Residence Times, Distribution, and Production of Juvenile Chum Salmon, *Oncorhynchus keta*, in Netarts Bay, Oregon

William G. Pearcy, Christopher D. Wilson, Alton W. Chung, and John W. Chapman

ABSTRACT: Juvenile chum salmon resided in Netarts Bay, a small, shallow estuary at the southern spawning range of chum salmon in the Northeast Pacific, from mid-March until June during each of three years from 1984 to 1986. Early in the spring they were most abundant in beach seine catches during high tide in the upper bay, indicating extensive intertidal excursions. Later in the spring, when temperatures exceeded 14°–16°C in the upper bay, they were most common in catches at low tide in the lower bay. Based on recaptures of fin-clipped hatchery fish, the residence of juveniles varied inversely with size of fish at release. Large (6.5 g) fish immediately emigrated from the estuary and 3–4 times as many returned as adult fish as 1.0 and 2.2 g juveniles, which had residence half-lives of 5–16 days. Growth rates of juvenile chum salmon during the 3 years were similar, but were low (1.6–2.3% body weight/day) compared with other studies. Production was also low. This may be related to high metabolic costs at above optimal temperatures and the large size of available prey in Netarts Bay.

The period of early marine residence is thought to be a critical stage in the life history of Pacific salmon, affecting the survival of young and the numbers of adults returning in subsequent years (Parker 1968; Peterman 1978; Pearcy 1984). The period of estuarine residence may be especially important for chum salmon, *Oncorhynchus keta*, (Healey 1982a; Simenstad and Wissmar 1984). They enter estuaries at a small size and presumably need to grow rapidly to avoid intense predation after they enter the ocean (Parker 1971; Simenstad and Salo 1980; Healey 1982b; Simenstad and Wissmar 1984). The capacity of an estuary to produce salmon may be limited, however, and the availability of prey resources may affect salmon emigration, growth, ability to avoid predation, and thus survival (Reimers 1973 Bailey et al. 1975; Healey 1979, 1980a; Sibert 1979; Simenstad and Salo 1980).

The hypothesis that the estuarine phase of the early life history of chum salmon is critical needs to be tested (Simenstad and Wissmar 1984; Levings 1984). If this phase is essential, increased releases of hatchery fish from private or public hatcheries may not be beneficial unless release strategies minimize or circumvent density-dependent growth and survival in estuaries, e.g., by modifying size, time, or numbers of fish released. Healey (1979, 1982a) concluded that seaward migration was size dependent, and Ioka (1978, unpubl. data) reported that large (>8 g) juvenile chum salmon were capable of migrating directly into offshore waters. This suggests that estuarine rearing may not be essential for chum salmon released from hatcheries at a large size.

To evaluate the capacity of estuaries to produce chum salmon, we studied their downstream movement, distribution, abundance, residence time, growth, and production in Netarts Bay, OR. Netarts Bay is a small estuary along the northern Oregon coast, near the southern distribution of chum salmon along the coast of the northeastern Pacific Ocean (Henry 1953). Netarts Bay was selected for this study because the Oregon State University chum salmon hatchery (Lannan 1975, 1983) enabled experimental releases of chum salmon at different times and sizes, and because the residence times and growth of chum salmon in a small estuary needed to be compared with the results found in estuaries farther north.

Netarts Bay (Fig. 1), located along the northern Oregon coast, has an area of only 10 km^2 at mean high water (MHW). The bay is strongly influenced by the ocean. Salinities generally approach ocean levels. The intertidal volume is about 75% of the volume at MHW; 12% of the Netarts Bay is subtidal (Glanzman et al. 1971;

William G. Pearcy, College of Oceanography, Oregon State University, Corvallis, OR 97331.
Christopher D. Wilson, College of Oceanography, Oregon State University, Corvallis, OR 97331; present address: Department of Oceanography, University of Hawaii, Honolulu, HI 96822.
Alton W. Chung, College of Oceanography, Oregon State University, Corvallis, OR 97331.
John W. Chapman, Hatfield Marine Science Center, Newport, OR 97365.

Manuscript Accepted March 1989.
Fishery Bulletin, U.S. 87: 553–568.

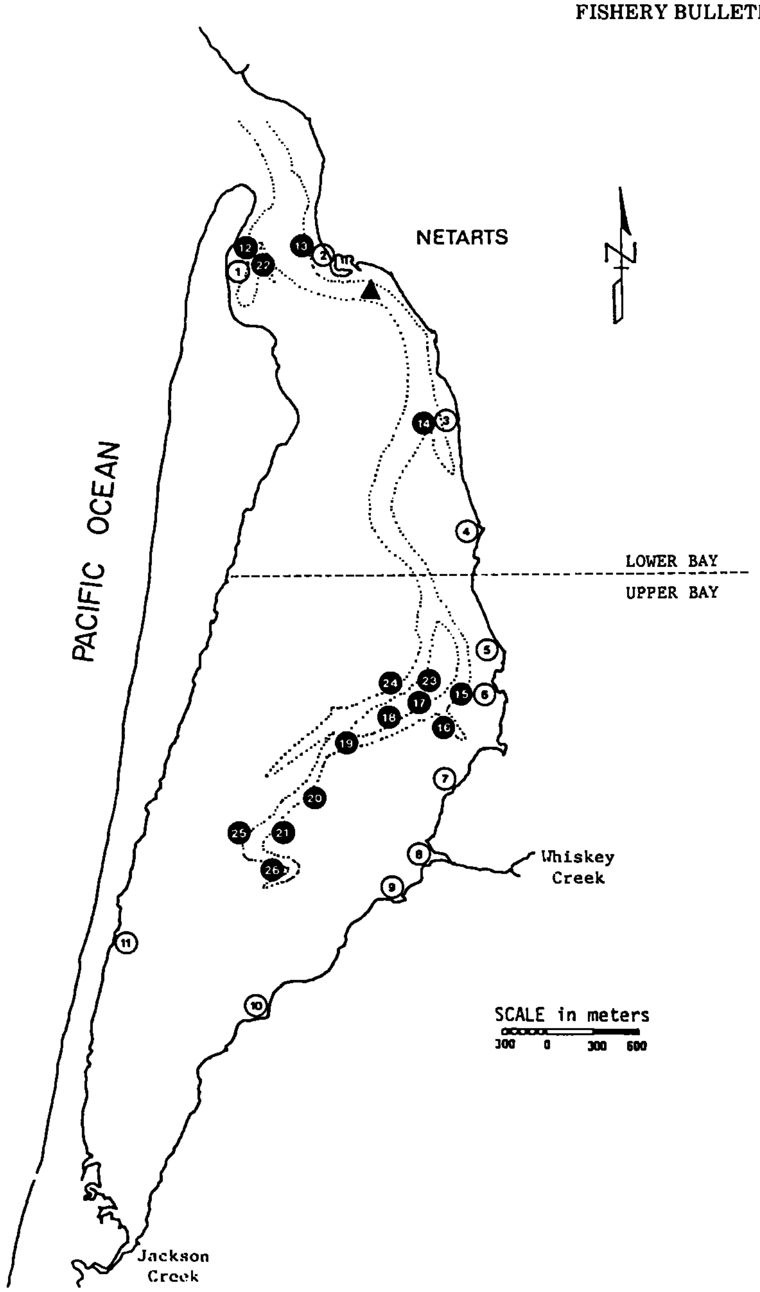

FIGURE 1.—Netarts Bay with locations of high tide (open) and low tide (solid) seine stations and the tow net stations (triangle).

Kreag 1979). The watershed area is small (about 36 km^2), and its only tributaries are small creeks. Whiskey Creek, the site of the Oregon State University experimental hatchery for rearing chum salmon (Lannan 1975), and Jackson Creek are the two largest streams that drain into Netarts Bay and are the major spawning habitats for chum salmon in Netarts Bay. Besides cutthroat trout, only a few rainbow (steelhead) trout and coho salmon were found in Whiskey or Jackson Creek.

