

Klamath Basin Chinook Salmon in Crisis: Factors of Decline

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INTRODUCTION

Chinook salmon have been a prominent feature of the Klamath River basin for millennia, yet the last several decades have seen a gradual decline in their abundance, culminating in the large fish kill of September 2002. The path of events leading up to today has been extensively studied from many angles, and numerous human and natural factors have been implicated in the crash. It seems no one factor alone has caused the decline, but each has contributed to the problem in its own negative fashion. Habitat has been altered or destroyed by sedimentation, water diversions, riparian vegetation removal, and elevated water temperatures. The natural equilibria of predation and competition have been shifted by human activities. Infection and disease have become increasingly prominent as water temperatures rose, dams were built, and hatcheries were operated. Chinook harvest over the years (both legal and illegal) has caused further detriment to the species. Finally, natural events combined with human activity have culminated in a distinct crisis for the Klamath species. This paper will review each of these factors in order to provide a complete picture of the long term decline in the Klamath chinook salmon.

SPECIES SUMMARY

Within the Klamath River Basin, there are two distinct runs of chinook salmon, the fall run and the spring run. Each has its own distinct life history, decline, and status.

The fall run chinook is the most abundant run remaining, with a predicted spawning population in 2003 of 43,100 adults (KRTAT 2003). The decline of the fall run can be evaluated by comparing this number to historic escapements (the number of fish that make it past fishermen). In 1972, 148,500 individuals entered the Klamath River system, while between 1978 and 1995, the average annual fall chinook escapement was 58,820 (CDFG 1995). Contrast these figures with the annual catch and escapement from 1915 through 1928, which neared 400,000 adults (Rankel 1978). The decline of the fall- run has been steady and continuous over the years.

The spring run of chinook was, at one time, the dominant run in the Klamath River basin (Myers et al 1998). The Shasta, Scott, and Salmon rivers all provided for large runs. The 19th century saw the fall of the spring run, as their numbers plummeted dramatically (Snyder 1931). The 20th century saw continued decline, as new insults to the fish pushed their abundance down even further. By the time the 1980s rolled around, the spring run was gone from the majority of its former range, with small holdouts left in the Salmon River and Wooley Creek. What once was the most abundant run is now reduced to between 150 and 1500 individuals in total (Campbell and Moyle 1990, Barnhart 1994). At least seven spring run populations that once existed in the Basin have gone extinct, and those that remain are severely threatened (Myers et al 1998).

In general, the causes of the decline can be summarized into the statement that conditions exist today that do not fully meet the needs of the chinook. Chinook require cool, clear water in sufficient quantities that will allow migration, rearing, spawning, and survival of young. Complex habitat is a necessity; large woody debris, streamside vegetation, deep pools, and riffle stretches are all necessary for resting, hiding from predators, and feeding on aquatic insects. When spawning occurs, a clean gravel stream bottom is needed for the embryos to settle into and remain fully oxygenated until emergence. Sufficient water flows and access to suitable upstream habitat are essential for the successful migration of the fish and the temperature regulation of all life stages. A water temperature of less than 14°C is optimal for fall run chinook when they migrate from early September through late October, spawn two to four weeks later and die; however, these temperatures are rarely found in the lower Klamath Basin (Trihey and Associates 1996, USFWS 1998). The fall run have a typical ocean-type life history pattern, as juveniles spend less than a year in fresh water, and the rest of their lives out in the ocean. Alternately, the spring run have more of a stream-style life history pattern, where the juveniles are in the river for more than a year before heading out to sea (Healey 1991). Between April and July, spring run chinook enter the Klamath Basin and head for the high reaches of their remaining waterways, where they hold in deep pools through September and spawn into October in waters cooler than 16°C (Barnhart 1994, McCullough 1999). The fall run chinook are currently more successful in the Klamath basin than the spring run chinook, which have been placed in the “high extinction risk” category by Nehlsen et al (1991). For more background information on the Klamath chinook, refer to (Andersson 2003) in this same volume.

