# FRED Reports

EARLY LIFE HISTORY OF CHUM SALMON
IN THE NOATAK RIVER AND KOTZEBUE SOUND

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Margaret F. Merritt
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**Alaska Department of Fish & Game**
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Enhancement and Development

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ABSTRACT

Chum salmon spawning grounds investigated on the Noatak River were characterized by water temperatures 3 to 5°C higher than temperatures in the Noatak River main stem. Intragravel temperatures dropped from approximately 9°C in September to a minimum of 2°C in April. Chum salmon eggs and alevins residing in these gravels would have acquired approximately 1,130 temperature units during the period 15 September to 30 April. During the 1979-1980 winter, the water level at one spawning site dropped by approximately 2.5 m which resulted in the drying and freezing of some of the spawning gravels. During the following winter only a 20-cm drop in water level was observed.

Chum salmon females were found to have an average fecundity of 3,120 eggs which is larger than fecundities reported for other Alaskan chum salmon. Observations on the spawning grounds suggested that the peaks of spawning, eyeing, hatching and emergence occurred, respectively in mid to late September, early November, late December through January and early May. Diptera and Plecoptera were the most common prey of chum fry in the Noatak River. The fullness of the guts was found to increase during the period May-June. The catch of chum salmon fry per unit effort in Kotzebue Sound indicated that the peak of the outmigration from the Noatak River occurred in mid June. Zooplankton abundance, about 2,000 to 7,000 organisms per cubic meter, was similar to that reported for other near-shore waters of Alaska. Juvenile chum salmon appeared to grow rapidly once they reached Kotzebue Sound. They remained in near-shore waters until early July, after which they were difficult to find. The major food of the chum fry caught in Kotzebue Sound in June continued to be Diptera.

No evidence for a food shortage or predation could be found. The availability of spawning areas appeared to be the factor limiting chum salmon production in the Kotzebue Sound area.

KEY WORDS: chum salmon, *Oncorhynchus keta*, Noatak River, Kotzebue Sound, Kelly River Lake, spawning, incubation, egg development, freezing of spawning gravels, migration, feeding, growth, predation, water temperature, salinity, zooplankton, chinook salmon, *Oncorhynchus tschawytscha*.

## INTRODUCTION

Although many chum salmon (Oncorhynchus keta) spawn above the Arctic Circle in Alaska, little is known about how they endure the arctic climate during their larval and juvenile stages. A decision to build a chum salmon hatchery in the Kotzebue Sound area in Northwestern Alaska (Fig. 1) provided an opportunity to investigate water temperatures, development rates, food availability and other factors that are important to the chum salmon's survival in this region. We report here the results of those investigations.

Previous work on chum salmon in the Kotzebue Sound area has been confined primarily to adults (Regnart 1967; Yanagawa 1970; Cunningham 1976; Kuhlman 1979; Bird 1980a, 1980b, 1981a, 1981b). Roughly 200,000 chum salmon spawn in the Noatak River each year, mostly in September and October. The spawning grounds are mostly sloughs on the east bank of the river between the mouths of the Eli and Kelly Rivers (Fig. 1). In addition to the Noatak River run, about 30,000 chum salmon spawn in the Kobuk River drainage and about 5,000 spawn in the Inmachuk River (Fig. 1).

The only work on juvenile chum salmon in this area, besides our own, is that of Bird (1980b) who monitored the downriver migration of chum fry on the Noatak River.

Oceanographic data for the Kotzebue Sound area have been reported by Kinder et al. (1976), Fleming and Heggarty (1966), Coachman et al. (1977) and Burbank (1979). However, data on near-shore habitats likely used by chum salmon fry were unavailable prior to this study.

## MATERIALS AND METHODS

Chum salmon fecundities were obtained from unripe females collected on 1 September 1981 on the Noatak River, 13 km below Noatak Village. Eggs were loosened from their skeins by boiling for 5 min, then drained and weighed. The total number of eggs was obtained by counting approximately 50-g subsamples of the eggs for each fish.

Chum salmon eggs and alevins were recovered from spawning grounds on the Noatak River in shallow, unfrozen areas with a shovel. Eggs were placed in 5% acetic acid for 15 min to make the shell transparent. Intragravel and surface water temperatures were measured with a mercury thermometer having 0.1°C divisions and a recording thermograph (model J, Ryan Instruments, Inc., Kirkland, WA 98033). Well water temperatures at Noatak Village were obtained at the village pump house after allowing the water to run for a few minutes. The well was 10 m deep and located on a gravel bar on the bank of the Noatak River about 100 m from the pump

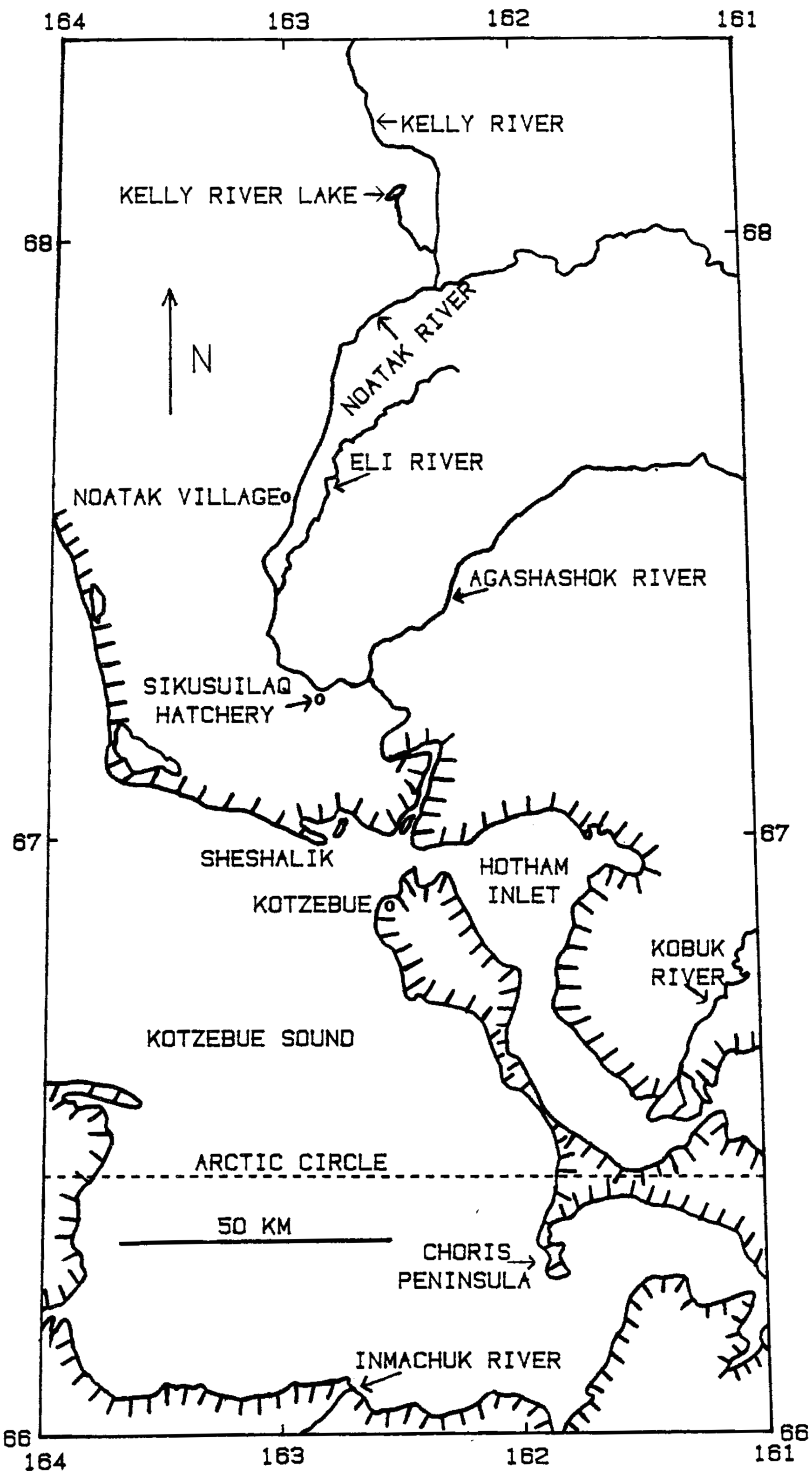



Fig. 1. Map of the Kotzebue Sound area.

house. Dissolved oxygen measurements were made with a titration kit (model AL-36B, Hach Chemical Co., Loveland, CO 80537). Water samples were returned to Kotzebue where pH was measured with a digital pH meter (model 88, Markson Science, Del Mar, CA 92014). Conductivity was measured with a model PG-2 conductivity meter (Barnstead Co., Boston, MA 02132).

Winter water levels at two spawning sites (on which Fig. 6 is based) were estimated from photographs and from observations of water depths at specific points at different times of the year.

Chum salmon fry were collected with three beach seines having the following dimensions: 6.1 m x 1.8 m x 3-mm square mesh, 46 m x 1.8 m x 6-mm square mesh and 61 m x 1.8 m x 3-mm square mesh. Hauls with the latter net were made with Craig Whitmore and Joe Dinnocenzo of the Commercial Fisheries Division. The catch of seine-caught chum salmon fry per unit effort was obtained by dividing the number of fry caught by the square of the length of the seine since the distance a seine was pulled was roughly equal to its length.

A tow net, a trawl and traps were also used to catch juvenile chum salmon. The tow net was kindly provided by David Waltemeyer of the Commercial Fisheries Division. It had a 2.74-m square opening, was 8.2 m long and had a mesh size of 3 mm at the cod end. It was towed 50 m behind a 17-ft Boston Whaler at approximately 115 cm/s for 5 to 45 min. The trawl, kindly provided by Frank Bird of the Commercial Fisheries Division, was 4.9 m wide, 0.8 m deep and 5.8 m long and had a 3-mm mesh. The trawl was pulled 60 m behind the Boston Whaler at about 100 cm/s for 5 to 17 min. Minnow traps were wrapped with a 3-mm mesh netting, baited with small fish and salmon eggs and anchored to the bottom in areas 1 to 2 m deep.

Potential predators of chum salmon fry were obtained to examine their stomach contents. Sheefish and arctic char were purchased from fishermen who had caught them with gill nets. Other fish were examined after being incidentally caught during attempts to catch chum salmon.

Dry weights of stomach contents of chum salmon fry were determined by Terri Tobias of the F.R.E.D. Division Limnology Laboratory, Soldotna, by combining stomach contents of a small group of fish and drawing off excess water with a vacuum through a 10-um pore filter.

Wet weight of stomach contents as a percent of body weight were calculated as follows. Because wet weights were not reported for some of the samples, all dry weights were converted to wet weights by multiplying by a wet weight:dry weight ratio of 3.54. This was the average of 4 samples that had been both wet- and dry-weighed. Body weights were calculated from lengths with the formula $W = aL^n$. A linear regression of log(W) vs. log(L) for

Kotzebue chum fry provided values for a and n of $7.31 \times 10^{-6}$ and 3.042, respectively. Additional chum fry stomachs were examined by Joyce Hanson Landingham of the National Marine Fisheries Service Auke Bay Laboratory. The fullness of these stomachs was reported on a fullness scale of 0 to 6 (0 = empty, 5 = full, 6 = distended). Stomach content as a percent of body weight was calculated for these samples by arbitrarily assigning a fullness of 6 to the maximal percent calculated above (3.344%).

Plankton samples were taken with 50.8-cm and 30.5-cm diameter, 243-um mesh nets towed 50 m behind a boat with the net at the surface. A flow meter (model 2030, General Oceanics, Inc., Miami, FL 33127) recorded the distance of each tow. Many of the samples collected near Kotzebue contained a large amount of detritus. These samples were returned to shore unpreserved and poured through a large-mesh screen which removed most of the detritus. Most of the detritus that passed through the screen precipitated and allowed the zooplankton, still alive, to be poured off as a supernatant. Samples were preserved in buffered 5% formalin. Plankton identification and measurements were done by Terri Tobias on 3-ml subsamples.

In 1980 salinity was calculated from conductivity and temperature according to the method of Bennett (1976). In 1981 salinity was calculated from density and temperature with a programmable calculator. The program was based on Knudsen's equations (U. S. Navy 1953). Density was measured with a hydrometer with 0.0005 g/cc divisions (model 89H, Brooklyn Thermometer Co., Farmingdale, NY 11735).

## RESULTS

### NOATAK RIVER

#### Water temperatures

Surface water temperatures in the Noatak River at Noatak Village (which is within the section of the river in which the chum salmon spawn) decreased rapidly during the months of August and September and stayed close to $0^{\circ}$C through most of the winter (Fig. 2). Between 15 September and 30 April, the approximate period that salmon eggs and alevins remain in the gravel, these temperatures would provide a thermal exposure of only 215 temperature units (T.U.)(Wallich, 1901). This is far less than the 700 to 900 T.U. that are usually required for the successful incubation of chum salmon (Raymond 1981a).

Ground water temperatures obtained from the well at Noatak Village (see Materials and Methods) were higher than Noatak River surface water in winter (Fig. 2). However, the ground water would provide only 485 T.U. during the above period.

Twelve sites within the chum salmon spawning area on the Noatak River were selected for winter observation (Fig. 3). Most of these sites were on sloughs on the east side of the river. Sites 7, 9 and 12 were chosen because they were known spawning sites.

The remaining sites were chosen because they were ice-free while the main stem and sloughs of the Noatak River were ice-covered. These sites were the most accessible ones and appeared to be likely spots to find chum salmon eggs.

Surface and intragravel water temperatures at the study sites between September 1979 and May 1980 (Figs. 4a and 4b, respectively) were generally several degrees higher than surface temperatures observed in the main stem (Fig. 2). Intragravel temperatures were approximately $8^{\circ}$C at the start of spawning and reached a minimum of about $2^{\circ}$C in March and April, at which time the surfaces of some sites (marked ⊕ in Fig. 4) froze.

Intragravel water on the spawning grounds was characterized by temperature differences of several degrees within distances of a few meters and as much as 5 degrees at different spawning sites (Fig. 4b). As a result thermal exposures, estimated from the temperatures shown in Fig. 4b, ranged between 650 and 1,440 T.U. and averaged 1,130 T.U. during the period 15 September to 30 April.

A comparison of Figs. 4a and 4b will show that intragravel temperatures were generally higher than surface temperatures, especially during February, March and April when ground water temperatures reached their lowest levels for the year. This is

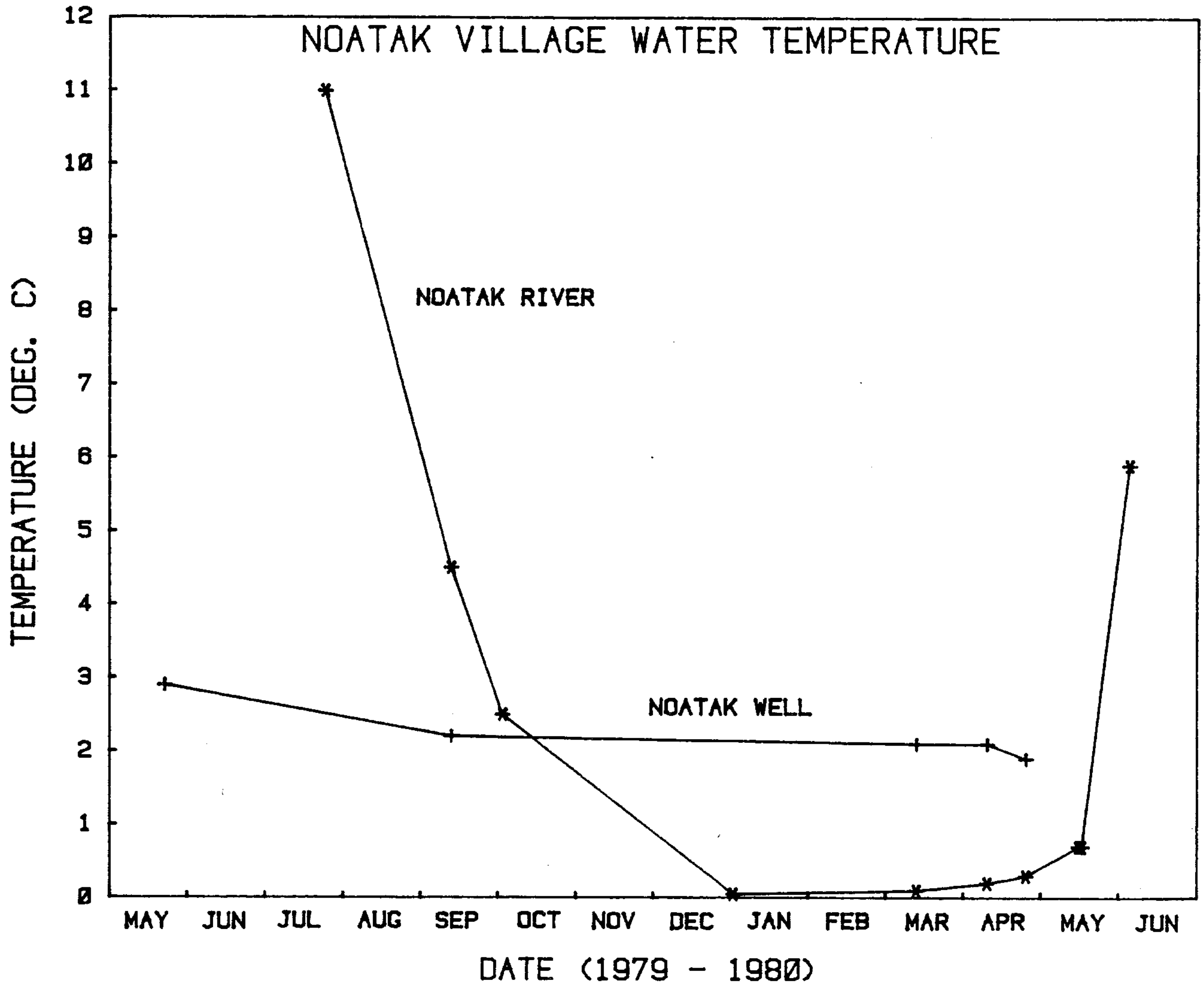



Fig. 2. Water temperatures in the Noatak River and in a well, both at Noatak Village.

