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KARLUK LAKE SOCKEYE SALMON STUDIES 1984.

PART I: COMPETITION, PREDATION, AND LAKE FERTILITY

PART II: KARLUK LAKE SMOLT OUTMIGRATION - 1984

U.S. Fish and Wildlife Service
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PART I

COMPETITION, PREDATION, AND LAKE FERTILITY

Background

Based on available data of the Karluk Lake sockeye salmon run, McIntyre (1980) concluded that the historic stability region shown in the stock-recruit curve for these fish collapsed and has been re-established at a much lower level. A project was initiated at Karluk Lake in 1982 to investigate alternative explanations that could account for collapsing stability regions. We concluded from the available evidence that the two most promising lines of investigation were depensitory mortality (i.e. predation/competition) and lake fertility. The possibility of a change in lake fertility is being addressed by analysis of sediment cores taken from Karluk Lake and other nearby sockeye salmon systems for comparison. Predation is being investigated by analyzing the stomach contents of potential predators (coho salmon, Dolly Varden char, and Arctic char) to determine the incidence of sockeye salmon juveniles consumed. The possibility of competition is an area of much greater complexity. Inferences must be made from determinations of the distribution, relative abundance, age and growth, and food habits of the fish species involved.

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Objectives

The specific objectives for the 1982, 1983 and 1984 field seasons were:

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1. To collect sediment core samples from Karluk Lake and other nearby sockeye salmon lakes.

2. To determine the incidence of predation by char and coho salmon on juvenile sockeye salmon.

3. To determine the spatial and temporal distribution, and relative abundance of fish species in Karluk Lake to identify where potential areas of competition can occur.

Results

Objective 1

Lake Fertility: A total of eleven sediment core samples have been collected from Karluk (4), Red (4), Frazier (2), and O'Malley (1) lakes. These samples are presently being analyzed by SNFRC (see separate report by T. Terrell). Attempts to collect a larger number of samples from each lake have been unsuccessful. Lake bottoms predominately consist of soft muds or rock. Areas where successful cores can be taken are extremely limited and randomly located. Our core sampler (Wildco Ball Check Corer) does not sample soft bottoms well. Sediment cores consistently fall out of the sampling tube upon retrieval. Successful sampling will require either an alternative sampling device or a much greater sampling effort.

Objective 2

Predation: Arctic char and Dolly Varden char. Examination of the

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stomach contents of 57 char collected within Karluk Lake during May 1984 supported findings from 1982 and 1983 (Table 1). That is, there is no indication that char are an important predator on sockeye fry within Karluk Lake. During May, insects were the major food item in char stomachs. These results are also supported by the findings of Delacy (1941) and Morton (1982). In contrast, char in the Karluk River were apparently preying heavily on sockeye fry (Table 1). Observed char predation on sockeye fry was intense from the first sampling day, 26 April, through mid May (Table 2). During this time, thousands of sockeye fry were observed migrating upstream and into Karluk Lake. Char were easily collected with rod and reel. As predation levels fell, angling success for char also declined and few char were collected in late May and June. In 1983, the Karluk River was also the only area where char predation was observed. (No char from Karluk River were examined during 1982.)

Sockeye smolt were not found in any of the char examined in either 1983 or 1984. During peak sockeye smolt outmigration, few char were occupying the river (based on sport fishing effort). At dusk during the period early to mid June, however, large numbers of smolt were moving from the lake into the river. Large salmonids (400 mm+) were observed rushing through these schools of smolt and were apparently feeding on them. Adult salmon are not present in the Karluk River until late June, thus these fish were probably char and possibly rainbow trout. Attempts to capture these fish with sport fishing gear were unsuccessful. During the 1985 field season, sampling will be done to monitor for possible predation on sockeye smolt in the Karluk River.

Predation: Coho. An additional 595 juvenile coho salmon stomachs,

Table 1. Incidence of Dolly Varden/Arctic char predation on sockeye salmon fry at Karluk River and Karluk Lake, May 1982, 1983, and 1984. (N = number of stomachs examined.)

	1982			1983			1984		
Location	N	Fry per stomach	Percent w/fry	N	Fry per stomach	Percent w/fry	N	Fry per stomach	Percent w/fry
Karluk River mouth to ≈2.5 km downstream	0	No effort	-	95	1.168	28	64	15.188	33
Karluk Lake outlet beach seine site	50	0	0	166	0	0	13	0	0
Lower Thumb River and beach seine site	1	0	0	13	4.538	23	1	0	0
Thumb Lake	0	No effort	-	9	0	0	19	0	0
Grassy Point Creek beach seine site	0	-	-	6	0	0	0	-	-
Moraine Creek beach seine site	0	-	-	3	0	0	2	0	0
O'Malley River beach seine site	0	-	-	6	0	0	9	0	-
Camp Island area	0	No effort	-	8*	0	0	13**	0	0

* Fish sampled on 29 April 1983. ** Fish sampled on 22 April 1984.

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Table 2. Incidence of Dolly Varden/Arctic char predation on sockeye salmon fry 26 April through 22 June 1984. All fish were taken from the river origin at Karluk Lake to about 2.5 km downstream. (N = number of stomachs examined.)

Date	N	Fry/stomach	Percent w/fry	FL (mm) range
26 April	9	5.1	89	429-538
27 April	14	23.0	57	375-585
28 April	33	34.0	61	375-588
29 April	8	3.5	38	374-580
April Total	64	23.7	67	374-588
05 May	21	0.7	19	384-546
08 May	11	73.7	82	357-495
11 May	7	16.4	57	373-525
12 May	11	2.8	36	391-510
17 May	10	0	0	305-451
23 May	4	0	0	415-470
May Total	64	15.2	33	305-525
13 June	3	0.7	67	345-460
15 June	5	0.2	20	381-470
22 June	1	0	0	450
June Total	9	0.33	22	345-470

collected during May through July 1984, were examined. The 1984 data are consistent with findings from 1982 and 1983 (Table 3). That is, coho predation on sockeye salmon fry does not appear to be an important factor throughout Karluk Lake but predation does appear to be localized. Coho collected from the Thumb River (beach seine site) accounted for 73% of the observed predation in 1984. During 1982, Thumb River accounted for 23%, and during 1983 for 12% of the observed predation.

A review of coho stomach data from 1982, 1983, and 1984 showed that the most comparable samples (fish collected with the same gear, at the same

Table 3. Incidence of juvenile coho salmon predation on sockeye salmon fry (prey) in the Karluk River System, 1982-1984: sockeye fry per coho stomach (prey per predator), percent of coho with sockeye fry in their stomachs (percent with prey) and numbers of stomachs examined (N).

	May			June			July		
Sampling sites	Prey per predator	Percent with prey	N	Prey per predator	Percent with prey	N	Prey per predator	Percent with prey	N
1982									
O'Malley River	-	-	-	0.12	12	8	-	-	-
Thumb River	-	-	-	0.94	47	17	0.16	9	134
Karluk Lake outlet	-	-	-	0	0	13	0	0	10
Moraine Creek	-	-	-	0	0	92	-	-	-
Grassy Point Creek	-	-	-	0.77	39	57	0.09	5	57
Grassy Point Cove	-	-	-	0.25	25	4	0	0	6
Bear Point Cove	-	-	-	-	-	-	0.01	1	122
Tent Point Cove	-	-	-	-	-	-	0.08	3	66
Cottonwood Cove	-	-	-	0.16	11	55	-	-	-
All sites combined	-	-	-	0.29	15	246	0.09	5	395
1983									
O'Malley River	-	-	-	0.04	4	24	-	-	-
Thumb River	0.10	6	68	0.09	6	255	-	-	-
Karluk Lake outlet	0.04	2	46	0.08	7	76	0	0	35
Moraine Creek	-	-	-	0	0	88	0	0	20
Grassy Point Creek	0	0	2	0.08	8	86	0	0	15
Bear Point Cove	0	0	57	0.01	1	111	0.10	3	30
Karluk River	0.06	5	218	0.01	1	453	-	-	-
O'Malley Lake	0	0	10	0	0	41	0	0	50
Thumb Lake	0.13	7	204	0	0	9	0.05	3	39
All sites combined	0.08	5	605	0.04	3	1143	0.03	1	189
1984									
O'Malley River	-	-	-	-	-	-	0	0	3
Thumb River	0	0	30	0.99	42	102	0.75	14	57
Karluk Lake outlet	0	0	4	0.10	8	39	-	-	-
Moraine Creek	-	-	-	0.19	14	37	-	-	-
Grassy Point Creek	-	-	-	0.08	8	52	0	0	20
Grassy Point Cove	-	-	-	-	-	-	0	0	21
Bear Cove	0.14	7	14	0.07	7	14	0	0	29
Karluk River	0.04	3	90	0.02	2	83	-	-	-
All sites combined	0.04	3	138	0.36	18	327	0.33	6	130

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locations, and during the same time period) were from June at the Thumb River, Grassy Point Creek, and Moraine Creek beach seine sites. The June samples from the above locations were selected for additional comparisons.

There appeared to be little predation by coho less than 80 mm forklength (Table 4), and only data from coho greater than 77 mm (approximate preserved length of an 80 mm fish) were used in these additional comparisons. Coho predation was highest in the Thumb River samples (Table 5). Indeed, 44% of the coho examined from Thumb River samples were preying on sockeye fry. This compares to 12% and 14% at Grassy Point Creek and Moraine Creek, respectively. Predation does not appear to be related to sockeye fry "abundance", as determined by beach seine catches. During June, the average CPUE (sockeye fry/seine) was 618, 563, and 45 fry at Grassy Point Creek, Moraine Creek and Thumb River, respectively. The average CPUE of juvenile coho during June, however, was highest at Thumb River: 53 coho per seine haul, compared to 14 at Moraine Creek and 1 at Grassy Point Creek. CPUE is a static measure of abundance and may not be reflective of the number of fry available over a period of time. Sockeye fry from natural reproduction and from the FRED rehabilitation project within the Lower and Upper Thumb River

Table 4. Comparison of the incidence of juvenile coho stomachs containing sockeye fry in Karluk Lake, 1982, expressed as a percentage. (Number of fish stomachs examined are listed in parentheses.)

	Karluk Lake - 1982		
Coho FL (mm)	June	July 1-15	July 16-30
≤59	0 (7)	--	
60-79	2 (90)	<1 (166)	0 (44)
80-99	10 (68)	10 (112)	0 (39)
100-119	34 (59)	13 (23)	0 (71)
≥120	32 (22)	67 (3)	0 (1)

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Table 5. Incidence of coho predation on sockeye salmon fry (prey) at the Thumb River, Grassy Point Creek, and Moraine Creek Beach seine sites during June 1982, 1983, and 1984. (All coho were from beach seine catches and were greater than 77 mm long.)

	1982		1983		1984	
Location	Prey / predator	N	Prey / predator	N	Prey / predator	N
Thumb River	1.0667	15	0.1667	90	1.0412	97
Grassy Point Creek	0.7592	54	0.1228	57	0.1250	32
Moraine Creek	0	29	0.0239	86	0.1944	36
All sites combined	0.5816	98	0.1159	233	0.6788	165
	30% with prey		9% with prey		32% with prey	

drainage migrate into Karluk Lake during April through June. Estimates of fry produced by the FRED rehabilitation project are 1.9, 2.9, and 4.8 million for 1982, 1983, and 1984, respectively (Lorne White pers. comm.). These migrating fry may be more available to coho as the fry move into Karluk Lake and attempt to establish themselves in suitable habitat even though there may be fewer fry at a given point in time. We intend to closely monitor coho predation in the Thumb River area in conjunction with the FRED fry migration project during the 1985 field season. Also, we are presently evaluating other parameters (temperature profiles, etc.) to attempt to explain why a great proportion of coho predation occurs in the Thumb River area.

