ZOOPLANKTON 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

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ABSTRACT

Juvenile pink salmon, *Oncorhynchus gorbuscha*, and chum salmon, *O. keta*, 28 to 56 mm long (fork length) from Traitors River in southeastern Alaska, fed little in freshwater but fed heavily in the estuary, mainly on pelagic zooplankters. Fry did not feed on cloudy moonless nights. The rate of evacuation of pink salmon stomachs ranged from 6 h at 12.8°C to 16 h at 8.5°C. The abundance of zooplankton ranged from 9 to 154 organisms per liter and quantitatively did not change noticeably while fry were in the estuary. In 1964, 1965, and 1966, the estimated numbers of fry in Traitors Cove was 7, 1, and 4 million, respectively. An attempt was made to estimate the carrying capacity of Traitors Cove, using food consumption and evacuation rates in conjunction with estimates of standing crop of zooplankton. It was concluded that 50 to 100 million additional fry from hatcheries would probably exceed the carrying capacity of the estuary.

With the rapidly growing demand for animal protein and the emergence of new hatchery techniques for pink salmon, *Oncorhynchus gorbuscha*, and chum salmon, *O. keta* (Bams 1972; Bailey and Heard 1973; Bailey and Taylor 1974), we believe that it is timely to speculate on the capacity of estuaries to support more fry. The Japanese, Russians, and Canadians have a number of major pink and chum salmon hatcheries and spawning channels in operation. Japanese hatcheries released over 800 million pink and chum salmon fry in 1973 (source: Japan Fishery Agency). Individual Russian hatcheries are capable of releasing up to 120 million fry annually (Kanid'yev et al. 1970). The Qualicum River in British Columbia, Canada, now produces about 50 million chum salmon fry annually through a combination of flow control in the natural spawning areas and the operation of a spawning channel (Fraser 1972). The problem of evaluating the carrying capacity of estuaries for artificially produced fry is most pertinent. What, for example, would be the impact of 100 million fry on the available food in Traitors Cove?

Recent technological advances in rearing salmon in hatcheries and spawning channels now make it possible to release tens of millions of pink and chum salmon fry into individual estuaries, but lack of knowledge of the food requirements of these two species in nature makes even the immediate results of such releases uncertain. It is conceivable that a spawning channel or hatchery operation could produce such large numbers of fry that their migratory behavior might be altered, or growth and survival might be reduced because of severe competition for a limited food supply. Ivankov and Shershnev (1968) reported that young pink and chum salmon (50 to 80 mm) had fuller stomachs in years of "scarcity" of salmon than in years of "abundance" in the coastal zone of the southern Kuril Islands.

The survival of fry to a large extent depends on their rate of growth and on their ability to escape from predators. Rapid growth requires suitable temperature, an abundance of food, and a rapid transition from endogenous nutrition, based on yolk reserve, to exogenous feeding on small aquatic organisms. In a study of size-selective predation, Parker (1971) demonstrated that predation decreases with increase in size of the prey species.

The study reported in this paper was undertaken in a southeastern Alaska estuary, Traitors Cove (Figure 1), in 1964-66 to gain further insight into the food requirements and feeding habits of pink and chum salmon fry. Questions asked were: How soon in life does feeding begin? How does the diet of the fry compare with the available food organisms? What are the food consumption rates

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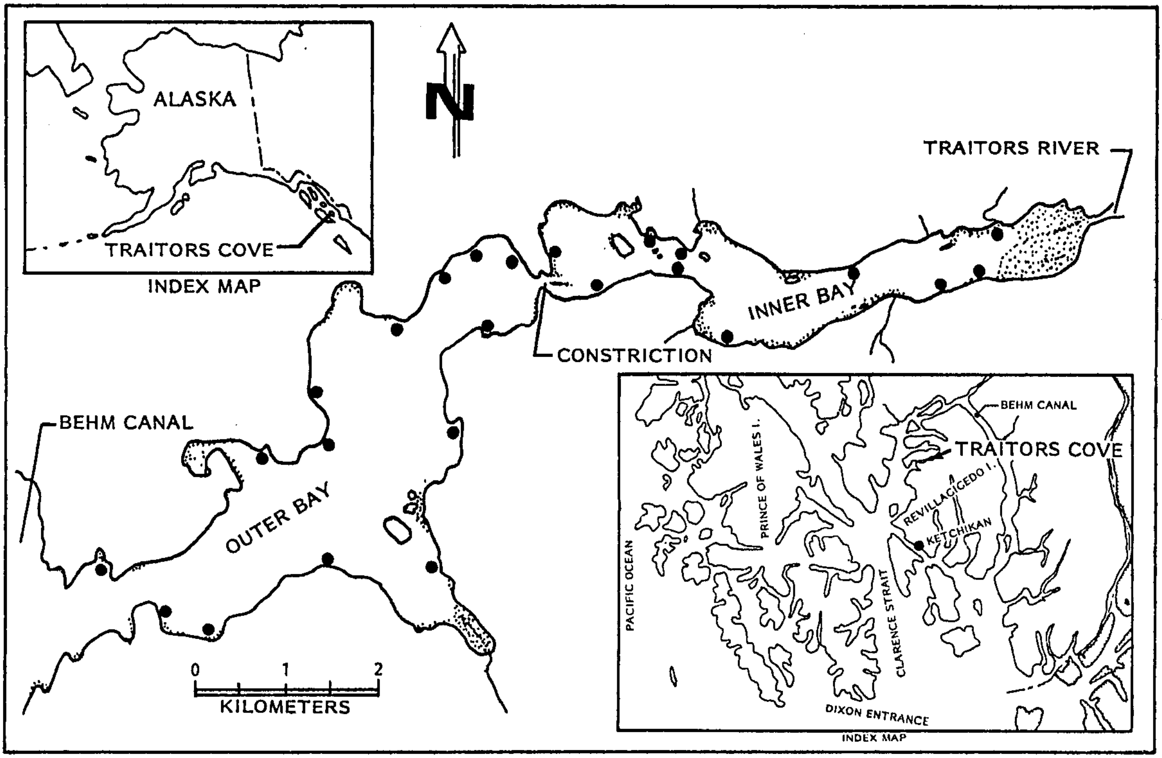

FIGURE 1.–Traitors Cove estuary, Revillagigedo Island, Alaska, 1963-65 (from McLain 1968), showing locations of plankton sampling stations.

for fry in relation to water temperature? How many fry can the estuary support based on estimates of abundance of food organisms and grazing rates?

Traitors Cove is about 50 km north of Ketchikan, Alaska. Several tributaries used by pink and chum salmon enter Traitors Cove, the major one being Traitors River, which has about 55,000 m^2 of spawning grounds. The dominant feature of the estuary is a narrow constriction with a sill, 1 or 2 m below mean low water, which divides the estuary into two basins. The inner bay is about 5.9 km long and 0.7 km wide and has a maximum depth of 46 m. The outer bay is about 6.5 km long and 1.3 km wide and has a maximum depth of 130 m. The tidal range of about 7 m and the constricted flow at the sill create exceptionally strong currents and a reversing tidal falls throughout the year. The turbulence and surface currents affect distribution and movement of fry for at least 0.5 km on both sides of the constriction. We measured surface temperatures of 5° to 13°C in the estuary when fry were present. Some aspects of the oceanography of Traitors Cove have been described by McLain (1968).

Pink and chum salmon fry from the tributary streams enter the estuary from mid-April to late June. Schools with thousands of fry are typically present until late June.

METHODS

To determine if juvenile salmon feed while still in Traitors River, we compared the contents of the entire digestive tracts of individuals excavated from redds with those trapped in nets while migrating downstream at night. All specimens were preserved whole in 10% Formalin solution.[2] The contents of the digestive tract were later removed in the laboratory and examined under a stereoscopic microscope. To determine the kinds and numbers of food organisms eaten in the estuary, we compared stomach contents of fry samples collected in the estuary in 1964, 1965, and

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

1966. Individual food items were measured to the nearest 0.01 mm of body length and diameter with an ocular micrometer to determine volume. Fry in the estuary were collected with a dip net from a skiff and by floating traps anchored near the shoreline. The dip nets and traps were effective in collecting fry less than 60 mm long, which are the subject of this report, but were not effective in collecting larger salmon. The larger fish were able to evade capture by sounding. Most of the fry examined for stomach contents were collected from the estuary during daylight (1100 to 1500). On three occasions, however, fry were collected during nights (0230) when the sky was overcast or moonless and incident light intensity was 0.0 footcandle near the water surface. No stomachs were collected during bright moonlight nights, which were rare.

