Fishery Data Series No. 06-17

Summary of Limnology and Fisheries Investigation of Chilkoot Lake, 2001–2004

by

Renate Riffe

April 2006

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$log_{2,}$ etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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TABLE OF CONTENTS

Page

LIST OF TABLES....ii

LIST OF FIGURES....ii

LIST OF APPENDICES....iii

ABSTRACT....1

INTRODUCTION....1

OBJECTIVES....2

METHODS....3

Study site....3
Limnological Assessment....3
  Field Surveys....3
  Morphometry and Vertical Light Profiles....4
  Laboratory....4
Assessment of juvenile sockeye fry....5
  Hydroacoustic Surveys....5
  Laboratory....6
  Data Analysis....6

RESULTS....7

Limnological Assessment....7
  Morphometry and Physical Environment....7
  Water and Nutrient Chemistry....7
  Chlorophyll....8
  Organic Particulates....8
  Zooplankton Species, Composition, and Density....8
Assessment of juvenile sockeye fry....9

DISCUSSION....9

RECOMMENDATIONS....12

ACKNOWLEDGEMENTS....13

REFERENCES CITED....14

FIGURES AND TABLES....17

APPENDIX A: SUMMARY OF WATER SAMPLE ANALYSIS WITHIN THE EPILIMNION AND HYPOLIMNION OF CHILKOOT LAKE....41

APPENDIX B: SUMMARY OF ALGAL PIGMENT ANALYSIS FOR CHILKOOT LAKE....55

LIST OF TABLES

Table **Page**

1. Estimates of annual escapement, catch, total return, and exploitation rate of returning adult Chilkoot Lake sockeye salmon, from 1980 to 2004. 29
2. Descriptive morphometric parameters for Chilkoot Lake. 30
3. Estimated surface area by depth zone for Chilkoot Lake. 30
4. Estimated volume by depth zone of Chilkoot Lake....31
5. Calculated euphotic zone depths and vertical extinction coefficients for sampling sites 1 and 2 on Chilkoot Lake between May and October, from 2001 to 2004. 32
6. Seasonal mean values for general water quality parameters, metal concentrations, nutrient concentrations, and atom ratios for samples collected at 2 sites, monthly from May to November, at depths of 1 m and 50 m from Chilkoot Lake in 2001....33
7. Seasonal mean values for general water quality parameters, metal concentrations, nutrient concentrations, and atom ratios for samples collected at 2 sites, monthly from May to November, at depths of 1 m and 50 m from Chilkoot Lake in 2002....34
8. Seasonal mean values for general water quality parameters, metal concentrations, nutrient concentrations, and atom ratios for samples collected at 2 sites, monthly from May to November, at depths of 1 m and 50 m from Chilkoot Lake in 2003....35
9. Estimated zooplankton densities in number m^{-2} by site, by collection date, and by species, from samples collected at Chilkoot Lake in 2004. 36
10. Estimated zooplankton densities in number m^{-2} by site, and by collection date, from samples collected at Chilkoot Lake from 2001 to 2004. 37
11. Average length in mm of non-ovigerous *Cyclops* by site and collection date, from zooplankton samples collected at Chilkoot Lake, from 2001 to 2004. 38
12. Average length in mm of ovigerous *Cyclops* by site and collection date, from zooplankton samples collected at Chilkoot Lake, from 2001 to 2004. 39
13. Estimated number of targets, number and percentage of fish collected in trawl samples by species, and estimated number of sockeye fry present in Chilkoot Lake in autumn, as calculated from hydroacoustic surveys between 1987 and 2004. 40

LIST OF FIGURES

Figure **Page**

1. Map of Upper Lynn Canal, showing fishing sub-districts and major inlet streams....18
2. Estimated total adult sockeye salmon returning to Chilkoot Lake between 1980 and 2004. Returns are separated into fish caught and fish that migrated past Chilkoot weir to spawn. 19
3. Bathymetric map of Chilkoot Lake, and location of limnology sampling sites. 20
4. Hypsometric (depth-area) plot of Chilkoot Lake....21
5. Depth-volume plot of Chilkoot Lake. 21
6. Euphotic zone depth by month in Chilkoot Lake, between May and October, in years 2001 to 2004. 22
7. Estimated percentage of volume of Chilkoot Lake within the euphotic zone depth, by month, between May and October, in years 2001 to 2004....22
8. Depth-time isotherms (ºC) by month for Chilkoot Lake in: 2001, 2002, 2003, 2004. 23
9. Seasonal changes in total nitrogen, Kjeldahl and nitrate nitrogen concentrations within the 1-m stratum for Chilkoot Lake in 2001, 2002, and 2003....24
10. Seasonal changes in total phosphorus, total filterable phosphorus, and filterable reactive phosphorus concentrations within the 1-m stratum in Chilkoot Lake in 2001, 2002, and 2003. 25
11. Seasonal changes in chlorophyll α concentrations within the 1-m stratum and 50-m stratum (hypolimnion) in Chilkoot Lake during 2001, 2002, and 2003. 26
12. Seasonal changes in Chilkoot Lake zooplankton density between May and October, 2001 to 2004. 27
13. Seasonal changes in Chilkoot Lake zooplankton weighted biomass between May and October, 2001 to 2004....27
14. Estimated abundance of Chilkoot Lake sockeye fry in autumn, as calculated from a series of hydroacoustic surveys conducted from 1987 to 1991, 1995 to 2001, 2002 to 2003, and in 2004. 28

