LIMNOLOGY AND FISHERIES INVESTIGATIONS
AT CRESCENT LAKE (1979-1982)

302.4

File

by

J. P. Koenings
Principal Limnologist

and

Gary B. Kyle
Project Leader

of the

Alaska Department of Fish and Game
Division of Fisheries Rehabilitation,
Enhancement, and Deveolpment (FRED)

Ronald O. Skoog
Comissioner

Stanley D. Moberly
Director

P. O. Box 3150
Soldotna, Alaska 99669

May 1982

PART I: Crescent Lake Limnology Data Summary

TABLE OF CONTENTS

LIST OF TABLES

ACE 8100082

LIST OF FIGURES

LIST OF FIGURES (continued)

INTRODUCTION

As part of the lake fertilization program within the pre-fertilization phase, Crescent Lake will have completed over two years of intensive study this spring (1982). This report summarizes the information collected from 1979 to 1982 that will serve as a baseline or control from which an assessment will be made on the effects of the nutrient enhancement of Crescent Lake.

Many prior studies on the effect of nutrient enrichment on trout and salmon production [Canada: Smith (1955), LeBrasseur et al. (1978), Stockner (1981); England: Frost and Smyly (1952); Scotland: Munro (1961); Australia: Weatherley and Nicholls (1955); the United States: Juday and Schloemer (1938), Hasler and Einsele (1948), Nelson (1958, 1959); Tanner (1960), and Sweden: Milbrink and Holmgren (1981a and b)] have demonstrated a positive cause and effect relationship between increased nutrient supply and fish production. This direct cause and effect relationship was recently supported by an empirical model which linked total phosphorus concentrations and yield of fish biomass from several lakes (Hanson and Leggett 1982) i.e., as the level of the nutrient limiting primary production increased from lake to lake, the fish yield increased. Other lake fertility-fish production models (e.g. morphoedaphic index) were also tested with significantly less precise results especially when applied to a comparison of different lake types found over a broad geographic area. Thus, we feel that a link has been firmly established between nutrient loading rates and the resultant fish production achieved whether it is within a year and between lakes, or within a lake and between years.

It is our intention to show that: an increase in readily available phosphorus in Crescent Lake will result in stimulating this system's production of sockeye salmon smolts. In addition, we feel that the information collected to date will allow the quantitative evaluation of the effect of the nutrient addition within each trophic level. That is, a precisely designed addition of inorganic nutrients [within the pre-existing critical loading rate (Vollenweider 1976)] will stimulate primary and secondary production and consequently lead to an increase in sockeye smolt biomass without a detrimental change in water quality.

Description of Study Area

Crescent Lake is located at 60°22' North and 152°65' West on the western side of Cook Inlet, southwest of Kenai (Figure 1). The lake lies at an elevation of 183 m and is connected to Cook Inlet by the 40 mile long Crescent River. The lake has a surface area of 1,647 ha with a watershed area of 97,125 ha, and a maximum depth of approximately 31 m. Because of its typically glaciated U-shaped basin with a small littoral zone and a broad flat bottom, the mean depth (23 m) is only slightly less than the maximum depth. Several inlet streams flow into the lake on an intermittent basis. Most of the inflow comes from overland runoff and from snow melt, which originates from over three meters of snow pack. Primary inflow from definable streams comes from a glacial melt fed system located on the southwest side of the basin, approximately mid-way from each end of the lake. However, this stream is considerably clearer, less defined, and more meandering than the glacier fed lateral system mentioned previously.

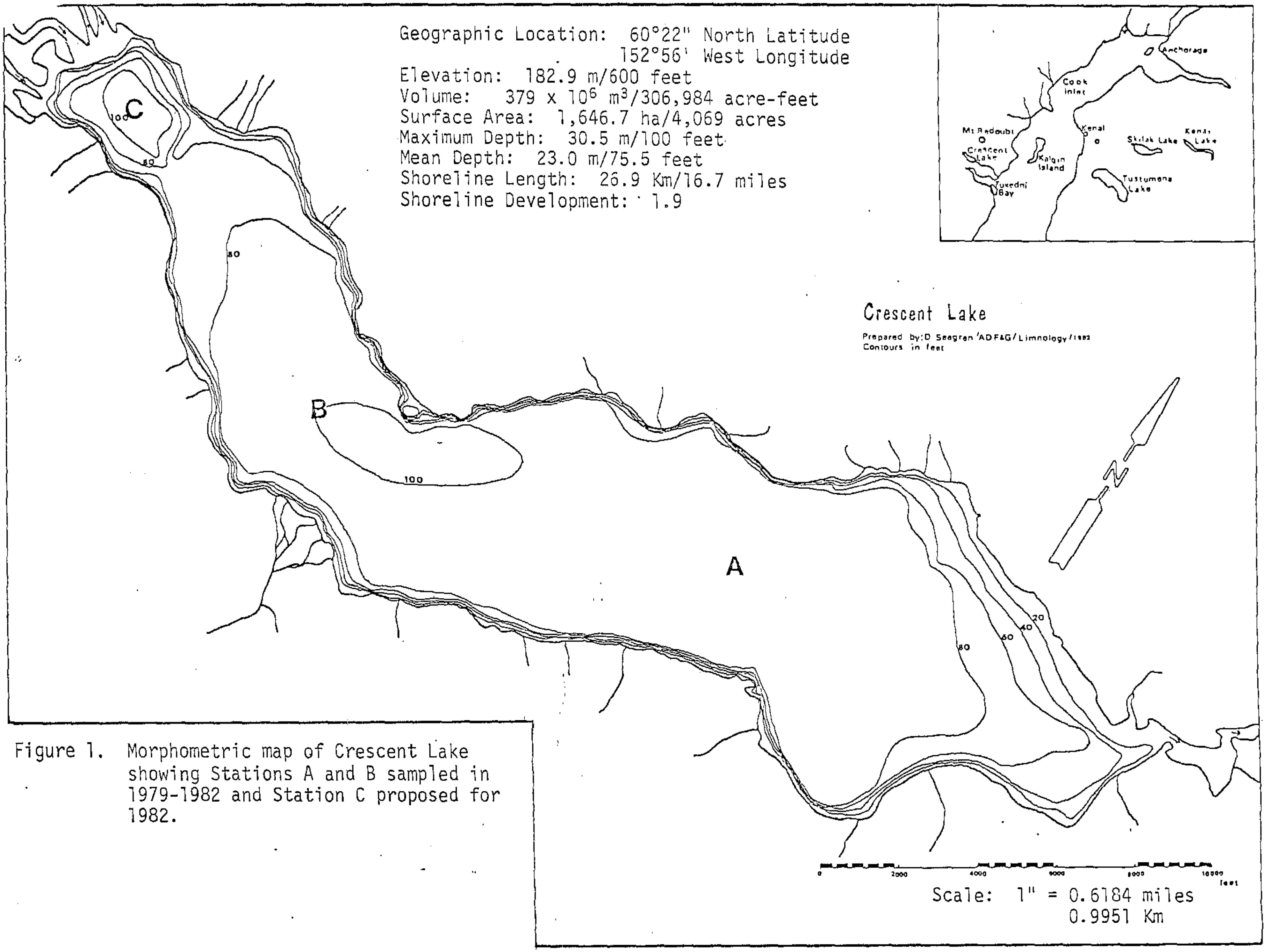


Figure 1. Morphometric map of Crescent Lake showing Stations A and B sampled in 1979-1982 and Station C proposed for 1982.

Consequently, the major source of cold, turbid runoff originates from the mid-lake lateral stream.

The estimated summer discharge of Crescent River is calculated to be 6.2×10^8 m^3 (40 m^3/sec.) which results in a summer water residence time of 0.6 years or a flushing rate of once each summer period (June-October).

METHODS

Crescent Lake was sampled every three weeks during the period of ice-on to ice-out as well as one to three trips (by plane) during the ice-over period. One station (A) was sampled from July 1979 to the present while a second station (B) was added in September of 1979. The lake was sampled for algal nutrients (nitrogen, phosphorus, silicon and carbon) as well as other water quality parameters (see Alaska Department of Fish and Game, Lake Fertilization Guidelines) from both the epilimnetic (1m) and mid-hypolimnetic zones. Water samples consisted of multiple (4) casts with a non-metalic Van Dorn sampler which were pooled, stored in 8-10 liter transluscent carboys, cooled, and transported in light proof containers to Soldotna for analysis. Subsequent filtered and unfiltered water samples were stored either refrigerated or frozen in acid cleaned pre-rinsed polybottles.

All chemical and biological samples were analyzed by methods detailed in the Alaska Department of Fish and Game limnology manual. 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 following Stainton et al. (1977) after cadmium reduction of nitrate. Ammonium analysis followed Stainton et al. (1977) using the phenolhypochlorite methodology, while silica analysis followed the procedure of Strickland and Parsons (1972). Inorganic carbon was calculated according to Saunders et al. (1962) after determining alkalinity by acid titration to pH 4.5 using a Corning model 399A specific ion meter.

Particulate carbon, nitrogen and phosphorus were esitmated by filtering 1-2 liters of lake water through pre-cleaned 4.2 cm GF/F filters. The filters were stored frozen in individual plexislides.

Because of the intermittant level of inorganic glacial slit in Crescent Lake, particulate phosphorus was split into particulate organic and particulate inorganic phosphorus following the method in Kuenzler et al. (1979). Acidified NH_4F was added to individual filters within a 15 ml centrifuge tube. The tube was shaken for 60 seconds and then filtered. The filtrate was analyzed for reactive phosphorus, and the filter residue for total phosphorus. Particulate inorganic phosphorus was obtained directly from the filtrate analysis while particulate organic phosphorus was obtained by the difference between the phosphorus remaining on the filter residue and the reactive phosphorus of the filtrate.

Primary production (algal standing crop) was estimated by chlorophyll a (chl a) analysis after the fluorometric procedure of Strickland and Parson (1972) using the low strength acid addition recommended by Reimann (1978) to estimate phaeophytin. Samples (1-2 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.

Primary productivity (rate of photosynthesis) was assayed by use of radioactive carbon (C-14) following the method of Saunders et al. (1962). Samples (two light, one dark, and one dark-killed 100 ml bottles) were placed in situ for four hours at 1 m, mid-euphotic and 1% incident light levels during mid-day (10:00 a.m. to 2:00 p.m.). After incubation, the samples (100 ml bottles) were fixed with 1 ml of Lugols-acetate and filtered under low vacuum (to prevent cellular rupture) on 2.4 cm GF/F glass fiber filters. The filters were placed in plastic scintillation vials, acidified with 0.2 ml of 1N HCL (Lean and Burnison 1979) to remove residual inorganic carbon-14 from the filters, and assayed after adding 10 ml of Aquasol scintillation fluor on a Packard Tri-carb liquid scintillation spectrometer..

Algal uptake rates were calculated as the difference between the uptake observed in the light bottles minus the uptake observed in the dark bottles. Seasonal mean uptake rates were obtained from an integrated curve of time versus photosynthetic activity. Non-photosynthetic uptake of inorganic carbon was determined as the difference between dark bottle values and abiotic uptake from the dark-killed bottle.

Zooplankton were collected from duplicate bottom to surface vertical tows using a 0.5 m diameter, 153 μ mesh conical zooplankton net. The net was pulled at a constant 1m/sec., and rinsed well before preserving the organisms in 10% neturalized sugar-formalin (Haney and Hall 1973). Identification followed that of Brooks (1959) and Wilson and Yeatman (1959), while enumeration consisted of counting triplicate 1 ml subsamples taken with a Hansen-Stempel pipette in a 1 ml Sedgewick-Rafter cell. Size (length) of individual zooplankton were obtained by counting at least ten individuals along a transect in each of the 1 ml subsamples used in identification and enumeration. Zooplankton were measured to the nearest 0.01 mm as described in Edmondson and Winberg (1971). Cyclopoid zooplankton were split into five size groups:

Nauplii <0.40 mm

Post-nauplii $\geqslant 0.40$ mm <0.55 mm

Pre-adult I $\geqslant 0.55$ mm <0.70 mm

Pre-adult II $\geqslant 0.70$ mm <0.05 mm

Mature adult $\geqslant 0.85$ mm

Photosynthetic available radiation (PAR) levels were determined with a Protomatic underwater photometer (Wetzel and Likens 1979) which measures only the 400-700 nm wavelengths of light. In addition, water clarity was measured with a 20 cm Secchi disk by observing the depth at which the disk disappeared from view.

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

Surface specific loading:

$$Lp\ (mg\ P/m^2 \cdot y) = [P]_c^{sp} \cdot Qs\ (1 + \bar{z}/Qs)$$

Surface critical loading:

$$Lc\ (mg\ P/m^2 \cdot y) = 10 \cdot Qs\ (1 + \bar{z}/Qs)$$

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

$Qs = \bar{z}/t_w$

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

t_w = water resident time (y)

RESULTS

Temperature Profiles

Crescent Lake was covered with approximately 1 to 1.2 m of ice from mid-November to mid-June. The ice-free period lasted for 5 months from mid-June to mid-November (Figures 2 and 3). Isotherms at Station A in 1979 show an isothermal state of 4°C in mid-June followed by the entire water column rapidly warming to 6°C before weak thermal stratification slowly developed above 5 m through the month of July. Maximum temperatures

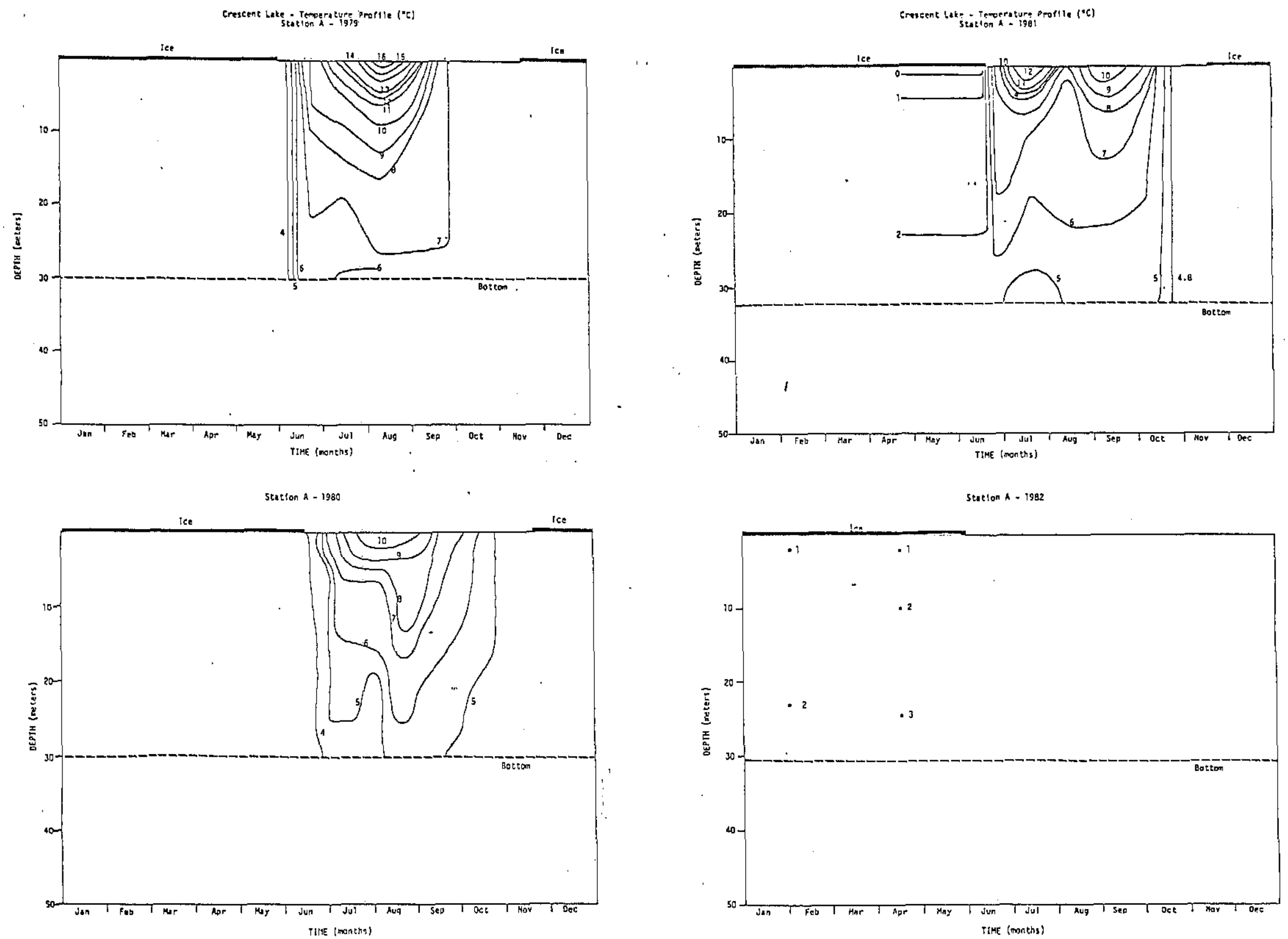


Figure 2. Temperature isopleths (°C) for Station A in 1979, 1980 and 1981.

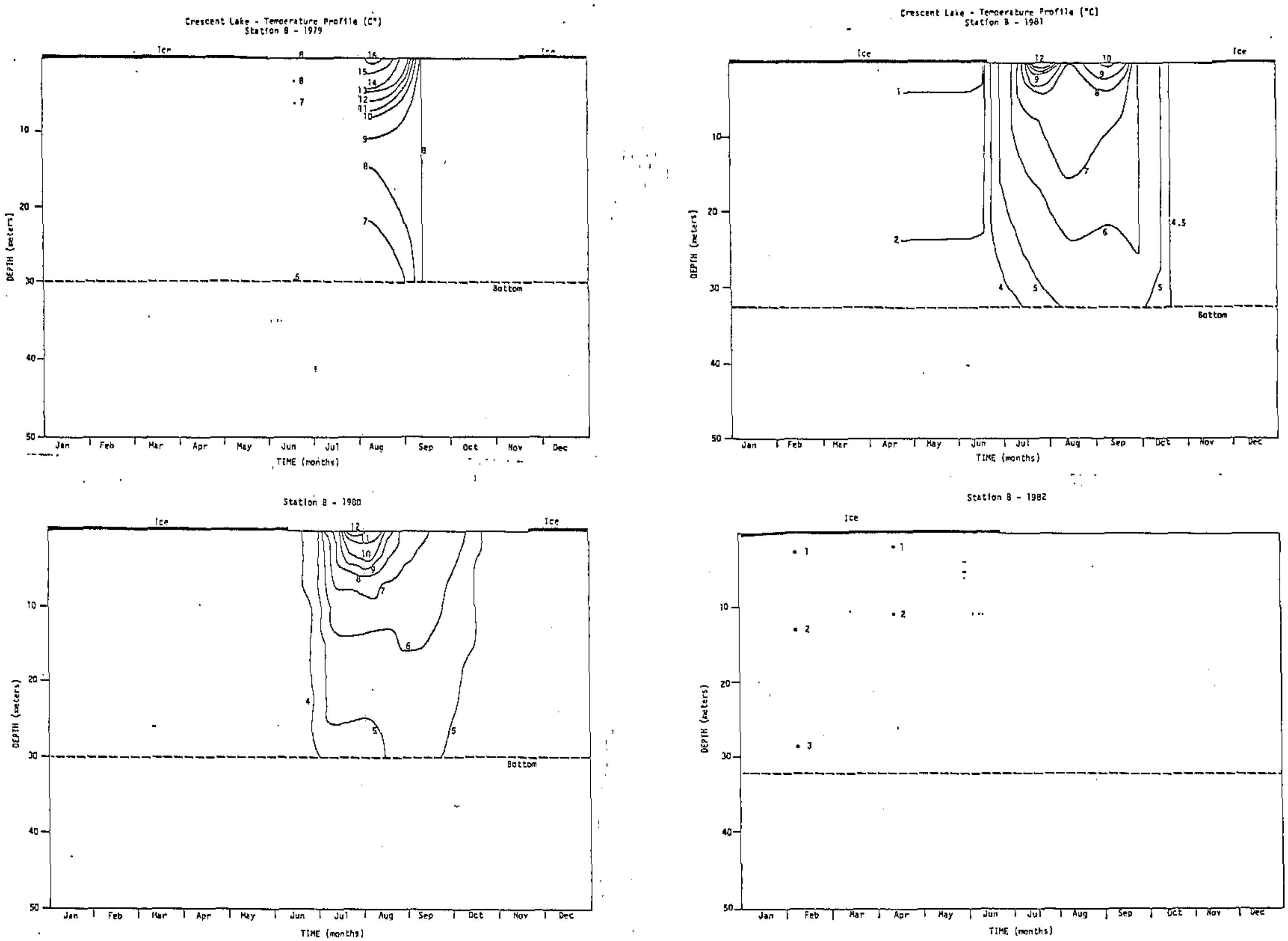


Figure 3. Temperature isopleths (°C) for Station B in 1979, 1980 and 1981.

of 16°C were found in August after which the lake rapidly cooled to become isothermal at 7°C in the latter part of September. In 1980, temperatures again were at 4°C soon after ice-out, however warming was less rapid with thermal stability lacking for most of the year. In 1980, maximum temperatures of only 10°C were reached in July and August. In August 1980, wind generated mixing warmed the lake as isotherms were pushed deep into the lake almost to the bottom. Following this, the lake cooled reaching an isothermal 5°C in October. In 1981, the lake was isothermal for only a very short time in the spring before a strong thermal structure developed in July at $\sim$4 m. Maximum temperatures of >12°C were recorded for this period. However, in August the lake cooled dramatically with almost a complete loss of thermal structure. Following this cooling period the lake warmed, but only to 10°C, and then cooled again to an isothermal of 5°C during October.

The general trends in thermal structure at Station A were repeated at Station B however, some significant differences were noted. In 1980, thermal stability at Station B was achieved earlier than at Station A and developed much more strongly. Maximum temperatures exceeded 12°C, and the subsequent cooling was significantly slower. In 1981, the rate of warming at Station B was slower in the spring period, but temperatures generally equalled those at Station A. In addition, the cooling of the lake in August was still in evidence at Station B, but the degree of heat loss was less severe i.e., the 6°-7°C isotherms remained low in the water column whereas at Station A they rose almost to the surface. Finally, temperatures under the ice during the winter period remained at <4°C at both stations however, temperatures reported for April of 1981, and those in April of 1982 were slightly, but consistently, higher at Station B compared to those at Station A. This suggests that Station A and B contain different water masses under different thermal influences.

Light Penetration

The penetration of photosynthetically available radiation varied considerably in Crescent Lake at both stations (Figures 4 and 5). In 1979, light penetrated to 10-11 m at Station A early in the spring soon after ice-out. At the end of June, light penetration was rapidly reduced so that by the end of September, the euphotic zone (defined as the deepest penetration of 1% surface incident light) was reduced to only 3 m. In 1980, the oscillations of the light isopleths were considerably dampened and showed a distinct change from 1979. Instead of the light compensation depth decreasing with time from July through October as in 1979, light penetration actually increased after August through September and October. The depth of the photic zone varied from ∿9 m in the spring to ∿4 m in August and increased to 6 m by the end of October. This pattern was amplified in 1980, as the photic soon extended to 8 m in June then decreased dramatically to 4 m in August and again increased to ∿10 m by late October.

Light penetration at Station B followed the same general seasonal pattern as Station A however, important differences were noted. In 1980, light penetration at Station B was dramatically deeper in June and July, but from August followed the same trend noted at Station A i.e., a decreasing photic

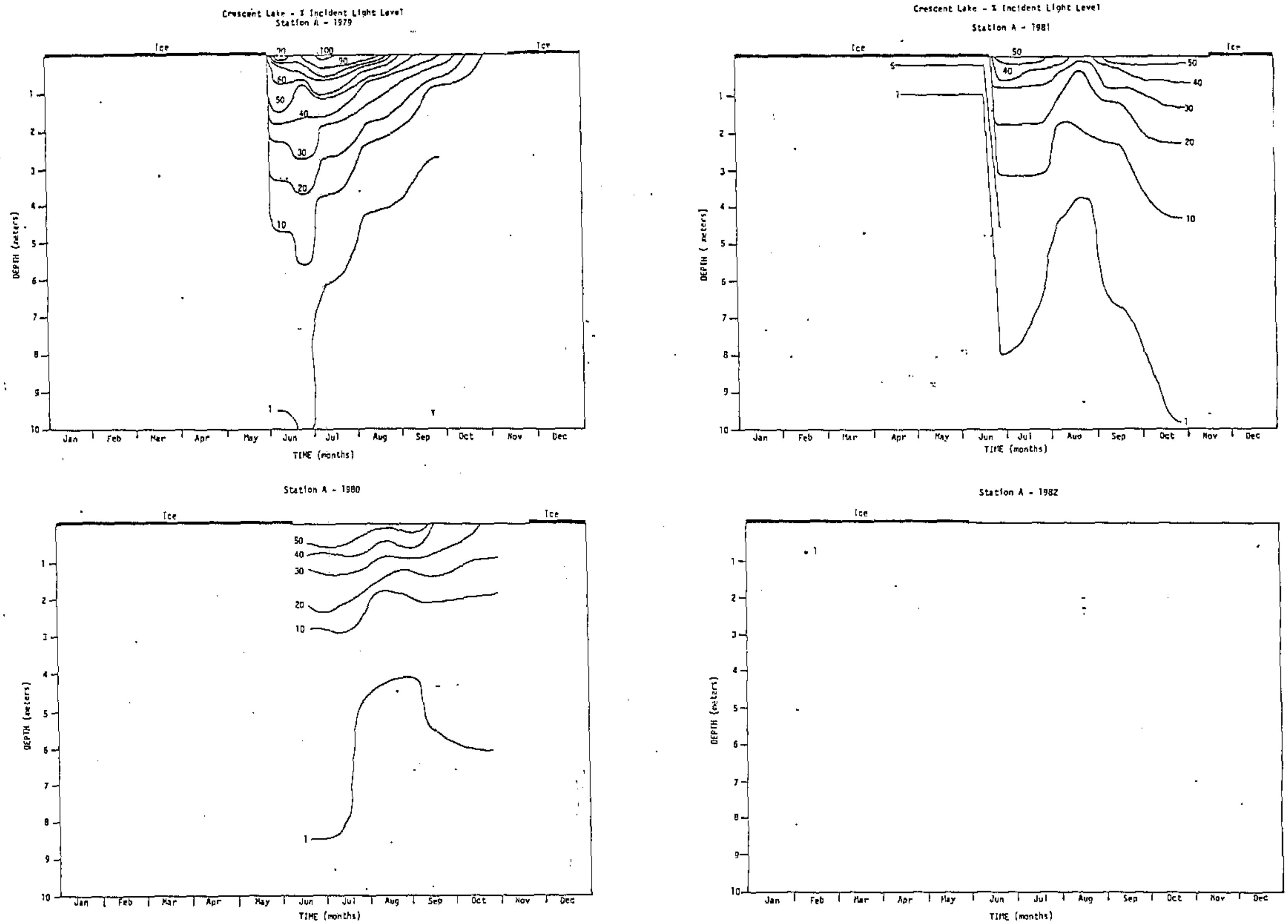


Figure 4. Photosynthetically available radiation (light) by depth for Station A in 1979, 1980 and 1981.