To estimate the volume of water grazed per day by fry, we measured velocities of water currents close to shore-oriented fry while observing their behavior in relation to the current and food items. Current velocities close to shore-oriented schools of fry were measured by two methods. One method was to record the time it took suspended particles in the water to drift 1 to 5 m along a floating anchored line graduated to 0.1 m. The second method was to measure the velocity by holding a current meter near a school of fish; the meter was attached to the end of a rod about 4 m long. The current meter dial was calibrated to read to the nearest 3 cm/s. Both methods required the observer to operate either from an anchored skiff or from shore. Polaroid glasses were used to reduce glare from the water surface and improve visibility.

Feeding at night by fry was tested in two experiments in an aquarium with known densities of zooplankton. The aquarium consisted of a 7-mil plastic bag suspended in the estuary from a float and containing 76 liters of seawater. The fry were captured in the outer bay and held in a 1-m no. 10 mesh (158-μm openings) plankton net for 20 h to deny them food and to ensure that their stomachs were empty. The starved pink and chum salmon fry together with a known quantity of zooplankton were then placed in the aquarium and held under various light intensities. After timed intervals in the aquarium, fry were removed, killed, and their stomach contents removed.

In the first experiment, fry (length, 32 to 41 mm) in groups of five were placed in an aquarium that contained 240 zooplankters per liter of seawater. A cursory examination of the zooplankters revealed that they were predominantly copepods and barnacle nauplii. Each group of fish was allowed to feed 13 to 28 min before being removed and preserved in 10% Formalin solution. The experiment was started in the evening before sunset and continued until the light meter read 0.0 footcandle. In the second experiment, 14 fry were placed in an aquarium containing about 260 zooplankters per liter; they were kept there for 4 h and 20 min at night before they were removed and preserved in Formalin. The light meter read 0.0 footcandle throughout the experiment.

The time required for fry to evacuate their stomach contents was determined experimentally at 8.5°, 10.0°, and 12.8°C. The procedure was to capture 200 to 300 salmon fry in the estuary and place them in strained seawater in a floating cage of no. 10 mesh plankton net, which prevented entry of prey from the surrounding water. At the start of each test, 10 pink and 5 chum salmon were killed and preserved; at hourly intervals thereafter 5 fish of each species were killed and their stomach contents examined until all 10 fish of two successive samples contained no food in their stomachs. The pink salmon fry examined in these tests ranged from 32 to 57 mm in length and the chum salmon from 34 to 54 mm. Water temperatures were recorded by a thermograph to the nearest 1°C. The sensing probe of the thermograph was located 1 m below the water surface.

The zooplankton in Traitors Cove was sampled only in 1965 and 1966 while fry were in the bay. A 5-inch Clarke-Bumpus sampler with a no. 10 mesh net was towed at a depth of about 0.5 m until about 50 liters of water (2 to 10 s) had been strained. Seventy-nine samples were collected—in 1965, 7 stations in the outer bay were each sampled in 1 day; and in 1966, 10 stations in the inner bay and 14 in the outer bay were each sampled on 3 different days (Figure 1). Only one sample was taken at each station. The zooplankton catch was preserved in 5% buffered Formalin solution. The plankton samples were subsampled by two methods for analysis. In the first method, each of the 79 samples was analyzed from 1-ml subsamples (approximately 1/100 of the sample) placed in a Sedgewick-Rafter chamber. The kinds, numbers, and size of the various plankters were determined. Volumes of the different plankters were computed from lengths and average diameters, assuming a cylindrical shape for each plankter. In the second method, all 7 of the 1965 samples and 66 of the 1966 samples were examined to determine numbers of plankters from larger subsamples (1/64 to ¼ of the sample) taken with a Cushing subsampler (Cushing 1961). A comparison of the results of the two analyses indicated that the data from 1-ml subsamples overestimated the number of organisms by an average of 20% (range 15 to 30%). Therefore, estimates of zooplankton densities using the first method were reduced by 20%. Plankton samples contained protozoans (mostly tintinnids) and phytoplankton, but these were not included in the estimate of standing stock of plankton because salmon fry consumed only the larger zooplankters. Rotifers and copepod nauplii were the smallest plankters included in the counts.

FEEDING IN TRAITORS RIVER

Although most of the pink and chum salmon excavated from redds in Traitors River contained items such as sand or detritus in their digestive tracts, only a few individuals contained food organisms. Chironomids (dipterans) were the most frequently observed food item. Seventy juvenile pink salmon (fork length, 33 to 41 mm) were collected from spawning gravels for analysis of contents; only three contained food–a chironomid pupa and some unidentifiable insect remains (Table 1). Seventy juvenile chum salmon (fork length, 33 to 41 mm) were collected from spawning gravels; nine contained food. Chum salmon had eaten only chironomid larvae and pupae, plecopteran nymphs, ephemeropteran nymphs, and an arachnid (spider). One chum salmon (41 mm) contained the remains of 24 chironomid pupae, 2 chironomid larvae, 3 ephemeropteran nymphs, and 3 plecopteran nymphs. The other eight chum salmon that contained food were 37 to 38 mm long and had eaten only one to three items each.

TABLE 1.–Frequency of occurrence of items in digestive tracts of 70 pink and 70 chum salmon juveniles excavated from redds in Traitors River in 1964-65.

Item	Pink salmon		Chum salmon	
	Number	Percent	Number	Percent
Arachnids	0	0	2	3
Ephemeropterans	0	0	2	3
Plecopterans	0	0	2	3
Dipterans	1	1	4	6
Insect remains	2	3	3	4
Plant detritus	15	21	16	23
Fine sand	33	47	44	63
Empty	22	31	12	17

TABLE 2.–Frequency of occurrence of items in digestive tracts of 40 pink salmon fry and 40 chum salmon fry trapped in nets while migrating down Traitors River, May 1964.

Item	Pink salmon		Chum salmon	
	Number	Percent	Number	Percent
Plecopterans	0	0	2	5
Dipterans	0	0	9	22
Insect remains	0	0	2	5
Detritus	1	2	1	2
Fine sand	8	20	22	55
Empty	31	78	19	48

Although none of the 40 downstream-migrating pink salmon fry (length, 32 to 37 mm) contained food, 9 of the 40 chum salmon (length, 35 to 42 mm) contained substantial numbers of chironomid pupae and plecopteran nymphs (Table 2). The average for those that contained food was 6.7 food items (range 1 to 27 items).

Fine sand (diameter, 0.05 to 0.90 mm) and plant detritus were common items in the digestive tracts of both the gravel-resident and the migrating pink and chum salmon (Tables 1, 2). The sand and detritus were more common in fish taken from the redds than in those captured in the downstream traps.

FEEDING IN THE ESTUARY

We studied four aspects of the feeding of pink and chum salmon fry in the estuary: 1) stomach contents, 2) feeding behavior in relation to water currents, 3) effect of daylight on feeding, and 4) time required for evacuation of stomach contents.

Stomach Contents of Pink Salmon Fry

In the springs of 1964, 1965, and 1966, a total of 140 pink salmon (length, 28 to 56 mm) were collected from the estuary during daylight, and 30 (length, 31 to 58 mm) were collected at night (Table 3). All of the stomachs from the fry collected in daylight contained food. Copepods (calanoids and cyclopoids) occurred in 94% of the stomachs and constituted 77% of the total volume of stomach contents. Barnacle nauplii (cirripedes) and cladocerans (*Podon* sp. and *Evadne* sp.) each occurred in 56% of the stomachs and constituted 6% of the total volume. The remaining 11% of the food volume consisted of various other planktonic forms and occasional epibenthic organisms. Most of the food items were between 0.3 and 3.0 mm long. The smallest item in pink salmon stomachs was a disc-shaped diatom and the largest were fish

TABLE 3.–Zooplankters and other organisms from stomachs of 140 pink salmon fry (length, 28 to 56 mm) collected in daylight and 30 (length, 31 to 58 mm) collected at night in Traitors Cove, 1964-66, and percentage relative importance by volume.