METHODS

The contribution of naturally spawned chum fry to Netarts Bay and the timing of their outmigration were estimated from samples of chum salmon fry captured in a fyke net, located in Whiskey Creek about 100 m from the bay at MHW, from late March to early May 1984, and from late February through late May 1985 and 1986. The net, which was used for 35, 51, and 53 days in 1984, 1985, and 1986, respectively, was constructed of 3.2 mm mesh with a 1.3 m wide mouth opening and two 2.7 m wings. The net was positioned across 95% of the width of the stream except during periods of high stream flow (Wilson and Pearcy 1985a). Catches were monitored during day and night periods. The net was removed from the stream on a few occasions during daylight hours and periods of high stream flow. The sampling error resulting from removing the net during daylight hours is assumed to be minimal as <1% of the total number of chum fry were caught in the fyke net during these hours (Wilson and Pearcy 1985a). Outmigrating juvenile chum salmon were also sampled in Jackson Creek with a 3.2 mm mesh bag net stretched across this stream two nights per week between 19 March and 25 April 1986. Water depth, temperature, cloud cover, and flow rates (1986 only) were recorded from both Whiskey Creek and Jackson Creek during sampling periods. Juvenile chum salmon in the catches were counted and fork lengths (FL) were measured to the nearest 1 mm for all fish or for a subsample of 100 fish per sampling period.

Fin-clipped (ventral and adipose) chum salmon were released from the Whiskey Creek hatchery to estimate residence time and growth of fish entering the bay at different times and different sizes. Data on the releases of marked and unmarked fish are summarized in Table 1. Eggs from adult chum salmon returning to Whiskey Creek were reared at the hatchery and at the Oregon Aqua-Foods, Inc. (OAF) hatchery in Springfield, OR. OAF fish were returned to raceways and acclimated at the Whiskey Creek facility for 10–13 days before release into Netarts Bay. These OAF fish were smaller at release than fish reared at Whiskey Creek in 1984, but were larger than Whiskey Creek fish in 1986 (Table 1). Differential mortality of finclipped vs. unclipped fish was not evident for fish held 3–4 days after marking in 1984 and 1985, or for OAF fish marked 10–13 days before release in 1986.

Two problems affected releases of juvenile chum salmon from the Whiskey Creek facility. Some marked fish escaped from the raceway and were caught in the bay before their planned release on 16 April 1984. The second problem was a bacterial disease that afflicted many fish reared at the Whiskey Creek facility in April 1986. About 4.4% of the fish died during marking operations, and 7.7% of the fish that survived marking died after being held in the raceway for 24 hours. Thus the numbers of fish released on 28–29 April 1986 are overestimates of the numbers of healthy fish actually entering the Netarts Bay. The raceway was sterilized with formalin after this release, and no apparent adverse effects were observed on the OAF fish transported to the Whiskey Creek facility in May 1986.

Netarts Bay was sampled for juvenile chum salmon from mid-March through late June 1984 and 1986 and from late February through early

TABLE 1.—Summary of releases of marked and unmarked juvenile chum salmon from the Whiskey Creek hatchery in 1984, 1985, and 1986.

Date	Total no. released × 1000	× FL (mm)	× Wt. (g)	Marks	No. marked × 1,000	% marked
1984						
1 April	215.1–344.1	52	1.4	0		
16 April	516.2–645.2	58	1.9	RV	24.0	
16 April		46	[1]0.75	LV	[2]20.5	
Total	731.3–989.3				44.5	4.5–6.1
1985						
19 April	155.6	56	1.8	RV	18.2	
26 April	218.4	59	1.9	LV	20.2	
Total	374.0				38.4	10.3
1986						
28–29 April	609.0	48	0.97	RV	[3]14.7	
11 May	43.6	62	2.2	RV + A	[2]21.4	
11 May		92	6.5	LV + A	[2]22.2	
Total	652.6				58.3	8.9

[1]Measured on 3 April 1984.
[2]Oregon Aqua-Foods Inc. fish reared offsite.
[3]Estimated no. released after mortality.

July 1985. A 37 m long, tapered, floating beach seine, set in a semicircle from the shoreline from a 4.6 m boat with an 18 hp outboard motor, was used for sampling. Sets encompassed about 100 m^2. The seine had a maximum depth of 2.5 m in the bunt and 0.7 m at the ends of the wings. The wings were made of 2.5 cm (stretch) mesh and the bag was made of 0.64 cm mesh. We sampled 11 high tide stations (1–11) and 10 low tide stations (12–21) in 1984–85 and 11 high tide stations (1–11) and 8 low tide stations (12, 13, 14, 22–26) in 1986 (Fig. 1). (Specific beach seine stations are described by Wilson and Pearcy (1985a) and Chung and Pearcy (1986).) The numbers of beach seine hauls made in 1984, 1985, and 1986 were 435, 333, and 388, respectively. Surface water temperatures were measured to the nearest 0.1°C with a bucket thermometer, and surface salinities were determined to the nearest 2‰ with an American Optical Model 10419[1] refractometer after each set. Each station was sampled several times each month during the field seasons.

We used a Kvichak towed net[2] with a 2.7 × 2.7 m mouth opening and a 8.2 m long body section with mesh grading from 3.8 cm to 0.3 cm and a cod end of 0.3 cm mesh to sample juvenile chum salmon in the main tidal channel during slack tide at approximately 2 wk intervals from late March through late June 1985. One nighttime tow was made. Two boats were used to pull the net along a 900 m long transect in the main channel of the lower bay (Fig. 1) at speeds of about 1–2 m/s.

Approximately 100 individual juvenile chum salmon from each seine haul were checked for fin clips. We assumed negligible regeneration of clipped fins during the 3 mo sampling period. A subsample of 5–50 juvenile chum salmon was preserved in 10% formalin or 95% ethanol for length measurements and stomach content analysis or age determination, respectively. The remaining fish were released. Fork lengths of all preserved fish were measured to the nearest mm. These lengths were converted to fresh fish lengths or weights from the regressions of individual preseved lengths and weights on fresh lengths and weights (Wilson and Pearcy 1985a, b).

For data analysis, the 1984, 1985, and 1986 field seasons were divided into 21, 17, and 18 sampling periods, respectively, in which every beach seine station was usually sampled at least once. Stations were divided into the lower bay (stations 1–4, 12–14, and 22) and upper bay (stations 5–11, 15–21, and 23–26) (Fig. 1). Sand sediments predominate in the lower bay, whereas fine sands and silt, with high organic carbon, are common in the extensive tidal flats of the upper bay (Kreag 1979). Ninety-five percent confidence intervals of the median number of fish caught per set were calculated by the method presented in Snedecor and Cochran (1980). Mean lengths of fish from different regions of the bay were compared using a t-test for unequal variances (Sokal and Rohlf 1981). Growth rates among years were estimated from regressions of the size of recaptured marked fish and compared, using analysis of covariance (Snedecor and Cochran 1980). Growth in weight was calculated from length-weight regressions.

The total numbers of juvenile chum salmon remaining in the bay were estimated by a modified Peterson model (Healey 1980), where on day t,

$$N_t = \frac{CM}{R} \qquad (1)$$

where N_t = total population,
C = total catch,
M = estimated number of marked fish present in the bay, and
R = number of marked fish recaptured.

The estimated number of marked fish present, M, was calculated assuming a constant loss rate of marked fish with time:

$$M = M_0 \, e^{-kt}$$

where M_0 = total number of marked fish released,
k = instantaneous rate of disappearance of marked fish, and
t = days since release.

The actual number of marked fish recaptured and the estimated number of marked fish from each release group were pooled for each year and used in a modified Peterson model to estimate population numbers (N_t). The instantaneous rate of disappearance of marked fish was estimated for each marked group by the slope of the regression of time on catch per effort. This instan-

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[2]Research Nets, Inc., Bothell, WA.

taneous loss rate, k, also provided an estimate of the residence time for each marked group in the estuary. Solving Equation (2) for t when $M/M_0 = \frac{1}{2}$ gave the residency half-life in days, the time in which the number of fish had declined by 50%.

The estimated number of fish in the estuary (N_t) was multiplied by the average weight of marked fish to estimate the biomass of juvenile chum salmon present during each sampling period. These biomass estimates were multiplied by the number of days between sampling periods, summed over the entire period that juvenile chum salmon were present, and multiplied by an average instantaneous growth rate in weight of the marked groups to estimate net production for each year.

