

Nicole Goehring  
REU Abstract  
Interannual Comparison of Juvenile Chinook Growth, Residency, and Diet

The mechanisms influencing early ocean survival of Chinook salmon are currently poorly understood. In order to assess factors potentially driving interannual disparities within a Chinook population, otolith growth, residency times, and diet were compared between two collections of juvenile Chinook. Samples were taken from the surf zone at Bastendorff Beach, Oregon in the summers of 2006 and 2007. While the 2006 individuals are larger in size than those collected in 2007, the densities were smaller in 2006. The fish's otoliths were extracted and analyzed by mass spectrometer for variations in calcium, strontium, and barium concentrations. Significant increases in strontium, relative to calcium, mark the transition period as the fish move from fresh water to salt water; correspondingly, drops in barium levels indicate fish exiting fresh water systems. These data, coupled with microstructure analysis allowed for the estimation of residency times and growth rates in fresh and brackish/salt water. Stomach analyses revealed species consumed and their relative quantities. Stomach contents were identified to the lowest identifiable taxonomic level and weighed. The traits examined here may serve as a proxy for survival, as studying the condition of fish when they enter the ocean enhances our limited understanding of the factors affecting Chinook salmon survival.



## **Interannual Variation in Diet, Growth, and Residency of Juvenile Chinook Salmon**

Nicole Goehring, Whitman College

HMSC REU 2008

Mentor: Jessica Miller

### **Abstract**

The mechanisms influencing early ocean survival of Chinook salmon are currently poorly understood. In order to assess factors potentially driving interannual disparities within a Chinook population, otolith growth, residency times, and diet were compared between two collections of juvenile Chinook. Samples were taken from the surf zone at Bastendorff Beach, Oregon in the summers of 2006 and 2007. While the 2006 individuals are larger in size than those collected in 2007, the densities were smaller in 2006. The fish's otoliths were extracted and analyzed by mass spectrometer for variations in calcium, strontium, and barium concentrations. Significant increases in strontium, relative to calcium, mark the transition period as the fish move from fresh water to salt water; correspondingly, drops in barium levels indicate fish exiting fresh water systems. These data, coupled with microstructure analysis allowed for the estimation of residency times for 2007 juveniles. Growth rates in fresh and brackish/ocean water for juveniles of both years were moderate. Stomach analyses revealed a similar suit of prey for both years; however, stomach fullness was lower for 2007 juveniles. The traits examined here may serve as proxies for survival, as studying the condition of fish when they enter the ocean enhances our limited understanding of the factors affecting Chinook salmon survival.

### **Introduction**

Salmonid species display a wide variety of complex life histories, even within populations (Bisbal and McConnaha, 1998). While scientists still debate over the relative importance of conditions in freshwater versus saltwater for survival of anadromous fishes, it has become clear that the transition from freshwater to saltwater, as well as early ocean residence, are crucial stages of salmon life history. The estuary has been acknowledged as a nursery, providing a transition habitat for juvenile salmonids (Beck et al., 2001). Nurseries are often defined as areas in which a species occurs at higher densities, more successfully avoids predation, and/or grows at a faster rate than in other habitats. A nursery habitat, therefore, contributes disproportionately to the adult

populations. Of the Pacific salmon species, Chinook salmon, *Oncorhynchus tshawytscha*, especially utilize estuaries—this species is the most estuary dependent of the salmonid species.

The period of shallow ocean residency immediately following migration from the estuary has not been well studied in anadromous species. Like the estuary, the surf zone may provide another valuable nursery. A recent study in Mauritius found that the surf zone acts as a nursery, offering abundant feeding opportunities and reduced predation pressure (Sato et al., 2008). Generally, though, little recognition has been given to this early ocean phase in salmonid life history.

For spring-run Chinook, which in the Pacific Northwest out-migrate as yearlings, robust year-class size estimates can be made based on offshore sampling. Therefore, the interactions of physical and biological factors during early ocean residency appear to be crucial to determining yearly population survival for spring-run Chinook. Indicators for sub-yearling fall-run Chinook survival are less clear, warranting further investigation, especially because sub-yearlings enter the ocean younger and smaller than their yearling stream-type counterparts.

The ocean distribution of juvenile Chinook salmon 8-12 cm in length is not well understood. This size range has, however, been found in the surf zone (Marin Jarrin In Review). For this study, samples from the surf zone were taken by beach seine several times throughout the summers of 2006 and 2007 at Bastendorff Beach, Oregon (Fig. 1). Sub-yearling fall-run ocean-type Chinook juveniles were separated and preserved. The immediately apparent disparities in the samples of Chinook are that the 2007 juveniles were found in greater densities, but in smaller sizes than the 2006 juveniles.

Overall ocean conditions in both 2006 and 2007 were considered to have similar favorability for salmon survival (NOAA). These conditions were marked improvements from 2005, with 2007 considered better than 2006. Indicators used to rate overall environmental conditions included water temperatures, upwelling timing and duration, copepod biomass, and the time of spring transition.

