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VARIATION IN USE OF THE KLAMATH RIVER ESTUARY BY JUVENILE CHINOOK SALMON

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Use of the Klamath River estuary by young-of-the-year (YOY) chinook salmon, *Oncorhynchus tshawytscha*, varied between high (1993) and low (1994) river flow years. From May to September, mean flows in the Klamath River were 400 m³/s in 1993 and 109 m³/s in 1994. In the lower Klamath River estuary, YOY chinook salmon catch-per-unit-effort was higher during 1994 than during 1993. Also, weekly mean fork lengths of YOY chinook salmon in the Klamath River estuary after mid-July were significantly smaller in 1994 than 1993. These observations suggest that more estuarine rearing by YOY chinook salmon took place in the low flow year of 1994 than the high flow year of 1993, potentially because of better up-river rearing conditions in 1993. In 1993, most YOY chinook salmon reached the estuary at a size large enough to immediately enter the ocean. In 1994, many juvenile chinook salmon may have been forced downstream by increasing water temperatures before they reached optimal size for ocean entry. Thus, they were more likely to rear in the estuary.

INTRODUCTION

Chinook salmon, *Oncorhynchus tshawytscha*, life history patterns are the most complex of the Pacific salmon. In California and Oregon, life history varies from rearing in freshwater for a short period before migrating to the ocean (ocean type) to rearing in the stream for a full year before seaward migration (stream type); intermediate life history patterns also exist. Freshwater life history of juvenile chinook salmon is suspected to strongly influence survival and return as adults (Nicholas and Hankin 1989, Healey 1991). Growth rate, emigration timing, distribution, and rearing patterns determine when and at what size juveniles enter the marine environment. Examination of these factors will help to identify important habitats and critical times to better understand chinook salmon population dynamics.

Though many estuaries along the Pacific Coast of North America are important rearing areas for some salmonid species (Reimers[1] 1971, Healey 1980, Kjelson et al. 1982, Levy and Northcote 1982, Myers and Horton 1982), evidence about the extent to which chinook salmon rear in the Klamath River estuary is contradictory. Evidence that some emigrating chinook salmon rear for a period of time in the Klamath River estuary is provided by mark-recapture studies (CDFG[2] 1993a, CDFG[3] 1994a), scale circuli analysis (Snyder 1931), recapture of coded-wire-tagged chinook salmon in the estuary up to 4 months after their release into Hunter Creek within a few kilometers of the estuary (Wallace 1995), and peak chinook salmon catches in the lower estuary typically occurring 1–2 weeks later than in the upper estuary (CDFG[4] 1992a). Conversely, other studies have concluded that extended rearing of young-of-the-year (YOY) chinook salmon rarely takes place in the Klamath estuary. Krakker[5] (1991) found that YOY chinook salmon captured from the lower estuary and the lower mainstem river upstream of the estuary were similar in size and had similar emigration timing, thus concluding that few fish reared in the estuary. Sullivan[6] (1989) used scale circuli analysis to describe juvenile life histories of fall chinook salmon from the Klamath basin and concluded that they did not rear extensively in the estuary. These contradictory conclusions about the use of the Klamath estuary by juvenile chinook salmon may result from the fishes' response to annual changes in physical or biological processes, thereby resulting in variable patterns of estuarine use by chinook salmon.

Pacific Coast estuary conditions exhibit wide annual variations (Simenstad and Wissmar 1984) that probably affect chinook salmon rearing patterns in estuaries. For example, Healey (1980) found annual differences in abundance and size of chinook salmon fry in the Nanaimo River estuary, British Columbia. Other researchers have also noted annual differences in distribution or size of juvenile chinook salmon captured in estuaries (Kjelson et al. 1982, Simenstad and Wissmar 1984, McCabe et al. 1986).

Physical conditions in the relatively small Klamath River estuary are dominated by river flow and vary greatly both seasonally and annually (CDFG[7] 1992b.

[1] Reimers, P.E. 1971. The length of residence of juvenile fall chinook in Sixes River, Oregon. Ph.D. Dissertation, Oregon State University, Corvallis, Oregon, USA.

