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Assessment of Lacustrine Productivity Relative to Juvenile Sockeye Salmon (*Oncorhynchus nerka*) Production in Chignik and Black Lakes: Results from 1991 Surveys

by G. B. Kyle

Number 119

Alaska Department of Fish & Game
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ABSTRACT

Limnological investigations of general water-quality parameters, nutrients, phytoplankton, zooplankton, and fall fry were conducted in Chignik and Black lakes during 1991 to characterize lake productivity relative to juvenile sockeye salmon (*Oncorhynchus nerka*) production, historical information, and other sockeye nursery lakes. None of the water-quality parameters, nutrient concentrations or ratios, and phytoplankton data indicated any prominent limitation to productivity in either lake. The seasonal mean density of macrozooplankton in Chignik and Black lakes ranked seventh and sixteenth respectively, compared to 25 other sockeye nursery lakes in Alaska. In 1991, sampling suggests that the zooplankton community of Chignik Lake resembles one that sustains predation pressure by juvenile sockeye in the form of a cladoceran composition dominated by *Bosmina* and the presence of small size *Bosmina*. Finally, a fall hydroacoustic/townet survey in Chignik Lake indicated an underestimate of the number of rearing sockeye juveniles, moderate size fall fry, and the possibility of a higher abundance of sticklebacks compared to historical information.

INTRODUCTION

Sockeye salmon production in the Chignik system was studied extensively in the late 1960's and early 1970's (Narver 1966; Dahlberg 1968 and 1973; Phinney 1968; Burgner *et al.* 1969; Parr 1972). Although pertinent information relative to sockeye production and lake productivity resulted from these studies, these data are now over 20 years old and may not reflect current conditions. The purpose of this report is to characterize existing limnological conditions in Black and Chignik Lakes to investigate if lake conditions may be limiting freshwater production of sockeye. Also, if freshwater sockeye production is being limited in some manner, it is the intent of this investigation to understand the reason(s) for the limitation and determine if actions can be taken to lessen impediments to sockeye growth and survival.

Study Site Description- The Chignik system is located approximately 315 km south east of Kodiak on the south side of the Alaska Peninsula (Figure 1). Chignik Lake lies at an elevation of 15 m, has a total surface area of 24.1 million m^2, and a mean depth of 26 m and a maximum depth of 64 m (Figure 2). The estimated water residence time for Chignik Lake is 0.6 years. Black Lake lies at the same elevation and is larger but shallower than Chignik Lake with a 1960 measured surface area of 41.1 million m^2, a mean depth of 3 m and a maximum depth of 6 m (Figure 3). However, in recent years the water level in Black Lake has dropped considerably and the mean and maximum depths are 1.5 m and 3.8 m, respectively (G. Ruggerone[1] pers. comm.). Both lakes are classified as oligotrophic, and were ranked relatively high in sockeye production (Burgner *et al.* 1969).

The Chignik system comprises two runs of sockeye salmon; the earlier migrating stock of Black Lake and the latter migrating stock of Chignik Lake. Juvenile sockeye in both lakes contrast in growth and freshwater residence time. In Chignik Lake, smolts are

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[1]University of Washington, School of Fisheries, Fisheries Research Institute, Seattle, WA

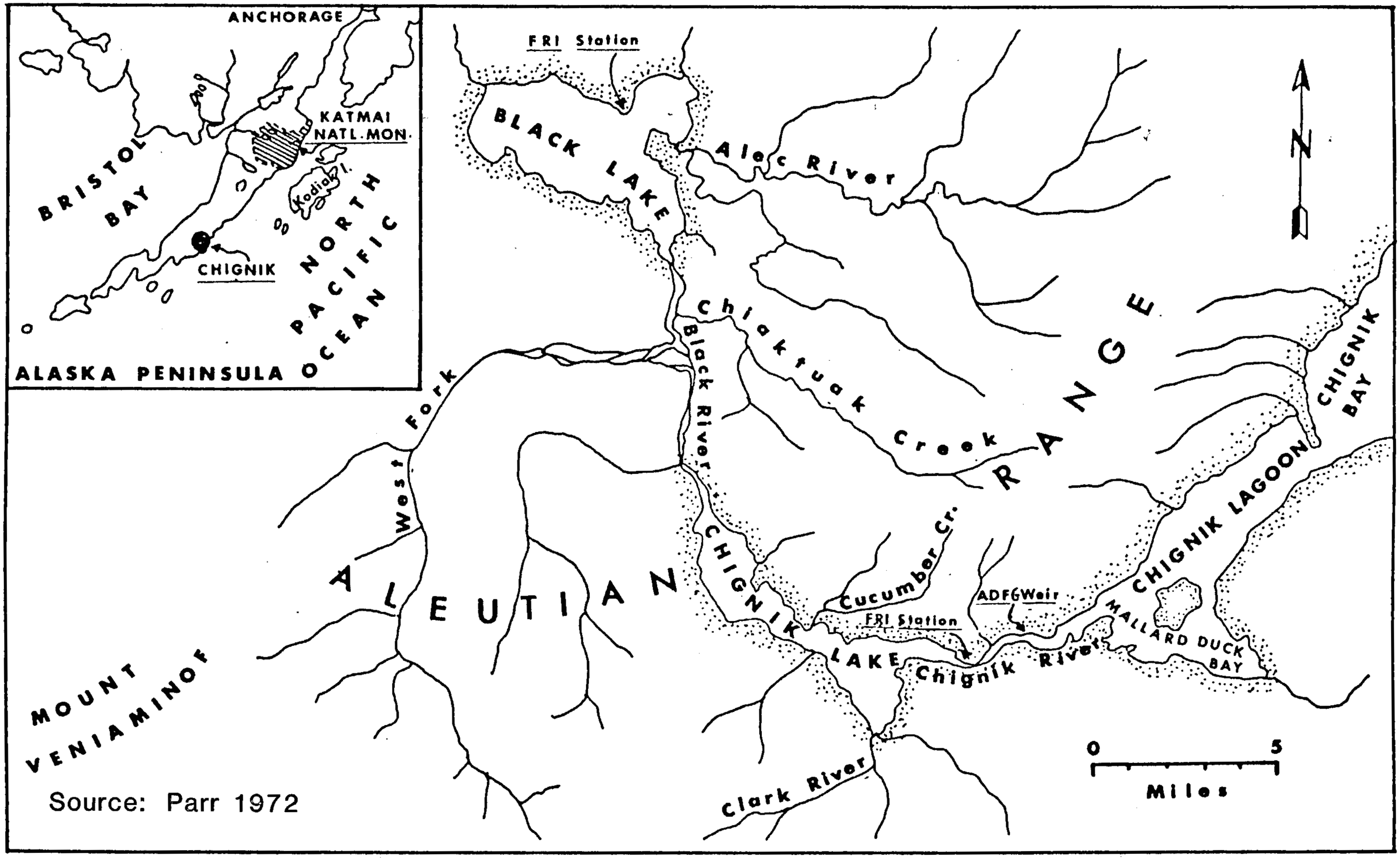

Figure 1. Area map of the Chignik River drainage showing location of Chignik and Black Lakes.

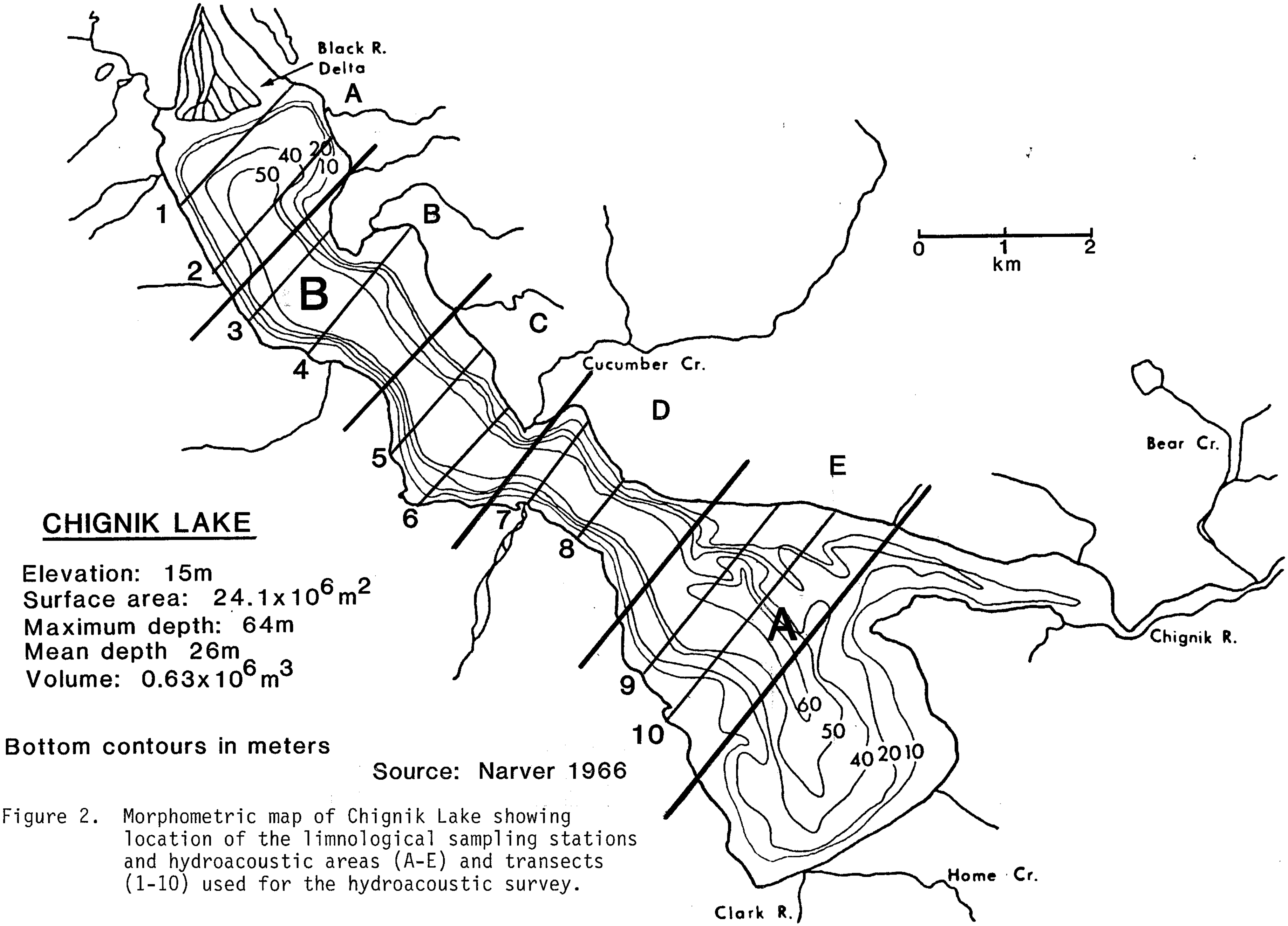

Figure 2. Morphometric map of Chignik Lake showing location of the limnological sampling stations and hydroacoustic areas (A-E) and transects (1-10) used for the hydroacoustic survey.