Potential mechanisms leading to discrepancies in the fish's characteristics include one or a combination of many circumstances. Prey quality and availability can affect growth rate, as can foraging ability. Better foragers expend less energy on food acquisition. The abundance of predators can influence the survival of juveniles and the amount of energy spent on predator avoidance. River conditions may be favorable or unfavorable to migration downstream. The number, condition, and characteristics of hatchery fish can alter the diversity and average characteristics of the overall population. Carrying capacity effects may force fish out of freshwater or estuaries sooner (Bisbal and McConnaha, 1998; Reimers, 1973). These, as well as other factors, are capable of influencing early ocean survival. Generally, cooler summer ocean conditions due to upwelling are positively correlated with juvenile salmon abundance (Quinn, 263). However, the mechanisms leading to spatial variation in survival are not well understood.

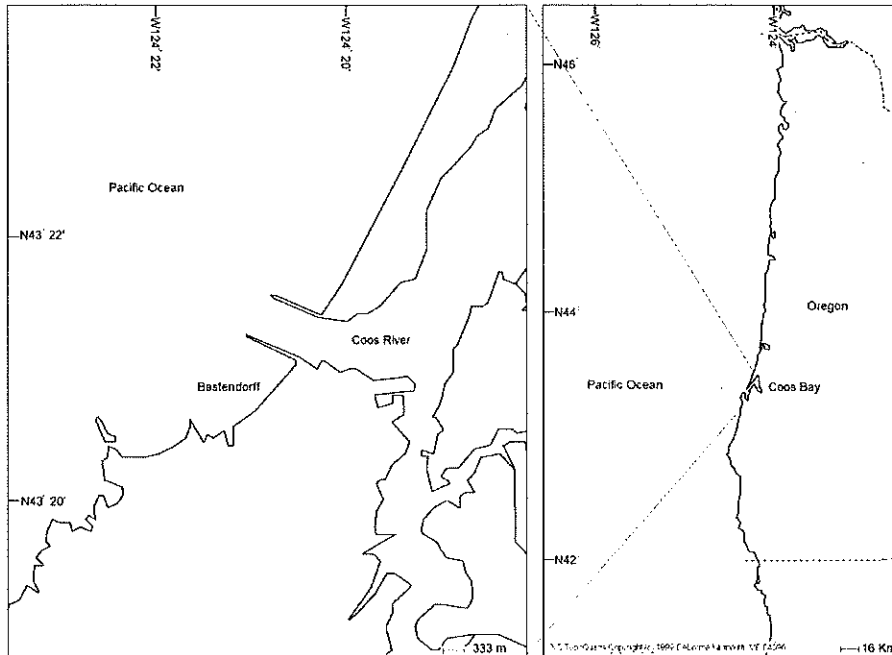
Inter-annual comparisons of the 2006 and 2007 juvenile Chinook salmon collected in the surf-zone were made in order to determine: (1) taxa composing the fish's diets; (2) quantities of taxa consumed; (3) rates of growth in brackish/ocean water; (4) brackish/ocean water residence times. Size, density, diet, growth, and residency may serve as indicators of fitness and survival later in life. A clearer understanding of factors

that regulate growth and abundance of juvenile salmon populations may lead to improvements in management and conservation efforts.

## **Methods**

### **-Collection**

Juvenile Chinook salmon were collected at Bastendorff Beach (43°35'N, 124°35'W), just south of the Coos Bay jetty in Charleston, OR (Fig. 1). This 3-km long dissipative sandy beach is bordered by a rock jetty to the north and a rocky shore to the south (Marin Jarrin In Review). Samples were taken at low tide on all days in 2007; in 2006, samples were collected at all tides, and multiples times per day. A beach seine (1.5m wide x 15 m long with 5.00 mm mesh) was carried into the surf zone to about 1 meter depths by three people, opened, and pulled back to the beach parallel to shore. Collected fish were anesthetized with MS-222 (150 mg/L seawater) and frozen. Standard lengths (SL) were measured to the nearest mm.



**Figure 1. Bastendorff Beach, site of collection for 2006 and 2007 juvenile Chinook salmon.**

### **-Diet Analysis**

Stomach analyses included both identifying and weighing the consumed contents of the dissected stomachs. The contents were identified to the lowest possible taxonomic level and enumerated. Each taxonomic category was weighed on an analytical scale. The scale used for 2006 salmon stomach contents only measured to the hundredths place, while that used for 2007 measured to the ten thousandths. The mass of the entire stomach contents as a ratio to body weight indicated fullness. Prey items were ranked using an Index of Relative Importance (IRI) (Brodeur and Pearcy 1990; Miller and Simenstad 1997; Pinkas et al. 1971). The equation used expressed IRI for each prey category as

$$IRI = F(N + G)$$

where F = frequency of occurrence (%) among entire sample;

N = numerical composition (%) of contents; and

G = gravimetric composition (%) of contents.