Sockeye escapement to the Karluk system in 1983 was about 436,000 spawners, compared to 223,000 in 1981 and 164,000 in 1982. The overall increase of coho predation observed in 1984 (Tables 3 and 5) is consistent with a density-dependent predation hypothesis. The combined (Thumb River, Moraine Creek, and Grassy Point Creek) 1982, 1983, and 1984 predation rates were regressed on log ($\ln_x$) of the parental escapement (Fig. 1). These data fit

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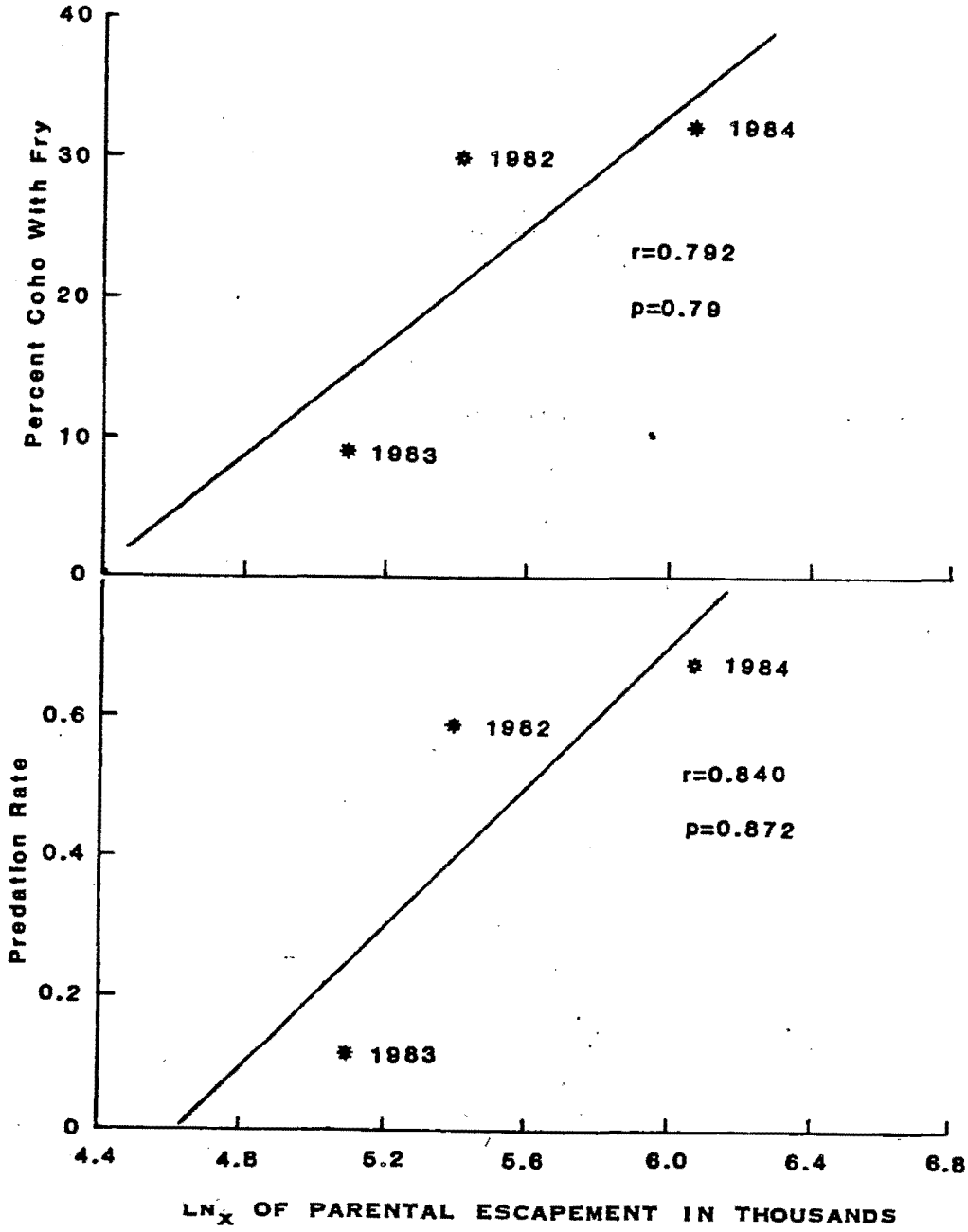

Figure 1. Predation rate (sockeye fry per coho stomach) and percent coho containing fry regressed on ln of the parental escapement of sockeye. (Thumb River, Moraine Creek, and Grassy Point Creek, June 1982, 1983, and 1984 data.)

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well with our hypothesis of density-dependent predation (r = 0.84). The 1982, 1983, and 1984 predation rates for Thumb River coho (Table 5) were regressed on parental escapement (Fig. 2). Again, predation rates agree with the density-dependent hypothesis (r = 0.77). A factor that compounds the analysis of Thumb River data is the additional fry added to the system by the ADF&G, FRED rehabilitation project. The addition of these fry to those produced naturally may explain the higher rate of predation observed at Thumb River. A combination of predators during certain sockeye life history events (fry predation by char in the Karluk River; fry predation by coho in the Thumb River area; mortality of spawners induced by mammals such as bears) may be preventing Karluk sockeye from attaining historic levels of abundance.

Objective 3

Distribution and Abundance: Fish distribution and species abundance within the littoral rearing habitat of young-of-the-year sockeye were investigated by beach seining during 1982, 1983 and 1984. Standard sites adjacent to stream mouths were seined weekly from May through October (Fig. 3). Overall catch composition was dominated (>95% total catch) by sticklebacks. Bureau of Commercial Fisheries data are only roughly comparable (Table 6), because their seining sites were not identified by Gard and Drucker (1963), however, the comparison seems to indicate that the already large percentage of sticklebacks continues to increase while the percentage of sockeye declines.

Seasonal changes in the species composition within the littoral zone of Karluk Lake were evident. Changes in the species composition of beach seine catches were similar for 1982, 1983, and 1984 (Figs. 4-8). Young-of-the-

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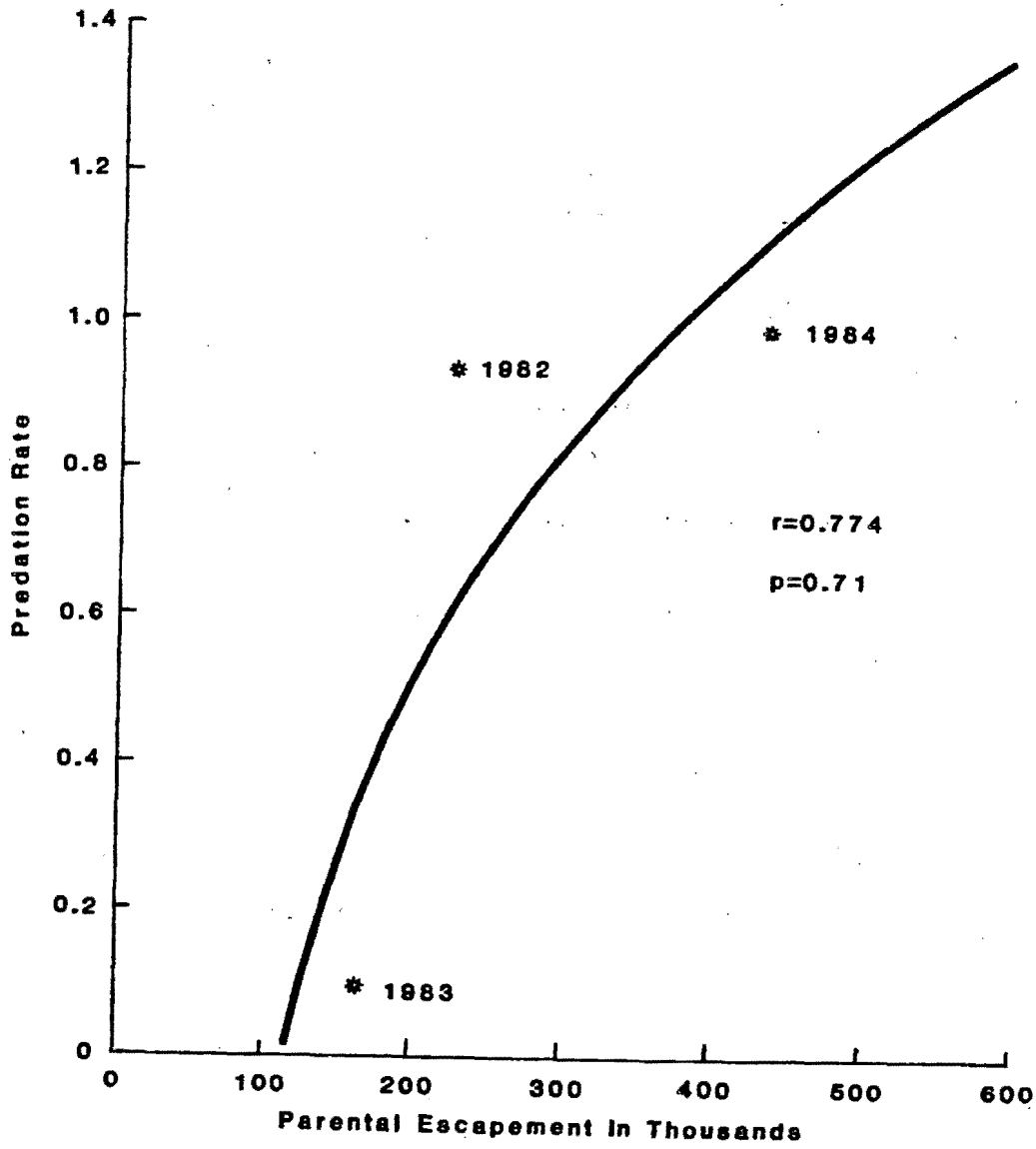

Figure 2. Predation rate (sockeye fry per coho stomach) regressed on parental escapement of sockeye. (Thumb River, June 1982, 1983, and 1984 data.)

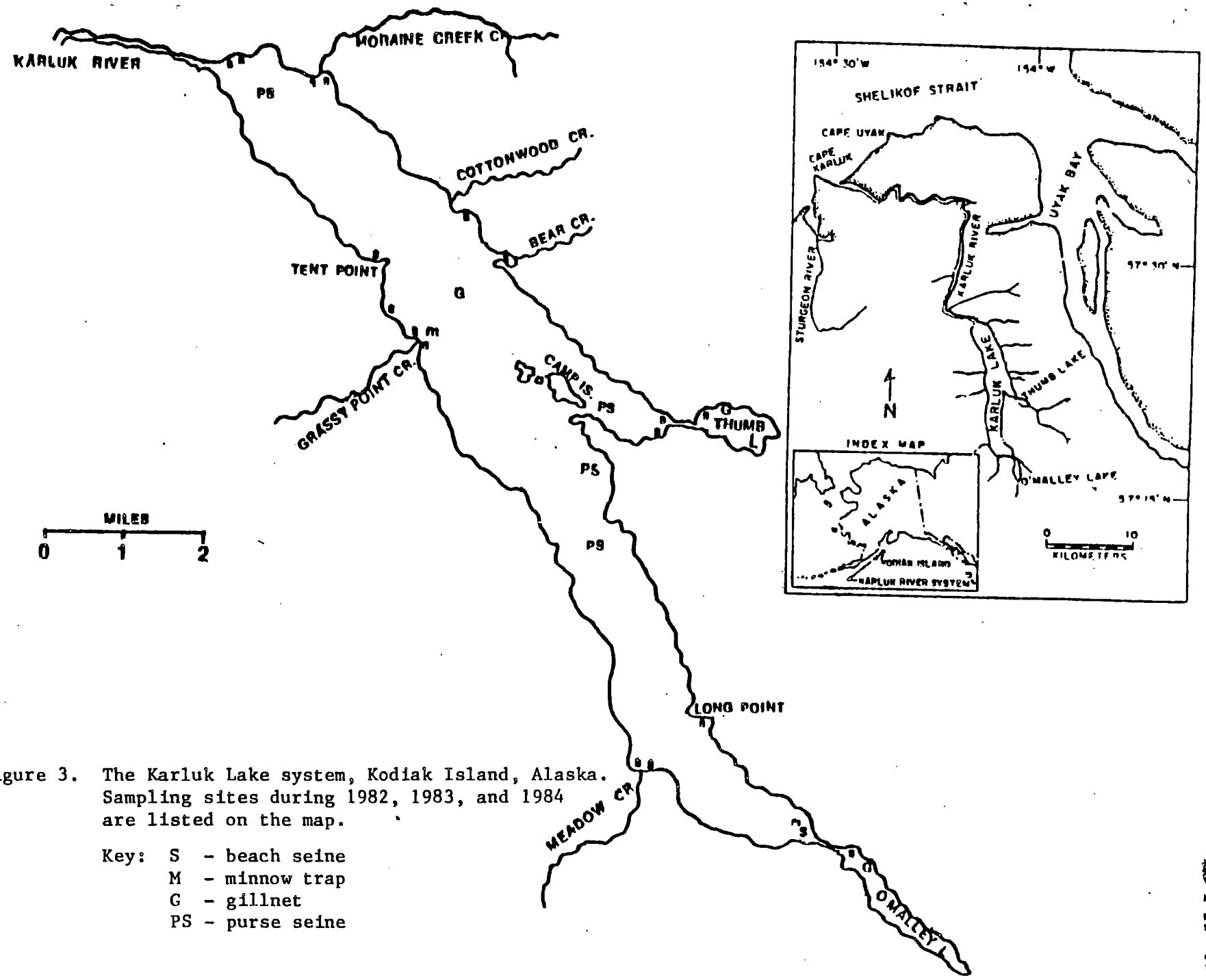

Figure 3. The Karluk Lake system, Kodiak Island, Alaska. Sampling sites during 1982, 1983, and 1984 are listed on the map.

