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Editor

# Hydrological and Biological Responses to Forest Practices

## The Alsea Watershed Study

Foreword by George W. Brown and James T. Krygier

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# Chapter 14
# Long-term Trends in Habitat and Fish Populations in the Alsea Basin

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The Alsea Watershed Study (AWS) was the earliest long-term basin study to document effects of timber harvest practices on stream habitat quality and salmonid populations (Hall and Lantz 1969; Moring and Lantz 1975). The 16-year project was initiated in 1958. Three coastal basins with mature forests of Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*) were selected in the upper Drift Creek drainage of the Alsea River (See Chapter 1). Flynn Creek, a 202-ha basin, was the reference stream. Deer Creek, a 303-ha basin, was clearcut in three patches, each approximately 25 ha in area, with mixed deciduous/conifer buffers along the stream. Needle Branch, a 71-ha basin, was completely logged by clearcutting with no buffers. Logging continued in the Deer Creek basin after the original AWS was completed in 1973. An additional 45 ha were harvested in three clearcut units in 1978, 1987, and 1988.

Salmonid communities in these study streams are dominated by two species, coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*O. clarkii*). During the AWS, small numbers of steelhead (*O. mykiss*) were observed in Deer Creek (Moring and Lantz 1975). A few straying Chinook salmon (*O. tshawytscha*) passed through the upstream trap in Deer Creek but all returned downstream without spawning. Nonsalmonid fishes found in these streams are the reticulate sculpin (*Cottus perplexus*), Pacific lamprey (*Lampetra tridentata*), and western brook lamprey (*Lampetra richardsoni*).

The original AWS included a 7-year prelogging phase (1959–1965) to document the natural annual variation in environmental factors and salmonid populations, a year of logging (1966), and a 7-year post-logging phase (1967–1973) to measure effects on fish populations and habitat. Limited sampling of salmonid populations was continued in the summer of 1974. Responses of fish assemblages in the early pre- and post-logging periods

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have been reported in numerous publications (e.g., Chapman 1961, 1965; Lowry 1964, 1965; Hall and Lantz 1969; Au 1972; Lindsay 1975; Moring 1975; Moring and Lantz 1975; Knight 1980; Hall et al. 1987) and are summarized in Chapter 5.

Pretreatment and posttreatment studies such as the AWS and the Carnation Creek watershed study (Hartman and Scrivener 1990) have documented changes in habitat and fish populations in the first decade after forest harvest. In general, these studies have observed short-term effects (1–4 years) on habitat quality, including increased maximum stream temperature, decreased dissolved oxygen, and increased suspended sediments. Densities of juvenile coho salmon generally increased after logging, and cutthroat trout populations decreased.

Basin comparisons such as the AWS provide an important context for evaluating responses of salmonid populations to land-use practices across ranges of natural variation. We extended the time frame for this type of land-use experiment by reexamining fish populations in the AWS streams 22–30 years after harvest. This chapter builds on an analysis of data collected in 1988 and 1989 as part of a comparison to the earlier work on the AWS (Schwartz 1991). From 1988 to 1996, we measured habitat conditions and fish populations during summer in Flynn Creek, Deer Creek, and Needle Branch. Long-term fluctuations in juvenile coho salmon and cutthroat trout populations, even in the reference stream, demonstrate the value of long-term investigations such as this one.

## Methods

Measurements of stream habitat and fish populations that were used from 1959 to 1974 are described briefly in Chapter 5 and in greater detail in publications from the original study. We did not attempt to follow the original measurement protocols, but we used the spatial framework of the AWS to extrapolate our reach measurements to the full stream length for each basin.

### *Stream Habitat Measurements*

During 1988–1996, physical habitat was measured by a visual estimation method (Hankin and Reeves 1988) during the second or third week of August each year. Major bedforms or channel units were classified as pool, riffle, glide, rapid, cascade, step, or side channel. Physical habitat measurements at each channel unit included wetted channel length, wetted channel width, active channel width, mean depth, and maximum depth. The active channel was visually estimated by observing high-flow markings. We estimated mean width of the wetted channel from three measurements in each unit and mean depth from nine measured depths (three at each width transect). We calculated means for each reach by weighting channel unit dimensions according to the proportion of reach length represented by channel unit length.

## *Salmonid Population and Biomass Estimates*

During 1988–1996, we estimated salmonid populations by the two-pass removal method, using backpack electroshockers as described by Armour et al. (1983). Peterson and Cederholm (1984) had previously shown that estimates of coho salmon populations made by the removal method were similar to estimates made by the mark-recapture method when at least 1 hour was allowed between electrofishing passes. We allowed approximately 1 hour or more to elapse between electrofishing passes at most sites while we were measuring and weighing fish from the preceeding pass.

Abundances of cutthroat trout were estimated by stratifying the population into fry (age 0) and older trout (age 1+). Age groups for each stream were determined by length-frequency analysis. Trout were grouped into 2-mm size intervals and assigned to either age 0 or age 1+ by evaluation of breaks between size classes. Demarcations between age-0 and 1+ trout differed between years, ranging from approximately 70 to 90 mm. Size classes for these age groups are similar to ranges reported by Sumner (1962) and Lowry (1964), which were based on scale analysis. Estimates of numbers for the two age groups were computed separately. Based on freshwater age of returning adult coho salmon (Moring and Lantz 1975), we estimated that about 95% of the juveniles left the streams as smolts after 1 year of rearing. Because such a small percentage remained in the streams for an additional year, we combined all juvenile coho salmon in one group for estimating population size.

We estimated salmonid populations and biomass for the entire fish-bearing stream length using stratified sampling by reach type. Within each stream, four to five electrofishing sites were selected randomly in morphologically different sections to stratify the sampling by reach-scale characteristics. Major reach types included constrained (valley floor width <2 active channel widths) and unconstrained (valley floor width >2 active channel widths) (Gregory et al. 1991). Lengths of reach types were measured in each stream. We electrofished approximately 20% of the total length in each stream.

Areal and lineal estimates of fish density and biomass for each stream reach were derived by dividing the estimate of population number at an electrofishing site by the proportion of the area or length of the major reach type represented by the sampled site. Reach estimates were summed to obtain estimates for the entire stream. Trout biomass (g $m^{-2}$) was estimated for each site by multiplying the population estimates for age-0 and 1+ fish by the average fish weight for each age group and dividing by the sampled site area. We used coefficient o variation [(standard deviation/mean) · 100] as a measure of interannual varia tion in population abundance. This statistic, expressed as a percentage anc abbreviated as CV, provides a measure of relative variation, independent o absolute abundance.

