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Limnological and Fisheries Evidence
For Rearing Limitation of
Sockeye Salmon, *Oncorhynchus nerka*,
Production From Packers Lake,
Cook Inlet Alaska (1973-1983)

by

J. P. Koenings, Ph.D.
Gary B. Kyle
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Number 56

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TABLE OF CONTENTS

(Part I)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

ABSTRACT

In order to apply the appropriate sockeye salmon, *Oncorhynchus nerka*, enhancement strategy at Packers Lake, an assessment was made of the fisheries and limnological conditions that determine successful rearing of juveniles to smolt. We utilized a two-tier approach that specifically covers fishery ecology (Part I) as one tier and limnetic production patterns (Part II) as the second.

An initial (1972-1976) sockeye enhancement program centering on eliminating the competition for forage between limnetic-rearing sockeye juveniles and three- and nine-spine sticklebacks, *Gasterosteus aculeatus* and *Pungitus pungitius*, respectively, by rotenone treatment was largely unsuccessful. However, the experiment did reveal a positive response of the cladoceran zooplankters to decreased fry-predation pressure. Consequently, following stocking a high fry-to-age-1.0 smolt survival of 74% occurred because of this vastly improved forage base.

Our recent investigations (1980-1982) revealed that sockeye smolts are now predominently age 2.0 (38%-95%) and returning adults are age 2.2 (37% to 74%). Estimates of outmigrating smolts equalled 310,130 in 1981 and 486,000 in 1982; however, the 1981 count does not include a significant number of the earlier migrating, age-2.0 component. Adult returns equalled 16,500, 13,024, and 15,826 fish in 1980, 1981, and 1982, respectively.

Packers Lake is an oligotrophic-mesotrophic system that has total phosphorus levels in the 10 $\mu g\ L^{-1}$ to 20 $\mu g\ L^{-1}$ range. However, seasonal chlorophyll a levels were characteristic of phosphorus concentrations of only 4 $\mu g\ L^{-1}$ to 5 $\mu g\ L^{-1}$. We found that filterable phosphorus and iron within the lake was not in true solution but was held in colloidal suspension by the colloidal-sized organic stain. The presence of the organic stain may limit phosphorus availability to the phytoplankton and may further limit production by decreasing the volume of the trophogenic zone

through decreasing the light-compensation point. Finally, the zooplankton community of Packers Lake is dominated by copepods, particularly by the large-body-sized *Diaptomus*, which represented from 56% to 88% of the macro-zooplankters. In addition to being less numerous, cladoceran mean body sizes never exceeded 1.00 mm, while all three copepod species exceeded 1.00 mm in body size for much of the sampling season. Both the density and large body sizes of the copepods suggest a low vertebrate predator pressure; whereas, the exact opposite is indicated for the cladocerans, especially *Bosmina*.

The second phase of sockeye enhancement should emphasize improving freshwater rearing by expanding the population density of the cladoceran zooplankters. Such an increase in preferred prey items may enhance fry-to-smolt survival and increase the percentage of age-1.0 smolts. Similar benefits of enhanced rearing conditions were observed following the rotenone treatment in 1973 and subsequent fry stocking in 1974.

KEY WORDS: Organic stain, sockeye salmon, Oncorhynchus nerka, lake enrichment, lake fertilization, lime, coho salmon, Oncorhynchus kisutch, euphotic zone, phosphorus limnology, smolt, hydroacoustics, nutrient loading.

PART I: PACKERS LAKE FISHERIES PROGRAM

by

Gary B. Kyle

INTRODUCTION

Packers Lake, located on Kalgin Island in Cook Inlet, (Figure 1) has produced recorded sockeye salmon, *Oncorhynchus nerka*, escapements as high as 25,000-30,000 in 1939 and 1940; however, recent escapements have declined considerably (e.g., 500-8,000 during 1960-1975). More recently (1980-1982), sockeye escapements have averaged 15,000 (Table 1). Even though the early surveys were not weir counts and are not strickly comparable to later counts, the early 1950s saw a substantial decline in adult escapements.

The general reduction in escapement counts led to a series of sockeye enhancement efforts that began in 1973. The Commercial Fisheries Division of the Alaska Department of Fish and Game (ADFG) treated Packers Lake with rotenone in an attempt to eliminate three- and nine-spine sticklebacks, *Gasterosteus aculeatus* and *Pungitus pungitius*, respectively (Davis 1973; Barton 1975). The goal of the rotenone treatment was to eliminate the stickleback population and thus provide an improved rearing habitat for juvenile sockeye salmon. A total of 1.4 million sockeye eggs were taken from the 1973 brood stock returning to Packers Lake and incubated at Kasilof Hatchery; the resulting fry were released into Packers Lake after detoxification in 1974. Also, in 1973 a control structure was installed in Packers Creek at the lake outlet (Figure 1) to control discharge during excessive runoff periods and to deter upstream migration of undesirable fish species.

Beginning in 1980 and continuing each consecutive year, the Cook Inlet Aquaculture Association (CIAA) has investigated the problem of smolt and adult migrational hinderance through the intertidal area located at the mouth of Packers Creek. In addition, smolt and adult enumeration and age, weight, and length sampling were initiated by CIAA in 1981 and have continued each year since (Mears 1981, 1982; Marcuson 1984).

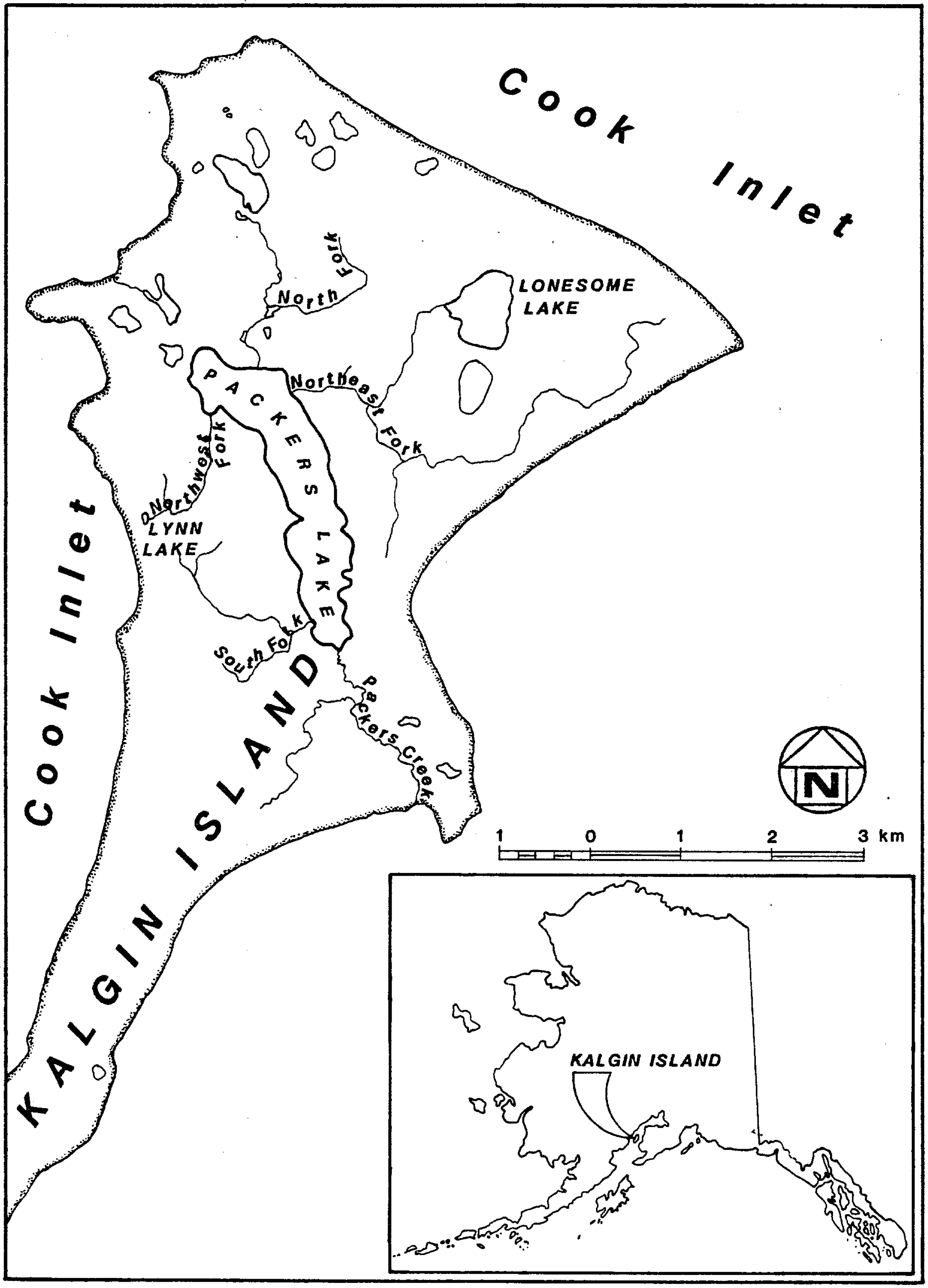

Figure 1. Location map of Packers Lake on Kalgin Island, Central District, Cook Inlet.

Table 1. Chronologic stream surveys and weir counts of adult sockeye salmon at Packers Lake, 1926-1982.

Date	Escapement	Survey method[1]	Area covered	Remarks
1926	100,000	--	--	Agent's estimate
1927	9,415	SG	Creek	Daylight tide counts
1929	10,864	SG	Creek	Daylight tide counts
1930	7,100	SG	Creek	Daylight tide counts
1931	9,335	SG	Creek	Daylight tide counts
1932	19,280	SG	Creek	All flood tides, light permitting
1936	18,670	SG	Creek	Daylight tide counts
1937	20,820	SG	Creek	Unknown
1938	5,026	SG	Creek	Unknown
1939	27,424	W	Creek	6/25-8/10 + 2,500
1940	25,602	W	Creek	6/2-8/10 + 1,500
1941	8,585	W	Creek	6/4-8/4 + 1,000
1947	3,000	--	--	6/21-7/19 only
1951	3,400	--	--	Stream clearance activity
1952	450	--	1/8 mi. creek	Stream clearance activity 3-4,000 RS off mouth
1953	20	--	N.W. corner lake spring	2,000 in lake, past peak
1954	215	--	Entire	6,000 in lake and feeder streams
1955	204	--	100 yards	30 RS off mouth 35 live, 36 dead near lake
1956	132	F	--	400 in lake
1957	100-125			
1958	654	--	100 yards	--
1959	483	F	Entire	--
1960	237	A	1/4 mi.	145 dead
	2,500			
	3,500			
1966	205	B	--	285 dead
1967	452	B	--	168 dead
1968	707	B	--	--
1969	500	B	--	--
1971	3,356	B	--	--
1972	2,980	A	--	--
1973	7,477	W	Entire	(Davis 1973)
1974	1,454	W	Entire	(Barton 1975)
1975	883	W	Entire	(Florey 1977)
1976	168	W	Entire	(Florey 1977)
1980	16,457	W	Entire	(Mears 1980)
1981	13,025	W	Entire	(Mears 1981)
1982	15,826	W	Entire	(Mears 1982)

[1]SG = Stream guard, W = Weir count, F = Foot survey, A = Aerial survey, B = Boat survey.

The purpose of this report is to summarize the results of fisheries research conducted at Packers Lake prior to fertilization and to provide a base of information from which the proposed lake-treatment/fertilization enhancement program can be evaluated.

PREREHABILITATION FISHERIES INVESTIGATIONS (1973)

In 1973 background fisheries information was initially collected from Packers Lake before rotenone treatment in order to evaluate effects of the rehabilitation project; fishery data previous to 1973 is limited. The following summarizes key results of the 1973 fisheries investigations but does not present specific details of methods, which may be obtained from Davis (1973).

Downstream Migrants

A downstream migrant trap was placed for the first time in Packers Creek in 1973 to enumerate all migrating fish species and to obtain age-length information on sockeye salmon smolts. A total of 85,424 sockeye salmon smolts were enumerated during 15 May-22 June (Table 2). The peak of migration occurred during 25-29 May. In addition, 9,980 coho salmon, *Oncorhynchus kisutch*, smolts, 642 coho salmon fry, 73 rainbow trout, *Salmo gairdneri*, 15,373 Dolly Varden, *Salvelinus malma*, and 1,052 three- and nine-spine sticklebacks were caught during the sampling period.

Sockeye salmon age information and out-migration proportions, which are based on scale samples collected from smolts caught in the downstream migrant trap, revealed that 29.3% were age 1.0, 67.2% were age 2.0, and 3.5% were age 3.0 (Table 3). The mean lengths (FL) of sockeye salmon smolts sampled in 1973 were 90.6 mm, 106.0 mm, and 106.4 mm for age-1.0, age-2.0, and age-3.0 smolts, respectively.

Table 2. Number and species of fish by five-day period that migrated downstream through the trap in Packers Creek during 15 May-22 June 1973.

Five-Day period	Sockeye salmon smolts	Coho salmon smolts	Coho salmon fry	Dolly Varden	Rainbow trout	Sticklebacks
May 15-19	15,164	10	68	1,628	27	417
20-24	21,887	69	122	5,349	16	500
25-29	28,301	1,147	75	5,659	15	33
Jun 30-03	8,752	651	238	1,055	5	56
04-08	7,837	3,459	57	756	3	3
09-13	2,443	2,202	82	760	3	3
14-18	943	1,928	0	60	2	28
19-22	97	514	0	96	2	12
Total	85,424	9,980	642	15,373	73	1,052

Table 3. Weekly age information and out-migration proportions of sockeye salmon smolts sampled from Packers Creek, 1973.

Age	Number sampled	Percent composition	Out-migration proportions	
May 15-21				
Age-1	16	10.9	2,514	
Age-2	121	82.3	18,985	
Age-3	10	6.8	1,569	
				23,068
May 22-28				
Age-1	35	25.4	10,319	
Age-2	99	71.7	29,128	
Age-3	4	2.9	1,178	
				40,625
May 29-Jun 4				
Age-1	86	61.4	8,344	
Age-2	51	36.5	4,960	
Age-3	3	2.1	285	
				13,589
Jun 05-17				
Age-1	108	46.8	3,810	
Age-2	122	52.8	4,299	
Age-3	1	0.4	33	
				85,424
Total				
Age-1	245	29.3	24,987	
Age-2	393	67.2	57,372	
Age-3	18	3.5	3,065	
			85,424	

Char Tagging

A total of 4,667 Dolly Varden char (30% of the total enumerated) that migrated from Packers Lake in 1973 were tagged to determine their migration pattern. Of the total, 60 fish were recovered in Packers Lake or in the outlet (Packers Creek) and 8 were recovered at sites other than the Packers Lake drainage (Table 4). Although the tag returns were minimal, the results suggest that Dolly Varden from Packers Lake remained on the west side of Cook Inlet and did not migrate to the east side and into popular fishing areas such as the lower Kenai Peninsula streams.

Townet Sampling

Townetting for rearing sockeye salmon juveniles, sticklebacks, and other species was conducted in Packers Lake during late August to early October in 1973. The sockeye salmon juveniles were sampled for lengths (FL) and age compositions, and the sticklebacks were sampled for lengths (FL). The sampling area (per tow) approximated one acre of the lake.

The highest sockeye salmon juveniles and stickleback catches occurred on 9 September and 27 August, respectively; an average of 20.8 sockeye juveniles and 207 sticklebacks were caught (Table 5). These represent a catch-per-unit effort (CPUE) of 1.04 for the sockeye salmon juveniles and 12.2 for the sticklebacks. The average CPUE during the sampling period was 0.46 for the juveniles and 4.18 for the sticklebacks. The length frequency of the sockeye salmon juveniles caught by townet during 27 August and 19 September indicated that 25.4% were age 0.0, 69.7% were age 1.0, and 4.9% were age 2.0 (Figure 2). These age compositions of juveniles rearing in the fall compared favorably to the age compositions of smolts that out-migrated in the spring of 1973 (i.e., 29.3% age 1.0, 67.2% age 2.0).

Table 4. Dolly Varden tag and recovery information from Packers Lake, 1973.

Tag colors	Tag numbers	Number tagged	Tag recovery date	Color of Tag recovered	Recovery location
Yellow	0601-1000	400			
	1050-1149	100	Jun 25	Red	Lockwood SN site--Kalgin Island
	1600-1999	400	Jul 05	Red	Johnson SN sit--Kalgin Island
Orange	0026-0600	575	Jul 16	Red	SN site--2 mi south of Clam Gulch
White	1176-1325	250	Jul 27	Yellow (1633)	Lcokwood SN site--Kalgin Island
Yellow	None	1,326	Aug 06	Red	Chinitna Bay
Red	None	900	Sep 03	Orange (00420)	Chinitna Bay
			Sep 30	Orange (00314)	Polly Creek
Pink	None	716	Sep 30	Yellow	Polly Creek
	Total Tagged	4,667	Total recovered 8		

Table 5. Townet catches of sockeye salmon juvenile and sticklebacks captured in Packers Lake during 27 August-1 October 1973.

Sample date	Total catch: Sockeye salmon fry	Total catch: Sticklebacks	CPUE: Sockeye salmon fry	CPUE: Sticklebacks	Number of tows	Total towing time (minutes)
08/27	13	1,035	0.15	12.18	6	85
09/06	26	250	0.31	2.94	5	85
09/09	104	650	1.04	6.50	5	100
09/12	14	244	0.14	2.44	5	100
09/15	53	316	0.53	3.16	5	100
09/17	71	371	0.71	3.71	5	100
09/19	33	245	0.41	3.06	4	80
09/20	17	189	0.17	1.89	5	100
10/01	31	4	0.78	0.10	2	40
Total	362	3,304	$\bar{x}$= 0.46	4.18	42	790

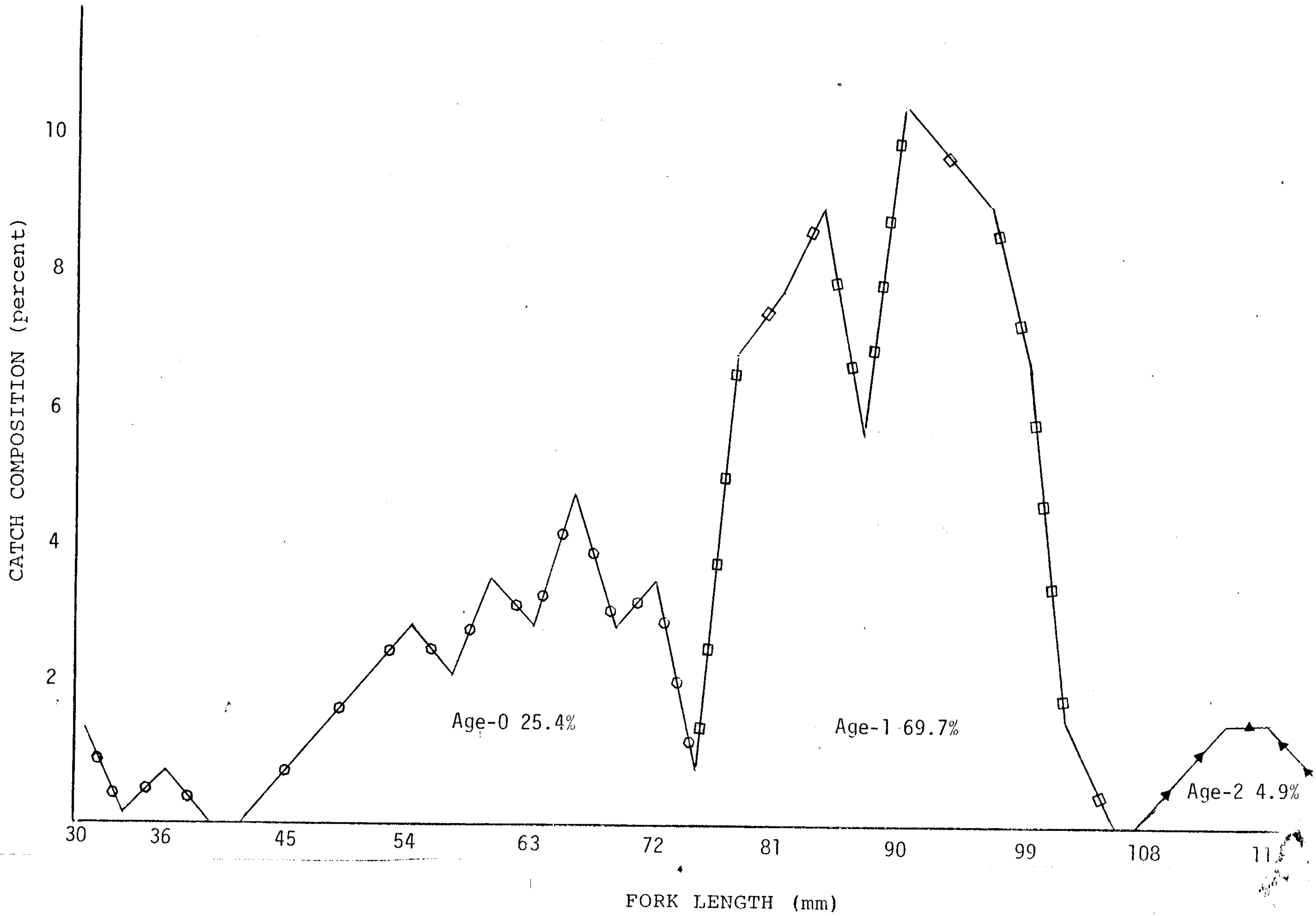

Figure 2. Length frequency of townet captured sockeye salmon juvenile from Packers Lake, 27 August-19 September 1973.

The length frequency of the sticklebacks caught by townet during 27 August and 17 September revealed two distinct age classes (Figure 3). One age class, presumably young-of-the-year, ranged in length from 17 to 36 mm, while the older, presumably mature adults, ranged in length from 40 to 80 mm. The larger length range was comprised of a bimodal distribution (the separation at 55-60 mm) that may have been two different age groups or sub-populations, since sticklebacks are known to spawn at varying times and to occupy a wide range of niches (Manzer 1976; Cannon 1981).

Gillnet Sampling

Monthly gillnet (33-m-long variable-mesh net) sampling that was conducted at one station for a 24-hour period revealed that Dolly Varden were the most abundant of all species caught (Figure 4). The average catch of Dolly Varden during the sampling period (May-October per 24-hour period) was 55, or a CPUE of 2.3. The catch of Dolly Varden substantially decreased after the June sampling, which could have been the result of Dolly Varden leaving the lake (15,373 were counted through the downstream trap during 15 May-22 June).

The average catch of rainbow trout during the sampling period was 12 per 24-hour period, or a CPUE of 0.5. Unlike the Dolly Varden, few (73) rainbow trout migrated out of Packers Lake. After the Dolly Varden migration (end of June), both species had similar CPUEs until September; subsequently, the Dolly Varden catch rate increased (a possible function of migration back into the lake to spawn), and the rainbow trout catch rate decreased (a possible function of low capture probability due to deep-water residence). The gillnets were sampled for a total of 144 hours, resulting in a CPUE of 3.5 for all species.

