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(Oncorhynchus keta) in Netarts Bay, Oregon

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Estuarine residence and growth of juvenile chum salmon (*Oncorhynchus keta*) from Netarts Bay, Oregon were estimated from daily-formed growth increments of sagittal otoliths which are distinguishable from accretion patterns formed during freshwater residence. Estuarine residence time was inversely related to the average size at which juvenile chum salmon entered Netarts Bay. Among fin-clipped, hatchery fish, large individuals disappeared from Netarts Bay more rapidly than smaller members of the same release group during the first 9 days of estuarine residence. This selective removal was not evident among creek-reared chum which were smaller than the fin-clipped fish. Size-related emigration explains this variation in residence time.

Growth rates were estimated from back-calculations of fork length from otoliths. The growth rates of juvenile chum salmon in Netarts Bay (0.6 mm FL/d; 3.5% bw/d) were lower than growth rates in other estuaries where harpacticoid copepods were a major prey item. Juvenile chum salmon that entered the estuary early in the spring grew faster than those which entered later in the year, possibly because of lower water temperature and lower density of small (50 mm FL) chum during the early period. High water temperature reduced apparent growth rates by slowing growth and causing emigration of larger, faster-growing individuals.

Residence and Growth of Juvenile Chum Salmon
(Oncorhynchus keta) in Netarts Bay, Oregon

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Residence and Growth of Juvenile Chum Salmon (Oncorhynchus keta) in Netarts Bay, Oregon

INTRODUCTION

Year class strength of Pacific salmon (Oncorhynchus spp.) may be determined during their early marine life (Parker 1968; Bax 1983; Fisher and Pearcy 1988) thus underscoring the importance of understanding how these fish initially utilize the marine environment. In particular, estuaries are considered to be important nursery areas for chum salmon (Oncorhynchus keta) which depend more on estuaries as nurseries than any other species of Pacific salmon except chinook salmon (Oncorhynchus tshawytscha) (Healey 1982b).

Outmigrating juvenile chum salmon may experience high mortality rates during estuarine residence but the survivors may be well prepared for survival in the ocean. Mortality rates during the first 40 days of marine residence vary but may be as high as 40% per day (Parker 1968; Bax 1983). A portion of this mortality is attributed to size-selective predation (Parker 1971; Healey 1982a; Hargreaves and LeBrasseur 1985, 1986). Although mortalities may be high, survivors may benefit from brackish, estuarine water enabling them to acclimate to sea water with less physiological stress (Mason 1974; Iwata 1980; Iwata and Komatsu 1984; Koshiishi 1986a,b). Estuaries also provide prey organisms in quantities sufficient to enable rapid growth of juvenile chum salmon (Simenstad and Salo 1980). Rapid growth rates, as high as 6.7% body weight per day (Salo et al. 1980), may substantially reduce the vulnerability of these fish to predation (Parker 1968).

Residence times and growth rates are good indicators of the degree to which juvenile chum salmon utilize estuaries as nurseries, and these indicators can be studied by analyzing otolith microstructure. Because otoliths provide

age and growth data over very short periods of time, they are a useful method to study juvenile chum which reside in estuaries for only a matter of days or weeks (Healey 1979; Levy and Northcote 1982; Pearcy et al. 1989). Otoliths form visible daily growth increments and otolith size is positively correlated with fish size (Wilson and Larkin 1980, 1982; Marshall and Parker 1982; Neilson and Geen 1982, 1984; Volk et al. 1984; Campana and Neilson 1985; Neilson et al. 1985; Bradford and Geen 1987; West and Larkin 1987). Additionally, otoliths are thought to indicate the transition from fresh water to marine habitats (Simenstad et al. 1980; Neilson et al. 1985; Neilson and Geen 1986; Volk et al. unpublished manuscript).

Otoliths were used to study the estuarine residence and growth of juvenile chum in Netarts Bay, Oregon. Objectives of this study were to determine if residence time and growth rate varied with fish size, date of estuarine entrance or time of year. However, before these objectives could be achieved, otoliths had to meet three criteria. They had to: 1) indicate estuarine entrance, 2) exhibit growth increments formed at a constant rate, and 3) be positively correlated with fish size. Part of this study involved a test of these three requirements.

METHODS AND MATERIALS

Field

Field sampling was conducted in Netarts Bay, a coastal estuary located on the northern Oregon coast (Figure 1). The bay has a surface area of 10.1 km² at mean high water. About 12% of the bay is subtidal (Kreag 1979). The basin is composed of fine-to-medium sands and silts (Glanzman et al. 1971; Stout 1976) with eelgrass beds found in both intertidal and subtidal areas. Several small creeks empty into Netarts Bay; of these, Whiskey Creek is the largest with an average annual flow rate of 28.3 liters/sec (Glanzman et al. 1971).

Whiskey and Jackson Creeks support chum salmon runs each producing about 15,000 downstream migrating fry (Pearcy et al. 1989). Juvenile chum salmon outmigrate in the spring from February to May at an average size of 40-41 mm fork length (FL; Pearcy et al. 1989). Additionally, chum salmon reared at Oregon State University's Whiskey Creek Experimental Hatchery (WCH) and off-site at Oregon Aqua Foods Inc.'s (OAF) facility in Springfield, Oregon, were released at night into the mouth of Whiskey Creek during 1984 and 1986 (Table 1). Hatchery production contributed more than 90% of the juvenile chum entering Netarts Bay in 1984 and 1986 when about 860,000 and 653,000 individuals, respectively, were released into Whiskey Creek. Some of these hatchery fish were marked with fin clips (Table 1; Pearcy et al. 1989).

Juvenile chum salmon were collected as groups of fish entered and migrated through Netarts Bay (Pearcy et al. 1989). Samples of immigrants were used to determine their size when they entered Netarts Bay and to provide otoliths. Downstream migrants were collected with trap nets placed in Whiskey and Jackson Creeks just upstream of the mouth and hatchery fish were dip-netted from the hatchery. Fish were

collected in Netarts Bay using a beach seine.

Only juvenile chum captured in Netarts Bay that could be positively identified as belonging to one of several specific immigrant groups were used since these groups entered the bay at different sizes and times. During 1984, two groups of fish released on April 16 could be identified to release group by fin-clips. Size estimates for these groups were from recaptures of 22 and 26 fin-clipped WCH and OAF fish, respectively, on April 17, the day following release. Otoliths were collected from these two groups of fin-clipped fish caught in Netarts Bay from April 24 to May 15 (Table 2). However, 25% of all recaptures of these fish occurred 1 to 13 days before the recorded release (Table 18 in Wilson and Pearcy 1985a), indicating that many fish escaped into the bay prior to the release on April 16.

Fish representing three groups of 1986 immigrants were identified among all those captured in Netarts Bay during 1986. Creek-reared fish could be identified because they were captured in the bay prior to any hatchery releases. Immigrating creek-reared fish were measured from March 10 to April 24 which encompassed the period of downstream migration. As in 1984, two groups of hatchery fish were identified by fin-clips. To estimate their size at release (immigration) individuals were dip-netted from the raceway just prior to release (see Table 1 for dates). Individuals representing these three groups were collected for their otoliths from Netarts Bay throughout their occurrence in the spring of 1986 (Table 2).

Otoliths were extracted from 505 juvenile chum salmon collected during 1984 and 1986 from fresh water (creeks and hatchery) and Netarts Bay (Table 2). The paucity of otoliths made it impossible to analyze the 1984 data as thoroughly as the 1986 data. During 1984 none of the creek-reared chum collected from Netarts Bay were preserved in ethanol so as to protect their otoliths.

Laboratory

Preparation of otoliths prior to viewing their microstructural features generally followed the procedure of Neilson and Geen (1982). Both sagittal otoliths were extracted from each fish. Otoliths were cleaned, dried, and then mounted, medial side down, onto a microscope slide using the histological fixative Histoclad. Next, the distal surface of each otolith was ground with 600 grit silicon carbide grinding paper. A jig was used to hold the slide and grinding surface stable. During grinding each otolith was periodically viewed through a compound microscope with transmitted light to ensure a clear view of the otolith center (primordia) and the marine increments in the posterior-dorsal region (Figure 2). Measurements were made in the posterior-dorsal region of the otolith where increment accretion was clearest and most uniform.

Otolith measurements and marine increment counts were made with a transmitted-light microscope equipped with an ocular micrometer. Two distances were each measured twice at 312.5X magnification in the mid-dorsal region along a radius extending from a postero-dorsal primordium in the nucleus to the edge of the otolith. The radial line was placed so as to intersect all increments at 90 degrees thereby simplifying the measurement of radial distances across growth increments (Figure 2). On some otoliths, slight variation in the placement of this transect was possible and this did not affect the measurements taken from several otoliths where the magnitude of this variation was examined. The first measurement, the otolith radius at capture, was the distance from the primordium to the otolith margin. The second measurement, the otolith radius at estuarine entrance, was the radial distance out to the first marine increment. The total number of marine increments were also counted. Straying from the radial transect was

sometimes necessary when counting marine increments to avoid unclear areas.

Otoliths with at least 5 marine increments (mean of both counts) were examined at 1250X and again at 312.5X magnification. At 1250X magnification, groups of 5 marine increments ($1^{\text{st}}-6^{\text{th}}$, $6^{\text{th}}-11^{\text{th}}$, $11^{\text{th}}-16^{\text{th}}$, and so on) were measured along the previously described radial line (Figure 2 and 3). From these measurements, a series of otolith radii at every 5^{th} increment during estuarine residence was constructed for each fish.

The re-examination at 312.5X was necessary to verify methodological consistency in measuring otoliths initially at 312.5X, and later, at 1250X since measurements from these two examinations were added together. Also, this ensured that a FL-otolith radius relationship with the most points could be used for all back-calculations. First and second averages were not significantly different for each radial measurement and the marine increment count (paired t-test, $P>0.05$: radius at capture ($n=162$), radius at entrance ($n=162$), marine increment count ($n=169$)).

Specific procedures were followed during otolith reading. Left otoliths were used unless unreadable, in which case, the right one was examined. However, otolith radii and marine increment counts made at 312.5x magnification on right otoliths did not significantly differ from those made on the left otoliths of the same fish (paired t-test, $P>0.05$: radius at capture ($n=57$), radius at entrance ($n=38$), marine increment count ($n=44$)). Chum collected from fresh water were separated from bay-caught chum and no attempt was made to detect marine increments on the former. Otoliths from bay-caught individuals were grouped according to fin-clips and read in a random order within each group. Finally, at each magnification, all otoliths were read once before any otolith was read a second time. Then these two readings were averaged to reduce the

random error associated with each measurement.

