

Juvenile Chinook salmon, *Oncorhynchus tshawytscha*, use of the Elwha river estuary prior to dam removal

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Abstract The estuary of the Elwha River, on Washington's Olympic Peninsula, has been degraded and simplified over the past century from sediment retention behind two large dams, levee construction, and channelization. With the removal of Elwha Dam and initiation of Glines Canyon Dam's removal in fall 2011, sediment deposits will change the estuary and affect anadromous and nearshore marine fishes. Juvenile Chinook salmon commonly use estuaries and the river's population is part of

an Evolutionarily Significant Unit listed as Threatened under the U.S. Endangered Species Act. This study reports on monthly sampling in part of the river's estuary from March 2007 through September 2011 to characterize the seasonal changes in relative abundance of yearlings and sub-yearlings, and size distributions prior to dam removal. Most (69 %) of the yearlings were caught in April, when this life history type was released from the hatchery, and to a lesser extent in May (28 %) and June (3 %). Yearlings caught in the estuary were smaller than those released from the hatchery (means: 153 mm±28 SD vs. 175 mm±5 SD), suggesting more rapid departure by larger fish. Sub-yearlings were much more abundant in the estuary, and were caught from March through November, increasing in mean fork length by 8.7 mm month⁻¹. The hatchery-origin sub-yearlings were not marked externally and so were not distinguishable from natural origin fish. However, 39 % of the sub-yearlings were caught prior to June, when sub-yearlings were released from the hatchery, indicating substantial use of the estuary by natural-origin fish. Thus, even in a reduced state after a century of dam operation, the highly modified estuary was used over many months by juvenile Chinook salmon. The information on juvenile Chinook salmon prior to dam removal provides a basis for comparison to patterns in the future, when the anticipated increase in estuarine complexity may further enhance habitat use by juvenile Chinook salmon.

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Introduction

Salmon and trout populations have been affected by many anthropogenic stressors including habitat degradation, contaminants, over-fishing, and genetic changes, which, along with impassable dams, have contributed to declines in many Atlantic and Pacific river systems (Netboy 1968; Nehlsen et al. 1991; NRC 1996; Lichatowich 1999; Montgomery 2003). In recent years several dams have been modified to allow passage such as Landsburg Dam on the Cedar River, Washington (2003), and other dams have been breached such as Condit Dam on the White Salmon River, Washington (2011), Edwards Dam on the Kennebec River, Maine (1999), and Great Works Dam on the Penobscot River, Maine (2012). However, the largest dam breaching project undertaken in the United States is occurring on the Olympic Peninsula of Washington, where two dams on the Elwha River blocked migratory fishes and altered sediment transport and other physical and ecological processes since 1910–1913 (Duda et al. 2008).

To learn from any large project or activity, it is important to understand the conditions prior to the change for comparison to subsequent conditions, although this is challenging when both physical and biotic features of the system are likely to change. In the case of the Elwha River, dam removal is releasing sediment that had been trapped by the dams, and its downstream transport will modify and expand the estuary. Estuaries are the transition zone as juvenile anadromous salmonids enter marine habitats (Thorpe 1994). In general, smaller individuals and life history types with short freshwater residency rely more heavily on estuaries for rearing than do fish that enter marine waters at a larger size (Healey 1982a; Simenstad et al. 1982; Quinn 2005). For example, sub-yearling Chinook salmon, *Oncorhynchus tshawytscha*, use estuarine and nearshore habitats more extensively than do yearling smolts (Healey 1980, 1991). The transition from freshwater to saltwater has important implications for salmon growth and survival (Magnusson and Hilborn 2003; Greene et al. 2005; Duffy and Beauchamp 2011).