[2] California Department of Fish and Game. 1993a. Utilization of the Klamath River estuary by juvenile salmonids. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Project No. F-51-R-5, Subproject No. IX, Study No. 10, Job No. 3.

[3] California Department of Fish and Game. 1994a. Length of residency of juvenile chinook salmon in the Klamath River estuary. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Project Number F-51-R-6, Project No. 32, Job No. 4.

[4] California Department of Fish and Game. 1992a. Utilization of the Klamath River estuary by juvenile salmonids. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Project No. F-51-R-4, Subproject No. IX. Study No. 10, Job No. 3.

[5] Krakker, J.J., Jr. 1991. Utilization of the Klamath River estuary by juvenile chinook salmon (*Oncorhynchus tshawytscha*). 1986. M.S. Thesis, Humboldt State University, Arcata, California, USA.

[6] Sullivan, C.M. 1989. Juvenile life history and age composition of mature fall chinook salmon returning to the Klamath River, 1984-1986. M.S. Thesis, Humboldt State University, Arcata, California, USA.

[7] California Department of Fish and Game. 1992b. Assessment of fish habitat types within the Klamath River estuary. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Project Number F-51-R-4, Subproject No. IX, Study No. 22, Job No. 1.

CDFG[8] 1993b, CDFG[9] 1994b, CDFG[10] 1995). The magnitude and timing of river flow probably determines the amount of rearing habitat available to juvenile chinook salmon in the basin, which, in turn, influences emigration timing and fish condition upon entering the estuary.

Studies of the Klamath River estuary since 1986 have documented emigration timing, size, distribution, habitat use, and diets of juvenile salmonids (Wallace[11] 1993, Wallace 1995, Wallace and Collins[12] 1995a, Wallace and Collins[13] 1995b). Intensive sampling in the Klamath River estuary in 1993 and 1994 to determine juvenile chinook salmon length of residence provided an opportunity to compare patterns of estuary use during high (1993) and low (1994) river flow years. This study reports our observations about emigration timing and patterns, relative abundance, and size of YOY chinook salmon in the Klamath River estuary in those 2 yr. Based on our observations of the behavior of juvenile chinook salmon at greatly different river flows, we provide insight on how YOY chinook salmon use the estuary and speculate how they reacted to flow conditions throughout the rest of the basin. This may help explain why different studies have come to different conclusions about the importance of the Klamath River estuary as a rearing area for YOY chinook salmon.

METHODS

Study Area

The Klamath River enters the Pacific Ocean about 51 km south of the California-Oregon border. Its estuary is relatively short and small when compared to the size of the watershed. The estuary provides numerous habitat types, even though it lacks the extensive tide flats and tidal marshes found in most larger estuaries (CDFG[7] 1992b, CDFG[8] 1993b). Saltwater intrusion varies seasonally and is controlled by freshwater flow and a sand berm which forms in late summer at the river mouth.

For this study, we divided the Klamath River estuary into lower and upper sections. The lower estuary (river km [rkm] 0–2.4) experiences tidal fluctuation up to 2 m and brackish water (15–30‰) is usually present along the bottom from May through October (CDFG[7] 1992b, CDFG[8] 1993b, CDFG[9] 1994b, CDFG[10] 1995). In the upper estuary (rkm 2.4–6.4), brackish water usually extends upstream to about rkm 4.8 at high tide, but reaches as far as rkm 6.4 when high tides coincide with low river discharge (CDFG[8] 1993b). However, a layer of fresh water 1–2 m deep is found along the surface throughout most of the estuary, causing shallow littoral areas to be primarily freshwater habitat.