#### **-Growth and Residency**

Otoliths were extracted from fish from both sampling years with acid washed forceps, and cleaned ultrasonically for 15 minutes in NANOpure water (Barnstead International, Dubuque, IA, USA). Otoliths from the 2006 collection were embedded in resin (Spurr's low viscosity resin, Electron Microscopy Sciences, Hatfield, PA, USA). Using Tri-m-ite wetordry paper (250-2000 grit, 3M™, St Paul, MN, USA) and lapping paper (30-0.1 μm), thin sections were prepared. Both sides of the otolith were ground until the growth axis in the dorsal posterior region was exposed. Polished otoliths were then cleaned again ultrasonically.

#### **-Microchemistry**

Using a VG PQ ExCell inductively coupled plasma mass spectrometer and DUV193 excimer laser (New Wave Research, Fremont, CA, USA), prepared otoliths were then analyzed for elemental composition at Oregon State University's WM Keck Collaboratory for Plasma Spectrometry in Corvallis, OR. The laser ablated designated transects at a pulse rate of 15 Hz with a 40-μm ablation spot size. Transects were preferentially made through the dorsal-posterior quadrant of the otoliths, perpendicular to the growth axis. Otoliths from the 2006 collection only had ablations from the core to the edge. 2007 otoliths had ablations across the entire diameter. Background levels of  $^{43}\text{Ca}$ ,  $^{138}\text{Ba}$ , and  $^{86}\text{Sr}$ ,  $^{25}\text{Mg}$ ,  $^{55}\text{Mn}$ ,  $^{208}\text{Pb}$  were measured 50 s prior to otolith ablation.

$^{43}\text{Ca}$ , which acts as an internal standard, was used to normalize the count rates of each isotope. Concentrations were obtained for each element by converting normalized ion ratios with the following equation (Kent and Ungerer 2006, Miller 2007):



$$C_i^O/C_{Ca}^O = (C_i^N/C_{Ca}^N)/(I_{ij}^N/I_{Ca,k}^N) * (I_{ij}^O/I_{Ca,k}^O)$$

where  $C_i^O$  = concentration of element I in otolith O,  $C_{Ca}^O$  = concentration of internal standard (calcium) in otolith O;  $C_i^N/C_{Ca}^N$  = ratio of known concentration of element i to internal standard (Ca) in reference standard NIST 612 (N);  $I_{ij}^O/I_{Ca,k}^O$  = normalized ion yield for isotope j of element I and isotope k of internal standard element in NIST 612 (N);  $I_{ij}^N/I_{Ca,k}^N$  = normalized ion yield for isotope j of element I and isotope k of the internal standard (Ca) in otolith O. Concentrations are reported in mmol element i/mol Ca.

Graphs of Sr/Ca versus distance ( $\mu\text{m}$ ) were used to calculate distances to increments laid down at transition points in the fish's migration. Rises in Sr/Ca concentrations to above approximately 1.5 mmol/mol indicated transition into brackish ocean water (Miller Unpublished Data). When Sr/Ca data were not clearly indicative of transition points out of fresh water and into ocean water, Ba/Ca data was used. Ba/Ca follows the opposite pattern: levels drop steeply during the transition to ocean water.

Total otolith widths (TOW) at freshwater exit and at ocean entry were recorded. This measurement was not possible in the 2006 data due to limitations in clarity of the rings and chemical scans of only radii, rather than diameters of the otoliths. For 2007 otoliths with TOW measurements at the transition points, back-calculations were made to estimate size at freshwater exit and ocean entry using the following equation:

$$FL_{OE} = 0.0053(TOW_{OE}) + 1.2792$$

where  $FL_{OE}$  = fork length at ocean entrance in cm;  $TOW_{OE}$  = total otolith width at ocean entrance. This equation is the regression through the otolith width-fork length

relationship data for Coos Bay juvenile Chinook salmon only. The Titus equation was not used due to the offset relationship in Coos Bay Chinook salmon.

#### **-Microstructure**

ImagePro Plus<sup>®</sup> software was used to measure otoliths and individual increment widths. Otoliths were photographed at 200x-400x to visualize increments. Where visible in 2007 otoliths, increments were counted and measured from the edge to the check marking freshwater exit. Freshwater increments were also measured as far inward as discernable. From the counts of the number of increments in brackish water as well widths of the increments in all waters, growth rates and residence times were estimated in these two environments. For 2006 otoliths, only recent growth was measured.

#### **-Growth Rate Estimates**

Three different methodologies were employed to estimate growth rates. The first was based on cohort analyses. The slope of the linear regression between 2007 fish size and otolith width indicated the first growth rate estimate. Cohorts analysis, however, assumes no immigration or emigration. 2006 fish did not follow a linear pattern, and therefore no linear regression was added. The second estimate was based on back-calculations to size at ocean entry for individual fish from the 2007 collection. Subtracting fish size at ocean entry from fish size at capture and dividing by the number of otolith increments from the ocean entry check to the edge gave this growth rate. Third, recent ocean growth increments were measured on otoliths from 2006 and 2007, and averaged for each year. The number of increments measured on each otolith varied depending on clarity.

