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Bisson, P.A., J.L. Nielsen, and J.W. Ward. 1985. Experimental release of coho salmon (Oncorhynchus kisutch) into a stream impacted by Mount Saint Helens volcano. Pages 422-435 in Proceedings of the 64th Annual Conference of the Western Association of Fish and Wildlife Agencies, and the Western Division American Fisheries Society, held July 16-19, 1984, Victoria, British Columbia. Published by the Western Association of Fish and Wildlife Agencies, Sacramento, California.

EXPERIMENTAL RELEASE OF COHO SALMON (Oncorhynchus kisutch) INTO A STREAM IMPACTED BY MOUNT SAINT HELENS VOLCANO

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ABSTRACT

The May 18, 1980 eruption of Mt. Saint Helens caused catastrophic disturbance to the Toutle River and many of its tributaries, resulting in the nearly complete elimination of fishes in the upper watershed. We studied the ability of Hoffstadt Creek, a stream in the volcanic impact zone, to rear juvenile coho salmon during the summer and early autumn of 1983. The poor habitat conditions that existed in Hoffstadt Creek provided an opportunity to examine the ecological resiliency of coho salmon to changes in their physical environment. Pool habitats comprised only 27% of the study area, instream cover was very scarce, and water temperature exceeded 15.6°C (60°F) on 47% of the days during which temperature was monitored (August-October). Despite the apparently unfavorable environment, production of coho in Hoffstadt Creek during summer (2.17 g/m^2) was not greatly different from other Pacific Northwest streams. Both growth and survival rates were higher from August-October than from June-August. The coho tended to prefer pool habitats but those in riffles generally maintained higher growth rates. Without the influences of competitor species and most predators, nearly the full range of available habitat types was utilized. Approximately one half of the total production occurred in cascades and low gradient riffles, which are often avoided by this species elsewhere. Of the 15,000 coho stocked in Hoffstadt Creek in June, almost 50% remained there in late October prior to the beginning of winter rainstorms. However, by the following spring only 164 fish (1.1%) were captured as smolts or yearling parr. Absence of interspecific competition and significant predation probably contributed to the success of the coho during the summer, while lack of suitable overwinter habitat may have accounted for the low number of smolts in the spring.

INTRODUCTION

The lateral explosion that intiated the May 18, 1980 eruption of Mt. Saint Helens in western Washington caused widespread catastrophic disturbance to a large coniferous forest ecosystem. The horizontal blast of superheated gas and volcanic debris killed nearly everything in a wide arc extending 16-25 km north of the mountain. Although losses of human life and property, commercial timber, and important fish and wildlife populations were considerable, the Mt. Saint Helens eruption created an unprecedented scientific opportunity to examine ecosystem recovery processes within a very large, massively disturbed area. This paper reports the results of an experimental release of juvenile coho salmon into Hoffstadt Creek, a stream within the volcanic impact zone.

The study was designed to test the ecological resilience of coho under severe environmental stresses. An earlier study of coho in tributaries of the Toutle River system which had been impacted by the eruption (Martin et al., 1984) suggested that high mid-summer stream temperatures and the lack of large organic debris strongly limited survival, growth, and habitat utilization. Our objective was to examine coho production in a near "worst case" situation in which channel morphology, cover, and water quality were believed to be very unfavorable for this species, and to compare the observed production rates with those of coho in other streams of the Pacific Northwest. The biologically sterile conditions produced by the Mt. Saint Helens eruption allowed us to experimentally control the initial population level and study its response to the physical stream environment without the confounding influences of competing species and most predators.

METHODS

Study Area

The study began in June 1983, approximately three years after the eruption. Hoffstadt Creek is located near the western boundary of the impact zone (Figure 1) where vegetation was killed by the heat of the lateral blast and either blown down or left standing and dead. The dominant vegetation at the time of the eruption was a young mixed species coniferous forest of Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*). In the intervening years since the eruption most of the Hoffstadt Creek watershed has been replanted with Douglas-fir, but the riparian zone of the stream possesses vigorously growing red alder (*Alnus rubra*), willow (*Salix sp.*), devil's club (*Oplopanax horridum*), salmonberry (*Rubus spectabilis*), swordfern (*Polystichum munitum*), buttercup (*Ranunculus uncinatus*), and fireweed (*Epilobium angustifolium*).

In addition to the eruption, Hoffstadt Creek was heavily impacted by a large debris torrent in early December 1981. The torrent originated high in the watershed and swept through the entire study reach, scouring the channel to bedrock in many places and removing nearly all of the pre-eruption woody debris as well as the trees which had been blown into the stream by the volcanic blast. As a result of the debris torrent, instream cover features such as logs were very nearly absent. The only remaining cover consisted of boulders, an occasional bedrock ledge, patches of overhanging terrestrial vegetation, and surface turbulence.