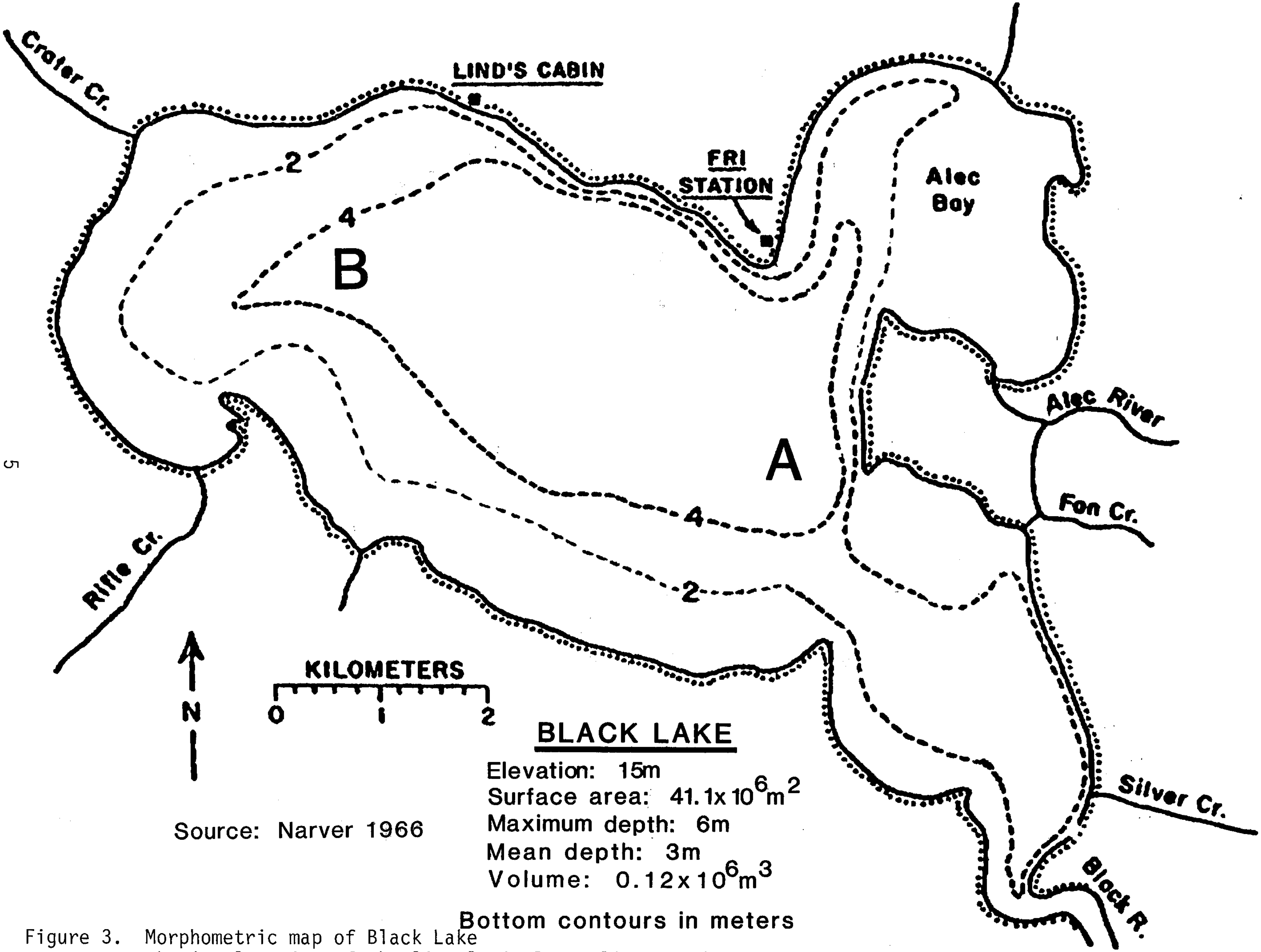

Figure 3. Morphometric map of Black Lake showing location of the limnological sampling stations.

smaller and rear for two years whereas in Black Lake smolts are significantly larger and smolt after only one year of residence (Dahlberg 1968).

Resident fish in both lakes include threespine stickleback (*Gasterosteus aculeatus*), ninespine stickleback (*Pungitius pungitius*), and pond smelt (*Hypomesus olidus*) which are potential competitors for food. Historical information suggests that Black Lake supports a higher abundance of resident fish than Chignik Lake, but interspecific competition for food may not be extreme due to divergence of food habits (Parr 1972).

METHODS AND MATERIALS

Limnological Assessment

Water Sampling-- Limnological surveys were conducted four times on both lakes during June-September of 1991. Transportation to and from both lakes was provided by an ADF&G aircraft, and with the assistance of Commercial Fisheries Division staff, limnological samples were collected by boat from two sample stations per lake (Figure 2 and 3). Lake water was sampled at the epilimnion (1 meter) and hypolimnion (~67% of sample station depth) zones for algal nutrients (nitrogen, phosphorus, and silicon) as well as general water quality parameters. Water samples from multiple casts with a non-metallic Van Dorn sampler were pooled, stored in 8-10 L translucent carboys, and immediately transported to Chignik Bay for filtering and preservation. Subsequent filtered and unfiltered water samples were stored either refrigerated or frozen in pre-rinsed polybottles. The pre-processed water samples were then sent to the ADF&G Limnology Laboratory in Soldotna for analysis after Koenings *et al.* (1987).

Physical Features-- The collection of physical data included the measurement of lake temperature, dissolved oxygen, and light penetration. Temperature and dissolved oxygen measurements were taken using a YSI® model-57 meter. These measurements were

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®Mention of commercial products and trade names does not constitute endorsement by ADF&G, FRED Division.

taken at 1-m increments from the surface to 5 m, and at 2-m increments from 6 m to the bottom of the lake. The algal light compensation point which defines the depth at which 1% of the subsurface light (photosynthetically available radiation [400-700 mm]) penetrates (Schindler 1971), was measured using a Protomatic submersible photometer. Light measurements (footcandles) were taken every 0.5 to 5 m, and every 1 m down to the light compensation depth. Water clarity was also measured with a 20-cm Secchi disk by recording the depth at which the disk disappeared from view.

General Water Quality Parameters-- Water samples were analyzed for the following parameters as detailed by Koenings *et al.* (1987). Conductivity (μmhos/cm) was measured with a YSI model-32 conductance meter. Alkalinity levels (mg/L) were determined by acid titration (0.02 N H_2SO_4) to pH 4.5, using a Corning model-399A specific ion meter. Calcium and magnesium (mg/L) were determined from separate EDTA (0.01 N) titrations after Golterman (1969), turbidity (nephelometric turbidity units [NTU]) was measured with a HF model-DRT100 turbidimeter, and color (Pt units) was determined with a spectrophotometer. Total iron (μg/L) was analyzed by reduction of ferric iron with hydroxylamine during hydrochloric acid digestion after Strickland and Parsons (1972).

Nutrients-- 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 using the FRP procedure, after persulfate digestion. Nitrate and nitrite (NO_3 + NO_2) were determined as nitrite, following cadmium reduction of nitrate, and total ammonia was determined using the phenolhypochlorite methodology after Stainton *et al.* (1977). Total Kjeldahl nitrogen (TKN) was determined as total ammonia following sulfuric acid block digestion (Crowther *et al.* 1980). Total nitrogen was calculated as the sum of TKN and NO_3 + NO_2. Reactive silicon was determined using the method of ascorbic acid reduction to molybdenum-blue after Stainton *et al.* (1977).

Phytoplankton-- Water samples (1-2 L) for chlorophyll a (chl a) analysis were filtered through 4.25-cm GF/F filters to which 1-2 mls of a saturated $MgCO_3$ solution were added just prior to the completion of filtration. The filters were then stored frozen in individual plexislides for analysis. Chlorophyll a analysis followed the fluorometric procedure of Strickland and Parsons (1972). The low-strength acid addition recommended by Riemann (1978) was used to estimate phaeophytin. Phytoplankton taxa composition and density (no/m^3) was analyzed on unfiltered samples collected from the epilimnion (1 m) under a State of Alaska contract with Eco-Logic Inc. of Vancouver, British Columbia, Canada.

Zooplankton-- Zooplankton were enumerated from duplicate 50-m (Chignik Lake) and 3.5-m (Black Lake) vertical tows using a 0.2-m diameter (153-μm mesh) conical net. The net was pulled at a constant 1 m/s, and all organisms were preserved in a 10% neutralized formalin solution. Identification of *Daphnia* followed Brooks (1957), *Bosmina* after Pennak (1978), and the copepods after both Wilson (1959) and Yeatman (1959). Enumeration consisted of counting triplicate 1-ml subsamples taken with a Hansen-Stempel pipette in a 1-ml Sedgewick-Rafter cell. Zooplankton body sizes were obtained by measuring the length to the nearest 0.01 mm of at least 10 individuals along a transect in each 1-ml subsample (Koenings *et al.* 1987). Finally, zooplankton biomass was estimated from an empirical regression between zooplankton body-length and dry weight, and was weighted by organism density (Koenings *et al.* 1987).