The Elwha River flows north into the Strait of Juan de Fuca from the Olympic Peninsula, Washington State, USA (Fig. 1). The Elwha River estuary has been affected by three events (Shaffer et al. 2008). In 1912, the Elwha Dam was completed at river kilometer (rkm) 7.8, forming Lake Aldwell. The 32 m high dam blocked access for migratory fish to 115 km of upriver habitat (Duda et al. 2008) and greatly reduced the transport of

sediment and large woody debris to the lower reach, estuary, and nearshore habitats. Completion of 64 m high Glines Canyon Dam in 1927 at rkm 22 further reduced sediment and wood transport (Curran et al. 2009). Estuarine habitat was also reduced by the construction of a rock levee in the west estuary parallel to the river in 1964, and by channelization (Shaffer et al. 2009; Draut et al. 2011).

The demolition of both dams started in the fall of 2011 and as of summer 2013, Elwha Dam has been completely removed, and Glines Canyon Dam partially removed. Sediment transport is underway as the river carves a new course across the newly emerged lake bottoms (Warrick et al. 2012). The present paper reports the relative abundance of yearling and sub-yearling juvenile Chinook salmon throughout the year in the Elwha River's west estuary from March 2007 through September 2011 prior to dam removal. Sampling is ongoing and characterization of the baseline condition is essential to detect future changes in the fish populations such as the proportions of yearlings and sub-yearlings, size distributions, and timing of estuary use. Accordingly, we used monthly sampling at two sites in the west estuary to document the presence of yearling and sub-yearling juvenile Chinook salmon, and to determine size distributions as an indicator of growth within the river-estuary system. The hatchery-produced Chinook salmon in this system were not marked externally but we used information on their release dates and mean sizes at release to assess the extent of estuary use by naturally spawned and hatchery origin fish. The expectation, based on general knowledge of juvenile Chinook salmon ecology (Healey 1991; Quinn 2005), was that sub-yearlings would be present in the estuary for a more protracted period than yearlings (McCabe et al. 1983; Fisher and Pearcy 1990). As noted by McHenry and Pess (2008), the Elwha River has no real "reference" or "control" against which the changes can be compared, so this is essentially the "before" in a "before-after" study design.

Materials and methods

Sampling took place within the west estuary of the Elwha River because initial sampling in 2007 revealed higher catch rates of juvenile Chinook salmon compared to the east side, even though the west estuary was smaller (Shaffer et al. 2009). Two sites were sampled; both were tidally influenced and disconnected from the

main channel during low tides, and longitudinally separated by 30 m of semi-permanent beach. The northern site had a maximum depth of 2 m with a substrate of

sand, gravel and cobble, and aggregated woody debris. The southern site was bordered by a rock levee forming the western edge of the tide channel, and had a