Item	Collected in daylight: Percentage stomachs containing item	Collected in daylight: Mean items per stomach, Number	Collected in daylight: Mean items per stomach, Percent	Collected in daylight: Percentage relative importance by volume[1]	Collected at night: Percentage stomachs containing item	Collected at night: Mean items per stomach, Number	Collected at night: Mean items per stomach, Percent	Collected at night: Percentage relative importance by volume[1]
Diatoms	32	3.3	3	+	26	0.4	2	+
Rotifers	15	4.0	3	+	0	0.0	0	0
Bryozoans (cyphonautes)	2	0.0	0	+	0	0.0	0	0
Gastropods (veligers)	12	0.5	0	+	3	0.1	1	+
Pelecypods (veligers)	26	0.9	1	+	6	0.1	1	+
Polychaetes (larvae)	31	1.1	1	1	9	0.3	2	1
Arachnids	2	0.0	0	+	3	0.0	0	+
Cladocerans	56	10.3	8	6	9	0.7	4	3
Copepods	94	70.7	52	77	76	10.7	67	85
Cirripedes (nauplii)	56	18.6	14	6	53	2.1	13	5
Cirripedes (cyprids)	25	1.9	1	2	9	0.4	2	3
Cirripedes (casts)	2	0.1	0	+	9	0.1	1	+
Mysids	4	0.1	0	+	0	0.0	0	0
Cumaceans	3	0.1	0	+	0	0.0	0	0
Isopods	1	0.0	0	+	0	0.0	0	0
Amphipods	4	0.0	0	+	0	0.0	0	0
Euphausiids (larvae)	2	0.1	0	1	0	0.0	0	0
Decapods (zoeae)	9	0.3	0	1	0	0.0	0	0
Unidentified crustaceans (nauplii)	23	1.4	1	+	9	0.1	1	+
Dipterans (larvae)	3	0.0	0	+	3	0.0	0	+
Dipterans (pupae)	6	0.1	0	+	3	0.0	0	+
Larvaceans	26	1.8	1	3	9	0.2	1	2
Eggs (invertebrates)	49	20.8	15	3	23	0.8	5	1
Fish	4	0.0	0	+	0	0.0	0	0

[1]+ indicates less than 0.5%

larvae (up to 8 mm long). Unidentifiable material occurred in only 11% of the stomachs and constituted an insignificant fraction of the volume.

The 30 pink salmon fry collected from the estuary at night all had food in their stomachs, but they probably had not feed recently. Many more food items were found in the stomachs of pink salmon fry collected in daytime than in those collected at night–an average of 136 items versus 16. Also, digestion had not progressed as far in the daytime fry–only 11% of their stomachs contained unidentifiable items, whereas 80% of the stomachs from nighttime fry contained unidentifiable items. On three moonlight nights, fry were seen dimpling the water surface while apparently feeding. Incident light intensity at the water surface at such times was 0.016 to 1.0 footcandle.

Stomach Contents of Chum Salmon Fry

In the springs of 1964, 1965, and 1966, a total of 124 chum salmon (length, 32 to 51 mm) were collected from the estuary during daylight and 20 (length, 35 to 43 mm) were collected at night (Table 4). All of the fry taken during daylight contained food. Copepods occurred in 73% of the stomachs and constituted 30% of the total food volume. Larvaceans occurred in 54% of the stomachs and constituted 34% of the total food volume. Dipteran (chironomid) pupae occurred in 51% of the stomachs and constituted 11% of the volume. The remaining 25% of the food volume was primarily other planktonic forms (including cladocerans and eggs) but also a few epibenthic animals. Unidentifiable material occurred in 20% of the chum salmon stomachs but constituted an insignificant fraction of the volume and was not included in the final comparisons. Food items eaten by chum salmon fry were similar in size to those eaten by pink salmon, mostly from 0.3 to 3.0 mm long. The largest item was a larval fish 20 mm long. Chum salmon fry, however, tended to feed on larger (Table 5) and harder shelled items than pink salmon, as evidenced by the greater incidence of harpacticoid copepods, collembolans (intertidal springtails), cumaceans, and chironomids in the chum salmon (Tables 3, 4). The chum salmon fry could have picked up some of the so-called epibenthic or intertidal organisms in the form of neuston, or drift material.

Many more food items were found in the stomachs of the chum salmon collected in daytime than in those collected at night–an average of 124 items versus 4. Only 20%of the stomachs collected in daytime contained unidentifiable items versus 70% at night.

TABLE 4.—Zooplankters and other organisms from stomachs of 124 chum salmon fry (length, 32 to 51 mm) collected in daylight and 20 (length, 35 to 43 mm) collected at night in Traitors Cove, 1964-66, and percentage relative importance by volume.

Item	Collected in daylight				Collected at night			
	Percentage stomachs containing item	Mean items per stomach		Percentage relative importance by volume[1]	Percentage stomachs containing item	Mean items per stomach		Percentage relative importance by volume[1]
		Number	Percent			Number	Percent	
Diatoms	15	0.4	1	+	4	0.2	5	+
Rotifers	7	0.5	1	+	0	0.0	0	0
Gastropods (veligers)	3	0.2	0	+	0	0.0	0	0
Pelecypods (veligers)	14	0.4	1	+	0	0.0	0	0
Polychaetes (larvae)	21	1.3	2	2	4	0.3	7	6
Arachnids	9	0.1	0	2	0	0.0	0	0
Cladocerans	58	12.9	18	8	0	0.0	0	0
Ostracods	1	0.0	0	+	0	0.0	0	0
Copepods	73	16.3	22	30	39	1.7	41	37
Cirripedes (nauplii)	34	2.3	3	1	29	0.5	12	4
Cirrepedes (cyprids)	20	0.6	1	1	14	0.1	2	1
Cirripedes (casts)	1	0.0	0	+	0	0.0	0	0
Cumaceans	6	0.1	0	1	0	0.0	0	0
Isopods	2	0.0	0	+	0	0.0	0	0
Amphipods	3	0.0	0	+	0	0.0	0	0
Euphausiids	1	0.0	0	+	0	0.0	0	0
Decapods (zoeae)	21	0.4	1	2	0	0.0	0	0
Unidentified crustaceans (nauplii)	10	0.8	1	+	4	0.0	0	+
Collembolans	18	0.4	1	1	0	0.0	0	0
Dipterans (larvae)	10	0.2	0	+	9	0.1	2	2
Dipterans (pupae)	51	3.4	5	11	59	1.3	31	50
Dipterans (adults)	4	0.1	0	+	0	0.0	0	0
Unidentified insect remains	6	0.1	0	+	0	0.0	0	0
Larvaceans	54	18.2	25	34	0	0.0	0	0
Eggs (invertebrates)	19	14.0	9	4	4	0.0	0	+
Fish	6	0.1	0	3	0	0.0	0	0

[1]+ indicates less than 0.5%

Feeding Behavior in Relation to Water Currents

Our visual observations of individual chum and pink salmon fry in shore-oriented schools indicated that their feeding varied with the speed of the water currents. At velocities of 0 to 10.7 cm/s, a fry would typically swim a darting course as much as three times its body length to capture a food item. At higher velocities, 10.8 to 19.8 cm/s, schools of fry sometimes held position relative to the shore or bottom while facing the current, and an individual would typically deviate up, down, or to the sides no more than one-third of its body length to capture oncoming food. At still higher velocities, 19.9 to 24.4 cm/s, fry in schools often held a constant position relative to shore or bottom but did not feed. Fry that appeared to be in visual contact with the shore or bottom avoided currents above 24.4 cm/s unless frightened.

Effect of Daylight on Feeding

The cessation of feeding at night by pink salmon fry was confirmed by the two feeding experiments we conducted in the aquarium. In the first experiment, feeding rate was directly related to light intensity. During a 78-min period when light intensity ranged from 65 to 170 footcandles (three tests), the average consumption was 2.2 to 3.1 zooplankters per minute per fry (Figure 2). At light intensities of 2 footcandles or less, the average feeding rate was only 0.5 zooplankter per minute per fry (three tests). In the second experiment, performed entirely in darkness, little feeding took place. One fry had eaten 48 plankters (less than 0.2 plankter per minute), and the remaining 13 had eaten 13 plankters (0 to 0.001 plankter per minute). These observations agree with laboratory experiments of Hoar (1942) in which young salmon fed little during darkness.

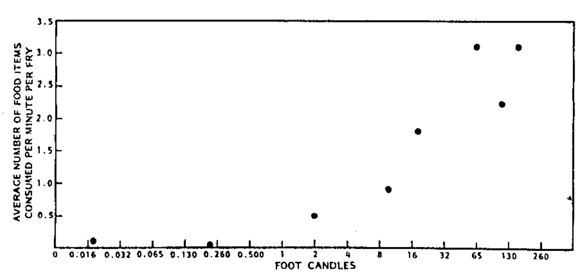

FIGURE 2.—Effect of darkness on feeding rate of pink salmon fry confined in an aquarium. Each dot represents a single test of feeding rate.