Otolith Criteria

To determine if otoliths from estuarine-resident juvenile chum salmon exhibited daily increments, the relationship between the number of marine increments and days of estuarine residence was examined for each of three groups of fin-clipped fish: 1984 WCH and OAF (pooled (n=39) due to low numbers), 1986 WCH (n=70), and 1986 OAF (n=52). In calculating the days of estuarine residence, the day of release or recapture was not counted if chum were in the estuary less than 12 hours on the day of question.

Geometric mean regression was used to describe the relationship between otolith radius at capture and fork length. This type of regression was appropriate since variability in the position of each point was associated with both axes (Ricker 1973). Otolith radii at capture and fork length data from all fish listed in table 2, with the exception of 49 points, were pooled (n=456) for this regression. Deletion of 18 points, those with radii-at-capture of 207 microns or less, coupled with the absence of outmigrants less than 35 mm FL approximates truncation of the data perpendicular to the major axis thus, the data are suitable for applying geometric mean regression (Ricker 1973). Thirty-one other otoliths were omitted because the radius at capture could not be measured.

The intercept from the geometric mean regression was used to back-calculate fork lengths from otolith radial measurements using Fraser and Lee's equation as described by Ricker (1971):

$$L_p = (R_p/R_c) * (L_c - a) + a$$

where,

L_p = chum FL at some previous otolith radius;
 R_p = previous otolith radius;
 L_c = chum FL at capture;
 R_c = otolith radius at capture and;

a = intercept from geometric mean regression.

Fork Length and Residence Time

Mean residence times in Netarts Bay were compared among groups having, on average, different-sized fish at estuarine entrance. An algorithm similar to that used by Healey (1979) was used to calculate a weighted mean residence time (RT_w), in days, each group of fin-clipped or creek-reared juvenile chum salmon resided in Netarts Bay:

$$RT_w = \{ \sum [(n_{ij}/n_i) * (CPUE_i) * (MI_{ij})] \} / \sum (CPUE_i)$$

where,

i = an interval of one or two days when samples were collected from Netarts Bay;

CPUE = number of fish per beach seine set for sampling interval i;

MI = marine increment count;

j = one of usually several marine increment counts for the sampling interval i;

n = number of otoliths (= fish).

To detect if size-related variations in residence time exist within groups of juvenile chum salmon in Netarts Bay, fish captured within the bay were examined to see if they were a characteristic size fraction of a group when it immigrated into the bay. The Fraser-Lee method was used to convert the otolith radii measured to the beginning of the first marine increment to FL, thus providing an estimate of FL-at-entrance for each bay-caught chum. The average of these back-calculated FL-at-entrance was calculated: first, for each known group of bay-caught juvenile chum (see Table 2), and second, within groups, by days of residence (0-9 days, 10-19 days, 20 or more days) as inferred from marine increment counts.

Growth Rate

A growth rate, expressed as an absolute rate in millimeters fork length per day (mm FL/day), for each juvenile chum salmon inhabiting Netarts Bay was estimated for each five day period of residence in the bay. For each

fish, the otolith radius at estuarine entrance plus the radii measured after each group of five marine increments were converted to FL using the Fraser-Lee method.

Differences between these consecutive estimates of FL were divided by five, the estimated number of days between estimates. Analysis of variance was used to compare growth rates among known groups of bay-caught fish (see Table 2). An absolute rate was used rather than a specific rate to avoid forcing an inverse relationship between growth rate and fish size (Dr. R. Methot pers. comm.).

The effect of fork length, date, and time spent in the estuary on the growth rate of juvenile chum in Netarts Bay was described using multiple regression. Each covariate was included in the model if its coefficient of partial determination (partial r^2) was significantly different from zero ($\alpha = 0.05$). Partial r^2 indicates the influence of one variable on growth rate after accounting for the influence of other variables and is particularly useful when, as is the case here, multicollinearity exists between the covariates (Table 3; Neter et al. 1983). Because each data point was from five-day intervals of residence time, one fish could contribute more than one point if its otolith had at least 10 marine increments. Fork length and date of estuarine residence were estimated as the median value over the 5-day growth interval, and residence time as the number of marine increments. The 1984 data were kept separate from the 1986 data. The 1984 WCH and OAF groups were pooled since their release times were equal, their mean size at release was similar, and each group had low numbers. Data from each of the 1986 groups were kept separate because there was no overlap in residence time between creek-reared and fin-clipped fish and the two groups of fin-clipped fish differed in size and perhaps health (Pearcy et al. 1989). Prior to release, the WCH fish experienced high mortalities caused by an unidentified affliction (personal observation).

Time series of mean catch of juvenile chum salmon per beach seine set and surface water temperature were visually compared with growth rate time series to determine if either of these factors was substantially related to day-to-day variations in growth rates. For plotting, the estimated growth rates for each 5 day period were averaged by median date and then these averages were plotted on median date. LOWESS, a scatterplot smoothing algorithm was used to enhance the visibility of trends in the growth rate data (Cleveland 1979; Chambers et al. 1983).

RESULTS

Otolith Criteria

Otoliths provide valuable information on the estuarine residence and growth of juvenile chum salmon if they 1) indicate estuarine entrance, 2) exhibit growth increments formed at a constant rate, and 3) their radius is positively related to fish size. Estuarine entrance was indicated by a distinct change in appearance of otolith growth increments. The marine increments were more translucent and the lighter part assumed a greater proportion of each increment, making them more distinct than growth increments formed during freshwater residence (Figure 4). Also, the crystalline structure (Campana and Neilson 1985) of marine increments was finer following estuarine entrance relative to previously formed otolith material.

Counts of marine increments were well correlated with the number of days between release and recapture of fin-clipped chum salmon from three release groups ($r^2 = 0.88$ to 0.90 , Figure 5, Table 4). The slope of each regression was close to, but significantly less than one for all but the 1986 WCH group (t -test, $0.01 < P < 0.05$, $n=70$).

Despite the fact that the slope was significantly less than one, a 1:1 correlation between marine increments and days of estuarine residence was assumed for all groups after considering several problems with the data. First, marine increment counts exceed the days of residence for two fin-clipped 1984 fish by 7 and 8 marine increments (see ? in Figure 5) strongly suggesting these fish were among those which escaped from the hatchery prior to the scheduled release (Pearcy et al. 1989). Deleting these from the 1984 data gives a slope (0.920) which is not significantly different from one (t -test, $0.05 < P < 0.10$). Second, variability of increment count for the two longest-resident 1986 OAF chum (see ? in Figure 5) caused by reading error (\pm

1.5 marine increment) affects the outcome of the slope test for this group. Due to the paucity of long-resident fish of this group and the small difference of the slope from 1 (11%), the slope was assumed to be 1.

Finally, the third criterion requisite for using otoliths to achieve the objectives of this study was met by the existence of a positive, linear relationship between fork length and total otolith radius ($r^2 = 0.79$, $P < 0.001$, $n = 456$, Figure 6). With these three criteria satisfied, otoliths appear to be suitable tools to study the estuarine residence and growth of juvenile chum salmon.

Fork Length and Residence Time

Weighted mean residence times were inversely related to mean FL-at-entrance among the three groups of juvenile chum salmon inhabiting Netarts Bay during 1986 (Table 5). The small-sized, creek-reared fish (41 mm mean FL) had the longest residence time (12.1 days) and the large-sized, fin-clipped OAF fish (64 mm mean FL) had the shortest residence time (2.5 days). The fin-clipped WCH chum were intermediate in both size (50 mm mean FL) and residence time (5.4 days). However, the two groups of 1984 fin-clipped fish had residence times of about 12 days, much higher than expected based on the 1986 relationship between mean FL at estuarine entrance and residence time. These higher than expected residence times result from the increase in mean CPUE about 15 to 25 days after their release into Netarts Bay.

Mean back-calculated FL-at-entrance was smaller than the mean FL-at-entrance determined from direct sampling of each group of fin-clipped juvenile chum salmon, and these differences were significant. However, this difference was not significant for the group of creek-reared fish. Differences between estimates of mean size at estuary entrance and known mean length at release or capture in

creeks ranged from 1.8 to 4.1 mm FL for fin-clipped fish but were only 0.5 mm FL for creek-reared fish (Table 6; Figure 7). Thus, within groups of fin-clipped chum, it appears that individuals which were small when entering Netarts Bay resided in the bay longer than did larger-sized members of the same group producing a reduced average back-calculated length at estuary entrance.

For the 1986 groups of fish, there were no significant differences in the mean back-calculated length at estuary entrance among fish caught 0-9, 10-19, and >19 days after estuary entrance (Table 7). This suggests that within groups, disappearance rates were faster for larger-sized fish only during the first 9 days.

Several outlying back-calculations of FL-at-entrance, evident in Figure 8, were not excluded from the statistical analysis. Although erroneous back-calculations may have been responsible for these outliers, reasonable explanations exist that justify their inclusion in the analysis. First, within groups of fin-clipped fish, the large and small outliers were not so extreme that fish of that size could not have been in the release group. Second, the sampling of creek-reared fish from the creeks was done such that it would have been possible for some individuals to rear in the reaches below the sampling site prior to entering Netarts Bay. Mason (1974) observed juvenile chum salmon to rear in the estuarial reaches of Lymn Creek on Vancouver Island, British Columbia, to as large as 70 mm FL. Juvenile salmonids were observed in these lower reaches of Whiskey Creek during 1986 but, unfortunately, were not sampled.

Growth Rate

Among the 5 groups of juvenile chum salmon mean growth rates ranged from 0.55 to 0.68 mm FL/day and were significantly different (ANOVA, $P < 0.001$; Table 8). Average growth rates of the 1984 fin-clipped WCH (0.68 mm FL/day)

and 1986 creek-reared fish (0.64 mm FL/day) were faster and significantly different from the 1986 OAF (0.58 mm FL/day) and the 1986 WCH (0.55 mm FL/day) fin-clipped fish. The 1984 fin-clipped OAF chum had an intermediate average growth rate (0.62 mm FL/day) that differed significantly only from that of the slow growing 1986 fin-clipped WCH group and the fast growing 1986 fin-clipped WCH fish.