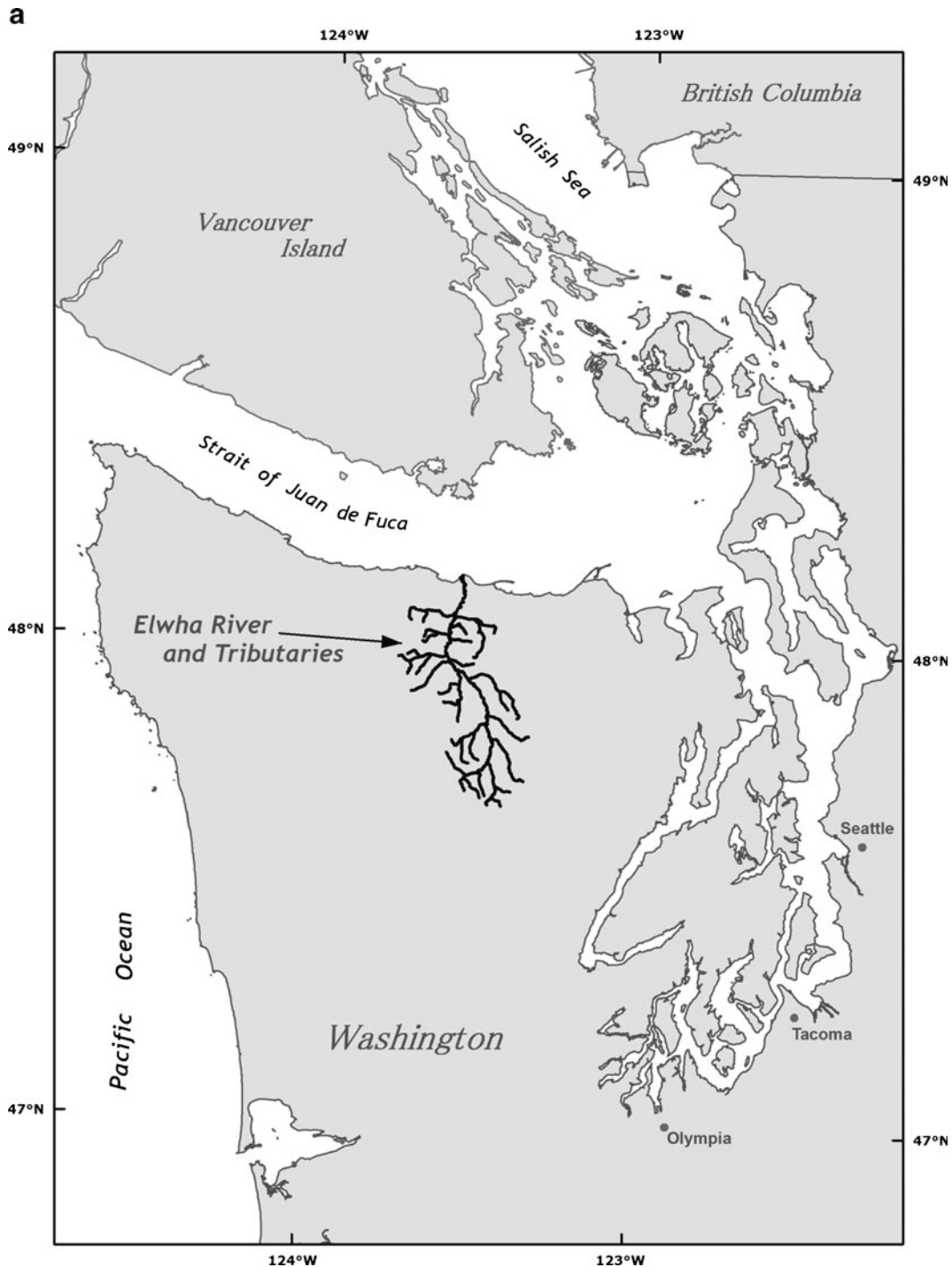


Fig. 1 Map showing the location of the Elwha River, in western Washington State, USA (**a**), and orthophoto showing the configuration of the estuary in 2011 (**b**). Sampling sites on the west side are indicated by X. From Quinn et al. (2013)



Fig. 1 (continued)

maximum depth of 2 m with a fine silt substrate and woody vegetation on the margins.

Sampling, conducted in mid to late morning on a single day each month during the first monthly neap tide, is ongoing but we report only sampling in years when the dams were in place (March 2007 to September 2011). Fishes were collected using a beach seine 24.4 m long $\times$ 1.8 m wide with a cod end of 1.8 m³ and knotless mesh of 5 mm. The seine, deployed using a rowboat and retrieved by hand, enclosed a volume of 174 m³ when fully submerged. Special care was taken to minimize handling stress because Chinook salmon, steelhead trout (*O. mykiss*) and bull trout (*Salvelinus confluentus*) are listed as Threatened under the U.S. Endangered Species Act. All fish were worked toward the submerged cod end, identified to species, and released at the capture site. Fork length (nearest mm) was recorded for approximately 20 juvenile Chinook salmon and the rest were counted.

We used length-frequency distributions to identify age classes of the Chinook salmon (Fisher and Pearcy 1990). The proportion of each age class among the

measured fish on each sampling event was used to estimate the numbers of sub-yearlings and yearlings among those counted but not measured. The overall proportion of yearlings and sub-yearlings for each month, based on length-frequency distributions, was applied for all years to compensate for small samples in some month/year combinations that would not have yielded reliable estimates.

