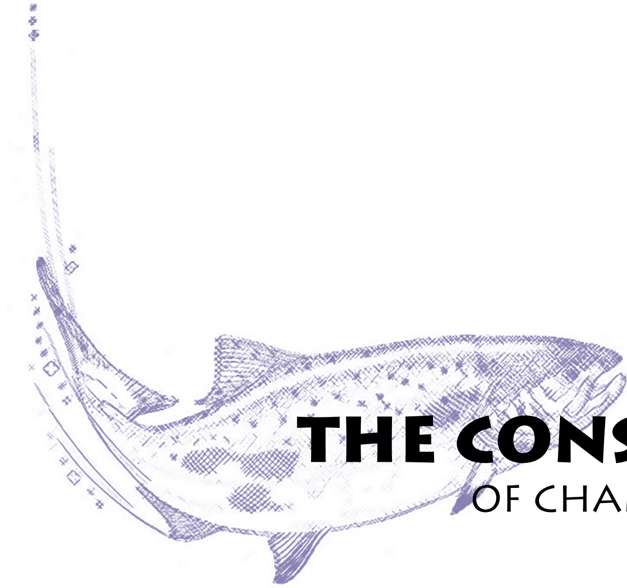


THE CONSEQUENCES OF CHANGE: SALMONIDS

Salmon Biology: One Million Years of Adapting

Salmon are remarkably resilient. Pacific salmon are approximately 1,000,000 years old and have survived four major ice ages, four warming periods, and the extinction of 35 genera of mammals, including wooly mammoths, camels, lions, and sabertooth cats.[203]

A salmon spends its life in two distinct places: a freshwater stream and the ocean.[204] Life begins when the female salmon lays about 2,000 to 4,000 eggs in a gravel nest in a streambed.[205,206] After it has hatched, juvenile salmon will live in the stream for 3 months to 3 years before leaving for the ocean as smolt.[207]

The salmon spends up to 95 percent of its life and grows to maturity in the ocean.[208] Before an adult salmon returns to its birth stream to breed, its weight will have increased by 20 to 160 times.[209,210]

The salmon returns to streams such as Redwood Creek to spawn in the late fall as water stages of the stream rise as a result of the first large storm. It is at about this same time that silt and clay particles begin to be transported to the sea and the creek becomes turbid and dark with suspended sediment.

Salmon and Sediment: A Love-Hate Relationship?

One of the great scientific debates has focused on the relationship between salmon health and sediment levels. More than 80 years of study have left us with ambiguous, inexact conclusions regarding the level at which the amount of fine sediment becomes a hindrance to salmonid reproduction and smolt production.[211,212,213]

A big part of the problem is that most attempts to define this relationship have been based on laboratory studies and single-factor analyses, both of which have run into difficulties extrapolating and applying findings to natural environments.[214,215]

SALMON 101

- **REDDS** A series of egg nests in one distinct grouping from one salmonid female in stream gravels
- **ALEVINS** Newly hatched, but incompletely developed, juvenile salmonids that are still in the redd or inactive on the stream bottom and are living off of their yolk sac
- **FRY** Life stage of a salmonid that begins after the yolk sac has been absorbed and active feeding has begun
- **FINGERLINGS** Fish life stage after fry
- **JUVENILES** Young salmon up until the time they have reached the sea
- **SMOLTS** A juvenile salmon that has undergone physiological changes to cope with the marine environment
- **ADULTS** Salmon that have returned from the sea

Even in the sediment-rich environment of Redwood Creek, measuring the effects of fine sediment on salmon survival has been difficult.[216]

Conventional thought is that the large amounts of sediment deposited into streams during great floods are harmful to fish and fish habitat.[217] Indirect evidence from laboratory studies suggests that salmonid embryo mortality increases and emergence of salmonid alevins declines as the percentage of fine sediment in redds increases.[218] Eggs can be smothered and alevins entrapped if the interstitial spaces in redds become clogged.