TABLE 5.—Average size of zooplankters and other organisms collected by Clarke-Bumpus sampler and present in the stomachs of pink and chum salmon fry at Traitors Cove, 1965-66.

Item and place collected	Number measured	Length (mm)		Diameter (mm)		Average volume (mm³)
		Average	Range	Average	Range	
Diatoms:						
Clarke-Bumpus sampler	24	0.09	0.06- 0.11	0.18	0.12-0.23	0.0023
Pink salmon	9	0.10	—	0.28	0.21-0.31	0.0062
Chum salmon	4	0.10	—	0.31	0.30-0.33	0.0075
Tintinnids:						
Clarke-Bumpus sampler	1	0.25	—	0.14	—	0.0038
Pink salmon	—	—	—	—	—	—
Chum salmon	—	—	—	—	—	—
Hydromedusans:						
Clarke-Bumpus sampler	2	0.18	—	0.31	—	0.0136
Pink salmon	—	—	—	—	—	—
Chum salmon	—	—	—	—	—	—
Rotifers:						
Clarke-Bumpus sampler	9	0.24	0.18- 0.31	0.16	0.11-0.20	0.0048
Pink salmon	9	0.32	0.30- 0.36	0.19	0.16-0.23	0.0091
Chum salmon	2	0.32	0.31- 0.33	—	—	0.0091
Gastropods (veligers):						
Clarke-Bumpus sampler	1	0.20	—	0.14	—	—
Pink salmon	9	0.58	0.30- 0.75	0.38	0.20-0.49	0.0658
Chum salmon	1	0.68	—	0.44	—	0.1034
Pelecypods (veligers):						
Clarke-Bumpus sampler	4	0.28	0.19- 0.40	0.18	0.15-0.21	0.0071
Pink salmon	12	0.34	0.22- 0.42	0.31	0.22-0.38	0.0257
Chum salmon	6	0.35	0.28- 0.38	0.32	—	0.0281
Polychaetes (larvae):						
Clarke-Bumpus sampler	2	0.46	0.38- 0.55	0.17	0.13-0.21	0.0104
Pink salmon	11	0.94	0.61- 1.60	0.24	0.19-0.30	0.0425
Chum salmon	10	2.04	1.01- 4.00	0.29	0.29-0.47	0.1347
Arachnids:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	1	1.20	—	1.20	—	1.3572
Chum salmon	9	1.38	0.30- 1.80	1.38	0.18-3.50	2.0641
Crustaceans (nauplii):						
Clarke-Bumpus sampler	11	0.30	0.23- 0.43	0.14	0.10-0.19	0.0046
Pink salmon	7	0.37	0.28- 0.45	0.17	—	0.0084
Chum salmon	7	0.45	0.30- 0.50	0.21	—	0.0156
Cladocerans:						
Clarke-Bumpus sampler	11	0.50	0.31- 0.71	0.28	0.20-0.39	0.0308
Pink salmon	33	0.62	0.32- 0.91	0.33	0.17-0.49	0.0530
Chum salmon	31	0.60	0.20- 1.10	0.32	—	0.0482
Copepods:						
Clarke-Bumpus sampler	13	0.62	0.40- 1.23	0.19	0.12-0.32	0.0176
Pink salmon	98	1.00	0.26- 3.20	0.37	0.10-1.12	0.1075
Chum salmon	62	1.12	0.30- 3.20	0.41	0.11-1.19	0.1479
Cirripedes (nauplii):						
Clarke-Bumpus sampler	24	0.39	0.39- 0.61	0.22	0.16-0.42	0.0148
Pink salmon	28	0.47	0.28- 0.82	0.29	0.17-0.50	0.0310
Chum salmon	10	0.55	0.30- 1.20	0.34	0.18-0.56	0.0499
Cirripedes (cyprids):						
Clarke-Bumpus sampler	1	0.53	—	0.28	—	0.0326
Pink salmon	18	0.85	0.60- 1.00	0.37	0.26-0.46	0.0914
Chum salmon	14	0.84	0.62- 1.00	0.37	0.27-0.46	0.0903
Mysids:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	1	2.10	—	0.25	—	0.1031
Chum salmon	—	—	—	—	—	—
Cumaceans:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	2	1.80	1.50- 2.10	0.46	—	0.2991
Chum salmon	3	2.11	1.52- 2.50	0.54	—	0.4832
Isopods:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	1	0.76	—	0.50	—	0.1492
Chum salmon	3	0.62	0.52- 0.80	0.31	0.26-0.40	0.0468
Amphipods:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	1	1.48	—	0.59	—	0.4046
Chum salmon	3	1.05	0.90- 1.25	0.42	—	0.1455
Euphausiids:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	3	2.67	2.50- 2.70	0.48	—	0.4832
Chum salmon	1	2.70	—	0.49	—	0.5092

TABLE 5.–Continued.

Item and place collected	Number measured	Length (mm)		Diameter (mm)		Average volume (mm³)
		Average	Range	Average	Range	
Decapods (zoeae):						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	10	1.79	0.54- 5.80	0.39	0.12-1.27	0.2138
Chum salmon	10	2.05	1.28- 3.04	0.45	0.28-0.67	0.3260
Collembolans:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	—	—	—	—	—	—
Chum salmon	14	1.57	0.67- 1.94	0.41	0.20-0.50	0.2073
Dipterans (larvae):						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	3	1.43	1.20- 1.60	0.13	0.11-0.14	0.0190
Chum salmon	8	2.96	1.40- 4.00	0.27	0.13-0.37	0.1695
Dipterans (pupae):						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	1	2.00	—	0.39	—	0.2389
Chum salmon	21	1.80	1.20- 2.90	0.43	0.27-0.70	0.2614
Dipterans (adults):						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	—	—	—	—	—	—
Chum salmon	4	2.58	1.60- 3.50	0.39	0.24-0.52	0.3082
Unidentified insect remains:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	—	—	—	—	—	—
Chum salmon	—	0.52	—	—	—	0.0616
Larvaceans:						
Clarke-Bumpus sampler	1	0.20	—	0.14	—	0.0031
Pink salmon	9	0.69	0.50- 1.05	0.39	0.28-0.60	0.1498
Chum salmon	30	0.69	0.41- 1.30	0.39	0.23-0.74	0.1498
Polyzoans:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	1	0.60	—	0.19	—	0.0032
Chum salmon	—	—	—	—	—	—
Eggs (invertebrate):						
Clarke-Bumpus sampler	7	—	—	0.32	0.20-0.40	0.0172
Pink salmon	11	—	—	0.31	0.11-0.40	0.0156
Chum salmon	14	—	—	0.34	0.10-0.42	0.0206
Eggs (vertebrate):						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	5	—	—	0.88	0.80-0.98	0.3568
Chum salmon	1	—	—	0.85	—	0.3216
Fish:						
Clarke-Bumpus sampler	—	—	—	—	—	—
Pink salmon	3	5.67	4.00- 8.00	0.14	—	0.0873
Chum salmon	3	16.70	15.00-20.00	0.42	—	2.3137

Stomach Evacuation

The time required for satiated fry in the aquarium to evacuate food in their stomachs was inversely related to temperature. In tests at 12.8°C, the stomachs of two of five pink salmon were empty after 2 h without food. However, 6 h elapsed before successive samples of five fish contained no food, and 6 h was therefore accepted as the time required for pink salmon to evacuate their stomachs at a temperature of 12.8°C (Table 6). For chum salmon, the first empty stomach was observed after 1 h without food at 12.8°C. Only after 10 h did successive samples of five chum salmon have empty stomachs. This longer evacuation time for chum salmon probably resulted from the larger and different kinds of organisms eaten. Using the same criterion for time of evacuation as described above for 12.8°C, pink salmon fry confined without food had empty stomachs after 9 h at 10°C and after 16 h at 8.5°C. We did not test chum salmon at the lower temperatures.

TABLE 6.–Time required for pink and chum salmon fry to evacuate food from their stomachs at various temperatures.

Temperature (°C)	Pink salmon (hours)	Chum salmon (hours)
8.5	16	—
10.0	9	—
12.8	6	10

ZOOPLANKTON ABUNDANCE AND DISTRIBUTION

The abundance of zooplankton in the near-surface waters was determined from the samples we collected in the inner and outer bays of Traitors

Cove in June 1965 and in April, May, and June 1966 when salmon fry were present. The lowest abundance in the inner bay, an average of 9 organisms per liter, occurred in April 1966, when the abundance was comparatively high in the outer bay, 51 per liter (Table 7). During the rest of the 1966 season, mean numbers ranged from 27 to 28 organisms per liter in the inner bay and 24 to 40 in the outer bay. The highest numbers were observed in the outer bay in June 1965 after most of the fry had passed through the estuary. Zooplankters tended to be more abundant at the mouth of the bay, near the constriction, and at the head of the bay than at intervening points along the shoreline.