Interannual comparisons of fish abundance required accurate estimates o reach lengths and areas to convert population estimates from this study and th original AWS to lineal and areal densities. We reviewed all original field note to confirm estimates of reach lengths and areas from 1959 to 1974. We als recalculated all population estimates for salmon and trout for 1959 to 197 from original data, resulting in some corrections to values reported in Morin and Lantz (1975) and Hall et al. (1987).

During the original AWS, researchers designated standard study lengths fo each stream that encompassed nearly all the stream length accessible to ana dromous fish. Estimates of density and biomass were based on average area during the study period. There were minor year-to-year variations in averag width of the three streams, but in contrast to the 1988–1996 period, thes variations were not sufficient to require modification of average area for given length of stream, even during the post-logging period in Needle Branc Fish populations were estimated in lengths of stream that differed somewhat b year and species. In Flynn Creek, estimates were made over a length of 1430 and area of 2660 m$^2$ for coho salmon smolts in all years, juvenile salmon fc 1959–1968, and juvenile cutthroat trout for 1962–1963. All other estimates i Flynn Creek covered a length of 1310 m and area of 2540 m$^2$, except for trout i 1964, when the respective values were 1460 m and 2700 m$^2$. In Deer Cree estimates were made over a length of 2320 m and area of 4720 m$^2$ for all yea and both species. In Needle Branch, estimates were made for a length of 970 and area of 1060 m$^2$ for salmon smolts for all years, juvenile salmon f 1959–1968, and juvenile trout for 1962–1963. All other estimates throu 1974 were made over a length of 870 m and area of 930 m$^2$.

Stream width was measured each year from 1988 to 1996, but we standa dized the total stream length to which reach estimates were applied. Tot stream lengths were close to those for the original AWS: Flynn Creek – 13 m, Deer Creek – 2070 m (East Fork of Deer Creek was not sampled after 197 and Needle Branch – 870 m.

Needle Branch was not sampled in 1988 and 1992 because of droug conditions in the Oregon Coast Range. In late summer of 1988, approximate 65% of the channel length was dry from the fish trap to the first falls. Electr fishing in the remaining shallow wetted pools would have excessively stress the fish remaining in the isolated sections. Consequently, we did not estim fish populations for 1988, but their abundance must have been quite low. 1992, only one residual pool contained water in the same distance of stream. fish were observed in this pool, thus the population in Needle Branch w assumed to be zero in 1992.

## Results

### Stream Habitat

Stream habitat composition and dimensions during the 1988–1996 period differed substantially from prelogging habitat conditions for Flynn Creek and Deer Creek, and minor changes occurred in Needle Branch (Table 14.1). Stream depths were greater in this period than depths recorded in 1959–1962 for all streams, but differences in measurement protocols between these periods limit comparisons. Beaver activity in Flynn Creek approximately doubled the stream area in the sampled stream reaches from 1991–1994, compared to 1988–1990. Average width more than doubled and average depth increased by about 80%. Stream area returned to earlier values when a flood during 1994–1995 removed the beaver dams. Beaver activity in Deer Creek, which varied greatly from year to year, caused considerable fluctuation in stream area. The average for mean widths during 1988–1996 was somewhat greater than the width during 1959–1962, and widths varied between years, ranging from 2.2 m to 3.0 m. The area of Needle Branch remained relatively more constant because of the absence of beaver activity. However, because of drought from 1994 to 1996, wetted channel area was 19% (range of 9% to 28%) less than the wetted area from 1989 to 1991. Composition of habitat types was similar in all streams, with average pool-riffle ratios close to 1:1. Though the percentage of the stream length in pool habitat varied considerably from year to year in each stream during 1988–1996, the averages were quite similar to those for 1959–1962.

### Salmonid Population and Biomass

Cutthroat trout populations decreased markedly in Needle Branch, the clearcut stream, in the period immediately following forest harvest in the AWS, whereas trout abundance increased in both Deer Creek and Flynn Creek (See Chapter 5). During 1989–1996, trout numbers (all ages combined) per meter of stream in Needle Branch recovered to levels similar to prelogging populations (Table 14.2). These lineal densities are closely related to estimates of populations for the entire study streams that were made during 1962–1974 and provide a basis for comparison with the earlier period. Both mean numbers (Table 14.2) and median numbers (Fig. 14.1) approached prelogging populations. Numbers of trout per stream length increased immediately after harvest in Deer Creek and Flynn Creek, but lineal densities for 1988–1996 returned to near prelogging levels.

Abundance estimates of trout for 1988–1996 adjusted for stream area (Table 14.2) differ from measures of abundance based on stream length, because stream area changed greatly over the 9-year period. Numbers of trout per $m^2$

**Table 14.1** Stream habitat composition and dimensions for the AWS streams from 1988 to 1996. Estimates of width and depth are expressed in meters and area in square meters. Estimates of percent pools are based on stream length. Field crews estimated that habitat conditions had not changed in Deer Creek during 1991 and 1992 and in Needle Branch in 1991, and habitat was not remeasured. All reaches were dry in Needle Branch in 1992. Areas marked with an asterisk indicate significant beaver influence. Also shown are means for years 1959–1962 (from Moring 1975) and 1988–1996

| | Flynn Creek | | | | Deer Creek | | | | Needle Branch | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | % pools | Mean width | Mean depth | Wetted area | % pools | Mean width | Mean depth | Wetted area | % pools | Mean width | Mean depth | Wetted area |
| 1988 | 54.6 | 1.85 | 0.10 | 2420 | 58.1 | 3.01 | 0.17 | *6240 | 68.3 | 1.30 | 0.10 | Dry[1] |
| 1989 | 38.8 | 1.85 | 0.09 | 2420 | 40.3 | 2.45 | 0.12 | *5080 | 67.7 | 1.33 | 0.14 | 1160 |
| 1990 | 42.7 | 1.85 | 0.15 | 2420 | 44.2 | 2.18 | 0.15 | 4510 | 54.9 | 1.33 | 0.10 | 1160 |
| 1991 | 60.2 | 4.65 | 0.24 | *6090 | 44.2 | 2.18 | 0.15 | 4510 | 54.9 | 1.33 | 0.10 | 1160 |
| 1992 | 48.1 | 3.29 | 0.21 | *4310 | 44.2 | 2.18 | 0.15 | 4510 | – | – | – | Dry |
| 1993 | 62.7 | 4.09 | 0.20 | *5360 | 50.9 | 2.92 | 0.17 | *6050 | 60.0 | 1.37 | 0.12 | 1190 |
| 1994 | 53.6 | 3.50 | 0.16 | *4590 | 44.9 | 2.39 | 0.15 | *4950 | 68.7 | 0.95 | 0.11 | 830 |
| 1995 | 53.4 | 2.06 | 0.13 | 2700 | 51.8 | 2.62 | 0.15 | *5420 | 66.8 | 1.22 | 0.09 | 1060 |
| 1996 | 45.8 | 1.83 | 0.11 | 2400 | 62.3 | 2.65 | 0.17 | *5480 | 58.7 | 1.07 | 0.13 | 930 |
| 59–62 | 54.1 | 1.86 | 0.11 | 2660 | 56.2 | 2.03 | 0.11 | 4720[2] | 59.7 | 1.09 | 0.07 | 1060 |
| 88–96 | 51.1 | 2.77 | 0.15 | 3630 | 49.0 | 2.51 | 0.15 | 5190 | 62.5 | 1.24 | 0.11 | 1070 |