In addition, suspended sediment can harm gill tissues of fish and make it difficult for them to find food; but turbid conditions also provide cover from predators.[219,220] The tolerance of juvenile coho salmon to suspended sediment varies seasonally. The highest tolerance is in the fall when increases in suspended sediment normally occur.[221]

However, there are numerous scientific studies that provide an alternative to the conventional thought about salmon and sediments. Studies have, for example, found that streams affected by landslides have enhanced fish production, and streams unaffected by recent landslides have reduced fish production.[222,223,224,225] Because sediment is what creates salmon habitat, streams with low sediment levels have low salmon production.[226]

Fish experts believe that the presence of sediment in streambeds is necessary for optimum survival of the salmon eggs laid there. Pea-gravel and sand-sized sediment helps form a sealing layer over the incubating eggs.[227] This seal prevents injurious stream agents such as predatory insects and organic matter from coming into contact with the eggs, and prevents deep penetration of fine sediments that could trap emerging salmon in their nests.[228,229] So, fine sediment can benefit egg survival because egg survival can be higher in streams rich with fine sediment.[230]

One of the adaptations developed by salmon for life in sediment-rich environments is the large size of their eggs, which provides an alevin with the food resources to swim out of a deep, gravel nest.[231] Another adaptation is the ability of female salmon to cleanse their nest of fine sediment during nest construction. Spawning females have been found to remove from 30 to 40 percent of the fine sediment in the streambed.[232,233,234]

Although the sediment conditions of Redwood Creek vary widely and certain land uses have increased the sediment load, few adverse effects on aquatic life have been measured. Several scientific studies at Redwood Creek found no adverse effects from higher levels of fine sediment on salmon. The findings held true for all aquatic organisms, with the exception of an isolated, temporary reduction in the numbers of three species of amphibians (see Case Study: Sedimentation and Salmon at Prairie Creek).

In addition, one researcher found that although recent logging apparently increased fine sediment levels in gravels from about 15 to 25 percent, the amount of dissolved oxygen was greater in logged areas, possibly compensating for the elevated sediment levels.[249] He concluded that salmonid production would not be limited by the increased levels of fine sediment, or dissolved oxygen concentrations, in any of the areas.[250]

SALMON AND SEDIMENT: IN A NUTSHELL

Laboratory tests reveal that high levels of fine sediment on nests can hinder the success of salmon spawning, but research in the field fails to support this theory. Perhaps several compensating and external factors confound the outcomes.

Numerous studies have concluded that: (1) streams draining timber-harvested areas with roads temporarily contain higher amounts of fine sediment after logging when compared with "control" streams, (2) temporary increases in fine sediment have virtually no short- or long-term adverse effects on aquatic organisms, and (3) salmon are physiologically and behaviorally adapted to living in a dynamic, sediment-rich environment.

The State of the Salmon and Steelhead Trout Populations

Distribution and Density of Juvenile Salmonids

Perhaps the best measure of stream health and salmonid productivity is the level of juvenile salmonid production. (The level of adult fish production is more indicative of ocean conditions.)

If adult returns are adequate and habitat is available, the amount of salmon fry production will far exceed the carrying capacity of the creek. Under consistent habitat conditions, the number of smolts migrating toward the sea may not vary at all, even though the number of spawning adults returning can vary dramatically from year to year by as much as a factor of ten.[251]

Periodic surveys of Redwood Creek portray juvenile fish distribution and density over time. In the earliest survey on September 22, 1945, fourteen casts of a net caught 128 small young steelhead, but no coho or chinook salmon at the State Highway 101 bridge.[252]

Subsequent surveys confirmed juvenile chinook, coho, and steelhead around Orick, including the Redwood Creek estuary.[253] Juvenile coho have been found no farther upstream than the lower Redwood Valley, and in Prairie Creek and its tributaries.[254,255,256] Young chinook have been found farther upstream. Steelhead trout were encountered throughout the Redwood Creek basin.[257,258,259,260,261]

The original field notes from a 1966 survey describe finding fry and larger steelhead that exceeded 7 inches, suggesting that the larger fish were in their third year of life.[262] Apparently as juveniles, these fish were present in the stream during the December 1964 flood and weathered the storm.