RESULTS

Emigration from Fresh water

We estimated an outmigration of 11,900, 23,300, and 15,300 chum salmon fry from Whiskey Creek in 1984, 1985, and 1986, respectively. The early portion of the run was not sampled in 1984. These estimates of naturally reared chum salmon fry equalled 1.4%, 6.2%, and 2.3% of the total chum salmon releases from the Whiskey Creek Hatchery in these years (Table 1). The abundances and temporal changes in catches of chum salmon were similar in Jackson and Whiskey Creeks in 1986 (Fig. 2). Since nearly all wild chum salmon spawned in Whiskey Creek or Jackson Creek, we assumed that the production of fry from naturally spawning chum salmon in the tributaries of Netarts Bay was about twice that of Whiskey Creek. The mean length of chum salmon fry caught was 40 mm in each of the three years in Whiskey Creek, and 41.0 mm in 1986 in Jackson Creek. Large fry (>45 mm), which were indicative of rearing in freshwater (Mason 1974), were not caught.

Nearly all wild chum salmon fry outmigrated into Netarts Bay by the end of April in all years (Fig. 2). Peak numbers of fry were caught in Whiskey Creek on 25 March 1984, 25 March 1985, 11 April 1985, and 8 April 1986. Numbers of emigrating fish were poorly associated with any measured physical variable. Peak catches of chum fry were not correlated with stream temperatures (Fig. 2), although the second outmigration pulse in 1985 followed an abrupt increase in water temperature. Increased outmigration activity of fry was not associated with phases of the lunar cycle as has been reported for other salmonid fry (Reimers 1973; Mason 1975). Stream flow estimated from stream heights appeared positively correlated with peak numbers of emigrating fry in 1984 when large numbers of fish were sampled during or immediately after three of four periods of high flow. The first peak of outmigration in 1985 also occurred during high stream flow; however, subsequent peaks in 1985 and 1986 occurred during periods of declining flow.

Distribution-Abundance in Netarts Bay

Chum salmon were present in Netarts Bay for about 2½ months, from mid-March until early June during each year (Fig. 3). The seasonal abundances of juvenile chum salmon in Netarts Bay were correlated with the emigration of wild fish from streams and with releases of fish from the Whiskey Creek Hatchery facility. Although small peaks in beach seine catches during late March 1984 and in early April 1986 coincided with the peak of outmigration of wild fish from Whiskey Creek, most of the naturally reared fry migrated into the bay before the major peaks in beach seine catches (Figs. 2, 3). The largest peaks in beach seine catches occurred within a few days after releases from the Whiskey Creek Hatchery in all years.

Catches of juvenile chum salmon were greater in the upper than the lower bay during March and April in all years. Conversely, catches were generally greater in the lower than the upper bay during May and June (Fig. 4). These trends indicate that juvenile chum salmon preferentially inhabited the upper bay early in the spring and then moved into the lower bay in late spring. Movement into the lower bay late in spring was correlated with the high water temperatures that occurred in the upper bay during May of each year.

Juvenile chum salmon appeared to avoid temperatures exceeding 14°C. Although they occurred at most temperatures observed in the upper bay during March and April, they usually inhabited waters of minimum temperatures during May and June, when average water temperatures exceeded 14°C (Fig. 5, left panel). The occurrence of juvenile chum salmon predominantly in the upper bay in early spring coincided with average upper bay temperatures of <15°C. Movements to the lower bay (Fig. 4) coincided with upper bay temperatures exceeding 16°C (Fig. 5, right panel). The percentages of chum

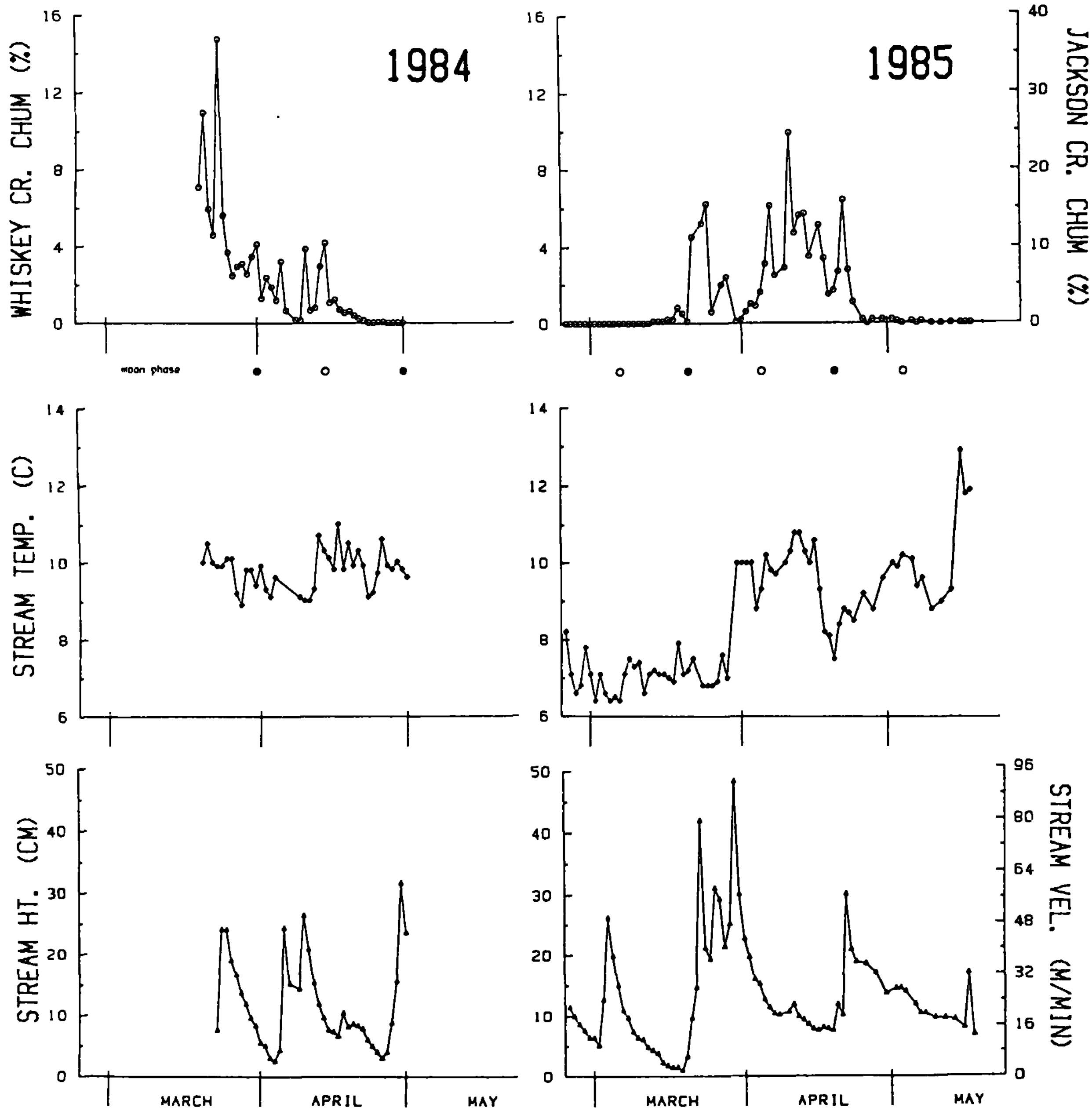

FIGURE 2.—Outmigration of juvenile chum salmon, stream temperatures, and stream height-velocity of Whiskey Creek (1984, 1985, 1986) and Jackson Creek (1986). Solid triangles indicate dates of hatchery releases.

salmon in the upper bay increased only once in all three years when temperatures exceeded 16°C (Fig. 5, 1985).

Schools of chum salmon were sometimes observed in shallow water and variability in the catches of juvenile chum salmon per set was high. The median number of chum caught per set during a sampling date, all stations combined, ranged from 0 to 280. A total of 90 pairs of beach seine sets were made during the three years. The mean (± standard deviation) of the quotient of the largest to smallest numbers of chum caught in the 47 pairs of two sets (each set containing fish) was 5.9 ± 8.8. This indicates that juvenile chum salmon were aggregated in Netarts Bay.