THE KLAMATH RIVER FISH KILL

Late in September 2002, a mass fish kill occurred in the lower reaches of the Klamath River. The U.S. Fish and Wildlife Service (USFWS) reported a minimum death toll of 33,000 fish, of which 96% were chinook salmon. Of these salmon, some 68% were natural spawners, while the remainder were from hatcheries. An investigation by the USFWS and California Department of Fish and Game (CDFG) ensued shortly thereafter. Autopsies determined the immediate cause of death was disease from the ciliated protozoan *Ichthyophthirius multifiliis* (ICH) and the bacterial pathogen *Flavobacter columnare* (columnaris). These pathogens have always been in the river without incident, so why did this massive infection occur in September 2002? CDFG hypothesized high water temperatures and low flows favored the rapid reproduction and growth of the two pathogens. However, temperature and flows of 2002 were similar to some previous years in which no fish kill occurred. Exposures to toxins as well as an unusual timing of the salmon run were both also ruled out as possible causes of the die-off. After much deliberation, CDFG concluded the kill was a result of an uncanny combination of many factors. High water flows from previous heavy winter runoff altered the channel characteristics, apparently creating a sediment barrier that prevented chinook from migrating upstream during the low flows of September. When the fish could no longer continue upstream, they crowded into pools in very high densities, causing increased stress for the chinook. The close proximity of the fish, combined with the high levels of stress and warm water temperatures made for ideal conditions for disease transmission and outbreak. Research continues to probe this disaster, as many contributing factors and effects remain unclear (CDFG 2003).

This massive fish kill is the visible culmination of the continuing chinook crisis. Factors that have contributed to the decline of the chinook for decades came together for a very sudden and dramatic demonstration of the seriousness of the chinook's plight. Understanding these and other factors involved may help prevent another disastrous fish kill, and hopefully halt the decline of the chinook.

POTENTIAL CAUSES OF DECLINE

Habitat Alteration and Destruction

Sedimentation

Fine particles have for millennia been washing from the granite slopes into the water. Natural levels of sediment are swept away in the natural flows. However, disturbances of man over the last century and a half have shifted the silt balance drastically. The Klamath and Scott River watersheds have been particularly plagued by this problem. Timber harvesting and road building destabilize soils and alter normal runoff patterns, allowing massive amounts of sediment and other debris to course unabated into the water (NMFS 1996). In 1964, entire hillsides of logging-denuded soil slid into the streams during heavy rains (Campbell and Moyle 1990). Due to riparian agriculture and grazing, bank side vegetation no longer exists to hold the soil in place; thus, the riverbanks have been continuously eaten away. Mining from the late 1800s through today scoured riverbeds and nearby hillsides, dumping large quantities of earthen materials either into the water itself or adjacent to it where rains could finish the sedimentation work (West 1991).

For chinook salmon, sedimentation is the number one type of habitat destruction (FEMAT 1993). Sedimentation affects all stages of the chinook's freshwater life cycle, from disturbing the migration to destroying eggs. Sediment that builds up where tributaries meet the main stem of the river can cut off surface flows, preventing the salmon from continuing their movement towards spawning grounds (Payne and Associates 1989). Spawning gravels are also easily filled with sediment, either forcing the female to lay her eggs in unfavorable locations, or causing the burgeoning eggs and embryos to suffocate when oxygen can no longer penetrate the silt. For example, spring run chinook survival to emergence in one river year was highest in areas of the South Fork Salmon River with the lowest volume of sediment, and lowest in areas with the most sediment (West et al 1990). Deep pools, bank pockets, and large woody debris can pack with sediment too, obscuring the key habitats juveniles require for feeding, resting, and predator avoidance. The chinook may have a difficult time finding food when sedimentation occurs, as aquatic invertebrate populations (the chinook's primary food source) decline in silty conditions as well. For more information on sedimentation and its effects, see (Bezemek 2003) in this volume.