Key: S - beach seine
M - minnow trap
G - gillnet
PS - purse seine

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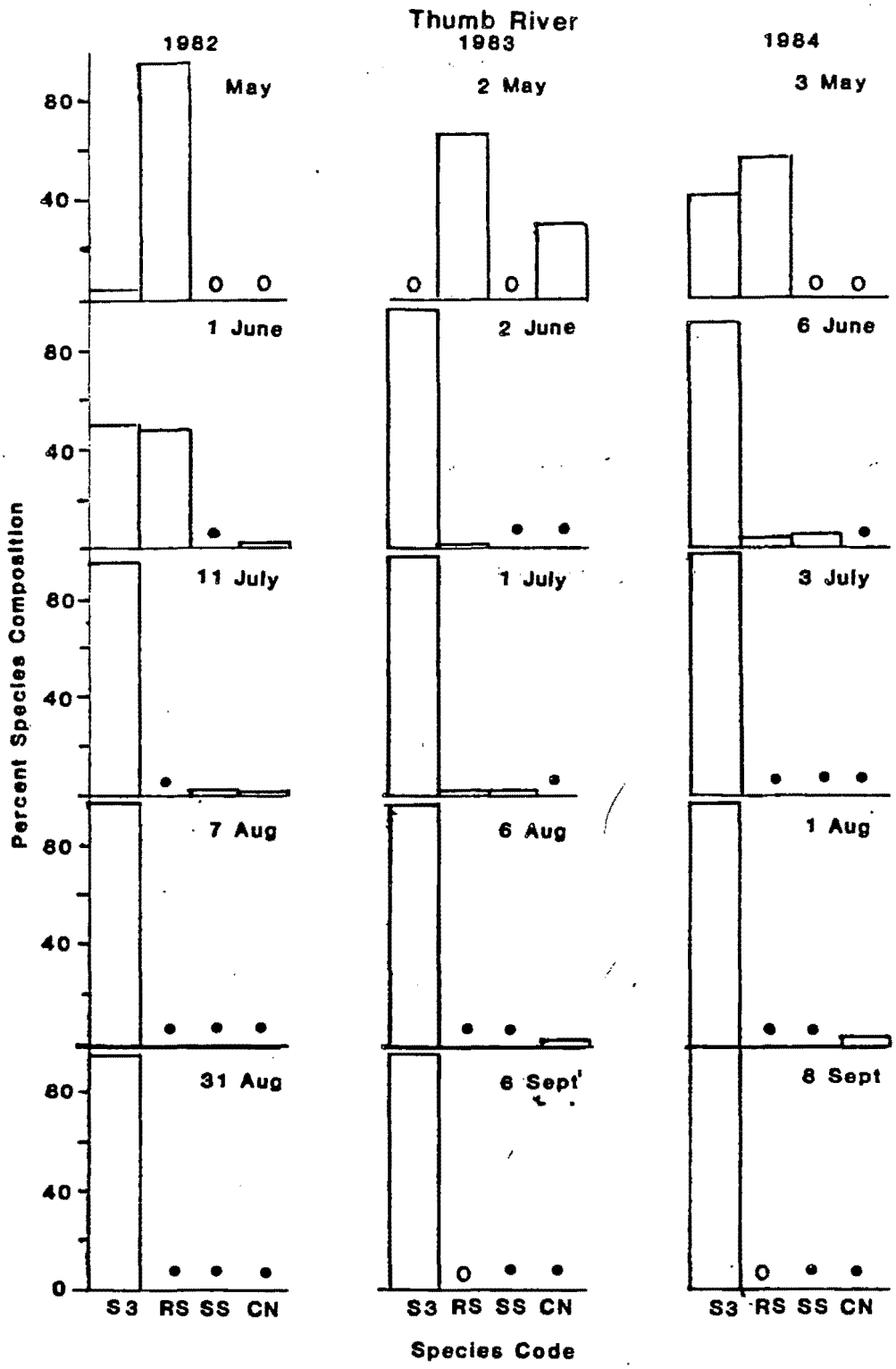

Figure 4. Percent species composition at the Thumb River beach seine site on selected dates during 1982, 1983, and 1984. S3 = threespine stickleback, RS = sockeye salmon fry, SS = juvenile coho salmon, CN = sculpin. o = no fish, ● = less than one percent.

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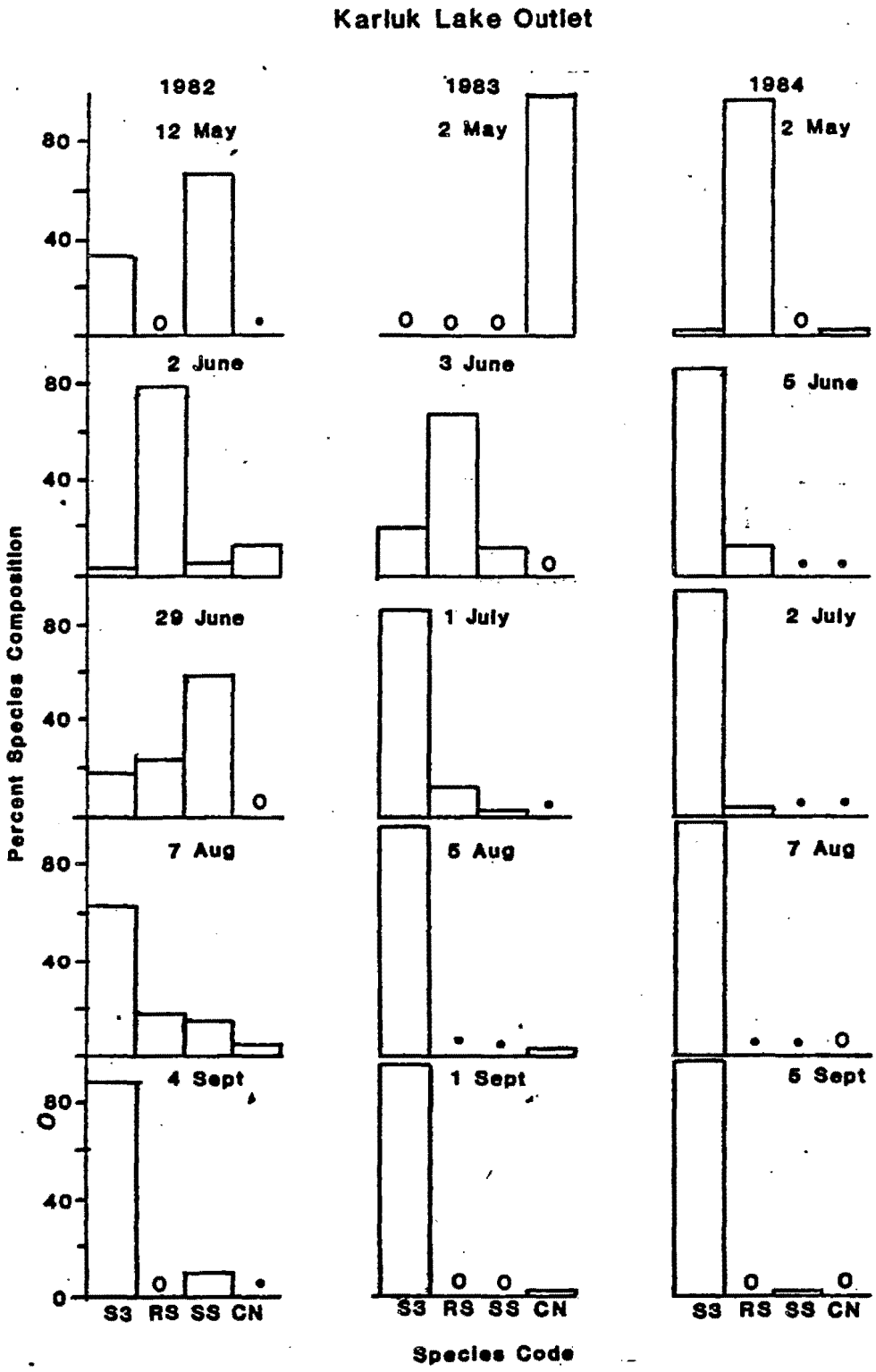

Figure 5. Percent species composition at the Karluk Lake outlet beach seine site on selected dates during 1982, 1983, and 1984. S3 = three-spined stickleback, RS = sockeye salmon fry, SS = juvenile coho salmon, CN = sculpin. o = no fish, • = less than one percent.

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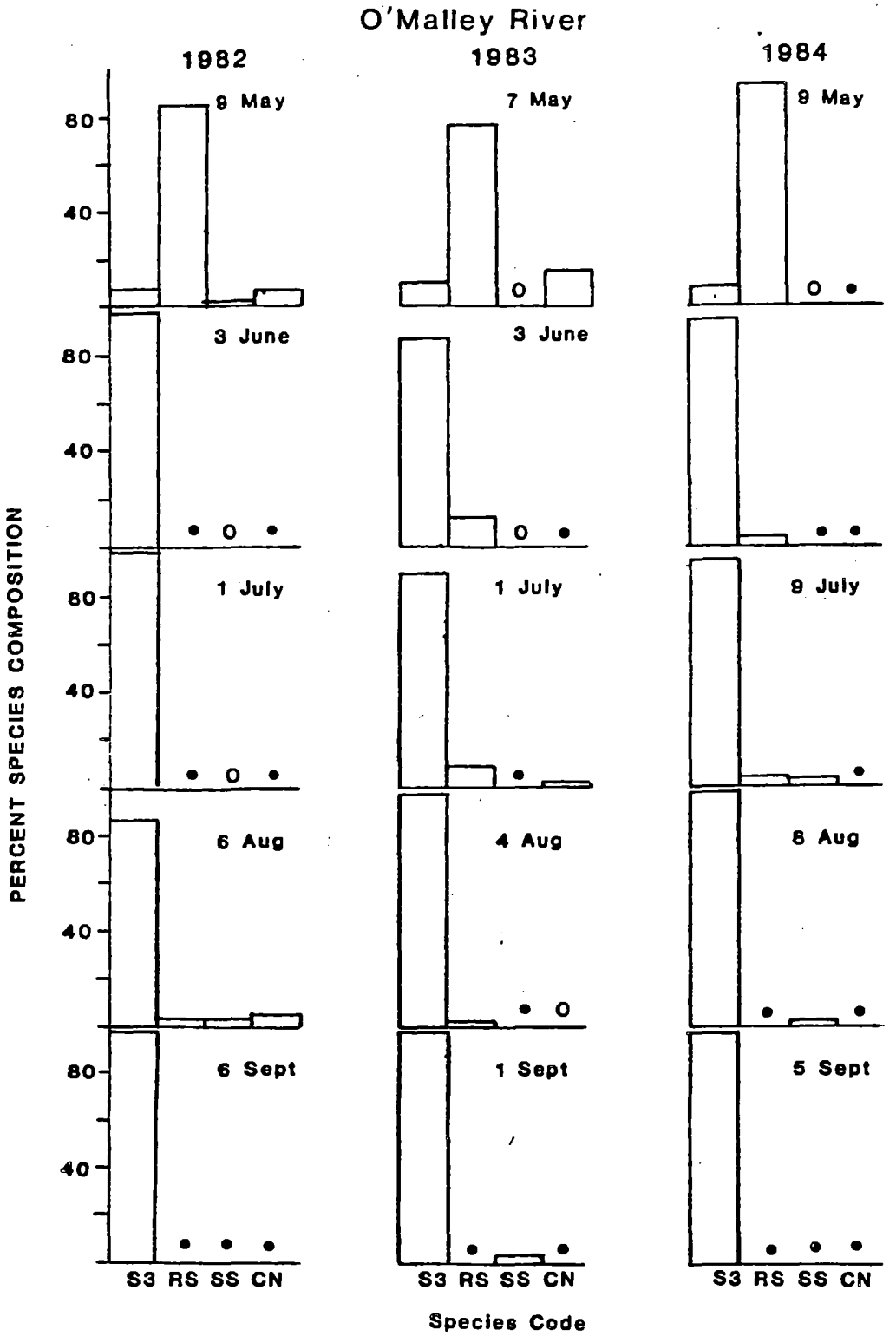

Figure 6. Percent species composition at the O'Malley River beach seine site on selected dates during 1982, 1983, and 1984. S3 = three-spined stickleback, RS = sockeye salmon fry, SS = juvenile coho salmon, CN = sculpin. o = no fish, ● = less than one percent.