#### **-Environmental quality and variation**

Data on qualitative ocean conditions were taken from the NOAA Northwest Fisheries Science Center's Ocean Ecosystem indicators webpage. Temperature data were collected off of Valino Island in lower Coos Bay's South Slough.

## Results

### -Size and Density

From late July on, Chinook salmon caught in 2006 had greater standard lengths than those caught in 2007 (Fig 2). Growth appears to follow a shallow linear trend for 2007 fish. A linear trend is not obvious in the 2006 data, possibly largely due to low sample sizes for August sampling dates and lack of data prior to July 22, but there was an overall mean increase of 0.84 cm over the sampling period. For 2007, the difference in means between the first and last sample is 2.21 cm. While 2006 samples had greater lengths, densities were lower: 2006 densities ranged from 0.5 to 11.5 individuals per haul, contrasting 2007 densities ranging from 7.5 to 47 individuals per haul (Table 1).

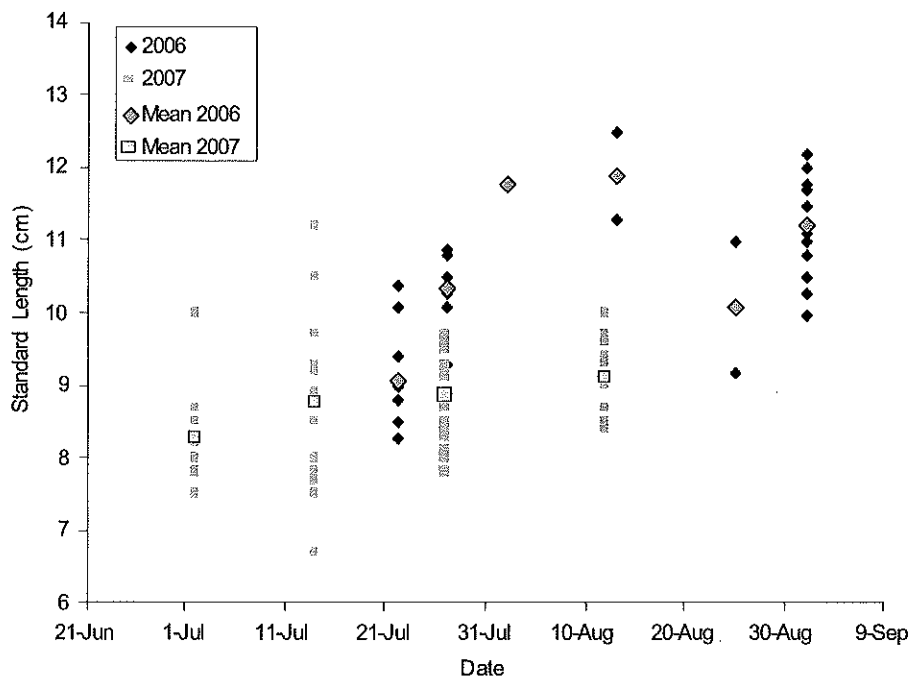


Figure 2. 2006 (n=48) and 2007 (n=75) individual and mean standard lengths of juvenile Chinook salmon by sampling date at Bastendorff Beach, Oregon. Black diamonds represent 2006 fish lengths; grey squares represent 2007 fish lengths. Means are shown as the larger diamonds for 2006 and as larger squares for 2007.

Table 1. Juvenile Chinook salmon catch for 2006 and 2007 sampling dates at Bastendorff Beach, Oregon.

<u>2006</u>	<u>Individuals/haul</u>	<u>2007</u>	<u>Individuals/haul</u>
22-Jul	6	2-Jul	26
22-Jul	0.5	14-Jul	47
27-Jul	0.5	31-Jul	29
27-Jul	1	14-Aug	7.5
27-Jul	4		
2-Aug	0.5		
13-Aug	2		
25-Aug	1		
1-Sep	11.5		

#### **-Diet Analysis**

Stomach analyses revealed 25 species represented in 2006 and 20 in 2007, for a total of 33 unique taxa overall. Twelve of the prey items were found both years. Over the course of the summer, 2006 juveniles shifted to a diet that included larger prey, primarily juvenile fish. The 2007 Chinook salmon did not follow this pattern—fish did not become an important part of their diet. Insects, a common item of estuarine diets, contributed more significantly to prey numbers early in 2007 than in 2006.