Water diversion and dams

Water diversions for irrigation, hydropower, flood control, and household uses have tremendously affected the chinook salmon, by denying the fish access to a high proportion of their historically important habitat (NMFS 1996). Dams impede virtually every salmon river in the West. Just as dams such as Iron Gate create problems on the Klamath River, its tributaries lose water and habitat to water diversions. The spring run chinook have been most afflicted by these structures, since they are adapted to spawn in the highest reaches of the Klamath Basin, areas now behind impoundments. When the Dwinnell Dam on the Shasta River was erected in 1926, the large spring run there coincidentally disappeared (Moyle et al 1995). In this way, dams and diversions may have permanently altered the life histories of these fish, which must now find new spawning grounds in order to perpetuate the species. New areas are surely to be less favorable than those used historically.

Dams and diversions have also modified natural flow regimes, thereby decreasing flows necessary for flushing of sediment from gravels and pools, gravel recruitment and large woody debris transport (NMFS 1996). In this way, the structures not only eliminate habitats by blocking upstream travel, but also prevent new ones from being formed by new gravel and wood coming downstream. The decreased flows also alter habitat by allowing invasive vegetation to propagate further into the channel when the water is low in the summer, and obstruct bank side hideaways the fish need when waters are high (Higgins et al 1992). Other holding areas such as rock outcroppings and woody debris become unavailable when the water is too shallow to cover them. Low flows make deep pools shallow, exposing the chinook to the perils of sunlight and visual predators (including humans). For a comprehensive overview of the effects of dams and diversions, refer to (Litton 2003) in this same volume.

Riparian Vegetation Removal

As farmers and ranchers utilize their land, vegetation such as shrubs, trees, and bushes are removed from the edge of the stream. Unfortunately, this has negative effects on the banks, stream, and fish. The roots of the plants bind the streamside soil, preventing it from being lost by erosion during high flows. Without the vegetation, the soil washes into the stream and increases sedimentation rates. Within the leaves and shoots of the shrubbery are housed lots of insects,

many of which would become food for the chinook after falling or flying into the water. The riparian plants also provide essential components of stream and salmon health, such as becoming woody debris habitat, contributing organic matter to the stream, supplying shade for cooler water temperatures and providing cover from predators (Spence et al 1996).

High Water Temperature

Chinook salmon have a relatively narrow range of physiologically acceptable temperatures in which to live, feed, and breed. This tight tolerance has been threatened by removal of riparian vegetation, water management resulting in low flows, and global warming. The impacts of elevated temperature are diverse. Water temperature is a complex issue, as higher temperatures increase stress, which leads to such problems as increased incidence and virulence of disease, susceptibility to predators, and toxicity of contaminants. At 19.1°C, chinook salmon juveniles are no longer able to grow, a major problem for a fish headed for the ocean (Armour 1990). Depending on how much the temperatures cycle, chinook may be unable to eat well, become weak and inactive, and have difficulty finishing their migration, often stopping to recuperate along the way (McCullough 1999). Spring run chinook especially require cold waters in order to have the lengthy egg incubation necessitated by their evolution; warm waters vastly lower their success to emergence rate (West 1991).

Predation and Competition

Predation

Predation is a natural process, but anthropogenic disturbances have created environments that often favor predators. Levees, low dams, and other waterside structures become perches for birds, which give them a distinct hunting advantage. Some observational studies have shown increased populations of avian predators around dams and other impoundments (NMFS 1998). Turbulent conditions from the same dams, as a result of bypasses, turbines, and spillways, disorient juvenile salmon; this decreases their response time and increases the success of predators (Sigismondi and Weaver 1988).

Habitat destruction plays a major role in predator success as well. When the complex habitat (i.e. large woody debris, deep pools, riparian vegetation) chinook normally use to avoid predators is removed or disturbed, the salmon are left exposed to any nearby predator. When

water levels are low, a similar catastrophe occurs, reducing hiding places and leaving the fish closer to the surface they are more vulnerable to avian predators (NMFS 1998).