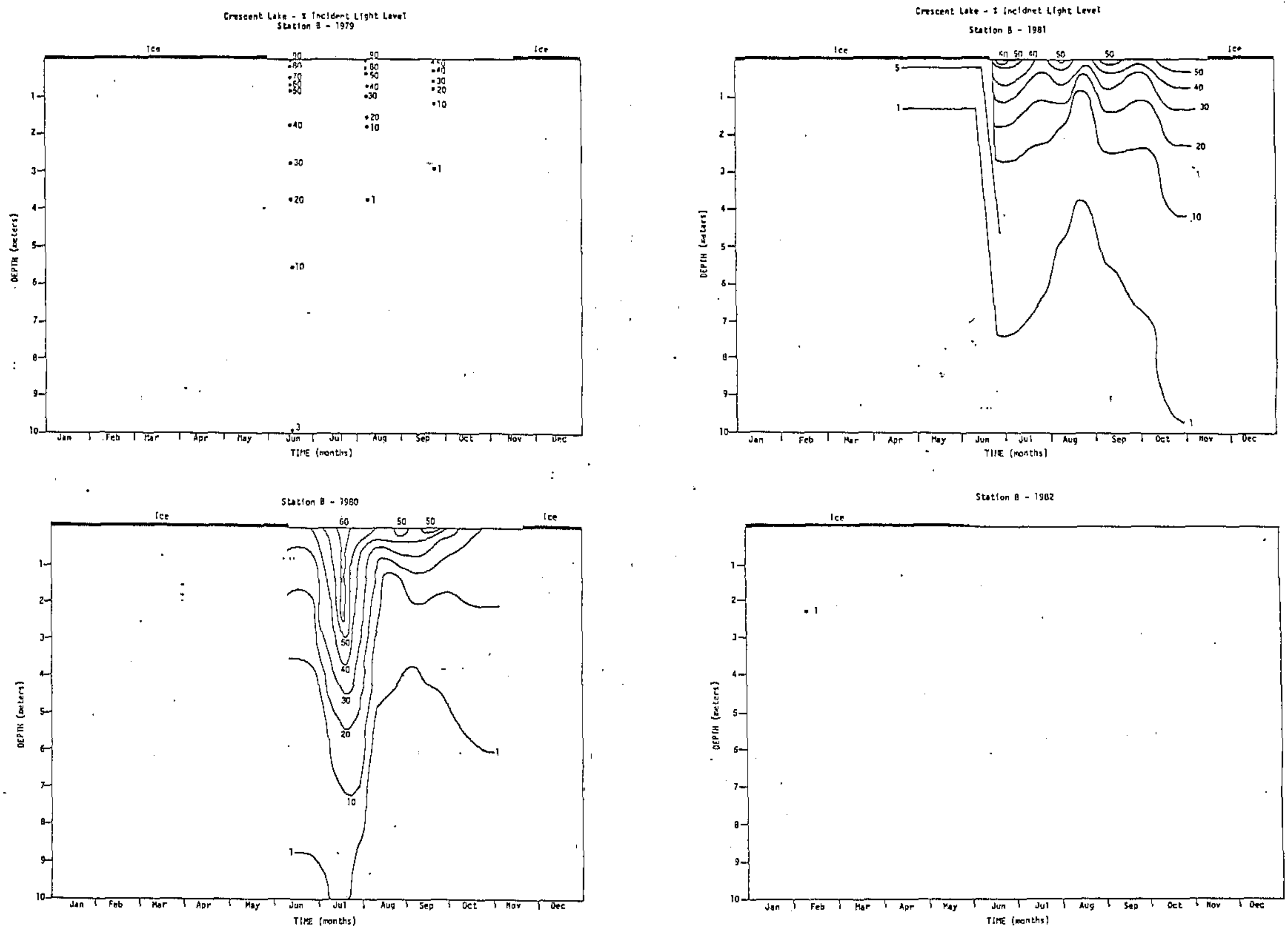


Figure 5. Photosythetically available radiation (light) by depth for Station B in 1979, 1980, and 1981.

zone until August (approximately 4 m) and then increasing to a depth of approximately 10 m in October. Again in 1980, light penetration followed the same overall trend as Station A, but Station B showed isolated pockets of surface clearing. Also, the depth of the photic zone extended to approximately 8 m in the spring, decreased in August to 4 m, and finally deepened to approximately 10 m in October. These differences again indicate the existence of separate water masses under separate environmental influences as was suggested by the thermal differences found to exist between the stations.

Dissolved Gases

Dissolved oxygen levels were consistently greater than 90% saturation during all dates and at all depths sampled. Increases and/or decreases in oxygen concentration were not biologically mediated and merely reflected a decrease and/or increase respectively in temperature.

General Water Quality Parameters

Overall, general water quality parameters (Table 1) varied little in Crescent Lake however, there was a consistent trend of lower alkalinity and conductivity levels during August and September compared to the rest of the year. The degree of within season variation appeared to be dependent on the magnitude of glacial melt input. That is, in 1980 when glacial input was not as extensive as in 1981, alkalinity levels remained virtually constant ($\sim$10 mg L^{-1}) and conductivity values dropped from $\sim$35 μ mhos cm^{-1} to

Table 1. General water quality parameters for Stations A and B (combined) for 1980 and 1981 at 1 m.

Parameter	Seasonal Mean Values ± S.D. 1980	1981
Conductivity (μmhos cm^{-1}) @ 25°C	28 ± 4.5 (n=28)	22 ± 8.2 (n=28)
pH*	6.80 (n=28)	6.17 (n=28)
Total Dissolved Solids (mg L^{-1})	23 ± 5.6 (n=28)	Not available
Alkalinity (mg L^{-1} as $CaCO_3$)	10 ± 1.6 (n=28)	10 ± 2.7 (n=28)
Calcium (mg L^{-1})	4 ± 0.7 (n=28)	5 ± 0.8 (n=28)
Magnesium (mg L^{-1})	<0.5 (n=28)	<0.5 (n=28)
Iron (μg L^{-1})	218 ± 144 (n=24)	186 ± 108 (n=19)

*Calculated from mean anti-logs.

25 μ mhos cm^{-1}. However, in 1981 when glacial melt (or the ratio of glacial melt to clear water runoff) was greater, alkalinity values dropped from ∿14 mg L^{-1} to 7 mg L^{-1} and conductivity levels decreased from ∿35 μ mhos cm^{-1} to ∿15 μ mhos cm^{-1}. However, this trend did not extend to metals as calcium levels reamined constant (4-5 mg L^{-1}) as did magnesium (i.e., undetectable), but iron concentrations rose from 100 microgram/L in the spring (June) to peak levels during the August-September period (>350 microgram/L) and then dropped in late October to equal the June concentrations.

Nitrogen Profiles

Inorganic nitrogen concentrations (nitrate + nitrite) showed distinct seasonal patterns (Figure 6). The amount of nitrate + nitrite throughout the year was consistently high (⩾150 microgram/L) with the highest concentrations occurring in early spring (June through July) at over 350 microgram/L (1980) and slightly less (>300 microgram/L) in 1981. Lower concentrations were observed in August which continued through to the beginning of November, dropping to minimum levels of ∿225 microgram/L in 1980 and ∿150 microgram/L in 1981. Nitrate levels increased in both years throughout the ice-over period to achieve the highest concentrations just after ice-off in the spring.

Differences in nitrate concentration between stations was slight however, small differences did arise between the hypolimnetic and epilimnetic zones. These differences arose during the summer period (July through the beginning of September) and were due to biological uptake of nitrate. However, large scale variations in the introduction of snow-melt water,

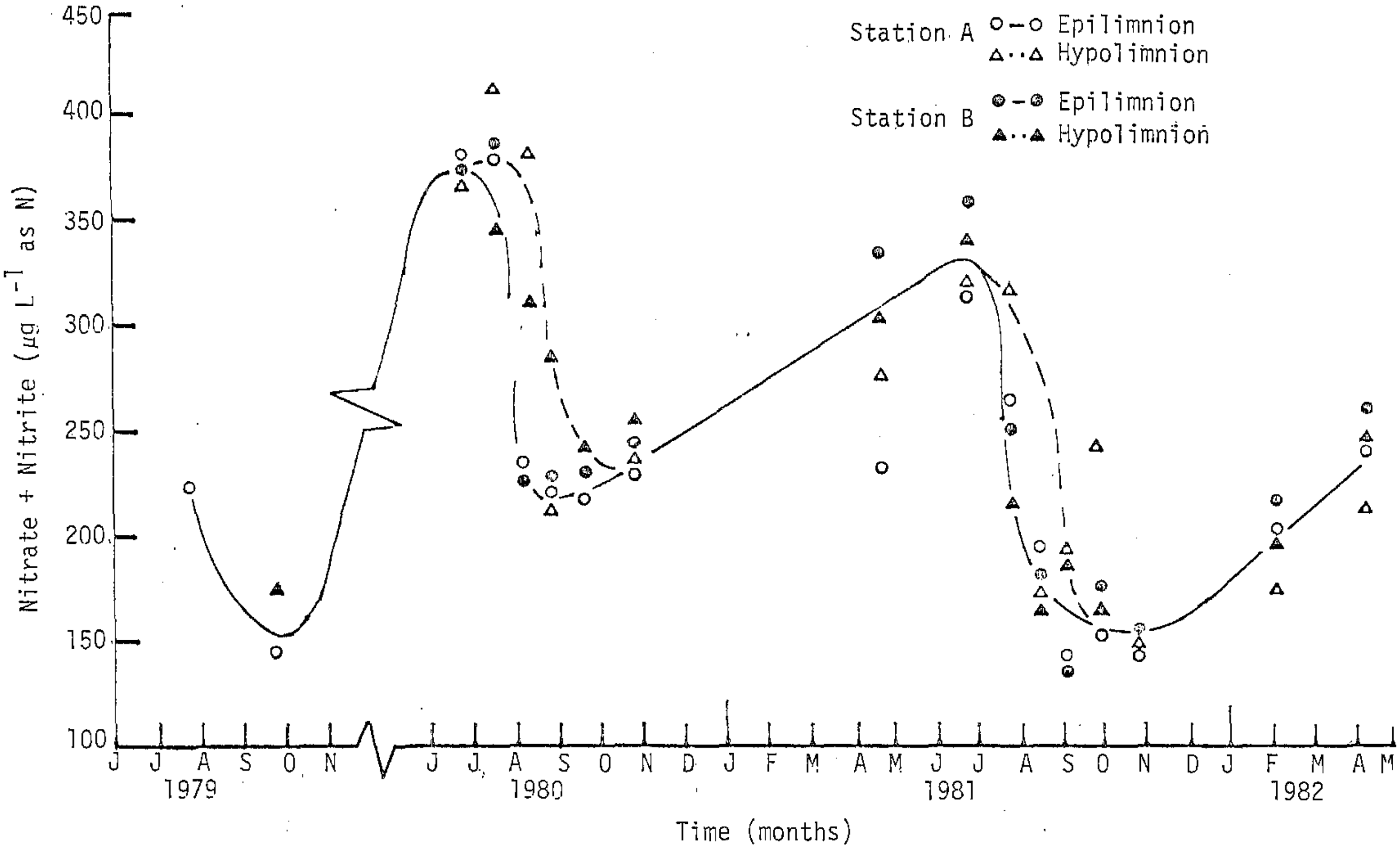


Figure 6. Seasonal profiles in inorganic nitrogen (nitrate + nitrite) in the epilimnion and hypolimnion of Crescent Lake in 1979, 1980, and 1981.

precipitation and glacial input combine to produce the larger part of the seasonal oscillation found for nitrate levels.

Ammonium levels within the lake varied seasonally with undetectable values (<0.5 microgram/L) being reached in July through September of 1980 and at the end of June 1981. Ammonium levels increased at the end of fall (October) preceeding the increase in nitrate in both 1980 and 1981. However, levels of ammonium were consistently low, usually falling below 20 microgram/L and showed a great variability between sampling dates, depths and stations. Thus, substantial and consistent differences between the epilimnion and hypolimnion were not apparent.

Silica Profiles

Levels of reactive silica (reported as silicon) were consistently high reaching nearly 3,000 microgram/L in the spring of 1980, and $\sim$2,500 microgram/L in the spring of 1981 (Figure 7). Low levels were reached in late August of 1980 at $\sim$2,200 microgram/L and in late September of 1981 at $\sim$1,800 microgram/L. Like the nitrate profiles, both stations contained equivalent concentrations of reactive silica, and small differences between epilimnetic and hypolimnetic zones arose only during the July-August period of 1980.

Phosphorus Profiles

Epilimnetic total phosphorus concentrations ranged from a low of 3.5 microgram/L in the spring (June) to peak levels of slightly greater than

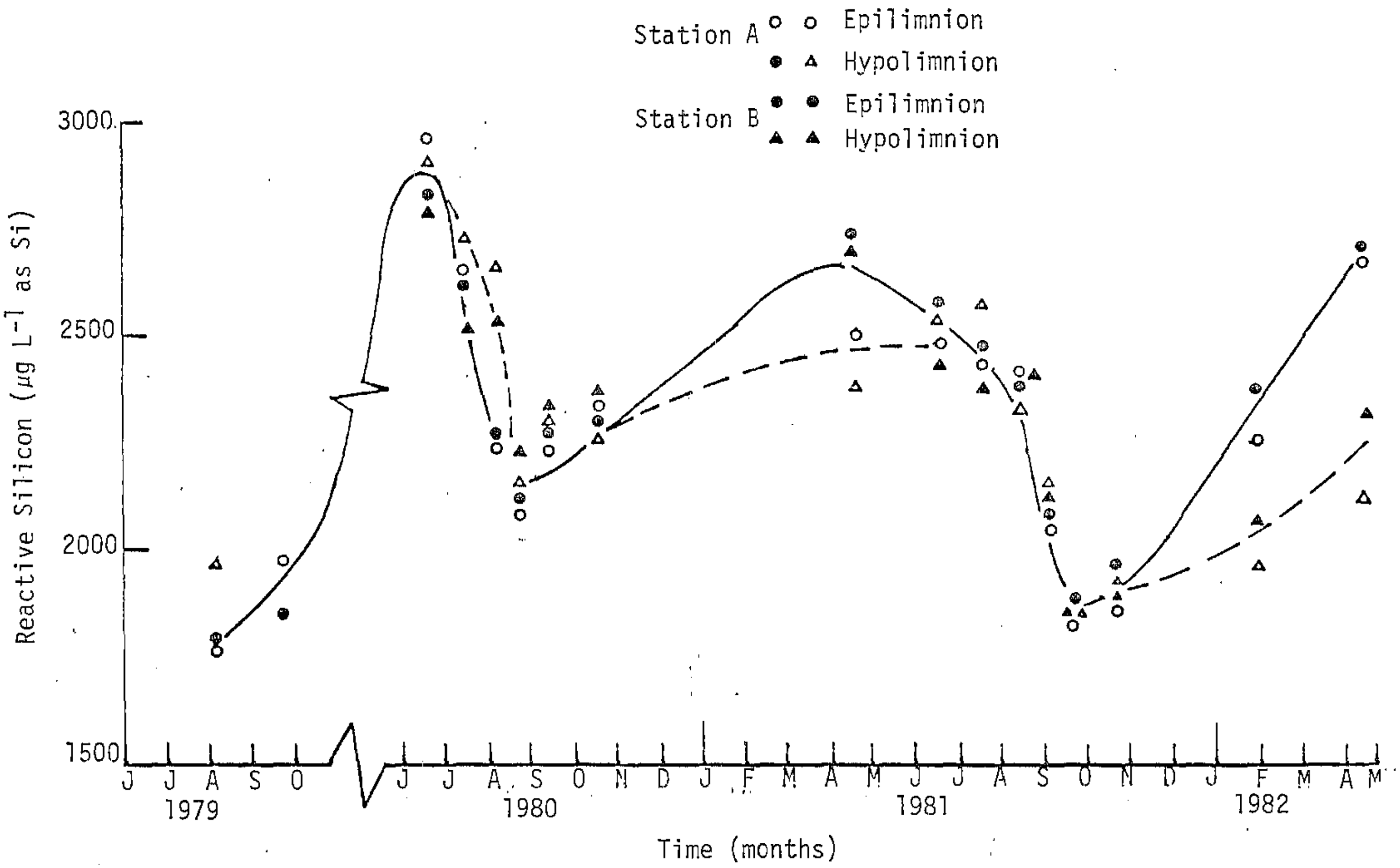


Figure 7. Seasonal profiles in reactive silica (as silicon) in the epilimnion and hypolimnion of Crescent Lake in 1979, 1980, and 1981.

10 microgram/L in early September, and then back to 3.5 microgram/L in late fall of 1980 (Figure 8). This general pattern repeated itself in 1981, ranging from ~4 microgram/L in April, to 9.5 microgram/L in August, and back down to ~4.5 microgram/L in the fall (October). This pattern repeated itself also at both stations with the slightly higher peak values at Station A preceeding those at Station B in both 1980 and 1981. Yearly mean concentrations of total phosphorus equalled 7.0 microgram/L and 7.3 microgram/L in 1980 and 1981 respectively.

Reactive phosphorus profiles were opposite of those found for total phosphorus; reaching low values (~1.0 microgram/L) in August and September with slightly higher values (>2.0 microgram/L) in both June and October of 1980 and 1981 (Figure 8). In general, reactive phosphorus levels were near the level of detectability throughout the lake soon after ice-out in the spring, reached their highest concentrations under the ice in April of 1981, and in February-April of 1982. Yearly mean concentrations of reactive phosphorus equalled 1.2 microgram/L and 1.8 microgram/L in 1980 and 1981 respectively.

Particulate Phosphorus

In 1979, 1980 and 1981, particulate phosphorus represented over 75% of the total phosphorus found in Crescent Lake. In clear water lakes, particulate phosphorus is considered to be organically bound phosphorus held primarily within the cells of phytoplankton and bacteria. As such, it becomes readily available to the pool of metabolically active phosphorus that is continually recycling through the plankton. However, in glacially influenced lakes,

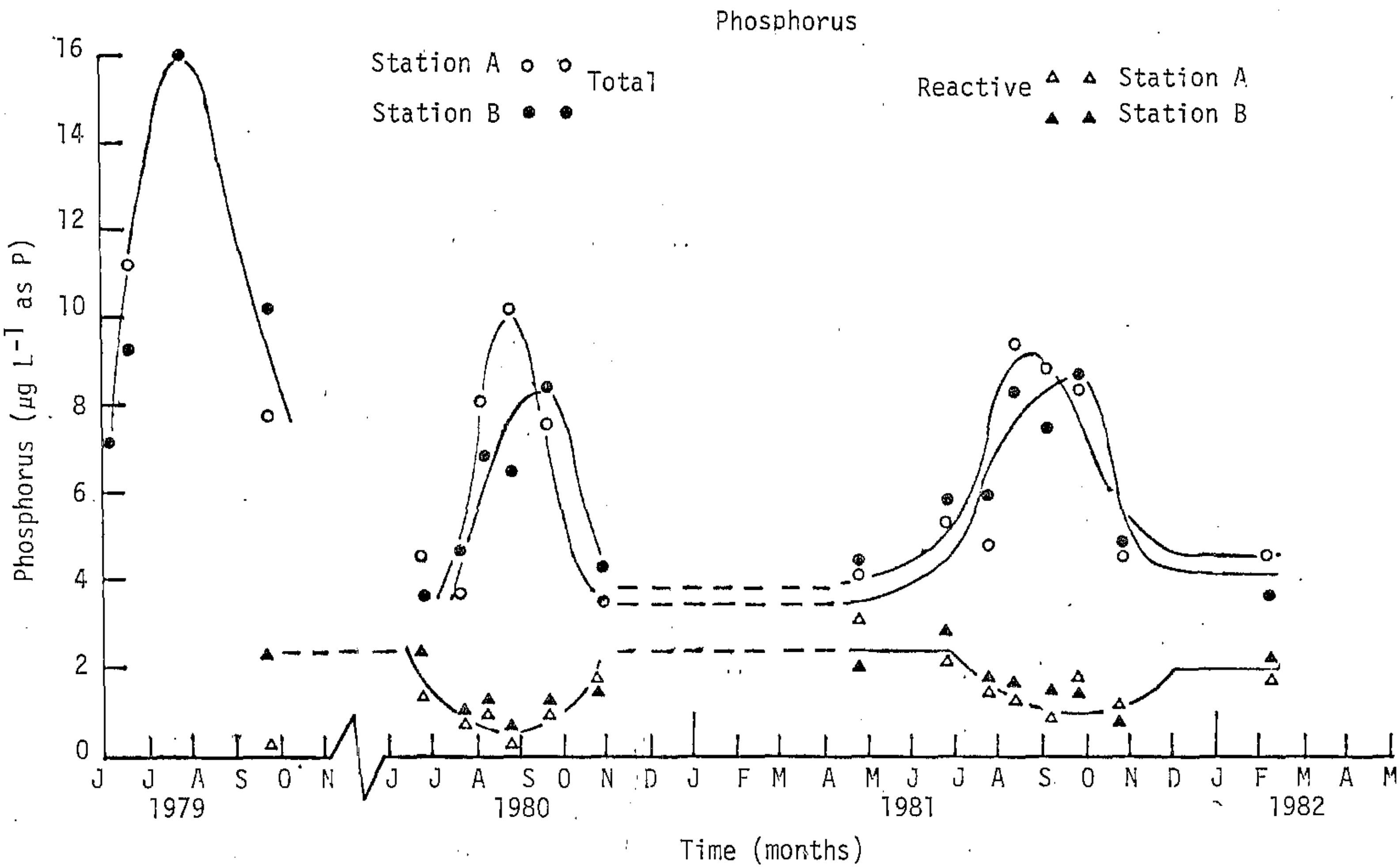


Figure 8. Seasonal profiles of total and reactive phosphorus in the epilimnion of Crescent Lake in 1979, 1980, and 1981.

inorganic silt clouds the water for most of the ice-free season. The question arose whether this silt bound phosphorus within the inorganic glacial flour rather than the phosphorus being held within the organic seston. If so, this fraction would not consist of biologically available phosphorus (BAP) and should be subtracted from loading calculations which are based upon BAP levels.

Indeed, over 65% of the particulate phosphorus fraction held in the epilimnion proved to be inorganic particulate-P (Figure 9a). This fraction increased to over 75% in the hypolimnion (Figure 9b) i.e., only 35% of particulate-P in the epilmnion and 25% of particulate-P in the hypolimnion is bound in the organic fraction. This in turn reduced the total phosphorus concentration considered to be biologically active by nearly 50%. In addition, the contribution of inorganic particulate-P was not consistent over time; varying from only 20% of particulate-P under the ice in April of 1981 and February of 1982 (when the lake is substantially clear) to over 70% during the summer period of August and September (Figure 9).