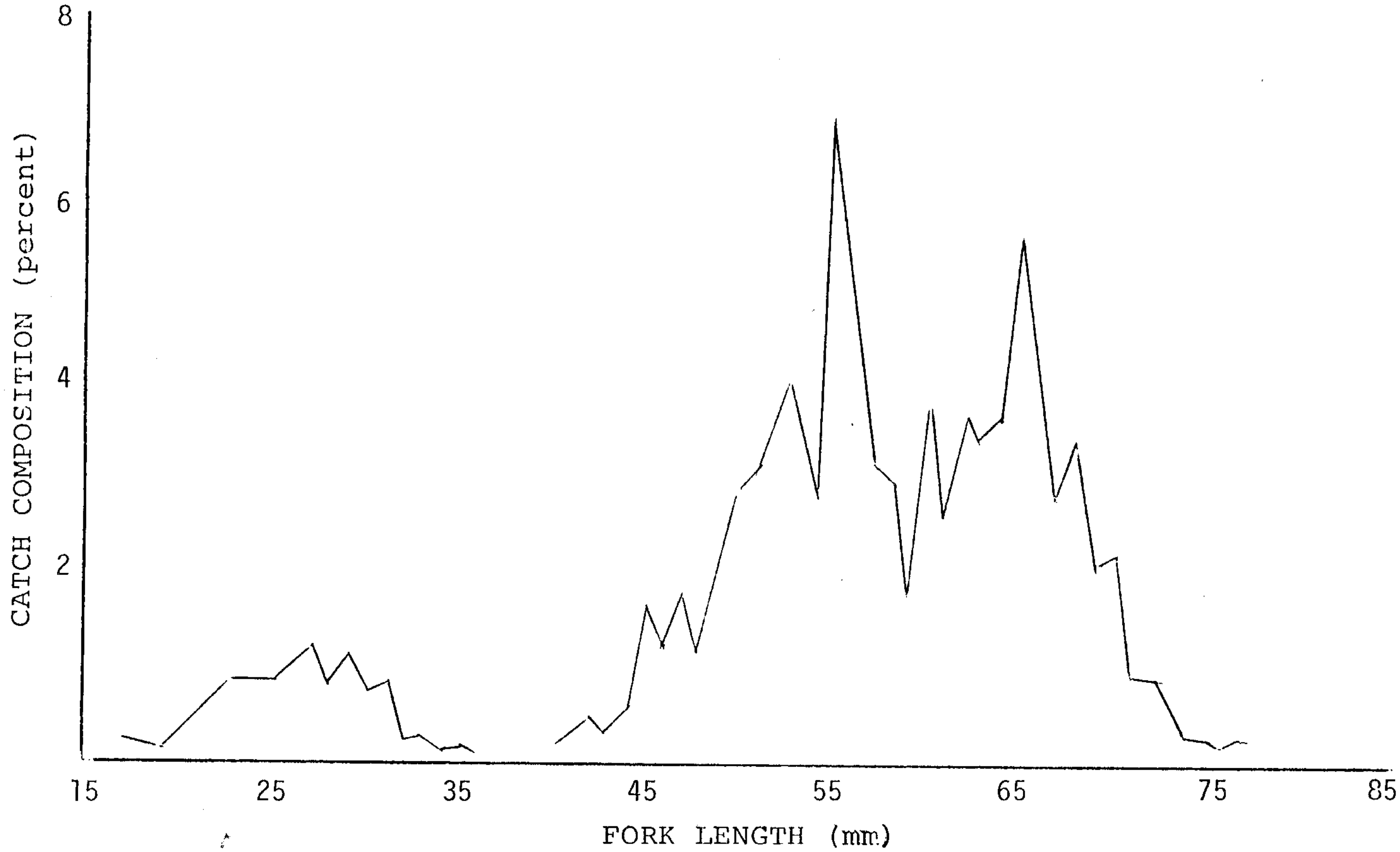

Figure 3. Length frequency of sticklebacks captured in Packers Lake by townet, 27 August-17 September 1973.

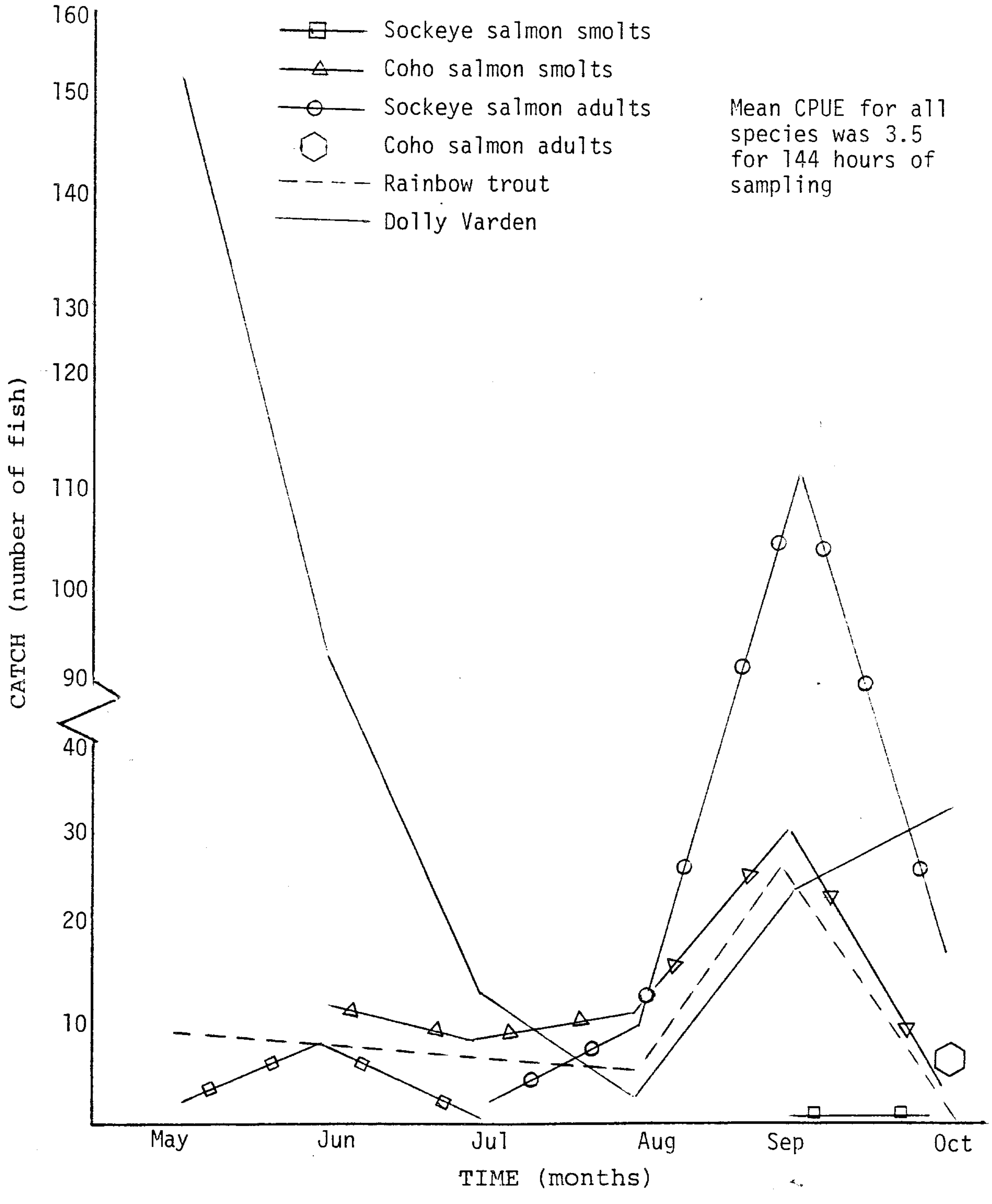

Figure 4. Gillnet catches of fish species caught in Packers Lake during May-October, 1973.

Minnow Trap Sampling

Minnow traps were set at two limnetic stations and one littoral station on a weekly basis from 8 July until 5 October 1973 to determine the vertical distribution of sticklebacks in Packers Lake. The traps were set at 1- to 6-m intervals from the surface for a 24-hour period at two limnetic stations. One trap was set each week at a maximal depth of 2 m in the littoral area of the lake near the outlet.

The catch data show that sticklebacks migrated to deeper depths until the end of September to early October (Table 6). Beginning in early August (5-18 August), more sticklebacks were caught in depths greater than 3 m than during the earlier sampling periods. During 2-15 September, the highest catch of sticklebacks occurred; 63% were caught in depths of 3 m or greater. The littoral trap did not catch many sticklebacks; however, the highest catch during 22 July to 4 August supported the observation that sticklebacks migrated to greater depths as the summer progressed.

Diet and Food Availability Comparisons

A limited number of stomach samples from sockeye salmon juveniles and sticklebacks were examined in 1973 to compare differences or similarities in their diets. In addition, a cursory comparison was made between the stomach content of sockeye salmon juveniles caught in the townet and a 5-m-vertical plankton-net haul in the same area.

In May, yearling sockeye salmon that were sampled for stomach contents contained primarily insects, while the sticklebacks contained primarily Cladoceran eggs (Figure 5). As the summer progressed, sockeye salmon juveniles fed primarily on *Holopedium*, *Bosmina*, and *Daphnia*, while sticklebacks fed on various other plankton forms (e.g., *Bosmina*, *Cladoceran* eggs, and *Cyclops*). A

Table 6. Bimonthly catches of sticklebacks in minnow traps at two limnetic stations and one littoral station during 8 July- 5 October 1973, Packers Lake.

	Sampling periods						
Depth (m)	08-21 Jul	22 Jul-04 Aug	05-18 Aug	19 Aug-01 Sep	02-15 Sep	16-29 Sep	30 Sep-05 Oct
0(Surface)	0	0	7	6	4	2	1
1	3	1	5	2	2	0	
2	2	6	2	3	4	1	1
3	3	4	4	4	4	0	0
4	2	2	4	5	5	0	3
5	1	1	1	2	14	0	3
6	1	0	1	1	3	12	0
7	0	0	1	0	2	0	0
Littoral Trap	1	12	7	9	3	2	1

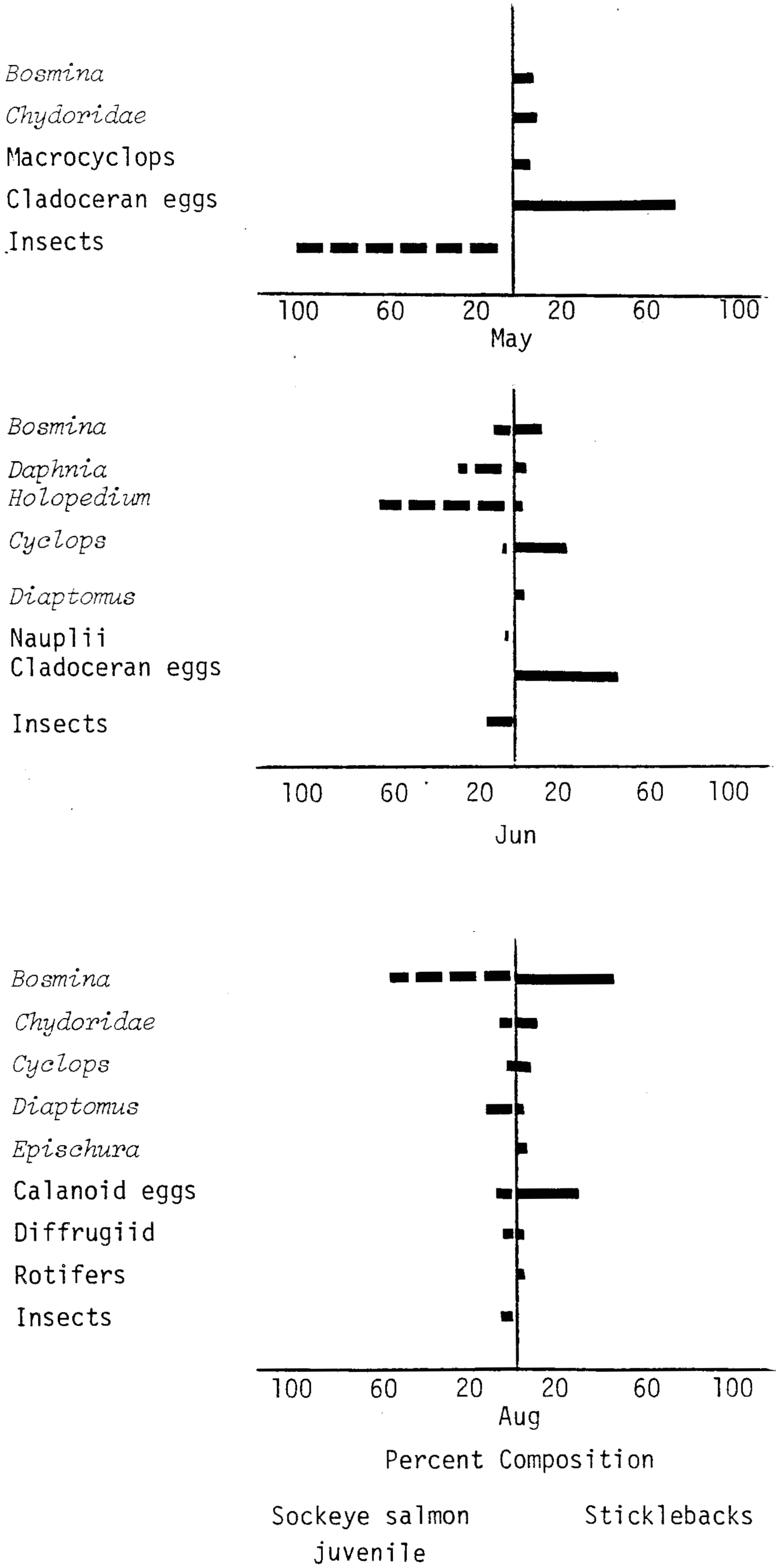

Figure 5. Comparison of the percentage composition of food between sockeye salmon juveniles and sticklebacks for three months in Packers Lake, 1973.

major overlap in the preferred diet (*Bosmina*) of the two fish species occurred in August. Summaries of the composition of food items found in sampled sockeye salmon juveniles and sticklebacks are presented in Tables 7 and 8, respectively.

The comparison of food availability to food items found in sockeye salmon juveniles (Figure 6) showed that, of the six planktonic items, *Bosmina coregoni* was the most abundant in the water column and inside sockeye salmon juveniles. However, based on the Ivlev electivity index (Ivlev 1961), sockeye salmon juveniles were on the borderline between randomly and actively selecting *Bosmina coregoni* and the less abundant *Diaptomus pribilofensis* (i.e., Ivlev electivity index equaled 0.17 and 0.67, respectively). The percent compositions of the other species of plankton (both in the fry and the water column) were less than 10% and, therefore, cannot be used to compute electivity indices.

Compared to the other planktonic organisms listed in Figure 6, *Bosmina coregoni* was more prevalent in sockeye salmon juveniles because of higher densities during August rather than because of individual body sizes. The recent (1981, 1982) average individual body size of *Bosmina* was 0.35 mm, while that of *Diaptomus* was much larger at 1.10 mm (Tobias unpublished data).

Adult Escapement and Sampling

The adult sockeye salmon migration into Packers Lake in 1973 was distributed over a relatively long time period (May-October); this was presumably due to placement of the weir in the shallow, slow-flowing outlet. It was necessary to dig a channel through the weir to provide sufficient water depth and flow to allow adult fish entry into the live-box. Most adult fish migrated through the weir only during darkness.

A total of 7,477 adult sockeye salmon were enumerated through the weir in 1973 (Table 9). In addition, 477 jacks (precocious

Table 7. Monthly summary of the composition of food items sampled from sockeye salmon juvenile in Packers Lake during May-October, 1973.

	Number of organisms									
	May		Jun		Aug		Sep		Oct	
	%	n	%	n	%	n	%	n	%	n
Mean length of fry (mm)		96		110		81.6		61.3		110
Number of stomachs examined		5		7		12		14		1
Empty stomachs		0	14.2	1		0	10.0	1		
Bosmina coregoni			2.2	3	59.7	2,655	773	3,165		
Holopedium gibberum			60.0	81			0.1	6		
Daphnia longeremis			21.4	29	0.2	13	5.3	217		
Leptodora kindtii					0.3	14	0.7	30		
Chydorus sp.					0.3	17				
Cladoceran eggs					2.7	123	0.7	30		
Cyclops scutifer			2.2	3	0.4	20	2.2	94		
Diaptomus pribilofensis					17.8	791	0.8	33		
Epischura nevadensis							3.3	136		
Paracamptus reductus					0.8	39				
Nauplii			1.4	2	0.1	2	0.1	1		
Calanoid egg clusters					13.2	590	7.3	302		
Ostracoda					0.1	5				
Diffrugiid					2.0	90	1.6	67		
Acrai					0.1	4	0.1	1		
Insects	97.2	35	12.5	17	1.5	70	0.2	11	100	3
Volvox sp.					0.1	8				
Trout eggs	2.7	1								
Crustacea only			14.2	1	33.3	4	80.0	8		
Crustacea and insect				0	66.7	8	10.0	3		
Insects only	100	4	85.7	6		0		0	100	1
Mean estimate % fraction										
Crustacea					86.0	4,100	98.9	464		
Insects					13.5	664	1.0	5		

Table 8. Monthly summary of the composition of food items sampled from sticklebacks in Packers Lake during May-August, 1973.

	May		Jun		Aug	
	%	n	%	n	%	n
Mean length of sticklebacks (mm)		60		61.8		68.2
Number of stomachs examined		2		26		7
Empty stomachs		0	23.0	6		2
Bosmina coregoni	11.4	4	14.9	7.2	50.3	442
Daphnia longeremis			0.9	11	0.2	2
Holopedium gibberum			1.6	19		
Alona affinis	2.8	1			5.7	50
Acroperus harpe	2.8	1				
Pleuroxos denticulata		1				
Cladoceran eggs	77.1	27	51.7	596		
Cyclops scutifer			26.9	310	8.2	72
Macrocyclops fucus	2.8	1				
Diaptomus pribilofensis			1.9	22		
Epischura nevadensis					1.1	10
Calanoid egg clusters					30.8	268
Diffrugiid			0.2	3		
Rotifers					3.7	33
Insects			1.1	13		
Clams			0.5	6		
Crustacea only	100	2	34.6	9		5
Crustacea and insects		0		0		0
Insects only		0	26.9	8		0

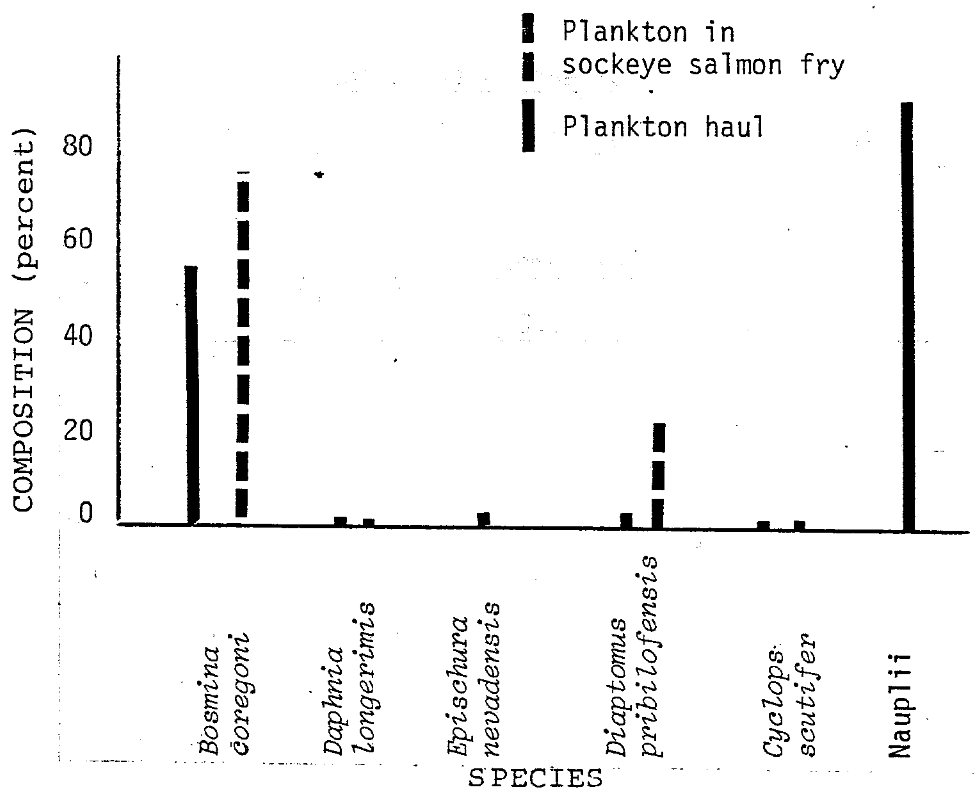

Figure 6. Comparison by percent of six zooplankton organisms collected by a vertical net tow, and composition of the same organisms found in sockeye salmon juvenile collected from Packers Lake, September 1973.

Table 9. Number of each type of fish species that migrated upstream through the weir in Packers Creek by five-day periods, 1973.

Date	Adult sockeye salmon	Jack sockeye salmon	Adult coho salmon	Dolly Varden	Rainbow trout
May 27-31	6	1		1	
Jun 01-05	29				4
06-10	56				
11-15	39				
16-20	74				
21-25	41				
26-30	39				
Jul 01-05	16				
06-10	55				
11-15	110				
16-20	224				
21-25	449			1	
26-30	322			4	
Aug 31-04	838				
05-09	1,026			15	
10-14	633			21	
15-16	554	4			
17-20	302	91			
22-26	803	62		36	2
27-31	181	20		2	
Sep 01-05	519	92	1	44	
06-10	402	62	3	24	
11-15	549	131	25	12	
16-20	57	15	5	27	
21-25	58				
26-30	74	3	9		
Oct 01	1		3		
Total	7,477	477	46	187	6

sockeye males), 46 adult coho salmon, 187 Dolly Varden (over 25 cm), and 6 rainbow trout (over 25 cm) were passed through the weir. Fish smaller than 25 cm in length were able to pass through the weir. The majority of adult coho spawned downstream from the weir in Packers Creek. Foot surveys revealed peak counts of 130 adult coho salmon in the creek (Table 10).

Age class 2.2 comprised 34.1% of the adult sockeye salmon escapement sampled in 1973 and was followed closely by the 2.3-age class, which comprised 32.9% of the total sampled (Table 11). The percent compositions of the freshwater ages of the adult escapement were consistent with that of smolts in 1973; 25.5% were age 1.0 and 74.5% were age 2.0. The respective adult-production contributions of the 1973 sockeye escapement by brood year shows that 53.1% were 5-year-old fish and, hence, from the 1968 brood year. Therefore, an estimated total of 3,970 adult sockeye salmon were produced in 1973 from the 1968 escapement, or a return per female spawner of 11. The male-to-female sex ratio for the sockeye escapement was 1.2 to 1.0. The lengths (ME-FL) of all age classes and sex of adult sockeye salmon ranged from 354.5 to 540.3 mm, with an average of 505.5 mm (Table 12).

Egg Stripping

In 1973 sockeye salmon eggs were taken and fertilized on six different days during 11 September to 5 October. An estimated total of 1,375,000 eggs were taken from 550 females, and these eggs were incubated at the Kasilof Hatchery. The fry were short-term reared at the hatchery until the following spring (1974), when they were transported back to Packers Lake and released.

POSTREHABILITATION FISHERIES INVESTIGATIONS (1974-1976)

Fishery investigations in 1974 were designed primarily to evaluate the success or failure of the rotenone treatment in Packers Lake

Table 10. Peak survey counts of adult coho salmon in Packers Creek, during 27 August-4 October, 1973.

