicated acceptable fits ($p \geq 0.05$) of transformed data to a normal distribution for length of pools, riffles, and side channels in 1987 (Appendix 2.6). Although the frequency distribution of transformed lengths of glides and all channel unit types combined did not fit a normal distribution, transformation reduced the C.V. to one third to one half of values before transformation. Log transformation is therefore desirable before any parametric analysis of length data is undertaken, such as calculation of means and confidence limits.

Mean water surface width and mean water depth of channel units could not be normalized with log transformation as well as length, possibly because of the smaller range of values for width and depth than for length. A square root transformation reduced the C.V. appreciably, generally to about one-half of the value before transformation, in every case except mean depth of riffles (Appendix 2.6). Chi-square tests showed less departure from normality following transformation compared to before transformation, but no p values equalled or exceeded 0.05. Graphical representations showed that the distribution of mean water surface width of different channel unit types following transformation, however, were a better fit visually to a normal distribution than were untransformed data.

Water surface slopes of pools, glides, and riffles were also not normally distributed, and a natural log transform effectively normalized riffle surface slopes (Appendix 2.6). Glide water surface slopes fit a normal distribution reasonably well, but the fit was better after log transformation. Pool gradients were dominated by zero values, and did not transform well with any method. Thus to calculate means and confidence intervals, pool water surface slopes were not transformed. Glide slopes were transformed with ln(s+1), where s=water surface slope in percent, to enable log transformation of zero values, and riffle slopes were transformed with ln(s).

Tests of Significance

Non-overlap of 95% confidence limits about the mean was used to test differences between means unless otherwise stated. Confidence intervals were calculated by multiplying standard errors by $t_{0.05[n-1]}$, where n=sample size (Sokal and Rohlf 1981, p109). Mann-Whitney *U* tests were used for small sample sizes of unknown distribution (Siegel 1956, p116).

Results

Streamflow, Geology, and Climate

Streamflows at the end of the prolonged summer drought of 1987 varied greatly between the two rock types, and there is evidence that streams in basalt have higher base flows than streams in sandstone. On 4 October 1987, the coastal streams in basalt were flowing at between 44 and 90 l/s, while streams in sandstone ranged from no surface flow to 5 l/s (Appendix 2.7). North Fork Wilson River, a stream in basalt inland in the northern Oregon Coast Range, had a base flow similar to coastal streams in basalt at the end of summer 1988. Geology, however, was not the only factor influencing streamflows. North Fork Beaver Creek, a coastal stream in sandstone, had a base flow similar to coastal streams in basalt at the end of summer 1988 (Figure 2.3, Appendix 2.7).

Surveys in 1988 were planned on the basis of streamflow recessions to provide a basis for comparison of habitat units in sandstone and basalt at similar streamflows (Figure 2.3, Appendix 2.7). Also, habitat surveys were conducted over a shorter period in 1988 than in 1987 (Appendix 2.2). Streamflows in basalt at the time of surveys in 1987 were back-calculated from a combination of flows on 4 October 1987 and a recession constant derived from the flow hydrographs from 1988 for the period between 14 July (julian day 195) and 22 September (julian day 265, Table 2.4, Appendix 2.7). The equation used to back-calculate flows was:

$$q_t = q_0 K_r^t,$$

where q_t=streamflow at time t, q_0=streamflow at time t=0, and K_r is a constant calculated from the slope of the semilog relationship of streamflow versus time (Linsley et al. 1982, equation (7-2), p207). Streamflows in streams in sandstone could not be calculated in the same manner because flows were too low in October 1987 (Appendix 2.7). Instead, streamflows in 1987 were estimated from those measured at approximately the same times in 1988.

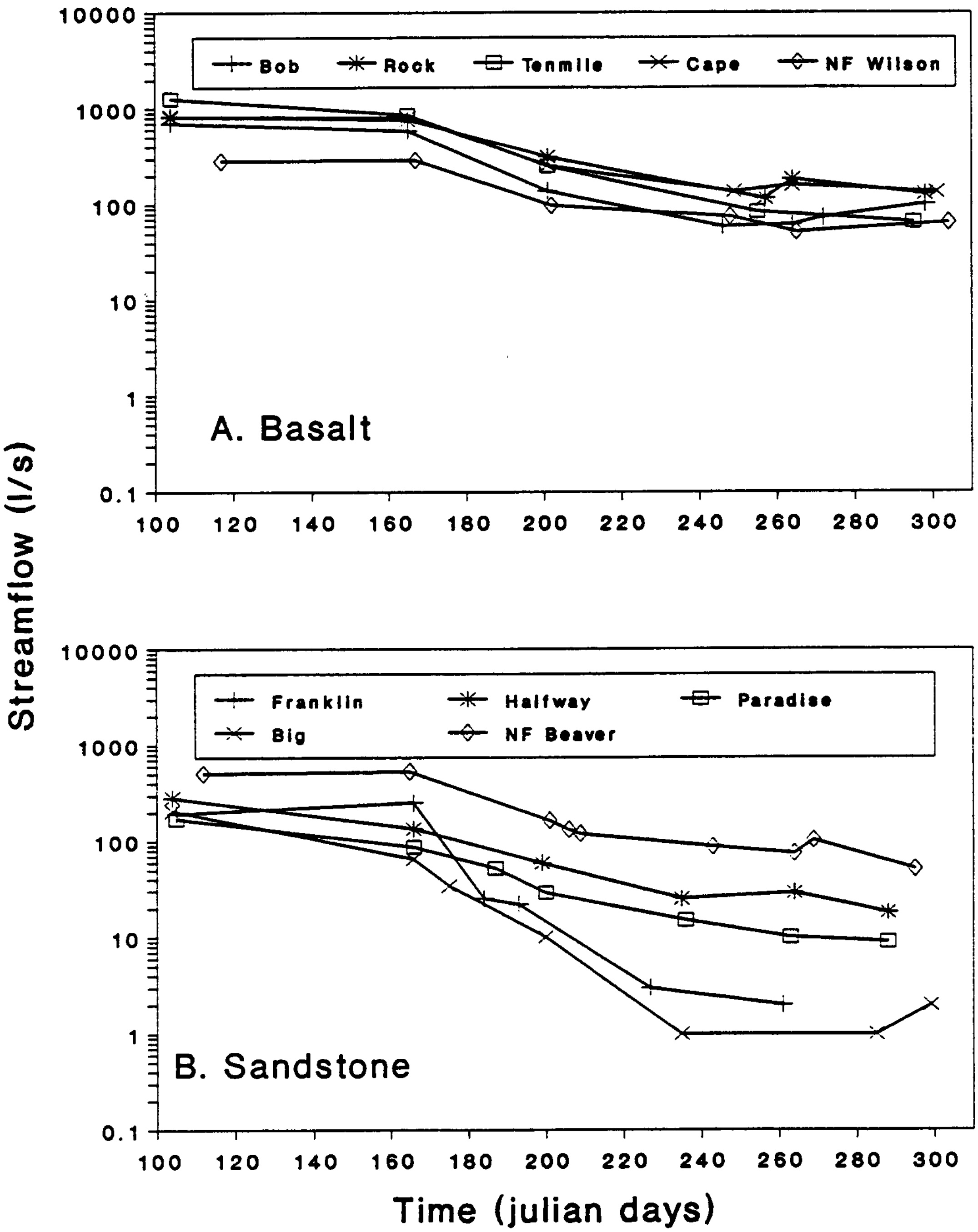

Figure 2.3. Streamflows in (A) basalt and (B) sandstone in the Oregon Coast Range in spring and summer 1988.

Table 2.4. Streamflows in ten Oregon Coast Range streams at the time of habitat surveys in summer 1987 and 1988. See Appendix 2.2 for dates of surveys.

Geology	Stream	Streamflow (l/s) 1987	Streamflow (l/s) 1988	K_r[a]
Basalt	Bob	65[b]	59	0.981
	Rock	139-237[b]	115	0.982
	Tenmile	113-163[b]	83	0.980
	Cape	216-274[b]	135	0.987
	NF Wilson	-[c]	78	0.994
Sandstone	Franklin	2-26[d]	26	0.936
	Halfway	25[d]	59	0.976
	Paradise	15[d]	83	0.982
	Big	1[d]	33	0.936
	NF Beaver	-	126	0.991

[a] recession constants (Linsley et al. 1982, equation (7-2), p207) calculated from streamflows between 14 July and 22 September 1988
[b] back-calculated from streamflows of 4 October 1987 and 1988 flow recession (Linsley et al. 1982, equation (7-2), p207)
[c] not surveyed
[d] estimated from streamflows at similar times in 1988

Streamflows at the beginning of summer recession (i.e., 14-16 July, or julian day 195-197, Appendix 2.7) were less in sandstone than basalt (Mann-Whitney *U* test, p=0.016), but flow recession constants (Table 2.4) were not different (p=0.222).

Stream Channel Morphology and Geology

Stream channels in basalt were more stable than those in sandstone, and the number, position, and dimensions of channel units in basalt did not change between summer 1987 and summer 1988. For this reason, only streams in sandstone were resurveyed in 1988. In 1988 streams in sandstone had greater mean frequency of pools (28 pools per kilometer) than streams in basalt (18 pools per kilometer, Mann-Whitney *U* test, p=0.016, Table 2.5). Mean frequency of glides (17 and 19 glides per kilometer) and riffles (26 and 23 riffles per kilometer) in streams in basalt and sandstone was not different (Mann-Whitney *U* test, p>0.15). However, riffles were almost twice as long in streams in basalt (14.6 m, geometric mean length) as in sandstone (7.7 m), and this difference in length was significant (Mann-Whitney *U* test, p=0.008, Figure 2.4, Appendix 2.8). Side channels were also longer in streams in basalt than in sandstone. Pools were slightly longer in sandstone (geometric mean length 13.2 m) than in basalt (11.4 m), but there was no difference in length of glides (13.2-13.8 m) between the two geologies. Side channels were more abundant in basalt than in sandstone, but were much less abundant than other channel unit types.

The proportions of channel length of pools and riffles were significantly different in the two rock types (Figure 2.5, Table 2.5). In 1988 streams in basalt had a greater proportion of their length as riffles (50±9%) than as pools (24±7%) or glides (27±5%), and streams in sandstone had a greater proportion as pools (47±9%) than as glides (33±4%) or riffles (20±6%).

Mean numbers and proportions of each channel unit type in streams in sandstone did not vary significantly with streamflow, that is, between 1987 and 1988 (Table 2.5). In individual streams, however, the number and proportion of glides and riffles was different. In Franklin Creek there were 44% more glides in 1988 than in 1987, and 14% fewer riffles. In Halfway Creek there were also more glides and fewer riffles in 1988 than in 1987, but in Paradise and Big Creeks there were fewer glides and riffles. Number of pools did not change between years except in Big Creek, where the number was reduced by 15% in 1988 compared to 1987. The net result of these differences was a reduction by 6-33% in the total number of pools, glides, and riffles in each stream from 1987 to 1988. Higher flows submerged the boundaries between some units, especially pools in Big Creek. The combined effect of increased depth and decreased water slope changed low gradient riffles into glides.

Table 2.5. Number of channel units and proportion of lengths of different channel unit types in streams of the Oregon Coast Range in basalt and sandstone rock types in summer 1987 and 1988[a].

Stream name	Length surveyed (m)[b]	Channel units: Number per kilometer					Percentage length		
		pools	glides	riffles	side channels	total	pools	glides	riffles
A. 1987									
Basalt									
Bob	3037	16.8	16.5	24.4	4.3	61.9	25	30	44
Rock	2895	19.0	18.7	29.0	3.8	70.5	27	28	46
Tenmile	3022	13.6	17.2	27.8	3.0	61.5	15	27	58
Cape	3078	21.1	19.5	29.6	4.9	75.0	29	29	43
Mean[c]	3008	17±5	18±2	28±4	4±1	67±11	24±10	29±2	48±11
Sandstone									
Franklin	3023	40.7	17.9	32.1	3.0	93.9	52	20	28
Halfway	3376	24.3	16.6	16.6	1.5	58.9	52	32	16
Paradise	3047	27.9	23.0	29.5	1.0	81.4	39	39	22
Big	3187	29.2	16.0	21.7	0.9	67.8	47	33	20
Mean	3158	31±11	18±5	25±11	2±2	75±25	48±10	31±13	22±8
B. 1988									
Basalt									
Bob	3037	16.8	16.5	24.4	4.3	61.9	25	30	44
Rock	2895	19.0	18.7	29.0	3.8	70.5	27	28	46
Tenmile	3022	13.6	17.2	27.8	3.0	61.5	15	27	58
Cape	3078	21.1	19.5	29.6	4.9	75.0	29	29	43
NF Wilson	2988	18.1	11.4	22.1	2.0	53.5	23	20	58
Mean	3004	18±4	17±4	26±4	4±1	65±10	24±7	27±5	50±9
Sandstone									
Franklin	2957	41.3	23.7	28.1	3.4	96.7	51	28	21
Halfway	3390	24.2	17.4	14.7	2.4	58.7	53	33	14
Paradise	3012	28.2	22.6	28.2	1.0	80.0	40	35	25
Big	3156	27.6	14.9	19.6	0.3	62.4	53	31	17
NF Beaver	3019	19.5	18.2	22.9	2.0	62.6	39	37	24
Mean	3107	28±10	19±5	23±7	2±2	72±20	47±9	33±4	20±6

[a] lengths of channel units in Bob, Rock, Tenmile, and Cape Creeks not remeasured in 1988.
[b] measured with a hip chain; surveyed length excludes side channels
[c] mean±95% confidence limits

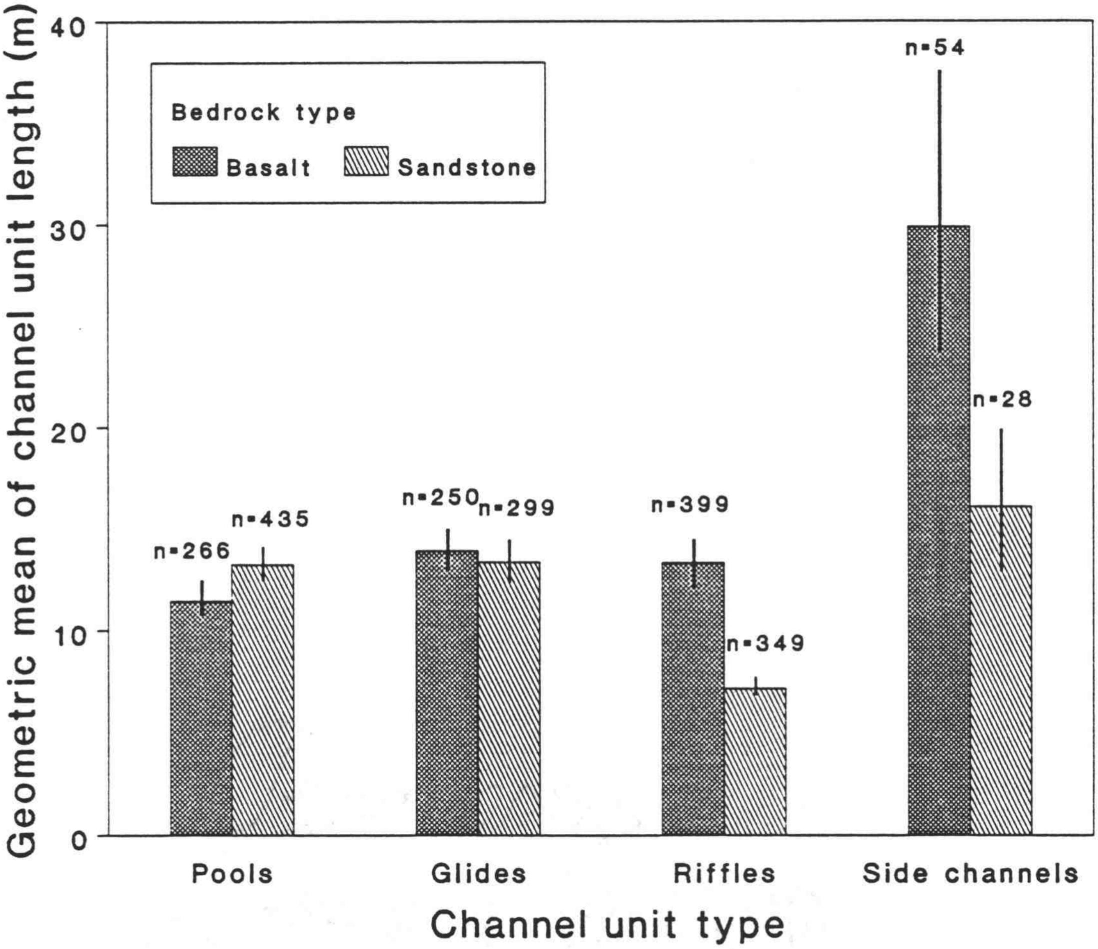

Figure 2.4. Geometric mean length of individual channel units in Oregon Coast Range streams in basalt and sandstone in summer 1988. Vertical bars represent 95% confidence intervals about means.

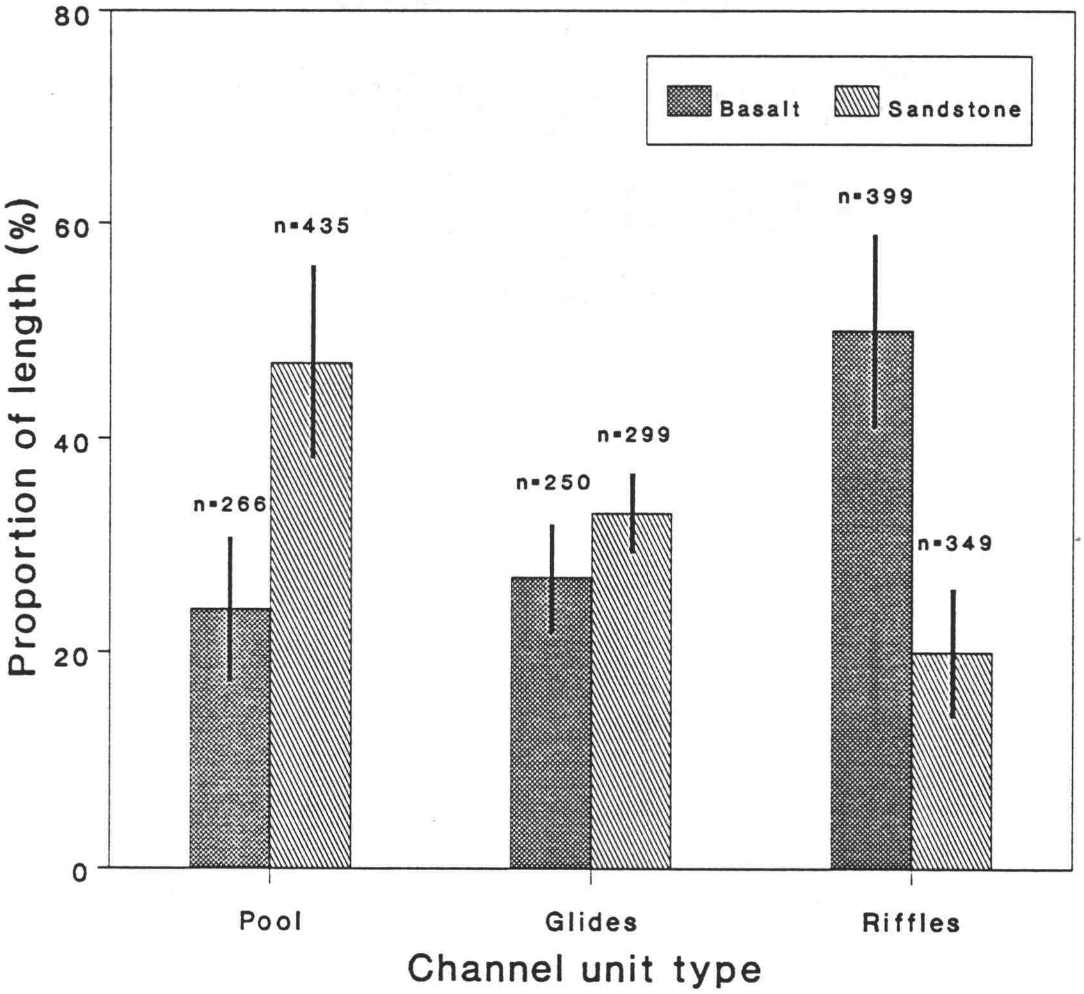

Figure 2.5. Proportion of channel length in each channel unit type in Oregon Coast Range streams in basalt and sandstone in summer 1988.

Streamflow in basalt was more similar between survey periods in 1987 and 1988 than was streamflow in sandstone (Table 2.4). Streams in basalt were not resurveyed in 1988 because there were very few changes in location and size of channel units between years.

The proportion of channel length in pools, glides, and riffles was related to channel gradient (Figure 2.6). Percentage of channel length in pools (Y_p) was related to gradient by the linear equation

$$Y_p = 63.21 - 14.58X \quad \text{- equation (3),}$$

where X=channel gradient in percent (r^2=0.76, p=0.001, Figure 2.6A). Percentage of channel length in glides (Y_g) was related to gradient by the linear equation

$$Y_g = 38.61 - 4.63X \quad \text{- equation (4)}$$

(r^2=0.64, p=0.005, Figure 2.6B). Percentage of channel length in riffles (Y_r) was related to gradient by the linear equation

$$Y_r = -1.71 + 19.32X \quad \text{- equation (5)}$$

(r^2=0.90, p=0.00003, Figure 2.6C). Streams in basalt and sandstone were grouped in these linear regressions. Channel morphology predicted by these equations conflicts at gradients above about 4.5%. Glides may become similar to riffles at these gradients.

Mean water-surface widths of glides and riffles calculated from square root-transformed data were narrower in sandstone than in basalt, especially as a result of lower flow in streams in sandstone in 1987 (Figure 2.7, Appendix 2.9). Riffles in streams in sandstone were less than half the width of riffles in basalt in 1987, but the difference was less pronounced in 1988 when streamflows were more similar. Pool widths were not different in either year. There was a trend towards increasing mean width among pools, glides, and riffles in streams in basalt, although only pools and riffles were significantly different. Mean widths of pools, glides, and riffles in sandstone showed the opposite trend. Glides were narrower than pools, and riffles were narrower than glides (Figure 2.7).

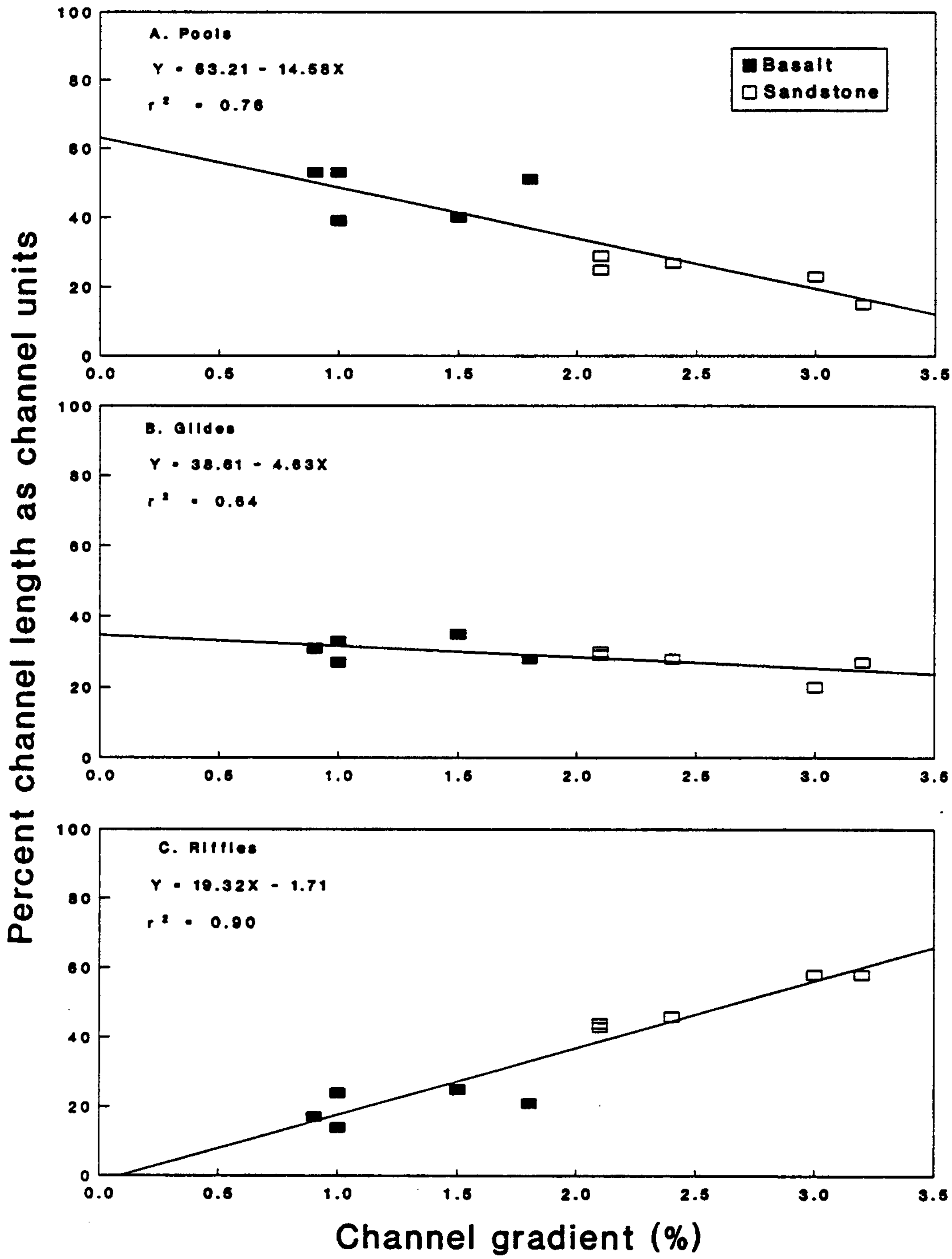

Figure 2.6. Relationship of proportion of channel length in (A) pools, (B) glides, and (C) riffles to channel gradient in Oregon Coast Range streams in basalt and sandstone in summer 1988.

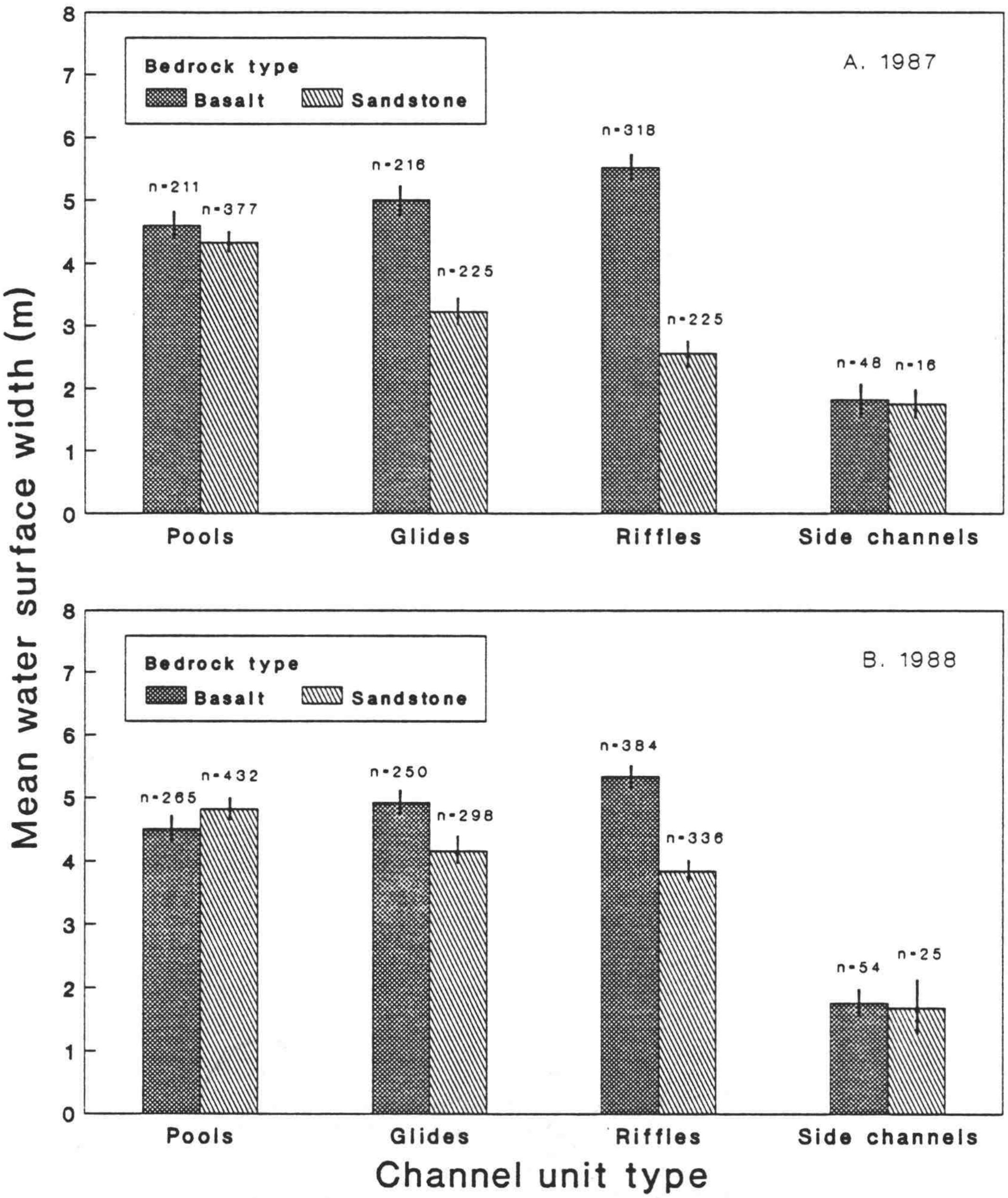

Figure 2.7. Means and 95% confidence intervals of water surface width in Oregon Coast Range streams in summer (A) 1987 and (B) 1988.

Mean widths of active channels calculated from square root-transformed data were generally wider in basalt than in sandstone (Table 2.6), but were not significantly different (Mann-Whitney *U* test, p=0.056). The active channel of Franklin Creek was about 2 m wider than those of other streams in sandstone, and had a large amount of stored gravel. The channel of North Fork Wilson River also had more stored gravel than other streams in basalt, thus active channel width appears to be related to the amount of gravel stored in stream channels.

Table 2.6. Mean width of active channel calculated from square root-transformed data for ten Oregon Coast Range streams.

Stream	Active channel width (m)		
	mean	lower 95% C.I.[a]	upper 95% C.I.
Basalt			
Bob	11.0	10.5	11.5
Rock	11.6	11.1	12.0
Tenmile	9.7	9.3	10.2
Cape	12.4	12.0	12.8
N.F. Wilson	12.6	12.0	13.3
Sandstone			
Franklin	11.4	11.1	11.8
Halfway	9.9	9.4	10.4
Paradise	9.4	9.1	9.6
Big	9.2	9.0	9.5
N.F. Beaver	9.7	9.3	10.1

[a] 95% confidence intervals about mean calculated with Student's t (Sokal and Rohlf 1981)

Water surface slopes were different for each channel unit type, but were not different between rock types for the same channel unit type (Table 2.7). Riffles had the most variable slopes of any channel unit, and pools were least variable.

Table 2.7. Means, 95% confidence intervals, and ranges of water slope of visually identified channel units in Oregon Coast Range streams in basalt and sandstone rock types.

Rock type	Channel unit type	Sample size	Water slope (%)[a]				
			mean	95% confidence limits		minimum	maximum
				lower	upper		
Basalt	pools	55	0.079	0.013	0.145	0.00	0.68
	glides	49	0.746	0.632	0.869	0.00	1.38
	riffles	62	4.033	3.458	4.704	1.24	11.69
Sandstone	pools	68	0.036	0.007	0.064	0.00	0.49
	glides	61	0.556	0.453	0.668	0.00	1.55
	riffles	63	3.286	2.756	3.917	1.13	23.61
All streams	pools	103	0.051	0.026	0.075	0.00	0.68
	glides	110	0.638	0.571	0.709	0.00	1.55
	riffles	125	3.637	3.295	4.015	1.13	23.61

[a] Mean slope of glides calculated from data transformed with ln(s+1), mean slope of riffles calculated from data transformed with ln(s), where s=water surface slope in %. Slopes of pools not transformed.

Mean depths calculated from square root-transformed data decreased with increasing slope of channel unit type in the order of pools, glides, and riffles (Figure 2.8). Mean depth of those three channel units were less in sandstone than in basalt during summer 1987 (Figure 2.8A, Appendix 2.10). In 1988 flows were more comparable (26-126 l/s in streams in sandstone, 59-135 l/s in streams in basalt, Table 2.4) when depths were measured, and there was no difference between mean depths of pools in streams in sandstone and basalt (Figure 2.8B). Mean depths of riffles and glides, however, were less in streams in sandstone than in basalt even at the higher flows of 1988. Mean depth of side channels was not significantly different between rock types in either year. Many riffles were actually dry when surveyed in 1987, especially in Franklin and Big Creeks.

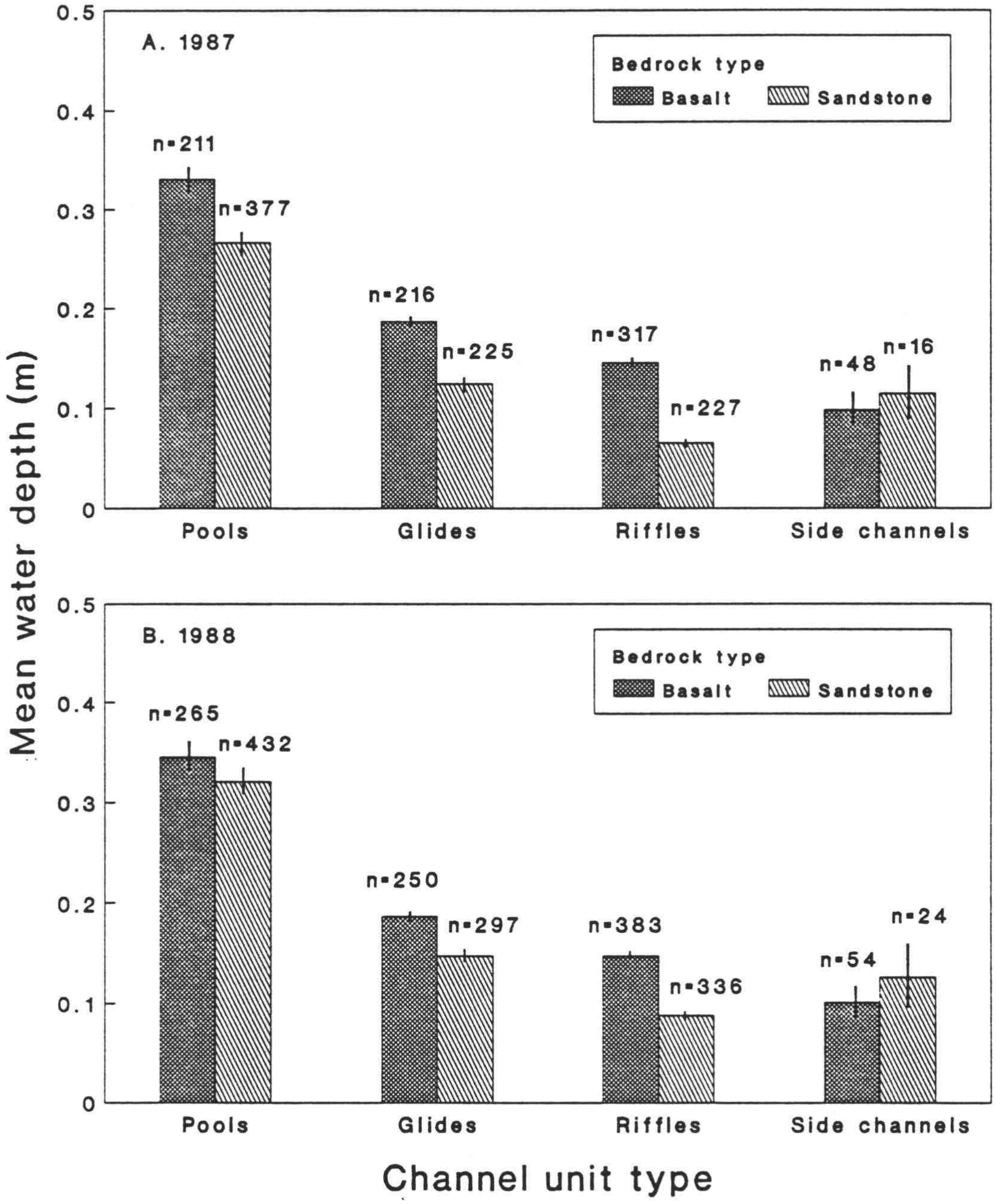

Figure 2.8. Means and 95% confidence intervals of water depths in different channel unit types in Oregon Coast Range streams in basalt and sandstone in summer in (A) 1987 and (B) 1988.

Geometric mean volume of channel units was different between streams in basalt and sandstone (Figure 2.9, Appendix 2.11). In streams in sandstone in both years, pools had greater mean volume than glides, and glides had greater mean volumes than riffles (Figure 2.9). In streams in basalt, however, glides had a mean volume similar to riffles. Mean volume was affected by lower streamflows in streams in sandstone in 1987 compared to 1988; volumes of glides and riffles were considerably less in 1987. Streamflows were not measured at the time of habitat surveys in 1987, but were measured in 1988. Mean volume of glides and riffles in 1988 was highly related to streamflow in streams in sandstone (r^2=0.90, Figure 2.10B). Flow was not measured in streams in basalt when volume was measured in 1987, so streamflow was back-calculated from flow in October 1987. Mean volume of channel units in basalt was not closely related to estimated streamflow (Figure 2.10A).

Total volume of pools, glides, riffles, and side channels reflected mean volume, except that side channels had the smallest total volume because of their low frequency compared to other channels units (Table 2.8). Riffles in sandstone had the lowest total volume of main channel unit types, whereas in basalt, riffles had total volumes similar to pools. Total pool volume was 2-3 times greater in sandstone than in basalt at similar streamflows in 1988. Total glide volume was similar in both rock types.

Substrate Characteristics. Mean size of dominant substrate in streams in both basalt and sandstone was larger in glides than in pools, and larger in riffles than in glides (Figure 2.11, Appendix 2.12). Substrate in sandstone was smaller than in the same channel units in basalt, especially in pools. The proportion of channel units with bedrock as the dominant substrate type was generally greater in streams in sandstone than in those in basalt (Table 2.9). Streams in sandstone except Franklin Creek had 47-63% of their combined channel units with bedrock as the dominant substrate type, compared to 6-13% in streams in basalt.

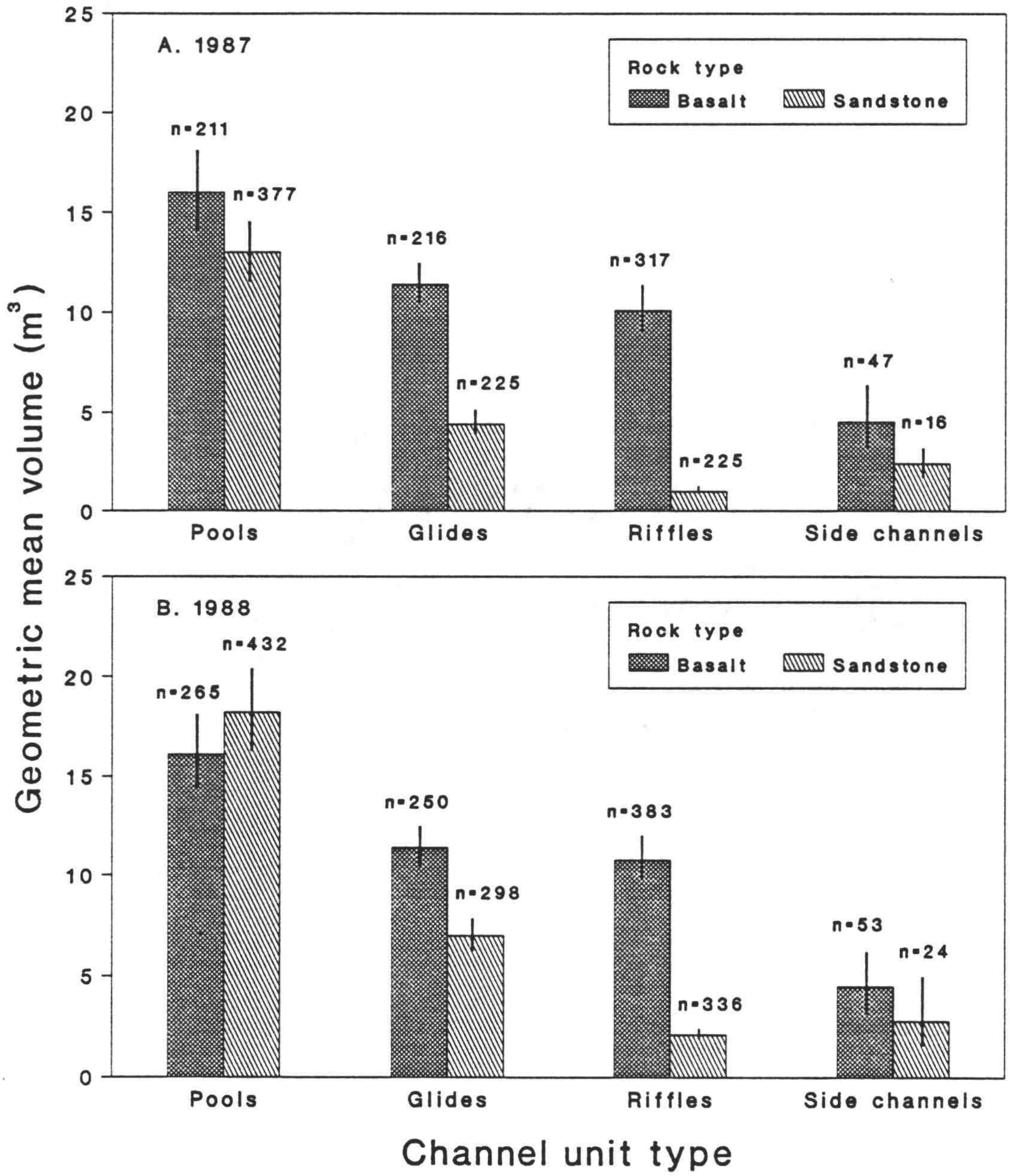

Figure 2.9. Geometric means and 95% confidence intervals of water volume in channel units in Oregon Coast Range streams in basalt and sandstone in summer (A) 1987 and (B) 1988.