Sampling

Sampling locations and methods were the same in both years of our study. We attempted to sample the upper and lower estuary each week. We established four transects in the upper estuary that consisted primarily of sand, gravel, and cobble flats and heavily vegetated cut banks (Fig. 1). We sampled each transect for 10 min at night using a boat-mounted electrofisher. The electrofisher was powered by a 5.0-kilowatt generator. The anodes were two 0.9-m diameter circular clusters of six

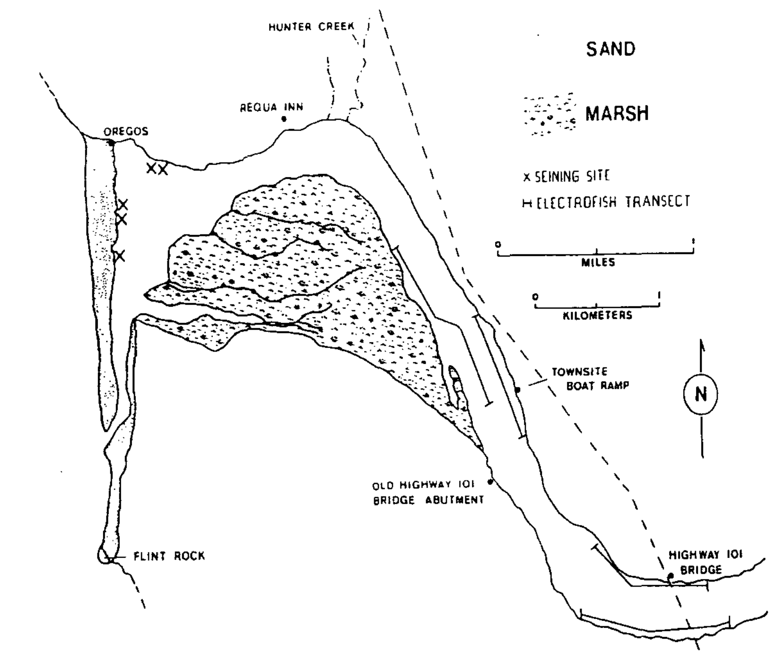

Figure 1. Sampling locations for young-of-the-year chinook salmon in the Klamath River estuary in 1993 and 1994.

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[8] California Department of Fish and Game. 1993b. Assessment of fish habitat types within the Klamath River estuary. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Project Number F-51-R-5, Subproject No. IX, Study No. 22, Job No. 1.

[9] California Department of Fish and Game. 1994b. Seasonal water quality monitoring in the Klamath River estuary. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Project No. F-51-R-6, Category: Surveys and Inventories, Project No. 33, Job No. 2.

[10] California Department of Fish and Game. 1995. Seasonal water quality monitoring in the Klamath River estuary. Annual Performance Report. Federal Aid in Sport Fish Restoration Act. Project No. F-51-R-6, Category: Surveys and Inventories, Project No. 33, Job No. 2.

[11] Wallace, M. 1993. Distribution, abundance, size, and coded-wire tag recovery of juvenile chinook salmon in the Klamath River estuary, 1986-1989. Final Performance Report. Federal Aid in Sport Fish Restoration Act. Project No. F-51-R; Subproject IX: Study No. 10; Job No. 3.

[12] Wallace, M. and B.W. Collins. 1995a. Food habits and preferences of juvenile chinook salmon in the Klamath River estuary. Final Performance Report. Federal Aid in Sport Fish Restoration Act. Project No. F-51-R; Project No. 32; Job No. 6.

[13] Wallace, M. and B.W. Collins. 1995b. Habitat type utilization of juvenile salmonids in the Klamath River estuary. Final Performance Report. Federal Aid in Sport Fish Restoration Act. Project No. F-51-R; Project No. 32; Job No. 7.

6.4-mm diameter stainless steel cables that were extended by booms to 2.4 m in front of the boat. The cathode was an array of seventeen 3.2-mm diameter stainless steel cables hung 152 mm apart and attached to the bow of the boat. We sampled fish at 250–300 v (passing 3–5 amps) at 120 pulses/s DC in 5- to 7-s bursts. Upstream and downstream boundaries were established for each transect to minimize the variation in the amount of area sampled. Catch-per-unit-effort (CPUE) was calculated as the number of fish captured per minute shocked. We electrofished in the upper estuary because it allowed sampling of a variety of habitats and was more efficient than beach seining at capturing larger juvenile salmonids.