Diseases and infections affect the chinook much like they affect humans, causing the fish to eat less, move little, and lack energy. These consequences make the salmon more prone to predation, as a lackadaisical chinook is much easier for a predator to catch. Anything that increases infection rates or transmission, such as increased water temperature or stress would also be expected to cause higher predation rates.

Competition

Competition with other wild fishes is likely to be minimal for chinook as adults, because they are the largest fish around. As juveniles, though, the competition between species is more intense. There is competition for food, cover, and cool water refugia. Humans' greatest negative effect of this natural process comes via hatcheries. Hatchery juveniles tend to be larger than the natives when released into the system. Competition between wild chinook and hatchery juveniles has been documented as a cause of wild stock decline (Steward and Bjornn 1990). The constant fight for food and space forces low survival of both natural and hatchery stocks (Higgins et al 1992). In warm weather, chinook are isolated to cooler deep pools and tributary mouths (Torgerson 1997). By destroying or altering many of these habitats, humans have artificially increased competition between salmonids by leaving less suitable space for the same amount of fish, many of which are of hatchery origin. The equilibrium number of chinook has been decreasing as a result, as no new habitat has been created.

Infection and Disease

Salmon are exposed to a wide variety of bacteria, protozoa, viruses, and parasites throughout their lives. At any point in its life cycle, a chinook may be infected with multiple parasites. A background infection level is always present in the stream, as fish contract diseases through the aquatic invertebrates and resident fishes (Buchanan et al 1983). It is when other factors become involved that infection and disease lead to significant declines in chinook salmon.

Dams and diversions

Dams and diversions play a major role in chinook infectious disease, behind which reservoirs of water support growing reservoirs of pathogens. The *Ceratomyxa shasta* parasite, which caused massive outbreaks in the 1980s and remains an issue in some areas today, thrives in the waters behind dams (Wood 1979). Massive mortality of salmonids as a result of this pest was seen shortly after Iron Gate Dam opened and created the ideal warm and calm habitat for it (CH2M Hill 1985). Smaller dams may play a role in the propagation and success of *C. shasta* as well, as some studies seem to indicate any impounding of a waterway can contribute to the spread of parasites.

Fish ladders bypassing stream impediments may be a major location of pathogen transmission and reproduction. As large numbers of salmon struggle up the ladders, they share a limited amount of water and come into unnaturally close proximity to one another, making transmission of disease very easy. The heightened metabolic rate and stress of the fish as they jump upstream increase the susceptibility of salmon to many dangerous pathogens and can spawn major outbreaks of disease (Moyle and Cech 2000).

Temperature

When water temperature increases due to unnaturally low flows from dams, loss of riparian vegetation or habitat, or other mechanisms, heightened infection rates are likely. Many pathogens chinook carry are dormant at cooler temperatures, but become virulent when the temperature exceeds 15.6°C; studies have shown there are greatly increased risks of massive salmonid mortalities above this limit (McCullough 1999). Fujihara and Nakatani (1970) found death is not only more likely, but also occurs more rapidly at higher temperatures. At higher temperatures (over 20°C) even low virulence strains break out in infection. The common Klamath Basin bacterial pathogen *Columnaris* becomes extremely deadly at warmer water temperatures. In one experiment, 100% of chinook salmon died during *Columnaris* outbreaks at 20°C (Ordal and Pacha 1963). Both *Columnaris* and *ICH* were implicated as the proximate causes of death in the Klamath fish kill of 2002. *ICH* too, has an accelerated life cycle, is more infectious, and more deadly at higher temperatures (CDFG 2003).

Hatcheries

Hatcheries are similar to fish ladders, in that large numbers of fish are restricted to a limited amount of water. Thus, it follows that the effects of stress and metabolism on the spread of infection and outbreaks of disease are essentially identical. In fact, pathogens have significantly limited the success of hatchery programs in the Klamath River Basin, as one virus alone killed 20% of the spring run chinook juveniles held at the Trinity River Hatchery (PFMC 1994). Hatcheries have additional propagative effects on infection as well. Hatcheries have the capability to introduce new diseases into a population. These facilities had, for a long time, brought in chinook juveniles and eggs from other areas to supplement their stocks. The transferred fish transmitted their watershed's pathogens to the chinook that were released into the Klamath Basin. Through mechanisms previously discussed, the released fish passed the diseases onto the natural chinook in the Basin (Higgins et al 1992). Such practices have been scaled back in recent years, but the pathogens have already established, and contributed to the decline of the Klamath chinook.

