UTILIZATION OF THE NANAIMO RIVER ESTUARY BY JUVENILE CHINOOK SALMON, *ONCORHYNCHUS TSHAWYTSCHA*

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ABSTRACT

Chinook salmon are considered, normally, to spend from a few months to a year rearing in freshwater before migrating to sea. Although large downstream movement of fry, recently emerged from spawning gravels, has been observed in several river systems, it has been suggested that most of these migrant fry are lost to the population. This report describes the fate of downstream migrant chinook salmon fry in the Nanaimo River, British Columbia. In 1975 and 1976 most of the potential fry production from the river system was estimated to have passed by a trapping location near the river mouth. Many of these fry were subsequently found rearing in the intertidal area at the river mouth where salinity was commonly above 20‰. Very few chinook salmon fry were captured at other sampling sites within a 10 km radius of the river mouth. Juvenile chinook salmon were present in the intertidal area of the estuary from March to July each year, but peak numbers occurred in April and May. Peak estuary population was estimated to be 40,000-50,000 in 1975 and 20,000-25,000 in both 1976 and 1977. While in the estuary, chinook salmon grew about 1.32 mm per day or 5.8% of their body weight per day. Individual fish probably spent an average of about 25 days rearing in the estuary and left the estuary when about 70 mm fork length. While in the estuary, juvenile chinook salmon fed on harpacticoid copepods, amphipods, insect larvae, decapod larvae, and mysids. After leaving the estuary, they fed mainly on juvenile herring. The stomach content of chinook salmon captured in the estuary averaged 5% of body weight or less, and varied seasonally and between years. It appears that in the Nanaimo and probably in other systems with well-developed estuaries, that the estuary is an important nursery for chinook salmon fry.

After they emerge from the spawning gravel in early spring, chinook salmon, *Oncorhynchus tshawytscha,* are considered, normally, to spend from a few months to a year in freshwater before migrating to sea (Reimers and Loeffel 1967; Stein et al. 1972; Mehan and Siniff 1962; Lister and Walker 1966). Recently, Reimers (1971) and Dunford (1975) showed that juvenile chinook salmon may also spend considerable time rearing in estuaries after their downstream migration and before moving into high salinity water. Although juvenile chinook salmon are known to occur in a number of British Columbia estuaries (Goodman[2]; Hoos and Vold[3]; Bell and Kallman[4]; Bell and Kallman[5]), the importance of estuarine habitats as nursery areas for young chinook salmon is not well documented. The purpose of this report is to present information on the utilization of the Nanaimo River estuary and adjacent marine areas by juvenile chinook salmon and to consider the importance of the estuary to the stock. Specifically, I shall discuss the timing of downstream movement and abundance of chinook salmon fry in the river; their distribution, abundance, and length of residence in the estuary and in marine waters adjacent to the estuary; and their growth rate and food habits. In this report the term "fry" refers to juvenile chinook salmon that recently emerged from the spawning gravel, often still with externally visible yolk.

METHODS

River Sampling

Downstream migrating chinook salmon fry were captured in seven inclined plane fry traps

[1]Department of Fisheries and Oceans, Resource Services Branch, Pacific Biological Station Nanaimo, B.C., Canada V9R 5K6.

[2]Goodman, D. 1975. A synthesis of the impacts of the proposed expansion of the V.I.A. and other developments on the fisheries resources of the Fraser River estuary. Unpubl. manuscr., 137 p. + append. Environ. Can., Fish. Mar. Serv., Vancouver.

[3]Hoos, L. M., and C. L. Vold. 1975. The Squamish River estuary: Status of environmental knowledge to 1974. Environ. Can., Fish. Mar. Serv. Spec. Estuary Ser. 2, 361 p.

[4]Bell, L. M., and R. J. Kallman. 1976. The Cowichan-Chemainus River estuaries: Status of environmental knowledge to 1975. Environ. Can., Fish. Mar. Serv. Spec. Estuary Ser. 4, 328 p.

[5]Bell, L. M., and R. J. Kallman. 1976. The Nanaimo River estuary: Status of environmental knowledge to 1976. Environ. Can., Fish. Mar. Serv. Spec. Estuary Ser. 5, 298 p.

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anchored in two narrow stream channels near the mouth of the Nanaimo River (Figure 1). (These traps were similar in design to those described by Lister et al. 1969.) The mouth opening of each trap was 30 cm wide by 60 cm deep. Four traps were set side by side in one channel and three in the other. Nylon netting of 5 cm mesh was run between the traps and shore in an attempt to lead additional fry into the traps. The traps were operated in 1975 and 1976 and were set and fished the same way each year. In 1975 the traps were in place from early March to late May, while in 1976 they were in place from early April to late May. Although the main river flow was down a third channel to the west of the traps, a significant fraction of the chinook salmon run passed down the trapping channels and, as will be shown later, the traps captured about 1.5% of the run.

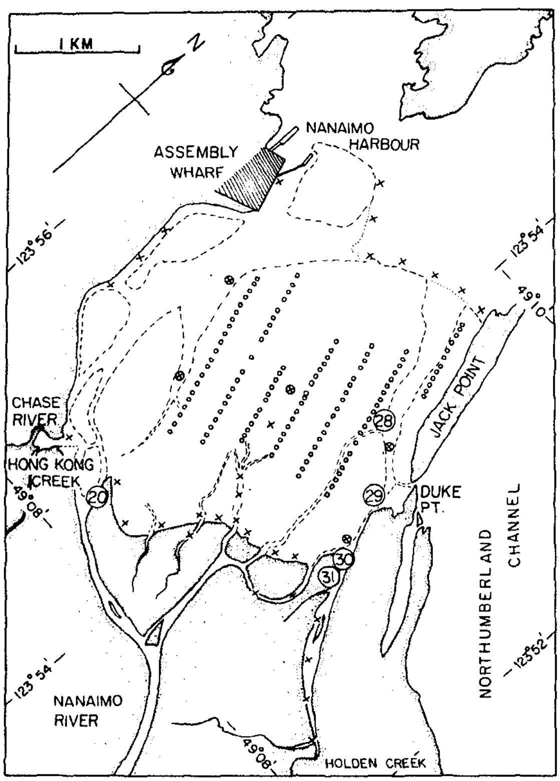

FIGURE 1.—The Nanaimo River estuary. Vancouver Island, showing the location of the fry traps (20) for juvenile chinook salmon; the stations sampled weekly on the east arm of the river and Holden Creek, (28), (29), (30), (31); the general location of seine sets made to determine the distribution of chinook salmon fry in the estuary, ×; and the location of purse seine sets made over the intertidal flats at high tide, ⊗. Small circles show the location of pilings to which log rafts are moored. Most raft storage is on the west side.

Fry captured in the traps between 0800 h of 1 day and 0800 h of the next were counted as a single day's catch. In 1975 the fry were held in live pens in the river and marked a few hours after capture by spraying with fluorescent grit (Healey et al.[6]). After they were sprayed, the fry were held a further 24 h to recover and then were released in the late evening into the river about 2.5 km upstream from the traps. Most mortality from marking occurred in 24 h and was normally <5% (Healey et al.[7]). Each daily catch was examined for marked fry, and total daily run was estimated by mark recapture techniques (Ricker 1975; Healey et al. see footnote 7). In 1976 the fry captured each day were counted and released downstream from the trapping site.

By changing the color of marking grit several times during the run I determined that, on average, 75% of recaptures from a single release were made the night of release, a further 17% on the next night, and the remaining 8% over the next 14 nights. I assumed that these percentages represent the proportions of the marked fry which migrate the night of release or delay migration one or more days. Also, <100% of sprayed fry received a mark. Samples of marked fry examined a few days after spraying showed that usually 95% or more of the fry were marked. The total number of marked fry migrating downstream each night was, therefore, estimated to be the number of fry released, corrected for the proportion unmarked, minus the number expected to delay migration, plus the number expected to be migrating from previous releases. Total daily run was estimated as the product of daily catch and the estimate of marks migrating divided by the number of recaptures. Trap efficiency was the ratio of recaptures to estimated marks migrating.

During about half the trapping days in 1975 no recaptures were made. On these days the run was estimated as the trap catch divided by the overall estimate of trapping efficiency for the year (total recaptures/total marks migrating). Total run in 1976 was estimated from the overall estimate of efficiency for 1975.

[6]Healey, M. C., F. P. Jordan, and R. M. Hungar. 1976. Laboratory and field evaluating of fluorescent grit as a marking material for juvenile salmonids. Fish. Res. Board Can. Manuscr. Rep. 1392, 17 p.