Date	Number of adult coho salmon observed	Number of adult coho salmon on redds
08/27	100	0
09/02	40	0
09/11	10	0
09/25	4	1
10/02	128	12
10/04	130	15

Table 11. Age, brood-year, and sex composition of adult sockeye salmon sampled from Packers Lake, 1973. Numbers in parenthesis are percentages.

	Age compositions						Number sampled
	1.1	1.2	1.3	2.1	2.2	2.3	
No.	3(1.8)	14(8.6)	31(18.9)	6(3.7)	56(34.1)	54(32.9)	164

	Freshwater ages		
	Age-1	Age-2	
No.	82(25.5)	239(74.5)	321

	Ocean ages			
	1-Ocean	2-Ocean	3-Ocean	
No.	9(5.5)	70(42.7)	85(51.8)	164

	Brood-Year contributions				
	1967	1968	1969	1970	
No.	54(32.9)	87(53.1)	20(12.2)	3(1.8)	164

	Sex compositions			
	Males		Females	
No.	293(54)	1.2:1	250(46)	543

Table 12. Mean lengths (mm) by age classes and sex of adult sockeye salmon sampled at Packers Lake, 1973.

Sex	Age Class 1.1	1.2	1.3	2.1	2.2	2.3	Number sampled
Male	354.5	522.9	548.6	472.1	502.8	533.7	
Number sampled	3	8	17	6	30	28	92
Female	---	533.9	535.2	---	510.9	540.3	
Number sampled	---	6	14	---	26	26	72
						Total	164

and to monitor the detoxification time in order to allow safe restocking of the lake with sockeye fry. In addition, the effectiveness of the control structure in preventing reinfestation of undesirable fish species in the lake was evaluated during 1974-1976.

In keeping with the objectives of the rehabilitation program, most of the fishery investigations conducted in 1973 were repeated during 1974-1976. The results of those investigations are summarized below. A description of methods used in 1974, which also apply to those used in 1975 and 1976, and of specific results may be found in the report by Barton (1975).

Fed Fry Stocking

After Packers Lake was bioassayed for the rotenone toxicant (Pro-Nox Fish) in May 1974 and found to be nontoxic to fish, the sockeye salmon fry that were incubated and reared at Kasilof Hatchery were released into Packers Lake.

The fed fry were released on two different occasions, approximately one month apart; thus, there was a difference in the release size of each group (Table 13): 142,410 fry and 184,095 were released on 29 May and 3 July, respectively. The total number of fed fry released (326,505) represents only 23.7% of the 1,375,000 eggs that were taken in 1973. These fed fry were released in two separate groups because the second group (3 July) showed symptoms of infectious hematopoietic necrosis (IHN) virus. Although the second group of fry were tested for IHN virus and found negative, the adult brood stock of these fry (1973) were tested and found positive. Since the fry released on 29 May may also have been infected, the risk of infecting the first group was considered insignificant and, consequently, the second group of fry were released at the latter date.

Table 13. Hatchery-release information on sockeye salmon fry released in Packers Lake, 1974.

Release information	Release dates 29 May	3 Jul
Total number of kilograms transported	23.7	43.8
Number of fry per kilogram	6,017	4,317
Total number of fry transported	142,610	189,095
Hatchery water temperature	8.4°C	13.2°C
Lake water temperature	13.4°C	16.5°C
Fry mortalities during transport	200	5,000
Total number of fry released	142,410	184,095
	326,505 (total)	

Downstream Migrants

In 1974 the downstream migrant trap caught 7,861 sticklebacks, 302 coho salmon smolts, 35 Dolly Varden, and 8 sockeye salmon smolts (Table 14). No rainbow trout were counted through the trap. This information revealed that the rotenone treatment was ineffective in eliminating sticklebacks (competitors) and Dolly Varden (predators) from the lake system. On 1 August 1974, the trap was removed because it impaired the migration of returning adult sockeye. However, visual observations after 1 August indicated that thousands of sticklebacks were passing downstream of the control structure daily.

In 1975 a total of 119,293 age-1.0 sockeye salmon smolts were produced from the 1974 fry release (Table 15). The peak migration occurred during 29 May-2 June. Only 785 coho salmon smolts were caught. In addition, a large number of Dolly Varden (11,885) migrated through the trap; however, few rainbow trout were observed (4). A total of 4,261 sticklebacks were counted. The average length of the age-1.0 sockeye salmon smolts was 94.1 mm.

A total of 193,577 sockeye salmon smolts were enumerated in 1976 (Table 16). The peak migration occurred at approximately the same time as in 1975 (28 May-1 June). A total of 16,639 coho salmon smolts were caught. An even larger number of sticklebacks was enumerated in 1976 than in 1975 (70,362); nearly twice as many Dolly Varden (21,166) were also enumerated. No rainbow trout were enumerated during the sampling in 1976.

In 1976 the dominant age class of sockeye salmon smolts was age 2.0, representing 63.7% of the total. These smolts (123,309) represented the age-2.0 smolt production from the 1974 fry release. Together, the age-1.0 sockeye salmon smolts produced in 1975 (119,293) and the age-2.0 smolts produced in 1976 represented a fry-to-smolt survival of 74%. The age-1.0 smolts that outmigrated

Table 14. Number and species of fish by five-day period that migrated downstream through the trap in Packers Creek during 21 May-1 August 1974.

Five-day period	Sockeye salmon smolts	Coho salmon smolts	Dolly Varden	Sticklebacks
May 21-25	0	0	13	4,614
26-30	1	5	3	773
Jun 31-04	0	12		1,090
05-09		124		853
10-14		62		108
15-19		87		237
23[1]		10		3
Jul 06			1	
10			2	
13			1	
16	3		2	
18				1
22	1			1
25	3	1	12	
Aug 01				1
Total	8	302	35	7,681[2]

[1]Fyke net was removed and a smaller trap was installed.
[2]Thousands of sticklebacks were observed after 1 August.

Table 15. Number and species of fish by five-day period that migrated downstream through the trap in Packers Creek during 14 May-3 July 1975.

Five-Day period		Sockeye salmon smolts	Coho salmon smolts	Dolly Varden	Rainbow trout	Sticklebacks
May	14-18	206	14	10	0	363
	19-23	15,632	6	629	2	446
	24-28	13,174	2	1,461	1	226
Jun	29-02	46,646	5	6,227	0	311
	03-07	13,953	10	2,002	0	337
	08-12	10,651	58	1,106	0	522
	13-17	10,508	201	305	0	400
	18-22	3,277	286	89	1	369
	23-27	2,668	110	17	0	300
	28-02	2,356	83	39	0	519
Jul	03	222	10	0	0	468
Total		119,293	785	11,885	4	4,261

Table 16. Number and species of fish by five-day period that migrated downstream through the trap in Packers Creek during 18 May-27 June 1976.

Five-Day period		Sockeye salmon smolts	Coho salmon smolts	Dolly Varden	Sticklebacks
May	18-22	634	472	2,295	1,554
	23-27	5,865	169	5,196	3,336
Jun	28-01	64,151	915	6,675	16,015
	02-06	61,363	2,486	4,625	13,957
	07-11	30,294	5,097	1,389	18,864
	12-16	22,581	4,901	802	8,049
	17-21	7,006	1,645	138	4,522
	22-26	1,611	795	35	3,635
	27	72	159	11	430
Total		193,577	16,639	21,166	70,362

in 1976 (36.3% of the total) were produced from the 1974 brood stock. The average length of age-1.0 and age-2.0 sockeye salmon smolts in 1976 were 96.7 mm and 114.6 mm, respectively (Table 17).

Outlet Control Structure

The Packers Creek control structure was found to be inadequate in preventing fish entry into the lake. The structure was unable to control discharge during the spring and fall high-water periods in 1975 and 1976, because lake water flowed over the top and around the structure. As a result, the structure was removed at the end of the field season in 1976.

Townet Sampling

Townetting for sockeye salmon juveniles and sticklebacks was conducted in 1974 to compare with 1973 (pre-treatment) townetting data. Sampling was conducted at approximately the same time in 1974 (6-28 September), at the same locations, and with similar amounts of effort (790 tow minutes in 1973 versus 627 in 1974).

Results of townetting in 1974 (Table 18) revealed a CPUE of 0.73 for sockeye salmon juveniles and 16.58 for sticklebacks, which was much higher than in 1973 (0.46 for the juveniles and 4.18 for the sticklebacks). Thus, in 1973 the CPUE ratio of sockeye salmon juveniles to sticklebacks was 1.0 to 9.1, while in 1974 the ratio was 1.0 to 22.7. These data strongly suggest that there was a greater number of sticklebacks and a greater potential for interspecific competition with sockeye salmon juveniles in 1974 than in 1973.

In 1974 subsamples of sockeye salmon juveniles that were taken from the townet catches revealed that most were age 0.0; in 1973 approximately 25% were age 0.0 (Figure 7). The larger variation in lengths of age-0.0 sockeye salmon fry in 1974 was probably the result of the two different sizes of the hatchery-released fry.

Table 17. Weekly age information, average lengths, and out-migration proportions by age group of sockeye salmon smolts sampled from Packers Creek, 1976.

Weekly period	Number sampled	Percent composition	Average length (mm)	Length range (mm)	Out-Migration proportions (numbers)
May 18-24					
Age-1	30	23.6	92.8	70-116	257
Age-2	97	76.4	115.6	103-132	834
					1,091
May 25-31					
Age-1	30	21.7	92.2	78-107	12,154
Age-2	108	78.3	113.5	103-148	43,802
					56,056
Jun 01-07					
Age-1	18	13.0	96.2	88-109	10,700
Age-2	120	87.0	113.5	103-151	71,620
					82,332
Jun 08-14					
Age-1	73	52.1	95.5	88-108	20,403
Age-2	67	47.9	112.7	101-147	18,759
					39,162
Jun 15-21					
Age-1	84	57.5	98.3	91-114	7,633
Age-2	62	42.5	118.6	105-174	5,672
					13,325
Jun 22-28					
Age-1	37	61.7	102.5	89-115	1,028
Age-2	23	38.3	115.7	106-126	635
					1,683
Total					
Age-1	272	36.3	96.7	70-116	52,185
Age-2	477	63.7	114.6	101-174	141,392
					193,577

Table 18. Comparison of 1973 and 1974 townet catches of sockeye salmon juveniles and sticklebacks based on catch-per-unit-effort (CPUE) for Packers Lake.

1974						1973					
	Total catch		CPUE				Total catch		CPUE		
Sample date	Sockeye salmon	Stickleback	Sockeye salmon	Stickleback	Fishing time (minutes)	Sample date	Sockeye salmon	Stickleback	Sockeye salmon	Stickleback	Fishing time (minutes)
09/06	13	1,911	0.16	23.89	80	08/27	13	1,035	0.15	12.18	85
09/09	4	489	0.06	6.99	70	09/06	26	250	0.31	2.94	85
09/12	19	4,523	0.21	49.70	91	09/09	104	650	1.04	6.50	100
09/15	12	1,992	0.14	23.44	85	09/12	14	244	0.14	2.44	100
09/20	68	627	0.68	6.27	100	09/15	53	316	0.53	3.16	100
09/22	207	784	2.07	7.84	100	09/17	71	371	0.71	3.71	100
09/25	83	744	0.83	7.44	100	09/19	33	245	0.41	3.06	80
09/28	121	964	1.21	9.64	100	09/20	17	189	0.17	1.89	100
						10/01	31	4	0.78	0.10	40
	Total=527	12,034	$\bar{x}$= 0.73	16.58	Total=726		Total=362	3,304	$\bar{x}$=0.46	4.18	Total=790

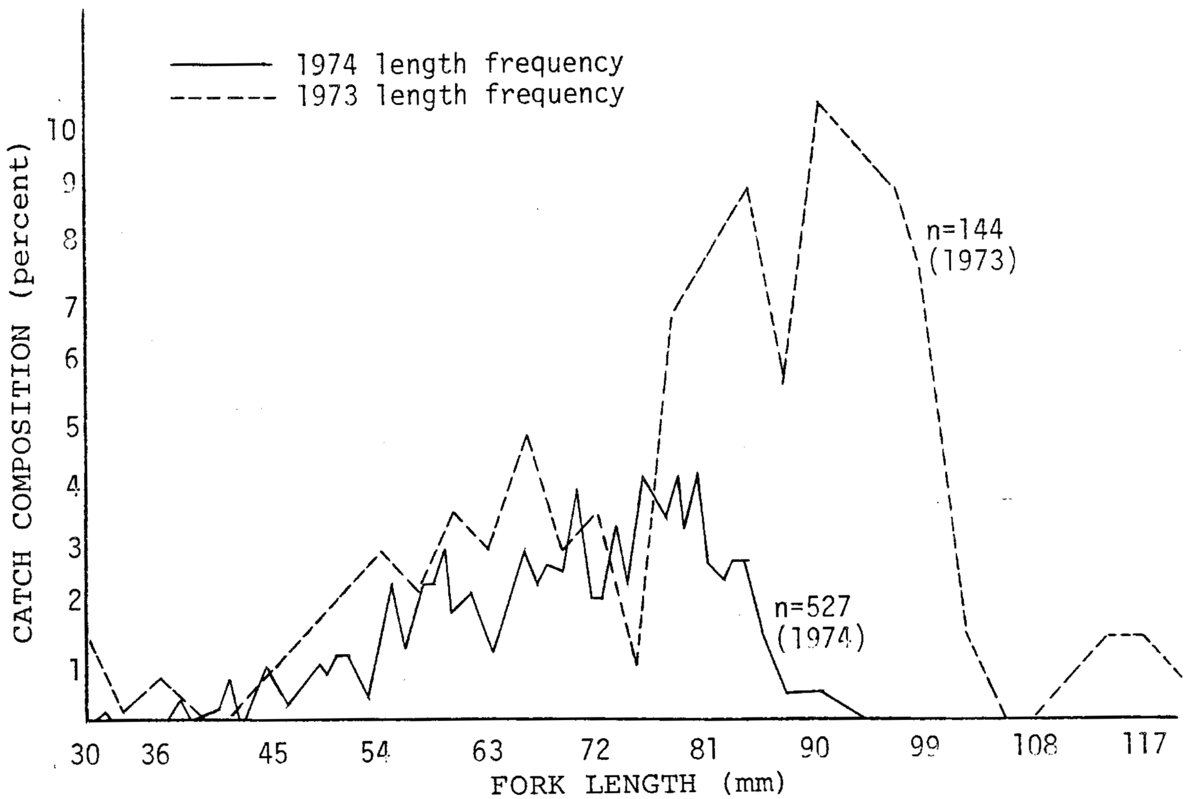

Figure 7. Length frequencies of sockeye salmon juveniles captured in Packers Lake by townet, 27 August-17 September 1973 and 6-28 September 1974.

The length-frequency comparison of sticklebacks in 1973 and 1974 indicate that only one age class of sticklebacks was captured in 1974 (Figure 8); however, as mentioned above, they were relatively more abundant.

Gillnet Sampling

Gillnet sampling was conducted in 1974 to compare catches and CPUE with those observed in 1973. In 1974 the gillnets were sampled for a total of 192 hours (Table 19); this is compared to 144 hours in 1973 (Figure 4). However, the CPUE was dramatically less in 1974 (0.14) than in 1973 (3.5) for all fish species. In addition, in 1974 no Dolly Varden or rainbow trout were caught.

A total of four adult sockeye salmon and 22 coho salmon (10 juveniles and 12 adults) were caught by gillnetting during May and October in 1974. The presence of age-2.0 juvenile coho salmon indicated that they had overwintered and had consequently survived the rotenone treatment.

Food Availability

Overall, the standing crop of zooplankton decreased 48.2% in 1974, when compared to 1973 (Figure 9), which is not uncommon in rotenone-treated lakes (Kiser et al. 1963). For example, after treatment the copepods decreased by 42%-99%. In addition, some of the major zooplankters (including Copepods), with the exception of nauplii, were not abundant until later in the season (after August) in 1974.

Of the Cladocerans, *Bosmina* and *Holopedium* increased dramatically (85% and 343%, respectively, from 1973 to 1974); whereas, *Daphnia* disappeared completely (Figures 9 and 10). Although there was an increase in the density of *Bosmina*, relatively few were available to the hatchery-released juveniles until mid-August.

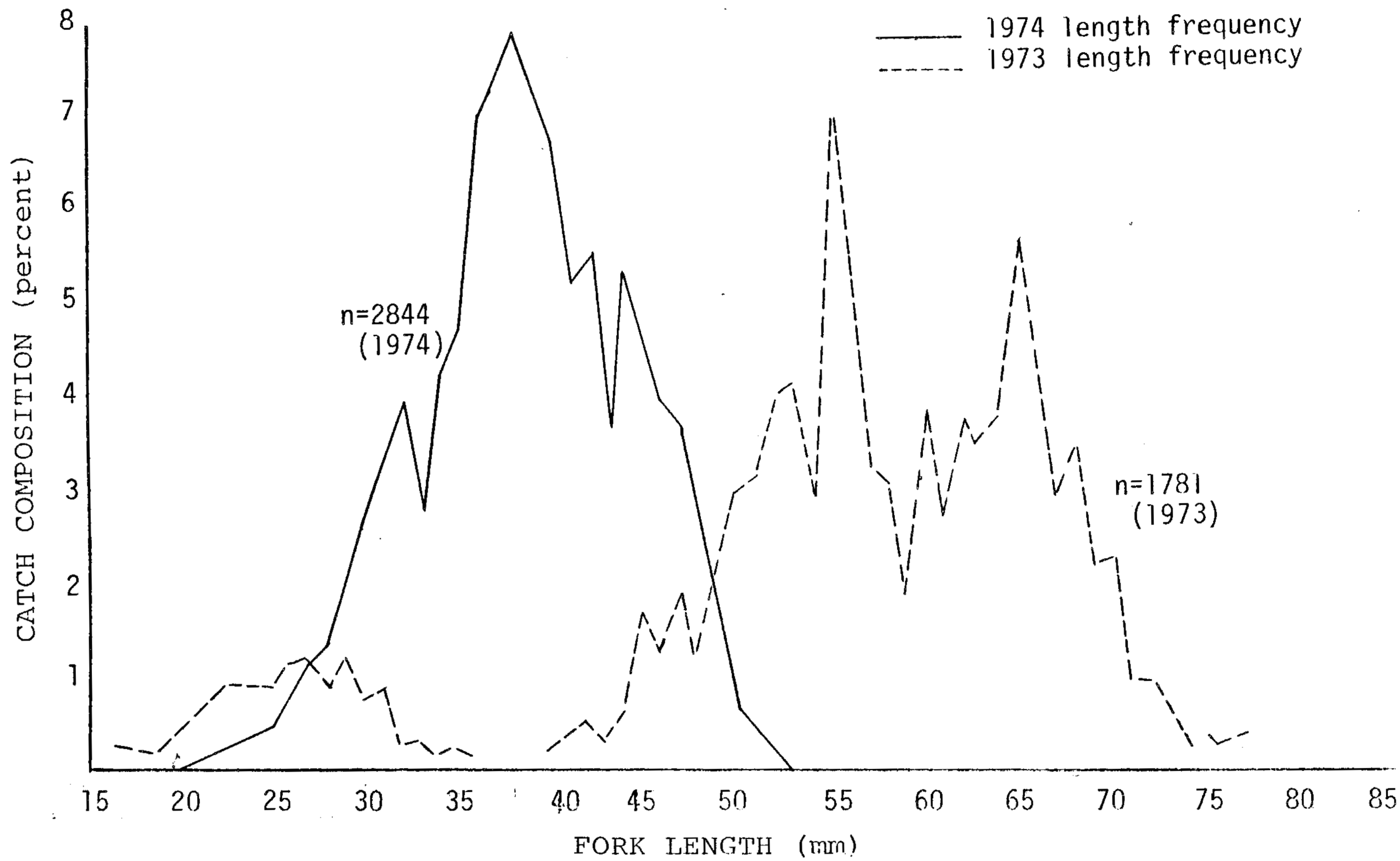

Figure 8. Length frequencies of sticklebacks captured in Packers Lake by townet, 27 August-17 September 1973 and 6-28 September 1974.

Table 19. Gillnet catches of fish species caught in Packers Lake during 22 May-31 August 1974.

Sample site	Date[1]	Juvenile coho salmon	Adult sockeye salmon	Adult coho salmon	Dolly Varden	Rainbow trout
1	5/22	0	0	0	0	0
	5/26	2	0	0	0	0
	7/31	2	0	0	0	0
	8/30	0	0	5	0	0
2	5/23	0	0	0	0	0
	6/29	0	1	0	0	0
	8/04	6	3	0	0	0
	8/31	7	0	0	0	0
	Total	17	4	5	0	0

[1]Each date the net was sampled for 24 hours (i.e., total sampling time was 192 hours, CPUE for all species caught was 0.14).

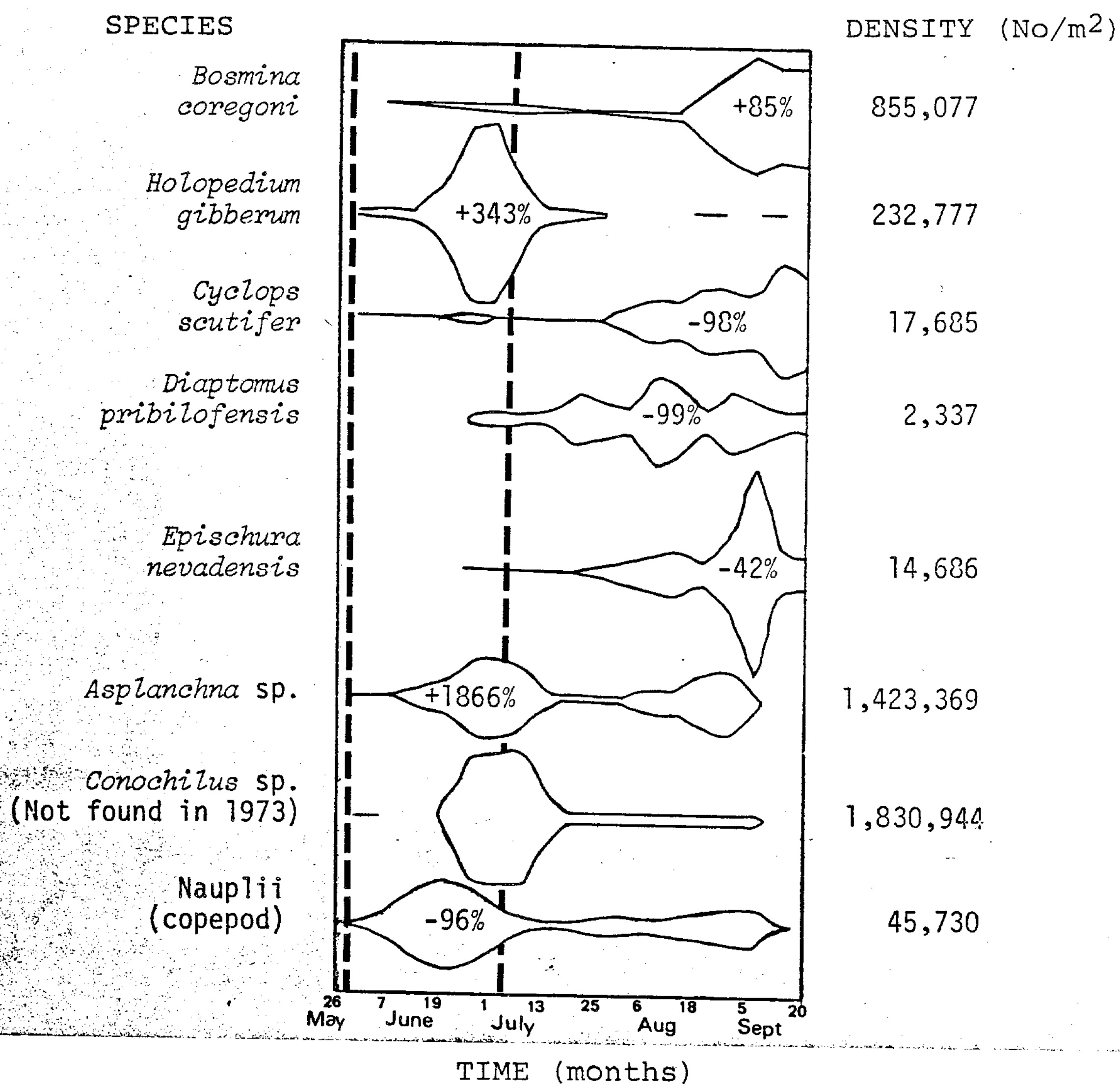

Figure 9. Seasonal abundance of zooplankton in Packers Lake, 1974. The percentages indicate increase or decrease in abundance of each organism from 1973 to 1974. The two heavy broken lines indicate the dates sockeye salmon fry were released in 1973.