Median catches of juvenile chum salmon during high tide generally exceeded catches at low tide in March and April, and catches at low tide were greater than high tide during May and

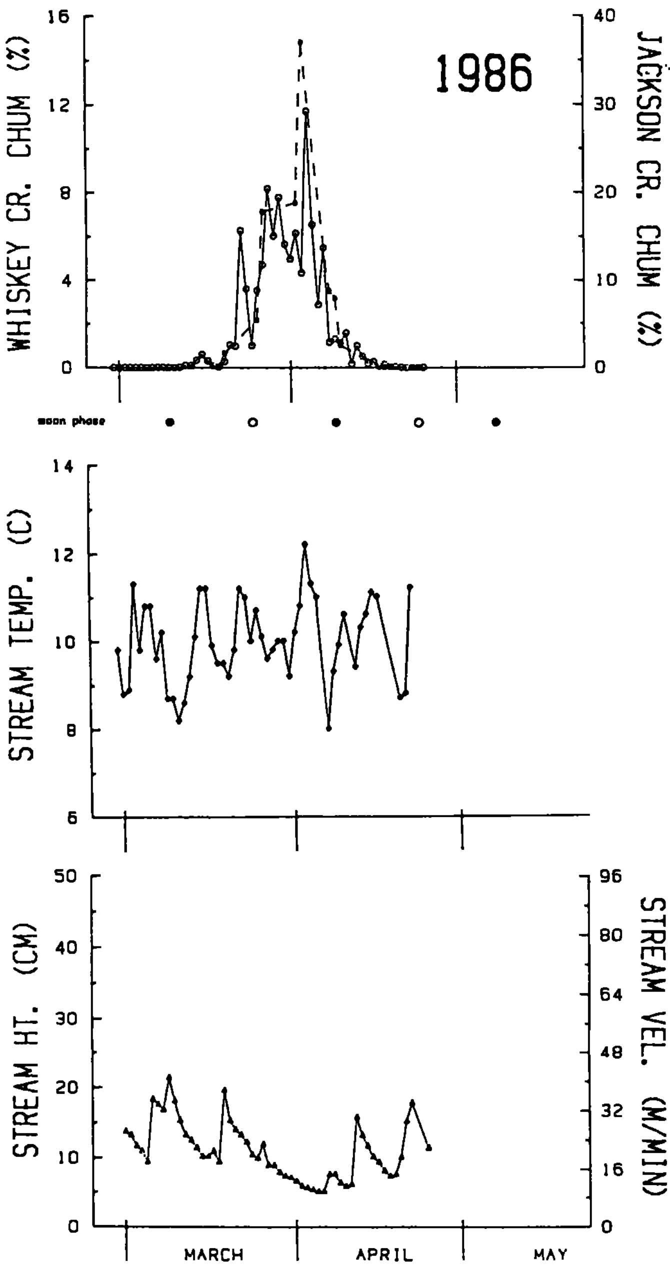

FIGURE 2.—*Continued.*

June of 1984 and 1985 (but not 1986) (Fig. 6). The large catches of juvenile chum salmon along the margins of the bay at high tide, often over 500 m from the low-tide channels in the upper bay, show that they make extensive tidal excursions over the tidal flats during daylight in early spring and actively aggregate along the fringes of the estuary in shallow water.

Juvenile chum were not concentrated in the main channel of lower Netarts Bay between 25 March and 20 June 1985 when tow net hauls were made. Only 38 juvenile chum salmon were caught in the 31 tows (about one fish per 2,000 m^2). Catches in night tows on 22 May were not different from day tows on 21 May (Mann-Whitney U test, $P > 0.1$). Also, the average lengths of chum salmon fish caught in day and night tow net collections and in beach seine collections on 22 May were not significantly different (t-test, $P > 0.1$).

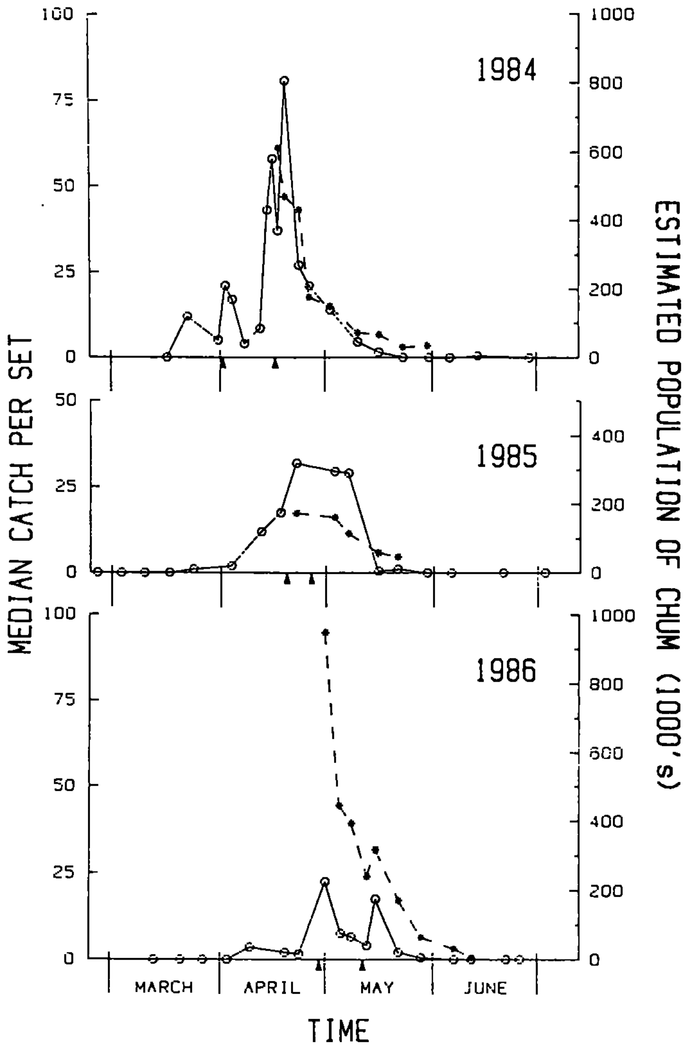

FIGURE 3.—Median catch per beach seine haul of juvenile chum salmon, from all stations combined (solid line) and population estimates based on recaptures of marked fish (dashed line).

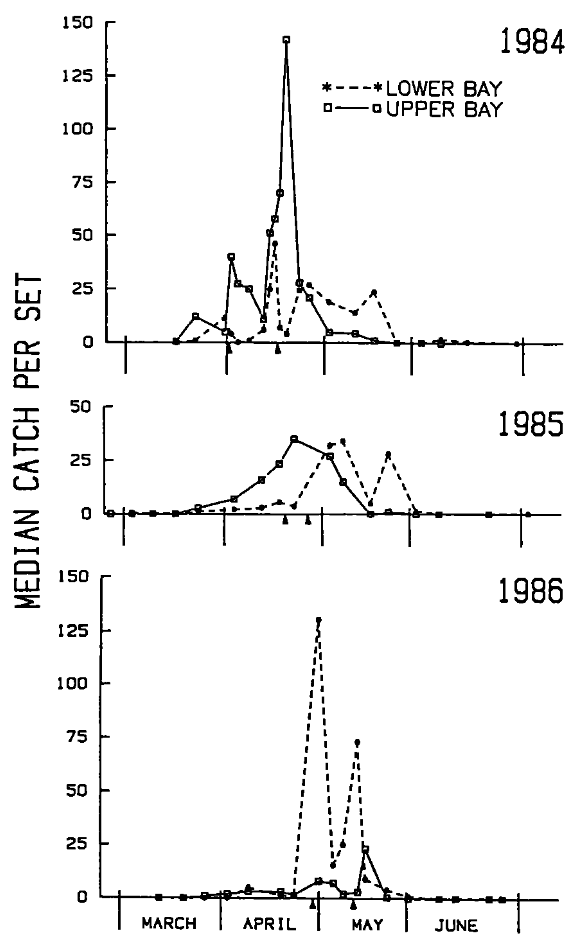

FIGURE 4.—Median catch per seine haul of juvenile chum salmon in the upper (solid line) and lower (dashed line) estuary, and release dates (black triangles).