[7]Healey, M. C., R. V. Schmidt, F. P. Jordan, and R. M. Hungar. 1977. Young salmon in the Nanaimo area 1975: 1. Distribution and abundance. Fish. Res. Board Can. Manuscr. Rep. 1369, 161 p.

During April and May 1975, samples of downstream migrant chinook salmon were measured for fork length (millimeters) and wet preserved weight (±0.01 g) to provide an estimate of the body size of downstream migrants.

During 1975 and 1976 the temperature of the river near the trapping site was measured morning and evening. Daily discharge of the river was available from Inland Waters Directorate, Environment Canada, Ottawa. The measurements were made about 12 km upstream from the traps.

Estuary Sampling

In the intertidal area of the estuary most sampling was by beach seine (18 m long × 3 m deep of 12 mm mesh). Stream channels crossing the intertidal mud flat and the delta front were sampled at low tide, and the edges of the tidal marshes at high tide. During March and April 1975 widely scattered locations on the estuary were sampled, but during the latter half of April and May, sampling was concentrated in the east channel of the river and Holden Creek (Figure 1) at low tide. During 1976 and 1977 four specific sampling sites were established in the east channel of the river and Holden Creek and these were fished weekly (Stations 28-31; Figure 1) except that Station 28 was not fished until June 1976, and fishing at Stations 30 and 31 was discontinued after the chinook salmon disappeared from these stations. Sampling at other locations at high and low tide was performed occasionally, as time permitted, to determine the distribution of chinook salmon in the estuary. In addition to beach seining, five sets with a 90 × 7 m hand-hauled purse seine were made over the intertidal mud flat at high tide on 12 May 1976 to determine if juvenile chinook salmon remained over the mud flat at high tide. Catch data are presented as average catch-per-set (CPUE) in this report.

Estuary sampling began during the second or third week of March of each year. In 1975, sampling terminated in early June; in 1976, in mid-July; and in 1977, at the end of June. In 1975, samples of chinook salmon for analysis of length, weight, and stomach contents were preserved in only 6 of 12 sampling weeks. In 1976 and 1977, however samples of 20 or more were preserved each week.

In 1977, temperature (° C) and salinity (per mil) were measured at the time of beach seining at each sampling location in the east channel of the river and Holden Creek with a Yellow Spring Instruments Model 33 Thermister/Salinometer[8].

In 1977 the total population of chinook salmon in the estuary was estimated twice by mark and recapture techniques. Between 18 and 21 April, 3,187 chinook salmon were captured along the east channel of the river and Holden Creek, mainly at Stations 30 and 31, marked with a left pelvic fin clip, and released at the point of capture. Catch and recaptures were recorded on 19-22 April, and on all subsequent sampling days. Between 16 and 19 May, 1,554 chinook salmon captured mainly at Stations 28 and 29 were marked with a right pelvic fin clip. Recaptures of these marks were recorded on 17-19 May, 22 May, and all subsequent sampling days.

Recaptures after the final mark release for each fin clip provided an estimate of the rate of disappearance of marked fish from the sampling area. This rate was assumed constant for each mark and was calculated as the slope of the regression of $\log_e$ (CPUE marks) on days since marking. In calculating the rate for left pelvic clips, catches during the second marking period were ignored since sampling on these days was performed in a way to maximize catch, and was different from our normal sampling procedure. The number of marks released was reduced each day in accordance with these estimated rates of disappearance to give an estimate of the total marks present on each sampling day. Population estimates for each day were, therefore, the product of total catch and estimated marks present divided by recaptures. Left pelvic marks were still present at the time of the second marking, so that it was possible to make two independent estimates of population size at this time.

A sample of chinook salmon was preserved from those captured each day for marking, and these provided an estimate of the average size of marked fish at the time of release. Marked fry captured after the last release of each fin clip were preserved and their fork length and weight measured to provide an estimate of growth rate.

Marine Sampling

Up to 18 different locations within a 10 km radius of the river mouth were sampled in 1975 and 12 locations in 1976 (Figure 2). In 1975 nine

[8]Reference to trade names does not imply endorsement by Fisheries and Oceans, Canada, or by the National Marine Fisheries Service, NOAA.

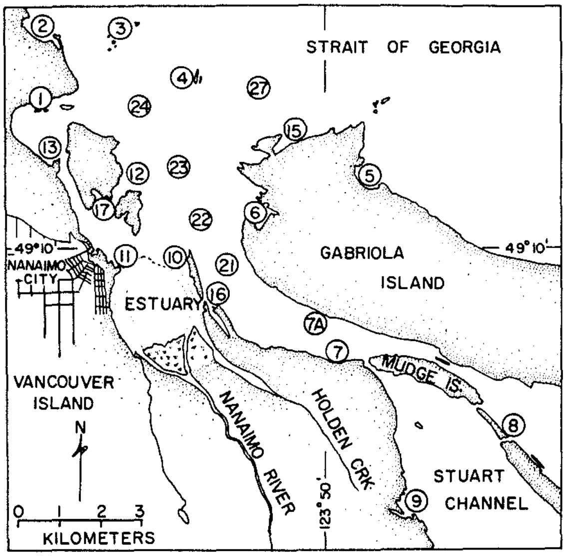

FIGURE 2.—Map of the Nanaimo area, Vancouver Island, showing the locations where beach seine and purse seine sets were made for juvenile chinook salmon (circled numbers).

locations (1, 2, 4, 5, 8, 9, 15, 16, 17; Figure 2) were sampled during the second and third week of May by beach seine (18 × 3 m). Twelve locations (1, 2, 5, 6, 7, 8, 9, 10, 11, 13, 15, 17; Figure 2), were sampled weekly from March to July by hand-hauled purse seine (90 × 7 m). Sixteen locations (1, 2, 3, 4, 5, 6, 7a, 8, 9, 10, 11, 12, 13, 21, 22, 23, 24; Figure 2) were sampled weekly from April to July by drum seine (216 × 18 m), except locations 21-24 which were sampled at 2-wk intervals from late May until early July. In 1976 seven locations (1, 2, 4, 5, 6, 16, 17; Figure 2) were sampled weekly from April to June by beach seine. Ten locations (1, 2, 4, 5, 6, 7a, 10, 23, 24, 27; Figure 2) were sampled by drum seine weekly from early April until the end of July, then approximately monthly until March 1977. In 1977, Area 10 was sampled weekly from late April to late August by the 90 m hand-hauled purse seine.

Sample Processing

Fork length and weight of preserved fish were measured in all years, and in 1976 and 1977, stomach analyses were also performed. The lengths of fish in small catches at sea were occasionally measured at the time of sampling and the fish released. This was especially true of early catches in 1975. In 1977, fish captured by the hand-hauled purse seine in Area 10 were all measured for length, and a subsample of 15-20 was preserved for weight and stomach analyses. Scales of some of the preserved fish from both 1976 and 1977 were examined under 20 × magnification to determine age structure of the catch. Preserved samples were sometimes not analyzed until weeks or months after capture so preserved weights are likely to overestimate live weights. Length, however, is only slightly affected by preservation (Parker 1963).

Wet weights of the stomach contents of individual fish from the intertidal area of the estuary were measured in 1975. Sample size was small except for the 9 May sample (see Table 6). In 1976 and 1977, dry weight of the stomach contents of 10-20 fish from the estuary and a similar sample from off the estuary was recorded each week and converted to percent of body weight by assuming that preserved fish were 20% (average of >20 determinations) dry matter.

Detailed taxonomic analysis of stomach contents was not made. However, in 1976 and 1977 the dominant components of the stomach contents of each sample were recorded.

DESCRIPTION OF STUDY AREA

The Nanaimo River discharges into the Strait of Georgia just south of the City of Nanaimo on the east coast of Vancouver Island (Figure 2). It supports spawning populations of chinook; coho, *O. kisutch;* and chum, *O. keta,* salmon as well as steelhead, *Salmo gairdnerii,* and cutthroat trout, *S. clarki.* Since 1950, chinook salmon escapement has averaged 2,100 spawners, and there has been a gradual decline in abundance from 3,700 spawners between 1950 and 1954 to 1,400 between 1972 and 1976 (Aro[9]; Canada, Fisheries and Marine Service[10]). Adult chinook salmon enter the river between April and October, and spawn from September to November (Aro see footnote 9). In 1974, 1975, and 1976 (the brood years reported in this study) escapement was estimated to be 2,400, 525, and 1,100 respectively.