Fifty-two categories of zooplankters were identified from the Clarke-Bumpus samples, and seasonal qualitative and quantitative changes were evident in the composition of the zooplankton (Table 8). The peak abundance for polychaete larvae and cirrepede (barnacle) nauplii occurred in April, whereas the peak for other invertebrate larvae occurred in May. Rotifers, copepods (including nauplii), and barnacle nauplii were also very abundant in May. Cladocerans did not become abundant until June. Variation between years is indicated by the high abundance of rotifers in June 1965 (~120,000/m^3) and the much lower abundance of rotifers (~3,000/m^3) and possibly higher abundance of other forms in June 1966.

The predominant zooplankters during the period of fry outmigration were larvae of barnacles, polychaetes, and molluscs and nauplii and early copepodites of the copepods *Acartia clausii*, *A. longiremis*, and *Oithona helgolandica*. Over 98% of the zooplankters in the outer bay on 16 April 1966 were larvae, and as late as 7 June 1966 larvae constituted more than 65% of the zooplankton. In the inner bay on 18 April 1966 and 7 June 1966, the proportions of larvae in the zooplankton were 72 and 58%, respectively. Late copepodites and adults of calanoid and cyclopoid copepods were the next most abundant groups of zooplankters and contributed relatively more to the zooplankton as the season progressed. An abundance of larval forms was also characteristic of another southeastern Alaska estuary, Auke Bay (Wing and Reid 1972). Rotifers, although of minor importance in the diet of salmon fry, were often the most abundant zooplankters in the samples. Cladocerans and larvaceans were rare in April and May but by June constituted a significant portion of the zooplankton. Adults and juveniles of benthic invertebrates were rare in the plankton samples. Species composition of zooplankters differed between the inner and outer bays of Traitors Cove (Table 8).

TABLE 7.—Abundance of zooplankters determined from Clarke-Bumpus sampler with no. 10 mesh net (158μm) at Traitors Cove.

	Inner bay			Outer bay		
	Number of	Organisms per liter		Number of	Organisms per liter	
Date	samples	Mean	Range	samples	Mean	Range
16 June 1965	—	—	—	7	154	8-563
16-18 Apr. 1966	10	9	1-28	14	51	6-180
16 May 1966	10	28	2-76	14	24	10-44
7 June 1966	10	27	2-62	14	40	4-95

The plankton samples contained zooplankton of the kinds and sizes eaten in great numbers by pink and chum salmon fry as well as smaller plankters, which were not important in the diet of fry. As a result, the average size of plankters in the net was slightly smaller than the average size of items eaten (Table 5).

DISCUSSION

Initiation of Feeding

Neither pink nor chum juvenile salmon ate very much before leaving Traitors River, although chum salmon fed more than pink salmon. Some fry may have fed before they emerged from the redds. The size (41 mm) of the largest fry collected in the river suggests that at least a few individuals actually grew as a result of exogenous feeding before they finally left the river. Mason (1974) collected chum salmon fry up to 70 mm long from Lymn Creek on Vancouver Island, British Columbia, where they moved into and out of high-salinity water and apparently fed in both media over a period of 1 to 4 wk or more.

Immature stages of chironomids were most commonly eaten, but other bottom-dwelling aquatic organisms also occurred in stomachs of pink and chum salmon from Traitors River. Two workers (Disler 1953; Sparrow 1968) reported that zooplankton and bottom-dwelling aquatic organisms occurred in the diet of chum salmon in freshwater. Although pink salmon apparently eat little or nothing while migrating seaward in short streams (Kazarnovskii 1962; Kobayashi 1968), as at Traitors River, they are more likely to feed while migrating long distances from large rivers (Levanidov and Levanidova 1957; McDonald 1960).

Once they had left the stream, pink and chum salmon fry in Traitors Cove fed extensively on such zooplankters as calanoid copepods, lar-

TABLE 8.—Average species composition of zooplankton samples during salmon fry outmigration at Traitors Cove, June 1965[1] and April to June 1966. (See Table 4 for number of samples. Numbers of zooplankters per cubic meter rounded to nearest whole number. Percentages rounded to 0.1%; + indicates less than 0.5%.)

Item	Inner bay						Outer bay							
	18 Apr. 1966		16 May 1966		7 June 1966[2]		16 June 1965		16 Apr. 1966		16 May 1966		7 June 1966[2]	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Hydromedusans:														
Bougainvillia sp.	—	—	1	+	—	—	—	—	—	—	2	+	—	—
Obelia sp.	4	+	26	+	—	—	17	+	—	—	5	+	—	—
Phialidium sp.	—	—	2	+	—	—	—	—	—	—	1	+	—	—
Sarsia tubulosa (M. Sars)	—	—	1	+	—	—	—	—	—	—	1	+	45	+
Unidentified	2	+	—	—	—	—	15	+	—	—	—	—	—	—
Ctenophores:														
Pleurobrachia pileus (Müller)	—	—	1	+	—	—	—	—	—	—	—	—	—	—
Nemertines (pilidium)	—	—	—	—	—	—	—	—	—	—	3	+	—	—
Rotifers	930	10.0	1,523	5.4	229	0.8	124,670	80.8	10	+	1,514	6.4	2,802	6.8
Bryozoans (cyphonautes)	10	+	30	+	—	—	—	—	—	—	108	+	89	+
Molluscs:														
Littorina scutulata Gould (egg cases)	—	—	41	+	107	+	35	+	8	+	280	1.2	46	+
Gastropoda (veligers)	221	2.4	345	1.2	84	+	53	+	102	+	127	0.5	—	—
Pelecypoda (veligers)	716	7.7	1,008	3.6	228	0.8	322	+	22	+	694	2.9	1,929	4.7
Polychaetes (larvae)	1,370	14.8	685	2.4	—	—	62	+	891	1.7	547	2.3	205	0.5
Tardigrades	2	+	—	—	—	—	—	—	—	—	—	—	—	—
Cladocerans:														
Evadne nordmanni Loven	2	+	4	+	—	—	419	+	4	+	8	+	—	—
Podon leuckarti Sars	—	—	3	+	—	—	670	+	—	—	3	+	—	—
Unidentified	—	—	—	—	1,096	3.8	—	—	—	—	—	—	2,104	5.1
Ostracods	—	—	1	+	—	—	—	—	—	—	—	—	—	—
Copepods (late copepodites and adults):														
Acartia clausii Giesbrecht	8	+	783	2.8	—	—	3,087	2.0	2	+	47	+	—	—
A. longiremis (Lilljeborg)	17	+	723	2.6	—	—	336	+	110	+	148	0.6	—	—
Acartia spp.	79	0.9	4,571	16.2	—	—	4,498	2.9	45	+	2,852	12.1	—	—
Calanus finmarchicus (Gunnerus)	—	—	399	1.4	—	—	—	—	—	—	159	0.7	—	—
Centropages abdominalis Sato	—	—	—	—	—	—	—	—	—	—	9	+	—	—
Metridia sp.	2	+	155	0.0	—	—	—	—	2	+	111	+	—	—
Pseudocalanus minutus (Krøyer)	84	0.9	1,621	5.8	—	—	95	+	143	+	862	3.6	—	—
Tortanus discaudatus (Thompson and Scott)	1	+	16	+	—	—	—	—	—	—	4	+	—	—
Calanoids spp.	14	+	—	—	—	—	81	+	—	—	1	+	—	—
Oithona helgolandica Claus	486	5.2	687	2.4	—	—	981	0.6	469	0.9	514	2.2	—	—
Cyclopoids spp.	58	0.6	158	0.6	—	—	—	—	7	+	134	0.6	—	—
Harpacticoids spp.	58	0.6	14	+	—	—	34	+	2	+	21	+	—	—
Unidentified	—	—	—	—	10,422	36.5	—	—	—	—	—	—	9,201	22.4
Copepods (nauplii)	1,980	21.4	10,237	36.3	—	—	9,972	6.5	909	1.8	4,264	18.0	—	—
Cirripedes (nauplii)	2,334	25.2	4,041	14.3	10,261	35.9	6,994	4.5	48,067	93.9	9,714	41.1	13,706	33.4
Cirripedes (cyprids)	—	—	236	0.8	131	+	70	+	—	—	893	3.8	92	+
Cumaceans:														
Cummella vulgaris Hart	1	+	—	—	—	—	—	—	—	—	—	—	—	—
Amphipods:														
Corophiidae	—	—	1	+	50	+	—	—	—	—	—	—	—	—
Euphausiids (calyptopis)	—	—	—	—	—	—	—	—	—	—	10	+	—	—
Euphausiids (nauplii)	99	1.1	429	1.5	—	—	—	—	206	+	168	0.7	—	—
Carids (zoeae)	—	—	—	—	—	—	—	—	2	+	1	+	—	—
Brachyurans (zoeae)	—	—	16	+	—	—	—	—	—	—	7	+	—	—
Pagurians (zoeae)	—	—	—	—	—	—	—	—	2	+	—	—	—	—
Crustaceans (nauplii):														
Unidentified	—	—	—	—	5,955	20.8	—	—	6	+	1	+	10,418	25.4
Chaetognaths:														
Sagitta elegans Verrill	4	+	2	+	—	—	—	—	9	+	—	—	—	—
Echinoderms:														
Echinopleutei	4	+	32	+	—	—	—	—	1	+	19	+	—	—
Bipinnaria	—	—	—	—	—	—	—	—	—	—	3	+	—	—
Tunicates:														
Fritillaria borealis Lohmann	5	+	12	+	—	—	—	—	8	+	—	—	—	—
Oikopleura sp.	—	—	—	—	—	—	—	—	11	+	—	—	92	+
Tunicata (larvae)	—	—	—	—	—	—	107	+	2	+	—	—	—	—
Tunicata (eggs)	—	—	20	+	—	—	12	+	33	+	—	—	—	—
Unidentified invertebrate larvae	17	+	39	+	—	—	51	+	9	+	15	+	—	—
Unidentified invertebrate eggs	764	8.2	309	1.1	—	—	1,765	1.1	86	+	379	1.6	—	—
Fish larvae	—	—	—	—	—	—	—	—	1	+	1	+	—	—
Fish eggs	—	—	5	+	—	—	—	—	—	—	—	—	362	0.9
Total	9,272	—	28,177	—	28,563	—	154,346	—	51,169	—	23,630	—	41,091	—