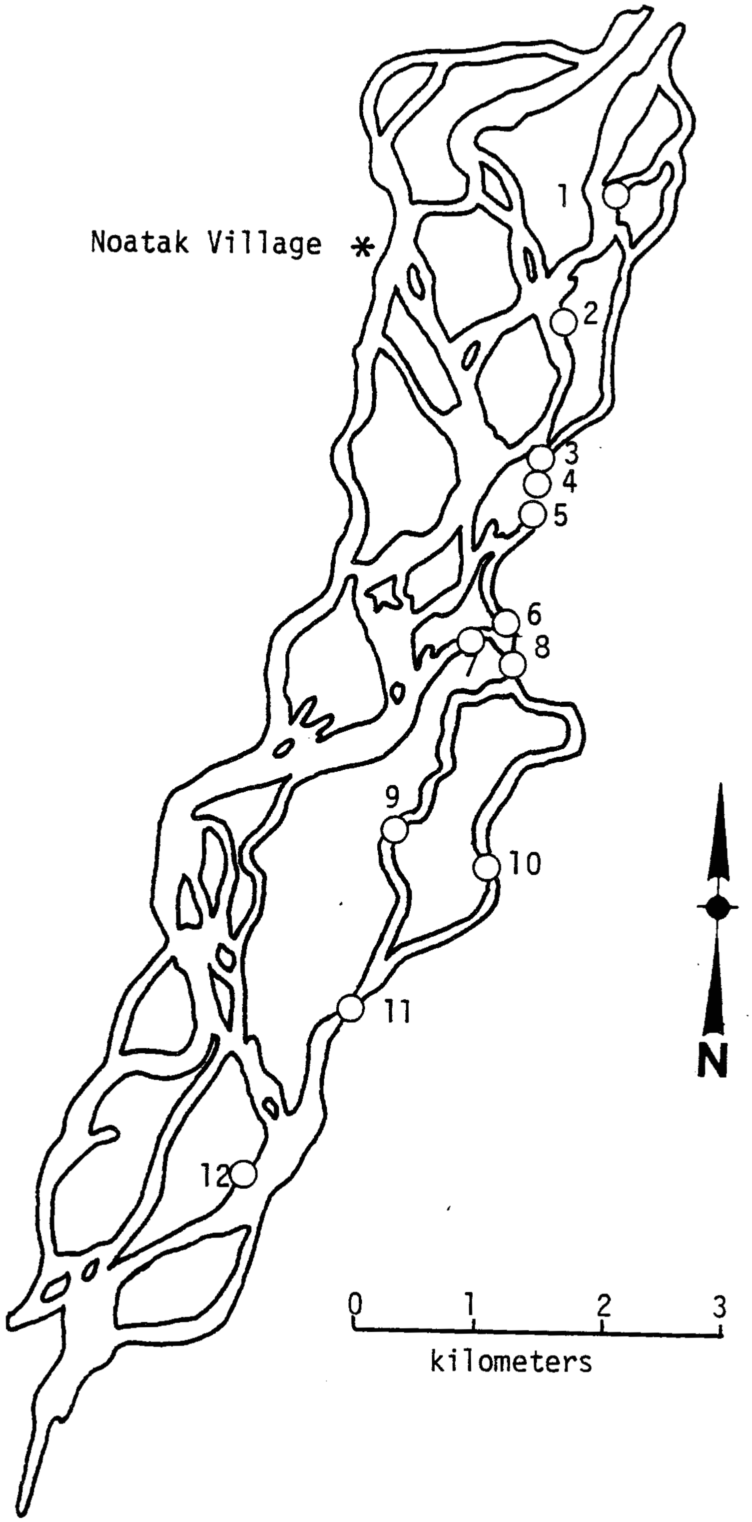



Fig. 3. Locations of winter study sites in a chum salmon spawning area on the Noatak River near Noatak Village.

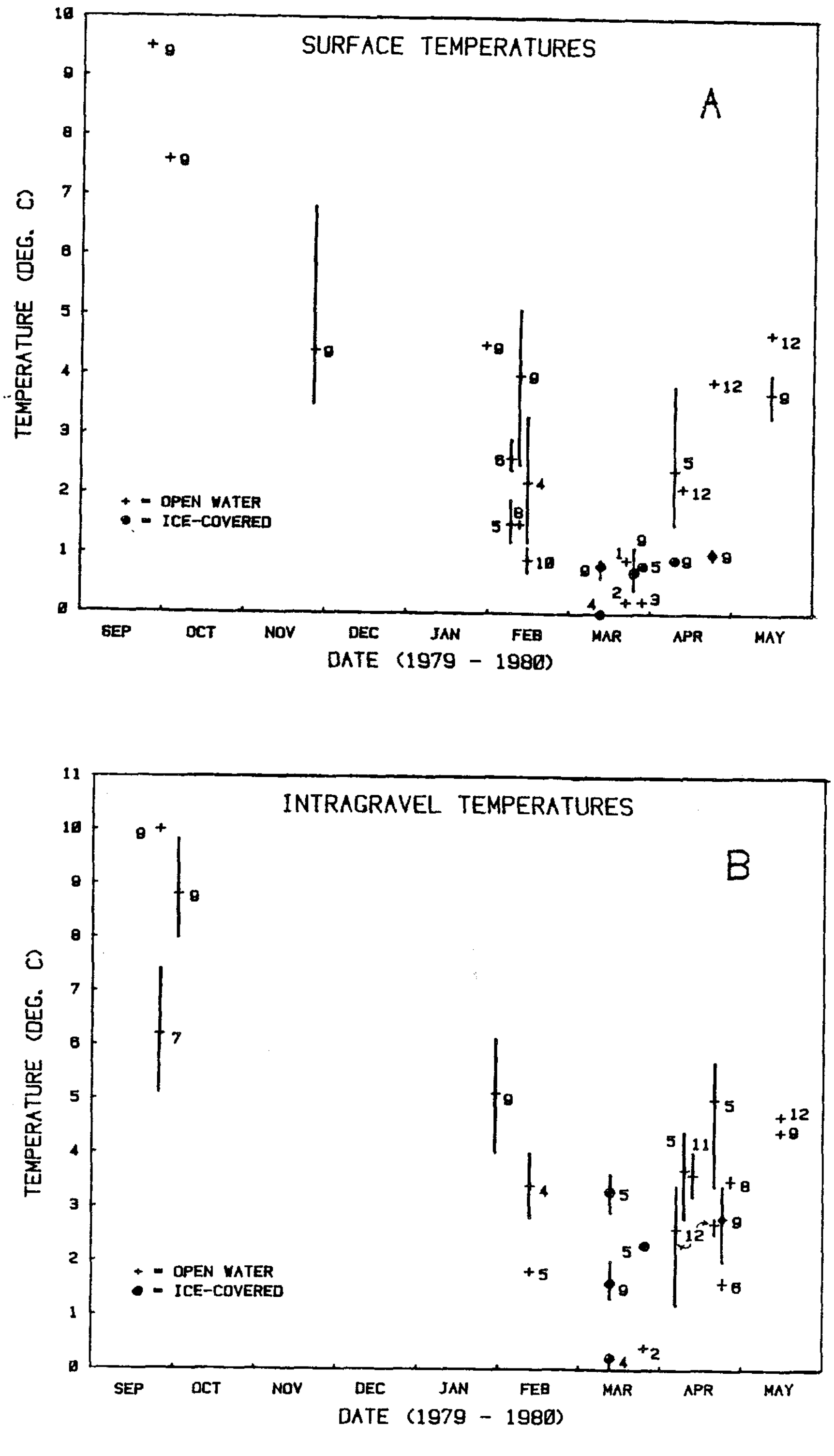



Fig. 4. Surface (A) and intragravel (B) water temperatures at winter study sites on the Noatak River. Vertical bars show the range of temperatures observed and cross-marks show the averages. Locations of sites are shown in Fig. 3.

more clearly shown in Fig. 5 where, for two sites, intragravel and surface temperatures are plotted together. The warmer intragravel temperatures suggest that these sites are supplied with upwelling springs.

Spawning and development--sites 9 and 12

Two spawning sites, sites 9 and 12, were observed more freqently than the others and are described in the following paragraphs. Approximate winter water levels at these two sites are shown in Fig. 6.

Site 9. Several thousand chum salmon were observed at site 9 on 12 September 1979 (Frank Bird, Commercial Fisheries Division, private communication). The Noatak river was unusually high at this time because of heavy rains in August and early September. By 26 September the water level had dropped about 1 m. Hundreds of salmon carcasses were found and live chum salmon were observed in pools. Intragravel temperatures ranged between 9.5 and 10 °C. Dead eggs were recovered from the gravel at one location (point A) where the water depth was about 8 cm.

By 3 October the open water area had receeded to a point (B) 15 m downstream from point A which indicated another drop in water level of about 12 cm. A surface flow of 400 liters per second was observed in the open water area even though both the inlet and outlet of the slough were now above the water level. Intragravel temperatures ranged between 8.0 and 9.8 °C. At point B, eggs containing embryos approximately 6 mm long were found between 20 and 30 cm below the gravel surface.

By 27 November most of the Noatak River and its sloughs were ice-covered. Only small areas with springs or high water velocities remained ice-free. At site 9 the water's upstream edge had receded about 6 m below point B which indicated another drop in water level of about 12 cm. The gravel at point B was covered with 60 cm of snow but was still moist. Eggs containing embryos approximately 18 mm long with well developed eyes ("eyed eggs") were found at point B at a depth of about 40 cm. Here the temperature was 1 °C but farther downstream in the open water, surface temperatures ranged from 3.4 to 6.8 °C. These temperatures suggested that the point at which the warmer spring water was emerging from the gravel was moving downstream as the water level dropped. It appeared unlikely that the eggs observed at point B would survive.

By 31 January 1980 the upper end of the open water area had receded to a point 80 m below point B (point C). This corresponded to a drop in water level of 100 cm since 27 November. (The relative elevations of points B and C were determined the following May when both points were submerged). At point B the gravel was now dry at a depth of 60 cm. No eggs or alevins were found. At point C, chum alevins with almost no yolk were found in the gravel. Intragravel temperatures here ranged between 4.0 and 6.1 °C

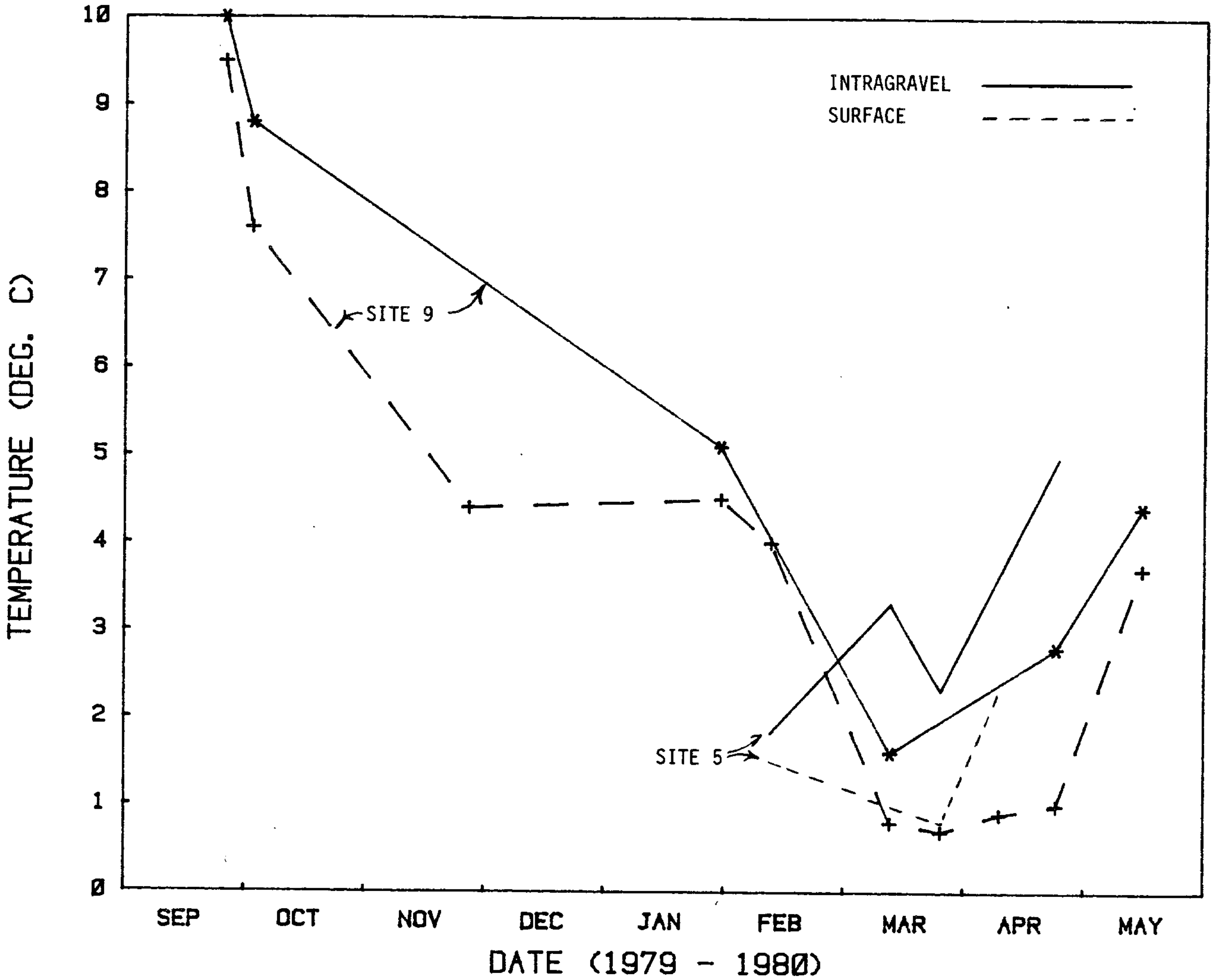



Fig. 5. Surface and intragravel water temperatures at sites 5 and 9 on the Noatak River.

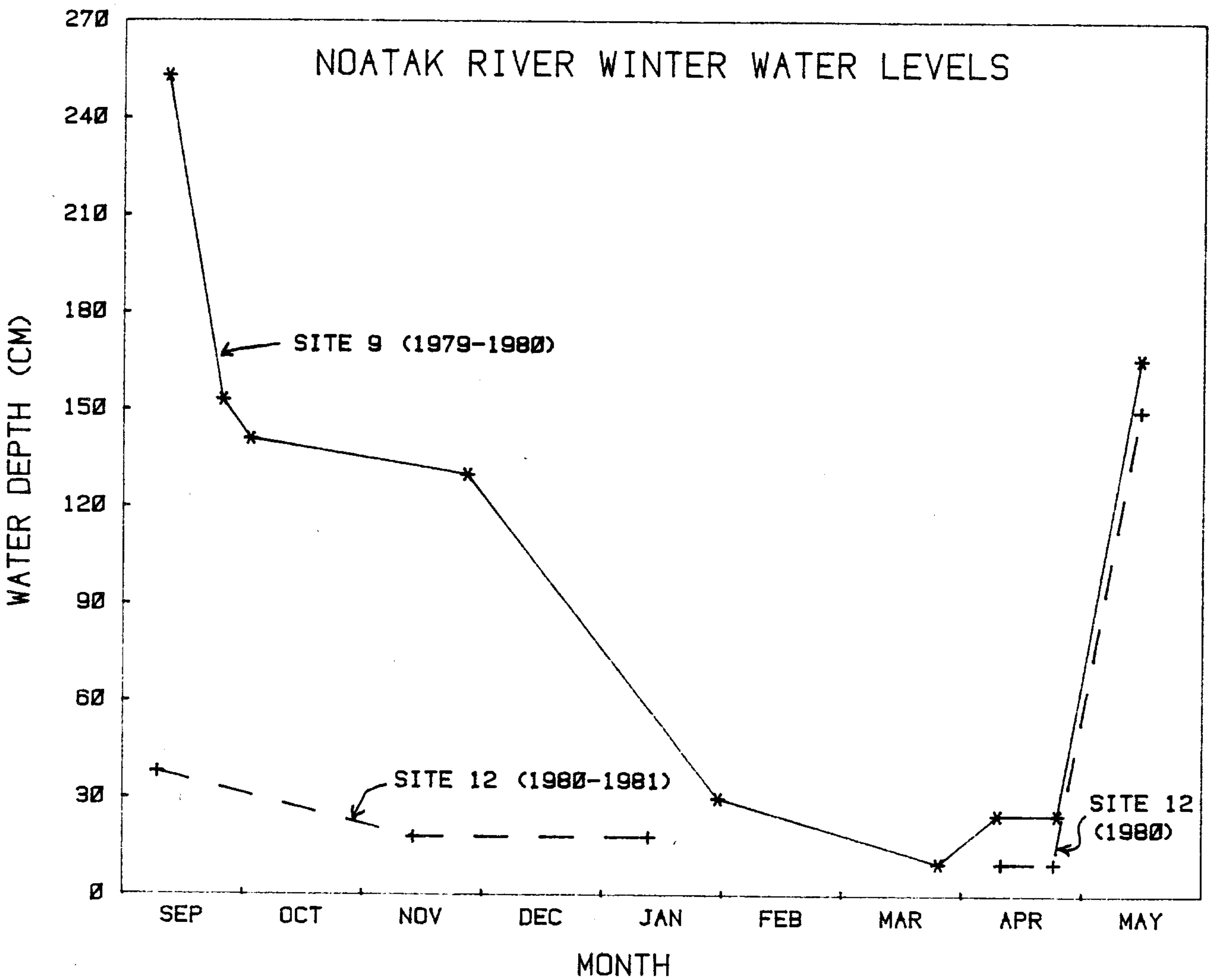



Fig. 6. Winter water levels at sites 9 and 12 on the Noatak River. The values shown are approximate since they were based on a number of factors.

and surface flow was about 0.1 liter per second. Little change was noted on 12 February except that the open water area had expanded slightly because of a warming in the weather. Chum alevins, nearly at the fry stage, still remained in the gravel.

