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Fluctuations in Chinook Salmon (Oncorhynchus tshawytscha) Counts at three lower Columbia River spawning sites

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Fluctuations in Chinook Salmon (*Oncorhynchus tshawytscha*) Counts at Three Lower Columbia River Spawning Sites

by

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Abstract

Several hypotheses were developed to explore the pronounced increase in Chinook salmon (*Oncorhynchus tshawytscha*) returning to spawning grounds at the Cowlitz, Kalama, and Lewis Rivers, three tributaries of the lower Columbia River. The study was conducted using data compiled over a ten-year span from 1991-2001. Preliminary indications are that trends in climate are linked to these increases, with the absence of El Niño events and fluctuations in winter precipitation as likely explanations of these phenomena. The unique nature of Chinook life cycles causes them to utilize a variety of habitats that require ideal conditions for maximum survival rates. Correlations between ideal environmental conditions and the decision by hatcheries to release greater stocks were also analyzed. Overall, considerations were made that each of these hypotheses are inter-connected in explaining the fluctuations. Status report data from the Washington Department of Fish and Wildlife served as the baseline for this study. The data provided a means to graph population trends over time, along with climate patterns over the same time period in an attempt to explain why some years experience higher Chinook counts at spawning grounds than others. The importance of Pacific salmon abundance as an indicator of ecosystem health stresses the need to improve our understanding of the mechanisms regulating their dynamic fluctuations.

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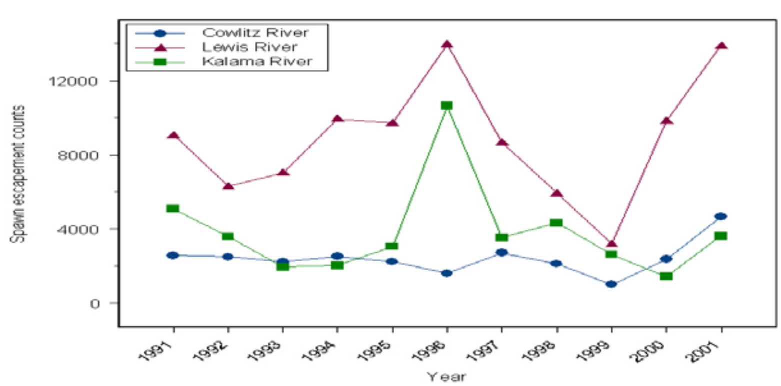
Introduction

Since the 1940s salmon populations have experienced accelerated declines across much of the Pacific Northwest (Behnke, 2002). Many factors have contributed to this decline, most notably the construction of dams along the lower Columbia River, which have driven salmon populations to the brink of extinction (NOAA, 1997). A curious phenomenon has been occurring periodically, however, in which the number of salmon counted at various spawning grounds in a given year has shown a noticeable increase from the overall trend of declines (Bisson et al., 1997).

The purpose of this study was to explain fluctuations in adult Chinook (*Oncorrhynchus tshawytscha*) salmon counts at three tributaries of the lower Columbia River over time from 1991-2001. The question I attempted to answer was: What is causing an increase in the amount of Chinook counted at various spawning grounds in a given year? Fig. 1 shows spawn escapement (count value) data for three lower Columbia River tributaries from 1991-2001 provided by the Washington Department of Fish and Wildlife (WDFW) Fish program (Robinson, 2002).

Figure 1. Spawn Escapement Numbers for Columbia River Tributaries, 1991-2001.