Finally, the difference between particulate-P and total-P was much greater in the hypolimnion compared to the same time periods within the epilimnion. For example, on August 12 non-particulate-P equalled <1 microgram/L in the epilimnion, but was over 8 microgram/L in the hypolimnion. This might suggest that within the euphotic zone inorganic P was being converted to a larger extent to particulate-P. However, particulate-P in both zones were approximately 8 microgram/L so the difference was due to a larger fraction of non-particulate-P entering the hypolimnion perhaps from the

CRESCENT LAKE - 1981

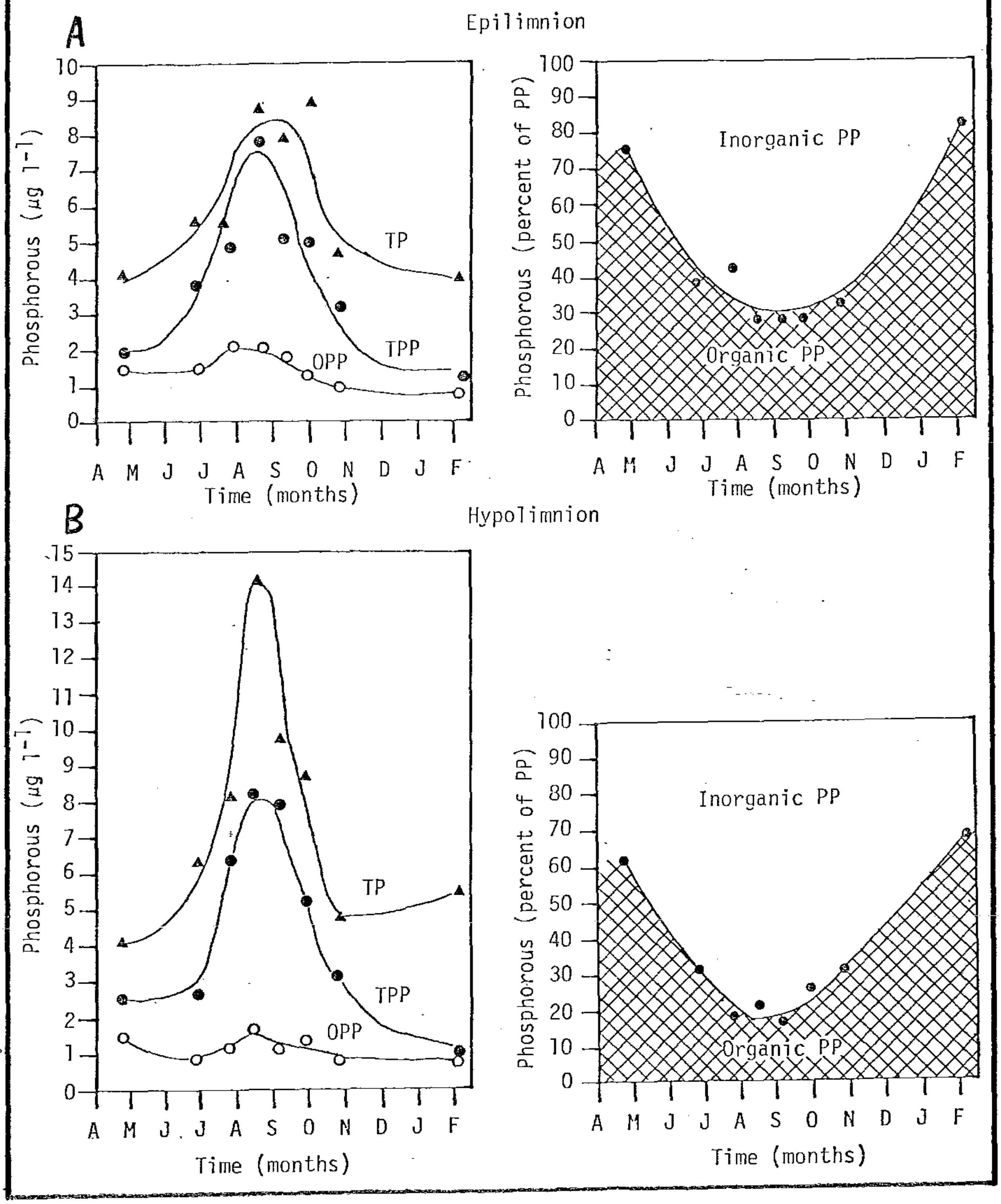


Figure 9. Seasonal profiles of chlorophyll a and photosynthesis in the epilimnion of Crescent Lake in 1979, 1980, and 1981.

sediments. In addition, the comparable levels of particulate-P in both the epilimnion and the hypolimnion suggested the lack of settling of glacial silt throughout the year in Crescent Lake.

Phytoplankton Standing Crop

The standing crop of phytoplankton showed a fairly distinct pattern in Crescent Lake with peak chl a concentrations occurring in August (1979) and in early September (1980 and 1981) (Figure 10a). Peak chl a values ranged from 1.71, 1.93 and 1.96 microgram/L at Station B, to 1.97, 2.05 and 5.20 microgram/L at Station A respectively during the three years of sampling. At both stations, the largest concentration of chl a occurred in 1980, and the lowest in 1981. In general, Station A contained a slightly greater quantity of chl a both in terms of peak concentration and of summer seasonal averages. Epilimnetic chl a for the June through October period averaged 1.24 microgram/L (n=6) and 0.64 microgram/L (n=6) at Station A, and 0.78 microgram/L (n=6) and 0.45 microgram/L (n=6) at Station B in 1980 and 1981 respectively.

Hypolimnetic (>30 m) chl a levels were consistently lower and less variable than those found in the epilimnetic zone. Mean concentrations for the June through October period were 0.35 microgram/L (n=6) and 0.37 microgram/L (n=6), at Station A, and 0.24 microgram/L (n=6) and 0.27 microgram/L (n=6) at Station B in 1980 and 1981 respectively. However, unlike the epilimnion, the large increase in chl a during the later part of August and early September never developed. Peak levels of chl a within the hypolimnion

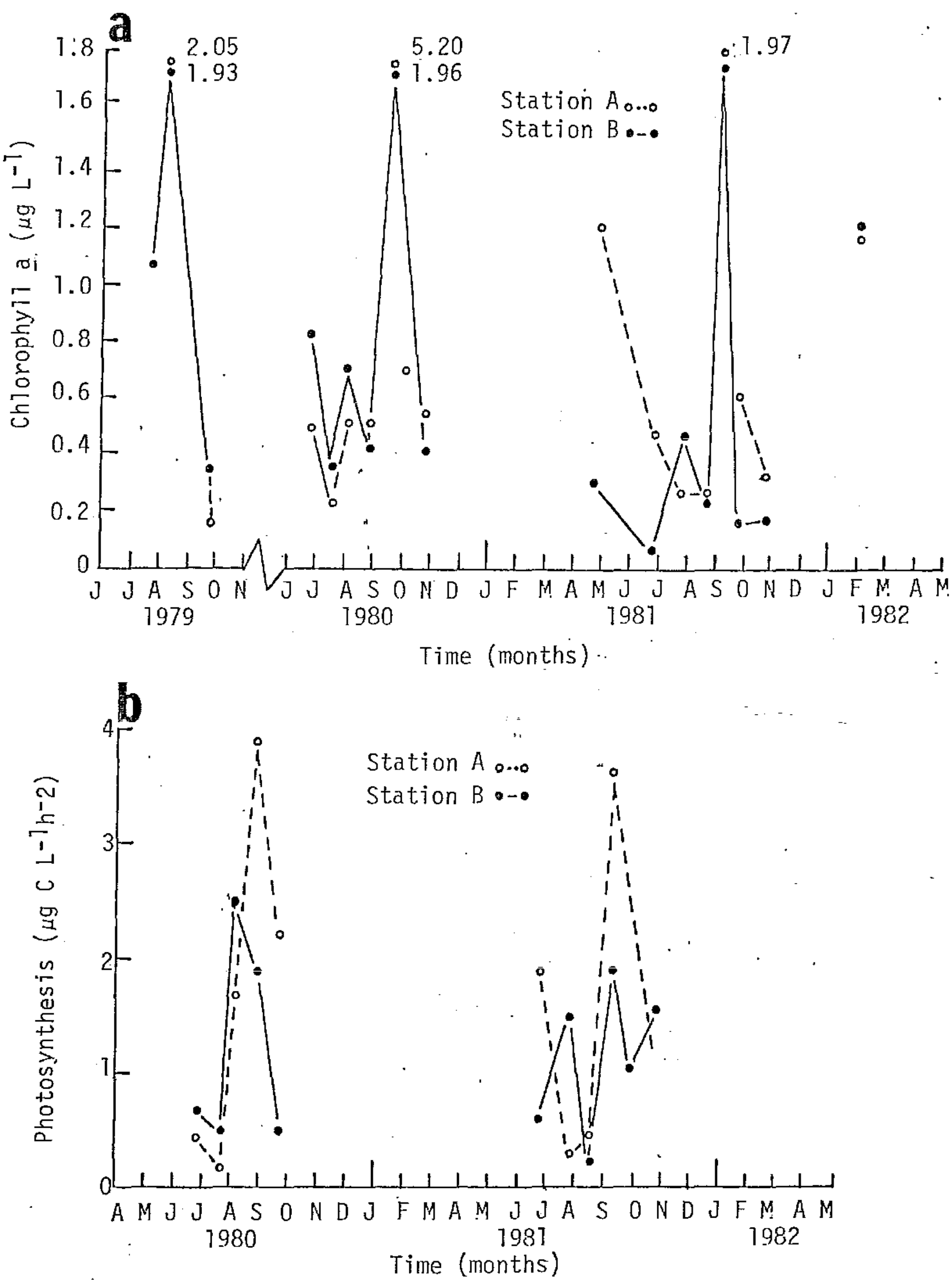


Figure 10. Seasonal profiles of chlorophyll a and photosynthesis in the epilimnion of Crescent Lake in 1979, 1980, and 1981.

ACE 8100110

occurred in the spring and fall as a consequence of mixing with the epilimnetic layer during the turnover periods.

The rate of algal uptake of inorganic carbon (photosynthesis) followed the general seasonal pattern of chl a concentrations (Figure 10b). That is, low uptake rates found during the spring-early summer period ($\leqslant 5\ \mu g\ C\ L^{-1}h^{-2}$) were followed by 5-10 fold increases in August and September (2-5 $\mu g\ C\ L^{-1}h^{-2}$) and then a decline in late fall (0.5-1.0 $\mu g\ C\ L^{-1}h^{-2}$).

Unlike the chl a concentrations, which are somewhat constant within a definable water body, photosynthesis is dependent not only on biomass levels but also on day to day variations in light, temperature and nutrients. Consequently, the magnitude and shape of the photosynthesis-depth curve varied considerably by sampling period. For example, in early summer (July) and late fall (October) of 1981, light penetration was at its greatest depth with a photic zone extending to ∿10-11 m. However, in August and September, the photic zone was diminished by nearly one-half (4-6 m). The same trend can be seen in 1980, where in July the photic zone extended to >11 m, whereas in August the photic zone decreased to 5 m. Thus, the amount of photosynthetic activity per square meter of lake surface depended both on depths, and on the depth of the photic zone.

Phytoplankton Composition and Relative Abundance

The phytoplankton community within the epilimnion is dominated by diatoms and green algae (Table 2). In fact, two taxa comprise the bulk of the volume of algae within the lake i.e., the diatom *Cyclotella* sp. and the chrysophyte *Dinobryon* sp.. These two combined taxa represented from 56 to 93% of the total algal volume in June and July.

All the algal taxa identified in Crescent Lake (except for *Microcystis* sp.) are classified by Hutchinson (1967) to be indicative of unproductive, oligotrophic waters. In fact, *Dinogryon* sp. growth (in culture) has been found to be inhibited by a phosphorus level exceeding 5 microgram/L, and is generally viewed as an indicator of very low available phosphorus concentrations. Nearly all of the data from many different lakes suggest that *Dinobryon* sp. does not appear in the spring (after diatom blooms) until the ratio of inorganic nitrogen to phosphorus rises, i.e., as inorganic phosphorus levels fall to less than some threshold concentration between 1 and 5 microgram/L.

We have not been able to define seasonal trend or biomass levels of the phytoplankton because of a backlog of unanalyzed samples. However, the samples do exist and are currently being analyzed.

Zooplankton

The zooplankton community of Crescent Lake is composed of three organisms: *Cyclops scutifer, Kellicottia longispina,* and *Asplanchna* sp. Of these,

Table 2. Phytoplankton specie composition by total number of cells/m^3 and total volume of cells at Stations A and B at 1 m in 1980.

Phytoplankton	Number of cells/m^3 x 10^{+6}				Volume of cells (mm^3/m^3)			
Date:	6/26/80		7/16/80		6/26/80		7/16/80	
Station:	A	B	A	B	A	B	A	B
Diatoms								
Fragilaria crotonensis		24				3		
Asterionella formosa			12				2	
Synedra acus				24				6
Tobellaria sp.				73				73
Cyclotella sp.	109	73	230	206	11	7	28	30
Chrysophytes								
Chromulina sp.	230	97	49		5	2	1	
Chrysochromulina sp.	61		49	24	5		4	2
Dinobryon sp.	24	73	449	739	9	25	157	259
Ochromonas sp.	24				2			
Kephyrion sp.	61	12	133	109	3	<1	7	5
Cyanophytes								
Microcystis sp.	145	170		182	1	2		2
Others								
Roya sp.		121				9		
μ-algae		182				<1		
Gleocystis sp.	36				<1			
Total	690	752	922	1,357	36	50	199	377

only the macro-zooplankton *Cyclops* is considered to be food for rearing sockeye fry. The seasonal abundance pattern of this raptorial feeder was found to be fairly consistent over the three years (1979-1982) sampled Figure 11). In general, the initial overwintering population density (as determined in October) was gradually reduced to low population densities by April of the following year. Thereafter, population densities expanded to slightly greater densities in June and July and then erupted to maximum densities in August (Station A) and September-October (Station B). Population densities during the June through October period averaged 111,476/m^2 and 134,417/m^2 at Station A, and 137,643/m^2 and 105,741/m^2 at Station B in 1980 and 1981 respectively. So although the population densities peaked at slightly different times, the overall numbers of adult copepods found at each station in both years were very comparable.

In terms of relative abundance, the predaceous rotifer *Asplanchna* sp. followed the most numerous *Cyclops*. Mean population densities of *Asplanchna* reached 52,305/m^2 (n=6) and 156,908/m^2 (n=6) at Station A during the June through October period and averaged 23,350/m^2 (n=5) and 125,331/m^2 (n=5) at Station B during the same time period in 1980 and 1981 respectively. The seasonal abundance pattern of *Asplanchna* closely resembled that of the raptorial feeding *Cyclops*. Again, population densities were low in the spring and early summer followed by an explosive population increase in September and October. However, unlike *Cyclops*, population densities of *Asplanchna* were vastly different in 1980 compared with 1981. Average numbers of *Asplanchna* sp. in 1981 (June through October) were nearly 4 times those in 1980; rising from 40,495/m^2 (n=11) to 154,484/m^2 (n=11).

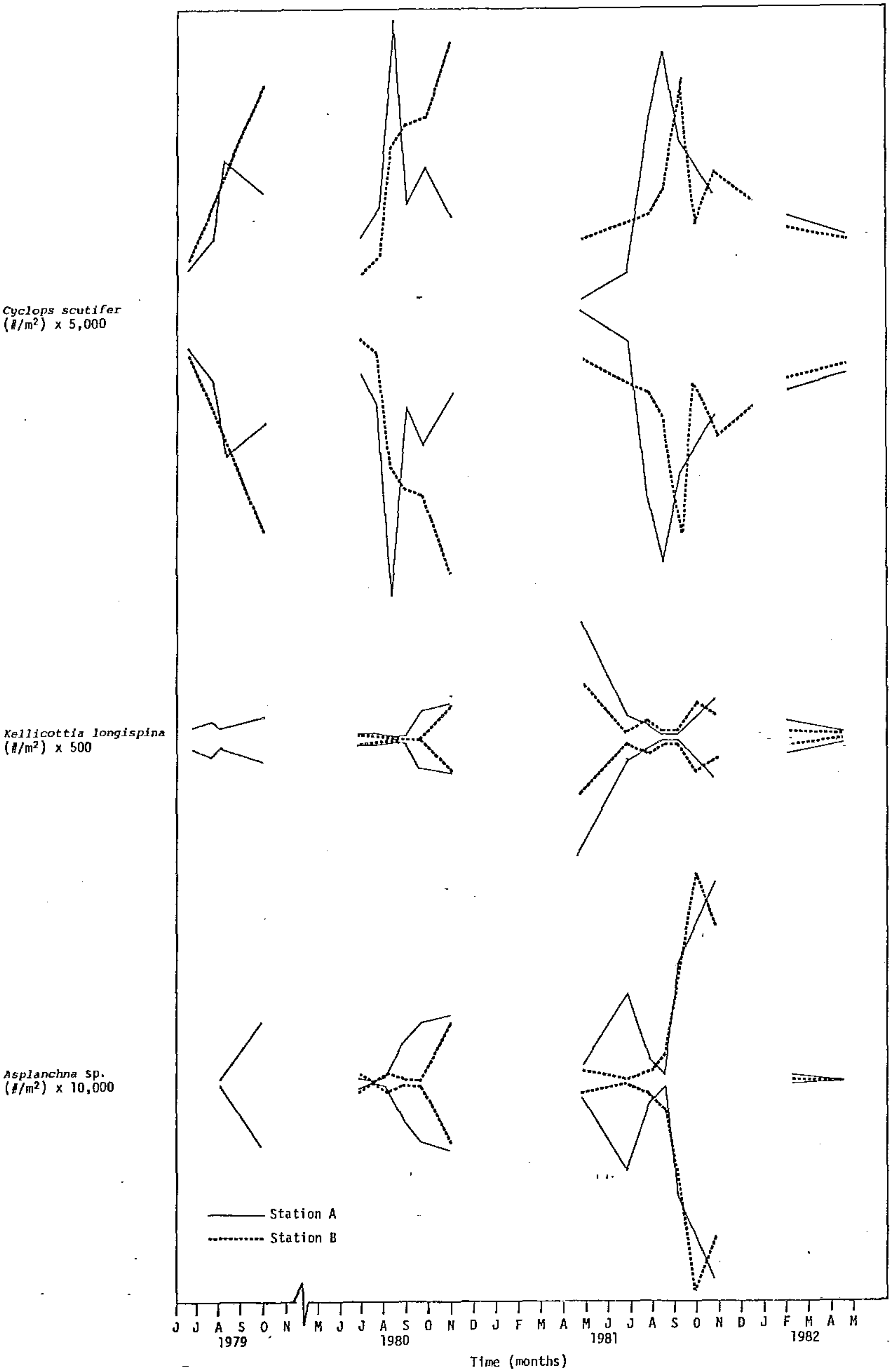


Figure 11. Seasonal oscillations in zooplankton densities by species in Crescent Lake in 1979, 1980, and 1981.

ACE 8100115

Unlike the predaceous rotifer *Asplanchna*, the herbivorous rotifer *Kellcottia longispina* never achieved large densities. Seasonal means ranged from only 5,069/m^2 (n=11) to 6,551/m^2 (n=11) in June through October of 1980 and 1981 respectively. Like densities of *Asplanchna* in 1980 and 1981 and *Cyclops scutifer* in 1981, the density of *Kellicottia* was only slightly larger at Station A compared to Station B in both years sampled. Mean densities of *Kellicottia* during June through October equalled 5,761/m^2 (n=6) and 6,518/m^2 (n=5) at Station A and 4,239/m^2 (n=5), and 4,898/m^2 (n=5) at Station B during 1980 and 1981 respectively. Peak numbers were found in late winter of 1981, which then declined through the summer, and showed only a slight rise in the fall. The timing of the yearly seasonal peak in the number of *Kellicottia* was less consistent when compared to the timing of peak numbers of *Asplanchna* and *Cyclops*. For example, in April of 1981, numbers reached the highest of any sampled date (38,854/m^2) however, in April of 1982, numbers were exceedingly low (2,700/m^2).

Since *Cyclops scutifer* is the primary forage for rearing sockeye fry, its population dynamics (size, sexual maturity, egg production) were studied in some detail. The univoltine *Cyclops* overwinters as small sized (≤0.85 mm) pre-mature adults (Figure 12a) along with a small number of nauplii. After ice out, the sub-adults grew to become sexually mature (≥0.85 mm), and by late June egg sacs begin to appear in the females. At this time nearly 80% of the population consisted of mature adults with few post-nauplii or sub-adults present (Figure 12b). By July, the population expanded (Figure 12a) with nearly 60% of the population consisting of a new year class of post-nauplii (i.e., ≥0.40 mm <0.55 mm). In addition, the number of large sized adults (≥0.85 mm) decreased to only 25% of the population compared to nearly

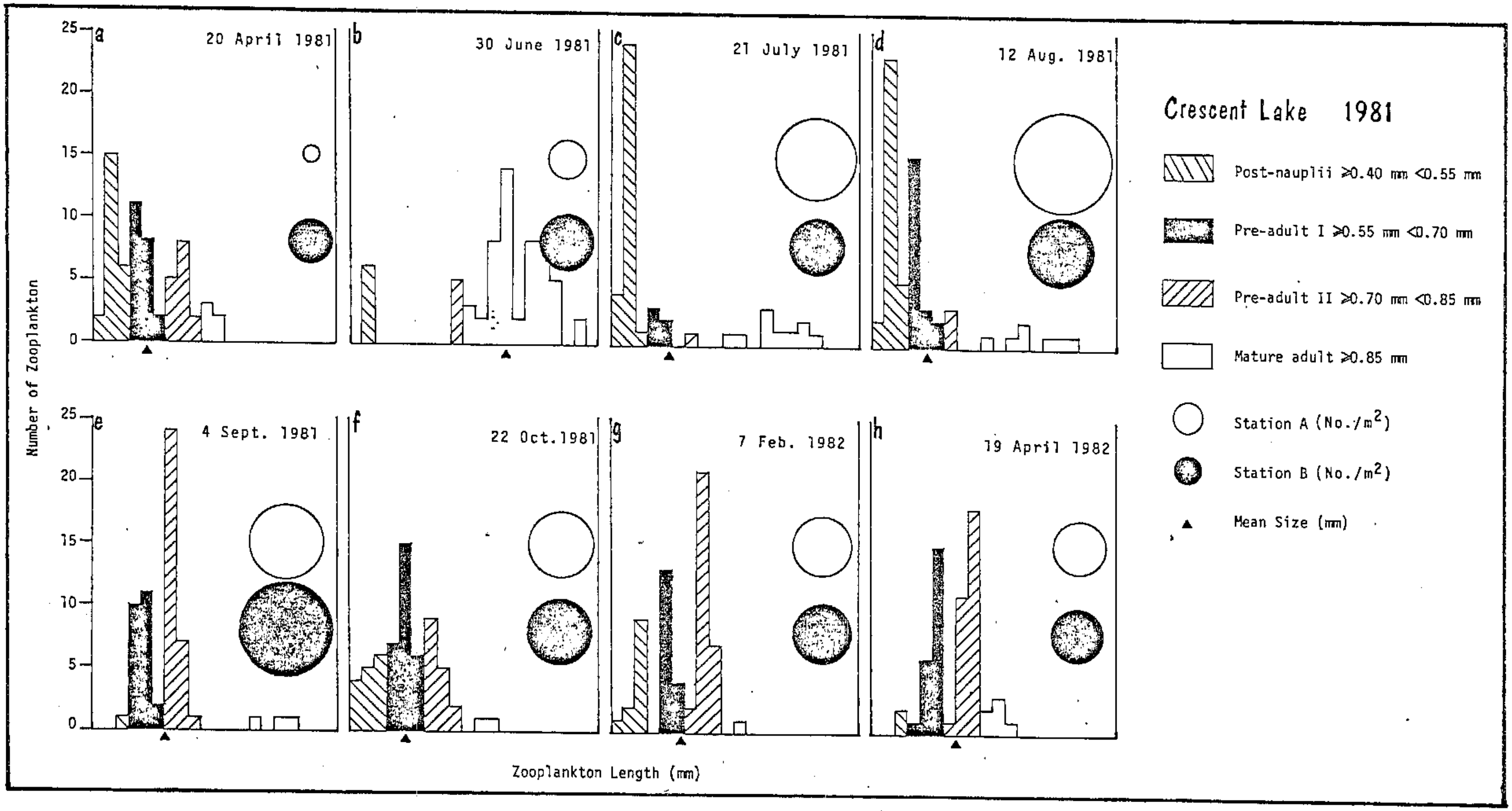


Figure 12. Changes in body size and developmental stage of *Cyclops scutifer* by date in Crescent Lake in 1981.

80% a month earlier. In August, maximum egg production took place and was accompanied by 1) a further decline in the number of larger adults to 14% of the population, 2) a decrease in the smaller size class to 40% of the population, and 3) the emergence of the pre-adult I size class (⩾0.55 <0.70 mm) as the dominate group (Figure 12d). By September, the larger sized individuals represented <5% of the population, and the smaller, younger size class (post-nauplii) represented 2% of the population (Figure 12e). By now, nearly 92% of the population was within the pre-adult I and pre-adult II stages with 54% being within the pre-adult II size class (⩾0.70 mm <0.85 mm). Thus, during September/October the overwintering population began to form which consisted of the three smaller pre-mature adult stages (Figure 12f). This structure is reminiscent of the population structure found both in April of 1981 and spring of 1982 (Figure 12g-h).

Seasonally, a pronounced change in the overall average size of *Cyclops scutifer* developed only in June when the sexually mature adults first obtained their maximum size (Figure 12b). After this, both the appearance of small post-nauplii and the disappearance of the larger size class combined to drastically decrease the average size. Subsequently, the average size of an individual slowly rose as the new year class moved through progressively older and larger life stages.

Finally, *Cyclops scutifer* like other cyclopoid copepods, is a raptorial feeder. Reagrdless of the type of food seized, (animal or plant) this copepod has not developed a filtration mechanism i.e., the mouth parts are modified for seizing and biting. Food consists of unicellular plants (algae), animals (e.g., small metazoans), and especially other crustaceans including its own nauplii. In addition, organic debris is utilized and it has now been well established that debris may, under some circumstances, form a majority of material ingested.

DISCUSSION

Glacial Melt

A major influence on the fertility of Crescent Lake is the glacial melt water. This can potentially reduce the production achieved within the lake by: 1) decreasing the photic zone, 2) decreasing epilimnetic temperatures, and 3) increasing the flushing rate (thereby decreasing the concentration of available nutrients by dilution). Operating together in the critical summer-early fall period, these processes could potentially depress the productive capacity of the lake. Hence, Crescent Lake would have all the characteristics of an extremely unproductive oligotrophic system.

