CYCLIC REBOUND OF SALMONID PRODUCTIVITY IN MOUNT ST. HELENS STREAMS: IMPLICATIONS FOR LONG-TERM MONITORING

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Abstract

We monitored the recovery of salmonid productivity in three Mount St. Helens streams using controlled releases of juvenile coho salmon _Oncorhynchus kisutch_. For a period of two years after the 1980 eruption, populations were depressed. From 1983 to 1986, coho production in summer rose sharply and in 1986 reached an average of 11.3 g/m^2 for the three streams, about twice as high as comparable streams in the area. Since 1986, coho production has declined to normal levels (1.4-4.7 g/m^2). We speculate that production increases in the mid-1980s were caused by an unusual abundance of aquatic and terrestrial foods, while production decreases in the late 1980s were caused by declining food availability, high coho population densities, and increased abundance of potentially competing fish species such as steelhead _O. mykiss_ and cutthroat trout _O. clarki_. Long-term monitoring studies should recognize the possibility of cyclic oscillations in salmonid populations after large disturbances. Our results suggest that a minimum of 10 years continuous monitoring is required to establish the recovery pattern, and to determine whether the catastrophe has caused irreversible damage that prevents restoration of natural levels of production.

Introduction

The immediate impact of a large catastrophic event on a predator population such as a stream-dwelling salmonid is often to severely depress production. The decline is caused by mortality directly related to the catastrophe as well as to loss of foraging habitat and food resources (Figure 1). As the affected ecosystem begins to recover, the predator population rebounds and in time may even exceed its former abundance level. This productivity rebound may be triggered by a temporary superabundance of prey. Eventually, physical and biological controlling mechanisms may return to a state of dynamic equilibrium and production of the population is restored to natural levels. Recovery rates of habitat and prey, in addition to the environmental tolerance, mobility, and fecundity of the predators, may influence the duration of cyclic oscillations.

Although the effect of the May 18, 1980, eruption of Mount St. Helens was catastrophic, the eruption created an unprecedented scientific opportunity to examine production recovery processes utilizing long-term experimental plantings of salmonids. Martin et al. (1986) reported that underyearling coho salmon _Oncorhynchus kisutch_ released in Mount St. Helens streams during 1981 and 1982 were killed or stressed by high temperatures and unusually large diel temperature fluctuations. Bisson et al. (1988) reported that summer production of juvenile coho during the period 1983-1988 had increased to a level that was significantly greater than summer coho salmon production in other coastal streams in the Pacific Northwest. It was apparent from these two studies that the production capacity of Mount St. Helens streams for coho salmon had passed through a period of initial depression followed by a surge in production in the mid-1980s.

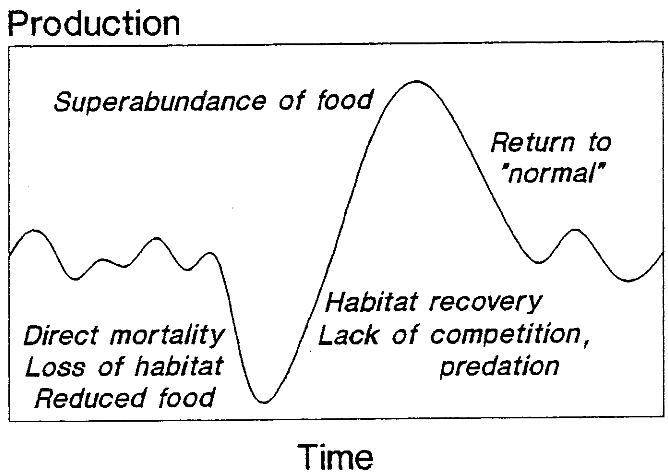

Figure 1. Hypothetical causes of cyclic rebound in a stream-dwelling salmonid population after a catastrophic disturbance.

Since 1986 we have been continuing to follow the recovery of productivity in Mount St. Helens streams using techniques described in Bisson et al. (1988). We believe that the advantages of long-term monitoring coupled with an experimental approach will yield additional insight into biological recovery processes. Ultimately, we hope to gain a better understanding of the factors that regulate recovery in salmon and trout streams after a variety of types of disturbances.