[1] Channel was dry along 65% of its length

[2] Area of East Fork Deer Creek was included during 1959–1962, but not during 1988–1996.

**Table 14.2** Estimates of cutthroat trout populations in AWS streams from 1962 to 1996, expressed as lineal density (# $m^{-1}$), areal density (# $m^{-2}$), and biomass (g $m^{-2}$). Dash indicates that stream was not sampled. (1962–1965: prelogging, 1966–1974: early post-logging, and 1988–1996: later post-logging)

| Year | Number per meter | | | Number per square meter | | | Grams per square meter | | |
|---|---|---|---|---|---|---|---|---|---|
| | Flynn | Deer | Needle | Flynn | Deer | Needle | Flynn | Deer | Needle |
| 1962 | 0.55 | 0.46 | 0.20 | 0.30 | 0.23 | 0.18 | 6.23 | 4.26 | 3.58 |
| 1963 | 0.43 | 0.36 | 0.39 | 0.23 | 0.18 | 0.35 | 2.72 | 1.68 | 2.80 |
| 1964 | 0.45 | 0.37 | 0.35 | 0.24 | 0.18 | 0.33 | 3.20 | 2.71 | 4.01 |
| 1965 | 0.36 | 0.32 | 0.23 | 0.18 | 0.16 | 0.21 | 2.45 | 2.29 | 2.98 |
| 1966 | 0.47 | 0.36 | 0.07 | 0.24 | 0.18 | 0.06 | 2.41 | 1.98 | 1.40 |
| 1967 | 0.55 | 0.27 | 0.11 | 0.28 | 0.18 | 0.10 | 3.48 | 2.36 | 0.72 |
| 1968 | 0.82 | 0.39 | 0.10 | 0.42 | 0.19 | 0.09 | 3.39 | 2.23 | 1.61 |
| 1969 | 0.71 | 0.59 | 0.20 | 0.37 | 0.29 | 0.19 | 4.29 | 3.79 | 2.95 |
| 1970 | 0.64 | 0.58 | 0.06 | 0.33 | 0.29 | 0.06 | 3.28 | 2.97 | 1.11 |
| 1971 | 0.66 | 0.52 | 0.12 | 0.34 | 0.26 | 0.11 | 3.64 | 3.15 | 1.22 |
| 1972 | 0.58 | 0.42 | 0.08 | 0.30 | 0.20 | 0.07 | 3.60 | 3.11 | 1.97 |
| 1973 | 0.44 | – | 0.06 | 0.23 | – | 0.06 | 3.17 | – | 1.51 |
| 1974 | 0.55 | – | 0.24 | 0.28 | – | 0.22 | 3.63 | – | 2.93 |
| 1988 | 0.58 | 0.14 | – | 0.31 | 0.05 | – | 3.39 | 0.96 | – |
| 1989 | 0.51 | 0.34 | 0.15 | 0.28 | 0.14 | 0.11 | 3.11 | 2.42 | 0.76 |
| 1990 | 0.34 | 0.32 | 0.15 | 0.19 | 0.15 | 0.11 | 2.15 | 2.02 | 2.06 |
| 1991 | 0.69 | 0.30 | 0.32 | 0.15 | 0.14 | 0.24 | 2.40 | 1.93 | 2.65 |
| 1992 | 0.53 | 0.42 | 0.00 | 0.16 | 0.19 | 0.00 | 1.88 | 2.80 | 0.00 |
| 1993 | 0.52 | 0.39 | 0.37 | 0.13 | 0.14 | 0.27 | 1.10 | 1.83 | 0.94 |
| 1994 | 0.56 | 0.47 | 1.09 | 0.16 | 0.20 | 1.14 | 1.22 | 2.14 | 3.72 |
| 1995 | 0.35 | 0.66 | 0.21 | 0.17 | 0.25 | 0.17 | 2.34 | 2.45 | 2.42 |
| 1996 | 0.35 | 0.36 | 0.24 | 0.19 | 0.14 | 0.22 | 1.88 | 2.31 | 1.77 |

(continued)

**Table 14.2** (continued)

| Year | | Number per meter | | | Number per square meter | | | Grams per square meter | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Flynn | Deer | Needle | Flynn | Deer | Needle | Flynn | Deer | Needle |
| Mean and standard deviation | | | | | | | | | | |
| 1962–65 | mean | 0.446 | 0.377 | 0.290 | 0.239 | 0.186 | 0.267 | 3.650 | 2.735 | 3.343 |
| | S.D. | 0.079 | 0.062 | 0.093 | 0.046 | 0.030 | 0.086 | 1.748 | 1.101 | 0.556 |
| 1966–74 | mean | 0.601 | 0.445 | 0.114 | 0.311 | 0.226 | 0.107 | 3.432 | 2.799 | 1.713 |
| | S.D. | 0.120 | 0.120 | 0.062 | 0.062 | 0.049 | 0.058 | 0.498 | 0.635 | 0.776 |
| 1988–96 | mean | 0.492 | 0.378 | 0.316 | 0.193 | 0.155 | 0.283 | 2.163 | 2.096 | 1.790 |
| | S.D. | 0.121 | 0.140 | 0.333 | 0.061 | 0.055 | 0.357 | 0.764 | 0.521 | 1.191 |
| Ratio of means (%) | | | | | | | | | | |
| 1966–74/1962–65 | | 134.8 | 118.0 | 39.5 | 130.3 | 121.8 | 40.0 | 94.0 | 102.3 | 51.3 |
| 1988–96/1962–65 | | 110.3 | 100.2 | 109.1 | 80.9 | 83.6 | 105.8 | 59.3 | 76.6 | 53.5 |
| Coefficient of variation | | | | | | | | | | |
| 1962–65 | | 17.7 | 16.4 | 32.2 | 19.1 | 16.3 | 32.2 | 47.9 | 40.3 | 16.6 |
| 1966–74 | | 19.9 | 27.1 | 54.1 | 19.9 | 21.7 | 53.9 | 14.5 | 22.7 | 45.3 |
| 1988–96 | | 24.6 | 37.2 | 105.1 | 31.6 | 35.4 | 126.4 | 35.3 | 24.8 | 66.5 |