The delta estuary of the river occupies about 9 km^2 of which about 6 km^2 is intertidal mud flat (Figure 1). At the southern margin of the delta the

[9]Aro, K. V. 1973. Salmon and migratory trout of the Nanaimo River and adjacent streams (Revised 1973). Fish. Res. Board Can. Manuscr. Rep. 1284, 15 p.

[10]Annual stream bank estimates of spawning escapement available from Fisheries and Oceans, Canada, Field Services Branch, 1090 West Pender Street, Vancouver, B.C..

river divides into two main channels which cross the intertidal mud flat on the east and west sides. The west channel carries most of the flow, however, and during low river flows in the spring and summer a gravel berm blocks the east channel, probably preventing any fish movement down this channel. Holden Creek flows across the delta on the east side and joins the east channel of the river about half way across the intertidal mud flat. Hong Kong Creek and Chase River enter the delta from the west and join the west channel of the river near the upper margin of the mud flat. The mud flat between the two main channels of the river is dissected by numerous small stream channels fed by seepage from the main river channels. The smaller streams contributing to the delta do not support chinook salmon spawning but do support chum and coho salmon.

Salt marshes at the top of the delta are dominated by black grass, *Juncus gerardii*. The intertidal area has three floral associations: *Fucus-Salicornia* in the upper tidal area, *Ulva-Enteromorpha* in the midtide area, and *Zostera-Ulva* in the low tide area (Foreman[11]). *Zostera* extends in a band across delta front, and well up the east channel of the river.

The intertidal area of the delta is used for log storage by local sawmills and a pulp mill. Part of the northwest corner of the estuary has been filled in during development and expansion of the Port of Nanaimo. Intermittent dredging occurs at the delta front to keep the shipping lane into Nanaimo Harbor open. Some dyking has occurred along the southern margin of the delta to create farm land. Further details of physical and biological features of the estuary and adjacent lands are given in Bell and Kallman (see footnote 5).

Seaward from the intertidal area of the delta a wide variety of habitats provide potential nursery area for juvenile salmon, from sheltered bays and lagoons to exposed rocky or sandy beaches. Many of these habitats were sampled during 1975 and 1976 to estimate the extent of utilization of habitats away from the river mouth as nursery areas (Figure 2). Some details of the physical and biological features of the habitats sampled are given by Healy et al. (see footnote 7). Apart from sampling locations 10, 11, and 17, within the Nanaimo Harbor area (Figure 2), salinity was usually above 27‰, while spring and summer temperature ranged 6°-15° C (Healey et al. see footnote 7).

RESULTS AND DISCUSSION

Downstream Run of Fry

Downstream movement of the chinook salmon fry had two peaks in 1975, the first on 19 April and the second 14 days later (Figure 3). Fry were moving in small numbers throughout March, but most movement occurred in April and May. A total of 10,876 fry entered the traps between 10 March and 24 May.

Trapping began on 8 April 1976, and chinook salmon were already moving downstream. One peak occurred in the 1976 run, although isolated large catches occurred before and after the peak (Figure 3). Only 4,360 fry entered the traps in 1976 suggesting that the total run was about half that in 1975.

Downstream migrants averaged 38.3 mm long (0.57 g) and ranged 33-45 mm long (0.33-1.02 g). Many of the fry still had visible yolk.

River discharge during the the fry run in 1975 ranged 16-100 m^3/s, and increases in fry run were generally associated with increases in discharge.

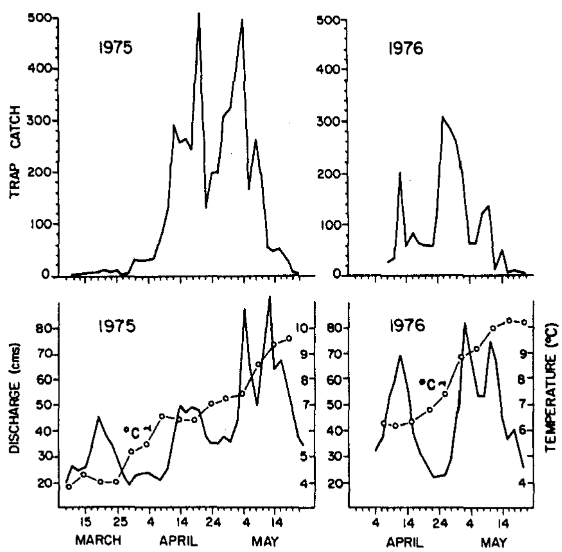

FIGURE 3.—The trap catch of chinook salmon fry (upper panels), river discharge (solid line lower panels), and weekly average river temperature (circles, lower panels) in 1975 and 1976 in the Nanaimo River. Trap catch and discharge are averaged at 2-day intervals for ease of plotting.

[11]Foreman, R. E. 1975. Nanaimo River estuary macrophyte study: Seasonal aspects of macrophyte distribution and standing crop on the Nanaimo River estuary mudflats. BERP Rep. 75-3, final report on Fish. Mar. Serv. Contract OSU4-0217 prepared by R. E. Foreman, Botany Dep., Univ. B.C., 41 p.

Temperature in 1975 ranged 3.1°-11.2° C and was increasing during the run. Greatest fry movement in this year occurred when river temperature was 6°-9° C (Figure 3). In 1976 discharge ranged 18-91m³/s and was higher early in the season than in 1975. Increases in the 1976 fry run often preceeded increases in discharge (Figure 3). River temperature ranged 5.0°-13.3° C and greatest fry movement was when temperature was 8°-11° C (Figure 3).

In addition to temperature and discharge, the catch of chinook salmon in the traps was probably influenced by tide. The traps were set very near the river mouth and at high tide flow past the traps was often negligible. To examine the potential contribution of discharge, river temperature, and tide height to variations in trap catch, I performed a stepwise multiple regression analysis on the data. The dependent variable was trap catch and the independent variables were river discharge, river temperature (morning and evening measurements averaged), average tide height during three periods of the "trapping day" (0800-1800 h, 1800-0000 h, 0000-0800 h), and Julian day of capture. I performed separate analyses on catches preceding and following the peak catch each year. The hypotheses tested were: 1) catch is positively correlated with discharge and temperature and negatively correlated with tide height for all data sets; 2) catch is positively correlated with day of capture prior to peak catch and negatively correlated after peak catch.

The regression analysis failed to confirm or reject either of these hypotheses unequivocally. Discharge was positively correlated with trap catch while catches were increasing, but was not correlated while catches were decreasing (Table 1). Temperature was not significantly correlated with catch in any of the analyses. Tide height was negatively correlated with trap catch while catches were increasing as predicted. While catches were decreasing, however, tide height was uncorrelated with trap catch in 1975 and positively correlated in 1976 (Table 1). The correlation of trap catch with Julian day was positive while catches were increasing and negative while catches were decreasing, as predicted, except that the correlation with increasing catch was not significant in 1976 (Table 1). The multiple correlation coefficients were highly significant and explained 50-79% of the variation in trap catch (R^2, Table 1). Some of the results, like the positive correlations between trap catch and tide height, were counterintuitive, however, and cast doubt on any interpretation of the regression analysis. In spite of these difficulties the regression analysis suggests that discharge and tide height may have influenced trap catch, while temperature probably did not.

Recaptures of marked fry in the traps in 1975 ranged 0-16.6% of the daily estimate of marks migrating. The ratio of recaptures to marks migrating for the whole run was 0.0175, indicating an overall trap efficiency of 1.75% (Table 2).

Peterson estimates of total daily run were made

TABLE 1.—Results of stepwise multiple regression analysis of fry trap catch of juvenile chinook salmon regressed on river discharge, river temperature, average tidal height during three daily time periods (0800-1800 h, 1800-2400 h, 2400-0800 h) and Julian day of capture. Only the regression coefficients for the variables that made a significant ($P<0.05$) contribution to the multiple regression are shown.