Methods

Study Sites

Coho salmon were planted in two streams in the volcanic blast area and one stream on a volcanic mudflow terrace, all part of the Toutle River drainage system. The two blast area streams, West Fork of Schultz Creek (Schultz Creek) and Hoffstadt Creek, were tributaries of the Green River and the North Fork of the Toutle River, respectively. The mudflow terrace stream, Herrington Creek, was a tributary of the South Fork of the Toutle River. Although their watershed areas differed somewhat (Bisson et al. 1988), the study sites were typical of third- and fourth-order streams in the Toutle River basin in which most coho salmon spawning and summer rearing takes place. Sites were picked to represent a range of volcanic effects, riparian conditions, and stream habitat. Of the two blast area streams, Schultz Creek was most heavily affected by the eruption. All standing trees in the watershed were blown down and many were burned or pulverized by the heat and force of the lateral explosion. The site also received a layer of tephra that exceeded 10 cm deep. Hoffstadt Creek was near the periphery of the blast area and some trees remained standing, although nearly all were heat killed. Tephra deposition in the Hoffstadt Creek watershed was considerably less than in the Schultz Creek watershed. The mudflow terrace study site was unique in that it consisted of a channel formed when a volcanic mudflow dammed the mouth of Herrington Creek, forcing it to create a new channel that ran parallel to the South Fork of the Toutle River for nearly 2 km. As such, this site did not exist before the eruption. The watershed of upper Herrington Creek was relatively unaffected.

Cover was scarce in all the streams (Bisson et al. 1988). Hoffstadt Creek was influenced by a debris torrent in early December 1981, which scoured the channel to bedrock in many places and removed nearly all of the pre-eruption large organic debris as well as trees that had been blown into the stream by the volcanic explosion. Schultz Creek did not experience a debris torrent after the eruption, but winter rainstorms scoured most of the volcanic ash out of the channel, leaving a streambed dominated by boulders and bedrock. Herrington Creek continued to erode into the mudflow terrace during the early years of the study, but the rate of channel downcutting slowed considerably in the latter years as the substrate gradually developed an armor layer of gravel and cobbles. In 1988 the first beaver ponds were observed in Herrington Creek, and in 1989 beaver ponds were very abundant in this stream. In the latter 1980s riparian vegetation along Herrington Creek had recovered to a point that the deciduous trees were large enough to form stable beaver dams.

<u>Fish Populations</u>

Young-of-the-year coho salmon from the Cowlitz River Salmon Hatchery were stocked at the upper end of each study reach in the late spring or early summer. Most fish spread downstream from the initial point of entry and colonized the entire study reach within a few days. The intent was to establish coho salmon densities at or above the presumed summer carrying capacity of the streams (2-3 fish/m^2). Therefore, uniform numbers were planted each year, with a few exceptions that were governed by availability of fry at the hatchery (Table 1).

Table 1. Numbers of underyearling coho salmon released into the streams.

	Hoffstadt Cr.	Schultz Cr.	Herrington Cr.
1983	15,000		22,400
1984	15,000	15,000	15,000
1985	15,000	15,000	15,000
1986	15,000	15,000	15,000
1987	37,600	18,880	15,000
1988			5,700
1989	14,900	14,900	14,900

A few cutthroat trout O. clarki apparently survived the Mount St. Helens eruption in Hoffstadt Creek and Schultz Creek; this species was present but rare initially. Rainbow trout O. mykiss were collected in the blast area streams in the mid-1980s, and originated from outplantings of hatchery steelhead. Some rainbow trout did not migrate to sea and attained reproductive maturity in the study sites. No sculpins Cottus spp. were collected from either Hoffstadt or Schultz Creeks over the entire monitoring period, leading us to conclude that sculpins did not survive the eruption and had not reinvaded steep blast area streams during the first post-eruption decade. Herrington Creek was available to spawning by anadromous salmonids and was extensively used by steelhead throughout the study. We saw little evidence of coho salmon spawning in Herrington Creek from 1983 to 1985, but from 1986 to 1989 young-of-the-year coho from natural spawning appeared in the stream. The extent to which naturally spawned coho salmon contributed to the total population in Herrington Creek was not known. Herrington Creek also contained abundant sculpins.