The study reach itself was a 1.1 km long segment of Hoffstadt Creek located in the middle of the watershed. At this point the stream was a fourth order channel with an average gradient of 2.4% and a drainage area of 33 km^2. The estimated wetted surface area of the study reach at low streamflow was 5,860 m^2 and the volume was 1,130 m^3. Although a considerable amount of tephra and volcanic ash had eroded into the stream since the eruption, very little fine sediment was actually stored in the channel due to the absence of sediment retention structures. Most of the fine sediment had been transported downstream and deposited near the confluence of Hoffstadt Creek and the North Fork Toutle River. Therefore, the study reach was notably lacking in sand and gravel-sized substrate, and was instead dominated by boulders and bedrock.

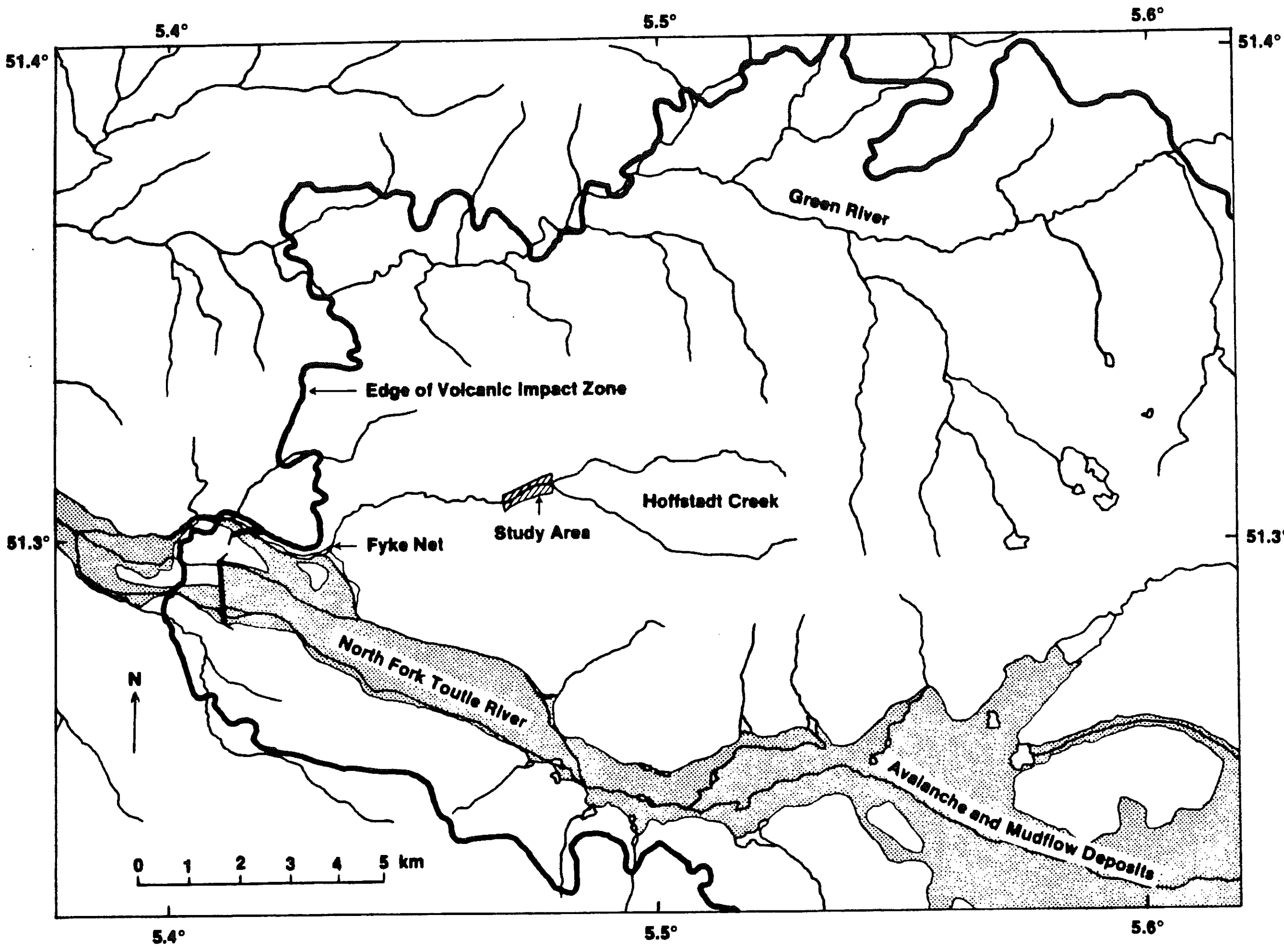

Figure 1. Location of Hoffstadt Creek relative to the boundary of the volcanic impact zone and the Toutle River mudflow.