Juvenile sockeye Assessment

Hydroacoustic Surveys-- A fall (September) hydroacoustic survey was conducted in 1991 to estimate the number and distribution of juvenile fish (sockeye salmon fry) rearing in Chignik Lake. Ten transects perpendicular to the longitudinal axis of the lake were surveyed (Figure 2). The lake was divided into 5 equal areas (A-E) and 2 transects per area were selected randomly. The recording of down-looking acoustic data along the transects was done at night when juvenile sockeye salmon are more evenly dispersed. Flashing strobe lights were placed at one end of each transect to assist in maintaining transect course. A BioSonics model-105 echosounder with a model-171 tape recorder interface system with a 6/15° dual-beam transducer was used. Fish signals were recorded electronically using a Sony digital audio tape recorder (model TCD-D10) and on chart paper using a BioSonics model-115 chart recorder. Analysis was conducted under a State of Alaska contract with BioSonics, Inc. using procedures described by Kyle (1990).

Identification of fish species from the acoustic target data was accomplished with the use of a 2 m by 2 m tow net (Gjernes 1979). Three 15-m tows (30 minutes each) were conducted along the axis of the lake. Species composition and abundance were recorded for each tow and half of the samples were preserved in 75% isopropyl alcohol and half in a 10% buffered formalin solution. A sample of captured sockeye salmon juveniles from each tow were measured for fork length to the nearest 1.0 mm and weight to the nearest 0.1 g. To maintain consistency, age analysis of collected sockeye juveniles was conducted by personnel of Commercial Fisheries Division that also read the adult scales from the Chignik system. Finally, paired length and weight measurements of sockeye juveniles were used to determine the ponderal index (K), commonly referred to as the coefficient of condition after Bagenal (1978).

RESULTS AND DISCUSSION

Limnological Assessment

Light Penetration-- During 1991, the one percent light level which defines the compensation depth (euphotic zone depth [EZD]) for algal photosynthesis penetrated to a depth ranging from 3.8 to 11.6 m in Chignik Lake and 1.5 to 3.1 m in Black Lake (Table 1 and 2). The seasonal average EZD for both stations was 6.6 m in Chignik Lake or 25% of the mean depth and 2.1 m or 70% of the mean depth in Black Lake. In addition, the Secchi disk depth ranged from 0.8-1.9 m, and averaged 1.3 m in Chignik Lake and 0.8 m (range 0.4-1.9 m) in Black Lake (Table 1 and 2). The euphotic volume (EZD x lake area) for Chignik Lake is 158.9 x 10^6 m^3 (or 159 EV units), and for Black Lake is 86.4 x 10^6 m^3, for a total of 245 EV units.

Table 1. Euphotic zone depth (one percent light level) and Secchi disk depth by sample date and station in Chignik Lake, 1991.

Sample date	Secchi disk (m) A	Secchi disk (m) B	1% light level (m) A	1% light level (m) B
06/27	NA \a	0.8	8.5	11.6
07/16	1.9	0.9	6.7	6.9
08/20	1.3	1.3	5.2	4.4
09/09	1.8	0.8	5.8	3.8
Seasonal mean	1.6	0.9	6.6	6.7

\a Denotes not available.

Table 2. Euphotic zone depth (one percent light level) and Secchi disk depth by sample date and station in Black Lake, 1991.

Sample date	Secchi disk (m) A	Secchi disk (m) B	1% light level (m) A	1% light level (m) B
06/27	0.8	NA \a	NA	NA
07/08	NA	1.9	NA	2.7
07/18	0.4	0.6	1.9	2.1
08/19	0.4	1.3	1.6	3.1
09/06	0.4	0.4	1.5	2.0
Seasonal mean	0.5	1.1	1.7	2.5

\a Denotes not available.

Temperature and Dissolved Oxygen Regimes-- In Chignik Lake, a weak thermocline (stratified water due to temperature differences) was evident at 15 to 20 m for both stations only during June and July (Figure 4 and 5). Surface temperatures ranged from 6° C in June to 11° C in September. During August and September water temperature was isothermal at ~10.5° C and had not begun to cool. Hence, thermal stratification in Chignik Lake does appear to occur but strong and persistent winds cause frequent overturn and the predominance of isothermal conditions, which results in a large volume of water (deep strata) to be relatively warm. In Black Lake, a thermocline was evident only during July at Station B (Figure 6 and 7). Surface temperatures ranged from 8.5° C in June to 13° C in September. Similar to Chignik Lake, strong winds mix a large volume of water in Black Lake which broadens lake heating both vertically and seasonally.

In Chignik Lake, dissolved oxygen (DO) concentrations generally ranged between 9.5-12 mg/L (80-97% saturation); however, near the bottom in August concentrations decreased to as low as 6 mg/L (~55% saturation) (Figure 4 and 5). Dissolved oxygen concentrations generally <5 mg/L are considered harmful to salmonids (Davis *et al.* 1979). The lower DO concentration near the bottom of Chignik Lake is not that unusual as oxygen depletion can occur within the lower strata due to decomposition of organic material. However, because Chignik Lake undergoes frequent vertical mixing, the low DO is most likely not persistent and therefore does not warrant serious concern relative to oxygen depletion. In Black Lake, DO ranged from a low of 8.4 mg/L near the bottom in July to 12.4 mg/L at the surface in June (Figure 6 and 7). These concentrations were within a saturation range of 84-110% and indicate that a problem of oxygen deficiency during June-September does not exist.

General Water Quality Parameters-- With the exception of the September 09 hypolimnetic (deep) samples taken from Chignik Lake, turbidity levels during 1991 ranged between 0.4 and 4.8 NTU and averaged 2 NTU (Table 3), which defines this lake as clearwater (Edmundson and Koenings 1986). The elevated turbidity levels in the hypolimnion of Chignik Lake (6 NTU Station A; 8.4 NTU Station B) are most likely due

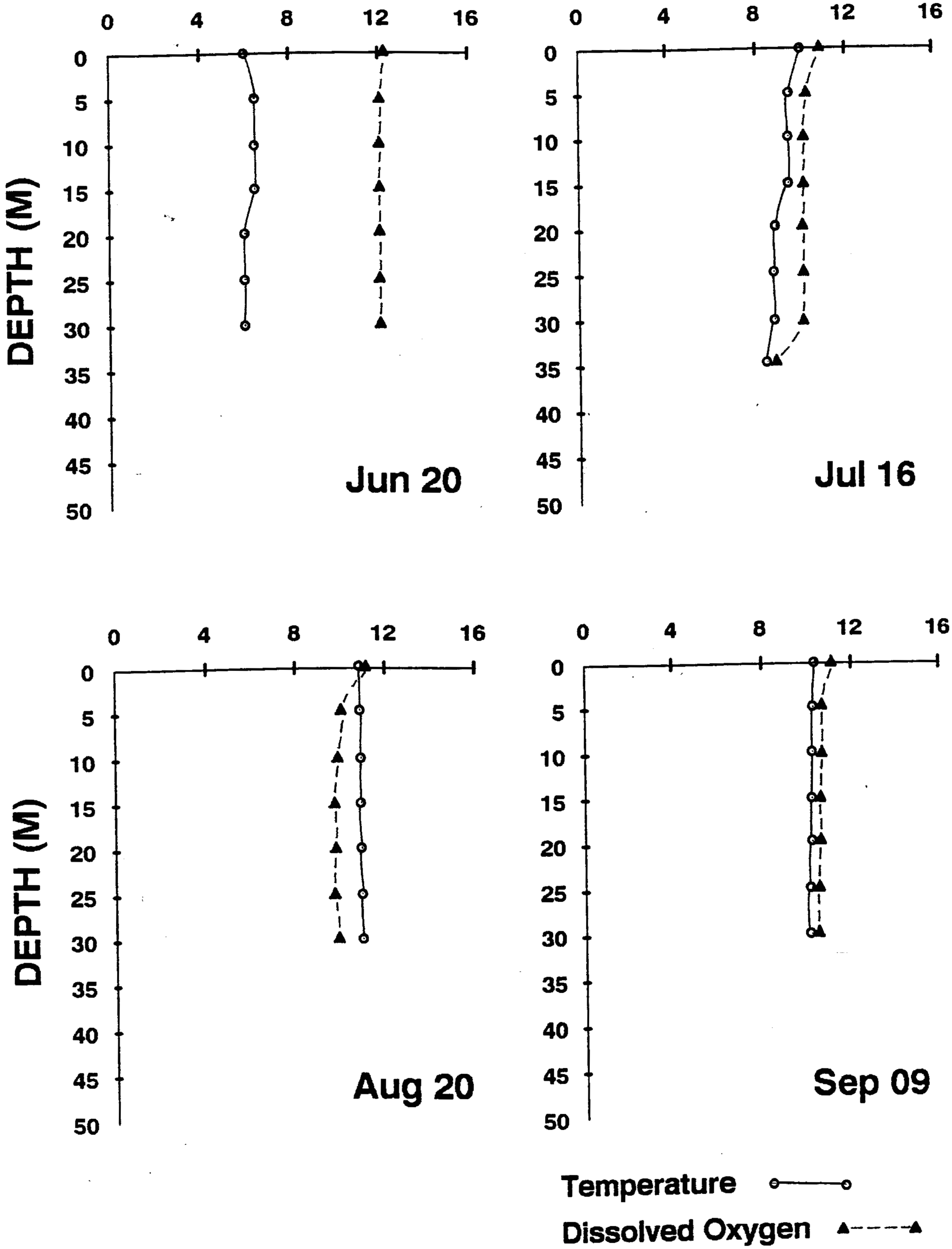

Figure 4. Seasonal temperature and dissolved oxygen profiles for station A in Chignik Lake, 1991.