We sampled fish populations after stocking using a combination of seining and a backpack electrofisher (Bisson et al. 1988). Habitat-specific population estimates were obtained by isolating individual channel units (riffles or pools) and electrofishing or seining three times. Fish densities within individual riffles and pools were calculated by the removal summation procedure of Carle and Strub (1978). We estimated average density within the entire reach by multiplying habitat-specific density by the proportion of the total stream area occupied by each habitat type (Bisson et al. 1982) and summing these values for all habitat types present in the reach. Weight estimates were figured from length versus weight relationships determined each summer at the final population census. Production calculations followed the numerical procedure of Chapman (1978), in which it was assumed that instantaneous rates of growth and apparent "mortality" (true mortality plus emigration) in the streams were exponential and that the distribution of coho salmon throughout a measurement interval was reflected in the relative proportions of fish observed in each habitat type.

Results and Discussion

Post-eruption Coho Salmon Production Trends

Coho salmon production increased from 1983 to 1986 and generally declined from 1987 to 1989 (Figure 2). Likewise, average coho biomass rose through the early 1980s (Figure 3), but remained at a fairly stable level from 1987 to 1989 (two of the sites were not stocked in 1988). The decline in coho production in the latter part of the decade was most strongly influenced by declining growth rates. Overall, coho in the three study sites responded similarly throughout the post-eruption monitoring period.

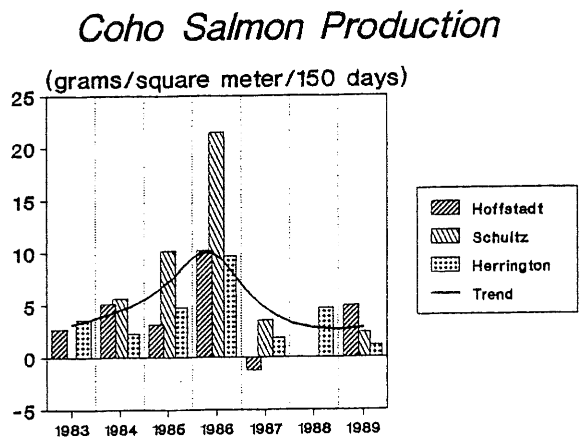

Figure 2. Summer production of coho salmon in the three study sites.

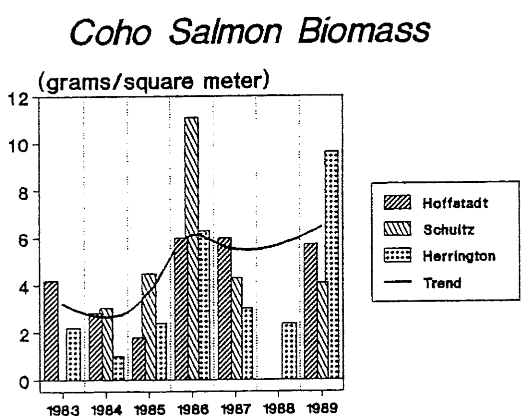

Figure 3. Trend in coho biomass.

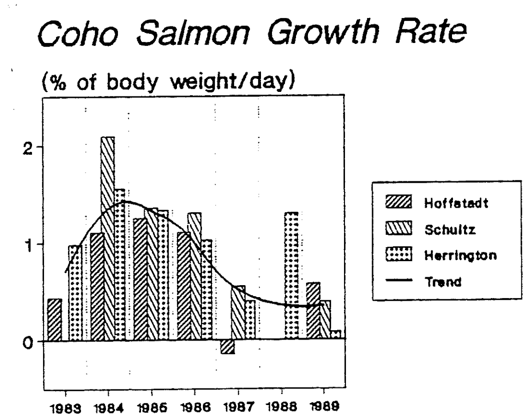

Figure 4. Trend in coho growth rate.