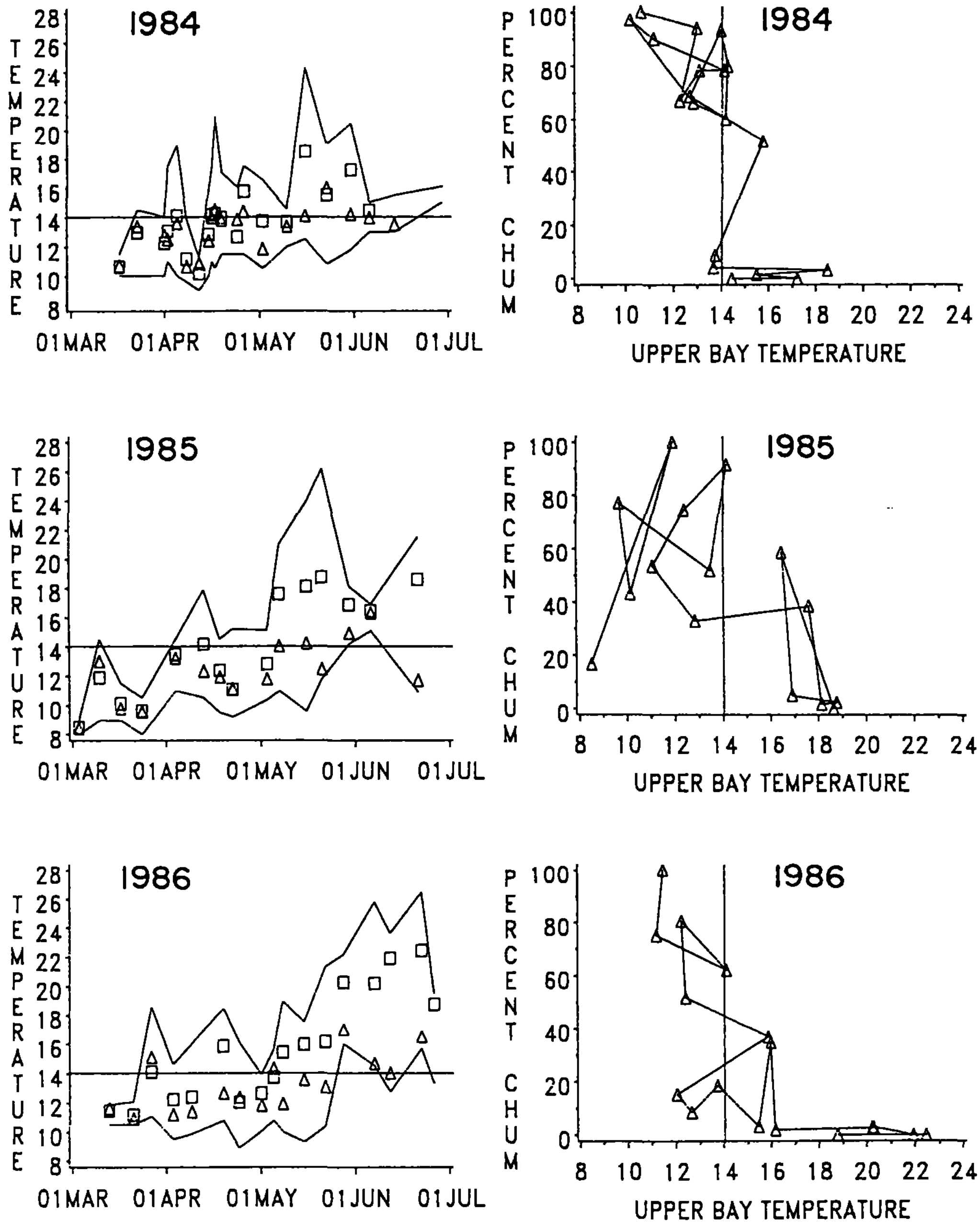

FIGURE 5.—(Left) average temperatures occupied by chum salmon (triangles), average upper bay temperatures (squares) and maximum and minimum temperatures temperatures per collection period (solid lines), and (Right) the percent of juvenile chum salmon collected in upper bay stations vs. average upper bay temperatures (lines connect sequential sampling periods) for 1984, 1985, and 1986. Reference lines indicate 14°C.

Residence Times – Loss Rates

Population estimates based on the total catch showed that the number of marks present, and numbers of marked fish recaptured (Equation (1)), rapidly declined during 1984 and 1986 (Fig. 3 dashed lines; Table 2). The trends shown by mark and recapture estimates and by median seine haul catches were similar in 1984 (Fig. 3). Population estimates on 17 and 18 April 1984 and 3 and 4 May 1985 (1–2 days and 7–8 days after release of all marked fish) were 30% and 57% smaller than the actual numbers of fish released, suggesting rapid decline in numbers soon after release. In 1986, however, the initial population estimate was 55% larger than the number of fish released a week earlier. Marked fish released in April 1986 probably experienced higher mortal-

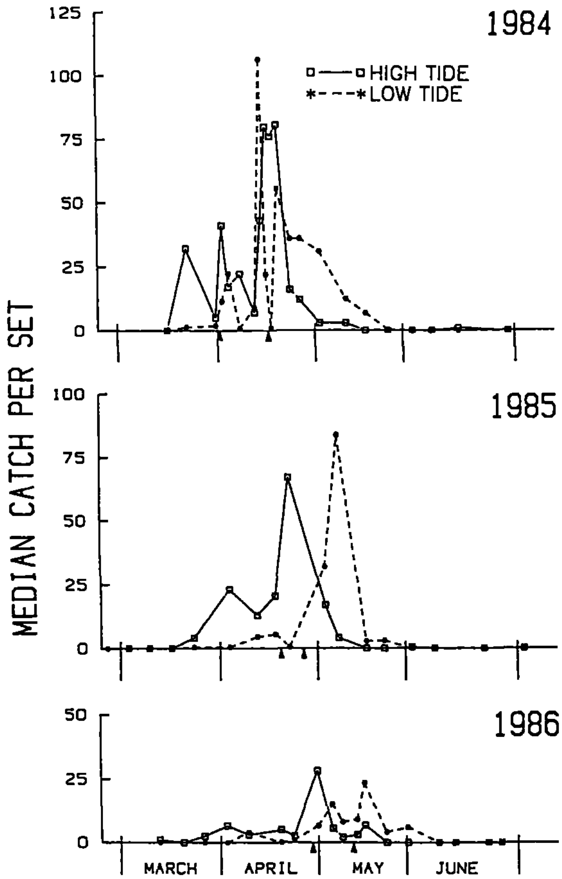

FIGURE 6.—Median catches per seine haul of chum salmon at high tide (solid line) and low tide stations (dashed line), 1984–86. Solid triangles indicate dates of hatchery releases.

ity after release than unmarked fish as a result of the added stress of marking and the debilitating bacterial disease that afflicted this release group. As a result of higher mortality of marked fish, R was low and M was probably overestimated, leading to overestimation of the population (N_t, Equation (1)).

Higher loss rates were found for small than for large fish hatchery chum salmon in Netarts Bay from the decline in the natural logarithm of catch per effort of fin-clipped fish (Table 3). In 1986, the residence half-life (the time for the catch rates to decrease by one-half (Myers and Horton 1982)) was 7.4 days for fish released at 1.0 g, 4.9 days for fish released at 2.2 g and <2 days for fish released at 6.5 g. None of the largest fish was captured 2 days after release or during subsequent sampling. Presumably these large fish emigrated rapidly from the estuary. An anomaly in the trend for loss rates to be positively correlated with size of juvenile chum salmon released arose for the 1.9 g right ventral (RV) clipped fish in 1984. Their residency half-life was 16 days, about the same as for 0.75 g fish released on the same day, and three times that of 1.9 g fish released in 1985 (Table 3). The significantly higher ($P < 0.01$, analysis of covariance) residency half-lives of fish released in 1984 than in other years may have arisen because these fish were released earlier in the spring. In other years, early release groups also had longer half-lives than later groups, but the slopes of the catch vs. time were not significantly different ($P > 0.05$).

Juvenile chum salmon actively maintained themselves in the bay. Residency half-lives of marked chum were 10–30 times longer than predicted from random loss with tidal flushing. Assuming that the mean intertidal volume of Netarts Bay is 75% of the total volume at MHW (Glanzman et al. 1971; Kreag 1979) and does not reenter the bay on subsequent tidal cycles, the half-life of water in Netarts Bay is <0.5 day.

Growth

Instantaneous growth rates in weight of fin-clipped chum salmon averaged 1.6–2.3% body weight per day (Table 3). No differences (analysis of covariance, $P > 0.05$) were found in growth in weight among these groups released within or among years. However, linear growth rates estimated from changes in fork length over time indicate that fish released at a smaller size grew more rapidly in 1984 (0.48 mm/d for 46 mm fish vs. 0.41 mm/d for 52 mm fish) and in 1986 (0.53 mm/d for 48 mm fish vs. 0.33 mm/d for 62 mm fish). Growth rates were similar for both 56 mm vs. 59 mm fish in 1985. Slopes derived from linear regression of mean individual lengths of all fish during a sampling period vs. elapsed time in days did not differ significantly ($P > 0.05$) from the rate of increase of lengths of marked fish in 1984, 1985, or 1986. These slopes were also similar among years. Increases in mean length probably reflected growth. None of the regressions of FL vs. time showed trends for decreasing size late in the spring that would be due to emigration of large individuals from the bay.