For three of the four groups of estuarine resident chum salmon, only 7 to 22 percent of the variability in growth rate was explained by the duration of residence time and/or fork length (Table 9). Within the fourth group, 1986 fin-clipped OAF, variations in growth rate were not significantly associated with any of the covariates, but the sample size was small (F-test, $P > 0.05$; $n = 21$). For the three significant regressions, the regression coefficient for the duration of estuarine residence was negative implying that fish new to the estuary grew faster than those which had been there longer (Table 9). Only among creek-reared fish was FL significantly correlated with growth rate suggesting that big individuals grew fastest (Table 9). Variability in the time of entrance into Netarts Bay was not significantly associated with growth rate variability among any of the groups of juvenile chum.

The 1984 growth rates of juvenile chum declined slightly for about 15 days following release, mean surface water temperatures were fairly steady at 13°C and never exceeded 15°C during the residence of fin-clipped chum (Figure 9). During 1986, the growth rates of creek-reared fish remained fairly uniform during some small fluctuations in mean surface water temperature, but the growth rates of fin-clipped fish decreased when mean surface water temperature steadily increased to more than 15°C after May 18 (Figure 9 and 10). Thus, warming of surface water above 14°C in Netarts Bay during late spring was associated with reduced growth of juvenile chum salmon.

Reductions in apparent growth rate of fin-clipped juvenile chum salmon during the late spring of 1986 resulted from both slowed individual growth and selective loss of individuals from Netarts Bay. Growth rates were reconstructed by back-calculation for two groups of fish: 1) those collected in Netarts Bay prior to May 18 ("Early" in Figure 10), and 2) those collected in Netarts Bay after May 18 ("Late" in Figure 10). Reconstructed growth rates for the May 1 to May 18 period for fin-clipped WCH juvenile chum salmon collected from Netarts Bay after May 18 ("Late" group) were similar to the growth rates of WCH fish which were collected from the bay prior to May 18 ("Early" in Figure 10). Following May 18, when bay water warmed rapidly, the average growth rates of these late resident WCH fish declined. The average growth rates of late resident, fin-clipped OAF fish also slowed following May 18. Unlike the WCH group, the average growth rates of the early resident fin-clipped OAF fish from May 13 to May 18 were higher than the average growth rates of the late resident OAF fish for this same time period (Figure 10). Furthermore, the average FL of these late resident fish were less than the average FL of the "Early" resident fin-clipped OAF fish (Figure 11). Thus, concurrent with warming in the bay after May 18, the large, fast growing fin-clipped OAF fish disappeared before the smaller, slower-growing, longer-resident individuals.

Growth rates of juvenile chum salmon in Netarts Bay during 1984 were not reduced during periods of high chum abundance following hatchery releases. During 1984, the mean catch of juvenile chum peaked on April 17 (mean, 157 fish/set) and generally declined for the remainder of the season. However, growth rates did not increase with the decline in chum density, instead they declined following release and eventually levelled off (Figure 9).

During 1986, the growth rates of creek-reared fish were

higher than fin-clipped groups inhabiting the bay later during periods of high chum density (Figure 9). Following the first release of hatchery fish, chum density peaked on May 1 (mean, 280 fish/set) and declined rapidly but was never less than pre-release densities. Despite declining abundance, the growth rates of fin-clipped WCH fish did not change substantially and they were not affected by the second hatchery release when the OAF fish were liberated. Although the mean number of chum caught per beach seine set did not increase following release of the OAF fish on May 11, growth rates of these fish did increase for a short period following their release (Figure 9). Thus, the very low chum densities early during 1986 enabled creek-reared fish to grow rapidly relative to the growth rates of fin-clipped fish inhabiting Netarts Bay later when density of small juvenile chum was higher.

DISCUSSION

Unlike in other studies of the estuarine residence or growth of juvenile salmon (Neilson and Geen 1986; Neilson et al. 1985; Volk et al. 1984; Simenstad et al. 1980), I did not distinguish the daily otolith growth increments formed during estuarine residence (Figures 2, 3, and 4) from increments formed during previous freshwater residence by increases in their mean width. Increase in increment width was not used to identify marine increments because 1) variability in the appearance of freshwater growth increments made it difficult to consistently perceive them individually, a prerequisite for measuring their width, and 2) freshwater increments which did appear individually were not consistently narrower than the later-formed marine increments.

Volk et al. (1984) report a direct relationship between the number of otolith growth increments and the number of days for juvenile chum salmon held in the laboratory. Their relationship was much stronger ($r^2 = 0.98$) than that found here ($n=456$, Figure 5), probably because of the stability of laboratory conditions relative to the field and the long duration of their experiment (more than 100 days) relative to the residence time of juvenile chum salmon in estuaries.

Fork Length and Residence Time

The estuarine residence times of juvenile chum salmon from daily growth increments of otoliths (Table 5) are reasonable in light of other estimates from the literature. Healey (1979) estimated weighted mean estuarine residence times of marked, wild chum fry to be as high as 18.5 days in the Nanaimo estuary in British Columbia. The difference between the 18.5 days found by Healey and the 12.1 days calculated here using a similar algorithm for unmarked, similar-sized, creek-reared fish may reflect incomplete

sampling of creek-reared fish in Netarts Bay. Creek-reared fish in Netarts Bay were only sampled before hatchery fish were released; thus, none of the creek-reared individuals that remained in the bay after the first hatchery release were included here. Because different indices were used by other researchers, direct comparisons with my results are impossible. Despite this discrepancy, results in the literature agree with those presented here in indicating that the usual residence time for juvenile chum salmon in estuaries is less than one month. Levy and Northcote (1982) found 11 days to be the maximum time after which marked juvenile chum could be recaptured from tidal marshes of the Fraser River in British Columbia. Pearcy et al. (1989) show residence half-lives, the number of days for catch rates to be halved, of juvenile chum salmon in Netarts Bay ranged from <2 to 7.4 days.

More rapid emigration of larger juvenile chum salmon from Netarts Bay probably caused the inverse relationship between weighted mean residence time and mean FL-at-entrance observed among the 1986 differently-sized fish (Table 5). An inverse relationship between emigration rate and juvenile chum salmon size has also been documented by Healey (1982b), Myers and Horton (1982), and Pearcy et al. (1989). Faster migration by larger juvenile chum implies a reduced dependancy on estuarine nurseries as fish size increases. Thus, varying the size at which chum salmon are released from hatcheries may prove to be a useful release strategy if densities of salmon in estuaries are found to limit their production. Unfortunately, at this time, there is no information concerning differences in survival rates between those which emigrate immediately and those which linger in the estuary (but see Pearcy et al. 1989).

Selective predation on smaller juvenile chum salmon has been postulated as an important mechanism removing these fish from nearshore nursery areas (Parker 1971; Bax et al.

1980; Healey 1982a; Hargreaves and LeBrasseur 1985, 1986; Pearcy et al. 1989). If predators of juvenile chum salmon prefer the smaller individuals, one would expect this to be reflected by selective removal of small fish resulting in larger back-calculated length at bay entrance and reduced apparent residence times of small fish. Evidence from Netarts Bay in 1986 does not indicate that small fish experience shorter residence times than larger fish. Instead, the only size-selective disappearance observed within groups was the rapid loss of fin-clipped fish that were relatively large at estuarine entrance which was probably due to their faster emigration. Not even among the small creek-reared fish was size-selective disappearance observed (Table 6 and 7, Figure 7 and 8). Thus, selective predation on small juvenile chum salmon in Netarts Bay is not implicated.

Growth Rate

The average growth rate of juvenile chum in Netarts Bay during 1984 and 1986 (0.6 mm FL/day, 3.5% bw/d) was similar to that for similar-sized, marked chum in the Nitinat Estuary, British Columbia (3.5%bw/d; Healey 1982b) and that for similar-sized chum in Steamer Bay, southeastern Alaska (0.4 mm FL/day; Murphy et al. 1988) as estimated by changes in mean FL (Table 10). All of these growth rates are less than those reported for groups of similar-sized, marked, juvenile chum salmon in the Nanaimo Estuary, British Columbia (5.7%bw/d; Healey 1982b) and Hood Canal, Washington (5.8-6.7%bw/d; Bax and Whitmus 1980). The more rapid growth rates of chum fry from these latter two estuaries may reflect the presence there of harpacticoid copepods as a principal component in juvenile chum diets (Healey 1982b; Bax and Whitmus 1980). Harpacticoid copepods were not a principal prey item of chum from the estuaries where their growth rates were slower (Healey 1982b; Murphy et al. 1988).

Despite the occurrence of harpacticoid copepods in Netarts Bay, their very low abundance may explain why they were not a major prey item of juvenile chum salmon in that bay (Chapman and Pearcy in prep.).

Volk et al. (1984) found that juvenile chum salmon held in seawater aquaria and fed harpacticoid copepods had a maximum food conversion efficiency (40.1%) of at least twice that of fish fed either calanoid copepods (20.0%) or gammarid amphipods (16.3%). This high efficiency may explain why juvenile chum salmon grow more rapidly when rearing in estuaries that provide an abundance of harpacticoid copepods.

Differences in major prey items may account for much of the variability in growth rates of juvenile chum salmon between estuaries but different methods used to produce these estimates also introduce variability. Pearcy et al. (1989) employed mark-and-recapture to estimate growth rates for the fin-clipped groups used in this study. Mark-and-recapture produce a series of mean FL for each group during estuarine residence with growth rate being estimated by the change in mean FL over time. This method is biased by the emigration of large members of a release group (Healey 1982b). It is evident from Table 11, that mark-and-recapture estimates of growth rate for each group of fin-clipped chum are less than the estimates of growth rate for the same group using otolith growth increments. The different methods produce estimates which differ by only 0.02 mm FL/d for the group of small-sized fish (50 mm FL) and by 0.25 mm FL/d for the group of large-sized fish (64 mm FL). Because residence time decreases with mean FL at estuarine entrance for these groups (Table 5), it is reasonable to conclude that differences between the two growth rate estimation methods are attributable to the more rapid emigration of large-sized members of each group being more pronounced among groups of large fish than groups of

smaller fish. Thus, the method used to estimate growth rates does introduce variability particularly for groups of large-sized fish and otoliths provide a means to reduce bias in growth rate estimates.