LIST OF APPENDICES

Appendix		Page
A1.	Summary of water sample analysis at site 1 within the epilimnion of Chilkoot Lake during 2001.	42
A2.	Summary of water sample analysis at site 2 within the epilimnion of Chilkoot Lake during 2001.	43
A3.	Summary of water sample analysis at site 1 within the hypolimnion of Chilkoot Lake during 2001.	44
A4.	Summary of water sample analysis at site 2 within the hypolimnion of Chilkoot Lake during 2001.	45
A5.	Summary of water sample analysis at site 1 within the epilimnion of Chilkoot Lake during 2002.	46
A6.	Summary of water sample analysis at site 2 within the epilimnion of Chilkoot Lake during 2002.	47
A7.	Summary of water sample analysis at site 1 within the hypolimnion of Chilkoot Lake during 2002.	48
A8.	Summary of water sample analysis at site 2 within the hypolimnion of Chilkoot Lake during 2002.	49
A9.	Summary of water sample analysis at site 1 within the epilimnion of Chilkoot Lake during 2003.	50
A10.	Summary of water sample analysis at site 2 within the epilimnion of Chilkoot Lake during 2003.	51
A11.	Summary of water sample analysis at site 1 within the hypolimnion of Chilkoot Lake during 2003.	52
A12.	Summary of water sample analysis at site 2 within the hypolimnion of Chilkoot Lake during 2003.	53
B1.	Summary of algal pigment analysis (in µg L^{-1}), by sampling visit, site and (euphotic) depth for Chilkoot Lake in 2001.	56
B2.	Summary of algal pigment analysis (in µg L^{-1}), by sampling visit, site and (euphotic) depth for Chilkoot Lake in 2002.	57
B3.	Summary of algal pigment analysis (in µg L^{-1}), by sampling visit, site and (euphotic) depth for Chilkoot Lake in 2003.	58

ABSTRACT

Beginning in 1992, the number of adult sockeye salmon (*Oncorhynchus nerka*) returning to Chilkoot Lake decreased substantially from the mean abundance levels seen between 1980 and 1990. The adult sockeye population has only partially recovered, starting about 2000. The Chilkoot Lake Productivity Assessment Project was initiated to ascertain present productivity and carrying capacity of the lake, to examine trends in carrying capacity, and to identify management and enhancement strategies for optimizing sockeye production. Abundance of zooplankton, a chief food item for sockeye fry, was negatively affected by interannual reductions in summer euphotic zone depth. Chilkoot Lake functions as a clear lake during spring and early summer, changing to a glacial lake in the summer. With increasing air temperatures, glaciers melt more rapidly, and more silt is deposited, increasing the lake's turbidity. Increased turbidity causes a reduction in euphotic zone depth, in primary production, and in carrying capacity at all trophic levels. The intensity of the change depends on summer weather patterns. During hot dry summers, glacial melting is enhanced, more silt flows into the lake, and turbidity levels rise accordingly. The carrying capacity during such years is greatly reduced. Most glaciers in northern Southeast Alaska are receding, probably due to faster melting from increased air temperatures. Chilkoot Lake's productivity has probably been reduced from the 1980s. Stocking or lake fertilization will not be effective in mitigating the reduction in productivity. At present, the best management actions for Chilkoot Lake may be to monitor turbidity and zooplankton populations, and to reevaluate escapement ranges for the lake's salmon stocks in response to medium- or long-term changes in summer turbidity that correlate with changes in the size of the Chilkoot Lake sockeye spawning migration.

Key words: sockeye salmon, *Oncorhynchus nerka*, fry, glacial lakes, Chilkoot Lake, euphotic zone depth (EZD), zooplankton, turbidity

INTRODUCTION

The Chilkoot River watershed is one of two primary producers of sockeye salmon (*Oncorhynchus nerka*) in the Lynn Canal portion of Southeast Alaska (Figure 1). Historically, about 30% of the annual commercial harvest of sockeye salmon in Southeast Alaska comes from Lynn Canal (Barto 1995). The relative contribution of Chilkoot Lake sockeye stocks to the Lynn Canal commercial sockeye fishery between 1980 and 1990 ranged from 38% to 89%, with a median of 53% of the total harvest (Bachman 2002).