Biomass-Production

The biomass of juvenile chum salmon in Netarts Bay, estimated from population numbers (N_t) and average weight of the marked groups of fish during the week after release of

TABLE 2.—Estimates of the mean weight and length, of the population numbers based on marked fish, of the population biomass, and of the cumulative production of juvenile chum salmon in Netarts Bay, 1984–86.

	Average (g)	Average (mm)	Estimate number × 1000 (N_t)	biomass (kg)
1984				
17–18 April	1.6	56	610.5	977
19–20 April	1.6	56	468.0	772
23–24 April	1.9	59	429.6	816
26–27 April	1.8	58	176.6	323
2–3 May	1.9	58	150.3	280
10–11 May	2.1	62	71.1	151
16–17 May	2.1	62	65.9	141
23–24 May	2.9	62	28.6	84
30–31 May	3.2	71	34.2	109
Cumulative biomass (45 d)(kg)		13,591		
Instantaneous growth rate		0.02075		
Total production (kg)		282		
22–23 April	1.5	54	173.3	253
3–4 May	1.8	58	161.1	284
7–8 May	1.8	58	114.7	207
15–17 May	2.2	63	58.3	130
21–22 May	1.9	60	46.0	89
Cumulative biomass (19 d)(kg)		6,169		
Instantaneous growth rate		0.01675		
Total production (kg)		103		
1986				
1 May	0.8	45	947.4	805
5 May	1.0	47	444.5	449
8–9 May	1.1	49	392.6	440
13 May	1.4	53	240.0	331
15–16 May	1.4	53	317.3	444
21–3 May	1.7	57	171.1	294
28–29 May	1.9	60	63.4	122
7 June	2.6	65	30.6	78
12 June	2.6	66	5.3	14
Cumulative biomass (45 d)(kg)		11,154		
Instantaneous growth rate		0.0211		
Total production (kg)		235		

TABLE 3.—Data on the releases into Whiskey Creek, and the residency half-lives and growth rates of marked juvenile chum salmon in Netarts Bay, 1984–86.

Release data	Length at release (mm)	Weight at release (g)	Mark	Residency half-life (d)	Growth rate (% wt/d)
1984					
16 April	46	0.75	LV	14.94	2.27
16 April	58	1.9	RV	15.89	1.88
1985					
19 April	56	1.8	RV	5.54	1.61
26 April	59	1.9	LV	4.95	1.74
1986					
28–29 April	48	0.97	RV	7.38	2.26
11 May	62	2.2	RV + A	4.92	1.96
11 May	92	6.5	LV + A	<2.0	

both groups of marked hatchery fish, were estimated about 800–980 kg in 1984, 250–280 kg in 1985, and 450–800 kg in 1986 (Table 2). Increases in the biomass, indicative of accumulation of biomass from growth exceeding loss of biomass from migration or mortality, were not apparent in any year.

Total production or net growth of juvenile chum salmon (a product of the cumulative biomass over all days after the release of marked fish times the instantaneous growth rate of marked fish) measured 282 kg, 103 kg, and 235 kg in 1984, 1985, and 1986, respectively (Table 2). Total production is underestimated because production before the release of marked fish is not included. These production estimates are only 32%, 38%, and 37% of the estimated average biomass of the first two collection periods after releases in 1984, 1985, and 1986, respectively.

DISCUSSION

Netarts Bay is an important nursery area for juvenile chum salmon. Despite the small size and high flushing rate of Netarts Bay, juvenile chum salmon were captured during about a 2 mo duration in all three years. This is about the same duration as reported for wild juvenile chum salmon in Yaquina Bay, Oregon (Myers and Horton 1982), but is less than the three or more months reported for Tillamook Bay, Oregon (Henry 1953; Forsberg et al. 1977), Grays Harbor, Washington (Herrmann 1970), the Skagit River salt marsh, Washington (Congelton et al. 1982), and the Nanaimo Estuary, British Columbia (Healey 1979, 1982a). Juvenile chum salmon were reported in Hood Canal from January through July by Bax (1982). The mean residence times (see Healey 1979 for equation) of marked groups of hatchery-reared juvenile chum salmon (0.75–2.2 g at release) ranged from 5 to 23 days in Netarts Bay. These residence times are about the same as those found by Healey (1979) in the Nanaimo Estuary, but were more than the residence time of about 2 days in a small tidal channel reported by Congelton et al. (1982). Clearly, juvenile chum actively maintain themselves in many estuaries during early development.

Catches of juvenile chum salmon in the bay declined rapidly over time. The proportions lost from emigration and mortality are difficult to separate. Healey (1982a) concluded that some fish immediately emigrated from the Nanaimo and Nitinat Estuaries. Bax (1982) reported initial dispersal of marked hatchery fish, and net movements of 3–14 km/d for juvenile chum salmon in the elongated fjord of Hood Canal that would rapidly remove chum salmon from a small estuary. Lannan (1983) noted fish and bird predation on juvenile chum salmon in Netarts Bay. Most of the fish predation was caused by cutthroat trout, *Oncorhynchus clarki*, during downstream migration of chum fry and by Pacific staghorn sculpin, *Leptocottus armatus*, as fry entered the bay (J. Lannan, pers. comm.[3]). We examined 57 large (>100–215 mm FL) staghorn sculpin, 34 cutthroat trout (95–365 mm FL), and 28 coho salmon (95–156 mm FL) caught in our beach seine collections in Netarts Bay and found three juvenile chum salmon in staghorn sculpin stomachs and one in a coho salmon stomach. Gulls, mergansers, cormorants, and herons were common in the bay, but we have no data on their food habits. Harbor seals, *Phoca vitulina*, were also common in Netarts Bay in late spring; their scats were analyzed, but otoliths of juvenile salmon were not identified (Brown and Mate 1983), perhaps because the smallest sieve they used had a mesh size of 0.5 mm, a mesh that would retain otoliths of only large juvenile chum.

The distribution of juvenile chum salmon in Netarts Bay, with higher catches generally in the upper than lower bay early in the spring, and the reverse later in the spring is similar to that found by Healey (1979, 1982a) in the Nanaimo Estuary, by Myers and Horton (1982) in Yaquina Bay, and by Forsberg et al. (1977) in Tillamook Bay; but in the Nitinat Estuary no evidence of seaward progression was found (Healey 1982a). In Netarts Bay, juvenile chum salmon moved extensively over the tidal flats, aggregating in shallow water during periods of both high and low tide (cf. Mason 1974; Forsberg et al. 1977; Healey 1979, 1982a). In late spring, fish curtailed their movements into shallow warm waters of the upper bay at high tide and were concentrated instead in the lower estuary.

Based on limited pelagic sampling, we found no evidence for movement of fish into the deep channel areas of the lower bay later in the season. Juvenile chum salmon larger than 45–55 mm were caught in large numbers at some shallow seine stations in the lower bay in May and June. Some individuals were as large as 89

[3]J. Lannan, Oregon State University, Hatfield Marine Science Center, Newport, OR 97365, pers. commun. 22 December 1988.

mm and over 4 g wet weight. Fish averaged over 60 mm and 2 g by the end of May in all years (Table 2). Many juvenile chum salmon apparently stayed in shallow water in Netarts Bay beyond the size of 45–55 mm, the length at which they are thought to migrate from shallow estuarine waters into open neritic waters of other estuaries (Kaczyinski et al. 1973; Healey 1980a, 1982b; Simenstad and Salo 1980; Myers and Horton 1982). Large chum salmon apparently did not aggregate in the deep channels of Netarts Bay but emigrated directly out of the bay into open coastal waters.