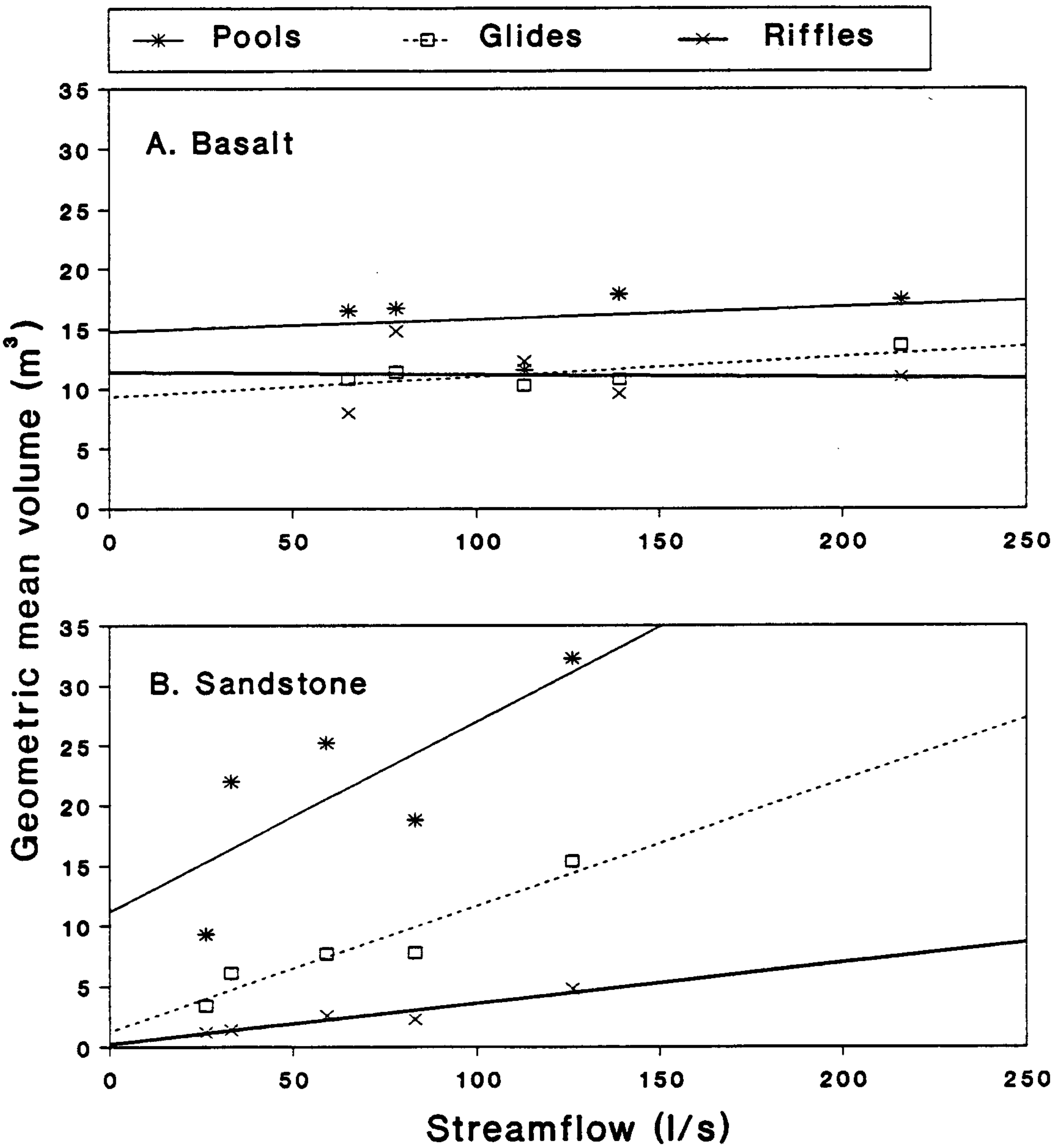

Figure 2.10. Relationship of geometric mean volume of channel units in Oregon Coast Range streams in (A) basalt and (B) sandstone to streamflow in summer 1988. Volume of channel units not measured in 1988.

Table 2.8. Total volume of pools, glides, riffles, and side channels in streams in basalt and sandstone in the Oregon Coast Range in 1987 and 1988[a].

Stream	Total channel unit volume (m^3)											
	1987						1988					
	pools			glides			pools			glides		
	N	volume	95% C.I.[b]	N	volume	95% C.I.	N	volume	95% C.I.	N	volume	95% C.I.
Bob	51	1241	61	50	672	58	51	1241	61	50	672	58
Rock	55	1405	72	54	736	65	55	1405	72	54	736	65
Tenmile	41	664	29	52	645	62	41	664	29	52	645	62
Cape	64	1435	95	60	1000	75	64	1435	95	60	1000	75
N.F. Wilson	-[c]	-	-	-	-	-	54	1424	69	34	467	30
Mean		1186			763			1234			704	
95% C.I.[d]		570			259			407			240	
Franklin	118	1666	224	51	221	60	119	2276	226	69	346	90
Halfway	82	5420	139	56	515	69	82	4817	139	59	784	74
Paradise	85	1758	146	70	634	92	85	2368	146	68	856	89
Big	92	2098	163	48	337	55	87	3038	151	47	482	53
N.F. Beaver	-	-	-	-	-	-	59	3482	83	55	1090	67
Mean		2735			427			3196			711	
95% C.I.		2862			292			1282			370	

Stream	riffles			side channels			riffles			side channels		
	N	volume	95% C.I.[b]	N	volume	95% C.I.	N	volume	95% C.I.	N	volume	95% C.I.
Bob	74	1066	135	13	185	-	74	1066	135	13	185	
Rock	79	1124	147	11	60	-	79	1124	147	11	60	
Tenmile	74	1333	135	8	72	-	74	1333	135	8	72	
Cape	90	1395	174	15	73	-	90	1395	174	15	73	
N.F. Wilson	-	-	-	-	-	-	66	1332	115	6	40	
Mean		1229			98			1250			86	
95% C.I.		253			93			180			71	
Franklin	80	135	150	8	17	-	75	181	138	9	37	
Halfway	50	173	75	4	16	-	50	218	75	5	29	
Paradise	55	108	88	3	12	-	80	307	150	3	19	
Big	40	50	47	1	1	-	62	150	105	1	13	
N.F. Beaver	-	-	-	-	-	-	69	434	123	6	36	
Mean		116			11			258			27	
95% C.I.		82			11			142			13	

[a] dimensions of channel units in Bob, Rock, Tenmile, and Cape Creeks not remeasured in 1988
[b] 95% confidence intervals calculated from equation (4), Hankin and Reeves (1988)
[c] no information
[d] 95% confidence intervals about mean calculated with Student's t (Sokal and Rohlf 1981)

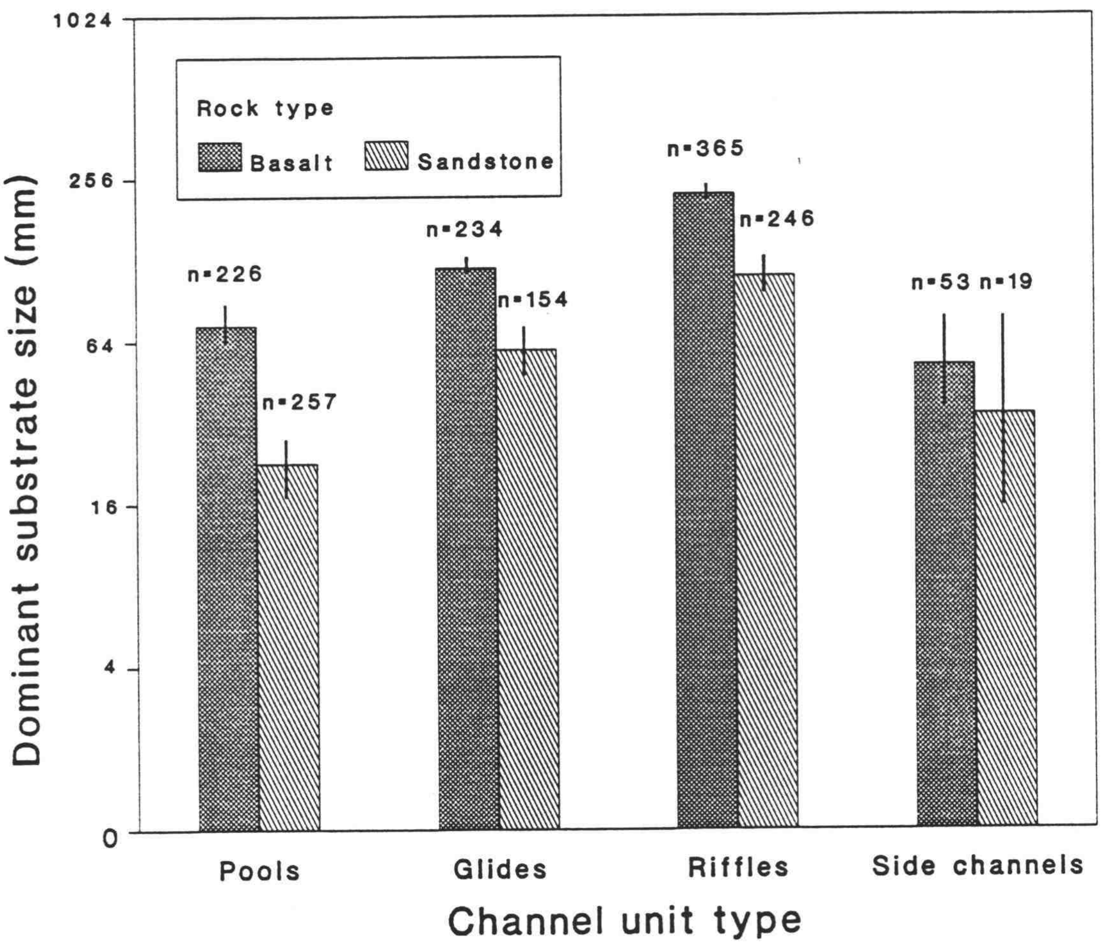

Figure 2.11. Geometric means and 95% confidence intervals of dominant substrate size in pools, glides, riffles, and side channels in ten streams in basalt and sandstone in the Oregon Coast Range. Y axis based on $\log_2$ scale.

Table 2.9. Proportion of channel units with bedrock as the dominant substrate type in streams in basalt and sandstone in the Oregon Coast Range.

Stream	Proportion of channel units with bedrock as dominant substrate (%)			
	pools	glides	riffles	total
Basalt				
Bob	9.8	12.0	5.4	8.6
Rock	10.9	3.7	2.5	5.3
Tenmile	12.2	9.6	0.0	6.0
Cape	15.6	5.0	6.6	9.3
N.F. Wilson	24.1	0.0	10.6	13.0
Mean	14.5	6.1	5.0	8.5
95% C.I.[a]	7.2	5.9	5.0	6.0
Sandstone				
Franklin	5.0	5.9	3.3	4.9
Halfway	54.9	48.2	38.0	48.4
Paradise	62.4	70.0	55.1	62.7
Big	54.8	45.1	31.9	45.5
N.F. Beaver	47.5	49.1	43.5	47.0
Mean	44.9	43.7	34.3	41.0
95% C.I.	28.5	28.9	24.0	27.1
Mean[b]	54.9	53.1	42.1	50.0
95% C.I.	9.7	18.1	15.7	12.6

[a] 95% confidence intervals about means calculated with Student's t (Sokal and Rohlf 1981).
[b] Mean and 95% C.I. of streams in sandstone excluding Franklin Creek.

Stream Channel Morphology and Timber Harvest

Timber harvest affected the number of debris scour pools. There was a trend of decreased frequency of debris scour pools in 1988 with increased extent of timber harvest (Figure 2.12). Amount of timber harvest explained two-thirds of the variablity in density of debris scour pools (r^2=0.63), and the linear relationship was

$$Y = 2.74 - 0.021X \qquad \text{- equation (6)},$$

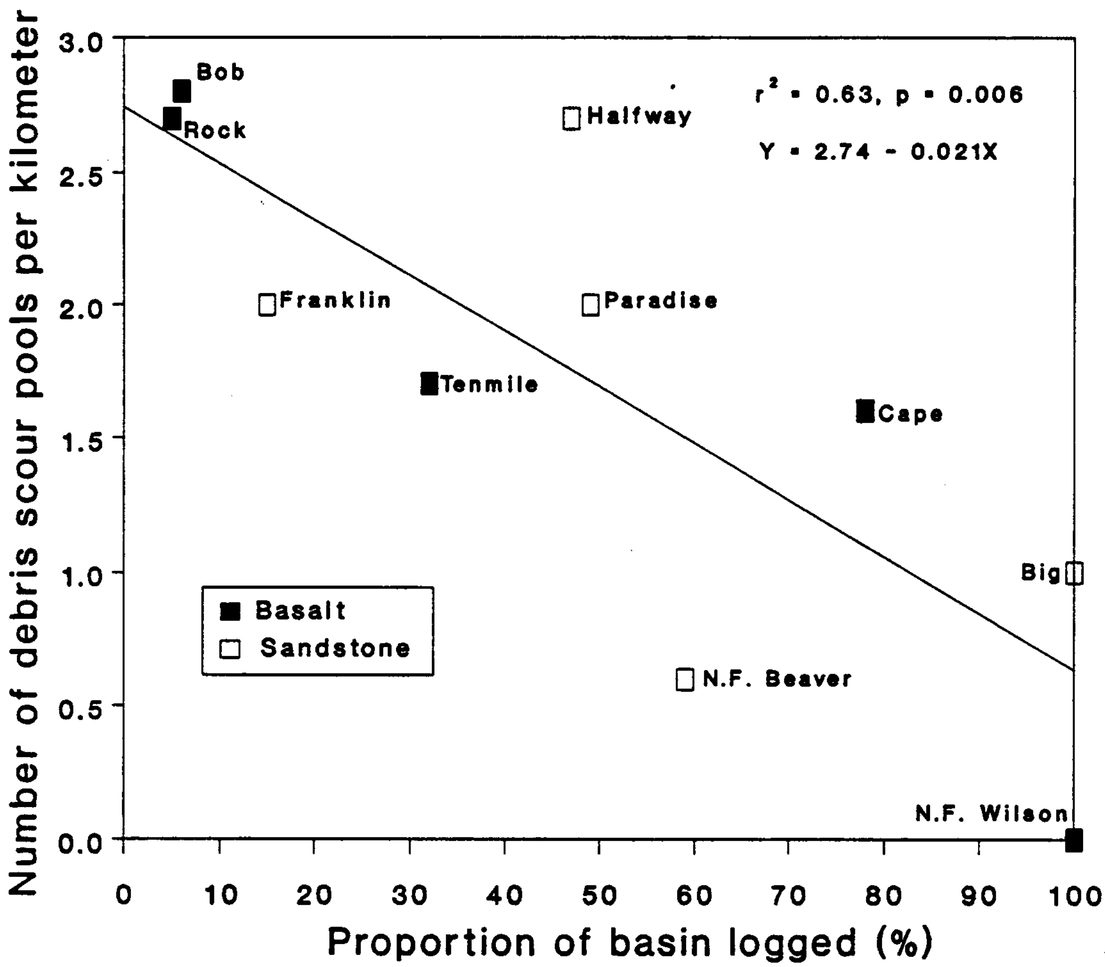

Figure 2.12. Relationship between number of debris scour pools in 1988 and proportion of basin logged in ten Oregon Coast Range streams in basalt and sandstone.

where Y=number of debris scour pools per kilometer, and X=percent of basin area harvested. The density of pools associated with large woody debris was low in all streams, ranging between 0 and 2.8 per kilometer (Table 2.10). By comparison, all pool types combined ranged in density in 1988 from 14 to 41 per kilometer (Table 2.5). Number of debris scour pools per kilometer was not related to volume or number of pieces of large woody debris. Wood was generally ineffectively positioned. Many pieces of wood were lying on the dry, active channel bed, and were parallel to streamflow.

During the course of this study, large woody debris was placed in the channel of Cape Creek by the U.S. Forest Service to enhance salmonid habitat. Wood placed as part of habitat enhancement was not included in Table 2.10.

Table 2.10. Frequency of debris scour pools and large woody debris in ten Oregon Coast Range streams in 1988.

Stream	Density of pools associated with large woody debris (number/km)	Abundance of large woody debris	
		volume (m^3/km)	pieces/km
Basalt			
Bob	2.6	82.1	231
Rock	2.8	64.0	197
Tenmile	1.7	53.1	183
Cape	1.6	195.3	435
N.F. Wilson	0.0	58.6	125
Mean±95% C.I.	1.7±1.3		
Sandstone			
Franklin	2.0	111.3	195
Halfway	2.6	140.0	369
Paradise	2.0	64.6	182
Big	0.6	67.9	182
N.F. Beaver	1.0	45.8	186
Mean±95% C.I.	1.7±1.1		

Shading

Stream shading was caused by deciduous and evergreen vegetation and valley sides, and was generally greater in streams in sandstone than in basalt (Figure 2.13). Shading was not related to timber harvest activities. Among streams in basalt, shading was similar in Bob, Rock, Tenmile, and Cape Creeks (median 85-90%), but was lowest in North Fork Wilson River (median 65%). Among streams in sandstone, shading was similar in Halfway, Paradise, Big, and North Fork Beaver Creeks (median 90-95%), but was lowest in Franklin Creek (median 75%). Mean active channel width for each stream was correlated with median shading estimates of each stream (r^2=0.60, Figure 2.14). Median was a better measure of central tendency than mean because no simple transformation normalized the data. The relationship of mean active channel width in meters (X, calculated with a square root transform) to median percent shading (Y) was

$$Y = 150 - 6.0X \qquad \text{- equation (7).}$$

Dissolved Oxygen

Dissolved oxygen concentrations were well below full saturation by fall 1988 in Big Creek, a watershed in sandstone that was burned and salvage logged. Between 12 and 18 October dissolved oxygen concentrations at the stream bed were 0.7-6.8 g/m^3, or 6-59% of saturation (Appendix 2.13). Concentrations at the water surface (24-74% saturation) were higher than at the stream bed. This difference, combined with differences in temperature between the water surface and stream bed, revealed stratification. Low dissolved oxygen concentrations were accompanied by black-colored water. Black water was also seen in late summer and fall 1987, but oxygen concentrations were not measured then. Dense packs of leaves dropped by red alder were decaying in the stream in late summer and fall.

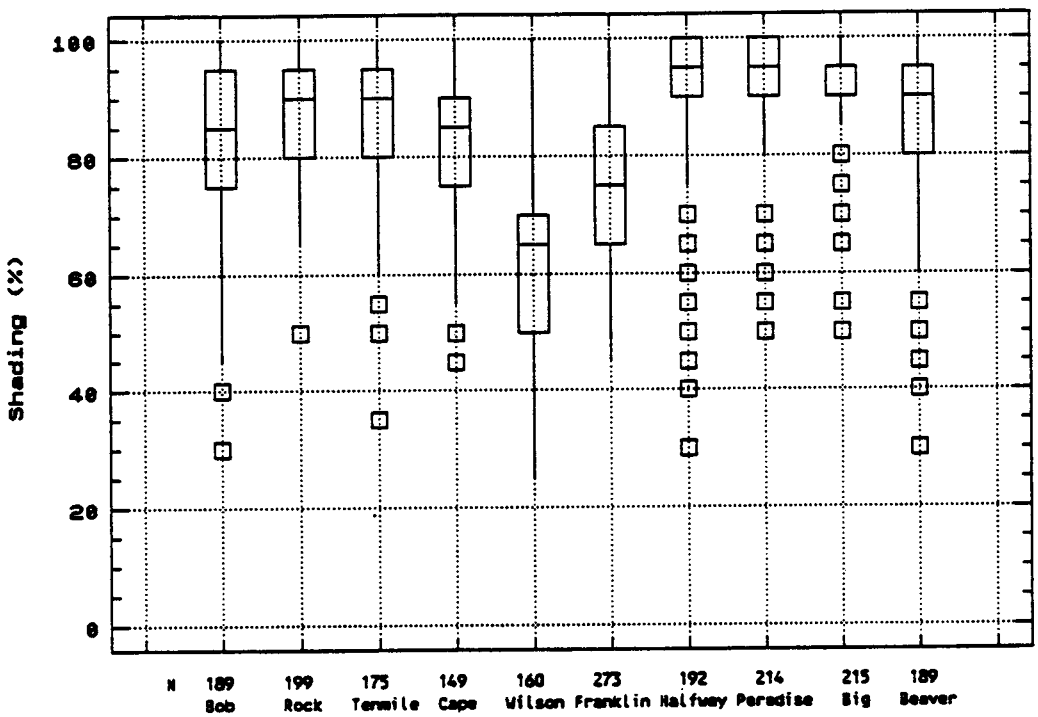

Figure 2.13. Median channel shading of ten Oregon Coast Range streams. Ends of boxes are upper and lower quartiles. Whiskers extend to 1.5 times interquartile range, and data outside this range are plotted as individual points.

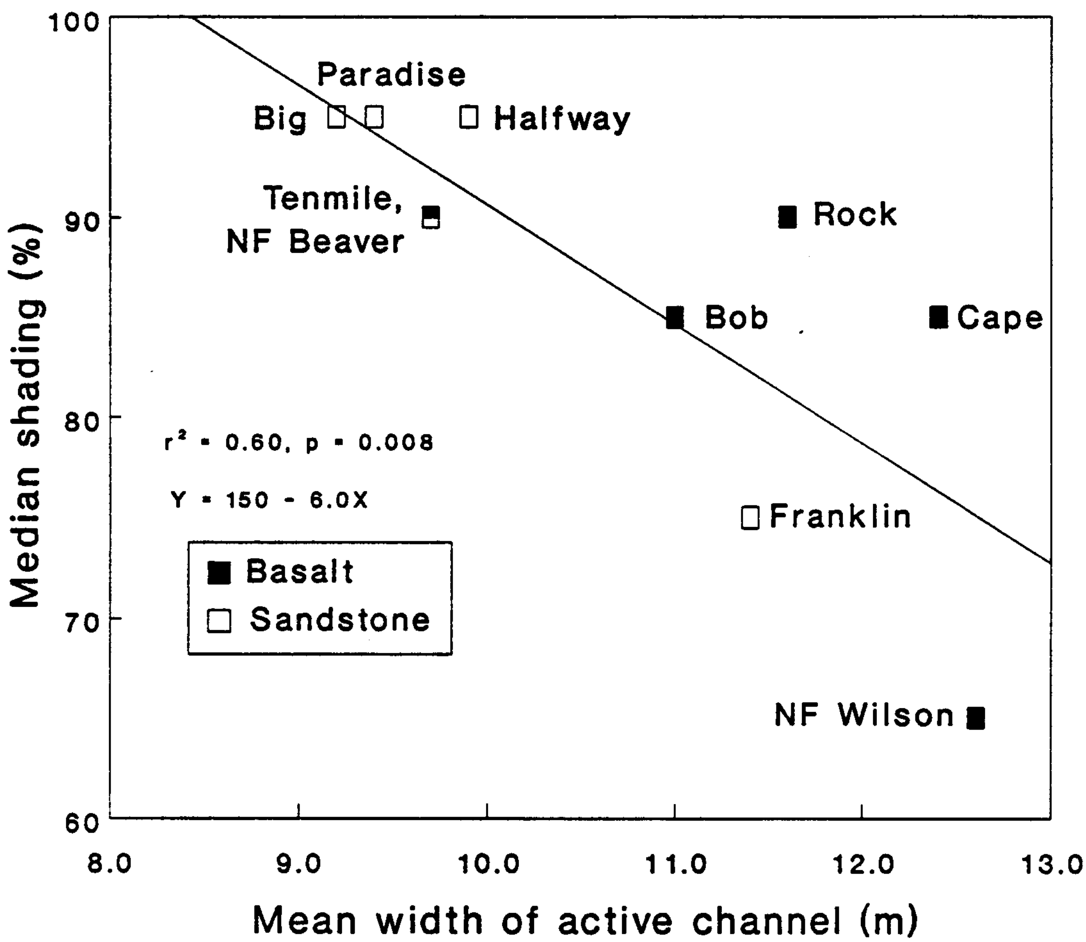

Figure 2.14. Relation of median shading of ten Oregon Coast Range streams to mean width of active channel in basalt and sandstone. Mean active channel width calculated from square-root transformed data.

Franklin Creek, which also had very low streamflow, had higher dissolved oxygen concentrations (61-99% of saturation, Appendix 2.13) than Big Creek. In the absence of dense alder leaves, low dissolved oxygen did not occur. Although there were many leaves in the water in Franklin Creek, they were predominantly from bigleaf and vine maple. Oxygen concentrations measured in streams other than Big and Franklin Creeks between 15 and 31 October 1988 ranged from 7.2-11.6 g/m^3 (67-100% of saturation).

Discussion

Influence of Rock Type and Timber Harvest on Stream Channel Morphology

Channel gradient was steeper in basalt than in sandstone (Table 2.1), which resulted in substantial differences in channel morphology. Channel morphology was related to gradient by the frequency, size, and total volume of the channel units with different slopes (pools, glides, and riffles) present in each stream (Figure 2.6, Table 2.5, Table 2.8). Riffles dominated streams in basalt, and pools dominated streams in sandstone. Comparison of similar-sized basins was of key importance in this analysis. Widely accepted theories of channel formation apply mainly to alluvial channels and involve endogenous factors of channel gradient slope, streamflow, and sediment transport (Richards 1982). Debate continues about the extent to which these endogenous factors control the channel morphology of mountain streams. For instance, pool formation in Jacoby Creek, a gravel-bed stream in northern California of similar size to the streams in this study, was attributed largely to exogenous factors such as large streamside obstructions and bedrock bends (Lisle 1986).

In my study, amount of bedrock outcropping in stream channels varied considerably between rock types. Bedrock was generally the dominant substrate type in streams in sandstone, but was much less common in streams in basalt (Table 2.9). The position of bedrock was also different between the two rock types. In sandstone, bedrock commonly formed the bottom of channel units, whereas in basalt, bedrock was typically a lateral boundary. That pools were not generally associated with large streamside obstructions and bedrock on bends suggests that pool formation was probably a function of hydraulic energy dissipation and sediment transport, and thus largely related to endgenous factors rather than to exogenous factors. Common obstructions in the channels of the study streams were large woody debris and boulders. Frequency of debris scour and boulder scour pools can show the role of exogenous factors in pool formation.

Pools Formed by Large Woody Debris and Boulder Scour. Proportion of basin area logged influenced the number of debris scour pools among streams (Figure 2.12). The relation of debris scour pools to timber harvest, however, was not well shown by number of pieces or volume of large woody debris (Table 2.10). Size of debris was the likely cause of the poor relationship between debris scour pools and wood abundance. Small pieces of cut wood that result from timber harvest activities are less effective than larger uncut pieces in influencing channel morphology; logged streams have smaller pieces (Hogan 1986; Bilby and Ward in press). Short pieces of wood tend to lie parallel to streamflow, and hence are less effective in formation of debris scour pools (Hogan 1986). In Halfway Creek, for instance, though debris volume was high (140 m^3/km) compared to other study streams (Table 2.10), piece size was small, and many logs had cut ends.

The influence of large woody debris on stream channel morphology in my study was generally less than was anticipated on the basis of some previous studies (for example, Keller and Tally 1979, Swanson and Lienkaemper 1978). Density of debris scour pools was low (up to 2.8/km). Even in largely unlogged basins, debris scour pools were only between 5% and 16% of all pools. Removal of large trees from the riparian zone of the surveyed segments in unlogged basins probably did not occur because of the difficulty of access. Thus timber harvest is unlikely to account for the limited influence of debris on pool formation in unlogged basins.

Influence of large woody debris on channel morphology can decrease with increasing stream width (Swanson et al. 1982; Harmon et al. 1986; Lienkaemper and Swanson 1987; Bilby and Ward in press). Frequency of log steps has been related to stream order in central Oregon Coast Range streams of first- through fifth-order (Marston 1982). In Marston's study, third-order streams had the highest density of log steps (4 log steps/km), and fifth-order streams had 0.2 log steps/km. While log steps are not necessarily the same as debris scour pools, the relation of frequency of log steps to stream order shows that the streams in my study may be too wide compared to debris length for large woody debris to have a substantial influence on pool formation.

Large woody debris was more influential in pool formation in a 650 ha sub-basin of Big Creek (Lincoln County) in the Oregon Coast Range (Andrus et al. 1988). Bankfull channel width ranged from 2.5 to 7.8 m. Volume of large woody debris decreased with increasing channel width, but the number of pools formed primarily by wood increased from 8 to 43 pools/km as channel width increased from 5.5 to 7.8 m. Total volume of wood was 181-644 m^3/km (Andrus et al. 1988), considerably greater than that estimated in my study (46-195 m^3, Table 2.10). Wood volumes in other Oregon Coast Range streams range up to about 200 m^3/km, assuming a channel width of 10 m (Heimann, unpublished data, in Andrus et al. 1988). Thus wood volumes and influence of wood in pool formation were low in my study streams compared to other Oregon Coast Range streams.

Stream width and debris length are not the only factors that control volume and influence of large woody debris. Fires have occurred widely in the Oregon Coast Range, and are likely to have reduced the volume of wood in streams. Historical accounts of the locations of fires from 1849 to 1868 suggest that fire destroyed forests in the Beaver, Bob, Rock, Tenmile, Cape, and Franklin Creek basins (Juday 1977).

Pools were also formed by scour of gravel around boulders. Boulder scour pools were important in Franklin Creek, where there were 10.6 such pools per kilometer, or 26% of all pool types (Chapter 4). Excavation of the streambed around the boulders probably forms boulder scour pools. Franklin Creek was the only stream in this survey with gravel and medium to large boulders, and consequently boulder scour pools were common there. The source of boulders was probably fractured, vertical canyon walls that formed the active channel margin in places. Canyon walls of this type were rare in other streams. Boulder scour pools were absent or very nearly so from other streams (Chapter 4).

Pool formation in these streams was, therefore, only partly attributable to exogenous factors such as bedrock obstructions and large woody debris, and boulders. Endogenous factors related to sediment transport probably exerted greater control of channel morphology than exogenous factors. The close relationship of the length of channel in pools, glides, and riffles with channel gradient is consistent with endogenous control (Figure 2.6).

Channel Complexity. Channels in basalt were generally more complex than those in sandstone. Streams in sandstone commonly had planar bedrock outcropping in the wetted channel. Streams in basalt had larger size of dominant substrate, and thus more channel roughness, than did streams in sandstone. Lower flows and fewer side channels in streams in sandstone compared to those in basalt also contributed to less channel complexity in sandstone. However, Franklin Creek, a stream in sandstone with little timber harvest, had a very complex channel structure, with 2-3 times as many side channels as other streams in sandstone. Lack of timber harvest may not be the sole reason for channel complexity in Franklin Creek. There is evidence of fault activity in the vicinity of Franklin Creek (Beaulieu and Hughes 1975). About 150 m upstream from the start of the segment surveyed in this study there is a narrow canyon with steep side walls and a jumble of very large, angular boulders in the channel that may be the result of fault activity. Despite its complex channel, low surface streamflows in Franklin Creek at the end of summer reduced the stream volume substantially. Side channels were not important fish habitats as they were shallow when surveyed in early summer (0.10 to 0.13 m mean depth, Appendix 2.10), and usually dried as flows reduced.

Influence of Geology and Timber Harvest on Streamflows

Streamflows in Oregon Coast Range streams were related to precipitation and rock type. Streams in basalt had higher summer flows, and may be less sensitive to changes in summer water yield following timber harvest than streams in sandstone (Appendix 2.7). Higher ground water yields from basalt than from adjacent sandstone and siltstone formations have been identified from wells in the central Oregon Coast Range (Frank and Laenan 1977). Higher groundwater yields from basalt were attributed to greater permeability of basalt than sandstone. Frank and Laenan (1977) found that Siletz River Volcanics, with base streamflows of 5-8 $l/s/km^2$, had 4-10 times more base flow than adjacent Tyee Formation sandstones with base streamflows of 0.5-2 $l/s/km^2$. Base streamflows in my study between 12 and 31 October 1988 were 3.8-8.2 $l/s/km^2$ in basalt, and 0.13-3.3 $l/s/km^2$ in sandstone (Appendix 2.7). Active channels were generally wider in basalt than in sandstone (Table 2.6), suggesting that mean annual flows too were greater in streams in basalt (Riggs 1978, Orsborn and Stypula 1987).

Summer flow in streams between 35 and 55 km from the coast in sandstone that flowed principally on bedrock was inversely related to proportion of the basin logged or burned, suggesting that a long term effect of timber harvest is reduced summer streamflow. Halfway, Paradise, and Big Creeks had flows of 1.2, 0.56, and 0.13 $l/s/km^2$ (Appendix 2.7), and their basins were 47, 59, and 100% logged or burned respectively. Despite a strong gradient of decreasing annual precipitation with increasing distance from the coast (Table 2.2), Big Creek had lower summer streamflow than Halfway or Paradise Creeks, which were further from the coast.

Reduced summer streamflows as a long-term result of timber harvest was also found in a study of paired watersheds in the Oregon Cascades (Harr 1983, Hicks et al. MS). Streamflows in August were on average 77% greater during 8 years following the start of logging in 1962 than before logging. However, from 9-19 years after the start of logging (up to 1988) flows were on average 47% less than before logging (Hicks et al. MS). The climate of the Pacific Coast of North America is characterized by low rainfall in summer, and as a result summer streamflows are low (Everest et al. 1987). In view of naturally low summer streamflows, timber harvest may critically reduce summer stream habitat for salmonids in sandstone. Streamflow is of key importance in determining the volume of water in different channel unit types. Volume of glides and riffles in streams in sandstone was especially sensitive to diminishing streamflows (Figure 2.10B). As flows reduced during prolonged periods without rain, the volume of glides and riffles decreased much more than the volume of pools.

Extreme low streamflows in summer, in combination with red alder leaf drop, can also lead to oxygen depletion. Red alder is high in nitrogen, and decomposes more rapidly than bigleaf maple (Triska et al. 1982). Low dissolved oxygen also has been reported in streams in sandstone in Indiana at the end of summer (Slack 1955). Further work is needed to determine the extent and frequency of low oxygen conditions in Oregon Coast Range streams, and the effect on salmonids. Reduction of streamflows brought about by the long-term effects of timber harvest could increase the frequency of oxygen depletion.

Shading

Positive, short-term response of salmonid productivity to increases in light and temperature associated with timber harvest is convincing evidence of the influence of shading (Murphy and Hall 1981; Hawkins et al. 1983; Bilby and Bisson 1987). Canopy opening has been widely shown to increase production of age 0 salmonids. However, salmonid production may fall to below that found in streams in undisturbed forest as shading increases following regrowth of vegetation, and may remain low for many years (Gregory et al. 1987).

Shading was not related to amount of timber harvest in my study. Even where timber had been removed from riparian zones by logging or fire, the size of alders suggested that riparian zone vegetation had generally been undisturbed for 15 years or more. Shading was, however, inversely related to active channel width (Figure 2.14). This relationship seems to hold for a range of timber harvest conditions in the two rock types, basalt and sandstone, that are widespread in the Oregon Coast Range. Streams in this study with alder-dominated riparian zones had the highest shading (Figure 2.13). Predominance of red alder in the riparian zone causes intense shading because of its dense, broadleaf foliage and high density of trees in the riparian zone. Median active channel width had a strong influence on shading. Active channel width can be related to percent available energy for April to September by combining equations (1) and (7) (above) to yield

$$Y = 5.3X - 41.5 \quad \text{- equation (8)},$$

where Y=percent available energy for April to September, and X=median active channel width in meters. Equation (8) predicts that a 12-m wide active channel would allow 22% of the solar energy available between April and September to reach a stream, whereas a 9 m-wide active channel would allow just 6% of energy to reach a stream.

My study has shown that rock type strongly influences channel gradient. I suggest that channel gradient, measured from topographic maps, can be used to predict differences in channel morphology in basins of similar area. Timber harvest was shown to influence channel morphology through the number of debris scour pools. However, large woody debris did not affect the channel morphology of an appreciable proportion of channel length. Streamflow controls the volume of channel units in streams in sandstone, and to a lesser extent in streams in basalt. I have some evidence suggesting that summer low flows in Oregon Coast Range streams further than about 20 km from the coast in sandstone are inversely related to the proportion of basin area logged. I strongly recommend streamflows should be measured when stream channels are surveyed for habitat availability.

Steeper channel gradients in streams of comparable size in basalt than in sandstone, combined with lower base flows in sandstone, have implications for habitat suitability for salmonids. Steelhead and trout generally use riffles more than pools, and coho salmon use pools more than riffles (Hartman 1965, Allee 1974). In streams in the Oregon Coast Range of 1500 ha basin area or less, the dominance of riffles in basalt suggests greater suitability for steelhead and trout than for coho salmon; the dominance of pools in sandstone suggests greater suitability for coho salmon than for steelhead and trout.

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Chapter 3. Relationship of Salmonid Populations to Channel Morphology and Timber Harvest in Oregon Coast Range Streams in Basalt and Sandstone Bedrock

Abstract

I related abundance of salmonids to channel morphology in ten Oregon Coast Range streams of about 1500 ha drainage area in two rock types. Streams in basalt had channel gradients, measured from topographic maps as fall in elevation, of between 2.1 and 3.2%, and were dominated by steelhead, resident rainbow trout, and cutthroat trout. In contrast, streams with the same basin area in sandstone had channel gradients between 0.9 and 1.8%, and were dominated by coho salmon. Age 0 coho salmon occupied pools more than glides or riffles in streams in basalt, whereas coho salmon used pools and glides equally in sandstone. Age 0 trout showed no preference for any habitat in streams in basalt, but used glides and riffles more than pools in sandstone.

Mean density of salmonids in streams in sandstone in 1987 (3.82 fish per lineal meter) was greater than that in basalt (1.75 fish/m). However, biomass estimates in 1987 in basalt (17.9 g/m) and in sandstone (16.3 g/m) were similar because fish in streams in basalt were larger. Biomass in 1988 in streams in basalt (21.5 g/m) and sandstone (11.4 g/m) were similar to estimates from 1987. Salmonids of the same species and age class were larger in streams in basalt than in sandstone, and there were more age 1 and older steelhead, resident rainbow trout, and cutthroat trout in streams in basalt (0.50 fish/m) than in sandstone (0.16 fish/m) in 1987, and in 1988 (0.62 compared to 0.15 fish/m). Apparent survival of age 0 trout from summer 1987 to summer 1988 decreased with decreasing summer low flows in streams in sandstone, and these flows were inversely related to amount of timber harvest.

Introduction

The response of salmonids to timber harvest on the Pacific coast of North America has been varied, and few factors have so far explained this variability. Short-term increases in light and temperature following removal of riparian vegetation can increase salmonid production, though accompanying loss of channel structure has contributed to lower over-winter survival and reduction of age class and species diversity (Hicks et al. in press). Rock type is one factor that exerts a powerful influence on channel morphology (Hack 1957; Keller and Tally 1979; Chapter 2), and to some extent on summer streamflow (Chapter 2).

Streams in resistant rock types such as granite and basalt tend to have steeper gradients than streams in the same sized basins in more friable rock types such as sandstone and mudstones (Hack 1957, 1973; Chapter 2). Channel morphology adjusts to these different gradients in the proportions of pools, glides, and riffles present. Streams of 600 to 1500 ha basin area in sandstone tend to be dominated by pool habitat, whereas streams of the same size in basalt tend to be more dominated by riffle habitat (Chapter 2).

Salmonid species have preferences for different habitat types at different life history stages. These preferences, combined with different emergence times, allow the same age classes of different species to coexist in the same stream reach (Hartman 1965; Everest and Chapman 1972; Bisson et al. 1988). The mechanism for coexistence is segregation of species and sizes of salmonids into different habitat types, such as pools and riffles. Thus it may be hypothesized that substantial differences in channel morphology caused by different rock types or by timber harvest could control the distribution and abundance of stream-dwelling salmonids.

The Oregon Coast Range is an ideal study area in which to test this hypothesis, because it combines a variety of rock types, of which sandstone and basalt are the most widespread. Timber harvest is a pervasive land use in the Oregon Coast Range, and the area provides a good opportunity to study the response of salmonid species to logging in different rock types. The objective of this study was to determine the association of abundance of salmonids with channel morphology and logging in streams in basalt and sandstone.

Study Design

In 1987 eight streams of 1500 ha basin area each in the central Oregon Coast Range were studied (Figure 3.1). Four were in basalt, and four were in sandstone, and between 5 and 100% of the area of original forest in the study basins had been removed by timber harvest or recent fire (Table 3.1). Bob, Rock, Tenmile, and Cape Creeks were in the basalt headlands of the Cape Perpetua region, and Franklin, Halfway, Paradise, and Big Creeks were tributaries of the Smith and lower Umpqua Rivers in Tyee Formation sandstone near Elkton. In 1988 the same streams were studied. Because of the inland location of the grouped streams in sandstone compared to the coastal location of the streams in basalt, two further streams were added. North Fork Beaver Creek, a coastal stream in sandstone, is in the central Oregon Coast Range, and North Fork Wilson River, an inland stream in basalt, is in the north of the Oregon Coast Range (Figure 3.1).

Coho salmon (*Oncorhynchus kisutch*), steelhead and resident rainbow trout (*O. mykiss*), and cutthroat trout (*O. clarki*) were present in the study streams. Chinook salmon (*O. tshawytscha*), widespread in streams of the Oregon Coast Range, have been reported in Beaver Creek and tributaries of the Wilson and Umpqua Rivers (State Water Resources Board 1960; Lauman et al. 1972; Nicholas and Hankin 1988). Several races of some salmonid species are present in Oregon Coast Range streams. The winter-run race of steelhead use all the study streams. Summer-run steelhead are released into the Wilson River, and some of these adults are likely to use the North Fork Wilson River for spawning and rearing. The Umpqua River system has a natural population of summer-run steelhead, but these have not been reported to use my study streams in this basin (Lauman et al. 1972).

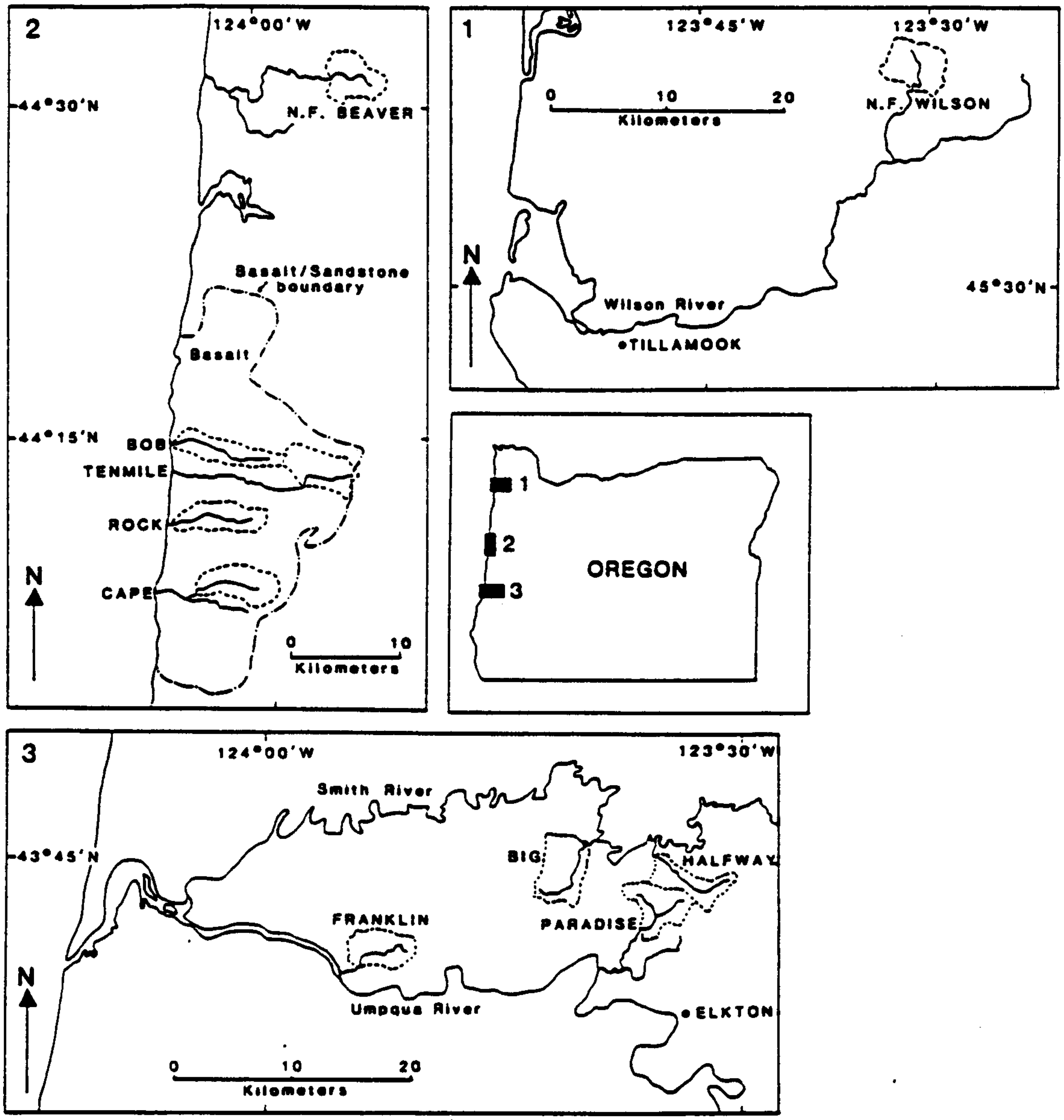

Figure 3.1. Location of study sites in the Oregon Coast Range.