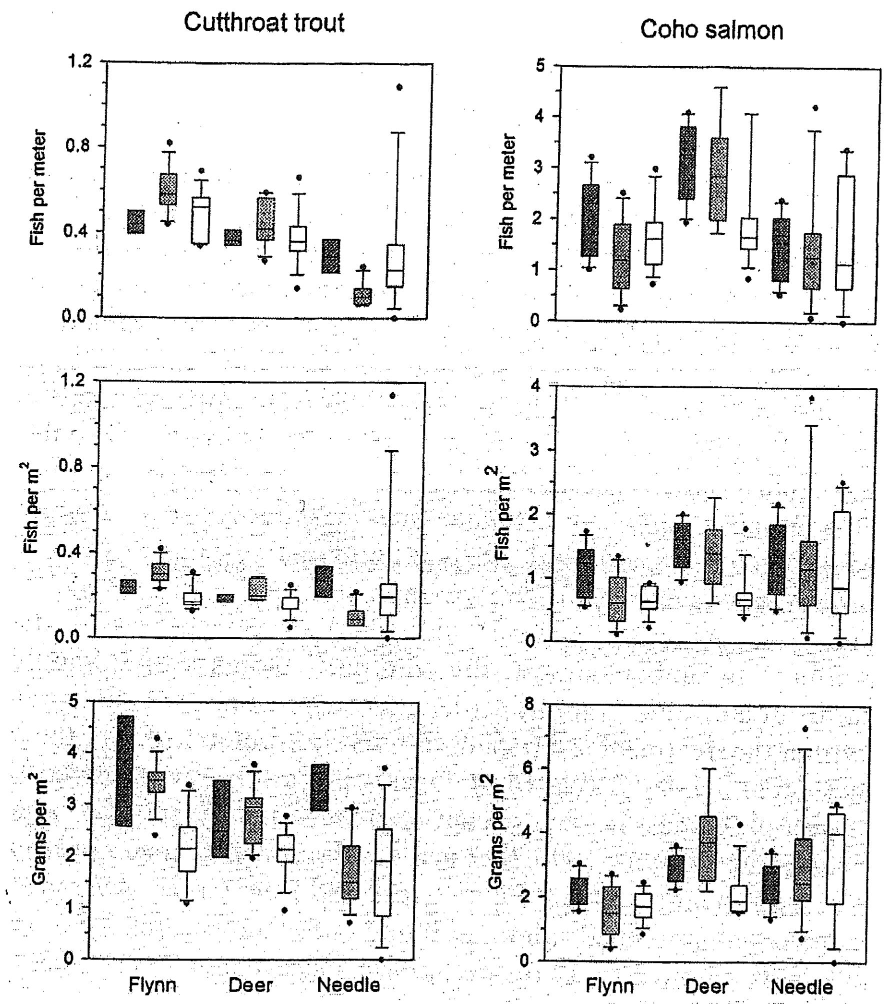


**Fig. 14.1** Abundance of juvenile cutthroat trout and coho salmon in the AWS streams for the periods 1959–1965, 1966–1974, and 1988–1996. Bars within boxes are median values, boxes represent 25th to 75th percentiles, whiskers show 10th and 90th percentiles, and dots show extreme outliers. Whiskers are omitted for small sample sizes. Dark shading indicates 1962–1965 for trout and 1959–1965 for salmon (prelogging), light shading indicates 1966–1974 (early post-logging), and no shading indicates 1988–1996 (later post-logging)

in Needle Branch approached prelogging levels (Table 14.2, Fig. 14.1). In contrast to the density measure, estimates of biomass of trout per $m^2$ in Needle Branch remained close to the low levels observed immediately after logging. Trout biomass (g $m^{-2}$) in Flynn Creek and Deer Creek decreased to 60–75% of the biomass observed during the prelogging years.

The fact that trout numbers in Needle Branch during 1989–1996 recovered to levels approaching prelogging populations but biomass did not increase indicates that the recovery was based on responses of age-0 trout. This increase in numbers of young fish masked a continued decrease in older fish and potential spawners in the population. Separation of age classes of trout reveals that there were major increases in production of cutthroat trout fry in Needle Branch but no significant change in fry numbers in Flynn Creek (Fig. 14.2). In sharp contrast, mean numbers of age-1+ trout in Needle Branch, which had decreased by 60% in the early post-logging period, were even lower during 1989–1996, averaging about 20% of prelogging abundance. Mean and median numbers of age-1+ trout in Flynn Creek were just slightly lower than prelogging values.

Abundances of juvenile coho salmon did not change appreciably between prelogging and early post-logging periods in the two logged streams, but there was a notable decrease in Flynn Creek, the reference stream (Table 14.3, Fig. 14.1). From 1988–1996, abundances in Flynn Creek were similar to populations observed in the early postlogging period. Numbers and biomass of juvenile salmon in Deer Creek from 1988–1996 were approximately 60% of the early postlogging values. In contrast, numbers and biomass of coho salmon in Needle Branch did not decrease in the early post-logging period, and during 1988–1996 remained equal to or higher than abundances of salmon observed prior to logging. These results indicate that timber harvest had no clear effect on summer populations of juvenile coho salmon.

Though numbers and biomass of individual species changed in the AWS streams following timber harvest, the combined biomass of salmonids (i.e., cutthroat trout and coho salmon) per length of stream did not change substantially in either the treatment watersheds or reference watershed over the 30 years between 1966 and 1996 (Table 14.4). Grams per meter is considered the best index of overall biomass in each stream because of the substantial variation in stream widths during 1988–1996. Biomass of salmonids per meter of stream was greatest in the two larger basins, Flynn Creek and Deer Creek. Averages for the lineal estimates of combined salmonid biomass for the periods 1966–1974 and 1988–1996 were within 10% of the preharvest averages for 1962–1965, with the exception of the 17% decrease in Needle Branch for 1966–1974, which was due to the substantial decrease in older cutthroat trout.