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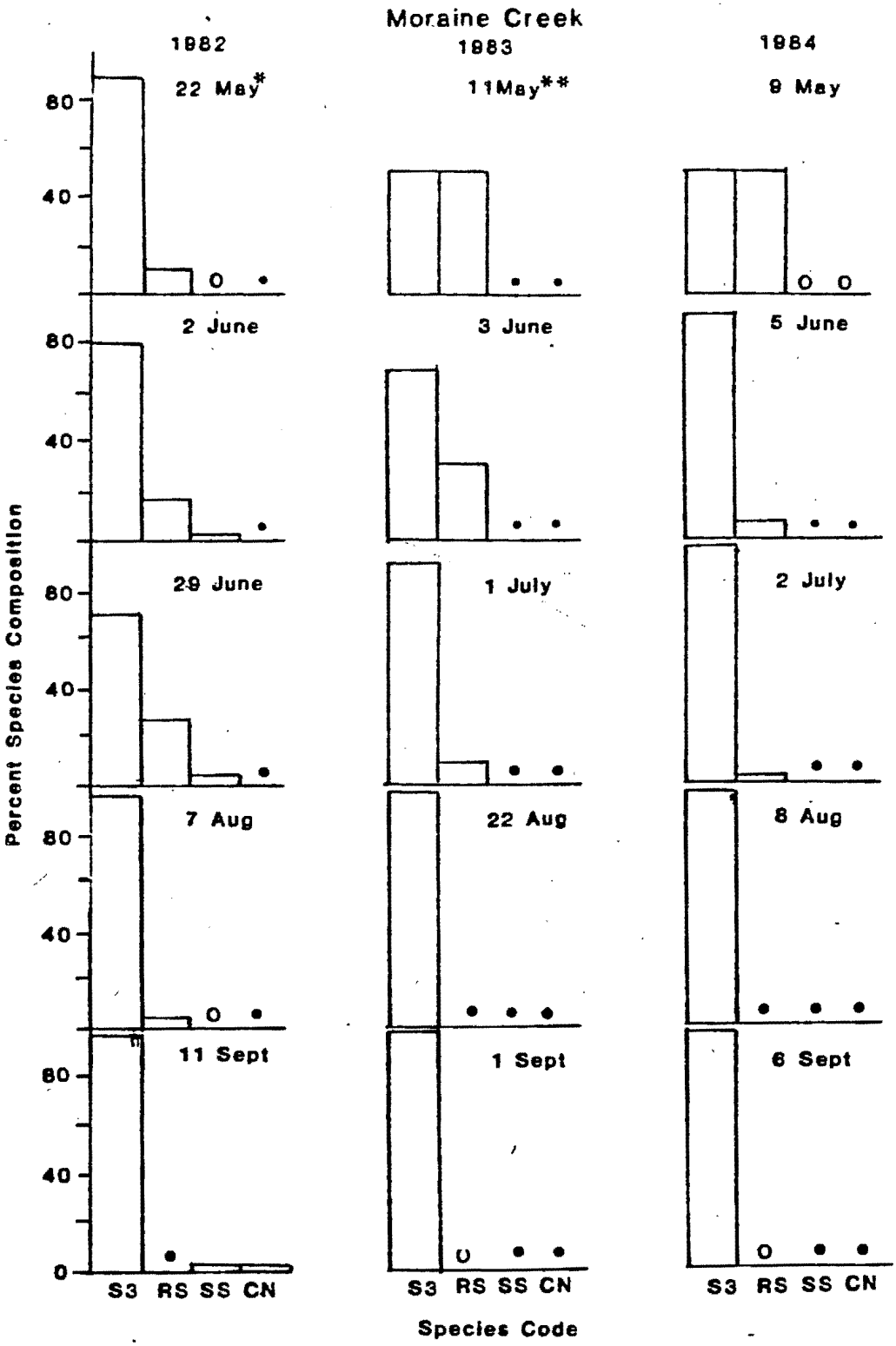

Figure 7. Percent species composition at the Moraine Creek beach seine site on selected dates during 1982, 1983, and 1984. S3 = threespined stickleback, RS = sockeye salmon fry, SS = juvenile coho salmon, CN = sculpin. o = no fish, ● = less than one percent. (*First 1982 sample date. **Based on 2 fish.)

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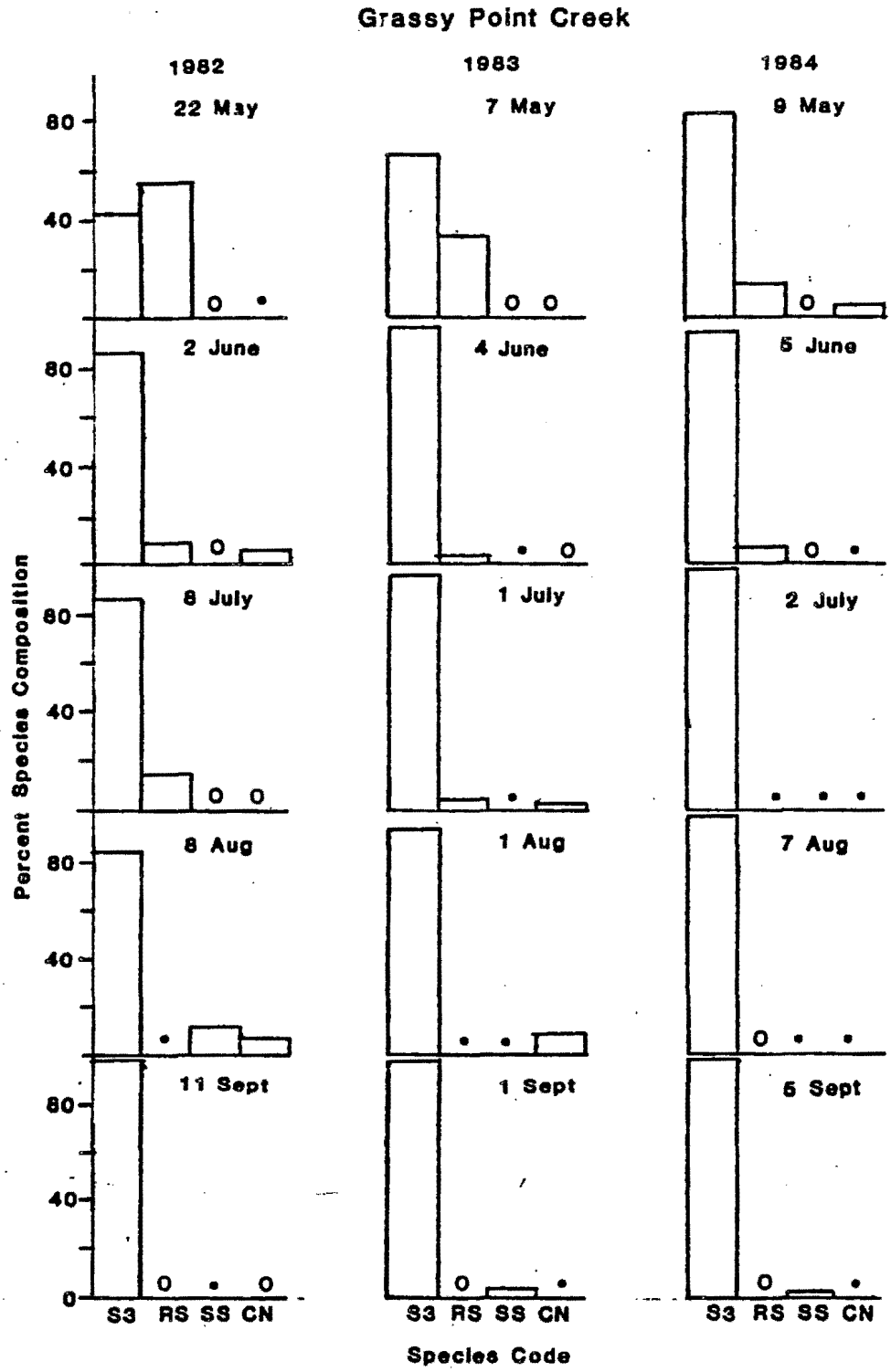

Figure 8. Percent species composition at the Grassy Point Creek beach seine site on selected dates during 1982, 1983, and 1984. S3 = three-spined stickleback, RS = sockeye salmon fry, SS = juvenile coho salmon, CN = sculpin. o = no fish, • = less than one percent. (* First 1982 sample date.)

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Table 6. Comparison of species composition in beach seine hauls at Karluk Lake for the period mid-June through September 1962, 1982, 1983, and 1984.

	Percent Composition			
Species	1962*	1982	1983	1984
Three-spined Stickleback	93.5	95.6	95.4	98.3
Sockeye Salmon Fry	5.4	2.5	3.5	1.1
Coho Salmon Juveniles	1.0	1.2	0.6	0.4
Sculpin	Trace	0.7	0.4	0.2

* Gard and Drucker, 1963.

year sockeye comprised a large percentage of the catch each May, when seine hauls generally contained less than 500 fish. The first appearance of large numbers of sticklebacks occurred during early June 1982, and late May in 1983 and 1984 near the O'Malley and Thumb rivers. Massive schools of adults began to concentrate nearshore adjacent to the river mouths. We believe the sticklebacks were congregating in preparation for a spawning migration upstream and into O'Malley and Thumb lakes. Adult males were in spawning coloration and females were ripe with eggs. Unusually high catches of sexually mature adults were made in O'Malley Lake throughout June, while in July, large numbers of dead, spawned-out adults were found along the shoreline.

Sticklebacks were the dominant species in shoreline waters from July through October. The abundance of all species declined throughout the fall, and by mid-October generally less than 100 fish were caught per seine haul. Apparently, the colder water temperatures alongshore during spring and fall cause fish to move into deeper water.

The seasonal catch-per-effort (fish/seine haul) for young-of-the-year sockeye caught at 5 beach seining areas at Karluk Lake (1982-1984) is shown

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in Fig. 9. Sockeye fry abundance peaked in most areas during June. By early August, fry had moved offshore and were no longer present in beach seine hauls.

The unusually large peaks in stickleback catches, which occurred at the Thumb (June 1983 and 1984) and O'Malley (June 1982, 1983, and 1984) sites (Fig. 10), were due to the massive numbers of adults concentrated off the stream mouths prior to spawning migrations. Subsequent peaks were caused mostly by young-of-the-year sticklebacks.

Juvenile coho did not appear in beach seining catches until June each year (Fig. 11). Their later appearance in the littoral area shows that coho are spatially segregated from sockeye fry in May. Large coho catches were made near the lake outlet in June. These were likely a result of coho congregating near the Karluk River before their smolt outmigration to the ocean. Young-of-the-year coho first appeared alongshore in July, and late in the field season they constituted greater than 90% of the total coho catch. Thus, while coho juveniles do not appear to compete with sockeye fry for space, the stickleback concentrations suggest that this species may be acting in synergy with predators by outcompeting sockeye fry for food and space in littoral areas.