Table 3.1. Physical attributes of study sites in ten Oregon Coast Range streams.

Rock type	Stream name	Basin area (ha) start of survey	Basin area (ha) gauge point	Length surveyed (m)	Timber harvest (% of basin upstream of gauge point)	Dates of timber harvest	Height above sea level[a] (m) down-stream	Height above sea level[a] (m) up-stream	Channel slope (%)
Basalt	Bob	1613	1613	2834	5	1950-1960	4	67	2.1
	Rock	1559	1559	2805	6[d]	1930-1962	21	82	2.4
	Tenmile	1705	1705	3059	32	1959-1986	150	251	3.2
	Cape	1670	1670	3242	78	1946-1986	41	107	2.1
	N.F. Wilson	1839	1407	2808	100	1933-1951[b]	335	415	3.0
Mean±95% confidence interval									2.5±0.6
Sandstone	Franklin	1448	1448	2580	15	1963-1972	27	73	1.8
	Halfway	1914	1514	3327	47	1950-1988	159	191	1.0
	N.F. Beaver	1571	1523	2587	49	1957-1987	43	70	1.0
	Paradise	2011	1617	2710	59	1950-1988	62	105	1.5
	Big	1614	1570	2669	100	1951-1966[c]	142	165	0.9
Mean±95% confidence interval									1.2±0.5

[a] interpolated from nearest contour intervals
[b] burned in Tillamook Burn in successive wildfires, and then salvage logged (Oregon State Forestry Department 1980, in McCullough (1987), p53)
[c] burned in successive wildfires, and then salvage logged
[d] unknown but limited amount of timber harvest occurred in riparian zone before Forest Service ownership

Chinook salmon have fall-run and spring-run races in the Oregon Coast Range. Beaver Creek supports a population of chinook salmon, presumably the fall-run race because it is the most widespread (Nicholas and Hankin 1988). In the Umpqua River system, spring-run chinook salmon use the upper part of the basin, and fall-run fish use the lower part. No chinook salmon have been recorded to use my study streams in the Umpqua River basin (Lauman et al. 1972). Chinook salmon spawning has been reported in the North Fork Wilson River (State Water Resources Board 1960).

Methods

Streams were subdivided into channel units longer than one water surface width. Channel units were classified as pools, glides, or riffles on the basis of water surface slope and depth; these channel units types became strata that were systematically sampled. Each channel unit was identified in sequence, working from the downstream to the upstream ends of the survey segment. Variables of channel morphology such as length, width, and depth of channel units were assessed by methods previously described (Chapter 2). Dominant substrate size and amount of large woody debris were also assessed. Habitat complexity of each channel unit was assessed as four components on a subjective and relative scale of 0-5, where 0 indicates no complexity and 5 indicates considerable complexity. The influence of large woody debris was identified as a low flow component (i.e., in the water at summer low flows), and a high flow component (i.e., on the dry active channel where it might provide winter cover for fish at high flows). A further component was substrate complexity, rated 0-5 on the basis of the fish cover it might provide. Last, edge and bank complexity was rated 0-5. Large substrate particle size with abundant crevice space was rated highly for substrate complexity; smooth bedrock and sand and silt was rated low. Deeply undercut banks with tree roots protruding into the water and crenulated plan-view water profiles were rated highly for edge complexity, and gently-shelving, straight-edged shorelines were rated low. Habitat complexity ratings were combined by summing to produce an overall rating.

Salmonid abundance was estimated by diving in a systematic subsample of channel units in 3 km of main channel of each stream. Fish were counted in every fifth pool, fifth glide, and tenth riffle. The number of channel units of different types sampled in each stream was variable because of variation in the number of channel units among stream types (Appendix 3.1). The proportion of channel units in which fish were counted ranged between 13 and 17% of the total. The total length of different types of channel units in a stream segment varied among streams as a function of underlying rock type (Appendix 3.2, among streams as a function of underlying rock type (Appendix 3.2, Chapter 2). Pools were the predominant channel unit type in streams in sandstone, and riffles were predominant in streams in basalt. Length of stream in which fish were counted ranged between 356 and 727 m, or 12 to 22% of the total.

On commencing a fish count, I cautiously approached the channel unit to be dived from the downstream end, and carefully slipped into the water, face mask first, to cause least disturbance to fish before observation. I used a flashlight to search for fish hiding under boulders, rock ledges, woody debris, and other obstructions. One diver was sufficient to count fish in a channel unit, though a few long riffles in streams in basalt, and glides in streams in sandstone, were subsampled to reduce the time taken for diving. In these instances at least 20% of the channel unit length was dived, and the total number of fish was estimated by extrapolating the observed density of fish in the subsample to the whole unit.

Fish were grouped into species and age classes according to size and color pattern. Fish <10 cm fork length (FL) were considered to be age 0, and fish >10 cm were considered to be age 1 or older. Fish of about 10 cm FL were classified as age 0 or 1 on the basis of their color patterns. Parr marks were usually pronounced on trout and steelhead <10 cm FL, but were faint or absent from larger fish. Fish >10 cm FL, especially cutthroat trout, were more heavily spotted than smaller fish, and often had a broad horizontal pink to red band on their sides. The species identity of age 0 steelhead, resident rainbow trout, and cutthroat trout could not be readily distinguished underwater, and so these species were not separated during dive counts. It was possible to distinguish age 1 and older steelhead and resident rainbow trout from cutthroat trout, but age 1 and older resident rainbow trout could not be distinguished from steelhead. Few age 1 coho salmon could be distinguished from age 0. Length-frequencies of fish caught by electroshocking indicated few if any age 1 coho salmon were present in these streams.

Time of Surveys

Fish populations were surveyed between 11 July and 24 September 1987, between 18 and 29 November 1987, and between 15 August and 20 September 1988 (Appendix 3.3). High flows curtailed diving in November 1987 after only five of eight study streams had been dived, and low water temperatures (5.5-10.0°C) made population estimates suspect in those streams that were dived, so fall diving was not repeated in 1988. Low water temperatures in fall affected fish behavior, causing fish to seek crevice cover and making them much more difficult to see than in summer.

Estimated streamflows varied considerably during the dive surveys in summer 1987, in part because surveys were spread over a 70-day period, and in part because of geologic and climatic differences between streams (Table 3.2). Streamflows measured at the time of dive surveys were less variable in 1988 because of the shorter period (37 days) in which surveys were conducted.

Comparison of Dive Counts to Electroshocking Population Estimates

Forty-four channel units were selected in Bob, Cape, Franklin, and Paradise Creeks and in North Fork Wilson River in which to make comparisons between diving and electroshocking population estimates. Eighteen pools, 14 glides, and 12 riffles were surveyed between 16 August and 20 September 1988 (Appendix 3.3). Block nets of 5-mm stretched-mesh multifilament polyester were positioned at the upstream and downstream ends of the channel unit to be surveyed, and any gaps between the net and the stream bed were sealed with gravel and cobbles. A period of at least 30 minutes elapsed between setting the nets and diving to allow the water to clear and the fish to resume normal behavior. I used the procedure outlined above to count fish, and then the fish from the same channel unit were caught with a portable back-pack electroshocker in the hands of experienced personnel.

Table 3.2. Streamflows in ten Oregon Coast Range streams at the time of diving surveys in summer 1987 and 1988.

Rock type	Stream	Streamflow (l/s)		Date		K_r[a]
		1987	1988	1987	1988	
	Bob	64[b]	59	14-15 Sep	30 Aug	0.981
	Rock	101-237[b]	115	4 Aug, 21 Sep	14 Sep	0.982
Basalt	Tenmile	110[b]	83	24 Sep	12 Sep	0.980
	Cape	216-274[b]	135	11, 16, 28-30 Jul	6-8 Sep	0.987
	NF Wilson	-[c]	78	-	5, 16 Sep	0.994
	Franklin	2-26[d]	26	15-24 Jul, 11 Aug, 9 Sep	15-17 Aug	0.936
	Halfway	25[d]	59	24, 28 Aug	29 Aug	0.976
Sandstone	Paradise	15[d]	83	27 Aug	24-25 Aug	0.982
	Big	1[d]	33	14-24 Aug	22 Aug	0.936
	NF Beaver	-	126	-	31 Aug	0.991

[a] recession constants (Linsley et al. 1982, equation (7-1), p207) calculated from streamflows between 14 July and 22 September 1988
[b] back-calculated from streamflows of 4 October, 1987, and 1988 flow recession (Linsley et al. 1982, equation (7-2), p207)
[c] not surveyed
[d] estimated from streamflows at similar times in 1988

The electroshocker operator and two or more catchers with dip nets and buckets made a pass, fishing in an upstream direction between the block nets. The downstream block net was then fished for salmonids immobilized or attempting to escape downstream. Three passes were made in this fashion in an upstream direction only, and equal effort was used in each pass. The number of fish from each pass was recorded separately to enable population estimates to be made by the removal method (Zippin 1958; White et al. 1982). The underlying model is a maximum likelihood estimator essentially equivalent to that given by Zippin (1958). This model allows for behavioral response to capture (model M_b, White et al. 1982).

Data from diving fish counts and electroshocking population estimates from the same channel unit were used to estimate a correction factor ($\hat{R}$, equation (5), Hankin and Reeves (1988)). These correction factors were used to make population estimates from diving counts for other channel units. Calculated $\hat{R}$ values (i.e., sum of population estimates divided by sum of dive counts) ranged between 1.2 and 4.3 (Table 3.3).

Table 3.3. Comparison of dive counts and population estimates for salmonids in pools, glides, and riffles in five Oregon Coast Range streams.

Channel unit	Species and age age class	Dive count (a)	Population estimate (b)	N[a]	$\hat{R}$[b] (b/a)
pools	0 trout	275	333	13	1.21
	1 steelhead[c]	36	70	15	1.94
	1 cutthroat[d]	11	21	10	1.91
	0 coho	108	134	7	1.24
glides	0 trout	117	175	9	1.50
	1 steelhead	4	8	6	2.00
	1 cutthroat	0	1	1	-
	0 coho	7	19	4	2.71
riffles	0 trout	49	76	9	1.55
	1 steelhead	4	17	5	4.25
	1 cutthroat	0	0	0	-
	0 coho	7	1	1	-

[a] number of channel units with valid population estimates and dive counts

[b] $\hat{R}$ as defined in equation (5), Hankin and Reeves (1988), p836.

[c] includes age 1 and older steelhead and resident rainbow trout.

[d] includes age 1 and older cutthroat trout.

Failed comparisons were excluded from the derivation of $\hat{R}$. The comparison of dive count to population estimate was considered to have failed if: (1) the population estimate failed, for example, the number captured in one pass was less than the number captured in a previous pass; (2) the population estimate was zero; or (3) the ratio of the 95% confidence interval to the population estimate exceeded X, where X declined as follows:

population estimate	X
1	1.00
2-4	0.50
5-9	0.33
10-40	0.26
41-137	0.20.

Reduction of X as the population estimates increased was a compromise between using only the most accurate population estimates and keeping the number of comparisons as large as possible. No channel units were used in the calculation of $\hat{R}$ values in which fish numbers were estimated by extrapolating from a subsection.

In some instances, too few channel units of a particular type were found to contain fish of a particular species or age class to estimate $\hat{R}$. Thus estimates of $\hat{R}$ for age 1 and older steelhead and resident rainbow trout in glides and riffles (2.0 and 4.3 respectively) were used to estimate numbers of age 1 and older cutthroat trout in these habitats, and the estimate of $\hat{R}$ for coho salmon in glides (2.7) was used for coho salmon in riffles. The correction factor $\hat{R}$ was not assessed independently for each stream in which dive counts were made. Because of this, and because of the small number of channel units in which valid comparisons of dive count and population estimate were made, estimates of $\hat{R}$ for each channel unit type were pooled across streams.

Estimates of total population and variance were made from dive counts of fish per channel unit with the estimators described in Hankin and Reeves (1988) for two-stage systematic sampling. Use of an auxiliary variable, for example, channel unit length, to improve the precision of the population estimate was investigated. This technique, known as ratio estimation, uses fish density (e.g., fish per lineal meter) multiplied by length of each channel unit to estimate total fish population. Correlations (r) between fish numbers and length, area, and volume of channel units were calculated to test the basis for using ratio estimation. Hankin (1986, p24) suggested that r should $\geq$0.5. Some correlations $\geq$0.5 were found, particularly between the number of age 0 steelhead and trout and length of riffles, and between the number of age 1 and older steelhead, resident rainbow, and cutthroat trout and pool volume. Because of these r values, and because channel unit sizes had a range >4-fold, the ratio estimation technique described by Hankin (1986, p28) was used to calculate population estimates and variances from dive counts in riffles in streams in basalt. Population size was estimated from counts of fish per channel unit rather than from fish per meter for pools and glides in basalt, and for all channel units in sandstone.

There was no difference (Student's t-test, equation 9.2, p226, Sokal and Rohlf 1981, $0.2 \geq p \leq 0.4$) in the geometric mean length of riffles in basalt streams between the subsample that was dived (mean=16.0, n=49) and the total number present (mean=13.3, n=399, Appendix 2.8). The number of riffles dived in each stream was less than 12 (6-8, Appendix 3.1), which can result in a negative bias in the estimation of variance (Hankin 1986, p28). However, the strong correlations of numbers of age 0 trout steelhead and age 1 and older resident rainbow trout, cutthroat trout, and steelhead with riffle length (r=0.81 to 0.92), combined with the magnitude of the range of riffle lengths (1.0-91.2 m), were considered to justify the use of ratio estimation. No channel units in which fish numbers were estimated by extrapolating from a subsection were used in the calculation of r values.

Species and age class diversity was calculated from the Shannon-Wiener equation:

$$H' = -\mathrm{Sum}_{i}(p_i \ln p_i),$$

where H'=species and age class diversity, and p_i=abundance of the ith species as a proportion of total number of all animals present (Emlen 1984, p181). There were four possible groups of species and age classes: (1) age 0 steelhead and trout, (2) age 0 coho salmon, (3) age 1 and older steelhead and resident rainbow trout, and (4) age 1 and older cutthroat trout.

Habitat use (preference) was estimated with the following calculation

$$U = \frac{\text{habitat specific density}}{\text{average total density}}$$

for each species and age class. This expression was adapted from a habitat utilization index used by Bisson et al. (1982). The index of Bisson et al. (1982) is derived from habitat specific density minus average total density, and ranges from -1 to large positive values. As used in my study, U ranges from 0, indicating absence of species and age class from a habitat (avoidance), through 1, indicating abundance equal to the average density, to large positive values, indicating concentration a of species or age class in a habitat (preference). Although U is not evenly distributed about 1, it has the advantage that it directly represents habitat utilization as a proportion of average density. Salmonid densities from summer 1987 and 1988 were combined in this analysis. Habitat utilization indices (U) from each habitat and year were averaged to obtain a mean value for each habitat.

Overlap of 95% confidence limits about the mean was used to test significance of differences between means unless otherwise stated. Confidence intervals were calculated by multiplying standard errors by $t_{0.05[n-1]}$, where n=sample size (Sokal and Rohlf 1981, p109). Mann-Whitney *U* tests were used for small sample sizes of unknown distribution (Siegel 1956, p116).

Results

Salmonid Abundance in Streams in Basalt and Sandstone

Salmonid species composition was different between streams in each rock type. The most abundant species and age class in streams in sandstone in summer 1987 was age 0 coho salmon, with a range of densities of 1.6-6.0 fish/m (Figure 3.2A, Table 3.4). Trout (age 0, 1, and older resident rainbow trout, cutthroat trout, and steelhead) were more abundant than age 0 coho salmon in streams in basalt; the range of trout densities in basalt was 0.8-2.8 fish/m (Figure 3.2A, Table 3.4). In Franklin Creek, a stream in a sandstone basin with little timber harvest, trout were almost as abundant as coho salmon. Similar patterns of distribution of species were seen in summer 1988, but generally there were fewer age 0 coho salmon than in 1987 (Figure 3.2B, Table 3.4). This was especially so in Franklin Creek, where coho salmon density was 2.3 fish/m in 1987, but only 0.04 fish/m in 1988. Coho salmon were virtually absent in 1988 from reaches in Franklin Creek occupied in 1987, presumably owing to recruitment failure. The two streams added to the survey in 1988, North Fork Wilson River and North Fork Beaver Creek, showed species composition similar to other streams in the same bedrock types (Figure 3.2B). Steelhead, resident rainbow trout, and cutthroat trout were the only salmonid species in North Fork Wilson River, a stream in basalt. In contrast, age 0 coho salmon dominated salmonid populations in North Fork Beaver Creek, a stream in sandstone. In Big Creek, estimates of age 0 trout numbers in summer do not reflect natural production alone because hatchery-reared age 0 steelhead (unfed fry) were released each April (pers. comm. Ron Anglin, Oregon Department Fish and Wildlife, Roseburg) as follows:

Year of release	Number released
1983	90,000
1984	0
1985	50,000
1986	0
1987	45,460
1988	43,890

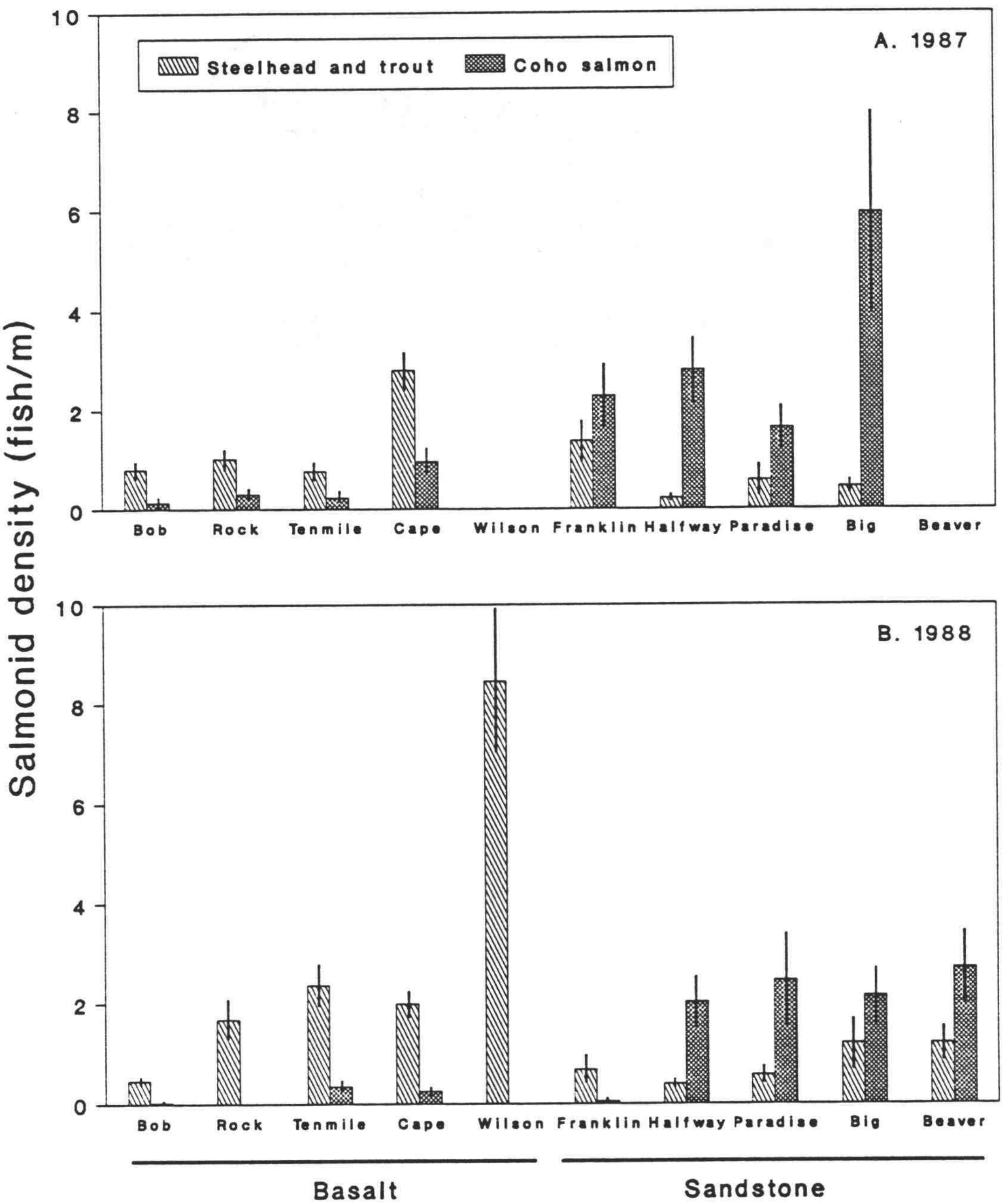

Figure 3.2. Densities and 95% confidence intervals of steelhead, resident rainbow trout, cutthroat trout, and coho salmon in 3 km of main channel in Oregon Coast Range streams in basalt and sandstone in summer (A) 1987 and (B) 1988.

Table 3.4. Estimates of salmonid densities and approximate 95% confidence limits in about 3 km of Oregon Coast Range streams in summer (A) 1987 and (B) 1988.

Stream	Salmonid density (fish/m)					
	age 0 trout	age 1 and older steelhead	age 0 coho salmon	age 1 and older cutthroat trout	all species and ages	all age 1 and older fish
A. 1987						
Bob	0.62±0.16	0.13±0.05	0.13±0.12	0.05±0.04	0.93±0.21	0.18±0.07
Rock	0.63±0.15	0.21±0.09	0.30±0.11	0.18±0.08	1.32±0.21	0.39±0.12
Tenmile	0.61±0.17	0.13±0.09	0.23±0.10	0.04±0.02	1.00±0.20	0.16±0.09
Cape	1.50±0.27	1.04±0.24	0.96±0.27	0.24±0.11	3.74±0.40	1.28±0.26
Franklin	1.10±0.43	0.23±0.09	2.28±0.65	0.04±0.03	3.65±0.77	0.27±0.10
Halfway	0.08±0.03	0.10±0.04	2.79±0.65	0.04±0.02	3.01±0.65	0.14±0.05
Paradise	0.36±0.22	0.16±0.24	1.64±0.45	0.05±0.03	2.21±0.50	0.21±0.25
Big	0.41±0.16	0.03±0.03	5.96±2.03	0.01±0.02	6.41±2.04	0.04±0.03
Basalt mean	0.84	0.38	0.40	0.13	1.75	0.50
Sandstone mean	0.49	0.13	3.17	0.03	3.82	0.16
B. 1988						
Bob	0.16±0.06	0.24±0.07	0.02±0.03	0.06±0.03	0.48±0.08	0.31±0.08
Rock	0.83±0.28	0.57±0.23	0.00±0.00	0.27±0.16	1.68±0.33	0.84±0.28
Tenmile	1.36±0.25	0.76±0.31	0.34±0.11	0.24±0.10	2.70±0.29	1.00±0.33
Cape	1.47±0.20	0.43±0.12	0.25±0.09	0.09±0.05	2.24±0.23	0.52±0.13
NF Wilson	8.05±1.46	0.36±0.15	0.00±0.00	0.05±0.04	8.46±1.46	0.41±0.15
Franklin	0.59±0.27	0.05±0.03	0.04±0.04	0.02±0.02	0.71±0.27	0.08±0.04
Halfway	0.32±0.10	0.06±0.03	2.03±0.54	0.01±0.01	2.41±0.55	0.07±0.03
Paradise	0.45±0.17	0.09±0.08	2.46±0.94	0.03±0.02	3.03±0.96	0.12±0.09
Big	1.14±0.50	0.04±0.02	2.14±0.58	0.02±0.02	3.34±0.77	0.06±0.03
NF Beaver	0.76±0.30	0.32±0.16	2.71±0.72	0.12±0.06	3.90±0.78	0.43±0.17
Basalt mean	2.37	0.47	0.12	0.14	3.11	0.62
Sandstone mean	0.65	0.11	1.87	0.04	2.68	0.15

Densities of age 1 and older steelhead, resident rainbow trout, and cutthroat trout were generally greater in streams in basalt than in streams in sandstone (Figure 3.3). However, differences in densities between basalt and sandstone were less pronounced in 1987 than in 1988. Comparisons were weakened by large confidence intervals of the density estimates, caused by the absence of age 1 and older trout from many channel units. Mean densities of all species and ages combined were greater in streams in sandstone (3.8 fish/m) than in streams in basalt (1.8 fish/m) in 1987. Densities were similar in these eight streams in 1988 (sandstone - 2.4 fish/m, basalt - 1.8 fish/m). However, salmonid density in North Fork Wilson River was much greater than that of other streams in basalt, which inflated the mean for all streams in basalt in 1988 to 3.1. The mean for streams in sandstone, including North Fork Beaver, was 2.7 fish/m (Table 3.4).

Fish densities of all species and ages combined in five of eight streams were significantly different between years, as shown by 95% confidence intervals around density estimates (Table 3.4). Salmonid numbers were lower in Bob, Cape, Franklin, and Big Creeks in 1988 than in 1987, but were greater in Tenmile Creek. Densities in 1987 and 1988 were more variable between streams in basalt (range 0.5-8.5 fish/m) than in sandstone (range 0.7-6.4 fish/m, Table 3.4). Salmonid density appeared to increase with increasing area of timber harvest (Figure 3.4). Correlations of fish density with proportion of basin logged were significant (r^2=0.61, n=8, p=0.022 in 1987, r^2=0.54, n=10, p=0.015 in 1988). The relationship was stronger in streams in basalt than in sandstone.

Biomass of salmonids differed less between streams in basalt and sandstone than did density (Figure 3.5, Appendix 3.4). The larger size, and hence greater weight, of fish in streams in basalt than in streams in sandstone (Appendix 3.5), combined with higher densities of age 1 and older trout (Figure 3.2A and B), compensated for the lower numbers of salmonids. Means of salmonid biomass for streams in each rock type were not different between years or between rock types. Mean biomass in streams in basalt was 18 g/m in 1987 and 22 g/m in 1988, and in streams in sandstone was 16 g/m in 1987, and 11 g/m in 1988 (Appendix 3.4). On an areal basis, biomass ranged from 0.83 to 7.93 g/m^2 (Appendix 3.4). Biomass was less correlated with proportion of basin area logged (r^2=0.41, n=8, p=0.089 in 1987, r^2=0.024, n=10, p=0.665 in 1988) than was density.

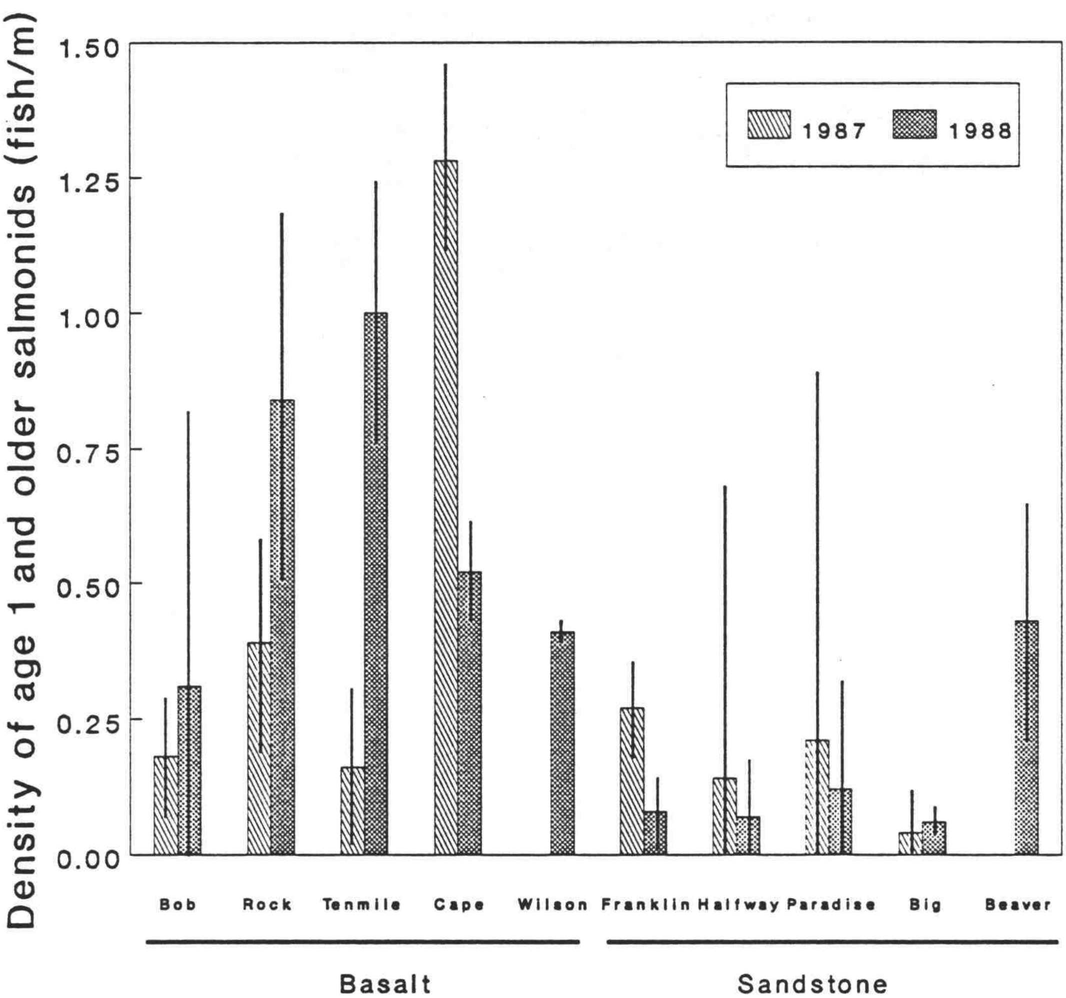

Figure 3.3. Densities and 95% confidence intervals of age 1 and older steelhead, resident rainbow trout, and cutthroat trout in 3 km of main channel in Oregon Coast Range streams in basalt and sandstone in summer.

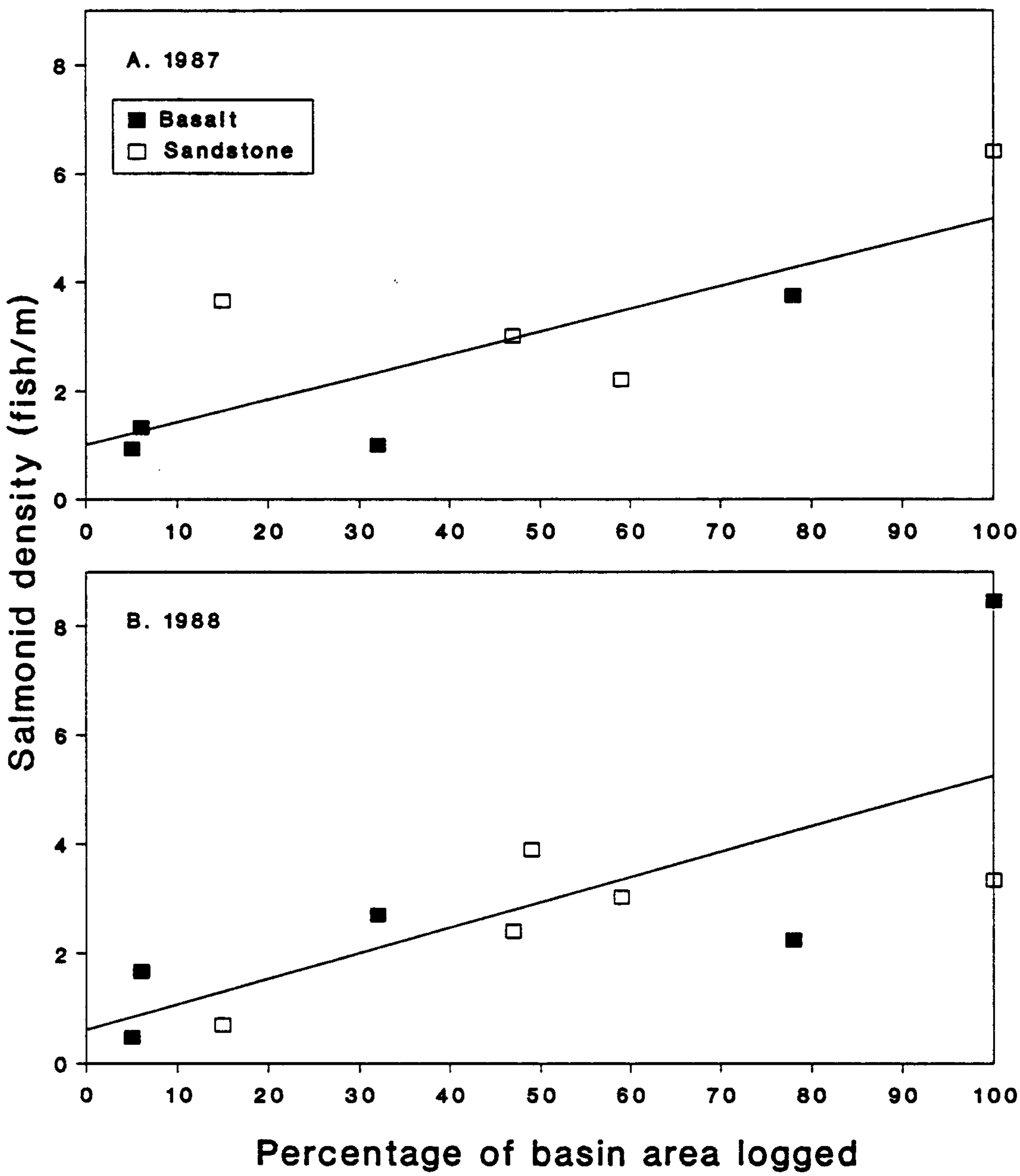

Figure 3.4. Relationship of salmonid density to proportion of basin area logged in 3 km of main channel in Oregon Coast Range streams in basalt and sandstone in summer (A) 1987 and (B) 1988.

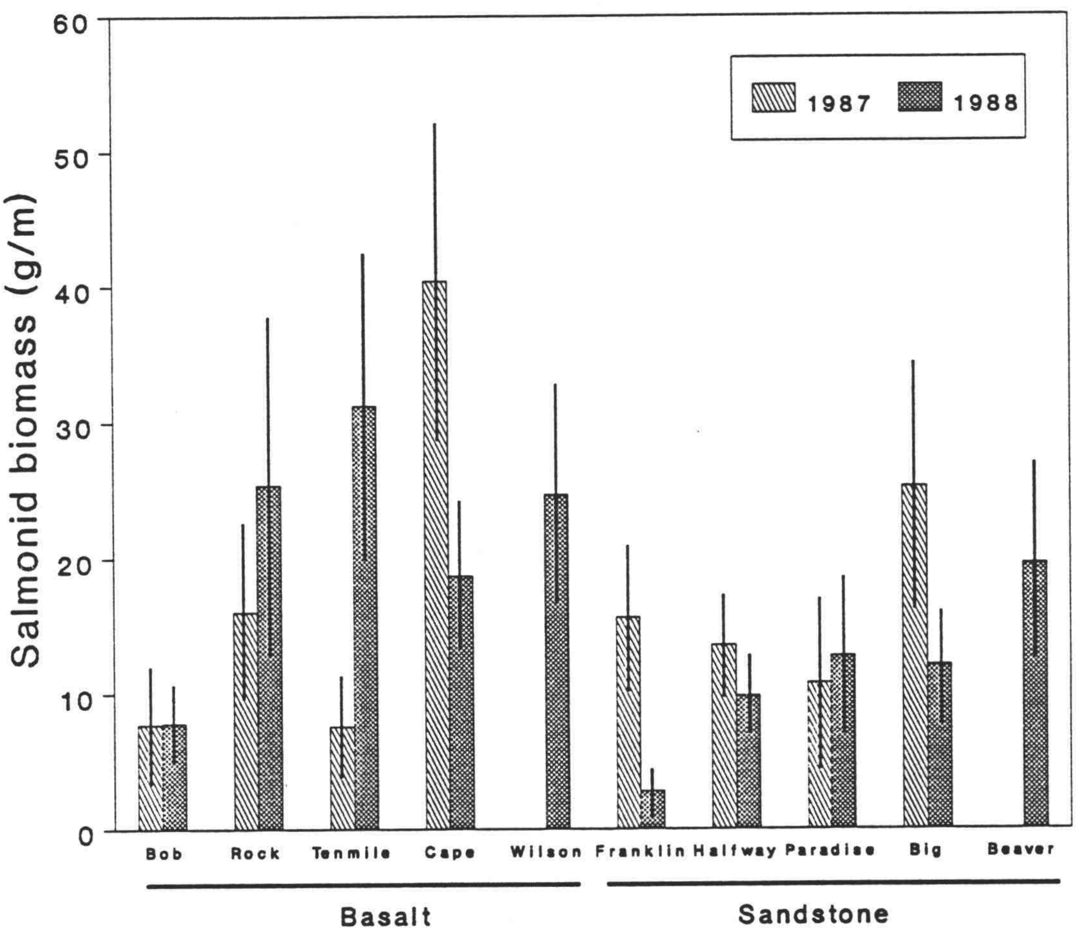

Figure 3.5. Biomass of salmonids and 95% confidence intervals in 3 km of main channel in Oregon Coast Range streams in basalt and sandstone in summer 1987 and 1988.

Species and age class diversity (H′) was higher in streams in basalt than in sandstone (Mann Whitney *U* test, p=0.028 in 1987, p=0.016 in 1988, Figure 3.6A and 3.6B). Age 0 trout, age 1 and older steelhead and resident rainbow trout, and age 1 and older cutthroat trout were considered as separate groups in calculating H′. The proportion of each species and age group of the total salmonids present was more nearly equal in streams in basalt, compared to salmonid communities in streams in sandstone, in which age 0 coho salmon dominated (Figure 3.6A and B). Mean percentages of age 0 steelhead and trout, age 0 coho salmon, age 1 and older steelhead and resident rainbow trout, and age 1 and older cutthroat trout in streams in basalt were 54:21:18:7, but were 14:81:4:1 in streams in sandstone. Age 0 coho salmon were a smaller proportion of the total in 1988 than in 1987 in all eight streams. Mean percentages of different species and age groups in 1988 in the order used above were 58:6:27:9 in streams in basalt, and 33:61:4:2 in streams in sandstone. One age 0 chinook salmon was seen in the lower segment of Tenmile Creek (below Wildcat Creek) in summer 1987.

Survival of steelhead and trout between summers in streams in sandstone appeared to be dependent on end-of-summer streamflow. Apparent survival was estimated from the combined number of age 1 and older steelhead, resident rainbow trout, and cutthroat trout in 1988 divided by the estimated number of age 0 steelhead and trout in 1987. Apparent survival was linearly related to streamflow between 12-31 October 1988 (r^2=0.97, p=0.017, Figure 3.7). Streamflow from October 1988 was considered a more appropriate indicator of the comparative water yield for these streams than flow measurements made in October 1987, because the extremely low flows encountered in 1987 made flow estimation inaccurate. In Big Creek, low streamflows combined with decay of red alder leaves caused dissolved oxygen concentrations to fall well below saturation (Appendix 2.13, Chapter 2). The effect of these low oxygen concentrations in fish survival is unknown. Survival of steelhead and trout in streams in basalt did not show a relationship to late summer stream flow in either year. Estimates of apparent

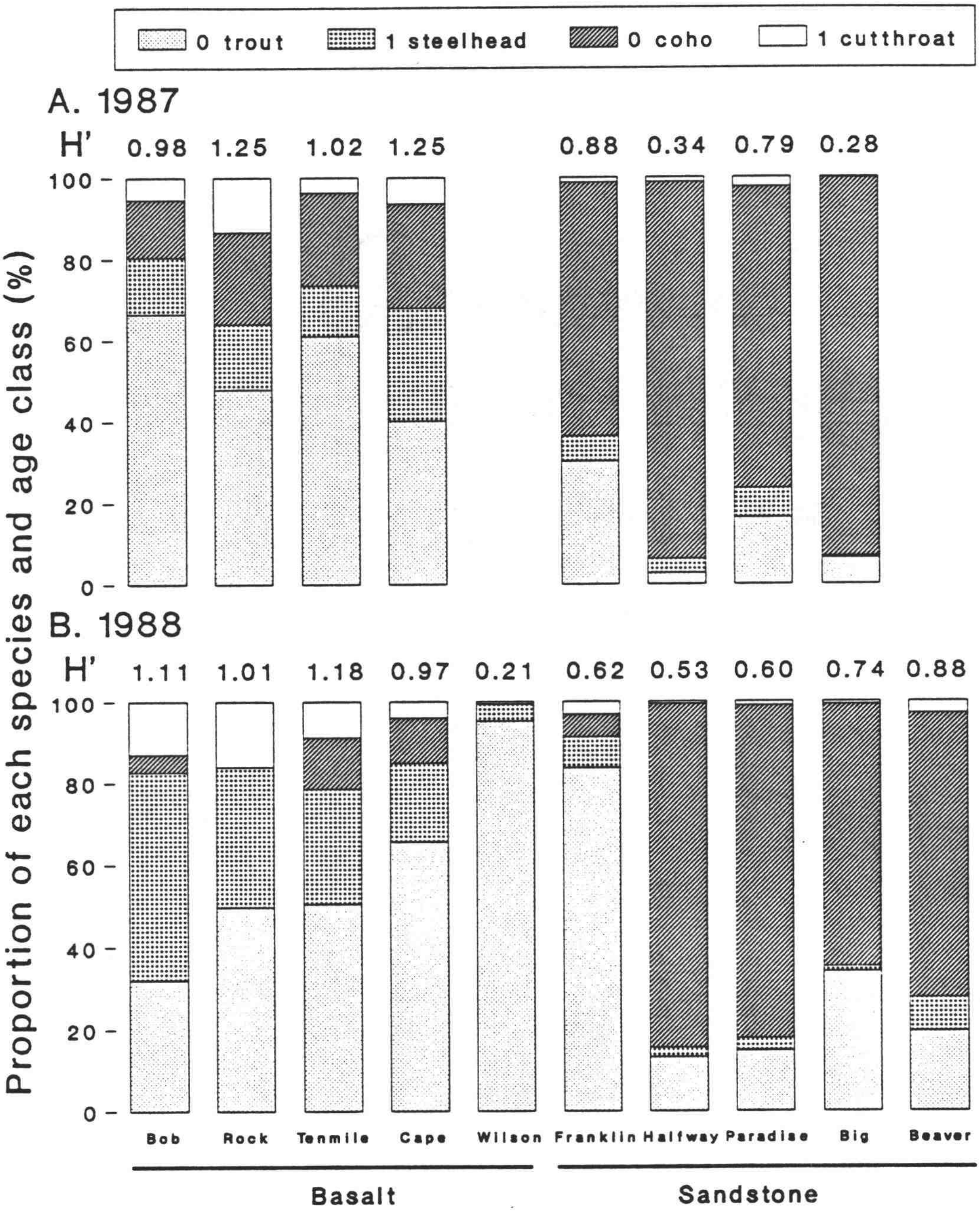

Figure 3.6. Diversity of salmonid populations in Oregon Coast Range streams in basalt and sandstone in summer (A) 1987 and (B) 1988. ($H' = -\text{Sum}(p_i \ln p_i)$ (Emlen 1984, p181), considering age 0 trout, age 1 and older steelhead, age 0 coho salmon, and age 1 and older cutthroat trout as separate groups).