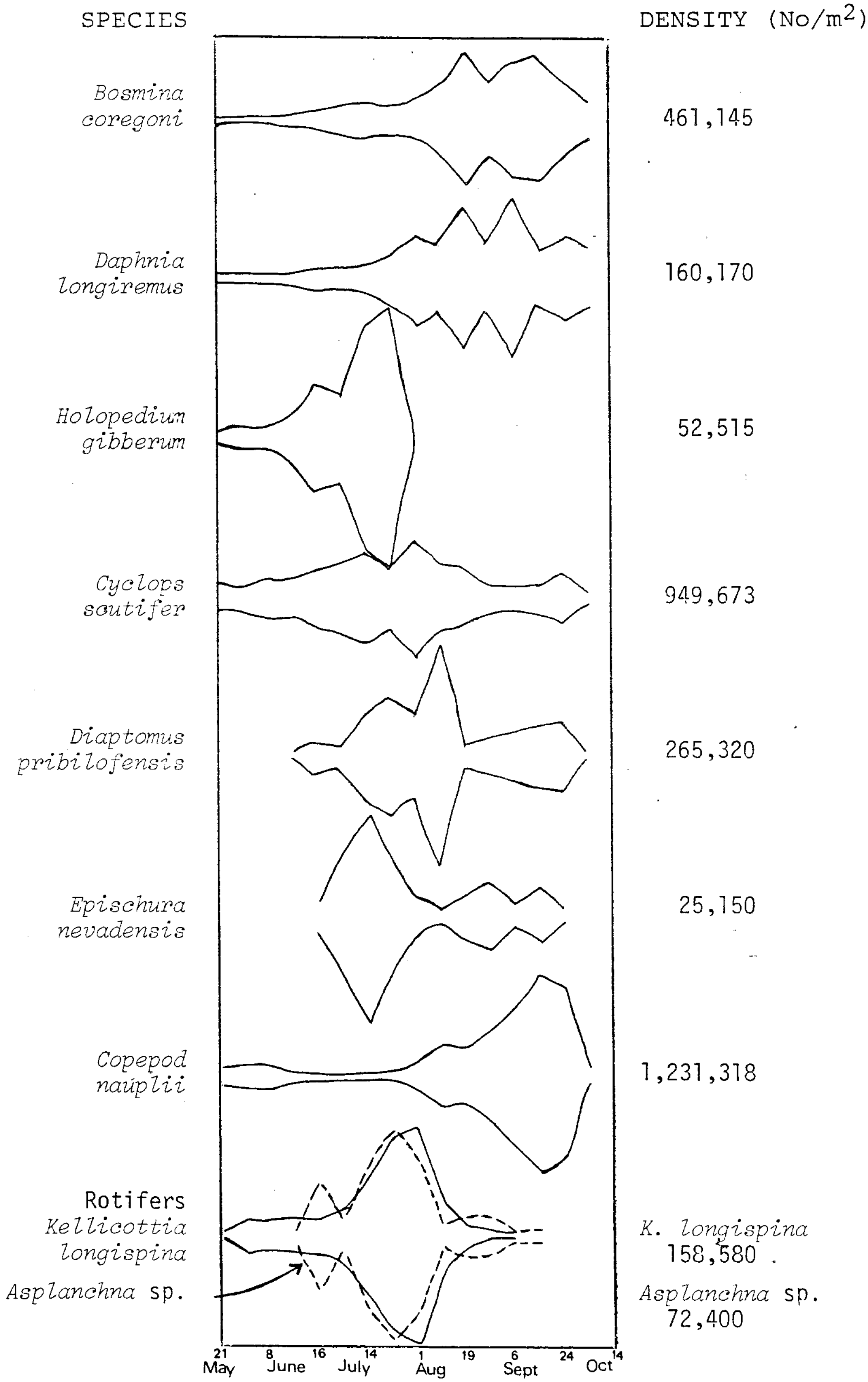

Figure 10. Seasonal abundance of various plankton organisms in Packers Lake, 1973.

The limited number of stomach contents analyzed in 1973 indicated that the major food constituents of sockeye salmon juveniles were *Holopedium* in June and *Bosmina* in August (Figure 5). If these samples were representative, it appears that the hatchery-released fry had a sufficient food source, because *Holopedium* and *Bosmina* significantly increased in abundance in June and August, respectively, in 1974.

Adult Escapement and Sampling

A total of 1,454 adult sockeye salmon was enumerated from 10 June to 30 September 1974; the peak of migration occurred during the week of 31 August to 6 September. In 1975 and 1976, a total of 883 and 168 adult sockeye salmon were enumerated during 1 June to 2 September and 24 May to 4 August, respectively. In 1976 an additional 24 jacks were enumerated. No surveys were conducted during 1974 and 1976 to enumerate adult coho salmon in Packers Creek. As in 1973, during 1974 and 1976 the extended adult sockeye salmon migration was due to extremely low water levels in Packers Creek. In addition, as a result of low water levels in 1974, low dissolved-oxygen levels were observed, which presumably caused 157 mortalities among the migrating adult sockeye salmon.

A summary of age, brood-year, and sex compositions of adult sockeye salmon sampled during 1973-1976 is presented in Table 20. During 1973-1975, the dominant age class was 2.2; this was followed by 2.3. In 1976 the dominant age class was 1.3; this was due to the loss of the 2-year ocean adults, resulting from the 1973 rotenone treatment. The respective adult production contributions to each year's escapement by brood year indicate that the majority of returning adults (53.1%-66.5%). was five-years-old (age-1.3 and age-2.2 adult fish). With the exception of 1976 when the number of males decreased in the escapement (0.65:1), the sex ratio was approximately 1:1.

Table 20. Age, brood-year, and sex composition by percentage of adult sockeye salmon sampled from Packers Lake, 1973-1976.

Year of return	Age compositions 1.1	1.2	1.3	2.1	2.2	2.3	Number sampled(n)
1973	1.8	8.6	18.9	3.7	34.1	32.9	164
1974	1.0	6.7	6.1	6.1	60.4	19.6	326
1975	0.0	10.7	6.6	0.0	51.3	31.4	561
1976	7.1	0.9[1]	57.1	0.0	0.0[1]	34.9	112

	Freshwater ages Age-1	Age-2	
1973	25.5	74.5	321
1974	13.1	86.9	343
1975	17.3	82.7	561
1976	65.2	34.8	112

	Ocean ages 1-Ocean	2-Ocean	3-Ocean	
1973	5.5	42.7	51.8	164
1974	7.0	66.8	26.2	326
1975	0.0	62.0	38.0	561
1976	7.1	0.9[1]	92.0	112

	Brood-Year contributions 1967	1968	1969	1970	1971	1972	1973	
Age / 1973	6 / 32.9	5 / 53.1	4 / 12.2	3 / 1.8				164
Age / 1974		6 / 19.6	5 / 66.5	4 / 12.8	3 / 1.0			326
Age / 1975			6 / 31.4	5 / 57.9	4 / 10.7	3[1] / 0.0		561
Age / 1976				6 / 34.9	5 / 57.1	4[1] / 0.9	3 / 7.1	112

	Sex ratio: Sex Male	Female	Ratio Male		Female	
1973	54.0	46.0	1.2	:	1.0	543
1974	48.7	51.3	1.0	:	1.1	464
1975	49.7	50.3	1.0	:	1.0	724
1976	38.6	61.4	0.65	:	1.0	104

[1]This brood-year was sacrificed during the 1973 rotenone-treatment of Packers Lake.

The mean lengths ranged from 336 mm for age-class 1.1 to 571 mm for age-class 2.3 during 1974 and 1976 (Table 21). The female average length was greater than the males sampled in 1974 and 1976, but it was the same as that of the male sockeye salmon sampled in 1975. The average lengths of all age classes (regardless of sex) of adult sockeye salmon sampled in 1974, 1975, and 1976 were 517.0, 515.7, and 518.0 mm, respectively.

RECENT FISHERIES INVESTIGATIONS (1980-1982)

Details of methods and specific results by year may be obtained in the projects annual reports (Mears 1980, 1981, 1982; Marcuson 1984). The following summarizes key fisheries data collected by CIAA from Packers Lake during 1980-1982.

Downstream Migrants

The out-migration of sockeye and coho salmon smolts from Packers Lake was enumerated in 1981 and 1982. In addition, the number of Dolly Varden and rainbow trout leaving the lake was also recorded. In 1981 a total of 267,906 sockeye salmon smolts and 16,179 coho salmon smolts were enumerated during 11 May to 7 June (Table 22). The smolts were already migrating when the sampling gear was installed in 1981 (26,000 smolts were captured the first night); thus, the total migration was not enumerated. The high handling mortalities (42,224) were the result of the poor sampling site and the inadequate size of the live-box. Consequently, in 1982 smolt sampling was conducted below the control structure (at the outlet of Packers Lake) with a compartmentalized live-box. A total of 486,400 sockeye salmon smolts and 42,850 coho salmon smolts were estimated by sub-sampling during 2 May to 26 June in 1982 (Table 23). The peak of migration in 1982 occurred near the end of May. Finally, a total of 6,085 Dolly Varden and 52 rainbow trout were caught in the downstream trap in 1981, while 2,133 Dolly Varden and 30 rainbow trout were caught in 1982.

Table 21. Mean lengths (mm) by age classes and sex of adult sockeye salmon sampled at Packers Lake, 1974-1976.

Year of return	Sex	Age class 1.1	1.2	1.3	2.1	2.2	2.3	Average length of all age class	Number sampled
1974	Male	374.3	534.9	558.4	483.1	518.7	552.8	503.7	153
	Female	---	543.5	543.1	506.9	512.1	545.9	530.3	175
					Average length of both sexes			517.0	
1975	Male	---	465.1	557.2	---	482.3	558.6	515.8	280
	Female	---	482.9	543.7	---	488.3	548.4	515.5	283
					Average length of both sexes			515.7	
1976	Male	336.4	520.0	576.2	---	---	570.9	510.8	49
	Female	---	---	556.3	---	---	556.1	525.2	63
					Average length of both sexes			518.0	

Table 22. Number of sockeye and coho salmon smolts by five-day period that migrated downstream through the trap in Packers Creek during 11 May-7 June 1981.

Five-day period	Sockeye salmon smolts	Sockeye salmon mortalities	Coho salmon smolts
May 11-15	105,415	16,453	0
16-20	94,022	22,941	3
21-25	25,859	1,079	1,851
26-30	26,137	1,202	7,492
Jun 31-04	12,719	441	4,861
05-07	3,754	108	1,963
Total	267,906	42,224	16,179

Table 23. Number of sockeye and coho salmon smolts by five-day period that migrated downstream through the trap in Packers Creek during 3 May-27 June 1982.

Five-day period	Sockeye salmon smolts	Coho salmon smolts
May 03-07	4,850	1,730
08-12	21,730	1,220
13-17	40,270	960
18-22	95,100	1,370
23-27	45,670	2,100
Jun 28-01	145,010	6,610
02-06	68,410	10,960
07-11	42,830	9,670
12-16	16,720	5,910
17-21	4,070	1,560
22-26	1,740	760
Total	486,400	42,850

The age, weight, and length information presented in Table 24 reveals that in 1981 62% of the sockeye salmon smolts were age 1.0. However, it is assumed that in 1981 a large percentage of age-2.0 smolts migrated before the installation of sampling gear; thus, the age-2.0 composition in 1981 could have been higher and the age-1.0 composition lower. The age-1.0 smolts averaged 74 mm in length and 3.4 g in weight; the age-2.0 smolts averaged 98 mm in length and 7.6 g in weight.

In 1982 the dominant age composition shifted to age-2.0 sockeye salmon smolts (Table 25). The age-1.0 smolts averaged 78.0 mm in length and 4.2 g in weight, while the age-2.0 smolts were 88 mm and 5.4 g. The age composition of coho salmon smolts in 1982 follows: 6% age 1.0; 69% age 2; and 25% age 3.0. Respective lengths and weights for age-1.0, age-2.0, and age-3.0 coho salmon smolts were 74 mm and 3.8 g, 120 mm and 15.5 g, and 141 mm and 25.8 g, respectively.

Adult Escapement and Sampling

Adult sockeye and coho salmon escapements were enumerated at the mouth of Packers Creek in 1980 and 1981 and at the control structure near the outlet of Packers Lake in 1982. In addition to age, weight, and length data, fecundities of sockeye salmon were taken during 1980 and 1982 to determine potential egg deposition.

During 1980 and 1982, the adult sockeye salmon escapement was fairly consistent, ranging from 13,024 to 16,456 and averaging 15,102 for the three years (Table 26). In 1981 and 1982, 2,440 and 339 adult coho salmon were also enumerated, respectively. Adult sockeye salmon generally entered Packers Creek in late May to early June. The migration peaked in late July, and the run was essentially over by the end of August.

Table 24. Five-day average lengths and weights and out-migration proportions by age groups of sockeye salmon smolts sampled from Packers Creek, 1981.

Five-day period	Average length (mm)	Average weight (g)	Out-migration proportions (%)
May 11-15			
Age-1	76.6	3.8	18.5
Age-2	98.2	7.6	81.5
May 16-20			
Age-1	75.0	3.3	84.2
Age-2	95.2	7.0	15.8
May 21-25			
Age-1	72.0	3.1	98.4
Age-2	91.8	6.5	1.6
May 26-30			
Age-1	73.2	3.3	100.0
May 31-Jun 04			
Age-1	75.0	3.7	100.0
Jun 05-07			
Age-1	76.5	3.8	100.0
Total			
Age-1	74.0	3.4	62.3
Age-2	98.0	7.6	37.7

Table 25. Five-day average lengths and weights and out-migration proportions by age groups of sockeye salmon smolts sampled from Packers Creek, 1982.

Five-day period	Average length (mm)	Average weight (g)	Out-migration proportion (%)
May 03-07			
Age-1	---	---	0
Age-2	89.6	5.6	100.0
May 08-12			
Age-1	80	4.2	0.3
Age-2	91	5.7	99.7
May 13-17			
Age-1	82.5	4.1	0.6
Age-2	89.0	5.4	99.4
May 18-22			
Age-1	---	---	0
Age-2	88.5	5.3	100.0
May 23-27			
Age-1	79.0	4.2	0.5
Age-2	89.4	5.6	99.5
May 28-Jun 01			
Age-1	80.0	4.2	4.9
Age-2	88.6	5.5	95.1
Jun 02-06			
Age-1	77.2	3.9	6.9
Age-2	86.2	5.3	93.1
Jun 07-11			
Age-1	77.0	4.1	10.7
Age-2	85.8	5.4	89.3
Jun 12-16			
Age-1	78.4	4.5	28.2
Age-2	86.6	5.5	71.8
Jun 17-21			
Age-1	82.6	5.1	27.3
Age-2	88.6	6.2	72.7
Jun 22-26			
Age-1	84.5	5.8	32.2
Age-2	90.0	6.8	67.8
Total			
Age-1	78.0	4.2	5.0
Age-2	88.0	5.4	95.0

Table 26. Escapements and length-weight compositions of adult sockeye salmon during 1980-1982, Packers Lake.

Year	Escapement	Mean length (mm)	Length range (mm)	Mean weight (kg)	Weight range (kg)
1980	16,457	517.0	312-572	2.4	0.5-3.3
1981	13,024	474.0	332-575	1.9	0.6-3.3
1982	15,826	470.0	313-594	2.3	0.5-4.0
Average	15,102	487	312-594	2.2	0.5-4.0

Table 27. Age composition of adult sockeye salmon during 1980-1982, Packers Lake.

Year	Age composition (%)						Number sampled
	1.1	1.2	1.3	2.1	2.2	2.3	
1980	2.7	60.6	11.3	0.2	12.3	12.9	373
1981	3.9	73.5	15.7	0	2.0	4.9	102
1982	0.3	37.0	6.7	16.4	33.4	6.2	341
Average	1.8	52.3	14.0	2.9	19.9	9.1	816

The average length of all age classes and sex of adult sockeye salmon returning during 1980 and 1982 was 487 mm; lengths ranged from 312 to 594 mm. For all age classes and sex, the weights ranged from 0.48 to 4.0 kg (Table 26). Unlike the 1973 to 1976 age compositions, in which the majority of adults were either 2.2 (1973 to 1975) or 1.3 (1976), the dominant age class was 1.2 during 1980 and 1982 (Table 27).

Fecundity estimates were made on 54 female sockeye salmon during 1980 and 1982. The average fecundity was 2,893 eggs (Table 28). Sockeye salmon less than 500 mm averaged 2,415 eggs, while those greater than 500 mm averaged 3,306 eggs. Sex ratios during 1980 and 1982 were consistent at 1:1.

Intertidal Migration

The Packers Lake sockeye salmon (smolts and adults) have a history of mortality related to their vulnerability of beaching on the intertidal bar during low tide (Florey 1977). In 1980 the mortalities were 0.5% of the total escapement; most of these were due to the location of the weir (near the mouth of Packers Creek) and a lack of understanding of the migration behavior. We found that the adults migrated into Packers Creek only during high tides. If the weir was closed during high tide, the adults would hold in the creek several hours before migrating back to salt water. By this time, the tide usually had receded enough to make the intertidal gravel bar impassable. As a result of the receding water, the adult salmon became stranded on the beach and died. After moving the adult weir to the control structure at the outlet of Packers Lake and keeping the weir open during high tides, the mortality was reduced to 0.2% of the total escapement in 1981 and to 0.3% in 1982. Finally, during the smolt migrations in 1980-1982, there was sufficient discharge from Packers Creek to prevent smolts from migrating over the intertidal gravel bar and becoming beached, even during low tide.

Table 28. Fecundity estimates on adult female sockeye salmon sampled from Packers Lake, 1980-1982.

Year	Mean length (mm)	Mean weight (kg)	Mean number of eggs	Range of number of eggs	Number sampled
1980	516	2.2	2,920	1,887-4,767	23
1981	519	2.3	3,662	2,566-4,928	6
1982	496	2.1	2,683	1,594-4,002	25
Average	507	2.2	2,893	1,594-4,928	54

DISCUSSION

Although the 1973 Packers Lake rehabilitation project failed to achieve its original objectives, the project did provide meaningful results that were typical of a lake rotenone-treatment project.

The catch-per-unit effort (CPUE) (based on townetting for sticklebacks after treatment of the lake) was four-times greater than before treatment (Table 18); however, only one age class (young-of-the-year) was represented. This is not an extraordinary result, when considering two other occurrences of rotenone treatment in lakes similar to Packers Lake. First, the dense organic material in weedy areas, where sticklebacks are known to spawn (Cannon 1981), makes even distribution of rotenone difficult and the rate of absorption and breakdown of rotenone more rapid than in open water. Hence, the eggs of sticklebacks deposited in 1973 were probably not drastically affected by the rotenone treatment. Second, certain species of cladocera are known to inhabit the dense, weedy areas of a lake (Kiser et al. 1963); in Packers Lake these species were probably able to survive. Thus, a preferred food source was available, because analysis of a limited number of stomachs revealed that littoral cladocera were a major food component of sticklebacks (Figure 5). In addition, without the potential competition for similar food resources from the sockeye salmon fry (due to their near elimination after treatment), the sticklebacks were able to flourish in the less-toxic littoral environment.

Another interesting and explainable result from the rotenone-treatment project was the extraordinarily good survival rate of hatchery-released sockeye fry following treatment. The 74% fry-to-smolt survival was the result of increased preferred-food items following treatment. Even though the seasonal standing crop of zooplankton was reduced by 48.2% after treatment, most of the zooplankton that was affected were copepods (Figure 9), which were not found to be preferred-food items for sockeye salmon fry in

Packers Lake (Figure 5). Conversely, following the treatment, the zooplankton species that are important to the diet of sockeye salmon fry (i.e., cladocerans: *Holopedium gibberum* and *Bosmina coregoni*) and other nonpreferred organisms (such as rotifers) increased. The reasons for these changes are due to differences in the physiology of these organisms. That is, *Holopedium gibberum*, *Bosmina coregoni*, and rotifers are herbivorous filter-feeders that reproduce asexually and, hence, have short generation times; whereas, the copepods reproduce sexually (i.e., have longer generation times) and are selective particle-feeders. The cladocerans and rotifers were able to outcompete the copepods for limited food resources following treatment because of their non-selective filter feeding and their reproductive advantages (Brooks 1969).

Because of the lack of recruitment data, such as survival rates and fry densities before rehabilitation, it cannot be determined if the rehabilitation project directly increased the biomass (i.e., average size and/or numbers) of sockeye salmon smolts; however, the average size of sockeye salmon smolts increased following treatment. In 1973 age-1.0 smolts averaged 90.6 mm, while in 1975 the age-1.0 smolts produced from the hatchery-fry release in 1974 averaged 94.1 mm. In 1976 age-1.0 and age-2.0 smolts were even larger, averaging 96.7 mm for age-1.0 smolts and 114.6 mm for age-2.0 smolts (compared to age-2.0 smolts in 1973 that averaged 106 mm in length). Even though the size of sockeye salmon smolts increased after treatment, the age compositions remained the same (29.3% were age 1.0 in 1973 and 67.2% were age 2.0, while in 1976 36.3% were age 1.0 and 63.7% were age 2.0). However, even these data are compromised, since the 1976 smolts were not entirely from natural spawn.

In recent years (1981 and 1982), the size of sockeye salmon smolts has substantially decreased to a size less than the 1973 pretreatment (Tables 24 and 25). In addition, age compositions of smolts during 1981 and 1982 have fluctuated (i.e., 62% age 1.0 in 1981 and 5% age 1.0 in 1982). The larger escapements that have occurred more recently may partially explain the reduction in smolt size; however, the escapements have been consistent, so the the age composition of the smolts should have remained fairly constant. Considering the recent smaller smolt sizes, the fluctuating age classes, and the possibility of the dominance of age-2.0 smolts in future years, the need for a sockeye enhancement strategy, such as nutrient enrichment for Packers Lake, should be considered.