The timing, as well as the magnitude, of the glacial melt is of considerable importance to the biological community within the lake as initiation of the melt period coincides with the initial pulse of autochthonous production. By shortening the spring pulse, major food production for spring rearing sockeye fry could be considerably reduced. That is, cohort recruitment by *Cyclops scutifer* occurred in July just prior to glacial melt. Consequently, food for the emerging nauplii could be reduced at a time when needed most.

Maximum glacial water influence was observed to occur in August and September of 1979, 1980 and 1981. At this specific time in each of the three years, the photic zone was indeed drastically reduced (Figures 4 and 5), epilimnetic temperatures were reduced over July-early August maximums (Figures 2 and 3), and minimums occurred in the concentrations of the specific algal nutrients; nitrogen, silica, and reactive phosphorus (Figures 6, 7 and 8). Prior to late August, a significant input of glacier melt, beginning in late June, initiated the changes noted above. The only nutrient parameter which began to increase in concentration by late June was total phosphorus (Figure 8) which increased by nearly 33%.

If the introduction of the glacial water which begun in June acted to depress primary production by the mechanisms discussed above, then algal standing crop and productivity should have remained depressed over the period of maximum glacial influence i.e., late August through September. However, the evidence we have suggests the contrary.

Standing crop estimates (chl a concentrations) indicate maximum levels in either August or September at both stations in 1979 through 1981 (Figure 10a). In addition, in 1980 and 1981, maximum rates of photosynthesis were observed again in August and September at both stations (Figure 10b). Not only are the surface rates increased during this period, but in both years the integrated depth versus time curve shows that maximum rates of photosynthesis per m^2 took place at both stations in September. Interestingly, the reduction in photic zone volume caused by the glacial silt was compensated for by increased algal activity within the remaining photic zone.

This stimulation of primary production caused the differences between both hypolimnetic and epilimnetic inorganic nitrogen (Figure 6) and silica values (Figure 7) during July and August. The stimulation of primary production may have been triggered by the increase found in phosphorus loading from glacial melt (Figure 9).

Photic Zone Volume

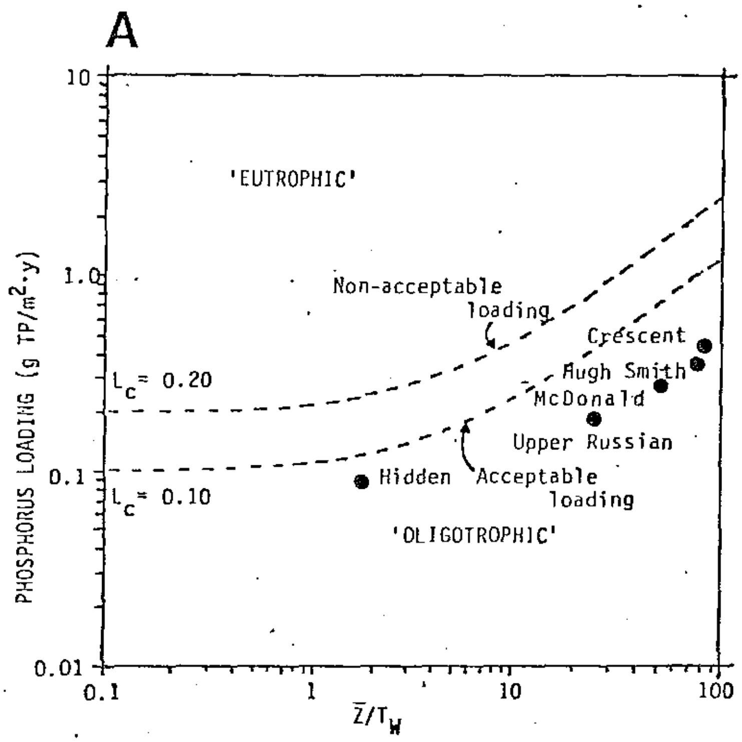
The magnitude of the photic volume is of concern because light penetration powers the photosynthetic process which is the basis of the autochthonous food chain. In this regard, the photic volume of Crescent Lake compares favorable with other lakes systems (Table 3). Consequently, the decrease in light penetration caused by glacial melt water does not drastically reduce the photic zone volume below those of other sockeye systems. For example, Tustumena Lake is 270 times the size of Hidden Lake by volume and 33 times greater by surface area, but has essentially the same euphotic zone volume. Again Crescent Lake is 3 times Hidden Lake by volume, 2.5 times by surface area, but both have comparable euphotic volumes. A pertinent question arises; would these three lakes be expected to produce the same number of fish (or fish biomass) per m^2 of surface area?

Nutrient Demand and Supply

In regard to phosphorus loading (supply), Crescent Lake is classified as oligotrophic (Figure 13a), and fits well within a total phosphorus summer chl *a* response model (Figure 13b). In order to fit within the latter relationship, phosphorus is required to limit system production i.e., an

Table 3. Comparison of the physical features of several Alaskan lakes that are used to normalize fisheries potential.

Lake	Volume ($m^3 \times 10^{+6}$)	Lake Type (water clarity)	Surface Area ($m^2 \times 10^{+6}$)	Water Residence Time (yr)	Light Compensation Level (m)	Euphotic Volume ($m^3 \times 10^{+6}$)
Upper Trail	116	Glacial	7.1	0.19	0.5	3.6
Tustumena	37,000	Glacial	225.0	17.20	0.6	135.0
Skilak		Glacial	99.0		1.5	148.5
Kenai		Glacial	56.0		1.5	56.0
Crescent	389	Semi-Glacial	16.2	0.3	6.5	105.3
Hugh Smith	209	Organic Stain	2.9	1.1	5.0	14.5
Packers	26	Organic Stain	2.1	0.9	6.0	12.6
McDonald	123	Organic Stain	3.4	0.7	7.5	25.5
Bear	19	Clear	1.8	0.8	9.5	17.1
Hidden	138	Clear	6.8	11.2	15.0	102.0
Upper Russian	122	Clear	4.6	1.1	13.0	60.0
Karluk	1,920	Clear	39.0	6.0	20.0	780.0



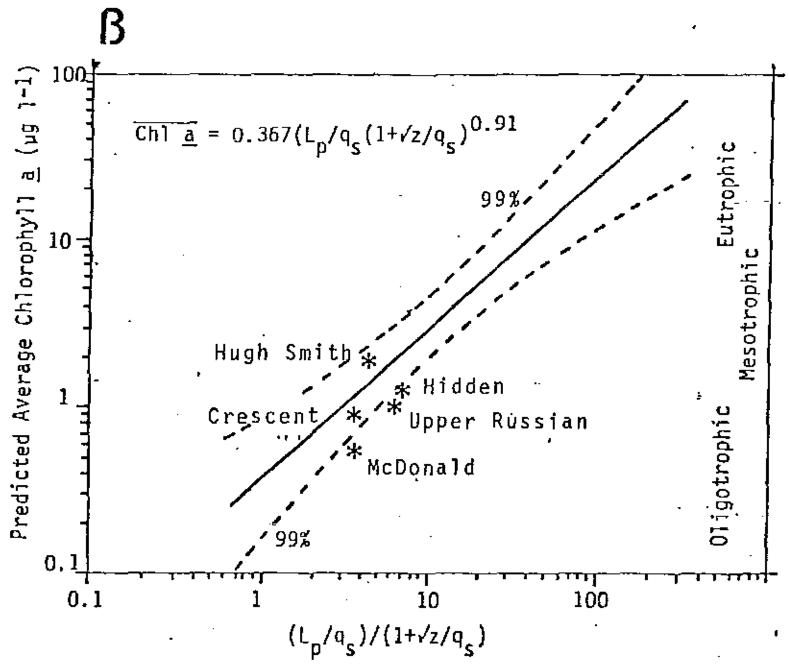


Figure 13. Phosphorus loading characteristics of several oligotrophic Alaska lakes (A), and the relationship between phosphorus concentration and resultant summer chlorophyll a production (B) [after Vollenweider (1976)].

increase/decrease in phosphorus loading results in a direct and proportional increase/decrease response by the phytoplankton. This is based on a demand/supply relationship for the primary nutrients (C, Si, N, P). The nutrient with the highest demand per its supply controls production. In general, the nutrients C, Si, N, and P are in demand by phytoplankton at atom ratios of 106:17:16:1 respectively. In Crescent Lake, C:Si:N:P supply ratios are 320:380:91:1; a clear indication of the importance of phosphorus supply to autochthonous production within Crescent Lake i.e., demand/supply values of P=1.00 C=0.33 N=0.18, and Si=0.05.

Phosphorus Loading Criteria

Lakes differ in morphometric features [e.g. mean depth ($\bar{z}$), surface area, and flushing rate or water residence time (Table 4)] which combine to define the supply of nutrients e.g. phosphorus, to lake systems. Like euphotic zone volume, these features fluctuate from lake to lake e.g. mean depth extends from 71 m to 20 m and water residence time ranges from 0.3 y to 11.3 y. Such variation results in the well known differential fertility of lake systems. The empirical relationship that bound these factors together into a predictive tool was developed by Vollenweider (1976). The phosphorus loading criteria evolved from this model. In particular, the surface specific loading (Lp) and the surface critical loading (Lc). The former describes the present phosphorus loading rate, and the latter describes the loading rate not to be exceeded in order to prevent unwarranted change in pre-existing lake water quality. Again, vast differences were found between lake systems (Table 4) as existing surface specific loading rates ranged from 53 to 650 mg P/m^2/y. A third term (Lf) is introduced here for

Table 4. Comparison of surface specific loading (Lp), surface critical loading (Lc) and salmon carcass loading (Lp) in several Alaskan lakes.

Parameter	Date: / Lake:	1981 Crescent	1980 Upper Russian	1980 Hidden	1980 Hugh Smith	1982 McDonald
Area ($x10^{+6}$ m^2)		16.2	4.6	6.8	2.9	3.4
Volume ($x10^{+6}$ m^3)		389.0	122.0	138.0	208.5	123.0
Mean Depth ($\bar{z}$)(m)		24	27	20	71	37
Water Residence Time (yr) (Tw)		0.3	1.1	11.3	0.9	0.6
$\bar{z}$/tw (qs)		80	24.6	1.8	77	53
Lp ($mgP/m^2/yr$)		458	276	53	650	373
Lc ($mgP/m^2/yr$)		1,238	503	77	1,512	691
Lp/Lc		.37	.55	.68	.43	.54
Lf ($mgP/m^2/yr$)		50.0	181.0	5.2	33.0	342.0
Lf/Lp		.13	.66	.10	.05	.92
Escapement		90,000 (sonar)	125,000 (weir)	5,000 (weir)	<10,000 (weir)	129,000 (weir)
Escapement/m^2		.006	.027	.0007	.003	.038

use in salmon nursery lakes and is the phosphorus loading from decaying salmon carcasses. Fish loading (Lf) is a sub-function of surface specific loading (Lp), and it too changes from lake to lake ranging from 5.2 to 342 mg P/m^2y. However, even though Lf is part of Lp they are not directly related i.e., Lf and Lp can rise and fall independently of each other.

For the lake systems studied in Table 4, present loading (Lp) of phosphorus extended from 37 to 68% of critical loading (Lc). Of the present phosphorus loading (Lp), Lf represented from 5 to 92%. That is, the fertility of lakes which received a high nutrient income (as a percent of Lp) from a fall escapement of salmon e.g. Upper Russian Lake, can be correlated to an increase or decrease in the number of spawning fish. If a decrease in the number of spawning fish repeats itself over many years, a lake can be drastically reduced in fertility. However, since Lf and Lp can rise and fall independently, a short fall in Lf can be made up by a greater Lp. Thus, oscillations in lake fertility can arise by not only changing Lf, but also by changing Lp. Concurrent decreases or increases in Lp and Lf result in minimum and maximum phosphorus loading rates respectively. Directly coupled with the flucuations in P-loading are changes in lake fertility.

Nutrient loading rates (Lp) change by alterations in edaphic and climatic influences. However, a long term decrease in Lf can lower the amount of nutrients delivered to a system by a definable amount. As an example, Hugh Smith Lake has a Lp of 650 mg $P/m^2/y$ (Table 4). Presently, 5% of Lp is supplied by Lf from an escapement of <10,000 sockeye adults. On a yearly basis, 1,901 kg P enters Hugh Smith Lake (Figure 14) of which 5% or 96 kg P

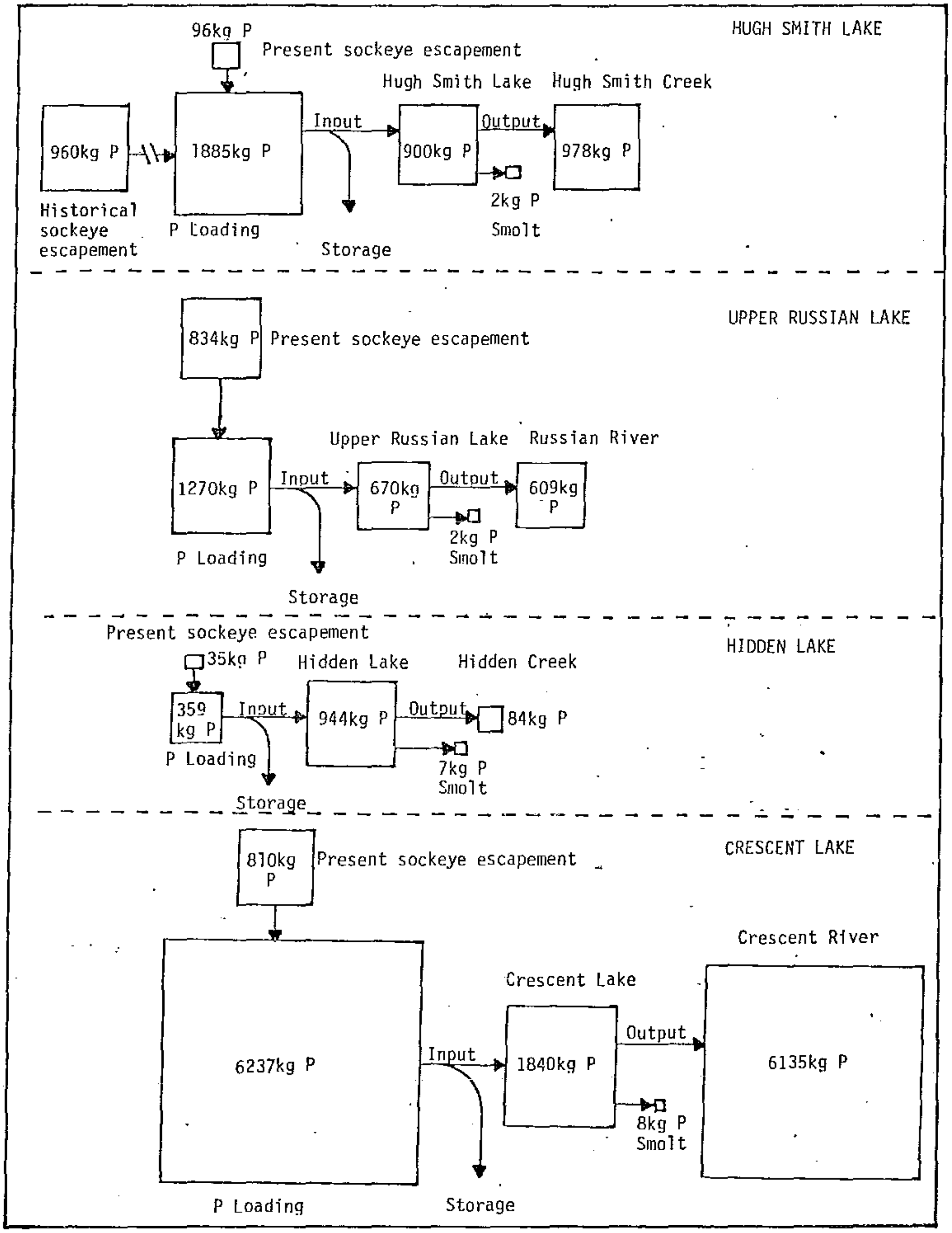


Figure 14. Graphical representation emphasizing several components of the lake's influence of fish decomposition on phosphorus loading. (Size of compartments are equal to the amount of phosphorus present in a year).

comes from the adult escapement, and 95% enters from other sources e.g. sediments and watershed. Loses of phosphorus from the lake include the 2 kg lost by the smolt migration (thus adult fish import considerably more nutrients from the sea back to the lake then are lost by the migrating smolt. However, 978 kg P is lost by drainage out of Hugh Smith Creek, an amount equal to nearly 49% of the P entering the lake. Thus, a major portion of the phosphorus lost from the system leaves via the outlet. This flushing continues year after year irregardless of the magnitude of Lf, but when coupled with a decrease of Lf it is the major cause of decreased lake fertility.

Finally, historical escapements of sockeye into Hugh Smith Lake have been placed at approximately 100,000 adults. Historically, instead of Lf equalling 5% of Lp, as is presently the case, Lf equalled 50% of Lp (given that the other components of Lp were roughly equal then and now). Increasing Lf from 5% to 50% of Lp should increase the fertility of Hugh Smith Lake. Thus, in 1980, the nutrient equivalent of 100,000 sockeye (310 mg $P/m^2/y$) was added to Hugh Smith Lake through the lake fertilization program.

The pattern of nutrient supply and removal places upper and lower limits on productivity (lake fertility), and is found in diversified combinations in Upper Russian, Hidden and Crescent lakes. In essence, all lakes metabolize phosphorus differently (Figure 14), but the dissimilarity of considerable importance to Crescent Lake is the flushing rate. Much of the phosphorus entering the lake leaves the outlet (especially the non-BAP connected with the glacial silt). Consequently, the nutrient addition must be judiciously timed and placed as a function of temperature, flow, and biological production.

RECOMMENDATIONS

Fertilization

Irregularities were noted in the temperature and light regimes at Stations A and B in both 1980 and 1981 suggesting a variable effect of the glacial melt at the two stations. This, in turn, suggests a pattern of water flow (Figure 15) from the major glacial tributary stream that in large part bypasses the upper third of the lake (i.e., Station B). Thus, the water retention time of the upper third of the lake may be considerable greater than that for the lower two-thirds of the lake.

Representative temperature profiles (Figure 16) indicate a period of epilimnetic thermal stability between the latter part of June through the first week in September or approximately 10 weeks. This period of time coincides with minimal algal and zooplankton standing crops, decreasing nutrient levels, and the period of emergence of a new crop of immature zooplankton. In addition, the end of the proposed fertilization period (early September) is the point at which the system can carry itself i.e., preexisting production is already high. Thus, fertilization is recommended for the upper third of the lake, including Station B, but excluding Station A and the new Station C (Figure 17) with application taking place once a week for 10 weeks.

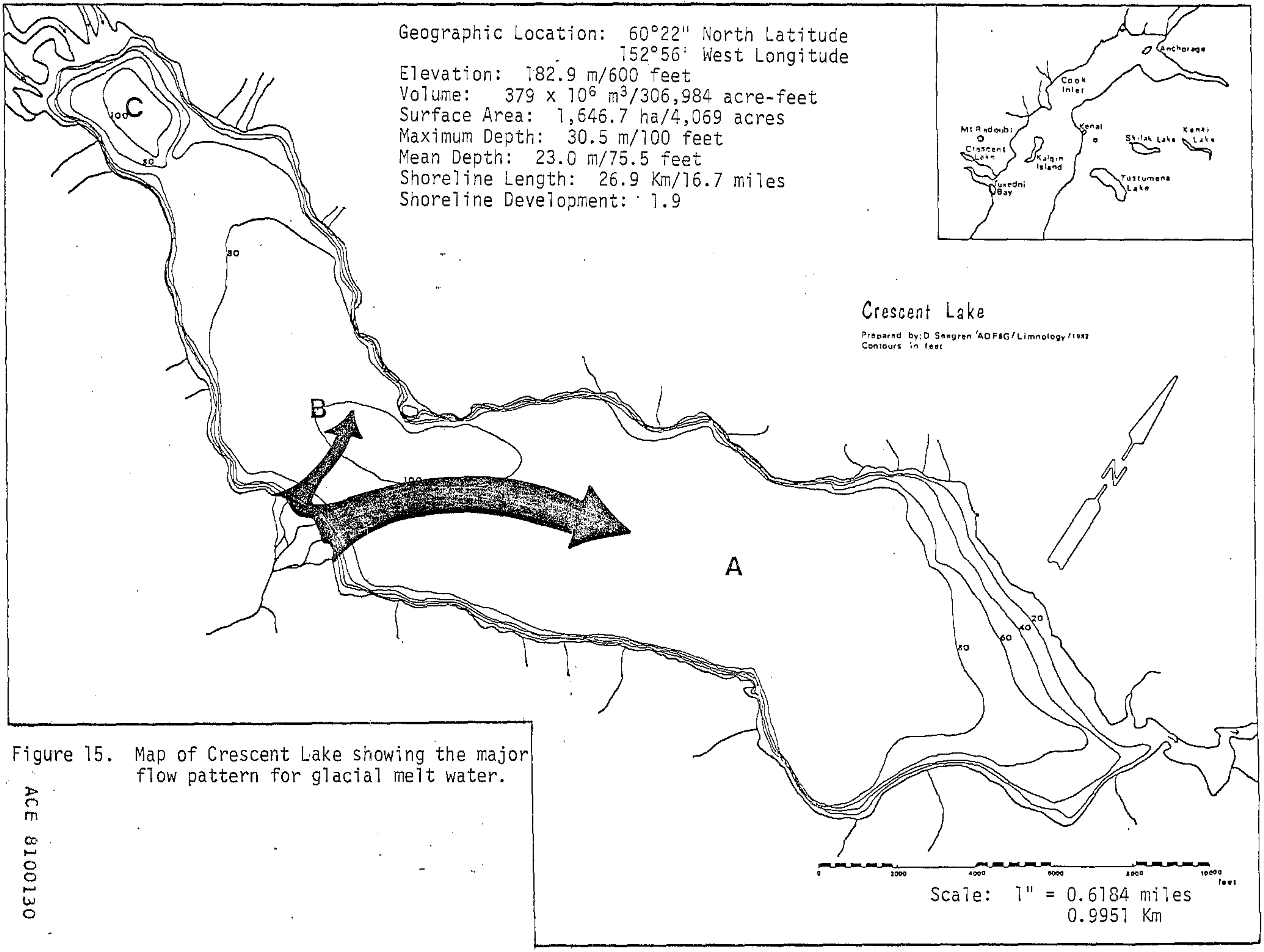


Figure 15. Map of Crescent Lake showing the major flow pattern for glacial melt water.

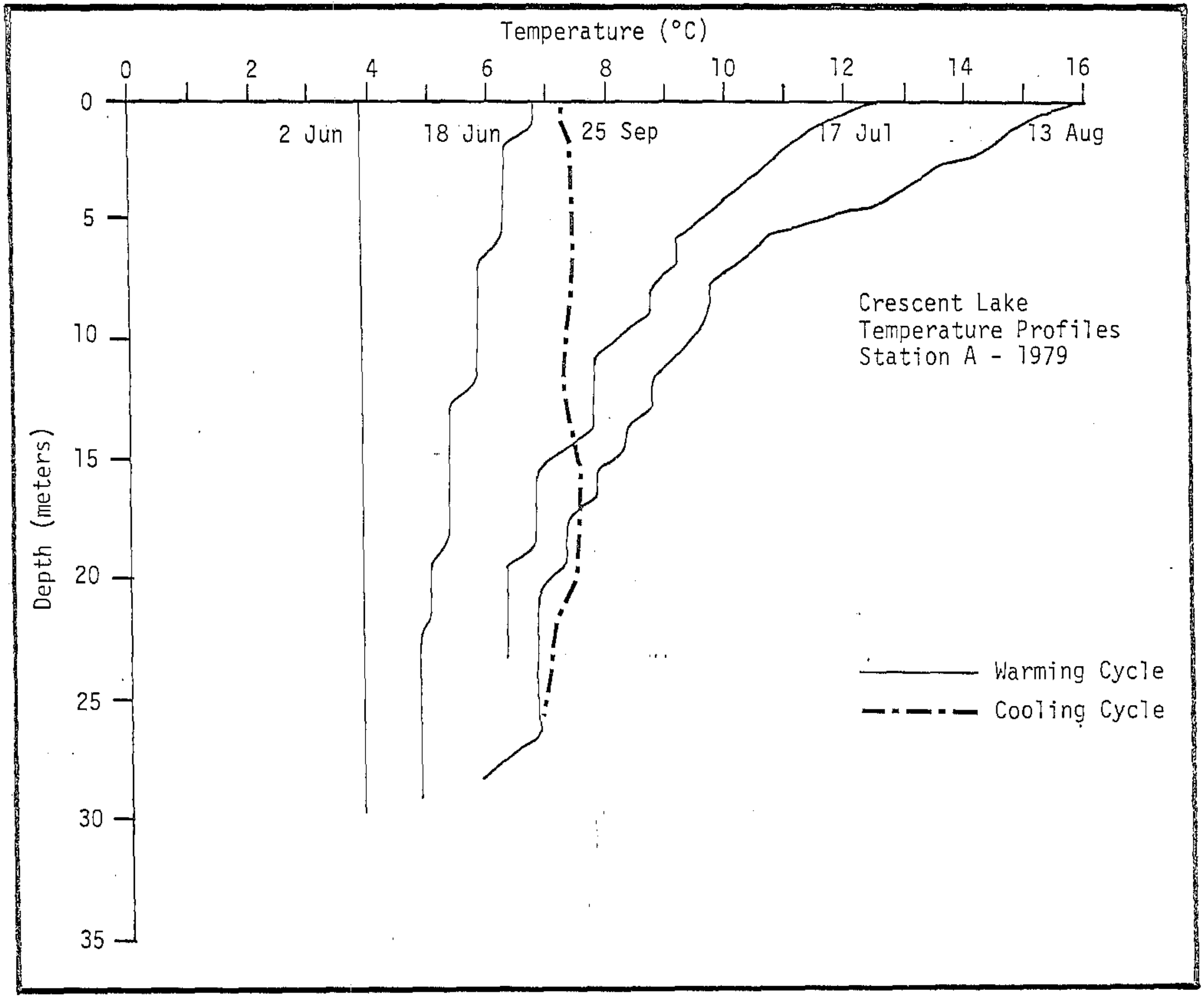


Figure 16. Temperature profiles showing warming and cooling cycles, and thermal stratification in Crescent Lake in 1979.