Throughout the surveyed period from 1945 to 1997, summertime "densities" of the juvenile salmonid populations in Redwood Creek ranged from 0.2 to 1.5 fish per foot of stream length without a discernible trend.[263,264,265,266,267,268] Within this range, the number of juvenile salmonids living in Redwood Creek can vary significantly from year to year under natural conditions. For instance, the numbers of juveniles in Godwood Creek and other pristine streams in northern California can vary by nearly 50 percent annually, and sometimes some species are completely absent.[269]

The data on natural out-migrations of juvenile salmonids is less clear. Most estuary surveys since 1980 were taken after the majority of juvenile salmon had migrated to the ocean.[270] The surveys have estimated juvenile chinook salmon populations between 4,000 and 117,000; juvenile steelhead populations between 3,400 and 46,000; juvenile coho salmon populations between 2 and 200; and few cutthroat trout.[271,272,273,274,275,276,277,278]

The only estimates of downstream juvenile salmon migration above the estuary were made at pristine Prairie Creek. Yearly trap catches have yielded between 30,000 and 40,000 migrating chinook, coho, steelhead, and cutthroat trout.[279,280,281]

Case Study: Sedimentation and Salmon at Prairie Creek

In 1989 to 1990, an accidental discharge of sediment into the tributaries of Prairie Creek, the largest tributary to Redwood Creek, created an opportunity to study the effects of sediment on salmon in a natural setting. A highway construction project—the Redwood Highway Bypass—had left a layer of fine sediment in streambeds measuring 0.1 to 2.0 inches thick.[235] Observations of redds test the hypothesis that higher amounts of fine sediment in redds affects the amount of emerging fry.

After 1 year, the affected reaches of the creek had greater amounts of suspended sediment when compared to unaffected sections. Also, the amount of fine sediment in salmonid nests in the affected reaches was either unchanged or at higher levels.[237,238]

Despite the sedimentation that had occurred, salmonid egg survival was often no different—or even higher—in affected streams than in unaffected streams.[239,240] Also, higher rates of emergence of fry were found in stream reaches with more fine sediment.[241,242,24] Most importantly, the number of salmon smolts was not reduced in streams that had large volumes of fine sediment washed into them.[244] Also, the aquatic insect community showed no obvious differences between the sedimented reaches and either the unaffected reaches or reaches prior to the sedimentation incident.[245] This indicates that the food available for juvenile salmon was not reduced.

By 1992 and 1993, fine sediment in salmon egg hatching baskets was 9.0 to 24.1 percent in affected reaches and 12.2 to 20.9 percent in unaffected reaches.[246]

The 1994 spawning salmon and steelhead runs were at abundances found prior to the incident, in spite of lingering fine sediment levels that as late as 1996 were still higher in the affected reaches.[247,248]

Eggs from adult salmon caught at a Chilula dam like this one supplied the Redwood Creek fish hatchery.