In 2006, stomachs were fuller than 2007 stomachs (mean FI=0.038±0.022 SD in 2006, mean FI = 0.020±0.013 SD in 2007). There was a significant difference in fullness (Welch Modified Two-Sample t-Test,  $t=4.65$ ,  $df=76.09$ ,  $p<0.001$ ). Over time, average 2007 stomach fullness decreased steadily, but 2006 fullness showed a large increase (Fig. 3). Plotting the fullness index for each fish against its standard length revealed a positive



**Figure 4. FI vs. SL (cm) for 2006 and 2007 juvenile Chinook salmon stomachs (2006 n=48, 2007 n=32).**

In 2007, 10 different prey items comprised 98% of the total stomach IRI, while in 2006 only 7 items composed 98% of the IRI (Table 2). Six of these 7 2006 items were also in the top 10 2007 prey items. *Atylus tridens* dominated the 2006 IRI. For 2007 stomachs, the spread is, relatively, more even: *Lophopanopeus bellus*, insects, and *Jassa shawi* make up the top three items in the IRI, respectively. When grouped more broadly (Fig. 6), a similar pattern remains in the spread of prey item dominance. 2006 stomachs contained mostly amphipods, followed by fish. 2007 stomachs have a more even spread between amphipods, brachyura, and insects as the greatest contributors in the IRI.

**Table 2. Prey items composing top 98% of stomach contents in 2006 and 2007 juvenile Chinook salmon, expressed as % of Index of Relative Importance (IRI) for each year.**

Prey Item	2006	2007
<i>Atylus tridens</i>	51.95	6.29
N. anchovy	15.03	
<i>Jassa shawi</i>	12.35	18.43
<i>Archaeomysis grebnitzkii</i>	10.43	1.80
<i>Dogielinotus loquax</i>	5.08	7.95
Insect	1.59	21.50
<i>Lophopanopeus bellus</i>	1.59	29.03
Caprellid sp.		6.45
<i>Excirolana chiltoni</i>		3.10
Unidentified fish		0.93
<i>Eohaustorius washingtonianus</i>		2.61

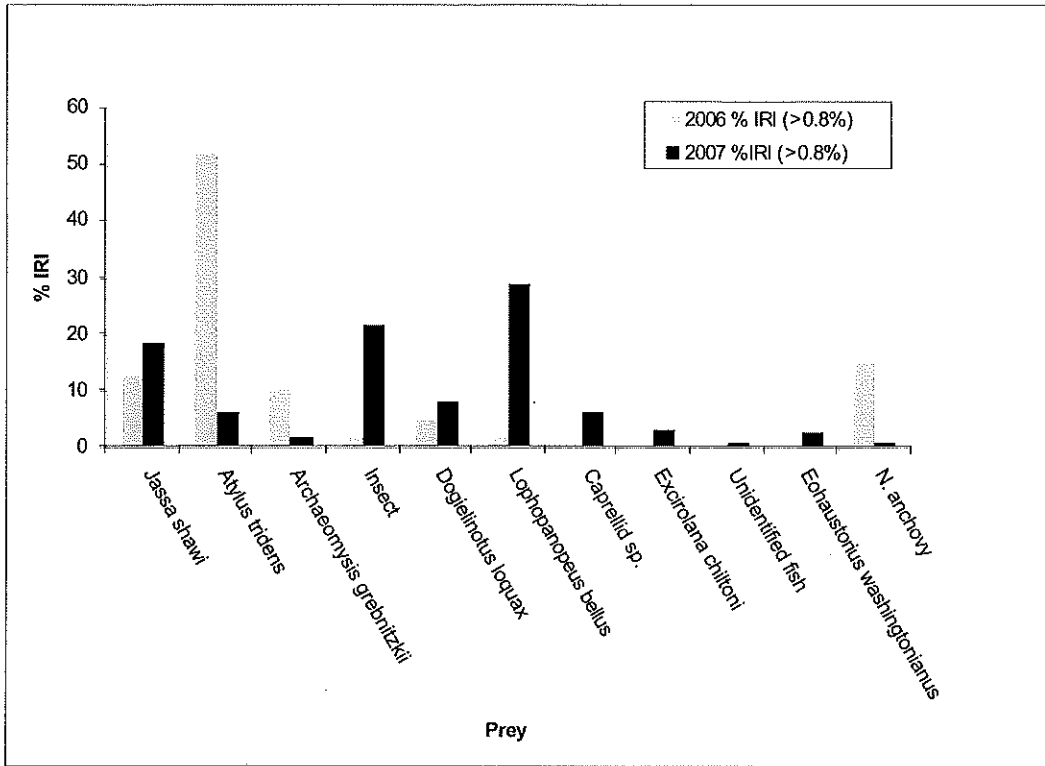


Figure 5. Percent IRI for prey items with a % IRI greater than 0.8% in 2006 and 2007 juvenile Chinook stomachs.