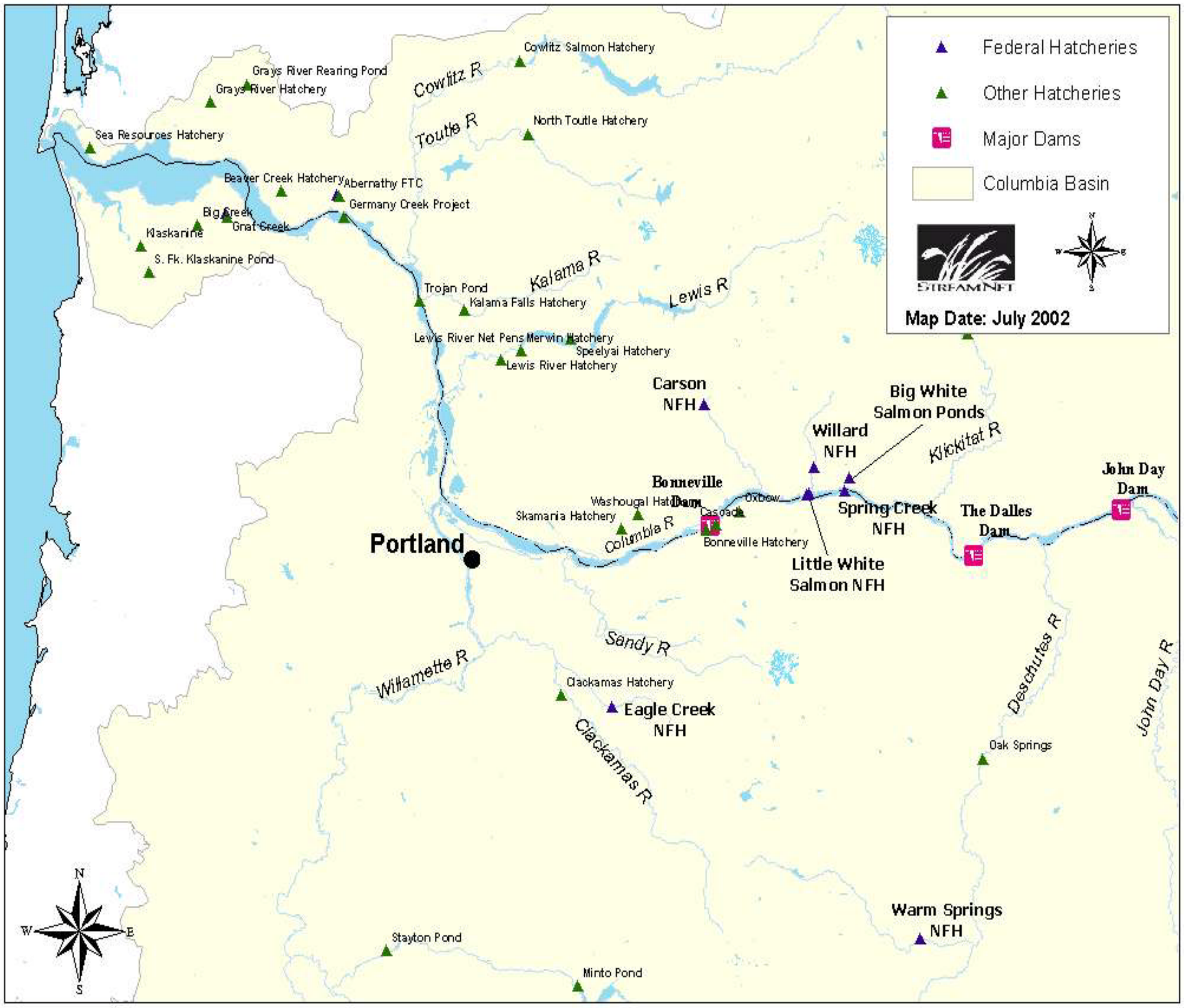
Two of the three rivers (the Lewis and Kalama Rivers) show a similar pattern in the number of

Chinook counted for a given year, but the other (the Cowlitz River) exhibits much less pronounced fluctuations over the same time period. A map provided by the WDFW StreamNet Project (2003) shows the three rivers analyzed in this study, along with each river's primary hatchery location, that serve as tributaries to the Columbia (Fig. 2). The Lewis, Kalama, and Cowlitz Rivers were chosen for study owing to their close proximity to each other in the lower Columbia River and similar directional flow into the main river. In addition, the greatest numbers of fall-run Chinook were counted at the spawning grounds in these three tributaries, respectively.

Jackson et al. (2000) have noted that salmon are indicators of ecosystem health and that unhealthy salmon runs mean unhealthy ecosystems. This was an important study to undertake because salmon affect many people in the Pacific Northwest. Levin et al. (2001) note that because millions of people compete with salmon for the waters in which fish spawn and migrate, such practices as dams, irrigation, mining, logging and cattle grazing all act to destroy salmon habitat. Commercial fisheries rely on abundance of salmon to expand their economic base. Also, environmentalists and conservation biologists want to be able to enhance population sizes across the region, not only to protect the many endangered species listed, but also to maintain genetic diversity in those few wild populations that still exist.

To appreciate salmon as a valuable resource requires an understanding of their biology. Salmon are unique in that they are generally an anadromous species–that is, they utilize two distinct habitats during their life-cycle (Behnke, 2002). After hatching from spawning grounds in a freshwater system, they migrate to the ocean where they grow to adults. The time spent in the ocean varies, but is primarily utilized for feeding in order to become reproductively mature. They then return to the same freshwater spawning grounds where they were born to repeat the cycle and die shortly after spawning.

Figure 2. Lower Columbia tributaries and hatcheries.



Since the Columbia has been harnessed to provide hydroelectric power to a burgeoning human population, dams have had a detrimental effect on nearly all salmon populations, including Chinook. Alterations in flow rates, riparian habitat, and water temperatures have all influenced this decline in some manner dating back to the 1940s.