In the lower estuary, during daytime, we deployed a 45.7-m x 3.1-m beach seine with 6.4-mm mesh from the bow of a 4.9-m boat. We could not electrofish the lower estuary due to widespread presence of salt water. We sampled five standard locations consisting of sand and gravel flats and sand beaches (Fig. 1). The length and width of each haul was estimated to calculate the area seined. Catch-per-unit-effort was calculated as the number of fish captured per 100 m^2 seined.

Captured salmonids were anesthetized with quinaldine sulfate prior to measurements. Fork lengths were recorded to the nearest millimeter for up to 30 fish per species per transect or haul. All salmonids were counted and examined for marks.

River flows were determined from a California Department of Water Resources gaging station located near the mouth of Turwar Creek approximately 1.6 km above the estuary. We collected monthly water quality data at high and low tides using conductivity and oxygen meters. Water quality data were collected at three stations (right, middle, and left) along predetermined transects 0.4–0.8 km apart throughout the estuary at surface, midwater, and bottom depths (CDFG[8] 1993b, CDFG[9] 1994b, CDFG[10] 1995). We also routinely sampled surface water temperature with a hand-held thermometer during fish collections.

We used Student's-t to test for significant differences in mean fork lengths of YOY chinook salmon between years and two-tailed Mann-Whitney U test to compare CPUE between years.

RESULTS

Environmental conditions in the Klamath River estuary were much different in 1993 than in 1994. Average river flow from May to September was 400 m^3/s in 1993 and 109 m^3/s in 1994 (Fig. 2). Water temperatures in the upper estuary ranged from 14 to 21°C in 1993 and 15 to 24°C in 1994. In the lower estuary, surface freshwater temperatures ranged from 14 to 21°C in 1993 and 16 to 23°C in 1994. However, water temperature in the salt wedge near the bottom was normally 5–10°C cooler during both years. Due to high river flows in 1993, we did not detect any salt water in the estuary until July, but it was present the rest of the summer. In 1994, the salt wedge was already present in May, but was absent in August and September, resulting in water temperatures of about 21°C throughout the water column during those months (CDFG[9] 1994b, CDFG[10] 1995). The change in location and configuration of the river mouth likely kept salt water from entering the lower estuary during late summer in 1994.

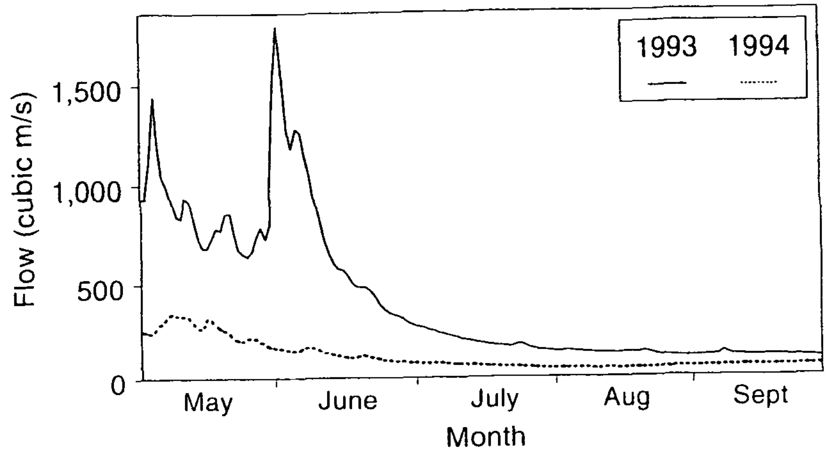

Figure 2. Average daily Klamath River flows at the Turwar gaging station from May to September 1993 and 1994.