Sampling Methods

Stream habitat was classified and mapped in June 1983 according to the technique of Bisson et al. (1982). In the 1,097 m study reach of Hoffstadt Creek we found 102 separate habitat units comprising eight habitat types. Habitat frequency was compared to the average frequency of the same habitat types found in other southwest Washington streams at low streamflow (Bisson and Nielsen, unpublished).

A recording thermograph (Partlow Model RFT) was installed at the downstream end of the study reach on August 8, 1983. The thermograph recorded air temperature as well as stream temperature and was calibrated every two weeks with a mercury thermometer. The recorder failed to function on two occasions: September 23-October 3 and October 10-October 12.

Approximately 15,000 coho salmon fry were stocked at the upstream boundary of the study reach on June 22, 1983. The fish were obtained from the Cowlitz River Salmon Hatchery and were of a late-run stock that is native to the Toutle River system. Average weight at stocking was 2.25 g (SD = 0.72) and average condition factor was 1.07 (SD = 0.07, n = 33). The coho population remaining in the study reach was censused in early August, 48 days after stocking, and again in late October, 77 days later. Other than a single age 4+ cutthroat trout (*Salmo clarki*), no fishes were present in the study reach of Hoffstadt Creek prior to the experimentally stocked coho. In addition, we sampled no other aquatic vertebrates during the study and saw little evidence of bird or mammal predation. The impact of the lone cutthroat on the coho population was considered to be negligible.

Habitat specific population estimates were obtained by isolating a given habitat (e.g., a plunge pool) with blocking nets and electrofishing three times. In a few instances where the habitat was too large to effectively electrofish, a small seine was used. Care was taken to isolate individual habitats as quickly as possible prior to sampling in order to prevent fish from moving into different areas. Calculation of population size followed the removal summation procedure of Carle and Strub (1978). Weight estimates were obtained from the formula

$$W = (1.1434 \times 10^{-6})\ L^{3.538} \quad (1)$$

where W = blotted wet weight (g) and L = fork length (mm). Conditon factor (Bagenal and Tesch, 1978) was calculated from samples taken August 8 and September 23.

Habitat specific utilization (Bisson et al., 1982) was defined as the density of coho in a particular habitat type relative to the average coho density over the entire reach. The formula was

$$U_h = \frac{D_h - \bar{D}_t}{\bar{D}_t} \quad (2)$$

where U_h = the habitat specific utilization coefficient, D_h = the average density of coho in a particular habitat type, and $\bar{D}_t$ = the average coho density over the entire reach, adjusted for relative habitat frequency. Values of this coefficient range from minus one (no fish present in the habitat) to positive infinity as a greater proportion of the population resides in the habitat type of interest. Values of zero indicate that a habitat is used in proportion to its abundance in the stream.

Production estimates conformed to the numerical procedure of Chapman (1978) in which it was assumed that instantaneous rates of growth and "mortality" (i.e., actual mortality plus emigration) were exponential. We further assumed that the distribution of coho during the June to early August interval was reflected in the relative proportions of fish observed in each habitat type in the early August census, and that all fish captured in a particular habitat had actually spent the entire measurement interval there. Because fish were not individually marked, these assumptions were untested.

Beginning in early March 1984, a fyke net was fished in lower Hoffstadt Creek near the margin of the volcanic mudflow of the Toutle River. The net was fitted with a floating live car that permitted continuous fishing of the net throughout the smolt migration period. The purpose of the fyke net was to capture coho that had survived the winter in Hoffstadt Creek and had reached smolt stage. On several occasions during the 1984 spring the net washed out or was severely damaged by freshets; therefore, the figure for smolt yield underestimated actual smolt production by an unknown quantity. To partially compensate for fish lost when the fyke net was inoperable, electrofishing was conducted in early March between the net and the Toutle River. We found that coho remained in this area prior to entering the highly turbid Toutle River mainstem.

RESULTS

Compared with most other western Washington streams of similar size, Hoffstadt Creek possessed infrequent pool habitat and very abundant riffle habitat (Table 1). Most pool types, with the exception of plunge pools, were present at about one half the relative percentage that occurred at other sites. Reduced pool areas were related to a lack of large, flow-controlling structures in the channel. Among the riffle habitats, cascades were most abundant and were the dominant habitat type in the study reach. Many of the cascades consisted of stair-stepped series of small waterfalls with tiny pools less than one meter in diameter.