Photo courtesy of Phoebe Apperson Hearst Museum of Anthropology

Distribution and Abundance of Adult Salmonids

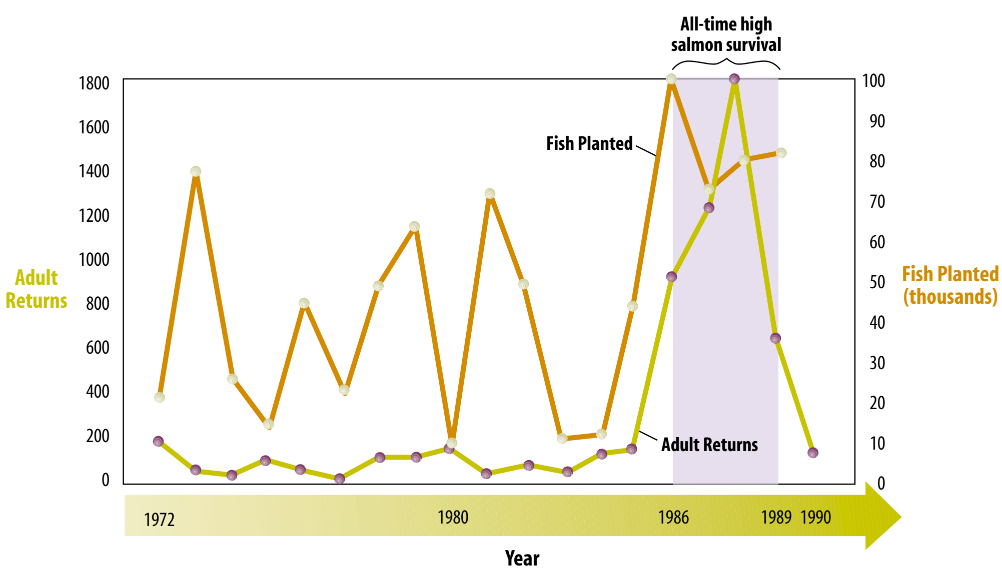
Many ask, "how do anadromous salmon and steelhead populations today compare with those of the past?" Unfortunately, few historical records of the numbers of adult salmon returning from the ocean to spawn in Redwood Creek were kept; thus, only qualitative comparisons between the current and historical populations of spawning salmon are possible.

Indigenous people found the salmon of Redwood Creek to be "negligible," less than nearby streams.[282] As early as the 1890s, there were concerns that salmonid populations in northern California were becoming extinct from over fishing.[283,284] Consequently, a salmon hatchery was established at that time to alleviate the apparent declines in local fisheries.[285] The salmon egg collecting station and fish hatchery were located in the upper portion of Redwood Creek, near the mouth of Minor Creek. Adult chinook, coho, steelhead, and trout were captured by means of a government-built weir just above the confluence of Minor Creek, and from an Indian-operated trap in the same vicinity.[286]

Salmon eggs collected at the station supplied hatcheries at Fort Gaston and Blue Lake, California, as well as the Redwood Creek hatchery. Apparently, the absence of canneries on Redwood Creek made it the most profitable source for salmon eggs relative to other local rivers.[287] The earliest records for the years 1892 to 1898 show that about 49 to 563 female chinook and coho salmon and about 17 to 375 female steelhead were collected annually.[288]

Another hatchery was located on Prairie Creek near Lost Man Creek.[289] During the first year of operation in 1928, 208,000 coho eggs and 1,400,000 steelhead eggs were collected, which would have required about 83 native coho females and 560 native steelhead females.[290] By fall of 1937, the salmon population immediately below the junction of Prairie Creek and Lost Man Creek was reported as "about 500 [coho] salmon" and only a "few" chinook salmon came in each year, "perhaps seven or eight."[291]

Most fish records over the last century provide little more than sketchy information about the strength of populations; however, it is believed that the number



Adult coho returns to Prairie Creek Fish Hatchery are independent of the number of juvenile coho salmon planted each year.

Source: L.R. Brown and P.B. Moyle. 1991. Report to National Marine Fisheries Service.

of coho salmon adults between 1986 and 1989 were dramatically higher than known returns before or after these years, probably due to documented favorable ocean conditions around that time.[292,293,294,295,296]

In 1960, the adult salmon runs in Redwood Creek were estimated to be about 17,000 fish—5,000 chinook, 2,000 coho spawners, and 10,000 winter steelhead—based on estimates of available spawning habitat, not actual counts.[297,298,299] There are only three other estimates for salmon run sizes in Redwood Creek. The first, for 1973, reported 2,000 coho salmon adults.[300] The second, for the 1990s, reported 2,000 coho salmon adults.[301] The third, for 1979, reported 1,850 chinook salmon adults.[302] Adult summer steelhead counts in Redwood Creek have ranged from zero to 44 fish annually since 1981.[303]

The removal of wild Redwood Creek salmon ended when hatchery operations ceased in 1992.[304,305,306,307,308]

Spawner surveys that began in the early 1980s provide the longest record of standardized population data on Redwood Creek. Three Redwood Creek tributaries where standardized spawning surveys have been conducted are Prairie Creek, Bridge Creek, and Tom McDonald Creek. For the period from 1990 to 1994, the number of live salmonids observed in Bridge Creek and Tom McDonald Creek ranged from 0.00 to 0.01 fish per foot of stream length.[309] The range for Prairie Creek and its tributaries over the same time period was 0.00 to 0.08 fish per foot, but only half that if the heavily supplemented hatchery fish of Lost Man Creek are ignored.[310]