From 1990 to 2000, the Chilkoot Lake sockeye stocks experienced dramatic reductions in number of adult returns. The reductions did not correlate with the number of spawning adults in respective brood years or with the size of adult returns to neighboring sockeye systems. Between 1980 and 1990, the estimated number of adult sockeye salmon returning to Chilkoot Lake (catch plus weir count) averaged about 230,000 fish annually (McPherson and Olsen 1992). In 1993, the estimated total return was 103,000 sockeye salmon, about 45% of the average return between 1980 and 1990, and 12% below the smallest estimated return for that time period (Table 1; Figure 2). In 1995, the estimated total adult sockeye return was about 15,000 fish, less than 7% of average return between 1980 and 1990. The estimated total adult return remained below 100,000 sockeye salmon between 1994 and 2000, and averaged about 45,000 fish (with a median of 58,000 fish). Between 2001 and 2004, the estimated annual adult sockeye returns have ranged from 82,000 to 143,000 fish, with an average of 119,000 fish and a median of 124,000 fish (Bachman 2002, and *personal communication*). No other sockeye salmon stock in the vicinity exhibited such drastic changes during the same time period.

To rebuild the Chilkoot Lake sockeye salmon stocks, area management biologists implemented time and area closures, and gear restrictions on commercial fishers. The management biologists also directed subsistence fishing effort away from Chilkoot Lake stocks, and towards Chilkat River stocks.

Despite these efforts, adult returns did not rebound to the levels seen during the 1980s. The Northern Southeast Regional Aquaculture Association (NSRAA) proposed a fertilization project, to increase the number of sockeye salmon smolts exiting Chilkoot Lake.

Alaska Department of Fish and Game (ADF&G) biologists postulated that freshwater conditions in Chilkoot Lake were driving the decline of its sockeye stocks, specifically a reduction in the principal food sources within the lake. Evidence for the decline in food resources came from a limnological study conducted by ADF&G between 1987 and 1991 (Barto 1995). This time period coincided with the freshwater life stage of many adult sockeye salmon that returned to Chilkoot Lake between 1991 and 1996. Between 1987 and 1991, Barto documented a 95% decrease in zooplankton densities, and an 88% decrease in zooplankton abundance. Hydroacoustic estimates of rearing sockeye fry in autumn dropped by 83%, from 2.82 million in 1988 to 476 thousand in 1991. Several individuals independently hypothesized that the reduction in sockeye food sources occurred because overescapement of sockeye adults into the lake produced an overabundance of fry that in turn overwhelmed the prey base.

In 2001, the Alaska Department of Fish and Game initiated the Chilkoot Lake Productivity Assessment project, to evaluate present productivity in Chilkoot Lake, and to assess the feasibility of a lake fertilization project. The 4 goals of this study were: to obtain information on present physical and chemical characteristics of Chilkoot Lake, as well as forage species densities and size of current fry populations; to use this information to determine present productivity and carrying capacity of Chilkoot Lake; to examine trends in carrying capacity for Chilkoot Lake; and, to identify management and enhancement strategies for optimizing sockeye salmon production in Chilkoot Lake.

OBJECTIVES

To meet the goals of the Chilkoot Lake Productivity Assessment project, the following objectives were identified:

1. Collect and analyze water chemistry samples taken at 2 sites in Chilkoot Lake on a monthly basis from May through October/November from 2001 to 2004.

2. Collect and analyze zooplankton samples taken at 4 sites in Chilkoot Lake on a monthly basis from May through October/November for 2001 to 2004.

3. Collect and analyze hydroacoustic data on sockeye salmon fry densities collected at Chilkoot Lake during the fall of years 2001 to 2004.

4. Compare and contrast data between years of this study, and from previous studies, to identify trends in carrying capacity in Chilkoot Lake.

METHODS

STUDY SITE

Chilkoot Lake (59.35ºN 135.59ºW; Anadromous Waters Catalog Johnson 2006, No. 115-33-10200-0010) is the primary nursery area for sockeye salmon originating from the Chilkoot River system. The lake has a volume of 382 million m^3 a mean depth of 54.5 m, and a maximum depth of 89 m (Barto 1995). The main inlet stream is fed by glaciers, and consequently deposits glacial silt into the lake. Resident fish within Chilkoot lake include sockeye salmon, coho salmon (*O. kisutch*), cutthroat trout (*O. clarki*), Dolly Varden (*Salvelinus malma*), threespined sticklebacks (*Gasterosteus aculeatus*), and sculpin (*Cottus spp.*).

LIMNOLOGICAL ASSESSMENT

Field Surveys

Between 2001 and 2004, I and one assistant conducted six surveys annually, or one limnological survey a month between 1 May and 31 October. Between 2001 and 2003, we collected water samples, vertical profiles of light temperature and dissolved oxygen, and zooplankton samples. In 2004, I reduced the surveys to vertical profiles of light and temperature, and collection of zooplankton samples, primarily because the lab that had been conducting the water and zooplankton analyses was closing.

Prior to the onset of the study, the area management biologist deployed four anchored buoys along the major axis of the lake (Figure 3). The location of the sampling stations coincided roughly with the sampling stations deployed by Barto (1995). The two main sampling stations were located at opposite ends of the lake, and the two secondary stations were located between them. We conducted the limnological surveys using a skiff that we anchored to each sampling station.