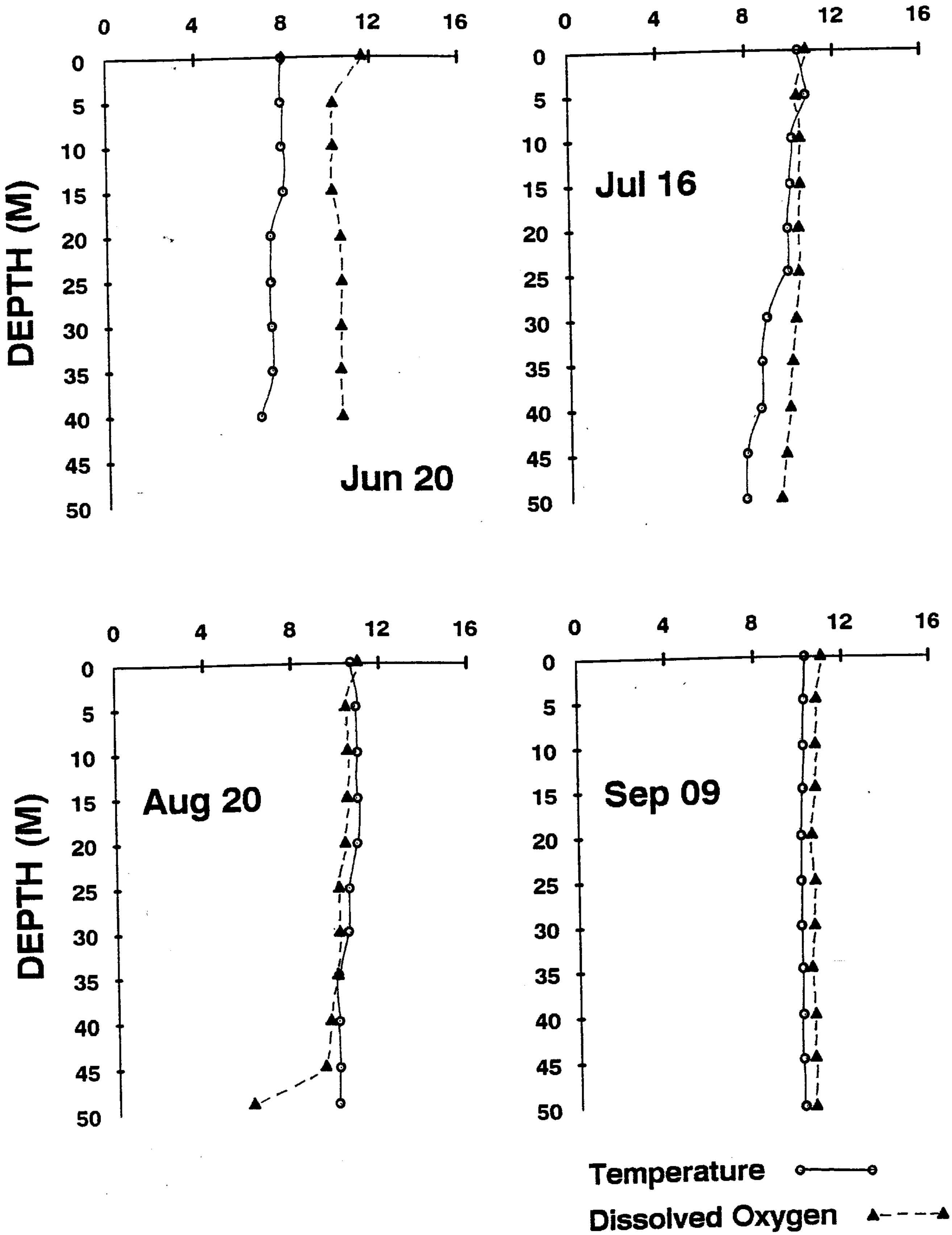

Figure 5. Seasonal temperature and dissolved oxygen profiles for station B in Chignik Lake, 1991.

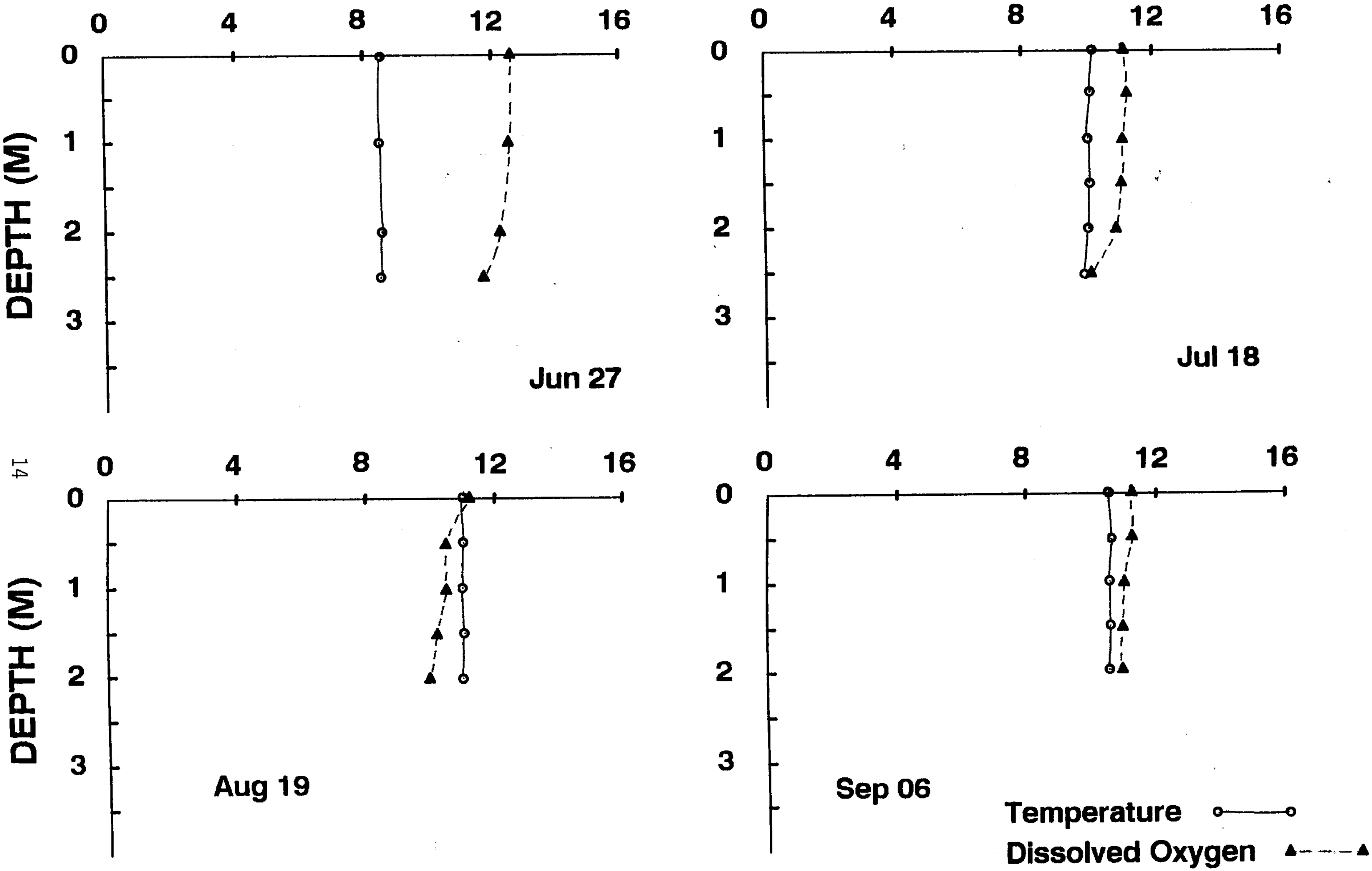

Figure 6. Seasonal temperature and dissolved oxygen profiles for station A in Black Lake, 1991.

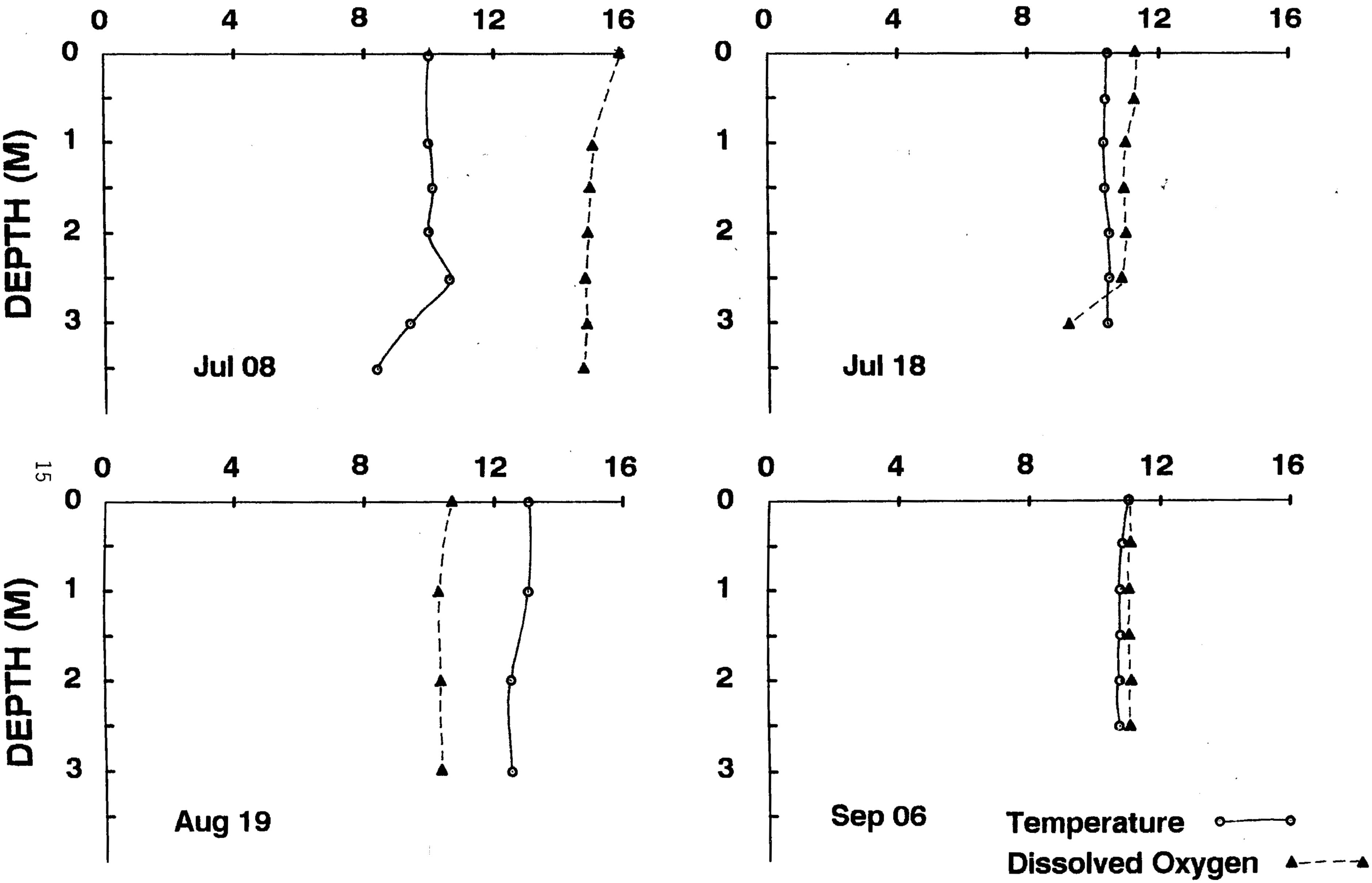

Figure 7. Seasonal temperature and dissolved oxygen profiles for station B in Black Lake, 1991.