Although otoliths provide reasonable estimates of daily growth of juvenile chum salmon in Netarts Bay, these rates are probably not free from bias associated with the more rapid emigration of large fish. Presumably, large fish are the fast growing members of a group and because they leave the bay before smaller, slower-growing fish the mean group growth rate estimated from otoliths is an underestimate of the true growth rate. This tendency to underestimate the true growth rate is reflected by the negative regression coefficients for residence time (Table 9) which is probably explained by the more rapid emigration of faster-growing fish.

Temporal environmental variability within estuaries may affect their ability to support juvenile chum salmon. The concurrent increase of mean surface water temperature and decline in growth rates of juvenile chum salmon observed in Netarts Bay during mid to late May 1986 (Figure 9 and 10) suggest a temperature-related decline in the quality of Netarts Bay as a nursery area for these fish. This adverse effect of temperature is also suggested by the findings of Pearcy et al. (1989) who reported that juvenile chum salmon avoid areas where the average surface water temperature exceeded 15°C. The decline in growth rates of the WCH and OAF fin-clipped chum may stem from 1) slowed growth and 2) selective emigration of fast growing fish. Depression in growth rate from suboptimal water temperatures may result from the lowering of prey availability (Pearcy et al. 1989) or decreased metabolic efficiency (Kepshire 1971) or both. Selective removal of rapidly growing individuals probably occurs because faster growing fish are large and large fish, as previously mentioned, are more likely to emigrate than

smaller fish.

Release strategies employed by salmon hatchery managers may affect the ability of estuaries to support the released fish. Relative to the creek-reared fish, growth of fin-clipped chum in 1986 may have been slowed, and residence times shortened, by a shortage of benthic prey caused by the release of half a million small (50 mm mean FL) chum salmon (Table 1) into the approximately 10 km² of Netarts Bay. Releases of similar magnitude but of larger fish (56 mm mean FL) during 1984 may not have caused prey shortages because these large fish may be more able than small fish to feed pelagically when benthic prey is scarce (Simenstad et al. 1980). Implications of prey shortages during peak outmigration of juvenile chum salmon was found by Simenstad et al. (1980) in Hood Canal, Washington.

To date, there has not been a great deal of work using otoliths to study estuarine utilization by juvenile salmonids. The production of meaningful information concerning the dynamics of estuarine residence and growth of juvenile chum by this study demonstrates the utility of otoliths for this kind of application. Further investigation is necessary to fully understand the potential otoliths have as a tool for investigating the role estuaries play in the survival of anadromous fishes.

TABLES

Table 1. Summary of juvenile chum entering Netarts Bay during 1984 and 1986 (Wilson and Pearcy 1985a; Chung and Pearcy 1986). CRK = Creek-reared, WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua-Foods, R = right, L = left, A = adipose, V = ventral.

<u>Release Date</u>	<u>Number Entering (x 1000)</u>	<u>Rearing Site</u>	<u>Fin Clip</u>	<u>Number Clipped (x 1000)</u>	<u>Mean Fork Length (mm)</u>
1984 March 27 ^b	24	CRK		0	41
April 1	210-336	WCH		0	52
April 16	504-630	WCH	RV	24	56 ^a
April 16	21	OAF	LV	21	51 ^a
1986 March 31 ^b	30	CRK		0	41
April 28-29	610	WCH	RV	15	50
May 11	21	OAF	RV+A	21	64
May 11	22	OAF	LV+A	22	92

- a) Estimates from fin-clipped fish beach-seined on 17 April.
 b) Date when the outmigration from Whiskey and Jackson Creeks was approximately half over.

Table 2. Collection dates and the number of juvenile chum salmon collected from fresh water (FW) or Netarts Bay from which otoliths were extracted.

	<u>Whiskey Creek Hatchery</u>	<u>Oregon Aqua Foods</u>	<u>Creek- reared</u>	<u>Unknown</u>
1984				
FW	12 3/16-4/13	0 --	15 3/21-4/18	0 --
Bay	17 4/24-5/15	23 4/24-5/15	0 --	16 4/1-5/31
1986				
FW	8 4/28-4/29	3 5/10	37 3/19-4/20	0 --
Bay	92 4/30-6/6	83 5/12-6/6	179 3/13-4/24	20 4/30-6/22

Table 3. Coefficients of simple determination (r^2) among fork length (FL, mm), date of residence (DR, days since January 1), duration of estuarine residence time (RT, day) within each of 4 groups of juvenile chum salmon in Netarts Bay, Oregon. Asterisks indicate significant difference from zero (NS = $P > 0.05$, ** = $P < 0.01$). WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua-Foods, CRK = creek-reared.

		Simple Determination		
		<u>n</u>	<u>FL, DR</u>	<u>FL, RT</u> <u>DR, RT</u>
1984	WCH+OAF	56	0.43**	0.24** 0.71**
1986	WCH	126	0.43**	0.48** 0.73**
	OAF	21	0.01NS	0.04NS 0.81**
	CRK	258	0.19**	0.59** 0.28**

Table 4. Relationship between marine increment count (MI) and duration of residence time in days (RT) for groups of fin-clipped juvenile chum salmon in Netarts Bay. WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua-Foods.

<u>Group</u>	<u>Least Squares Equation</u>	<u>n</u>	<u>r²</u>
1984 WCH+OAF	MI=0.882(RT)+1.416	39	0.88
1986 WCH	MI=0.965(RT)-1.111	70	0.88
1986 OAF	MI=0.894(RT)+0.073	52	0.90

Table 5. Weighted mean residence times and mean FL-at-entrance for each of five groups of juvenile chum salmon residing in Netarts Bay. WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua-Foods, CRK = creek-reared, n = number of otoliths from which marine increments were counted.

<u>Group</u>	<u>n</u>	<u>Weighted Mean Residence Time (days)</u>	<u>Mean FL-at-entrance (mm)</u>
1986 CRK	151	12.1	41
WCH	70	5.4	50
OAF	52	2.5	64
1984 OAF	23	12.0	51 ^a
WCH	15	12.1	56 ^a

a) Estimates from fin-clipped fish beach-seined on 17 April.

Table 6. Comparisons of observed FL-at-entrance with back-calculated FL-at-entrance and the difference between the two measurements. WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua- Foods, CRK = creek-reared, sd = standard deviation, n = sample size. Significance of difference between means is indicated by; * ($P < 0.05$), ** ($P < 0.01$), or NS ($P > 0.05$).

Group		FL-at-entrance						Diff
		Observed			Back-calculated			
		Mean	sd	n	Mean	sd	n	
1986	CRK	40.46	1.867	1552	39.95	3.919	151	0.51NS ^b
	WCH	49.56	3.151	70	45.97	3.232	73	3.59**
	OAF	63.64	4.861	81	60.68	4.751	47	2.96**
1984	WCH	56.05 ^a	3.401	22	52.00	4.408	15	4.05**
	OAF	51.04 ^a	2.200	26	49.25	3.275	20	1.79*

a) estimated using fin-clipped chum beach-seined on 17 April.

b) approximate t-test for groups with unequal variances and sample sizes Snedecor (1956).

Table 7. Comparison of means of back-calculated FL-at-entrance of juvenile chum salmon among three residence periods (1 = <10 days, 2 = >9 and <20 days, and 3 = >20 days; ANOVA). Comparison of each back-calculated mean with the observed mean FL-at-entrance (t-test). sd = standard deviation, n = sample size. Significance of difference between means is indicated by; * ($\alpha = 0.05$), ** ($\alpha = 0.01$), or NS (not significant).

Group	Mean FL-at-entrance					t-test	ANOVA
	Observed Mean	Back-calculated			n		
		Mean	sd				
Whiskey Creek Hatchery	49.56	1) 45.27 2) 47.53 3) 46.04	3.144 3.944 2.865	26 15 25	** * **	NS	
Oregon Aqua-Foods	63.64	1) 60.89 2) 60.00 ^a	4.536 5.244	35 9	** *	NS	
Creek-reared	40.46	1) 39.77 2) 39.53 3) 41.08	3.758 4.988 3.088	69 36 38	NS ^b NS ^b NS ^b	NS	

a) Includes an individual with 22 days of residence.

b) approximate t-test among means with unequal variances and sample sizes Snedecor (1956).

Table 8. Significant differences ($P < 0.05$) exist among mean daily growth rates (mm FL/d) for groups of juvenile chum salmon during 1984 or 1986 in Netarts Bay.

Student-Newman-Keuls multiple comparison test was used to detect these differences (lines connect means that are not significantly different, $P > 0.05$). WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua-Foods, CRK = creek-reared.

Group	n	Growth Rate		FL (mm)		Entrance Date
		(mm FL/d)	(%bw/d) ^a	Mean	Range	
1984 WCH	21	0.68	3.6	56	47-61	April 16
1986 CRK	258	0.64	3.8	41	34-66	March 31
1984 OAF	35	0.62	3.5	51	41-63	April 16
1986 OAF	21	0.58	2.8	64	51-69	May 11
1986 WCH	126	0.55	2.9	50	41-71	April 28-29

a) Calculated using $\ln(WT(\text{grams})) = 2.82(\ln(FL(\text{mm})) - 10.87)$ from Wilson and Pearcy (1985b), fork length ranges, and assuming exponential growth.

Table 9. Regressions including only the independent variables (FL = fork length (mm) and RT = duration of estuarine residence time (day)) which correlated significantly with growth rate (GR, mm FL/day) of juvenile chum salmon in Netarts Bay, Oregon. Asterisks indicate a significant coefficient of determination (R^2 ; NS = $P > 0.05$, ** = $P < 0.01$). WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua Foods, CRK = creek-reared.

Group	Least Squares Equation	n	R^2
1984 WCH+OAF	GR=0.725-0.00969(RT)	56	0.22**
1986 WCH	GR=0.596-0.00364(RT)	126	0.07**
1986 CRK	GR=0.250-0.00593(RT)+0.00997(FL)	258	0.15**

Table 10. Comparing growth rates (%bw/d or mm FL/d) of juvenile chum in Netarts Bay with those of juvenile chum in other estuaries.