Independent variable	Partial Regression coefficient 1975	1976	Standardized partial regression coefficient 1975	1976	Multiple correlation coefficient (R) 1975	1976	R^2 1975	1976
Analysis 1: trap catch from first capture to maximum capture: n = 53, 1975; n = 24, 1976								
Discharge	+0.20	+0.40	0.481	0.800				
Temperature	—	—	—	—				
Tidal height:								
0800-1800	—	—	—	—				
1800-2400	—	−15.0	—	0.160				
2400-0800	−78.0	—	0.162	—				
Julian day	+ 6.3	—	0.507	—				
All significant variables					0.873	0.710	0.76	0.51
Analysis 2: trap catch from maximum capture to last capture: n = 22, 1975; n = 31, 1976								
Discharge	—	—	—	—				
Temperature	—	—	—	—				
Tidal height:								
0800-1800	—	+159.8	—	1.77				
1800-2400	—	+122.0	—	1.55				
2400-0800	—	—	—	—				
Julian day	−22.3	−14.2	0.705	1.10				
All significant variables					0.705	0.891	0.50	0.79

TABLE 2.—Trap catch, estimate of marks migrating downstream, recaptures in the traps, and estimated daily run of chinook fry in the Nanaimo River in 1975. Population estimates in italics were derived from trap catch divided by average trap efficiency (0.0175). All other estimates are Peterson type estimates.

Date	Trap catch	Marks migrating	Recap-tures	Population estimates	Date	Trap catch	Marks migrating	Recap-tures	Population estimates
Mar. 10	2	0	0	*114*	Apr. 17	200	251	3	16,733
11	2	0	0	*114*	18	481	254	8	15,272
12	1	0	0	*57*	19	776	206	10	15,986
13	6	0	0	*342*	20	261	265	21	3,294
14	6	1	0	*342*	21	152	569	9	9,610
15	2	2	0	*114*	22	100	309	4	7,725
16	3	5	0	*171*	23	166	179	0	*9,474*
17	2	3	0	*114*	24	227	116	2	13,166
18	4	3	0	*228*	25	372	162	8	*7,533*
19	7	2	0	*400*	26	56	120	0	*3,196*
20	11	4	0	*628*	27	425	107	0	*24,255*
21	9	6	1	54	28	190	66	0	*10,844*
22	6	10	0	*342*	29	249	333	2	41,459
23	8	8	0	*457*	30	396	210	2	41,580
24	15	6	0	*856*	May 1	324	233	6	12,582
25	5	8	1	40	2	509	337	5	34,307
26	6	11	0	*342*	3	822	326	2	133,986
27	2	6	0	*114*	4	167	383	6	10,660
28	2	6	0	*114*	5	202	684	19	7,272
29	9	3	0	*514*	6	133	284	4	9,443
30	11	3	0	*628*	7	272	202	5	10,989
31	61	1	0	*3.481*	8	234	144	4	8,424
Apr. 1	14	15	0	*799*	9	497	238	11	10,753
2	49	49	0	*2,797*	10	440	218	6	15,987
3	27	22	0	*1,541*	11	312	409	2	63,804
4	54	39	0	*3 082*	12	104	397	2	20,644
5	36	29	1	1,044	13	48	327	2	7,848
6	57	49	3	931	14	65	150	1	9,750
7	75	37	0	*4,280*	15	51	78	0	*2,911*
8	67	35	0	*3,824*	16	47	60	1	2,820
9	92	64	2	2,944	17	48	59	0	*2,739*
10	173	66	2	5,709	18	66	48	0	*3,767*
11	194	81	0	*11,072*	19	20	45	0	*1,141*
12	381	138	1	52,578	20	14	59	0	*799*
13	293	177	2	25,930	21	5	29	1	145
14	215	311	3	22,288	22	4	18	0	*228*
15	276	288	3	26,496	23	3	6	0	*171*
16	256	210	3	17,920	24	1	6	0	*57*

for 37 days of the 1975 run and ranged 40-133,986 fish/day. The sum of these estimates was 687,568 chinook salmon, and total trap catch for the days when estimates were made was 9,188. The ratio of catch to total run for the Peterson estimates was 0.013, indicating only 1.3% trap efficiency. This estimate was strongly influenced, however, by the large population estimate for 3 May, which resulted from a large catch in which there were few recaptures (Table 2). Ignoring this estimate, the ratio of trap catch to Peterson population estimates was 0.0151, closer to the average efficiency based on mark recaptures.

Population estimates for all days of the run totaled 784,155 in 1975. Assuming trap efficiency was similar in 1976, the run was about 300,000 during the trapping period.

Although most chinook salmon are expected to go to sea after about 2 mo of residence in their natal stream, downstream movement of fry shortly after emergence has been observed in other systems. In the Big Qualicum River, 100 km north of the Nanaimo, between 3,000 and 241,000 fry migrated downstream mainly in March and April from 1961 to 1965, although the time of greatest movement varied from late March to early May (Lister and Walker 1966; Lister and Genoe 1970). The fry migration was followed by a fingerling migration in June which was usually larger than the fry migration. In the Cowichan River, 50 km south of the Nanaimo River, a large downstream movement of fry was recorded during March and April in 1966 and 1967 followed by a smaller fingerling movement in June (Lister et al.[12]). The survival of these fry and their contribution to the adult population were unknown, but presumed to be slight (Lister and Walker 1966).

The number of chinook salmon fry, estimated to have migrated downstream in the Nanaimo River in 1975 and 1976, was 5-10 times greater than in the Big Qualicum River which has a similar escapement (Lister and Walker 1966). This

[12]Lister, D. B., C. E. Walker, and M. A. Giles. 1971. Cowichan River chinook salmon escapement and juvenile production 1965-1967. Can. Dep. Fish. For. Tech. Rep. 1971-3, 48 p.

raises the question: What proportion of the fry population migrates out of the Nanaimo River each year? Information on sex and age of the 1974 and 1975 spawning population in the Nanaimo River is not available so egg deposition can only be surmised. If one assumes, however, that of the 2,400 escapement in 1974, 800-1,000 were females, and that of the 525 spawners in 1975, 200-225 were females, and that the fecundity of Nanaimo River chinook salmon is in the range 6,000-8,000 (Godfrey[13]; Schutz[14]), then potential egg deposition in 1974 was on the order of 6-6.5 million, and in 1975 on the order of 1.2-1.6 million. (The female population was estimated to be <50% of the escapement because of the "jacks.") In the winters of 1974 and 1975 there were no extreme freshets, so survival was probably quite good, perhaps as high as 15-20% (Lister and Walker 1966; Coots[15]). Fry production may be estimated to be, therefore, on the order of 0.9-1.3 million in 1975 and 0.18-0.32 million in 1976. These values are similar to the estimated fry migration each year and indicate that a high proportion of Nanaimo River chinook salmon left the river as recently emerged fry.

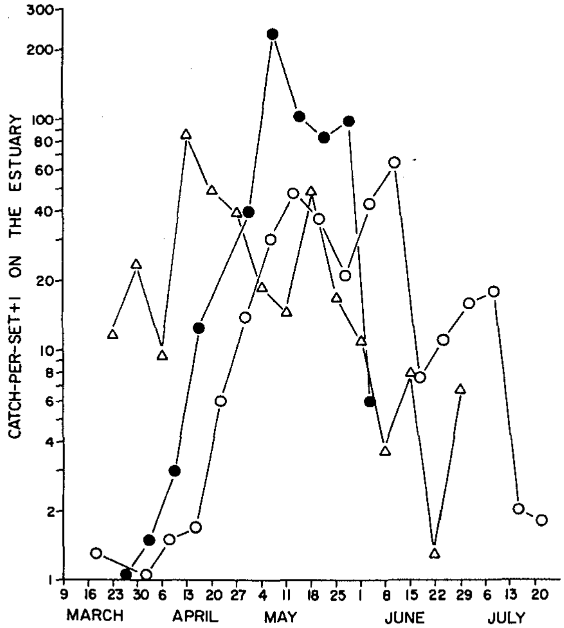

FIGURE 4.—Catch of chinook salmon fry per beach seine set at Stations 28-30 on the Nanaimo River estuary in 1975 (dots), 1976 (circles), and 1977 (triangles).

Distribution and Relative Abundance of Chinook Salmon in the Estuary

Sampling in the intertidal area of the estuary revealed chinook salmon were abundant there in spring and early summer of each year (Figure 4). Juvenile chinook salmon were first captured at the beginning of April 1975, were most abundant in May, and had declined in abundance by early June when sampling terminated (Figure 4). Chinook salmon were captured from mid-March until late July 1976 but increased in abundance later than in 1975, and were generally less than half as abundant as in 1975. Juveniles were already abundant in the estuary when sampling began in late March 1977 and reached maximum abundance in early April, 3 wk earlier than in 1975 and 1976 (Figure 4).