Both yearling and sub-yearling Chinook salmon were released from a hatchery operated by the Washington Department of Fish and Wildlife but were not externally marked. In 2007–2011 an average of 1.9 million sub-yearlings and 0.2 million yearlings were released (Table 1). Smolts were assumed to be of natural origin if they were caught prior to the release from the hatchery each year (early April for yearlings and early June for sub-yearlings). We also compared the length-frequency distribution of juvenile salmon in our sample to the mean length at release of hatchery fish, estimated from the mean weight and a weight-length relationship ($W(g) = 0.0000049 \cdot FL(mm)^{3.147}$) (David Beauchamp, University of Washington, pers. comm.).

Table 1 Numbers of juvenile Chinook salmon released from the Washington Department of Fish and Wildlife hatchery facility into the Elwha River, 2007–2011. Release dates (in parentheses)

Year	Sub-yearlings (date)	Yearlings (date)	% yearlings
2007	2,618,000 (11–14 June)	140,900 (18 April–26 May)	5.1
2008	1,868,000 (4 June)	276,950 (1–3 April)	12.9
2009	939,000 (2–4 June)	340,946 (25 March–1 April)	26.6
2010	3,047,730 (3 June)	201,017 (7 April)	6.2
2011	1,236,562 (7 June)	200,824 (13 April)	14.0
Mean	1,941,858 (early June)	232,127 (early April)	10.7

correspond to the great majority of fish and do not include very small numbers released on other dates

Results

We caught 18,717 juvenile Chinook salmon in 127 sets from March 2007 through September 2011. There was an extreme outlier event in June 2010, when 13,224 fish were caught immediately after a release of sub-yearlings from the hatchery. These fish were omitted from analysis, leaving 5,493 fish, of which 1,322 were measured for length. Based on length frequency distributions (Fig. 2), juveniles >90 mm long in April and May, and ≥ 120 mm long in June were considered to be yearlings, and smaller fish were assumed to be sub-yearlings. Yearlings were not caught prior to releases from the hatchery, in April, when 69 % of the yearlings were observed (Table 2). Yearling catches declined in May (28 % of the total) and June (3 %), and none was caught thereafter. Expansion based on estimated ages of the subsample indicated that the yearlings comprised only 3 % ($n=522$) of the total catch in the estuary although they represented 10.7 % (range 5.1 %–26.6 % among years, Table 1) of the fish released from the hatchery. Hatchery-produced yearlings averaged 175 mm at release in early-mid April. In contrast, the mean length of yearlings caught in the estuary was $148.0 \text{ mm} \pm 28.6 \text{ SD}$ in April and $127.8 \text{ mm} \pm 28.2 \text{ SD}$ in May. In both months the 95 % confidence interval did not include the 175 mm mean value for hatchery fish (April: $SE=4.08$, May: $SE=12.62$). One fish, 95 mm long, was caught in January and no others were caught in December or February (Tables 2, 3). This 95 mm individual was listed as a yearling but it might also be considered the last of the sub-yearlings.

Small numbers of sub-yearling Chinook salmon were caught in March (approximately three months prior to the hatchery release of sub-yearlings), and catches increased markedly in April, remained high through July–

August, and extended almost the entire year (Table 3). Omitting the outlier catch of 13,224 from analyses, 39 % ($n=2,013$) of all sub-yearlings were caught before the hatchery releases took place, indicating that those juveniles were of natural origin. The remaining 61 % of the juvenile salmon caught, after the hatchery releases, included both natural and hatchery origin fish. The mean FL in March was $46 \text{ mm} \pm 4.5 \text{ SD}$, and increased steadily ($8.7 \text{ mm month}^{-1}$) through September (Table 3). The hatchery origin sub-yearlings released in June averaged 92 mm, exceeding the 95 % confidence interval of the mean length of juvenile salmon captured in the estuary in June (80.6 mm , $SE=0.51$), July (83.72 mm , $SE=0.60$) and August (88.1 mm , $SE=1.06$), two months after the hatchery release.