During four succeeding visits (13 and 26 March and 10 and 25 April) the gravel at point C was frozen and no open water was visible. Attempts to collect chum alevins and fry during each visit were unsuccessful. On 13 March a water layer 5 to 8 cm deep was found under 7 cm of ice at distances of 20 and 40 m below point C. Intragravel temperatures ranged between 1.3 and 2.0°C. On 26 March this water layer was found to extend between 15 and 180 m below point C. Frozen gravel was found on both the upstream and downstream boundaries of the water layer. By 17 May the ice was gone and the water depth at point C had increased to 1.4 m.

Minnow traps were placed at site 9 on 26 and 27 March and 10 April 1980 for a total of 33 trap-hours. The traps caught several slimy sculpins (Cottus cognatus), a chinook salmon (O. tschawytscha) smolt and a round whitefish (Prosopium cylindraceum), but no chum salmon.

In September 1980 the water level appeared to be about 2 m lower than it was in September 1979 and this resulted in the blocking of both ends of the slough in which site 9 was located. No spawning was observed there in the fall of 1980.

Site 12. On 10 April 1980 an ice-free area about 230 m long and about 10 to 40 cm deep was found at site 12. Water velocity was about 15 cm/sec. On 11 April alevins averaging 34 mm in length were found in the gravel at a depth of 20 cm (point D). Upwelling water was observed in the same area and intragravel temperature was 2.9°C. Another sample of alevins taken on 24 April had a similar length. On 16 May the ice was gone and the water level had risen about 1.4 m. Several chum-like fry were seen swimming about 180 m below point D.

Minnow traps were placed at site 12 on 10 April for a total of 48 trap-hours but caught only slimy sculpins.

Observations of spawning and egg development were continued at site 12 in September 1980. On 10 September 1980 about 6,000 chum salmon were in three large pools at site 12 and an additional 4,000 chum salmon were milling in the river below the pools. Of four females captured in the pools, three were ripe (gametes mostly unspawned and easily extruded with a ventral squeeze) and one was spent (gametes mostly spawned). Of five males captured, four were ripe and one was spent. These observations indicated that spawning was just beginning. Intragravel temperature at point D was 7.5°C.

On 12 November many chum salmon carcasses were observed in the slough but some spawning was still in progress. Water level appeared to have dropped about 20 cm since 10 September. Eggs containing eyed embryos approximately 11 mm long were found in two redds near point D where intragravel temperatures ranged from 5.6 to 5.9°C.

On 9 January 1981 the water level had not changed. Alevins 22-24 mm long were found in 3 redds near point D. In one of them eggs containing eyed embryos approximately 16 mm long were also found indicating that superposition of spawning had occurred. Intragravel temperatures were now 3.2 to 3.6°C. A thermograph placed in the gravel over the period 13 November to 9 January appeared to read low, but it showed a nearly linear decrease in temperature.

Spawning and development--general

A summary of salmon eggs, alevins and fry collected at sites 4, 5, 9 and 12 is given in Table 1. Attempts to find eggs at sites 1-3, 6-8, 10 and 11 were unsuccessful. The collections revealed large differences in the stages of development of the chum eggs and alevins. For example, alevins that had consumed nearly all their yolk were found on 31 January at site 9 and on 24 April at site 12.

Although the stages of development of eggs and alevins at these sites at any particular time were characterized by a wide range, the data in Table 1 suggest that the peaks of spawning, eyeing, hatching and emergence occurred, respectively, in mid to late September, early November, late December through January, and early May.

Many of the eggs recovered on the spawning grounds were dead (Table 1). Both pH (7.56-7.97) and conductivity (240-630 umhos /cm) in the spawning areas were in their normal ranges. However, dissolved oxygen concentrations measured at some of the sites were low (3 to 5 ppm) and may have been the cause of mortality. The sites with the lower oxygen levels were generally those with low water velocities. Dissolved oxygen concentration, pH, con ductivity, and surface current measurements are given in Appendix Table 1.

Freshwater feeding

The guts of several alevins collected on 31 January were examined for evidence of intragravel feeding. The yolk in these alevins was almost completely consumed. None of the guts contained any food but six of them contained small gravel fragments (Appendix Tables 2 and 3).

On 13 March stonefly (Order Plecoptera) and cranefly (Order Diptera) larvae 3-8 mm long were found within the top 3 cm of gravel at site 9. Larger Plecoptera larvae (15 mm long) were found in the gravel at site 5. On 10 April, adult Plecoptera were found on the water surface under the ice at site 5. On 24

Table 1. Observations of chum salmon eggs, alevins and fry at spawning sites on the Noatak River. Locations of sites are shown in Fig. 3.

| Date | Site | Items collected or observed | Comment |
|---|---|---|---|
| --------------------1979 Brood Year------------------------------ | | | |
| 26 Sep 79 | 9 | 12 eggs | Dead (periodic exposure above water level). |
| 3 Oct 79 | 9 | 200 eggs | Almost eyed |
| 27 Nov 79 | 9 | 60 eggs | Eyed |
| 31 Jan 80 | 9 | 30 alevins | 37 mm, yolk consumed, in gravel |
| 12 Feb 80 | 9 | 30 alevins | 37 mm, yolk consumed, in gravel |
| 12 Feb 80 | 5 | 200 eggs | Dead |
| 13 Feb 80 | 4 | 5 eggs | Dead |
| 13 Mar 80 | 5 | 50 eggs | Dead |
| 26 Mar 80 | 5 | 50 eggs | Dead |
| 26 Mar 80 | 9 | 12 eggs | Dead |
| 26 Mar 80 | 9 | 1 king salmon | 95 mm smolt |
| 10 Apr 80 | 5 | 50 eggs | Dead |
| 10 Apr 80 | 12 | 67 alevins | 34 mm, stomach unsealed, in gravel |
| 24 Apr 80 | 12 | 50 alevins | 34 mm, stomach unsealed, in gravel |
| 16 May 80 | 12 | 10 fry | Swimming |
| 16 May 80 | 9 | 20 fry | Swimming |
| | | 2 alevins | Dead, in gravel |
| ---------------------1980 Brood Year---------------------------- | | | |
| 13 Nov 80 | 12 | many eggs | Eyed |
| 9 Jan 81 | 12 | 12 eggs | Dead, probably from 13 Nov digging |
| | | eggs | Eyed in redd C |
| | | 30 alevins | in gravel in redds A, B & C |

April adult Diptera were seen flying near the water surface at site 12.

In agreement with these observations, stomach contents of chum fry caught in the Noatak River were primarily Diptera and Plecoptera but several other types of prey were also found (Appendix Tables 2 and 3). About 96% of the prey were insects and the remainder were zooplanktors. Chum fry were caught both in the main stem and in clear tributaries and backwaters of the Noatak River. However, sample sizes were insufficient to detect significant differences in stomach contents in these two groups.

The fullness of the stomachs of chum fry caught in the Noatak River (see Materials and Methods) appeared to increase through the spring and summer (points marked with + in Fig. 7), suggesting that food was becoming more available as the summer progressed. A strong correlation between fullness and date was found ($r = .71$, $P < .01$).

The lengths and weights of chum fry caught in the Noatak River are shown in Figs. 8a and 8b (solid lines) as a function of date. Steady increases in mean length and mean weight were observed in chum fry caught between early April and early July, but the individual sizes, as shown by the vertical bars in Fig. 8a, varied widely.

Noatak River water quality

Temperature, water level and turbidity of the Noatak River during the period of chum salmon downstream migration are shown in Fig. 9. The water temperature rose from about 5°C to about 12°C during this period. The water level peaked in early June at about 2 m above the normal low water level and smaller peaks occurred during the rest of the month. The turbidity, which ranged from near 0 to 95 nephelometric turbidity units (NTU), closely followed changes in the water level. Correlations between these quantities are given elsewhere (Raymond 1981b).

1981 observations

Twenty unspawned female chum salmon taken from the Lower Noatak River on 1 September had an average fecundity of 3,120 eggs. Individual fecundities ranged from 1,860 to 4190 eggs. The eggs in each of these females were still firmly in their skeins.

Several thousand Noatak River chum salmon spawn every year in Kelly River Lake, a spring-fed lake on the west bank of the Kelly River 13 km from its mouth (Fig. 1). On 3 September 1981 the springs at the north end of the lake were flowing at temperatures between 2.5 and 2.9°C. Since it is unlikely that winter temperatures would be any higher, it appears that the springs would provide a maximum of about 700 T.U. from 1 September to 30 April. Fourteen females were collected near the springs and all were found to be partially spawned. The ripeness of Kelly River Lake

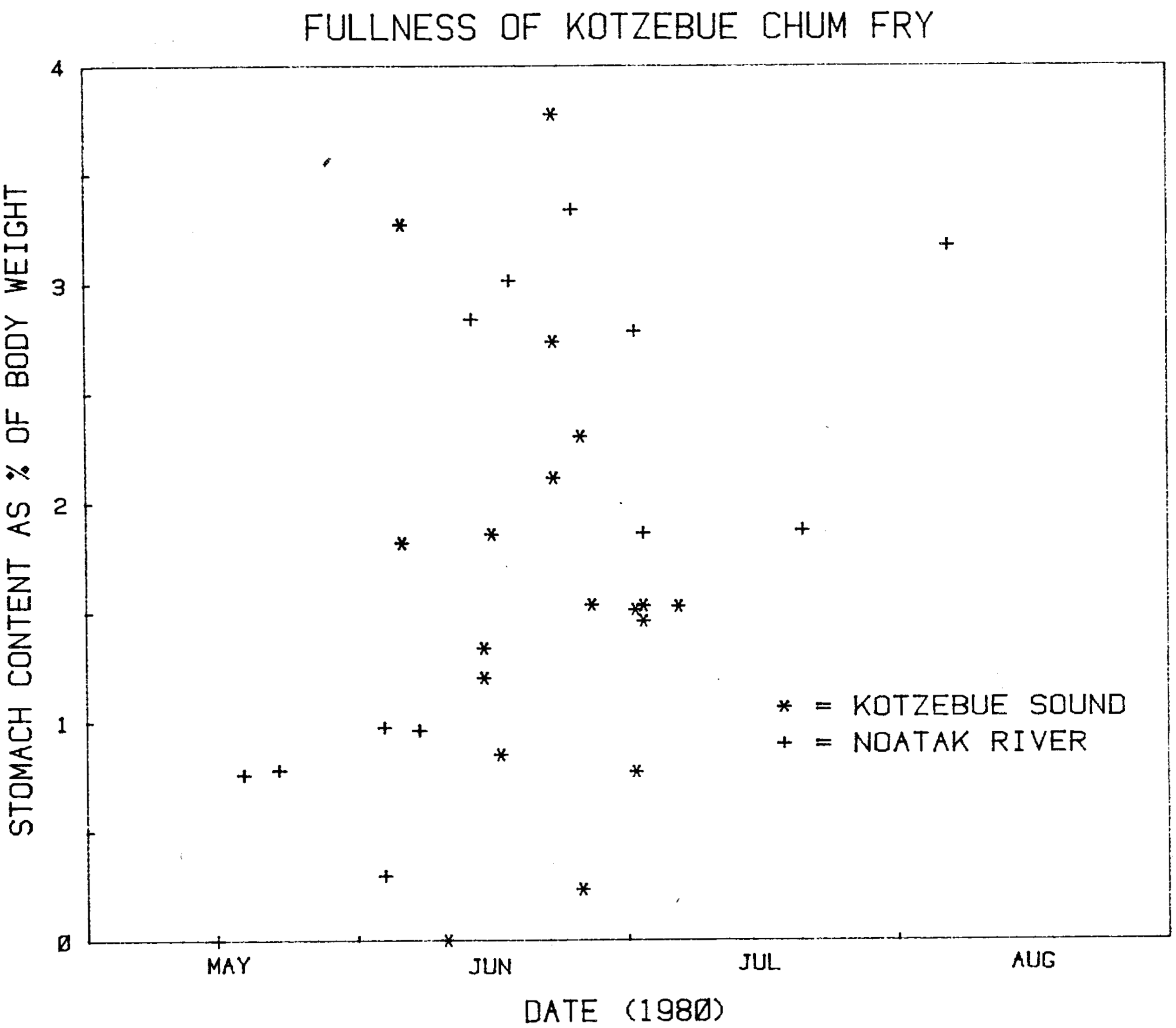
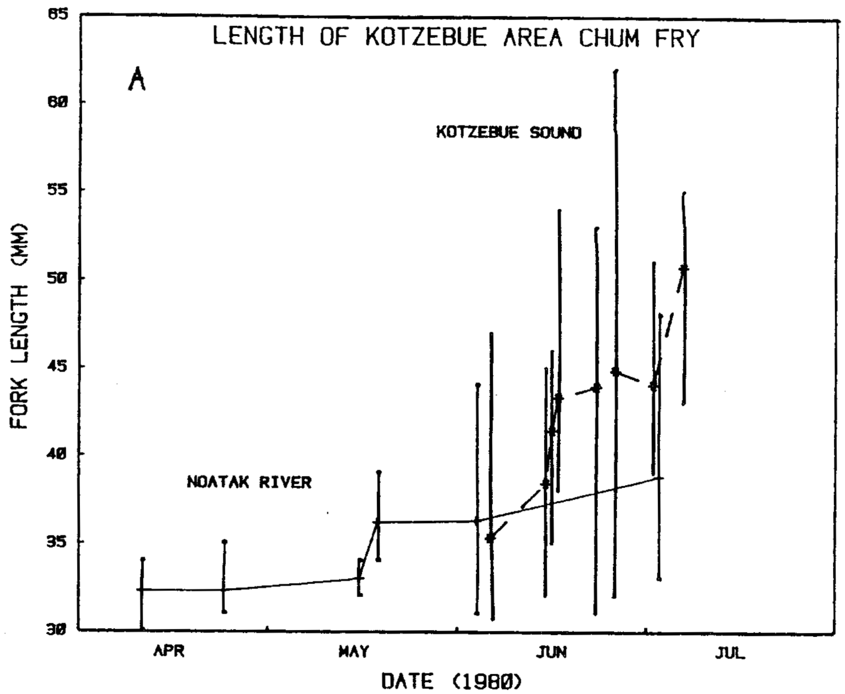



Figure 7. Fullness of stomachs of chum fry caught in the Noatak River and in Kotzebue Sound. Fullness is expressed as stomach contents as a percent of body weight.



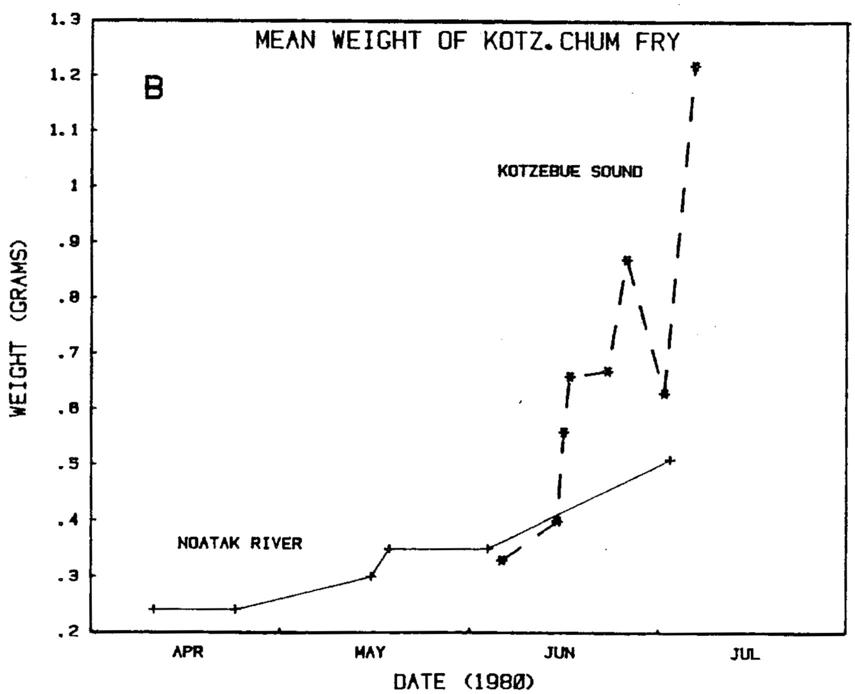
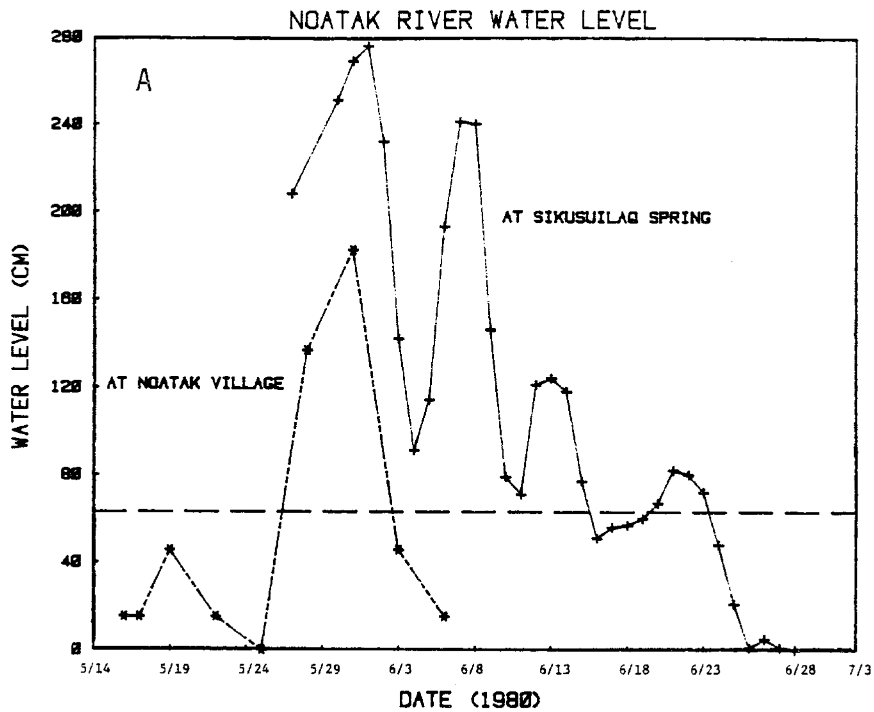




Fig. 8. Lengths (A) and weights (B) of chum fry caught in the Noatak River and Kotzebue Sound in 1980.