[1]No sampling was done in the inner bay in 1965.
[2]June 1966 samples were not available for taxonomic breakdown.

vaceans, barnacle nauplii, cladocerans, and other small crustaceans. Chum salmon fry tended to eat more larger hard-shelled organisms and epibenthic organisms than did pink salmon fry. The food of pink and chum salmon fry at Traitors Cove in general was similar to that reported at Uala and Anapka bays on the east side of the Kamchatka Peninsula (Andrievskaya 1968), the San Juan area of northern Washington (Annan 1958), the Strait of Georgia in southern British Columbia (Barraclough 1967; Robinson et al. 1968), Chatham Sound off the northern coast of British Columbia (Manzer 1969), and Moser Bay of southeastern Alaska (Chamberlain 1906). In contrast, in Puget Sound epibenthic organisms (especially harpacticoid copepods) were more important than pelagic zooplankters to pink and chum salmon fry (Gerke and Kaczynski 1972).

Food Selection

Salmon fry in Traitors Cove did not eat the same kinds and sizes of zooplankters in the same relative numbers as they appeared in the samples of zooplankton, i.e., the fry fed selectively. Selective feeding in relation to sizes of prey and juvenile chum salmon has been reported by LeBrasseur (1969). The average size of the zooplankton eaten bv the fish was greater than the zooplankton collected by the Clarke-Bumpus sampler (Table 5). A coarser net such as a no. 6 mesh (233 μm) would probably have collected the zooplankters that were usually eaten by salmon fry and would not have collected so many of the small forms that are seldom eaten such as tintinnids, rotifers, and others.

Selective feeding by pink and chum salmon fry was also demonstrated by the occurrence of certain food items relatively more often in the stomachs of fry (Tables 3, 4) than in the plankton samples (Table 8). Relatively more cladocerans, decapod zoeae, and larvaceans were eaten by salmon than appeared in the plankton samples. Another example of the marked disparity is the barnacle nauplii which were very abundant in most of the plankton samples (4 to 94% of the number of plankters) but constituted only 14% of the animals actually eaten by pink salmon and only 3% of the number of food items eaten by chum salmon.

The high incidence of larvaceans in the stomach samples, especially in the chum salmon, may be the result of selective feeding on a scarce but very visible plankter. Larvaceans, in particular *Oikopleura* spp., form mucous feeding nets which may increase the visibility of the larvacean to the salmon fry. Once learning to capture *Oikopleura*, the fry may prefer that food item.

Benthic and intertidal forms of mysids, cumaceans, isopods, amphipods, and insects were rare in the plankton samples and their presence in some of the stomachs shows that pink and chum salmon fry did on occasion feed in these ecological niches. This type of feeding behavior could not predominate at Traitors Cove because most of the shoreline is rocky and precipitous and offers little opportunity for benthic feeding.

Grazing Rate

The average number of zooplankters comsumed daily by a pink salmon fry in Traitors Cove was calculated from estimates of average stomach contents and evacuation rates. Stomachs of pink salmon collected from Traitors Cove estuary during daylight contained an average of 136 zooplankters. Stomach evacuation required 6 and 16 h at temperatures of 12.8°C and 8.5°C, respectively, although Brett and Higgs (1970) observed slower stomach evacuation rates at comparable temperatures in sockeye salmon fingerlings that had been fed a commercial pelleted food. The fry did not feed during darkness, which extended from about one-half hour after sunset to one-half hour before sunrise on cloudy or moonless nights. The duration of feeding at Traitors Cove when fry are present typically is about 16.5 h (range 15 to 18 h); the water temperature at 1 m ranges from 5° to 13°C.

Thus, it appears that fry would consume a volume of food required to fill their stomachs once a day at cooler temperatures (8.5°C) and four times a day at warmer temperatures (12.8°C). The number of zooplankters consumed daily would, therefore, range between 136 and 544 per pink salmon fry for temperatures that are normal during the time fry are in Traitors Cove. By the same line of reasoning, chum salmon would consume about 120 to 480 food items per fry per day in Traitors Cove.

Some insight into the availability of food for salmon fry at Traitors Cove was obtained by considering the abundance of plankton in relation to the feeding habits of the fry. For example, fry 39 mm long that were holding a position relative to the shore while feeding in a current of 11 cm/s were in effect grazing a cylindrical mass of water at the rate of about 3.5 liter/min. Even at the lowest observed abundance of 1 zooplankter per liter (Table 5), each fry would theoretically encounter about 3.5 zooplankters per minute, which is slightly greater than the estimated feeding rate of 3 zooplankters per minute in floating aquaria at 10°C. At this rate of feeding, a single fry could fill its stomach in about 39 to 155 min and could therefore easily ingest zooplankters faster than they could be evacuated.

Abundance of zooplankton in the outer bay of Traitors Cove ranged from 4 to 563 organisms per liter (Table 7), and this was theoretically enough to satiate feeding fry as shown above. Furthermore, the abundance of zooplankton as estimated from Clarke-Bumpus samples did not decrease during the time that salmon fry were in the estuary. Therefore, we conclude that there was an abundant food supply in Traitors Cove for salmon fry. LeBrasseur et al. (1969), who conducted feeding experiments with wild juvenile pink and chum salmon in the Fraser River estuary in 1967 (an off-cycle year of pink salmon in the Fraser system), arrived at a similar conclusion for that area.

Carrying Capacity of Traitors Cove

Fry of pink and chum salmon emerged from the gravel of Traitors River at night, and most of them migrated to the estuary before dawn. Some of the fry, as evidenced by their size and the contents of their digestive tracts, lingered a few days in the stream where they fed on freshwater organisms. The tendency to linger and feed in freshwater, most pronounced for chum salmon, has been described by Mason (1974). After the fry left Traitors River, they gathered in schools close to shore and began feeding and migrating oceanward. The time spent in the estuary is unknown but was probably from a few days to a few weeks.

We estimated the abundance of pink and chum salmon fry in Traitors Cove by making counts each day along the shore from a moving skiff or by a mark-and-recapture technique. In 1965, the greatest number estimated from counts on any day was 7 million fry, but in 1966 the greatest estimate was under 1 million fry. The number of salmon fry in Traitors Cove in 1968 was estimated by mark and recapture to be 4 million (±1.3 million, 95% confidence limits). The mark-and-recapture estimate was made on a different annual fry migration than those covered by this study of feeding habits, but it strengthened our confidence in the visual estimates of fry abundance in 1965 and 1966.