These trends suggest that productivity of the streams for coho salmon followed a cyclical pattern from 1983 to 1989 that consisted of an increase in summer production from 1983-86, driven by increased growth rates and increased average biomass at the sites, followed by declining productivity from 1987-89 that was controlled chiefly by reduced growth rates, but not lower biomasses. Apparently the productivity had recovered within three years of the eruption to yield production rates that were typical of the region, and by 1986 the production of coho was approximately twice as great as values reported by Chapman (1965), Dolloff (1983), and Bilby and Bisson (1987) for Pacific

Northwest streams. Although coho salmon production was not measured by Martin et al. (1986) at their Mount St. Helens study sites, we infer from their data that productivity in the first two years post-eruption was very low.

<u>What Caused These Changes?</u>

In the 1981-82 study, Martin et al. (1986) suggested that coho salmon in Mount St. Helens streams had suffered from several factors that contributed to diminished populations and poor survival of stocked fish. These factors included (1) direct mortality of resident fish during the May 18 eruption, (2) effects of deposited volcanic ash on alevins that had not yet emerged from spawning gravels or on invertebrates that provided food resources for rearing juveniles, (3) effects of suspended volcanic ash on physiological processes of the fish themselves, (4) extremely high mid-summer stream temperatures, sometimes exceeding the incipient lethal threshold of approximately 25°C, (5) very wide diel temperature fluctuations, up to almost 17°C, and (6) loss of instream and overhead cover. It was clear from their observations that coho salmon populations during the initial two years after the eruption were depressed.

In the 1983-86 study, Bisson et al. (1988) speculated that the increased production of coho salmon observed over the period was related to a combination of both physical and biological factors. The physical factors included flushing of much of the deposited volcanic ash from the streams during the first two years after the eruption and re-establishment of more normal pools and riffles (although pools continued to be scarce). They also noted that the diel temperature extremes were diminished with recovery of riparian vegetation. More importantly, Bisson et al. (1988) felt that the rebound in coho production was a response to temporarily elevated food availability and relatively scarce predators and competitors.

The temporary abundance of food in Mount St. Helens streams during the mid-1980s was probably an outcome of both terrestrial and aquatic processes. On the land there were luxuriant growths of herbs and shrubs, including salmonberry, buttercup, coltsfoot, fireweed, and pearly everlasting, as well as vigorously-growing deciduous trees (red alder, willow) along riparian zones. These plants contributed an abundance of terrestrial invertebrates; tiger beetles, aphids, spiders, and springtails were among the invertebrates that commonly fell into streams and were eaten by coho. Within the streams themselves, leachates from decomposing trees and other plants killed by the eruption contributed to elevated organic nutrient concentrations. The nutrients, in combination with the unusually warm stream temperatures, promoted heavy growths of filamentous green algae and diatoms, which in turn stimulated the production of aquatic insects. Among the insects benefiting from increased primary production were baetid Ephemeroptera and orthocladiid Chironomidae (Charles Hawkins, Utah State Univ., personal communication). These two taxa are known to be favored prey of juvenile coho (Mundie 1969).

Declining production of coho salmon during the late 1980s was likely related to several factors that included the recovery of biological controls (competitors and predators) and to reduced food availability. Other salmonid species became more abundant in the latter part of the decade and tended to command a larger share of the total salmonid biomass (Figure 5). Underyearling steelhead and cutthroat trout may have competed with coho for rearing space, while yearling and older trout may have preyed upon coho fry soon after release. One notable exception to the trend of increasing trout dominance occurred in Herrington Creek in 1989, when the creation of numerous beaver ponds apparently favored coho salmon at the expense of steelhead. In the late 1980s, we also noted increased evidence of non-salmonid predation on underyearling coho by fish-eating birds (mergansers, belted kingfishers, great blue herons, and water ouzels) that had recolonized the Mt. St. Helens blast area.