The average CPUE of YOY chinook salmon in the upper estuary during 1993 was significantly higher than in 1994 ($U = 237$, $df = 32$, $P < 0.001$). Although CPUE did not differ between years in the lower estuary ($U = 215$, $df = 36$, $P > 0.20$), it was significantly higher from mid-July to early September in 1994 than in 1993 ($U = 54.5$, $df = 14$, $P < 0.05$). In the upper estuary, during 1993, we captured 3,411 chinook salmon (mean CPUE = 6.61 fish/min), while during 1994 we captured 1,265 chinook salmon (mean CPUE = 1.54 fish/min). In the lower estuary, during 1993, we captured 1,194 chinook salmon (mean CPUE = 3.38 fish/100 m^2), while during 1994 we captured 2,468 chinook salmon (mean CPUE = 4.86 fish/100 m^2). In the lower estuary from mid-July to early September, we captured 190 chinook salmon (CPUE = 1.11 fish/100 m^2) in 1993 and 1,596 chinook salmon (mean CPUE = 9.27 fish/100 m^2) in 1994.

The average CPUE of YOY chinook salmon in the upper estuary also remained high longer in 1993 than in 1994, but the opposite was true in the lower estuary, where CPUE remained high longer in 1994 than in 1993 (Fig. 3). In 1993, we obtained 50% of our upper estuary YOY chinook salmon catch about a month later than 50% of our lower estuary catch (Fig. 4). In contrast, in 1994, we obtained 50% of our upper estuary YOY chinook salmon catch about a month earlier than 50% of our lower estuary catch.

Juvenile chinook salmon in the Klamath River estuary differed in size between years only in late summer (Fig. 5). Mean lengths of juvenile chinook salmon from June to mid-July were similar in both years: 87.3 mm in 1993 vs. 87.6 mm in 1994 in the upper estuary ($t = 0.31$, $df = 810$, $P > 0.20$) and 85.4 mm in 1993 vs. 86.0 mm in 1994 in the lower estuary ($t = 0.94$, $df = 846$, $P > 0.20$). However, after mid-July, mean length in the upper estuary in 1993 (95.8 mm) was significantly larger ($t = 14.51$, $df = 965$, $P < 0.001$) than in 1994 (85.5 mm). The same was true in the lower estuary, where the mean length of 100.2 mm in 1993 was significantly larger than the mean length of 88.5 mm in 1994 ($t = 9.14$, $df = 713$, $P < 0.001$).

DISCUSSION

The differences in timing and magnitude of our YOY chinook salmon catches in the upper and lower estuary between years may be explained by either annual differences in emigration timing or differences in number of chinook salmon rearing in the two areas.

A change in emigration timing rather than increased numbers of rearing chinook salmon was the most probable cause for higher catches observed in the upper estuary in 1993. The U.S. Fish and Wildlife Service (USFWS) also noted later emigration of chinook salmon at traps on the mainstem Klamath River in 1993 than in 1994 (J. Lang, USFWS, pers. comm.). Higher river flows in 1993 likely created more rearing habitat (Bjornn and Reiser 1991) and cold-water refugia upstream of the estuary and, therefore, may have allowed more juvenile chinook salmon to rear later into the year before emigrating. Flows from cold-water tributaries such as the Salmon River, Scott River, and Indian Creek were higher in 1993 than in 1994 (Palmer et al.