The most efficient use of natural lakes as rearing areas for sockeye fry occurs if the lake is capable of producing age-1.0 smolts, because freshwater mortality accounts for a large portion of the total mortality a brood of sockeye fry encounters. The ability of fry to grow quickly to a large size allows for both reduced freshwater residence times and a large body size for smolts. If both occur, then survival in fresh and marine waters increases; hence, the number of harvested adults increase, which is the key strategy for enhancement projects.

In respect to Packers Lake, which currently produces a large percentage of age-2.0 smolts, the question is one of balancing the freshwater and marine survival of larger two-year-old smolts with the production of a greater percentage of one-year-old smolts and their accompanying marine survival. Thus, the aims of nutrient enrichment are to cause a decrease in freshwater residence time and, at the same time, produce larger smolts. The potential importance of smolt size lies in its relation to marine survival. For clear-water environments, the size of smolts has been positively related to marine survival (Burgner 1962; Ricker 1962; Barraclough and Robinson 1972). Whether this is caused by decreased predation rates, by an increased amount of food available to larger smolts, or by a combination of both is unknown.

In summary, the addition of inorganic nutrients should enhance and/or alter the trophic relationships so that juvenile sockeye will experience higher survival rates within lakes. That is, the juvenile sockeye salmon should attain larger size and/or younger age prior to seaward migration and should experience a higher brood-year survival. In essence, as a reflection of the sum of increased freshwater and marine survival, the stock (adult return) should exhibit positive changes in size.

RECOMMENDATIONS

As recommended in the limnology section (Part II), Packers Lake should be treated with lime to increase the depth of the euphotic zone; in combination with this application, inorganic nitrogen should be applied to balance the release of phosphorus from the lime treatment. Both treatments should act in concert to increase the salmon production from this lake. However, we envision the one-time lime addition to be secondary to the annual addition of nitrogen and phosphorus to the lake.

In addition, a study should be conducted to evaluate the feeding relationship and diet of juvenile sockeye salmon and sticklebacks in Packers Lake. It is important to determine if there is competition between sockeye salmon fry and sticklebacks so that a response to the enhancement program can be predicted and/or evaluated. Furthermore, the study should include the comparison of preferred-food items present in the water column versus those found in juvenile sockeye so that a cause-and-effect relationship can be correlated to survival and/or growth of sockeye salmon smolts.

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PART II: PACKERS LAKE LIMNOLOGY PROGRAM

by

J. P. Koenings

and

Pat Marcuson

TABLE OF CONTENTS
(Part II)

LIST OF TABLES

LIST OF TABLES (continued)

LIST OF TABLES (continued)

LIST OF FIGURES

INTRODUCTION

The detailed study of particular (and usually unique) chemical and biological properties of lakes (lake typology) as determinants of of sockeye salmon, *Oncorhynchus nerka*, smolt production is slowly evolving to the point of identifying causative factors. For example, a feature of brown-water lakes that appears to set an upper limit to their productive base is the shallow depth of the euphotic zone, or the depth to which light penetrates. The dark color of the water is caused by the presence of yellow organic colloids, which not only limit light penetration (James and Birge 1938) but also participate in chemical reactions involving metal ions, particularly iron (Shapiro 1957, 1966). In turn, this iron-containing colloid can act to reduce the availability of nutrient ions, especially phosphorus (Golachowska 1971; Koenings 1976; Koenings and Hooper 1976). In addition, these organic acids impart a dissolved oxygen load to the lake that reduces the oxygen content of bottom waters; the acids act to increase the heating rate of the surface layers and, thereby, raise epilimnetic temperatures. Finally, the organic colloids selectively absorb light within the photosynthetic wavelengths (James and Birge 1938) and are thereby able to effectively compete with the phytoplankton for this energy source. This further diminishes the quality and quantity (depth) of the trophogenic zone.

The source of these organic acids is primarily allochthonous, yet delivery to the lake takes place through the inlet streams and through the surrounding vegetation (by seepage). This difference is not just academic, because the water source has profound effects on the ultimate productive capacity of each lake type; i.e., drainage versus seepage.

Seepage lakes characteristically have very slow water-renewal rates that, when combined with a marshy- or peat-dominated drainage basins, tend to produce a high concentration of organic acids.

When the water percolates through a *Sphagnum* dominated watershed, further changes result, because polyuronic acids within living and dead *Sphagnum* have been identified as very efficient ion-exchangers (Clymo 1963). That is, metal ions (especially calcium and iron) are selectively removed from the percolating water and are replaced by H_3O^+ ions. This action reduces the pH of the open water (to as low as 3.8 to 4.0) and reduces the calcium content, and because the peat mats are notoriously nitrogen poor (Wetzel 1975), it reduces the supply of inorganic nitrogen to the open water. On the other hand, drainage lakes that receive flow from inlet streams have faster water renewal rates that tend to reduce the concentration of organic acids, even if the drainage basin contains a high percentage of marshy areas. Thus, the open lake water may be stained, but the pH will be higher (closer to 6.0), the cation content will be higher (detectable levels of calcium and magnesium), and the supply of inorganic nitrogen will be significantly greater (Dugdale and Dugdale 1961).

Thus, within the broad category of lakes defined as brown water, two distinct sub-types emerge; i.e., drainage versus seepage systems. Nonetheless, the overwhelming impact on fish production is common to both: the direct and indirect effects of the presence of the colloidal organic acids. In addition, when compared to drainage systems, seepage systems are further affected in terms of a reduced productive capacity by the general lowering of the pH. A pH level lowered to ≥5 not only restricts fish production (and the species present) but also diminishes every aspect of the aquatic food chain (Bergtsson, 1980; Ellis and Golomb 1981). Since Packers Lake has the lowest light penetration of any nonglacial sockeye system studied to date, our initial approach to enhancing the fry-rearing capacity involved decreasing the concentration of the yellow organic acids. This approach has been tested previously through the addition of lime as a management tool to increase the production of trout in brown-water lakes (Waters 1948; Hasler et al. 1951; Barnett 1953 Johnson and Hasler 1954; Waters and Ball 1957; and Brynildson 1958).

Description of Study Area

Packers Lake is located on the north end of Kalgin Island and drains an area of 20.3 km^2 (5,010 acres). Packers Creek watershed drains into Cook Inlet on the east side of the island. The drainage contains Sitka spruce, *Picea sitchensis*, western hemlock, *Tsuga heterophylla*, wet-area sedges, *Sphagnum* sp., and meadow grasses. The outlet flows approximately 2.4 km (1.5 mi) to the inlet; however, the actual overland distance to the inlet is approximately 1.2 km (0.75 mi).

The four small tributaries to Packers Lake range from 0.85 m^3/sec to 3.4 m^3/sec (3-12 cfs) of accumulated inflow during typical summer conditions. However, at times the stream channels are split, and actual flows within each segment are vague because of vegetation in and along the stream banks. The northeast fork (Figure 1) was the largest contributor, providing fully one-third of the inflow.

Packers Lake (Figure 1) occupies 205 surface hectares (506 acres), has a volume of 24.9 x 10^6 m^3 (20,172 acre-feet), a maximal depth of 30.5 m (100 feet), and a mean depth of 12.2 m (40 feet). The lake has bog-type shorelines that have a shoreline development index of 1.9. The lake is 14.6 m (48 feet) above sea level, has 9.6 km (5.95 mi) of shoreline, and has a length of 3.8 km (2.37 mi).

METHODS

Transportation to and from Packers Lake was limited to float- or ski-equipped aircraft. Limnological samples were collected from these aircraft during open-water and ice-covered periods. Samples were collected monthly from June through October of 1980, 1981, and 1982. One or two winter samples were collected in 1981 and 1982. The lake was sampled for algal nutrients (nitrogen, phosphorus,

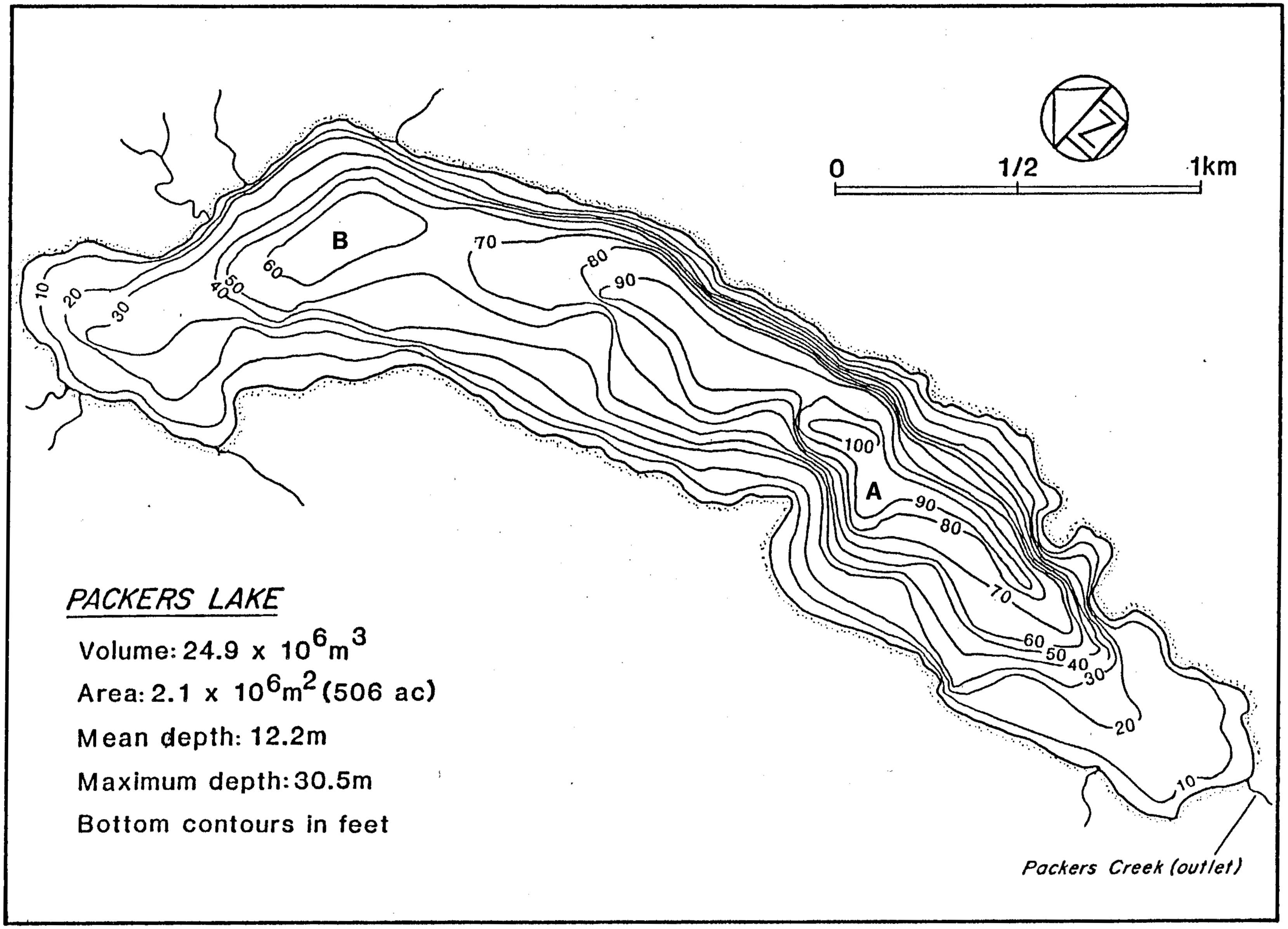

Figure 1. Morphometric map of Packers Lake showing the location of the limnological sampling Stations A and B.

silicon and carbon) as well as for other water-quality parameters (*see* Alaska Department of Fish and Game, Lake Fertilization Guidelines) from both the epilimnetic (1 m) and mid-hypolimnetic zones. Water samples from multiple (4) casts with a nonmetalic Van Dorn sampler were pooled, stored in 8-10 liter translucent carboys, cooled, and transported in light-proof containers to Soldotna for preprocessing. Subsequent filtered and unfiltered water samples were stored (refrigerated or frozen) in acid-cleaned prerinsed polybottles until analyzed by the Soldotna Limnology Laboratory.

All chemical and biological samples were analyzed by methods detailed in Koenings et al. (1985). In general, filterable reactive phosphorus (FRP) was analyzed by the molybdate-blue/ ascorbic-acid method of Murphy and Riley (1962), as modified by Eisenreich et al. (1975). Total phosphorus was determined by the FRP procedure, after persulfate digestion. Nitrate and nitrite were determined as nitrite, after Stainton et al. (1977), following cadmium reduction of nitrate. Ammonium analysis followed Stainton et al. (1977), using the phenolhypochlorite metholodolgy, while silicon analysis followed the procedure of Strickland and Parsons (1972). Alkalinity was determined by 0.02 N H_2SO_4 acid tritration to pH 4.5, using a Corning model-399A specific-ion meter.

Particulate carbon, nitrogen, and phosphorus were estimated directly from filtered plankton prepared by drawing 1-2 liters of lake water through precleaned 4.2-cm GF/F filters. The filters were frozen in individually marked plexislides for storing.

Primary production (algal standing crop) was estimated by chlorophyll a (chl a) analysis, after the fluorometric procedure of Strickland and Parsons (1972). We used the low-strength acid addition recommended by Riemann (1978) to estimate phaeophytin. Water samples (12 liters) were filtered through 4.2-cm Whatman

GF/F filters to which a few mls of saturated $MgCO_3$ solution were added just prior to the completion of filtration. The filters were then stored (frozen) in plexislides for later analysis.

Samples for identification and enumeration of phytoplankton species were collected with a Van Dorn bottle from the 1.0-m, mideuphotic zone and 1% light-level depths at Stations A and B. Phytoplankton were counted by using the Utermohl (1958) settling method and identified according to Prescott (1938).

Zooplankton were collected from duplicate bottom-to-surface vertical tows, using a 20.0-cm-diameter, 153-μ mesh, conical zooplankton net. The net was pulled at a constant 1 m/sec and washed well before removing, and then the organisms were preserved in 10% neutralized sugar-formalin (Haney and Hall 1973). Identification within the genus *Daphnia* followed Brooks (1957); of the genus *Bosmina*, Pennak (1978); and of the Copepods, Wilson (1959), Yeatman (1959), and Harding and Smith (1974). Enumeration consisted of counting triplicate 1-ml subsamples taken with a Hansen-Stempel pipette in a 1-ml Sedgewick-Rafter cell. Sizes (lengths) of individual zooplankter were obtained by measuring individuals along a transect in each of the 1-ml subsamples used in identification and enumeration. Zooplankter were measured to the nearest 0.01 mm, as described in Edmondson and Winberg (1971).

Estimates of yearly phosphorus loading of Packers Lake were calculated after Vollenweider (1976):

Surface specific loading:

$$Lp\ (mgP/m^2/yr) = [P]_{c}^{sp} \cdot Qs\ (1 + \sqrt{\bar{z}/Qs})$$

Surface crtitical loading:

$$Lp\ (mgP/m^2/yr) = 10 \cdot Qs\ (1 + \sqrt{\bar{z}/Qs})$$

Where: $[P]_c^{sp}$ = spring overturn period total P (mg/m^3)

$Qs \quad \bar{z} / tw$

tw = water residence time (yr)

$\bar{z}$ = mean depth (m)

Bottom profiles were recorded with a Raytheon fathometer along several lake transects, and from these depth recordings, a bathymetric map was developed. Using this map, the area of component depth strata was determined with a polar planimeter, and lake volume (V) was computed by summation of successive strata, after Hutchinson (1957):

$$\text{Lake Volume} = \sum_{i=1}^{n} = \frac{h}{3} (A_1 + A_2 + \sqrt{A_1 A_2})$$

Where: $\sum_{i=1}^{n}$ = sum of strata volumes i through n.

A_1 = surface area of upper depth strata (m^2)

A_2 = surface area of lower depth strata (m^2)

h = distance between A_1 and A_2 (m)

Lake surface area (A_L) and drainage area (A_D) were computed from topographic maps, using a polar planimeter. Lake mean depth ($\bar{z}$) was calculated as follows:

$$\bar{z} = V/A_L$$

Where: z = lake mean depth (m)
V = lake volume ($\cdot 110^6 m^3$)
A_L = lake surface area ($\cdot 10^6 m^2$)

The theoretical water residence time (T_w) was then calculated as:

$$T_w \text{ (yr)} = V/TLO$$

Where: T_w = theoretical water residence time (years)

V = total lake volume ($\cdot 10^6 m^3$)

TLO = total lake outflow ($\cdot 10^6 m^3 yr$)

The collection of physical data included the measurement of lake temperatures and light penetration at both Stations A and B. Lake-temperature profiles were measured using a Y.S.I. model-57 meter. These recordings were taken at 1-m increments from the surface to the bottom. The algal light-compensation point was defined as the depth at which 1% of the subsurface light (photosynthetically available radiation [400 to 700 mm]) penetrated (Schindler 1971) and was measured with a Protomatic submersible photometer. Recordings were taken at several depths between the surface and the compensation depth. Using this data, the natural logarithm of light intensity was plotted against depth, and the slope of this line was calculated to determine the mean extinction coefficient. In addition, water transparency was estimated, using a 20-cm Secchi disk.

Finally, in both the tables and figures we have used the designation of either mg L^{-1} or µg L^{-1} to report concentration data. However, in the body of the report we have used either parts per million (ppm) in lieu of mg L^{-1} and parts per billion (ppb) in lieu of µg L^{-1}. We have made this conversion in order to reduce the handling time of the report by our support staff.

RESULTS

Flushing Rate

The annual precipitation at Packers Lake ranges from 51 to 76 cm per year. From the watershed area, the total annual outflow of Packers Lake is estimated to be from $6.7 \times 10^{+6}$ m^3/yr to $24.9 \times 10^{+6}$ m^3/yr, which results in a residence time of once every 4 and 2 years, respectively. Part of this inflow is from tributary streams draining an extensive bog-marsh watershed; however, a portion is also derived from seepage through the surrounding *Sphagnum*-dominated vegetation.

Heating/Cooling Cycle

The heating/cooling cycle within Packers Lake involves the entire water column (Figure 2). Under the ice in March, the entire water column was below 4°C; the temperatures approached 0°C just beneath the ice, and it rose to 3°C below 15 m. After ice-off in mid-May, the surface layers rapidly warmed, reaching 12°C, while temperatures within the hypolimnion increased to ≧5°C before a stable thermocline formed at approximately 5 m. From May through the first week in August, epilimnetic temperatures increased, reaching above 17°C, and the epilimnion deepened to nearly 15 m at both stations. During the same time period, hypolimnetic temperatures increased from 5° to 7°C at the deeper Station A and rose from 5° to nearly 8°C at the shallower Station B. By the

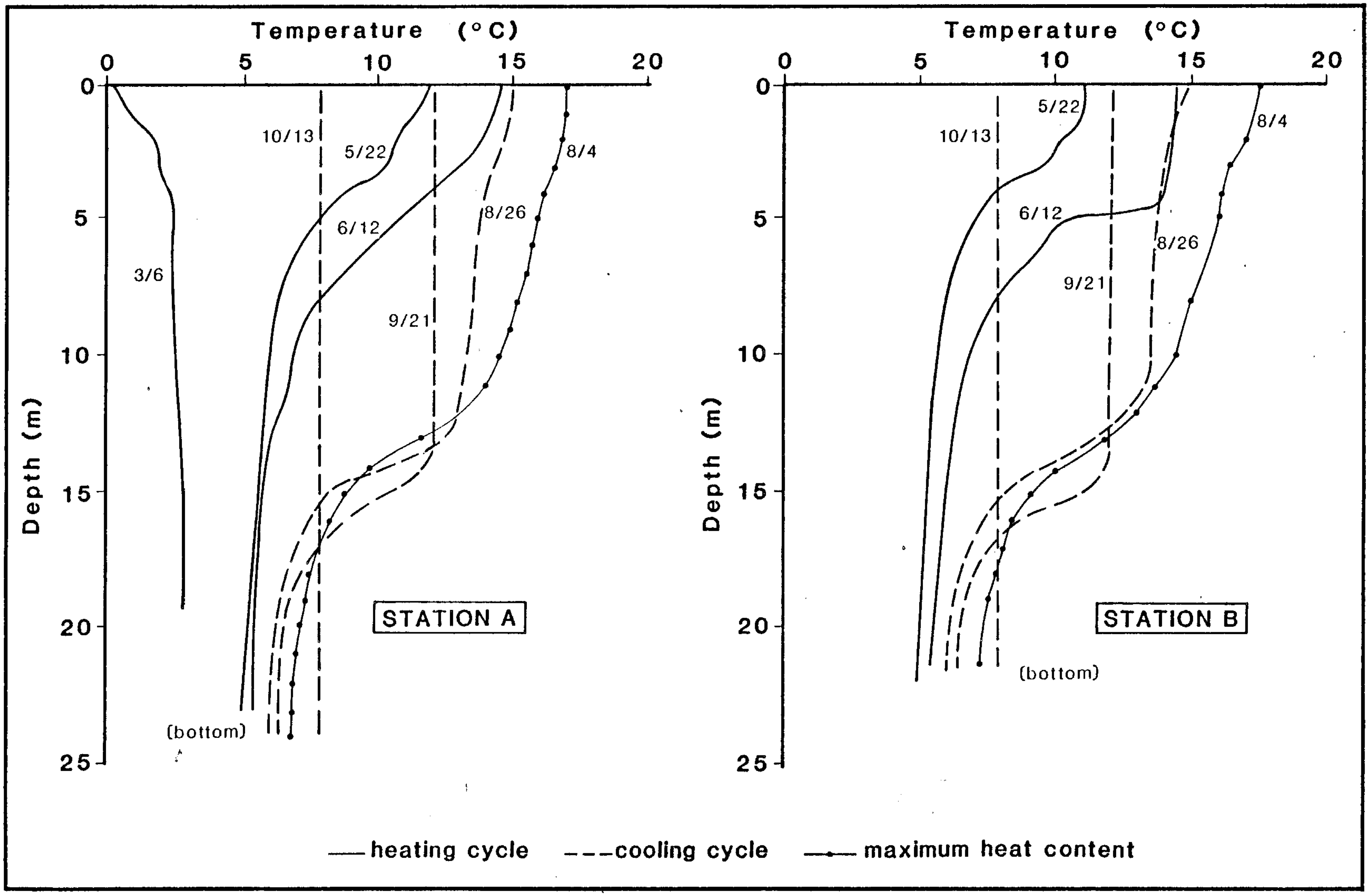

Figure 2. Vertical temperature profiles found within Packers Lake at Stations A and B during 1981 showing the sequential depression of the metalimnion during the heating cycle and the pattern of thermal dispersion during the cooling cycle.

end of August, epilimnetic temperatures began to decline, reaching 12°C by the end of September. Three weeks later the lake was isothermal and mixing from top to bottom at 8°C. Thus, the period of thermal stability lasted from approximately the end of May to the end of September, or for nearly 4 months; and by the beginning of August, the thermocline had deepened to its greatest extent, with the epilimnetic volume representing nearly 85% of the total lake volume.