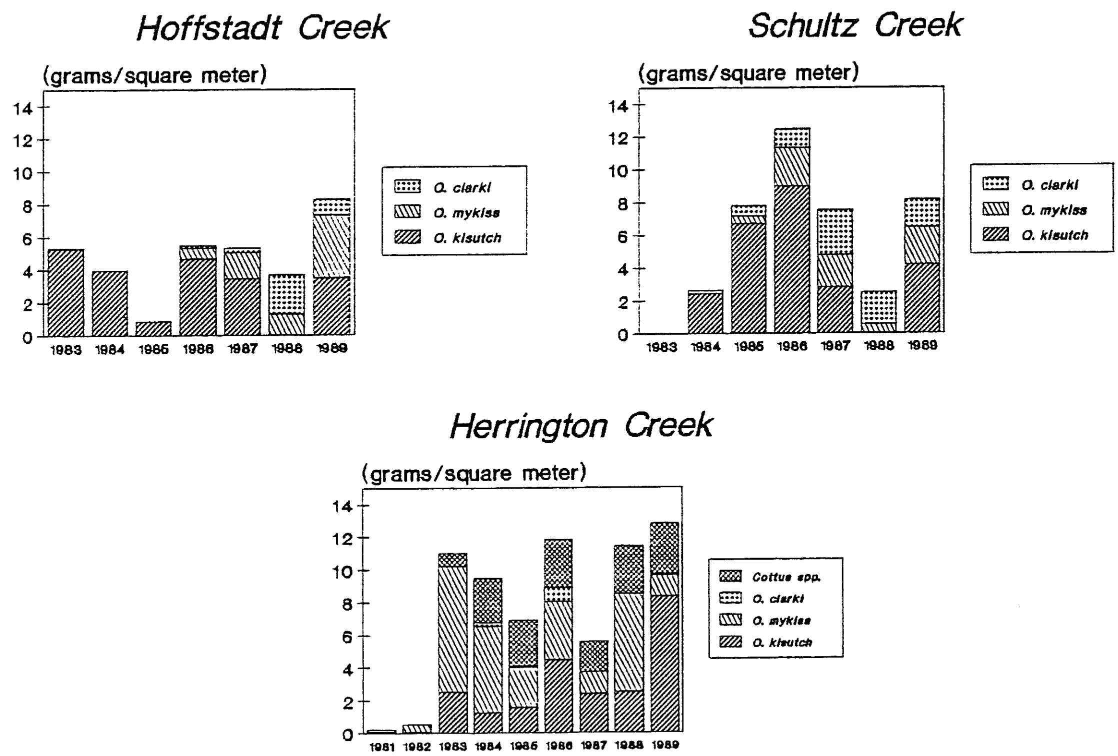

Figure 5. Late summer biomass of fishes in the Mount St. Helens study sites.

There was indirect evidence that food availability was diminished in the late 1980s. Herbaceous vegetation in the blast area watersheds was beginning to be replaced by Douglas-fir, and the abundance of terrestrial insects was noticeably reduced. Dense stands of young willow and red alder along stream banks increased shading and probably caused a reduction in aquatic primary production, leading to lower densities of mayflies and midges. During this period growth rates of coho sharply dropped (Figure 4), further suggesting that less food was available.

The results of decade-long monitoring in Mount St. Helens streams support the hypothesis that the productive capacity for coho salmon underwent an oscillation that began with an initial depression of about two years followed by a fairly rapid rebound that led to unusually high production rates in the mid-1980s. This rebound was in turn followed by a return to production levels that are typical of the region. A summary of the most important factors contributing to the cycle is given in Figure 6.