Greatest catches of chinook salmon were in the east channel of the Nanaimo River and Holden Creek. Catches in other stream channels crossing the intertidal mud flat and along the delta front at low tide were small by comparison. Catches in the stream channels in the center of the mud flat averaged only two fish/set, and on the west side of the delta only one chinook salmon was captured in eight sets.

Catches across the delta front at low tide averaged eight fish/set. At the same time catches in the east channnel and Holden Creek averaged 20-40 chinook salmon/set. Catches along the edges of the salt marshes at high tide were lower than in the east channel in 1975, but of similar size in 1977. Purse seine sets over the intertidal flats at high tide, even near locations 29 and 30 where chinook salmon were abundant at low tide, produced no chinook salmon (Figure 1).

Catches at Stations 28-31 in 1976 and 1977 indicated that the area of greatest concentration of juvenile chinook salmon moved seaward along the channel as the season progressed (Table 3). The difference in time of maximum abundance between Station 31 and Station 28 was about 5 wk.

Physical conditions during low tide at the sampling stations along the east channel and Holden

[13]Godfrey, H. 1968. Ages and physical characteristics of maturing chinook salmon of the Nass, Skeena, and Fraser rivers in 1964, 1965 and 1966. Fish. Res. Board Can. Manuscr. Rep. 967, 38 p.

[14]Schutz, D. C. 1975. Rivers Inlet chinook sport fishery, 1971-1974. Environ. Can. Fish. Mar. Serv. Tech. Rep. PAC/T-75-9, 24 p.

[15]Coots, M. 1957. The spawning efficiency of king salmon (*Oncorhynchus tshawytscha*) in Fall Creek, Siskiyou County 1954-55 investigations. Calif. Dep. Fish Game, Inland Fish. Branch, Inland Fish. Adm. Rep. 57-1:1-15.

TABLE 3.—Catch of juvenile chinook salmon per beach seine set at different points along the east channel of the Nanaimo estuary during 1976 and 1977. Station locations are shown in Figure 1.

Sampling week starts	Station 28	29	30	31	Sampling week starts	Station 28	29	30	31
Mar. 21, 1976					Mar. 20, 1977		22.5	5.5	4.0
28					27		16.0	22.0	30.0
Apr. 4		0.0	0.5	1.0	Apr. 3	6.5	7.5	1.5	18.5
11		0.3	0.0	0.5	10	0.5	158.5	76.5	99.5
18		0.5	3.5	8.0	17	12.0	31.4	76.0	58.9
25		20.0	13.0	10.0	24		12.0	79.5	23.0
May 2		2.0	15.5	37.0	May 1	35.0	35.0	7.5	1.5
9		34.5	63.7	31.0	8	20.0	24.0	11.5	0.0
16		64.5	24.0	3.0	15	63.8	47.9	3.5	2.0
23		50.0	9.0	1.0	22	31.0	23.0	7.5	2.0
30		68.0	0.0		29	36.0	0.5	1.5	1.5
June 6	85.7	32.5			June 5	6.0	4.5	0.0	0.0
13	3.0	7.3			12	13.5	0.5		
20	1.5	25.0			19	0.0	1.0	0.0	0.0
27	31.5	5.0			26	11.5	0.0		
July 4	21.5	13.0							
11	2.0	0.0							
18	1.0	0.5							

Creek varied considerably with season in 1977. Temperature ranged 9.5°-26.0° C and salinity 2-24‰ (Table 4). In general, temperature increased at all stations from April through June, but this was strongly influenced by variations in river discharge and weather conditions on the day of sampling. Salinity increased throughout the season, but was also dependent on river discharge and local conditions. Large, local variation in physical conditions was indicated by measurements of temperature and salinity at two locations at Stations 28 and 30 in May and June. At Station 28 a small steam channel joined the main east channel. Temperature of the river above where this stream entered was usually lower, and on one occasion 4.5° C lower, than below the entrance. Salinity above the entrance of this stream channel was sometimes higher and sometimes lower than below the entrance, the greatest observed difference being 6‰ (Table 4). At Station 30, Holden Creek joined the east channel of the river. The river was usually cooler than Holden Creek, although on one occasion it was warmer, and salinity of the river was usually lower than Holden Creek. Temperature and salinity values reported, therefore, should be taken as indications of the kind of conditions in which the fish lived at low tide, with considerable latitude for selection by the fish.

The appearance of juvenile chinook salmon in the intertidal area of the estuary was coincident with the buildup of the downsteam run and the rate of increase in catch on the estuary was similar to the cumulative increase in the number of chinook salmon which had moved downstream. In both 1975 and 1976 the estuary population con-

TABLE 4.—Temperature (° C) and salinity (‰) at sampling locations for juvenile chinook salmon on the Nanaimo estuary during 1977. Station locations are shown in Figure 1.

Sampling week starts	Station 28		Station 29		Station 30		Station 31	
	° C	‰	° C	‰	° C	‰	° C	‰
Apr. 3	12.0	16.0	12.0	14.8	13.0	9.5	12.0	10.5
10	10.5		9.5		15.5		15.3	
17	13.0	20.0	13.6	17.8	12.7	13.0	17.8	11.0
24			11.8	2.0	17.0	10.4	17.2	11.3
May 1	17.0	22.8	15.0	12.8	15.8	14.3	20.0	17.0
8	18.0	20.8	18.2	19.8	21.3	21.6	21.4	20.4
					17.0	18.1		
15	16.7	[1]22.1	16.1	22.2	15.0	[2]19.0	15.4	17.8
	18.2	24.5			14.6	20.0		
22	15.8	[1]20.0	15.2	20.8	15.6	[2]22.2	16.9	18.3
	18.2	24.5			15.1	20.4		
29	13.0	[1]20.0	13.2	21.6	13.3	[2]20.6	13.8	19.1
	13.0	14.0			15.1	20.4		
June 5	19.0	[1]17.5	19.0	20.0	25.1	[2]19.8	26.0	19.4
	23.5	14.0			19.9	18.9		
12	19.0	[1]17.8	18.7	18.2	—	—		
	19.3	17.4			19.9	[2]18.9		
19	21.0	24.6	20.2	24.6	20.5	24.0	24.0	24.0
26	21.0	[1]22.3	19.0	22.0	—	—		
	20.3	23.2			19.9	[2]18.9		

[1]Upper measurement above small tributary, lower below small tributary.
[2]Upper measurement in Holden Creek, lower in main river channel.

tinued to increase after the peak in the downstream run. These observations indicated that the fry which migrated downstream remained in the estuary for some time.

At low tide the chinook salmon population in the estuary was clearly concentrated in the east channel of the river and Holden Creek. Some juveniles were found in stream channels crossing the center of the mud flat, and some also found their way down to the delta at low tide. The channels crossing the western side of the mud flat, however, were little used by juveniles.

With the incoming tide the chinook salmon moved to the landward margin of the mud flat and at high tide were found in scattered schools all across the landward margin of the intertidal area. Apparently no chinook salmon, or very few, remained over the intertidal flats at high tide The redistribution of chinook salmon on each tidal cycle, and their concentration in one of several low tide refuges implied active habitat selection. Active selection of habitats at low tide is further indicated by the seaward movement of the center of the population in the east channel and Holden Creek as the season progressed.

The habitats in which chinook salmon were captured ranged from a few centimeters to a meter or more in water depth, on gravel, sandy, or muddy substrates, with and without eelgrass, *Zostera* sp. In the east river channel, concentrations of fry were found mainly in pools and back eddies. There were, however, no obvious qualitative differences between preferred sites in Holden Creek where chinook salmon were abundant and stream channels crossing the central and west sides of the intertidal area where chinook salmon were scarce. The upstream portions of the stream channels in the central area of the delta, where they cut through the marsh areas, were used as low tide refuges in early spring. Where these stream channels cross the intertidal mud flat deep pools are scarce and the water flow small. These features may have made them unsuitable as refuges during May. The absence of chinook salmon from the west branch of the river could not be explained in this way; however, disturbance of the estuary by log rafting is greatest along the west branch and this may have influenced chinook salmon distribution.

Temperature and salinity in the east channel of the river and Holden Creek indicated that the chinook salmon were tolerating moderate salinities and relatively high temperatures. Occasional measurements of temperature and salinity in other areas sampled at low and high tide were comparable with those in the east channel at low tide. Weisbart (1968) reported that juvenile chinook salmon (parentage not identified) were intolerant of direct transfer from freshwater to 31.8‰ seawater, but that they had greater resistance to seawater than either coho or sockeye salmon, *O. nerka.* McInerney (1964) reported that juvenile chinook salmon from the Samish hatchery, Washington State, avoided all salinites above 0‰ except for a brief preference for about 5‰ salinity in September tests. Presumably both tolerance and preference for salinity will vary among stocks of salmon, and Nanaimo River chinook salmon appear adapted to life in moderate salinity on the estuary. Temperatures experienced by the chinook salmon at low tide were within their tolerance range but were generally above the 12°-13° C reported to be their preferred temperature (Brett 1952).