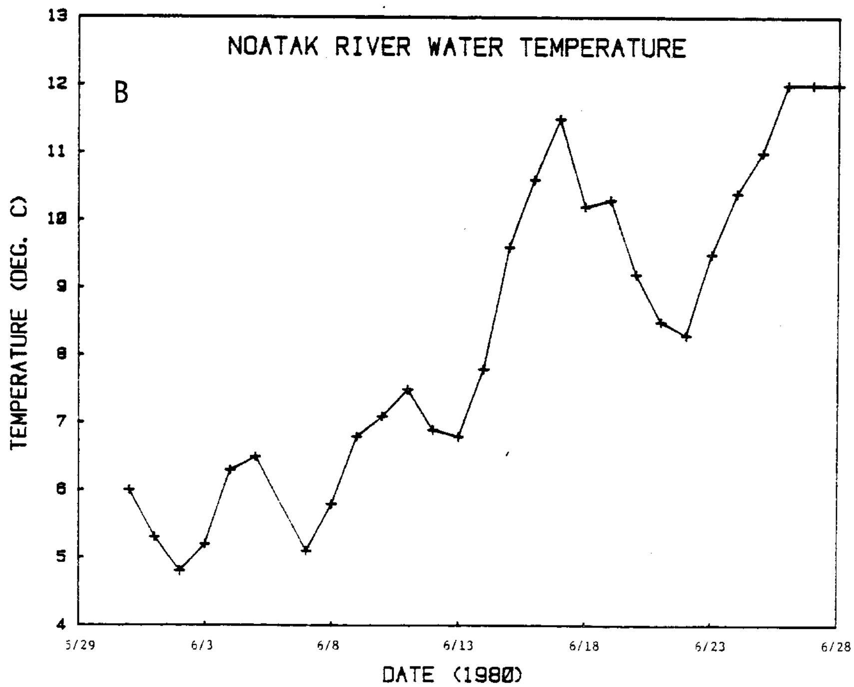




Fig. 9. Water level (A) and water temperature (B) of the Noatak River in May and June, 1980. Figure continued on following page.

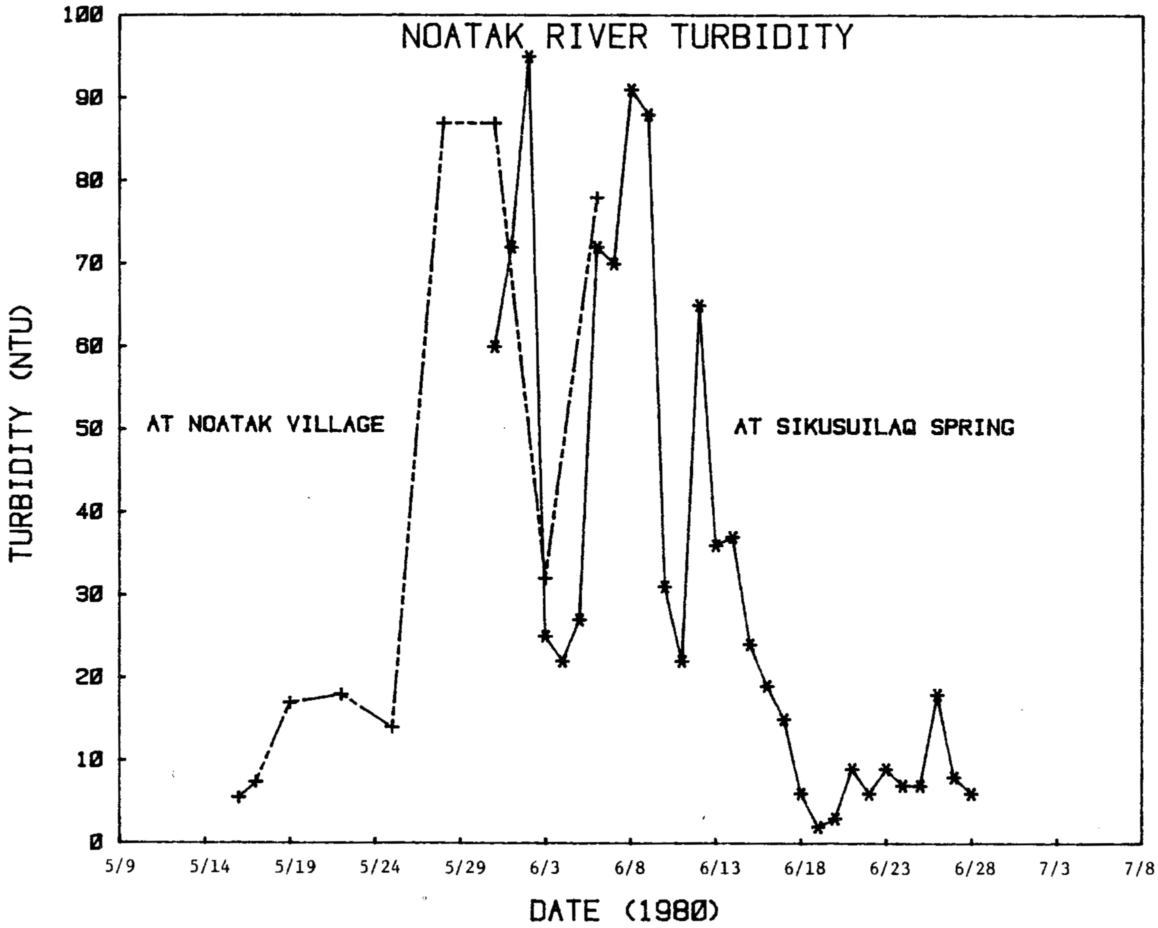



Fig. 9 (continued). Turbidity in the Noatak River in May and June, 1980.

females contrasted with that of females collected two days earlier in the Lower Noatak River. These chum salmon thus appeared to spawn earlier than, and in cooler water than those that spawn in the sloughs of the Noatak River farther downstream.

## KOTZEBUE SOUND

Our studies in Kotzebue Sound were mostly confined to an area within 25 km of Kotzebue (Fig. 10). This area is characterized by many sand bars and water depths typically under 5 m.

### Temperatures and salinities

Water temperatures at several locations near Kotzebue are shown in Fig. 11. Water temperatures generally rose rapidly during June and early July. Three of the locations, Lockhart Point, the mouth of Kotzebue Lagoon and the shore near the ADF&G office, are strongly influenced by the main Noatak River current. Additional temperatures for locations on the north coast of Kotzebue Sound are shown in Fig. 12. Sheshalik Lagoon and Sheshalik Spit, which are relatively shallow and close to the Noatak River outflow, reached temperatures between 16 and 18°C in July. However, farther west between Aukukak Lagoon and Cape Krusenstern the temperature was lower, probably because of a smaller influence from the Noatak River.

Salinities at various locations in Kotzebue Sound are shown in Fig. 13. Near Kotzebue they generally remained below 5 ppt, except at South Kotzebue which is protected form the main Noatak River current. The north coast of Kotzebue Sound near Cape Krusenstern, which was also distant from the Noatak River current, had higher salinities (22-34 ppt).

Additional water temperatures and salinities were taken in early August 1981 at locations south of Kotzebue and are given in Appendix Table 4. Water temperatures were generally in the range 11 to 16°C and salinities were generally below 21 ppt. However, on one occasion after 24 hr of strong winds, a body of cold (4.7°C), high salinity (29 ppt) water was found several km south of Kotzebue.

### Plankton abundance

The density of zooplankton in Kotzebue Sound in 1980, measured at several points near Kotzebue, is shown in Fig. 14. A large peak was observed in July (7,400 organisms/$m^3$) and a smaller one was observed in late September (4,000 organisms/$m^3$). In terms of biomass, the zooplankton density ranged from 1.3 to 143 mg per $m^3$. The higher ratio of number of zooplankters to biomass

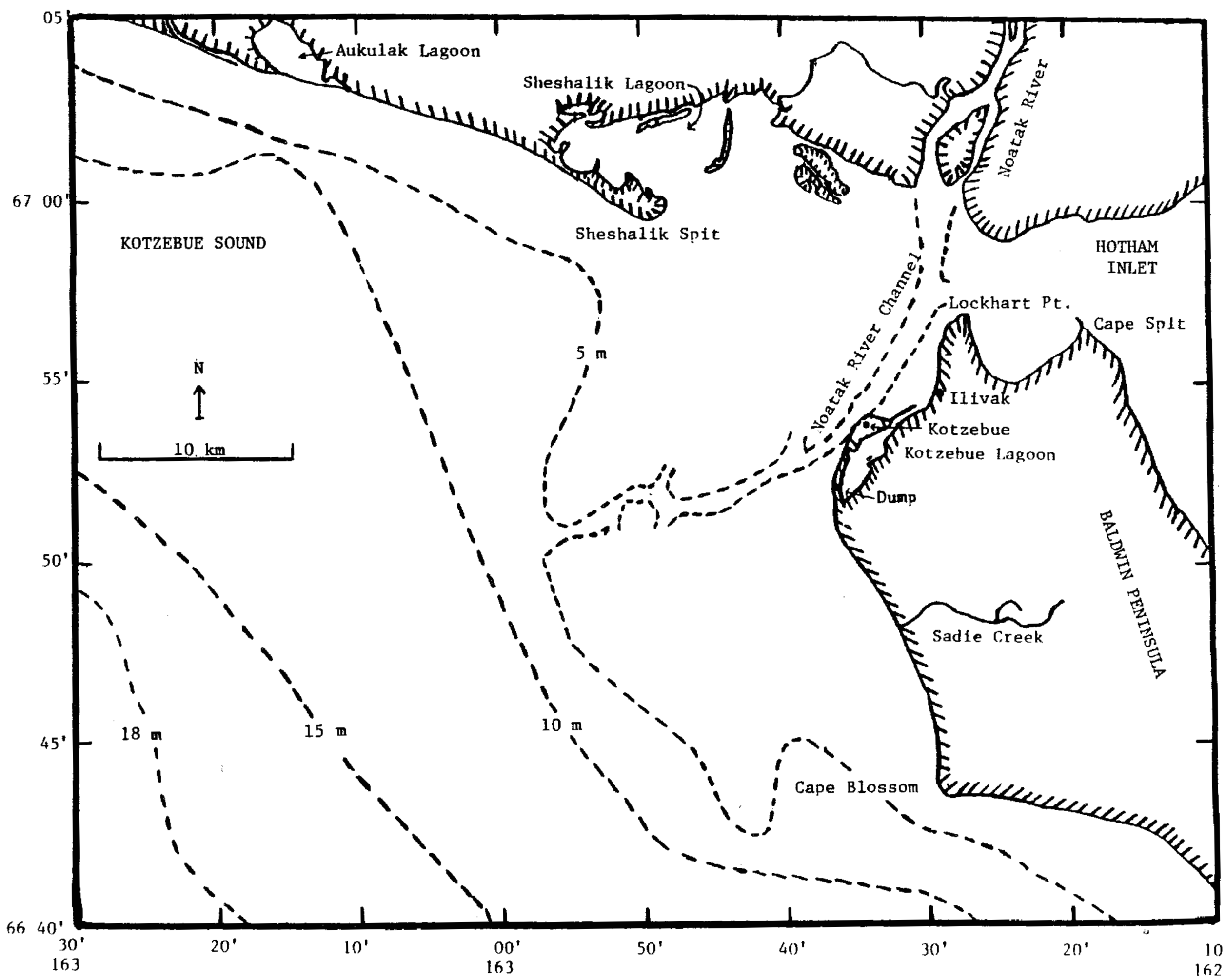



Figure 10. Map of the Kotzebue area in which juvenile chum salmon were collected.

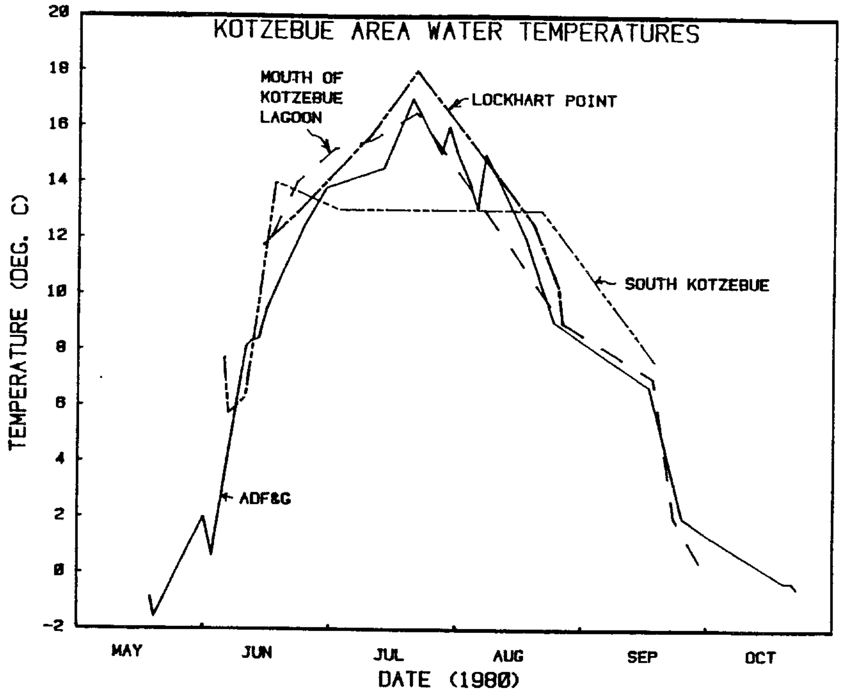



Fig. 11. Water temperatures in Kotzebue Sound near Kotzebue for the period June-August 1980.

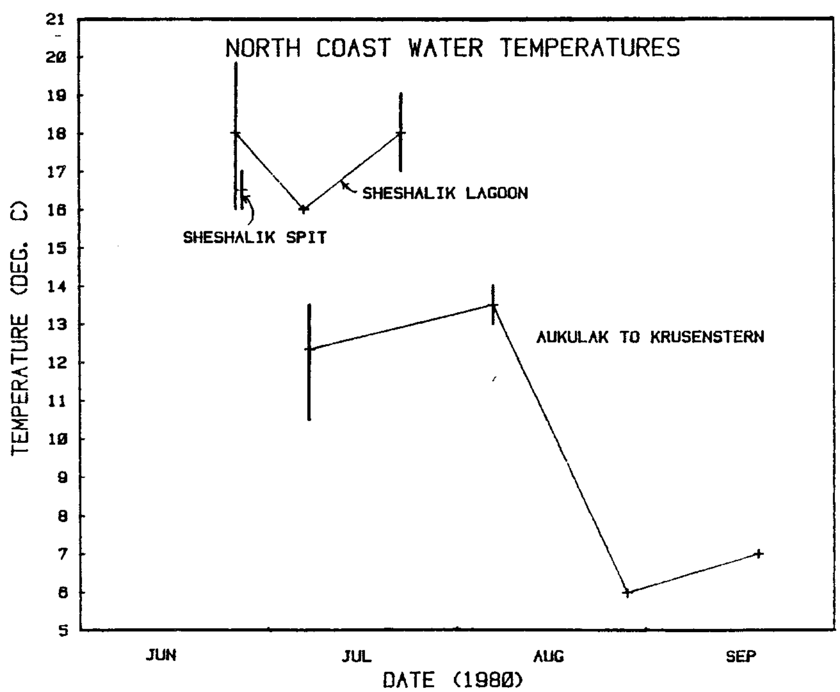



Fig. 12. Water temperatures in the northern part of Kotzebue Sound during July and August 1980.