This extended study provided an opportunity to document long-term variation of salmonid populations in both undisturbed and disturbed habitats. Interannual variation in abundance of juvenile coho salmon and cutthroat trout was high in these small streams (Tables 14.2 and 14.3). In the undisturbed Flynn Creek, the overall CV from 1959–1996 was 49% for juvenile salmon and 24% for trout, based on lineal density. Over this 38-year period, densities of juvenile salmon in late summer differed by an order of magnitude (Table 14.3). Substantial variation in salmon density was also observed in prelogging data from Deer Creek and Needle Branch, which had CVs of 26% and 49%, respectively. Trout densities from prelogging years in Deer Creek and Needle Branch showed CVs of 16% and 32%, respectively. In general, juvenile salmon densities were more variable than trout densities. Estimates of biomass of juvenile salmon almost always had lower CVs than estimates of density, for all streams and periods of record (Table 14.3). For cutthroat trout, this relationship was consistent only for Needle Branch (Table 14.2).

The clearcut logging in Needle Branch appeared to cause substantial increases in variation in density and biomass of cutthroat trout. In the early

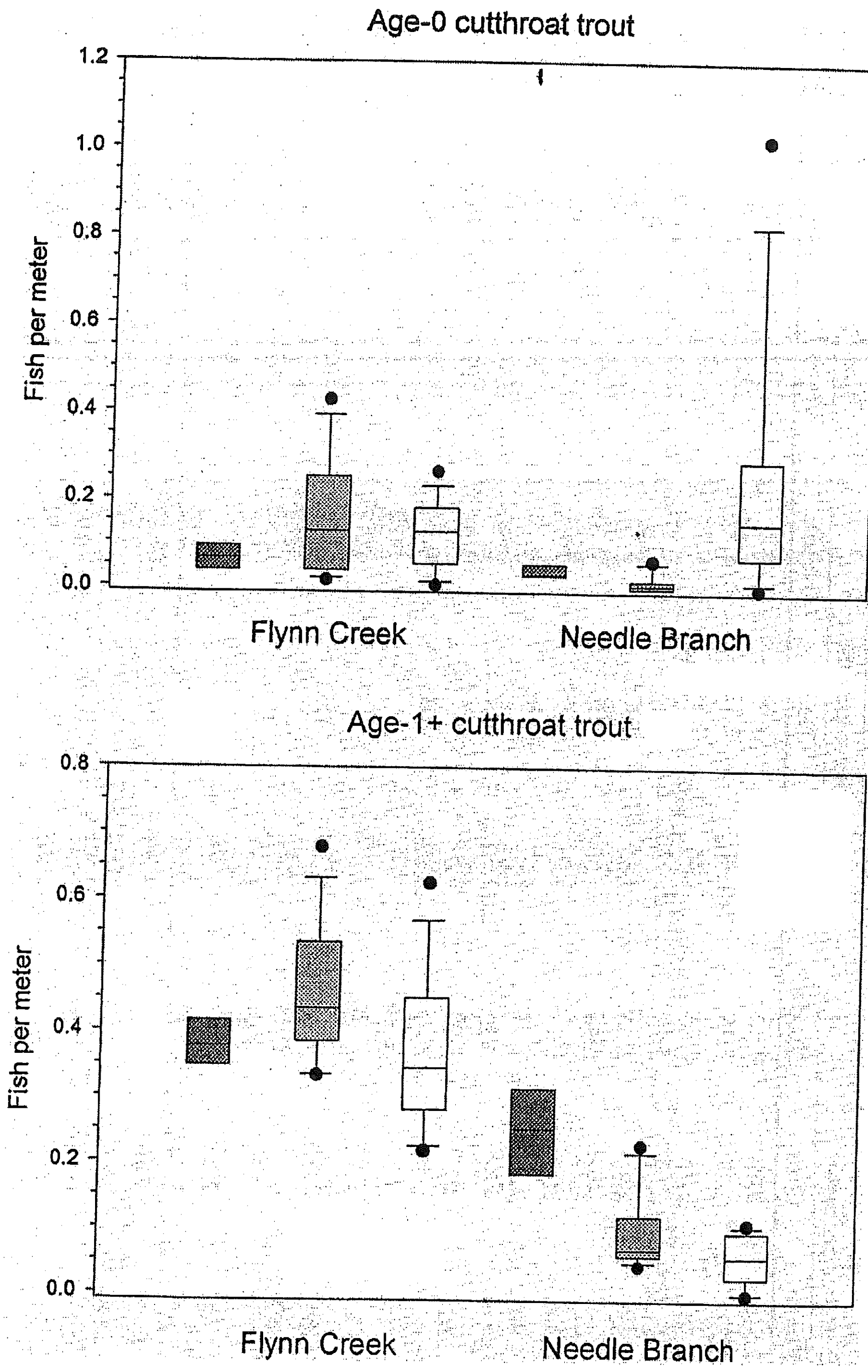


**Fig. 14.2** Lineal density of age-0 and age-1+ cutthroat trout in Flynn Creek and Needle Branch for the periods 1962–1965, 1966–1974, and 1988–1996. Bars within boxes are median values, boxes represent 25th to 75th percentiles, whiskers show 10th and 90th percentiles, and dots show extreme outliers. Whiskers are omitted for small sample sizes. Dark shading indicates 1962–1965 (prelogging), light shading indicates 1966–1974 (early post-logging), and no shading indicates 1988–1996 (later post-logging)