Light Penetration

Light penetration (as defined by the penetration of 1% of the subsurface photosynthetically available radiation) is severely restricted in Packers Lake throughout the open-water period (Table 1). In the fall of 1980, the euphotic zone extended from only 3.1 to 3.2 m and occupied nearly 24% of the total lake volume. More importantly, the euphotic zone occupied only 27% of the epilimnetic volume, because the metalimnion deepened to 19 m. In 1981 the euphotic zone extended from 3.2 to 4.3 m and averaged 3.7 m. However, after the thermocline formed (by the end of June), the metalimnion extended from 14 to 16 m. Thus, while the epilimnion occupied from 79% to 84% of the total lake volume at Station A and from 65% to 82% at Station B, the euphotic zone occupied only 26% to 32% (at the two stations) of the total lake volume. In 1982 the results were very much the same; i.e., the euphotic volume was only 40% to 46% of the epilimnetic volume, which was slightly (but consistently) greater than that observed in 1980 (27%) and 1981 (32% to 35%). Overall, compared to an euphotic volume equal to only 29% of the lake volume (from July through to the end of September), the epilimnetic volume represented (on the average) nearly 80% of the total lake volume.

Finally, the Secchi-disk depth represented 88% of the depth of the euphotic zone at Station A during the fall period of 1980; while in 1981 the Secchi-disk depth represented only 76% (at Station A) and 74% (at Station B) of the euphotic depth; and in 1982 it represented from 70% to 73% of the euphotic depth at Stations A and B, respectively (Table 1).

Dissolved Gases

The concentration of dissolved oxygen (D.O.) at Station A varied considerably with depth throughout the yearly sampling period (Table 2). In general, D.O. levels within the epilimnion were consistently near or above 9 ppm and ranged from 91% to 135% of saturation. These levels were present even beneath the ice during late winter and early spring. In contrast, the bottom layer (≥20 m in depth) varied between 0.7 and 11.9 ppm and ranged from 5% to 100%. In general, the lower layers showed a decrease in saturation to below 50% and a concentration of 7.0 ppm during the ice-over period. In addition, in every year there was a consistent trend for the concentration of oxygen (and the percent of saturation) to drop during the spring-through-fall period, especially within the hypolimnion. Finally, while taking a series of shallow samples in August 1980, we observed a drop in oxygen concentration near the bottom. Apparently, localized conditions exist where the dissolved-oxygen level remains low despite being within the epilimnion. If such pockets of low D.O. occur frequently in Packers Lake, the ability of salmon juveniles to effectively forage within these areas would be reduced.

Dissolved-oxygen profiles at Station B were very much the same as those found at Station A. That is, the epilimnion was well supplied with oxygen (even during ice-over conditions), and the hypolimnion showed a depression of oxygen levels as the summer-stratification period lengthened. In 1982, Station B was sampled during the winter period at a location that was significantly

Table 1. The seasonal variation in the depth of the euphotic zone and the Secchi disk depth compared to that of the metalimnion within Packers Lake during 1980-1982.

Date	Euphotic depth (m)		Extinction co-efficient* (m)		Secchi disk (m)		Metalimnion depth (m)		Euphotic volume (percent of total volume)		Epilimnetic volume (percent of total volume)		Euphotic volume· Epilimentic volume^{-1} (%)	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1980														
17 Jul	---	---	---	---	---	---	---	---	---	---	---	---	---	---
08 Aug	---	---	---	---	---	---	---	---	---	---	---	---	---	---
18 Sep	3.2	---	1.36	---	2.3	---	18.0	---	24	---	90	---	27	---
29 Oct	3.1	---	1.43	---	3.3	---	Isothermal		24	---	100	---	24	---
1981														
06 Mar	Ice-covered													
22 May	4.1	2.7	1.04	1.70	2.0	2.0	4.0	3.5	30	21	29	26	87	79
12 Jun	3.3	2.6	1.41	1.83	3.0	2.3	5.0	4.5	25	20	35	33	76	61
09 Jul	3.5	3.3	1.30	1.30	2.8	2.9	14.0	10.5	26	25	79	65	32	39
04 Aug	3.3	3.6	1.35	1.33	2.6	2.1	14.0	13.0	25	27	77	74	35	36
26 Aug	3.2	3.2	1.43	1.42	2.2	2.5	16.0	14.0	26	24	84	78	38	31
21 Sep	4.3	4.1	1.01	1.04	3.5	2.8	16.0	15.0	32	30	84	82	35	37
13 Oct	3.9	4.2	1.08	1.02	3.3	3.0	Isothermal		29	31	100	100	29	31
1982														
28 Jan	Ice-covered													
20 Apr	Ice-covered													
15 Jun	4.1	3.7	1.05	1.20	---	2.6	---	9.0	30	28	---	59	---	47
02 Aug	4.5	4.7	0.98	0.95	3.3	3.8	15.0	13.0	33	34	82	74	40	46
26 Aug	4.9	4.7	0.92	0.95	3.2	3.0	14.0	15.0	35	34	78	82	45	42

*For photosynthetically available radiation shallower than the location sampled during the ice-free season. Consequently, the oxygen concentrations as well as the percent-saturation levels were much higher than those found during the same time period at the deeper Station A (Table 2).

General Water-Quality Indicators

The conductivity within Packers Lake was relatively low, but it was very consistent (both with depth and over time [Table 3]). Values ranged from 40 μmhos to 47 μmhos in 1980, from 32 μmhos to 45 μmhos in 1981, and from 34 μmhos to 45 μmhos in 1982. Similarly, pH levels remained very consistent, generally lying slightly on the acidic side of neutral. In 1980 the pH ranged from 5.9 to 7.1, compared to a range of 5.6 to 6.9 in 1981 and 6.4 to 7.3 in 1982. Of additional interest are the levels of calcium, magnesium, and iron. Calcium levels tended to center within the 2.5 to 4.5 ppm range, but magnesium levels were somewhat lower (and more erratic), ranging from the undetectable (<0.3 ppm) to over 4.0 ppm. Iron levels were very high, ranging from 500 to almost 1,100 ppb and, unlike the pattern shown by the calcium and magnesium concentrations, were slightly higher in the hypolimnion than in the epilimnion. However, iron levels within the oxygenated epilimnion remained high throughout the three-year sampling period, indicating the existence of colloidal organic iron (Koenings 1976).

Nutrient Cycles

The concentration of ammonium ($NH4^{+}$) ion was low throughout the year in both the epilimnion and hypolimnion of Packers Lake (Table 3). Values ranged from undetectable levels to nearly 40 ppb, but usually they were $\leq$20 ppb. No consistent differences were observed between the epilimnion and the hypolimnion, even during the summer-stratification period. Indeed, the only discernable cyclic features of this nutrient was its consistently low

Table 2. Temperature and dissolved oxygen levels found in Packers Lake within the epilimnion (surface) and hypolimnion (bottom) over the three years of study (1980-1982).

	Station A						Station B					
			Dissolved Oxygen						Dissolved oxygen			
	Temperature (°C)		Surface		Bottom		Temperature (°C)		Surface		Bottom	
Date	Surface	Bottom	(mg L^{-1})	(% Sat.)	(mg L^{-1})	(% Sat.)	Surface	Bottom	(mg L^{-1})	(% Sat.)	(mg L^{-1})	(% Sat.)
07/17/80	--	--	--	--	--	--	--	--	--	--	--	--
08/08/80	16.0	13.5*	8.7	87	4.0	37	--	--	--	--	--	--
09/18/80	12.3	8.0	14.5	135	8.2	68	--	--	--	--	--	--
10/29/80	6.0	6.0	11.4	91	11.4	91	--	--	--	--	--	--
03/06/81	0.1	3.0	13.5	93	10.9	80	--	--	--	--	--	--
05/22/81	12.0	5.0	11.4	105	10.6	83	11.0	5.0	12.0	107	11.0	85
06/12/81	14.5	5.5	11.8	115	11.2	88	14.5	5.5	12.2	118	11.9	94
07/09/81	14.0	6.1	10.8	104	9.8	78	15.0	6.1	11.0	108	9.9	79
08/04/81	17.0	6.9	8.9	91	9.1	74	17.5	7.2	9.6	99	9.4	77
08/26/81	15.0	6.0	9.8	96	7.1	56	14.9	6.2	9.9	97	7.2	57
09/21/81	12.1	6.2	10.8	100	7.0	56	12.2	6.5	10.5	97	6.6	53
10/13/81	7.9	7.9	12.3	103	11.9	100	7.9	7.9	11.9	100	11.6	97
01/28/82	1.2	4.0	14.4	102	0.7	5	0.9	2.9**	13.1	92	11.4	84
04/20/82	1.0	3.8	14.0	106	2.5	19	1.5	3.2***	14.0	99	6.5	49
06/15/82	--	--	--	--	--	--	11.5	6.2	11.6	105	10.9	87
08/02/82	18.0	6.8	11.0	114	10.0	82	18.0	7.0	10.7	111	9.9	82
08/25/82	15.5	7.5	10.5	105	10.3	85	15.0	7.4	10.5	103	10.5	87

*10 m depth
**11.5 m depth
***16.0 m depth

concentration and its slight increase in concentration during the August-September period.

In contrast, nitrate + nitrite ions showed a definite seasonal cycle, with a depression occuring within the epilimnion during the summer period (Table 3). Values ranged from 16 to nearly 200 ppb; higher levels appeared within the hypolimnion during the late fall-winter period and within the upper strata during both the winter and isothermal periods. During the summer, when the lake was strongly stratified, epilimnetic nitrate + nitrite levels reached yearly lows, but they were always detectable; i.e., concentrations were usually ≧50 ppb. Thus, the inorganic nitrogen present within the epilimnion of Packers Lake showed a seasonal depression only during the summer stratification period.

Like the inorganic nitrogen species, reactive silicon was always detectable (regardless of both the year and time of year), reaching over 4,000 ppb in 1980 (Table 3). In addition, when compared to hypolimnetic levels during the summer period,the seasonal cycle showed a distinct lowering of epilimnetic concentrations, a trend for silicon levels to be generally higher within the hypolimnion in the late fall-winter period, and a decrease in concentration during the spring period. However, reactive silicon levels were not challenged by the phytoplankton within Packers Lake.

Total phosphorus (TP) concentrations were high within the lake, often reaching beyond 20 ppb and on occasion peaking to just under 30 ppb. Over the three years of study, TP concentrations averaged in excess of 15 ppb within the epilimnion and over 14 ppb in the hypolimnion. Within a seasonal cycle, higher TP levels were generally observed in the fall (August-September); lower levels occurred in the mid-summer period after ice-out.

Reactive phosphorus (inorganic phosphorus) was always detectable within both the epilimnetic and hypolimnetic strata. Nearly 30%

Table 3. General water quality parameters and algal nutrient levels found for Packers Lake within both the epilimnion and hypolimnion throughout three years of study (1980-1982).

Date/Depth	07/17/80		08/08/80		09/18/80		10/29/80		03/06/81		05/22/81				06/12/81				07/09/81			
	Station A		Station A		Station A		Station A		Station A		Station A		Station B		Station A		Station B		Station A		Station B	
Parameter	1 m	10 m	1 m	8 m	1 m	20 m	1 m	20 m	1 m	18 m	1 m	20 m	1 m	15 m	1 m	15 m	1 m	15 m	1 m	18 m	1 m	18 m
Conductivity (μmhos cm^{-1})	40	42	43	47	42	42	41	41	45	45	40	43	43	43	45	43	43	45	42	42	43	42
pH	6.7	6.7	6.6	5.9	7.1	6.7	6.7	6.7	6.6	6.7	6.3	6.3	6.4	6.2	6.3	6.2	6.4	6.3	5.8	5.7	5.6	5.6
Alkalinity (mg L^{-1} as $CaCO_3$)	11	8	13	4	10	10	9	9	10	10	8	8	8	8	8	8	8	7	9	12	11	12
Calcium (mg L^{-1})	4.9	4.9	2.5	3.4	2.6	2.6	3.3	2.8	2.6	2.9	2.4	2.4	2.4	2.4	2.5	2.5	2.5	2.5	4.0	4.8	4.0	4.1
Magnesium (mg L^{-1})	1.7	1.1	1.4	1.4	1.2	1.2	1.1	0.8	1.0	1.0	3.2	3.9	3.2	3.2	2.0	2.0	2.5	2.0	<0.3	<0.3	3.3	0.4
Iron (μg L^{-1})	1,078	698	623	640	509	656	626	678	939	657	917	901	995	1,016	606	595	854	947	786	817	794	906
Total Dissolved Solids (mg L^{-1})	102	69	40	38	58	54	50	53	38	52	52	--	--	70	--	--	--	--	80	--	--	54
Total Phosphorus (μg L^{-1} as P)	11.2	11.5	10.7	10.0	11.4	12.4	11.5	9.9	14.7	14.2	28.9	13.5	--	11.7	9.7	9.2	12.9	10.5	15.9	14.3	16.1	15.4
Total Filterable Phosphorus (μg L^{-1} as P)	5.3	6.1	9.8	4.8	5.5	8.2	7.2	6.9	7.3	11.5	--	13.3	5.9	14.9	5.4	7.9	6.3	6.5	7.6	7.6	7.0	6.1
Filterable Reactive Phosphorus (μg L^{-1} as P)	3.4	3.9	2.7	2.4	4.4	5.3	5.2	4.7	4.8	6.8	--	6.4	4.0	--	3.7	6.2	4.5	3.7	6.4	2.5	4.3	6.6
Nitrate+Nitrite (μg L^{-1} as N)	--	49	23	51	62	178	118	120	165	199	71	142	106	142	80	146	83	125	77	143	78	150
Ammonium (μg L^{-1} as N)		<0.5	<0.5	8	9	7	19	21	9	3	7	2	7	15	15	19	27	30	14	--	8	15
Reactive Silica (μg L^{-1} as Si)	3,408	3,716	3,231	3,540	3,466	4,088	3,477	3,520	3,617	3,664	3,277	3,424	3,334	3,638	3,270	3,436	3,255	3,487	3,368	3,563	3,220	3,400

- Continued -

Table 3 continued. General water quality parameters and algal nutrient levels found for Packers Lake within both the epilimnion and hypolimnion throughout three years study of (1980-1982).

Date/Depth Parameter	08/04/81				08/26/81				09/17/81				10/13/81				01/28/82			
	Station A		Station B		Station A		Station B		Station A		Station B		Station A		Station B		Station A		Station B	
	1 m	18 m	1 m	18 m	1 m	18 m	1 m	18 m	1 m	18 m	1 m	18 m	1 m	18 m	1 m	18 m	1 m	20 m	1 m	10 m
Conductivity (μmhos cm^{-1})	37	36	32	32	37	36	37	36	37	37	37	37	36	36	41	37	42	40	42	40
pH	6.0	6.4	6.9	6.4	5.8	6.0	6.0	5.8	6.0	6.0	5.9	5.9	6.5	6.1	5.7	6.0	6.9	6.8	6.9	6.9
Alkalinity (mg L^{-1} as $CaCO_3$)	9	10	9	10	8	9	10	11	10	11	11	11	8	8	4	9	11	11	12	11
Calcium (mg L^{-1})	4.1	3.3	3.3	4.1	9.7	9.7	9.7	9.7	3.3	3.3	4.2	2.5	2.5	2.5	2.5	3.4	4.4	3.5	4.4	4.4
Magnesium (mg L^{-1})	1.5	1.5	1.5	1.5	<0.3	<0.3	<0.0	<0.3	1.3	1.3	1.3	1.3	3.1	0.4	1.5	0.2	3.8	2.8	3.8	0.3
Iron (μg L^{-1})	748	777	652	819	704	870	713	929	589	871	678	1,033	525	549	564	599	837	968	943	802
Total Dissolved Solids (mg L^{-1})	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total Phosphorus (μg L^{-1} as P)	9.9	16.9	16.5	15.9	15.5	16.4	14.9	18.8	21.4	17.1	8.9	22.4	16.6	16.9	12.4	17.2	11.3	14.7	10.4	12.1
Total Filterable Phosphorus (μg L^{-1} as P)	4.1	7.9	5.5	8.7	5.1	7.6	5.2	9.3	7.3	11.1	4.9	9.8	7.7	6.4	7.2	7.2	8.4	11.5	8.8	7.9
Filterable Reactive Phosphorus (μg L^{-1} as P)	2.3	2.9	2.2	3.9	2.1	3.0	3.4	4.3	6.4	7.6	2.4	5.8	4.4	3.6	2.2	3.3	6.3	5.7	4.5	4.5
Nitrate+Nitrite (μg L^{-1} as N)	53	164	59	168	65	179	70	181	87	187	82	188	105	117	124	126	173	179	176	168
Ammonium (μg L^{-1} as N)	5	7	16	17	39	22	17	14	26	17	20	14	3	9	16	19	13	14	12	13
Reactive Silica (μg L^{-1} as Si)	3,375	3,642	3,268	3,684	3,349	3,909	3,444	3,867	3,398	3,868	3,396	3,932	3,256	3,263	3,344	3,311	3,701	3,593	3,774	3,331

- Continued -

Table 3 continued. General water quality parameters and algal nutrient levels found for Packers Lake within both the epilimnion and hypolimnion throughout three years of study (1980-1982).

Date/Depth	04/20/82				06/16/82				08/02/82				08/25/82				02/02/83			
	Station A		Station B		Station A		Station B		Station A		Station B		Station A		Station B		Station A		Station B	
Parameter	1 m	18 m	1 m	12 m	1 m	15 m	1 m	15 m	1 m	17 m	1 m	10 m	1 m	20 m	1 m	18 m	1 m	12 m	1 m	17 m
Conductivity (μmhos cm^{-1})	41	41	43	41	34	34	34	34	34	36	34	34	44	44	45	44	47	45	49	46
pH	6.7	6.7	6.9	6.8	6.4	6.5	6.7	6.5	7.1	6.5	6.8	6.7	7.3	6.6	7.3	6.7	6.6	6.6	6.6	6.6
Alkalinity (mg L^{-1} as $CaCO_3$)	11	12	12	12	10	10	10	10	11	13	12	12	12	11	12	11	12	12	12	12
Calcium (mg L^{-1})	4.9	4.1	3.3	3.3	3.7	3.7	3.7	3.0	3.0	3.4	2.6	3.0	3.4	2.5	2.5	2.5	3.4	2.9	3.9	3.9
Magnesium (mg L^{-1})	2.4	1.4	2.4	2.4	2.9	3.5	4.0	2.9	0.4	1.0	0.7	1.3	0.9	0.9	0.9	1.2	1.8	0.2	2.1	0.5
Iron (μg L^{-1})	728	913	939	939	925	1,007	932	1,005	728	913	695	763	662	1,031	678	1,081	875	730	970	1,022
Total Dissolved Solids (mg L^{-1})	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Total Phosphorus (μg L^{-1} as P)	12.7	16.9	21.9	14.2	13.1	12.8	27.3	12.1	19.5	17.2	18.1	16.9	16.4	12.3	17.2	22.8	18.2	25.1	15.9	20.2
Total Filterable Phosphorus (μh L^{-1} as P)	8.5	12.4	8.7	8.6	15.5	--	14.4	8.8	9.7	12.6	8.2	9.4	8.8	11.3	6.6	10.9	11.3	10.9	8.6	12.0
Filterable Reactive Phosphorus (μg L^{-1} as P)	2.9	7.4	4.3	4.1	11.2	--	11.4	7.3	5.6	7.8	5.9	5.4	4.9	8.4	3.4	5.6	3.6	3.9	4.1	6.3
Nitrate+Nitrite (μg L^{-1} as N)	142	189	144	188	101	122	96	118	49	134	53	82	17	133	16	152	137	143	135	167
Ammonium (μg L^{-1} as N)	30	12	12	12	11	14	11	27	5	29	5	14	4	3	3	3	15	6	7	7
Reactive Silica (μg L^{-1} as Si)	3,714	3,902	3,890	3,890	3,017	3,083	2,981	3,047	3,214	3,677	3,227	3,393	3,219	3,749	3,234	3,745	3,541	3,260	3,736	3,526

of the total phosphorus present was in the reactive state, compared to only 53% in the particulate fraction. Reactive phosphorus levels ranged from a low of 2.3 ppb to a high of 11.3 ppb but often centered around 4.0 ppb. In addition, we found little evidence for hypolimnetic enrichment of reactive phosphorus, but we could discern a light summer-period depression of the reactive-phosphorus concentration within both the hypolimnion and the epilimnion.

Because reactive-phosphorus levels were very consistent within the lake (both over time and with depth), we questioned its ultimate availability to the phytoplankton. This question was raised by our ability to divide the reactive phosphorus of Packers Lake into fractions that could pass through a GF/F filter (0.5 micron normal pore size) and, additionally, through an ultrafilter (a nominal molecular weight cut-off of 10,000) (Table 4). The first fraction is termed filterable reactive phosphorus and represents colloidal forms of reactive phosphorus as well as reactive phosphorus in true solution. This latter soluble fraction of reactive phosphorus is recovered after passage through the ultrafilter. In Packers Lake, from 0% to 41% of the filterable reactive phosphorus was recovered in the ultrafiltrate; this means that nearly 60% to 100% of the reactive phosphorus was not in true solution but, rather, was in colloidal suspension (Table 4). Within the reactive-phosphorus component (typically interpreted as soluble reactive phosphorus), a highly significant portion is actually not in true solution within both the epilimnion and the hypolimnion; i.e., it is present during the spring-to-early-fall period as colloidal reactive phosphorus. This colloid formation may act to significantly reduce the availability of inorganic phosphorus to the phytoplankton of Packers Lake. Finally, our preliminary measurements of the relative concentration of the organic acids (by ultraviolet absorption) indicate that nearly 40% were colloidal in size. If these percentages hold in our future work (and are duplicated in our iron-fractionation experiments), it would mean

Table 4. The distribution of filterable reactive phosphorus (FRP) between the amount in solution (dialyzable) and that in colloidal suspension in the spring and summer at Packers Lake in 1982.

Date	Station	Depth (m)	Filterable reactive phosphorus ($\mu g\ L^{-1}$)	Dialyzable reactive phosphorus ($\mu g\ L^{-1}$)	Colloidal reactive phosphorus (%)
8/2/82	A	1 m	5.6±0.00	2.3±0.21	59
		17 m	7.8±0.00	0.9±0.21	88
	B	1 m	5.9±0.49	<0.5±0.00	100
		10 m	5.4±0.28	0.6±0.14	89
6/16/82	A	1 m	11.2±0.71	1.6±0.07	86
		15 m	149.4±2.69*	22.5±0.71*	85
	B	1 m	11.4±0.64	4.1±0.21	64
		15 m	7.3±0.21	2.6±0.64	64
4/20/82	A	1 m	2.9±0.15	<0.5±0.00	100
		18 m	7.3±0.23	0.7±0.15	90
	B	1 m	4.3±0.35	<0.5±0.00	100
		12 m	4.1±0.12	<0.5±0.00	100

*Probable bottle contamination

that the colloidal fraction is the principle size category affecting the availability of inorganic phosphorus and that it does so at a much lower organic-acid-to-phosphorus ratio than would the non-colloidal organic acids.