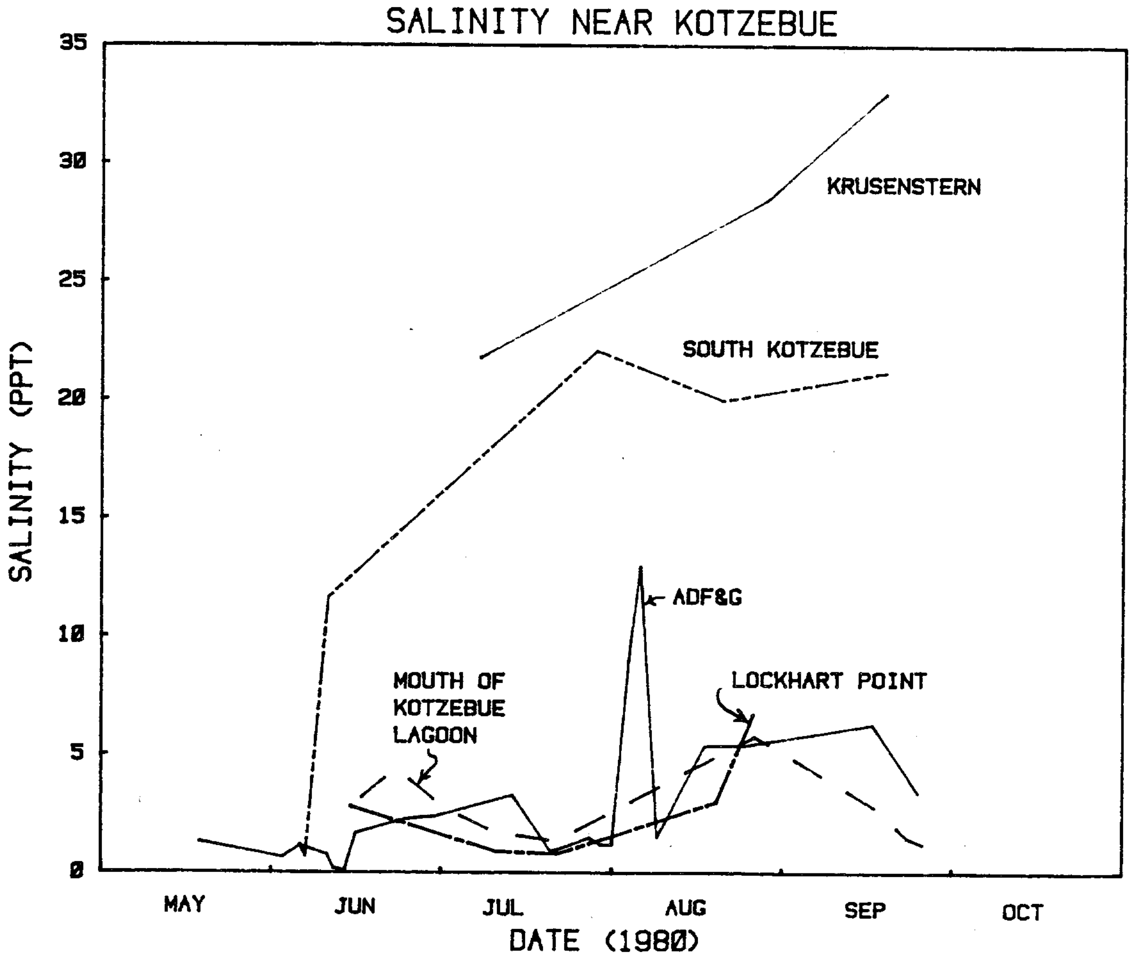



Figure 13. Salinities at several points near Kotzebue for the period June-August 1980. Locations of sampling areas are shown in Figure 10.

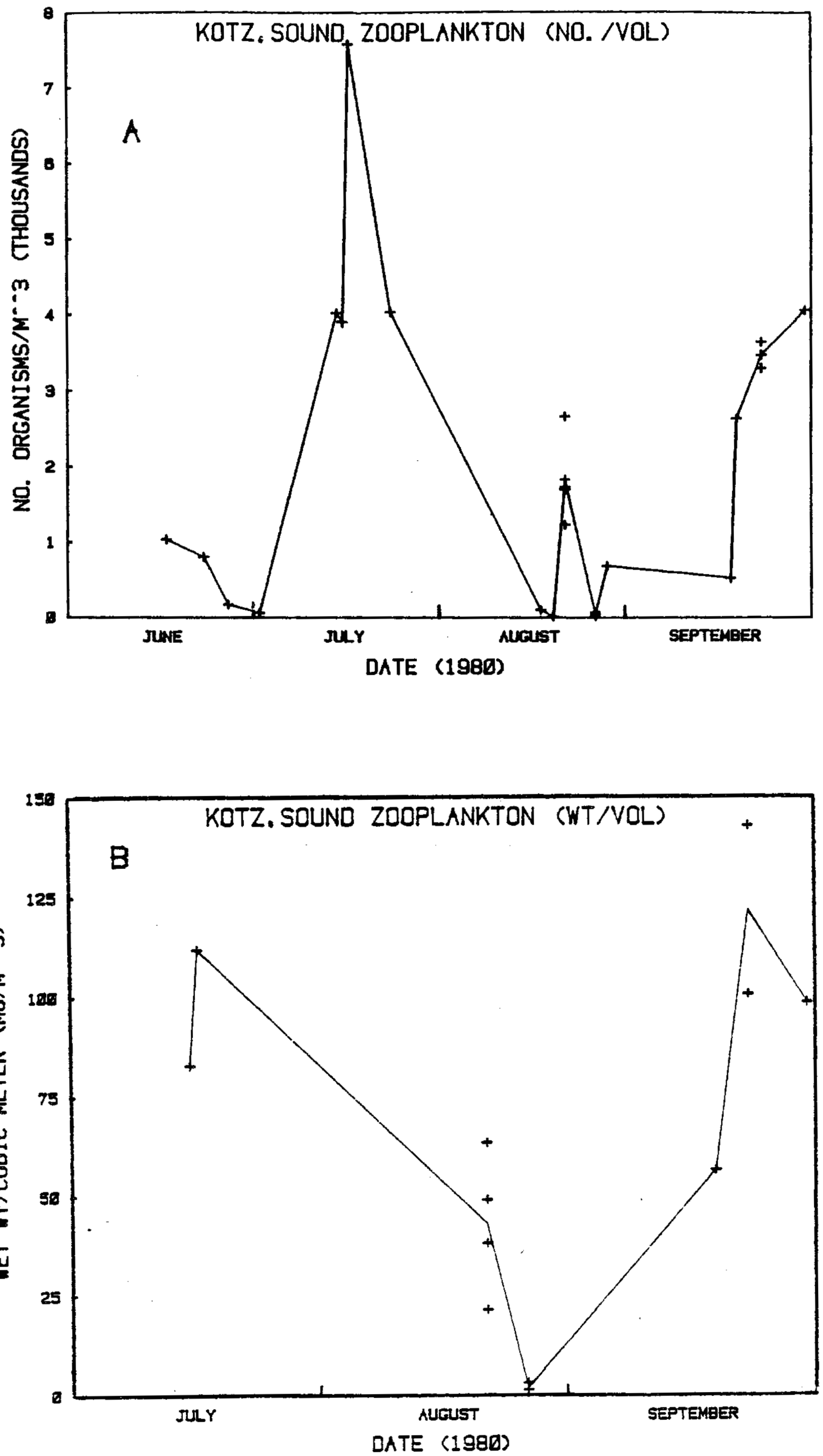



Figure. 14. Zooplankton number density (A) and mass density (B) in Kotzebue Sound during the period July-September 1980. Locations and contents of plankton hauls are given in Appendix Table 5.

observed in the July peak resulted from the presence of many light-weight rotifers in two of the July samples. Overall, calanoid copepods accounted for 91% of the zooplankton (Appendix Table 5). Two plankton tows in late July and early August 1981 obtained high to moderately high plankton densities. Polyphemus accounted for 23 and 97% of the zooplankton in these samples (Appendix Table 5).

On occasion, zooplankton density was observed to vary widely over a short distance and over a short time period. Near Cape Blossom, zooplankton densities obtained on 22 August 1980 within half a kilometer of each other differed by a factor of two, and others obtained on 31 July 1981 within 5 km of each other differed by a factor of five. At Kotzebue, zooplankton densities obtained on 16 and 17 July 1980 differed by a factor of 2.5.

Juvenile chum salmon catches

The lengths and weights of chum salmon caught in Kotzebue Sound near the mouth of the Noatak River are shown in Fig. 8 as a function of date. Both the length and weight data indicate that growth is more rapid once the chum smolts leave the Noatak River and enter Kotzebue Sound. The length data also indicate that chum salmon smolts caught in Kotzebue Sound vary widely in size.

Figure 15 shows the catch of chum salmon fry per unit effort in Kotzebue Sound as a function of the date. These catches, which were mostly obtained in shallow areas between Lockhart Point and the Kotzebue dump, show that the smolts entered the Sound between early June and early July. A failure to catch chum smolts after 7 July in the 1980 summer season suggested that they had moved into deeper water.

Attempts to catch juvenile chum salmon with a tow net, a trawl, minnow traps and a gill net were unsuccessful. The tow net was used 9 times in 1980 and 5 times in 1981 and the trawl was used 11 times in 1980 (Appendix Table 6). Four minnow traps were set for a total of 24 trap-days in mid-June and late July 1980 but caught no fish. A variable mesh gill net was used twice in 1981 and caught starry flounder (Platicthys stellatus), saffron cod (Eleginus gracilis), rainbow smelt (Osmerus mordax) and other fish, but no chum salmon.

Attempts to collect juvenile chum salmon from the stomachs of potential predators were also unsuccessful. The stomachs of 69 sheefish (Stenodus leucicthys), 25 arctic char (Salvelinus alpinus), 18 least cisco (Coregonus sardinella) and other fish were examined (Appendix Table 7).

Several attempts to catch juvenile chum salmon were made in 1981 in nearshore and offshore waters south of Kotzebue. On 4 August 35 chum salmon juveniles averaging 55.46 mm in length and 1.22 g in weight were caught with a beach seine near Cape Blossom. The catch per unit effort at this location was 42 fish per hectare.

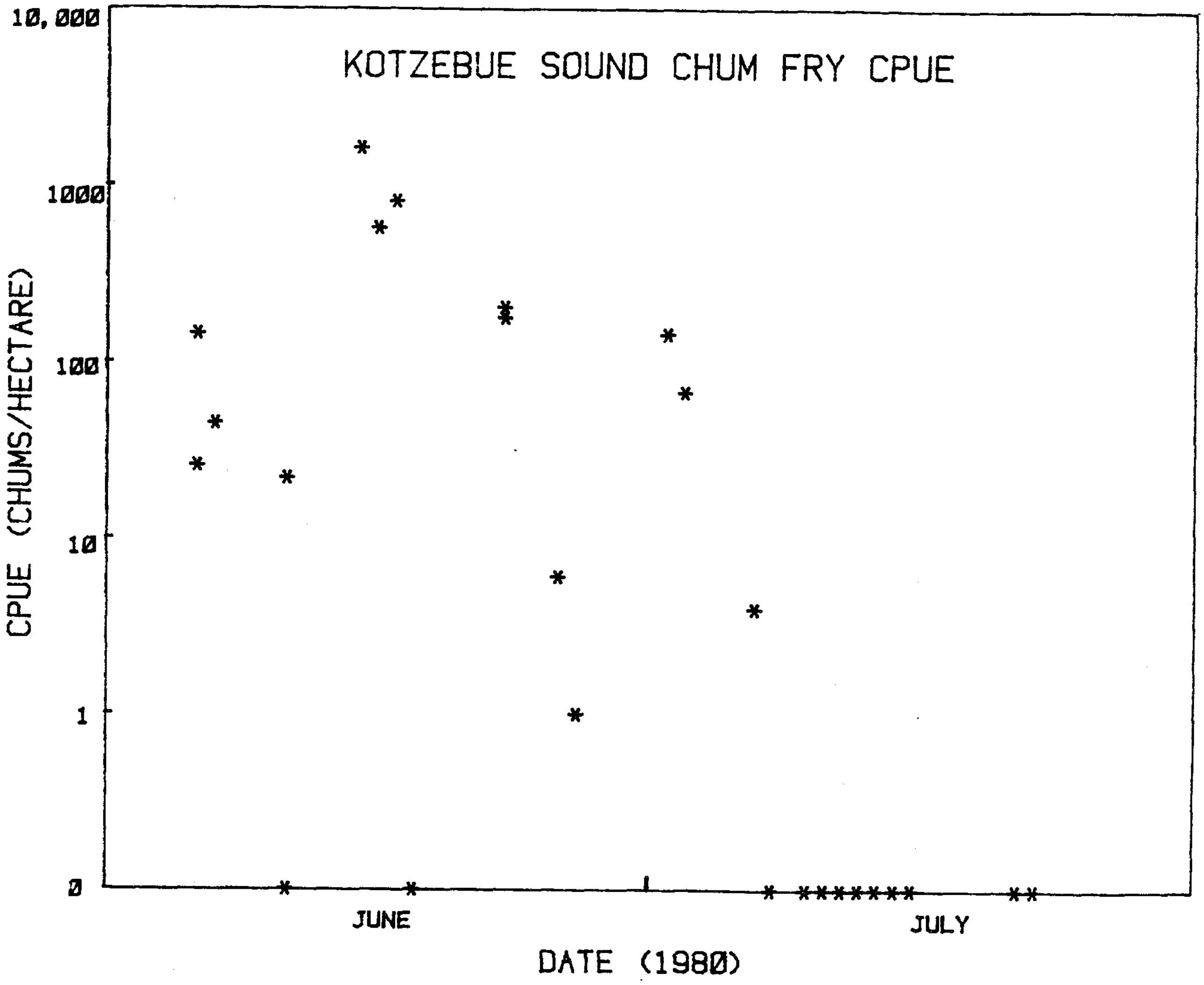



Figure 15. Catch of chum fry per unit effort (CPUE) in Kotzebue Sound during the period June-August 1980. CPUE is expressed as the number of chum fry caught per hectare seined. Catch per unit effort is expressed as chum salmon fry caught per hectare seined. Note that Y-axis is logarhythmic. Points on the X-axis represent zero catches per seine-haul.

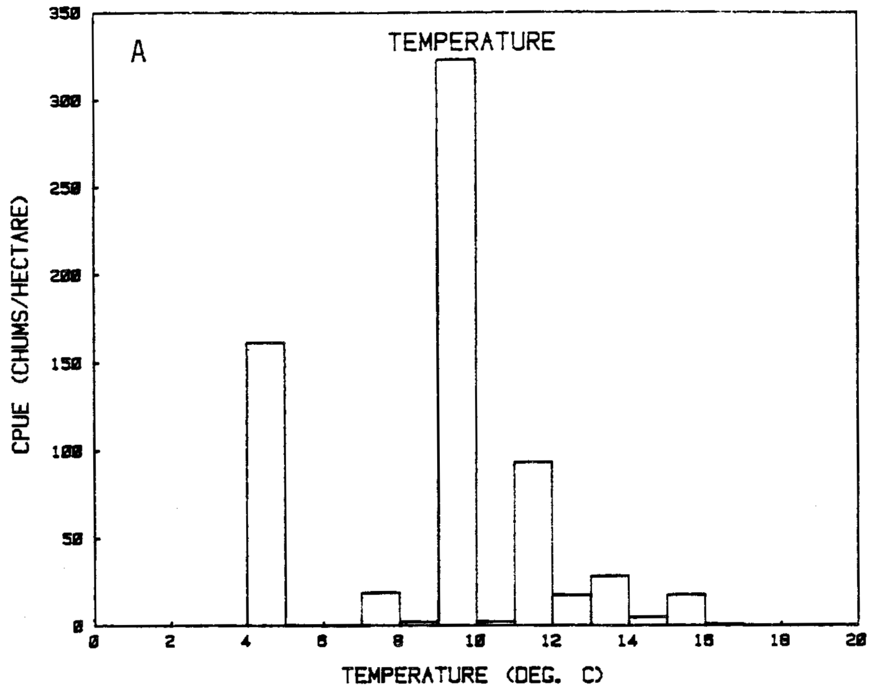
Seven additional beach seines between the mouth of Sadie Creek and the Choris Peninsula failed to catch chum salmon between 3 and 5 August.

The catch of chum salmon fry per unit effort caught in beach seines in Kotzebue Sound in June and July 1980 is shown as a function of habitat type in Fig. 16. The fry appeared to prefer temperatures around 10°C, salinities below 5 ppt, water visibilities near 50 cm, and areas having currents in the range 6 to 9 cm/s. Also the fry appeared to prefer bays with gentle slopes (<10°) and relatively coarse gravel bottoms.

Feeding

As in the Noatak River, the food of chum fry caught in brackish water areas in Kotzebue Sound through early July consisted largely of insects (58%). Zooplankton, which made up most of the remainder, were mostly copepods (Appendix Tables 8 and 9). However, fry caught in August in more saline water were found to be feeding primarily on cladocerans (*Chydorinea*) and copepods.

The fullness of the stomachs of chum salmon caught in Kotzebue Sound (see Materials and Methods) is plotted as a function of the date in Fig. 7. Unlike chum fry caught in the Noatak River, the Kotzebue Sound chum fry did not show any correlation ($r = -.12$, $P > .1$) between the fullness of their stomachs and the date.



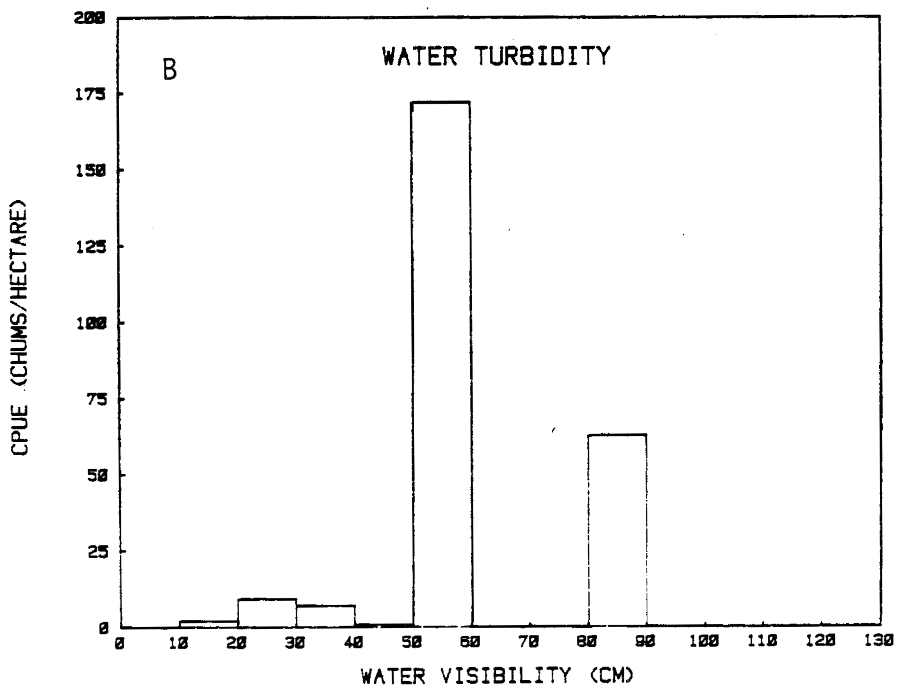
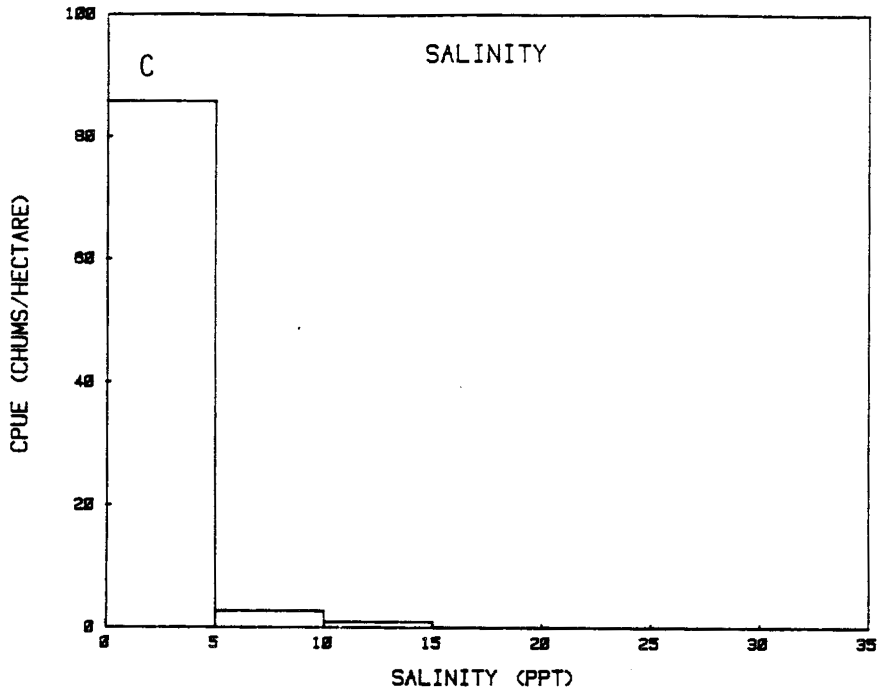




Figure. 16. Catch of chum fry per unit effort in Kotzebue Sound as a function of water temperature (A) and turbidity (B). Figure continues on next page.