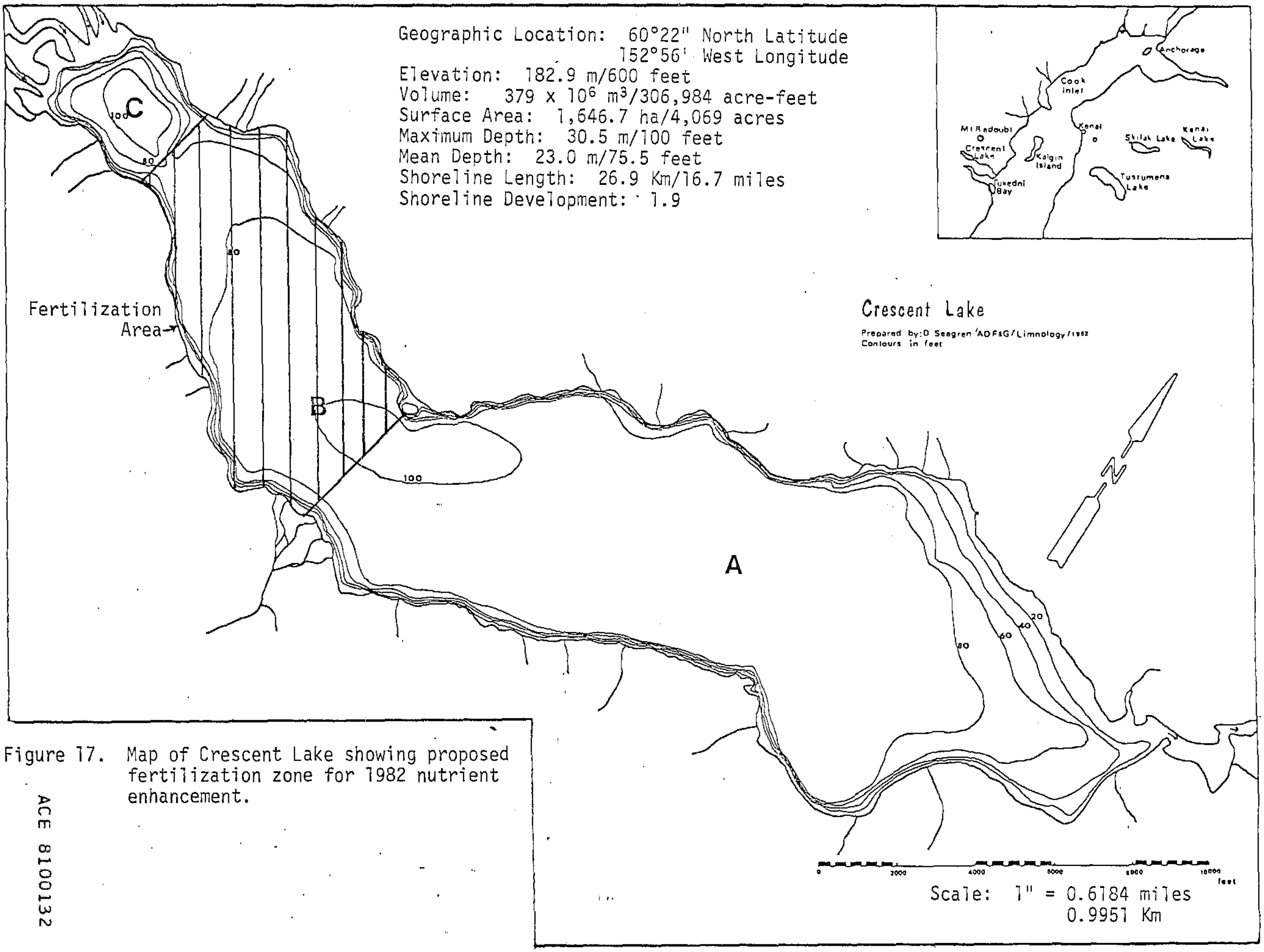


Figure 17. Map of Crescent Lake showing proposed fertilization zone for 1982 nutrient enhancement.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Don Seagren for drafting the tables and figures in this report.

REFERENCES

Brooks, J. L. 1959. Cladocera. In: W. T. Edmondson [ed.], Fresh-water Biology, 2nd ed. John Wiley and Sons, Inc. p. 587-656.

Edmondson, W. T., and G. G. Winberg (eds). 1971. A manual for the assessment of secondary productivity in fresh waters. International Biological Program Handbook. 12:358 pp.

Eisenreich, S. J. Bannerman, R. T., and D. Ed. Armstrong. 1975. A simplified phosphorus analysis technique. Environ. Letters (:43-53.

Frost, W. E., and W. J. P. Smyly. 1952. The brown trout of a Moorland fishpond. J. Animal Ecol. 21:62-86.

Haney, J. F., and D. J. Hall. 1973. Sugar coated *Daphnia*: A preservation technique for cladocera. Limnol. Oceanogr. 18:331-111.

Hanson, J. M. and W. C. Leggett. 1982. Empirical production of fish biomass and field. Canadian Journal of Fish. and Aquatic Sci. 39:257-263.

Hasler, A. D., and W. G. Einsele. 1948. Fertilization for increasing productivity of natural inland lakes. Trans. Thirteenth North American Wildlife Conf., p. 527-555.

Hutchinson, G. E. 1967. A Treatise on Limnology: Vol. II. Introduction to lake biology and the limnoplankton. John Wiley and Sons, N.Y. 1115 pp.

Juday, C., and S. L. Schloemer. 1938. Effects of fertilizers on plankton production and on fish growth in a Wisconsin lake. Progr. Fish Cult. 40:24-27.

Kuenzler, E. J., Stanley, D. W., and J. P. Koenings. 1979. Nutrient kinetics of phytoplankton in the Pamlico River, North Carolina. Water Reserach Institute, Report. 139:163 pp.

Lean, D. R. S., and B. K. Burnison. 1979. An evaluation of errors in the 14C method of primary production measurement. Limnol. Oceanogr. 24:917-928.

LeBrasseur, R. J., McAllister, C. D., Barraclough, W. E., Kennedy, D. O., Manzer, J., Robinson, D. and Stephans, K. 1978. Enhancement of sockeye salmon (*Oncorhynchus nerka*) in British Columbia, Canada. Verh. Internat. Verin. Limnol. 21:261-267.

Milbrink, G. and S. Holmgren. 1981. Fish species interactions in a fertilized reservoir. Rep. Inst. Freshw. Res., Drottningholm 59:121-127.

______________________________. 1981. Addition of artificial fertilzers as a means of reducing negative effects of "Oligotrophication" in lakes after inpoundment. Rep. Inst. Freshw. Res., Drottningholm 59:97-120.

Munro, W. R. 1961. The effect of mineral fertilizers on the growth of trout in some Scottish lochs. Verh. Int. Ver. Limnol. 14:718-721.

Murphy, J. and J. P. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Anol. Chem. Acta. 27:31-36.

Nelson, P. R. 1958. Relationship between rate of phytosynthesis and growth of juvenile red salmon. Science. 128:205-206.

___________. 1959. Effects of fertilizing Bare Lake, Alaska, on growth and production of red salmon (*O. nerka*). Fish Bull. (U.S. Fish and Wildlife Serv.) 159:59-86.

Reimann, B. 1978. Carotenoid interference in the spectrophotometric determination of chlorophyll degradation products from natural populations of phytoplankton. Limnol. Oceanogr. 23:1059-1066.

Saunders, G. W., Trama, F. B., and R. W. Bachmann. 1962. Evaluation of a modified C14 technique for shipboard estimation of photosynthesis in large lakes. Univ. Michigan, Great Lakes Res. Div., Spec. Rep. No. 8. 61 p.

Smith, M. W. 1955. Fertilization and predator control to improve trout angling in natural lakes. J. Fish. Res. Bd. Canada. 12:210-237.

Stainton, M. P., M. J. Capel, and F. A. J. Armstrong. 1977. The chemical analysis of freshwater, 2nd ed. Fish. Mar. Serv. Misc. Spec. Publ. 25:166 p.

Stockner, J. G. 1981. Whole-lake fertilization for the enhancement of sockeye salmon (*Oncorhynchus nerka*) in British Columbia, Canada. Verh. Internat. Verein. Limnol. 21:261-267.

Strickland, J. D. H., and T. R. Parsons. 1972. A practical handbook of seawater analysis, 2nd ed. Fisheries Research Board of Canada Bulletin. 167:310 p.

Tanner, H. A. 1960. Some consequences of adding fertilizer to five Michigan trout lakes. Trans. Amer. Fish. Soc., 89:198-205.

Vollenweider, R. A. 1976. Advances in defining critical loading levels for phosphorus in lake eutrophication. Mem. Ist. Ital. Idrabiol. 33:53-83.

Weatherley, A. and A. G. Nicholls. 1955. The effects of artificial enrichment of a lake. Australian J. Marine Freshwater Res. 6:443-468.

REFERENCES (continued)

Wetzel, R. G., and G. E. Likens. 1979. Limnological Analysis. W. B. Waunders, Philadelphia. 357 pp.

Wilson, M. S., and H. C. Yeatmna. 1959. Free-living copepoda. In: W. T. Edmondson [ed.], Fresh-water biology, 2nd ed. John Wiley and Sons, Inc. p. 735-861.

Part II: Crescent Lake Fisheries Data Summary

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

INTRODUCTION

The Crescent River drainage, located on the west side of central Cook Inlet directly north of Tuxedni Bay (Figure 1), encompases 300 km^2. Crescent Lake is a semi-glacial lake approximately 10 km long, 3 km wide and 23 m in average depth (Figure 2), containing all five species of Pacific salmon but primarily sockeye salmon, *Oncorhynchus nerka*. This summary presents all existing Alaska Department of Fish and Game (ADF&G) fisheries data, particularly data pertaining to sockeye salmon production in Crescent Lake. Most of the fisheries data collected from the Crescent Lake system is limited since major investigations did not begin until 1979.

The Commercial Fisheries Division of the ADF&G has monitored the Crescent Lake fisheries since 1979 to determine: 1) the sockeye salmon escapement; 2) the magnitude and timing of the sockeye salmon return; 3) the stock composition of the sockeye salmon harvest and; 4) the age, length, sex, and scale characteristics of the sockeye salmon adults.

The Fisheries Rehabilitation, Enhancement, and Development Division (FRED) of the ADF&G as part of the comprehensive pre-fertilization evaluation of Crescent Lake has monitored the sockeye salmon smolt migration since 1981 to determine smolt size, age composition, total number, and migration timing.

Further information or comments regarding juvenile sockeye salmon, other species of adult salmon, resident fish species, and the recreational sport fishery are presented from available data and cursory surveys conducted on Crescent Lake.

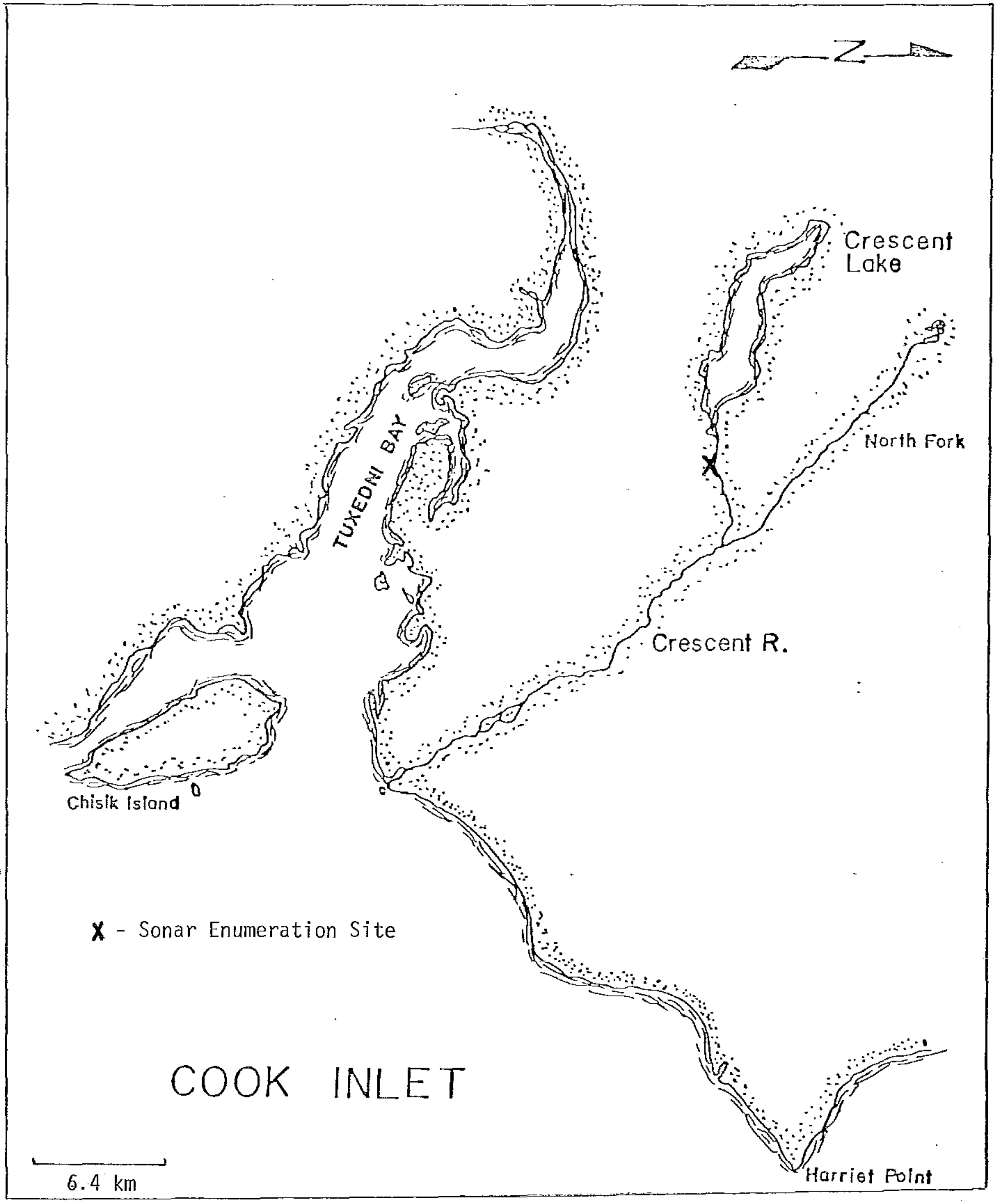


Figure 1. Map showing the Crescent River drainage system and location of the adult sonar enumeration site.

ACE 8100143

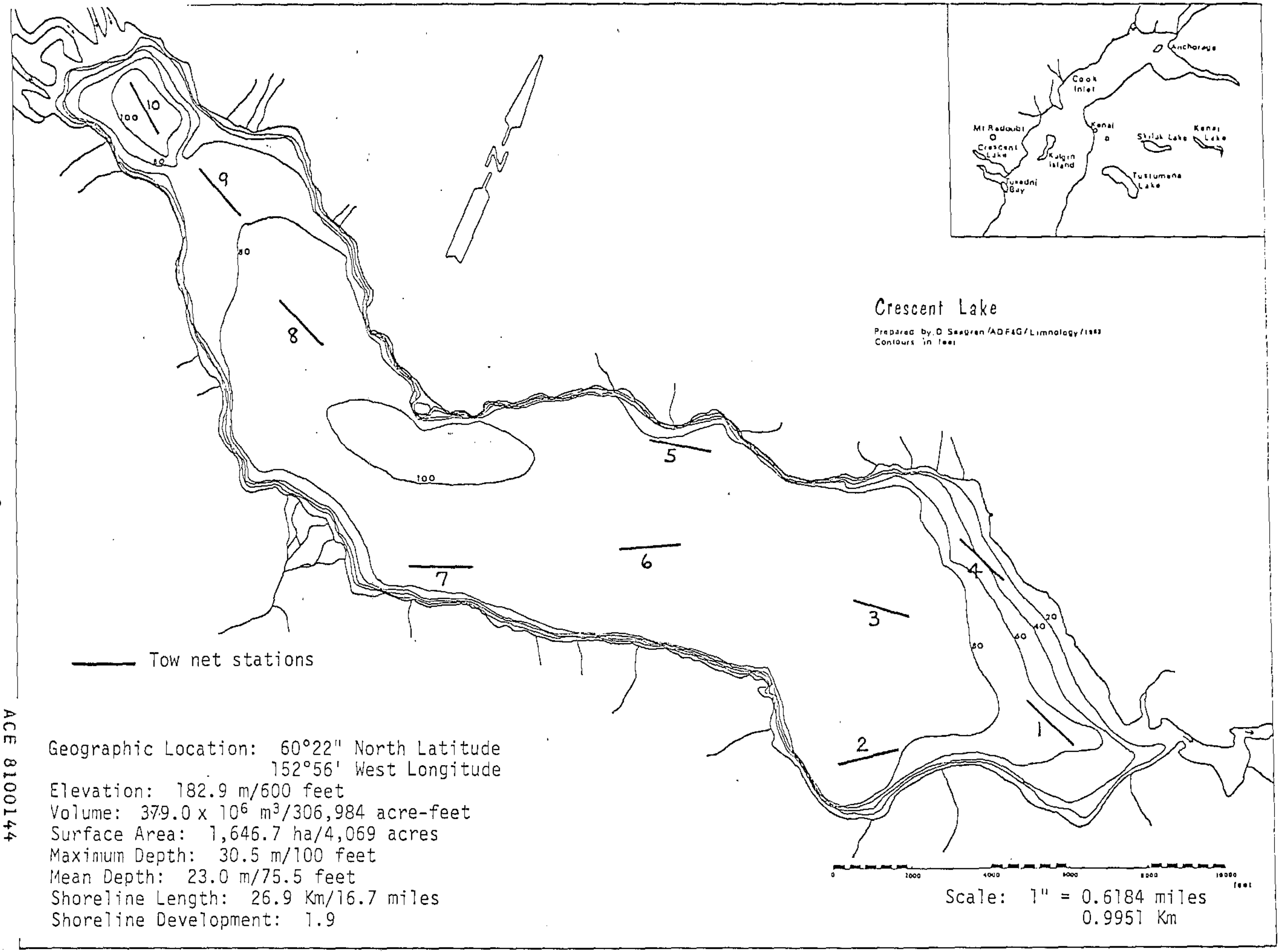


Figure 2. Bathymetric map of Crescent Lake showing geographic location and tow net stations.

MATERIALS AND METHODS

Juvenile Sampling

Tow net sampling for juvenile sockeye salmon was conducted in Crescent Lake on 25 September 1979. The objective of this sampling in Crescent Lake was to determine the age, length, weight, relative abundance, and distribution of rearing juvenile sockeye salmon. The methods used are discussed in detail by Barton (1974) and Waltemyer (1976) however, basically a standard 2.7 m wide, by 2.7 m deep, by 3.2 m in length Burgner tow net (Burgner and Green 1963) was used to sample 10 stations (Figure 2). Surface tows were made approximately 61 m behind the boat at a velocity of approximately 1.2 m/second such that in 20 minutes approximately one surface acre of water was sampled.

A minimum of 300 juvenile sockeye salmon were preserved in 10% formalin for analysis of age, weight and length. A scale smear was taken from the primary scale growth area (Scarnecchia 1979), mounted between two glass slides, and analysed for age with a Microfische projector. Snout to fork lengths were measured to the nearest millimeter and weights to the nearest 0.1 g.

Smolt Enumeration and Sampling

Migrating sockeye salmon smolts were captured in Crescent River using two fyke nets each measuring 1.2 m wide, by 1.2 m deep, with 0.95 cm mesh, and 7.6 m wings. Due to the movement of lake ice down the river, between

19 May-19 June the nets were fished only between 2000-0100 h. Afterwards, the nets were fished 24 h daily until the end of the project on 7 July 1981. Multiple mark and recapture experiments with Bismark Brown stain were conducted each week of the migration to determine the catch efficiency of the nets during changing river conditions. Specific details of the techniques used to smolt in Crescent River are described in the project report by Kyle and Koenings (1982) (Appendix A).

Each day, a representative subsample of 20 sockeye salmon smolts were anesthetized with MS-222 and sampled for scales, weights and lengths. Scale smears, weights and lengths were taken and analysed in the same manner as described for the juvenile sockeye salmon samples.

Adult Enumeration and Sampling

Since 1979 returning adult sockeye salmon to Crescent Lake have been enumerated with Bendix side scanning sonar counters located in Crescent River near the outlet of the lake (Figure 1). Reliable escapement estimates for other salmon species in Crescent River are lacking because the counting site is upstream of major stream spawning areas. However, in 1979 species apportionment escapements to Crescent Lake (past the sonar counting site) were estimated with the use of seine catches. The sonar counters were installed the end of June and removed mid-August of each year. More detailed discussion of the operation of the sonar counters in Crescent River may be found in the annual report by Tarbox et al. (1981).

Adult sockeye salmon were collected from Crescent River by seine and gill net in 1979 and 1980, and by seine and fishwheel in 1981 to obtain length, weight, sex, age, and scale pattern information. A sample of at least 500 adults each year were sampled from the escapement. Lengths (mid-eye to fork) and weights were measured to the nearest 0.5 cm and 0.1 kg respectively. Age and scale pattern analysis were conducted by the ADF&G Commerical Fisheries Division stock separation personnel as described by Cross et al. (1981 and 1982). Scale samples were also collected from commercial catches of the Crescent Lake stock (west-side set net fishery) by the stock separation group for comparison to scale samples from the escapement. Through stock separation techniques, exploitation rates and hence total returns of Crescent Lake sockeye salmon were estimated for 1979-1981.

Resident Specie Composition and Recreational Sport Fishery

Available information on the resident specie composition and recreational sport fishery in Crescent Lake is limited to a survey conducted by the ADF&G Sport Fish Division (Richard Russell) during 20-23 July 1978.

Portable electroshocking equipment, dip net and minnow traps were used to capture rearing fish in the littoral areas of the lake. Electroshocking was conducted for an unknown time period and four baited minnow traps were soaked for approximately 19 h each. In addition, variable mesh gill nets were used in the deep areas of the lake to capture resident adult fish. Two gill nets were soaked for approximately 15 h each. The total number caught was recorded and the mean fork length was measured to the nearest millimeter.

Most of the recreational sport fishing occurs at the outlet of the lake in Crescent River. During the July survey in 1978, field personnel interviewed all fishermen at the outlet to obtain catch and effort data.

RESULTS

Juvenile Sampling

The distribution and abundance of juvenile sockeye salmon was quite variable throughout the lake as indicated in Table 1. The highest catches occurred near mid-lake (Stations 5, 6, and 7) while the lowest catches occurred at each end of the lake (the remaining stations). The relative abundance measured as the average number of fish captured per tow minute or catch-per-unit-effort (CPUE) for the total catch of sockeye fry ranged from zero to 10.05 with a mean CPUE of 3.02. The CPUE for age 0.0, age 1.0 and age 2.0 sockeye fry were 2.84, 0.15 and 0.01 respectively.

The age 0.0 sockeye fry were the most dominant age class caught accounting for 94.3% of the total catch (Table 1). Age 1.0 fry accounted for 5.4% while the age 2.0 fry accounted for less than one percent of the total catch. The average length for age 0.0 and age 1.0 fry were 43 and 57 mm respectively. The average weight for these fry were 0.9 and 2.1 g respectively.

Table 1. Relative abundance, mean lengths and weights, and ages of juvenile sockeye salmon fry sampled from Crescent Lake on 25 September 1979.

Date	Tow station	Catch per tow	Catch per tow minute (CPUE)	Age class	Number sampled	Age class composition (%)	Mean sample length (mm)	S.D.	Mean sample weight (g)	S.D.
9/25/79	1	15	0.75	0.0	282	94.3	43.0	6.0	0.9	0.3
	2	0	0.00	1.0	16	5.4	57.0	4.0	2.1	0.3
	3	29	1.45	2.0	1	0.3	82.0		6.3	
	4	8	0.40							
	5	201	10.05							
	6	138	6.90							
	7	152	7.60							
	8	27	1.35							
	9	8	0.40							
	10	25	1.25							
	$\bar{x}$	60	3.02							
	S.D.	73.6	3.68							

Mean CPUE		
Age 0.0	Age 1.0	Age 2.0
2.84	0.15	0.01

Smolt Enumeration and Sampling

The estimated number of sockeye salmon smolts migrating from Crescent Lake in 1981 based upon weekly catches and calibrations of fishing efficiency of the fyke nets was 2,011, 855 ± 262,553 at the 95% confidence interval (Table 2). In addition to the capture of sockeye salmon smolts, less than 100 each of king salmon, *Oncorhynchus twhawytscha* smolts, three-spine stickleback, *Gasterosteus aculeatus*, and coastrange sculpins, *Cottus aleuticus*, were also captured in the fyke nets. Nearly 80% of the sockeye smolts captured migrated past the smolting site before the ice had left the lake (19 June), before the water temperature reached 4.0°C, and before maximum river stage height. The peak of migration occurred during the week of 17-23 June.