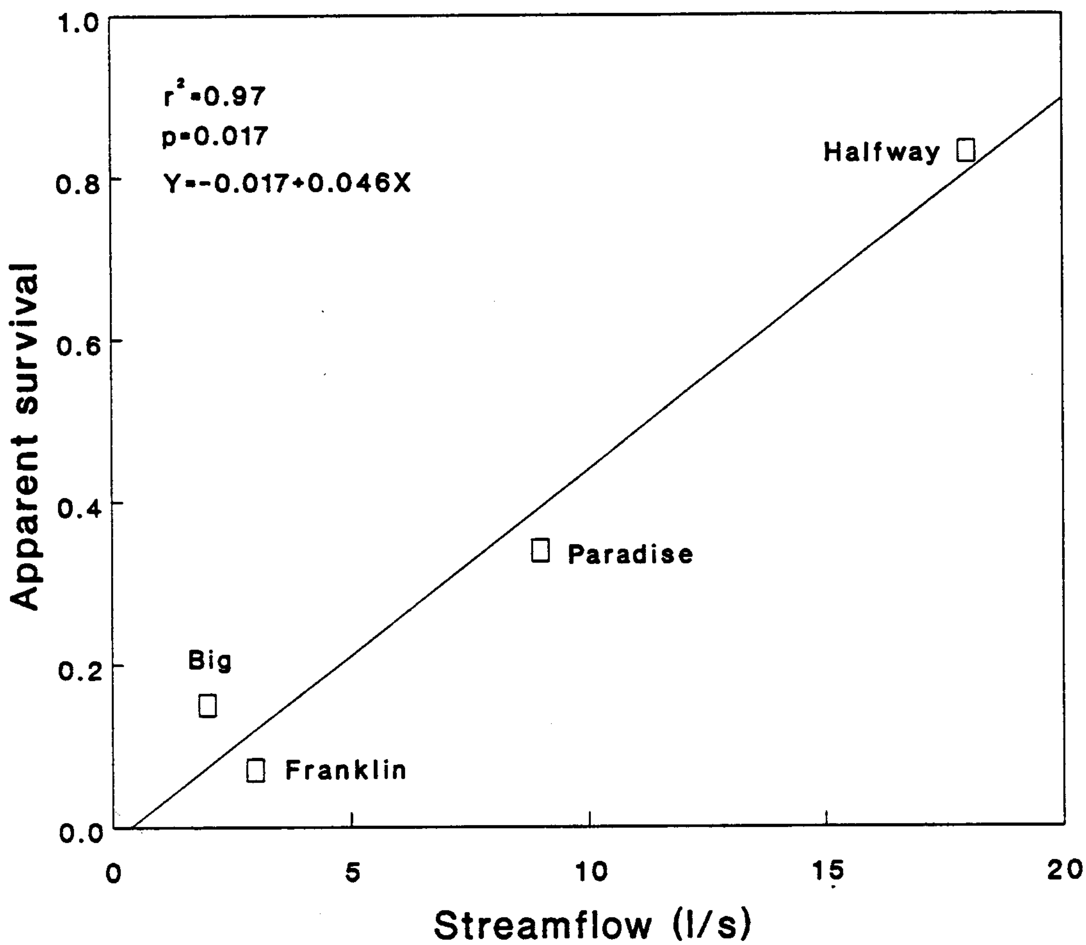

Figure 3.7. Relationship of apparent survival of steelhead and trout from age 0 in summer 1987 to age 1 in summer 1988 to late summer streamflow in Oregon Coast Range streams in sandstone.

survival of steelhead and trout in Rock and Tenmile Creeks were greater than 1, possibly indicating that age 1 and older fish moved into the survey segments.

Habitat Utilization and Channel Morphology

Age 0 coho salmon used pools in preference to glides or riffles, but age 0 steelhead and trout used pools, glides, and riffles about equally (Figure 3.8, Appendix 3.6). Pools in basalt were preferred by all salmonid species and age classes (Figure 3.8, Appendix 3.6). Preference for pools was most strongly displayed by age 0 coho salmon and age 1 and older cutthroat trout, and less strongly displayed by age 1 and older steelhead and resident rainbow trout and age 0 trout. Pools in sandstone were strongly preferred by cutthroat trout, and weakly so by age 0 coho salmon and age 1 and older steelhead and resident trout. Age 0 trout avoided pools in sandstone. Glides in basalt were preferred by age 0 trout, and glides in sandstone were preferred by age 0 trout and coho salmon. Age 1 and older salmonids avoided glides in both rock types. Riffles in basalt were slightly avoided by age 0 trout, but riffles in sandstone were slightly preferred. Age 1 and older steelhead and resident rainbow trout avoided riffles in basalt slightly. Riffles in sandstone were strongly avoided by age 0 coho salmon and all age 1 and older salmonids.

Low streamflows in Big Creek created anomalously high habitat use of riffles by age 0 coho salmon in 1987 (Appendix 3.6). Riffles were dry or were reduced to small pockets of virtually still water. Under these conditions, occupation of water remaining in riffles in Big Creek was higher than occupation of riffles in other streams in sandstone. Use of riffles in Big Creek in 1988 at higher streamflows was much lower than in 1987.

Mean depths of channel units in which fish were counted (Appendix 3.7) were not different from the means for all channel units of each type (Appendix 2.10, Chapter 2). Mean depths of channel units in streams in basalt were not measured in 1988, but maximum depths showed

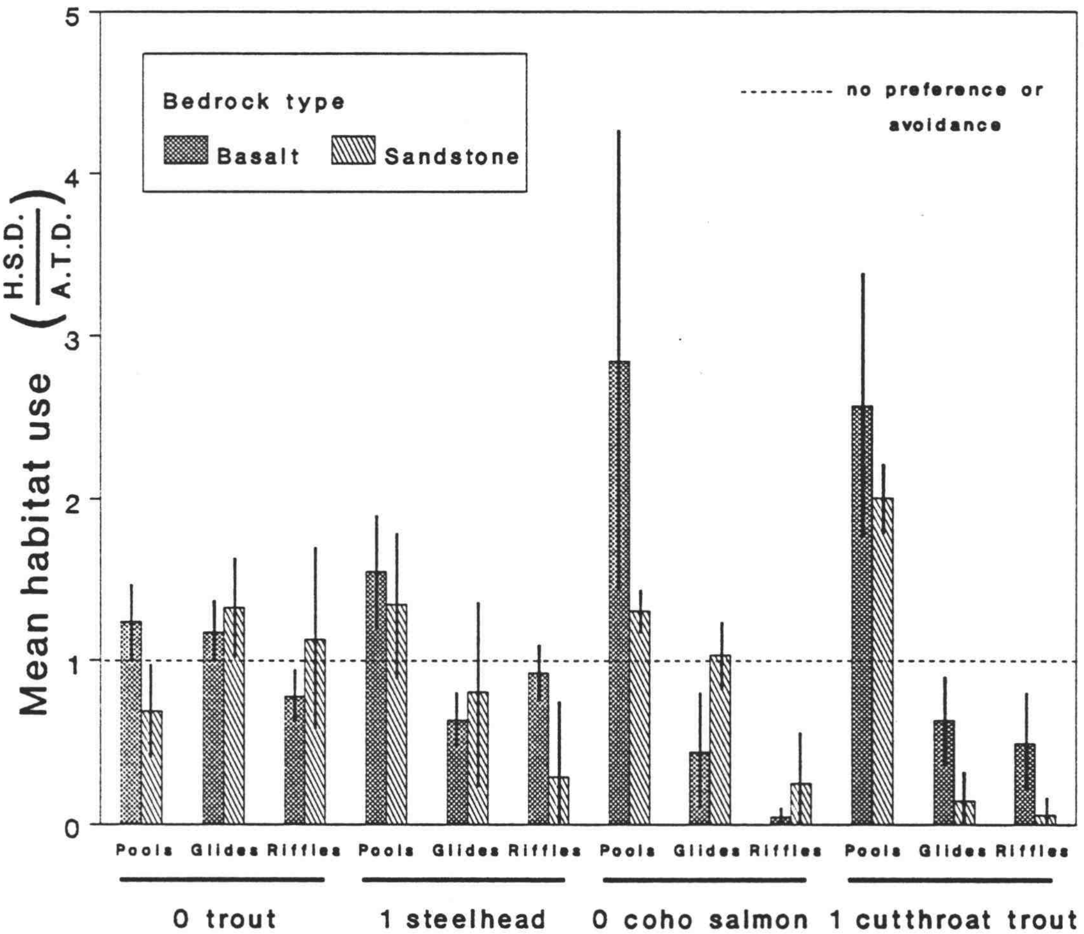

Figure 3.8. Mean habitat use by salmonids in Oregon Coast Range streams in basalt and sandstone in summer 1987 and 1988. (H.S.D. = habitat specific density, A.T.D. = average total density in all habitats. Vertical lines represent 95% confidence intervals about means)

that there had generally been little or no change from maximum depths measured in 1987. Streamflows were similar during the periods in which depths were measured in streams in basalt in both years (Table 2.4, Chapter 2).

Of any habitat variable, total salmonid biomass in summer was most highly correlated with channel unit volume (r^2=0.44, n=289, Table 3.5). Natural logarithms of volume and biomass were used because the data were log-normally distributed. All channel units were combined in this analysis, except those for which population estimates had been estimated from extrapolated data. Salmonid biomass was also correlated with channel unit length, area, and mean depth, but these variables were also highly correlated with volume. When streams in sandstone and basalt were examined separately, the correlation of salmonid biomass with volume was marginally stronger for streams in sandstone (r^2=0.46, n=166, Figure 3.9A) than for streams in basalt (r^2=0.36, n=123, Figure 3.9B). Biomass estimates of age 0 trout were highly correlated with volume of riffles (r^2=0.60, n=54, Table 3.5), and biomass estimates of age 1 and older steelhead and resident rainbow trout in glides were correlated with maximum depth (r^2=0.32, n=90, Table 3.5).

Table 3.5. Correlations of natural log of salmonid biomass with habitat variables.

Habitat variable	Correlation coefficients (r) of ln(biomass)			
	age 0 trout in riffles (n=54)	age 1 and older steelhead and resident rainbow trout (n=90)	age 0 coho salmon salmon in all habitats (n=236)	total salmonid biomass in all habitats (n=289)
ln(length)	0.56	0.10	0.31	0.49
ln(area)	0.69	0.21	0.29	0.54
ln(volume)	0.77	0.35	0.39	0.67
square root(average depth)	0.64	0.43	0.35	0.52
square root(maximum depth)	0.66	0.57	0.35	0.52
substrate complexity	0.15	0.21[a]	-0.45	-0.16
water surface slope	-0.17	0.23[a]	-0.50	-0.45

[a] n=81

Other correlations were caused by relationships among variables (Table 3.5). For instance, significant correlations between biomass of age 0 trout and length, area, and mean and maximum depths were

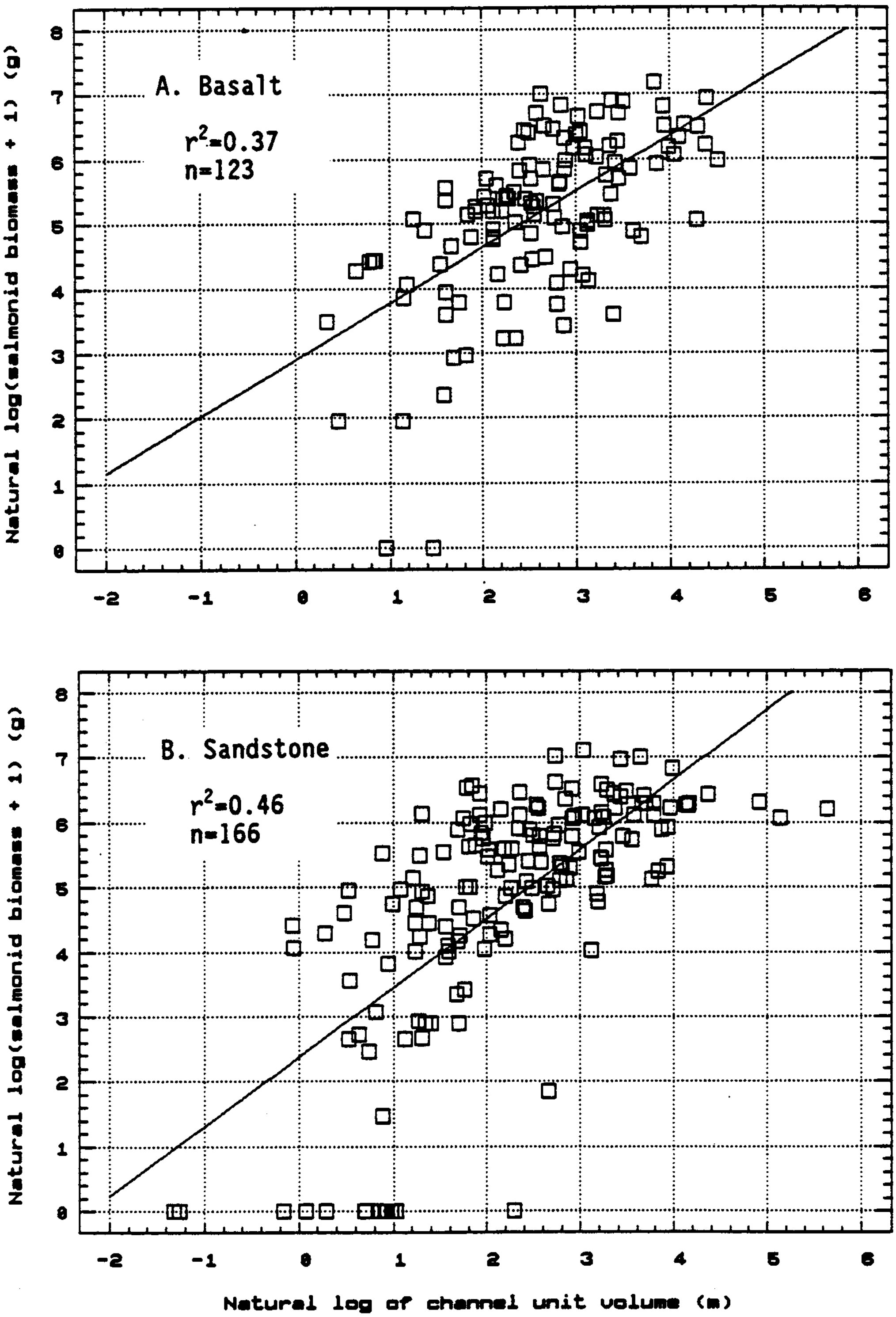

Figure 3.9. Relationship of biomass of salmonids to channel unit volume in Oregon Coast Range streams in (A) basalt and (B) sandstone in summer 1987.

associated with the high correlation coefficient for volume. As length, area, and depth are used to calculate volume, they are not independent of volume, and are thus not likely to explain any more of the variability of salmonid biomass than will volume alone. Similarly, the significant negative correlations between biomass of age 0 coho salmon, substrate complexity, and water surface slope was probably related to the affinity of coho salmon for pools. Pools had smaller substrate size and therefore lower substrate complexity, and lower water surface slopes (Chapter 2). Correlations between density (fish/m) of different salmonid species and age classes, and habitat variables such as size of dominant and subdominant substrate, width/depth ratio, amount of bedrock, water surface slope, and habitat complexity attributable to large woody debris, substrate, and channel edge were all less than r^2=0.25.

Evaluation of Sampling Methods

Reactions of Fish to a Diver. The reactions of fish to the submerged diver varied among species and sizes of fish. In most instances, age 0 salmonids appeared to be displaced little from their positions before the diver entered the water. Age 0 coho salmon tended to school and to appear to be unaffected by the diver, or even to be attracted, approaching to investigate sediment disturbed from the streambed by the diver's movements. Age 0 trout tended to be more solitary than coho salmon, but sometimes schooled with coho salmon. Age 0 trout were generally observed close to the bed, whereas age 0 coho salmon tended to be higher in the water column. Age 1 and older resident rainbow and steelhead were more mobile than either age 0 trout or coho salmon, and usually darted away from the diver, seeking out the deepest parts of a pool. Age 1 and older cutthroat trout also avoided the diver, generally darting to cover after being glimpsed only briefly. They were often found taking refuge under a boulder, rock ledge, or piece of woody debris.

Water temperature can influence the ease with which salmonids can be seen by a diver (Gardiner 1984). Population estimates were attempted in fall 1987, but a combination of low water temperatures and high streamflows made fish counts extremely inefficient. At low temperatures, steelhead, resident rainbow trout and cutthroat trout were dark-colored and torpid, and lay deep within crevices among cobbles and boulders. Coho salmon were under undercut banks or around large woody debris. These reactions were seen in streams with water temperatures ≤8.5°C (Appendix 3.8). Water temperatures in summer ranged between 10.5 and 19.0°C, above temperatures that normally cause fish to seek cover (Appendix 3.8).

Length-frequency Analysis. Lengths and weights of fish caught by electroshocking were compared to diving observations of fish size to test the accuracy of identification of fish as age 0 or age 1 and older. The distribution of sizes of age 0 steelhead and trout and age 1 and older steelhead and resident rainbow trout in all streams in which fish were sampled by electroshocking showed an overlap of fork lengths in the 90-95 mm size class. Size ranges and relative abundance of fish identified as these species and age classes during diving were generally consistent with frequency distributions of fish caught by electroshocking (Figure 3.10, Table 3.6). Length-frequency analysis of fish collected by electroshocking suggested that there were few if any age 1 coho salmon.

Table 3.6. Size ranges of age 0 trout, age 1 and older resident rainbow trout and steelhead, and age 1 and older cutthroat trout sampled by electroshocking in five Oregon Coast Range streams.

Stream	Fork length (mm)					
	age 0 trout		age 1 and older steelhead and resident rainbow trout		age 1 and older cutthroat trout	
	range	N	range	N	range	N
Bob Creek	59-88	23	94-184	36	116-219	11
Cape Creek	54-92	141	94-161	56	96-263	8
N.F. Wilson River	34-96	190	110-156	11	156	1
Franklin Creek	41-84	232	100-130	12	132-162	5
Paradise Creek	45-85	73	92-130	10	93-155	7

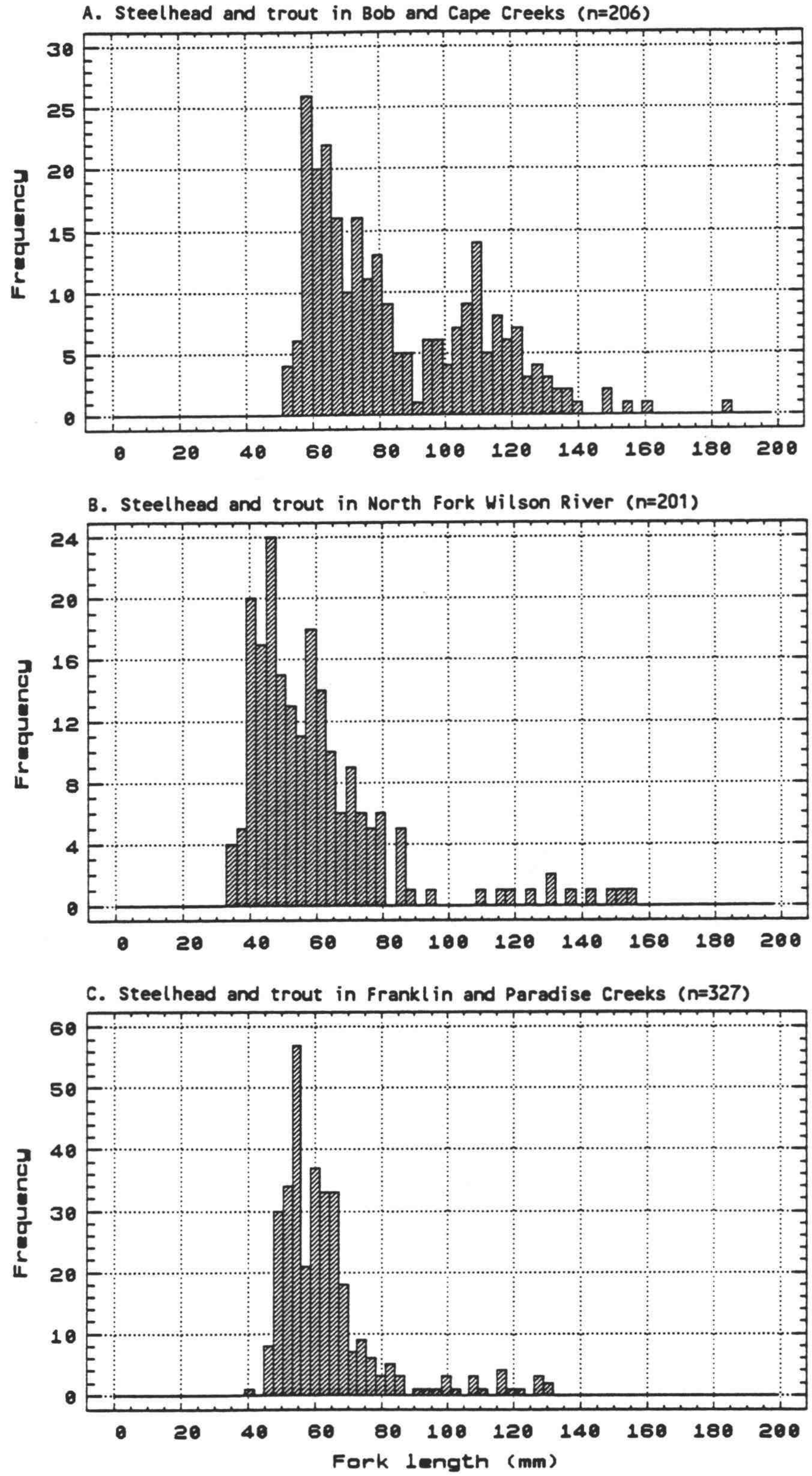

Figure 3.10. Length-frequency distribution of salmonids in streams of the Oregon Coast Range in summer 1988. Steelhead and trout in (A) Bob and Cape Creeks, (B) North Fork Wilson River, and (C) Franklin and Paradise Creeks.

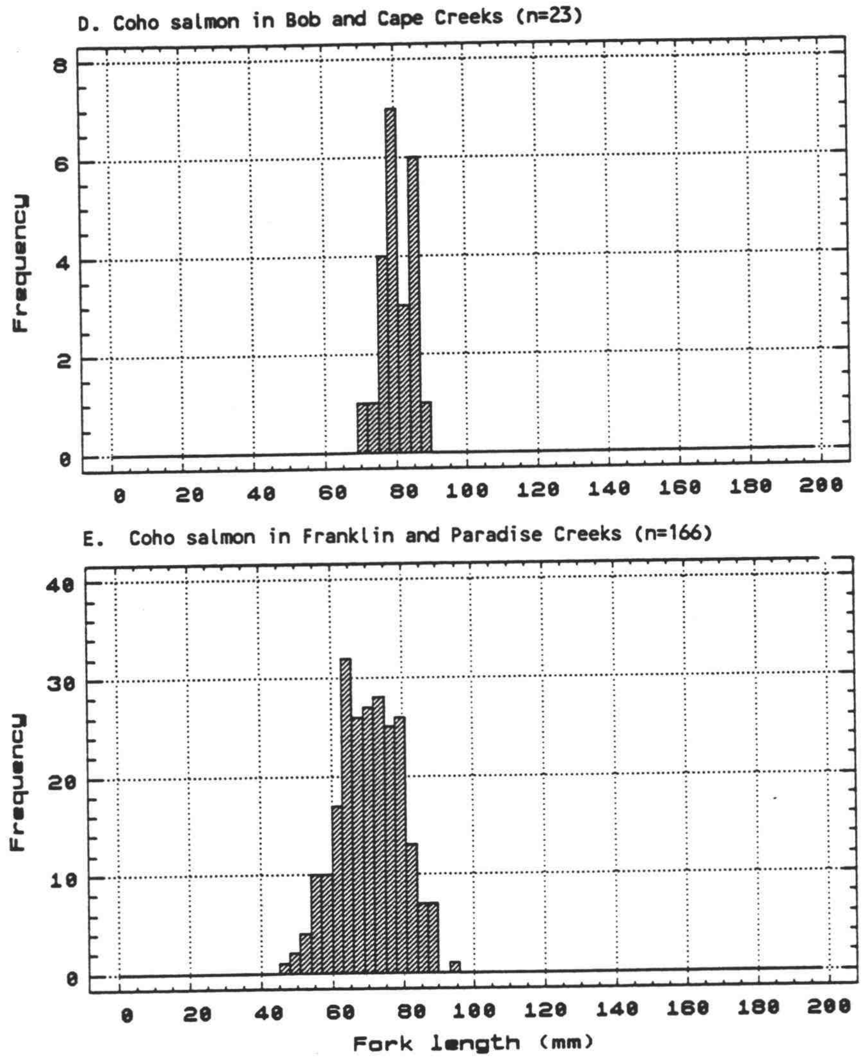

Figure 3.10 (continued). Length-frequency distribution of salmonids in streams of the Oregon Coast Range in summer 1988. Coho salmon in (D) Bob and Cape Creeks and (E) Franklin and Paradise Creeks.

Characters used to distinguish age 1 and older trout and steelhead from age 0 trout during diving were: (1) fork length (FL) >95 mm, and (2) color pattern. Fish electroshocked were classified as age 0 or older on the basis of color pattern before they were measured. Scale analysis of steelhead and trout showed that fish $\leq$92 mm FL were age 0 (n=7), and fish $\geq$105 mm FL were age 1 of older (n=4). One trout identified by color pattern as age 0 out of 645 electroshocked was >95 mm FL. Four trout out of 123 identified by color pattern as age 1 or older steelhead or resident rainbow trout were <95 mm FL. As fish <95 mm FL were generally more abundant than fish >95 mm FL, it was assumed that age 1 and older trout and steelhead could be consistently distinguished from age 0 fish.

Discussion

Influence of Geology and Timber Harvest

Relative abundance of different species and age classes of salmonids among streams in basalt and sandstone was related to channel gradient. The proportion of the stream channel in pools, glides, and riffles appeared to control species dominance. Streams in sandstone, which had lower gradients than those in basalt (Table 3.1), were dominated by coho salmon, a salmonid species adapted to pools and other low-velocity habitats (Hartman 1965; Everest and Chapman 1972; Bisson et al. 1988). Streams in basalt had less pool habitat and more riffle habitat, corresponding to their steeper gradients, and were dominated by steelhead, resident rainbow trout, and cutthroat trout. Larger fish size compensated for generally lower fish density in streams in basalt, yielding similar mean total biomass in each rock type (11-22 g per lineal meter, Appendix 3.4). Species and age class diversity was higher in streams in basalt than in sandstone as a result of more age 1 and older steelhead and trout.

Large mean size of dominant substrate in streams in basalt, combined with high summer streamflows compared to streams in sandstone, appear to make streams in basalt more resistant to habitat simplification and streamflow reduction resulting from the long-term effects of timber harvest. Three streams in sandstone flowing largely on bedrock had summer flows that were inversely related to the area of the watersheds subjected to timber harvest or fire and salvage logging. This result needs to be verified with a larger number of streams, but an unexpected reduction in summer streamflow as a long-term effect of timber harvest has also been demonstrated in the Oregon Cascades in an on-going study of paired watersheds (Hicks et al. MS). Clear-cut logging of a 96-ha watershed led to an initial increase in summer low flow for 8 yr, followed by a 19-yr period with an average of 47% less flow in August than that predicted. The drop in flow to below that predicted began nine years following the start of logging in 1962, and flow in August 1988 was still below that predicted.

A combination of extreme low summer streamflows and leaves dropped into a stream from overhanging red alder can reduce dissolved oxygen concentration to below that necessary to sustain salmonids. When I measured oxygen concentrations in 1988, they were well below saturation (Appendix 2.13, Chapter 2). Similar conditions were noted in Brummetts Creek, Indiana, which flowed through a predominantly sandstone and shale basin (Slack 1955). Fish and invertebrate fauna in Brummetts Creek were killed by the low oxygen concentrations. In my study some salmonids did survive the low oxygen conditions in shallow stream margins in Big Creek in 1988, though what proportion of the population this might have been is unknown. However, the low flow conditions were more prolonged in 1987, and are likely to have killed fish extensively.

Another stream in the Oregon Coast Range in sandstone is known to be prone to the effects of low flow and alder leaf decay. Juvenile coho salmon were observed in shallow pools in Knowles Creek, a tributary of the Siuslaw River, in the month of October (pers. comm. C. Dewberry, Forest Science Laboratory, Corvallis, Oregon). These fish occupied normal positions before passage of a diver, but came to the surface in distress and died as the diver passed near them. Mortality was probably a result of mixing of oxygen-deficient waters near the streambed with water above caused by passage of the diver. A similar situation occurred in isolated pools on the flood plain of the Hoh River, Olympic Peninsula, southwestern Washington. In the month of October, juvenile coho salmon died when anaerobic sediments were disturbed by wading, releasing sulfides, carbon dioxide, and methane (pers. comm. J.R. Sedell, Forest Science Laboratory, Corvallis, Oregon).

Apparent survival of trout between summer 1987 and summer 1988 was directly related to October streamflow (Figure 3.7). While there is no doubt that the drought in summer 1987 was an extreme climatic event (Table 2.2, Chapter 2), surface flow in Franklin and Big Creeks was discontinuous by early August 1987. Similar low flow conditions occur in Knowles Creek in the Oregon Coast Range, another sandstone watershed. Thus low streamflows seem to be a natural feature of some sandstone basins in the Oregon Coast Range, and forest management activities may further reduce summer streamflows.

Habitat Utilization and Factors Influencing Production

Habitat utilization of pools, glides, and riffles was different among species and age classes of salmonids (Figure 3.8). Age 1 and older steelhead, resident rainbow trout, and cutthroat trout both occupied pools preferentially, but steelhead and resident rainbow trout also occupied riffles in streams in basalt. Volume was the habitat variable most highly correlated with salmonid biomass, and the correlation was higher in streams in sandstone than in streams in basalt (Figures 3.9A and 3.9B). No other habitat variable, such as substrate complexity or amount of large woody debris, explained as much variability in biomass, suggesting that space is the factor most limiting to salmonids in Oregon Coast Range streams in summer. The greater correlation of biomass with volume in streams in sandstone than in basalt is consistent with lower streamflows in streams in sandstone, and with the predominance of coho salmon and their affinity for pools. Biomass of juvenile coho salmon has been linked to pool volume by others. High correlations between standing stock of juvenile coho salmon and pool volume were found in four north coast Oregon streams (r^2=0.935, Nickelson et al. 1979), and in a Puget Sound stream in Washington (r^2=0.62, Allee 1974). Number of steelhead have also been related to habitat volume (r^2=0.45, Allee 1974).

Volume of pools, glides, and riffles in streams in sandstone decreased with decreasing streamflows (Figure 2.10B, Chapter 2). Glides and riffles were virtually dry at the lowest flows. Low summer streamflows occur naturally in western Oregon (Harr 1983, Beschta et al. 1987), and conditions that further reduce summer flows may be of critical importance to summer survival of salmonids in streams. Reaches with large amounts of gravel in the channel had no surface flow under extreme low flow conditions, and thus management activities that increase stored sediment in channels may increase the susceptibility of salmonids to low flows. Volume of channel units in streams in basalt in this study was not as sensitive to decreasing streamflows as that in sandstone (Figure 2.10A).

Models explaining and predicting salmonid abundance have used a wide variety of variables, including drainage basin characteristics, channel morphometry, streamflow, habitat structure, and weighted usable area (Fausch et al. 1988). However, most models have been based on fewer than 20 observations, and have often lacked generality. Several other criticisms limit the usefulness of many models: (1) similar total standing stocks of salmonids may be made up of different species and age classes, (2) explanatory geomorphic and channel morphometric variables may show considerable correlation among themselves, and (3) different habitat types are usually combined, so that biomass of a relatively few large fish occupying mainly pools and avoiding shallow areas such as riffles may unduly influence the r^2 values. In this study, for instance, total salmonid biomass was correlated with channel unit volume (r^2=0.44). However, this correlation was greater for streams in sandstone (r^2=0.46) than in basalt (r^2 =0.36), and was driven by the number of age 0 coho salmon in pools and glides in streams in sandstone, and by the number of age 1 and older steelhead, resident rainbow trout, and cutthroat trout in pools in streams in basalt. Hence the investigation of a range of multiple regression models as part of the present study was not attempted.

Coho salmon. Abundance of juvenile coho salmon is not related solely to instream conditions. The numbers of adults returning to spawn and the distance they penetrate upstream also limit abundance of juvenile coho salmon. Upstream penetration is related to streamflow at the time of migration, and to the difficulty fish have in negotiating barriers. Penetration of chinook salmon into Fish Creek, Oregon Cascades, is dependent on fall freshets to raise streamflow sufficiently to allow fish to negotiate an alluvial boulder fan at the mouth (Everest et al. 1985). Similarly, in fall 1987, coho salmon failed to negotiate a steep cascade of large boulders with a fall of about 2 m in Franklin Creek about 2.2 km upstream from its junction with the Umpqua River. Mean monthly rainfall at Gardiner, the closest rain gauge, was 61% below normal in July-September, 95% below normal in

October, and 28% below normal in November (Table 2.2, Chapter 2). Streamflows in fall are likely to have been much lower than normal, and to have prevented access of adults to reaches in which they spawned in 1986. High precipitation in December (34% above normal at Gardiner), apparently did not compensate for lack of rainfall in fall. Consequently, in summer 1988 juvenile coho salmon were almost absent from the study segment, the downstream end of which was 2.1 km upstream from the Umpqua River. In summer 1987 juvenile coho salmon were abundant in the study segment of Franklin Creek. A steep bedrock cascade to the mouth of Bob Creek may also be a partial barrier to adult coho salmon during their upstream spawning migration.

Numbers of adult coho salmon returning to spawn in Oregon Coast Range streams showed considerable variability between 1950 and 1988. Adult run strength is related to production of smolts in freshwater and to ocean survival. Ocean survival of coho salmon is related to variation in natural ocean productivity (Nickelson 1986), which is dependent on upwelling in the coastal ocean. Rate of fishing also controls ocean survival. In 1986, a restricted fishing season lead to a harvest rate of 30% estimated from returns to Columbia River hatcheries (Pacific Fisheries Management Council 1987). In contrast, in 1987 the harvest rate was 55%, and there is evidence of even higher rates of 77% for Oregon mid-coast stocks (pers. comm. S. Jacobs, Oregon Department of Fish and Wildlife, Corvallis, Oregon).

Streams in which adult coho salmon have been routinely counted are useful indices of the strength of the run of wild fish. The Oregon Department of Fish and Wildlife has conducted spawning surveys in Cedar Creek (close to North Fork Wilson River), and Schofield and Dean Creeks (close to Franklin, Halfway, Paradise, Big Creeks). North Fork Beaver Creek itself has been used as an index stream. Index streams used by the Oregon Department of Fish and Wildlife are assumed to be free of the influence of hatchery fish.

The sizes of the spawning runs in 1986 and 1987 were closely linked to ocean harvest rates. Peak counts of spawners in North Fork Beaver Creek in brood year (year of fall migration) 1986 were about three times the average of counts between 1950 and 1988, but only one fifth of average in 1987 (Oregon Department of Fish and Wildlife unpublished data). In tributaries of the lower Umpqua River, spawner densities were 76% of average in 1986, and 36% of average in 1987. Peak counts of adult coho salmon near North Fork Wilson River have been low in the past ten years, and were 27% of average in 1986, and 37% of average in 1987. Absence of age 0 coho salmon from North Fork Wilson River may have been caused by successive years with poor returns of adults. The segment surveyed in my study has been recorded as a coho salmon rearing area (State Water Resources Board 1960), and there are no known barriers to upstream migration of adults. Debris jams thought to impede access to spawning adults have been removed (Oregon Department of Fish and Wildlife unpublished data). Thus it is clear that the strength of the coho salmon run in mid-coast streams was substantially lower in 1987 than in 1986.

Densities of juvenile coho salmon in summer 1988 as a percentage of densities in 1987 in Bob, Rock, Tenmile, and Cape Creeks were 15, 0, 147, and 26% (mean 47%), and in Franklin, Halfway, Paradise, and Big Creeks were 2, 73, 150, and 36% (mean 65% including Franklin, 86% excluding Franklin, Table 3.4). Thus, in general, mean densities of juveniles reflected the run sizes of the adjacent index streams.

<u>Steelhead, Resident Rainbow Trout, and Cutthroat Trout</u>. Year-to-year run strength is more difficult to establish for steelhead than for coho salmon. Like coho salmon, the numbers of adult steelhead returning to spawn and their upstream penetration limits abundance of juveniles. Densities of age 0 trout in summer 1988 as a proportion of densities in 1987 in Bob, Rock, Tenmile, and Cape Creeks were 26, 132, 223, and 98% (mean 120%), and in Franklin, Halfway, Paradise, and Big Creeks were 54, 400, 125, and 344% (mean 231% including Franklin, 290% excluding Franklin, Table 3.4). Low density of age 0 trout in Franklin Creek in 1988 suggests that adult steelhead may have been partially restricted from entry by a combination of low fall flows and the barrier in Franklin Creek that excluded adult coho salmon. Increases in densities of age 0 trout between summer 1987 and 1988 in streams other than Franklin Creek suggest that the steelhead run was larger in

brood year 1987 than in 1986 (Table 3.4).

A factor confounding estimates of natural steelhead and trout production in Big Creek was the release of hatchery-reared age 0 steelhead in April from 1983 on as part of the Salmon and Trout Enhancement Program (pers. comm. Ron Anglin, Oregon Department of Fish and Wildlife, Roseburg). Despite these releases, however, the abundance of age 1 and older steelhead and resident rainbow trout in Big Creek was the lowest of all ten streams (Table 3.4). Thus stocking has not overcome the inherent unsuitability of Big Creek for steelhead and trout.

Chinook salmon. I saw only a single chinook salmon in this study, in Tenmile Creek in summer 1987. Presumably the basin area drained by my study segments (about 1500 ha) was generally too small to support chinook salmon spawning.

Species Interactions and Response to Timber Harvest

Distribution of juvenile salmonids in my study partly contradicts a commonly accepted idea that age 0 steelhead and trout use riffles more than pools (Hartman 1965; Allee 1974; Bisson et al. 1982). Age 0 steelhead and trout used pools and glides more than riffles in streams in basalt in the absence of high densities of age 0 coho salmon (Figure 3.8). However, in the presence of high densities of coho salmon in streams in sandstone, age 0 steelhead and trout used glides and riffles more than pools. This suggests that interactive segregation, attributable to competitive exclusion (Nilsson 1967), occurred between age 0 coho salmon and age 0 steelhead and trout, with coho salmon displacing steelhead and trout from pools in streams in sandstone. The volume of glides and riffles in streams in sandstone decreased with decreasing streamflow, further reducing the habitat available to steelhead and trout.

Studies that have found selective segregation among salmonids attributable to different habitat requirements rather than to interactive segregation have generally found large size differences resulting from different emergence times (Lister and Genoe 1970; Everest and Chapman 1972). Chinook salmon were about 30 mm longer when steelhead fry emerged in Salmon River tributaries, Columbia River basin, and were about 20 mm longer at the end of summer (Everest and Chapman 1972). The larger size of chinook salmon leads them to use deeper, faster water than steelhead, and habitat occupancy by each species was different even in allopatry.

The small size difference among species appears to result in interactive rather than selective species segregation (Hartman 1965; Stein et al. 1972). Distribution of age 0 steelhead and coho salmon in tributaries of the Fraser River, British Columbia, was thought to be influenced by interactive segregation in spring and summer (Hartman 1965). Sizes of the two species overlapped considerably, but coho salmon were about 10-15 mm longer than steelhead through summer. Coho salmon occupied pools, and steelhead occupied riffles; both species appeared to be more aggressive in their respective habitats. In artificial stream channels in allopatry, however, steelhead and coho salmon occupied the same places, leading Hartman to conclude that interactive segregation occurred. Mean fork length of age 0 steelhead and trout in late summer in my study was only 12 mm less than that of age 0 coho salmon (Appendix 3.5), and there was considerable overlap in the ranges of length (Figure 3.10). Similar sizes of fish suggest that interactive segregation is likely to have affected the distribution of salmonids in my study.

With a similar difference in mean sizes (7-16 mm) Allee (1974) concluded that age 0 steelhead and coho salmon in Big Beef Creek, Washington, did not exhibit interactive segregation. He found that steelhead used riffles, and that pools were shared by steelhead and coho salmon through vertical stratification, with coho using the surface for feeding, and steelhead using the lower areas of pools. Study pools were 0.8 m deep. Allee's interpretation of the ability of age 0 steelhead and coho salmon to share pool habitat seems to rely on pools being sufficiently deep to allow vertical stratification. Mean depth of pools in my study was 0.35 m in basalt and 0.32 m in sandstone under comparable flows in 1988; in 1987, however, when flows were much lower in streams in sandstone than in basalt, mean pool depth was 0.27 m in sandstone (Appendix 2.10, Chapter 2). The aggression of coho salmon in pools (Hartman 1965; Nilsson 1967), combined with their pool-adapted body morphology (Bisson et al. 1988) and high densities in streams in sandstone in my study, probably caused competitive exclusion of age 0 steelhead and trout from pools by age 0 coho salmon.

A major proportion of food for salmonids in streams in sandstone is almost certainly of terrestrial origin. Riffles are important habitats for invertebrate production, and streams in sandstone had short, narrow riffles. Also, streams in sandstone basins that had been logged or burned had heavy shading (Chapter 2), and presumably little algal production (Bilby and Bisson 1987). Juvenile coho salmon may use food sources other than aquatic invertebrates, and are known to use terrestrial food (Fraser 1969). Invertebrates dropping from overhanging vegetation are a likely source of food in streams shaded by alder. Juvenile coho salmon in Deer Creek, a small Oregon Coast Range stream in sandstone, derived at least 33% of their production from terrestrial sources (Chapman 1966). Invertebrate food from riffle-based autochthonous production is likely to be greater in streams in basalt in my study. In streams in basalt riffles comprised the greatest proportion of channel length, and streams in basalt, especially North Fork Wilson, were less shaded than most streams in sandstone (Chapter 2).

Evaluation of Sampling Methods

Counts of salmonids by diving are limited by water clarity and by depth. Shallow depths and rough substrate limit the distance over which fish can be observed, and riffles are particularly shallow habitats with large substrate. Riffles were shallow in both rock types in my study, with mean depths of 0.15 m in streams in basalt, and 0.09 m in streams in sandstone in 1988 (Appendix 2.10, Chapter 2). Substrate was generally larger in riffles than pools or glides (Chapter 2), further obscuring fish in riffles. Capture of salmonids with electroshocking showed that it was necessary to multiply numbers of age

0 trout by a factor of 1.55 ($\hat{R}$, equation (5), Hankin and Reeves (1988), p836) to arrive at population estimates (Table 3.3). Dive counts of age 1 and older steelhead, resident rainbow trout, and cutthroat trout were far less efficient, with an $\hat{R}$ of 4.25. Such a large value of $\hat{R}$ seriously questions the validity of estimates of age 1 and older salmonids derived from diving alone. This potential source of error might not be serious if, like cutthroat trout, pools were the preferred habitat and few were found in riffles. However, age 1 and older steelhead and resident rainbow trout were moderately abundant in riffles in streams in basalt, and therefore substantial errors in estimating abundance are possible. Because riffles present particular sampling difficulties, a reasonable number of reliable estimates of the number of age 0 and age 1 and older steelhead and trout from diving and electroshocking are required. Hankin and Reeves (in press) have suggested 10 is sufficient.