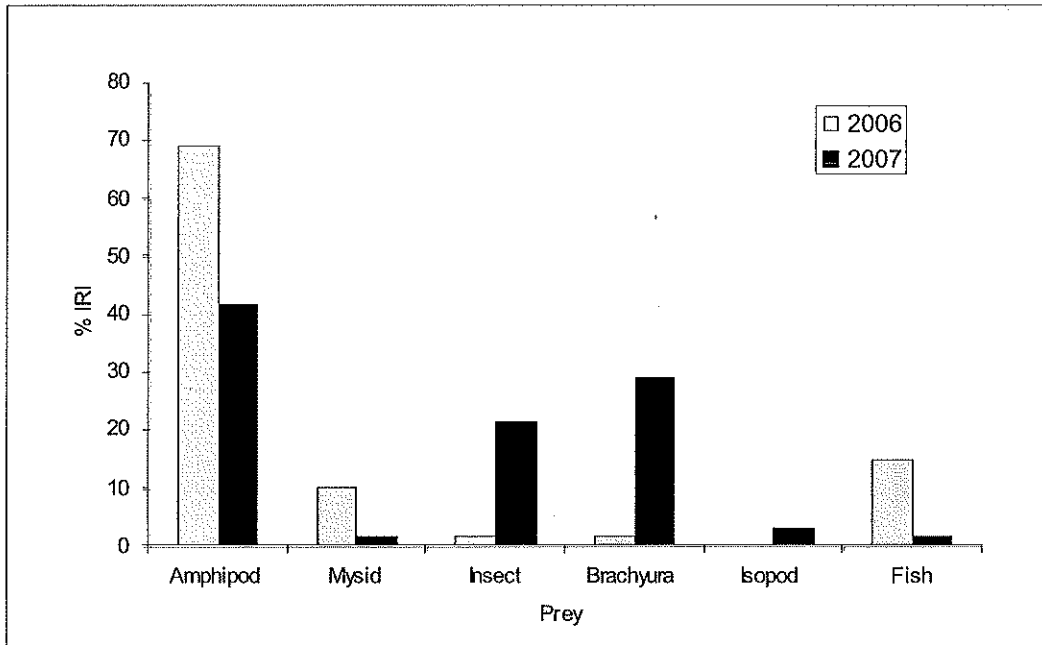


Figure 6. Percent IRI for broader taxonomic levels in 2006 and 2007 juvenile Chinook stomachs.

### -Growth and Residency

Based on measurements of recent growth increments, the 2006 average of recent brackish/ocean otolith growth increments was  $2.27 \mu\text{m} \pm 0.15 \text{ 2SE}$ . The 2007 average rose to  $2.64 \mu\text{m} \pm 0.16 \text{ 2SE}$ , but the difference between the years was not statistically significant. Recent growth rates show much overlap, although several individual juveniles in 2007 exceed the average rate (Figure 7). The growth rate values in  $\mu\text{m}$  translate to  $0.24 \text{ mm/day} \pm 0.01 \text{ 2SE}$  for 2006, and  $0.28 \text{ mm/day} \pm 0.02 \text{ 2SE}$  for 2007.



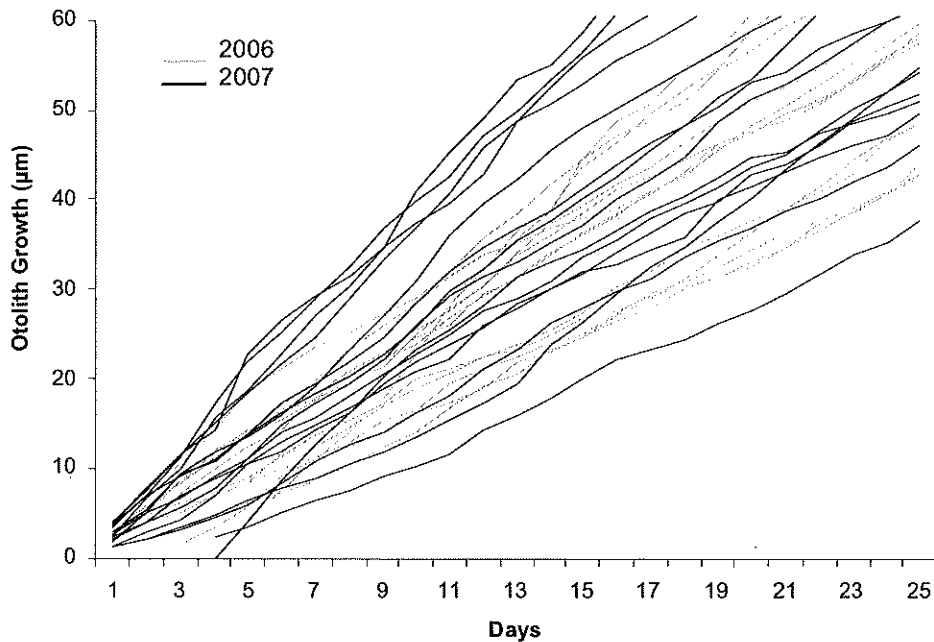


Figure 7. 2006 and 2007 juvenile Chinook salmon cumulative growth from 25 days before capture to day of capture, based on cumulative width of otolith increments. Day 25 is day of capture.