**Table 14.3** Estimates of coho salmon populations in AWS streams from 1959 to 1996, expressed as lineal density (# $m^{-1}$), areal density (# $m^{-2}$), and biomass (g $m^{-2}$). Dash indicates that stream was not sampled. (1959–1965: prelogging, 1966–1974: early post-logging, and 1988–1996: later post-logging)

| | Number per meter | | | Number per square meter | | | Grams per square meter | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | Flynn | Deer | Needle | Flynn | Deer | Needle | Flynn | Deer | Needle |
| 1959 | 2.51 | 3.40 | 0.93 | 1.46 | 1.66 | 0.97 | 3.05 | 3.06 | 1.88 |
| 1960 | 2.72 | 2.28 | 1.55 | 1.41 | 1.12 | 1.35 | 2.66 | 2.25 | 1.97 |
| 1961 | 2.30 | 2.75 | 0.78 | 1.24 | 1.36 | 0.71 | 2.23 | 3.19 | 1.84 |
| 1962 | 3.21 | 4.09 | 2.38 | 1.73 | 2.01 | 2.17 | 2.39 | 3.34 | 3.08 |
| 1963 | 1.01 | 3.27 | 1.66 | 0.55 | 1.61 | 1.51 | 2.15 | 3.27 | 2.84 |
| 1964 | 1.22 | 1.94 | 0.54 | 0.66 | 0.95 | 0.50 | 1.64 | 2.33 | 1.33 |
| 1965 | 1.40 | 3.96 | 2.17 | 0.75 | 1.95 | 1.98 | 1.56 | 3.61 | 3.47 |
| 1966 | 1.99 | 2.84 | 1.27 | 1.07 | 1.40 | 1.16 | 2.74 | 3.72 | 3.31 |
| 1967 | 2.51 | 4.60 | 4.22 | 1.35 | 2.27 | 3.84 | 2.44 | 6.03 | 7.30 |
| 1968 | 1.62 | 3.27 | 1.92 | 0.87 | 1.61 | 1.75 | 2.03 | 4.03 | 4.05 |
| 1969 | 0.23 | 1.73 | 0.62 | 0.12 | 0.63 | 0.54 | 0.39 | 2.22 | 2.18 |
| 1970 | – | – | 0.24 | – | – | 0.22 | – | – | 0.64 |
| 1971 | – | – | 0.18 | – | – | 0.17 | – | – | 0.98 |
| 1972 | 0.64 | 2.08 | 1.27 | 0.33 | 1.02 | 1.18 | 0.73 | 2.67 | 2.48 |
| 1973 | 0.65 | – | 0.08 | 0.34 | – | 0.08 | 1.24 | – | 0.74 |
| 1974 | 1.19 | – | 0.85 | 0.62 | – | 0.79 | 1.51 | – | 1.87 |
| 1988 | 1.62 | 2.36 | – | 0.88 | 0.78 | – | 2.48 | 2.65 | – |
| 1989 | 1.67 | 1.94 | 3.38 | 0.90 | 0.79 | 2.52 | 2.00 | 2.31 | 4.70 |
| 1990 | 1.72 | 1.69 | 2.46 | 0.93 | 0.78 | 1.83 | 2.22 | 1.91 | 4.20 |
| 1991 | 2.98 | 1.48 | 0.89 | 0.64 | 0.68 | 0.66 | 2.10 | 1.61 | 2.22 |
| 1992 | 0.73 | 0.85 | 0.00 | 0.23 | 0.39 | 0.00 | 0.86 | 1.54 | 0.00 |
| 1993 | 2.61 | 5.23 | 3.31 | 0.64 | 1.79 | 2.41 | 1.35 | 4.29 | 4.94 |
| 1994 | 1.57 | 1.45 | 0.93 | 0.45 | 0.61 | 0.97 | 1.40 | 1.90 | 4.60 |
| 1995 | 1.13 | 1.40 | 0.44 | 0.55 | 0.54 | 0.36 | 1.72 | 1.60 | 1.47 |
| 1996 | 1.08 | 1.66 | 1.35 | 0.59 | 0.63 | 1.26 | 1.59 | 2.00 | 3.81 |

**Table 14.3** (continued)

| Year | | Number per meter | | | Number per square meter | | | Grams per square meter | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Flynn | Deer | Needle | Flynn | Deer | Needle | Flynn | Deer | Needle |
| Mean and standard deviation | | | | | | | | | | |
| 1959–65 | mean | 2.05 | 3.10 | 1.43 | 1.11 | 1.52 | 1.31 | 2.24 | 3.01 | 2.34 |
| | S.D. | 0.84 | 0.81 | 0.71 | 0.46 | 0.40 | 0.63 | 0.53 | 0.52 | 0.78 |
| 1966–74 | mean | 1.26 | 2.90 | 1.46[1] | 0.67 | 1.39 | 1.33[1] | 1.58 | 3.73 | 3.13[1] |
| | S.D. | 0.82 | 1.13 | 1.35 | 0.45 | 0.62 | 1.23 | 0.87 | 1.48 | 2.12 |
| 1988–96 | mean | 1.68 | 2.01 | 1.60 | 0.65 | 0.78 | 1.25 | 1.75 | 2.20 | 3.24 |
| | S.D. | 0.72 | 1.28 | 1.30 | 0.23 | 0.40 | 0.93 | 0.50 | 0.86 | 1.80 |
| Ratio of Means (%) | | | | | | | | | | |
| 1966–74/1959–65 | | 61.4 | 93.7 | 102.1 | 60.3 | 91.0 | 101.7 | 70.7 | 124.2 | 133.6 |
| 1988–96/1959–65 | | 82.0 | 64.8 | 111.9 | 58.6 | 51.3 | 95.5 | 78.1 | 73.1 | 138.6 |
| Coefficient of variation | | | | | | | | | | |
| 1959–65 | | 41.1 | 26.3 | 49.3 | 41.1 | 26.3 | 47.9 | 23.7 | 17.2 | 33.5 |
| 1966–74 | | 65.1 | 38.8 | 92.1 | 66.4 | 44.7 | 92.0 | 55.0 | 39.7 | 67.6 |
| 1988–96 | | 42.9 | 63.7 | 81.3 | 35.4 | 51.3 | 74.5 | 28.6 | 39.1 | 55.7 |

[1] Means do not include 1970 and 1971 because there was no estimate for the reference stream.

**Table 14.4** Estimates of combined biomass of juvenile coho salmon and cutthroat trout in the AWS streams from 1962 to 1996, expressed as grams per meter of stream length. Dashes indicate that stream was not sampled for both species