Hankin (1984) astutely observed that the variance of any population estimate made from a sample of a habitat combined with a sampling technique that has its own error of estimation is a two-stage sampling problem. Comparison of first-stage variance (the error in extrapolating from the sampled channel units to the total habitat) to second-stage variance (the error in estimating the number of fish in a single channel unit) showed that second-stage variance is generally relatively small (Hankin and Reeves 1988). In my study the mean of estimates of second-stage variance for each species in 3 km of each stream was 2.7±0.56% of the first-stage variance (mean±95% confidence interval, n=70). A few estimates were, however considerably larger than this. Second-stage variance was 11% of first-stage variance for age 1 and older steelhead and resident rainbow trout combined in riffles in Cape Creek in 1987, and in riffles in Tenmile Creek in 1988.

A further limitation to diving estimates of salmonids is low water temperatures. Water temperatures of less than 5°C caused young Atlantic salmon to seek shelter among substrate, but at 6-7°C fish emerged and lay on the substrate (Gardiner 1984). Similar observations of temperature-related activity of salmonids were made in fall in this study; dive counts were ineffective at about 9°C or less. Mean stream temperatures during diving and electroshocking to estimate salmonid abundance in summer were between 11.0 and 16.1°C (range 10.5-19.0; Appendix 3.8). These temperatures were generally above those at which salmonids exhibited cryptic behavior.

Size and color pattern were used to distinguish age 0 trout from age 1 and older fish. Though length-frequency data from fish captured by electroshocking showed a separation of size classes at about 95 mm FL, with a limited number of verifications from scale analysis, it is not certain that all fish were correctly assigned to one or other age class on the basis of size visually estimated underwater. This is a source of error of unknown size, though I suspect it was minimal because I was careful to look periodically at a reference length underwater.

Conclusions

Oregon Coast Range streams of about 1500 ha drainage area seem to fall into three classes with regard to the response of their salmonid populations to timber harvest. (1) Streams in basalt had relatively high channel gradients with channel morphology more conducive to production of steelhead, resident rainbow trout, and cutthroat trout than to production of coho salmon. Such streams had large substrate that inherently provided considerable habitat stability and complexity. High summer streamflows rendered salmonid populations in streams in basalt relatively insensitive to flow reductions that appear to be a long-term outcome of timber harvest. (2) A stream in sandstone within about 20 km of the coast (i.e., on the west slope of the Oregon Coast Range) had gradient, channel morphology, and substrates more conducive to production of coho salmon than steelhead and trout, but had summer streamflows sufficient to maintain age 1 and older steelhead and trout. Correspondingly, this stream was dominated by coho salmon, but had diverse species and age class composition of steelhead, resident rainbow trout, and cutthroat trout. Summer streamflows would probably not limit salmonid survival. (3) Streams in the Oregon Coast Range in sandstone more than 20 km from the coast, that is, further inland than west-slope streams, had gradients, channel morphologies, and substrates more conducive to production of coho salmon than steelhead and trout. Summer streamflows were also naturally low compared to coastal streams and streams in basalt. The long-term effects of timber harvest might reduce summer streamflows still further, compromising survival of salmonids in summer, especially steelhead, resident rainbow trout, and cutthroat trout, which need longer residence in freshwater than do coho salmon. These streams could be moderate producers of steelhead and trout if they had complex channels and summer streamflows sufficient to allow survival of age 0 trout over summer in riffles.

Thus streams in basalt appear to be less sensitive to some effects of timber harvest than do streams in sandstone, especially those streams in sandstone in areas of naturally low summer flows. From a management perspective, it is especially important to protect channel complexity in streams in sandstone during timber harvest activities. Complex channels give the maximum habitat diversity necessary to maintain diverse salmonid populations. The mechanism of streamflow depletion associated with second-growth forest is not known, but phreatophytes such as red alder in the riparian zone may be a factor causing reduced low summer flows. Thus minimal disturbance of the original riparian vegetation could be especially important in streams prone to low summer flows. Efforts to replace alders in the riparian zone with conifers may increase summer streamflows.

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Chapter 4. Application of Geologic Information to Classification of Salmonid Habitats and Populations in Streams of the Oregon Coast Range

Abstract

Systems of land and stream channel classification were applied to ten streams of 1500 ha basin area in the Oregon Coast Range. Salmonid populations and stream channel morphology of five streams in basalt and five in sandstone were studied in summer 1987 and 1988. Streams in landtype associations of volcanic uplands, igneous headlands, and igneous/sedimentary contact lands (basalt) were dominated by steelhead, resident rainbow trout, and cutthroat trout, with few coho salmon. Streams in dense-textured fluvial lands and coastal fluvial lands (sandstone) were dominated by coho salmon, with fewer steelhead, resident rainbow trout, and cutthroat trout than streams in basalt. Distinction of riffle types by mean depth and gradient was useful to group associated salmonid habitat utilization, but distinction among pool types was not particularly useful. Mean width/depth ratios were different for pools (15), glides (27), shallow riffles (47-49), and deep riffles (25-31). The ratios were not different for individual pool types.

Introduction

Aims of Classification

One aim of most systems of classification of the habitats of plants and animals has been to evaluate patterns in the physical environments (Bailey 1983; Bailey et al. 1985; Frissell et al. 1986). These patterns might then be used to explain and predict the variation in distribution of biota. A second aim is to improve knowledge of the functional links within stream ecosystems, which may change with stream order and gradient (Huet 1959; Vannote et al. 1980; Minshall et al. 1985). A third aim is to reduce the amount of field investigation necessary to explain and predict the response of salmonids to land management-induced habitat changes. Classification could enable prediction of biotic distribution and functional links within stream ecosystems from appropriate maps and other information, integrating climate, geology, geomorphology, stream gradient, and watershed size. The sensitivity of various aquatic plant and animal associations to disturbance, for example timber harvest, might then be determined.

Hydrologic and geomorphic processes determine stream channel morphology and streamflow. Geology, soils, climate, and vegetation in a basin determine aquatic productivity (Minshall et al. 1983). Hynes (1975) has pointed out that a river cannot be separated from its associated watershed. Any stream classification system should therefore consider climate and land type of the basin in addition to aquatic conditions.

Schemes of Classification

Scale of classification determines the precision of predictions of biotic distribution. To begin classification at the level of stream reach usually increases the complexity of habitat classes compared to the original number of streams under consideration, for example, the system of Pennak (1971). Thus hierarchical systems of classification that use a minimum of information to discriminate patterns at the desired level are generally most useful. Hierarchical systems of classification have been proposed for land (Bailey 1984; Lotspeich and Platts 1982) and streams (Frissell et al. 1986). In such systems, sub-levels are nested within each higher level. Bailey (1984) proposed that the terms domain, division, province, section, district, landtype association, landtype, landtype phase, and site, in order of diminishing level, be used to classify land. Frissell et al. (1986) propose the terms stream, segment, reach, pool/riffle, and microhabitat systems.

The system of stream classification put foward by Rosgen (1985) operates at the reach to segment scale. Attributes of gradient, sinuousity, width to depth ratio, dominant particle size of channel materials, and steepness and stability of valley walls are used to create 25 classes of streams. Rosgen's system has been developed for assessing wildlife and fish habitat relationships, and has been tested around the U.S. by the U.S.D.A. Forest Service.

A classification system that has been applied at the channel unit scale is that of Bisson et al. (1982). Primary channel units -- pools, glides, riffles, and side channels -- have been further subdivided under this scheme with a combination of their water surface slope, depth, shape, and origin. However, the criteria are specific to small streams, and do not translate well to large rivers. A system comprised entirely of dimensionless criteria would be preferable. Water surface slope was the criterion most useful for separating channel unit types in the western Cascades in Oregon (Grant 1986).

Methods

The system of Bailey (1983, 1984) was used to classify the lands through which streams in this study flowed. Channel units were identified in ten Oregon Coast Range streams of about 1500 ha basin area. Five streams flowed through basalt, and five through sandstone. Three kilometers of main channel in each stream were surveyed. Channel units were classified with a modification of the channel unit classification described by Bisson et al. (1982). Primary channel unit types (i.e., pools, glides, and riffles) were identified on the basis of water surface slope and depth (Table 4.1). The same criteria were used to further subdivide primary channel units into secondary channel unit types. Debris scour pools were substituted for plunge pools of Bisson et al. (1982) to broaden the type of pools associated with large woody debris. Pools formed by debris at high streamflows were included in this category even if the debris was suspended above the water surface during summer flows.

The classification of Bisson et al. (1982) has three classes of riffles. Rapid riffles and cascade riffles are high gradient riffles distinguished principally by depth (Table 4.1). Low gradient riffles as proposed by Bisson et al. (1982) include both deep and shallow riffles. I have separated a fourth class, low gradient cascade riffles, from low gradient riffles, on the basis of depth. Low gradient cascade riffles are deeper than low gradient riffles, and generally have transverse ribs of cobbles, boulders, or bedrock (Table 4.1).

Width, depth, water surface slope, and substrate characteristics of channel units were estimated, using methods described in Chapter 2. Fish abundance was estimated with snorkel diving and electroshocking (Chapter 3). Mean and 95% confidence intervals of width, depth, width/depth ratio, and shape index were calculated from square root transforms.

Table 4.1. Channel units into which streams were visually classified (after Bisson et al. 1982).

Primary channel unit types	Secondary channel unit types	Criteria	
		water surface slope (%)	maximum depth (m)
1. Pools	1. lateral scour pool (LSP) 2. trench pool (TP) 3. debris scour pool (DSP) 4. boulder scour pool (BSP) 5. backwater pool (BP) 6. beaver-dammed pool (BDP)	<0.5	≥0.40
2. Glides	1. glide (G)	≥0.5, <1.5	<0.40
3. Riffles	1. low gradient riffle (LGR)	≥1.5, <4.0	<0.30
	2. low gradient cascade riffle (LGCR)	≥1.5, <4.0	≥0.30
	3. rapid riffle (RR)	≥4.0	<0.30
	4. cascade riffle (CR)	≥4.0	≥0.30
4. Side channels	1. side channel (SC)		

Mean and 95% confidence intervals of individual channel unit lengths and fish densities were calculated from natural log transforms (Chapter 2, Chapter 3).

Habitat use (preference) was estimated with methods described in Chapter 3, where

$$U = \frac{\text{habitat specific density}}{\text{average total density}}$$

for each species and age class. Means for each habitat were calculated from U values for 1987 and 1988.

Tests of Significance

Overlap of 95% confidence limits about the mean was used to test significance of differences between means unless otherwise stated. Confidence intervals were calculated by multiplying standard errors by $t_{0.05[n-1]}$, where n=sample size (Sokal and Rohlf 1981, p109). Mann-Whitney *U* tests were used for small sample sizes of unknown distribution (Siegel 1956, p116).

Results

Land Classification

Study sites were classified with the system of Bailey (1983) as follows:

- Domain - humid temperate
  - Division - marine
    - Province - Pacific forest
      - Section - sitka spruce, cedar, hemlock forest (Bob, Cape, Rock Creeks)
        - cedar, hemlock, Douglas-fir forest (N.F. Wilson River, Tenmile, N.F. Beaver, Franklin, Halfway, Paradise, Big Creeks)
        - Landtype association
          - Nehalem Subsection (2)
            - Volcanic upland lands (P) - (N.F. Wilson River)
          - Alsea Subsection (3)
            - Igneous headland lands (M) - (Bob, Rock, lower parts of Tenmile and Cape Creeks)
            - Igneous/sedimentary contact lands (T) - (upper parts of Tenmile and Cape Creeks)
            - Coastal fluvial lands (D) - (N.F. Beaver Creek)
          - Umpqua Subsection (4)
            - Dense-textured fluvial lands (G) - Franklin, Halfway, Paradise, and Big Creeks)

Comparative densities of salmonids were broadly grouped according to landtype association. Age 0 steelhead and trout were most abundant in streams in igneous headlands, volcanic uplands, and igneous/sedimentary contact lands, with age 1 and older steelhead and resident rainbow trout next in abundance (Figure 4.1). Age 0 coho salmon dominated streams in fluvial lands (dense-textured and coastal), with age 0 trout next in abundance. Igneous headlands, volcanic uplands, and igneous/sedimentary contact lands are largely equivalent to basalt areas in my study, and fluvial lands are equivalent to sandstone areas.

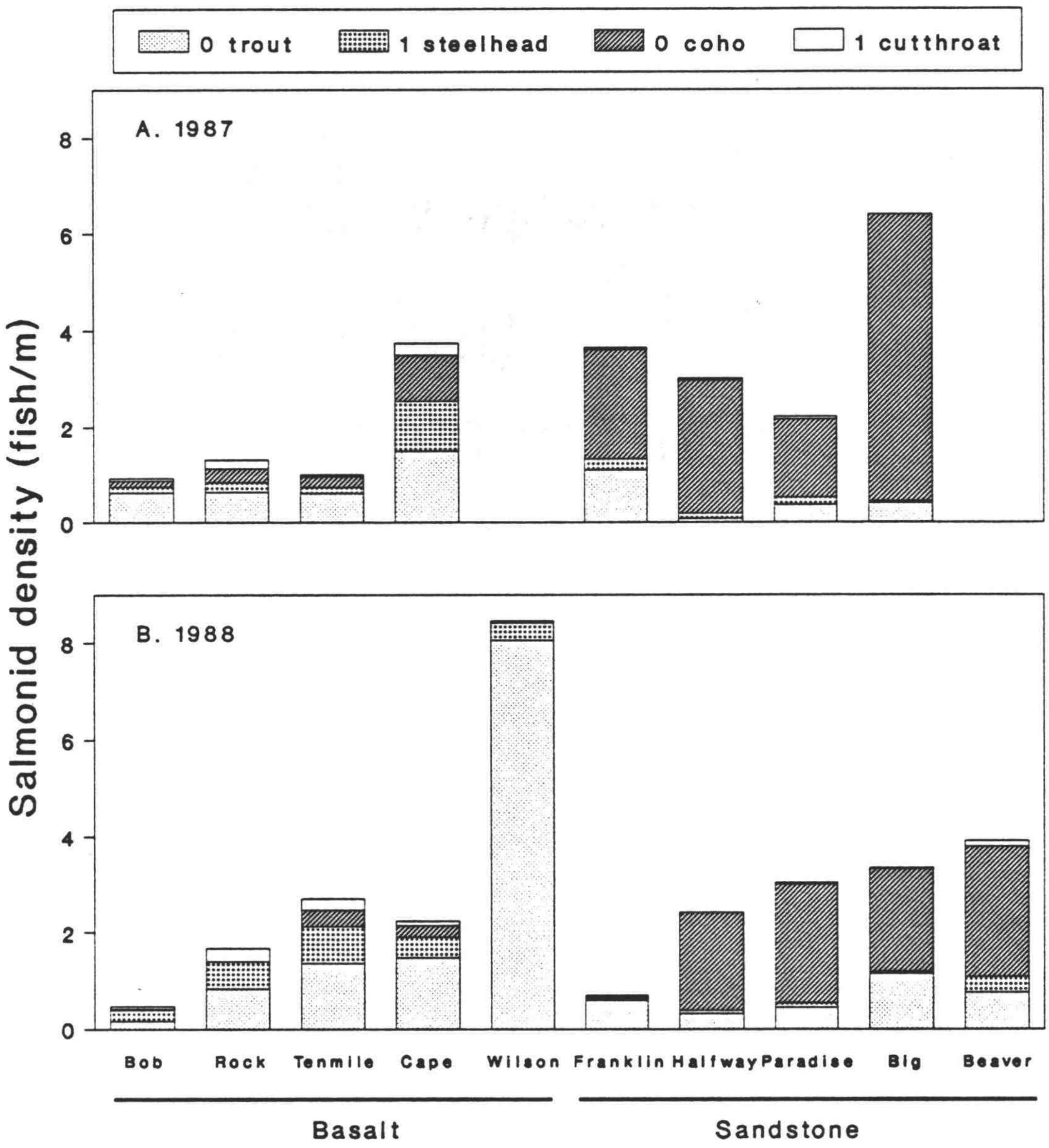

Figure 4.1. Densities of all salmonids in 3 km of main channel of Oregon Coast Range streams in summer (A) 1987 and (B) 1988.

Comparison with Usefulness of Another Classification Scheme

To relate salmonid species and relative abundance to stream type, I classified my study streams with Rosgen's (1985) system. The surveyed segment of Tenmile Creek in basalt is B1 on the basis of overall gradient, but B3 on the basis of bed composition. North Fork Wilson River is also B1 for gradient, but is B2 for substrate. Bob, Rock, and Cape Creeks in basalt are classified as B2. Franklin Creek in sandstone is B4, and other streams in sandstone (Halfway, Paradise, Big, and North Fork Beaver Creeks) are C1-1 on the basis of gradient, width/depth ratio, and the dominant size of bed material (Table 4.2, Appendix 4.1). Width/depth ratios agree fairly well with Rosgen's criteria.

I considered channel gradient and substrate to be more important than other classification criteria; channel entrenchment, valley confinement, and landform features were not specifically investigated. Sinuosity was estimated from the ratio of the channel length measured with a hip chain in the field to straight-line distance measured from maps (Table 4.3). Bob, Rock, and Cape Creeks in basalt had lower sinuosities than streams in sandstone; Tenmile Creek and North Fork Wilson had higher sinuosities. Overall, sinuosities were not different between streams in basalt and sandstone (Mann Whitney *U* test, $p=0.420$). Sinuosities estimated by this method were generally lower than Rosgen's criterion for each stream type (Table 4.2).

Stream classes B1, B2, and B3 (Bob, Rock, Tenmile, and Cape Creeks, and North Fork Wilson River) were in landtype associations dominated by igneous rock, for example, basalt, and corresponded to stream segments dominated by steelhead, resident rainbow trout, and cutthroat trout (Figure 4.1). Stream class B4 (Franklin Creek) was dominated by coho salmon in 1987, but had a relatively large number of age 0 trout compared to C class streams. Class C1-1 streams (Halfway, Paradise, Big, and North Fork Beaver Creeks) were dominated by coho salmon. Age 0 steelhead and trout were generally a low proportion of the total salmonid population in class C-1 streams.

Table 4.2. Classes from Rosgen's (1985) stream classification applicable to study streams of 1500 ha drainage area in the Oregon Coast Range.

Stream type	Gradient (%)	Sinuosity	Width/depth ratio	Dominant particle size	Channel entrenchment/ valley confinement	Landform feature - soils/stability
B1	2.5-4.0 ($\bar{x}$=3.5)	1.2-1.3	5-15 ($\bar{x}$=10)	Predominantly small boulders, very large cobble.	Moderately entrenched/ well confined.	Moderately stable, coarse textured resistant soil materials. Some coarse river terraces.
B2	1.5-2.5 ($\bar{x}$=2.0)	1.3-1.5	8-20 ($\bar{x}$=14)	Large cobble mixed with small boulders and coarse gravel.	Moderately entrenched/ moderately confined.	Coarse textured, alluvial terraces with stable, moderately steep side slopes.
B3	1.5-4.0 ($\bar{x}$=2.5)	1.3-1.7	8-20 ($\bar{x}$=12)	Cobble bed with with mixture of gravel and sand - some boulders.	Moderately entrenched/ well confined.	Glacial outwash terraces and/or rejuvenated slopes. Unconsolidated coarse textured unstable banks. Depositional landforms.
B4	1.5-4.0 ($\bar{x}$=2.0)	1.5-1.7	8-20 ($\bar{x}$=10)	Very coarse gravel and cobble mixed with sand and finer material.	Deeply entrenched/ well confined.	Relatively fine river terraces. Unconsolidated, coarse to fine depositional material. Steep side slopes. Highly unstable banks.
C1-1	≤1.5 ($\bar{x}$=1.0)	1.5-2.5	≥10 ($\bar{x}$=30)	Bedrock bed, gravel, sand, of finer banks.	Shallow entrenchment/ poorly confined.	Bedrock controlled channel with fine-grained bank material.

Table 4.3. Channel sinuosity of ten Oregon Coast Range streams of 1500 ha drainage area in basalt and sandstone.

Stream	Channel length (m)		Sinuosity [a]
	channel length	straight-line distance	
Basalt			
Bob	3037	2604	1.07
Rock	2895	2653	1.09
Tenmile	3022	2151	1.40
Cape	3078	3033	1.01
N.F. Wilson	2988	1793	1.67
Sandstone			
Franklin	2957	1936	1.53
Halfway	3390	2988	1.13
Paradise	3012	2319	1.30
Big	3156	2390	1.32
N.F. Beaver	3019	1960	1.54

[a] channel length measured with hip chain divided by straight-line distance measured from 1:24,000 scale topographical map

North Fork Beaver Creek had moderate densities of age 1 and older steelhead, resident rainbow trout, and cutthroat trout compared to Halfway and Paradise Creeks.

Channel Unit Characteristics and Classification

There were differences in length of channel units within streams and between streams in basalt and sandstone. Beaver-dammed pools were the longest of any secondary pool type in both rock types, although there was a wide variation in lengths (Figure 4.2, Appendix 4.2). Secondary riffle types and side channels showed the most difference between rock types. Low gradient riffles, low gradient cascade riffles, cascade riffles, and side channels were about twice as long in streams in basalt as in sandstone. Glides and rapid riffles were about the same length in both rock types.

Mean water surface slopes were different for pools, glides, and riffles (Appendix 4.3). For both rock types combined, high gradient riffles, that is, cascade riffles and rapid riffles, had mean slopes of 5.9 and 6.0%.

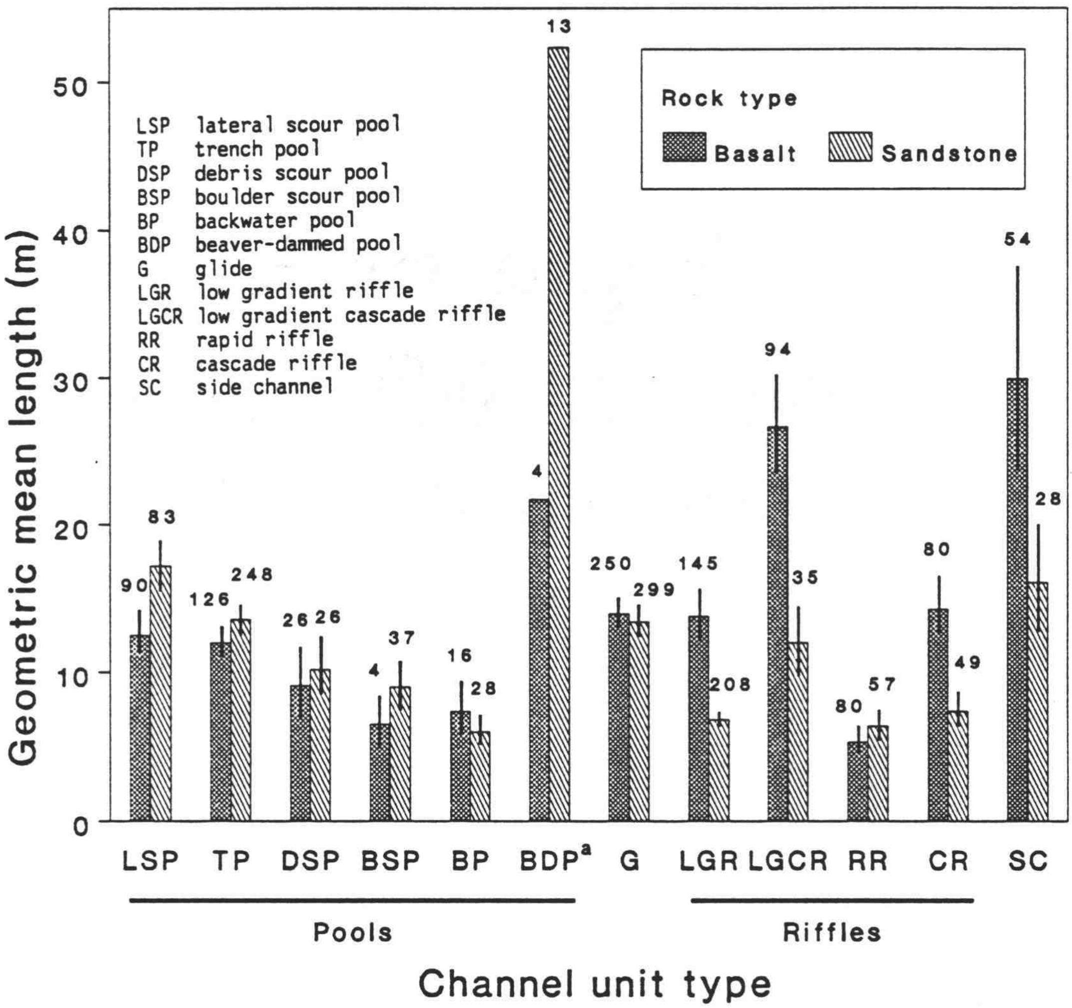

Figure 4.2. Geometric means and 95% confidence intervals of length of individual channel units in ten Oregon Coast Range streams in basalt and sandstone in summer 1988. Sample sizes above bars.

[a] 95% confidence intervals of BDP in basalt - 6.7 to 70.5 m; in sandstone - 30.6 to 89.4m.

Low gradient riffles and low gradient cascade riffles had mean slopes of 2.2 and 2.8%. Mean slope of glides (0.6%) was less than all riffle types, and greater than all pool types (Appendix 4.3).

Some secondary pool types had mean depths distinct from others (Figure 4.3, Appendix 4.4). Beaver dam pools were deeper (mean depth 0.50 m) than other pool types, and backwater pools were shallower (mean depth 0.18 m) than other pool types. Lateral scour pools, trench pools, debris scour pools, and boulder scour pools could not be separated on the basis of mean depth (range of mean depths 0.30-0.37 m).

Glides, low gradient cascade riffles, and cascade riffles had similar mean depth and depth range, but different water slopes (Figure 4.4, Appendix 4.4). Low gradient riffles and rapid riffles also had similar mean depths but different slopes. The combination of mean depth and water slope distinguished 75% of glides, low gradient riffles, low gradient cascade riffles, rapid riffles, and cascade riffles. The greatest overlaps were between depths of low gradient riffles and low gradient cascade riffles, and between depths of rapid riffles and cascade riffles.

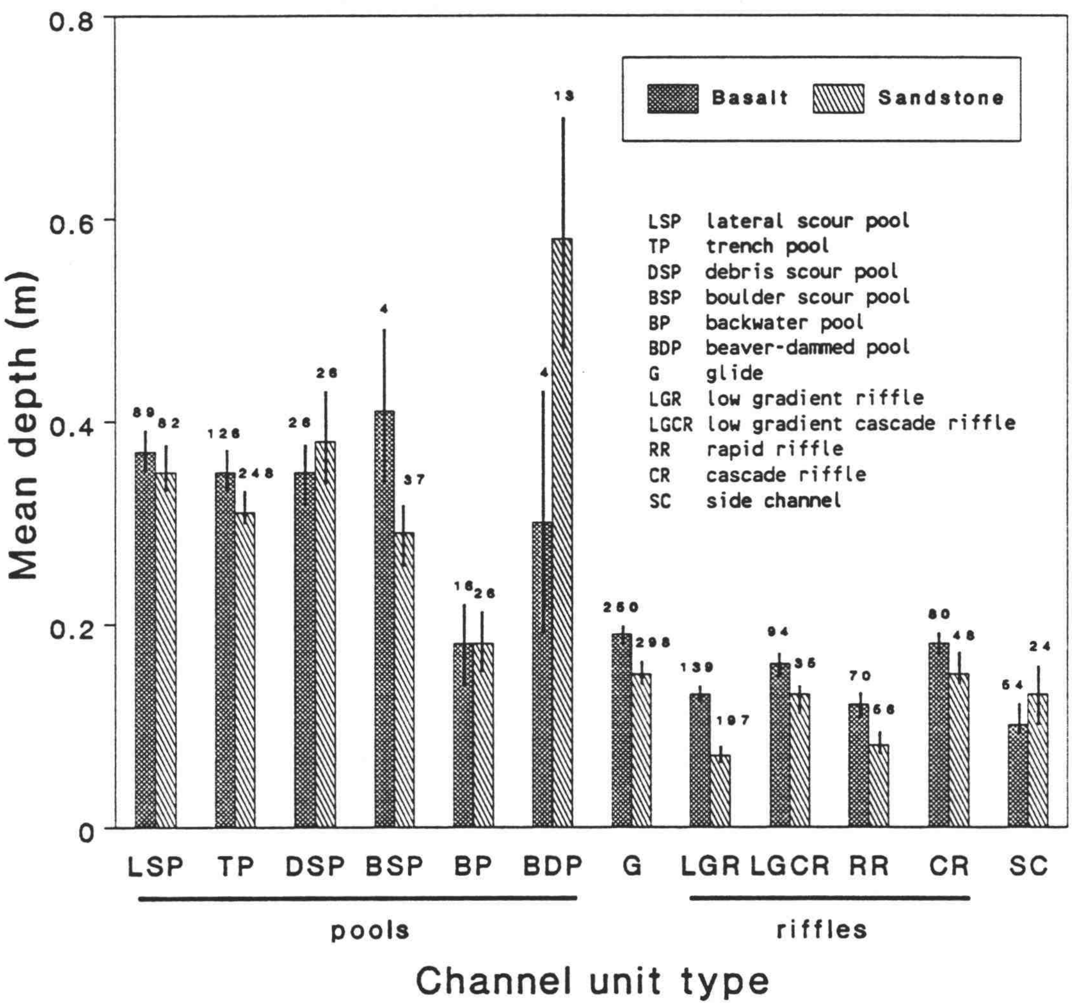

Figure 4.3. Means and 95% confidence intervals of depth of channel units in ten Oregon Coast Range streams in basalt and sandstone in summer 1988. Means calculated with data transformed with square root, sample sizes above bars.

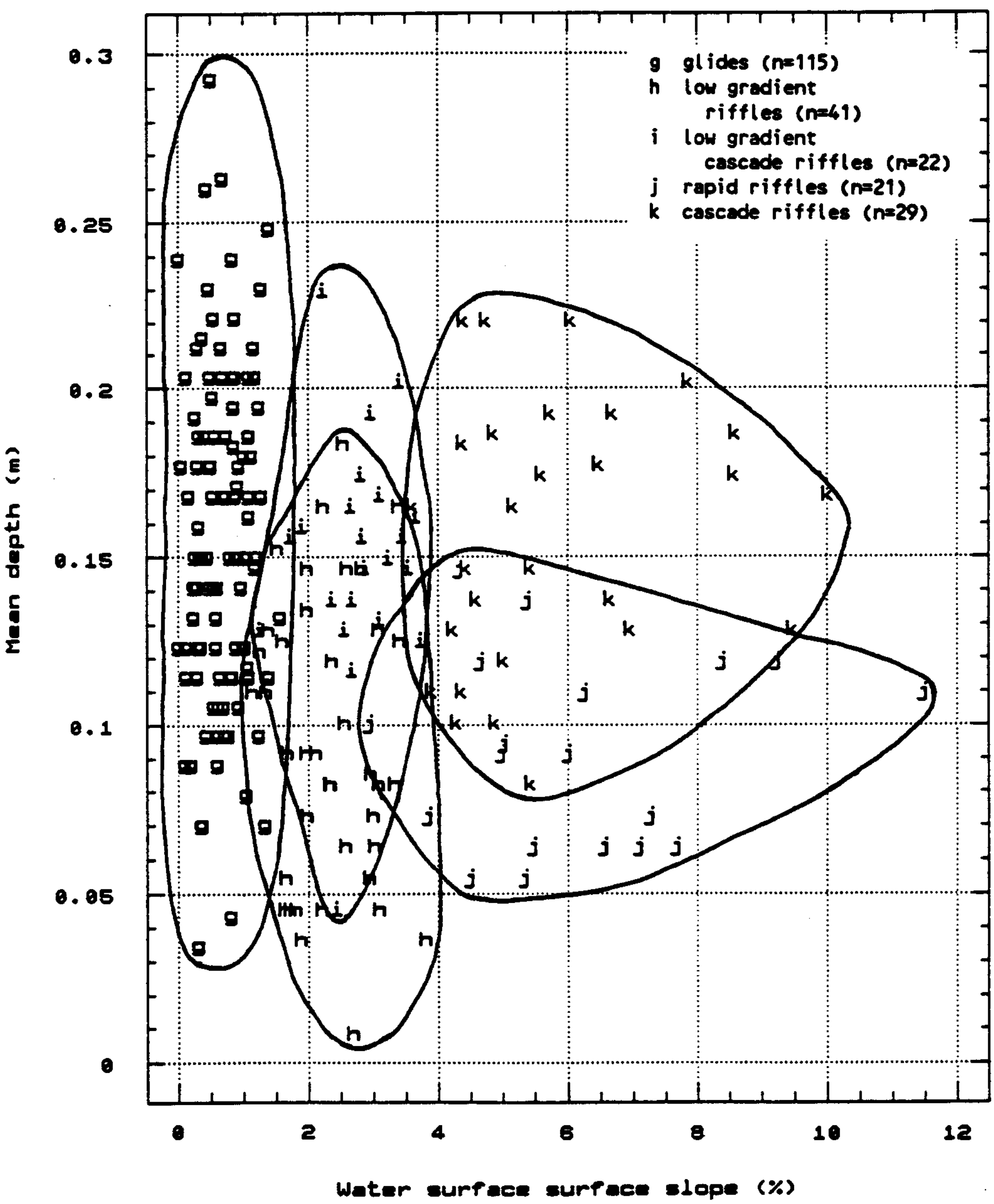

Figure 4.4. Depth and water surface slope of glides and riffles in ten Oregon Coast Range streams in summer.

Dominant substrate size was generally smaller in streams in sandstone than in basalt, and increased with increasing slope of channel units (Figure 4.5, Appendix 4.5). All pool types in both rock types, except boulder scour pools and beaver-dammed pools, had smaller dominant substrate than riffles. Dominant substrate size in pools was generally more variable than in glides and riffles, partly because of smaller sample sizes. Mean dominant substrate size in pools was smaller in sandstone than in basalt, though only lateral scour pools and trench pools had significantly different mean substrate sizes between rock types. Boulder scour pools had the largest mean dominant substrate size of all types in both rock types, and beaver-dammed pools had the smallest. Substrate in boulder scour pools was usually composed of large boulders on a bed of gravel which could be scoured by high flows.

Among glides and riffles in both rock types, steeper habitats had larger dominant substrate than lower gradient habitats (Figure 4.5). Low gradient cascade riffles, however, had larger mean substrate size than the shallower low gradient riffles. Cascade riffles had the largest dominant substrate of any channel unit type, and size was larger in sandstone than in basalt.

Width/depth ratio was a useful dimensionless criterion with which to distinguish pools, glides, and riffles (Figure 4.6A, Appendix 4.6). Higher values express greater widths for equivalent depths. All channel unit types within a rock type except side channels had significantly different width/depth ratios (i.e., as determined by 95% confidence limits around means derived from square-root transforms). Pools and riffles had greater width/depth ratios in streams in sandstone compared to streams in basalt, but glides were not different (Figure 4.6A). As riffles were also narrower in sandstone than in basalt (Figure 2.7, Chapter 2), their mean depths were much less than in riffles in basalt. Mean width/depth ratios of both rock types combined were different for glides (26.9) and side channels (17.0), and for riffle types (cascade riffles 25.3; low gradient cascade riffles 30.8; low gradient riffles 47.2; and rapid riffles 49.3 - Figure 4.7A,

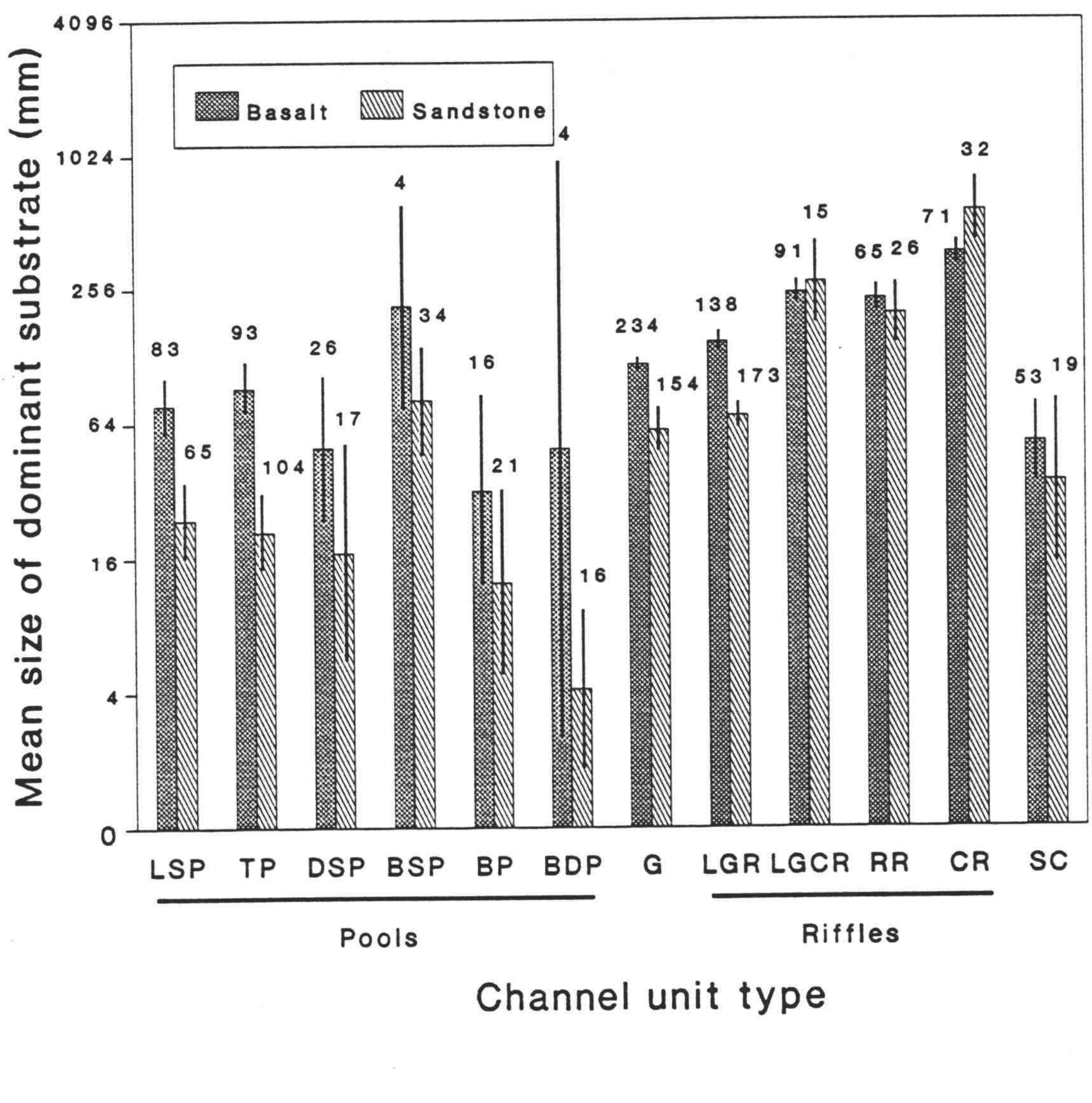

Figure 4.5. Geometric means and 95% confidence intervals of size of dominant substrate in channel units in Oregon Coast Range streams in basalt and sandstone in 1987 and 1988. Sample sizes above bars, Y axis based on $\log_2$ scale.

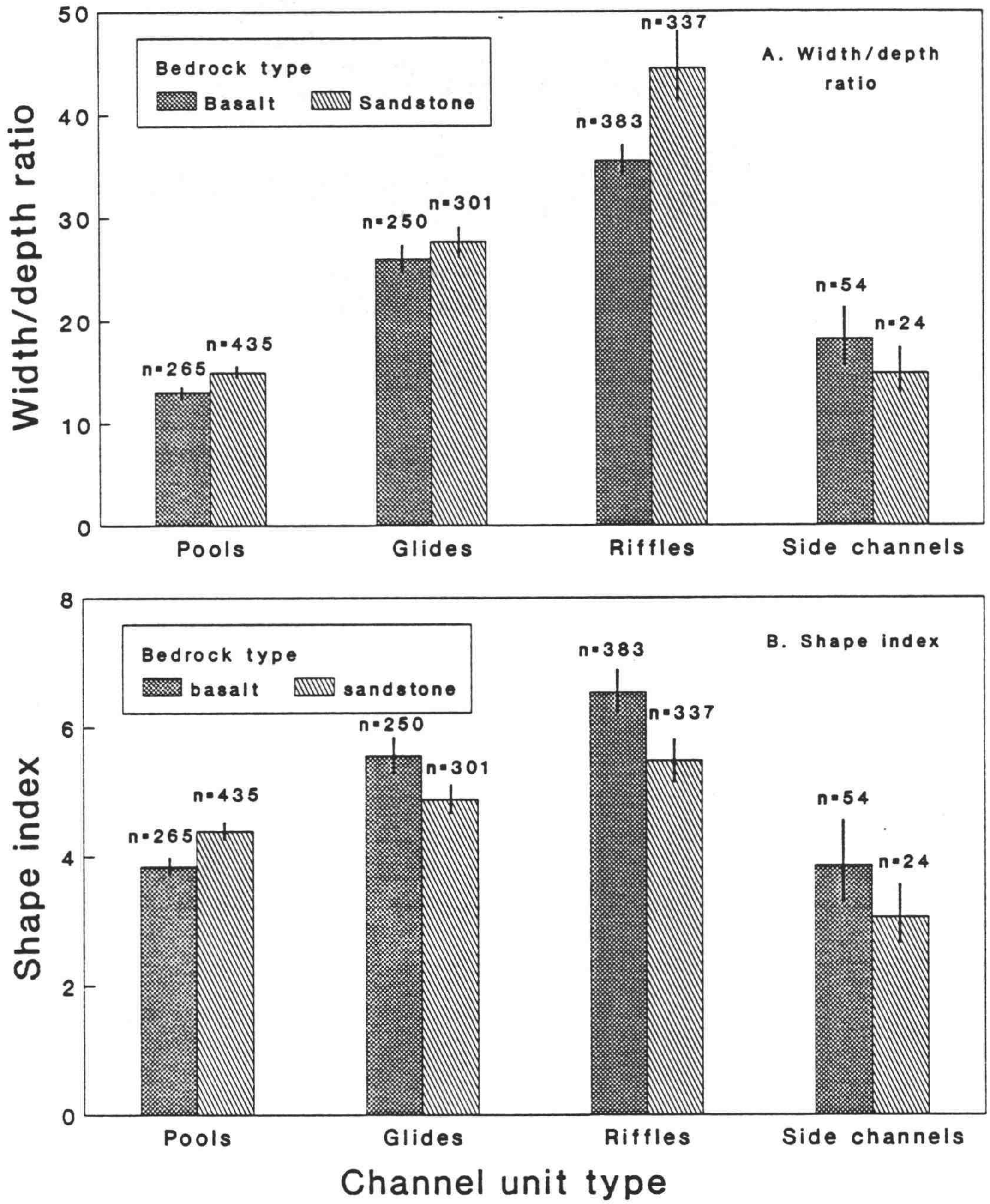

Figure 4.6. Means and 95% confidence intervals of (A) width/depth ratio and (B) shape index (Orth 1983) of channel units in ten Oregon Coast Range streams in basalt and sandstone in summer 1988.