Analysis of inter-annual catch patterns was limited because sampling occurred for just five years and the June 2010 sample had to be excluded. Nevertheless, we did not find the expected positive correlations (using Pearson's product moment) between numbers of Chinook salmon released from the hatchery and catch rates of yearlings (annual smolt release vs. catch rates of yearlings in April: $r=0.137$; catch rates in May: $r=0.331$). Indeed, the catch rates of sub-yearlings tended to be lower in years when the hatchery released more sub-yearlings ($r=-0.804$ in June, when the releases took place). However, none of these correlations was significant, as low statistical power resulted from the limited period of record.

Discussion

Sampling in the Elwha River's west estuary revealed several patterns commonly seen in Chinook salmon in larger estuarine systems. The hatchery-origin yearlings

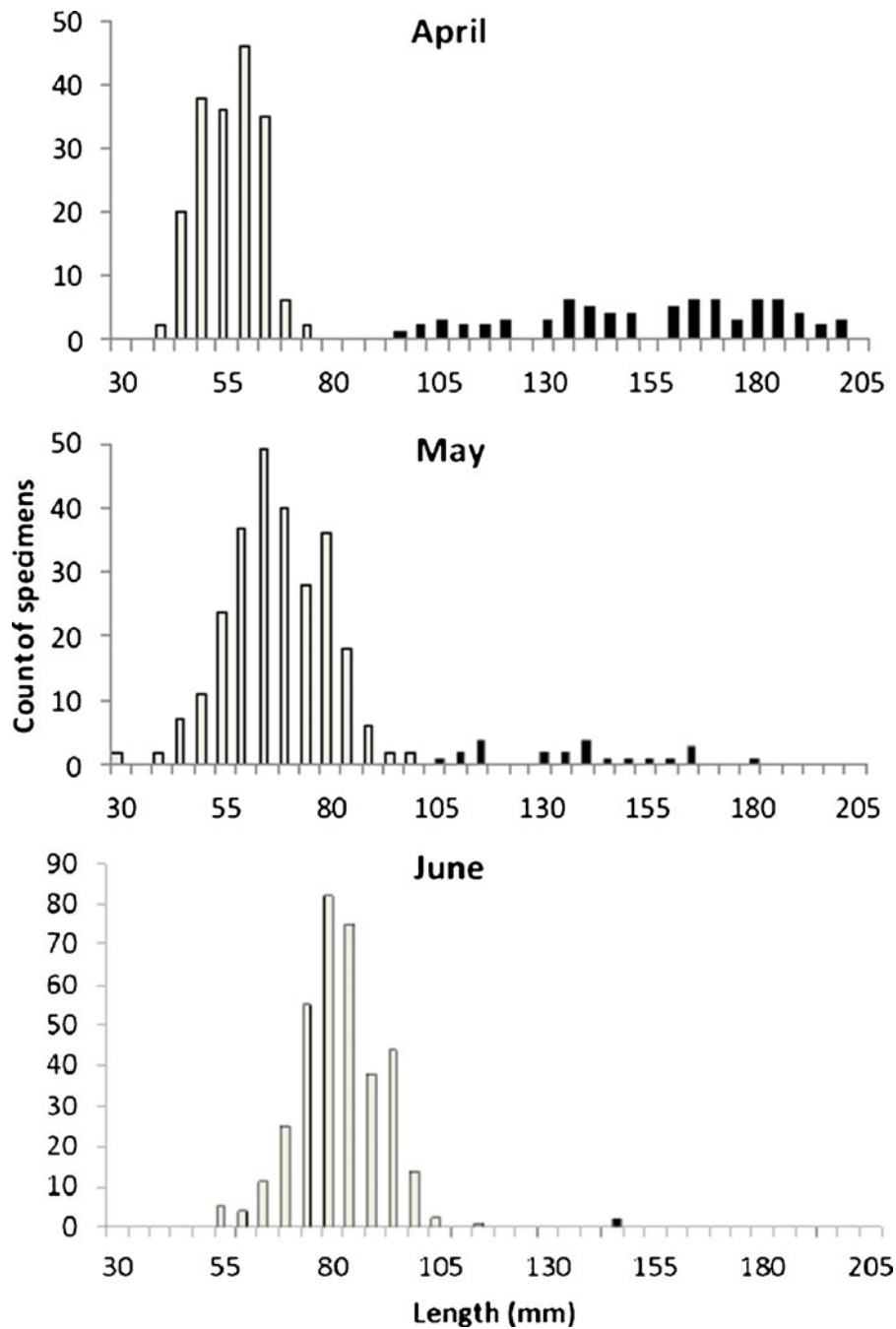


Fig. 2 Length-frequency histograms of juvenile Chinook salmon sampled in the Elwha River estuary. Gray bars indicate fish classified as sub-yearling and black bars indicate yearlings, all years combined

were present in the estuary for only a short time after release (primarily in April) and their mean size was smaller than that of yearlings released from the hatchery. The mean length of yearlings caught in the estuary declined from April to May, further indicating that the

yearlings in the estuary were the small, slow-growing members of the cohort. The hatchery fish were not externally marked but it is likely that yearlings caught in the estuary were largely of hatchery origin because no yearlings were caught prior to the hatchery releases