| | Year | Flynn Creek | Deer Creek | Needle Branch |
|---|---|---|---|---|
| Prelogging Period | 1962 | 16.03 | 15.46 | 7.28 |
| | 1963 | 9.13 | 10.07 | 6.16 |
| | 1964 | 8.97 | 10.25 | 5.74 |
| | 1965 | 7.65 | 12.00 | 6.98 |
| Early Post-logging Period | 1966 | 9.77 | 11.60 | 5.11 |
| | 1967 | 11.29 | 17.07 | 8.75 |
| | 1968 | 10.35 | 12.74 | 6.15 |
| | 1969 | 9.07 | 12.23 | 5.48 |
| | 1970 | – | – | – |
| | 1971 | – | – | – |
| | 1972 | 8.40 | 11.76 | 4.76 |
| | 1973 | 8.55 | – | 2.41 |
| | 1974 | 9.97 | – | 5.13 |
| Later Post-logging Period | 1988 | 10.84 | 10.88 | – |
| | 1989 | 9.44 | 11.61 | 7.28 |
| | 1990 | 8.07 | 8.56 | 8.35 |
| | 1991 | 20.92 | 7.71 | 6.49 |
| | 1992 | 9.01 | 9.46 | 0.00 |
| | 1993 | 10.02 | 17.89 | 8.04 |
| | 1994 | 9.18 | 9.66 | 7.94 |
| | 1995 | 8.37 | 10.60 | 4.73 |
| | 1996 | 6.36 | 11.41 | 5.96 |
| Statistics for Study Periods | Mean | | | |
| | 1962–65 | 10.45 | 11.95 | 6.54 |
| | 1966–74 | 9.63 | 13.08 | 5.40 |
| | 1988–96 | 10.25 | 10.86 | 6.10 |
| | 1962–96 | 10.07 | 11.72 | 5.93 |
| | CV | | | |
| | 1962–65 | 36.2 | 20.9 | 10.9 |
| | 1966–74 | 10.7 | 17.4 | 34.9 |
| | 1988–96 | 41.0 | 27.0 | 45.1 |
| | 1962–96 | 31.6 | 23.1 | 35.4 |

post-logging period, CVs increased by about 70% to 170% over the prelogging values (Table 14.2). During 1989–1996 CVs increased even further, reaching 3–4 times the prelogging values. Variation in the other two streams either decreased in the post-logging period, or increased by a substantially smaller amount. For coho salmon there was no clear relationship between disturbance and the coefficient of variation. The CVs tended to increase in both post-logging periods in all three streams. However, changes were variable, often greater in Deer Creek, the patchcut watershed that experienced almost no disturbance, than in Needle Branch (Table 14.3). Variance in combined salmonid biomass per length of stream was similar between study periods for Flynn Creek and Deer Creek, but variance (CV) in Needle Branch was 3–4 times greater after timber harvest than before.

## Discussion

There was no clear evidence of a change in stream channel dimensions due to logging. The average pool-riffle ratio has not changed markedly in the last 30 years. Changes in habitat structure were not detectable at a channel-unit scale. Microhabitat structure, such as cover from undercut banks, boulders, and large wood, was not measured during the AWS, and thus cannot be compared to recent data. However, preexisting large wood was nearly totally removed by stream cleaning after logging in Needle Branch, and wood volumes in Needle Branch remain lower than in the other streams in the AWS (Veldhuisen 1990). Blowdown of alder in Needle Branch in recent years has begun to provide undercut banks and rootwads, creating more complex habitat for salmonids.

Beaver activity caused major changes in stream habitat area and complexity in Flynn Creek and Deer Creek during 1988–1996. Beaver also moved into Deer Creek during the early post-logging period, but a desire to focus solely on logging effects caused researchers to remove beaver from Deer Creek during the original study. Both width and depth increased in Flynn Creek from 1991 to 1994 after beaver dammed the lower study reaches. Changes in Deer Creek were generally less extensive and more variable from year to year. In general, lineal abundances of both juvenile coho salmon and cutthroat trout (numbers per meter and grams per meter) were greater in both streams during years of beaver activity. At the same time, abundances and biomass per square meter often were lower during these years. Results were extremely variable. With the exception of the increase in area in both streams and in grams per meter of both coho salmon and the two combined species in Deer Creek, none of the changes were statistically significant. Other studies in the Pacific Northwest and Alaska have suggested the importance of beaver as an agent of habitat formation for salmonids (Sanner 1987; Leidholdt-Bruner et al. 1992; Nickelson et al. 1992).

Beaver potentially increase food production and area and volume of stream habitat (Naiman et al. 1984; Naiman et al. 1986), which potentially influence abundance of fish. If fish populations are habitat limited but not food limited, any increase in habitat should increase total numbers of fish (i.e., numbers $m^{-1}$). Under such conditions, density (number $m^{-2}$) would increase only if depth increased. Fish abundance could also increase if beaver create a different type of habitat that was not present previously, such as accumulations of large wood. If fish populations are food limited and beaver activity causes an increase in channel dimensions but does not change the rate of food production per unit area, total abundance (numbers $m^{-1}$) would increase but density (number $m^{-2}$) would not change.

The cutthroat trout population in Needle Branch has not recovered over the long term, though in recent years (1989–1996) there have been intermittent increases in abundance of age-0 trout. The failure of age-1 and older trout to recover 30 years after logging is remarkable. The occasional high numbers of fry indicate that recruitment is possible, but survival of age-0 trout after the summer season is unusually low.

There are several possible explanations for the failure of older cutthroat trout to rebound. The initial decrease may have been due in part to the substantial increase in stream temperature during the first few years following logging. In Carnation Creek, British Columbia, temperature changes as a result of riparian cover removal influenced trout abundance and shifted life-history patterns of salmonids (Hartman and Scrivener 1990). However, temperatures in Needle Branch returned to prelogging levels within a few years and cannot be a factor in the long-term decline. Cover associated with large wood was removed by the stream-cleaning operations during the AWS, and undercut banks were destroyed. Thus the long-term detrimental effects on trout in Needle Branch may reflect degraded habitat.

Interaction with juvenile coho salmon, which remained abundant after logging, may also have influenced trout abundance in Needle Branch. In general, similarity of preharvest and post-harvest estimates of combined salmonid biomass (Table 14.4) reflects the interaction of cutthroat trout and coho salmon and potential compensatory effects of competition for food and habitat. The stream's small size and altered morphology may exacerbate such interaction. During late summer the stream often flows subsurface through the low-gradient gravel riffles, leaving only isolated small pools occupied by both trout and salmon. In such habitat, the body morphology of juvenile coho salmon may give them an advantage over age-0 cutthroat trout (Bisson et al. 1988). In addition, coho salmon have generally been thought to be more aggressive than cutthroat trout (Glova 1986, 1987). However, more recent work has shown that size-matched cutthroat trout may be equally competitive with coho salmon (Sabo and Pauley 1997). In our streams coho salmon emerge from the gravel earlier and at a larger size than trout and thus may gain an early advantage. In four of the seven recent years, juvenile coho salmon were on average larger than age-0 cutthroat trout at the time of the summer population estimates (Table 14.5). But even in years when the average size of trout fry was larger than the salmon, the trout were so outnumbered that substantial numbers of juvenile salmon were larger than any age-0 trout. However, this circumstance also prevailed in the prelogging period, when total biomass of cutthroat trout in Needle Branch exceeded that of the juvenile salmon. If competition has played a role in the continued low population of larger cutthroat trout, factors other than size-related dominance alone must have been responsible for competitive effects.