Table 3. General water quality parameters, nutrient concentrations, and chlorophyll a concentrations within the epilimnion (1 m) and hypolimnion (30–50 m) by sample date and station for Chignik Lake, 1991.

Date	6/27				7/16				8/20				9/09			
Station	A		B		A		B		A		B		A		B	
Depth	1 m	50 m	1 m	50 m	1 m	34 m	1 m	50 m	1 m	32 m	1 m	50 m	1 m	30 m	1 m	50 m
Conductivity (umhos/cm)	86	87	82	85	81	82	80	83	82	85	85	84	83	83	83	84
pH	7.2	7.3	7.3	7.2	7.2	7.2	7.3	7.2	7.2	7.3	7.3	7.0	7.5	7.5	7.5	7.5
Alkalinity (mg/L)	24.5	24.5	23.0	24.0	21.5	22.0	21.0	23.5	21.0	21.5	21.0	22.0	22.0	22.5	22.0	21.5
Turbidity (NTU)	0.8	1.6	NA	1.3	0.5	0.4	2.6	1.8	3.0	2.3	3.2	2.5	2.2	6.0	4.8	8.4
Color (Pt)	4.0	8.0	4.0	6.0	5.0	6.0	6.0	6.0	4.0	3.0	8.0	3.0	10.0	6.0	5.0	5.0
Calcium (mg/L)	6.8	6.8	6.8	6.8	6.5	7.4	9.3	10.9	7.8	7.7	7.7	8.6	6.8	6.8	6.8	6.8
Magnesium (mg/L)	1.8	1.8	1.8	1.8	2.3	1.4	<0.2	<0.2	2.2	2.1	2.1	0.8	1.4	1.4	0.5	0.5
Iron (ug/L)	116	310	230	182	12	26	222	188	148	164	202	202	76	320	225	412
TP (ug/L)	8.0	11.3	9.0	8.4	6.7	9.0	13.2	10.3	11.5	13.4	13.9	13.1	4.9	13.7	10.2	18.2
TFP (ug/L)	3.0	3.0	3.2	3.3	2.7	3.5	4.5	4.4	3.9	3.2	4.9	4.1	4.2	4.9	4.6	6.1
FRP (ug/L)	2.3	2.2	2.7	2.2	2.7	3.2	4.7	4.3	3.9	3.6	5.3	4.0	3.4	5.2	4.9	6.8
TKN (ug/L)	80.0	81.6	49.0	68.4	46.0	69.2	40.4	80.8	41.1	57.5	50.5	51.2	44.7	61.7	53.6	58.5
Ammonium (ug/L)	2.3	<1.1	1.2	6.4	12.5	18.6	4.3	\a	<1.1	<1.1	<1.1	6.4	4.7	5.2	3.7	4.2
Nitrate + Nitrite (ug/L)	81.4	82.8	75.5	88.7	91.1	96.9	87.2	93.0	119.4	124.2	108.1	154.4	126.4	128.4	124.8	116.4
Reactive Si (ug/L)	4,654	4,706	4,811	4,811	4,439	4,439	4,552	4,530	5,156	4,936	5,123	5,030	4,546	4,546	4,569	4,662
Chl a (ug/L)	0.55	0.88	0.72	0.43	0.63	0.39	0.64	0.39	2.02	1.81	1.69	1.13	5.57	2.79	4.12	3.24
Phaeo a (ug/L)	0.43	1.07	0.26	0.36	0.27	0.26	0.33	0.23	0.59	0.76	4.80	0.83	0.67	5.62	0.65	1.29

\a Suspected contaminated sample.

to a large amount of phytodetritus as phaeophytin a, the decomposition product of chlorophyll a, was also relatively high for this sample date (Table 3). In Black Lake, epilimnetic turbidity levels ranged from 0.8 to 13 NTU, and averaged 5.8 NTU (Table 4). Thus, as turbidity values in Black Lake averaged slightly greater than 5 NTU, this lake is classified as semi-turbid (Edmundson and Koenings 1986).

Conductivity, which is an indirect measure of dissolved materials and an index of lake fertility, was moderate in both lakes and averaged $> \sim 80$ μmhos/cm for both stations and depths (Table 3 and 4). Alkalinity (the measurement of the ability of water to resist changes in pH which is important in chemical reactions such as photosynthesis) was also moderate as in both lakes it averaged greater than ~22 mg/L for both stations and depths. The pH in both lakes was slightly above neutral and varied between 7.0 and 7.5 units. Epilimnetic (1 m) iron concentrations for both lakes were high and ranged between 12-230 μg/L in Chignik Lake and 58-852 μg/L in Black Lake. Iron is an essential element for phytoplankton and is coupled with the phosphorus cycle in lakes. In clearwater lakes, under conditions of chemical equilibrium, iron exists primarily as soluble ferric hydroxide (Fe III) in concentrations of <20 μg/L (Stumm and Lee 1960). In contrast, nearly 90% of the total iron present in turbid/glacial lakes is comprised of particulate iron derived from silt (Edmundson and Koenings 1986; Koenings *et al.* 1986). Thus, in Black Lake the higher concentration of total iron is in part attributed to its semi-turbid nature; however, in Chignik Lake the high concentrations of total iron provide the potential for high primary productivity assuming other parameters/factors are not limiting. Finally, concentrations of calcium (6.8-10.9 mg/L) and magnesium (<0.2-3.1 mg/L), which are micronutrients needed by aquatic plants for metabolism, in both lakes for all samples were within the general range of other oligotrophic lakes in Alaska.

Nutrients-- Compounds of nitrogen, and in particular phosphorus, are major cellular components of all organisms and can regulate or limit the productivity of organisms in freshwater ecosystems. Concentrations of nitrogen and phosphorus are dynamic because they are constantly being utilized, stored, transformed, and excreted by various aquatic organisms. Other elements such as iron, silica, calcium, and magnesium are essential

Table 4. General water quality parameters, nutrient concentrations, and chlorophyll a concentrations within the epilimnion (1 m) and hypolimnion (2-4 m) by sample date and station for Black Lake, 1991.

Date	6/27		7/08 \a		7/18				8/19				9/06			
Station	A		B		A		B		A		B		A		B	
Depth	1 m	3 m	1 m	4 m	1 m	2 m	1 m	3 m	1 m	2 m	1 m	3 m	1 m	2 m	1 m	3 m
Conductivity (umhos/cm)	77	78	52	52	99	104	113	112	84	111	131	129	101	99	111	109
pH	7.2	7.2	7.5	7.5	7.3	7.3	7.4	7.5	7.2	7.1	7.4	7.5	7.3	7.4	7.5	7.5
Alkalinity (mg/L)	16.0	16.5	25.0	25.0	20.0	21.0	26.0	26.0	17.0	18.0	28.0	28.0	21.0	20.0	23.0	23.0
Turbidity (NTU)	2.6	0.2	0.8	1.1	5.5	3.5	3.8	3.2	13.0	12.0	3.2	2.3	11.0	6.8	6.4	5.6
Color (Pt)	5.0	6.0	6.0	8.0	9.0	9.0	6.0	8.0	9.0	9.0	6.0	5.0	11.0	5.0	5.0	8.0
Calcium (mg/L)	6.8	6.8	9.5	9.5	7.7	8.5	10.1	9.3	7.8	8.6	9.6	10.6	8.9	8.9	8.9	8.9
Magnesium (mg/L)	1.8	1.8	2.5	2.5	1.6	1.6	1.6	0.7	1.4	1.5	2.8	2.8	2.2	3.1	3.1	3.1
Iron (ug/L)	360	252	58	44	504	343	502	513	852	791	250	198	719	590	376	296
TP (ug/L)	9.7	9.7	11.0	10.6	21.9	15.6	36.5	29.2	25.9	22.8	19.9	18.9	29.5	28.0	16.2	19.7
TFP (ug/L)	1.5	1.9	4.1	3.6	2.9	3.4	3.8	3.5	3.1	3.1	4.1	4.6	5.2	4.0	4.2	4.6
FRP (ug/L)	1.2	1.5	3.4	3.2	3.0	2.7	2.3	2.1	1.9	2.1	3.2	3.0	3.5	3.0	2.3	2.2
TKN (ug/L)	40.2	38.0	114.2	122.7	137.5	114.2	204.2	184.8	96.4	94.8	132.1	118.1	230.1	157.2	130.5	134.6
Ammonium (ug/L)	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	<1.1	27.9	28.9	<1.1	<1.1	6.8	9.8	4.7	4.7
Nitrate + Nitrite (ug/L)	48.3	41.4	<3.4	<3.4	<3.4	<3.4	<3.4	<3.4	115.9	119.8	<3.4	<3.4	77.3	63.7	<3.4	<3.4
Reactive Si (ug/L)	3,283	3,336	1,816	1,702	2,204	2,204	1,392	1,346	3,676	3,518	1,342	2,066	2,460	2,600	1,594	1,594
Chl a (ug/L)	0.89	NA	1.04	1.05	3.03	2.99	4.07	0.76	0.96	0.91	1.10	1.34	5.80	3.77	5.05	6.79
Phaeo a (ug/L)	0.27	NA	0.23	0.29	1.21	1.39	1.85	0.39	0.56	0.58	0.64	0.62	1.70	0.95	1.40	2.63

\a During shipment to the Limnology Laboratory this sample was temporary lost and consequently thawed; thus some of the measured parameters may have been affected (e.g. conductivity, iron, and silicon).

cellular constituents but are required in relatively low concentrations in relation to availability in fresh waters.