We collected one vertical zooplankton tow at each of the four sampling stations. The net we used was 0.5 m in diameter, and had a mesh size of 153 µm. Zooplankton hauls were pulled manually from 50-m depth to the surface at approximately 0.5 m sec^{-1}. The contents were preserved in 10% buffered formalin.

At the two main sampling stations (1 and 2), we measured vertical profiles of temperature and dissolved oxygen at 1-m increments from the surface of the lake to 20 m depth, and then at 5-m increments from 25 m to 50 m depths, using a YSI model 57 oxygen analyzer equipped with a thermistor. On each survey, we measured the oxygen content of the water at 1 m by the Winkler method (APHA 1985). The measurement of oxygen content was then used to calibrate the YSI oxygen probe. We measured underwater light intensity just below the surface of the water, then at 0.5-m increments, using a Protomatic submarine photometer. We ceased measuring light intensity at the depth where ambient light levels equaled 1% of the light levels just below the surface.

Also at the 2 main sampling stations, we collected water samples at depths of 1 m and 50 m. At each depth, we collected approximately 8 L of water using a Van Dorn sampler. We poured samples into separate (pre-cleaned) polyethylene carboys and transported to a lab in Haines, where the samples were filtered and preserved for shipment.

Water samples for dissolved nutrients (filterable Phosphorus, filterable reactive Phosphorus, ammonia-N, and nitrate-N) and color were filtered under low vacuum pressure (15 psi) through a 0.7 µm-GFF filter 2 to 6 hours after collection, then frozen until laboratory analysis. Unfiltered samples were refrigerated, for later analysis for general water chemistry (conductivity, pH, alkalinity, and turbidity), metals (calcium, magnesium, and iron), and reactive silicon. Unfiltered samples for analysis of total Kjeldahl nitrogen and total phosphorus were stored frozen. For analysis of chlorophyll *α* (chl*α*) and phaeophytin *α*, we filtered a 1 L aliquot of each water sample through a 0.7 µm-GFF filter, to which we added 2 ml of $MgCO_3$. The filters were stored frozen in Plexiglas Petrislides until analyzed. After filtering and processing, I shipped the water, filter, and zooplankton samples to the Soldotna limnology for analysis. After the Soldotna limnology lab closed in July 2004, I ceased taking and processing water samples; zooplankton samples were shipped to Kodiak for analysis.

Morphometry and Vertical Light Profiles

Morphometric data for Chilkoot Lake were derived from bathymetric maps previously developed by ADF&G. Drainage area was delineated on ArcGIS. Morphometric parameters, such as mean depth (Z), maximum depth (Z_x), and shoreline development (D_L), were calculated in accordance with Wetzel (2001). In addition, hypsographic curves and depth volume curves were plotted in accordance with Wetzel (2001).

Measurements of underwater light intensity were used to determine vertical light extinction coefficients and algal compensation depths. Light extinction coefficients (K_d) were estimated by fitting regression lines to the standard formula for exponential light extinction: $I_d = I_0 e^{-Kd}$, where I_d is the light intensity at depth *d* (Kirk 1994). The Euphotic Zone Depth (EZD) was calculated by substituting ln (100) into the regression equation.

Laboratory

In the laboratory, cladocerans and copepods were identified using standard taxonomic keys. Enumeration consisted of counting the animals in triplicate 1-ml subsamples taken with a Hansen-Stempel pipette in a 1-ml Sedgewick rafter cell. Zooplankton biomass was estimated from species-specific regression equations that correlated zooplankton body length and weight (Koenings et al. 1987).

Conductivity (compensated to 25ºC) was measured using a YSI conductance meter, and pH was measured with an Orion model 420A pH meter equipped with an automatic temperature compensation probe. Alkalinity was determined by acid titration (0.02 N H_2SO_4) to pH 4.5 units. Turbidity, expressed as nephleometric turbidity units (NTU) were measured with an HF model 00B meter. Color was determined on a filtered (GFF) sample by measuring spectrophotometric absorbance at 400 nm and converting to equivalent platinum-cobalt (Pt) units. Calcium and magnesium were determined from separate EDTA (0.01 N) titrations; total iron was analyzed by reduction of ferric iron with hydroxylamine during hydrochloric acid digestion. Reactive silicon was determined using the method of ascorbic acid reduction procedure as modified by Eisenreich et al. (1975). Total phosphorus (TP) utilized the FRP procedure after acid-persulfate digestion. Nitrate + nitrite was analyzed as nitrite following cadmium reduction, and total ammonia utilized the phenylhypochloroite method. Total Kjeldahl nitrogen (TKN) was determined from ammonia following acid-block digestion. Total nitrogen (TN) was calculated as the sum of TKN and nitrate + nitrite. All chemical and nutrient methods are detailed in Koenings et al. (1987).