A modified Fyke net was fished in Karluk Lake from 12 July through 6 October 1984 to further investigate species composition and distribution. The Fyke net was a slightly modified version of the net described by Morton (1982). The frame at the mouth of the trap was 1.5 m^2 and the terminal frame, at the mouth of the cod end, was 1.0 m^2. From mouth to cod end the trap was about 5 m long. Two 12-m wings extended from the trap mouth, all of which was constructed with 12-mm stretched-measure netting. The Fyke net was fished without a lead line. Unlike the rigid frame described by Morton

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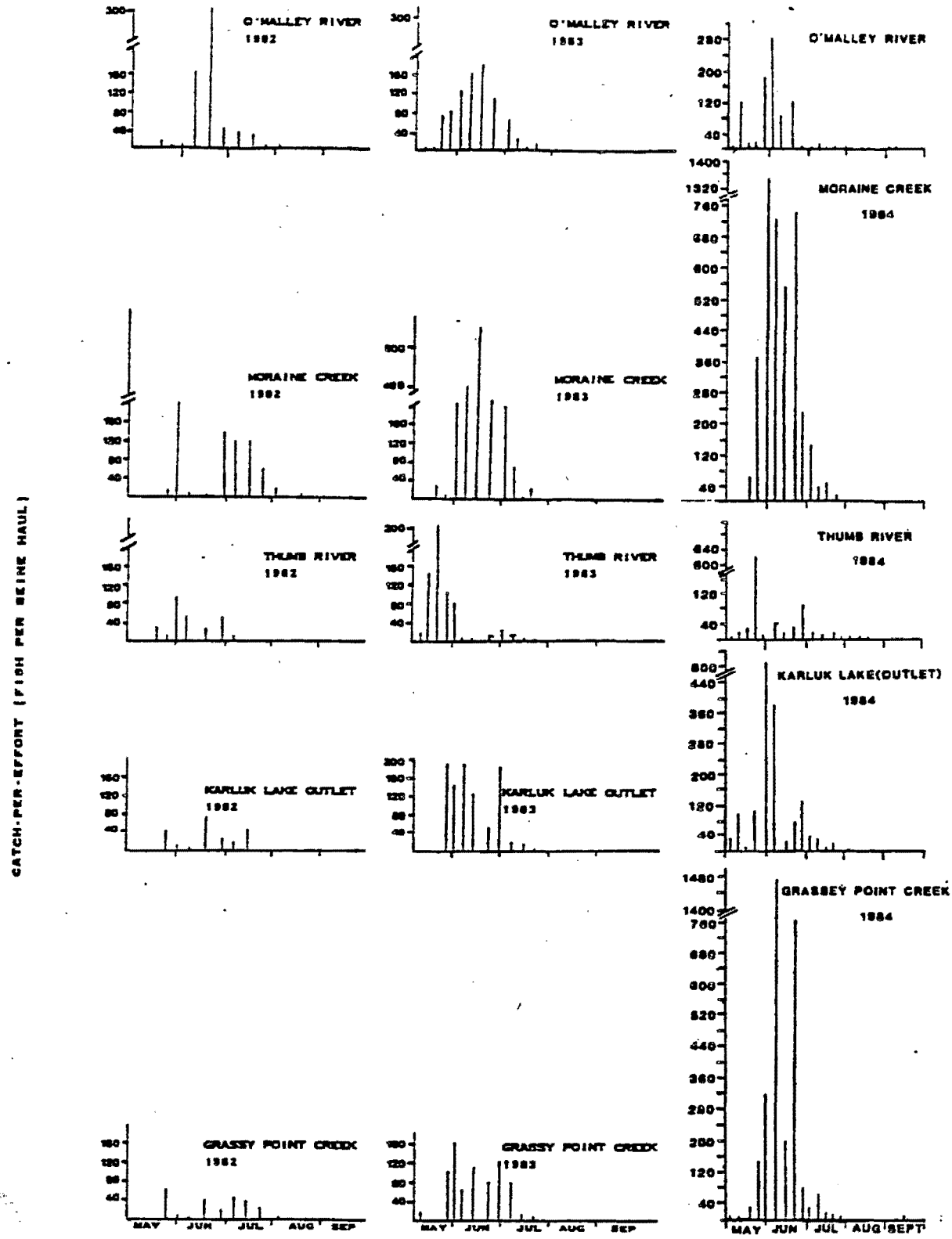

Figure 9. Seasonal (May-October) catch-per-unit-effort (fish per seine haul) of young-of-the-year sockeye salmon at five beach seine sites adjacent to Karluk Lake tributaries.

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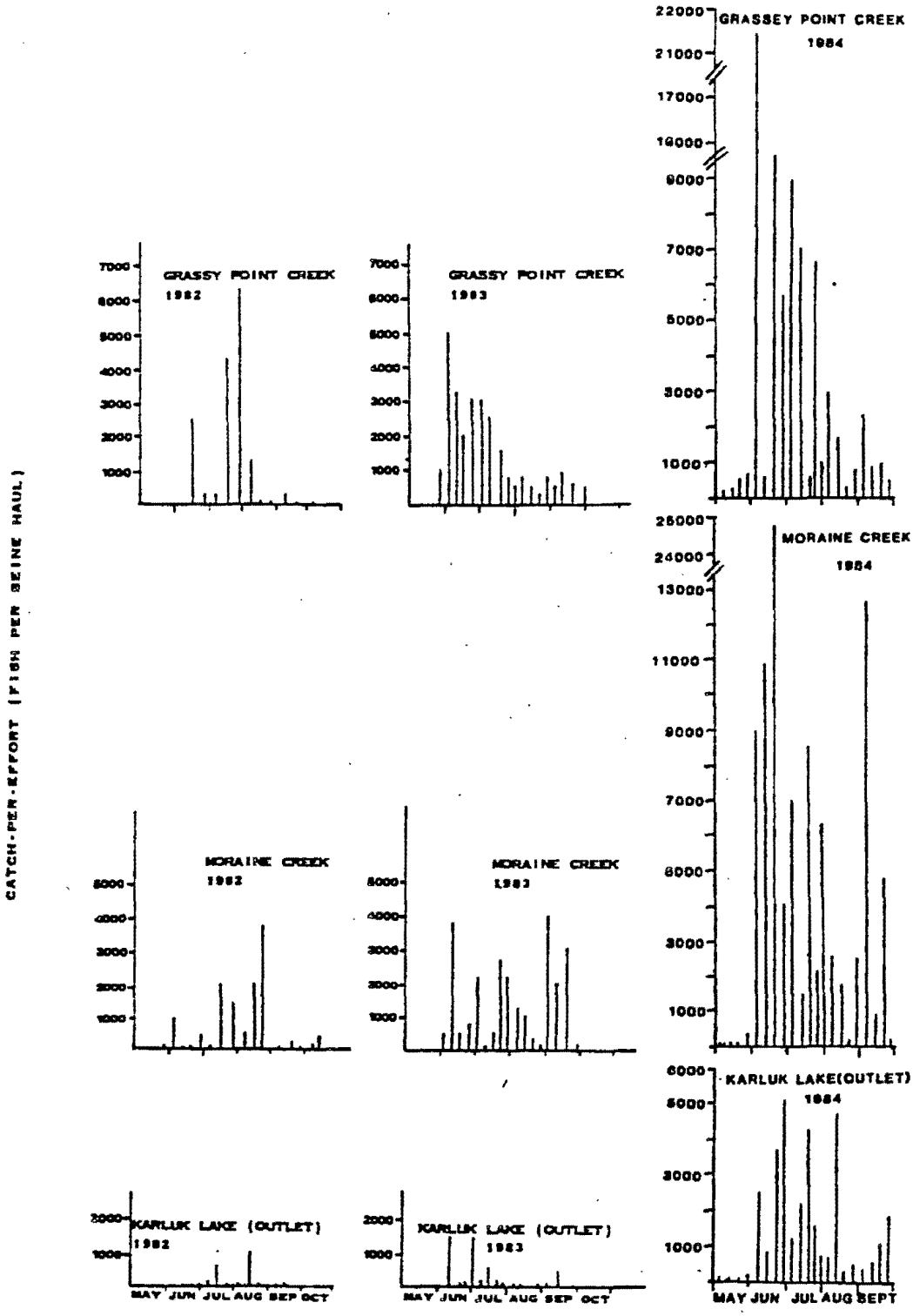

Figure 10. Seasonal (May-October) catch-per-unit-effort (fish per seine haul) of threespine sticklebacks at five beach seine sites adjacent to Karluk Lake tributaries.

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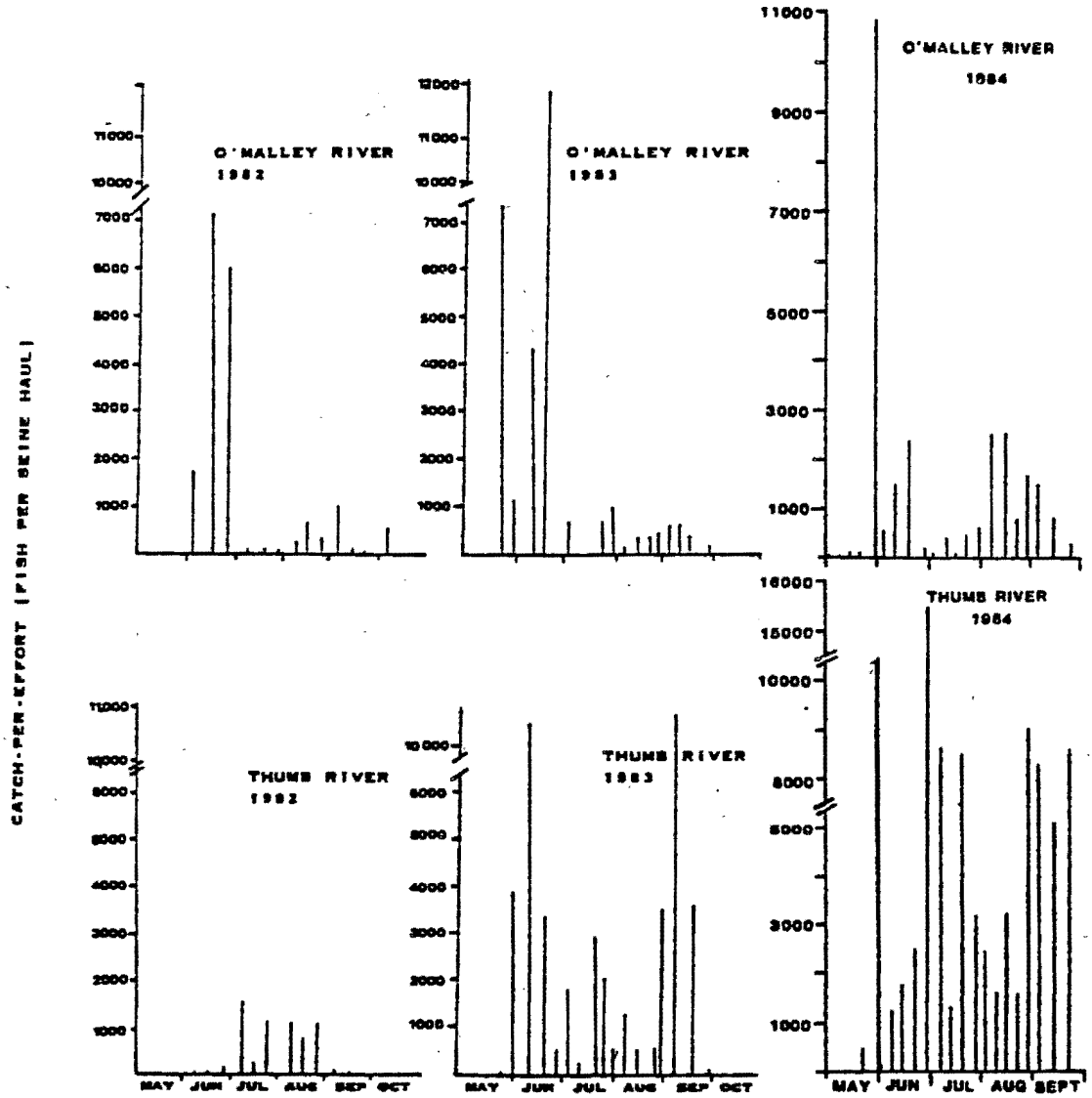

Figure 10. (Continued.) Seasonal (May-October) catch-per-unit-effort (fish per ceine haul) of threespine sticklebacks at five beach seine sites adnacent to Karluk Lake tributaries.