This question as to why, in a particular year, Chinook return in higher numbers to spawning grounds requires the consideration of many variables. One such sub-question concerns optimal habitat. What characteristics of the Chinook's habitat contribute to a successful run? A run, for the purposes of this study, is that portion of the Chinook population which returns back to spawning grounds during the fall. Levin et al. (2001) state that Chinook must have plenty of gravel in which to spawn. Further, they must have enough clean, cool water to swim, escape predators and find food. In terms of riparian habitat, there must be sufficient vegetation along the river banks to protect the stream bed from excessive erosion or sedimentation, and to add nutrients to the water and provide woody debris as shelter from strong currents. Since Chinook utilize the ocean during a portion of their life cycle, another question arises. Which features of the ocean environment are most beneficial in ensuring maximum fitness and increased survival before the trek back to freshwater? Ocean conditions most conducive to this survival include a cooler temperature regime, which reduces the risk of predation by better-adapted, warmer water species (Petersen and Kitchell, 2001). Cooler ocean temperatures could also inhibit the onset of mortality caused by disease. Assessing the dynamics of habitats may aid in explaining why in a given year, more Chinook reach spawning grounds.

Another question, perhaps linked to habitat quality, concerns climate trends. What role do trends in climate have with fluctuations in Chinook viability? Hare et al. (1999) have correlated variations in salmon production with climate forcing associated with a phenomenon referred to as the Pacific Decadal Oscillation (PDO), affecting Pacific atmosphere-ocean variability over predictable time periods. The PDO functions as a result of ocean circulation patterns which periodically reverse, transporting warmer water off the coast of Washington and cooler water towards the Gulf of Alaska. Events such as this may improve prey densities, causing better fitness in the developing Chinook populations in the ocean-stage. Beamish et al. (1999) have linked trends in climate with fluctuations in Pacific salmon abundance as well, noting synchronous fluctuations in Japanese sardine abundance, a possible dietary staple of Chinook.

What role do hatchery-reared Chinook have on fluctuations in the amount of fish returning to spawning grounds? Large releases of juveniles from hatcheries located in the lower Columbia system prior to a spike in the numbers returning to spawn could have a major impact. Hedrick et al.(2000) think that supplementation of young raised at a protected site, such as a hatchery, may influence the effective population size of an endangered species, in this case, winter-run Chinook from the Sacramento River, California.

What are the physical characteristics of the Cowlitz, Lewis, and Kalama tributaries with respect to navigability and access to spawning grounds? With much higher numbers observed returning to these rivers than others along the lower Columbia, river morphology could have a positive influence on Chinook survival, especially when other factors are taken into consideration, including water temperature and adequate riparian conditions working in concert.

Finally, what guidelines are imposed on commercial fisheries in the amount of Chinook they are allowed to harvest in a given year? When a portion of the Columbia is deemed depleted, they could be required to shift their business to another section of the river that contains a high enough population of Chinook to sustain an accepted harvest rate. This may help to explain the disparity in spawning counts associated with the Cowlitz tributary not exhibiting the same trend as the Kalama and Lewis systems, respectively.

Approach

Based on the dynamic fluctuations shown in Fig. 1, a number of factors may help to explain why significantly more Chinook have been counted at spawning grounds than during the previous year. The bulk of this study incorporated an extensive review of published data focusing primarily on changes in naturally occurring phenomena during the Chinook's life cycle. The data were used to compare historic climatic events with high spawning ground counts recorded simultaneously, particularly from 1991-2001.

In addition to analyzing studies conducted pertaining to climate trends, biologists currently working for the Washington Department of Fish and Wildlife (WDFW) that have intimate knowledge of the lower Columbia River were contacted. Data were collected primarily pertaining to Chinook population dynamics and characteristics of hatcheries in the region. Three main hypotheses were considered in this project dealing with atmospheric anomalies related to ocean conditions and climate patterns, Columbia River flow regimes, and hatchery information related to conducted counts of returning spawners.

The first hypothesis developed concerned climate trends. It was believed that the absence of an El Niño event in the year prior to a high count total at the Lewis and Kalama spawning ground sites allowed for significantly higher survival rates due to optimal habitat conditions. Beamish et al. (1999) point to a close correspondence in the persistence of climate trends and show that a common event may cause the regime shifts. Dalton (2001) has also shown that El Niño events have significant effects on effort and prices for fisheries, and a negative effect does indeed exist in the abundance of Chinook available for harvest. In the absence of an El Niño event, ocean conditions are typically cooler, which is an advantage in survival rates of Chinook as they continue to develop before migrating back to the river.

A second hypothesis involved the role of management strategies in promoting stocks of Chinook for optimal population abundance. Therefore, it was hypothesized that more hatchery-released Chinook are released during different years–increasing the adult survival rate in a given year. The Oregon/Washington Department of Fish and Wildlife's Columbia River Fish Runs and Fisheries, 1938-1997 Status Report (1998) contains data from hatcheries that release juveniles at each of the tributaries under study. The Cowlitz, Kalama, and Lewis Rivers each support a hatchery and counts of returning spawners are recorded each year for Chinook. Conditions may exist in which decisions are made by the hatcheries to release more fish when they believe optimal survival can be achieved. Hedrick et al. (2000) cite a breeding protocol instituted in 1992 that seeks to maximize the effective population size from the captive spawners by equaling their contributions to the released progeny. Hedrick et al. (2000) have also provided findings of an optimistic outlook for the success of supplementation programs, based on a broad representation of returning spawners from many different families.