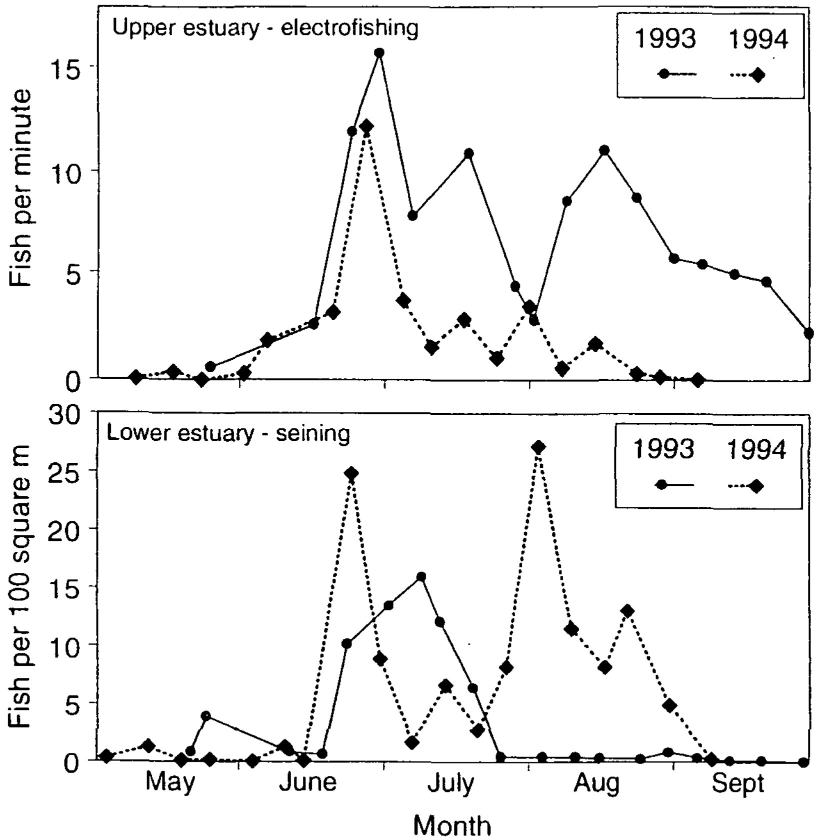

Figure 3. Catch-per-unit-effort of young-of-the-year chinook salmon from the upper and lower Klamath River estuary in 1993 and 1994.

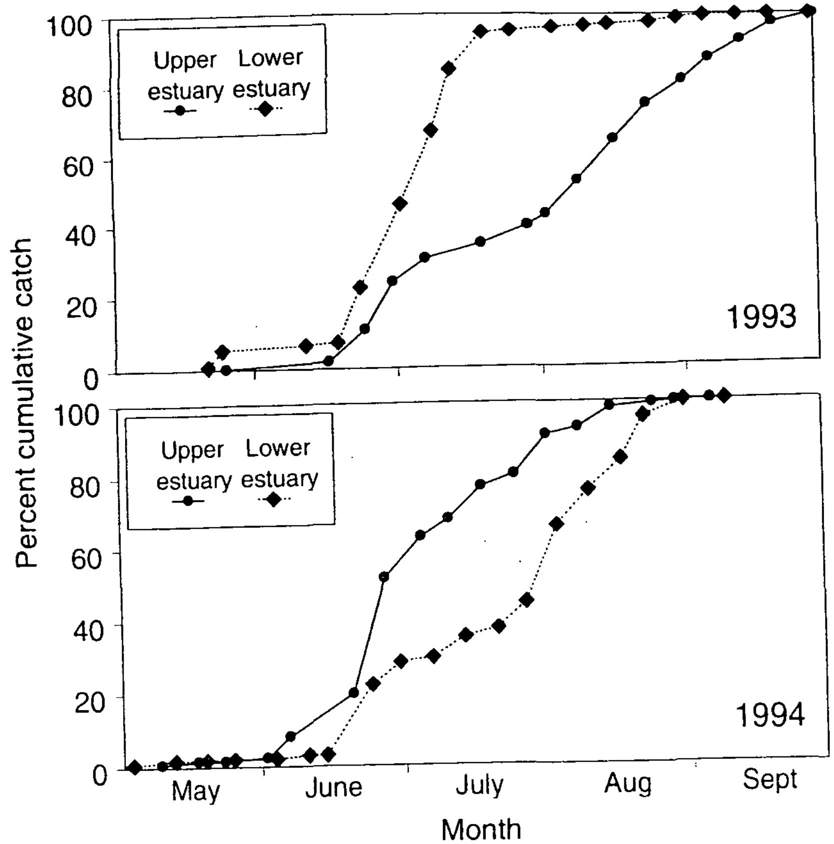

Figure 4. Cumulative catch of young-of-the-year chinook salmon from the upper and lower Klamath River estuary in 1993 and 1994.