Table 1. Habitat composition (% total wetted area) in Hoffstadt Creek and other western Washington streams

Habitat Type	Hoffstadt Creek	Other Washington Streams (n = 28)
Pools		
Backwater	2.1	4.6
Lateral scour	14.6	25.5
Plunge	7.3	8.0
Trench	2.2	4.9
Dammed	0	1.1
2nd channel	0.4	1.2
Total Pools	26.6	45.3
Riffles		
Low gradient	29.0	28.7
Rapids	4.2	10.6
Cascades	40.2	8.1
Total Riffles	73.4	47.4
Glides	0	7.1

Lack of pool habitat and scarcity of cover (especially large organic debris) created physical stream conditions that we judged to be very unfavorable for age 0+ coho. The affinity of coho for pools and cover has been well documented (Hartman, 1965; Mundie, 1969; Lister and Genoe, 1979) and the swiftly flowing, bedrock and boulder-dominated Hoffstadt Creek channel with relatively few breaks in the current appeared to provide little rearing area that was suitable for the species. This was particularly evident along the stream margin where coarse volcanic ash deposits had filled secondary channel and backwater areas.

The destruction of nearly all streamside vegetation in the Hoffstadt Creek watershed during the 1980 Mt. Saint Helens eruption resulted in water temperatures that exceeded the 15.6°C (60°F) threshold for Washington State "temperature sensitivity" classification on 47% of the days during which temperature was monitored (August-October). Maximum daily water temperature closely tracked air temperature (Figure 2) but was several degrees colder. The summer of 1983 was unusually cool and maximum air temperature reached only 27°C in August. Nevertheless, during one consecutive 11-day period (August 12-22) the average daily maximum in Hoffstadt Creek was 21°C (70°F) and the temperature remained above 15.6°C for nearly half of each day (Figure 2). During this warm period the average diel fluctuation was 15.3°C, in contrast to an average diel variation of 6.8°C for the rest of August.