It did not appear that the Traitors Cove estuary was overgrazed by wild fry at the time of this study. In 1966, zooplankton abundance was always greater than 1.0 zooplankter per liter, which would allow maximum feeding rates by fry. During May and June 1966, when 1 million fry were present, the average abundance was about 29 zooplankters per liter. In June 1965, abundance was 154 zooplankters per liter after 7 million fry passed through the estuary.

The number of fry that migrate through Traitors Cove each year is probably limited to less than 20 million by the productivity of the spawning grounds in Traitors River and Margaret Creek, the major salmon streams in the cove. We used stream survey data from Martin (1959) and applied a correction factor of 0.5 to correct for pools and stream bottoms of mud, sand, and bedrock to calculate 66,000 m^2 of spawning grounds—55,000 m^2 in Traitors River and 11,000 m^2 in Margaret Creek. These spawning grounds would yield about 7 million fry if they produced 100 fry per square meter or about 20 million fry if they produced 300 fry per square meter. Fry densities of 0.1 to 589 per square meter (average 250 fry per square meter) have been observed in Traitors River,[3,4] but these densities were in sections of the stream consistently favored by spawning salmon. Less favored areas were not sampled.

The installation of a hatchery or spawning channel in a drainage system such as Traitors River could potentially result in a production of 100 million fry annually, or 5 to 100 times the estimated production of wild fry. Available data are inadequate to determine the carrying capacity of Traitors Cove with certainty, but it is possible to make very speculative estimates based on the standing crop of zooplankton.

Before presenting the estimates of carrying capacity, we wish to cite 10 necessary assumptions (required because we lack knowledge of the ecology of estuarine nursery areas) and some of the factors which may invalidate the estimates.

1. Zooplankton abundance was the same in Behm Canal as in Traitors Cove. Plankton samples

[3]Mattson, C. R., and J. E. Bailey. 1966. Chum and pink salmon studies at Traitors Cove, September 1963 to September 1964. On file, Auke Bay Laboratory.

[4]Mattson, C. R., and R. G. Rowland. 1963. Chum salmon studies at Traitors Cove Field Station June 1960 to March 1963. On file, Auke Bay Laboratory.

were not collected outside Traitors Cove in Behm Canal. Several years later extensive plankton collections were made in open channels and several small adjacent bays of northern southeastern Alaska as a part of the 1972 MARMAP[5] investigation. Within the May 1972 samples, average zooplankton abundance was nearly twice as great at 14 outside stations as at 4 stations within bays. Therefore, our estimates of carrying capacity based on influx of zooplankton from Behm Canal would be conservative.

2. Salmon fry were the only predators on zooplankton. We ignored the requirements of all other planktivorous animals of the area. The requirement of local planktivores other than salmon are only qualitatively and poorly known. Herring were not seen in large numbers during the years of this food study. A school of herring entered the inner bay in 1967 while being fed on by a whale. We do not know how long these herring remained in Traitors Cove, but they were not conspicuous 2 wk after their entry.

3. Zooplankton concentrations were constant. We ignored the strong seasonality of reproduction and growth in the holoplankton and the fact that meroplankton may be present for only a limited time. We ignored the probability that some larval forms reach a life history stage where their behavior would make them unavailable to the salmon fry. We ignored natural mortality of larval forms other than from predation by salmon fry. Some of these factors would increase zooplankton concentrations while others would decrease them. In the absence of information on reproduction, growth, mortality, and life histories, we assumed these factors would balance so that the zooplankton concentration would be constant.

4. Distribution of the zooplankton was uniform. Physical and biological factors controlling the patchiness of zooplankton in estuaries and nearshore environments are poorly understood and not easily modeled.

5. All zooplankton were equally available, equally desirable, and of equal quality as feed for salmon fry. We ignored the size selectivity and preference for calanoid copepods shown in our own data. It is highly probable that the species of zooplankton vary in quality as food.

6. Salmon fry had a constant feeding requirement of 544 zooplankters per day. This is the highest of our estimates of pink salmon feeding rates and ignores variations in food requirements that would accompany variations in physical environment and physiological state.

7. No behavioral changes in either the salmon fry or zooplankton were induced by changes in densities, physical environment, or biological states.

8. The number of salmon fry was constant.

9. All the zooplankton would be utilized as food. If this actually occurred, no survivors would be left to produce new zooplankton crops or to replenish stocks of other resources that have planktonic larval stages such as herring, crabs, and shrimp.

10. Models of circulation in the estuary would be of the simplest type. We do not know the flushing rates in Traitors Cove or the potential of transport of zooplankton food to and from the bay by estuarine circulation.

Some additional assumptions peculiar to each estimate are described with each estimate. Only the outer bay is considered because fry in Traitors Cove appeared to move quickly through the inner bay and then spend a longer time in the outer bay.

Our first estimate of carrying capacity is based on standing stock of zooplankton in the top meter of water of the outer bay. Fry were in the outer bay in relatively high densities for about 30 days each year. The surface area of the outer bay is about 7.6×10^6 m^2, and the average density of zooplankters was estimated to be 24,000 per cubic meter or higher. The product of area and plankton density divided by 544 (the estimated maximal number of organisms consumed per day by pink salmon fry) results in a plankton stock equivalent to 335×10^6 fry feeding days. This estimate divided by 30 days expresses the food supply in fry months—11 million fry could feed for 1 mo on the standing stock of food in the surface meter of outer bay. This establishes a lower limit for the carrying capacity of Traitors Cove because it ignores saltwater entrainment by outflowing freshwater and the consequent addition of plankton from deeper water.

For our second estimate, we calculated the quantity of zooplankton that would be brought into the outer bay from Behm Canal each day by a combination of two factors: circulation due to freshwater runoff from Traitors River and circulation due to tidal action. Records of the U.S. Geological Survey indicate that discharge from Traitors River generally averages about 8 m^3/s in

[5]Marine Resources Monitoring, Assessment, and Prediction—program sponsored by National Marine Fisheries Service on a nationwide scale.

the spring when fry are migrating. Assuming an equal flow of seawater with plankton density of 24,000 organisms per cubic meter into Traitors Cove from Behm Canal and surface entrainment near the constriction, we calculated that 16.5×10^9 organisms would be brought daily into Traitors Cove by freshwater-driven circulation. Dividing the number of organisms by 544 (the high estimate of organisms eaten by one fry daily) yields a conservative estimate of 30 million fry that could be fed by an amount of food added daily by circulation. Although it is naive to assume that all of the plankton brought into Traitors Cove as a result of circulation would become available to the fry, the upwelling and thorough mixing that occur at the constriction between the two bays result in a continual resupplying of zooplankton to the upper meter of depth where grazing apparently takes place. Field observations did indicate that the largest concentrations of fry were consistently found in eddies near the constriction, lending some credence to the theory that upwelling of deep water created a favorable supply of food in this area.

The effects of tidal circulation and freshwater-runoff-driven circulation are often additive. Therefore, we calculated the influx of food organisms by tidal exchange. We assumed that the surface waters were flushed completely by the outgoing tide; that complete mixing of incoming water with water present occurred on each tide; and that all zooplankton in the upper meter had been consumed before the waters were mixed. The influx of new food can then be estimated from the tidal prism as

$$F = [T/V] \times P$$

where F is the net influx of new food organisms as zooplankters per cubic meter per tide; T is the volume of the tidal prism; V is the volume of the outer bay; and P is the density of zooplankton outside the bay. (We used $P = 24 \times 10^3/\mathrm{m}^3$ because we assumed that abundance was the same outside the bay as it was inside.)

The resulting calculation assuming a mean tidal range of 4.11 m (McLain 1968) and a mean depth of 90 m gives for the net influx of organisms per tide:

$$F = \frac{4.11\ \mathrm{m/tide}}{90\ \mathrm{m}} \times 24 \times 10^3/\mathrm{m}^3 = 1.09 \times 10^3$$

zooplankters per cubic meter per tide.