Table 2 Mean monthly catch per seine haul (SD) of juvenile Chinook salmon in the Elwha River estuary, 2007–2011. An outlier sample ($n=13,224$) in June 2010 was removed because the hatchery released smolts on that day

Month	Sub-yearlings	Yearlings
January	0.0 (0.0)	0.3 (0.6)
February	0.0 (0.0)	0.0 (0.0)
March	1.9 (3.8)	0.0 (0.0)
April	39.1 (21.6)	16.1 (8.9)
May	76.5 (54.4)	6.7 (4.7)
June	150.0 (54.7)	0.7 (0.5)
July	99.5 (38.1)	0.0 (0.0)
August	17.9 (17.5)	0.0 (0.0)
September	10.9 (16.8)	0.0 (0.0)
October	0.7 (1.2)	0.0 (0.0)
November	3.2 (5.1)	0.0 (0.0)
December	0.0 (0.0)	0.0 (0.0)

in April. In addition, all 27 yearlings caught in April 2012 had coded wire tags, indicating hatchery origin. Sub-yearlings were the dominant juvenile life history type in the Elwha River during the immediate pre-dam removal period but yearlings may become more abundant as upriver habitat becomes accessible (Pess and McHenry 2008).

In contrast, 39 % of the sub-yearlings were caught prior to releases from the hatchery and presumably

Table 3 Mean monthly fork length (SD) of sub-yearling Chinook salmon (identified from length-frequency distributions) caught in the Elwha River estuary, March 2007–September 2011 (years combined). Sample refers to the number of fish measured; values in parentheses are the range of fish measured among years

Month	Sample	Mean Length (SD)
January	1	95
February	0	
March	15 (1–13)	45.7 (1.2)
April	182 (13–89)	54.5 (7.1)
May	252 (3–117)	66.0 (11.5)
June	356 (25–180)	80.6 (9.6)
July	306 (30–180)	83.7 (10.4)
August	95 (7–31)	88.1 (10.4)
September	37 (7–30)	98.6 (14.1)
October	4 (4)	99.0 (7.4)
November	18 (1–17)	98.0 (5.4)
December	0	