Brackish/ocean water residency times were calculated for 2007 juveniles only. At the time of capture, the fish were approximately 5 months old. Residence ranged widely from 8 to 62 days, with an average of 34 days  $\pm$  16 SD. Back-calculations from length at capture to length at ocean entry revealed that the Bastendorff Beach Chinook salmon do not have the same otolith width/fork length relationship as other Chinook salmon coast-wide (Fig. 7). The equation based on coast-wide data overestimated fork length at ocean entrance. A regression through the Bastendorff Beach samples ( $R^2 = 0.639$ ) provided a better estimate for back-calculated sizes. The growth rate calculated for 2007 juveniles in brackish/ocean water was 0.295 mm/day  $\pm$  0.239 SD. The growth rate based on a cohort analysis for 2007 is 0.19 mm/day (Fig. 8). The results of all three growth estimation

methods are summarized in Table 3. These values all fall within the range of moderate growth rates.

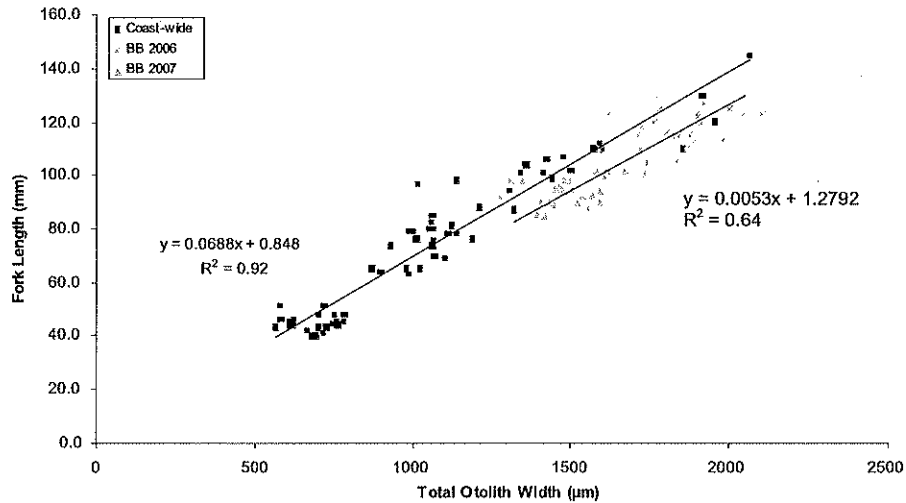


Figure 7. Fork length to total otolith width relationship for coast-wide Chinook salmon with regression ( $R^2=0.92$ ), and offset 2006 and 2007 juvenile Chinook ( $R^2=0.64$ )

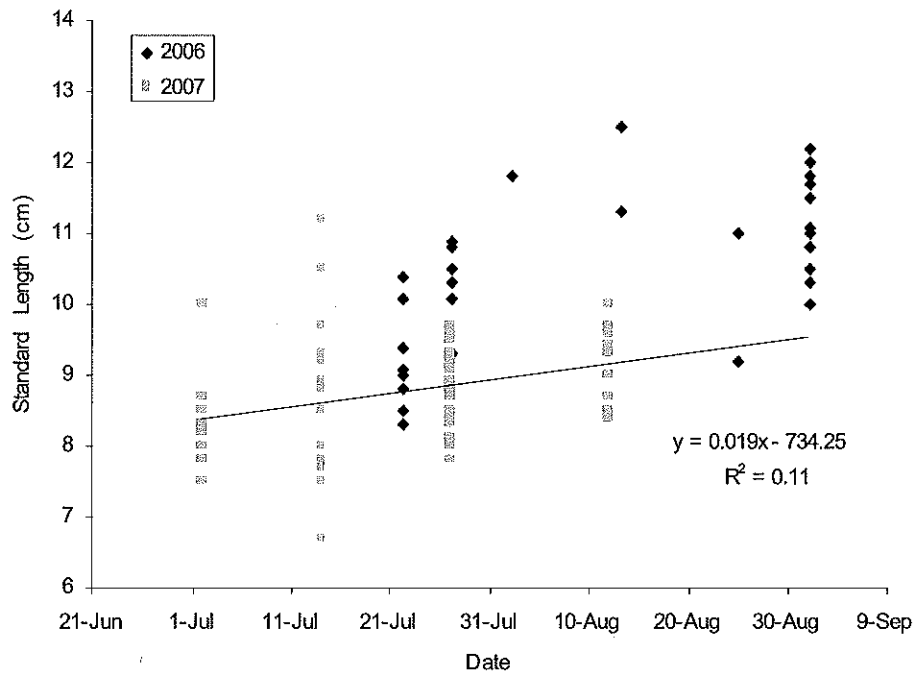


Figure 8. Slope of regression through 2007 (grey squares) juvenile Chinook salmon standard lengths by catch date represents a growth rate estimate.