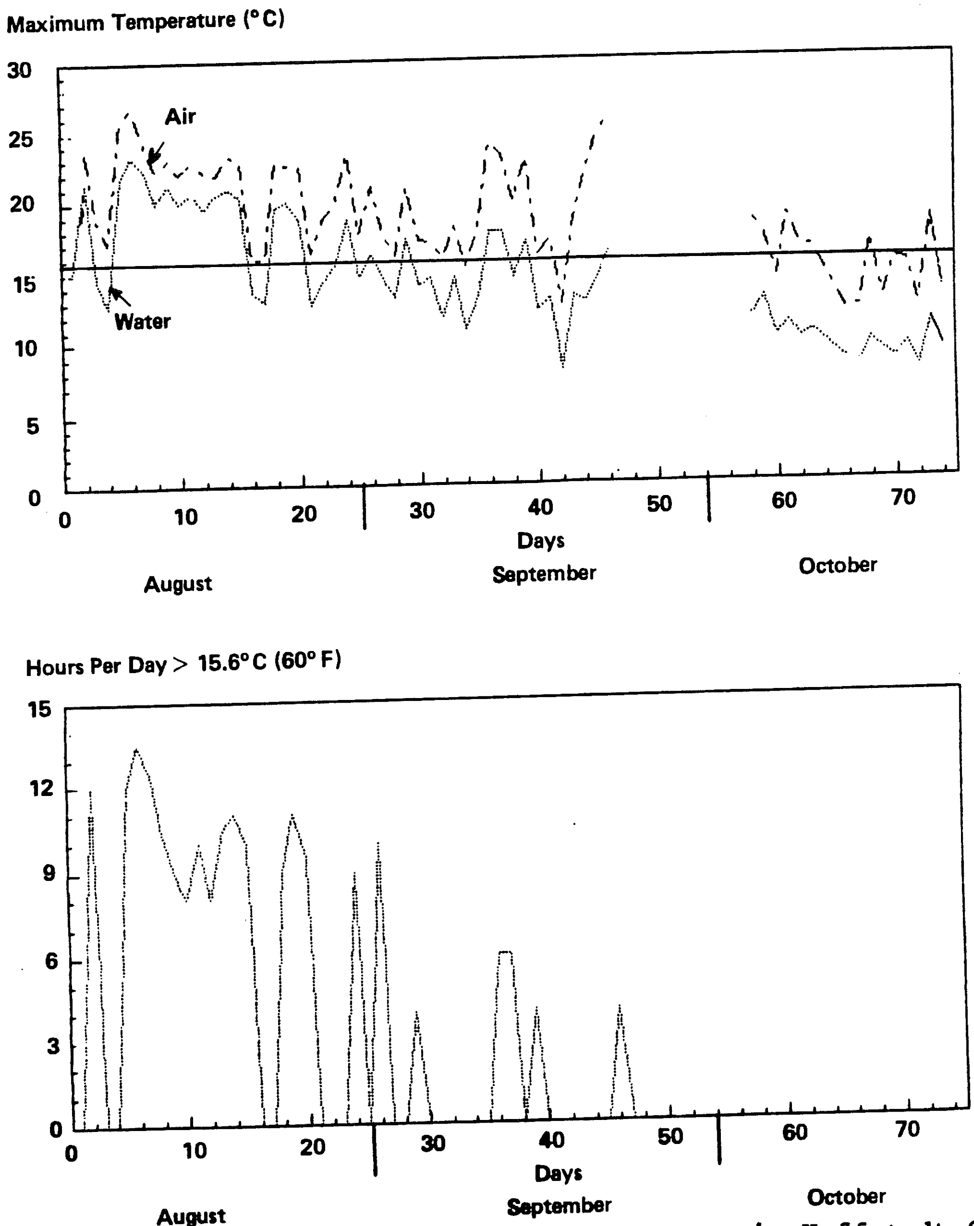

Figure 2. Top: Maximum air and stream temperatures in Hoffstadt Creek from August 8 to October 21, 1983. The 15.6°C (60°F) reference line denotes the threshold for Washington State "temperature sensitivity" stream classification. Bottom: Number of hours per day in which stream temperature exceeded 15.6°C.

Although the cool 1983 summer prevented temperatures from reaching lethal thresholds in Hoffstadt Creek, prolonged exposure to levels above 15.6°C and broad diel fluctuations during warm periods probably exerted thermal stress on the coho. Similar temperature regimes in other Mt. Saint Helens streams (Martin et al., 1984) and in a small devegetated watershed in western Oregon (Hall and Lantz, 1969) have been shown to cause decreased growth and production in salmonids, and Averett (1969) found that food conversion efficiency for coho was reduced when temperatures reached the levels that were observed in Hoffstadt Creek in August and early September. Thus, based on a combination of relatively high summer temperatures and lack of suitable rearing habitat, as well as a presumed scarcity of aquatic invertebrates in the scoured stream channel, we expected that the summer and early autumn production of coho would be low when compared to other Pacific Northwest streams.

It was surprising, then, to find that the survival rate of coho in the study reach from stocking in late June to late October was approximately 50% (Figure 3). Although the fish were free to leave the study area, an estimated 7,700 remained in the reach in August and 7,300 were still there in October. As expected, however, there was considerable variation in the density, biomass, and average weight of coho within different habitat types (Table 2). Lateral scour pools held both the highest density and biomass during August, but average fish weight in this pool type was lowest of any habitat. In contrast, rapids contained only a few coho but their average weight in August was nearly twice that of fish in lateral scour pools. Average density declined slightly in October but average biomass rose to 4.78 g/m^2, not far from the inital biomass of 5.76 g/m^2 at stocking. As was the case in August, coho in late October exhibited broad variation in habitat specific abundances and average weights. Overall, pool habitats supported higher densities and biomasses than riffle habitats, although fish residing in cascades were larger than those in pools. In October there was a marked increase in coho density and biomass in plunge pools, as well as a movement into secondary channel pools where in August there had been no fish.

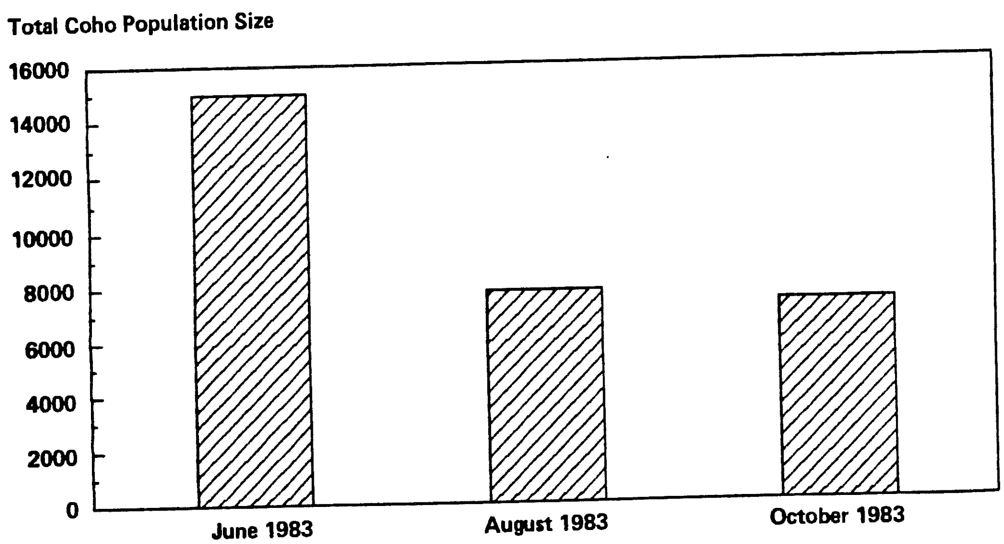

Figure 3. Estimated total coho population in the Hoffstadt Creek study reach.