In the laboratory, algal pigments were extracted by grinding filters containing filtrate and $MgCO_3$ in 90% acetone and refrigerating the slurry in the dark for two hours. The slurry was then centrifuged, and the chlorophyll *α* concentrations (corrected for inactive phaeophytin) was determined by the fluorometric procedure using a calibrated (Sigma Co. chlorophyll α standards) Turner model 112 fluorometer (Koenings et al. 1987).

ASSESSMENT OF JUVENILE SOCKEYE FRY

Hydroacoustic Surveys

We used hydroacoustic and mid-water trawl sampling in autumn, to estimate the distribution and abundance of sockeye salmon fry in Chilkoot Lake. Hydroacoustic surveys were conducted in 2001 through 2004.

The 2001 survey was conducted under a prior sampling protocol that has since been abandoned. From 1987 to 2001, Chilkoot Lake was divided into six sections, based on lake area and shape. Before conducting a survey, one orthogonal transect was randomly chosen within each section to survey. Thus, location of transects were changed annually. These cross-lake transects started and ended at a depth of 10 m and each transect was surveyed twice (repeated measures).

The sampling protocol was altered in 2002. Chilkoot Lake was still divided into six sections, based on lake area and shape. Ten evenly spaced orthogonal transects were identified within each section and two transects in each lake section were randomly selected to be surveyed. Transects selected in 2002 became permanent and were to be repeated in all future surveys. By surveying the same transects each year, we were more likely to recognize trends in annual population size. This altered transect sampling protocol was used from 2002 to the present (2005).

The field crew consisted of two people who specialized in hydroacoustic surveys, and who sampled lakes throughout Southeast Alaska. Surveys were generally carried out over one or two nights. The crew surveyed each selected transect from shore to shore, beginning and ending the sampling at the depth of 10 m. Hydroacoustic sampling was conducted during the darkest part of the night. The crew tried to maintain a constant boat speed of about 2.0 m sec^{-1} for all transects. The acoustic equipment consisted of a Biosonics[a] DT-4000™ scientific echo sounder (420 kHz, 6° single beam transducer); Biosonics Visual Acquisition © version 4.0.2 software collected and recorded the data in electronic format. The ping rate was set at 5 pings sec^{-1} and pulse width at 0.4 ms. Only target strengths ranging between –40 dB to –68 dB were recorded, because this range represents fish within the size range of juvenile sockeye salmon and other small pelagic fish.

In conjunction with the hydroacoustic surveys, the crew conducted midwater trawl sampling, to estimate the species composition of pelagic fish and the age distribution of sockeye fry. The sampling equipment consisted of a 2 m x 2 m elongated beam-trawl net with a cod-end for the trawl sampling. The crew deployed the beam-trawl in the area of the lake with the highest concentration of fish, as identified during the hydroacoustic survey. The first tow occurred at the surface, to determine whether fish were present on the surface, which had not been detected by the down-looking hydroacoustic gear. To make a surface tow, the crew attached floats to the top of the tow net, such that it floated just beneath the lake surface 30 m astern of the boat. The crew then removed the floats, and conducted additional tows at two depths previously identified during the hydroacoustic survey as being within the volume of highest fish concentrations. At each depth, the crew conducted two replicate tows. The second tow at a given depth was started

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[a] Product names used in this publication are included for scientific completeness but do not constitute product endorsement.

at the termination point of the first tow. The crew selected the direction of the second tow for each depth, so that that the volumes sampled in each tow were completely separate. The trawl duration ranged from 15 to 30 minutes, depending on fish density as well as lake size and morphology. If warranted, a second complete set of tows was conducted in a morphologically distinct section of the lake and in a second area of high fish densities.

All adult fish caught in the midwater trawl were identified, counted, and released. All small fish from the trawl net were euthanized with MS 222, and preserved with 90% alcohol. Samples from individual tows were kept in separate bottles. Bottle labels included the date, lake name, tow number, tow depth, time of tow, and initials of collectors. The crew brought the tow samples to the laboratory, and identified the preserved fish by species and (for sockeye salmon) by age, to develop species composition of samples, and age distribution of sockeye juveniles. The species composition of the midwater trawl samples was applied to the total target estimate to calculate each species-specific population. The sockeye fry density for the entire lake was also calculated from the species composition of the trawl samples.

Laboratory

In the laboratory, technicians soaked preserved fish in water for 60 minutes to re-hydrate the samples. Technicians then identified each fish to species, measured the snout-fork length (to the nearest millimeter) and weighed it (to the nearest 0.1 gram). All sockeye salmon fry smaller than 50 mm were assumed to be age-0. Technicians collected scales from sockeye fry over 50 mm long, and mounted the scales onto a microscope slide. Sockeye fry scales on slides were examined through a Carton microscope with a video monitor and aged using methods outlined in Mosher (1968). Two trained technicians aged each slide independently. The lab technicians then compared the age determinations for each slide. If the technicians had aged a specific slide differently, a third independent examination was conducted on that slide. The relative proportion of sockeye fry in each age class was used to allocate the hydroacoustic estimates of sockeye fry by age.