Diel sampling when there was still ice on the lake indicated that 93% of the sockeye smolts migrated between 0000-0600 h. However, after ice-off when the turbidity was much greater due to glacial silt, the diel migratory pattern was inconsistent. Thirty-five percent of the sockeye smolts migrated between midnight and noon and 65% between noon and midnight. Half of the sockeye smolts however, migrated during the brightest part of the day (0600-1800 h) and half during the darkest (1800-0600 h).

Of the eleven days sampled on a 24 h cycle, 6 days were clear and 5 days were overcast and/or raining (Figure 3). The diel migratory pattern was virtually the same under both conditions. The only migratory pattern differences noted were a decrease in sockeye smolts migrating during 0600 h to noon on overcast days (20%) to 13% on clear days, and an increase in sockeye smolts

Table 2. Weekly catches and estimates of sockeye salmon smolts migrating from Crescent Lake in 1981.

Week Period	Weekly catch	Net recapture efficiency	Estimated number of sockeye smolts ± 95% confidence interval
5/20-5/26	4	--	--
5/27-6/02	778	--	--
6/03-6/09	5,855	0.028	246,747 ± 167,962
6/10-6/16	10,707	0.040	286,198 ± 146,982
6/17-6/23	5,956	0.007	1,357,968 ± 1,250,774
6/24-6/30	4,838	0.044	119,045 ± 59,069
7/01-7/07	313	0.176	1,896 ± 927
Total 5/20-7/07	28,451	Estimated Seasonal Total	2,011,855 ± 262,553

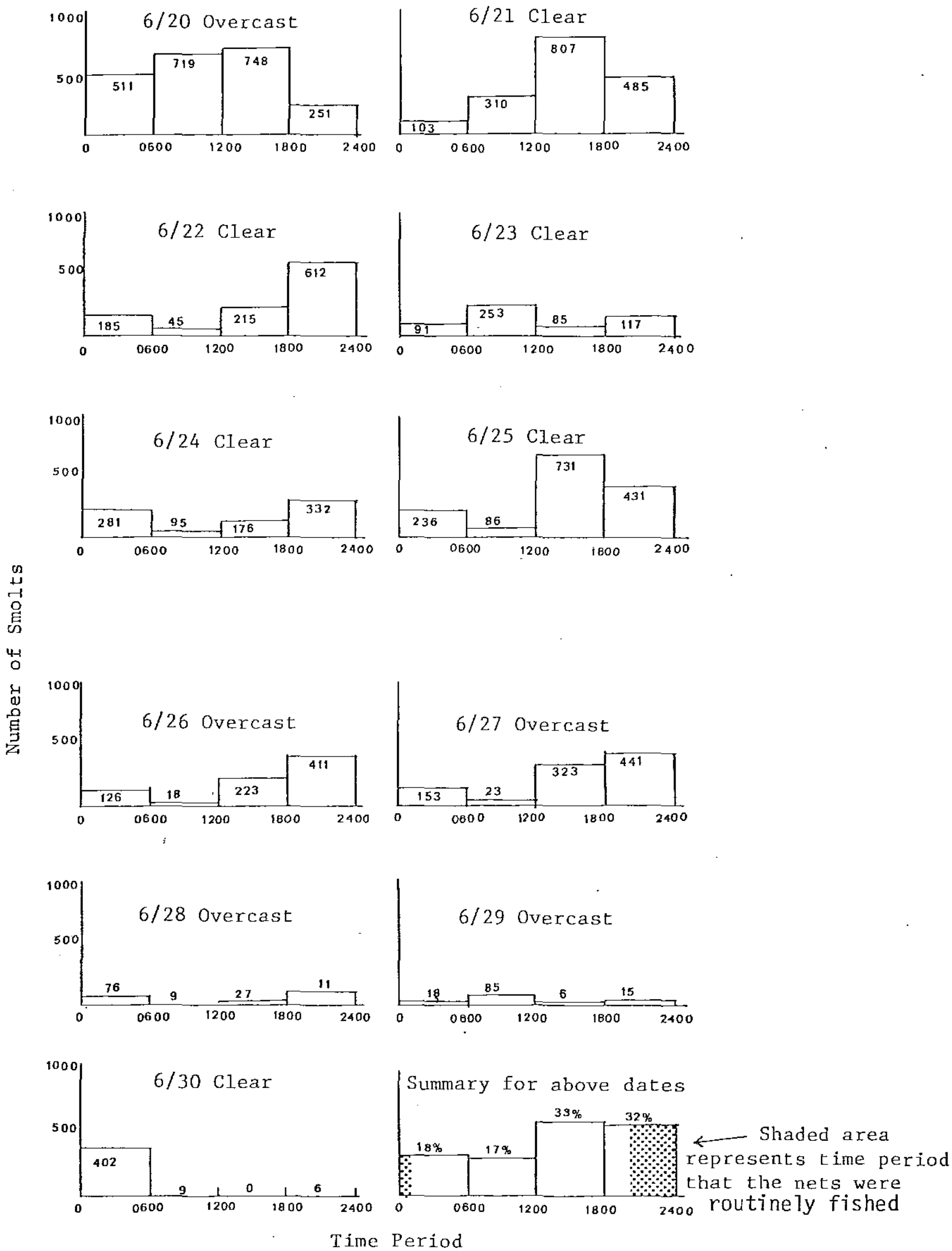


Figure 3. Diel migration pattern of Crescent River sockeye salmon smolts, 1981.

ACE 8100152

migrating during 1800 h to midnight on overcast days (28%) to 33% on clear days.

Scales, weights and lengths were taken from 2.1% (589) of the sockeye smolts captured from Crescent River in 1981 (Table 3). Seventy two percent of these smolts were age 1.0. They averaged 68.1 mm in length and 2.8 g in weight. The age 2.0 sockeye smolts averaged 75.6 mm in length and 3.8 g in weight. No age 3.0 sockeye smolts were collected.

Sixty seven percent of the sockeye smolts sampled were 66-75 mm long (Figure 4) and hence there appeared to be little change in the average length of most of the Crescent Lake smolts. However, a slight decrease in length and weight occurred during the last sampling period (Figure 5). In addition, during the early part of the run (20 May), the sockeye smolts were approximately 0.25 g heavier (Figure 5).

Considering the weekly age distribution for each 5 mm size increment (Table 4), a slight trend develops of longer sockeye smolts (>71 mm) representing 66% of those caught during the first two sampling periods in May, compared to 33% of those caught during the last two periods in the end of June. In contrast, smolts <71 mm represented 34% of the total sampled in May and 67% of the total sampled during the end of June.

Similar to the decreasing trend in sockeye smolt size is the decreasing trend of age 2.0 smolts representation in the sample from early to late spring (i.e., from 35% during the first two sampling periods to 22% during

Table 3. Ages, weights and lengths of sockeye slamon smolts sampled from Crescent River, 1981

Age class	Number sampled	Age class composition (%)	Mean sample length (mm)	S.D.	Length range (mm)	Mean sample weight (g)	S.D.	Weight range (g)
1.0	424	72.0	68.1	3.9	53.5-79.5	2.8	0.5	1.3-4.8
2.0	165	28.0	75.6	3.0	68.5-86.0	3.8	0.5	2.7-6.1

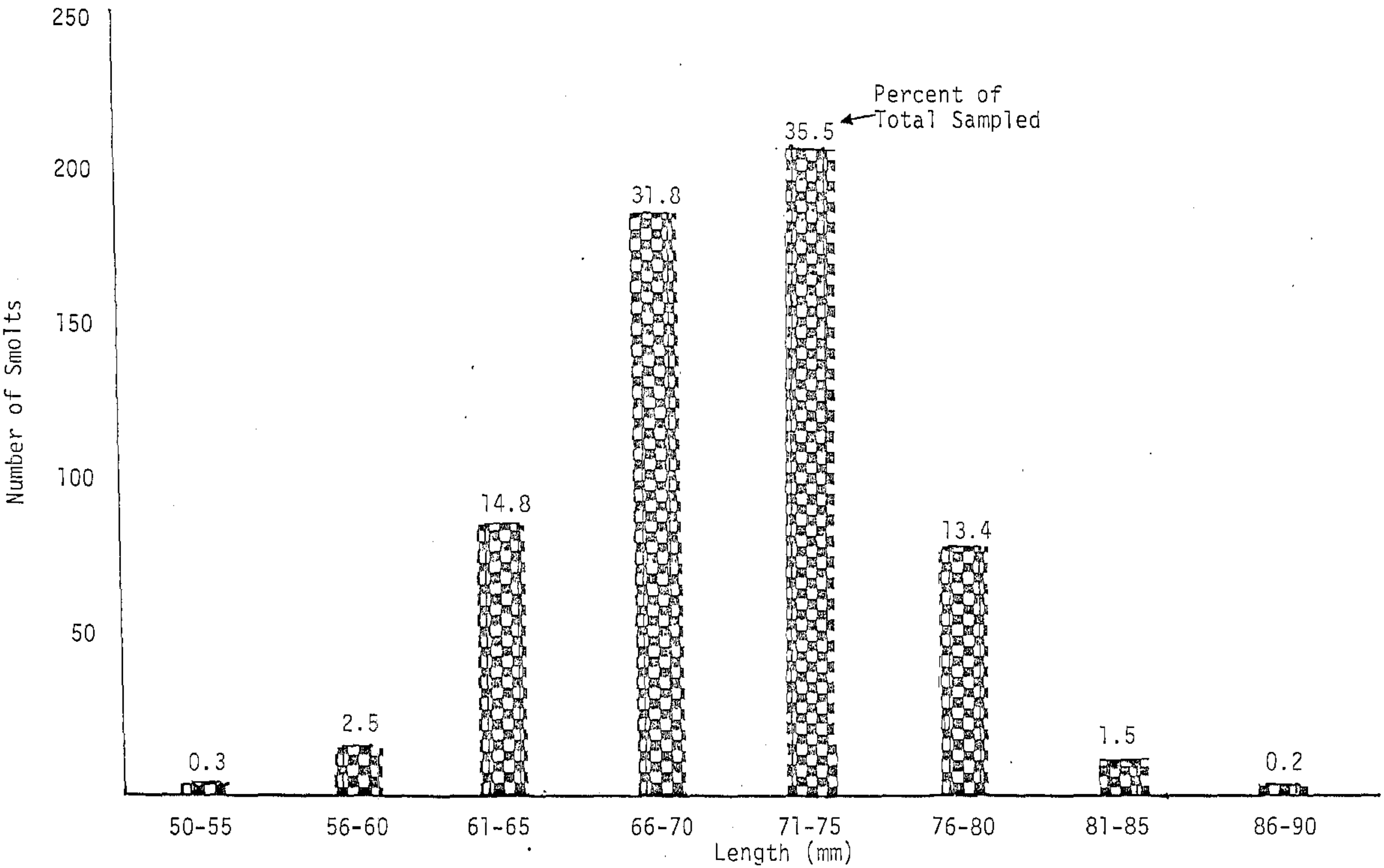
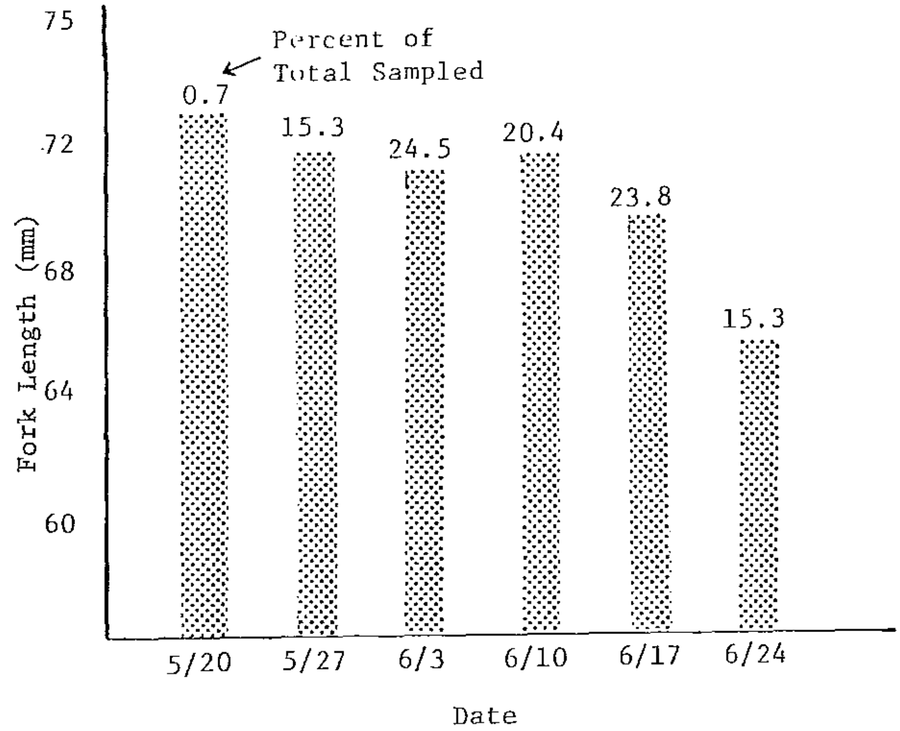


Figure 4. Length frequency distribution of sockeye salmon smolts sampled from Crescent River, 1981.



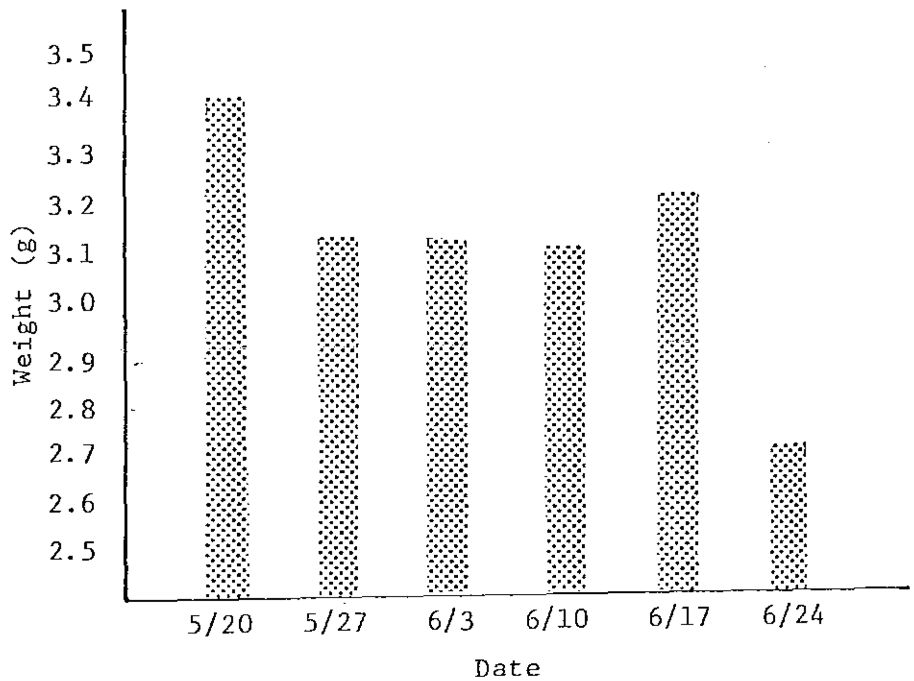


Figure 5. Weekly mean lengths and weights of sockeye salmon smolts sampled from Crescent River, 1981.

Table 4. Weekly age distribution within each 5 mm size increment of sockeye salmon smolts sampled from Crescent River, 1981.

Length	Age	Week Period 5/20-5/26	5/27-6/2	6/3-6/9	6/10-6/16	6/17-6/23	6/24-6/29	Total Sampled
50-55	1.0			2				2
	2.0							
56-60	1.0		1	2	1	1	10	15
	2.0							
61-65	1.0		6	12	7	29	33	87
	2.0							
66-70	1.0		25	40	39	51	28	183
	2.0			1		1	2	4
71-75	1.0	1	27	48	33	20	6	135
	2.0	2	9	13	16	24	10	74
76-80	1.0		1		1	1		3
	2.0	1	19	23	22	10	1	76
81-85	1.0							
	2.0		2	3	1	3		9
86-90	1.0							
	2.0			1				1
Total Sampled		4	90	145	120	140	90	589

$\frac{32}{94}$=34%

$\frac{154}{230}$=67%

$\frac{62}{94}$=66%

$\frac{75}{230}$=33%

the last two), and hence an increasing trend to age 1.0 smolts from 65 to 78% (Table 4).

Adult Enumeration and Sampling

Total escapements of 87,000, 91,000 and 41,000 sockeye salmon adults were recorded by the sonar counters for the years 1979-1981 respectively (Table 5). The estimated commercial fishery exploitation rates for the Crescent Lake sockeye stock based on stock separation techniques and the west-side set net fishery ranged from 41-59%. The estimated total sockeye adult reutrns based on the exploitation rates and sonar-enumerated escapements were 210,000 in 1979, 154,000 in 1980 and 69,000 in 1981 (Table 5). Species apportionment based on seine catches conducted in 1979 at the sonar site (Table 6) resulted in the following estimated escapements of other salmon species into Crescent Lake during that year: 3,700 pink salmon, *Oncorhynchus gorbuscha*; 95 chum salmon, *Oncorhynchus keta*; and 122 king salmon, *Oncorhynchus tshawytscha*.

Seventy percent of the total sockeye adults examined in 1979 and 87% of those examined in 1980 were age 1.3 (Table 5). In 1981 the age composition changed somewhat in that 50% were age 2.3 and 32% were age 1.3. Sockeye salmon average lengths ranged from 46.6 to 50.0 cm during 1979-1981 for all age classes. The dominant age class (1.3) in 1979 and 1980, had an average length of 57.8 and 55.7 cm respectively. In 1981 the dominant age class (2.3) had an average length of 56.6 cm. The average weight range for all age classes in 1980 and 1981 was 1.7-2.9 kg and 2.0-3.2 kg respectively. The average sex ratio of females to males during 1979-1981 was 1.5 to 1.0.

Table 5. Summary of escapements, exploitation rates, adult returns, sex and age compositions, lengths, and weights for Crescent Lake sockeye salmon, 1979-1981.

Year	Escapement	Estimated commercial fishery exploitation rate (%)	Estimated adult return
1979	87,000	59.0[1]	210,000
1980	91,000	41.0[1]	154,000
1981	41,000	41.0[2]	69,000

Year	Number sampled	Percent composition by age class[3]						Sex composition	Mean length	Mean weight
		1.1	1.2	1.3	2.2	2.3	Other	Female:Male	range (cm)	range (kg)
1979	643	tr	27.8	70.1	tr	tr	tr	1.3:1	48.8-59.0	--
1980	511	--	6.5	86.9	2.9	1.6	2.1	1.5:1	46.6-55.7	1.7-2.9
1981	1,117	--	8.2	32.1	9.6	49.9	tr	1.7:1	47.2-56.6	2.0-3.2

[1]Taken from Cross et al. (1981 and 1982).
[2]Calculated from preliminary catch statistics for west-side set net fishery.
[3]Percentages weighted for total number in escapement.

Table 6. Daily seine catch by species from Crescent River, 17 July through 9 August 1979.

Date	Daily seine catch	Sockeye	Pink	Chum	Chinook
7/17/79	31	30	1	0	0
7/18/79	32	30	1	0	1
7/19/79	0[1]	0	0	0	0
7/20/79	0[1]	0	0	0	0
7/21/79	36	32	4	0	0
7/22/79	30	27	3	0	0
7/23/79	0[1]	0	0	0	0
7/24/79	0[1]	0	0	0	0
7/25/79	14	10	4	0	0
7/26/79	24	15	9	0	0
7/27/79	27	15	12	0	0
7/28/79	31	28	2	1	0
7/29/79	27	21	6	0	0
7/30/79	23	22	1	0	0
7/31/79	24	22	2	0	0
8/01/79	22	21	1	0	0
8/02/79	27	25	2	0	0
8/03/79	24	23	1	0	0
8/04/79	17	15	1	1	0
8/05/79	21	20	1	0	0
8/06/79	21	21	0	0	0
8/07/79	0	0	0	0	0
8/08/79	17	16	0	0	1
8/09/79	18	18	0	0	0
Total	466	411	51	2	2

[1]No seining conducted.

The beginning run of sockeye salmon through the sonar counters occurred the end of June during 1979-1981. The peak escapement counts began approximately 10 July which indicates a lag time of 10 days to 2 weeks after commercial catches in the west-side set net fishery began to increase. The 50% date or mid-point of the sockeye run was approximately 15 July and the run terminated mid-August. In 1979 and 1980 the dominant age class (1.3) entered Crescent River first, then decreased from approximately 80% in early July to 50% after 25 July. A seasonal change in age composition was also apparent in the west-side set net fishery in which the catch of age class 1.2 increased in numbers after 9 July (Cross et al. 1981). This is an indication that earlier entry into the fishery and escapement of 5-year-old fish is probably characteristic of the Crescent Lake sockeye run.

Stock separation techniques revealed that the Crescent Lake sockeye stock accounts for a substantial apportionment of catch in the total west-side set net fishery. For example, in 1979 64% and in 1980 79% of the total catch in this set net fishery were Crescent Lake sockeye salmon (Cross et al. 1981 and 1982).

Resident Specie Composition

Results of the 1978 survey of fish species residing in Crescent Lake are presented in Table 7. Species caught by electroshocking were Dolly Varden, *Salvelinus malma*, and coastrange sculpin, *Cottus aleuticus*. They averaged 61.5 mm in length for the Dolly Varden and 51.0 mm for the sculpin. Gill nets provided the largest catches including 41 Dolly Varden, 29 Lake Trout,

Table 7. Summary of resident fish species caught in Crescent Lake during 20-23 July 1978.

Species	Method of capture	Number caught and sampled	Mean length (mm)
Dolly Varden	Electroshocking	4	61.5
Sculpin	Electroshocking	2	51.0
Dolly Varden	Gill net	41	196.8
Lake Trout	Gill net	29	435.7
King salmon	Gill net	2	123.0
Sockeye salmon	Dip net	20	31.8
Stickleback	Dip net	1	29.0

Salvelinus namaycush, and 2 juvenile king salmon fry. The Lake Trout were the largest species with an average length of 435.7 mm. Twenty sockeye salmon fry and 1 three-spine stickleback, *Gasterosteus aculeatus*, were caught by dip net near the outlet of Crescent Lake. The sockeye fry average 31.8 mm in length and the stickleback was 29.0 mm. No fish were caught in the lake during the 19 h of soaking baited minnow traps.

Recreational Sport Fishery

During two of the three days of the survey conducted in July of 1978 sport fishermen were present at the outlet of Crescent Lake. During these two days a total of 19 anglers visited the lake with as many as 23 fish (primarily Dolly Varden and Lake Trout) taken in 20 angler hours by 3 anglers. Two of the fishing parties were repeat visitors to Crescent Lake. Russell (Sport Fish Division - unpublished data) noted that Crescent Lake receives continuous sport fishing during June-August at a level that may reach 5 anglers/day.

DISCUSSION

Based on the cursory survey of juvenile sockeye salmon fry conducted in Crescent Lake during September 1979, the surface estimates of CPUE and thus the horizontal distribution pattern of sockeye fry were highly variable and should be viewed with caution. However, if the data is indeed representative, it indicates a non-random horizontal distribution of sockeye fry during September in Crescent Lake (Table 1).

The Crescent Lake sockeye fry age composition is similar to that of other Cook Inlet glacial lake systems sampled in September, however their size is considerably smaller (Tables 1 and 8). For example, the Crescent Lake age 0.0 fry averaged 43.0 mm in length and 0.9 g in weight, whereas the age 0.0 sockeye fry from Skilak, Kenai and Tustumena lakes averaged 51.7, 52.4 and 58.8 mm in length and 1.4, 1.6 and 2.4 g in weight respectively.

Superficially, the smaller size sockeye fry in Crescent Lake indicates inferior rearing conditions compared to the other glacial lake systems in Cook Inlet. However, considering the comparison of sockeye smolt sizes between the glacial lake systems and other clear water systems located in nearby geographic locations (Table 9), the quality of Crescent Lake smolts is comparable to the other glaical systems yet differ considerably from the clear water systems.

A possible reason for the Crescent Lake sockeye fry being smaller in September yet the smolts similar in size compared to the other glacial lake systems may be the difference between the timing of peak zooplankton production. In Part I of this report, the timing of peak zooplankton production in Crescent Lake is shown to occur during late August-early September. In the other Cook Inlet glacial lake systems (e.g., Kenai and Tustumena lakes) peak zooplankton production occurs earlier during mid-June (FRED Division, Soldotna - unpublished data). This difference in peak zooplankton production could significantly reflect the difference in the size of sockeye fry between these systems when sampled in September.

Table 8. Summary of population characteristics of juvenile sockeye salmon sampled from Kenai, Skilak and Tustumena lakes during September 1974-1981.