There is a sharp contrast in the trends shown in Fig. 1 between returning spawning counts from the Cowlitz River and those from the Kalama and Lewis Rivers. Since the Cowlitz has not shown pronounced increases in the amount of Chinook returning to spawning grounds in a given year, it was believed that access to and from the spawning grounds may be more difficult for Chinook to navigate based on morphology of the river, which likely is more sensitive to perturbations in the system. The hatchery on the Cowlitz may follow a different protocol than those on the Kalama and Lewis in the techniques used for counting, or it may be a smaller facility, not equipped with adequate resources for collecting reliable data. It is also of note that habitat quality plays a key role at each of the tributaries. Riparian habitat probably has been deteriorated at a faster pace in and around the Cowlitz River, diminishing critical elements of Chinook health, including increased erosion in the area caused by farming practices in nearby areas. This erosion can lead to destruction of critical spawning grounds where optimal gravel substrate ideal for depositing eggs is replaced by high levels of sedimentation caused by silt.

The high annual precipitation in the Pacific Northwest has been well documented and may have a positive influence in the survival rates of Chinook. It was believed that increased spring runoff in a given year improves river flow rates and contributes to easier access for Chinook to reach spawning grounds up-river. Variables for this hypothesis may include increases in the amount of mountain precipitation in which snowmelt could contribute greatly to optimal cool water temperatures. Increased flow from runoff could also impact accessibility at the catchment sites, causing greater probability of navigation to spawning grounds.

There is a high likelihood that the aforementioned hypotheses are linked. In the analysis of data collection, it was expected that there would be correlations between El Niño events and ocean conditions with an increase or decrease in precipitation indices. Also, variations in water temperature at various stages of the Chinook life cycle could have an impact on prey densities and/or increased risk of mortality caused by disease. In addition, climatic conditions may have management implications related to the number of juveniles allocated for release in a given year or season.

Methods

The method used for conducting research for this study involved a comparative research approach where in secondary sources were used to compare the data that were available with what was hypothesized in the approach section. Where possible, data sets were collected from government and state sources or related links stemming from those various agencies.

In order to assess the impact El Niño events may have on Chinook viability, research was conducted to determine when those events occurred in the time-span, 1991-2001. Data provided by the National Oceanic and Atmospheric Administration (NOAA) and the United

States Geological Survey (USGS) served as the starting point for comparisons with spawning ground data collected by the WDFW Fish Program findings. NOAA's National Marine Fisheries Service data were analyzed to determine when an El Niño event may have occurred during the decade under study. Pacific salmon abundance has been shown to coincide with periodic climate oscillations such as those described by Hare et al. (1999), specifically, a pattern known as the Pacific Decadal Oscillation (PDO). Furthermore, a comprehensive review of data conducted by Hare et al. (2001) documenting the effects of the PDO was analyzed. Once the El Niño events were isolated, the next step was to compare those effects with trends in lower Columbia temperature regimes, flow rates, and turbidity from data provided in the Oregon/Washington Department of Fish and Wildlife's Columbia River Fish Runs and Fisheries Status Report (1998). Graphs were then constructed using data compiled by the U.S. Army Corps of Engineers Coastal Data Information Program (2003) showing the differences in surface ocean temperatures from 1991-2001 at the Grays Harbor, WA Buoy, as well as average annual rainfall data compiled by the NOAA Climate Diagnostics Center for the southwest region of Washington State. The Mean precipitation was calculated using measurements taken in August and September for each year in order to illustrate conditions at time of fall spawning.

Hatchery data were compiled and comparisons made between the amount of Chinook released and the amount counted upon returning to spawn. Release data were collected from the Pacific States Marine Fisheries Commission (2002) and compiled using a database from its Regional Mark Information System (RMIS) for the Lewis River Hatchery, Cowlitz Salmon Hatchery, and Kalama Falls Hatchery. The releases included tagged and untagged Chinook. The locations of release coincided with the count locations where the fish returned to spawn (Fig. 1). Next, comparisons of those graphs were analyzed by Cross (2003) using a combination of a correlation coefficient and regression analysis for a more accurate representation (see below).

Correlated with El Niño events, secondary sources were utilized to see what is known about how Chinook achieve optimal metabolic fitness in the ocean prior to migration back to spawning grounds. Variables of focus included optimal water temperatures, prey density, and risks associated with contracting disease. An attempt was then made to locate data showing fluctuations in ocean temperatures in El Niño years and in the absence of El Niño. Once the data had been compiled, comparisons were made with those years in which ocean conditions were ideal for Chinook health provided it contained a correlation with an increase in count numbers at spawning grounds.