Appendix 4.6). All were different except low gradient riffles and rapid riffles. Mean width/depth ratios were not different among secondary pool types, except for trench pools, which had larger values (15.5) than lateral scour pools (12.5) or backwater pools (12.4).

A shape index based on mean width ($\bar{w}$), average depth ($\bar{d}$), and maximum depth (d_{max}) has been used to separate pools and riffles (Orth 1983), and is as follows:

$$\text{Shape index} = \left(\frac{\bar{w}}{\bar{d}}\right)^{\left(\frac{\bar{d}}{d_{max}}\right)} .$$

Because pools generally have lower width/depth ratios than riffles and glides, and greater maximum depth compared to mean depth, the shape index should increase the difference between them.

Mean shape index of primary channel units was different for pools, glides, and riffles in this study, and different between rock types (Figure 4.6B). Confidence limits around means for all streams in both rock types combined were 4.2-4.4 for pools, 5.2-5.6 for glides, 6.2-6.8 for riffles, and 3.4-4.5 for side channels (Appendix 4.7). Mean shape index of pools was lower in basalt than in sandstone, but mean shape index of glides and riffles was higher in basalt than in sandstone, reflecting greater maximum depths compared to mean depths in sandstone. All secondary riffle types in sandstone showed greater maximum depths compared to mean depths than did riffles in basalt (Figure 4.7B); that is, shape indices for riffles in sandstone had lower values relative to those in basalt than did width/depth ratio. Shape index of side channels was not different between the two rock types.

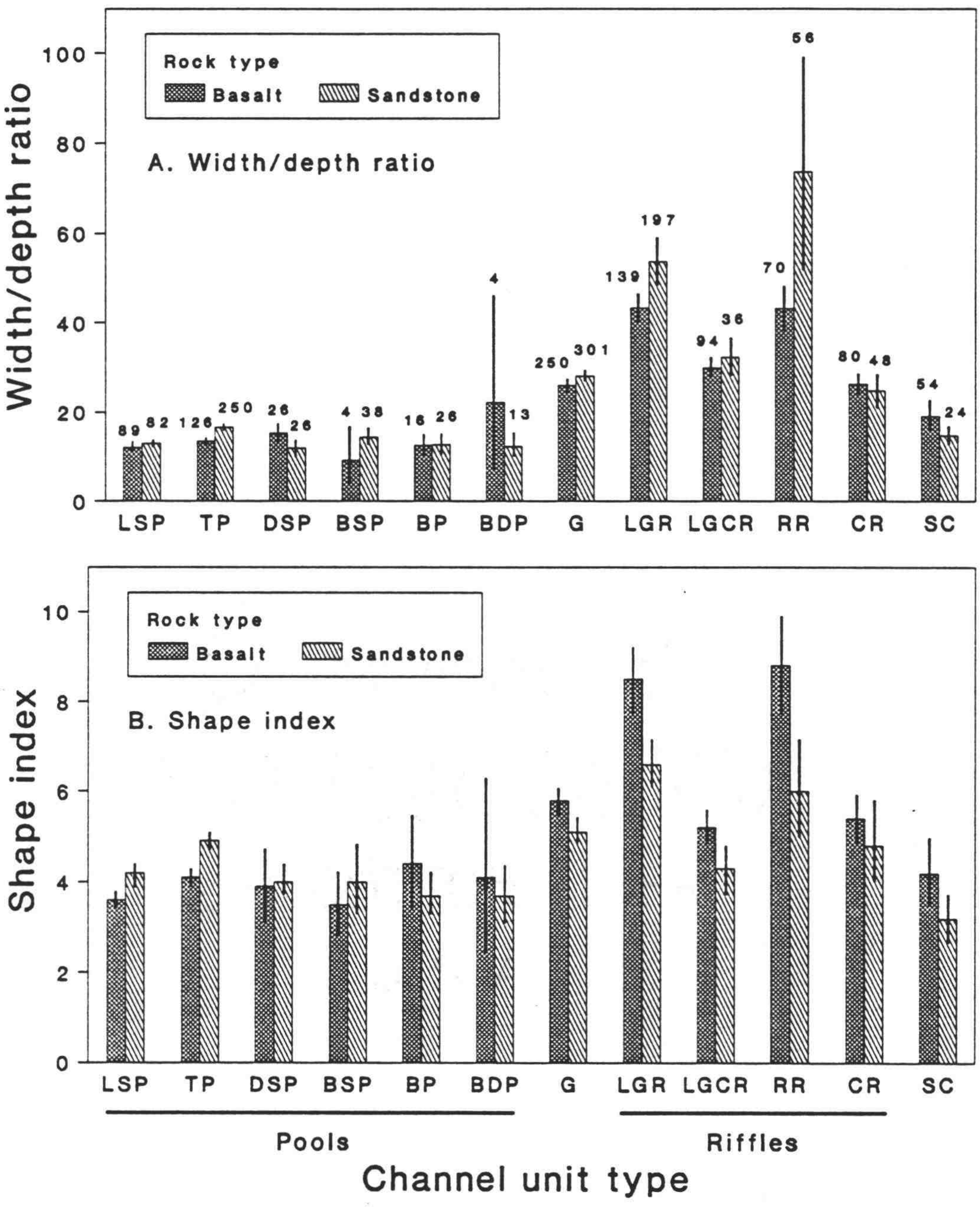

Figure 4.7. Means and 95% confidence intervals of (A) width/depth ratio and (B) shape index (Orth 1983) of channel units classified with a modification of the scheme of Bisson et al. (1982) in ten Oregon Coast Range streams in summer 1988. Sample sizes above bars.

As a classification criterion the shape index performed similarly to width/depth ratio (Figure 4.7, Appendices 4.6 and 4.7). However, some differences between secondary channel units were greater with the shape index than with width/depth ratio, for example, between lateral scour pools and trench pools. Thus mean shape index was proportionately more different than mean width/depth ratio between channel unit types and between rock types, and showed useful morphometric differences between rock types.

Habitat Use by Salmonids

Salmonids were specific in their habitat use. Age 0 coho salmon used pools in preference to glides or riffles in both rock types (Figure 4.8). Riffles and glides were avoided by age 0 coho salmon. In streams in basalt, boulder scour pools, debris scour pools, and backwater pools were highly preferred by age 0 coho salmon (Figure 4.8A), though there were very few of these channel units (<4% of all pool types by length, Appendix 4.8). In streams in sandstone, age 0 coho salmon used debris scour pools, trench pools, and lateral scour pools preferentially (Figure 4.8B).

Age 0 steelhead and trout used backwater pools in basalt and boulder scour pools in sandstone most preferentially (Figure 4.8). Debris scour pools in both rock types, which were preferred by age 0 coho salmon, the most aggressive species, were avoided by age 0 steelhead and trout. Boulder scour pools were preferred by trout in basalt, yet age 0 coho salmon also displayed a high preference for this habitat. The large size of substrate in boulder scour pools (Figure 4.5), and hence abundant crevice habitat, may have allowed age 0 steelhead, trout, and coho salmon to share the same pool habitat. Glides, low gradient cascade riffles, and cascade riffles in both rock types were occupied by about average densities of age 0 steelhead and trout. Glides and riffles are thus important summer rearing areas in streams in basalt because together they constitute about 80% of the channel length (Appendix 4.8).

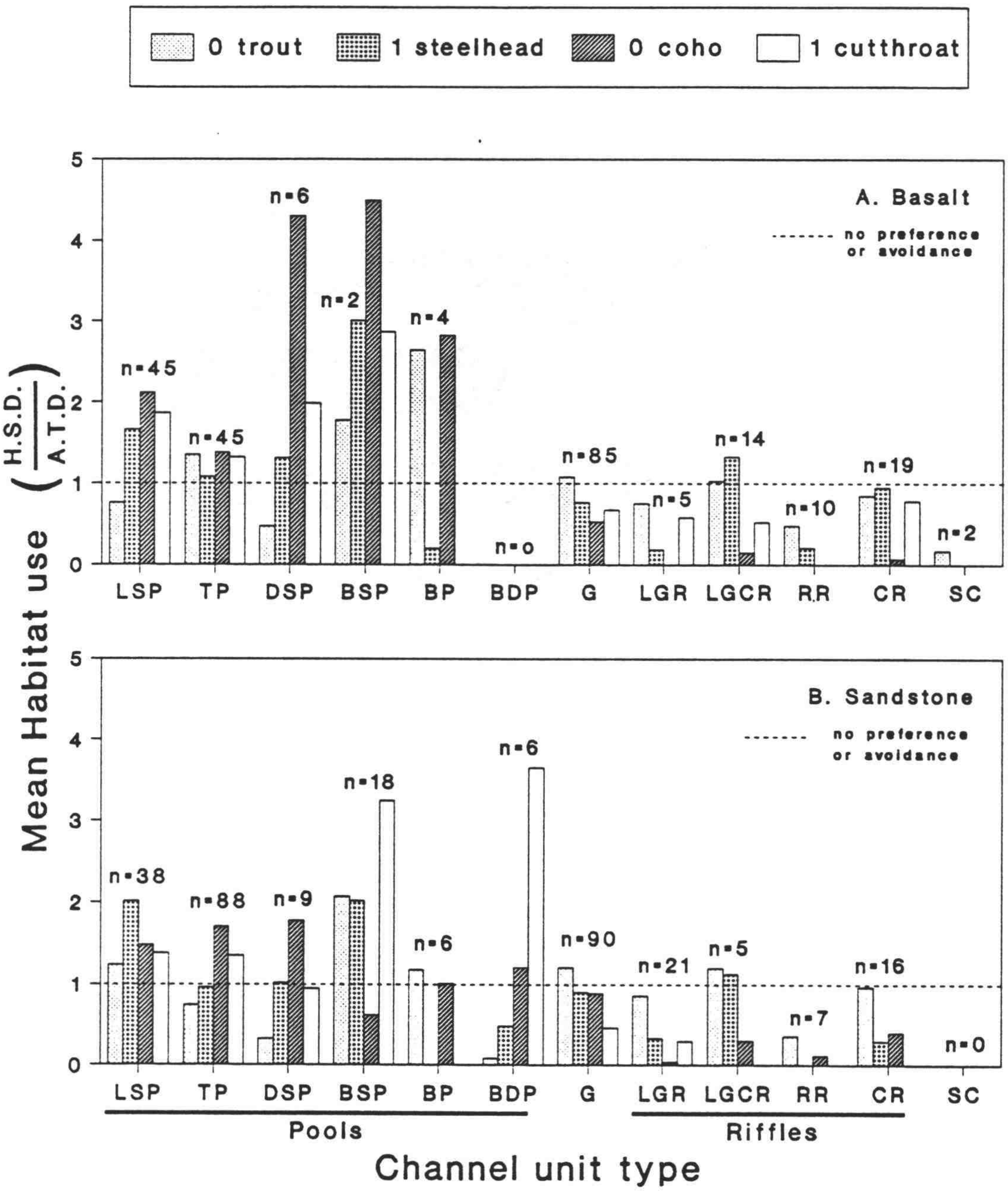

Figure 4.8. Mean habitat use by salmonids in Oregon Coast Range streams in (A) basalt and (B) sandstone in summer 1987 and 1988. (H.S.D. = habitat specific density (fish/m); A.T.D. = average total density (fish/m)).

Age 1 and older steelhead and trout in both rock types preferred boulder scour pools and lateral scour pools most strongly. (Figure 4.8A and B). Cutthroat trout showed a strong preference for beaver-dammed pools in streams in sandstone, and for debris scour pools in basalt. The main difference between habitat use by age 1 and older steelhead and resident rainbow trout, and by cutthroat trout, was the preference of low gradient cascade riffles by age 1 and older steelhead and resident rainbow trout in both rock types. Cascade riffles in basalt and glides in sandstone had about average densities of age 1 and older steelhead and resident rainbow trout. The use made of deep riffles (low gradient cascade riffles and cascade riffles) by age 1 and older steelhead and resident rainbow trout is especially significant in streams in basalt because deep riffles were 24-29% of the channel length (Appendix 4.8).

Low gradient riffles were avoided strongly by all species and age classes except age 0 steelhead and trout, which avoided these habitats only slightly. Too few beaver-dammed pools in basalt, and side channels in both rock types, were dived to assess their significance to salmonids.

Distribution of Channel Units

The clear differences among proportions of primary channel units that were seen between streams in basalt and sandstone (Chapter 2) were not apparent among secondary channel units. However, there were 6 times more length in low gradient cascade riffles in streams in basalt than in sandstone in 1988 (Appendix 4.8). Lateral scour pools and trench pools were the most abundant pool types by length, but there was considerable variability in the proportions of secondary channel units between streams within a rock type (Appendix 4.8). Length of glides was not different between rock types. Numbers of secondary channel units per kilometer, and proportion of length in different secondary channel unit types, were generally not significant between rock types (Appendices 4.8 and 4.9). However, there were more trench pools in streams in sandstone than in basalt, and more low gradient cascade riffles in basalt than in sandstone (Mann-Whitney *U* test, p=0.008).

Individual streams reflected their gradient and substrate in their channel morphologies. For instance, the steepest stream studied, Tenmile Creek in basalt, had the greatest length in riffles of any stream (58.3% of its length). Franklin Creek, with boulder and gravel bed composition, had the greatest proportion of boulder scour pools of any stream (11.9% of its length in 1988).

Discussion

Because patterns of habitat use by salmonids differed, splitting primary channel units into secondary units had value in predicting the importance of various habitats to salmonids. These patterns may also have value in determining sampling strategies. Low gradient cascade riffles in both rock types and cascade riffles in basalt had special importance among riffle types, and were used more than other riffle types by age 1 and older steelhead and resident rainbow trout. Age 0 steelhead and trout, and age 1 and older cutthroat trout, also used low gradient cascade riffles and cascade riffles more than low gradient riffles or rapid riffles. Pattern of fish utilization of deep riffles (i.e., low gradient cascade riffles and cascade riffles) was more similar to glides than to low gradient riffles or rapid riffles (Figure 4.8A). Occupancy of low gradient cascade riffles and cascade riffles by steelhead and trout was probably attributable to their mean depths, which are greater than in low gradient riffles or rapid riffles, giving a larger volume.

Width/depth ratio and shape index indicate that glides, low gradient cascade riffles, and cascade riffles have similar width and depth. However, water slopes, and hence hydraulic energy and water velocities, differ considerably. Cascade riffles are high-energy environments because of their steep water surface slopes (geometric mean 6%, Appendix 4.3), but present a mixture of fast and slow water velocities because of ribbed structure and large dominant substrate size (small boulders in basalt, medium boulders in sandstone). Such mixtures of water velocities provide optimum feeding conditions for salmonids, especially steelhead and trout, which can shelter in slow velocity water, but move out to feed in adjacent fast velocity water (Smith and Li 1983). Age 0 coho salmon avoided cascade riffles in streams in sandstone less than cascade riffles in streams in basalt (Figure 4.8B). Streamflows were so low in streams in sandstone when salmonids were counted in 1987 that cascade riffles were reduced to a series of still, deep pockets of water, usually with a bedrock base. Thus cascade riffles in sandstone under conditions of low summer streamflows did not have the high energy, turbulent environment present in cascade riffles in streams in basalt.

Salmonid numbers were estimated in too few low gradient cascade riffles and cascade riffles in this survey because the importance of these habitats was not known a priori. Only one-tenth of all riffles were sampled, and low gradient cascade riffles and cascade riffles together were only 24% and 43% numerically of riffles in streams in sandstone and basalt respectively in 1988 (Appendix 4.9). Riffles were generally longer in basalt than in sandstone. Low gradient cascade riffles were nearly 20% of the channel length in basalt, but only 3% in sandstone in 1988 (Appendix 4.8). Low gradient cascade riffles and cascade riffles were more important to steelhead and trout than were shallow riffle types, and were inadequately sampled numerically. Dive counts of salmonids in riffle habitats were difficult because of their shallow depths. In low gradient cascade riffles dive counts were particularly difficult because of considerable length of individual riffles (geometric mean 27 m, Appendix 4.2). However, the importance of these habitats suggests that they should be sampled with the same frequency as pools and glides.

Pool habitat was sought after by large (age 1 and older) salmonids. In streams in basalt, boulder scour pools, debris scour pools, lateral scour pools, and trench pools were important to cutthroat trout, resident rainbow trout, and steelhead. In streams in sandstone, beaver-dammed pools and boulder scour pools were very important for age 1 and older cutthroat trout. Beaver-dammed pools may have been equally important to cutthroat trout in streams in basalt, but none were sampled.

Age 0 steelhead and trout may have been competitively excluded from debris scour pools by age 0 coho salmon. This would explain low habitat utilization by steelhead and trout accompanied by high habitat utilization by age 0 coho salmon. Exclusion of age 0 steelhead and trout by age 0 coho salmon may also account for occupancy patterns in lateral scour pools in basalt and beaver-dammed pools in sandstone. However, age 0 trout showed a preference for boulder scour pools, which had abundant crevice habitat. Large substrate size found in boulder scour pools offers more crevice habitat for salmonids than small substrates. Crevices may have allowed steelhead and trout to avoid intense competition with coho salmon while still occupying the same habitat. Age 0 steelhead and trout were also not excluded from backwater pools by age 0 coho salmon, but were found to avoid backwater pools by Bisson et al. (1982). Backwater pools in my study were generally isolated from the main channel, and steelhead and trout may have been trapped in them with coho salmon by receding streamflows.

The channel unit classification described by Bisson et al. (1982), and modified in this study, has as its basis a combination of shape and morphogenic characteristics. Glides and riffle types were readily identified on the basis of mean depth and water surface slope. Secondary pool types, however, were less easily distinguished with shape characteristics that were easily measured at low flows. The maximum size of stream to which this classification system can be applied is uncertain. The modified scheme of primary and secondary channel units was relatively robust over a range of streamflows in two very different rock types, sandstone and basalt, with streams draining about 600 to 2000 ha. Bisson et al. (1988) have used the original system of Bisson et al. (1982) in streams with basin areas up to 3300 ha, and my modifications are likely to be appropriate in streams of that size. The usefulness of either classification scheme is uncertain in basins smaller than 600 ha or larger than 3300 ha.

Mean width/depth ratios of primary channel unit types were distinct, and were an auxiliary variable for classifying channel units. Approximate width/depth ratios of pools were <20; glides, low gradient cascade riffles, and cascade riffles had width/depth ratios of about 25-30; and low gradient riffles and rapid riffles had width/depth ratios of greater than about 40 (Figure 4.7A, Appendix 4.6). Mean shape indices of pools, glides and riffles in this study were 3.4 to 6.8 (Figure 4.7B, Appendix 4.7), considerably less than the criteria for distinguishing pools (shape index <9) from riffles (shape index >9) reported by Orth (1983). The data for shape index reported by Orth (1983) were taken from Shirvell (1982). Mean widths of the streams from which the data came were 6.3-14.0 m (Shirvell 1982), wider than mean widths in my study (3.3-5.5 m, Appendix 2.9, Chapter 2). The difference between the mean shape index for pools (9.2) and riffles (13.3) from Shirvell (1982), and my data (pools, 4.2; riffles, 6.0), suggests that the shape index is not independent of stream size.

Width/depth ratio may be less dependent on stream size than shape index. Representative values of width/depth ratio from the 14-m wide Deep Stream in New Zealand were 15 for pools and 37 for riffles (Shirvell 1982), very close to the values for pools (14) and riffles (39) for all streams combined in this study (Appendix 4.6). Comparison of shape index and width/depth ratio was useful to show differences in channel unit morphology between rock types, especially in glides and riffles.

The system of Rosgen (1985) was useful as a broad categorization of stream types, separating streams dominated by steelhead and trout from those dominated by coho salmon. However, a decision was required about the importance of classification criteria. Criteria conflicted when, for example, stream gradients did not match substrate types for a particular stream class; Tenmile Creek was in class B1 for overall gradient, but in class B3 for substrate. Rosgen's scheme was applied simply in this study, using topographic gradient as the primary criterion of classification. Minor local variations in gradient, substrate, and channel width were ignored, and the predominant Rosgen classification for an entire 3 km segment was chosen as the stream class.

Salmonid abundances for the whole 3 km segment of each stream were also compared. Streams of type B1, B2, and B3 were dominated by steelhead and trout, and streams of type C1-1 were dominated by coho salmon. The salmonid population of Franklin Creek, the only class B4 stream in my study, was dominated by age 0 coho salmon, but had relatively high abundance of age 0 and age 1 and older steelhead and trout in early summer 1987 compared to adjacent type C1-1 streams. Low streamflows in late summer 1987, however, might have been responsible for very low survival of age 0 trout, reflected in low abundance of age 1 and older steelhead and resident rainbow trout in 1988. The large amount of gravel in the channel of Franklin Creek caused sub-surface flow, and the stream was dry in many places in late summer 1987 and 1988. In addition, low streamflows in fall 1987 (Chapter 2) prevented adult coho salmon from reaching much of the stream segment in which age 0 fish were present in summer 1987. Consequently, their abundance in Franklin Creek was much lower in 1988 than in 1987 (Figure 4.3).

North Fork Beaver Creek had more age 0 trout, and age 1 and older steelhead, resident rainbow trout, and cutthroat trout than other C1-1 streams. Summer streamflows were much greater in North Fork Beaver Creek than in other streams in sandstone, probably due to its coastal position (Chapter 2). Greater summer streamflows compared to streams further inland result in greater volume in coastal streams, especially in glides and riffles (Chapter 2). Steelhead and trout use glide and riffle habitats (Figure 4.8A and B), and their abundance is related to volume (Chapter 3).

In another comparison of fish populations related to Rosgen's classification, Reeves and Everest (in press) took a smaller-scale approach. Five streams were compared in the Oregon Coast Range. Segments within a single stream were sometimes divided into several different classes on the basis of local variations in channel morphology (Table 4.2). Stream reaches could be classified into any of nine stream types, and it was concluded from this fine-scale approach that Rosgen's system had little power to predict salmonid abundance. Reeves and Everest's primary criticism of Rosgen's system of stream classification was that streams in the Oregon Coast Range were generally too variable between reaches to allow characterization as one uniform Rosgen channel type. Habitat types identified with the Rosgen system were poorly correlated with salmonid abundance, although Reeves and Everest (in press) concluded that coho and chinook salmon densities were greatest in class C streams, and steelhead densities were greatest in class B streams.

As few streams were compared in my study, I recommend that comparison of salmonid populations in streams of different Rosgen types be extended before the conclusions are considered to hold for a wider area. Broad-scale application of Rosgen's clasification, however, appears to have some utility in predicting salmonid abundance in the

Oregon Coast Range, assuming basins of similar size are compared.

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Chapter 5. Concluding Discussion

Variability of the Response of Salmonids to Timber Harvest

Studies of the response of salmonids to timber harvest have shown increased salmonid production in some instances and decreased production in others (Hicks et al. in press). One reason for these mixed results might be the influence of different local geoclimatic conditions. A major aim of my study was to compare salmonid populations in streams in which the geologic context was different by design. As an unintended consequence of grouping streams in basalt and sandstone bedrock, however, climatic conditions were not the same in all watersheds. I have shown that geology and climate interact in small streams (about 1500 ha drainage area) in the Oregon Coast Range to produce salmonid populations characteristic of the conditions of channel morphology and streamflow in each stream. Streams in basalt have higher standing stocks of steelhead, resident rainbow trout, and cutthroat trout than of coho salmon. Streams in sandstone have higher standings stocks of coho salmon than of steelhead and trout (Appendix 3.5). Although chinook salmon occur widely in larger streams and rivers of the Oregon Coast Range (Nicholas and Hankin 1988), they were not important in basins of the size I studied.

Instream production is only one part of the life history of anadromous fish. Anadromy is a widespread life history strategy in streams of the Pacific Coast of North America. Space limitations of streams, unstable instream conditions of drought and flood, and the highly productive ocean environment available to Pacific coastal salmonids have made anadromy a viable life history (Gross 1987; McDowall 1987; Gross et al. 1988). However, the marine environment is not free from fluctuations in productivity. Marine survival of hatchery and wild coho salmon has been linked to variations in the strength of ocean upwelling and sea-surface temperatures (Nickelson 1986). In addition, harvest of adult anadromous salmonids in the ocean or on their return to freshwater causes variability the numbers of spawners. As a consequence, the number of juvenile salmonids present in streams is a result of variable density of spawning adults, and of variable stream habitat conditions.

Response of salmonids to timber harvest should be viewed against a complex background of life histories of several species involving anadromy and stream residency (Hicks et al. in press). In addition, forest management practices have not remained static in the past 100 years. Timber harvest has moved from lowland, coastal forest to progressively higher elevations further inland. Forest practice regulations have also changed. Transport of logs has changed from splash damming and water transport to log hauling on extensive road networks. In the process, problems for salmonid populations and fishery managers have shifted from drastic channel simplification caused by log drives down stream channels (Wendler and Deschamps 1955; Sedell and Luchessa 1982; Sedell and Duval 1985) to debris avalanches caused by clear-cut logging and road-related slope failures (Swanson et al. 1981; Rood 1984; Tripp and Poulin 1986a and 1986b).

Perspectives on management of riparian zones and stream channels, both in association with logging and independent of it, have also changed. During the 1950's and 1960's, accumulations of large woody debris in streams were viewed almost universally as impediments to upstream passage of adult salmonids, and jams and other large wood in streams were consequently extensively removed (Hall and Baker 1982; Bisson et al. 1987). The importance of large woody debris to salmonids began to be realized in the 1970's, but not before the amount of wood present in many streams had been seriously depleted compared to undisturbed watersheds (Sedell and Swanson 1984). The legacy of past management activities will be obvious in low debris loadings and simplified channel morphology for many years to come, despite the more careful treatment of stream channels now being practiced (Long 1987; Andrus et al. 1988; Heimann 1988).

Links Between Timber Harvest and Salmonid Production

Timber harvest can modify the habitat of salmonids through changes to channel morphology, streamflow, incident radiation, and nutrient regime (Hicks et al. in press; Hicks et al. MS). Large woody debris in stream channels interacts with coarse sediment and channel hydraulics to control channel morphology and energy dissipation (Heede 1972; Swanson and Lienkaemper 1978; Keller and Tally 1979; Marston 1982; Hogan 1986). However, in the streams I studied, channel morphology seemed to be little influenced by large woody debris, even in streams in undisturbed forest.

Increased yield of coarse sediment is a usual consequence of clear-cut logging and roading, and can lead to substantial changes in channel width and morphology (Lyons and Beschta 1983; Grant 1988). However, I found no convincing evidence of changes in channel width resulting from timber harvest. Active channel width was variable among streams, and controlled light availability.

Density of salmonids was positively correlated with proportion of basin area logged. Biomass of salmonids, however, was not correlated with amount of timber harvest or with shading. The productive capacity of the study streams for coho salmon might have been expected to be dependent on light availability, because Bilby and Bisson (in press) have demonstrated that coho salmon appeared to be limited by food derived from autotrophic production. I did not investigate the diets of salmonids in this study, but I suspect that terrestrial invertebrates were an important food of coho salmon in heavily shaded streams. Channel morphology inherent in basalt and sandstone, however, appears to control production of salmonid species relative to each other.

The importance of streamflow in controlling salmonid production was highlighted in this study, which was conducted in a particularly dry period. Streamflows appeared to control salmonid survival between summers, and to control access of adult salmonids to spawning areas. Age 1 and older steelhead, resident rainbow trout, and cutthroat trout were especially vulnerable to summer low flows because of their long period of freshwater residence. Coho salmon survival was also affected by low flows. Many channel units in sandstone that contained fish in early to midsummer 1987 were dry by late summer. Fish in these units died because the intermittent nature of the streams prevented fish from migrating downstream as flows diminished, but the effect on smolt output was not assessed. The desirability of coupling smolt sampling in spring with diving surveys in summer to assess survival of salmonids through the winter is evident.

Streamflow measurements were an extremely important adjunct to estimates of habitat availability. With flow gaugings, I was able to identify streams with serious summer habitat limitations, and to relate habitat availability to streamflow. Thus flow measurements were vital to quantify changes in habitat availability at different flows. Habitats changed qualitatively as well as quantitatively with changing streamflows. In two streams in sandstone there was a reduction in the number of riffles and an increase in the number of glides due to increased water depth and reduced water surface slope at higher streamflows in 1988 compared to 1987. In two other streams in sandstone, the number of all channel units was reduced in 1988 compared to 1987. The latter streams had the lowest flows of streams surveyed in 1987, and increased streamflow in 1988 submerged the boundaries between many units. Increased depth joined pools and flooded riffles and glides seen in 1987, thus reducing the total number of channel units but increasing volume. Volume of channel units was the variable of physical habitat most highly correlated to salmonid biomass.

Conclusions

I began this study with specific hypotheses. I feel these have been largely confirmed, though I did not demonstrate that changes in channel morphology were caused by timber harvest. My findings can be summarized as follows:

(1) Channel morphology was consistently different between streams in basalt and sandstone. The proportions of pools, glides, and riffles were adjusted to channel gradients that could be measured from topographic maps, and stream channels were steeper in basalt than in sandstone.

(2) Differences in channel morphology were reflected in differences in salmonid populations in each stream. Steelhead, resident rainbow trout, and cutthroat trout were dominant in streams in basalt, where riffles were the dominant habitat. In the less steep streams in sandstone, which had mostly pool habitat, coho salmon predominated.

(3) Salmonid densities appeared to increase with proportion of basin area logged, but biomass was not significantly correlated with amount of timber harvest. Salmonids in streams in sandstone may be more susceptible to habitat changes than salmonids in basalt because of lower summer streamflows and less stable channel morphology in sandstone.

(4) Stream channels were wider in logged streams in basalt than in unlogged streams, but the evidence was not convincing. Pool depths and abundance were not reduced by the effects of logging in streams of this basin area (1500 ha).

My study has answered some basic questions about factors controlling the distribution of coho salmon, steelhead, resident rainbow trout, and cutthroat trout. Knowledge of rock type, channel gradient, and precipitation, all available from maps or other documentation, allows predictions to be made about streams in the Oregon Coast Range that are most suitable for steelhead and trout or for coho salmon. These results may also be extended to other areas with similar rock types, though further tests of the validity of these predictions are desirable.

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APPENDIX

Appendix Table 2.1. Latitudes and longitudes of upstream and downstream ends of surveyed stream segments in the Oregon Coast Range.

Stream	Upstream end		Downstream end	
	latitude	longitude	latitude	longitude
<u>Basalt</u>				
Bob	44° 14' 44"	124° 06' 38"	44° 14' 47"	124° 04' 43"
Rock	44° 11' 11"	124° 06' 27"	44° 11' 34"	124° 04' 33"
Tenmile	44° 12' 55"	123° 58' 23"	44° 13' 10"	123° 56' 49"
Cape	44° 08' 01"	124° 05' 05"	44° 08' 27"	124° 02' 55"
N.F. Wilson	45° 38' 49"	123° 31' 23"	45° 39' 41"	123° 30' 50"
<u>Sandstone</u>				
Franklin	43° 40' 16"	123° 53' 58"	43° 40' 57"	123° 52' 56"
Halfway	43° 45' 49"	123° 35' 36"	43° 44' 26"	123° 33' 45"
Paradise	43° 42' 00"	123° 36' 28"	43° 42' 43"	123° 35' 04"
Big	43° 45' 24"	123° 40' 00"	43° 44' 38"	123° 40' 39"
N.F. Beaver	44° 31' 18"	123° 57' 10"	44° 31' 24"	123° 55' 45"

Appendix Table 2.2. Dates of surveys of physical characteristics of ten streams in the Oregon Coast Range.

Stream	Dates of physical surveys	
	summer 1987	summer 1988
Bob	10-13 Sep	30 Aug
Rock	4 Aug, 2-4 Sep	14 Sep
Tenmile	5, 16, 22-23 Sep	12 Sep
Cape	11, 16, 28-30 Jul	6, 8 Sep
NF Wilson	-[a]	8-10 Aug
Franklin	15, 21-24 Jul, 11 Aug, 9 Sep	12 Jul
Halfway	18-20 Aug	18 Jul
Paradise	21, 25-26 Aug	29 Jun
Big	14-17 Aug	24 Jun
NF Beaver	-	25-27 Jul

[a] not surveyed

Appendix Table 2.3. Estimated correction factors, $\hat{Q}$, of estimates of mean water surface width, mean active channel width, mean water depth, area, and water volume.

Channel unit	Estimated correction factor[a]					
	Width		Mean depth	Area	Volume	N
	water surface	active channel				
Pools	0.97	0.96	0.91	0.96	0.87	37
Glides	0.98	0.96	0.89	0.96	0.83	24
Riffles	1.02	1.01	0.92	1.05	0.96	30

[a] $\hat{Q}$ in equation (3), Hankin and Reeves (1988), p836.

Appendix Table 2.4. Size classes used to classify substrate (after Lane 1947)[a].

Substrate size classes				Phi class[b] (mm)
description	abbreviation	length of intermediate axis (mm)	(inches)	
bedrock		massive	massive	not applicable
very large boulders	VLB	4100-2050	160-80	11.5
large boulders	LB	2050-1020	80-40	10.5
medium boulders	MB	1020-510	40-20	9.5
small boulders	SB	510-255	20-10	8.5
large cobbles	LC	255-128	10-5	7.5
small cobbles	SC	128-64	5-2.5	6.5
very coarse gravel	VCG	64-32	2.5-1.3	5.5
coarse gravel	CG	32-16	1.3-0.6	4.5
medium gravel	MG	16-8	0.6-0.3	3.5
fine gravel	FG[c]	8-4	0.3-0.16	2.0
very fine gravel	VFG[c]	4-2	0.16-0.08	2.0
sand and silt	SS	<2	<0.08	0.5

[a] Lane, E.W. 1947. Report to the subcommittee on sediment terminology. Transactions of the American Geophysical Union 28:936-938.
[b] phi=$-\log_2$(length of median axis in mm)
[c] grouped for classification

Appendix Table 2.5. Rating scale used to visually determine volume of large woody debris.

Size class rating	Size (diameter (m) x length (m)) lower bound	upper bound	Volume (m^3) lower bound	mid-point	upper bound
1	≥0.1 x 3	<0.2 x 3	≥0.024	0.046	<0.094
2	≥0.2 x 3	<0.3 x 5	≥0.094	0.172	<0.353
3	≥0.3 x 5	<0.4 x 10	≥0.353	0.648	<1.257
4	≥0.4 x 10	<0.8 x 10	≥1.257	2.438	<5.027
5	≥0.8 x 10	<1.0 x 23	≥5.027	9.440	<18.064

Appendix Table 2.6. Chi-square tests of fit of frequency distributions to a normal distribution of (A) channel unit length, (B) mean water surface width, (C) mean water depth, and (D) water surface slope of Oregon Coast Range streams (data for summer 1987 only).

Channel unit type	Channel unit length (m)												
		Untransformed data						Transformed data					
	n	X^2	d.f.	p	mean	SD	CV	X^2	d.f.	p	mean	SD	CV
A. Channel unit length[a]													
pools	595	150.9	2	0.000E+00	14.99	14.30	95.4	10.5	8	2.332E-01	2.51	0.609	24.2
glides	447	257.2	11	0.000E+00	16.43	12.28	74.7	30.4	13	4.167E-03	2.60	0.600	23.1
riffles	645	381.6	12	0.000E+00	13.11	12.43	94.8	22.6	22	4.224E-01	2.20	0.887	40.3
side channels	68	98.4	5	0.000E+00	37.91	49.88	131.6	8.1	4	8.980E-02	3.20	0.869	27.2
all types	1756	1006.7	5	0.000E+00	15.57	16.77	107.7	46.7	16	7.642E-05	2.45	0.767	31.3
B. Mean water surface width[b]													
pools	588	88.1	12	1.137E-13	4.41	1.59	35.9	50.4	10	2.218E-07	2.07	0.380	18.4
glides	441	96.8	12	2.332E-15	4.09	1.79	43.7	41.7	12	3.709E-05	1.97	0.440	22.3
riffles	543	183.1	15	0.000E+00	4.32	2.34	54.2	61.5	13	2.855E-08	2.00	0.573	28.7
side channels	64	50.0	5	1.377E-09	1.81	0.83	45.8	67.0	6	1.685E-12	1.32	0.286	21.7
all types	1636	198.3	18	0.000E+00	4.19	1.96	46.8	141.8	15	0.000E+00	2.00	0.486	24.4
C. Mean water depth[b]													
pools	588	73.2	8	1.155E-12	0.299	0.12	40.5	29.1	10	1.216E-03	0.54	0.102	19.0
glides	441	56.3	14	5.072E-07	0.158	0.05	32.3	24.3	8	2.078E-03	0.39	0.068	17.4
riffles	544	95.6	20	7.574E-12	0.115	0.05	46.1	175.3	16	0.000E+00	0.33	0.086	26.2
side channels	64	14.8	5	1.120E-02	0.109	0.05	49.5	21.8	5	5.716E-04	0.32	0.086	27.0
all types	1637	339.4	12	0.000E+00	0.192	0.12	60.9	57.0	17	3.271E-06	0.42	0.127	30.2
D. Water surface slope[c]													
pools	103	468.8	6	0.000E+00	0.051	0.13	245.0	482.3	5	0.000E+00	0.05	0.117	243.8
glides	110	12.5	11	3.256E-01	0.677	0.36	53.2	12.7	9	1.757E-01	0.49	0.220	44.5
riffles	125	52.1	6	1.761E-09	4.269	2.84	66.5	6.4	8	5.980E-01	1.29	0.552	42.6

[a] ln transformation
[b] square-root transformation
[c] pools and glides transformed as ln(s+1), riffles as ln(s), where s=water surface slope in %

Appendix Table 2.7. Flows of ten Oregon Coast Range streams of 1500 ha basin area in basalt and sandstone rock types.

Stream	Surface water flow														
	l/s														l/s/km^2
	1987	1988													
	Oct	April	June		July				August		September			Oct	Oct
	4	14-27	14-16	24-29	3-13	18-21	25	27	3-15	23-31	3-20	21-22	26-29	12-31	12-31
Basalt															
Bob	44	699	576	-[a]	-	138	-	-	-	-	59	61	72	99	6.1
Rock	80	832	748	-	-	312	-	-	-	-	115	185	-	127	8.2
Tenmile	90	1280	856	-	-	215	-	-	-	-	83	-	-	65	3.8
Cape	89	811	807	-	-	255	-	-	-	-	135	157	-	133	8.0
Nth Fork Wilson	-	282[c]	287[c]	-	-	97[c]	-	-	78	-	74	51	-	64	4.6
Sandstone															
Franklin	2[b]	195	253	-	26	-	-	-	3[b]	-	2[b]	-	-	3[b]	0.21
Halfway	5	285	135	-	-	59	-	-	-	25	-	29	-	18	1.2
Paradise	1	172	87	83	52	29	-	-	-	15	10	-	-	9	0.56
Big	0[d]	208	65	33	-	10	-	-	-	1[b]	-	0[d]	-	2	0.13
Nth Fork Beaver	-	509	535	-	-	166	133	120	-	88	-	75	103	51	3.3

[a] flow not measured
[b] flow intermittent in places
[c] flow proportioned from adjacent Cook Creek
[d] no flow in study reach

Appendix Table 2.8. Geometric mean lengths and 95% confidence intervals of channel units in 10 Oregon Coast Range streams in (A) 1987 and (B) 1988[a].