Data Analysis

The biologist in charge of hydroacoustic surveys generated a fish density (targets m^{-2}) for each transect, using echo integration methods (MacLennand and Simmonds 1992). Data were analyzed using Biosonics Visual Analyzer© version 4.0.2 software. A mean target density for each sample section was calculated as the average of the two replicate transects. The mean target density for the whole lake was calculated as a weighted average of target density per section, with the area of each section as the weights. A target estimate for each of the sample sections was calculated as the product of the mean target density and the surface area of each of the sample sections. Summing the section estimates generated a total target estimate for the whole lake. The variance of this total target estimate was calculated based on 1 degree of freedom estimates for each pair of transects in each section. Because each section was sampled independently from other sections, the estimated sampling variance for the whole lake estimate was calculated as the sum of the target estimate variances for each section. Sampling error for the estimate of total targets for the whole lake was measured and reported using coefficient of variation (CV; Sokal and Rohlf 1981).

Apportionment of targets into species composition changed between 2001 and 2004, and continues to be revised. Because of small sample sizes and clumped distributions, accurate estimates of proportions by species were often difficult or impossible to obtain. The methods used in 2002 were equivalent to those documented for Klawock Lake in 2002 (Cartwright and

Lewis 2004) and for Hetta Lake in 2002 (Lewis and Cartwright 2004). The methods used in 2003 were equivalent to those documented for Thoms, Salmon Bay and Luck Lakes in 2003 (Cartwright et al. 2006), and for Klawock in 2003 (Cartwright et al. *In prep*).

RESULTS

LIMNOLOGICAL ASSESSMENT

Morphometry and Physical Environment

Chilkoot Lake has a mean depth (Z) of 55 m, and a maximum depth of 89 m (Z_x; Tables 2 to 4). The Z:Z_x ratio is greater than 0.5, which is common for many fjord-type lakes (Wetzel 2001). The depth-area plot for Chilkoot Lake (Figure 4) is typical of a deep lake with a small littoral zone. In the depth-volume plot (Figure 5), about 50% of the volume of the lake is below a depth of 33 m. The hypsometric and depth-volume plots are consistent with oligotrophic lakes (Wetzel 2001).

In all years of the study (2001 to 2004), Chilkoot Lake was quite clear at the first visit of the season, with light extinction coefficients (K_d) of less than 0.50 m $^{-1}$ (Table 5). As the summer progressed, the light extinction coefficients became larger, and the euphotic zone depths (EZD) became smaller. For 2001 and 2002, the changes over the summer were fairly comparable (Figure 6). Over 20% of the lake volume was within the EZD in May of 2001 and of 2002 ((Figure 7). The smallest EZD for the 2001 and 2002 seasons was about 4 m in August, with a corresponding lake volume within the EZD of about 7%. In 2003, the EZD dropped by $^2/_3$ between May and June. The August EZD was less than ½ that of 2001 and 2002, the corresponding percentage of lake volume within EZD was about 2.5%. In 2004, the May EZD was about $^2/_3$ that of 2001 to 2003, and continued to drop. The 2004 EZD for August was slightly higher than for 2003. However, the decrease in EZD continued into September; EZD increased only slightly in late October.

Chilkoot Lake developed thermoclines over all summers of the study, but the depth and duration varied between years. In 2001 and 2002, Chilkoot Lake developed a weak thermocline in July and August, at 1 to 2 meters depths (Figure 8). In 2004, the lake had developed a thermocline in late May or early June, which appeared to last well into September. The surface temperature in June 2004 was the highest recorded for either the present study (2001-2004), or the previous one (1987-1991; Barto 1995).

Water and Nutrient Chemistry

Chilkoot Lake is slightly acidic, with pH values of about 6, and poorly buffered with total alkalinity ranging from 6–11 mgL^{-1} (Tables 6 to 8). The small conductivity values (23–50 µmhos cm^{-1}) are evidence that the lake has low ion content (total dissolved inorganic chemicals; Ryder 1965). The similar conductivity measurements between the epilimnion and hypolimnion in May (for 2001–2003) is indicative of complete vertical mixing of the water column at that time (Appendices A1 to A4 for 2001, Appendices A5 to A7 for 2002, Appendices A8 to A11 for 2003). There is very little organic (humic) stain in Chilkoot Lake; color values ranged between 4–6 Pt units at the 1 meter depth. At the 50 meter depth, Pt units ranged from 4 to 13, and annual mean by site ranged from 5.5 to 7.2 between 2001 and 2003. Concentrations of reactive silicon (RSI) ranged from 880 µgm L^{-1} to 1,650 µgm L^{-1}, and were not considered low enough to inhibit phytoplankton (diatom) production (Wetzel 2001).

Turbidity values were lowest in May; about 1 NTU in all years (Appendices A1–A12). Over the summer, turbidity in the epilimnion (1 m) increased, reaching a peak of 12.9 NTU in August of 2001, 11.1 NTU in September of 2002, and 47.5 NTU in August of 2003. In 2003, the June epilimnetic turbidity had already surpassed the peak turbidities for 2001 and 2002. Iron concentrations in the epilimnion fluctuated in concert with turbidity.