Finally, in an attempt to further determine the concentration of biologically available phosphorus (BAP), we fractionated particulate phosphorus into two components; namely, inorganic particulate phosphorus (IPP) and organic particulate phosphorus (OPP) (Table 5). Compared to glacial systems in Cook Inlet, which contain a high amount of particulate phosphorus (31.6 to 45.0 ppb) and a large percentage of IPP (73% to 82%), Packers Lake contained a smaller amount of particulate phosphorus (4.0 to 9.1 ppb) and a smaller percentage of IPP (19% to 22%). In addition, we found a common feature between clear-water systems and brown-water systems: the amounts of IPP were very similar as were the overall percentages of IPP. In contrast, the glacial systems that share with brown-water systems the common feature of low-light penetration (i.e., small euphotic zone) have extremely high levels of IPP, relative to both Packers Lake and other clear-water systems. Thus, IPP was not found to be a major pool of nonbiologically available phosphorus in Packers Lake.

Nutrient Ratios

Within Packers Lake, the ratio of inorganic nitrogen to filterable reactive phosphorus (IN:RP) was generally greater than 14:1 (Table 6) within both the epilimnetic and hypolimnetic strata. In general, the epilimnetic IN:RP ratio was higher during the winter period, but subsequent to ice-out, it dropped, reaching yearly minimums during the July-August period. Within the hypolimnion (especially during the 1981 season), the IN:RP ratio rose principally as a response to a curious decrease in the reactive-phosphorus concentration. Overall, the lake demonstrated a healthy IN:RP balance (during the three years of study), except for the summer of 1982

Table 5. Distribution of total particulate phosphorus (TPP) between inorganic particulate phosphorus (IPP) and organic particulate phosphorus (OPP) for several lakes on the Kenai Peninsula geographically adjacent to Packers Lake.

Lake (type)	Station/ Depth (m)	Date	TPP ($\mu g\ L^{-1}$)	IPP ($\mu g\ L^{-1}$)	IPP (%)	OPP ($\mu g\ L^{-1}$)	OPP (%)
Tustumena (glacial)	A/ 1	06/05/81	42.8	29.9	70	12.9	30
	A/30	06/05/81	36.3	29.1	80	7.3	30
	B/ 1	06/05/81	45.0	36.2	80	8.8	20
	B/30	06/05/81	43.1	34.2	79	8.9	21
	C/ 1	06/05/81	44.4	35.9	81	8.6	19
	C/30	06/05/81	42.2	34.6	82	7.7	18
Tustumena (glacial)	A/ 1	07/09/81	41.0	30.1	73	10.9	27
	A/30	07/09/81	33.7	24.5	73	9.2	27
	B/ 1	07/09/81	38.3	29.2	76	9.1	23
	B/30	07/09/81	31.6	23.8	75	7.8	25
Kenai (glacial)	A/ 1	06/23/81	6.7	4.6	69	2.1	32
	A/25	06/23/81	6.9	5.2	75	1.8	25
	B/ 1	06/23/81	7.4	4.7	64	2.7	36
	B/30	06/23/81	6.7	5.4	81	1.3	19
	C/ 1	06/23/81	6.9	5.3	77	1.6	23
Bear (clear)	A/ 1	03/03/82	2.3	0.4	18	1.9	83
	A/12	03/03/82	9.7	0.7	7	9.0	93
	B/ 1	03/03/82	2.6	0.3	11	2.3	88
	B/12	03/03/82	8.2	0.6	7	7.6	93
Hidden (clear)	A/ 1	10/28/82	2.5	0.2	9	2.3	91
	A/15	10/28/82	3.0	0.6	21	2.4	79
	B/ 1	10/28/82	2.2	0.5	23	1.7	77
	B/28	10/28/82	3.1	0.9	31	2.1	69
Packers (stained)	A/ 1	06/15/82	4.8	0.9	19	3.9	81
	A/15	06/15/82	4.0	0.9	21	3.1	79
	B/ 1	06/15/82	9.1	2.0	22	7.1	78
	B/15	06/15/82	4.2	0.9	22	3.3	78

Table 6. The ratios (by atoms) between inorganic nitrogen (IN) and filterable reactive phosphorus found in the epilimnion and hypolimnion of Packers Lake. Inorganic nitrogen represents the sum of ammonia + ammonium, nitrate + nitrite.

Date	Station A Epilimnion	Station A Hypolimnion	Station B Epilimnion	Station B Hypolimnion
07/17/80	--	28:1	--	--
08/08/80	19:1	54:1	--	--
09/18/80	36:1	77:1	--	--
10/29/80	58:1	66:1	--	--
03/06/81	80:1	66:1	--	--
05/22/81	--	50:1	63:1	--
06/12/81	57:1	59:1	54:1	93:1
07/09/81	32:1	127:1	44:1	55:1
08/04/81	53:1	131:1	75:1	105:1
08/26/81	110:1	148:1	57:1	100:1
09/17/81	39:1	59:1	94:1	77:1
10/12/81	54:1	78:1	141:1	97:1
01/28/82	65:1	75:1	93:1	89:1
04/20/82	131:1	60:1	80:1	108:1
06/16/82	22:1	--	21:1	44:1
08/20/82	21:1	46:1	22:1	39:1
08/25/82	9:1	36:1	12:1	61:1

when the ratio within the epilimnion decreased to below 14:1 for the first time.

Primary Production

The magnitude and seasonal pattern of primary production was followed by using standing-crop estimates of the phytoplankton through chlorophyll a (chl a) content and through species composition, density, and calculated-carbon content.

The concentration of chl a within the epilimnion varied considerably over time, with depth, and between stations. In 1980 our sampling began in July and extended through October. During this period, epilimnetic chl a concentrations at Station A were fairly high, ranging from 1.23 to 7.8 ppb (Table 7). At the same time, the chl a content within the lower stratum sampled ranged from 0.57 to 1.4 ppb. However, while the lower depths sampled were consistently below the euphotic zone, they were always located within the extreme lower limit of the epilimnion.

In 1981 within-lake, seasonal chl a patterns were estimated from an additional Station (B), and the sampling regime began earlier in March and ended in October. The chl a content within the surface stratum ranged from 0.23 to 3.24 ppb, while within the hypolimnion, chl a levels were considerably lower, ranging from 0.05 to 0.44 ppb. A seasonal pattern, evident at both stations, emerged from an early pulse in chl a production during early spring (after ice-out); this was followed by a decrease in chl a during June and then by a summer peak in August. After the August pulse (3.24 and 3.18 ppb at Stations A and B, respectively), chl a levels declined, reaching seasonal lows in September at Station A and in October at Station B.

In 1982 the seasonal chl a pattern followed that established for the lake during 1981. Under one meter of ice in January, chl a

Table 7. The seasonal variation in algal standing crop [chl *a* ($\mu g\ L^{-1}$)] within the epilimnion (1 m)) and hypolimnion of Packers Lake at Stations A and B from 1980-1982.

Date	Station A Epilimnion	Station A Hypolimnion	Station B Epilimnion	Station B Hypolimnion
07/17/80	3.45	0.57	--	--
08/08/80	3.00	0.83	--	--
09/18/80	7.80	1.40	--	--
10/29/80	1.23	1.19	--	--
03/06/81	0.30	--	--	--
05/22/81	3.84	0.19	2.96	0.39
06/12/81	0.77	0.14	0.50	0.25
07/09/81	2.66	0.25	1.55	0.22
08/04/81	3.24	0.44	3.18	0.23
08/26/81	1.77	0.05	1.48	0.11
09/21/81	0.23	0.17	0.38	0.06
10/13/81	0.45	0.15	0.22	0.02
01/28/82	0.39	0.22	0.26	--
04/20/82	2.07	0.26	6.51	0.49
06/16/82	0.38	0.15	0.98	0.38
08/02/82	1.20	0.23	0.90	0.15
08/25/82	2.64	0.15	2.96	0.15

levels were very low, ranging from 0.22 ppb at Station B to 0.39 ppb at Station A. During April under 1.3 m of ice and 6 cm of snow, the chl a concentrations near the bottom of the ice layer increased to 2.07 ppb at Station A and to 6.51 ppb at Station B. However, shortly after stratification in June, chl a levels had decreased 0.38 ppb at Station A and to 0.98 ppb at Station B. During August we found that chl a levels again increased, reaching an open-water period high of 2.64 ppb at Station A and 2.96 ppb at Station B. In contrast, within the hypolimnion chl a levels were very low throughout the study period, ranging from 0.15 to 0.26 ppb at Station A and from 0.15 to 0.49 ppb at Station B.

Composition of the Phytoplankton

The major taxonomic groups of phytoplankton in Packers Lake were characterized by the amount of cell carbon (Table 8). The major taxonomic groups included diatoms, *Bacillariophyta*, greens, *Chrysophyta*, the small-celled μ-algae, and the blue-greens, *Cyanophyta*. Overall, in both the epilimnion and hypolimnion, we found very high percentages of diatoms, greens, and μ-algae; also a few blue-green species were represented. Comparisons of μ-algae between the two strata revealed a consistent difference. That is, during the strongly stratified period of both years, i.e., June through August, we observed a lower (2%-6%) component of the μ-algae within the epilimnetic phytoplankton, compared to a much larger percentage (19%-29%) in the hypolimnion. We did not observe the same consistent difference between the two depths for the larger-sized diatoms and green algae. In addition, during periods when the lake was isothermal, i.e., May and October of 1981, the percent contribution of the μ-algae, relative to the other taxa, was low and was essentially equal between the two strata. Moreover, in February under the ice, we found a very substantial contribution (32% to 57%) of this fraction in the phytoplankton community. Since the lowered percent compositions were found only in the photic zone above an existing metalimnion,

Table 8. The composition of Packers Lake phytoplankton at Stations A and B within the epilimnion and hypolimnion expressed as a percent of total cell carbon.

Date	Depth	Bacillariophyta		Chrysophyta		Cyanophyta		μ-Algae		Others	
		A	B	A	B	A	B	A	B	A	B
05/22/81	Epilimnion	4	6	37	49	0	9	8	6	50	30
	Hypolimnion	2	86	77	6	1	0	9	8	10	0
08/04/81	Epilimnion	37	36	17	15	0	6	5	5	40	39
	Hypolimnion	42	54	17	11	2	1	23	20	15	14
08/26/81	Epilimnion	51	54	20	25	5	2	6	5	19	13
	Hypolimnion	42	46	16	24	0	0	20	19	21	12
10/13/81	Epilimnion	5	17	47	36	0	<1	7	9	41	38
	Hypolimnion	16	12	20	21	0	0	9	15	54	52
06/15/82	Epilimnion	<1	12	60	53	0	0	6	3	33	32
	Hypolimnion	5	10	48	24	0	0	18	20	29	46
08/25/82	Epilimnion	23	23	25	17	8	10	2	3	41	47
	Hypolimnion	--	--	--	--	-	--	--	--	--	--
02/02/83	Epilimnion	4	5	39	21	0	0	57	67	--	8
	Hypolimnion	5	3	33	51	0	0	44	32	18	14

one would argue for a greater usage of this component by the zooplankton within the epilimnion, compared to that occurring within the hypolimnion.

Seasonal and/or vertical trends within or between remaining taxa were not as apparent, although early spring and winter percent compositions of the diatoms generally appeared to be somewhat lower (2%-12%), when compared to those present when the lake was well stratified (23%-54%) over the summer period. Overall, the phytoplankton community was well balanced with a healthy representation by both diatoms and green algae and by a lack of blue-green species.

<u>Secondary Production</u>

The zooplankton community within Packers Lake consists of four species of cladocerans, three species of copepods, and three major taxa of rotifers (Table 9). In general, the rotifer community consists of the herbivorous feeding *Kellicottia longispina*, *Conochiloides* sp., and *Filinia* sp. While numerically important in assessing secondary production, the rotifers are not directly important food items for rearing salmonid fry. Furthermore, the rotifers compete with the smaller herbivorous macrozooplankton (e.g., Bosmina) for food so that useable forms of fish forage are reduced.

The macrozooplankton community is comprised of the cladoceran species, *Daphnia longiremus*, *Bosmina longirostris*, *Holopedium gibberum*, and the rare *Leptodora kindti*. Except for *Leptodora*, a large predator, the cladoceran-feeding mode is primarily herbivorous through a slightly selective form of filter feeding. The copepod community is comprised of the omnivorous *Cyclops columbianus* and the herbivorous *Diaptomus pribilofensis* and *Epischura nevadensis*. The copepods as a group are highly selective feeders, compared to the cladocerans; *Cyclops* is

Table 9. The seasonal variation in the standing crop [density (No/m^2)] of zooplankton by major taxa at Stations A and B of Packers Lake in 1980-1983.

	Station A							
	1981							
	03 Mar	22 May	12 Jun	09 Jul	04 Aug	26 Aug	21 Sep	13 Oct
Cladocera								
Daphnia longiremus	28,196	12,757	30,179	26,672	15,433	12,978	5,864	16,050
Bosmina longirostris	0	14,403	9,088	11,943	18,930	21,497	43,519	19,891
Holopedium gibberum	0	1,372	10,289	0	309	0	0	0
Leptodora kindti	0	0	0	0	27	Rare	309	Rare
Subtotal	28,196	28,532	49,556	38,615	34,699	34,475	49,692	35,941
Copepoda								
Cyclops columbianus	38,816	20,576	42,867	14,331	5,762	4,538	25,309	26,749
Diaptomus pribilofensis	0	1,372	96,022	349,124	71,708	43,790	118,004	35,185
Epischura nevadensis	0	0	14,232	5,573	8,539	2,866	720	1,098
Subtotal	38,816	21,948	153,121	369,028	86,009	51,194	144,033	63,032
Total macrozooplankton	67,012	50,480	202,677	407,643	120,708	85,669	193,725	98,973
Rotifera								
Kellicottia longispina	3,477	14,884	67,558	22,293	36,626	7,166	5,865	43,210
Conochiloides sp.	0	2,538	119,342	144,507	3,087	797	2,778	412
Filinia sp.	3,760	19,890	64,644	0	1,029	0	720	5,761
Others	0	2,264	2,230	1,115	720	0	2,058	206
Subtotal	7,237	39,576	253,774	167,915	41,462	7,963	11,421	49,589
Total zooplankton	74,249	90,056	456,451	575,558	162,170	93,632	205,146	148,562

- Continued -

Table 9 continued. The seasonal variation in the standing crop [density (No/m^2)] of zooplankton by major taxa at Stations A and B of Packers Lake in 1980-1983.

	Station B							
	1981							
	03 Mar	22 May	12 Jun	09 Jul	04 Aug	26 Aug	21 Sep	13 Oct
Cladocera								
Daphnia longiremus	---	12,551	51,852	26,433	12,346	11,625	16,873	14,198
Bosmina longirostris	---	12,826	11,283	7,962	14,678	14,331	42,113	19,685
Holopedium gibberum	---	1,577	32,648	1,592	Rare	0	0	0
Leptodora kindti	---	0	0	80	Rare	Rare	Rare	0
Subtotal	---	26,954	95,783	36,067	27,110	25,956	58,986	33,883
Copepoda								
Cyclops columbianus	---	30,865	23,285	22,771	10,563	5,255	30,590	25,378
Diaptomus pribilofensis	---	412	241,736	150,319	97,394	115,128	66,804	43,004
Epischura nevadensis	---	0	8,882	11,147	9,602	3,185	3,155	686
Subtotal	---	31,277	273,903	184,237	117,559	123,568	100,549	69,068
Total macrozooplankton	---	58,231	369,686	220,304	144,669	149,524	159,535	102,951
Rotifera								
Kellicottia longispina	---	16,667	42,490	31,370	38,409	5,733	7,683	21,948
Conochiloides sp.	---	8,916	145,714	80,255	9,602	1,593	6,447	0
Filinia sp.	---	24,691	49,452	955	1,372	0	7,408	2,332
Others	---	3,636	3,841	0	0	0	0	0
Subtotal	---	53,910	241,497	112,580	49,383	7,326	21,538	24,280
Total zooplankton		112,141	611,183	332,884	194,052	156,850	181,073	127,231

- Continued -

Table 9 continued. The seasonal variation in the standing crop [density (No/m^2)] of zooplankton by major taxa at Stations A and B of Packers Lake in 1980-1983.

	Station A					
	1982					1983
	28 Jan	20 Apr	15 Jun	02 Aug	25 Aug	02 Feb
Cladocera						
Daphnia longiremus	49,682	32,166	---	6,370	17,516	---
Bosmina longirostris	0	0	---	5,255	23,647	---
Holopedium gibberum	0	0	---	955	239	---
Leptodora kindti	0	0	---	0	0	---
Subtotal	49,682	32,166		12,580	41,402	
Copepoda						
Cyclops columbianus	76,752	25,239	---	2,548	4,220	---
Diaptomus pribilofensis	2,389	0	---	225,478	54,459	---
Epischura nevadensis	0	0	---	3,662	5,892	---
Subtotal	79,141	25,239	---	231,688	64,571	
Total macrozooplankton	128,823	57,405	---	244,268	105,973	
Rotifera						
Kellicottia longispina	54,936	2,866	---	21,816	113,376	---
Conochiloides sp.	0	0	---	0	80,971	---
Filinia sp.	4,299	2,070	---	0	239	---
Others	0	0	---	478	0	---
Subtotal	59,235	4,936	---	22,294	194,586	
Total zooplankton	188,058	62,341	---	266,562	300,559	---

- Continued -

Table 9 continued. The seasonal variation in the standing crop [density (No/m^2)] of zooplankton by major taxa at Stations A and B of Packers Lake in 1980-1983.

	Station B					
	1982					1983
	28 Jan	20 Apr	15 Jun	02 Aug	25 Aug	02 Feb
Cladocera						
Daphnia longiremus	36,067	23,209	14,809	11,704	13,217	31,847
Bosmina longirostris	0	0	42,039	5,334	51,433	0
Holopedium gibberum	0	558	17,516	0	Rare	0
Leptodora kindti	0	0	Rare	0	0	0
Subtotal	36,067	23,767	74,354	17,038	64,650	31,847
Copepoda						
Cyclops columbianus	36,067	15,566	17,994	239	4,777	63,933
Diaptomus pribilofensis	478	0	28,662	37,182	42,994	0
Epischura nevadensis	0	0	10,669	6,688	6,370	0
Subtotal	36,545	15,566	57,325	44,109	54,141	63,933
Total macrozooplankton	72,582	39,333	131,679	61,147	118,791	95,780
Rotifera						
Kellicottia longispina	76,672	9,594	13,854	11,625	131,051	65,287
Conochiloides sp.	239	0	0	0	233,408	0
Filinia sp.	3,503	8,081	0	0	478	0
Others	478	239	956	0	0	797
Subtotal	80,892	17,914	14,810	11,625	364,937	66,084
Total zooplankton	153,474	57,247	146,489	72,772	483,728	161,864

primarily a predator, and both *Diaptomus* and *Epischura* are primarily herbivorous.

Comparing the overall seasonal densities of zooplankton at Stations A and B for 1981, we observed little numerical differences between the stations. The macrozooplankton density ranged from 50,400/m^2 to 407,643/m^2 (n=8) at Station A and from 58,231/m^2 to 401,669/m^2 (n=7) at Station B. However, we did find major differences in density between the two major macrozooplankton groups. Using Station A as an example, cladoceran densities ranged from a seasonal low of 28,196/m^2 to a high of 49,692/m^2, while copepod densities ranged from a low of 21,938/m^2 (comparable to that of the cladocerans) to a high of 369,028/m^2. Thus, generally, as a group copepods numerically dominated the macrozooplankton community. In particular, copepods comprised 58% to 91% of the community (except for a 44% contribution on 22 May) at Station A and from 54% to 84% of the macrozooplankton at Station B.

Within this overall distributional pattern, several distinct cycles were evident, and each was dependent on the species involved. Within the cladoceran community, *Daphnia* peaked in early spring at 30,179/m^2 at Station A and 51,852/m^2 at Station B. In contrast, *Bosmina* densities peaked in the fall at 43,519/m^2 at Station A and 42,113/m^2 at Station B. Both of these species were generally present throughout the season at both stations; however, a third species, *Holopedium*, was seasonally restricted to the spring, peaking at the same time that *Daphnia* became abundant; but it quickly died out. Such divergent seasonal cycles were also evident for species within the copepod community, and since the copepods numerically dominated the macrozooplankton community, the cyclic pattern of the copepods reflected that of the total macrozooplankton. Both *Cyclops* and *Diaptomus* showed two distinct but variable peaks. The first pulse appeared in the spring-to-early summer period; the second one appeared in the late-summer-to-early fall period. As an example, the *Cyclops* density at Station A ranged from 20,576/m^2

to $42,867/m^2$ in the spring-to-summer period; it reached a seasonal low in density of between $4,538/m^2$ to $5,762/m^2$ during mid-summer, and then it expanded to $c25,000/m^2$ by late fall. The pattern exhibited by *Diaptomus* differed, because while the spring pulse was much larger, reaching $349,124/m^2$ (Station A) and $241,736/m^2$ (Station B), the mid-summer low and the less dramatic rebound in the fall were most muted (Table 9). Thus, over the entire sockeye fry rearing period, i.e., except for the very early spring samples taken before and just after ice out, *Diaptomus* was numerically the dominate macrozooplankton in Packers Lake.

In addition to numerically dominating the zooplankton community, *Diaptomus* was also found to have one of the largest body sizes (Table 10). Only the rare *Leptodora* and the numerically subdominant *Epischura* were found to be of greater body size than *Diaptomus*. *Epischura* ranged in mean body size from 1.27 to 1.49 mm, while *Diaptomus* ranged in size from 0.56 mm in the early spring to 1.15 mm in the summer; however, they were usually greater than 1.00 mm in size from July through October. In addition, *Cyclops* also achieved a mean body size in excess of 1.0 mm from June through August. These large body sizes are in total contrast to the body sizes found for the cladoceran community. *Daphnia* body sizes ranged from 0.61 to 0.95, mm, while *Bosmina* lengths ranged still lower from (0.35 to 0.40 mm). Finally, *Holopedium* lengths ranged from 0.64 to 0.93 mm. Thus, except for the rare predaceous *Leptodora*, cladoceran mean body sizes never exceeded 1.00 mm, falling between the overall range of 0.35 to 0.93 mm. The three copepod species all exceeded 1.00 mm in body size for much of the sampling season and ranged in size from 0.56 to 1.49 mm.

Although the data set in 1982 are less complete, compared to that in 1981, we observed the same species composition for cladocerans, copepods, and rotifers (Table 9). That is, *Diaptomus* dominated the copepod community, and the copepods as a group remained a strong component of the macrozooplankton but were generally less abundant

Table 10. Body size of the macrozooplankton species of Packers Lake at Stations A and B for 1981-1983.