A. 1987

Stream	N	Total length (m)	Channel unit length (m)				
			mean[b]	lower limit	upper limit	minimum	maximum
All channel units[c]							
Bob	188	3037	14.5	12.9	16.3	2.5	349.7
Rock	204	2895	12.8	11.6	14.2	1.1	134.1
Tenmile	186	3022	13.3	11.6	15.2	1.0	138.9
Cape	231	3078	12.3	11.4	13.3	1.7	71.9
Franklin	284	3023	8.9	8.2	9.7	1.0	54.8
Halfway	199	3376	12.6	11.2	14.0	1.8	291.5
Paradise	248	3047	9.3	8.4	10.3	1.0	59.0
Big	216	3187	11.9	10.8	13.0	2.4	95.1
Basalt streams							
Pools	212	2865	11.6	10.7	12.6	2.0	64.6
Glides	216	3416	13.8	12.9	14.8	4.3	57.1
Riffles	333	5751	12.3	11.1	13.5	1.0	81.4
Side channels	48	2177	29.8	23.2	38.3	4.7	349.7
Sandstone streams							
Pools	383	6034	12.7	12.0	13.6	1.0	291.5
Glides	231	3912	13.2	12.1	14.4	3.4	95.1
Riffles	312	2686	6.5	6.0	7.1	1.0	46.1
Side channels	20	398	15.3	11.2	20.9	4.2	84.9
Pools							
Bob	51	762	12.5	10.6	14.8	3.3	64.6
Rock	55	777	12.4	10.7	14.3	4.2	30.8
Tenmile	41	443	9.3	7.7	11.1	3.0	36.0
Cape	65	883	12.0	10.5	13.7	2.0	35.9
Franklin	123	1576	10.7	9.6	12.0	1.0	48.4
Halfway	82	1753	15.8	13.6	18.4	3.6	291.5
Paradise	85	1194	11.9	10.5	13.5	2.6	41.7
Big	93	1510	14.1	12.6	15.8	3.9	54.8

Appendix Table 2.8
A. 1987 (continued)

Stream	N	Total length (m)	Channel unit length (m)				
			mean[b]	lower limit	upper limit	minimum	maximum
Glides							
Bob	50	912	15.7	13.4	18.3	5.5	57.1
Rock	54	798	13.0	11.2	15.0	4.3	39.2
Tenmile	52	820	14.0	12.2	16.1	5.0	37.1
Cape	60	886	13.0	11.4	14.8	5.4	40.5
Franklin	54	601	9.8	8.5	11.3	3.7	28.7
Halfway	56	1092	14.5	11.8	17.7	3.4	80.9
Paradise	70	1174	13.8	12.0	16.0	3.9	59.0
Big	51	1046	15.5	12.7	18.8	5.3	95.1
Riffles							
Bob	74	1363	12.7	10.4	15.7	2.5	79.5
Rock	84	1320	11.7	9.8	14.1	1.1	50.1
Tenmile	84	1759	13.3	10.5	16.8	1.0	81.4
Cape	91	1309	11.5	10.0	13.3	1.7	71.9
Franklin	97	845	6.4	5.4	7.5	1.0	46.1
Halfway	56	531	7.5	6.1	9.1	1.8	36.7
Paradise	90	679	5.4	4.5	6.4	1.0	34.5
Big	69	631	7.6	6.6	8.9	2.4	37.2
Side channels							
Bob	13	840	41.5	25.5	67.6	10.6	349.7
Rock	11	410	28.8	19.2	43.2	15.6	134.1
Tenmile	9	615	49.3	27.1	89.7	16.3	138.9
Cape	15	312	17.0	11.9	24.1	4.7	53.1
Franklin	9	154	13.0	7.8	21.6	4.2	54.8
Halfway	5	140	19.4	8.9	42.2	9.6	84.9
Paradise	3	41	13.6	10.8	17.2	10.8	15.4
Big	3	62	18.9	9.9	36.2	10.3	31.3

Appendix Table 2.8 (continued)
B. 1988

Stream	N	Total length (m)	Channel unit length (m)				
			mean[b]	lower limit	upper limit	minimum	maximum
All channel units[c]							
Bob	188	3037	14.5	12.9	16.2	2.5	349.7
Rock	204	2895	12.8	11.6	14.1	1.1	134.0
Tenmile	186	3022	13.2	11.6	15.1	1.0	138.9
Cape	231	3078	12.2	11.3	13.3	1.7	71.8
Wilson	160	2988	16.0	14.4	17.8	2.1	91.1
Franklin	286	2957	9.0	8.3	9.7	0.6	115.5
Halfway	199	3390	12.7	11.4	14.2	2.7	225.5
Paradise	241	3012	10.0	9.1	10.9	1.0	59.9
Big	197	3156	12.2	11.0	13.5	1.5	117.1
Beaver	189	3019	13.2	12.0	14.6	3.0	96.5
Basalt streams							
Pools	266	3538	11.4	10.7	12.3	2.0	64.6
Glides	250	4007	13.9	13.0	14.9	4.3	57.1
Riffles	399	7475	13.3	12.2	14.6	1.0	91.1
Side channels	54	2389	29.9	23.8	37.5	4.6	349.7
Sandstone streams							
Pools	435	7379	13.2	12.4	14.1	2.2	225.5
Glides	299	5061	13.4	12.4	14.5	2.9	80.3
Riffles	349	3095	7.2	6.7	7.7	0.6	37.2
Side channels	28	544	16.1	13.0	19.9	8.2	89.9
Pools							
Bob	51	762	12.4	10.5	14.7	3.3	64.6
Rock	55	777	12.3	10.6	14.3	4.2	30.8
Tenmile	41	443	9.2	7.7	11.0	3.0	35.9
Cape	65	883	11.9	10.4	13.6	2.0	35.8
Wilson	54	673	11.0	9.5	12.7	2.1	26.4
Franklin	122	1508	10.3	9.2	11.5	2.2	63.6
Halfway	82	1810	15.8	13.5	18.5	4.5	225.5
Paradise	85	1212	11.8	10.4	13.5	2.9	59.9
Big	87	1664	15.6	13.7	17.9	3.6	117.1
Beaver	59	1184	16.1	13.6	19.0	4.0	96.5

Appendix Table 2.8
B. 1988 (continued)

Stream	N	Total length (m)	Channel unit length (m)				
			mean[b]	lower limit	upper limit	minimum	maximum
Glides							
Bob	50	912	15.6	13.4	18.2	5.4	57.1
Rock	54	798	12.9	11.2	14.9	4.3	39.2
Tenmile	52	820	14.0	12.1	16.1	4.9	37.1
Cape	60	886	12.9	11.3	14.8	5.3	40.5
Wilson	34	591	15.3	12.8	18.2	5.0	49.3
Franklin	70	830	10.3	9.1	11.7	3.9	30.3
Halfway	59	1116	13.8	11.3	17.0	2.9	80.3
Paradise	68	1044	12.5	10.8	14.6	3.2	56.0
Big	47	965	15.7	12.8	19.3	5.3	71.6
Beaver	55	1106	17.0	14.5	20.0	4.2	60.9
Riffles							
Bob	74	1363	12.7	10.3	15.6	2.5	79.4
Rock	84	1320	11.7	9.7	14.0	1.1	50.1
Tenmile	84	1759	13.3	10.5	16.8	1.0	81.3
Cape	91	1309	11.4	9.9	13.2	1.7	71.8
Wilson	66	1724	20.9	17.6	24.9	2.7	91.1
Franklin	83	617	6.0	5.2	7.0	0.6	27.8
Halfway	50	464	7.6	6.3	9.0	2.7	37.2
Paradise	85	755	6.9	5.9	8.1	1.0	34.3
Big	62	528	7.1	6.1	8.2	1.5	37.0
Beaver	69	729	9.0	7.8	10.3	3.0	29.4
Side channels							
Bob	13	840	41.4	25.4	67.5	10.6	349.7
Rock	11	410	28.7	19.1	43.1	15.5	134.0
Tenmile	9	615	49.3	27.1	89.6	16.2	138.9
Cape	15	312	16.9	11.9	24.0	4.6	53.0
Wilson	6	212	30.9	18.3	52.2	9.1	58.9
Franklin	10	173	14.7	10.4	20.9	9.1	43.0
Halfway	8	207	18.6	10.5	32.9	8.2	89.9
Paradise	3	41	13.6	10.8	17.1	10.8	15.3
Big	1	15	15.0	15.0	15.0	15.0	15.0
Beaver	6	108	17.0	12.3	23.3	11.1	29.4

[a] lengths of channel units in Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988.
[b] geometric mean calculated from ln(length)
[c] side channels not included in totals

Appendix Table 2.9. Water surface width in different channel unit types in Oregon Coast Range streams flowing through basalt and sandstone in summer (A) 1987 and (B) 1988[a].

A. 1987

Stream	N	Water surface width (m)		
		mean[b]	95% C.I. lower limit	95% C.I. upper limit
All channel units combined				
Bob	189	4.56	4.26	4.86
Rock	199	4.71	4.43	5.00
Tenmile	175	4.57	4.31	4.83
Cape	230	5.47	5.20	5.74
Franklin	257	3.28	3.11	3.46
Halfway	192	3.82	3.57	4.08
Paradise	213	3.63	3.38	3.88
Big	181	3.18	2.89	3.49
Pools				
Bob	51	4.67	4.17	5.20
Rock	55	4.40	4.00	4.82
Tenmile	41	4.23	3.81	4.67
Cape	64	4.96	4.59	5.34
Franklin	118	3.84	3.57	4.11
Halfway	82	4.68	4.31	5.07
Paradise	85	4.54	4.22	4.87
Big	92	4.54	4.17	4.94
Glides				
Bob	50	4.45	4.09	4.84
Rock	54	4.96	4.55	5.39
Tenmile	52	4.54	4.14	4.95
Cape	60	5.96	5.54	6.40
Franklin	51	3.27	2.94	3.61
Halfway	56	3.39	3.04	3.77
Paradise	70	3.49	3.06	3.95
Big	48	2.61	2.26	2.98

Stream	N	Water surface width (m)		
		mean[b]	95% C.I. lower limit	95% C.I. upper limit
Riffles				
Bob	74	5.26	4.75	5.79
Rock	79	5.31	4.83	5.81
Tenmile	74	5.17	4.77	5.58
Cape	91	6.22	5.84	6.61
Franklin	80	2.71	2.44	3.00
Halfway	50	3.22	2.77	3.71
Paradise	55	2.65	2.25	3.08
Big	40	1.45	1.14	1.80
Side channels				
Bob	14	1.65	1.30	2.04
Rock	11	1.62	1.17	2.15
Tenmile	8	1.78	1.22	2.44
Cape	15	2.16	1.54	2.89
Franklin	8	1.78	1.51	2.07
Halfway	4	1.66	0.94	2.58
Paradise	3	2.06	0.96	3.55
Big	1	1.04		
Basalt				
Pools	211	4.60	4.38	4.82
Glides	216	5.00	4.79	5.22
Riffles	318	5.52	5.29	5.75
Side channels	48	1.82	1.57	2.08
Sandstone				
Pools	377	4.34	4.18	4.52
Glides	225	3.22	3.02	3.42
Riffles	225	2.55	2.35	2.75
Side channels	16	1.75	1.51	1.99

Appendix Table 2.9 (continued). B. 1988

Stream	N	Water surface width (m)		
		mean[b]	95% C.I.	
			lower limit	upper limit
All channel units combined				
Bob	189	4.56	4.26	4.86
Rock	199	4.71	4.43	5.00
Tenmile	175	4.57	4.31	4.83
Cape	230	5.47	5.20	5.74
N.F. Wilson	160	4.23	4.01	4.45
Franklin	272	3.29	3.11	3.47
Halfway	197	4.27	4.01	4.53
Paradise	236	4.68	4.45	4.91
Big	197	4.24	3.98	4.50
N.F. Beaver	189	5.20	4.90	5.50
Pools				
Bob	51	4.67	4.17	5.20
Rock	55	4.40	4.00	4.82
Tenmile	41	4.23	3.81	4.67
Cape	64	4.96	4.59	5.34
N.F. Wilson	54	4.15	3.82	4.49
Franklin	119	3.74	3.46	4.03
Halfway	82	4.88	4.54	5.22
Paradise	85	5.26	4.97	5.55
Big	87	5.24	4.88	5.62
N.F. Beaver	59	5.84	5.32	6.39
Glides				
Bob	50	4.45	4.09	4.84
Rock	54	4.96	4.55	5.39
Tenmile	52	4.54	4.14	4.95
Cape	60	5.96	5.54	6.40
N.F. Wilson	34	4.44	4.11	4.78
Franklin	69	3.11	2.80	3.44
Halfway	59	4.10	3.71	4.52
Paradise	68	4.68	4.22	5.16
Big	47	3.78	3.37	4.23
N.F. Beaver	55	5.41	4.99	5.85

Stream	N	Water surface width (m)		
		mean[b]	95% C.I.	
			lower limit	upper limit
Riffles				
Bob	74	5.26	4.75	5.79
Rock	79	5.31	4.83	5.81
Tenmile	74	5.17	4.77	5.58
Cape	91	6.22	5.84	6.61
N.F. Wilson	66	4.52	4.22	4.84
Franklin	75	2.97	2.67	3.30
Halfway	50	3.98	3.49	4.51
Paradise	80	4.19	3.80	4.60
Big	62	3.33	2.94	3.74
N.F. Beaver	69	4.90	4.47	5.36
Side channels				
Bob	14	1.65	1.30	2.04
Rock	11	1.62	1.17	2.15
Tenmile	8	1.78	1.22	2.44
Cape	15	2.16	1.54	2.89
N.F. Wilson	6	1.32	0.88	1.84
Franklin	9	1.82	1.24	2.51
Halfway	6	1.15	0.33	2.49
Paradise	3	2.40	1.18	4.06
Big	1	3.12		
N.F. Beaver	6	1.57	0.59	3.02
Basalt				
Pools	265	4.50	4.32	4.69
Glides	250	4.92	4.73	5.12
Riffles	384	5.34	5.14	5.54
Side channels	54	1.76	1.54	1.99
Sandstone				
Pools	432	4.82	4.65	4.99
Glides	298	4.16	3.96	4.37
Riffles	336	3.84	3.65	4.04
Side channels	25	1.69	1.29	2.15

[a] widths of channel units in Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988.
[b] mean calculated from square root transformations of individual widths

Appendix Table 2.10. Mean water depth in different channel unit types in Oregon Coast Range streams flowing through basalt and sandstone in summer (A) 1987 and (B) 1988[a].

A. 1987

Stream	N	Mean water depth (m) mean[b]	95% C.I. lower limit	upper limit
All channel units combined				
Bob	189	0.182	0.169	0.195
Rock	199	0.206	0.191	0.222
Tenmile	175	0.189	0.177	0.202
Cape	229	0.203	0.192	0.215
Franklin	258	0.142	0.131	0.153
Halfway	192	0.182	0.163	0.201
Paradise	213	0.161	0.145	0.177
Big	182	0.159	0.143	0.177
Pools				
Bob	51	0.316	0.292	0.341
Rock	55	0.368	0.336	0.401
Tenmile	41	0.325	0.300	0.352
Cape	64	0.315	0.293	0.337
Franklin	118	0.222	0.207	0.238
Halfway	82	0.315	0.284	0.348
Paradise	85	0.287	0.266	0.309
Big	92	0.265	0.247	0.283
Glides				
Bob	50	0.174	0.165	0.183
Rock	54	0.189	0.178	0.200
Tenmile	52	0.184	0.174	0.195
Cape	60	0.198	0.188	0.208
Franklin	51	0.122	0.112	0.133
Halfway	56	0.128	0.118	0.139
Paradise	70	0.131	0.118	0.144
Big	48	0.112	0.101	0.124

Stream	N	Mean water depth (m) mean[b]	95% C.I. lower limit	upper limit
Riffles				
Bob	74	0.129	0.122	0.137
Rock	79	0.147	0.139	0.155
Tenmile	74	0.142	0.134	0.150
Cape	90	0.160	0.153	0.166
Franklin	81	0.070	0.062	0.078
Halfway	50	0.081	0.072	0.089
Paradise	55	0.060	0.050	0.070
Big	41	0.047	0.037	0.059
Side channels				
Bob	14	0.100	0.068	0.139
Rock	11	0.089	0.056	0.131
Tenmile	8	0.106	0.068	0.152
Cape	15	0.097	0.068	0.131
Franklin	8	0.088	0.057	0.126
Halfway	4	0.151	0.070	0.261
Paradise	3	0.133	0.083	0.195
Big	1	0.140		
Basalt				
Pools	211	0.331	0.317	0.344
Glides	216	0.187	0.181	0.192
Riffles	317	0.145	0.141	0.149
Side channels	48	0.098	0.082	0.114
Sandstone				
Pools	377	0.266	0.255	0.277
Glides	225	0.124	0.118	0.130
Riffles	227	0.065	0.060	0.070
Side channels	16	0.114	0.089	0.141

Appendix Table 2.10. (continued). B. 1988

Stream	N	Mean water depth (m) mean[b]	95% C.I. lower limit	95% C.I. upper limit
All channel units combined				
Bob	189	0.182	0.169	0.195
Rock	199	0.206	0.191	0.222
Tenmile	175	0.189	0.177	0.202
Cape	229	0.203	0.192	0.215
N.F. Wilson	160	0.238	0.216	0.260
Franklin	272	0.169	0.154	0.184
Halfway	195	0.212	0.192	0.233
Paradise	236	0.180	0.164	0.196
Big	197	0.165	0.149	0.183
N.F. Beaver	189	0.206	0.189	0.224
Pools				
Bob	51	0.316	0.292	0.341
Rock	55	0.368	0.336	0.401
Tenmile	41	0.325	0.300	0.352
Cape	64	0.315	0.293	0.337
N.F. Wilson	54	0.406	0.359	0.457
Franklin	119	0.279	0.257	0.303
Halfway	82	0.364	0.333	0.397
Paradise	85	0.330	0.307	0.354
Big	87	0.297	0.277	0.318
N.F. Beaver	59	0.379	0.351	0.407
Glides				
Bob	50	0.174	0.165	0.183
Rock	54	0.189	0.178	0.200
Tenmile	52	0.184	0.174	0.195
Cape	60	0.198	0.188	0.208
N.F. Wilson	34	0.187	0.176	0.199
Franklin	69	0.126	0.114	0.138
Halfway	58	0.157	0.146	0.169
Paradise	68	0.154	0.143	0.166
Big	47	0.119	0.108	0.130
N.F. Beaver	55	0.187	0.179	0.196
Riffles				
Bob	74	0.129	0.122	0.137
Rock	79	0.147	0.139	0.155
Tenmile	74	0.142	0.134	0.150
Cape	90	0.160	0.153	0.166
N.F. Wilson	66	0.163	0.154	0.173
Franklin	75	0.081	0.068	0.094
Halfway	50	0.097	0.087	0.108
Paradise	80	0.084	0.074	0.095
Big	62	0.067	0.060	0.074
N.F. Beaver	69	0.118	0.108	0.128
Side channels				
Bob	14	0.100	0.068	0.139
Rock	11	0.089	0.056	0.131
Tenmile	8	0.106	0.068	0.152
Cape	15	0.097	0.068	0.131
N.F. Wilson	6	0.132	0.070	0.214
Franklin	9	0.115	0.091	0.143
Halfway	5	0.125	0.037	0.265
Paradise	3	0.171	0.055	0.351
Big	1	0.280		
N.F. Beaver	6	0.105	0.028	0.230
Basalt				
Pools	265	0.345	0.331	0.360
Glides	250	0.187	0.182	0.191
Riffles	383	0.148	0.144	0.152
Side channels	54	0.101	0.086	0.117
Sandstone				
Pools	432	0.321	0.310	0.333
Glides	297	0.148	0.142	0.154
Riffles	336	0.088	0.083	0.093
Side channels	24	0.126	0.097	0.160

[a] depths of channel units in Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988.
[b] mean calculated from square root transformations of individual mean depths

Appendix Table 2.11. Geometric mean volume of channel units in Oregon Coast Range streams in basalt and sandstone in summer (A) 1987 and (B) 1988[a].

Stream	N	Channel unit volume (m^3)				
		mean[b]	lower limit	upper limit	minimum	maximum
All channel units						
Bob	188	10.4	9.0	12.2	0.2	130.8
Rock	199	11.1	9.7	12.8	0.5	90.4
Tenmile	175	11.2	9.9	12.7	1.1	87.6
Cape	229	12.1	10.8	13.7	0.3	91.8
Franklin	257	3.3	2.8	4.0	0.1	78.6
Halfway	192	7.2	5.8	8.9	0.2	2966.9[c]
Paradise	213	5.2	4.2	6.3	0.1	99.6
Big	181	4.8	3.7	6.3	0.0	170.1
Both rock types						
pools	588	14.0	12.8	15.3	0.4	2966.9
glides	441	7.0	6.4	7.7	0.1	67.4
riffles	542	3.9	3.4	4.5	0.0	91.8
side channels	63	3.8	2.9	5.0	0.2	83.9
Basalt streams						
pools	211	16.0	14.1	18.1	0.6	130.8
glides	216	11.4	10.4	12.5	2.1	53.4
riffles	317	10.1	9.1	11.3	0.8	91.8
side channels	47	4.5	3.2	6.3	0.2	83.9
Sandstone streams						
pools	377	13.0	11.6	14.6	0.4	2966.9
glides	225	4.4	3.8	5.1	0.1	67.4
riffles	225	1.0	0.9	1.2	0.0	39.6
side channels	16	2.4	1.7	3.3	0.7	7.9
Pools						
Bob	51	16.5	12.7	21.6	1.6	130.8
Rock	55	17.9	13.7	23.3	0.6	90.4
Tenmile	41	11.6	8.8	15.2	1.1	72.3
Cape	64	17.4	14.3	21.2	1.4	80.3
Franklin	118	8.1	6.6	9.9	0.4	78.6
Halfway	82	20.5	15.7	26.6	0.7	2966.9
Paradise	85	13.8	11.3	16.9	1.4	99.6
Big	92	15.1	12.4	18.4	0.7	170.1

Appendix Table 2.11. (continued). A. 1987.

Stream	N	Channel unit volume (m³)				
		mean[b]	lower limit	upper limit	minimum	maximum
Glides						
Bob	50	10.8	8.9	13.0	2.1	43.6
Rock	54	10.8	8.9	13.1	2.1	50.1
Tenmile	52	10.3	8.7	12.3	3.1	29.8
Cape	60	13.6	11.5	16.1	2.8	53.4
Franklin	51	3.3	2.7	4.1	0.7	16.9
Halfway	56	5.4	4.1	7.1	0.8	53.7
Paradise	70	5.1	3.8	6.8	0.1	46.3
Big	48	3.9	2.9	5.1	0.8	67.4
Riffles						
Bob	74	8.0	6.1	10.4	0.8	72.5
Rock	79	9.6	7.8	11.9	1.0	48.4
Tenmile	74	12.3	10.0	15.2	1.3	87.6
Cape	90	11.0	9.2	13.2	1.1	91.8
Franklin	80	0.9	0.7	1.2	0.1	11.1
Halfway	50	1.9	1.4	2.6	0.2	39.6
Paradise	55	1.2	0.9	1.6	0.1	12.1
Big	40	0.5	0.3	0.8	0.0	7.3
Side channels						
Bob	13	6.9	3.0	16.1	0.2	83.9
Rock	11	3.5	1.8	6.9	0.5	24.0
Tenmile	8	7.1	3.8	13.1	1.9	23.4
Cape	15	2.9	1.5	5.6	0.3	18.6
Franklin	8	1.9	1.2	3.0	0.7	3.9
Halfway	4	3.1	0.8	12.1	1.0	7.9
Paradise	3	3.5	0.8	14.6	1.9	6.1
Big	1	1.4				

Appendix Table 2.11. (continued). B. 1988.

Stream	N	Channel unit volume (m³)				
		mean[b]	lower limit	upper limit	minimum	maximum
All channel units						
Bob	188	10.4	9.0	12.2	0.2	130.8
Rock	199	11.1	9.7	12.8	0.5	90.4
Tenmile	175	11.2	9.9	12.7	1.1	87.6
Cape	229	12.1	10.8	13.7	0.3	91.8
N.F. Wilson	160	14.0	12.2	16.1	1.0	161.8
Franklin	272	3.9	3.3	4.7	0.0	181.0
Halfway	196	9.3	7.6	11.5	0.3	1530.6[c]
Paradise	236	7.0	5.9	8.4	0.2	171.2
Big	197	6.8	5.5	8.5	0.1	409.1
N.F. Beaver	189	11.9	9.9	14.2	0.2	571.7
Both rock types						
pools	697	17.4	16.0	18.9	0.3	1530.6
glides	548	8.7	8.1	9.5	0.2	94.5
riffles	719	5.1	4.6	5.6	0.0	96.3
side channels	77	3.9	3.0	5.2	0.2	83.9
Basalt streams						
pools	265	16.1	14.4	18.1	0.6	161.8
glides	250	11.4	10.5	12.4	2.1	53.4
riffles	383	10.8	9.8	11.9	0.8	96.3
side channels	53	4.5	3.3	6.2	0.2	83.9
Sandstone streams						
pools	432	18.2	16.3	20.4	0.3	1530.6
glides	298	7.0	6.2	7.9	0.2	94.5
riffles	336	2.1	1.9	2.4	0.0	45.5
side channels	24	2.8	1.6	5.0	0.2	19.1
Pools						
Bob	51	16.5	12.7	21.6	1.6	130.8
Rock	55	17.9	13.7	23.3	0.6	90.4
Tenmile	41	11.6	8.8	15.2	1.1	72.3
Cape	64	17.4	14.3	21.2	1.4	80.3
N.F. Wilson	54	16.7	12.7	22.0	1.0	161.8
Franklin	119	9.3	7.4	11.8	0.3	181.0
Halfway	82	25.2	19.6	32.4	0.8	1530.6
Paradise	85	18.8	15.5	22.7	2.1	171.2
Big	87	22.0	18.0	26.8	2.0	409.1
N.F. Beaver	59	32.2	24.5	42.4	1.7	571.7

Appendix Table 2.11. (continued). B. 1988.

Stream	N	Channel unit volume (m^3)				
		mean[b]	lower limit	upper limit	minimum	maximum
Glides						
Bob	50	10.8	8.9	13.0	2.1	43.6
Rock	54	10.8	8.9	13.1	2.1	50.1
Tenmile	52	10.3	8.7	12.3	3.1	29.8
Cape	60	13.6	11.5	16.1	2.8	53.4
N.F. Wilson	34	11.4	9.3	14.1	3.0	48.0
Franklin	69	3.4	2.7	4.3	0.2	22.4
Halfway	59	7.7	5.7	10.3	0.4	94.5
Paradise	68	7.8	6.1	9.9	0.4	72.7
Big	47	6.1	4.6	8.1	0.8	93.5
N.F. Beaver	55	15.4	12.6	18.8	2.5	86.2
Riffles						
Bob	74	8.0	6.1	10.4	0.8	72.5
Rock	79	9.6	7.8	11.9	1.0	48.4
Tenmile	74	12.3	10.0	15.2	1.3	87.6
Cape	90	11.0	9.2	13.2	1.1	91.8
N.F. Wilson	66	14.8	12.1	18.1	1.2	96.3
Franklin	75	1.2	0.9	1.6	0.0	16.3
Halfway	50	2.6	2.0	3.5	0.4	45.5
Paradise	80	2.3	1.8	2.9	0.2	20.3
Big	62	1.4	1.1	1.9	0.1	15.6
N.F. Beaver	69	4.8	4.0	5.8	0.6	22.4
Side channels						
Bob	13	6.9	3.0	16.1	0.2	83.9
Rock	11	3.5	1.8	6.9	0.5	24.0
Tenmile	8	7.1	3.8	13.1	1.9	23.4
Cape	15	2.9	1.5	5.6	0.3	18.6
N.F. Wilson	6	4.7	2.0	11.4	2.1	19.6
Franklin	9	2.7	1.3	5.7	0.9	10.9
Halfway	5	2.4	0.3	18.3	0.3	14.5
Paradise	3	5.2	0.9	31.5	2.6	11.0
Big	1	12.7				
N.F. Beaver	6	1.9	0.3	14.2	0.2	19.1

[a] dimensions of channel units in Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988.
[b] geometric mean calculated from ln(volume)
[c] beaver pond

Appendix Table 2.12. Mean size[a] of (A) dominant and (B) subdominant substrate in pools, glides, riffles, and side channels in ten Oregon Coast Range streams.

(A) Dominant substrate[b]

Stream	N	Substrate size (phi)				
		mean	lower[c] limit	upper limit	minimum	maximum
Basalt						
pools	226	6.2	6.0	6.5	0.5	9.5
glides	234	6.9	6.8	7.0	2	8.5
riffles	365	7.8	7.7	7.9	4.5	10.5
side channels	53	5.7	5.2	6.3	0.5	8.5
Sandstone						
pools	257	4.5	4.1	4.8	0.5	11.5
glides	154	5.9	5.6	6.2	0.5	9.5
riffles	246	6.8	6.6	7.0	0.5	11.5
side channels	19	5.1	4.0	6.3	0.5	9.5
Pools						
Bob	46	6.2	5.7	6.8	0.5	8.5
Rock	49	6.1	5.4	6.7	0.5	8.5
Tenmile	36	6.7	6.1	7.3	0.5	9.5
Cape	54	6.2	5.6	6.9	0.5	8.5
N.F. Wilson	41	6.1	5.4	6.8	0.5	9.5
Franklin	115	5.8	5.5	6.2	0.5	10.5
Halfway	37	2.5	1.6	3.4	0.5	9.5
Paradise	32	3.1	2.0	4.3	0.5	11.5
Big	42	3.5	2.7	4.2	0.5	8.5
N.F. Beaver	31	4.5	3.6	5.5	0.5	8.5
Glides						
Bob	44	6.7	6.5	6.9	4.5	7.5
Rock	52	6.8	6.5	7.0	2.0	8.5
Tenmile	47	6.9	6.7	7.1	5.5	8.5
Cape	57	6.9	6.7	7.1	5.5	8.5
N.F. Wilson	34	7.2	6.9	7.5	4.5	8.5
Franklin	48	6.5	5.9	7.0	0.5	9.5
Halfway	29	5.7	4.9	6.4	0.5	9.5
Paradise	21	5.7	4.4	7.0	0.5	9.5
Big	28	5.3	4.8	5.8	0.5	8.5
N.F. Beaver	28	5.9	5.5	6.3	3.5	8.5
Riffles						
Bob	70	7.3	7.1	7.5	4.5	8.5
Rock	77	7.7	7.5	7.9	4.5	9.5
Tenmile	74	7.5	7.3	7.7	5.5	9.5
Cape	85	7.9	7.7	8.1	5.5	9.5
N.F. Wilson	59	8.4	8.1	8.7	6.5	10.5
Franklin	89	7.1	6.7	7.5	3.5	11.5
Halfway	31	7.1	6.6	7.6	4.5	9.5
Paradise	40	6.8	6.1	7.4	3.5	9.5
Big	47	6.0	5.5	6.4	0.5	9.5
N.F. Beaver	39	6.9	6.6	7.2	5.5	8.5
Side channels						
Bob	14	5.3	4.0	6.6	0.5	7.5
Rock	11	5.6	3.8	7.4	0.5	8.5
Tenmile	8	6.1	5.7	6.6	5.5	6.5
Cape	14	5.5	4.3	6.8	0.5	8.5
N.F. Wilson	6	6.8	5.3	8.4	4.5	8.5
Franklin	8	6.6	5.4	7.8	5.5	9.5
Halfway	4	1.8	0.0	5.7	0.5	5.5
Paradise	1	7.5				
Big	1	5.5				
N.F. Beaver	5	4.9	3.5	6.3	3.5	6.5

Appendix Table 2.12 (continued). (B) Subdominant substrate[d]

Stream	N	Substrate size (phi)				
		mean	lower[c] limit	upper limit	minimum	maximum
Basalt						
pools	252	6.1	5.8	6.4	0.5	9.5
glides	245	7.2	7.0	7.3	0.5	9.5
riffles	373	7.8	7.7	7.9	2	9.5
side channels	52	6.3	5.8	6.8	0.5	9.5
Sandstone						
pools	412	5.1	4.8	5.4	0.5	11.5
glides	248	5.9	5.6	6.3	0.5	9.5
riffles	288	6.6	6.3	6.8	0.5	11.5
side channels	22	4.8	3.2	6.5	0.5	11.5
Pools						
Bob	49	5.9	5.2	6.5	0.5	8.5
Rock	51	6.2	5.6	6.7	0.5	8.5
Tenmile	40	7.1	6.4	7.7	0.5	9.5
Cape	62	5.5	4.7	6.3	0.5	9.5
N.F. Wilson	50	6.2	5.4	7.0	0.5	9.5
Franklin	120	5.9	5.4	6.4	0.5	11.5
Halfway	77	4.5	3.7	5.3	0.5	9.5
Paradise	78	5.0	4.2	5.8	0.5	9.5
Big	87	5.0	4.3	5.7	0.5	9.5
N.F. Beaver	50	4.7	4.0	5.5	0.5	9.5
Glides						
Bob	47	7.3	7.0	7.6	5.5	8.5
Rock	54	7.2	6.8	7.5	2.0	9.5
Tenmile	51	7.0	6.6	7.4	2.0	9.5
Cape	59	7.3	6.9	7.7	0.5	9.5
N.F. Wilson	34	7.0	6.6	7.3	5.5	8.5
Franklin	51	6.9	6.4	7.4	3.5	9.5
Halfway	50	6.2	5.6	6.9	0.5	9.5
Paradise	54	5.4	4.4	6.4	0.5	9.5
Big	43	5.1	4.4	5.9	0.5	9.5
N.F. Beaver	50	5.9	5.3	6.5	0.5	9.5
Riffles						
Bob	73	7.3	7.0	7.6	2.0	9.5
Rock	78	7.8	7.6	8.0	5.5	9.5
Tenmile	74	7.8	7.5	8.0	5.5	9.5
Cape	85	7.9	7.7	8.1	5.5	9.5
N.F. Wilson	63	8.2	8.0	8.5	5.5	9.5
Franklin	92	7.1	6.7	7.5	3.5	11.5
Halfway	46	7.1	6.5	7.7	0.5	9.5
Paradise	44	6.6	5.9	7.3	2.0	10.5
Big	50	6.0	5.5	6.5	0.5	10.5
N.F. Beaver	56	5.9	5.4	6.4	0.5	10.5
Side channels						
Bob	13	6.2	5.2	7.1	2.0	8.5
Rock	11	5.9	4.0	7.7	0.5	8.5
Tenmile	7	7.2	6.2	8.2	5.5	8.5
Cape	15	6.4	5.5	7.2	3.5	8.5
N.F. Wilson	6	6.3	4.5	8.1	4.5	9.5
Franklin	9	8.1	6.1	10.0	4.5	11.5
Halfway	4	1.9	0.0	4.9	0.5	4.5
Paradise	2	4.5				
Big	2	3.5				
N.F. Beaver	5	2.1	0.0	4.8	0.5	4.5

[a] size expressed in phi, where phi=-$\log_2$(length of intermediate axis in mm)
[b] channel units with bedrock as dominant substrate excluded
[c] 95% confidence interval
[d] channel units with bedrock as subdominant substrate excluded

Appendix Table 2.13. Dissolved oxygen concentrations measured at low streamflows of 2-3 l/s from 12-18 October 1988. See Table 2.3 for an explanation of channel unit codes.

Unit code and number	Dissolved oxygen				Temperature (°C)		Time (h)	Date
	surface		bottom		surface	bottom		
	(g/m³)	saturation (%)	(g/m³)	saturation (%)				
Big Creek								
TP 15	3.8	34	-	-	10.0	-	1210	12 Oct
TP 15	4.3	41	3.0[a]	28[a]	13.3	12.0	1510	15 Oct
TP 15	6.6	57	2.6[a]	22[a]	8.8	8.1	1255	26 Oct
TP 15	-	-	4.8	41	-	8.1	1300	26 Oct
TP 16	5.3	47	-	-	9.6	-	1201	12 Oct
TP 16	5.3	52	4.2	40	14.2	12.8	1520	15 Oct
TP 16	7.9	69	0.7[a]	6[a]	9.3	8.4	1330	26 Oct
TP 16	-	-	6.8	58	-	8.4	1335	26 Oct
BP 18	2.7	24	-	-	10.6	-	1226	12 Oct
TP 19	7.3	65	6.8	59	10.0	9.1	1231	12 Oct
CR 14	6.9	61	-		10.0	-	1248	12 Oct
CR 14	7.1	61	5.4	46	8.7	8.8	1405	26 Oct
TP 20	5.5	49	5.0	44	10.2	9.3	1303	12 Oct
TP 20	8.4	73	6.9	58	8.9	8.1	1420	26 Oct
G 10	6.4	58	-	-	11.0	-	1313	12 Oct
G 10	8.4	72	-	-	8.8	-	1430	26 Oct
G 25	-	-	3.6[b]	32[b]	10.3	-	1344	12 Oct
LSP 50	4.7	41	4.6	39	9.5	8.5	1403	12 Oct
TP 85	8.3	74	5.4	47	10.3	9.4	1424	12 Oct
Franklin Creek								
BSP 3	10.0	89	10.2	91	10.2	10.2	1325	18 Oct
CR 4	9.4	83	10.2	90	9.8	9.7	1333	18 Oct
BSP 5	8.6	77	9.1[c]	80[c]	10.2	9.8	1338	18 Oct
LSP 10	9.3	85	7.0[d]	61[d]	11.5	9.6	1355	18 Oct
LSP 20	7.8	74	8.7	78	12.8	10.5	1530	18 Oct
TP 75	10.0	92	9.5[c]	87[c]	11.8	11.3	1445	18 Oct
TP 76	10.6	98	10.8	99	12.0	11.6	1452	18 Oct

[a] reading taken in deep area
[b] streambed covered in alder leaves - reading taken in this layer
[c] streambed covered in maple leaves - reading taken in this layer
[d] beaver droppings on streambed

Appendix Table 3.1. Number of channel units dived compared to total in about 3 km of ten Oregon Coast
Range streams in (A) 1987 and (B) 1988.

Stream	Length of reach surveyed (m)	Number of channel units								Percent dived
		total				dived				
		pools	glides	riffles	total	pools	glides	riffles	total	
A. 1987										
Basalt										
Bob	3013	51	50	74	175	10	9	7	26	15
Rock	2879	55	54	84	193	13	10	7	30	16
Tenmile	3019	41	52	84	177	11	10	6	27	15
Cape	3066	65	60	91	216	11	12	8	31	14
Sandstone										
Franklin	2964	126	57	98	281	26	10	7	43	15
Halfway	3382	82	56	56	194	17	10	6	33	17
Paradise	3052	85	70	90	245	17	13	6	36	15
Big	3182	93	51	69	213	18	8	3	29	14
B. 1988										
Basalt										
Bob	3013	51	50	74	175	10	9	7	26	15
Rock	2879	55	54	84	193	13	10	7	30	16
Tenmile	3019	41	52	84	177	11	10	6	27	15
Cape	3066	65	60	91	216	13	12	8	33	15
NF Wilson	2988	54	34	66	154	11	6	6	23	15
Sandstone										
Franklin	2950	122	70	83	275	21	12	4	37	13
Halfway	3388	82	59	50	191	16	8	6	30	16
Paradise	3018	85	68	85	238	17	14	6	37	16
Big	3145	87	47	62	196	19	7	3	29	15
NF Beaver	3004	59	55	69	183	11	11	7	29	16

Appendix Table 3.2. Length of channel units dived compared to total in about 3 km of ten Oregon Coast Range streams in (A) 1987 and (B) 1988.

Stream	Length (m)[a]								Percent of length dived
	reach total				dived				
	pools	glides	riffles	total	pools	glides	riffles	total	
A. 1987									
Basalt									
Bob	765	915	1366	3046	165	140	51	356	12
Rock	780	801	1324	2905	238	114	180	533	18
Tenmile	444	823	1763	3030	150	185	136	470	16
Cape	887	889	1313	3089	175	154	120	449	14
Sandstone									
Franklin	1637	642	857	3136	342	136	76	553	18
Halfway	1756	1094	532	3382	354	332	41	727	22
Paradise	1196	1176	680	3052	277	254	80	611	20
Big	1513	1047	632	3192	326	135	24	485	15
B. 1988									
Basalt									
Bob	765	915	1366	3046	165	140	51	356	12
Rock	780	801	1324	2905	238	114	180	533	18
Tenmile	444	823	1763	3030	150	185	136	470	16
Cape	887	889	1313	3089	205	154	120	478	15
NF Wilson	676	592	1727	2995	150	111	117	378	13
Sandstone									
Franklin	1513	833	623	2969	307	162	40	509	17
Halfway	1814	1118	467	3399	335	186	47	567	17
Paradise	1216	1048	759	3023	292	229	65	585	19
Big	1668	967	531	3166	387	162	23	572	18
NF Beaver	1187	1108	732	3028	178	176	77	431	14

[a] Length of channel units in Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988

Appendix Table 3.3. Schedule of dates during which diving and electroshocking were carried out.

Stream	Summer 1987	Fall 1987	Summer 1988	
	diving survey	diving survey	diving survey	electroshocking and diving comparison
Bob	14-15 Sep	25 Nov	30 Aug	3 Sep
Rock	4 Aug, 21 Sep	18 Nov	14 Sep	-
Tenmile	24 Sep	27 Nov	12 Sep	-
Cape	11, 16, 28-30 July	20 Nov	6-8 Sep	7-8 Sep
NF Wilson	-[a]	-	5, 16 Sep	15 Sep
Franklin	15, 21-24 July 11 Aug, 9 Sep	-	15-17 Aug	16-17 Aug
Halfway	24, 28 Aug	-	29 Aug	-
Paradise	27 Aug	-	24-25 Aug	20 Sep
Big	14-16, 24 Aug	29 Nov	22 Aug	-
NF Beaver	-	-	31 Aug	-
Cummins	31 Jul, 1-2 Aug	-	-	-

[a] not surveyed

Appendix Table 3.4. Estimates of biomass of salmonids and approximate 95% confidence limits in about
3 km of ten Oregon Coast Range streams in summer (A) 1987 and (B) 1988.

Stream	Estimated biomass (g/m)[a]					Estimated biomass	Mean water surface
	age 0 trout	age 1 and older steelhead	age 0 coho salmon	age 1 and older cutthroat trout	total	(g/m²)	width[b] (m)
A. 1987							
Basalt							
Bob	2.42±0.65	2.16±0.87	0.82±0.77	2.31±2.06	7.70± 4.34	1.69±0.95	4.56
Rock	2.48±0.60	3.51±1.55	1.85±0.69	8.20±3.69	16.04± 6.53	3.41±1.39	4.71
Tenmile	2.39±0.66	2.08±1.41	1.41±0.61	1.69±1.13	7.57± 3.81	1.66±0.83	4.57
Cape	5.90±1.06	17.30±3.92	5.94±1.68	11.23±5.00	40.37±11.65	7.38±2.13	5.47
Sandstone							
Franklin	2.43±0.94	3.14±1.31	9.06±2.56	0.99±0.62	15.62± 5.43	4.76±1.66	3.28
Halfway	0.19±0.07	1.45±0.54	11.05±2.58	0.85±0.56	13.54± 3.76	3.54±0.98	3.82
Paradise	0.80±0.49	2.22±3.39	6.51±1.79	1.21±0.65	10.74± 6.33	2.96±1.74	3.63
Big	0.91±0.36	0.39±0.37	23.63±8.05	0.30±0.37	25.23± 9.14	7.93±2.88	3.18
Basalt x̄	3.30	6.26	2.50	5.86	17.92	3.53	4.83±0.69
Sandstone x̄	1.08	1.80	12.56	0.84	16.28	4.80	3.48±0.48
B. 1988							
Basalt							
Bob	0.61±0.24	4.06±1.20	0.13±0.21	2.97±1.48	7.77± 3.13	1.70±0.69	4.56
Rock	3.27±1.11	9.49±3.76	0.00±0.00	12.62±7.53	25.39±12.41	5.39±2.63	4.71
Tenmile	5.35±0.96	12.58±5.18	2.11±0.69	11.16±4.44	31.20±11.27	6.83±2.47	4.57
Cape	5.78±0.80	7.14±1.96	1.56±0.58	4.20±2.30	18.68± 5.64	3.41±1.03	5.47
NF Wilson	13.26±2.40	8.97±3.63	0.00±0.00	2.44±2.03	24.67± 8.06	5.83±1.91	4.23
Sandstone							
Franklin	1.30±0.59	0.74±0.41	0.16±0.17	0.54±0.55	2.75± 1.71	0.83±0.52	3.29
Halfway	0.70±0.22	0.81±0.42	8.04±2.13	0.28±0.29	9.83± 3.06	2.30±0.72	4.27
Paradise	0.99±0.39	1.31±1.15	9.76±3.74	0.68±0.57	12.74± 5.85	2.72±1.25	4.68
Big	2.52±1.12	0.55±0.26	8.48±2.28	0.53±0.50	12.07± 4.17	2.85±0.98	4.24
NF Beaver	1.69±0.66	4.41±2.16	10.73±2.87	2.78±1.47	19.61± 7.16	3.77±1.38	5.20
Basalt x̄	5.65	8.45	0.76	6.68	21.54	4.63	4.71±0.57
Sandstone x̄	1.44	1.56	7.43	0.96	11.40	2.50	4.34±0.87

[a] biomass calculated from a combination of salmonid densities (Table 3.4) and geometric mean weights (Appendix Table 3.5). Weights of age 0 and age 1 and older steelhead and resident rainbow trout and age 0 coho salmon from Bob and Cape Creeks were used for all streams in basalt except North Fork Wilson River, for which results derived directly from the latter stream were used. For cutthroat trout in streams in basalt, pooled mean weights from Bob, Cape, and North Fork Wilson were used. Mean weights of all species and age classes from Franklin and Paradise Creeks were used to calculate biomass in streams in sandstone.

[b] widths of Bob, Rock, Tenmile, and Cape were not remeasured in 1988

Appendix Table 3.5. Geometric means of fork length and weight of salmonids caught by electroshocking. See Appendix Table 3.3 for dates of sampling.

	Fork length (mm)			N	Measured weight (g)			N
	mean	lower[a] limit	upper limit		mean	lower limit	upper limit	
<u>Basalt</u>								
Bob and Cape Creeks								
age 0 trout	69	67	70	164	3.93	3.69	4.18	162
age 1 and older steelhead	114	111	117	92	16.58	15.38	17.89	91
age 0 coho salmon	81	80	83	23	6.20	5.75	6.68	23
N.F. Wilson River								
age 0 trout	54	53	56	190	1.65	1.48	1.83	180
age 1 and older steelhead	133	123	144	11	24.82	19.57	31.49	11
Bob, Cape, and N.F. Wilson								
age 1 and older cutthroat trout	166	147	188	20	45.93	31.89	66.16	20
<u>Sandstone</u>								
Franklin and Paradise Creeks								
age 0 trout	59	58	60	305	2.21	2.11	2.32	304
age 1 and older steelhead	111	106	117	22	13.87	12.02	16.01	22
age 1 and older cutthroat trout	135	124	148	12	24.04	18.50	31.24	12
age 0 coho salmon	71	69	72	236	3.97	3.77	4.17	236

[a] 95% confidence intervals

Appendix Table 3.6. Habitat specific and average total densities of salmonids in Oregon Coast Range streams in basalt and sandstone in summer (A) 1987 and (B) 1988.