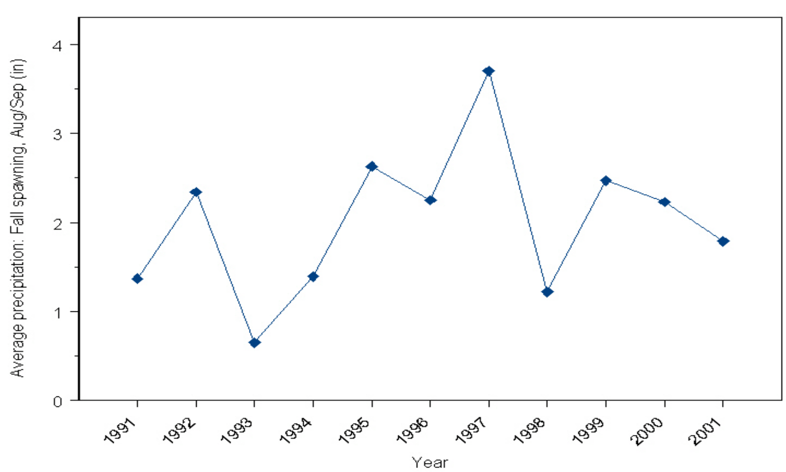
The data needed to describe the anomaly in the Cowlitz River counts (Fig. 1) was collected from NOAA's National Marine Fisheries Service (1997). In addition, information regarding the Cowlitz anomaly was retrieved via electronic correspondence from Bob Woodard of the WDFW Fish Program. Three questions were addressed: (1) Are there significant differences in accessibility in or around the catchment areas for Chinook along the Cowlitz? (2) Do counting techniques or other related management protocols differ significantly at the Cowlitz Salmon Hatchery than from those at the Lewis and Kalama Hatcheries? (3) Is there a program that transplants fish from the Cowlitz to the Lewis and/or Kalama River systems?

To test the hypothesis that increased runoff has a positive effect on Chinook populations, secondary sources were utilized to determine if increased flow is positively correlated with salmon returning to spawn, particularly whether it is due to ease in swimming back or temperature considerations related to cool mountain water runoff. The USGS/Cascades Volcano Observatory (1998), in cooperation with the State of Washington, provided hydrologic summaries from 1991-1997 specifically detailing annual mean runoff. USGS water resource data (2003) were collected showing gauge height and stream-flow peaks, along with the specific date in which those events occurred for the span of the study. The hydrologic measurements were taken from the Cowlitz River at Castle Rock, WA and the East Fork Lewis River near Heisson, WA, as they provided the most complete data available for analysis.

Results

Overwhelming evidence indicates that the winter of 1997-98 experienced a particularly pronounced El Niño event. Fig. 3 shows the average precipitation at the time of fall spawning, August and September, for each year from 1991-2001. The Mean precipitation for the southwest region of Washington State was 2.0 in. (5.08 cm) with a pronounced measurement of 3.7 in. (9.40 cm) in 1997.

Figure 3. Average precipitation (August-September) 1991-2001.



Average annual mean runoff statistics provided by the USGS (1998) indicated that 1991 was near or above normal in western Washington, 1992 was far below normal throughout

Washington and 1993/1994 was below normal. In 1995, runoff was significantly above normal during the winter months, but the annual mean was near normal. In 1996, snow-pack in the mountains averaged above-normal and helped produce average to above average flows during the summer at most gauging stations throughout the state. The year also experienced periods of high water and flooding throughout the state because of above normal precipitation. In 1997, average to above average snow-pack in the mountains produced average to above average stream-flow throughout the summer.

Peak gauge height data provided by the USGS (2003) Water Resources branch for the Cowlitz River at Castle Rock, WA and the East Fork Lewis River near Heisson, WA is shown in Fig. 4. Peak gauge height at the Cowlitz site occurred on 26 November 1998 at a height of 46.59 feet, with a peak stream-flow of 112,000 cfs occurring on 8 February 1996 (Fig. 5). At the Lewis River site, gauge height reached an optimal level of 25.26 feet on 8 February 1996 and stream-flow reached a high of 28,600 cfs on the same date.

Figure 4. Peak gauge height for Cowlitz River at Castle Rock, WA and East Fork Lewis River near Heisson, WA, 1991-2001.

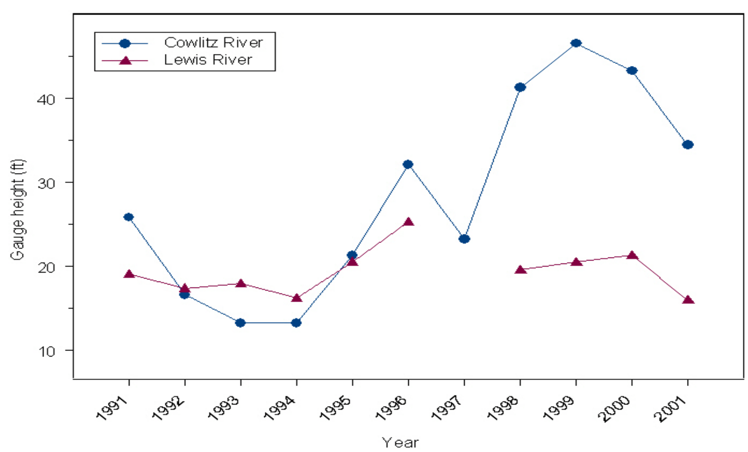


Figure 5. Peak stream-flow for Cowlitz River at Castle Rock, WA and East Fork Lewis River near Heisson, WA, 1991-2001.