		Age 0.0			Age 1.0		
Year	Date	Percent of catch	Length (mm)	Weight (g)	Percent of catch	Length (mm)	Weight (g)
Kenai Lake							
1974	9/26	90	60.6	--	10	98.0	--
1975	9/26	94	58.5	2.4	6	80.3	7.5
1976	9/01	97	61.9	2.3	3	81.6	7.3
1977	9/23	99	60.1	2.5	1	77.0	4.8
1978	8/27	100	40.0	0.7	0	--	--
1979	9/05	99	41.1	0.6	1	59.5	2.2
1980	9/19	58	43.2	0.8	42	57.9	2.1
1981	10/14	96	54.1	1.6	4	68.7	3.2
	$\bar{x}$ =	91.6	52.4	1.6	8.4	74.7	4.5
Skilak Lake							
1974	9/21	92	57.9	--	8	83.3	--
1975	9/24	88	56.3	1.8	12	74.8	4.7
1976	9/01	85	56.0	1.8	15	79.0	5.2
1977	8/21	100	59.0	2.2	0	--	--
1978	8/31	100	43.0	1.0	0	--	--
1979	9/06	99	47.6	0.9	1	76.0	3.8
1980	9/10	88	40.3	0.6	12	53.8	1.6
1981	10/12	89	53.7	1.6	11	62.1	2.8
	$\bar{x}$ =	92.6	51.7	1.4	7.4	71.5	3.6
Tustumena Lake							
1973	9/23	49	55.8	--	51	75.7	--
1974	9/08	62	61.0	--	38	81.3	--
1975	9/22	86	62.7	2.7	14	86.0	10.0
1976	9/13	97	62.9	3.7	3	84.3	6.6
1977	9/07	96	61.0	2.4	4	83.0	6.2
1978	9/04	95	57.0	2.1	5	81.2	6.2
1979	9/12	97	55.3	1.9	3	81.4	6.3
1980	9/22	92	58.5	2.3	8	79.7	5.7
1981	9/19	91	54.6	1.6	9	73.2	3.8
	$\bar{x}$ =	85.0	58.8	2.4	15.0	80.6	6.4

Table 9. Mean lengths and weights of age 1.0 and age 2.0 sockeye salmon smolts from different systems in Alaska compared to 1981 mean lengths and weights of sockeye salmon smolts sampled from Crescent Lake.

Location	Mean length (mm)		Mean weight (g)	
	Age 1.0	Age 2.0	Age 1.0	Age 2.0
Clear-water lakes				
Hidden Lake	143	200	27.3	83.9
Big Lake	132	166	25.5	48.1
Naknek River	100	113	9.2	12.6
Kvichak River	89	110	6.1	10.1
Togiak Lake	85	101	5.5	9.5
Red Lake	85	111	5.8	12.8
Russian River	84	93	5.1	6.5
Brooks Lake	83	109	5.2	10.1
Desire Lake	74	93	4.7	8.8
Delight Lake	71	81	3.6	5.4
Glacial lakes				
Tustumena Lake	68	85	2.7	4.8
Crescent Lake	68	76	2.8	3.8
Kenai Lake	62	72	2.1	3.1

The small mean size of sockeye smolts in glacial or semi-glacial lakes (Crescent Lake) may reflect inferior fry rearing conditions compared to the clear water lakes. However, it must be noted that because of varying escapements of adult sockeye per surface hectare, that smolt sizes are not a direct reflection of the rearing environment. Nevertheless, the quality and quantity of zooplankton in glacial or semi-glacial systems appear to be much lower than that found in the clear water systems (FRED Division, Soldotna - unpublished data).

Through the current stock separation program, the monitoring of escapements by sonar, and the revised smolting techniques, the means to evaluate the contribution of returning adult sockeye and smolt production from a possible nutrient enrichment program are available. The stock separation techniques and the escapement monitoring by sonar provides data within certain limitations. However, through improvements in these techniques such as placement of sonar counters or a fishwheel near the mouth of Crescent River to reduce the lag time between commercial catches and escapement counts would provide more timely data to make adjustments in the management of Crescent Lake sockeye salmon. Also since approximately 80% of the west side set-net fishery is composed of the Crescent Lake sockeye stock, closer monitoring of catches in this fishery would provide more accurate adult return data. In addition, the use of incline plane traps in Crescent River will increase the catch efficiency of migrating smolts and thus provide better estimates.

Finally, the amount of predation on sockeye fry by other species of fish inhabiting Crescent Lake is unknown however, the competition for food between sockeye fry and the other major zooplankton-eating fish (i.e., sticklebacks) would be negligible since stickleback populations appear to be very low.

LITERATURE REVIEW

Barton, L. H. 1974. Field and laboratory techniques manual. Unpub. Memeo Rpt., available from Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage, Alaska. 50 p.

Burgner, R. L. and J. M. Green. 1963. Study of interlake migration of red salmon fry, Agulowak River. Univ. of Wash., Fish. Res. Inst., Circ. No. 182. 13 p.

Cross, B. A., S. L. Marshall, T. L. Robertson, G. T. Oliver, and S. Sharr. 1981. Origins of sockeye salmon in the Upper Cook Inlet fishery of 1979 based on scale pattern analysis. Alaska Department of Fish and Game. Data Report No. 58. 75 p.

______ 1982. Origins of sockeye salmon in the Upper Cook Inlet fishery of 1980 based on scale pattern analysis. Alaska Department of Fish and Game. Data Report No. 68. 81 p.

Kyle, G. B. and J. P. Koenings. 1982. Crescent Lake sockeye salmon smolt enumeration and sampling, 1981. Alaska Department of Fish and Game. Unpub. Annual Report. 27 p.

Scarnecchia, D. L. 1979. Variation of scale characteristics of coho salmon with sampling location on the body. Progressive Fish Culturist 41(3). 132-135 p.

Tarbox, K. E., B. E. King, and D. L. Waltemyer. 1981. Cook Inlet sockeye salmon studies. Alaska Department of Fish and Game. Technical Report for Project No. AFC-62-2 for the period July 1, 1979 to June 30, 1980. 101 p.

Waltemyer, D. L. 1976. A summary report on tow netting juvenile sockeye salmon in three glacial lakes on the Kenai Peninsula for the years 1973 through 1976. Alaska Department of Fish and Game. Cook Inlet Data Report No. 76-2. 41 p.

APPENDIX A

Southcentral Lake Fertilization Project
Progress Report

CRESCENT LAKE SOCKEYE SALMON SMOLT ENUMERATION AND SAMPLING, 1981

by

Gary B. Kyle
Fisheries Biologist

and

Jeffery P. Koenings
Principal Limnologist

Alaska Department of Fish and Game
Division of Fisheries Rehabilitation,
Enhancement, and Development (FRED)

Ronald O. Skoog
Commissioner

John McMullen
Acting Director

P. O. Box 3-2000
Juneau, Alaska 99802

May 1982

TABLE OF CONTENTS

ACE 8100172

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

In 1981, a sockeye salmon, *Oncorhynchus nerka*, smolt enumeration and sampling program was initiated in Crescent River as part of the pre-fertilization evaluation of sockeye production in Crescent Lake.

The sockeye smolts were predominately age 1.0 (72% by composition) with 28% being age 2.0, and no age 3.0 smolts were captured. Age 1.0 smolts had an average length of 68.1 mm and a mean weight of 2.8 g whereas age 2.0 smolts had an average length of 75.6 mm and an average weight of 3.8 g.

The average size of sockeye smolts decreased slightly from May through June, but the age distribution showed no distinctive trend. Nearly 80% of the smolts captured migrated past the smolting site before maximum river stage height, prior to the water temperature reaching 4.0°C, and before the ice had left the lake.

Based upon multiple mark-recapture experiments conducted each week of the migration (except for the first two weeks), estimates of the number of migrating sockeye smolts were obtained. The seasonal migration estimate derived from computation described by Rawson (1981) was 2,011,855 ± 262,553 sockeye smolts. The mark-recapture technique served as an internal standard for net fishing efficiency during specific river conditions existing each week of the smolting season.

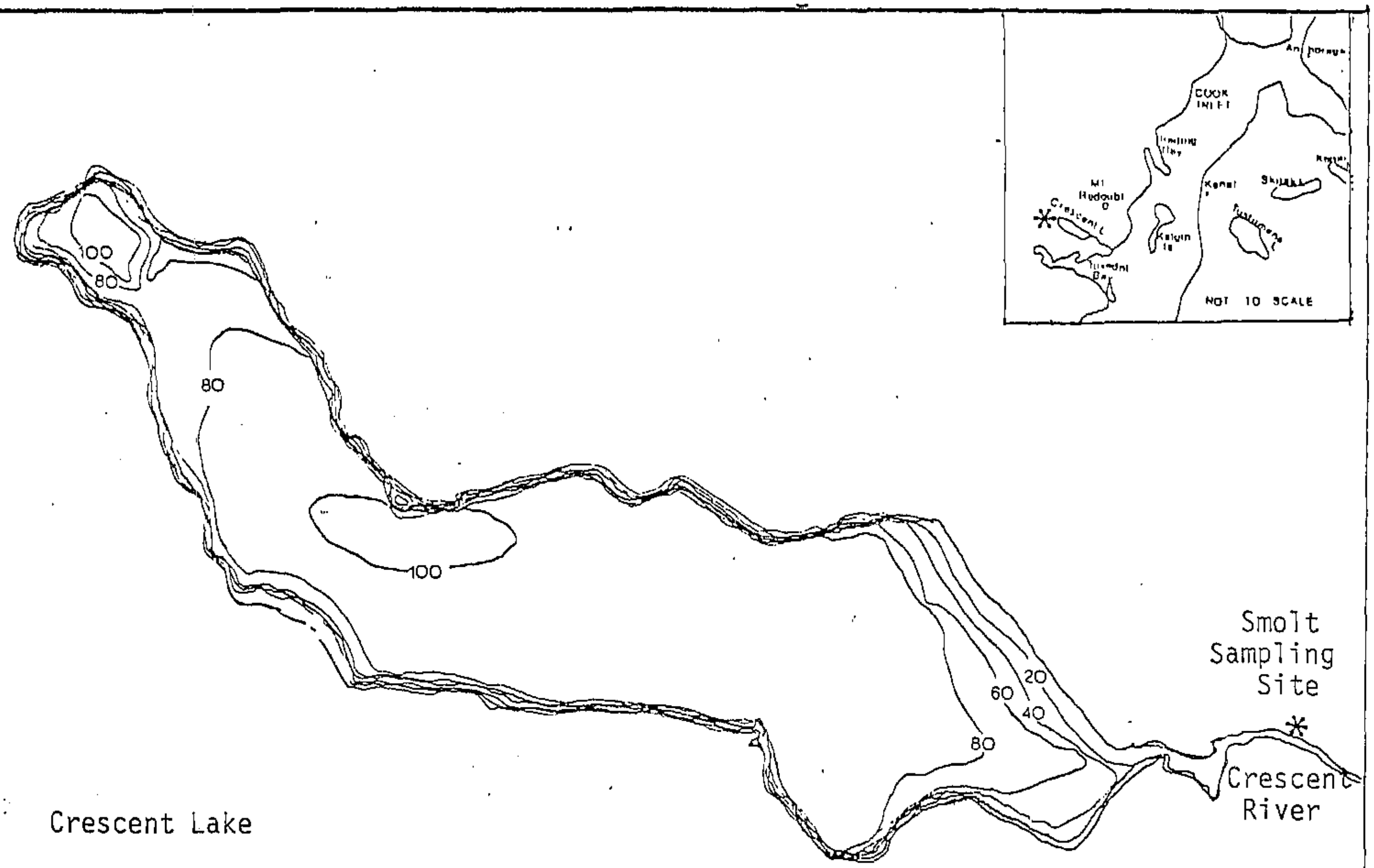
INTRODUCTION

This study was conducted as part of the comprehensive pre-fertilization evaluation of Crescent Lake and the purpose of this study was to define size, age composition, total number, and migration timing of sockeye salmon, *Oncorhynchus nerka*, smolts.

Minimal fishery data exists on the Crescent Lake sockeye salmon. During 1979-1981, the Commercial Fisheries Division of the Alaska Department of Fish and Game (ADF&G) has monitored the return of adult sockeye using side scanning sonar to determine the size and migration timing of the escapement. In addition, stock separation investigations were conducted to determine the contribution made by the Crescent Lake sockeye salmon stock to the sockeye salmon harvest in the Central District (west side) of Cook Inlet and to document the adult age composition and average length. The smolt assessment project, in conjunction with the adult escapement and age data, provides essential pre-fertilization information about the sockeye salmon production of Crescent Lake.

MATERIALS AND METHODS

Crescent Lake is a semi-glacial lake located between Tuxedi Bay and Mt. Redoubt on the west side of the Central District of Cook Inlet (Figure 1). Sockeye salmon smolts were collected from 19 May to 7 July 1981 from Crescent River, 1.3 km below the outlet of Crescent Lake.



Crescent Lake

Elevation	~150 m
Volume	389.0 x 10^6 m^3
Surface Area	16.2 x 10^6 m^2
Maximum Depth	30.5 m
Mean Depth	24.0 m
Shoreline Length	15.7 km
Shoreline Development	1.1

1.0 km

Scale: 2.8 cm = 1.0 km
Bottom contours in feet

Figure 1. Map of Crescent Lake showing geographical location, smolt sampling location and bathymetric data.

Migrating smolts were captured in Crescent River using two 1.2 x 1.2 m x 0.95 cm mesh fyke nets (Figure 2). A 0.9 x 1.5 x 1.1 m live-box was attached to the cod end of each net. The nets were suspended from a 0.95 cm cable stretched across the river. The nets fished the upper 1 m of the water column and the wings were 10 m wide; thus together they fished 34.2% of the linear width and 17.0% of the cross sectional area of Crescent River at the smolt sampling site (Figure 1). Due to the movement of lake ice down the river, between 19 May-19 June the nets were fished only between 2000-0100 h. Afterwards, the nets were fished 24 h daily until the end of the project (7 July). When possible, during 19 May-19 June 24 h sampling was conducted to determine the diel migration pattern of the smolts.

All fish captured were identified and individually enumerated. Each day, a representative subsample of 20 sockeye salmon smolts were anesthetized with MS-222 and measured for fork length to the nearest millimeter and weighed to the nearest 0.1 g. A scale smear was taken from the primary scale growth area (Scarnecchia 1979) and placed on one glass slide for later analysis (Koo 1962).

The fishing efficiency of the nets was determined by several mark and recapture experiments. Each week 200-300 smolts were placed in an aeriated tank containing a solution of Bismark Brown stain (1: 30,250) for 1-2 h until they became tinted gold and easily distinguishable from undyed smolts. The dyed smolts were immediately transported upstream 1.3 km and evenly distributed across Crescent River at the lake outlet.

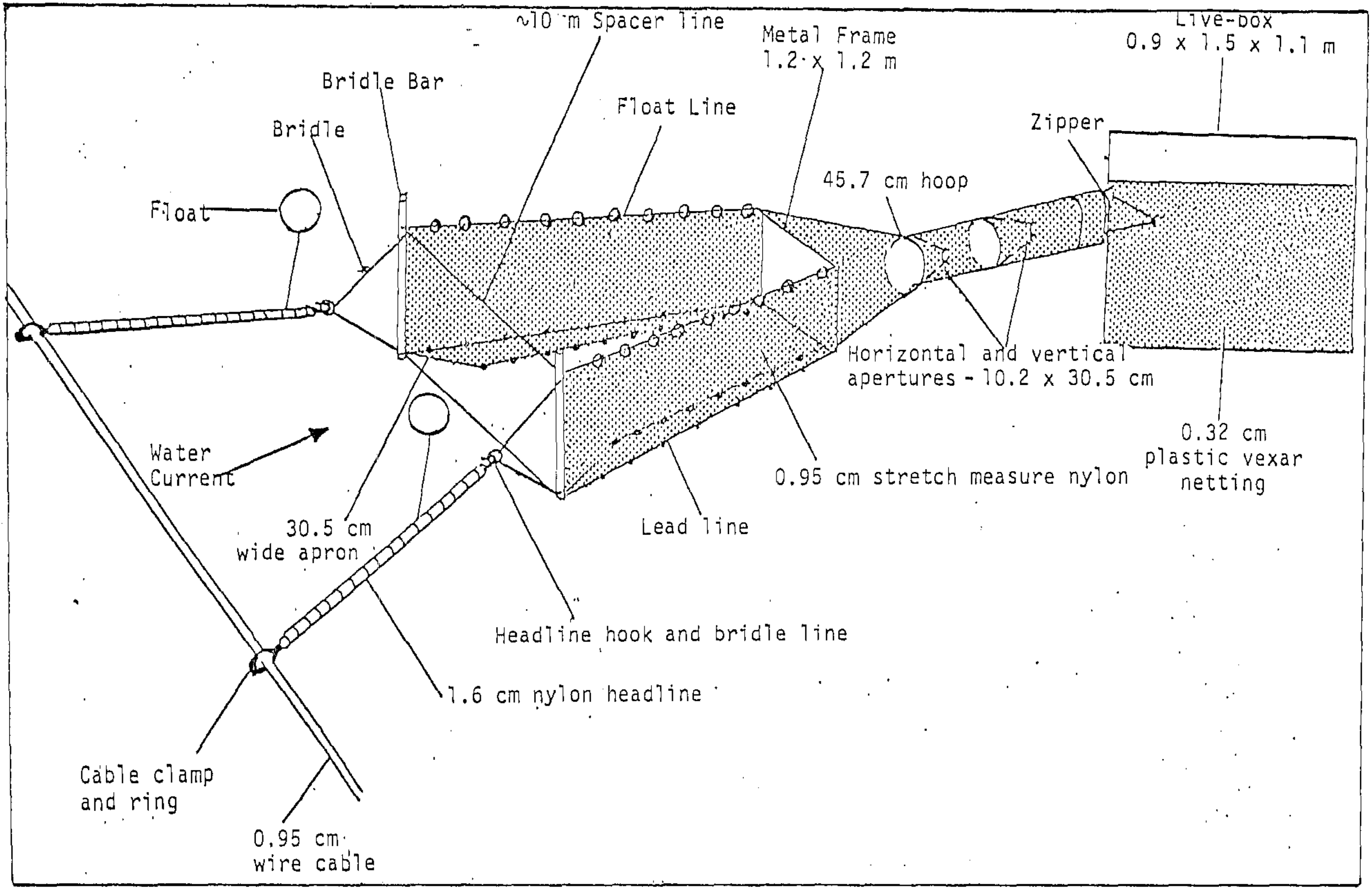


Figure 2. Fyke net and live-box design used to sample smolts in Crescent River, 1981.

A weekly total of migrating smolts was estimated by the method described by Rawson (1981):

$$\hat{N} = n \frac{D}{d} \left[1 + \frac{D-d}{Dd} \right] .$$

Where D is the number of individuals marked and released during the first mark-recapture experiment; n is the number of unmarked individuals captured before the next mark-recapture experiment; d is the number of marked individuals recaptured before the next mark-recapture experiment; and N is the estimated total number of migrating smolts. The variance (V) of the estimator, $(\hat{N})$ is:

$$V(\hat{N}) = n\ (n+d)\ D\ (D-d)/d^3.$$

Then, assuming $\hat{N}$ follows a normal distribution, the confidence interval (C.I.) is:

$$95\%\ C.I. = \hat{N} - 1.96 \sqrt{V(\hat{N})} \text{ to } \hat{N} + 1.96 \sqrt{V(\hat{N})} .$$

The weekly totals of migrating smolts were summed to obtain a total seasonal estimate. The sum of the variances for each weekly estimate was used to compute the overall confidence interval for the seasonal estimate.

Physical parameters including river stage height, mean high and low air and water temperatures (°C), and weather were recorded daily. River stage heights (ft) were measured using a Stevens staff gauge located downstream from the sampling site. Air and water temperatures were measured with a calibrated Taylor maximum-minimum recording thermometer.

RESULTS

Diel Migration Pattern

We were able to sample the smolt migration on a 24 h basis only once, 16 June, prior to ice-off because drifting ice interfered with sampling and clogged the nets. At that time, 93% of the smolts migrated between 0000 - 0600 h. After ice-off, when the turbidity was much greater, due to glacial silt, the diel migratory pattern for the eleven days sampled was inconsistent (Figure 3). Thirty five percent of the smolts migrated between midnight and noon and 65% between noon and midnight. Half of the smolts however, migrated during the brightest part of the day (0600-1800 h) and half during the darkest (1800-0600 h).

From the diel studies undertaken after ice-out, we found that smolts caught between 2000 - 0100 h (the sampling period) represented from 25-50% of the smolts emigrating within a 24 h cycle. Based on this information, the total number of smolts caught before ice-off could have been 50-75% higher. However, during the 24 h sampling experiment conducted before

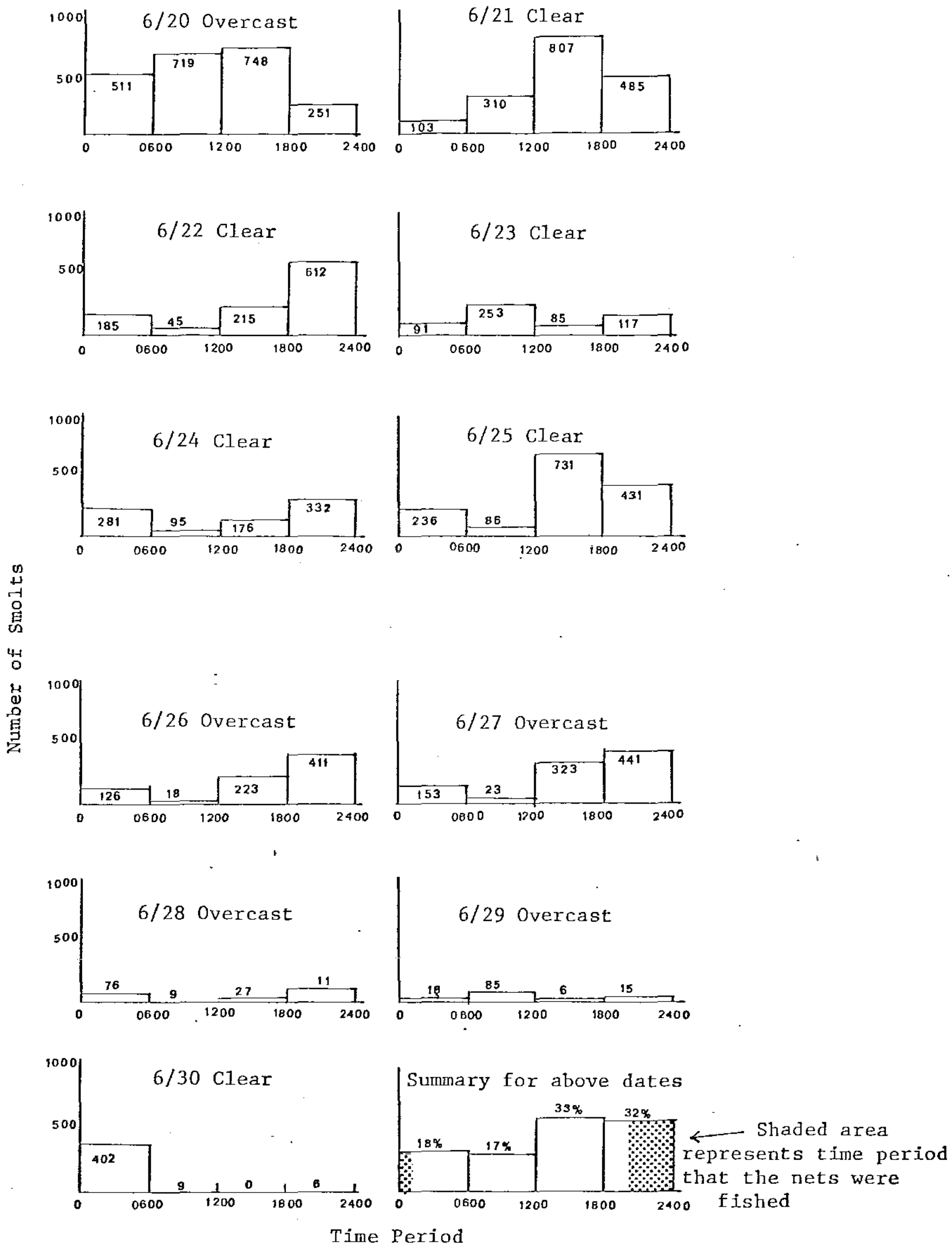


Figure 3. Diel migration pattern of Crescent River sockeye smolts, 1981.

ACE 8100182

ice-off, when the river was clearer, the smolts migrated during the early morning period of minimum light (0000-0600 h). Thus, smolts caught (as a percent of the total) between 2000-0100 h may have been higher before ice-out than the amount indicated by the diel experiments after ice-out, when the river was cloudy with glacial silt.

If a light period was a cue or trigger for migration we might expect weather conditions (i.e., overcast or clear) to affect the migration pattern. Of the eleven days sampled on a 24 h cycle, 6 days were clear and 5 days were overcast and/or raining (Figure 3). However, the diel migratory pattern was virtually the same under both conditions. The only differences noted were a decrease in smolts migrating between 0600 h and noon on overcast days (20%) to 13% on clear days, and an increase in sockeye smolts migrating between 1800 h and midnight on overcast days (28%) to 33% on clear days. However, the intensity of light may initiate migration as 65% of the smolts migrated between noon and midnight. Thus, light at noon being of the greatest intensity and penetration ability (i.e., perpendicular to the surface of the water) may trigger migration.

Smolt Enumeration

During three of the five times that the mark and recapture method was conducted the percent recaptures were fairly consistent; ranging from 2.8% to 4.4% (Table 1). The results from the other two recapture experiments were considerably different due to physical conditions within the river. The nets were periodically pulled out of the river because of drifting lake ice

Table 1. Mark and recapture data of sockeye smolts from Crescent River, 1981.

Date Marked	Time Marked	Number Marked	Time Released	Marking Mortalities	Date Recaptured	Number Recaptured	Percent Recaptured
6/04	1830	221	1930	3	6/04	1	
					6/05	1	
					6/06	1	
					6/07	1	
					6/08	2	
						6	2.8%
6/12	1800	302	1845	5	6/12	7	
					6/13	4	
					6/14	1	
					6/15	0	
						12	4.0%
6/16[1]	0745	306	0900	2	6/17	2	
					6/18	0	
					6/19	0	
					6/20	0	
						2	0.7%
6/25	1930	300	2130	2	6/25	10	
					6/26	1	
					6/27	2	
					6/28	0	
						13	4.4%
7/03[2]	1645	80	1730	12	7/04	12	
					7/05	0	
					7/06	0	
					7/07	0	
						12	17.6%

[1]The fyke nets were periodically pulled due to floating ice.
[2]The smolts were released further downstream in Crescent River near a riffle area. Stain used was Eriochrome Black.

on the 16 June experiment. On 3 July, the smolts were released in a riffle area further downstream (0.8 km) in Crescent River at which time the turbidity within the river was at a maximum.