Seasonal changes in the low tide distribution of chinook salmon were not obviously correlated with temperature and salinity in the east channel and Holden Creek. Temperature at the upstream stations often, though not always, exceeded that at the downstream stations. Chinook salmon were not captured at Stations 30 and 31 when temperature there exceeded 20° C. They were present at Stations 28 and 29, however, when temperature was 20°-21° C. Salinity was only slightly higher on the average at the downstream stations, and often the salinity at the upstream stations was the same or slightly higher than downstream (Table 4). Increasing adaptation to salinity, therefore, appeared not to be a factor in this seaward movement. Possibly the disappearance of chinook salmon from the shallow sampling stations in Holden Creek as the season progressed was an avoidance of the high temperatures that occurred there on sunny days.

The seasonal pattern of abundance of juvenile chinook salmon in the Nanaimo estuary was the same as that observed by Dunford (1975) in the Fraser River, but different from that in the Sixes River, Oreg. (Reimers 1971). In the Sixes River, most chinook salmon apparently spent some weeks in the river before moving into the estuary, although some were considered to have moved directly to the estuary, and some even directly to the sea. Reimers (1971) did not present information on the temperature and salinity of the estuary habitats he sampled. Dunford (1975) gave temperature measurements for two habitat types in the Fraser estuary, and these were lower than in similar areas of the Nanaimo River. Chinook salmon disappeared from Fraser River marsh habitats when temperature reached about 15° C (Dunford 1975).

Size and Growth of Chinook Salmon in the Nanaimo Estuary

Length and weight of chinook salmon captured in the intertidal area of the estuary were only slightly greater than those of downstream migrants throughout the fry run. Toward the end of the fry run, however, average length and weight of chinook salmon captured in the estuary increased rapidly and leveled off at around 70 mm fork length (FL) and 4.2 g (Figure 5). Chinook salmon captured in 1976 were slightly smaller on the average, than those captured in 1975, while those captured in 1977 were the largest of all. Average size of chinook salmon captured in 1977 increased rapidly 3-4 wk earlier than in 1975 and 1976, in keeping with the apparently earlier downstream run in 1977. The differences in size of chinook salmon captured in the 3 yr were not large, at least early in the sampling, and probably reflected differences in the timing of migration rather than differences in growth rate. The small change in length and weight of chinook salmon in the estuary during March and April probably resulted from continued recruitment of downstream migrant fry to the estuary population, while the increase in May and June reflected growth of the fish residing in the estuary. Seventy millimeters fork length is apparently the size at which chinook salmon leave the estuary and disperse into the marine environment. No young-of-the-year <70 mm were captured away from the estuary. The smallest young-of-the-year captured in area 10 were 70-75 mm FL. Weisbart (1968) commented that 70 mm was about the size at which juvenile chinook salmon became physiologically capable of tolerating high salinity water.

The increase in size of chinook salmon on the estuary in June was not representative of their true growth rate, as it was influenced by both the continued immigration of small fish from the river and the emigration of fish reaching 70 mm FL. Recaptured fin clipped fish in 1977, however, provided an estimate of the growth rate of a known group of juveniles. Total mark recaptures sampled for length and weight were 36 left pelvic clips and 19 right pelvic clips. Left pelvic clips averaged 44 mm and 0.92 g when marked, and five of these recovered 47 and 57 days after marking averaged more than 100 mm and 13 g (Table 5). Right pelvic clips averaged 63 mm and 3.36 g when marked, and increased to more than 100 mm and 13 g after 29 days (Table 5). The linear regressions of length or $\log_e$ weight on days since marking indicated no significant difference in the rate of growth between the two marked groups. The data were, therefore, combined by scaling to 0 length and weight at the day of release and growth rates were calculated for the combined data. Growth in length was 1.32 mm/day. Instantaneous daily growth in weight was 0.0566, or about 5.8% of body weight/day.

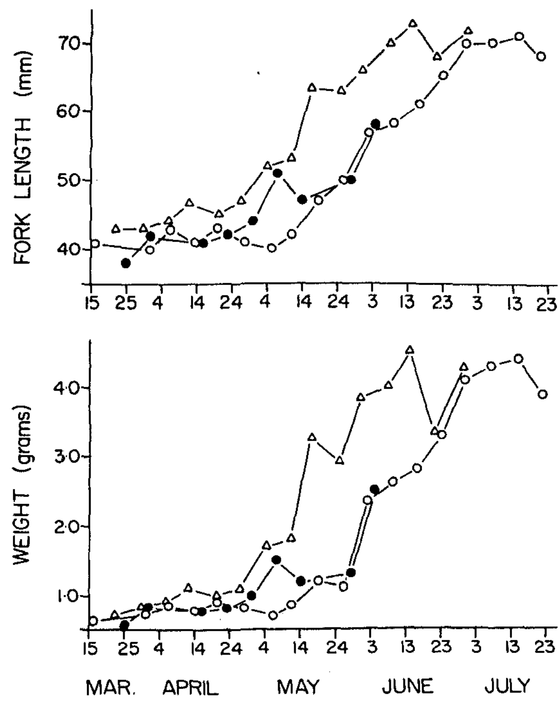

FIGURE 5.—Average fork length and round weight of juvenile chinook salmon captured on the Nanaimo River estuary in 1975 (dots), 1976 (circles), and 1977 (triangles).

Estimates of Total Estuary Population

Although the beach seine samples taken in this study provided an adequate measure of distribution and relative abundance of chinook salmon, they do not permit an estimate of the total number of chinook rearing in the estuary. Mark and recapture estimates of abundance in 1977 provided a reference point for comparing catches between years and for comparing the downstream run of fry with the estuary population. Between 18 and 21 April 1977, 3,187 fish marked with a left pelvic clip were released at Stations 29-31 of the east

TABLE 5.—Size at release and recapture of fin-clipped juvenile chinook salmon in the Nanaimo River estuary in 1977.

Left pelvic clips				Right pelvic clips			
n	Days since marking	Average length	Average weight	n	Days since marking	Average length	Average weight
55	0	44	0.94	36	0	63	3.36
10	5	47	1.05	12	5	65	3.32
10	13	54	1.90	2	13	71	4.67
1	14	55	1.95	2	19	84	8.29
2	19	60	2.72	1	26	76	5.28
6	26	70	4.60	2	29	107	13.55
2	33	77	5.36				
4	47	103	13.80				
1	57	115	18.60				

channel. Sampling along the east channel and Holden Creek on 22 April showed that the marked fish occurred all along the east channel and Holden Creek but were most concentrated at Station 31 and for several hundred yards farther upstream. Sampling in subsequent weeks indicated that marked fish remained concentrated at Stations 30 and 31 as long as chinook salmon were abundant there. With the shift in population center to Stations 28 and 29, the marked fish also shifted downstream, but remained most abundant at Station 29. A few marked fish were also captured in samples taken across the delta front and across the landward margin of the mud flat at high tide, but none were captured in stream channels in the center of the mud flat at low tide. In spite of their twice daily migration up and down the delta with the tide, therefore, marked fish remained concentrated in the area of marking, so that population estimates from the recaptures referred only to the east channel and Holden Creek, and underestimated the population in this region as well.

The instantaneous rate of disappearance of marks from the sampling area after the April marking was 0.117, or about 11%/day, and after the May marking the rate was 0.137, or about 13%/day. These disappearance rates were used to correct the summed release of marks each day to an estimate of the marks remaining in the area and to calculate estimates of the marked population on all sampling dates following the last release of marks (Table 6).

Estimates of population size throughout the first period of marking were consistent, ranging only 14,675-17,133, and estimates for 25 April and 3 May were also similar (Table 6). On May 9, the population estimate dropped to 5,708 and remained at this level or lower throughout May. The first population estimate from right pelvic clips was on 17 May. Estimates based on this mark ranged 4,629-9,544 between 17 and 19 May and remained at this level throughout May. Estimates for the first 2 wk of June from recaptures of right pelvic clips were 2,352 and 1,204, respectively.