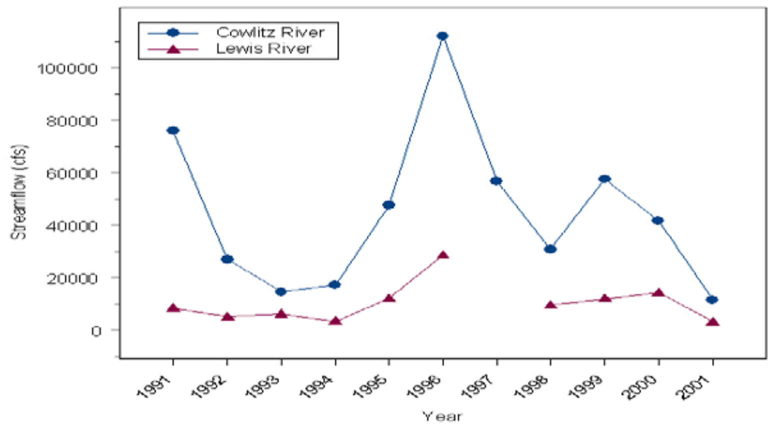
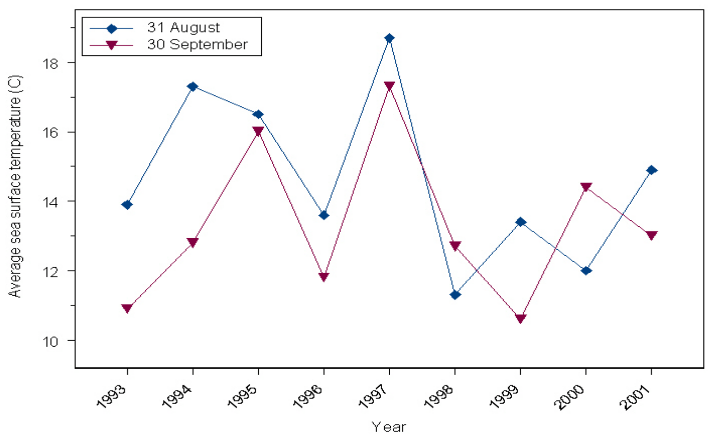


Fig. 6 depicts the average sea surface temperatures at Grays Harbor, WA for 31 August and 30 September. The highest recorded average temperature of 18.7C occurred on 31 August 1997, with a similarly high reading of 17.3C on 30 September 1997.

Figure 6. Average sea surface temperature at Grays Harbor, WA (31 August and 30 September) 1993-2001.



The number of released Chinook at the Lewis River, Kalama Falls, and Cowlitz Salmon Hatcheries are shown in Fig. 7, with the highest numbers consistently released from the Cowlitz Salmon Hatchery over the ten-year span. The average release counts for the Cowlitz was >6.5 million, Kalama >3.2 million, and Lewis >1.0 million. The highest releases occurred in 1997 when the Cowlitz released >9.1 million fish and Kalama >4.7 million.

Figure 7. Release numbers for Columbia River hatcheries, 1991-2001.

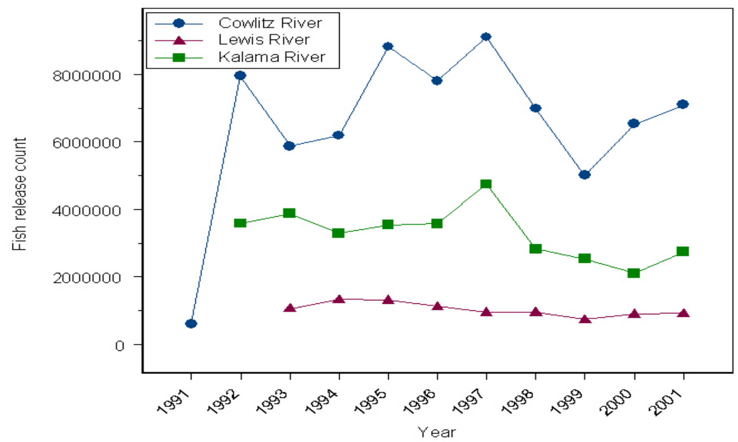


Table 1 shows the results of the linear regression analysis. This analysis revealed that the number of released fish was not predictive of the number in escapement counts (Cowlitz: $F_{1,9}$ =0.076, P =0.7893; Lewis: $F_{1,7}$=1.281, P =0.2949; Kalama: $F_{1,8}$=0.385, P =0.5524) (Cross, 2003).