Nitrogen (N) is necessary for aquatic and terrestrial life, and because nitrogen is more abundant it has been generally considered not as limiting to primary production as phosphorus. However, there is growing evidence to suggest that the nitrogen supply combined with phosphorus levels can significantly change biological responses (regulating photosynthesis and algal standing crop) in lakes (Smith 1982; Elser *et al.* 1990). There are various inorganic and organic fractions of nitrogen that are measured in water; however, both inorganic forms (ammonia and nitrate + nitrite) are readily utilized by aquatic plants for production. Except under alkaline conditions (pH>9.0), most of the ammonia in freshwater exists in the ionic form known as ammonium (NH_4^+).

Throughout the sampling period, epilimnetic (1 m) ammonium concentrations in Chignik Lake ranged from <1.1 to 12.5 μg/L (Table 3), and the seasonal average of just under 4 μg/L is comparable to other oligotrophic lakes in Alaska supporting sockeye salmon. In Black Lake, epilimnetic ammonium concentrations were less than the detection limit (<1.1 μg/L) for most of the samples (Table 4). However, in August a concentration of 28 μg/L was detected and in September concentrations between ~5-7 μg/L were found. These higher levels in the fall could reflect the nutrient input from salmon carcasses as Black Lake sockeye are an early run of fish. Epilimnetic nitrate + nitrite concentrations ranged from 76-126 μg/L in Chignik Lake, and ranged from the detection limit (3.4 μg/L) to 116 μg/L in Black Lake. In comparison to other sockeye lakes, nitrate + nitrite was moderate in Chignik Lake but low in Black Lake. Finally, to complete the nitrogen analysis, total Kjeldahl nitrogen (TKN) which measures organic N and ammonia (ammonium), averaged 51 μg/L and 136 μg/L in Chignik and Black Lake, respectively. In comparison, TKN in other sockeye nursery lakes in Alaska averages ~100 μg/L.

Phosphorus (P) has been considered as a limiting factor of primary productivity in lakes. In addition, biogenic input of nutrients from decomposing salmon carcasses (mainly phosphorus) has been strongly correlated to lake productivity (Gilbert and Rich 1927;

Juday et al. 1932; Krohkin 1967; Donaldson 1967). In Chignik Lake, total phosphorus (TP), which comprises both dissolved and particulate P, averaged 9.7 μg/L in the epilimnion and ranged from a low of 4.9 μg/L during September (Station A) to a high of 13.9 μg/L in August at Station B (Table 3). Total phosphorus in other clearwater sockeye nursery lakes in Alaska generally range between 5-10 μg/L. In Black Lake, epilimnetic TP concentrations were considerably higher ranging from 9.7-36.5 μg/L (Table 4) and averaged 21.3 μg/L; however, high TP concentrations in Black Lake are associated with turbidity. That is, in the analysis of TP, absorbance (analytical) measurements of turbid solutions are artificially high because of light backscattering, and therefore TP concentrations of turbid lakes need to be adjusted. For Black Lake, seasonal TP corrected for turbidity >5 NTU would average 12.0 μg/L over the season, which is slightly above the range for other oligotrophic sockeye lakes in Alaska. Soluable orthophosphate (filterable reactive phosphorus) is the form most readily available for algal uptake; however, it usually comprises a small portion of total phosphorus (TP). With minor exceptions filterable reactive phosphorus (FRP) in both lakes generally ranged between 1-4 μg/L, which is similar to other lakes. The large differences between TP and FRP are due primary to particulate P from turbidity (silt) in Black Lake and decomposition of algal matter in Chignik Lake.

Finally, for optimum algal growth the atomic ratio of total nitrogen (TKN + nitrate-nitrite) to total phosphorus (TN:TP) is generally between 10-17:1 (Smith 1982). Based on 1991 data, the TN:TP ratio for Chignik and Black Lake was 35:1 and 50:1, respectively. Smith (1983) found that a TN:TP ratio >29 does not favor the dominance of nitrogen-fixing phytoplankton species e.g., blue-greens which are unusable forms for consumption by zooplankton. Thus, nutrient ratios in Chignik and Black lakes do not appear to limit phytoplankton production (phosphorus is not limiting) or favor conditions for an undesired phytoplankton taxa. In addition, reactive silicon (Si), which is assimilated in large quantities by diatoms in the synthesis of their cell walls or frustules, was found in high concentrations in Chignik Lake (4,439-5,156 μg/L) and in moderate concentrations in Black Lake (1,342-3,676 μg/L).

Phytoplankton Standing Crop and Composition-- Chlorophyll a (chl a) levels in the epilimnion of Chignik Lake ranged from 0.55-5.57 μg/L and averaged 2.0 μg/L, while in Black Lake chl a ranged from 0.89-5.80 μg/L and averaged slightly higher at 2.7 μg/L (Table 3 and 4). Relative to other oligotrophic sockeye lakes in Alaska these levels are higher than average. Phaeophytin a, the decomposition product of chl a, exceeded 1.0 μg/L in both Chignik and Black lakes, which is above average and indicates an excess of phytodetritus. Higher values were found late in the growing season (September) when temperatures were relatively high. This is a natural and common phenomena and because of strong mixing from persistent winds throughout the summer does not present a concern. However, the accumulation of phytodetritus in the winter could lead to anoxic stagnation (e.g., low DO) which would present a concern to rearing sockeye.

Epilimnetic phytoplankton density and taxa composition for Chignik and Black Lakes are presented in Tables 5 and 6. In Chignik Lake throughout the season, diatoms comprised 19-79% of the composition (averaged 51%), chrysophtyceans (green algae) comprised 14-74% (averaged 37%), cyanophytes (blue-green algae) were rare (averaged 4%), and others comprised 4-11% and averaged 8% (Table 5). In Black Lake, diatoms dominated as >90% of the composition of phytoplankton comprised of this taxa (Table 6). Thus in both lakes blue-green algae, an unusable form of algae for consumption by zooplankton, was low in abundance; and diatoms, a major food item of herbivorous zooplankton, was relatively high in abundance.

Zooplankton Abundance, Size and Biomass-- The macrozooplankton community in Chignik Lake consists of three genera of copepods: *Cyclops*, *Eurytemora*, and *Harpacticoida*, and three genera of cladocerans: *Bosmina*, *Daphnia*, and *Chydorinae*. Seasonal mean total macrozooplankton (TMZ) density averaged 187,000/m^2 at Station A and 360,000/m^2 at Station B (Table 7). The two major cladoceran populations, *Bosmina* and *Daphnia* peaked in late August and early September and for both stations comprised 44% of the TMZ. In contrast, the two major copepods, *Cyclops* and *Eurytemora* populations peaked at different times; *Cyclops* peaked early in June-July while

Table 5. Epilimnetic (1 m) phytoplankton density (no/m^3 x 10^9) and percent composition by sample date and station in Chignik Lake, 1991.

	Sample date								Seasonal mean (no/m^3 x 10^9)	
	27 Jun		16 Jul		20 Aug		09 Sep			
Taxa/Station	A	B	A	B	A	B	A	B	A	B
Diatoms	0.89	0.54	0.21	0.24	0.70	0.30	0.80	0.89	0.65	0.49
	79%	67%	19%	19%	46%	41%	76%	73%	54%	49%
Chrysophyceans	0.19	0.18	0.63	0.95	0.67	0.37	0.15	0.26	0.41	0.44
	17%	22%	56%	74%	44%	50%	14%	21%	34%	43%
Cyanophytes	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.05	0.00
	0%	0%	17%	0%	0%	0%	0%	0%	4%	0%
Others	0.04	0.09	0.10	0.10	0.15	0.07	0.10	0.07	0.10	0.08
	4%	11%	9%	8%	10%	9%	10%	6%	8%	8%

Table 6. Epilimnetic (1 m) phytoplankton density (no/m^3 x 10^9) and percent composition by sample date and station in Black Lake, 1991.

	Sample date								Seasonal mean (no/m^3 x 10^9)	
	27 Jun		18 Jul		19 Aug		06 Sep			
Taxa/Station	A	B	A	B	A	B	A	B	A	B
Diatoms	2.20	NS \a	9.67	7.28	0.51	2.97	3.70	8.07	4.02	6.11
	80%	NS	94%	74%	100%	93%	90%	90%	91%	85%
Chrysophyceans	0.15	NS	0.46	0.66	0.00	0.20	0.19	0.73	0.20	0.53
	5%	NS	4%	7%	0%	6%	5%	8%	4%	7%
Cyanophytes	0.26	NS	0.00	1.72	0.00	0.00	0.00	0.17	0.07	0.63
	9%	NS	0%	17%	0%	0%	0%	2%	2%	6%
Others	0.15	NS	0.13	0.22	0.00	0.03	0.22	0.00	0.13	0.08
	5%	NS	1%	2%	0%	1%	5%	0%	3%	1%

\a NS denotes sample was not taken.

Table 7. Macrozooplankton density (no/m^2) by sample date and station in Chignik Lake, 1991.