Harvest

When the Klamath region was settled, the fish populations decline severely, because fishing was a popular method of providing sustenance. The populations were overfished so much that commercial fisheries were banned in the early 1930s due to dramatic drops in the number of spawners (McEvoy 1986). Before the ban, however, both the spring run and fall run chinook populations were greatly depleted. The recreational and Native subsistence fall run chinook fishery on the river is now viable, but the spring run population has never recovered, and is for the most part, off limits to fishermen. Harvest in general modifies the size, age structure, and migration timing of the salmon (NMFS 1996). These historical perturbations, coupled with such a low population level, places the spring run in a dangerous situation where even the least bit of exploitation may drive the stock to extinction.

By-catch

Salmon fishing is an old industry, but it has yet to reach a technological sophistication where fishermen can catch only the species of intent. While legally fishing in the ocean for what will be fall run chinook, the boats pull up a small percentage of future spring run fish as well

(Ricker 1980). All of the salmon share coastal waters at the same time, and are all subject to fishermen. Spring run chinook have been and continue to be caught as by-catch before they begin to migrate up the river and spawn. Spring run chinook may be caught and discarded in other ocean fisheries as well, such as in tuna or anchovy net operations. It has also been common practice to fish for hatchery fish upstream of the mouth of the Klamath River; but, by doing so at the same time the natural run is occurring, potential spawners are caught or injured.

Poaching

Poachers often take large salmon. The scant spring run fish are particularly vulnerable as they await spawning time in their deep pools. Their preference of very clear streams during the summer months places this chinook stock in plain view. Habitat degradation makes the poacher's more successful, because cover for view obstruction may no longer protect the banks of the salmon's natal streams, and warm temperatures make for sluggish fish.

Natural Events

Drought

It is not hard to imagine what effects drought has on fish populations, because water supply issues in the Klamath Basin have been the source of much controversy in recent years. Low flows allow for increased water temperature, where fish become stressed, diseased, eaten, or exhausted. In addition, there may not be enough water in the stream for the salmon to pass (NMFS 1996). Sediment bars (from various land and water uses) become exposed in low water years and may preclude the salmon's passage. When drought restricts access to tributaries eggs and young may have high mortality risks due to water speed and poor gravel quality in the main stem (Payne and Associates 1989).

Wildfire

Wildfire is a natural part of the ecosystem; small periodic fires keep the underbrush low and the forests healthy. In the Klamath Basin, decades of fire suppression have allowed high fuel loads to build up, resulting in explosively destructive fires. The region has, on two occasions, had 100,000 acres of land burned in a single year, in 1956 and 1987. More recently, the Big Bar Fire complex destroyed 49,000 hectares before firefighters could contain it (Frost and Sweeney

2000). These extensive wildfires (and others like them) have destabilized whole watersheds and removed riparian vegetation, leaving the ashen hillsides for the rains to drag into the river. Massive erosion events took place after each of the fires, adding massive quantities of sediment, ash, toxic chemicals, and debris to the stream channels. Salvage logging with heavy equipment after the fact further eroded the slopes, adding to the watershed devastation (Class Reader 2003).

Floods

The Klamath Basin is prone to erosion based on its geology; additionally, logging, riparian vegetation removal, water diversions, agriculture, and roads have contributed significantly to the increased rate of erosion in the area. Flood events have caused major soil loss in the Klamath River Basin (Janda et al 1995). Enormous amounts of sediment and debris become part of the river as it tears out its unprotected banks. Fields that are overwrought with water contribute pesticides and chemicals to the sediment-compromised streams. The surge of water washes away the large woody debris habitat and scours out the deep pools, rendering whole stretches of river without habitat (NMFS 1996). It takes a long time for riparian cover to regrow after a flood; recruitment of streamside conifers may take more than a century (Lisle 1981).