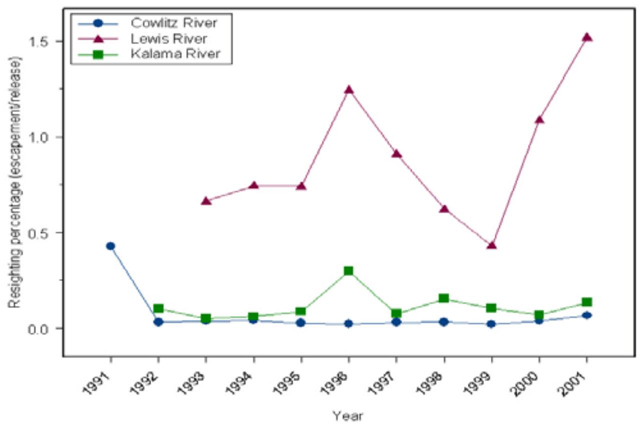
Table 1. Linear regression and coefficient of determination for escapement and release counts.

River	Slope	Intercept	R^2	F-Statistic	P-Value
Cowlitz	0.000	2174.803	0.008	0.076	0.7893
Lewis	0.007	1896.920	0.155	1.281	0.2949
Kalama	0.001	1266.668	0.046	0.385	0.5524

The coefficient of determination (R^2) is a measure of the total variation in the dependent variable (y-axis) that is being explained by the predictor/independent variable (x-axis) (Cross, 2003). In this case, the R^2 values indicate the total variation in escapement counts that can be explained by the number of fish released (Cross, 2003). The coefficient of determination for the

Cowlitz River was below 1%, with the Lewis and Kalama coming in at 15.5% and 4.6%, respectively. Fig. 8 shows the resighting percentage (number in escapement/number released x 100%) for each of the three rivers under study, with the Lewis River experiencing the highest percentage at >1.5% (Cross, 2003).

Figure 8. Resighting percentage for Columbia River tributaries, 1991-2001.



In regards to the hypothesis that the low spawning ground counts recorded at the Cowlitz River is related to accessibility for migrating fish, Bob Woodard, biologist with the WDFW (2003), explained that the index areas for each of the three tributaries are equally accessible. Furthermore, the question of differing protocols in counting techniques at the Cowlitz, as explained by Woodard (2003), is conducted based on redd counts with an expansion factor applied in order to develop a population estimate. The redd counts are counted by plane, with the biological data collected by boat and foot within the spawning ground. As for the Kalama and Lewis tributaries, spawn escapement estimates are based on peak count expansion factors and visibility factors. Techniques in data collection vary on the ground, ranging from raft, drift boat, pontoon boat, jet sled, and foot. In addition, an official policy does not exist which transplants fish from the Cowlitz to the Kalama or Lewis Rivers (Woodard, 2003). WDFW has transferred fish, however, out of the basin, but not out of basin stocks into the Cowlitz.

Discussion

The increase in count values for fall-run Chinook in the Kalama and Lewis Rivers in 1996 suggests that an El Niño event was not a factor in this observed pattern. Since Hare and Mantua (2001) have identified atmospheric and oceanic conditions as essentially reversed during a La Niña event, it is probable that during increased trends in abundance of fish, a La Niña event is likely at work. Research conducted by Smith and Sardeshmukh (1999) developed an index using the difference in heating degree days between La Niña and El Niño. Seasonal mean values were below the base values in both 1996 and 1997 using the base value of 0C (32F). These colder temperatures are consistent with La Niña conditions, according to Smith and Sardeshmukh (1999). Considering that sea surface temperatures showed a decrease between 1995-96, Behnke (2002) notes that optimal feeding temperatures are generally between 13-16C, a condition more conducive to increased growth and decreased mortality in the marine habitat. Furthermore, owing to cooler ocean temperatures, migration patterns to a more northerly location may not have been a factor, resulting in more Chinook returning to natal streams in the Columbia basin.

The term Pacific Decadal Oscillation (PDO) coined by Mantua et al. (1997) to describe variability in climate on multi-decadal time scales can help to explain increased trends in Chinook abundance, especially when correlated with La Niña events. The relationship of the PDO on salmon production revealed by Zhang et al. (1997) showed a long-lived El Niño Southern Oscillation (ENSO) pattern of Pacific climate variability. With regard to recent advances in the PDO climate research, Hare and Mantua (2001) point to a change in the PDO index in 1998 that could mark the onset of a new regime, citing that owing to anomalously cool coastal waters off the west coast, planktonic communities have flourished, which bodes well for salmon in the region. This shift in the climate regime could help to explain the positive count values experienced in 2000-01. Furthermore, Hare et al. (1999) point to the reversal in the PDO of 1998 as an indicator of a cooler ocean, a condition favorable to west coast salmon production. This reversal has shown to be representative of cooler coastal waters off of the Columbia River.