1993, Ayers and others 1994), which likely increased the area of cool-water habitat available to juvenile chinook salmon. High concentrations of juvenile chinook salmon were observed adjacent to the mouths of cold-water tributaries of the Klamath and Trinity rivers in the mid-1980s (T. Mills, California Department of Fish and Game, pers. comm.). These areas may act as cool-water refugia from warm mainstem water and provide important rearing areas for juvenile chinook salmon. Finally, the significantly larger mean length in 1993 is consistent with more favorable mainstem river conditions in 1993 than in 1994. However, whether the larger size was due to more food in 1993, less cool-water refugia area inhibiting chinook salmon growth in 1994, or some other reason is not known.

Several factors suggest that higher upper-estuary catches in 1993 were not the result of an increase in the number of YOY chinook salmon rearing there. We measured water temperatures up to 21°C during monthly water quality sampling and up to 22.5°C during fish sampling, which, though not as high as in 1994, still approach

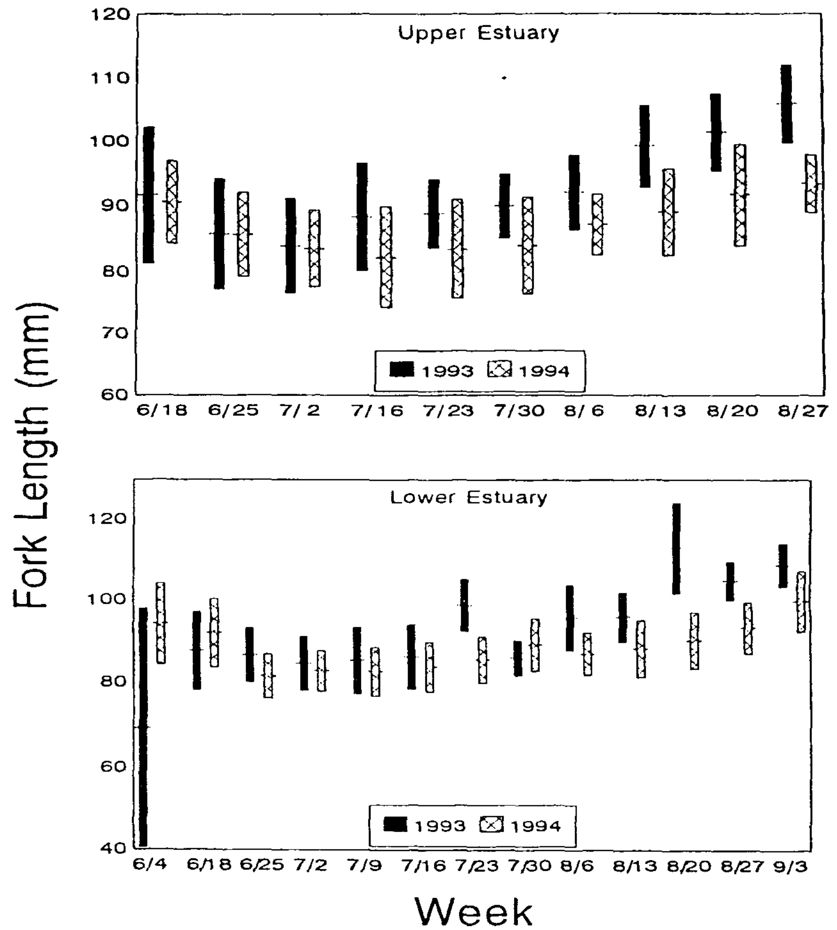

Figure 5. Weekly mean fork length ± 1 standard deviation of young-of-the-year chinook salmon captured from the upper and lower Klamath River estuary in 1993 and 1994.

the upper lethal limit for juvenile chinook salmon (Bjornn and Reiser 1991). Also, it is likely that catches of YOY chinook salmon in the lower estuary would have increased as the greater number of rearing fish dispersed throughout the entire estuary. Finally, the large size of fish captured in the upper estuary in 1993 suggested that they were already large enough for ocean entry by the time they reached the estuary (Nicholas and Hankin 1989) and, therefore, less likely to rear there. We were probably more likely to intercept these larger fish while electrofishing in the upper estuary than seining the lower estuary because they are more vulnerable to electrofishing than seining (Reynolds 1996) and less likely to occupy nearshore areas sampled by our seines (Myers and Horton 1982).