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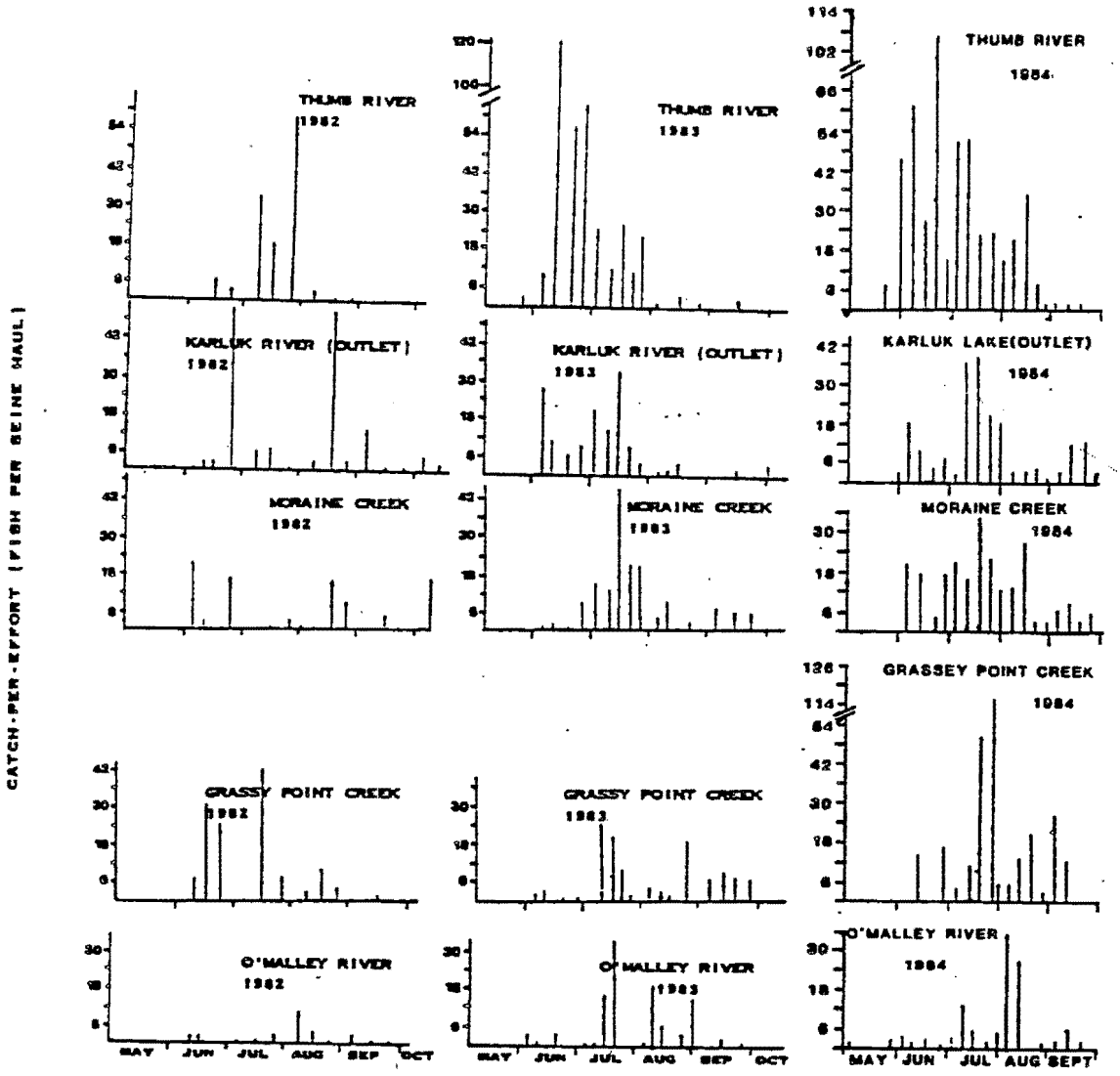

Figure 11. Seasonal (May-October) catch-per-unit-effort (fish per seine haul) of juvenile coho salmon at five beach seine sites adjacent to Karluk Lake tributaries.

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(1982), our Fyke net was collapsible. The trap portion of our net was held open by tension between an anchor at the cod end and anchors at the end of each wing.

The Fyke net was fished at 28 different sites (Fig. 12), at depths ranging from 2 to 24 m. With the exception of the first two sets, when the net was fished for 24 hr, the trap was fished for 48 hr at each site. Repeat sets were made at several sites. A total of 37 individual sets were made.

To date, the only reference we have seen to the 1941 Fyke net catches at Karluk Lake is a ratio of other species per sockeye salmon fry. We compare 1984 data in a ratio form to the 1941 data from Morton (1982) in Table 7.

Table 7. Species ratio (catch per one sockeye fry) for 1984 and 1941 Fyke net catches in Karluk Lake. 1941 data adapted from Morton (1982).

	Stickleback	Juvenile sockeye	Juvenile coho	Dolly Varden/ Arctic char	Sculpin	Rainbow trout
Species Ratio 1984	2840	1	297	54	66	0.5
Species Ratio 1941	1055	1	23	32	1	0

The numbers of other species per one sockeye were much greater in 1984 catches as compared to 1941 data. The number of threespine stickleback is about 2.7 times greater, juvenile coho about 13 times greater, and the number of sculpins 66 times greater. Initial comparisons indicate that the abundance, relative to sockeye fry, of potential competitors (stickleback) and predators (Dolly Varden/Arctic char and juvenile coho) may be much higher than during 1941. However, further analysis and more specific

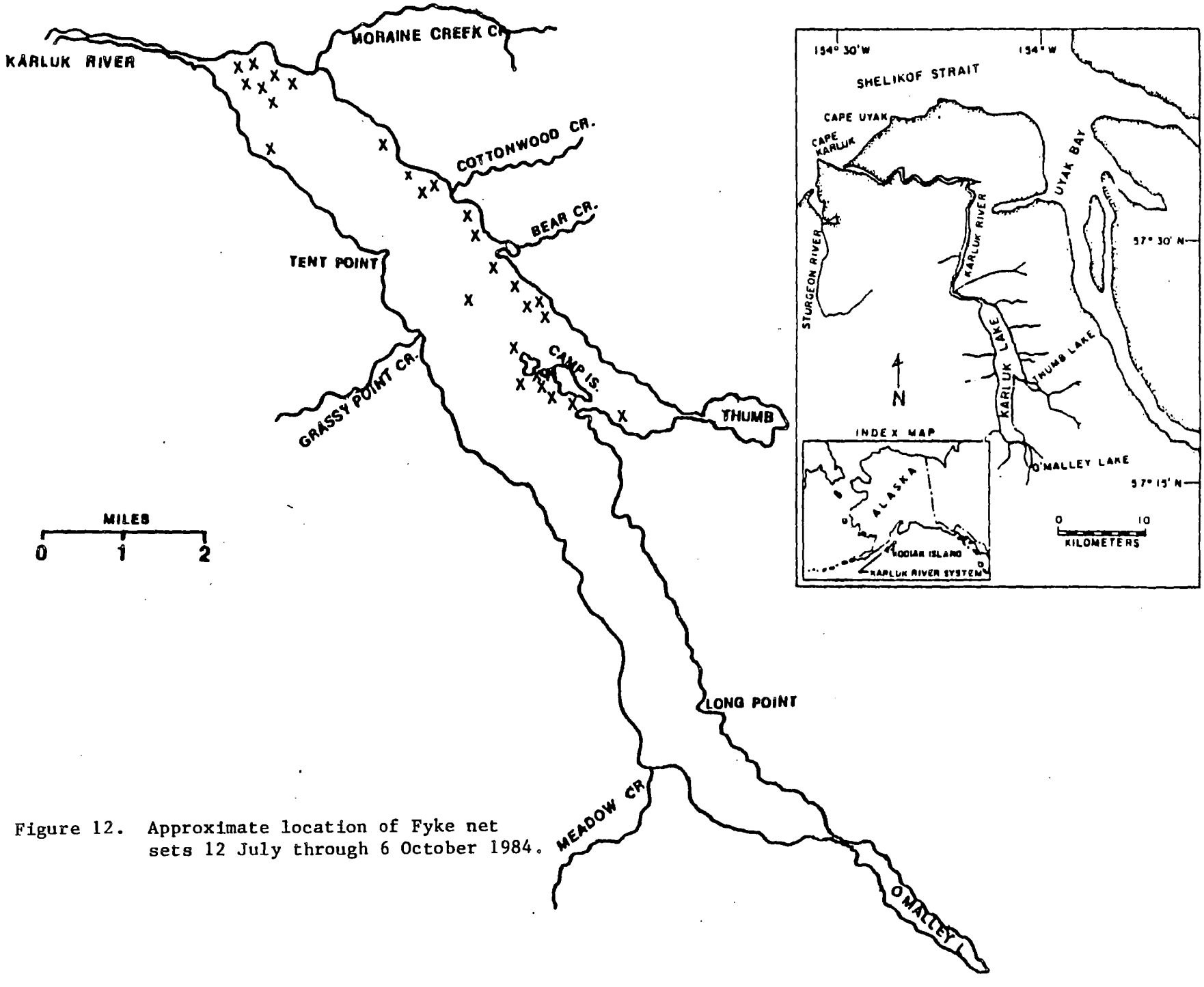

Figure 12. Approximate location of Fyke net sets 12 July through 6 October 1984.

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Table 8. Percent species composition of Fyke net catches by month, Karluk Lake, 1984.

Month	Stickleback	Juvenile sockeye	Juvenile coho	Dolly Varden/ Arctic char	Sculpin	Rainbow trout
July	97	<1	1	1	<1	<1
August	66	<1	28	1	5	<1
September/ October	22	<1	55	16	6	<1

information on the 1941 catches are needed.

Species composition of 1984 Fyke net catches apparently changed over time. Sticklebacks were dominant in July catches, and juvenile coho were dominant in September-October catches (Table 8).

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PART II

KARLUK LAKE SMOLT OUTMIGRATION - 1984

Introduction

In conjunction with the cooperative work agreement between ADF&G (FRED) and USFWS (Region 7) for the rehabilitation of Karluk Lake sockeye salmon, we operated a smolt trap on the Karluk River during the 1984 field season. Karluk sockeye smolt have been monitored by a number of investigators since 1925 (Barnaby 1944, Gard and Drucker 1962-1968, White 1980-1983, and Chatto 1984). Data on the age composition, condition of smolts, and smolts per spawner are important to NFRC's evaluation of the freshwater production of Karluk Lake sockeye salmon, and to the FRED rehabilitation program at Karluk Lake.

Materials and Methods

Smolt Trap

A Canadian fan trap was used to capture sockeye salmon smolts for mark and recapture and for age, length, and weight data. The trap was located in Karluk River about 0.75 km downstream from Karluk Lake. The trap consisted of a dewatering funnel and two perforated plate wings. The left (facing upstream) wing extended to within 4 m of the east bank of the river. The distance between the upstream ends of the wings was 15 m (about one-third of the river width). The terminal (downstream) end of the funnel was modified

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to alleviate turbulence and backwash problems noted by Chatto (1984). The conical hose coupling was removed from the funnel and a 1.2 m-wide by 1.8 m-long x 0.6 m-deep holding box was attached directly to the funnel. By adjusting the height of the end of the funnel, an 8 to 10-cm water drop between the funnel and the holding box was maintained. This type of modification has been used successfully on the Kasilof River, Alaska (Dave Waite ADF&G, pers. comm.).

Mark and Recapture

The trap was fished for 24 hr periods each day (1200 hr to 1200 hr) from 15 May through 2 July 1984. Each morning smolts were removed from the trap holding box, examined for brands and a subsample (15-30 smolts) was taken for age, length, and weight data. Liquid nitrogen freeze branding was used to mark fish. Prior to branding, smolts were anesthetized (MS-222). Two brand characters (T and V) were used. Each character was rotated to four different positions (e.g. T, , ,), thus creating eight distinct brands. Smolts were branded on the right side anterior to the insertion of the dorsal fin above the lateral line. Branded smolts were carried upstream of the trap, to about 50 m from the river's origin and placed in a holding pen. Branded smolts were released into the river at 2330 hr. In this way, smolts that were migrating the previous night were branded and reintroduced into the current night's' smolt outmigration as a test of trap efficiency.