Although the coho in Hoffstadt Creek tended to inhabit pools at greater than average densities and to inhabit riffle habitats at less than average densities (Table 2), their preferences for particular pool types differed from those of coho of mixed species communities in other streams (Figure 4). Bisson et al. (1982) reported that coho in western Washington streams where steelhead trout (Salmo gairdneri) and cutthroat trout (S. clarki) were also present preferentially utilized backwater pools and showed an avoidance of lateral scour pools; however, in Hoffstadt Creek the coho inhabited backwater pools at only average densities but did exhibit a strong preference for lateral scour pools.

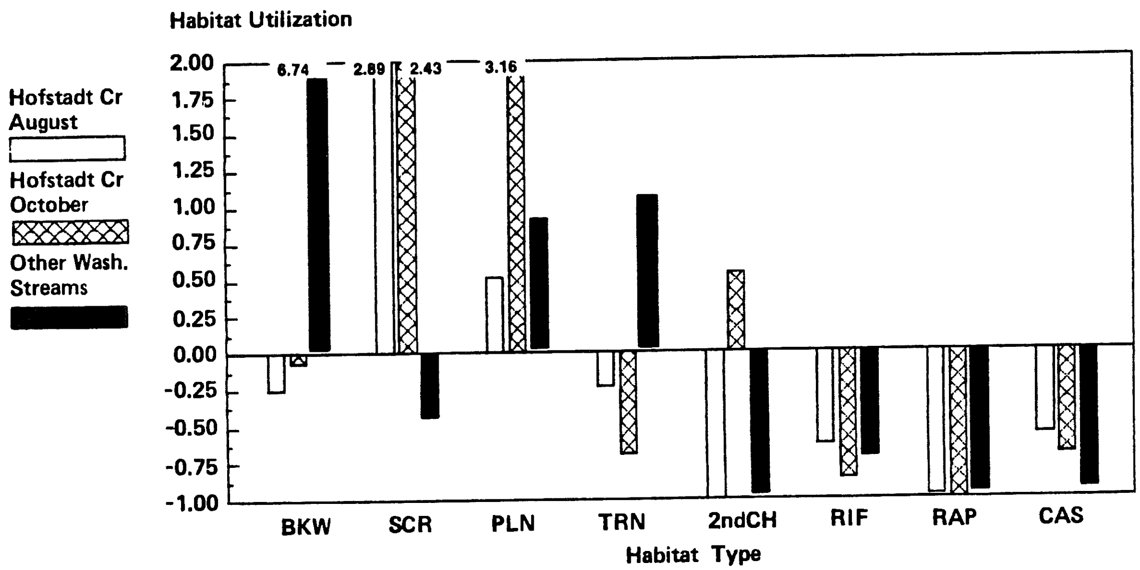

Figure 4. Comparison of habitat utilization between coho in Hoffstadt Creek and coho in other western Washington streams (latter data from Bisson et al., 1982). Habitat types as follows: BKW = backwater pools, SCR = lateral scour pools, PLN = plunge pools, TRN = trench pools, 2nd CH = secondary channel pools, RIF = low gradient riffles, RAP = rapids, CAS = cascades.

Other significant differences in habitat utilization between the Hoffstadt Creek population and coho in other streams included proportionately high densities in plunge pools in October, a general avoidance of trench pools, and a slight but noticeable decrease in the apparent avoidance of cascades. Many of the habitat types favored by coho in Hoffstadt Creek, but not heavily utilized elsewhere, were those in which steelhead and age 1+ and older cutthroat trout would have been likely to occur had they been present in the stream. Bisson et al. (1982) found plunge pools and lateral scour pools to be preferred pool types among older steelhead and cutthroat trout age classes, and also that both age 0+ and 1+ steelhead and age 1+ cutthroat favored cascades. It therefore appeared that while the Hoffstadt Creek coho utilized all available habitat types to some degree, they tended to favor some types that were not favored in other streams where potentially competing or predatory salmonids were present.

During late summer and early autumn (August-October) the production rate of coho in Hoffstadt Creek was approximately twice that of production in the June-August period (Table 3). Although mean biomass in the study reach during early summer was slightly higher than in late summer, the average instantaneous growth rate during the latter period was 2.3 times greater than the growth rate in early summer, and the average condition factor in late summer was 1.17, compared to 1.02 in early summer. In two notable instances, habitat types that possessed