**Table 14.5** Estimated number and size of age-0 cutthroat trout and juvenile coho salmon during August in Needle Branch, 1989–1996 (stream was dry in 1992). The population estimate is for the entire 870–m length of stream

| | Year | | | | | | |
|---|---|---|---|---|---|---|---|
| Population properties | 1989 | 1990 | 1991 | 1993 | 1994 | 1995 | 1996 |
| Cutthroat trout | | | | | | | |
| Estimated pop. | 87 | 35 | 193 | 313 | 889 | 97 | 165 |
| Mean length (mm) | 66.8 | 48.2 | 56.2 | 60.9 | 57.3 | 66.9 | 68.2 |
| Std. deviation (mm) | 4.97 | 6.70 | 10.75 | 12.62 | 8.83 | 5.56 | 9.39 |
| Size range | 56–77 | 39–58 | 38–69 | 34–78 | 35–79 | 54–74 | 38–79 |
| No. measured | 33 | 13 | 30 | 72 | 186 | 18 | 28 |
| Coho salmon | | | | | | | |
| Estimated pop. | 2,930 | 2,130 | 770 | 2,870 | 806 | 384 | 1,170 |
| Mean length (mm) | 54.3 | 55.1 | 64.5 | 53.2 | 68.1 | 70.1 | 60.8 |
| Std. deviation (mm) | 9.95 | 10.28 | 9.90 | 9.49 | 13.53 | 8.66 | 8.03 |
| Size range | 38–101 | 39–94 | 49–107 | 36–91 | 48–108 | 53–86 | 44–88 |
| No. measured | 520 | 440 | 180 | 560 | 135 | 69 | 222 |

Reeves et al. (1997) put forth one hypothesis that may help to explain the result. They suggested that a complex pool environment, which existed in Needle Branch prior to clearcut logging, would create physical heterogeneity, allowing trout and salmon to be segregated within pools. Removal of large wood and pool simplification after logging would increase potential for interactions, to the possible disadvantage of the smaller cutthroat trout. Data for the AWS streams are not adequate to support or refute these competitive mechanisms for change in trout population size. However, there is little doubt that the initial reduction in trout abundance was in part related to the logging, burning, and stream channel disturbance in the Needle Branch watershed. The persistent reduction in numbers of larger cutthroat trout may be related to stream size, but further work will be required to clarify the mechanisms.

Juvenile coho salmon showed no long-term shifts in density or biomass beyond the range of natural variation as a result of timber harvest. In the original AWS, summer populations of juvenile salmon did not decline significantly in the two logged streams, though smolt outmigration decreased, particularly in the reference stream (See Chapter 5). In all AWS streams, density and biomass of juvenile salmon exhibited greater variability in the post-logging periods than in the prelogging period. From 1989–1996, salmon density and biomass in Needle Branch were high compared to the average of AWS years. The high variability of juvenile salmon abundance makes interpretation of land-use impacts difficult, but increased variation of populations in streams in harvested basins was consistent both for the early post-harvest period and for the later period 22–30 years after harvest.

Trends in coho salmon populations in the AWS are affected by many factors in addition to freshwater habitat conditions, including ocean conditions, commercial and sport harvest, hatchery operations, and predation by marine mammals and birds. Natural trends in climate and ocean conditions have raised many management questions about coho salmon populations over the last two decades (Francis and Sibley 1991; Pearcy 1992). Changes in numbers of spawning adults could strongly influence patterns of juvenile salmon abundance the following summer. In the AWS streams, average numbers of female spawners did not change substantially from prelogging to post-logging (1958–1964: Flynn Creek – 19.5, Deer Creek – 26.2, Needle Branch – 10.8; 1965–1971: Flynn Creek – 17.6, Deer Creek – 28.0, Needle Branch – 14.3). For these same periods, spawner estimates for a standard survey reach in an adjacent stream, Horse Creek, were 13.3 spawners for 1958–1964 and 12.9 spawners for 1965–1971 (Oregon Department of Fish & Wildlife, unpublished data). Estimates of spawner numbers are not available for the AWS streams during the 1987–1995 period, but numbers of spawners estimated in the Horse Creek reach decreased by 30% to an average of 9.2. Decreases in coastwide escapement were even greater. From 1987–1995, two spawners or fewer were observed in the Horse Creek survey reach for four of the nine years. Such low numbers of spawners had been observed in only two years of the 32-year record for Horse Creek prior to 1987. It is likely that the lower density and biomass of juvenile coho salmon that occurred in some years (e.g., 1992, 1995) in all AWS streams from 1988–1996 were related in part to regional changes in climate and ocean conditions that reduced marine survival of adult coho salmon.

In addition to disturbance, tributary size may have influenced the degree of annual variation in salmonid populations. During both the prelogging and post-logging periods, Needle Branch, the smallest stream, had the greatest annual variation in population density and the lowest lineal abundance of salmonids compared to the two larger AWS streams. Correspondingly, CVs for juvenile coho salmon and cutthroat trout prior to harvest were lowest in Deer Creek, the largest stream. Large year-to-year fluctuations in salmonid populations have been observed in other studies, thus long-term data are essential for adequate evaluation of land-use effects (Hall and Knight 1981; Platts and Nelson 1988; House 1995, See Chapter 15).

Responses of salmonids to timber harvest practices are complex and reflect the array of environmental factors (e.g., elevation, temperature, precipitation, water chemistry), geological factors (e.g., parent geology, topography, floodplain development, groundwater supply), and biotic factors (e.g., riparian vegetation, litter inputs, algal production, invertebrate assemblages, fish assemblages, other vertebrates) that influence salmonids in streams (Gregory et al. 1987; Gregory et al. 1991; Bisson et al. 1992; Naiman et al. 1992). Many studies discuss potential impacts of forest practices on salmonid populations in streams, but few have directly measured responses of fish populations to land-use practices (Hicks et al. 1991). Overall, timber harvest has the potential to change fish populations over several decades. In the two longest-running studies of effects of forest harvesting, the AWS and Carnation Creek, British Columbia, fish populations in harvested basins were more variable than populations in undisturbed forests. During periods of increased risks to depressed salmonid stocks (e.g., poor ocean conditions, drought, frequent floods, high commercial harvest), the potential for detrimental effects of timber harvest increases the need for efforts to protect streams and basins from habitat degradation.

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