	<u>Growth Rate</u>		<u>Reference</u>
	<u>(%bw/d)</u>	<u>(mm FL/d)</u>	
Nanaimo Estuary	5.7	--	Healey 1982b
Hood Canal	5.8-6.7	--	Bax and Whitmus 1980
Netarts Bay ^a	3.5 ^b	0.6	present study
Nitinat Estuary	3.5	--	Healey 1982b
Steamer Bay	--	0.4	Murphy et al. 1988

a) Growth rate means calculated by averaging group growth rates from Table 8 weighted by sample size.

b) Calculated using $\ln(WT(\text{grams})) = 2.82(\ln(FL(\text{mm})) - 10.87)$ from Wilson and Pearcy (1985b), fork length range (see Table 8), and assuming exponential growth.

Table 11. Comparing otolith and mark-recapture techniques to estimate mean growth rates of groups of hatchery-reared, juvenile chum salmon released into Whiskey Creek at different mean fork length. WCH = Whiskey Creek Hatchery, OAF = Oregon Aqua Foods.

<u>Group</u>	<u>Growth Rates (mm FL/d)</u>		<u>Diff</u>	<u>Mean FL (mm) at Release</u>
	<u>Otolith</u>	<u>Mark-recapture</u>		
1986 WCH	0.55	0.53	0.02	50
1984 OAF	0.62	0.48	0.14	51 ^a
1984 WCH	0.68	0.41	0.27	56 ^a
1986 OAF	0.58	0.33	0.25	64

a) Estimates from fin-clipped fish beach-seined on 17 April.

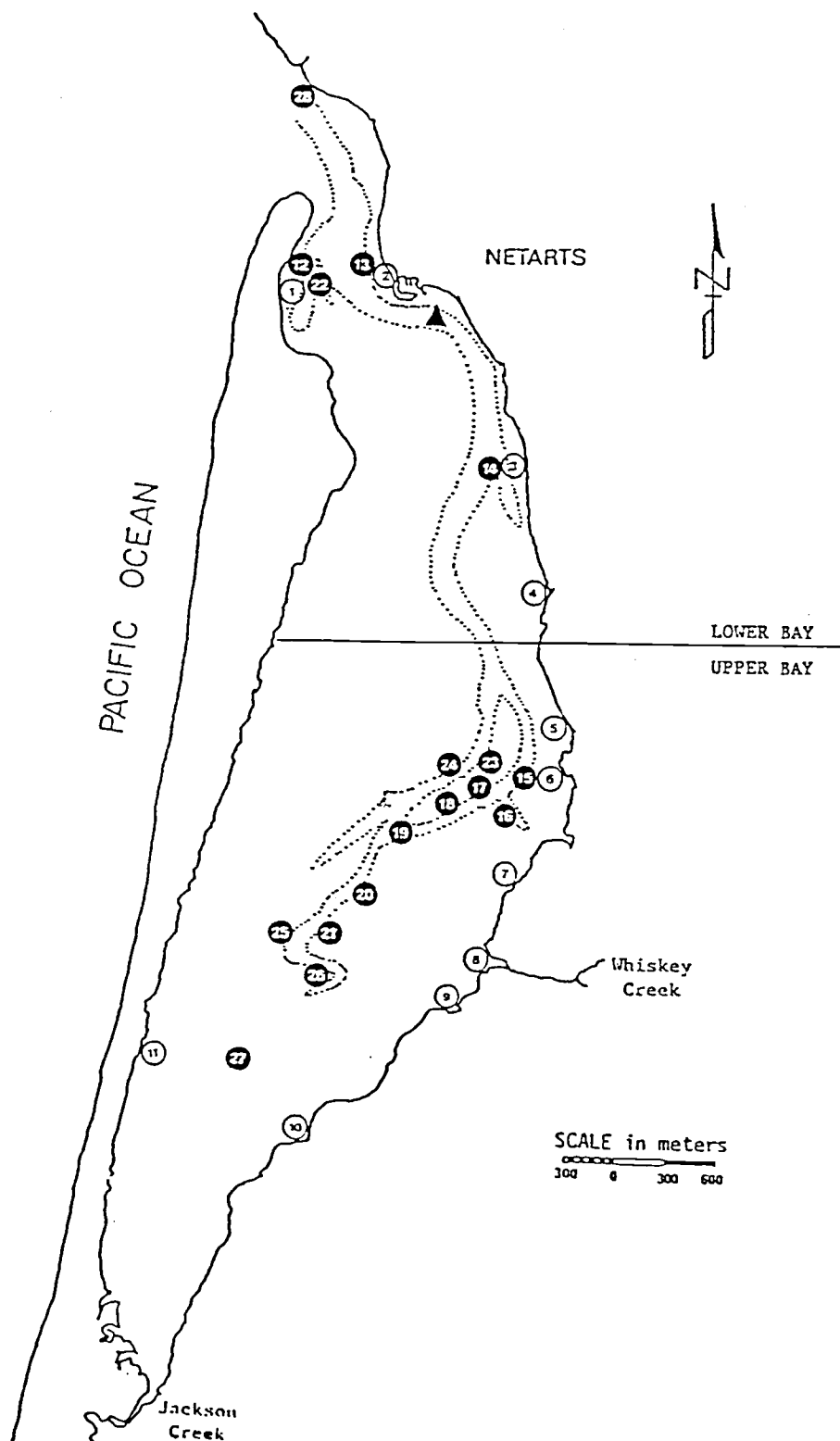


Figure 1. Map of Netarts Bay showing sampling sites.

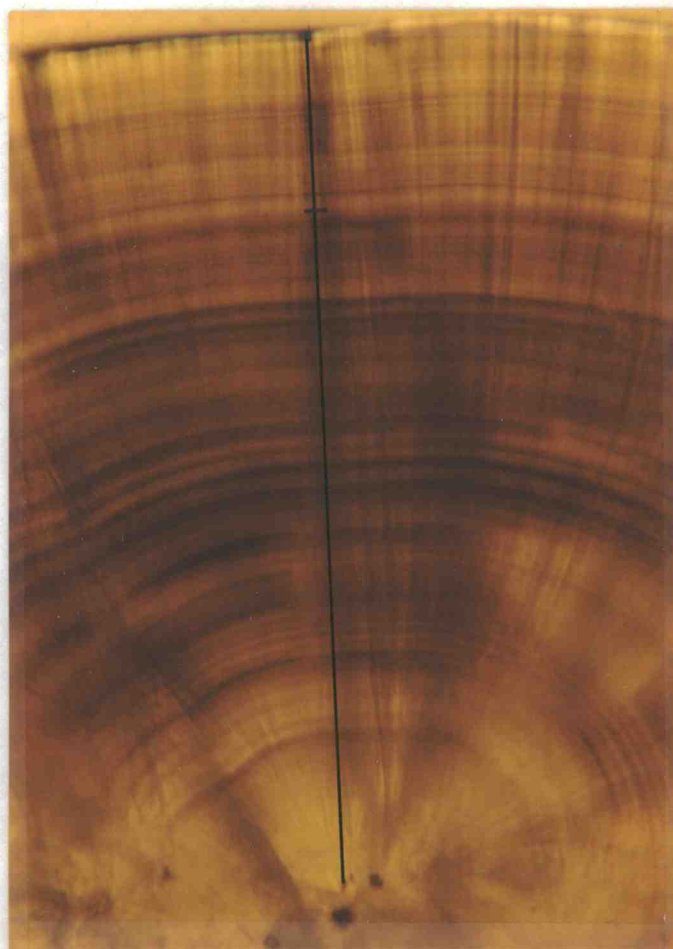


Figure 2. Photograph at 250X magnification of an otolith from a juvenile chum salmon showing radial measurement transect which extends from primordium (bottom of line) to otolith edge (top), crosshatch indicates start of marine increments. Otolith statistics: radius at estuarine entrance = 271 microns, radius at capture = 345 microns, 35 marine increments. Fish statistics; 70 mm FL, 32 days between release and recapture.



Figure 3. Photograph of the otolith in Figure 2 showing 35 marine increments at 1000X magnification. Arrow indicates start of marine increments.

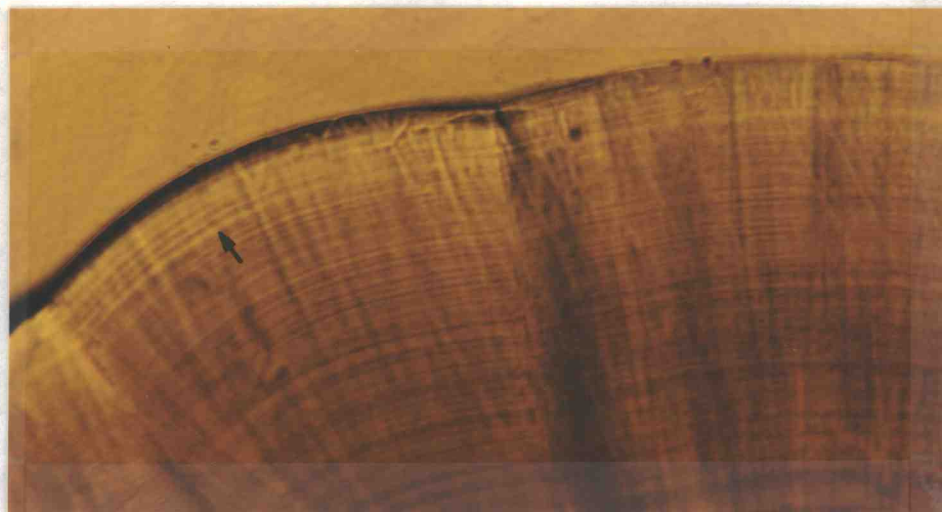


Figure 4. Photograph at 400X magnification of otoliths with A) 7, B) 9, and C) 28 marine increments from juvenile chum salmon in Netarts Bay for 8, 7, and 29 days, respectively. Arrows indicate start of marine increments.