Table 2. Density, biomass, and average weight of coho in Hoffstadt Creek

Habitat Type	Density (no./m^2)	Biomass (g/m^2)	Average Weight (g)
Backwater pool			
August	0.99	2.38	2.40
October	1.18	4.13	3.50
Lateral scour pool			
August	5.13	10.75	2.10
October	4.29	13.82	3.22
Plunge pool			
August	2.01	7.20	3.58
October	5.20	20.90	4.02
Trench pool			
August	1.01	2.95	2.92
October	0.38	2.25	5.76
2nd channel pool			
August	0	0	-
October	1.93	7.91	4.10
Low gradient riffle			
August	0.50	1.36	2.74
October	0.18	0.54	3.01
Rapids			
August	0.02	0.08	4.05
October	0	0	-
Cascade			
August	0.58	1.81	3.10
October	0.38	2.26	5.95
Weighted total*			
August	1.32	3.34	2.53
October	1.25	4.78	3.82

*Adjusted for relative habitat frequency.

high coho biomasses (lateral scour pools in early summer, plunge pools in late summer) supported low growth rates, and there were cases where high growth rates (trench pools, rapids, and cascades) accompanied low biomasses. However, while the correlation between biomass and growth tended to be negative (r^2 = -.48) it was not statistically significant. Thus, habitat specific production (Table 3) did not closely parallel the degree of relative habitat utilization (Figure 4) and could not be predicted by comparing population densities in each of the habitat types.

Table 3. Habitat specific production of coho in Hoffstadt Creek.

Habitat Type	Instantaneous Growth	Instantaneous Population Decrease	Mean Biomass (g/m^2)	Production ($mg/m^2/day$)
Backwater pool				
June-August	0.0014	0.0138	3.26	4.66
August-October	0.0049	-0.0023	3.17	15.38
Lateral scour pool				
June-August	-0.0014	0.0138	15.89	-22.88
August-October	0.0056	0.0023	12.20	67.74
Plunge pool				
June-August	0.0097	0.0138	7.96	77.01
August-October	0.0015	-0.0123	12.86	19.42
Trench pool				
June-August	0.0054	0.0139	3.65	19.80
August-October	0.0088	0.0127	2.55	22.49
2nd channel pool				
June-August	-	-	-	-
August-October	0.0063	0.0085	3.96	24.80
Low gradient riffle				
June-August	0.0041	0.0138	1.75	7.18
August-October	0.0012	0.0133	0.87	1.08
Rapids				
June-August	0.0123	0.0191	0.10	1.25
August-October	-	-	-	-
Cascades				
June-August	0.0067	0.0139	2.15	14.34
August-October	0.0085	0.0055	2.03	17.23
Weighted total*				
June-August	0.0024	0.0138	4.44	10.84
August-October	0.0054	0.0007	4.01	21.45

*Adjusted for relative habitat frequency.

It was apparent, however, that pool habitats did contribute to total coho production an amount that was high relative to their frequency in Hoffstadt Creek (Figure 5). This result was expected in view of the preference of coho for pools. Of great interest, however, was the observation that faster-flowing habitats (cascades and low gradient riffles) contributed fully half of the total production during the period of study. To our knowledge this is the first stream in which coho production in riffle habitats has comprised a significant portion of total production.

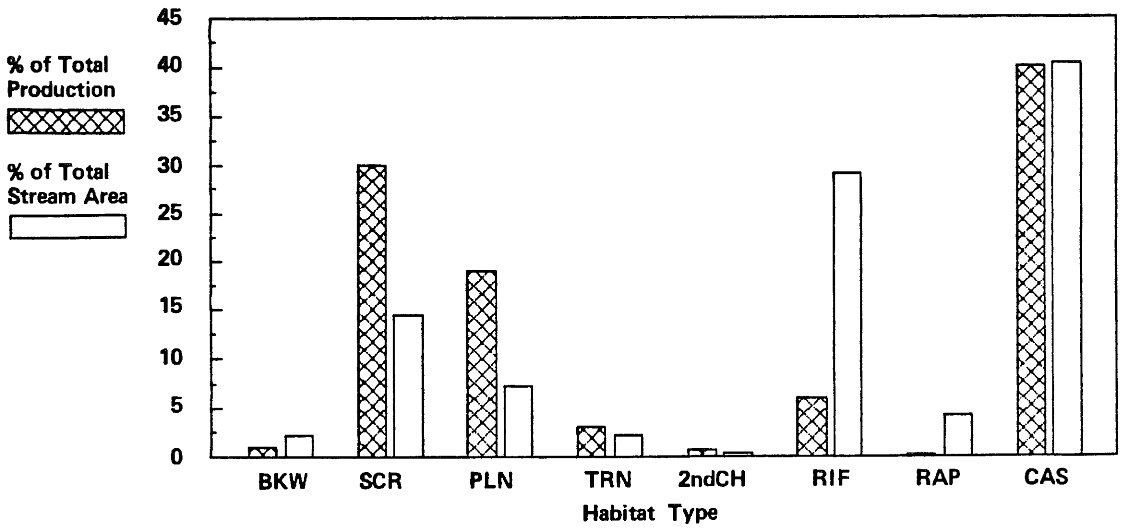

Figure 5. Comparison of habitat specific contribution to total coho production and habitat frequency. Habitat types labeled as in Figure 4.