Two methods were used to estimate daily smolt populations. The first method used daily trap efficiency. For example, if 100 marked smolts were released and a total of 10 recaptured, then the trap efficiency for the day the smolts were released would be 10 percent. The daily smolt population estimate would equal the number of unmarked smolt captured/0.10. The second

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method used a moving average of trap efficiency. That is, trap efficiency was averaged over five sample days (three days prior to the estimate day through one day after the estimate day). For example, the daily trap efficiencies for 3 through 7 June were 0.015, 0.023, 0.039, 0.022, and 0.039 respectively, thus the moving average trap efficiency for 6 June equals (0.015 + 0.023 + 0.039 + 0.022 + 0.039)/5. At this time it is felt that the moving average trap efficiency may be more realistic than daily trap efficiency (Kit Rawson pers. comm.).

Results

Smolt Estimates

Preliminary estimates of 1984 sockeye smolt outmigrations have been made by Kit Rawson (ADF&G). Analysis has not been completed and it is felt that at least one more year of data is necessary before confidence intervals are placed around the estimates.

Trap efficiency (daily and moving average) was used to expand actual smolt trap catches to daily smolt outmigration estimates (Table 1). Total smolt outmigration estimates are the sum of daily estimates. The total daily population estimate was about 1.13 million and the total moving average population estimate was about 1.07 million. The timing of the smolt outmigration in 1984 was similar to 1983 (Fig. 1A and 1B). Three peak migrations on 21, 24, and 30 May 1984, accounted for 55.7 percent of the total estimated smolt population.

Age Composition

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Table 1. Karluk sockeye salmon smolt population estimates 15 May through 2 July 1984. Estimates supplied by Kit Rawson ADF&G.

Date	Percent daily trap efficiency	Moving average percent trap efficiency	Unmarked fish caught	Daily population estimate	Moving average population estimate
15 MAY	--	3.7	112	112	3,024
16 MAY	0.0	2.5	5	5	203
17 MAY	7.4	1.9	4	54	216
18 MAY	0.0	1.5	23	23	1,553
19 MAY	0.0	1.7	221	221	13,280
20 MAY	0.0	0.2	30	30	16,425
21 MAY	0.9	0.6	370	40,515	65,508
22 MAY	0.0	1.6	213	213	13,078
23 MAY	1.9	2.0	377	19,730	19,151
24 MAY	5.3	1.9	1,449	27,241	77,873
25 MAY	1.7	2.6	676	39,771	25,811
26 MAY	0.4	2.4	734	196,272	30,117
27 MAY	3.8	1.8	463	12,212	25,739
28 MAY	1.0	2.0	97	9,686	4,869
29 MAY	2.1	2.6	1,211	56,917	46,686
30 MAY	2.7	2.1	9,700	363,750	454,512
31 MAY	3.4	3.1	367	10,850	11,673
01 JUN	1.5	3.0	998	66,866	32,930
02 JUN	6.1	2.8	570	9,420	20,307
03 JUN	1.6	2.6	197	12,621	7,582
04 JUN	1.5	3.1	514	33,217	16,694
05 JUN	2.3	2.3	472	20,178	20,453
06 JUN	3.9	2.8	384	9,856	13,866
07 JUN	2.2	3.4	415	18,906	12,189
08 JUN	3.9	5.4	110	2,843	2,034
09 JUN	4.7	5.0	197	4,170	3,936
10 JUN	12.4	5.2	152	1,230	2,920
11 JUN	1.9	5.3	305	16,267	5,746
12 JUN	3.2	6.3	1,284	40,125	20,277
13 JUN	4.4	7.0	635	14,490	9,134
14 JUN	9.8	7.3	109	1,107	1,500
15 JUN	15.5	7.5	1,408	9,109	18,883
16 JUN	3.4	8.4	393	11,397	4,654
17 JUN	4.2	6.6	153	3,687	2,307
18 JUN	9.3	4.1	141	1,513	3,466
19 JUN	0.8	3.8	356	45,212	9,281
20 JUN	2.6	3.6	130	4,940	3,599
21 JUN	2.3	1.7	82	3,585	4,693
22 JUN	3.0	2.5	522	17,226	20,984
23 JUN	0.0	2.1	362	362	16,860
24 JUN	4.5	3.8	237	5,280	6,195
25 JUN	0.9	3.2	17	1,830	528
26 JUN	10.7	4.0	4	37	99
27 JUN	0.0	4.0	19	19	475
28 JUN	0.0	4.0	30	30	750
29 JUN	0.0	4.0	29	29	725
30 JUN	0.0	4.0	21	21	525
01 JUL	0.0	4.0	16	16	400
02 JUL	0.0	4.0	16	16	400
Total	3.7	--	26,330	1,133,205	1,074,109

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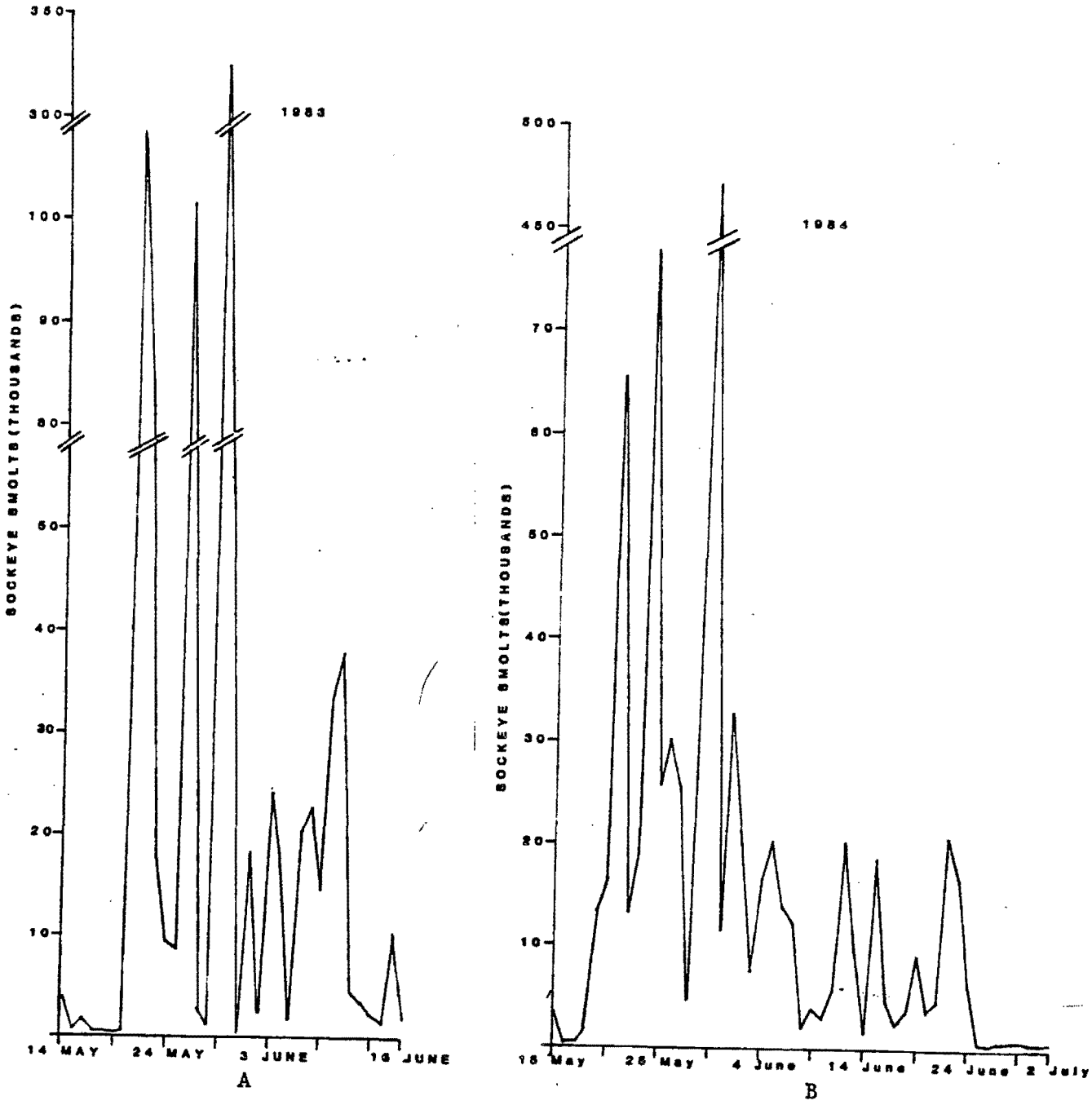

Figure 1. Estimated daily smolt outmigrations (in thousands) from Karluk Lake 1983 and 1984. 1983 data adapted from Chatto (1984).

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Scales from a total of 898 sockeye smolts were collected and aged (data supplied by Lorne White ADF&G), and verified by NFRC. The age composition of the scale-sampled smolts was 18.4% age 1+, 74.6% age 2+, and 7.5% age 3+. Age data were pooled over five-day periods to estimate the daily age composition of estimated smolt populations. The estimated age composition was 7.7% age 1+, 83.4% age 2+, and 8.9% age 3+. The age composition of 1984 smolts was comparable with previous years (Table 2). There were apparent shifts in the age composition of migrating smolt over the sample period (Fig. 2). Age 3+ smolt were present during the early portion of the smolt outmigration but were absent after mid-June. In comparison, age 1+ smolt did not appear until late May and persisted until 2 July. This apparent timing difference was not evident during 1983.

Table 2. Age composition of Karluk Lake sockeye salmon smolts by numbers (N = thousands) and percentages. Data for 1980-1983 are from Chatto (1984).

	1980		1981		1982		1983		1984	
Age	N	%	N	%	N	%	N	%	N	%
3+	131.2	7.8	260.9	12.8	108.4	13.2	118.6	12.6	82.9	7.7
2+	1061.0	62.9	1561.0	76.4	698.8	85.1	809.7	86.0	895.9	83.4
1+	495.0	29.3	220.0	10.8	14.0	1.7	13.2	1.4	95.2	8.9
Total	1687.2	--	2041.9	--	821.2	--	941.5	--	1074.1	--

Length, Weight, and Condition Factors

The mean length of age 1+, 2+, and 3+ smolts migrating from Karluk Lake in 1984 were 107.6 mm, 116.7 mm, and 130.1 mm, respectively. Mean weights were 11.5 g, 14.0 g, and 19.3 g, respectively and condition factors were

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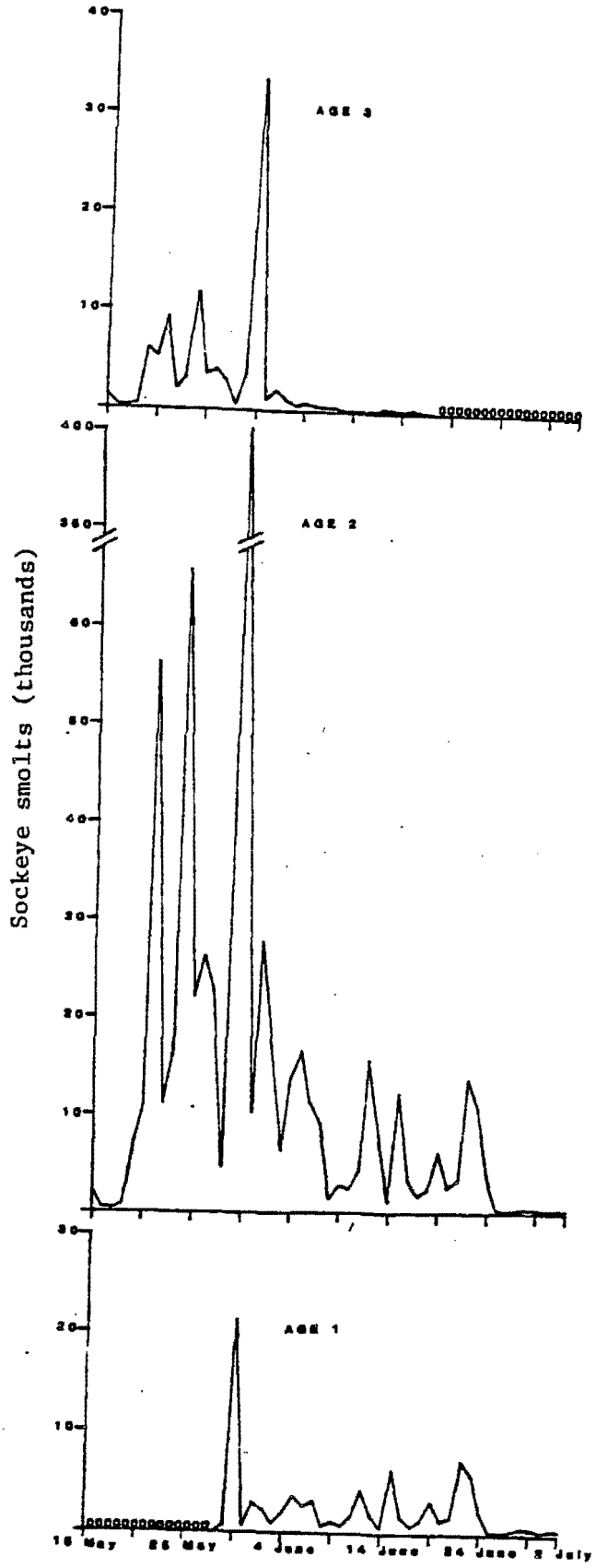

Figure 2. Estimated daily sockeye smolt outmigrations (in thousands) of age 1, age 2, and age 3 fish in the Karluk River, 1984. 0 = no fish.