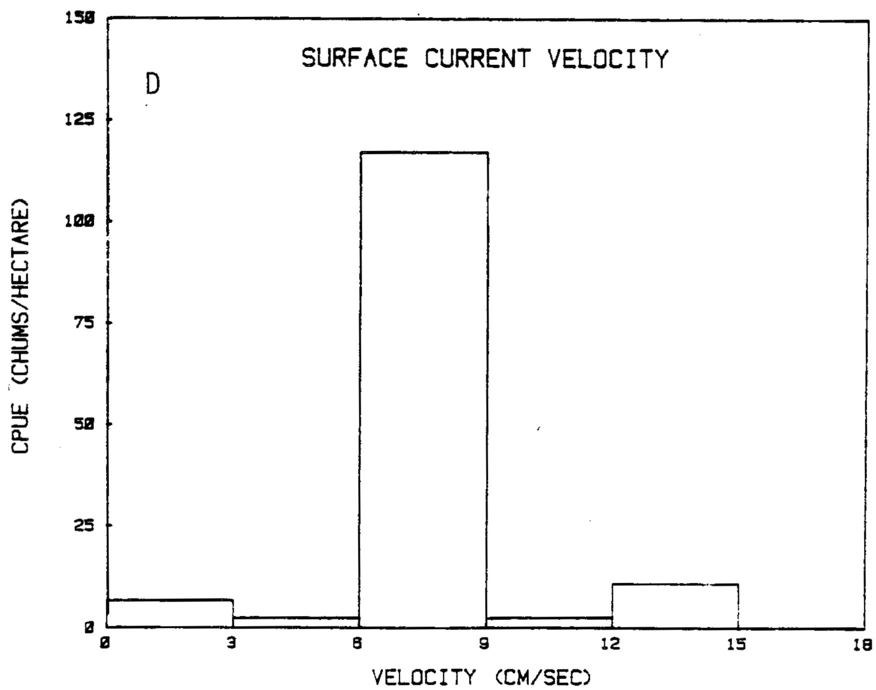
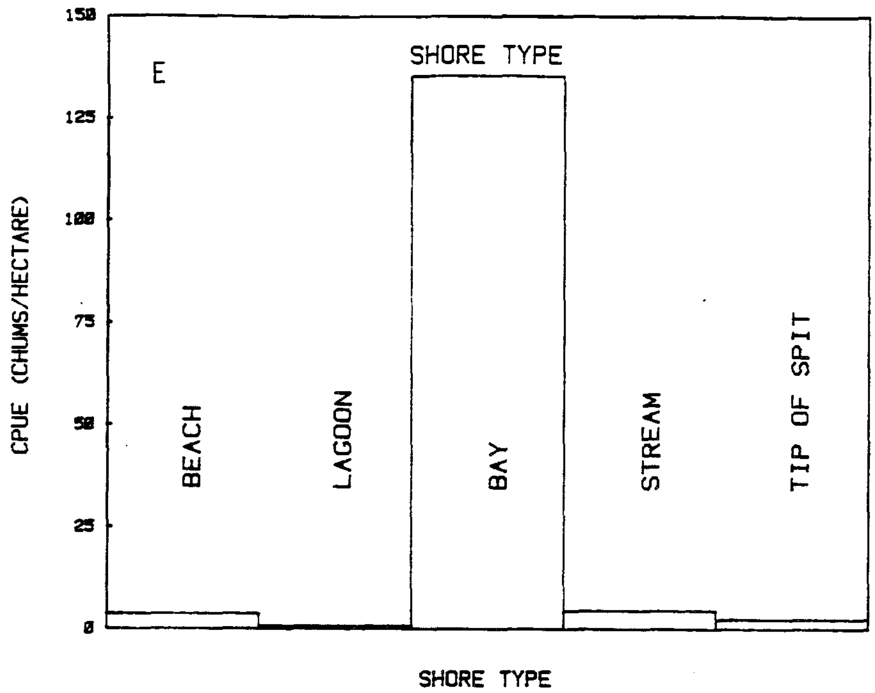




Figure 16 (continued). Catch of chum fry per unit effort in Kotzebue Sound as a function of salinity (C) and surface current velocity (D). Figure continues on next page.



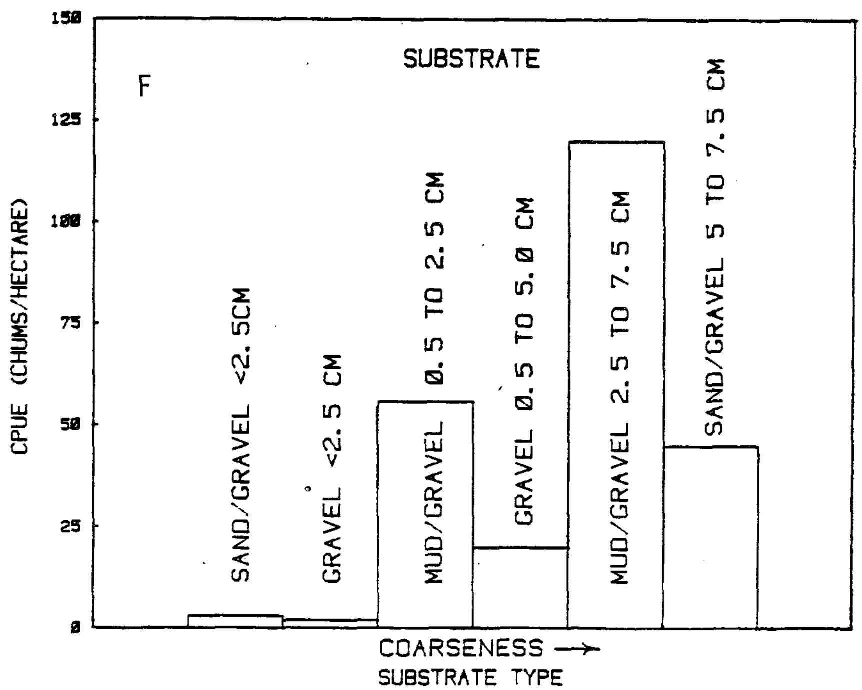




Figure 16 (continued). Catch of chum fry per unit effort in Kotzebue Sound as a function of shore type (E) and substrate (F).

## DISCUSSION

### Previous work in the Kotzebue Sound area

Prior to this study, little information was available on juvenile chum salmon in the Kotzebue Sound area. Bird (1980b) collected chum fry in the Noatak River about 13 km from its mouth from 9 June to 11 August 1979. His highest catches per unit effort occurred between 14 and 24 June. Fish collected in the Chukchi Sea and Kotzebue Sound by Alverson and Wilimovsky (1966)[1], Wolotira (1977) and Lowry[2] did not include juvenile chum salmon. Extensive seining for herring by Barton (1977) and Whitmore and Dinocenzo (1980) in Kotzebue Sound also failed to catch chum salmon. However, Barton (1977) caught one 188 mm chum salmon off the northwest coast of the Seward Peninsula on 6 September.

### Water levels

The sharp drop in water level that we observed at site 9 during the 1979-1980 winter appeared to cause high mortality since areas in which chum salmon spawned in September were frozen or dry by March. The lowered water level also may have reduced intragravel water flow. In areas where dense spawning occurred, a reduced flow could have caused the low dissolved oxygen concentrations and egg mortality that we observed. Decomposing eggs may have further reduced the dissolved oxygen levels. Brickel (1971) found that dead pink salmon eggs consumed four times as much oxygen as live eggs in the early stages of development.

The drop in water level during the 1979-1980 winter appeared to be a result of the unusually high water levels in September 1979. Although a relatively small drop in water level was observed in the following winter, it is unclear whether this would have resulted in reduced egg mortality since low flows following spawning have also been shown to cause high egg mortality [for a review, see Bakkala (1970), p. 54].

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[1] Chum salmon were caught but their sizes were not reported. Records of mesh sizes (4 and 6 inches) of gillnets used in their capture (Norman Parks, National Marine Fisheries Service, Seattle, private communication) indicate that the fish were adults.

[2] Four 20-min (bottom time) tows were made with an otter trawl (2.5 cm stretch mesh on the cod end) between 66°31' and 68°07'N in water 8-19 m deep during the period 18-21 September 1981 (Lloyd Lowry, Alaska Department of Fish and Game, Fairbanks, unpublished data).

## Incubation temperatures

Water temperatures shown in Figures 4 and 5 may be upwardly biased because we confined our winter investigations to areas having either open water or a thin ice cover. However, the presence of ice in other spawning areas may be a result of higher surface flows that dilute and cool the upwelling gravel flows. The areas that we investigated were characterized by low surface flows. Thus, the presence or absence of an ice cover may not provide much information about intragravel temperatures. Also, during a flight over the central part of the Noatak River in late January 1980 we observed many open water areas in addition to those described here. Additional open water areas between Noatak Village and the Kelly River are described by Cunningham et al. (1976)[1].

Water temperatures at the sites we observed in the middle Noatak River provided an average of 1,130 T.U. between 15 September and 30 April. This thermal exposure is equal to or higher than that experienced by chum salmon in more southerly parts of Alaska, and thus it appears that chum salmon in the Middle Noatak River are not adapted to lower temperatures. However, we can't rule out the possibility that there are some sites in the Middle Noatak River in which chum salmon are capable of successfully incubating with lower thermal exposures.

The lower temperatures (~2.5-2.9°C) observed in the Kelly River Lake springs in early September appeared capable of providing a thermal exposure of only about 700 degree days from 1 September to 30 April. This lower thermal exposure is still within the range experienced by other Alaskan chum salmon (Raymond 1981a), which indicates that no special temperature adaptation is present. These salmon appear to have adjusted to the lower temperatures by spawning earlier. However, it is interesting that these chum salmon spawn in water that is initially so cool. Previous work [for a review, see Raymond (1981a)] has shown that temperatures below 5°C during the initial stage of development of salmonid eggs result in increased mortality. Further work is necessary to see if this is true for the Kelly River Lake chum salmon.

## Possible adaptations

Although there is no strong evidence that the Noatak River chum salmon are adapted to low incubation temperatures, other adaptations to this environment are possible.

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[1] Cunningham (1976) reported water surface temperatures between 0 and -0.5°C for several open water sites. His temperatures were most likely incorrect because he used a thermistor attached to a dissolved oxygen meter that was not properly working, and because it is unlikely that enough salts would be present in the water to depress its freezing point by 0.5°C.

The Noatak River chum salmon exhibit many of the characteristics found in the fall runs of chum salmon in the Yukon River (Alaska Department of Fish & Game 1980) and in the Amur River in Siberia (Birman 1953). Chum salmon in the Yukon and Amur fall runs differ from those in the summer runs by their larger size, higher fat content, later spawning, longer river migrations and preference for shallow spring-fed areas for spawning habitat. The larger size and higher fat content are presumably adaptations to the longer river migrations (during which the salmon do not feed), and the preference for springs (whose temperatures usually remain a few degrees above ambient water temperatures in winter) is presumably an adaptation to compensate for the later spawning period.

Noatak River chum salmon, in addition to their relatively late (September-November) spawning period and selection of spring-fed areas for spawning, tend to be larger (Alaska Department of Fish & Game 1977 and 1978) and have a higher fat content[1] than other western Alaskan chum salmon. Their river migration (90 to 160 km) is moderately long. The higher fat content might have further use if, as some studies suggest (Andrievskaya 1957; Allen and Aron 1958), feeding is reduced during the ocean phase of the spawning migration. Because Kotzebue Sound chum salmon feed near the Aleutian Islands and in the Gulf of Alaska with other Alaskan chum salmon (French et al. 1975), their ocean migration is at least 600 km longer than that of Yukon River chum salmon.

Another possible adaptation of Noatak River chum salmon is that their fecundity (Bird 1980a; this report) is greater than the fecundities reported for other Alaskan chum salmon (Bakkala 1970). A somewhat similar result was found in the Amur River where fall chum salmon were found to have a higher fecundity than summer chum salmon (Lovetskaya 1948). A higher fecundity would presumably allow a female to spawn in a greater number of locations. This would be useful in an environment where interruptions in the water supply are common.

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[1] This is based on recollections of food processors who canned Kotzebue chum salmon in the years 1962-1964, the only years in which they were canned. We were unable to locate the actual records. According to H. W. Bodey (Bering Sea Fisheries, Inc., Seattle, WA), Kotzebue chum salmon averaged 12 to 15 cc "free oil" (oil that can be drained from the can) per 1 lb can. This compared to levels of 4 to 10 cc free oil per can for other Alaska chum salmon. Occasionally higher values were seen elsewhere. Yukon River fall chum salmon once were found to contain 21 cc free oil per can. According to Donald Crosgrove (National Food Processors Association, Northwest Research Laboratory, Seattle, WA), most chum salmon contain between 2 and 6.7% fat. The average is about 4.2%. Kotzebue chum salmon were recalled to have a fat content near the upper limit and possibly as high as 10%

## Predation

Although predation by sheefish on chum fry may be intense in some parts of Alaska (Alt 1972), it is apparently not an important cause of mortality in Kotzebue Sound. Sheefish caught in May and June in Kotzebue Sound (Appendix Table 7) and in June in the Kobuk River and at the mouth of the Selawik River (Fred DeCica, private communication) contained many small fish but no chum salmon fry. A report that the stomachs of two sheefish caught in the Noatak River contained chum fry was not confirmed at the time of this writing. Char, which are abundant in the Kotzebue Sound area, are also known to feed on chum fry in salt water (Blackburn et al. 1979). However most of the char stomachs that we examined were caught in Kotzebue Sound in late August at a time when the chum fry may not have been present and when the char did not appear to be feeding. We thus do not know to what extent the char were feeding on chum fry. A search of the literature failed to find any evidence of predation on chum salmon fry by seals (Johnson et al. 1966) or birds (Swartz 1966; Schamel et al. 1978) in the Kotzebue Sound area.

In the Amur River, several predators of fall chum salmon have been reported (Abramov 1949; Disler 1953). They include mergansers, kingfishers, whitefish, pike, burbot, grayling, large minnows and two Siberian salmonids (*Brachymstax lenok* and *Hucho taimen*).

## Feeding and growth

Although we did not find any food items in the stomachs of chum alevins residing in the spawning gravels, other workers have. Disler (1953) reported that the stomachs of fall chum salmon alevins in the Amur River contained detritus, diatoms, *Cyclops*, and chironomid larvae. Bailey et al. (1975) found that chum salmon alevins in Southeastern Alaska ingested sand grains, plant detritus and some chironomids.

The reduced feeding that we observed in chum fry in the Noatak River appears to be normal behavior. Levanidov and Levanidova (1957) who studied juvenile summer chum salmon in the Amur River observed that between late May and early July the frequency with which empty stomachs were found steadily decreased from 71% to 10%, the frequency with which yolk was found steadily decreased from 77% to 4% and the index of fullness increased from 137 to 228 (their units), although not steadily. Bailey et al. (1975) found that chum fry in one stream in Southeastern Alaska ate little while migrating downstream (48% had empty stomachs) but fed heavily once they reached the estuary. Possible causes of the increase in stomach fullness are a greater availability of food, and a greater appetite brought on by increased temperature and the disappearance of yolk. Increased skills at catching prey may also be a factor. Lebrasseur (1969) and Levy (1979) found that chum salmon fry unaccustomed to certain foods, did not feed on them as heavily as did fry that had been accustomed to them.

The reduced slope in the length-vs-date curve for chum fry in the Noatak River compared to Kotzebue Sound (Fig. 8a) is thus probably a result of the chum fry's reduced feeding activity.

The principal food of the chum fry while migrating in the Noatak River was chironomids. Similar results were found for chum fry in Southeastern Alaska (Bailey et al. 1975), British Columbia (Sparrow 1968), Japan (Kaeriyama et al. 1978; Kaeriyama and Sato 1979) and in the Amur River (Levanidov and Levanidova 1957).

Food in the stomachs of chum salmon fry caught in the Noatak River while migrating downstream does not necessarily mean that they feed while in the main river. The food may have been obtained in clear backwaters and tributaries where many chum fry were found at the same time others were moving downstream. Although our sample sizes were not large enough to show this, it appears reasonable in view of evidence that chum fry require good visibility for feeding. Bailey et al. (1975) found that chum fry did not feed during the night and Kaeriyama et al. (1978) found that chum fry migrating in colder turbid waters were smaller than fry migrating in warmer clearer waters. Hoar (1958) also concluded that chum fry were sight feeders.