Overwinter survival in Hoffstadt Creek was low. Of the 15,000 coho stocked in June 1983, only 142 were recovered as smolts and 22 were recovered as age 1+ parr. Estimated survival rates from stocking until smolting and from early autumn until smolting were 1.1% and 2.2%, respectively. The majority of coho smolts (107 of 142, or 65%) were captured by electrofishing in the lower part of the stream where debris from the volcanic mudflow of the Toutle River and from the debris torrent had been deposited. In this area, cover was much more abundant and the frequency of pools (72% of total area) was much higher than in the upstream study reach where the fish had been stocked.

DISCUSSION

The total production of coho in Hoffstadt Creek during June-October was 2.17 g/m^2. This figure compares favorably with production estimates of coho over similar intervals in other streams, in which values have ranged from 0.11 g/m^2 in a northern California stream (Burns, 1971) to 3.14 g/m^2 in a coastal Oregon stream (Chapman, 1965). Even where coho remain in fresh water for two years prior to smolting, production during summer has been shown to be in the same general range (Dolloff, 1983). It is important to note, however, that these studies examined wild coho populations, while we used hatchery fish which were stocked at initially high densities, and our production estimate may represent an inflated value compared with wild coho populations due to artificially high biomass at the onset of the study. Nevertheless, the survival and growth rates that were observed in Hoffstadt Creek provide strong support for the conclusion that the productive capacity of this stream was average during the summer and early autumn period of 1983 in spite of the lack of pool habitat, scarcity of cover, and relatively high temperatures.

Although food availability was not measured, we infer that at least moderate prey levels would have had to be present to account for the observed growth. This would have been especially true during those periods when elevated temperature reduced metabolic food conversion efficiency. An increase in autotrophic production may have accompanied higher light levels in the channel after the eruption, and greater invertebrate abundance may have resulted (Hawkins et al., 1983). However, the catastrophic disturbance to the stream caused by the 1981 debris torrent left a channel that was scoured to bedrock in many places and did not appear to possess an abundant or diverse benthic community. An alternate source of food organisms may have been the dense herbaceous vegetation that had recolonized the riparian zone in the wake of the eruption. Invertebrates originating from such vegetation may be more abundant than those originating from a conifer overstory (Mispagel and Rose, 1978), and Mundie (1969) has documented the importance of surface-drifting terrestrial insects to the diet of coho.

The low overwinter survival of coho in Hoffstadt Creek was similar to survival estimates of hatchery coho in other Mt. Saint Helens streams. In their 1981-1982 study, Martin et al. (1984) found that the average winter population decline in streams affected by the eruption was 93% (n = 5 sites), whereas the average decline in unaffected control streams was 70% (n = 3 sites). In this experiment the estimated population decline from late October to spring smolt migration was 98%. Martin et al. (1984) found a significant positive association between winter survival and area of cover, and concluded that the presence of large organic debris was an important factor in determining winter carrying capacity. The scarcity of debris in Hoffstadt Creek in all areas except the mouth of the stream, as well as the absence of a well-developed floodplain, suggests that little suitable habitat for overwintering was present and that large numbers of coho may have emigrated from the study area with the first heavy winter rainstorms. Tschaplinski and Hartman (1983) found that almost no coho remained during winter in sections of a coastal British Columbia stream with unstable stream banks and few resting areas. Our finding that most of the smolts originated from a short, debris-rich area of Hoffstadt Creek further strengthens the hypothesis that cover was a key feature controlling overwinter survival.

Perhaps our most unusual discovery was that the coho utilized different habitats than in streams where other fishes were present. These habitats included pools in which larger trout (potential predators) would normally have resided as well as fast-water habitats that would have been likely to hold underyearling steelhead (potential competitors), thus suggesting that coho may be able to use a greater range of habitat types than has previously been believed.

In summary, our study showed that coho were able to sustain normal production rates during the summer even though physical habitat and water quality conditions were far from optimal. This was achieved by making use of nearly all available stream habitat. However, only a very small fraction of the experimentally stocked population survived the winter in Hoffstadt Creek and emigrated as smolts the following spring. Lack of competitors and predators may have contributed to the relative success of the coho during summer; lack of cover may have accounted for the low apparent survival rate during winter.

Acknowledgments

We are grateful for the technical assistance of Lance Christianson, John Heffner, Stanley Duncan, Robert Bilby, James Rochelle and Kathleen Sullivan. The Washington Department of Fisheries, through Paul Peterson, kindly provided the fish used for the study.

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