Salmon: The Big Picture

Offshore salmonid harvest records can help us understand the extent to which adult salmon populations of Redwood Creek are influenced by the ocean more than the conditions of the creek.[311]

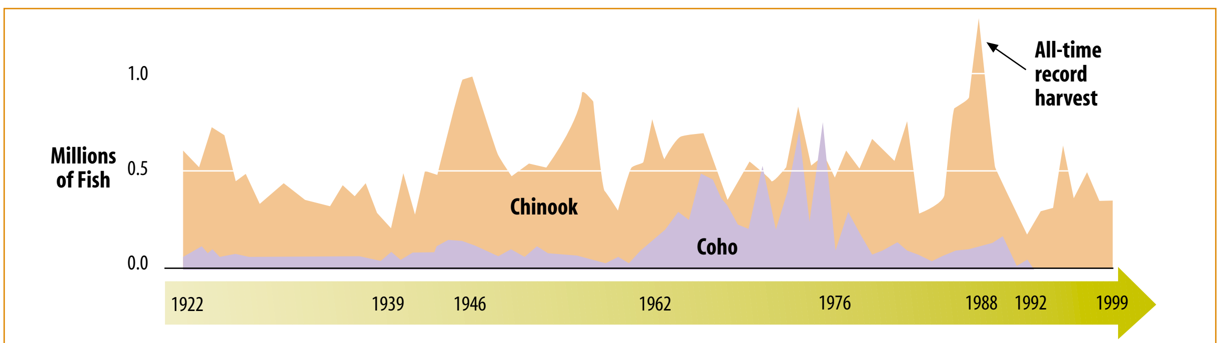
Between 1922 and 1999, the California Department of Fish and Game estimated that chinook salmon ocean harvests varied greatly within short time periods. For example, the harvest increased five-fold between 1939 and 1946 when the second highest catch of 988,000 fish was made. In a three-year span in the late 1950s, the harvest fell to one-third of the peak numbers, then it more than doubled in the following 3-year span. The most dramatic shift occurred in the 1980s, when a record high and low occurred within 2 years of each other. The all-time peak harvest of 1988—1,317,000 fish—occurred during the shortest commercial salmon fishing season allowed by the California Department of Fish and Game.

According to the California Department of Fish and Game, the ocean catches for coho from 1922 through 1962 were generally less than 100,000 fish annually. There was a substantial decline between 1955 and 1958; but during the 18-year period of 1958 through 1976 there was a gradual and significant

Salmon Populations: In a Nutshell

In general, juvenile coho salmon have been found in the lower reaches of the Redwood Valley and farther downstream, and chinook salmon and steelhead trout have been found throughout the system. Summertime densities of the juvenile salmonids ranged from 0.2 to 1.5 fish per foot of stream length, which could represent the natural expectation for juvenile fish densities in the creek. However, the number of juveniles may vary by nearly 50 percent from year to year under natural conditions.

The sizes of the adult salmon and trout populations probably fluctuated widely throughout history. This is as true for Redwood Creek as it is for other salmon spawning streams throughout northern California and southern Oregon.[312,313] However, the available historical data are incomplete and biased, making definitive conclusions about population trends and patterns of abundance elusive.[314,315,316]



The California commercial salmon catch increased after favorable ocean conditions and with improved harvest efficiency.

Source: California Department of Fish and Game.

increase. The ocean catch for coho went from 9,000 in 1958 to 695,000 in 1976.