We did not find any evidence that chum fry in Kotzebue Sound were having difficulty finding food. No significant change in fullness of their stomachs was found during June and July and their length-vs-date curve was similar to those of other Alaska chum salmon (see below). Also zooplankton densities which averaged about 2,000 organisms per cubic meter in Kotzebue Sound, were comparable to those found in other waters of Alaska where chum salmon juveniles rear [Prince William Sound (Cooney et al. 1981), Cold Bay (Bricker 1980), Kitoi Bay (Probasco and Blackett 1980) and Tutka Bay (Nick Dudiak, manuscript in preparation)]. In Traitors Cove estuary in Southeastern Alaska, however, zooplankton densities varied widely and occasionally exceeded 100,000 organisms per cubic meter (Bailey et al. 1975).

It should be noted that because chum fry feed selectively (Bailey et al. 1975; Cooney et al. 1981), zooplankton densities can provide only a rough approximation of food availability.

A comparison of lengths of juvenile chum salmon caught in salt water near Kotzebue and in other parts of Alaska is shown in Fig. 17. Because the data on which this figure is based are obtained from a changing population of fish, the curves provide a measure of the average length of chum fry caught at any particular time and do not necessarily indicate the rate at which the chum fry grow. The length curve for chum salmon in Kotzebue Sound was similar to that found by Barton (1977) for chum salmon in Norton Sound. The slope of the curves for these two northern stocks of chum salmon was similar to those observed for chum salmon in Cook Inlet (Blackburn et al. 1979) and in Southeastern Alaska (Jack E. Bailey and Herbert W. Jaenicke, National Marine Fisheries Service, Auke Bay Laboratory, private communication). However,

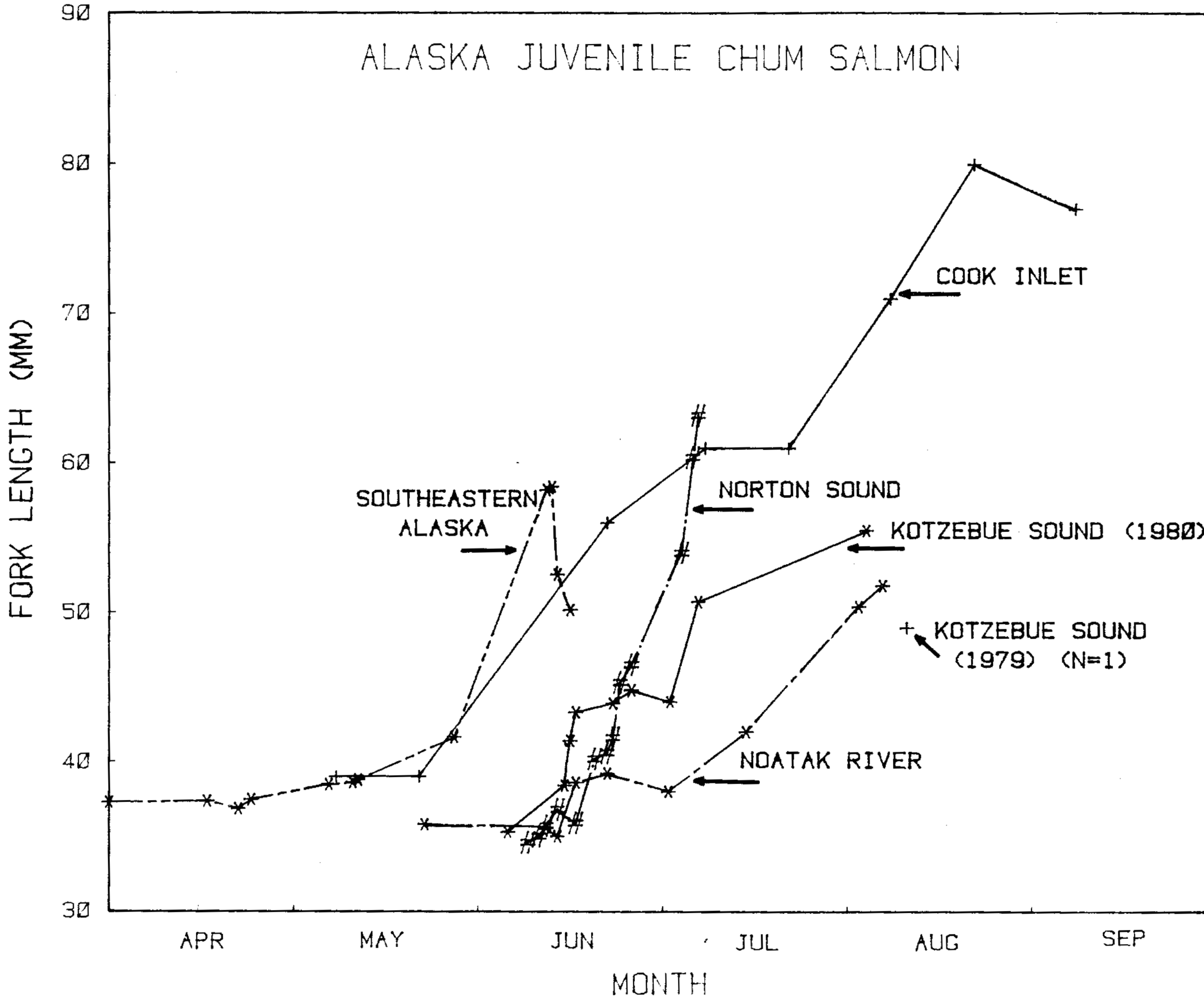


Figure 17. Comparison of lengths of chum fry caught in salt water in different Alaskan waters. Noatak River data (Bird 1980b) is included for comparison. Other sources of data are J. E. Bailey and H. W. Jaenicke, National Marine Fisheries Service, Auke Bay Laboratory, private communication (Southeastern Alaska); Blackburn et al. (1979) (Cook Inlet); Barton (1977) (Norton Sound); this report (Kotzebue Sound).

the period of rapid increase in length of the Cook Inlet and Southeastern chum salmon appeared to precede that of the northern chum salmon by several weeks.

The importance of Diptera in the diet of chum fry once they reached Kotzebue Sound remained high during June but appeared to decrease in July. Most workers have found that chum fry feed mostly on copepods, cladocerans, and amphipods when they enter salt water (Manzer 1969; Okada and Taniguchi 1971; Bailey et al. 1975; Feller and Kaczynski 1975; Sibert et al. 1977; Kayev 1979; Simenstad et al. 1980; Cooney et al. 1981). The importance of insects in the diet of chum fry in Kotzebue Sound might be a result of the low salinity (mostly below 5 ppt) and thus more river-like environment in the areas in which they were collected. Congleton (1979) also found that Diptera were the major part of the diet in chum fry in a tidal marsh. Because the salinities fluctuated widely in the marsh, these fry probably had not completed their transition to salt water. Feller and Kaczynski (1973) found that in one of three areas investigated in Puget Sound insects were the major food of chum fry but salinities were not reported.

Our observation that chum fry appeared to prefer areas in Kotzebue Sound with currents between 6 and 9 cm/s is consistent with those of Bailey et al. (1975). These workers found that chum fry fed more actively in currents below 10.7 cm/s and stopped feeding in currents above 19.9 cm/s.

Seaward migration

Noatak River chum fry appeared to migrate downstream later than chum fry found in more southerly locations. The catch per unit effort in the Noatak River (Bird 1980b) and in Kotzebue Sound (this report) indicated a peak of migration in mid to late June. Kirkwood (1962) found that in Olsen Creek in Prince William Sound the peak of the migration occurred in mid May and was over by early June. Farther south in Washington the peaks of the chum fry migration occurred even earlier: in mid April in the Satsop and Humptulips Rivers (Brix 1981) and between late April and early May in Big Beef Creek (Seiler et al. 1981).

The time at which Kotzebue Sound chum fry appeared to start leaving the nearshore area for deeper waters (mid-July) was similar to that observed elsewhere in Alaska. In Prince William Sound near Olsen Creek, juvenile chum salmon could be found in nearshore waters until as late as mid July (Helle 1979). In Icy Strait in Southeastern Alaska chum fry were abundant in nearshore waters during May and June, were less abundant in July and were gone in August. Farther south at Little Port Walter, chum fry were abundant in nearshore waters through July but were less abundant in August (Jack Bailey and Joyce Landingham, National Marine Fisheries Service, Auke Bay Laboratory, private communication).

Other than the single juvenile chum salmon caught by Barton (1977) off the northwest coast of the Seward Peninsula on 6 September, nothing is known about when and by which route the chum salmon leave Kotzebue Sound. Although Kotzebue Sound water is thought to move generally northward in the Chukchi Sea, there is evidence that some of it moves south towards Shishmareff (Coachman et al. 1975, p. 115). Similarly, currents through the Bering Strait are predominatly northward, especially in summer, but events of southerly currents become more frequent in the fall and winter (Bloom 1964; Shapiro and Burns 1975; Coachman and Aagaard 1981). Thus it may be possible for juvenile chum salmon to migrate into the Bering Sea without having to swim against northerly currents.

Factors limiting chum salmon production

Several lines of evidence suggest that the availability of spawning habitat is the factor limiting chum salmon production in the Noatak River: (1) the high fecundity of the chum salmon females, (2) the apparent confinement of spawning to spring areas, (3) the observed freezing and drying of these areas, (4) the normal feeding and growth of the fry, (5) the normal plankton densities in Kotzebue Sound and (6) the absence of any major predators.

Spawning ground mortalities have also been thought to limit the production of chum salmon in the Amur River (Birman (1957) and in three streams in Southeastern Alaska (McNeil 1965). McNeil estimated that egg and alevin mortality in these streams was seldom less than 75% and often over 90%.

## ACKNOWLEDGMENTS

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Appendix Table 1. Physical and chemical characteristics of open-water study sites on the Noatak River. Locations of sites are shown in Fig 3. Site 13 is the Noatak River at Noatak Village. "-" indicates no data taken.

| Date | Site | D.O. (ppm) | Surface current (cm/s) | Conductivity (u mhos/cm @ 25°C) | pH |
|---|---|---|---|---|---|
| 11-27-79 | 9 | - | - | 230 | 7.84 |
| 1-31-80 | 9 | 8 | 4.7* | - | 7.84 |
| 2-12-80 | 4 | - | - | 630 | - |
| 2-12-80 | 5 | 4 | 0.0 | 630 | 7.56 |
| 2-12-80 | 6 | 3 | 1.2 | 520 | 7.56 |
| 2-12-80 | 8 | 5 | 1.8 | 540 | 7.72 |
| 2-12-80 | 10 | 8 | 2.1 | 570 | 7.79 |
| 4-10-80 | 12 | 6 | 2.1 | 370 | 7.97 |
| 4-24-80 | 12 | - | 3.3 | 350 | 7.72 |
| 4-25-80 | 13 | - | - | 320 | 7.80 |
| 5-16-80 | 9 | 6 | 6.4 | 500 | 7.73 |
| 5-16-80 | 12 | 9 | 7.6 | 500 | 7.76 |
| 5-16-80 | 13 | 11 | 36.6 | 180 | 7.20 |
| 5-17-80 | 13 | - | - | - | 7.43 |
| 11-14-80 | 12 | 5 | 2.5 | | |
| 1-9-81 | 12 | 7 | 3.8 | | |

* units are liters per second

Appendix Table 2. Sample locations and lengths of chum salmon fry collected for stomach content analysis in the Noatak River. Fry were collected by authors (A) and Frank Bird of the Commercial Fisheries Division (B). Stomach contents were analysed by Terri Tobias of the FRED Limnology Laboratory, Soldotna (T) and by Joyce Hanson Landingham of the National Marine Fisheries Service, Auke Bay (L). Stomach contents were given as dry weight (D.W.) per fish by Tobias and as fullness (0 = empty, 5 = full, 6 = distended) by Landingham. The averages of the fullnesses reported by Landingham are given below. "Dist." is the distance from the mouth of the Noatak River.

| Samp No. | Date | Location | Dist. (Km) | No. Fish | Ave. Length (mm) | Stomach D.W. (ug) | Stomach Fullness | Ref. |
|---|---|---|---|---|---|---|---|---|
| 1 | 1/31/80 | in gravel @ site 9 | 101 | 3* | 34.3 | 0 | | A,T |
| 2 | 1/31/80 | in gravel @ site 9 | 101 | 10* | 35.1 | | 0.0 | A,L |
| 3 | 5/16/80 | Noatak Village | 106 | 3 | 32.7 | 0 | | A,T |
| 4 | 5/19/80 | Noatak Village | 106 | 5 | 36.4 | 878 | | A,T |
| 5 | 5/23/79 | shallow backwater | 118 | 10 | 35.1 | | 1.4 | A,L |
| 6 | 6/04/80 | Noatak Village | 106 | 4 | 36.4 | 1130 | | A,T |
| 7 | 6/04/80 | Noatak V. Crk. | 106 | 5 | 38.5 | 408 | | A,T |
| 8 | 6/08/80 | | | 15 | 35.5 | 1030 | | B,T |
| 9 | 6/14/79 | near mouth Aggie R. | 50 | 12 | 36.8 | | 5.1 | B,L |
| 10 | 6/18/80 | | | 15 | 38.2 | 4050 | | B,T |
| 11 | 6/25/80 | | | 15 | 38.9 | 4740 | | B,T |
| 12 | 7/02/79 | near mouth Hugo Ck. | 13 | 10 | 38.5 | | 5.0 | B,L |
| 13 | 7/03/80 | Noatak Village | 106 | 5 | 43.1 | 3610 | | A,T |
| 14 | 7/21/80 | | | 11 | 38.9 | 2660 | | B,T |
| 15 | 8/07/79 | near Big Bluff | 7 | 10 | 50.7 | | 5.7 | B,L |

* alevins

Appendix Table 3. Stomach contents (expressed as numbers of organisms per fish) of chum salmon fry collected in the Noatak River. Descriptions of samples are given in Appendix Table 2.

| Sample | Diptera | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| No. | larv | pup | adlt | Plec | Eph | Cop | Ins | Other |
| 1 | No identifiable organisms | | | | | | | |
| 2 | small gravel fragments | | | | | | | |
| 3 | | | | | | Ø.3 | Ø.7 | |
| 4 | 12.Ø | | | | 1.4 | | | Ø.2 Amphipoda |
| 5 | Ø.7 | | Ø.3 | | | | Ø.2 | |
| 6 | | | | Ø.2 | Ø.2 | | | |
| 7 | | | | | | 3.4H | | Ø.6 Nema, 2.6 Clad |
| 8 | Ø.1 | | | Ø.1 | | | Ø.3 | |
| 9 | 2Ø.8 | Ø.1 | 5.6 | 3.2 | Ø.5 | | Ø.1 | |
| 1Ø | 1.5 | Ø.2 | Ø.3 | 4.5 | Ø.2 | Ø.1C | | Ø.3 Hym, Ø.3 Hom Ø.1 Collembula |
| 11 | Ø.3 | 3Ø.1 | 1.3 | Ø.2 | | | | Ø.1 Hom, Ø.1 Nema |
| 12 | 4.1 | 2.4 | 27.6 | | 2.1 | | 1.2 | |
| 13 | 1.2 | | Ø.6 | | | | 2.Ø | Ø.2 Hym |
| 14 | 9.4 | 4.9 | Ø.6 | Ø.4 | Ø.1 | | | Ø.2 Hym, 1.4 Hom, Ø.1 Arachnida |
| 15 | 196.4 | | 17.4 | Ø.3 | | 21.1H | 4.3 | |

Abbreviations:

| | | | |
|---|---|---|---|
| Clad | Cladocera (Chydorinea) | Hom | Homoptera |
| Cop | Copepoda | Hym | Hymenoptera |
| | C = Cyclopoid | Ins | Insect Parts |
| | H = Harpacticoid | Nem | Nematoda |
| Eph | Ephemeroptera | Plec | Plecoptera |

Appendix Table 4. Nearshore oceanographic data for Kotzebue Sound. Temperatures and salinities are for surface waters.