Taxa	Copepoda						Cladocera							
	Cyclops		*Diaptomus*		*Epischura*		*Daphnia*		*Bosmina*		*Holopedium*		*Leptodora*	
Date/Station	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)
03/06/81	0.67	--	N.A.	--	N.A.	--	0.71	--	N.A.	--	N.A.	--	N.A.	--
05/22/81	0.79	0.97	0.59	0.56	N.A.	N.A.	0.64	0.66	0.36	0.36	N.A.	0.49	N.A.	N.A.
06/12/81	1.08	1.13	0.78	0.77	1.27	1.31	0.65	0.66	0.37	0.40	0.64	0.64	N.A.	N.A.
07/09/81	1.00	1.01	0.96	1.00	1.44	1.36	0.87	0.85	0.38	0.40	N.A.	0.85	N.A.	5.0
08/04/81	1.14	1.01	1.15	1.12	1.30	1.44	0.95	0.93	0.38	0.35	0.93	N.A.	N.A.	N.A.
08/26/81	0.82	0.87	1.10	1.10	1.34	1.42	0.87	0.90	0.36	0.35	N.A.	N.A.	N.A.	N.A.
09/21/81	0.62	0.61	1.07	1.08	1.43	1.44	0.75	0.83	0.37	0.37	N.A.	N.A.	9.4	N.A.
10/13/81	0.63	0.66	1.09	1.09	1.47	1.49	0.61	0.73	0.39	0.37	N.A.	N.A.	N.A.	N.A.
01/28/82	0.68	0.59	1.08	1.09	N.A.	N.A.	0.73	0.54	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
04/20/82	0.80	0.85	N.A.	N.A.	N.A.	N.A.	0.79	0.54	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
06/15/82	--	0.81	--	0.57	--	0.71	--	0.74	--	0.40	--	0.55	--	2.36
08/02/82	1.15	1.06	1.08	1.08	1.38	1.16	0.82	0.87	0.41	0.37	0.64	N.A.	N.A.	N.A.
08/25/82	0.45	0.66	1.09	1.10	1.42	1.35	0.97	0.96	0.34	0.35	N.A.	N.A.	N.A.	N.A.
02/02/83	--	0.61	--	N.A.	--	N.A.	--	0.66	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

than in 1981 and were, accordingly, a less dominating group. Finally, although the weaker data set precludes exact comparison, it appears that *Bosmina* densities were greater than or equal to those principally found in 1981 at Station B.

As in 1981, we found that all of the 1982 body sizes of *Cyclops*, *Diaptomus*, and *Epischura* exceeded 1.00 mm in length throughout most of the sampling season. *Cyclops* ranged in length from 0.59 to 1.15 mm, while *Diaptomus* body sizes ranged from 0.57 to 1.10 mm; *Epischura* lengths ranged from 0.71 to 1.42 mm. Again as in 1981, the observed body sizes of the cladocera in 1982 never exceeded 1.00 mm in length, except for the rare *Leptodora*. *Daphnia* ranged in size of from 0.54 to 0.97 mm, while *Bosmina* body sizes ranged from 0.34 to 0.41 mm and those of *Holopedium* ranged from 0.55 to 0.64 mm. Overall, the 1982 macro-zooplankton body sizes ranged from 0.34 mm to 1.42 mm; the cladocerans ranged from 0.34 to 0.97 mm and the copepods, from 0.47 to 1.42 mm.

DISCUSSION

Existing Limnetic Production Patterns

The enhancement of the sockeye rearing capacity within Packers Lake centers around an understanding of the principle driving functions for limnetic production. These would include the morphometric features of the lake itself, the influences of climate (e.g., light, temperature), the seasonal cycle of algal nutrients, and then the transfer of primary biomass production through the food chain to the rearing fry. The later transfer step is particularly important because it involves the limnetic-dwelling herbivorous zooplankton that serve to concentrate food energy into a size capable of being retained by rearing fry. This detailed study seeks to define the potentially unique rearing requirements for sockeye fry and the techniques to enhance it by assessing each part of the algorithm leading to successful smolt production in Packers Lake.

The brown color of the lake water not only provides a stark contrast to other sockeye-producing systems that are clear, but it also serves to define many features of importance to rearing sockeye. Primary among these are the effects on the light and temperature regimes of the lake. As the organic colloids, which are responsible for the brown stain, readily absorb solar radiation, light penetration is restricted to only the upper 3 to 4 meters of the lake. Compared to clear-water systems, this restriction of the photic zone drastically reduces the extent of the trophogenic zone and thereby reduces the volume of the epilimnion available for photosynthesis (Table 11). Such a restriction potentially decreases the efficiency of nutrient utilization and the ultimate conversion of inorganic nutrients into plankton biomass. However, the rapid absorption of light within the first meter of lake water also has the effect of rapidly warming the surface layers. Thus, the lake quickly stratified in the spring; epilimnetic temperatures reached 12°C by the third week of May. Additional heating took place within the surface strata throughout the summer until the first part of August. However, maximal recorded temperatures were below 17°C, because accumulated heat was transferred deep below the surface through the combined action of diel convection currents and strong winds, which continually mixed the warmer surface strata with the cooler, deeper lying layers. As a consequence, the metalimnion, established at 5 m in May, was pushed to 15 m by early August. Additional heating occurred within the hypolimnion, and temperatures approached 7° to 8°C by August; these were up from the 3° to 4°C found in March. Overall, temperatures throughout the lake were quickly and effectively elevated above 4°C for most of the open-water period.

While the epilimnion expanded in volume throughout the summer season, the photic zone remained relatively static; this condition resulted in algal cells circulating out of the photic zone for longer periods of time and, in turn, acting to decrease the effective photosynthetic efficiency of the algal population.

Table 11. A comparison between sockeye nursery lakes as to surface area, light compensation depth, and euphotic volume for glacially tinged, organically stained, and clear-water systems.

Lake	Volume ($m^3 \times 10^{+6}$)	Lake type (water clarity)	Surface area		Water residence time (yr)	Light compensation level (m)	Euphotic volume	
			($m^2 \times 10^{+6}$)	(acres)			($m^3 \times 10^{+6}$)	(% of total)
Trail Lakes	124	Glacial	8.1	1,754	0.19	0.5	3.6	3
Tustumena	37,000	Glacial	295.0	73,944	17.20	1.0	295.0	<1
Skilak	N.A.	Glacial	99.0	24,463	N.A.	1.5	148.5	<1 (est.)
Kenai	N.A.	Glacial	56.0	13,837	N.A.	4.0	224.0	<1 (est.)
Crescent	98	Semi-Glacial	3.3	805	0.2	8.0	26.4	27
Eklutna	512	Semi-Glacial	14.0	3,458	1.8	3.0	42.0	8
Ptarmigan	125	Semi-Glacial	3.0	750	1.1	6.0	15.6	17
Crescent	389	Semi-Glacial	16.2	4,002	0.3	5.5	89.1	23
Bakewell	67	Organic Stain	2.8	692	--	4.5	12.6	19
Hugh Smith	198*	Organic Stain	3.2	800	1.1	5.0	16.0	8
Packers	26	Organic Stain	2.1	519	3.0	4.0	8.4	32
McDonald	197	Organic Stain	4.2	1,035	0.7	7.5	31.5	16
Falls	30	Organic Stain	1.0	254	0.5	9.5	9.0	29
Bear	19	Clear	1.8	445	.0.8	9.5	17.1	90
Hidden	138	Clear	6.8	1,680	11.2	15.0	102.0	74
Upper Russian	122	Clear	4.6	1,137	1.1	13.0	51.0	42
Karluk	1,920	Clear	39.0	9,637	6.0	20.0	780.0	41
Tokun	38	Clear	1.8	448	1.0	16.0	25.0	65
Eshamy	122	Clear	3.6	890	2.7	20.0	72.0	59
Leisure	23	Clear	1.1	259	0.3	18.0	19.8	86
Larson	29	Clear	1.8	445	1.7	9.5	17.1	59
Sea Lion Cove	0.32	Clear	0.08	19	0.3	6.9	0.26	80
Nunavauguluk	4,489	Clear	79.0	19,513	6.0	25.0	1,975	44
Cultus	201	Clear	6.3	1,550	N.A.	23.0	145	72

*Volume of the mixolimnion

However, as the epilimnion deepened, inorganic nutrients that were previously held within the uncirculated hypolimnion were recirculated throughout the expanded epilimnetic layer. This acted to decrease the possibility of an inorganic nutrient deficiency, reducing the production of phytoplankton biomass. Thus, we observed two reactions initiated by the presence of the colored organic acids that would tend to exert opposite effects on the production of algal biomass.

A third effect of these organic acids was the formation of colloidal inorganic phosphorus. The presence of such colloids reduces the availability of inorganic phosphorus to an algal cell and allows a chemically detectable concentration of the nutrient to exist throughout the summer season. Such a pattern was observed in the epilimnion of Packers Lake during all three years of study. This chemical inactivation of phosphorus would function to counteract the positive effect of the continual increasing epilimnetic volume and may predestine a nutrient limitation to primary production. If so, the continually high epilimnetic nitrogen-to-phosphorus atom ratio would further argue for phosphorus as the primary limiting nutrient (Sakamoto 1966; Dillon and Rigler 1974; Smith 1979).

If phosphorus limits biomass accrual by the phytoplankton because it is less readily available, then the reduced light regime may act to further decrease production by limiting the total volume in which the net primary production takes place. While phosphorus may limit the per m^3 production, light may limit the entire lake production on a per m^2 basis; i.e., a reduced light regime may act to decrease areal production within a lake. Thus, given two lakes of equal surface area with equivalent available total phosphorus, the one which suffers from a non-chlorphyll _a_ related light reduction (i.e., organic stain and/or inorganic turbidity) will exhibit decreased areal production. Finally, it may be that a comparison of phosphorus loading (and/or spring total phosphorus [ppb]) to chlorophyll _a_ (ppb) production may result in a close fit to clear-water systems; however, a comparison of integrated whole-lake production may, on the whole, show substantially lower production from the light-restricted lakes (Oglesby 1977).

Consistent with the high nutrient ratios found throughout the lake, we observed little (if any) contribution to the phytoplankton from blue-green algae (Barica et al. 1980). The diatoms, greens, and μ-algae dominated the phytoplankton within both the epilimnion and the hypolimnion. In general, diatoms tended to dominate in the spring; this was followed by a pulse within the green-algae assembledge in the summer-fall period. Finally, the μ-algae, thought to be of the most benefit to the smaller species of zooplankton, showed a definite reduction in numbers within the epilimnion, compared to that within the hypolimnion and to that present in the lake before ice-out; i.e., the μ-algae showed a reduction in numbers when zooplankton densities were highest.

The major zooplankters (by density) in the lake were *Diaptomus pribilofensis, Bosmina longirostris, Daphnia longiremus, and Epischura nevadensis*. The primary feeding mode of all four species consists of varying forms of filter feeding; i.e., either highly selective in terms of the copepod component to relatively non-selective in terms of the cladocerans. However, all are herbivores that select food groups within the algal community either by size, shape, or ease of assimilation (Porter 1975, 1977).

The macro-zooplankton density dramatically increased in mid-June at Station B in both 1981 and 1982 and in mid-July at Station A in 1981. These early seasonal pulses in density are important to rearing sockeye fry, because entry into the lake is usually completed by June and July. Such a coincidence in timing affords the fry an excellent food source early in their life history when mortality is greatest. In addition, we found distinct differences between the two major groups of zooplankton: the cladocerans and the copepods. In particular, we observed the copepods (particularly *Diaptomus*) to both numerically dominate the macrozooplankton and to have the largest body sizes. Since predator pressure by planktivorous fishes can structure the zooplankton community (Brooks and Dodson 1965; Wells 1970; O'Brien 1979; Zarat 1980), the numerical density and body size of the zooplankters may reflect relative predator pressure (Stenson 1973).

Given that the zooplankters we sample and measure are present after predation has occurred, the number and large body size (>1.00 mm) of the copepods would indicate a low predator pressure. The exact opposite was found for the cladocerans; namely, as a group they were numerically subdominant and were consistently below 1.00 mm in body size. As sockeye fry are size-selective, visual feeders (Eggers 1978), the relative density and body sizes of the two taxa would argue for the cladocerans as being the primary forage group for the planktivorous fry (Stenson 1973). Moreover, as the cladocerans are relatively non-discriminating filter feeders that reproduce asexually several times a year (given the proper environmental conditions), they can undergo rapid population increases. In contrast, copepods reproduce sexually, usually produce one brood per season, and are either predatory or highly selective filter feeders. Thus, the cladocerans appear to be a key prey item to rearing fry that are capable of a quick population response (given an increase in primary production). In relation to enhancement efforts targeted at expanding the sockeye rearing capacity of the lake, the latter point is particularly important.

Enhancing Limnetic Production

Our intent is to improve the rearing environment of Packers Lake and to alter those features of the lake that currently limit the production of fish biomass. The results (discussed above) center on reducing the negative influences of the organic acids on the light regime and on the phosphorus cycle within the lake. One of the techniques used in the past to increase fish yield (and is currently used to restore the ability of acid rain damaged lakes to support fish stocks) is to apply lime or powdered limestone to the surface of the lake (Table 12).

Such additions have been accompanied by increased primary production (Waters 1952) and larger standing crops of zooplankton (Waters 1948; Johnson and Hasler 1954; Waters and Ball 1957). Following liming, Johnson and Hasler (1954) observed a specific increase in the standing crop of *Daphnia*, which was attributable to an increase in water clarity (transparancy), that left the euphotic zone of the treated lake expanded by 50% (Hasler et al. 1951; Stross and Hasler 1960; Stross et al. 1961). Whereas the addition of lime has increased the euphotic volume of several lakes (Brynildson 1958) by precipitation of the organic colloids, it has also been accompanied by algal blooms (principally unwanted blue-greens) by virtue of large increases in available phosphorus (Waters and Ball 1957). As blue-green algae are not readily edible and/or digestible forms of the phytoplankton community (Porter 1975, 1977), zooplankters would not benefit from their production. Such blooms can be favored by phosphorus levels in excess of the supply of inorganic nitrogen (Schindler 1977), but this can be controlled by the judicious application of nitrogen fertilizer (Barica et al. 1980).

Any improvement in the rearing environment of the lake caused by the lime-induced expansion of the euphotic zone should be transferred up the food chain to benefit plantivorous feeding fishes. However, Johnson and Hasler (1954) reported no increase in the production of rainbow trout following an increase in the standing crop of zooplankton; whereas, Waters and Ball (1957) showed an increase in the growth of yellow perch following an increase in zooplankton production. The reason for this difference may be because the total number of zooplankton is a poor indicator of the availability of the zooplankton to specific species of rearing fry (Brynildson 1958; Galbraith 1967; Brooks and Dodson 1965; O'Brien

Table 12. A partial summary of lakes that have received the addition of lime for fish restoration purposes and the quantity of material added to each system.

Lake(s)	Quantity of material added (tons/acre)	Management purpose	Reference
*Cather	0.225	Increase fish production	Brynildson(1958)
*Turk	0.168	Increase fish production	Brynildson(1958)
'7 Lakes'	0.290	Increase fish production	Reeves(1982)
++Starvation	1.600	Increase fish production	Waters(1948)
++Timijon	1.600	Increase fish production	Waters(1948)
+George	0.117	Increase fish production	Stross & Hasler(1960)
+Peter	Unknown	Increase fish production	Johnson & Hasler(1954)
+Corrine	0.139	Increase fish production	Stross & Hasler(1960)
'Several'	0.436	Neutralize acid pH	Bergtsson et al.(1980)
**Stoner	0.167	Increase fish production	Waters & Ball(1957)

*Finely ground lime stone
**$Ca(OH)_2$
+Hydrated lime (calcium and magnesium hydroxide)
++Meromictic lakes

1979). That is, rainbow trout were found to effectively feed on *Daphnia* only when the zooplankter body size was much greater than 1.00 mm (Brynildson 1958; Galbraith 1967). Yellow perch, on the other hand, are capable of accelerated growth rates on much smaller-body-sized zooplankters of ≅0.6 mm (Brooks 1968).

For sockeye salmon fry, the effective lower body size of zooplankton capable of being retained has been shown to be ≅0.4 mm (Goodlad et al. 1974). Thus, except for the smallest body sized individuals of *Bosmina*, the entire zooplankton assembledge (especially species of *Daphnia*) within Packers Lake should be available as forage. Indeed, as pointed out by Vinyard (1982), sockeye fry tend to select or elect to feed on species of cladocera and often ignore the copepod component. Such an observation is consistent with the large body size and numerical dominance of the copepods in Packers Lake, compared to the subdominant and small-body-sized cladoceran component.

Packers Lake Nutrient Loading and Lime Addition

The nutrient loading, based on phosphorus, for lake systems with an IN:IP ratio >12 is calculated after Vollenweider (1976). Prior to this, we used the following relationship to define the biologically active phosphorus (BAP) component from known Packers Lake chl a concentrations:

$$\text{Log Chl } \underline{a} = 0.91 \text{ Log TP} - 0.435$$

Using the BAP component the present loading of phosphorus (Lp) was calculated as follows:

$$Lp = 68.95 \text{ mg P/m}^2\text{/yr.}$$

The critical loading (Lc) was defined for both a lower (Lc_{10}) and upper level (Lc_{20}). Thus:

$$Lc_{10} \doteq 147.01 \text{ mg P/m}^2\text{/yr}$$

and

$$Lc_{20} = 294.02 \text{ mg P/m}^2\text{yr}$$

The required amount of a 27-7-0 (N-P-K) liquid fertilizer (0.16 kg P/gal) to achieve Lc_{10} is 1,000 gal (3,785 l); to achieve Lc_{20}, 2,884 gal (10,916 l) are required.

However, because of the potential for an unwanted nutrient imbalance caused by the addition of lime, we recommend the addition of 32-0-0 (N-P-K) liquid fertilizer prior to and after the initial addition of the lime. These nitrogen additions will serve to keep the N:P ratio high during the period of actual liming and will also help to stabilize the N:P ratio the following spring.

The powdered lime should be added to the surface of lake as a slurry (Waters and Ball 1957; Reeves 1982) and at a temperature equal to that of the epilimnion. In addition, the application should begin at the upper end of the lake and continue to an area covering Station B but not including Station A (Figure 3). Thus, our aim is to apply the lime to approximately 40% of the surface area of the lake and at a rate that will precipitate the organic colloids and, at the same time, avoid large surges in pH that have been associated with zooplankton die-offs (O'Brien and de Noyelles 1972). We recommend the addition of 0.1 tons/ acre (224 kg/ha), or approximately 21 tons of lime to 200 acres of lake surface.

Finally, for 1984 we recommend achieving at least the Lc_{10} loading level for phosphorus by daily additions of fertilizer, and at the same time, providing for the necessity of augmenting inorganic-nitrogen levels through pure-nitrogen additions. Fertilizer application should follow the pattern used for the lime additions; i.e., cover approximately 40% of the lake's surface area surrounding Station B. Addition of fertilizer can proceed after the

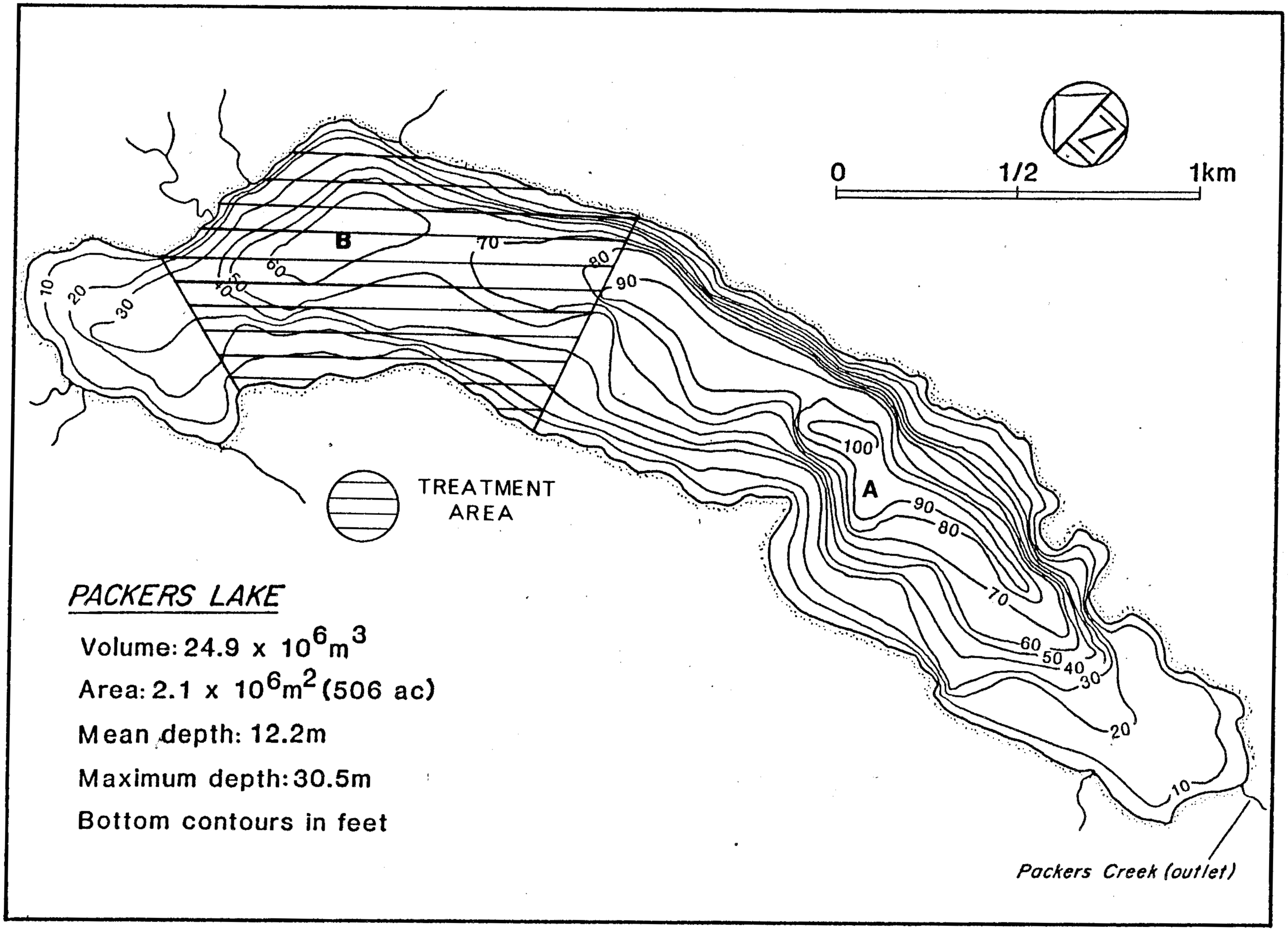

Figure 3. Location of the lime and fertilizer application areas in Packers Lake surrounding Station B.

establishment of a stable thermal structure, usually after the middle of May and extending through the end of September.

<u>Conclusions and Recommendations</u>

1. Many lakes in Alaska that support stocks of sockeye salmon are organically stained. These organic colloids restrict light penetration to the upper 2 to 4 meters, which drastically reduces the percent of the lake volume that lies within the photic zone.

2. These organic acids may restrict the biological availability of phosphorus to algal cells by the formation of iron-phosphorus-organic-acid colloids. The existence of such colloids would further reduce the productivity of the lake.

3. Both processes act to decrease limnetic production and, thereby, reduce the forage base for sockeye salmon fry.

4. The phytoplankton assembledge is dominated by diatoms and green algae, with little production of blue-greens. This is a consequence of high levels of silicon combined with N:P ratios greater than 15:1 within the epilimnion.

5. The zooplankton community is dominated by copepods, principally *Diaptomus* that exhibit large body sizes, compared to those of the sub-dominant cladocera. As large densities and large body sizes argue for light vertebrate-predator pressure, *Bosmina* and *Daphnia* are considered to be the primary forage for sockeye salmon fry.

6. Our recommendations are to add 21 tons of hydrated lime to the surface of Packers Lake, along with the addition of liquid ammonium-nitrate-urea fertilizer. Such additions should act to increase the euphotic volume of the lake by the precipitation of the organic colloids and prevent the

occurrence of nuisance blooms of blue-green algae that zooplankton avoid.

7. This combination of treatments should lead to an improved rearing environment for sockeye fry and result in an increased production of sockeye smolt biomass.

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