The 16 June experiment resulted in the lowest recapture efficiency of 0.7% while the 3 July experiment resulted in the greatest recapture efficiency of nearly 18%. Thus, we feel that the net efficiences reflected the fishing conditions within the river and therefore each recapture experiment served as an internal check or control on the efficiency of the fyke nets under specific conditions during the weekly time periods fished.

The seasonal migration estimate was 2,011,855 ± 262,553 at the 95% confidence interval (Table 2). This estimate does not include the small number of smolts outmigrating during May since no recapture calibration was accomplished for the nets.

The peak emigration occurred between 17-23 June when the average water temperature was <4.0°C and during the week that the ice disappeared (Table 2). Weekly migrations decreased substantially after ice-out (19 June) when the water temperature increased to >4.0°C.

The stain Bismark Brown was used on all of the recapture experiments conducted in June. In July, we tried a new stain; Eriochrome Black. The Eriochrome Black stained smolts were highly visable for at least 5 days (like the Bismark Brown stained smolts) however the higher mortality of

Table 2. Weekly mean temperatures and estimates for weekly and seasonal totals of sockeye smolts migrating from Crescent Lake, 1981.

Week Period	Mean Water Temperature °C	Weekly Catch	Net Recapture Efficiency[1]	Estimated Number of Smolts at 95% Confidence Interval
5/20-5/26	1.7	4	--	
5/27-6/02	2.1	778	--	
6/03-6/09	2.2	5,855	0.028	246,746 ± 167,962
6/10-6/16	2.6	10,707	0.040	286,198 ± 146,982
6/17-6/23	3.8	5,956	0.007	1,357,968 ± 1,250,774
6/24-6/30	6.6	4,838	0.044	119,045 ± 59,069
7/01-6/07	8.3	313	0.176	1,896 ± 927
Total 5/20-7/07		28,451		2,011,855 ± 262,553

[1]From Table 1.

15% compared to <2% with the Bismark Brown stain requires investigation. It may be that either the smaller smolts in July, when the water temperatures exceeded 8°C, were less hardy and resulted in a higher mortality, or that the Eriochrome Black stain was more toxic.

The reason for trying two distinct stains was a result of the recapture rate of smolts in early June extending 5 days. Thus, if a more frequent calibration of the nets was required, we would need two distinct stains. However, we noticed that later in the smolt migration that the smolts once released were progressively recaptured at the highest rate one day after release (Table 1). Apparently, the smolts held longer in the lake early in the spring when temperatures and flows were lowest. As the flow in the river and temperatures increased, the smolts migrated at a higher rate downstream from the lake outlet to the smolting site.

We tested two other stains; Rhodomine (red) and Eriochrome Blue Black (violet) both of which proved unuseable because of non-distinct staining of the smolts.

In addition, the smolt project revealed the presence of king salmon, *Oncorhyncus tshawytscha*, smolts migrating down Crescent River during the sockeye smolt sampling period. No significant numbers of sticklebacks, *Gasterosteus* sp., sculpins, *Cottus* sp., or other salmon smolts were captured by the fyke nets during the sampling period.

Smolt Size and Age

Scales, weight and length samples were taken from 2.1% (589) of the sockeye smolts captured from Crescent River in 1981 (Table 3). Seventy two percent of the sockeye smolts were age 1.0. The age 1.0 smolts averaged 68.1 mm in length and 2.8 g in weight. The age 2.0 smolts averaged 75.6 mm in length and 3.8 g in weight. No age 3.0 smolts were collected.

Sixty seven percent of the smolts were 66 to 75 mm in length (Figure 4). There was little change in the average size of the smolts during the sampling period except those caught during the last sampling period may have been slightly smaller (Figure 5).

Considering the weekly age distribution for each 5 mm size increment (Table 4), a slight trend develops of longer smolts (>71 mm) representing 66% of those caught during the first two periods (May) to 33% of those caught in the last two periods (late June). In contrast, smolts <71 mm represented 34% of the total sampled in May and 67% of the total sampled during the end of June.

Similar to the decreasing trend in smolt size is the decreasing trend of age 2.0 smolts representation in the catches from early to late spring (i.e., from 35% to 22% of the total caught), and an increasing trend to age 1.0 representation from 65% to 78% (Table 4). Thus, two trends are present, a stronger increasing trend to smaller smolts as the spring progressed, and a much weaker trend for age 1.0 smolts to increase during the same period.

Table 3. Age, weight and length data of sockeye smolts sampled from Crescent River, 1981.

Age Class	Number Sampled	Age Class Composition (Percent)	Mean Sample Length (mm)	S.D.	Length Range (mm)	Mean Sample Weight (g)	S.D.	Weight Range (g)
1.0	424	72.0	68.1	3.9	53.5-79.5	2.8	0.5	1.3-4.8
2.0	165	28.0	75.6	3.0	68.5-86.0	3.8	0.5	2.7-6.1

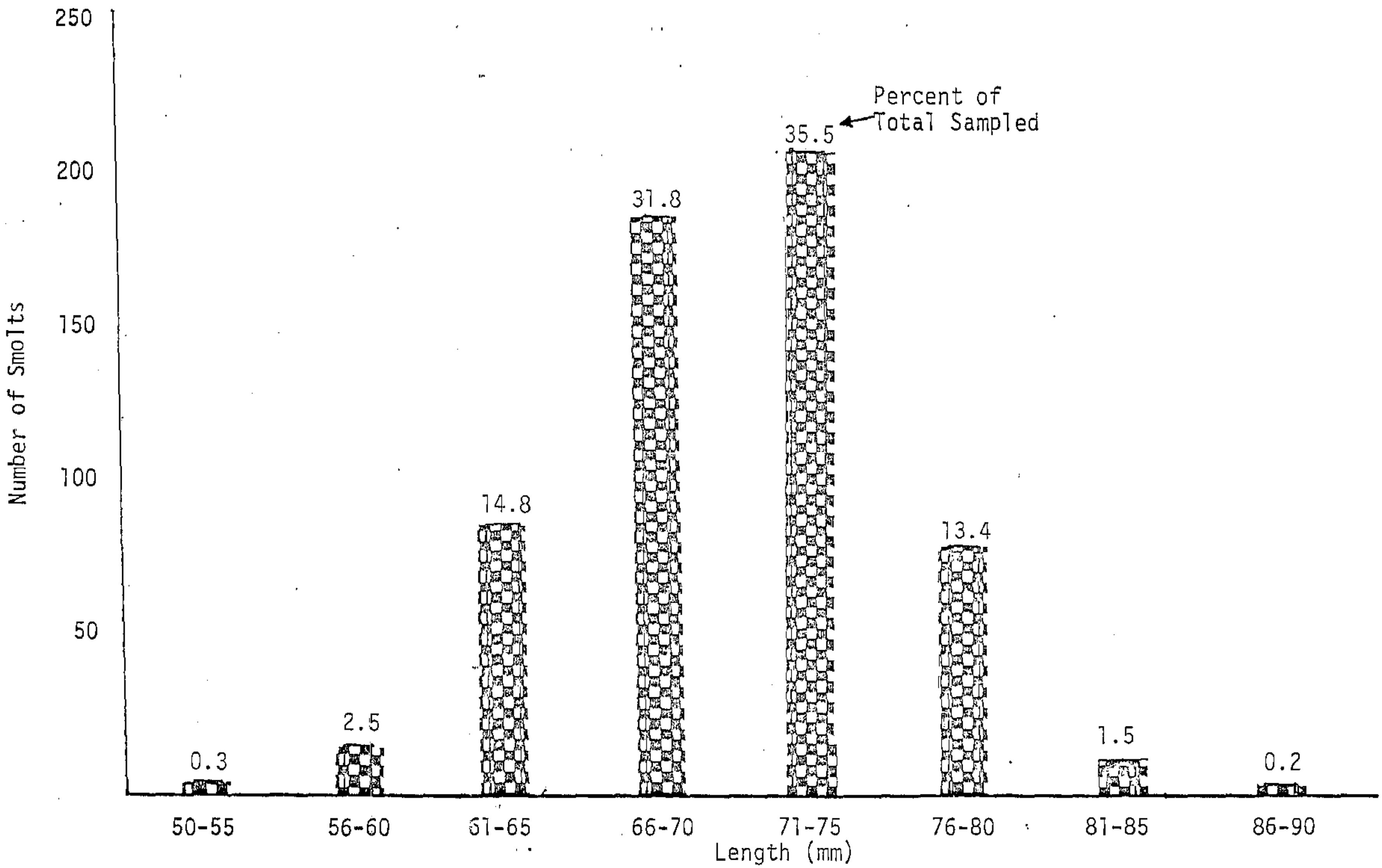
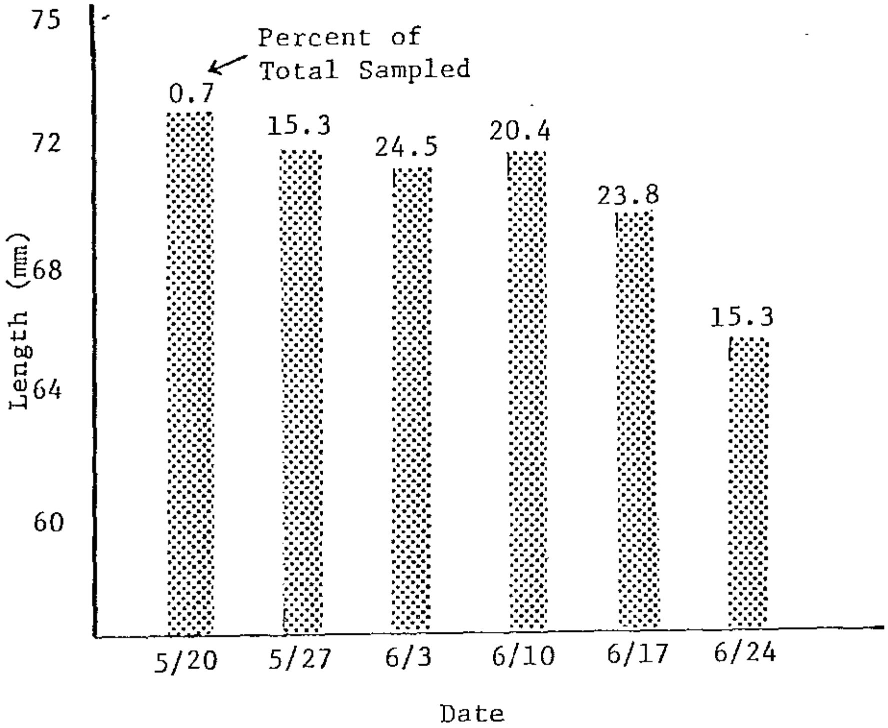


Figure 4. Length frequency distribution of sockeye smolts sampled from Crescent River, 1981.



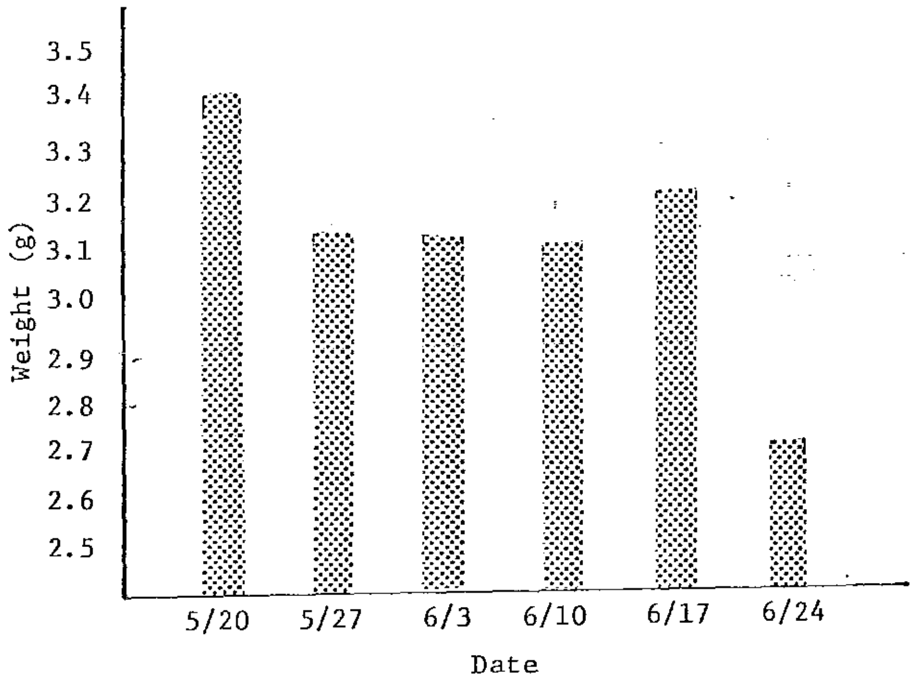


Figure 5. Weekly mean lengths and weights of sockeye smolts sampled from Crescent River, 1981.

Table 4. Weekly age distribution within each 5 mm size increment of sockeye salmon smolts sampled from Crescent River, 1981.

Length	Age	5/20-5/26	5/27-6/2	6/3-6/9	6/10-6/16	6/17-6/23	6/24-6/29	Total Sampled
		Week Period						
50-55	1.0			2				2
	2.0							
56-60	1.0		1	2	1	1	10	15
	2.0							
61-65	1.0		6	12	7	29	33	87
	2.0							
66-70	1.0		25	40	39	51	28	183
	2.0			1		1	2	4
71-75	1.0	1	27	48	33	20	6	135
	2.0	2	9	13	16	24	10	74
76-80	1.0		1		1	1		3
	2.0	1	19	23	22	10	1	76
81-85	1.0							
	2.0		2	3	1	3		9
86-90	1.0							
	2.0			1				1
Total Sampled		4	90	145	120	140	90	589

$\frac{32}{94}=34\%$

$\frac{154}{230}=67\%$

$\frac{62}{94}=66\%$

$\frac{75}{230}=33\%$

The opposite migration trend (i.e., decreasing) was noticed for the larger, age 2.0 smolts as the spring progressed. Age 1.0 smolts represented >98% of the total caught throughout the spring in the smaller size class (<71 mm), and from 36% to 61% of the total caught in the larger size class (>71 mm). Thus, we feel that the overall trend is for larger smolts to migrate earlier regardless of age, and smaller smolts to delay their migration until the later portion of the smolting period.

The lack of definition of a well documented trend for larger and older smolts to migrate earlier could be a function of sampling bias (i.e., capturing and selecting smaller smolts for measurement) or could be a naturally occurring characteristic of the migratory behavior of Crescent River sockeye smolts.

Physical Parameters

Stage heights varied as much as 1 m during the sampling period and reflect the spring increase in lake water as a result of snow melt and the melting of lake and glacier ice (Table 5). In May and the early part of June, the river was clear however, after the lake ice melted on 19 June the turbidity increased dramatically. During the last recapture experiment, (3 July) the river was cloudy with glacier silt and light penetration was minimal.

After the lake ice melted, the water temperature increased above 4.0°C and it increased to 9.0°C by the end of the smolt migration on 7 July.

Table 5. Crescent River stage height, mean water temperature and climatological data for the period 19 May through 7 July 1981.

Date	Mean Water Temp °C[1]	Mean Air Temp °C[1]	River Stage Height (ft)	Weather
5/19	1.0	4.0	1.37	Continuous rain
5/20	1.5	4.5	1.68	Intermittent rain
5/21	1.5	6.0	1.80	Intermittent rain
5/22	1.8	5.0	1.78	Overcast
5/23	1.5	6.0	1.65	Overcast
5/24	1.8	7.5	1.62	Continuous rain
5/25	2.5	8.5	1.59	Intermittent rain
5/26	2.0	9.0	1.64	Clear
5/27	2.0	5.0	1.76	Intermittent rain
5/28	2.5	9.0	1.88	Clear
5/29	2.5	9.5	2.20	Overcast
5/30	2.0	11.0	2.50	Intermittent rain
5/31	2.0	7.0	2.50	Intermittent rain
6/01	2.0	7.5	2.79	Intermittent rain
6/02	2.5	9.5	2.87	Overcast
6/03	2.0	6.0	2.89	Intermittent rain
6/04	2.0	10.0	2.89	Intermittent rain
6/05	2.5	12.0	2.86	Clear
6/06	2.5	8.0	2.84	Overcast
6/07	2.0	9.0	2.81	Intermittent rain
6/08	2.0	6.0	2.79	Continuous rain
6/09	2.5	6.0	2.76	Continuous rain
6/10	2.5	9.0	2.67	Clear
6/11	2.0	7.0	2.54	Clear
6/12	3.0	7.5	2.48	Clear
6/13	2.5	9.0	2.46	Clear
6/14	3.5	9.0	2.45	Overcast
6/15	2.5	11.0	2.54	Clear
6/16	3.5	13.0	2.74	Clear
6/17	3.5	12.5	2.97	Clear
6/18	3.5	12.5	3.30	Overcast
6/19	4.0	14.0	3.70	Clear
6/20	3.5	13.0	4.10	Overcast
6/21	4.0	12.0	4.32	Clear
6/22	4.5	11.0	4.42	Clear
6/23	4.5	10.0	4.36	Clear
6/24	6.3	10.7	4.28	Clear
6/25	6.0	10.5	4.15	Clear
6/26	7.5	9.5	4.05	Overcast
6/27	7.0	9.5	3.94	Intermittent rain
6/28	7.5	9.5	3.88	Overcast
6/29	7.5	11.5	3.90	Overcast
6/30	8.5	12.0	3.85	Clear

Continued

ACE 8100194

Table 5 continued. Crescent River stage height, mean water temperature and climatological data for the period 19 May through 7 July 1981.

Date	Mean Water Temp °C[1]	Mean Air Temp °C[1]	River Stage Height (ft)	Weather
7/01	8.0	7.3	3.70	Overcast
7/02	7.5	9.5	3.50	Overcast
7/03	8.5	14.5	3.42	Intermittent rain
7/04	8.5	12.5	3.44	Clear
7/05	8.0	14.0	3.48	Clear
7/06	9.0	14.0	3.70	Clear
7/07	9.0	10.5	3.82	Overcast

[1]Average of daily maximum and minimum temperatures.

It is interesting that prior to the week of maximum river stage height (20-27 June), over 80% of the smolts caught had migrated past the smolting site. In addition, 80% of the smolts had left the lake before the water temperature reached 4.0°C and before the last ice had left the lake.

DISCUSSION

Net fishing efficiency showed substantial variation when physical conditions within the river changed. Thus, when the nets had to be periodically pulled because of floating ice, our recapture rate was reduced to its lowest value of 0.7%. At the same time, the recapture rate was greatest (18%) towards the end of the smolt emigration when the turbidity within the system was at its maximum. A change in light penetration apparently alters the behavior of migrating smolts. In clearer waters, it is thought that smolts tend to migrate at night in schools towards the bottom and sides of the river to avoid predation. In turbid waters, the smolts tend to more randomly distribute themselves in the water column, and migrate closer to the surface of the river. Consequently, the fishing efficiency for the nets increased toward the end of the smolting season since there was less net avoidance and because the fyke nets sampled only the upper 1 m of the water column.

Thus, we feel that our method of weekly calibration of the net fishing efficiency reflected changes in efficiency of capturing smolts because of changes in the river as the smolting season progressed. Consequently, we feel our estimate based on this type of weekly calibration represents a valid estimate.

Calculating the smolt migration using the width (34.2%) and the cross section (17%) of the river fished by the nets, provides lower estimates by a factor of 12-24 fold compared to the mark-recapture estimate of 2,011,885 smolts. However, in a heavily glacial system (e.g., Kasilof River), the estimates of smolt migration derived from calibrated net efficiencies and percent of area or width of river fished were very similar (Todd et al. 1980).

We attribute the discrepancies found between the fishing area and mark-recapture methods of calculation in Crescent and Kasilof Rivers to the differences between the systems. That is, Crescent River changes from a clear water system to a glacial water system within the duration of smolt migration. This changes the behavior of the smolts, the physical conditions within the river and thus the net efficiencies. In addition, the traps in the Kasilof River extend from the surface to the bottom of the river, whereas the nets in Crescent River sampled one half to one third (dependent on flow) the depth of the river. Thus, if we compare the net efficiencies derived from our recapture experiments to the percent of the cross sectional area of the river fished when the system was glacial [i.e., 3 July (Table 1)], we find that both methods are equally subsampled ∿17%.

The size of smolts from Crescent Lake is similar to smolts from other Cook Inlet glacial systems, however differs from several other Cook Inlet and

Bristol Bay clear water systems (Table 6). We feel the small mean size of smolts may reflect the fry rearing conditions within glacial or semi-glacial lakes. However, it should be noted that because of the different years and resultant escapements of sockeye per surface hectare, the smolt sizes are not purely a function of environmental conditions. Nevertheless, the quality and quantity of zooplankton in the glacial and semi-glacial systems studied so far are much lower than that found for the clear water systems studied (unpublished data ADF&G Soldotna).

The smolts emigrating from Crescent Lake will be returning in 5 to 6 years as adult fish. We have found that the 1981 smolt migration consisted entirely of age 1.0 and age 2.0 smolts. However, there is some indication that Crescent Lake does produce a small number (2.1% in 1980) of age 3.0 smolts (Table 7). The age 1.0 (72% by composition) smolts migrating in 1981 was from an escapement of 87,000 in 1979. In 1981, the escapement was 41,000 fish. Hence, if environmental conditions remain roughly equal, we would expect even greater percentage of age 1.0 smolts in 1983.

Finally, if we assume a 10% survival rate from smolt to adult, from the smolt estimate of 2,011,885 in 1981, we could predict an adult return of 202,000 sockeye salmon. Based on the 1979 escapement, stock separation, and commercial catch data, the estimated adult sockeye return was 210,000 in 1979 (Waltemyer per. comm.). Thus, our estimate of the smolt production during 1981 is quite reasonable and is comparable to the predicted range of smolts produced from adult returns during other years.

Table 6. Mean lengths and weights of age 1.0 and age 2.0 sockeye smolts from different systems in Alaska compared to 1981 mean lengths and weights of sockeye smolts from Crescent Lake.

Location	Mean Length (mm)		Mean Weight (g)	
	Age 1.0	Age 2.0	Age 1.0	Age 2.0
Clear-water lakes				
Hidden Lake	143	200	27.3	83.9
Big Lake	132	166	25.5	48.1
Naknek River	100	113	9.2	12.6
Kvichak River	89	110	6.1	10.1
Togiak Lake	85	101	5.5	9.5
Red Lake	85	111	5.8	12.8
Russian River	84	93	5.1	6.5
Brooks Lake	83	109	5.2	10.1
Desire Lake	74	92	4.7	8.8
Delight Lake	71	81	3.6	5.4
Glacial lakes				
Tustumena Lake	68	85	2.7	4.8
Crescent Lake	68	76	2.8	3.8
Kenai Lake	62	72	2.1	3.1

Table 7. Age composition of adult sockeye salmon sampled from Crescent River, 1979-1981.

1981 Sample Period	Percent Composition by Age Class[1]								Sample Size
	1.1	1.2	1.3	1.4	2.1	2.2	2.3	Other	
6/21-7/14		7.8	25.1			3.8	62.9	tr	267
7/15-7/26		3.4	35.3			10.4	45.4		434
7/27-8/07		7.1	32.3			13.3	46.8	tr	416
Annual Summary									
1981		8.2	32.1			9.6	49.9	tr	1117
1980		6.5	86.9			2.9	1.6	2.1	511
1979	tr	27.8	70.1			tr	tr	tr	643

[1]Percentages weighted for total numbers in escapement. Data obtained from the Commercial Fisheries Division, Soldotna, Alaska.

RECOMMENDATIONS

We recommend continuing this project for pre-fertilization evaluation of sockeye production in Crescent Lake, but we also recommend the following changes in sampling technique: 1) discontinue the use of fyke nets and use modified incline plane traps similar to those described by Todd (1966) to reduce fouling of sampling gear by ice and debris; 2) increase the frequency of the dye mark and recapture method and increase the marked population to calibrate the traps' fishing efficiency; 3) reduce any sampling bias in the measurement of smolts by blind dipping or other methods; 4) estimate the proportion of smolts migrating in Crescent River below the fishing depth of the traps; and 5) take light penetration measurements in Crescent River.

ACKNOWLEDGEMENTS

The authors would like to express their appreciation to Jim Brighenti and Edward Ashmead, who conducted the field work and collected the resulting data. Additional appreciation is extended to Don Seagren for processing much of the field data and preparation of tables and figures.

LITERATURE CITED

Koo, T. S. Y. (ed). 1962. Studies of Alaska sockeye salmon. University of Washington Press. 449 p.

Scarnecchia, D. L. 1979. Variation of scale characteristics of coho salmon with sampling location on the body. Progressive Fish Culturist 41 (3):132-135.

Rawson, K. 1981. Statistical analysis of dye marking studies. Alaska Department of Fish and Game. Unpublished Report. 9 p.

Todd, G. L., Waite, D. C., and Flagg, L. B. 1981. Sockeye salmon smolt studies, Kasilof River 1980. Alaska Department Fish and Game. Unpublished Report. 38 p.

Todd, I. S. 1966. A technique for the enumeration of chum salmon fry in the Fraser River, British Columbia. J. Fish. Res. Bd. Canada. 38 (3) 3-35.

PERSONAL COMMUNICATION

Waltemyer, D. L. 1981. Alaska Department Fish and Game, Commercial Fisheries Division, Soldotna, Alaska.