**Table 3. Summary of growth rate estimates for juvenile Chinook salmon caught at Bastendorff Beach in 2006 and 2007. The slope of the regression through the cohort data gave the “cohort” estimate; the difference between back-calculated size at ocean entry and final size, divided by the number of increments added during brackish/ocean growth gave the “back-calculation” estimate; the widths of increments added most recently in the brackish/ocean water gave the “microstructure” estimate.**

	2006 (mm/day)	2007 (mm/day)
<b>Cohort</b>		<b>0.19</b>
<b>Back-calculation</b>		<b>0.30</b>
<b>Microstructure</b>	<b>0.24</b>	<b>0.28</b>

### **Discussion**

Compared to 2006 juvenile Chinook, juveniles caught in 2007 appear to have slightly better (though not significantly higher) growth and were found in greater densities; they entered the ocean at smaller sizes and earlier in the year. Despite their smaller size, the 2007 fish’s superior growth would correspond to the suggested overall better ocean conditions for that year. Trends in the stomach fullness indices do not support growth trends, with average fullness significantly less in 2007 than in 2006. However, looking more closely at the indicators of overall ocean conditions, it was found that water temperatures were warmer in 2007, exceeding even 20 degrees Celsius in the lower estuary. Warmer temperature would increase metabolic demand. More energy attained from food would be utilized for metabolic processes, and less would be available to go toward growth. The fish would then require more food and could process prey more quickly through its system. High temperatures may have spurred juveniles to exit the estuary earlier in 2007.

The larger 2006 juveniles ate significant amounts of fish, especially later in the sampling period. This may be an ontogenetic change—2006 juveniles may not have

reached a size at which they could consume such large prey. If growth was comparable between the two groups, the 2007 fish may simply have left the estuary earlier, and therefore at a smaller size, possibly spurred by temperature cues. Despite similarities in growth rates, size may play a much more influential role in ultimate survival.

The factors that drove density differences is unclear. Spawner return estimates (4250 in 2005; 3009 in 2006) do not suggest expectations for very different numbers of offspring between the years. Freshwater conditions, which were not examined in this study, may have played a significant role in determining larval and juvenile survival for one or both years.

Chinook salmon were caught in the surf zone over a span of 41 days both in 2006 and 2007. This suggests that the population was occupying the surf zone for at least this amount of time. However, since no sampling was done in June and early July 2007, the period of occupancy may have been much longer in 2007.

The data needed to further the conclusions of this study would include obtaining brackish/ocean residence times for 2006 juveniles, as well as completing 2007 community structure analysis so that prey availability can be analyzed.

The data that has been gathered so far supports that juvenile Chinook salmon utilize the surf-zone consistently during the summer, despite large variations in densities. Most major prey items were consumed year to year. Despite differences in size between the 2006 and 2007 samples, surf-zone growth rates are moderate. The factors leading juvenile Chinook salmon into the surf-zone appear to be leading the fish into a habitat that provides the resources to at least sustain growth. Growth at this time may be crucial for survival in the open ocean.

## References

- Beck, M. et al., 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *BioScience* 51, 9.
- Bisbal, G.A., McConnaha, W.E., 1998. Consideration of ocean conditions in the management of salmon. *Canadian Journal of Fisheries and Aquatic Sciences* 55, 2178-2186.
- Brodeur, R.D., Pearcy, W.G., 1990. Trophic reations of jvenile Pacific samon off the Oregon and Washington coast. *Fisheries Bulletin* 88: 617-636.
- Healy, M.C., 1991. Life History of Chinook Salmon. In: Groot, C., Margolis, L.s (Eds.), *Pacific Salmon Life Histories*. UCB Press, Vancouver.
- Kent, A.J.R., Ungerr, C.A., 2006. Analysis of light lithophile elements (Li, Be, B) by laser ablation ICP-MS: comparison between magnetic sector and quadrupole ICP-MS. *Am Mineral* 91. 1401-1411.
- Marin Jarrin, J.R., A.L. Shanks, M.A. Banks, In Review. New habitat of sub-yearling Chinook salmon discovered: the surf-zone of sandy beaches.
- Miller, J.A., 2007. Scales of variation in otolith elemental chemistry of juvenile staghorn sculpin (*Leptocotus armatus*) in three Pacific Northwest estuaries. *Marine Biology* 151: 483-494.
- Miller, J.A., Simenstad, C.A., 1997. A comparative assessment of a natural and created estuarine slough as rearing habitat for juvenile chinook and coho salmon. *Estuaries* 20, 792-806.
- NOAA Northwest Fisheries Science Center. Ocean Ecosystem Indicators of Salmon Marine Survival in the Northern California Current. Available online from <http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm>.
- Pinkas, L., M.S. Oliphant, and I.L.K. Iverson, 1971. Food habits of albacore, bluefin tune, and bonito in California waters. *California Fish and Game Fisheries Bulletin* 152, 1-105.
- Quinn, T.P., 2005. *The Behavior and Ecology of Pacific Salmon and Trout*. University Press, Seattle.
- Reimers, P.E. 1973. The length of residence of juvenile fall Chinook salmon in Sixes River, Oregon. *Oregon Fisheries Commission Res. Report* 4:1-43.

Sato, N., Asahida, T., Terashima, H., Hurbungs, M.D., Ida, H., 2008. Species composition and dynamics of larval and juvenile fishes in the surf zone of Mauritius. *Environmental Biology of Fishes* 81, 229-238.