Marine Conditions

Since most chinook spend the majority of their lifetime in the marine environment, it follows that ocean conditions affect their perpetuation. Cyclic marine conditions are important natural factors influencing chinook population abundance, distribution, and survival (NMFS 1996). Salmon productivity depends on ocean productivity, which is directly dependent on nutrient-rich cold waters that come about in shifting currents. As the currents and climate shift year to year and decade to decade, so do the populations of chinook. Francis and Sibley (1991) found correlations indicating that over the last twenty years, the marine environment has contributed to the variability and decline of chinook returning to their natal streams. When these oceanic cycles hit a low productivity, the small numbers of returning chinook are at risk because the freshwater habitats they return to are degraded as well. Because conditions in the freshwater streams are declining further, unfavorable natural factors can make it increasingly difficult to recover populations.

CONCLUSION

Chinook salmon in the Klamath River basin have, during the last several decades, suffered a major decline in abundance due to a combination of human and natural factors. Habitat alteration by sedimentation, dams and diversions, riparian vegetation removal, floods, and droughts is the biggest problem facing chinook today. Historic spawning grounds have been silted up or made inaccessible; holding and hiding areas have been destroyed; and, physiologically damaging water temperatures have occurred with altered water flows. An increase in predation and competition has also contributed to the decline of the chinook. Habitat destruction makes the salmon more prone to predation and increases competition with other species for the remaining suitable areas. Human-made structures near streams have become perches for fish-eating birds at the same time a loss of streamside vegetation allows the birds a better view of their prey. Hatchery fish compete with the natural stocks for food resources and cool-water refugia as well as transmit diseases to the natives. Infection and disease have been increased by these and other anthropogenic activities. Dams and fish ladders may provide breeding grounds for pathogens, which are more easily passed from fish to fish in limited amounts of water. Increased water temperatures result in higher infection rates, as the pathogens reproduce faster and are more virulent in warmer waters. New pathogens have been introduced by hatcheries importing fish for propagation and supplementation of their stocks. Foreign diseases and infections move to the native fish in the close quarters of the hatchery and out in the streams.

Chinook salmon were historically plentiful in the Klamath Basin, but an influx of settlers overexploited the stocks in the 19th and 20th centuries. Dramatic declines occurred before legislation banned the fishery. Chinook are still affected by fishing today, although much less so than in the past. Many may be killed as by-catch before they reach the streams, while others are caught in the river by anglers and tribal fishers. Poaching too, is a threat (especially to the spring run) when the chinook rests exposed in its summer holding grounds.

Natural events have taken their toll on the chinook salmon as well. Droughts bring sand bars to the surface that block salmon passage to spawning areas and lead to high water temperatures, increased fish stress, disease, and predation risk. Floods can be devastating to stocks as well, causing massive erosion of destabilized banks and sedimentation of the streams,

and the loss of large woody debris habitat. Large wildfires resulting from high fuel loads have destabilized slopes and removed riparian vegetation, allowing a massive erosion of ash, chemicals, sediment, and debris into the streams. Salvage operations after the fires can further erode the slopes and add more debris to the water. One of the most significant natural effects on the decline of the chinook is marine conditions. Chinook spend the majority of their lives in the ocean, so marine conditions can have a major impact on salmon abundance, distribution, and survival. Periodic poor ocean conditions are normally compensated by favorable freshwater conditions; however, in the Klamath Basin, the freshwater conditions have been severely degraded, leaving the chinook at risk.

The chinook salmon have been a part of the Klamath Basin for millennia, but are in crisis right now. No one single factor alone is responsible for this decline, as all factors, natural and human-caused, have contributed to the crisis in their own ways. If the Klamath chinook salmon are to persist, each factor must be intensively studied and its past impacts addressed singly and in combination with other factors. Science has made headway, but much work remains to be done.

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