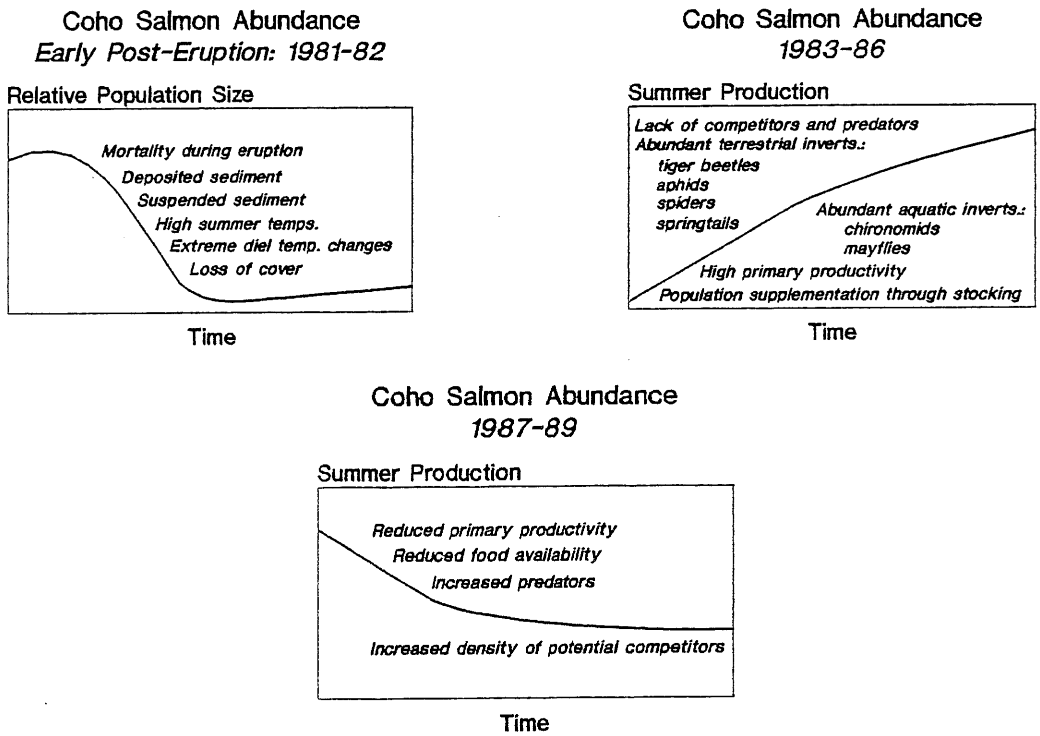

Figure 6. Summary of factors controlling the cyclic rebound of coho salmon production in Mount St. Helens streams from 1981-89.

Long-Term Monitoring and Environmental "Catastrophes"

Over the last decade there have been several large catastrophic events in North America that have affected stream-dwelling salmonids on a very large scale. Examples include the Mount St. Helens eruption, the Exxon-Valdez oil spill, and the Yellowstone wildfires. Each of these events has provided a somewhat unique research opportunity to study ecosystem recovery processes. To some extent these opportunities have been realized, but in most cases the majority of research has taken place within 1-2 years of the catastrophe and few studies have extended for more than a few years as research grants gradually expired. Unfortunately, short-term studies have failed to reveal the longer-term patterns that are critical to our understanding of recovery after severe disturbances.

Furthermore, short-term studies can give a misleading picture of the status of a resource of interest. In the case of coho salmon in Mount St. Helens streams, the prognosis for recovery would have been poor had research ceased at the end of 1982 (Martin et al. 1986). On the other hand, if research had been confined solely to the period from 1983 to 1986, we might have concluded that the Mount St. Helens streams were extremely productive (Bisson et al. 1988). This, too, would have been a misleading conclusion. Only by considering the entire cycle would we have seen the pattern that defined the extent and duration of the oscillation in coho production. Even a decade of monitoring leaves us unconvinced that the full effects of the 1980 eruption on salmon and trout in streams have been expressed. We note that the streams still possess relatively scarce cover and that pool formation has been inhibited by lack of large woody debris, and we suspect that this will limit carrying capacity over the long term. Recruitment of large woody debris is likely to be a matter of decades rather than a matter of years, although the recolonization of Herrington Creek by beavers has speeded the process of debris input. There are clearly many aspects of habitat recovery that require continued examination.

Although there have been few studies that have followed salmonid populations after severe disturbances, our results suggest that a minimum of 10 years is required to determine whether environmental damage has caused irreversible harm to the productive capacity of a stream. It is likely that our technique of stocking fish enhanced the recovery rate and that the cycle would have required a longer time period, had the coho populations been dependent upon natural recruitment. In view of these observations, we suggest that short-term impact studies will be inadequate substitutes for extended monitoring, and that assessment of long-term effects of catastrophic events will require sustained commitment from both scientists and funding organizations.

Acknowledgments

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