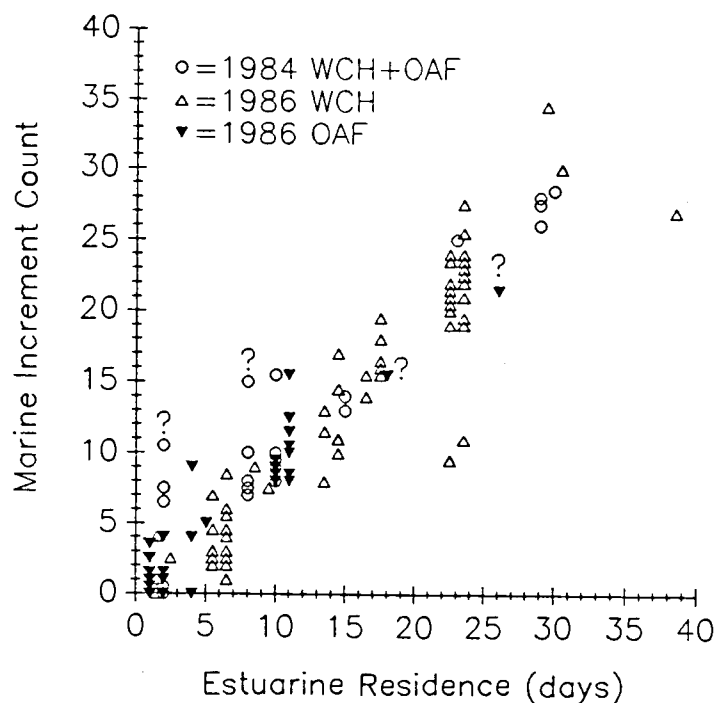


Figure 5. Marine increment count on days of estuarine residence for juvenile chum salmon in Netarts Bay, Oregon. The (?) is placed next to points influencing the slope test (see text).

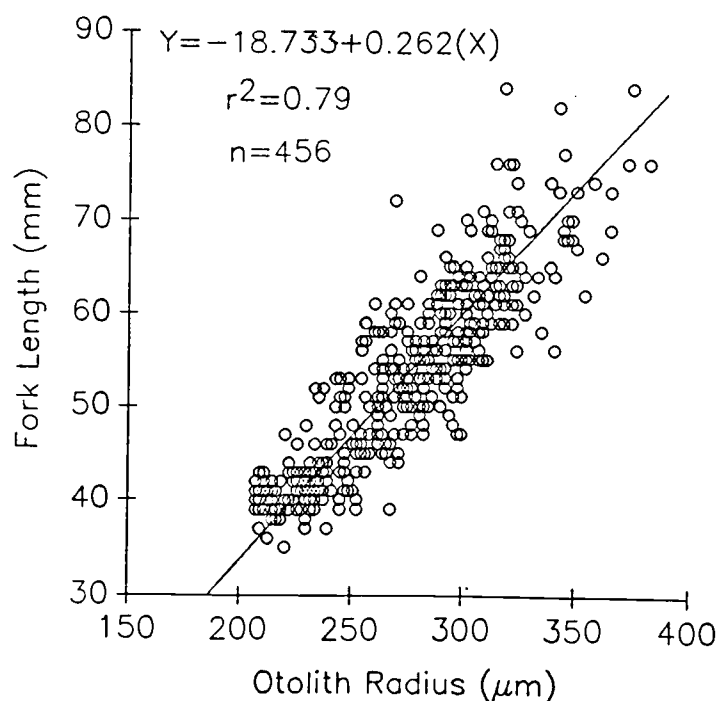


Figure 6. Fork length on otolith radius for juvenile chum in Netarts Bay, Oregon.

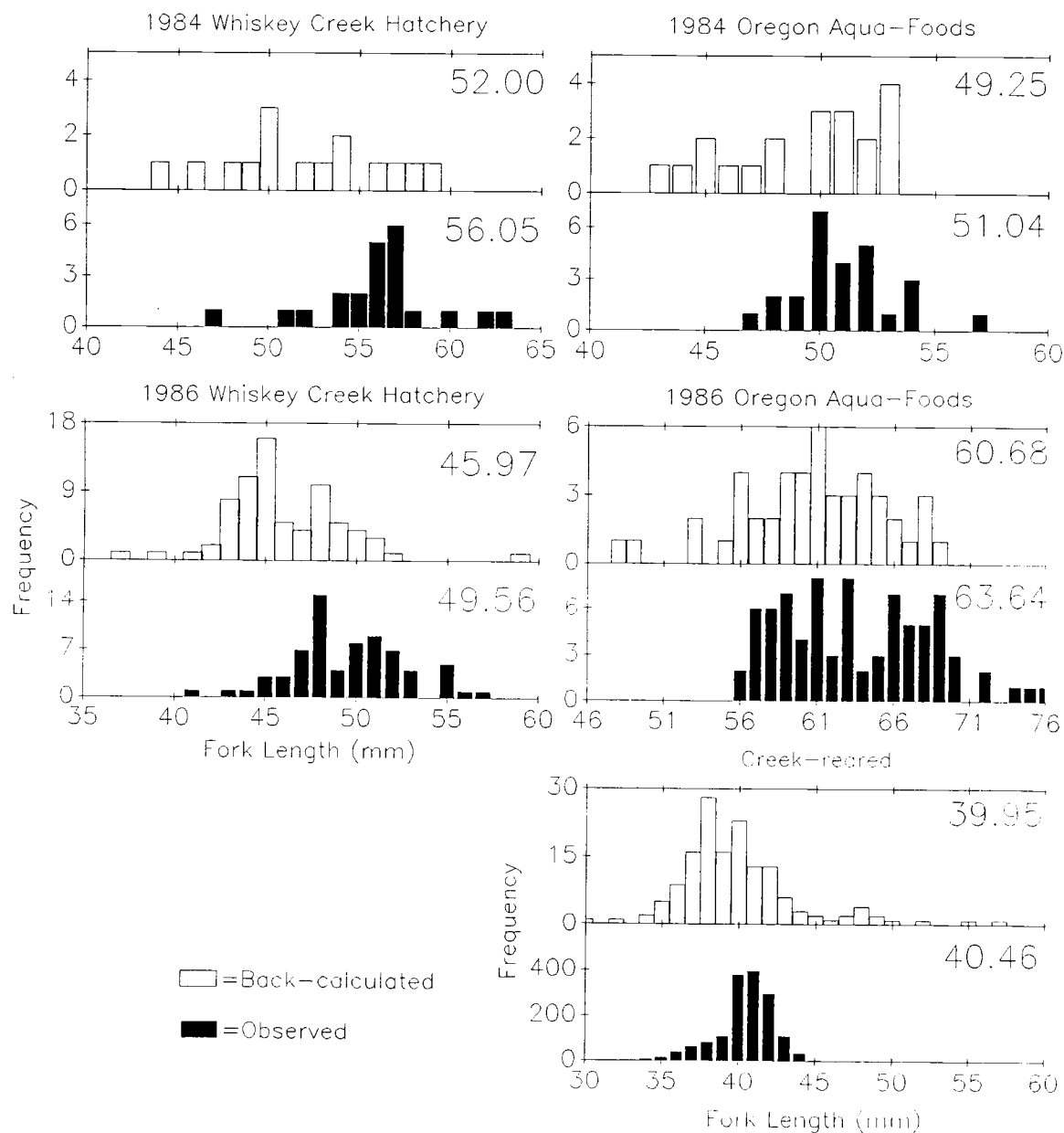


Figure 7. Length-frequency distributions and means for juvenile chum salmon entering Netarts Bay and frequency distributions of back-calculated FL-at-entrance.

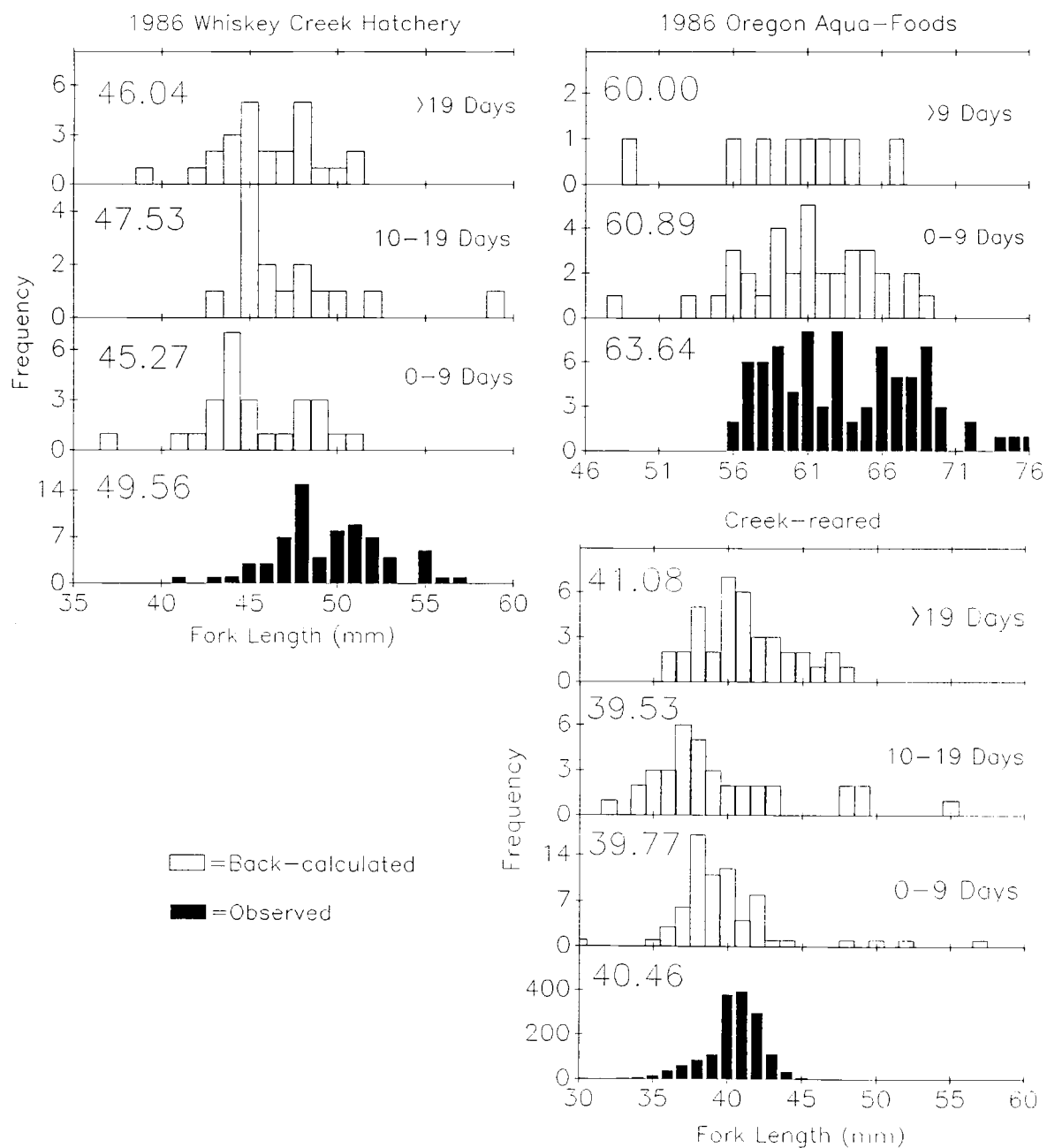


Figure 8. Length-frequency distributions and means for juvenile chum salmon entering Netarts Bay during 1986 and frequency distributions of back-calculated FL-at-entrance grouped by estuarine residence time within groups.