represented natural reproduction in the lower Elwha River. Some of the sub-yearlings caught later in the season were also presumably of natural origin. The hatchery released an average of 1.9 million sub-yearlings annually during the study period (Table 1). They probably contributed much less to the catches than fish of natural origin *per capita* because it is unlikely that natural production is this high, based on the numbers of adults (Pess et al. 2008). Catch rates in June, other than one day in 2010, which coincided with release from the hatchery, were not correlated with the numbers of sub-yearlings released from the hatchery. Indeed, the general relationship was inverse, similar to the inverse relationship between numbers of hatchery coho salmon smolts released into the Elwha River and catches in the estuary (Quinn et al. 2013). High densities of juvenile salmon may reduce residence time in the estuary through social interactions, resource depletion, or other processes. Sub-yearlings were present from March to November and steadily increased in mean length. These findings are consistent with the use of the estuary for rearing as part of a riverine system rather than serving merely as an interface between river and marine habitats. However, the extent to which the growth occurred in the river prior to arrival in the estuary is not known, so the role of the estuary for rearing and growth of fish is not clear. Upon emergence from the gravel, Chinook salmon may move downstream to sea that spring, as fry, or from early to late summer after several months of growth in the river (Healey 1980; Levings et al. 1986; Fisher and Pearcy 1990; Healey 1991; Quinn 2005). They also occupy estuaries, and the relative growth in river and estuarine environments can vary greatly among individuals within populations (Reimers 1971; Healey 1980; Hering et al. 2010).

The sub-yearling Chinook salmon sampled in the Elwha River estuary increased in mean length from March to September and were larger than conspecifics in the estuaries of the Skagit River, Washington (Congleton et al. 1982), Campbell River, British Columbia (Levings et al. 1986) and Situk River, Alaska (Johnson et al. 1992) but smaller than those in the Columbia River (McCabe et al. 1986). Early marine survival of juvenile Chinook salmon is positively affected by rapid early growth (Duffy and Beauchamp 2011), consistent with the positive effect of size within a cohort on marine survival in other salmon species (Healey 1982b; Holtby et al. 1990; Henderson and Cass 1991). The presence of hatchery-produced sub-yearlings

complicated our analyses and also complicates prediction of future trends in total and natural production of juveniles in the Elwha River system. However, larger smolts tend to migrate earlier (Durkin 1982; Beckman et al. 1998) and faster than smaller ones (Giorgi et al. 1997), so competition between wild (likely smaller) and hatchery produced fish may not be as great as might be the case if they used the river and estuary similarly. Research in Puget Sound indicated that hatchery-produced Chinook salmon were present over a less protracted period than naturally produced conspecifics (Rice et al. 2011).

The period following dam removal is ongoing as this paper is being prepared, and there will be many changes in the physical and biotic aspects of the estuary as more sediment and wood are deposited. Against the null hypothesis of “no change from pre-dam conditions”, one might pose two alternative hypotheses. First, the expansion of the estuary that is being observed might result in increased use of this habitat by sub-yearling Chinook salmon. This might be inferred from continued sampling if the population as a whole is present for a longer period of time after dam removal or from marking studies to directly measure duration of residence by individuals. Alternatively, dam removal will allow Chinook salmon to spawn farther upriver, and they may be able to achieve more growth in the river itself than was possible in the period prior to dam removal. Finally, increased sediment in the estuary may affect fish behavior and use of the estuary for rearing, further complicating assessment (Korstrom and Birtwell 2006). Thus, changes in juvenile Chinook salmon life histories following dam removal may indicate ecological changes within the river and the estuary, emphasizing the need for continued studies to distinguish between the changes in these two habitats. Such studies are complicated by many factors, including the selectivity of beach seines and other sampling methods that vary with species and substrate (Parsley et al. 1989), and the rapid, dramatic changes in the estuary, including the sampling sites. In addition, as has been noted by several authors, salmonid populations are subject to considerable natural variation, reducing the power to detect change when abundance or catch is the index (Lichatowich and Cramer 1979; Bisson et al. 2008; Dauwalter et al. 2009). Distribution, size, timing and other life history features may be more sensitive to change than catches.

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