Genera/Station	20 Jun A	20 Jun B	16 Jul A	16 Jul B	20 Aug A	20 Aug B	09 Sep A	09 Sep B	Seasonal mean (no/m^2) A	Seasonal mean (no/m^2) B
Harpacticoida		3,450	265	531					66	995
Eurytemora	15,393	32,643	25,212	61,040	61,040	178,344	86,518	202,229	47,041	118,564
Cyclops	130,573	59,713	35,563	131,900	24,416	83,333	33,174	46,709	55,932	80,414
Bosmina	7,431	22,028	22,558	55,202	75,106	170,382	71,921	202,229	44,254	112,460
Daphnia	4,777	2,919	5,308	11,146	56,529	47,771	90,499	122,081	39,278	45,969
Chydorinae		1,062				1,062	796	4,777	199	1,725
								TOTAL:	186,770	360,138

Table 8. Macrozooplankton body size (mm) and biomass (mg/m^2) by sample date and station in Chignik Lake, 1991.

Genera/Station	20 Jun A	20 Jun B	16 Jul A	16 Jul B	20 Aug A	20 Aug B	09 Sep A	09 Sep B	Seasonal mean weighted body size (mm) A	Seasonal mean weighted body size (mm) B	Seasonal mean weighted biomass (mg/m^2) A	Seasonal mean weighted biomass (mg/m^2) B
Harpacticoid		0.48								0.48		
Eurytemora	1.13	0.89	1.05	1.10	0.82	0.99	0.87	0.99	0.90	1.00	149.9	505.9
Cyclops	1.05	0.60	0.63	1.06	0.63	0.79	0.61	0.61	0.87	0.84	150.3	199.0
Bosmina	0.38	0.38	0.35	0.36	0.32	0.33	0.37	0.36	0.35	0.35	48.3	124.9
Daphnia	0.68	0.68	0.55	0.67	0.54	0.79	0.61	0.61	0.58	0.66	56.4	86.3
										TOTAL:	405.0	916.0

Eurytemora peaked in August-September. These two copepods (for both stations combined) comprised 55% of the TMZ. *Bosmina* body sizes ranged from 0.32-0.38 mm and averaged 0.35 mm (Table 8), which is below the minimum threshold size (0.40 mm) for elective feeding by sockeye salmon fry (Koenings and McDaniel 1983; Kyle *et al.* 1988) and is indicative of intense predation. In contrast, *Daphnia* body sizes ranged from 0.54-0.68 mm and averaged 0.61 mm, which is typical compared to other sockeye nursery lakes without intense predation. The average size of *Cyclops* (0.86 mm) was also comparable to other sockeye lakes.

The composition of macrozooplankton in Black Lake was similar to Chignik Lake except for the presence of immature calanoids and the absence of *Daphnia*. *Bosmina* peaked in August and comprised 83% of the TMZ (Table 9). The copepods were dominated equally by *Cyclops* and *Eurytemora*, peaked in abundance during July, and comprised 13% of the TMZ. The average size of *Bosmina* in Black Lake was also under the minimum threshold size for elective consumption by sockeye fry, and in addition, *Cyclops* and *Eurytemora* were much smaller than in Chignik Lake, averaging 0.58 mm and 0.69 mm, respectively.

The seasonal weighted mean TMZ biomass for Station A and B of Chignik Lake was 405 and 916 mg/m^2, and averaged 661 mg/m^2 (Table 8). In Black Lake, TMZ biomass for the season averaged 46 mg/m^2 for Station A and 287 mg/m^2 for Station B, for a combined average of 167 mg/m^2 (Table 10). Finally, a comparison of TMZ density and biomass for 25 sockeye nursery lakes reveals that the average standing stock of zooplankton (biomass) in Chignik Lake ranks seventh, and Black Lake ranks sixteenth (Table 11).

Juvenile Sockeye Assessment

Limnetic Fish Population Estimate and Distribution-- The September 08 1991 hydro-acoustic survey conducted in Chignik Lake revealed a population estimate of 3.7 million $\pm$ 570,000 juvenile fish (Table 12). Transects 1 and 2 representing lake area A in the upper part of Chignik Lake had the highest density and population of fish. In general,

Table 9. Macrozooplankton density (no/m^2) by sample date and station in Black Lake, 1991.

	Sample date								Seasonal mean (no/m^2)	
	08 Jul		18 Jul		19 Aug		06 Sep			
Genera/Station	A	B	A	B	A	B	A	B	A	B
Harpacticoida			265				265	265	133	66
Eurytemora		16,322		21,895		1,062		2,654		10,483
Immature Calanoid	5,839		4,246		159		531		2,694	
Cyclops	1,592	10,748	12,473	60,377	1,592	25,478	7,166	12,473	5,706	27,269
Bosmina	6,900	43,392	18,577	91,561	34,236	580,679	77,495	123,142	34,302	209,694
Chydorinae			1,062		955		1,858		969	3,848
								TOTAL:	43,803	251,360

Table 10. Macrozooplankton body size (mm) and biomass (mg/m^2) by sample date and station in Black Lake, 1991.

	Sample date								Seasonal mean weighted body size (mm)		Seasonal mean weighted biomass (mg/m^2)	
	08 Jul		18 Jul		19 Aug		06 Sep					
Genera/Station	A	B	A	B	A	B	A	B	A	B	A	B
Eurytemora		0.64		0.72		0.81		0.76		0.69		16.1
Immature Calanoid	0.56		0.75		0.64		0.47		0.63		3.2	
Cyclops	0.46	0.59	0.56	0.57	0.65	0.65	0.62	0.53	0.58	0.59	6.4	31.3
Bosmina	0.34	0.31	0.33	0.32	0.34	0.36	0.35	0.37	0.34	0.35	36.9	239.8
Chydorinae					0.37	0.26	0.31	0.29	0.33	0.27		
										TOTAL:	46.0	287.0

Table 11. Comparison of seasonal mean macrozooplankton density and biomass for a variety of sockeye nursery lakes.

Lake and geographical location \a	Sampled years	Seasonal mean weighted macrozooplankton: Density (no./m^2)	Seasonal mean weighted macrozooplankton: Biomass (mg/m^2)
Chenik (CI)	87–90	871,677	2,223
Hidden (CI)	81–90	619,203	2,331
Chelatna (CI)	84–85,88–90	409,413	1,313
Chilkat (NSE)	87–90	645,849	1,287
Karluk (Kodiak)	81–91	520,383	1,041
Eshamy (PWS)	81–86,89–90	439,595	972
Chignik (AK Penin)	91	273,454	661
Packers (CI)\b	81–90	177,815	617
Leisure (CI)	85–90	249,758	398
Skilak (CI)\c	86–91	230,361	556
Hugh-Smith (SSE)\b	81–87	290,404	523
McDonald (SSE)\b	81–90	91,245	297
Bakewell (SSE)\b	83–85,88–90	115,398	221
Frazer (Kodiak)	88–91	147,852	220
Afognak (Kodiak)	87–91	143,241	185
Black (AK Penin)	91	147,582	167
Redoubt (NSE)	84–87,90	137,040	159
Frazer (Kodiak)	85–87	114,086	155
Chilkoot (NSE)	87–90	88,443	145
Crescent (CI)\d	81–82	87,958	145
Tustumena (CI)\c	81–91	41,249	105
Virginia (NSE)	86,88–91	45,318	103
Redoubt (NSE)	82–83	76,818	90
Coghill (PWS)	86,88–91	47,465	79
English Bay (CI)	88–90	53,184	49

\a CI = Cook Inlet; PWS = Prince William Sound; NSE = Northern Southeast; SSE = Southern Southeast; AK Penin = Alaska Peninsula.

\b Denotes stained lakes.

\c Denotes glacial lakes.

\d Denotes semi-glacial lakes.

Table 12. Juvenile fish population estimates and variances for paired transect areas of Chignik Lake, September 08 1991.

Area	Transect	Mean fish density (no./1000 m^2)	Area (X 1000 m^2) transect	Area (X 1000 m^2) total	Weighted mean fish density (no./1000 m^2)	Variance	Fish population	Variance
	1	395.6	2327					
A				3465	361.3	2.40E+03	1,251,947	2.9E+10
	2	291.2	1138					
	3	388.3	1328					
B				2620	309.8	6.33E+03	811,789	4.3E+10
	4	229.2	1292					
	5	173.1	991					
C				2525	150.9	3.18E+02	381,087	2.0E+09
	6	136.6	1534					
	7	223.3	771					
D				2599	176.5	9.23E+02	458,795	6.2E+09
	8	156.8	1828					
	9	152.5	2503					
E				5534	140.4	1.21E+02	776,950	3.7E+09
	10	130.4	3031					
							3,700,000	8.43E+10
					95% confidence interval (+/-)		570,000	

weighted mean fish density declined from the upper to lower areas of the lake. The majority of fish (76.2%) were vertically distributed between 1.5 and 18 m (Table 13).

Townetting indicated juvenile sockeye comprised 30.3 to 64.1% of the catch in the three tows and averaged 46.6% (Table 14). Thus, of the total population estimate of juvenile fish, an estimated 1.7 million were sockeye juveniles. The remaining catch comprised of stickleback (25.1%), smelt (10.4%), and isopods (17.9%). Isopods are commonly referred to as aquatic sow bugs and can be recognized by their flattened bodies and lack of a carapace. They are characterized as scavengers that usually are found under rocks, vegetation, and debris (not in the open water), and are often nocturnal. The larvae of isopods are parasitic on copepods and remain attached until they molt several times and become a higher level larvae. The isopod found in Chignik Lake is *Mesidotea entomon* and belongs to the suborder *Valvifera*. This isopod thrives in brackish and freshwater, and collected specimens were as long as 60 mm for males and 25 mm for the females. In Chignik Lake, Narver (1968) found that *M. entomon* fed on zooplankton as 11 of 20 specimens collected at night in the pelagic zone of Chignik Lake contained fragments of copepods as well as remains of cladocerans.

Of the total sockeye catch, 36% were age-0 and 64% were age-1 (Table 15). The size of age-0 (64 mm; 2.6 g) and age-1 (70 mm; 3.6 g) sockeye juveniles in Chignik Lake were moderate compared to the size of fall juveniles in other nursery lakes. The mean condition coefficient for age-0 sockeye was 0.99, and for age-1 sockeye increased to 1.05 (Table 15).