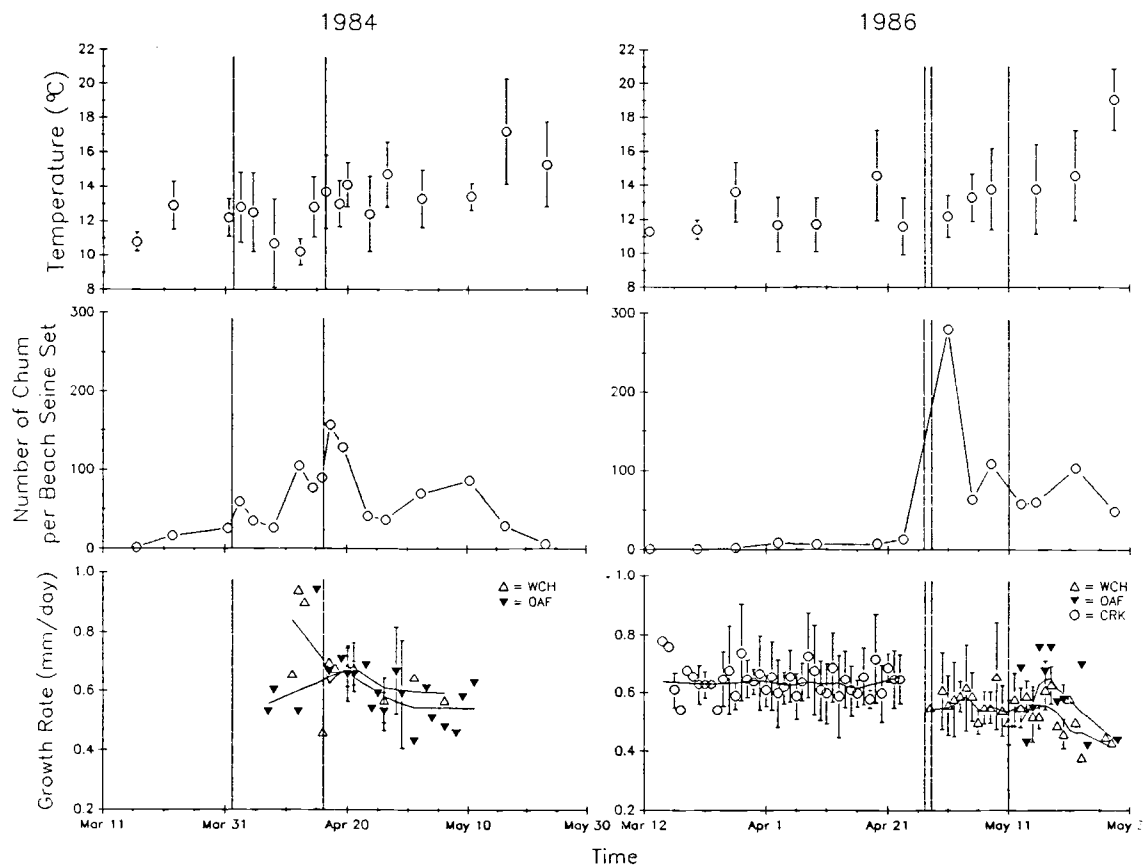


Figure 9. Average surface water temperature of Netarts Bay, mean number of chum salmon caught per beach seine set, and mean growth rates of juvenile chum salmon in Netarts Bay, Oregon (± 1 SD). Vertical lines indicate hatchery releases.

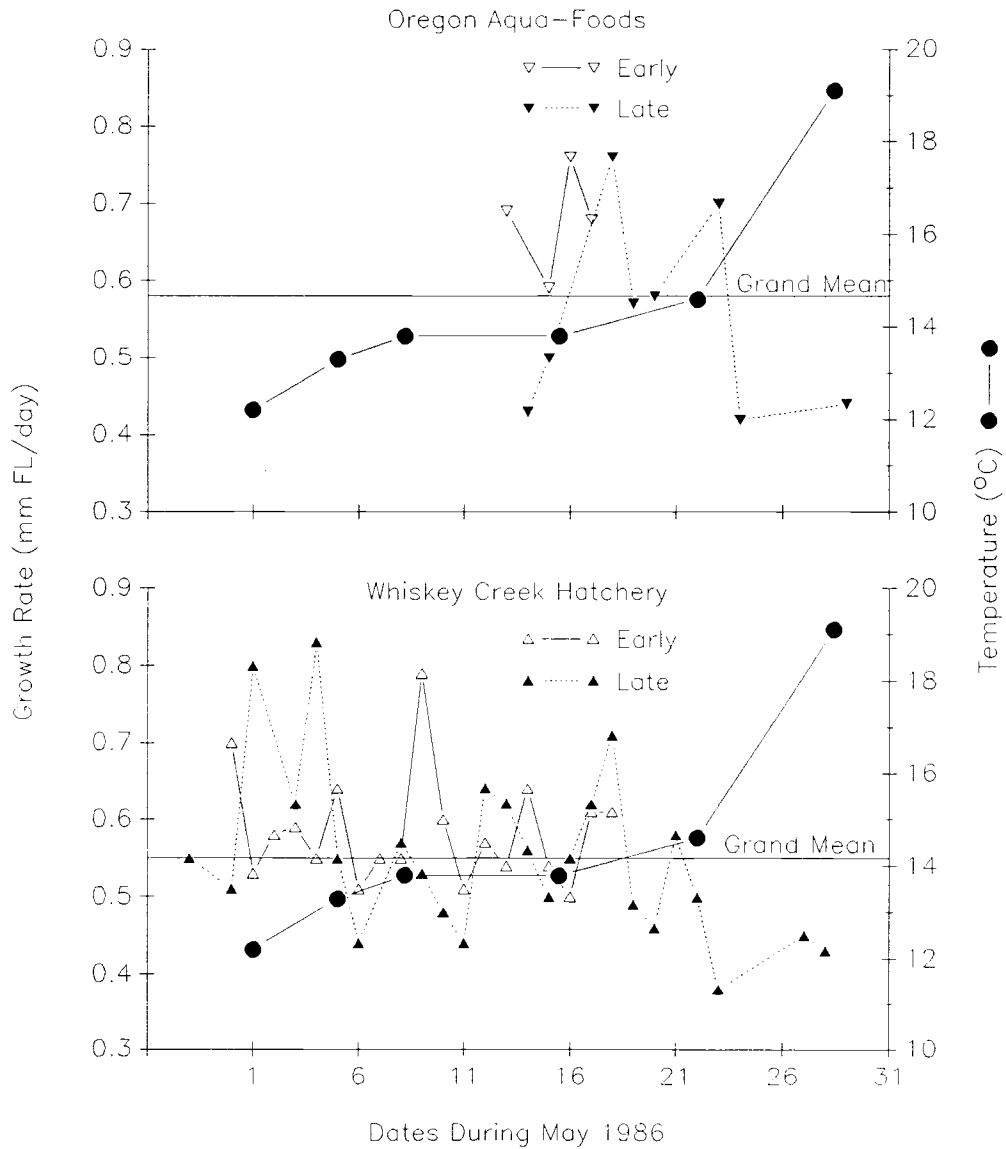


Figure 10. Reconstructed average growth rate history of juvenile chum occurring late in Netarts Bay compared with that of other chum captured earlier. Mean surface water temperature is included.

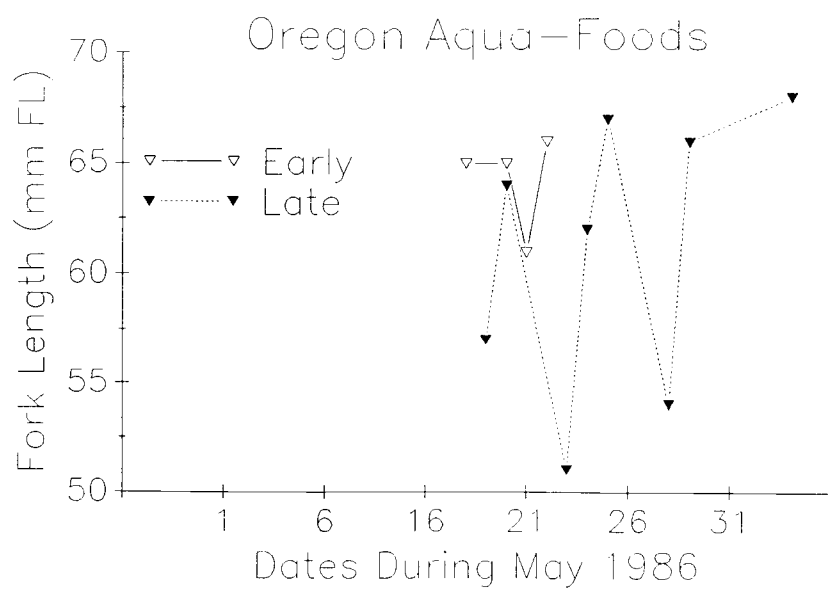


Figure 11. Estimated fork length means of juvenile chum salmon occurring late in Netarts Bay compared with that of other chum captured earlier.