Our observations suggest that, while juvenile chinook salmon spent little time rearing in the lower Klamath River estuary in 1993, they reared there more extensively in 1994. In 1993, relatively large numbers of chinook salmon continued to be caught in the upper estuary after lower estuary catches dropped to low levels, suggesting that most fish were moving quickly through the lower estuary or, possibly, residing in offshore areas of the estuary, thereby avoiding our seines. However, we observed different catch patterns in 1994. We captured relatively low numbers of chinook salmon in the upper estuary after mid-July, while high catches continued in the lower estuary. This suggests that YOY chinook salmon passed through the upper estuary earlier and spent a longer period of time in the lower estuary in 1994 than in 1993. Also, in 1994, cumulative and peak catches of chinook salmon occurred about a month later in the lower compared to upper estuary. If this later peak in the lower estuary was due to increased emigration, rather than increased rearing, we would have seen a similar increase in our upper estuary chinook salmon CPUE.

Increased estuary rearing by chinook salmon in 1994 was likely due to unfavorable rearing conditions upstream; thus, YOY chinook salmon probably reached the estuary at a smaller size than in 1993. After mid-July 1994, YOY chinook salmon were significantly smaller than during the same time in 1993. Low river flows in 1994 may have created poor rearing conditions that reduced chinook salmon growth rate or forced earlier emigration at a smaller than optimum size for ocean entry. Juvenile chinook salmon from Oregon coastal rivers that enter the ocean in late summer and early fall at 120–160 mm experience the highest ocean survival, though typically the greatest number of chinook salmon enter the ocean at 90–100 mm in length (Nicholas and Hankin 1989).

Assessing the prevalence of estuarine rearing by comparing chinook salmon lengths between the upper and lower estuary alone does not appear to be a reliable method. In both 1993 and 1994, sizes were similar between the upper and lower estuary. One reason is that size differences may be partially masked by our gear selecting smaller fish in the lower estuary. Wallace[11] (1993) reported that, when sampling the same areas of the Klamath River estuary, chinook salmon captured by electrofishing typically averaged 2–3 mm larger than those captured by beach seines. Another reason may be that the smaller chinook are more likely to rear in the estuary than larger chinook in order to attain adequate size for ocean entry. Therefore, we may be comparing the size of all chinook entering the upper estuary with predominately smaller, rearing chinook in the lower estuary. When fish reach a suitable size for ocean entry, it is likely that they migrate out of the lower estuary to the ocean.

Other explanations for the smaller size of chinook salmon observed in 1994 than in 1993 are that higher abundance in the lower estuary depleted the available food supply and that a change in the location and configuration of the river mouth kept cool saltwater from entering the lower estuary later in summer 1994 and inhibited chinook salmon growth as water temperatures reached 20–23°C (CDFG[7] 1992b, CDFG[8] 1993b, CDFG[9] 1994b, CDFG[10] 1995). The former hypothesis is supported by evidence that, in 1991 and 1992, abundance of preferred chinook salmon prey items was lowest in the summer immediately after peak catches of chinook salmon (Wallace and Collins[12] 1995a).

Substantial annual variations in physical and biological processes occur in Pacific Coast estuaries (Simenstad and Wissmar 1984) and this may explain why some studies have shown significant estuarine rearing by YOY chinook salmon (Reimers[1] 1971, Healey 1980, Kjelson et al. 1982, Levy and Northcote 1982, Myers and Horton 1982), whereas others have concluded that relatively little estuarine rearing takes place (Schluchter and Lichatowich 1977, Sullivan[6] 1989, Krakker[5] 1991). All of these studies were conducted over relatively few years and may not have encompassed the full range of variability in these processes. Although our study is no exception, it does suggests that changes in the Klamath River estuary, including annual differences in river flow and brackish water conditions of the lower estuary, elicited changes in estuarine use by YOY chinook salmon. Therefore, conclusions about the importance of estuaries to chinook salmon production need to be based on a longer time series that includes a wide range of variability in physical and biological processes. This may be especially true in smaller estuaries like the Klamath, where annual physical conditions can vary greatly.

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