EVALUATION AND SUMMARY

Limited historical/comparable) nutrient and water quality parameters are available to contrast with current data. However, the most striking differences between historical and current water sampling were the concentrations of nitrate nitrogen and phosphate phosphorus in both Chignik and Black lakes. Narver (1966) reported that nitrate N in Chignik Lake ranged from <6-32 μg/L and from <6-20 μg/L in Black Lake. Current

Table 13. Density of fish (no. per m^3) by depth and transect in Chignik Lake, September 08, 1991.

	Depth interval (m)					
Tansect	1.5–5	5–9	9–18	18–27	27–36	36–54
1	26.8	18.5	8.1	7.6	5.6	2.0
2	24.0	11.3	5.5	4.6	3.8	2.1
3	28.1	15.1	11.2	6.8	4.2	1.7
4	11.7	8.2	6.2	5.4	3.2	1.2
5	5.6	8.9	5.8	3.4	2.5	0.8
6	2.9	2.8	5.0	3.8	2.6	0.7
7	9.8	9.2	7.0	4.5	3.6	0.9
8	8.2	6.9	5.4	1.1	2.9	0.9
9	6.9	7.2	4.4	0.7	3.6	1.2
10	3.6	4.7	2.8	2.8	2.5	1.5
Distribution by depth for all transects (%)	34.5	25.1	16.6	11.0	9.3	3.5

Table 14. Catch of juvenile fish from townetting in Chignik Lake, September 09 1991.

Tow no./depth (m)		Tow duration (minutes)	Sockeye no.	Sockeye %	Sockeye CPUE \a	Stickle-back no.	Stickle-back %	Smelt no.	Smelt %	Isopod no.	Isopod %
1	15	30	49	41.5	1.6	15	12.7	5	4.2	49	41.5
2	15	30	66	30.3	2.2	95	43.6	43	19.7	14	6.4
3	15	30	148	64.1	4.9	32	14.0	11	4.8	38	16.6
	Total	90	263			142		59		101	
	Mean			46.6	2.9		25.1		10.4		17.9

\a Catch-per-unit-effort.

Table 15. Age, size and condition coefficient of juvenile sockeye salmon collected from townetting in Chignik Lake, September 09 1991.

Tow no.	No. sampled	Age	Age composition	Mean weight (g)	Mean length (mm)	Mean condition coefficient
	4	0	19%	2.8	66	0.97
1	17	1	81%	4.0	72	1.07
	11	0	46%	2.5	64	0.95
2	13	1	54%	3.3	69	1.00
	8	0	42%	2.7	63	1.08
3	11	1	58%	3.3	68	1.05
	23	0	36%	2.6	64	0.99
1-3	41	1	64%	3.6	70	1.05

sampling revealed nitrate N concentrations in Chignik Lake ranged between 76-126 μg/L and in Black Lake from the detection limit (3.4 μg/L) to 116 μg/L. Phosphate phosphorus from filtered samples collected in Chignik Lake during 1962 ranged from <6-50 μg/L and from <6-20 μg/L in Black Lake (Narver 1966). However, current sampling indicated total filtered phosphorus ranged from 2.7-6.1 μg/L in Chignik Lake and 1.5-5.2 μg/L in Black Lake.

The reported low concentrations of nitrate nitrogen in the 1960's would indicate a limiting factor for algal production; however, chlorophyll a concentrations reported in the 1960's were quite high consistently throughout the sampling season (Narver 1966). Thus, data from sampling in the 1960's suggest an underestimate of nitrate N concentrations. Conversely, concentrations of phosphate P was higher in the 1960's than current sampling, indicating a lowering of the input of phosphorus. However, the spring total phosphorus concentration in both lakes centered around 10 μg/L in 1991, which is the target concentration for optimum primary productivity in oligotrophic sockeye lakes of Alaska.

Although, chlorophyll a levels in both lakes are less than those reported during the 1960's, the current concentrations are higher than average for other oligotrophic sockeye lakes in Alaska. In addition, phytoplankton (i.e. blue-greens) inedible to zooplankton in both lakes were low in composition (<5%), while diatoms a food source for herbivorous zooplankton were abundant. The nutrient ratios were >29:1, which does not favor the production of unfavorable phytoplankton. In addition, as total phosphorus concentrations were not relatively low in either lake, the high N:P ratios indicate a slight excess of total nitrogen.

Stenson (1972; 1976) and Kerfoot (1975; 1977) found that when planktivorous salmonids (e.g., sockeye) are abundant, *Bosmina* spp. tend to be of small body sizes. Excessive planktivory by fish not only reduces prey size, but also structures zooplankton composition. For example, Brooks (1969) found that *Bosmina longirostris* was dominant in most ponds or lakes in North America and Eurasia where fish predation is intense.

He concluded that in zooplankton communities faced with intense planktivore pressure, smaller-sized *Bosmina* prevail because they can continue to reproduce at an adult size less than 0.40 mm. In Chignik Lake, *Bosmina* body sizes ranged from 0.32-0.38 mm and averaged 0.35 mm, which is below the minimum threshold size (0.40 mm) for elective feeding by sockeye salmon fry (Koenings and McDaniel 1983; Kyle *et al.* 1988) and is indicative of intense predation. In addition, *Bosmina* densities ranged from approximately 2 to 5 times those of the larger-sized *Daphnia*. The seasonal mean density of *Bosmina* and *Daphnia* in 1991 was 78,357/m^2 and 42,623/m^2 respectively. Thus, 1991 sampling suggests that the zooplankton community of Chignik Lake resembles one that sustains predation pressure by juvenile sockeye in the form of a cladoceran composition dominated by *Bosmina* and the presence of small size*Bosmina*.

In Black Lake, *Daphnia* were not found and *Bosmina* comprised the majority of zooplankton. The average size of *Bosmina* was also under the minimum threshold size for elective consumption by sockeye fry, indicating intense predation pressure, and in addition, *Cyclops* and *Eurytemora* were much smaller than in Chignik Lake. The absence of *Daphnia* in Black Lake is not unique for turbid lakes as silt particles such as those found in glacial lakes do interfere with feeding and reproduction of cladocerans (Edmundson and Koenings 1985; Koenings *et al.* 1990). Nonetheless, because of the relatively low turbidity of Black Lake, especially in the early season (before August) and the relatively enriched conditions of this lake; we would have expected higher cladoceran densities and the presence of *Daphnia*.

In both lakes, particularly in Chignik Lake, the peak standing stock of zooplankton did not occur until later in the growing season (August), which could hinder growth and potentially survival of sockeye fry, especially young-of-the-year. The timing of peak forage production is critical to sockeye fry entering the limnetic area of sockeye nursery lakes, and has been suggested as a reason for the decline of Karluk Lake sockeye (Koenings and Burkett 1987).

The hydroacoustic estimate of 1.7 million juvenile sockeye rearing in Chignik Lake in September represents a low population based on euphotic volume, the standing stock of macrozooplankton, and escapement level. That is, based on an euphotic volume (EV) model (Koenings *et al.* 1989) of 158.9 x 10^6 m^3 (or 159 EV units), Chignik Lake would be forecasted to support a total of 5.2 million sockeye juveniles in the fall. In contrast, based on a seasonal macrozooplankton biomass of 661 mg/m^2, Chignik Lake would be projected to produce 14.5 million threshold-size smolts (2.2 g) or 6.4 million optimum size (5.0 g) smolts (Koenings and Kyle 1991). Hindcasting the population of fall juveniles assuming a 65% fall fry-to-smolt survival, indicates that for the projected number of threshold size smolts, a total of 23 million juveniles would be rearing in the fall, and for optimum size smolts a total of 9.8 million fry would be rearing in the fall. In addition, the broodyear escapement in Chignik Lake from which the age-0 sockeye juveniles were produced was 335,867 (1990), and the age-1 juveniles were a product of the 1989 record-high escapement of 557,171. Thus, the fall population estimate of juvenile sockeye based on the hydroacoustic survey and townetting was well below the projected rearing capacity of Chignik Lake based on euphotic volume (Koenings *et al.* 1989), and standing stock of macrozooplankton (Koenings and Kyle 1991), and less than expected from the number of adult spawners. It is possible that a portion of the sockeye fry rearing in Chignik Lake during the hydroacoustic/townet survey was distributed such that they were not detected/represented by the survey equipment. However, even a doubling of the fall population estimate would still be a substantial underestimation of juvenile production based on euphotic volume and zooplankton biomass.

The size of age-0 sockeye fry collected from townetting in Chignik Lake during early September 1991 averaged 64 mm and 2.6 g. This compares with the 47 mm length of age-0 sockeye sampled in September of 1960 and 1961 (Burgner *et al.* 1969). The sizes of both age-0 and age-1 sockeye sampled in the fall of 1991 in Chignik Lake are moderate compared to other sockeye populations. Finally, in 1991, the average number of sticklebacks per 30-minute tow in Chignik Lake was 47. Although only three (15-m) tows were conducted in 1991, in 1962 the weighted mean catch of sticklebacks (over the summer) per standard surface tow (6 minutes) was 3.8 (Burgner *et al.* 1969) or equivalent to 19 for a 30-minute tow, a 2.5-fold lower abundance of sticklebacks. Finally, there was evidence of size-selectivity within the zooplankton community (e.g., undersized *Bosmina*) which is characteristic of intense foraging. Thus, there could be some interspecific competition for food among juvenile sockeye as well as intraspecific competition from sticklebacks.

RECOMMENDATIONS

1. Limnology data should be collected another year for comparison with 1991 data to characterize the freshwater productivity of Chignik and Black lakes.

2. Townetting in Black Lake should be considered to document the size and age of rearing sockeye fry, and to determine the relative abundance of sockeye fry relative to evaluating the magnitude of pre-smolts migrating into Chignik Lake.

3. Townetting in Chignik Lake should be done during the summer and fall to determine the relative abundance of sockeye fry, and to analyze the foreguts of sockeye fry and sticklebacks to evaluate if an overlap of specific food organisms (macro- zooplankton) is limiting production of sockeye juveniles.

4. Enumeration and sampling of smolts emigrating from both Chignik and Black lakes would provide data necessary to compare actual juvenile production with production models, determine the importance of each lake to total juvenile production of the Chignik system, and provide smolt age and size information which is critical to characterizing existing conditions of the rearing environment.

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