A. 1987

Stream	Habitat type	Density (fish per lineal meter)											
		Habitat specific density				Average total density				Habitat utilization (U)[a]			
		0 trt[b]	1 sthd	0 co	1 cut	0 trt	1 sthd	0 co	1 cut	0 trt	1 sthd	0 co	1 cut
Basalt													
Bob	pools	0.94	0.23	0.32	0.17	0.61	0.13	0.13	0.05	1.53	1.81	2.47	3.39
	glides	0.61	0.11	0.16	0.02					1.00	0.85	1.26	0.50
	riffles	0.43	0.08	0.00	0.00					0.70	0.65	0.00	0.00
Rock	pools	0.72	0.34	0.97	0.40	0.63	0.21	0.30	0.17	1.14	1.60	3.28	2.32
	glides	0.89	0.12	0.13	0.12					1.42	0.58	0.43	0.70
	riffles	0.41	0.19	0.00	0.07					0.66	0.90	0.00	0.41
Tenmile	pools	0.85	0.24	1.13	0.18	0.61	0.12	0.23	0.04	1.41	1.96	5.00	4.88
	glides	0.67	0.13	0.14	0.04					1.11	1.01	0.60	1.05
	riffles	0.51	0.09	0.04	0.00					0.85	0.75	0.18	0.00
Cape	pools	1.23	1.28	2.59	0.34	1.49	1.04	0.95	0.24	0.82	1.24	2.72	1.44
	glides	2.18	0.70	0.59	0.23					1.46	0.67	0.2	0.94
	riffles	1.20	1.10	0.09	0.18					0.81	1.06	0.10	0.74
Sandstone													
Franklin	pools	1.35	0.35	3.33	0.07	1.08	0.22	2.24	0.04	1.26	1.56	1.49	1.74
	glides	1.15	0.21	2.44	0.02					1.07	0.94	1.09	0.47
	riffles	0.51	0.00	0.04	0.00					0.48	0.00	0.02	0.00
Halfway	pools	0.04	0.11	2.72	0.07	0.08	0.10	2.79	0.04	0.47	1.07	0.98	1.93
	glides	0.18	0.14	4.22	0.00					2.18	1.37	1.51	0.00
	riffles	0.03	0.00	0.05	0.00					0.32	0.00	0.02	0.00
Paradise	pools	0.12	0.06	2.24	0.12	0.36	0.16	1.64	0.05	0.32	0.36	1.36	2.37
	glides	0.29	0.36	1.77	0.01					0.80	2.23	1.08	0.18
	riffles	0.92	0.00	0.36	0.00					2.55	0.00	0.22	0.00
Big	pools	0.30	0.06	6.72	0.03	0.41	0.03	5.94	0.01	0.73	2.11	1.13	2.11
	glides	0.55	0.00	4.04	0.00					1.34	0.00	0.68	0.00
	riffles	0.45	0.00	7.20	0.00					1.10	0.00	1.21	0.00

Appendix Table 3.6. (continued)
B. 1988

Stream	Habitat type	Density (fish per lineal meter)											
		Habitat specific density				Average total density				Habitat utilization (U)[a]			
		0 trt[b]	1 sthd	0 co	1 cut	0 trt	1 sthd	0 co	1 cut	0 trt	1 sthd	0 co	1 cut
Basalt													
Bob	pools	0.28	0.51	0.08	0.18	0.15	0.24	0.02	0.06	1.79	2.09	4.00	2.84
	glides	0.19	0.13	0.00	0.06					1.25	0.55	0.00	0.97
	riffles	0.06	0.17	0.00	0.00					0.40	0.69	0.00	0.00
Rock	pools	0.88	1.17	0.00	0.49	0.83	0.57	0.00	0.27	1.06	2.07	0.00	1.82
	glides	0.57	0.26	0.00	0.11					0.69	0.45	0.00	0.40
	riffles	0.96	0.40	0.00	0.24					1.16	0.71	0.00	0.88
Tenmile	pools	1.21	0.86	1.67	0.48	1.36	0.76	0.34	0.24	0.89	1.14	4.92	2.00
	glides	1.83	0.44	0.31	0.15					1.35	0.59	0.91	0.64
	riffles	1.18	0.88	0.02	0.22					0.87	1.16	0.06	0.92
Cape	pools	1.69	0.53	0.80	0.16	1.46	0.43	0.25	0.09	1.15	1.23	3.21	1.82
	glides	1.84	0.28	0.04	0.04					1.26	0.66	0.15	0.50
	riffles	1.06	0.46	0.02	0.07					0.73	1.08	0.09	0.80
Wilson	pools	0.86	0.30	0.00	0.14	8.03	0.36	0.00	0.05	1.35	0.82	0.00	2.67
	glides	8.36	0.12	0.00	0.00					1.04	0.32	0.00	0.00
	riffles	6.85	0.47	0.00	0.04					0.85	1.31	0.00	0.69
Sandstone													
Franklin	pools	0.73	0.10	0.06	0.04	0.59	0.05	0.04	0.02	1.25	1.97	1.44	1.97
	glides	0.61	0.00	0.04	0.00					1.04	0.00	0.96	0.00
	riffles	0.21	0.00	0.00	0.00					0.35	0.00	0.00	0.00
Halfway	pools	0.15	0.08	2.60	0.02	0.32	0.06	2.02	0.01	0.48	1.32	1.29	1.88
	glides	0.55	0.05	1.90	0.00					1.72	0.91	0.94	0.00
	riffles	0.42	0.00	0.10	0.00					1.32	0.00	0.05	0.00
Paradise	pools	0.20	0.07	3.36	0.07	0.45	0.09	2.46	0.03	0.46	0.76	1.37	2.49
	glides	0.63	0.07	2.72	0.00					1.42	0.79	1.11	0.00
	riffles	0.58	0.16	0.66	0.00					1.30	1.69	0.27	0.00
Big	pools	1.03	0.07	3.04	0.04	1.13	0.04	2.12	0.02	0.91	1.90	1.43	1.90
	glides	1.38	0.00	1.32	0.00					1.22	0.00	0.62	0.00
	riffles	1.03	0.00	0.74	0.00					0.91	0.00	0.35	0.00
Beaver	pools	0.26	0.33	3.41	0.19	0.76	0.32	2.68	0.11	0.35	1.06	1.27	1.66
	glides	0.88	0.32	3.53	0.07					1.16	1.00	1.31	0.63
	riffles	1.38	0.29	0.26	0.06					1.83	0.91	0.10	0.50

[a] $U = \frac{\text{habitat specific density}}{\text{average total density}}$, where habitat specific density is fish/m in a particular stratum, and average total density is fish/m in all strata. Densities in each stratum calculated from population numbers estimated by the methods of Hankin and Reeves (1988) divided by total length of each stratum. Results for 1987 and 1988 combined.

[b] 0 trt = age 0 steelhead and trout, 1 sthd = age 1 and older steelhead and trout, 0 co = age 0 coho salmon, and 1 cut = age 1 and older cutthroat trout.

Appendix Table 3.7. Mean depths of channel units in which salmonid numbers were counted by snorkel diving in ten Oregon Coast Range streams in summer 1987 and 1988.

Stream	N	Depth in 1987 (m)			N	Depth in 1988 (m)[c]		
		mean[a]	lower limit	upper limit		mean	lower limit	upper limit
Pools								
Bob	10	0.31	0.27	0.36	10	0.31	0.27	0.36
Rock	13	0.45	0.38	0.53	13	0.45	0.38	0.53
Tenmile	11	0.33	0.29	0.38	11	0.33	0.29	0.38
Cape	13	0.32	0.28	0.37	13	0.32	0.28	0.37
NF Wilson	-	-[b]	-	-	11	0.38	0.26	0.53
Franklin	26	0.26	0.23	0.30	24	0.31	0.26	0.38
Halfway	17	0.35	0.26	0.45	16	0.36	0.30	0.41
Paradise	17	0.29	0.25	0.34	17	0.33	0.27	0.39
Big	18	0.27	0.22	0.33	19	0.34	0.29	0.39
NF Beaver	-	-	-	-	11	0.35	0.30	0.42
Glides								
Bob	9	0.16	0.14	0.19	9	0.16	0.14	0.19
Rock	10	0.19	0.16	0.21	10	0.19	0.16	0.21
Tenmile	10	0.18	0.15	0.21	10	0.18	0.15	0.21
Cape	12	0.20	0.18	0.23	11	0.20	0.18	0.23
NF Wilson	-	-	-	-	4	0.21	0.15	0.28
Franklin	10	0.12	0.10	0.14	15	0.13	0.11	0.16
Halfway	7	0.14	0.11	0.18	7	0.16	0.11	0.21
Paradise	13	0.12	0.10	0.15	14	0.17	0.13	0.20
Big	8	0.12	0.09	0.15	5	0.12	0.08	0.17
NF Beaver	-	-	-	-	11	0.19	0.17	0.21
Riffles								
Bob	7	0.13	0.11	0.15	7	0.13	0.11	0.15
Rock	3	0.15	0.12	0.19	4	0.15	0.13	0.17
Tenmile	4	0.15	0.09	0.23	4	0.15	0.09	0.23
Cape	8	0.17	0.14	0.20	8	0.17	0.14	0.20
NF Wilson	-	-	-	-	4	0.17	0.13	0.21
Franklin	7	0.07	0.04	0.10	5	0.12	0.06	0.22
Halfway	6	0.08	0.06	0.11	6	0.11	0.09	0.13
Paradise	6	0.09	0.05	0.13	6	0.11	0.08	0.14
Big	3	0.13	0.01	0.40	3	0.09	.00	0.32
NF Beaver	-	-	-	-	7	0.12	0.10	0.15

[a] means and 95% confidence intervals calculated from square root transforms
[b] not measured
[c] depths of Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988

Appendix Table 3.8. Stream temperatures during dive counts in ten Oregon Coast Range streams.

Stream	Water temperature (°C)											
	summer 1987				fall 1987				summer 1988			
	mean	min	max	N	mean	min	max	N	mean	min	max	N
Basalt												
Bob	13.1	12.5	13.5	17	8.1	8.0	8.5	7	13.7	12.2	15.2	23
Rock	12.4	11.5	13.0	22	9.6	9.0	10.0	12	11.0	11.0	11.0	2
Tenmile	12.7	12.5	13.0	25	8.2	7.5	8.5	10	13.5	11.5	15.0	3
Cape	12.8	12.0	14.0	11	10.0	10.0	10.0	11	13.2	11.5	14.0	34
NF Wilson	-	-	-	-	-	-	-	-	15.6	13.0	17.5	10
Sandstone												
Franklin	12.9	12.0	17.0	18	-	-	-	-	13.5	11.5	16.0	10
Halfway	15.4	14.0	19.0	29	-	-	-	-	16.1	14.5	18.5	30
Paradise	15.1	12.0	17.0	34	-	-	-	-	13.3	10.5	17.0	9
Big	13.7	12.0	15.0	9	5.8	5.5	6.0	10	13.5	12.5	14.0	4
NF Beaver	-	-	-	-	-	-	-	-	12.3	11.0	13.5	29

Appendix Table 4.1. Mean width/depth ratio[a] and 95% confidence limits in ten Oregon Coast Range streams in summer 1987 and 1988.

Stream	Width/depth ratio 1987				Width/depth ratio 1988[b]			
	n	mean	lower limit	upper limit	n	mean	lower limit	upper limit
Basalt								
Bob	189	10.2	9.6	10.8	189	10.2	9.6	10.8
Rock	199	9.7	9.1	10.2	199	9.7	9.1	10.2
Tenmile	175	9.9	9.4	10.5	175	9.9	9.4	10.5
Cape	229	10.7	10.2	11.1	229	10.7	10.2	11.1
N.F. Wilson	-[c]	-	-	-	160	8.3	7.8	8.8
Basalt mean	792	10.1	9.9	10.4	952	9.8	9.6	10.1
Sandstone								
Franklin	257	10.0	9.5	10.5	272	9.1	8.6	9.6
Halfway	192	9.4	8.9	10.0	196	9.2	8.6	9.8
Paradise	213	10.0	9.4	10.6	236	11.0	10.3	11.6
Big	181	9.0	8.5	9.5	197	10.8	10.3	11.4
N.F. Beaver	-	-	-	-	189	10.5	9.9	11.1
Sandstone mean	843	9.6	9.4	9.9	1090	10.1	9.8	10.3

[a] means calculated from square-root transformations of individual width/depth ratios
[b] width/depth ratios of channel units in Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988.
[c] no data

Appendix Table 4.2. Geometric mean length of channel units in basalt and sandstone rock types in ten streams in the Oregon Coast Range in summer 1988[a].

Channel unit type	N	Individual channel unit length (m) geometric mean[b]	95% confidence intervals lower limit	upper limit	minimum	maximum
Primary channel unit types						
Basalt						
pools	266	11.5	10.7	12.3	2.0	64.6
glides	250	14.0	13.1	15.0	4.3	57.1
riffles	399	13.4	12.3	14.6	1.0	91.2
side channels	54	29.9	23.8	37.6	4.7	349.7
Sandstone						
pools	435	13.3	12.5	14.2	2.2	225.6
glides	299	13.4	12.4	14.5	2.9	80.4
riffles	349	7.2	6.7	7.7	0.6	37.2
side channels	28	16.1	13.0	20.0	8.3	90.0
Both rock types						
pools	701	12.6	12.0	13.2	2.0	225.6
glides	549	13.7	13.0	14.4	2.9	80.4
riffles	748	10.0	9.4	10.7	0.6	91.2
side channels	82	24.2	20.3	29.0	4.7	349.7
Secondary channel unit types						
Basalt						
LSP[c]	90	12.5	11.1	14.2	2.0	31.5
TP	126	12.0	11.0	13.1	2.1	36.0
DSP	26	9.1	6.9	11.8	3.0	35.9
BSP	4	6.5	4.9	8.5	5.5	7.8
BP	16	7.4	5.9	9.3	4.0	15.2
BDP	4	21.7	6.7	70.5	12.4	64.6
G	250	14.0	13.1	15.0	4.3	57.1
LGR	145	13.8	12.1	15.7	1.1	61.2
LGCR	94	26.6	23.5	30.2	5.4	91.2
RR	80	5.3	4.6	6.3	1.0	19.6
CR	80	14.3	12.5	16.4	3.8	58.1
SC	54	29.9	23.8	37.6	4.7	349.7
Sandstone						
LSP	83	17.2	15.5	19.0	4.8	54.0
TP	248	13.6	12.6	14.6	2.9	63.7
DSP	26	10.2	8.4	12.3	3.5	20.8
BSP	37	9.0	7.5	10.8	2.2	25.2
BP	28	6.0	5.1	7.0	3.2	13.5
BDP	13	52.3	30.6	89.4	12.6	225.6
G	299	13.4	12.4	14.5	2.9	80.4
LGR	208	6.8	6.2	7.5	0.6	34.4
LGCR	35	12.0	10.0	14.6	3.0	37.2
RR	57	6.4	5.6	7.3	1.5	17.0
CR	49	7.4	6.4	8.7	3.0	27.8
SC	28	16.1	13.0	20.0	8.3	90.0

Appendix Table 4.2. (continued)

Channel unit type	N	Individual channel unit length (m)				
		geometric mean[b]	95% confidence intervals		minimum	maximum
			lower limit	upper limit		
Both rock types						
LSP	173	14.6	13.4	15.8	2.0	54.0
TP	374	13.0	12.3	13.8	2.1	63.7
DSP	52	9.6	8.2	11.2	3.0	35.9
BSP	41	8.7	7.4	10.3	2.2	25.2
BP	44	6.5	5.7	7.4	3.2	15.2
BDP	17	42.5	26.6	68.1	12.4	225.6
G	549	13.7	13.0	14.4	2.9	80.4
LGR	353	9.1	8.3	9.9	0.6	61.2
LGCR	129	21.5	19.0	24.2	3.0	91.2
RR	137	5.8	5.2	6.4	1.0	19.6
CR	129	11.2	9.9	12.5	3.0	58.1
SC	82	24.2	20.3	29.0	4.7	349.7

[a] lengths of Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988
[b] means from ln(channel unit length)
[c] LSP = lateral scour pool
TP = trench pool
DSP = debris scour pool
BSP = boulder scour pool
BP = backwater pool
BDP = beaver-dammed pool
G = glide
LGR = low gradient riffle
LGCR= low gradient cascade riffle
RR = rapid riffle
CR = cascade riffle
SC = side channel

Appendix Table 4.3. Geometric mean water surface slopes of channel units in basalt and sandstone rock types in ten streams in the Oregon Coast Range.

Channel unit type	N	Water surface slope (%)				
		geometric mean	95% confidence intervals		minimum	maximum
			lower limit	upper limit		
Primary channel unit types						
Basalt						
pools	35	0.08	0.02	0.14	0.00	0.68
glides	49	0.75a	0.65	0.85	0.00	1.38
riffles	62	4.03[b]	3.55	4.58	1.24	11.69
Sandstone						
pools	68	0.04	0.01	0.06	0.00	0.49
glides	61	0.56	0.47	0.65	0.00	1.55
riffles	63	3.29	2.84	3.80	1.13	23.61
Both rock types						
pools	103	0.05	0.03	0.08	0.00	0.68
glides	110	0.64	0.57	0.71	0.00	3.71
riffles	125	3.64	3.29	4.01	1.13	23.61
Secondary channel unit types						
Basalt						
LSP[a]	17	0.08	0.00	0.17	0.00	0.68
TP	13	0.11	0.01	0.21	0.00	0.42
DSP	3	0.00	0.00	0.00	0.00	0.00
BSP	1	0.00	-[c]	-	0.00	0.00
BP	1	0.00	-	-	0.00	0.00
BDP	-	-	-	-	-	-
G	49	0.75	0.65	0.85	0.00	1.38
LGR	12	2.42	1.97	2.96	1.38	3.39
LGCR	20	2.96	2.63	3.34	1.24	3.73
RR	8	6.76	4.48	10.19	2.92	11.69
CR	22	5.85	5.23	6.54	3.59	8.59
Sandstone						
LSP	20	0.01	0.00	0.02	0.00	0.10
TP	34	0.05	0.01	0.09	0.00	0.45
DSP	2	0.00	0.00	0.00	0.00	0.00
BSP	6	0.08	0.00	0.29	0.00	0.49
BP	3	0.00	0.00	0.00	0.00	0.00
BDP	3	0.00	0.00	0.00	0.00	0.00
G	61	0.56	0.47	0.65	0.00	1.55
LGR	30	2.17	1.93	2.43	1.13	3.80
LGCR	7	2.40	1.96	2.94	1.70	3.22
RR	13	5.46	4.79	6.22	3.82	7.67
CR	13	6.13	4.52	8.31	3.87	23.61

Appendix Table 4.3. (continued)

Channel unit type	N	Water surface slope (%)				
		geometric mean	95% confidence intervals		minimum	maximum
			lower limit	upper limit		
Both rock types						
LSP	37	0.04	0.00	0.08	0.00	0.68
TP	47	0.07	0.03	0.11	0.00	0.45
DSP	5	0.00	0.00	0.00	0.00	0.00
BSP	7	0.07	0.00	0.24	0.00	0.49
BP	4	0.00	0.00	0.00	0.00	0.00
BDP	3	0.00	0.00	0.00	0.00	0.00
G	110	0.64	0.57	0.71	0.00	1.55
LGR	42	2.23	2.03	2.46	1.13	3.80
LGCR	27	2.81	2.54	3.11	1.24	3.73
RR	21	5.92	5.04	6.95	2.92	11.69
CR	35	5.95	5.25	6.74	3.59	23.61

[a] means of all glides calculated from ln(water surface slope + 1)
[b] means of all riffles calculated from ln(water surface slope)
[c] insufficient samples
[d] LSP = lateral scour pool
TP = trench pool
DSP = debris scour pool
BSP = boulder scour pool
BP = backwater pool
BDP = beaver-dammed pool
G = glide
LGR = low gradient riffle
LGCR= low gradient cascade riffle
RR = rapid riffle
CR = cascade riffle
SC = side channel

Appendix Table 4.4. Mean depth and 95% confidence limits of channel units in ten streams in the Oregon Coast Range in basalt and sandstone in summer 1988.

Channel unit type[a]	N	Depth (m) mean[b]	lower limit	upper limit
Basalt				
LSP	89	0.37	0.35	0.39
TP	126	0.35	0.33	0.37
DSP	26	0.35	0.32	0.38
BSP	4	0.41	0.34	0.49
BP	16	0.18	0.14	0.22
BDP	4	0.30	0.19	0.43
G	250	0.19	0.18	0.19
LGR	139	0.13	0.13	0.14
LGCR	94	0.16	0.16	0.17
RR	70	0.12	0.12	0.13
CR	80	0.18	0.17	0.19
SC	54	0.10	0.09	0.12
Sandstone				
LSP	82	0.35	0.33	0.38
TP	248	0.31	0.30	0.33
DSP	26	0.38	0.34	0.43
BSP	37	0.29	0.26	0.32
BP	26	0.18	0.15	0.21
BDP	13	0.58	0.47	0.70
G	298	0.15	0.14	0.15
LGR	197	0.07	0.07	0.08
LGCR	35	0.13	0.11	0.14
RR	56	0.08	0.07	0.09
CR	48	0.15	0.14	0.17
SC	24	0.13	0.10	0.16
Both rock types				
LSP	171	0.36	0.35	0.38
TP	374	0.33	0.32	0.34
DSP	52	0.37	0.34	0.39
BSP	41	0.30	0.27	0.33
BP	42	0.18	0.16	0.20
BDP	17	0.50	0.40	0.62
G	548	0.16	0.16	0.17
LGR	336	0.10	0.09	0.10
LGCR	129	0.15	0.15	0.16
RR	126	0.10	0.09	0.11
CR	128	0.17	0.16	0.18
SC	78	0.11	0.09	0.12

[a] see Table 4.1 for an explanation of secondary channel unit types

[b] means calculated with data transformed with square root

Appendix Table 4.5. Geometric mean size and 95% confidence limits of dominant and subdominant substrate in pools, glides, and riffles in ten Oregon Coast Range streams.

Secondary[a] channel unit type	N	Dominant substrate size (phi)[b]				
		mean	lower limit	upper limit	minimum	maximum
Basalt streams						
LSP	83	6.3	5.8	6.7	0.5	9.5
TP	93	6.5	6.1	6.9	0.5	9.5
DSP	26	5.7	4.6	6.7	0.5	9.5
BSP	4	7.8	6.2	9.3	6.5	8.5
BP	16	5.0	3.6	6.4	0.5	8.5
BDP	4	5.6	1.3	10.0	2.0	8.5
G	234	6.9	6.8	7.0	2.0	8.5
LGR	138	7.2	7.0	7.3	4.5	10.5
LGCR	91	7.9	7.8	8.1	5.5	9.5
RR	65	7.8	7.6	8.1	5.5	9.5
CR	71	8.5	8.4	8.7	6.5	9.5
SC	53	5.7	5.2	6.3	0.5	8.5
Sandstone streams						
LSP	65	4.6	4.0	5.2	0.5	9.5
TP	104	4.4	3.9	4.9	0.5	9.5
DSP	17	4.1	2.5	5.7	0.5	9.5
BSP	34	6.4	5.6	7.1	3.5	11.5
BP	21	3.6	2.3	5.0	0.5	10.5
BDP	16	2.1	0.9	3.2	0.5	6.5
G	154	5.9	5.6	6.2	0.5	9.5
LGR	173	6.1	5.9	6.3	0.5	9.5
LGCR	15	8.1	7.5	8.7	5.5	9.5
RR	26	7.6	7.2	8.1	5.5	9.5
CR	32	9.2	8.7	9.6	5.5	11.5
SC	19	5.1	3.9	6.3	0.5	9.5
Both rock types						
LSP	148	5.5	5.1	5.9	0.5	9.5
TP	197	5.4	5.0	5.8	0.5	9.5
DSP	43	5.0	4.2	5.9	0.5	9.5
BSP	38	6.5	5.8	7.2	3.5	11.5
BP	37	4.2	3.3	5.2	0.5	10.5
BDP	20	2.8	1.5	4.0	0.5	8.5
G	388	6.5	6.3	6.6	0.5	9.5
LGR	311	6.6	6.5	6.7	0.5	10.5
LGCR	106	8.0	7.8	8.1	5.5	9.5
RR	91	7.8	7.6	8.0	5.5	9.5
CR	103	8.7	8.5	8.9	5.5	11.5
SC	72	5.6	5.1	6.1	0.5	9.5

Appendix Table 4.5. (continued)

Secondary[a] channel unit type	N	Subdominant substrate size (phi)[b]				
		mean	lower limit	upper limit	minimum	maximum
<u>Basalt streams</u>						
LSP	86	5.9	5.4	6.5	0.5	9.5
TP	117	6.4	5.9	6.9	0.5	9.5
DSP	25	6.9	6.1	7.6	2	9.5
BSP	4	7.8	5.7	9.8	6.5	9.5
BP	16	3.0	1.6	4.3	0.5	7.5
BDP	4	6.8	5.2	8.3	5.5	7.5
G	245	7.2	7.0	7.3	0.5	9.5
LGR	139	7.4	7.2	7.6	2	9.5
LGCR	92	7.9	7.7	8.1	5.5	9.5
RR	68	7.7	7.5	7.9	5.5	9.5
CR	74	8.4	8.2	8.6	6.5	9.5
SC	52	6.3	5.8	6.8	0.5	9.5
<u>Sandstone streams</u>						
LSP	96	4.7	4.1	5.3	0.5	9.5
TP	227	5.3	4.8	5.7	0.5	11.5
DSP	17	3.9	2.3	5.5	0.5	9.5
BSP	34	7.3	6.3	8.3	0.5	11.5
BP	21	3.9	2.5	5.2	0.5	9.5
BDP	17	4.1	2.8	5.4	0.5	8.5
G	248	5.9	5.6	6.3	0.5	9.5
LGR	196	6.1	5.8	6.3	0.5	9.5
LGCR	15	8.0	7.1	8.9	5.5	10.5
RR	37	7.0	6.3	7.8	0.5	10.5
CR	40	8.2	7.3	9.0	0.5	11.5
SC	22	4.8	3.2	6.5	0.5	11.5
<u>Both rock types</u>						
LSP	182	5.3	4.9	5.7	0.5	9.5
TP	344	5.7	5.3	6.0	0.5	11.5
DSP	42	5.7	4.8	6.5	0.5	9.5
BSP	38	7.3	6.4	8.2	0.5	11.5
BP	37	3.5	2.5	4.4	0.5	9.5
BDP	21	4.6	3.5	5.8	0.5	8.5
G	493	6.5	6.3	6.7	0.5	9.5
LGR	335	6.6	6.5	6.8	0.5	9.5
LGCR	107	7.9	7.7	8.2	5.5	10.5
RR	105	7.4	7.1	7.7	0.5	10.5
CR	114	8.3	8.0	8.6	0.5	11.5
SC	74	5.9	5.3	6.5	0.5	11.5

[a] see Table 4.1 for explanation of secondary channel unit codes
[b] phi=$-\log_2$(length of intermediate axis in mm)

Appendix Table 4.6. Mean width/depth ratios[a] of different channel unit types in ten Oregon Coast Range streams in summer 1988[b].

Channel unit type	N	Width/depth ratio and 95% confidence limits mean	lower	upper	minimum	maximum
All streams combined						
Pools	700	14.2	13.8	14.6	1.3	46.5
Glides	551	26.9	25.9	27.9	5.5	101.6
Riffles	720	39.4	37.6	41.2	3.6	776.1
Side channels	78	17.0	15.0	19.2	4.3	75.0
Streams in basalt						
Pools	265	13.0	12.4	13.7	3.8	43.1
Glides	250	26.0	24.7	27.3	9.6	101.6
Riffles	383	35.4	33.8	37.2	6.9	141.1
Side channels	54	18.1	15.4	21.3	4.3	75.0
Streams in sandstone						
Pools	435	15.0	14.4	15.6	1.3	46.5
Glides	301	27.7	26.2	29.2	5.5	96.3
Riffles	337	44.4	41.1	48.1	3.6	776.1
Side channels	24	14.8	12.7	17.1	8.1	30.0
Streams in basalt						
LSP[c]	89	12.0	11.0	13.1	5.2	41.5
TP	126	13.4	12.5	14.3	4.3	33.9
DSP	26	15.2	13.1	17.3	7.5	27.2
BSP	4	9.1	4.0	16.2	5.9	13.7
BP	16	12.5	10.2	14.9	3.8	20.0
BDP	4	22.2	7.0	45.9	12.6	43.1
G	250	26.0	24.7	27.4	9.6	101.6
LGR	139	43.3	39.9	46.8	9.2	138.6
LGCR	94	30.0	28.0	32.1	12.3	76.8
RR	70	43.2	38.4	48.3	15.4	141.1
CR	80	26.3	24.0	28.6	6.9	66.5
SC	54	19.0	15.9	22.4	4.3	75.0
Streams in sandstone						
LSP	82	12.9	11.9	13.9	5.9	32.9
TP	250	16.6	15.9	17.3	1.3	38.5
DSP	26	11.8	9.9	13.8	4.6	25.6
BSP	38	14.3	12.4	16.4	6.4	46.5
BP	26	12.6	10.2	15.2	4.7	34.6
BDP	13	12.2	9.6	15.1	4.9	21.4
G	301	28.1	26.6	29.6	5.5	96.3
LGR	197	53.7	48.4	59.2	15.3	443.5
LGCR	36	32.3	28.0	36.9	13.4	83.2
RR	56	73.7	52.1	99.1	5.5	776.1
CR	48	24.8	21.1	28.7	3.6	68.0
SC	24	14.7	12.4	17.1	8.1	30.0

Appendix Table 4.6. (continued)

Channel unit type	N	Width/depth ratio and 95% confidence limits				
		mean	lower	upper	minimum	maximum
Both rock types						
LSP	171	12.5	11.8	13.2	5.2	41.5
TP	376	15.5	14.9	16.1	1.3	38.5
DSP	52	13.4	12.0	15.0	4.6	27.2
BSP	42	13.7	12.1	15.6	5.9	46.5
BP	42	12.4	10.8	14.3	3.8	34.6
BDP	17	14.0	11.1	17.7	4.9	43.1
G	551	26.9	25.9	27.9	5.5	101.6
LGR	336	47.2	44.4	50.1	9.2	443.5
LGCR	130	30.8	29.0	32.8	12.3	83.2
RR	126	49.3	43.1	56.3	5.5	776.1
CR	128	25.3	23.2	27.5	3.6	68.0
SC	78	17.0	15.0	19.2	4.3	75.0

[a] means calculated from square-root transformed data

[b] dimensions of channel units in Bob, Rock, Tenmile, and Cape Creeks measured in 1987 only

[c] LSP = lateral scour pool
TP = trench pool
DSP = debris scour pool
BSP = boulder scour pool
BP = backwater pool
BDP = beaver-dammed pool
G = glide
LGR = low gradient riffle
LGCR= low gradient cascade riffle
RR = rapid riffle
CR = cascade riffle
SC = side channel

Appendix Table 4.7. Mean shape index[a] of different channel unit types in ten Oregon Coast Range streams in summer 1988[b].

Channel unit type	N	Shape index and 95% confidence limits				
		mean	lower	upper	minimum	maximum
All streams combined						
Pools	700	4.29	4.18	4.40	1.18	17.98
Glides	551	5.41	5.20	5.62	1.58	48.09
Riffles	720	6.50	6.22	6.78	1.18	37.40
Side channels	78	3.88	3.35	4.45	1.40	20.01
Streams in basalt						
Pools	265	3.93	3.77	4.08	1.18	17.44
Glides	250	5.79	5.48	6.10	2.29	26.47
Riffles	383	6.97	6.60	7.36	1.24	37.40
Side channels	54	4.23	3.49	5.05	1.46	20.01
Streams in sandstone						
Pools	435	4.51	4.37	4.66	1.30	17.98
Glides	301	5.10	4.83	5.38	1.58	48.09
Riffles	337	5.98	5.58	6.39	1.18	36.58
Side channels	24	3.15	2.69	3.66	1.40	5.70
Streams in basalt						
LSP[c]	89	3.60	3.43	3.78	2.38	5.98
TP	126	4.12	3.91	4.34	1.18	9.03
DSP	26	3.88	3.12	4.72	2.44	17.44
BSP	4	3.46	2.79	4.20	3.05	3.94
BP	16	4.42	3.44	5.51	2.26	10.22
BDP	4	4.11	2.38	6.32	2.70	5.64
G	250	5.79	5.48	6.10	2.29	26.47
LGR	139	8.46	7.77	9.17	2.78	32.07
LGCR	94	5.22	4.82	5.64	2.06	12.43
RR	70	8.77	7.69	9.91	2.76	37.40
CR	80	5.36	4.82	5.91	1.24	15.33
SC	54	4.23	3.49	5.05	1.46	20.01
Streams in sandstone						
LSP	82	4.16	3.91	4.41	2.12	9.78
TP	250	4.90	4.71	5.09	1.30	11.60
DSP	26	4.02	3.66	4.39	2.48	5.91
BSP	38	4.01	3.33	4.75	1.69	17.98
BP	26	3.72	3.28	4.19	2.28	7.27
BDP	13	3.73	3.10	4.42	2.52	6.63
G	301	5.10	4.83	5.38	1.58	48.09
LGR	197	6.61	6.06	7.19	1.42	36.58
LGCR	36	4.26	3.72	4.84	1.90	9.39
RR	56	6.04	4.98	7.20	1.18	22.55
CR	48	4.84	3.97	5.80	1.67	26.12
SC	24	3.15	2.69	3.66	1.40	5.70

Appendix Table 4.7. (continued).

Channel unit type	N	Shape index and 95% confidence limits				
		mean	lower	upper	minimum	maximum
Both rock types						
LSP	171	3.86	3.71	4.02	2.12	9.78
TP	376	4.63	4.48	4.78	1.18	11.60
DSP	52	3.95	3.53	4.38	2.44	17.44
BSP	42	3.96	3.34	4.62	1.69	17.98
BP	42	3.98	3.54	4.45	2.26	10.22
BDP	17	3.82	3.27	4.42	2.52	6.63
G	551	5.41	5.20	5.62	1.58	48.09
LGR	336	7.35	6.90	7.81	1.42	36.58
LGCR	130	4.95	4.61	5.29	1.90	12.43
RR	126	7.49	6.69	8.34	1.18	37.40
CR	128	5.16	4.69	5.66	1.24	26.12
SC	78	3.88	3.35	4.45	1.40	20.01

[a] Shape Index = $\left(\frac{\hat{w}}{\bar{d}}\right)^{\left(\frac{\bar{d}}{d_{max}}\right)}$,

where $\hat{w}$=mean width, $\bar{d}$=mean width, and d_{max}=maximum depth (Orth 1983).
Means calculated from square-root transformed data

[b] dimensions of channel units in Bob, Rock, Tenmile, and Cape Creeks measured only in 1987

[c] LSP = lateral scour pool
TP = trench pool
DSP = debris scour pool
BSP = boulder scour pool
BP = backwater pool
BDP = beaver-dammed pool
G = glide
LGR = low gradient riffle
LGCR= low gradient cascade riffle
RR = rapid riffle
CR = cascade riffle
SC = side channel

Appendix Table 4.8. Proportion of lengths of different channel unit types in streams of the Oregon Coast Range in basalt and sandstone in summer (A) 1987 and (B) 1988[a].

Stream	Length of secondary channel unit type as a proportion of total channel length (%)										
	LSP	TP	DSP	BSP	BP	BDP	G	LGR	LGCR	RR	CR
A. 1987											
Bob	9.5	7.9	4.1	0.0	1.1	2.5	30.0	24.5	12.3	4.4	3.7
Rock	15.3	6.8	2.3	0.5	0.9	1.1	27.6	22.6	12.8	4.8	5.4
Tenmile	4.5	8.6	0.9	0.4	0.4	0.0	27.2	13.1	36.3	4.1	4.8
Cape	12.7	12.3	2.4	0.0	1.2	0.0	28.8	17.8	9.8	3.6	11.3
mean	10.5	8.9	2.4	0.2	0.9	0.9	28.4	19.5	17.8	4.2	6.3
C.I.[b]	7.4	3.8	2.1	0.4	0.6	1.9	2.1	8.2	19.7	0.8	5.5
Franklin	19.5	13.9	1.7	11.6	3.2	2.3	19.9	15.1	1.5	1.4	10.0
Halfway	10.5	23.4	2.4	0.0	0.4	15.2	32.3	10.6	1.8	2.1	1.3
Paradise	5.2	29.2	0.5	0.3	0.3	3.7	38.5	16.2	0.7	3.7	1.7
Big	17.9	28.9	0.3	0.0	0.3	0.0	32.8	15.9	1.7	1.6	0.6
mean	13.3	23.9	1.2	3.0	1.0	5.3	30.9	14.4	1.4	2.2	3.4
C.I.	10.6	11.4	1.6	9.2	2.3	10.8	12.5	4.2	0.8	1.7	7.0
grand mean	11.9	16.4	1.8	1.6	1.0	3.1	29.6	17.0	9.6	3.2	4.8
C.I.	4.9	8.4	1.1	3.6	0.9	4.5	4.8	4.2	10.7	1.2	3.5
B. 1988											
Bob	9.5	7.9	4.1	0.0	1.1	2.5	30.0	24.5	12.3	4.4	3.7
Rock	15.3	6.8	2.3	0.5	0.9	1.1	27.6	22.6	12.8	4.8	5.4
Tenmile	4.5	8.6	0.9	0.4	0.4	0.0	27.2	13.1	36.3	4.1	4.8
Cape	12.7	12.3	2.4	0.0	1.2	0.0	28.8	17.8	9.8	3.6	11.3
NF Wilson	1.4	20.5	0.0	0.0	0.7	0.0	19.8	8.6	28.0	0.9	20.2
mean	8.7	11.2	1.9	0.2	0.9	0.7	26.7	17.3	19.8	3.5	9.1
C.I.	7.1	6.9	2.0	0.3	0.4	1.4	5.0	8.2	14.5	1.9	8.6
Franklin	13.9	15.8	2.4	11.9	3.9	3.1	28.1	9.7	3.3	0.4	7.5
Halfway	10.7	24.3	3.1	0.5	0.5	14.2	32.9	8.9	1.8	1.9	1.1
Paradise	5.3	30.4	1.8	0.2	0.2	2.4	34.7	13.2	5.0	4.7	2.2
Big	16.1	31.3	1.0	0.0	0.6	3.7	30.6	13.0	1.8	1.2	0.7
NF Beaver	4.2	26.2	1.1	0.3	0.8	6.6	36.6	12.7	3.9	4.9	2.6
mean	10.0	25.6	1.9	2.6	1.2	6.0	32.6	11.5	3.2	2.6	2.8
C.I.	6.5	7.7	1.1	6.4	1.9	6.0	4.2	2.5	1.7	2.5	3.4
mean[c]	11.5	25.5	2.1	3.2	1.3	5.8	31.5	11.2	3.0	2.1	2.9
C.I.[c]	7.5	11.3	1.4	9.2	2.8	8.9	4.6	3.5	2.4	3.0	5.0
grand mean	9.3	18.4	1.9	1.4	1.0	3.4	29.6	14.4	11.5	3.1	5.9
C.I.	3.9	7.1	0.9	2.8	0.8	3.3	3.5	4.2	8.9	1.3	4.5

[a] lengths of channel units in Bob, Rock, Tenmile, and Cape Creeks were not remeasured in 1988.
[b] 95% confidence interval
[c] mean and 95% confidence interval of Franklin, Halfway, Paradise, and Big only.

Appendix Table 4.9. Number of channel units of different types in streams of the Oregon Coast Range in
basalt and sandstone in summer (A) 1987 and (B) 1988.

Stream	Number of secondary channel units per kilometer											
	LSP	TP	DSP	BSP	BP	BDP	G	LGR	LGCR	RR	CR	SC
A. 1987												
Bob	7.0	5.6	2.7	0.0	1.0	0.7	16.6	11.9	3.3	6.6	2.7	4.3
Rock	9.0	4.9	2.8	0.7	1.0	0.7	18.8	13.9	5.2	6.6	3.5	3.8
Tenmile	3.6	7.0	1.7	0.7	0.7	0.0	17.2	7.0	10.6	7.0	3.3	3.0
Cape	9.5	8.8	1.6	0.0	1.3	0.0	19.6	11.7	4.2	5.2	8.5	4.9
mean	7.3	6.6	2.2	0.3	1.0	0.3	18.0	11.1	5.8	6.4	4.5	4.0
C.I.[a]	4.2	2.7	1.0	0.6	0.4	0.6	2.2	4.7	5.2	1.2	4.3	1.3
Franklin	12.1	12.5	1.0	10.8	4.4	0.7	18.2	19.9	1.7	1.3	9.8	3.0
Halfway	5.6	12.7	2.4	0.0	0.9	2.7	16.6	11.2	0.6	3.3	1.5	1.5
Paradise	3.3	21.6	0.7	0.3	0.7	1.3	22.9	22.0	0.3	5.2	2.0	1.0
Big	9.1	19.2	0.3	0.0	0.6	0.0	16.0	18.5	0.6	1.6	0.9	0.9
mean	7.5	16.5	1.1	2.8	1.6	1.2	18.4	17.9	0.8	2.9	3.5	1.6
C.I.	6.2	7.3	1.4	8.5	2.9	1.8	5.0	7.4	1.0	2.9	6.7	1.6
grand mean	7.4	11.5	1.6	1.6	1.3	0.8	18.2	14.5	3.3	4.6	4.0	2.8
C.I.	2.6	5.2	0.8	3.1	1.1	0.8	1.9	4.3	2.9	1.9	2.8	1.3
B. 1988												
Bob	7.0	5.6	2.7	0.0	1.0	0.7	16.6	11.9	3.3	6.6	2.7	4.3
Rock	9.0	4.9	2.8	0.7	1.0	0.7	18.8	13.9	5.2	6.6	3.5	3.8
Tenmile	3.6	7.0	1.7	0.7	0.7	0.0	17.2	7.0	10.6	7.0	3.3	3.0
Cape	9.5	8.8	1.6	0.0	1.3	0.0	19.6	11.7	4.2	5.2	8.5	4.9
NF Wilson	1.0	15.7	0.0	0.0	1.3	0.0	11.4	4.0	8.0	1.3	8.7	2.0
mean	6.0	8.4	1.7	0.3	1.1	0.3	16.7	9.7	6.3	5.4	5.3	3.6
C.I.	4.5	5.4	1.4	0.5	0.3	0.5	4.0	5.1	3.7	2.9	3.7	1.4
Franklin	9.2	11.9	2.0	11.2	6.1	1.0	23.7	15.9	3.1	0.7	8.5	3.4
Halfway	5.6	13.3	2.7	0.6	0.9	1.2	17.4	9.4	0.6	3.0	1.8	2.4
Paradise	3.0	21.9	2.0	0.3	0.3	0.7	22.5	15.9	3.6	6.0	2.7	1.0
Big	6.4	19.4	0.6	0.0	1.0	0.3	14.9	15.6	1.0	2.2	1.0	0.3
NF Beaver	2.7	13.6	1.0	0.3	1.0	1.0	18.3	10.7	3.3	6.7	2.3	2.0
mean	5.4	16.0	1.7	2.5	1.9	0.8	19.4	13.5	2.3	3.7	3.2	1.8
C.I.	3.3	5.4	1.0	6.0	3.0	0.4	4.5	4.0	1.8	3.1	3.7	1.5
mean[b]	6.0	16.6	1.8	3.0	2.1	0.8	19.7	14.2	2.1	3.0	3.5	1.8
C.I.[b]	4.0	7.6	1.4	8.7	4.3	0.6	6.6	5.1	2.4	3.5	5.4	2.2
grand mean	5.7	12.2	1.7	1.4	1.5	0.6	18.0	11.6	4.3	4.5	4.3	2.7
C.I.	2.2	4.1	0.7	2.5	1.2	0.3	2.5	2.9	2.2	1.8	2.2	1.0

[a] 95% confidence interval
[b] mean and 95% confidence interval of Franklin, Halfway, Paradise, and Big only.