The average size of juvenile chum salmon increased during their residence in Netarts Bay, as well as in Tillamook Bay (Forsberg et al. 1977), Yaquina Bay (Myers and Horton 1982), and Grays Harbor (Herrmann 1970). This increase suggests growth. Since large chum salmon are thought to emigrate more rapidly than small chum (Healey 1982a) and recruitment of downstream migrants may be prolonged, these estimates based on size-frequency distributions probably underestimate growth rates. The growth rates for marked chum salmon in Netarts Bay, 0.4–0.6 mm/d and 1.6–2.3% body weight (BW)/d, may also be underestimates if rapidly growing fish exit the bay sooner than slow growing fish. Growth rates of juvenile chum salmon in Netarts Bay are considerably less than the 1 mm/d and 6% BW/d estimated from marked juvenile chum in the Nanaimo Estuary (Healey 1979, 1982a) and the 8.6% BW/d for marked chum in Hood Canal (Bax and Whitmus 1981), but they are more similar to the 0.8 mm/d and about 4.2% BW/d for unmarked juvenile chum salmon in the Fraser River and Gulf Islands (Phillips and Barraclough 1978; Healey 1982b), the 2.7% BW/d for unmarked chum in Nitinat Lake, and the 0.4 mm/d found for unmarked chum in Steamer Bay, southeastern Alaska (Murphy et al. 1988). They are also similar to the growth rates of juvenile chum reared in saltwater aquaria at daily rations of 6–10% BW/d (Volk et al. 1984).

The cumulative biomass of juvenile chum salmon in Netarts Bay (13.6, 6.2, and 11.2 × 10^3 kg) was generally lower than the 14–66 × 10^3 kg estimated for naturally reared chum salmon in the similarly sized Nanaimo Estuary by Healey (1979). Total production of juvenile chum in the Nanaimo Estuary during the two years studied was 1,100–2,400 kg (or 0.2–0.4 g/m^2 of intertidal area), over an order of magnitude higher than that estimated in Netarts Bay (0.01–0.03 g/m^2 of intertidal area). This suggests that the carrying capacity of Netarts Bay for juvenile chum is limited. However, we found no evidence for density-dependent growth. Growth rates and residence times were about the same among years with several-fold differences in numbers of fry released and estimated biomass of juvenile chum salmon in the estuary (Tables 1, 2, 3). Production may be limited by the short residence times of large hatchery fish released late in the spring as well as by environmental factors other than direct competition for food.

Elevated water temperatures may affect growth of juvenile chum salmon, especially since Netarts Bay is at the southern extremity of the spawning range of this species in the northeastern Pacific Ocean. Kepshire (1971) reported an optimum temperature of 13°C for growth of juvenile chum salmon, and at 15°C, a temperature often recorded in Netarts Bay, food consumption was higher than at lower temperatures, but food conversion efficiency and growth were low. Irie (1984) found that ocean temperatures where juvenile chum salmon were found along the coast of Hokkaido were below 14°C. Juvenile chum salmon in Netarts Bay may also be excluded from the best foraging habitat by high temperatures. Densities of crustacean prey were highest in the intertidal areas of the upper bay (Chapman unpubl. data) where highest temperatures occurred. Costs of metabolism, food conversion, prey capture, and swimming may limit allocation of energy to growth when temperatures are above optimal (Brett 1979; Wissmar and Simenstad 1988).

Growth efficiencies may also be influenced by the quality and quantity of available prey. Small harpacticoid copepods (viz., *Harpacticus uniremis*) have been found to predominate the diet of juvenile chum salmon in estuaries (Healey 1979; Sibert 1979; Simenstad and Salo 1980; Simenstad and Wissmar 1984) where growth rates are high, whereas large amphipods predominated the diet in Netarts Bay (Chapman, unpubl. data), and mollusk larvae, hyperiid amphipods, and larvaceans were important prey for juvenile chum salmon in Steamer Bay, AK (Murphy et al. 1988) where growth was slower. Large prey, such as amphipods, may require more energy to capture because of highly developed escape responses (Volk et al. 1984), may be digested less efficiently because of their thick chitinous exoskeletons (Pandian 1967; Brett and Groves 1979), and may have lower per unit weight caloric value (Cummins and Wuycheck

1971) than smaller prey, such as harpacticoid copepods. Volk et al. (1984) reported that food conversion efficiency was much higher for juvenile chum salmon fed harpacticoid copepods than larger amphipods. All these factors could affect growth. Furthermore, pelagic calanoid copepods, hyperiid amphipods, and larvaceans, known to be important prey for large (>45 mm) juvenile chum salmon as they move to open neritic waters (Simenstad and Salo 1980), were not abundant in Netarts Bay, perhaps further constraining growth and production in this small estuary.

A possible strategy to circumvent the need for estuarine rearing where habitat quality limits production is to release juvenile chum salmon at a large size. Healey (1980a, 1982a) observed that seaward movement of juvenile chum salmon is size-dependent, with large fish moving offshore first. Juvenile chum salmon entering estuaries late in the spring also emigrate after a short time (Sibert et al. 1977; Ioka 1978). In Japan, juvenile chum salmon reared in salt water (Kobayashi 1980) migrate to the open sea within a week after release and chum salmon reared to a large size (8 g) return to hatcheries at a high rate (Ioka unpubl. data).

Our experimental releases of different sizes of fry indicate that large juvenile chum salmon do not utilize Netarts Bay as a nursery area. The large (6.5 g) chum we released in 1986 apparently migrated immediately to the ocean. When these fish returned to Whiskey Creek as adults in 1988 (presumably at age 3, based on the age structure of previous runs (Lannan 1983; J. Fisher unpubl. data)), the ratio of fish with missing left: right ventral fins was 2:1 (W. McNeil, pers. commun.[4]). This ratio was 0.6:1 in the juvenile chum salmon released in 1986 (Table 1). This suggests that these large (6.5 g) juvenile chum salmon that were not dependent on the estuary survived at rates that were 3–4 times higher than the smaller (1.0–2.2 g) fish released that year. More experiments are needed to confirm these results. Rearing chum salmon fry to a large size may be a useful method to enhance hatchery runs into estuaries, especially if size-selective predation is intensified by retarded growth owing to high temperatures or low availability of prey. Furthermore, large hatchery fish released late in the spring may have minimal adverse impacts on wild stocks.

[4]W. McNeil, Oregon State University, Hatfield Marine Science Center, Newport, OR 97365, pers. commun., 5 December 1988.

ACKNOWLEDGMENTS

This research was supported by the Oregon State University (OSU) Sea Grant College Program (Grant No. NA 85-AA-D-SG 095, Project R/EM-13), the Northwest Alaska Fisheries Center (Contract 84-ABC-0009 and NA-85-ABN-00025), and Oregon Aqua-Foods, Inc. We thank M. Wilson, M. Bauwman, F. Ratti, R. Brodeur, B. Burkle, A. Chapman, R. Chitwood, M. Duffy, J. Fisher, L. Jang, K. Krefft, P. Lamberson, L. Mahn, and E. Rexstad for their invaluable assistance in the field; D. Miller (Oregon Department of Fish and Wildlife (ODFW)), for the use of a boat; H. Frolander and P. Kalk (OSU College of Oceanography), R. Tubb (OSU Department of Fisheries and Wildlife (DFW)), R. Irish (ODFW), and R. Swartz (U.S. Environmental Protection Agency (USEPA), Hatfield Marine Science Center (HMSC)) for the loan of boats and motors; Hiram Li (OSU, DFW) for the use of a tow net; R. Chitwood and L. Poole (Oregon Aqua-Foods, Inc.) for the loan of net pens and for rearing large chum fry. Marilyn Guin (HMSC) provided extensive help on bibliographic references, Lavern Weber (HMSC) provided laboratory space and facilities at HMSC, and J. Lannan (HMSC) and K. Hopkins (OSU, DFW) provided space at the Whiskey Creek Hatchery necessary to conduct this research. Bryan Coleman (USEPA, HMSC) provided assistance with computers. S. Phillips (OSU, DFW) helped both at the hatchery and in the field. We also thank A. Schoener, M. Healey, W. McNeil, C. Simenstad, and two anonymous reviewers for comments on the manuscript.

LITERATURE CITED

Bailey, J. E., B. L. Wing, and C. R. Mattson.
1975. Zooplankton and abundance and feeding habits of fry of pink salmon, *Oncorhynchus gorbuscha*, and chum salmon, *Oncorhynchus keta*, in Traitors Cove, Alaska, with speculations on the carrying capacity of the area. Fish. Bull., U.S. 73:846–861.

Bax, N. J.
1982. Seasonal and annual variations in the movement of juvenile chum salmon through Hood Canal, Washington. *In* E. L. Brannon and E. O. Salo (editors), Salmon and trout migratory behavior symposium, p. 208–218. Univ. Wash., Seattle.

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., and C. J. Whitmus.
1981. Early marine survival and migratory behavior of juvenile chum salmon released from the Enetai Hatchery, Washington in 1980. Univ. Wash. Fish. Res. Inst. Rep. 8109, 48 p.