Estimates from right pelvic recaptures in May were twice as great, or greater, than estimates from left pelvic recaptures. Possibly this difference occurred because fishing during 17-19 May was concentrated where fry marked with left pelvic clips were most abundant, so that recaptures of this mark were high.

The estimates indicated that the population in the east channel and Holden Creek was 12,000-19,000 throughout April and early May and that the population declined to 5,000-10,000 in the latter half of May and declined further to about 2,000 in early June. These changes are consistent with changes in beach seine catches.

During the first week of May sampling was performed across the landward edge of the mud flat at high tide (13 sets) in the east arm and Holden Creek (8 sets), across the delta front at low tide (8 sets), and in the stream channels crossing the center of the mud flat (7 sets). Although this sampling was not at random with respect to either the distribution of chinook salmon or marks, it does permit a population estimate based upon sampling areas outside the east channel and Holden Creek. A total of 406 chinook salmon were captured, of which 12 were recaptures. The average

TABLE 6.—Release and recovery of fin-clipped chinook fry, estimates of marks available and population estimates for the Nanaimo River estuary in 1977. LV = left pelvic clip; RV = right pelvic clip. Population estimates are the product of total catch and estimated marks present divided by marks recaptured.

Date	Total catch	Total marks released		Marks recaptured		CPUE recaptures		Estimated marks present			Population estimates		
		LV	RV	LV	RV	LV	RV	LV	RV	Both	LV	RV	Both
Apr. 18	589	370											
19	875	827		18				329			15,993		
20	858	791		55				1,028			16,037		
21	1,344	1,199		127				1,619			17,133		
22	609			104		8.00		2,506			14,675		
25	229			23		3.83		1,764			17,563		
May 3	168			10		1.25		692			11,558		
9	111			2		0.22		343			18,648		
16	233		203	6		0.75		151			5,708		
17	340		335	17	13	1.55	1.18	134	177	311	2,680	4,629	3,525
18	749		691	23	35	2.56	3.89	120	446	566	3,908	9,544	7,309
19	412		325	22	48	2.75	6.00	106	992	1,098	1,985	8,515	6,463
20	127			2	13	0.25	1.62	67	761	828	4,254	8,089	7,010
31	79			0	3	0.00	0.38	26	254	280		6,689	7,373
June 6	21			0	1	0.00	0.12	13	112	125		2,352	2,625
13	28			0	1	0.00	0.25	6	43	49		1,204	1,372
20	2			0	0	0.00	0.00	3	16	19			
28	13			0	0	0.00	0.00	1	5	6			

estimated marked population for the week was 655, giving a population estimate of 22,148 for the whole estuary. The average population of the east channel for the week was about 15,000, or about 68% of this estimate. Total estuary population may, therefore, be about 32% greater than the estimate for the east channel and Holden Creek.

Comparing beach seine catches for 1975-77 with the mark recapture estimates indicated that the peak population on the estuary was on the order of 20,000-25,000 in 1976 and 1977 but was probably closer to 40,000-50,000 in 1975. These estimates are comparable with a single day's fry migration in 1975 and 1976. However, the slow rate of disappearance of marked fry from the east channel indicated a relatively long residence of fry on the estuary (about 60 days). An accumulation of fry on the estuary during downstream migration would, therefore, be expected. Treating each daily run of fry as a single cohort arriving on the estuary, and reducing that cohort by 11-12%/day (the rate of disappearance of marked fry from the east channel), produced estimates for the estuary population of around 100,000 in 1975 and 50,000 in 1976, or about twice the estimate based on mark recapture results for 1977. Estimates of downstream run are for the release point of the marks, however, and significant mortality might occur between the release point and the estuary (Hunter 1959). Alternatively, the rate of disappearance of marked fry may underestimate the rate of disappearance of recent downstream migrants. A disappearance rate of 11-12%/day suggested an average residence time of about 60 days, whereas growth rates suggested that most fry should spend only 25 days in the estuary.

If downstream migrants spend only 25 days in the intertidal area, and their rate of disappearance is constant during that time, then peak estuary populations are 40,000 in 1975 and 20,000 in 1976, comparable with the estimate based on mark recaptures in 1977. The estimate of disappearance rate from mark returns has rather wide confidence limits, 25 days being within the range of 95% probability in estimates of residence time. The apparent discrepancy between mark recapture estimates of estuary population size and downstream run can be resolved by assuming residence of 25 days, therefore. The assumption of a constant rate of disappearance of chinook salmon from the estuary population, however, implies the disappearance of many juveniles <70 mm FL. Although high mortality of salmon fry is a common assumption, no predators or important diseases were obviously present in the Nanaimo estuary to justify the assumption of heavy losses of small fish. The tentative agreement between the various estimates of population size may therefore be spurious, and these estimates should be regarded as preliminary at best.

By comparison with the Fraser and the Sixes Rivers, chinook salmon were rare in the Nanaimo River. Dunford (1975) reported maximum densities in excess of 2 fish/m^2 in Fraser River marshes, compared with average densities of about 0.1 fish/m^2 in the east channel and Holden Creek. For the Sixes River estuary, an area about twice as large as the east channel and Holden Creek, Reimers (1971) reported maximum population estimates of 100,000-150,000. However, Reimers' estimates were made 5 days after the release of marked fish into the estuary, and, assuming his marked fish were disappearing at a rate similar to those in the Nanaimo River, the population in the Sixes River estuary may have been closer to half the values he reported. Nevertheless, this still represents a population significantly more dense than that in the Nanaimo estuary. In terms of suitable habitat, however, the Sixes River may not be greatly different from the Nanaimo River, as it is about twice as large as the east channel and Holden Creek, and probably supported about twice the population of chinook salmon.

Population of Juvenile Chinook Salmon Outside the Estuary

Beach seine samples in areas other than the intertidal area of the estuary produced few juvenile chinook salmon. In 1975, 19 sets made in mid-May yielded only 3 juveniles, and in 1976, 61 sets made during April-June yielded only 26. Twenty-four of these were captured in the lagoon behind Duke Point (area 16), adjacent to the estuary. Apparently onshore areas away from the estuary were not used by chinook salmon fry, although all the beaches sampled were used by pink and chum salmon fry.

Juvenile chinook salmon were captured in most locations sampled by the two purse seines in 1975 and 1976. Not all chinook salmon captured were young-of-the-year, however. Catches prior to May were mainly yearlings. In late May and early June there was a large influx of young-of-the-year and a subsequent decline in the catch of yearlings. The influx of young-of-the-year (Figure 6) coincided with the decline in abundance of chinook salmon in the intertidal area of the Nanaimo estuary. The periodicity of catches in the estuary and adjacent marine areas is indicative of a stage movement away from the estuary and into deeper water by young-of-the-year. Sampling by drum seine after July 1976 indicated the persistence of moderate numbers of juvenile chinook salmon in the Nanaimo area until the end of October, after which catches declined to the low levels observed in spring (Figure 6).

Catches of chinook salmon by the 92 m purse seine in 1975 were mainly in area 10 (338 of 434 chinook salmon captured), with smaller catches in areas 6, 7, 8, and 11 and few elsewhere. Catches by the 218 m drum seine in 1975 were also mainly in area 10 (101 of 205 captured), with the remaining catch scattered throughout the sampling areas. Chinook salmon were more scattered in 1976, area 10 yielding only 79 of 245 captured by drum seine between April and July and areas 1, 2, 5, and 6 also providing good catches. Chinook salmon were of similar abundance in drum seine catches between

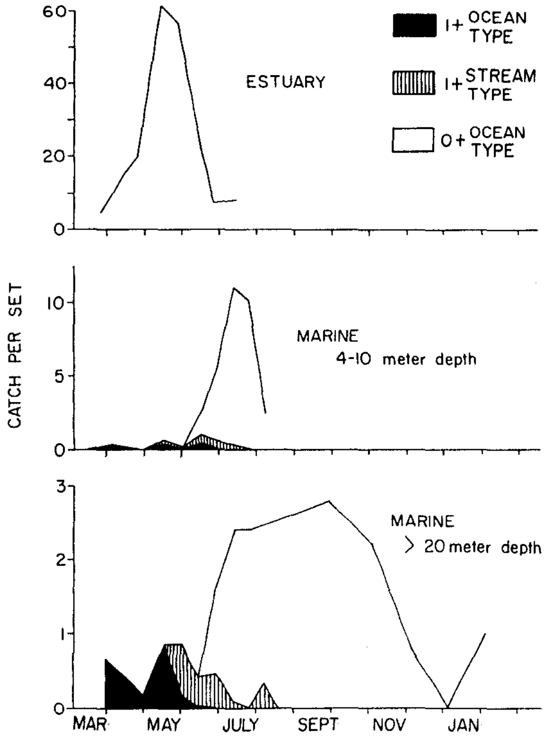

FIGURE 6.—Catch per set of juvenile chinook salmon by age and life history type, by beach seine on the estuary, and by shallow and deep purse seine in marine waters adjacent to the Nanaimo River estuary. Data are averages for 1975-77.