Only those in the upper meter are available, and since there are two tides per day, the calculated quantity of new food available to salmon fry per day is:

$$Q = 2 \times F \times [\text{area of bay}] \times 1\ \mathrm{m} = 2\ \text{tides/day}\ (1.09 \times 10^3\ \text{zooplankton per cubic meter per tide}) \times (7.6 \times 10^6\ \mathrm{m}^2 \times 1\mathrm{m}) = 16.6 \times 10^9\ \text{zooplankters per day.}$$

This number will feed 30×10^6 fry per day (16.6×10^9 zooplankters $\div$ 544 zooplankters per day per fry). The estimate is high because mixing is not complete, as implied by the calculations. By adding fry that could be fed from the effects of freshwater runoff to fry that could be fed by tidal action, we get an upper estimate of carrying capacity of 60 million fry.

The numbers of fry that could theoretically be fed by the two sources of zooplankton, i.e., standing crop in the surface water and plankton in the net circulation, are not strictly additive. Although some plankton in deep seawater would be continuously entrained upward to flow seaward on the surface, some would never reach the surface of the bay and a portion of the surface stock would be removed from the bay by outflow. Therefore, it would seem prudent to consider that populations numbering more than 30 million pink and chum salmon fry might cause reduced growth of fry (because of the competition for food). Also, such large populations might stimulate a more rapid migration of fry through the estuary to areas where food organisms were more abundant.

On the basis of available spawning grounds, it seems unlikely that Traitors Cove has ever had to support more than 20 million pink and chum salmon fry, although it is possible that 11 to 60 million fry could be supported in years when food abundance equaled or exceeded that observed in 1966. The release of 50 to 100 million additional hatchery fry into this estuary would probably exceed the carrying capacity of the area. Competition for food, especially if zooplankton production were lower than average, and increased potential infection by disease, parasitism, and predation could theoretically result in increased mortality, slower growth, or accelerated movement of fry out of the estuary. Further, a great increase in numbers of salmon fry in Traitors Cove could deplete planktonic food and planktonic larvae required to support other fisheries. We have used Traitors Cove to discuss carrying capacity of estuaries only because observations on fry and food were available. We know of no plans for the operation of a hatchery in Traitors Cove. The discussion is merely intended to focus attention on an important factor to be considered in choosing sites and operating salmon fry hatcheries.

LITERATURE CITED

ANDRIEVSKAYA, L. D.
1968. Feeding of Pacific salmon fry in the sea. [In Russ.] Izv. Tikhookean. Nauchno-issled. Inst. Rybn. Khoz. Okeanogr. 64:73-80. (Translated by Transl. Bur., Dep. Secretary of State of Canada, 1970, 16 p.)

ANNAN, M. E.
1958. Notes on the food of the young of three species of Pacific salmon in the sea. Can. Fish Cult. 23:23-25.

BAILEY, J. E., AND W. R. HEARD.
1973. An improved incubator for salmonids and results of preliminary tests of its use. U.S. Dep. Commer., NOAA Tech. Memo. NMFS ABFL-1, 7 p.

BAILEY, J. E., AND S. G. TAYLOR.
1974. Salmon fry production in a gravel incubator hatchery, Auke Creek, Alaska, 1971-72. U.S. Dep. Commer., NOAA Tech. Memo. NMFS ABFL-3, 13 p.

BAMS, R. A.
1972. A quantitative evaluation of survival to the adult stage and other characteristics of pink salmon (*Oncorhynchus gorbuscha*) produced by a revised hatchery method which simulates optimal natural conditions. J. Fish. Res. Board Can. 29:1151-1167.

BARRACLOUGH, W. E.
1967. Number, size and food of larval and juvenile fish caught with a two boat surface trawl in the Strait of Georgia April 25-29, 1966. Fish. Res. Board Can., Biol. Stn. Nanaimo, B.C., Manuscr. Rep. Ser. 922, 54 p.

BRETT, J. R., AND D. A. HIGGS.
1970. Effect of temperature on the rate of gastric digestion in fingerling sockeye salmon, *Oncorhynchus nerka*. J. Fish. Res. Board Can. 27:1767-1779.

CHAMBERLAIN, F. M.
1906. Some observations on salmon and trout in Alaska. Rep. U.S. Comm. Fish., 1906 (Doc. 627), 112 p.

CUSHING, C. E., JR.
1961. A plankton subsampler. Limnol. Oceanogr. 6:489-490.

DISLEŔ, N. N.
1953. Ecological and morphological characteristics of the development of the Amur autumn chum salmon–*Oncorhynchus keta* (Walb.). [In Russ.] Tr. Soveshch. Ikhtiol. Kom, Akad. Nauk SSSR 1:354-362. (Translated by Israel Program Sci. Transl., 1961; *In* Pacific salmon, selected articles from Russian periodicals, p. 33-41; available U.S. Dep. Commer., Off. Tech. Serv., Wash., D.C., as OTS 60-51139.)

FRASER, F.
1972. Evaluation of chum spawning channels (Abstr.). *In* J. E. Bailey (editor), Proceedings of the 1972 northeast Pacific pink salmon workshop, p. 55-64. Alaska Dep. Fish Game, Inf. Leafl. 161.

GERKE, R. J., AND V. W. KACZYNSKI.
1972. Food of juvenile pink and chum salmon in Puget Sound, Washington. Wash. Dep. Fish., Tech. Rep. 10, 27 p.

HOAR, W. S.
1942. Diurnal variations in feeding activity of young salmon and trout. J. Fish. Res. Board Can. 6:90-101.

IVANKOV, V. N., AND A. P. SHERSHNEV.
1968. (Biology of juvenile pink salmon and chum salmon in the sea.) [In Russ.] Rybn. Khoz. 44:16-17.

KANID'YEV, A. N., G. M. KOSTYUNIN, AND S. A. SALMIN.
1970. Hatchery propagation of the pink and chum salmons as a means of increasing the salmon stocks of Sakhalin. J. Ichthyol. 10:249-259.

KAZARNOVSKII, M. YA.
1962. Food of migrating fry of *Oncorhynchus gorbuscha* and *Salvelinus malma* in the rivers of Sakhalin. [In Russ.] Rybn. Khoz. 38(6):24-25. (Abstr. translated from Russ. in Biol. Abstr. 41:(20992).

KOBAYASHI, T.
1968. A note on the seaward migration of pink salmon fry. [In Jap., Engl. summ.] Sci. Rep. Hokkaido Salmon Hatchery 22:1-5.

LEBRASSEUR, R. J.
1969. Growth of juvenile chum salmon (*Oncorhynchus keta*) under different feeding regimes. J. Fish. Res. Board Can. 26:1631-1645.

LEBRASSEUR, R. M., W. E. BARRACLOUGH, O. D. KENNEDY, AND T. R. PARSONS.
1969. Production studies in the Strait of Georgia. Part III. Observations on the food of larval and juvenile fish in the Fraser River plume, February to May, 1967. J. Exp. Mar. Biol. Ecol. 3:51-61.

LEVANIDOV, V. Y., AND I. M. LEVANIDOVA.
1957. Food of downstream migrating young summer chum salmon and pink salmon in Amur tributaries. [In Russ.] Izv. Tikhookean. Nauchno-issled. Inst. Rybn. Khoz. Okeanogr. 45:3-16. (Translated by Israel Program Sci. Transl., 1961; *In* Pacific salmon, selected articles from Russian periodicals, p. 269-284; available U.S. Dep. Commer., Off. Tech. Serv., Wash., D.C.. as OTS 60-51139.)

MANZER, J. I.
1969. Stomach contents of juvenile Pacific salmon in Chatham Sound and adjacent waters. J. Fish. Res. Board Can. 26:2219-2223.

MARTIN, J. W. (editor)
1959. Stream catalog of eastern section of Ketchikan management district of southeastern Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 305 [615 p.].

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

MCDONALD, J.
1960. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. J. Fish. Res. Board Can. 17:655-676.

MCLAIN, D. R.
1968. Oceanographic surveys of Traitors Cove, Revillagigedo Island, Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 576, 15 p.

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

ROBINSON, D. G., W. E. BARRACLOUGH, AND J. D. FULTON.
1968. Number, size composition, weight and food of larval

and juvenile fish caught with a two-boat surface trawl in the Strait of Georgia May 1-4, 1967. Fish. Res. Board Can., Pac. Oceanogr. Group, Nanaimo, B.C., Manuscr. Rep. Ser. 964, 105 p.

SPARROW, R. A. H.
1968. A first report of chum salmon fry feeding in fresh water of British Columbia. J. Fish. Res. Board Can. 25:599-602.

WING, B. L., AND G. M. REID.
1972. Surface zooplankton from Auke Bay and vicinity, southeastern Alaska, August 1962 to January 1964. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Data Rep. 72, 765 p. on 12 microfiche.