The largest seasonal range in total nitrogen concentrations in the Chilkoot Lake epilimnion (1 m) occurred in 2001, from 47 µgm L^{-1} to 143 µgm L^{-1} (Figure 9). The ranges for 2002 and 2003 were 62–122 µgm L^{-1} and 78–136 µgm L^{-1}, respectively. In 2001 and 2002, nitrate concentrations decreased from May to August, and then began to rise. In 2003, the lowest nitrate concentrations occurred in July. The difference between highest and lowest nitrate levels was 74 µgm L^{-1} for 2001 and 2002, and 54 µgm L^{-1} in 2003.

Total epilimnetic phosphorus concentrations (TP) in May were roughly equal for all years (2001–2003), then increased over the summer (Appendices A1–A12). The increase was successively higher for each year. Total phosphorus concentrations increased by 248% in 2001, by 326% in 2002, and by 937% in 2003 (Figure 10). Mean TN:TP ratios in the epilimnion ranged from a low of 59:1 in May of 2001 to a high of 3:1 in August of 2003. The increases occurred in the fraction of TP in particulate form, which is unavailable for uptake by zooplankton. Total filterable phosphorus (TFP) and filterable reactive phosphorus (FRP) did not fluctuate in concert with total phosphorus.

Chlorophyll

The mean epilimnetic chlorophyll *α* concentrations for Chilkoot Lake for May to October were 1.6 µgm L^{-1} in 2001, 1.4 µgm L^{-1} in 2002, and 0.7 µgm L^{-1} in 2003 (Appendices B1–B3). The highest epilimnetic concentration in the study was 3.4 µgm L^{-1}, which occurred in June 2001. The trends in chlorophyll *α* concentrations were different in each year (Figure 11). The 2003 trends in chlorophyll *α* concentrations were substantially different from 2001 and 2002, with a very low initial chlorophyll *α* concentration, a peak in July, and essentially no change in concentration between August and October. The 2003 chlorophyll *α* concentrations at 1 m depth were somewhat similar to 2001 and 2002; concentrations at the mid-euphotic zone and the 1% light level were much more divergent. Chlorophyll *α* concentrations varied considerably, both horizontally (between sites) and vertically, for all years studied. The overall mean chlorophyll *α* concentration for 2003 was 63% less than that of 2001, and 53% less than that 2002.

Organic Particulates

In Chilkoot Lake, particulate organic carbon (POC) concentrations tracked that of chlorophyll *α* (chl *α*) concentrations (R^2= 0.93; chl α= -0.27 + 0.011×*POC*, P<<0.01). Removal of an outlier did not substantially change the regression equation or the R^2 value (R^2= 0.85; chl α= -0.16 + 0.010×*POC*, P<<0.01). This relationship is indicative of autochthonous loading of particulate carbon (Edmundson et al. 1998), namely that particulate organic carbon comes from within the lake, instead of being washed in from the watershed.

Zooplankton Species, Composition, and Density

The macrozooplankton community in Chilkoot Lake was composed almost exclusively of *Cyclops* copepods. The results of the 2004 zooplankton samples were unusual, in that the densities of *Cyclops* were very high in comparison to previous years. Also, *Bosmina* and *Daphnia* were found in most of the zooplankton samples (Table 9). Prior to 2004, *Bosmina* had been found in 1 of 4 samples taken in July 2001; *Daphnia* had never been found.

For all years in the study, mean zooplankton densities were highest in May, and generally decreased from month to month (Figure 12; Table 10). In 2001 and 2002, mean zooplankton densities became low (<50,000 m^{-2}) in August. The 2003 zooplankton density decreased to this level in June. The estimated 2004 zooplankton density did not approach 50,000 m^{-2} until late October. A lot of spatial heterogeneity existed between stations; densities sometimes varied by more than 100% between sampling stations on a given date. The sampling station with the highest zooplankton densities usually changed from month to month.

Temporal trends in zooplankton biomass were different for each year of the study (Figure 13). The average lengths for *Cyclops* in 2004 were smaller than for previous years (Table 11 and 12), and influenced the biomass calculations. The 2003 biomass estimates were either lowest, or second lowest between May and September.

ASSESSMENT OF JUVENILE SOCKEYE FRY

The range of Chilkoot Lake hydroacoustic estimates of small fish targets from 2002 to 2004 was smaller than the estimates generated using the first sample design from 1987 to 2001, and from 1987 to 1991 (Figure 14).

The hydroacoustics field crew collected small fish by deploying a trawl net in tandem with hydroacoustic surveys, to apportion the targets by species of pelagic fish (Table 13). In 2001, about 93% of the sockeye population was age-0 fry (27 out of 29 sockeye caught in the trawl samples). In 2002, 2003, and 2004 trawl net samples, 84% of the sockeye fry were age-0 (175 out of 187 sockeye caught). The average lengths for age-0 sockeye fry were 42 mm in 2001, 38 mm in 2002, 40 mm in 2003, and 42 mm in 2004.