The ocean harvests of coho show occasional dramatic year-to-year fluctuations similar to the chinook. For example, the catch dropped from 695,000 in 1976 to 64,000 in 1977, then rose to 238,000 in 1978. These fluctuations occurred in spite of continuous and high hatchery smolt production.[317]

There is an almost unbelievably high number of salmon that meet their demise in salt water, with ocean mortality rates of south coast coho salmon averaging close to 99.5 percent.[318,319]

Reduced growth rates of smolts during their first year at sea, based on poor ocean conditions (i.e., low productivity), appear to be the cause of this high mortality rate.[320,321,322] Ocean survival of coho salmon along the West Coast has decreased by 90 percent since the 1970s, attributed to generally declining ocean productivity.[323,324]

The ocean mortality rate for California salmon populations has not been less than 98 percent recently, which is the rate below which salmon populations need to stabilize.[325] Unfortunately, coho salmon mortality in the ocean increased to about 99.4 percent after 1990.[326,327]

The Regional Salmon Picture

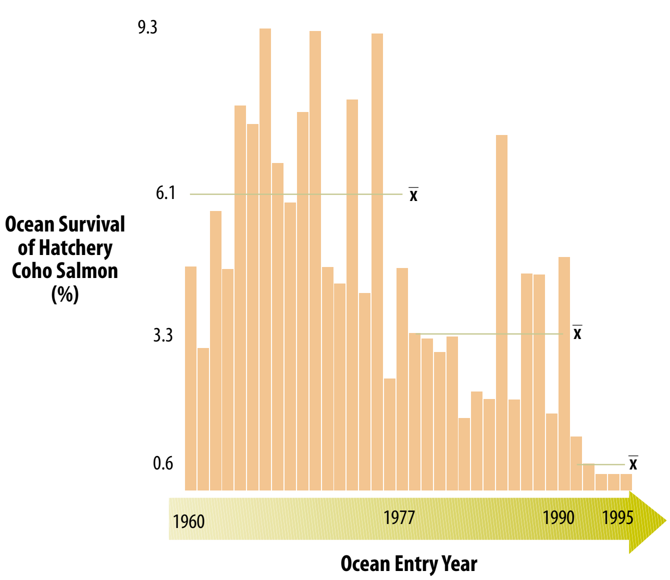
The regional commercial salmon harvest—chinook and coho combined—at ports located in Humboldt and Del Norte Counties ranged from 1.2 to 3.8 million pounds between 1916 and 1930.[328] During this time, major year-to-year fluctuations were apparent—the high and low are separated by only 2 years—just as the statewide ocean catches showed. The regional salmon harvest from 1986 to 1998 ranged between one thousand to one million pounds (the peak year was 1987 during La Niña conditions; the low year was 1992 during El Niño conditions).[329] Apparent differences among the annual regional harvests should not be taken at face value because the amount of effort it took to catch the fish varied over time. The recent regional harvests reflect a reduced fishing season and a diminished fishing fleet.[330]

The Overall Salmon Picture: In a Nutshell

The state of Redwood Creek's salmonid populations—whatever they may be—is largely governed by fluctuating ocean conditions. Because of the fluctuations, returning adult salmon counts are ineffective measures of the quality of the freshwater habitat.[334] Undoubtedly, ocean conditions have had a dramatic impact during the generally unfavorable conditions from 1977 through 1994. The effects of sediment deposition and transport on freshwater stream habitat may affect reproductive success, but have relatively minor effects on population strength.[335]

During 1916 to 1930, salmon were mostly caught in the 6-month period from April through September.[331] However, the season was reduced during 1986 to 1998, with most salmon caught during the 4-month period from June through September.[332]

Taking the shortened season and fleet reduction into account, it appears that the regional salmon harvests of the 1990s have been the most efficient since 1976. The average catch per day that a commercial fishing boat reported during the period from 1978 to 1980 was 11 salmon.[333] The average catch per day during 1986 to 1990 more than doubled to 26 salmon per day. In the 1988 La Niña period, the average commercial fisher was catching 41 salmon per day. The relatively low amount of effort fishers have had to expend to catch a salmon in the 1990s possibly indicates that the regional abundance of adult salmon has increased.



Along the West Coast, ocean survival of hatchery coho salmon has decreased in recent decades.

Source: D.W. Welch, B.R. Ward, B.D. Smith, and J.P. Eveson. 2000. Fisheries Oceanography 9:17-32.