REFERENCES

- Bax, N. J. 1983. Early marine mortality of marked juvenile chum salmon (Oncorhynchus keta) released into Hood Canal, Puget Sound, Washington, in 1980. Can. J. Fish. Aquat. Sci. 40:426-435.
- Bax, N. J., E. O. Salo, B. P. Snyder, C. A. Simenstad, and W. J. Kinney. 1980. Salmon outmigration studies in Hood Canal: A summary - 1977. Pages 171-202 in McNeil, W. J. and D. C. Himsworth (eds.) Salmonid ecosystems of the North Pacific. Oregon State Univ. Press, Corvallis, Oregon. 331 pp.
- Bax, N. J., and C. J. Whitmus. 1980. Salmonid outmigration studies. In Salo, E. O., N. J. Bax, T. E. Prinslow, C. J. Whitmus, B. P. Snyder, and C. A. Simenstad. The effects of construction of naval facilities on the outmigration of juvenile salmonids from Hood Canal, Washington. Univ. Washington, Fish. Res. Inst. Final Rep. FRI-UW-7920. 159p.
- Bradford, M. J., and G. H. Geen 1987. Size and growth of juvenile chinook salmon back-calculated from otolith growth increments. In: R. C. Summerfelt, and G. E. Hall, editors. The age and growth of fish. The Iowa State University Press, Ames, Iowa.
- Campana, S. E., and J. D. Neilson. 1985. Microstructure of fish otoliths. Can. J. Fish. Aquat. Sci. 42: 1014-1032.
- Chambers, J. M., W. S. Cleveland, B. Kleiner, and P. A. Tukey. 1983. Graphical methods for data analysis. Boston: Duxbury Press. 395 pp.
- Chapman, J. W., and W. G. Pearcy. in prep. Prey behavior and diel feeding by juvenile chum salmon (Oncorhynchus keta) in Netarts Bay, Oregon.
- Chung, A. W., and W. G. Pearcy. 1986. The utilization of Netarts Bay by juvenile chum salmon - 1986. Oregon State Univ. Sea Grant ORESU-T-86-002. 50 pp.
- Cleveland, W. S. 1979. Robust locally weighted regression and smoothing scatterplots. J. Am. Stat. Assoc. 74(368):829-836.
- Fisher, J. P., and W. G. Pearcy. 1988. Growth of juvenile coho salmon (Oncorhynchus kisutch) off Oregon and Washington, USA, in years of differing coastal upwelling. Can. J. Fish. Aquat. Sci. 45:1036-1044.

Glanzman, C. R., B. Glenne, and F. Burgess. 1971. Tidal hydraulics, flushing characteristics and water quality of Netarts Bay. Engineering Experiment Station, Oregon State Univ., Bull. No. 45. 33 pp.

Hargreaves, N. B., and R. J. LeBrasseur. 1986. Size selectivity of coho (Oncorhynchus kisutch) preying on juvenile chum (O. keta) salmon. Can. J. Fish. Aquat. Sci. 43:581-586.

Hargreaves, N. B., and R. J. LeBrasseur. 1985. Species selective predation on juvenile pink (Oncorhynchus gorbuscha) and chum salmon (O. keta) by coho salmon (O. kisutch). Can. J. Fish. Aquat. Sci. 42:659-668.

Healey, M. C. 1982a. Timing and relative intensity of size-selective mortality of juvenile chum salmon (Oncorhynchus keta) during early sea life. Can. J. Fish. Aquat. Sci. 39: 952-957.

Healey, M. C. 1982b. Juvenile pacific salmon in estuaries: the life support system. p. 314-341. In: V. S. Kennedy (ed.). Estuarine comparisons. Academic Press, New York, New York.

Healey, M. C. 1979. Detritus and juvenile salmon production in the Nanaimo Estuary: I. Production and feeding rates of juvenile chum salmon (Oncorhynchus keta). J. Fish. Res. Board Can. 36:488- 496.

Iwata, M. 1980. Downstream migration and seawater adaptability of chum salmon (Oncorhynchus keta) fry Proc. No. Pac. Aquaculture Symp. Anchorage, Alaska.

Iwata, M., and S. Komatsu. 1984. Importance of estuarine residence for adaption of chum salmon (Oncorhynchus keta) fry to seawater. Can. J. Fish. Aquat. Sci. 41:744-749.

Kepshire, B. M., Jr. 1971. Growth of pink, chum, and fall chinook salmon in heated seawater. Proc. 22nd Ann. N.W. Fish. Cult. Conf., p 25-26.

Koshiishi, Y. 1986a. Effect of salinity on food intake, growth and feed efficiency of chum salmon, Oncorhynchus keta (Walbaum), and ayu, Plecoglossus altivelis Temminck et Schlegel. Bull. Jap. Sea Reg. Fish. Res. Lab., (36):1-14.

Koshiishi, Y. 1986b. Effect of feeding level and dietary composition on growth and feed efficiency of chum salmon, Oncorhynchus keta (Walbaum), fed in seawater and freshwater. Bull. Jap. Sea Reg. Fish. Res. Lab., (36):15-27.

Kreag, R. A. 1979. Natural resources of Netarts estuary. Oregon Dept. Fish. Wildlife, Estuary Inventory Report 2:1. 45 pp.

Levy, D. A., and T. G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Marshall, S. L., and S. S. Parker. 1982. Pattern identification in the microstructure of sockeye salmon (Oncorhynchus nerka) otoliths. Can. J. Fish. Aquat. Sci. 39:542-547.

Mason, J. C. 1974. Behavioral ecology of chum salmon fry (Oncorhynchus keta) in a small estuary. J. Fish. Res. Board Can. 31:83-92.

Myers, K. W., and H. F. Horton. 1982. Temporal use of an Oregon estuary by hatchery and wild juvenile salmon, p. 377-392. In V. S. Kennedy (ed.), Estuarine Comparisons, Academic Press, New York. 709 pp. 908.

Murphy, M. L., J. F. Thedinga, and K. V. Koski. 1988. Size and diet of juvenile Pacific salmon during seaward migration through a small estuary in southeastern Alaska. Fish. Bull. 86(2):213- 222.

Neilson, J. D., and G. H. Geen. 1986. First-year growth rate of Sixes River chinook salmon as inferred from otoliths: effects on mortality and age at maturity. Trans. Am. Fish. Soc. 115(1):28- 33.

Neilson, J. D., and G. H. Geen. 1984. Effects of feeding regimes and diel temperature cycles on otolith increment formation in juvenile chinook salmon, Oncorhynchus tshawytscha. Fish. Bull. 83(1):91-101.

Neilson, J. D., and G. H. Geen. 1982. Otoliths of chinook salmon (Oncorhynchus tshawytscha): daily growth increments and factors influencing their production. Can. J. Fish. Aquat. Sci. 39:1340- 1347.

Neilson, J. D., G. H. Geen, and D. Bottom. 1985. Estuarine growth of juvenile chinook salmon (Oncorhynchus tshawytscha) as inferred from otolith microstructure. Can. J. Fish. Aquat. Sci. 42:899- 908.

Neter, J., W. Wasserman, and M. H. Kutner. 1983. Applied linear regression models. Irwin, Homewood, Illinois. 547 pp.

Parker, R. R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Bd. Canada 28:1503-1510.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, Central British Columbia. J. Fish. Res. Board Can. 25(4):757-794.

Pearcy, W. G., C. D. Wilson, A. W. Chung, and J. W. Chapman. 1989. Fish. Bull. 87 (in press). Residence times, distributions and production of juvenile chum salmon (Oncorhynchus keta) in Netarts Bay, Oregon.

Ricker, W. E. 1973. Linear regressions in fishery research. J. Fish. Res. Bd. Canada. 30:409-434.

Ricker, W. E. (ed.). 1971. Methods for assessment of fish production in fresh waters. International Biological Programme Handbook No. 3. Blackwell Scientific Publ., Oxford and Edinburgh. 348 pp.

Salo, E. O., N. J. Bax, T. E. Prinslow, C. J. Whitmus, B. P. Snyder, and C. A. Simenstad. 1980. The effects of construction of naval facilities on the outmigration of juvenile salmonids from Hood Canal, Washington. Final Rep., Fish. Res. Inst., Univ. Washington, Seattle, WA. FRI-UW-8006. 159p.

Simenstad, C. A., and E. O. Salo. 1980. Foraging success as a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon (Oncorhynchus keta) in Hood Canal, Washington. Proc. No. Pac. Aquaculture Symp. 21-37.

Simenstad, C. A., W. J. Kinney, S. S. Parker, E. O. Salo, J. R. Cordell, and H. Buechner. 1980. Prey community structure and trophic ecology of outmigrating juvenile chum and pink salmon in Hood Canal, Washington: A synthesis of three years' studies, 1977-1979. Fish. Res. Inst., Univ. Washington, Seattle, WA. FRI- UW-8026. 113p.

Snedecor, G. W. 1956. Statistical methods applied to experiments in agriculture and biology. Iowa State College Press. Ames, Iowa. 534p.

Stout, H. (ed.). 1976. The natural resources and human utilization of Netarts Bay, Oregon. Oregon State Univ., Corvallis. 247p.

Volk, E. C., R. C. Wissmar, C. A. Simenstad, and D. M. Eggers. 1984. Relationship between otolith microstructure and the growth of juvenile chum salmon (Oncorhynchus keta) under different prey rations. Can. J. Fish. Aquat. Sci. 41:126-133.

Volk, E. C., C. A. Simenstad, and R. C. Wissmar. unpublished manuscript. The use of otolith microstructure to determine estuarine entry and residence time of juvenile chum salmon (Oncorhynchus keta). Fish. Res. Inst., Univ. Washington, Seattle, WA.

West, C. J., and P. A. Larkin. 1987. Evidence for size-selective mortality of juvenile sockeye salmon (Oncorhynchus nerka) in Babine Lake, British Columbia. Can. J. Fish. Aquat. Sci. 44:712- 721.

Wilson, C. D., and W. G. Pearcy. 1985a. The utilization of Netarts Bay by juvenile chum salmon - 1984. Oregon State Univ., Sea Grant ORESU-T-85-002. 66 pp.

Wilson, C. D., and W. G. Pearcy. 1985b. The utilization of Netarts Bay by juvenile chum salmon - 1985. Oregon State Univ., Sea Grant ORESU-T-85-005. 62 pp.

Wilson, K. H., and P. A. Larkin. 1982. Relationship between thickness of daily growth increments in sagittae and change in body weight of sockeye salmon (Oncorhynchus nerka) fry. Can. J. Fish. Aquat. Sci. 39:1335-1339.

Wilson, K. H., and P. A. Larkin. 1980. Daily growth rings in the otoliths of juvenile sockeye salmon (Oncorhynchus nerka). Can. J. Fish. Aquat. Sci. 37:1495-1498.