Relating to aquatic habitat considerations, average daily water temperatures at Bonneville Dam were the lowest recorded during the fall run of 1996, according to a joint report filed by the Oregon and Washington Divisions of Fish and Wildlife (1998). Petersen et al. (2001) have examined the relationship in Columbia River water temperature with predation on juvenile salmon, identifying major predators as the northern squawfish (*Ptychocheilus oregonensis*), smallmouth bass (*Micropterus dolomieu*), walleye (*Stizostedion vitreum*), and channel catfish (*Ictalurus punctatus*), with only northern squawfish being native to the Columbia River basin. Considerations concerning exotic species predation need to be addressed because of the differing optimal water temperature parameters between salmonids and the piscivorous fish that prey upon them. When water temperatures increase, conditions are more favorable for predator survival and thus, salmon are consumed in greater numbers (Vigg et al. 1991). Walters and Ward (1998) also explore marine survival rates related to climate changes, especially in relation to increased exposure to ultraviolet radiation during freshwater residence. The importance of water temperature in the life history of salmonids cannot be understated. Beacham and Murray (1990) relate these controls to such things as days to hatch and emergence, feeding rate, and growth rate.

Average precipitation measurements conducted in the southwest region of the state also show a decline in the spawning months of August and September for 1996 and 2001, both years in which fish counts reached a maximum at the Lewis River site. Similar trends were observed for the Kalama, although less pronounced. The NOAA (1997) National Marine Fisheries Service has considered that a major determinant of trends in salmon abundance can be attributed to the conditions of the freshwater, estuarine, and ocean habitats on which salmon depend.

Stream-flow measurements and gauge height at the East Fork Lewis site and Cowlitz site each show an increase from 1994-96, suggesting that runoff from snow-pack in the surrounding mountains contributed to cooler river temperatures and increased flow, a valuable indicator in the success of fish reaching spawning grounds. Increasing measurements were also observed during 1999 and 2000, again consistent with trends of increasing count values at each of the three tributaries; therefore, the hypothesis that a positive correlation between high run-off and Chinook survivability is supported.

Release data from the hatcheries on the Cowlitz, Kalama, and Lewis tributaries exhibit more ambiguous observations and multiple sources of error were considered. Woodard (2003) notes there are no hatchery releases or hatchery returns of fall Chinook to the Lewis River because it is a self-sustaining wild run. Other factors to consider are the studies conducted by Bisson et al. (1997) who state that salmon abundance tends to be highly variable, with inter-annual fluctuations in the range of 40-70%. In addition, Bisson et al. (1997) have observed that salmon have evolved to adapt to variable systems. The release data collected consisted of all Chinook released in a given year, not exclusively fall-run units. Therefore, the trends exhibited from the escapement counts may not correlate with the release numbers. First, Chinook return to spawn at different times of their life cycle, between 1-5 years from birth, which may not accurately portray a linear progression. Second, the Cowlitz Salmon Hatchery and the Kalama Falls Hatchery are considered a Lower River Hatchery Stock (LRH), whereas the Lewis River is considered a Lower River Wild Stock (LRW). This may explain why tagged and/or untagged fish released near the Lewis River are significantly lower than at other hatcheries. Where an active hatchery release program is implemented, the highest releases occurred during 1997. Presumably, this was done to compensate for the decline in Chinook counts during the winter of 1997-98, which the Washington Department of Ecology (2002) concluded was one of the largest El Niño events of the 20th century.

The anomaly shown in Figure 1 regarding the reduced Cowlitz count values in comparison to the Kalama and Lewis tributaries may have several explanations. The hypothesis probing accessibility of fish back to spawning grounds was more difficult at the Cowlitz site was not supported. Woodard (2003) described the index areas visited each year to collect data as equally accessible. The second hypothesis that counting techniques and management options differ at each site may have validity. Since Cowlitz River spawn escapement estimates of redd counts are conducted by plane, a larger possibility of inaccuracies may turn up in data collection. However, biological data collection techniques conducted on the ground was very similar, either by foot or watercraft. The question of transplanting fish out of the Cowlitz and into the Kalama and Lewis systems as an accepted practice did not seem to be verified. Woodard (2003) says there are no official programs to transfer fish, but does admit that the Kalama has had other stocks raised at that particular hatchery. In a related instance, NOAA (1997) has seen considerable numbers of spring-run Chinook transplanted from the Cowlitz to the Kalama and Lewis Rivers based on subyearling smoltification patterns. It is possible that stocks may be equalized at various sites on a seasonal basis, depending on which facilities have experienced low counts over time.

Conclusions

It seems clear that climate variability has the most profound effect on fluctuations in Chinook abundance in a given year. There seems to be inconclusive evidence to suggest that hatchery releases are a prominent factor in a successful run. In addition, physical geomorphology and other catchment characteristics to the Cowlitz, Kalama, and Lewis tributaries for spawning fish suggest equal accession at each.

The impact salmon have as an indicator of ecosystem health could lead to a myriad of future studies. In order to enhance salmon sustainability for the future, research on El Niño events could be used to prepare for special mitigation efforts when such an event is forecasted. Also, since salmon have been shown to be sensitive to climatic alterations, future models could be constructed assessing the impacts of global warming on salmon health. In addition, since the lower Columbia basin lies in a region of high volcanic activity, in the event of a catastrophic eruption, questions related to alterations in river flow-rates and extremes in atmospheric climate owing to such a catastrophe could be explored as it pertains to salmon production.

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