| Date | Time | Longitude 162°W ' | Latitude 66°N ' | Depth (m) | Temp. (°C) | Salinity (ppt) |
|---|---|---|---|---|---|---|
| 7-31-81 | 1313 | 35.8 | 54.0 | | 13.0 | 3.3 |
| | 1319 | 36.6 | 53.4 | | 12.6 | 3.9 |
| | 1328 | 37.2 | 52.6 | | 12.6 | 3.2 |
| | 1343 | 37.0 | 51.0 | 2.0 | 12.7 | 5.2 |
| | 1356 | 33.6 | 48.6 | 2.6 | 12.7 | 16.9 |
| | 1412 | 31.8 | 47.0 | 3.7 | 12.9 | 16.3 |
| | 1446 | 31.7 | 46.2 | 4.7 | 12.9 | 16.3 |
| | 1538 | 30.4 | 44.3 | 2.0 | 13.2 | 16.3 |
| | 1549 | 29.5 | 43.7 | 5.5 | 12.8 | 16.9 |
| | 1633 | 22.5 | 43.1 | 6.0 | 12.9 | 16.9 |
| | 1714 | 16.0 | 42.3 | 6.3 | 13.0 | 16.3 |
| | 1729 | 17.3 | 41.6 | 9.1 | 12.7 | 16.2 |
| | 1842 | 33.0 | 47.7 | 4.7 | 12.9 | 16.3 |
| | 1851 | 34.9 | 48.5 | 5.7 | 13.0 | 15.6 |
| | 1944 | 36.2 | 49.3 | 5.0 | 12.7 | 9.1 |
| | 2004 | 38.8 | 50.8 | 1.5 | 12.65 | 12.3 |
| 8-1-81 | 1039 | 35.8 | 54.0 | | 12.25 | 1.2 |
| | 1146 | 32.9 | 48.7 | | 12.6 | 9.3 |
| 8-2-81 | 1225 | 34.9 | 48.5 | 4.0 | 4.85 | 27.1 |
| | 1237 | 31.7 | 46.2 | 4.6 | 4.7 | 29.0 |
| | 1620 | 37.6 | 50.9 | 1.5 | 12.9 | 2.0 |
| | 1654 | 33.5 | 48.4 | 2.0 | 12.6 | 4.5 |
| | 1658 | 33.2 | 48.1 | 2.2 | 12.3 | 4.5 |
| | 1703 | 32.5 | 47.8 | 2.6 | 12.35 | 5.8 |
| | 1708 | 31.7 | 46.9 | 3.3 | 11.75 | 7.0 |
| | 1714 | 31.7 | 46.6 | 4.0 | 11.4 | 7.9 |
| | 1717 | 31.3 | 46.1 | 3.2 | 10.95 | 8.8 |
| | 1723 | 31.0 | 45.5 | 3.0 | 9.67 | 12.8 |
| | 1729 | 32.3 | 45.7 | 4.5 | 10.3 | 11.3 |
| | 1739 | 31.4 | 44.3 | 2.2 | 10.1 | 12.5 |
| 8-3-81 | 1107 | 35.8 | 54.0 | | 12.9 | 1.1 |
| | 1119 | 36.8 | 51.0 | 2.0 | 12.9 | 1.3 |
| | 1130 | 33.6 | 48.6 | 3.0 | 8.5 | 19.7 |
| | 1136 | 34.9 | 48.5 | 4.5 | 7.6 | 22.4 |
| | 1334 | 34.2 | 48.5 | | 10.05 | 19.6 |
| | 1402 | 30.8 | 44.3 | | 9.85 | 22.1 |
| | 1418 | 21.5 | 42.3 | 7.0 | 10.8 | 21.0 |
| | 1528 | 17.4 | 41.8 | | 11.45 | 21.2 |
| | 1653 | 32.0 | 46.2 | | 12.0 | 20.6 |

Continued

Appendix Table 4. (cont.)

| Date | Time | Longitude 162°W ' | Latitude 66°N ' | Depth (m) | Temp. (°C) | Salinity (ppt) |
|---|---|---|---|---|---|---|
| 8-4-81 | 1610 | 35.8 | 54.0 | | 13.8 | 1.2 |
| | 1645 | 33.8 | 48.6 | | 15.3 | 5.7 |
| | 1651 | 32.7 | 47.4 | | 16.3 | 4.0 |
| | 1658 | 31.3 | 46.1 | | 16.3 | 5.9 |
| | 1703 | 34.6 | 45.9 | | 14.05 | 20.4 |
| | 1719 | 35.1 | 45.8 | 5.3 | 14.2 | 20.5 |
| | 1830 | 29.0 | 43.9 | | 14.8 | 21.9 |
| | 1940 | 26.7 | 43.8 | | 14.2 | 19.8 |
| | 2031 | 36.0 | 48.4 | | 14.0 | 4.8 |
| 8-5-81 | 0931 | 35.8 | 54.0 | | 14.1 | 0.9 |
| | 0953 | 34.9 | 48.5 | | 11.9 | 20.6 |
| | 1001 | 32.1 | 48.0 | | 11.4 | 21.1 |
| | 1050 | 28.0 | 43.8 | | 11.7 | 21.2 |
| | 1118 | 16.0 | 42.7 | | 11.7 | 21.2 |
| | 1130 | 11.1 | 41.5 | | 11.5 | 21.8 |
| | 1326 | 07.0 | 37.9 | | 11.9 | 21.9 |
| | 1430 | 05.7 | 36.5 | | 13.0 | 22.1 |
| | 1530 | 03.6 | 34.3 | 10.3 | 13.95 | 20.4 |
| | 1700 | 52.1* | 27.3 | | 12.3 | 22.6 |
| | 1830 | 56.4* | 19.6 | | 13.3 | 20.9 |

* Longitude 161°W

Appendix Table 5. Horizontal plankton tows and contents (rounded to nearest percent) taken in Kotzebue Sound in 1980 and 1981 with 243 u mesh nets. Vol. is the product of the distance of the plankton tow and the cross sectional area of the net. No. is the number of organisms.

| Date | Time | Long. 162°W ′ | Lat. 66°N ′ | Vol. ($m^3$) | No. $/m^3$ | Contents (%) Cal | Cy | Poly | Sn | Cm | Other |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1980 | | | | | | |
| 6/17 | 1530 | 31.7 | 54.5 | 57.4 | 1039 | 99 | | | | | 1B,N |
| 6/23 | 1200 | 30.9 | 54.7 | 61.5 | 803 | 97 | 1 | | | | 2Harp |
| 6/27 | 1430 | 52.0 | 59.6 | 47.9 | 177 | 59 | 38 | | | | 2CLE, 1CE |
| 7/02 | 1200 | 31.7 | 54.5 | 43.8 | 65 | 78 | 15 | | | | 8Harp |
| 7/15 | 2300 | 35.8 | 54.0 | 6.0 | 4025 | 74 | 1 | 24 | | | 1B,K |
| 7/16 | 1130 | 35.8 | 54.0 | 9.2 | 3904 | 50 | 1 | 11 | | | 36C,1K,1CE |
| 7/17 | 1800 | 35.8 | 54.0 | 12.2 | 7583 | 62 | 2 | 3 | | | 32C,1B,1K, |
| 7/24 | 0130 | 48.8 | 58.1 | 55.3 | 4034 | 84 | | 16 | | | |
| 8/18 | 1500 | 57.2 | 50.7 | 59.1 | 105 | 87 | 9 | 4 | | | |
| 8/20 | 1530 | 32.1 | 55.2 | 156.4 | 17 | 78 | 10 | 4 | | | 3K,2B,1CE, |
| 8/22 | 1618 | 30.9 | 44.9 | 49.0 | 1232 | 88 | | 9 | 4 | | |
| 8/22 | 1645 | 31.1 | 44.8 | 45.3 | 1725 | 88 | | 5 | 5 | 2 | |
| 8/22 | 1700 | 31.3 | 44.8 | 50.9 | 1697 | 81 | | 10 | 5 | 4 | |
| 8/22 | 1730 | 31.5 | 44.7 | 31.8 | 2664 | 89 | | 5 | 4 | 3 | |
| 8/27 | 1100 | 26.6 | 56.7 | 47.7 | 74 | 77 | | 10 | 1 | 11 | |
| 8/27 | 1145 | 31.7 | 54.5 | 60.7 | 20 | 87 | | 9 | | 3 | 1N, 1Chy, |
| 8/29 | 2100 | 18.1* | 03.6* | 55.0 | 683 | 91 | | 2 | 1 | | 3N, 2CE, |
| 9/18 | 1500 | 31.7 | 54.5 | 27.6 | 525 | 93 | 6 | | | | 1Daph |
| 9/19 | 1400 | 30.6 | 44.5 | 29.7 | 2633 | 92 | 1 | 6 | 1 | | |
| 9/23 | 1430 | 31.7 | 54.5 | 23.0 | 3643 | 96 | 3 | | | | 1Daph |
| 9/23 | 1445 | 31.7 | 54.5 | 32.0 | 3294 | 96 | 3 | | | | 1Daph |
| 9/30 | 1230 | 31.7 | 54.5 | 16.1 | 4056 | 99 | 1 | | | | |
| | | | | | 1981 | | | | | | |
| 7/31 | 1633 | 22.5 | 43.1 | 12.6 | 9401 | 77 | | 23 | | | |
| 8/5 | 1530 | 03.6 | 34.3 | 25.3 | 2546 | 3 | | 97 | | | |

* 163°W, 67°N

Abbreviations:

| | |
|---|---|
| B | Bosminidae (Cladocera) |
| Cal | Calanoid copepod |
| CE | Copepod eggs |
| Chy | Chydorinea (Cladocera) |
| CLE | Cladocera eggs |
| Cm | Clams (Pelecypoda) |
| C | Conochiloides (Rotifer) |
| Cy | Cyclopoid copepod |
| Daph | Daphnidae (Cladocera) |
| Harp | Harpacticoid copepod |
| K | Kellicottia (Rotifer) |
| N | Nauplii (Copepoda) |
| Poly | Polyphimidae (Cladocera) |
| Sn | Snail |

Appendix Table 6. Tow net and trawl data for Kotzebue Sound, 1980 and 1981. "Dist." is the distance in meters (m) that the nets were pulled. "Vol.", the product of distance and the cross-sectional area of the net, is an estimate of the volume of water sampled.

| Date | Time | Long. 162°W ' | Lat. 66°N ' | Dist. (m) | Vol. ($m^3$) | Contents |
|---|---|---|---|---|---|---|
| Tow net | | | | | | |
| 7/24/80 | 0130 | 48.8 | 58.2 | 350 | 2630 | sm, sh |
| 7/29/80 | 1027 | 33.0 | 54.5 | 2100 | 15770 | f, ca, sh, ci |
| 7/29/80 | 1155 | 38.0 | 53.7 | 1750 | 13140 | sh, ca, h |
| 7/29/80 | 1355 | 35.7 | 46.0 | 1750 | 13140 | c |
| 8/18/80 | 1320 | 57.2 | 50.7 | 3170 | 30400 | jf or salps, 250ca,7st,2h,29c |
| 8/02/81 | 1324 | 31.7 | 46.2 | 1000 | 7510 | larv, jf or salps |
| 8/02/81 | 1440 | 31.7 | 45.5 | 530 | 3980 | empty |
| 8/03/81 | 1232 | 35.0 | 48.5 | 2290 | 17200 | larv, st |
| 8/03/81 | 1437 | 21.5 | 42.3 | 2170 | 16290 | larv < 5 cm |
| 8/03/81 | 1528 | 20.5 | 42.3 | 1910 | 14340 | 12 juv. fish |
| Trawl | | | | | | |
| 8/20/80 | 1430 | 32.1 | 55.2 | 600 | 2340 | f, sc, sm, ca, c, sh, ci |
| 8/20/80 | 1530 | 29.1 | 57.3 | 1160 | 4540 | f |
| 8/20/80 | 1550 | 32.1 | 55.2 | 1380 | 5400 | c |
| 8/20/80 | 1630 | 32.1 | 55.2 | 1060 | 4150 | e |
| 8/21/80 | 1540 | 37.0 | 53.4 | 290 | 1140 | w, c, ci, f, sm, sc |
| 8/21/80 | 1610 | 37.5 | 52.1 | 310 | 1210 | f, sc, sh, c, ca |
| 8/22/80 | 1525 | 31.1 | 45.0 | 1060 | 4150 | f, s, sc, c, ca, sh, sm, p, sp |
| 8/27/80 | 1045 | 26.6 | 56.7 | 800 | 3120 | f, sc |
| 9/19/80 | 1445 | 30.5 | 44.4 | 130 | 510 | f, s, sh |

Abbreviations:

| | | | |
|---|---|---|---|
| c | saffron cod | p | pipefish |
| ca | candlefish | s | sole |
| ci | cisco | sc | sculpin |
| f | flounder | sh | shrimp |
| h | herring | sm | smelt |
| st | stickleback | w | whitefish |
| jf | jelly fish | larv | larval fish |
| sp | sturgeon poacher | | |

Appendix Table 7. Stomach analyses of potential predators of juvenile chum salmon in Kotzebue Sound in 1980. "n" is the number of fish in each sample. Ages of sheefish were based on length using the method of Alt (1973).

| Species | Date Sampled (1980) | Age (yr) | n | Average length (mm) | Stomach contents |
|---|---|---|---|---|---|
| Sheefish | 6/16 | 2 | 1 | 230 | btl |
| | 5/4-8/25 | 4 | 11 | 350 | ca, sh, st, sm |
| | 6/8-8/25 | 5 | 20 | 389 | ca, sm, st |
| | 5/4-7/7 | 6 | 5 | 459 | sh |
| | 6/8-6/26 | 7 | 5 | 511 | h, c |
| | 5/4-7/10 | 8 | 8 | 567 | h, st, c, unident. fish |
| | 3/18-7/8 | 9 | 12 | 614 | c, h, sm, ci, w |
| | 3/18 | 10 | 2 | 693 | No ID |
| | 3/18-5/7 | 11 | 2 | 745 | c, w, ci |
| | 3/6 | 12 | 2 | 780 | c, w, sm |
| | 11/16* | 13 | 1 | 833 | h, |
| Arctic Char | 6/10 | | 3 | 462 | empty |
| | 8/27 | | 21 | 656 | empty |
| Least Cisco | 6/6-6/23 | | 18 | 182 | btl,ins,aw,sh,cop |
| Flounder | 6/11 | | 5 | 158 | aw |
| Boreal smelt | 6/6-6/11 | | 4 | 156 | sh, |
| Sculpin | 6/6-6/11 | | 6 | 148 | sh, ins, btl |
| Saffron Cod | 8/25 | | 2 | 285 | ca, sh, |
| Herring | 6/17 | | 1 | 250 | No ID |
| Pike | 6/10 | | 1 | 580 | No ID |

* 1979 sample

Abbreviations:

| | | | |
|---|---|---|---|
| aw | annelid worms | ins | insects |
| btl | beetle | No ID | no identifiable organisms |
| c | saffron cod | sh | shrimp |
| ca | candlefish | sm | smelt |
| ci | cisco | st | stickleback |
| cop | copepods | w | whitefish |
| h | herring | | |

Appendix Table 8. Chum salmon juveniles collected for stomach content analyses in Kotzebue Sound. All samples were collected with beach seines. Locations are shown in Fig. 10.

| Sample No. | Date | Location | No. fish | Ave. Length (mm) | Temp. (°C) | Salinity (ppt) |
|---|---|---|---|---|---|---|
| 1 | 6/06/80 | Kotzebue dump | 5 | 36.2 | 7.7 | 1.3 |
| 2 | 6/06/80 | Kotzebue | 5 | 32.5 | 4.8 | 1.2 |
| 3 | 6/11/80 | Kotzebue | 1 | 33.5 | 8.7 | 0.8 |
| 4 | 6/15/80 | Lockhart Point | 5 | 41.0 | 12.0 | 2.9 |
| 5 | 6/15/80 | Lockhart Point | 3 | 33.7 | 11.5 | 2.7 |
| 6 | 6/16/80 | Kotzebue | 5 | 42.5 | 10.0 | 1.8 |
| 7 | 6/17/80 | Kotz. Lagoon mouth | 5 | 46.6 | 12.0 | 3.2 |
| 8 | 6/23/80 | Kotz. Lagoon mouth | 5 | 48.5 | 14.0 | 4.4 |
| 9 | 6/23/80 | Ilivak | 5 | 44.4 | 12.9 | 4.4 |
| 10 | 6/23/80 | Lockhart Point | 2 | 35.0 | 12.8 | * |
| 11 | 6/26/80 | Sheshalik Lagoon | 3 | 41.2 | 16.0 | # |
| 12 | 6/26/80 | Sheshalik Lagoon | 1 | 60.0 | NA | NA |
| 13 | 6/27/80 | Sheshalik Spit | 1 | 31.0 | 17.0 | NA |
| 14 | 7/02/80 | Kotz. Lagoon mouth | 1 | 44.5 | 15.0 | 2.7 |
| 15 | 7/02/80 | Kotz. Lagoon mouth | 5 | 45.2 | 15.5 | 2.6 |
| 16 | 7/03/80 | Sadie Ck, 100 m in | 1 | 41.0 | 13.0 | 11.2 |
| 17 | 7/03/80 | Kotzebue | 1 | 39.0 | | |
| 18 | 7/07/80 | Sheshalik Lagoon | 2 | 54.5 | 16.0 | 6.3 |
| 19 | 8/04/81 | Cape Blossom | 9 | 60.8 | 14.2 | 21.0 |

* slight salt taste
# fresh taste

Appendix Table 9. Stomach contents (expressed as numbers of organisms per fish) of chum salmon fry collected in Kotzebue Sound. Descriptions of samples are given in Appendix Table 8. Samples were collected by beach seine and analyzed by Terri Tobias of the FRED Limnology Laboratory, Soldotna.

| Sample | Diptera | | | | | |
|---|---|---|---|---|---|---|
| No. | larv | pup | adlt | Cop | Clad | Other |
| 1 | 0.2 | | 0.6 | | | 0.4 Plec |
| 2 | | | | 0.2Ca<br>0.2Cy<br>0.2H | | 0.6 Ins |
| 3 | No identifiable organisms | | | | | |
| 4 | 0.4 | | 0.2 | | 0.6C | 0.2 Nem, 0.6 Thy |
| 5 | 0.3 | | | 2.3 | | 0.3 Ins |
| 6 | 0.4 | | | | | |
| 7 | 0.2 | | 4 | | | |
| 8 | 0.8 | 9.2 | | 36.4 | 0.2P | |
| 9 | 31.2 | 7.6 | | | | 2.6 Amph, 0.2 Fish |
| 10 | 0.5 | | | 29.0<br>4.5Ca | | 1.0 Amph, 1.5 Hem |
| 11 | 23.3 | | 2.3 | | | |
| 12 | 1.0 | 20.0 | 1.0 | | | |
| 13 | 2.0 | | | 13.0<br>1.0H | | |
| 14 | | | 1.0 | | | 1.0 Ins |
| 15 | | 5.0 | | | | |
| 16 | 2.0 | | | | | |
| 17 | | | | | 2.0 | |
| 18 | 0.5 | | | | | |
| 19 | | 0.1 | 0.3 | 0.6H<br>13.6Ca | 151.9C | 5.8 Bos, 0.8 Eub |

Abbreviations:

adlt Adult
Amph Amphipodas
Bos Bosminidae
Cop Copepoda
  Ca = Calanoid
  Cy = Cyclopoid
  H = Harpacticoid
Clad Cladocerans
  C = Chydorinea
  P = Polyphemidae
Eub Eubranchiopoda
Hem Hemiptera
Ins Insect parts
Larv Larvae
Nem Nematoda
Plec Plecotera
pup Pupae
Thy Thysanoptera