April and June 1975 and 1976 (CPUE 0.73 in 1975 and 0.83 in 1976) but were significantly less abundant in July 1976 compared with 1975 (CPUE 3.30 in 1975 and 2.28 in 1976 $\chi^2 = 6.43, P<0.05$). The greater catch in July 1975 presumably reflected the greater contribution of young-of-the-year from the estuary in 1975.

The presence of juvenile chinook salmon in the Nanaimo area throughout the year in 1976 indicates a local resident population that is supplemented by young-of-the-year in June. The appearance of juveniles in large numbers in area 10 coincident with their disappearance from the intertidal area of the estuary indicates that these fish were from the estuary population. The evidence is not conclusive however, and examination of the catch at area 10 in June and July 1977 for fin clips from the estuary produced only 8 marked fish out of 555 examined. This compares with approximately 10% of the estuary population marked in April and May. Possible reasons for the low number of marks in the catch at area 10 include differential mortality of marks (the percentage of mark returns in the estuary declined after each marking), rapid dispersal of chinook salmon away from the estuary, dilution of the fish of local origin by fish from other systems, or dilution of the estuary population by late migrants from the Nanaimo River. In my view the most likely explanations are rapid dispersal of juveniles from the estuary population, and dilution of the estuary population by late migrants from the Nanaimo River. Chinook salmon reared in the intermediate salinity of the estuary are probably already adapted to seawater by the time they are ready to leave the estuary while late migrants from the river might be expected to stay close to the river mouth for some time, adapting to salt water. Samples from area 10 may, therefore, contain a disproportionate number of late migrants.

An unknown proportion of the Nanaimo River population probably disperses rather quickly away from the Nanaimo area after leaving the river. Some young-of-the-year, however, remain in the Nanaimo area, at first concentrated rather close to shore, but later moving to more offshore sampling locations where they persist until at least November (Figure 6). During the winter these fish decline in numbers until by the following spring there are only a few 1+ ocean fish in the local area. Most of these disappear from the surface waters in May coincident with a small influx of yearling smolts from the Nanaimo River (Figure 6). The yearling smolts dominate samples taken in late May and early June, after which they disappear and are replaced by young-of-the-year, presumably from the Nanaimo River. This sequence of events in which 1+ ocean fish are replaced by 1+ stream fish which in turn are replaced by 0+ ocean fish is not unique to the Nanaimo area but appears to be typical for the Gulf Islands region as a whole (Healey[16]).

Food Habits and Feeding Rates

A growth rate in excess of 5% body weight/day implies good feeding conditions in the estuary (e.g., LeBrasseur 1969). Diets of juvenile chinook salmon were similar in 1976 and 1977, and five taxonomic groups made up the bulk of the diet in the estuary. Harpacticoid copepods were important in March and early April, decapod larvae and amphipods in April and May, and mysids and insect larvae in May-July. Off the intertidal area of the estuary fish larvae, chiefly herring, dominated the diet of juvenile chinook salmon from May through August, while calanoid copepods, decapod larvae, and insects were occasionally important. A shift from a predominantly invertebrate diet to a predominantly fish diet, therefore, occurred as the young chinook salmon dispersed away from the intertidal area of the estuary.

Average weights of stomach contents varied considerably from sample to sample; nevertheless, some generalizations appear possible. Weights of stomach contents of juvenile chinook salmon captured on the estuary in 1975 ranged about 3-5% of body weight in April but dropped rapidly to a low of about 0.1% of body weight as the chinook salmon population on the estuary increased in May (Table 7). Weights of stomach contents of juveniles on the estuary were uniformly low in 1976, never rising above 2.2% of body weight (Table 7). Stomach contents of juveniles captured in 1977 ranged 2-5% of body weight except during the peak of fry abundance when contents dropped to 0.5% of body weight (Table 7). Assuming that stomach contents are a reflection of feeding conditions, it appears that feeding conditions were poorest in 1976, better in 1977, and possibly best of all in 1975 when the population was greatest. Peak population densities were associated with a decline in stomach contents, and by inference, a decline in food intake in the years of good feeding conditions.

TABLE 7.—Stomach contents as a percent of body weight for juvenile chinook salmon captured in the intertidal area of the Nanaimo River estuary and off the intertidal area 1975-77. Sampling week dates are for 1976. Add 2 days for 1975 and subtract 1 day for 1977 to get the correct starting date for those years.

Sampling week starts	On the estuary						Off the estuary			
	1975		1976		1977		1976		1977	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%
Mar. 14			1	1.4						
21					15	1.8				
28			1	1.7	19	3.4				
Apr. 4	9	3.3	2	2.0	24	2.4				
11	3	4.1	6	1.0	20	2.6				
18	1	2.9	20	1.4	57	1.9				
25	5	5.0	20	1.7	15	0.6				
May 2	1	3.8	20	1.6	18	2.0				
9	25	0.1	20	2.2	20	2.2			25	2.6
16	3	2.3	20	1.2	36	4.1				
23			20	1.4	15	2.1				
30			20	1.1	12	4.0	5	2.5		
June 6			20	2.2	10	3.3	1	0.1		
13					6	5.0	13	2.0	14	2.5
20			20	1.9	2	2.0	3	1.3		
27			20	2.0	5	4.0			15	3.4
July 4			20	2.0			3	0.8	17	3.0
11			24	1.8			20	1.2		
18			3	1.0			24	1.3	29	2.7
25							8	1.2	19	1.4
Aug. 15									4	2.3
22									10	1.2

Weights of stomach contents of juvenile chinook salmon captured away from the intertidal area of the estuary were similar to those in the estuary during May and early June, but in mid-June dropped below those from the estuary. Weights of stomach contents of chinook salmon captured offshore were lower in 1976 than in 1977, as was observed for the estuary population (Table 7).

The composition of the diet of juvenile chinook salmon in the Nanaimo estuary was similar to that reported by Sibert and Obrebski (1976) for the Nanaimo estuary in 1973 and to that recorded by Dunford (1975) in similar habitats on the Fraser estuary. The relative timing and importance of specific items in the diet was different than in the Fraser, but this probably reflects differences in abundance of the different diet items and the opportunistic feeding behavior of the fish. The change in diet of juvenile chinook salmon from invertebrates while in the intertidal area of the Nanaimo estuary, to larval fish when away from the intertidal area was consistent with observations on the Fraser estuary. Juveniles in the Fraser River and marsh area fed mainly on invertebrates, but those on Roberts and Sturgeon Banks fed mainly on juvenile herring (Goodman see footnote 2).

[16]Healey, M. C. 1978. The distribution, abundance and feeding habits of juvenile Pacific salmon in Georgia Strait, British Columbia. Fish. Mar. Serv. Tech. Rep. 788, 49 p.

Seasonal changes in the diet of chinook salmon in the intertidal area of the estuary indicated that a combination of size selection and availability influenced the diet. Very small organisms (harpacticoids and cladocerans) occurred in stomachs only in the early spring when the fish were 50 mm or less in length. Larger organisms (amphipods, mysids) were important later in the season when the fish were considerably larger. Insects were important diet items throughout, presumably because of their widespread availability in the habitats sampled.

CONCLUSIONS

The Nanaimo River population of juvenile chinook salmon is composed of fish which go to sea in their first year and fish which remain in freshwater for 1 yr, with those which go to sea in their first year most numerous. Chinook salmon which migrate to sea in their first year are the most common life history type in British Columbia (Milne[17]; Godfrey see footnote 13). In the Nanaimo River many of those chinook salmon which go to sea as young-of-the-year move downstream as recently emerged fry and rear to smolt size in the intermediate salinity of the estuary. Large numbers of chinook salmon fry are found in the marshes of the Fraser estuary in spring and summer (Dunford 1975) and in the estuaries of other rivers in which chinook salmon spawn (Healey unpubl. data). Estuaries, therefore, are important nursery areas for chinook salmon, a fact which has not hitherto been appreciated.

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