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0.923, 0.883, and 0.876, respectively. Comparison with age 2+ and 3+ smolts from previous years are shown in Table 3. Data for 1925 to 1940 are from Barnaby (1944), 1961 to 1968 are from the BCF reports on Karluk Lake, 1980 to 1982 from Lorne White (ADF&G), and 1983 from Chatto (1984). Mean lengths and weights for the three time periods appear to have declined

Table 3. Mean lengths, weights, and condition factors for age 2+ and 3+ sockeye salmon smolts migrating from Karluk Lake during 1925-1940, 1961-1968, and 1980-1984.

	Mean length (cm)		Mean weight (g)		Condition factor	
Year	2+	3+	2+	3+	2+	3+
1925	135.6	145.9	22.8	28.5	0.914	0.918
1926	135.8	145.9	22.9	28.5	0.914	0.918
1927	132.6	143.4	21.2	27.3	0.909	0.926
1928	129.8	145.7	19.9	28.4	0.910	0.918
1929	130.1	140.1	20.0	25.2	0.908	0.916
1930	126.7	139.7	18.5	25.0	0.910	0.917
1931	129.9	142.9	20.0	26.8	0.912	0.918
1932	131.8	147.2	20.9	29.5	0.913	0.925
1933	137.7	147.8	23.9	29.6	0.915	0.917
1934	138.9	153.7	24.8	33.3	0.925	0.917
1935	142.0	142.6	26.3	26.6	0.919	0.917
1936	132.7	125.8	21.3	18.2	0.912	0.914
1937	119.5	130.2	15.5	20.1	0.908	0.911
1938	120.2	142.9	15.7	26.8	0.904	0.918
1939	128.7	142.1	19.4	26.4	0.910	0.920
1940	131.8	138.3	21.0	24.3	0.917	0.919
Average	131.5	142.1	20.9	26.5	0.913	0.918
1961	114.8	123.5	13.7	16.5	0.907	0.876
1962	112.5	123.1	12.3	15.3	0.861	0.820
1963	118.7	128.6	14.6	18.5	0.873	0.870
1964	127.7	135.7	21.0	24.1	1.008	0.964
1965	126.6	142.4	19.1	26.7	0.941	0.925
1966	115.4	130.9	13.2	18.9	0.859	0.843
1967	112.8	133.1	13.8	23.1	0.962	0.980
1968	113.0	123.5	12.4	15.3	0.859	0.812
Average	117.7	130.1	15.0	19.8	0.909	0.886
1980	102.8	112.5	9.4	11.4	0.865	0.801
1981	111.4	119.7	13.4	18.0	0.969	1.049
1982	119.0	132.0	15.1	20.2	0.896	0.878
1983	116.7	132.0	12.2	18.6	0.765	0.809
1984	116.7	130.1	14.0	19.3	0.883	0.876
Average	113.3	125.3	12.8	17.5	0.876	0.883

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substantially - 131.5 cm to 113.3 cm and 20.9 g to 12.8 g for age 2+ smolts; and 142.1 cm to 125.3 cm and 26.5 g to 17.5 g for age 3+ smolts. An ANOVA was performed on the lengths, weights, and condition factors for the three time periods (Table 4) and statistically significant differences for lengths and weights between the time periods (P>0.99) were detected. There was no statistically significant difference between condition factors.

Linear regression was performed on the log ($\ln_x$) of the number of

Table 4. Analysis of variance of lengths, weights, and condition factors of Karluk Lake sockeye salmon smolts over three time periods, 1925-1940, 1961-1968, and 1980-1984.

Source of variation	SS	df	MS	F
	2+ Mean lengths			
Between groups	1777.38	2	888.69	23.38***
Within groups	988.07	26	38.00	P>0.99
Total	2765.45	28		
	3+ Mean lengths			
Between groups	1457.67	2	728.83	14.48***
Within groups	1308.27	26	50.32	P>0.99
Total	2765.94	28		
	2+ Mean weights			
Between groups	337.92	2	168.96	19.93***
Within groups	220.46	26	8.48	P>0.99
Total	558.38	28		
	3+ Mean weights			
Between groups	432.29	2	216.14	14.95***
Within groups	375.99	26	14.46	P>0.99
Total	808.28	28		
	2+ Condition factors			
Between groups	0.005	2	0.003	1.57
Within groups	0.044	26	0.002	P=0.77
Total	0.049	28		
	3+ Condition factors			
Between groups	0.008	2	0.004	1.51
Within groups	0.068	26	0.003	P=0.76
Total	0.076	28		

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parents versus the log ($\ln_x$) of the number of smolts produced per spawner (Fig. 3) for the period 1923 to 1937, and for 1958-1962 and 1978-1980. As expected, an inverse, density-dependent relationship is shown for both time periods. The relationship for the later years indicates a decrease in the production of smolts per spawner.

Discussion

We believe the present procedure for estimating the number of sockeye salmon smolt migrating from Karluk Lake is practical. The freeze branding technique allowed us to mark a large number of smolts, and this brand may be visable on returning adult spawners. NFRC and ADF&G will be monitoring for these brands over the next few years. (The brand will be changed next year so that unique yearly marks are maintained.)

The number of smolts estimated to be migrating from the lake as determined by sonar counting (ADF&G 1980, 1981, and 1982), by Chatto in 1983, and by NFRC in 1984 are remarkably similar. If these counts are accurate, the survival from smolt to returning adult at Karluk Lake is extremely high (25 to >50%). The decline in the number of smolts produced per spawner (Fig. 3) would appear to confirm the cause of the decline of the Karluk sockeye salmon run will be found in the freshwater residency of juveniles. The presence of large numbers of age 1+ smolts in the 1984 outmigration indicates a productive growing season in 1983. While Barnaby (1944) reported 1+ smolts comprised about 5% of the outmigration in the years 1925 to 1940, they have appeared only sporadically since then.

The apparent decrease in mean lengths and weights of age 2+ and 3+

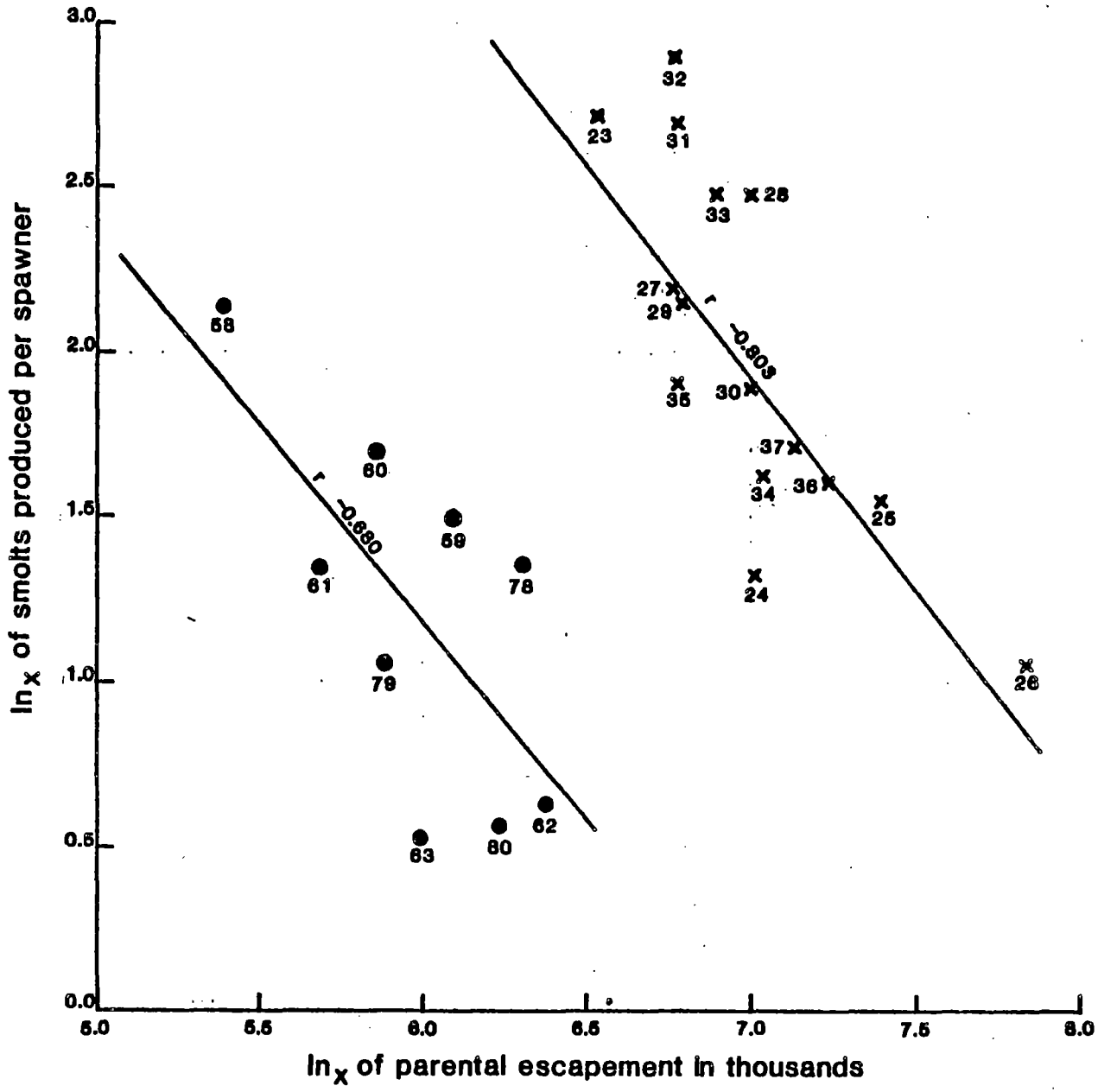

Figure 3. Relationship between parental escapement and the smolts produced per spawner at Karluk Lake; 1923-1937 (x), and 1958-1962, 1978-1980 (●). Numbers refer to parent year.

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smolts from the early years could indicate a decrease in lake fertility and/or increased competition with threespine stickleback for food and space. Stomach content analysis of tow-net caught sockeye juveniles and threespine stickleback in Karluk Lake this year showed the two species eating the same zooplanktors (ADF&G). The stickleback, however, were eating a distinctively smaller size class of zooplanktors, and thus, the stickleback are possibly "cropping out" the zooplankters before they reach a size preferred by juvenile sockeye.

The findings above suggest three important questions: 1) is production of plankton at a low level because of decreased lake fertility, or 2) have the number of competitors increased dramatically, and 3) at what stage is the juvenile sockeye most affected by the lack of sufficient food? ADF&G is considering fertilization of Thumb Arm of Karluk Lake, believing an increase in productivity will increase zooplankton populations enough to stimulate sockeye growth. An inherent danger, however, is that the stickleback population, given their faster reproductive rate, may also be stimulated, thus magnifying the problem. An assumption by ADF&G may be that food is a limiting factor throughout the sockeye freshwater phase. While it is true that the length and weights of age 2+ and 3+ smolts have dropped significantly from the 1920's and 1930's, the condition factor has not. In addition, the percent gain in length and weight from 2+ to 3+ fish has shown an increase in comparison with the early years (9% in the 1920's and 1930's versus 13% in the later years for length, and 32% versus 45% for weight). This suggests that the limiting time period occurs in the first year, possibly while the sockeye are still in the littoral zone, and that conditions improve once they enter the pelagic zone. Such findings are consistent with a competition hypothesis since it is in the littoral zone that young-

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of-the-year sockeye are sympatric with threespine sticklebacks.

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