Brett, J. R.
1979. Environmental factors and growth. *In* W. S. Hoar, D. J. Randall, and J. R. Brett (editors), Fish physiology, Vol. VIII, p. 599–675. Acad. Press, N.Y.

Brett, J. R., and T. D. D. Groves.
1979. Physiological energetics. *In* W. S. Hoar, D. J. Randall, and J. R. Brett (editors), Fish physiology, Vol. VIII, p. 279–352. Acad. Press, N.Y.

Brown, R. R., and B. R. Mate.
1983. Abundance, movements, and feeding habits of harbor seals, *Phoca vitulina*, at Netarts and Tillamook Bays, Oregon. Fish. Bull., U.S. 81:291–301.

Chung, A. W., and W. G. Pearcy.
1986. The utilization of Netarts Bay by juvenile chum salmon – 1986. Oregon State Univ. Sea Grant College Prog. ORESU-T-86-002, 50 p.

Congelton, J. L., S. K. Davis, and S. R. Foley.
1982. Distribution, abundance and outmigration timing of chum and chinook salmon fry inthe Skagit River marsh. *In* E. L. Brannon and E. O. Salo (editors), Salmon and trout, Migratory behavior symposium, p. 153–163. Univ. Wash., Seattle.

Cummins, K. W., and J. C. Wuycheck.
1971. Caloric equivalents for investigations in ecological energetics. Int. Assoc. Theor. Appl. Limnol. Commun. 18:1–158.

Forsberg, B. O., J. A. Johnson, and S. M. Klug.
1977. Identification, distribution, and notes on food habits of fish and shellfish in Tillamook Bay, Oregon. Oreg. Dep. Fish Wildl., Res. Sect., 117 p.

Glanzman, C. R., B. Glenne, and F. Burgess.
1971. Tidal hydraulics, flushing characteristics and water quality of Netarts Bay. Oreg. State Univ., Eng. Exp. Stn. Bull. 45, 33 p.

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.
1980a. The ecology of juvenile salmon in Georgia Strait, British Columbia. *In* W. J. McNeil and D. C. Hinsworth (editors), Salmonid ecosystems of the North Pacific, p. 203–229. Oreg. State Univ. Press, Corvallis.
1980b. Utilization of the Nanaimo River esturary by juvenile salmon, *Oncorhynchus tshawytscha*. Fish. Bull., U.S. 77:653–668.
1982a. Juvenile Pacific salmon in estuaries: The life support system. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 315–341. Acad. Press, N.Y.
1982b. 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.

Henry, K. A.
1953. Analysis of factors affecting the production of chum salmon (*Oncorhynchus keta*) in Tillamook Bay. Fish. Comm. Oreg. Contrib. 18, 35 p.

Hermann, R. B.
1970. Food of juvenile chinook and chum salmon in the lower Chehalis River and upper Grays Harbor. Wash. Dep. Tech. Rep. 7:59–82.

Ioka, C.
1978. Report on hatchery returns: summary of results of surveys in coastal waters. Can. Fish. Mar. Sci. Trans. Ser. No. 4338, 20 p.

Irie, T.
1984. Ecology of Japanese chum salmon (*Oncorhynchus keta*) in their early marine life. Bull. Jpn. Soc. Fish. Oceanogr. 45:55–60.

Kaczynski, V. W., R. J. Feller, and J. Clayton.
1973. Trophic analysis of juvenile pink and chum salmon (*Oncorhynchus gorbuscha* and *O. keta*) in Puget Sound. J. Fish. Res. Board Can. 30:1003–1008.

Kepshire, B. M., Jr.
1971. Growth of pink chum and fall chinook salmon in heated seawater. Proc. 22nd Annu. Northwest Fish. Cult. Conf., p. 25–26.

Kobayashi, T.
1980. Salmon propagation in Japan. *In* J. E. Thorpe (editor), Salmon ranching, p. 91–107. Acad. Press, N.Y.

Kreag, R. A.
1979. Natural resources of Netarts estuary. Oreg. Dep. Fish Wildl. Estuary. Inventory Rep. Vol. 2, No. 1, 45 p.

Lannan, J. E.
1975. Netarts Bay chum salmon hatchery: an experiment in ocean ranching. Oreg. State Univ. Sea Grant Coll. Program ORESU-H-75-001, 28 p.
1983. Development of a chum salmon broodstock: A case history. *In* P. M. Arana (editor), Proceedings of the International Conference on Marine Resources of the Pacific, p. 329–339. Vina del Mar, Chile.

Levings, C. D.
1984. Progress in attempts to test the null hypothesis that juvenile salmonids aren't dependent on estuaries. *In* W. G. Pearcy (editor), The influence of ocean conditions on the production of salmonids in the North Pacific, p. 287–296. Oreg. State Univ. Sea Grant Program ORESU-W-83-001.

Mason, J. C.
1974. Behavioural ecology of chum salmon fry (*Oncorhynchus keta*) in a small estuary. J. Fish. Res. Board Can. 31:83–92.
1975. Seaward movement of juvenile fishes, including lunar periodicity in movement of coho salmon (*Oncorhynchus kisutch*) fry. J. Fish. Res. Board Can. 32:2542–2547.

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., U.S. 86:213–222.

Myers, K. W., and H. F. Horton.
1982. Temporal use of an Oregon estuary by hatchery and wild juvenile salmon. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 377–392. Acad. Press, N.Y.

Pandian, T. J.
1967. Transformations of food in the fish *Megalops cyprinoides*: I. Influence of quality of food. Mar. Biol. (N.Y.) 1:60–64.

Parker, R. R.
1968. Marine mortality schedules of pink salmon of the Bella Coola area, British Columbia. J. Fish. Res. Board Can. 25:757–794.
1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28:1503–1510.

Pearcy, W. G. (editor).
1984. The influence of ocean conditions on the production of salmonids in the North Pacific. Oreg. State Univ. Sea Grant Program ORESU-W-83-001, 327 p.

Peterman, R. M.
1978. Testing for density-dependent marine survival in Pacific salmonids. J. Fish. Res. Board Can. 35:1434–1450.

Phillips, A. C., and W. E. Barraclough.
1978. Early marine growth of juvenile Pacific salmon in the Stait of Georgia and Saanich Inlet, British Columbia. Fish. Res. Board Can. Fish. Mar. Serv. Tech Rep. No. 830, 19 p.

Reimers, D. E.
1973. The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Res. Rep. Fish. Comm. Oreg. 4(2):1–43.

Sibert, J., T. J. Brown, M. C. Healey, B. A. Kask, and R. J. Naiman.
1977. Detritus-based food webs: Exploitation by juvenile chum salmon (*Oncorhynchus keta*). Science 196:649–650.

Sibert, J. R.
1979. Detritus and juvenile salmon production in the Nanaimo Estuary: II. Meiofauna available as food to juvenile chum salmon (*Oncorhynchus keta*). J. Fish. Res. Board Can. 36:479–503.

Simenstad, C. A., and O. Salo.
1980. Foraging success a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon (*Oncorhynchus keta*) in Hood Canal, Washington. Proc. North. Pac. Aquaculture Symp., p. 21–37. Anchorage, AK.

Simenstad, C. A., and R. C. Wissmar.
1984. Variability of estuarine food webs and production may limit our ability to enhance Pacific salmon (*Oncorhynchus* spp.). *In* W. G. Pearcy (editor), The influence of ocean conditions on the production of salmonids in the North Pacific, p. 272–286. Oreg. State Univ. Sea Grant Program ORESU-W-83-001.

Sokal, R. R., and F. J. Rohlf.
1981. Biometry. W. H. Freeman and Co., N.Y., 859 p.

Snedecor, G. W., and W. G. Cochran.
1980. Statistical methods. Iowa State Univ. Press, Ames, 583 p.

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

Wilson, C. D., and W. G. Pearcy.
1985a. The utilization of Netarts Bay by juvenile chum salmon – 1984. Oreg. State Univ. Sea Grant Coll. Program ORESU-T-85-002, 66 p.
1985b. The utilization of Netarts Bay by juvenile chum salmon – 1985. Oreg. State Univ. Sea Grant Coll. Program ORESU-T-85-005, 62 p.

Wissmar, R. C., and C. A. Simenstad.
1988. Energetic constraints of juvenile chum salmon (*Oncorhynchus keta*) migrating in estuaries. Can J. Fish. Aquat. Sci. 45:1555–1560.