DISCUSSION

Oligotrophic lakes in Alaska are classified into 1 of 3 categories: clear, stained and glacial. Each classification has its own range of productivity, with clear lakes usually being the most productive. Because of high loadings of colloidal stain and inorganic silt particles, both stained and glacial lakes exhibit shallower euphotic zones (Koenings and Edmundson 1991), colder water temperature (Edmundson and Mazumder 2002), less algal biomass (Edmundson and Carlson (1998), lower standing stocks of macrozooplankton, as well as producing smaller sized sockeye salmon smolts, compared to clear lakes (Edmundson and Mazumder 2002).

One method of defining lake type is to use turbidity (in NTUs) and color (in Platinum-cobalt units or Pt) to classify a lake (Koenings and Edmundson 1991; Edmundson and Carlson 1998). Clear lakes have color values less than 5 Pt, and turbidity values less than 5 NTU. Glacial lakes are characterized by having color values less than 15 Pt, and turbidity values greater than 5 NTU. Lastly, stained lakes have color values greater than color values above 15 Pt, and turbidity values below 5 NTU. For Chilkoot Lake, the color values were usually between 4 and 6 NTU. Chilkoot Lake turbidity values shift over the course of the growing season, from clear (about 1 NTU in May) to turbid (>5 NTU), usually by middle of July. An average turbidity reading for other glacial lakes in Alaska is 33 NTU (Barto 1995); Chilkoot Lake turbidity readings approached or surpassed these readings in June, July and August of 2003, but remained below 15 NTU in 2001 and 2002.

For most water quality parameters, Chilkoot Lake tended to fall into the intermediate range for Alaskan coastal lakes; nutrient parameters were within levels seen in glacial lakes (Barto 1995).

Increases in iron levels were a direct result of increased glacial runoff, which imports a large amount of particulate iron into the lake. Increases in (inorganic) particulate phosphorus were also a result of increased glacial runoff. Koenings et al. (1989, 1987) concluded that 80% to 90% of the total phosphorus measured in glacial lakes comes from glacial silt.

Hydroacoustic estimates of targets are comprised of actual information about the fish populations, a level of non-sampling error (due to sampling design or equipment), and a level of sampling error (due to the inability to measure entire population). Annual estimates developed from identical sampling protocols often maintain fixed levels of non-sampling error, thereby allowing population trends to become discernable. The hydroacoustic time series for 2002 and 2003, not to mention that of 2004, was too short to highlight population trends. While the 2001 sampling protocol had been in use for more than five years, the practice of annually changing locations of transects introduced extra variability into the estimates, and probably obscured actual changes in fry populations. Therefore, I deemed the hydroacoustic data set to be too unreliable to analyze trends in sockeye fry population size or interactions between the sockeye fry population and zooplankton populations.

The Chilkoot weir counts are probably underestimating the actual sockeye escapement into the lake, and by extension causes underestimates in total adult returns. Mark-recapture estimates are likely more accurate indicators of escapement, but are only available from 1996 to 2004, years after the apparent decline in Chilkoot Lake sockeye production. Although the annual weir counts may have underestimated actual escapement, the underlying trends in abundance are probably correct. Switching from weir counts to mark-recapture in the middle of the time series would have changed the amount of non-sampling error inherent in the annual estimates. I therefore chose to use weir counts, to make valid comparisons between all years.

Chlorophyll α concentrations function as indices of algal biomass. Light penetration and primary production are affected by glacial runoff, whereby increasing glacial runoff increases turbidity and EZD, which in turn decreases primary production (Koenings and Edmundson 1991; Edmundson and Carlson 1998). Not only were chlorophyll α concentrations smaller in 2003 vis-à-vis 2001 and 2002, the percentage of the lake volume suitable for photosynthesis during much of the growing season was at least 50% smaller in 2003.

Two different limnology labs analyzed the Chilkoot Lake zooplankton samples; the Soldotna limnology lab analyzed all samples from 2001 to 2003, and the Kodiak lab analyzed the 2004 samples. I removed the 2004 samples from the analysis, because of the apparent occurrence of *Bosmina* and *Daphnia* and harpactacoid copepod nauplii in the 2004 samples. These organisms were non-existent or nearly so in all prior Chilkoot Lake zooplankton samples. In addition, Chilkoot Lake was highly turbid in 2004; turbid water conditions retard growth of *Bosmina* and *Daphnia* populations (Koenings et al. 1990). The differences between the 2004 results and those of earlier years may have been due to a change in readers, or to a mixup of samples with those from a different lake.

Brood-year interactions may be linking sockeye smolt production in Chilkoot Lake, via the previous cohort's influence on the lake's zooplankton populations. Several experts have hypothesized that heavy grazing on crustacean zooplankton by large fry populations reduces survival of following year classes (Eggers and Rogers 1987; Levy and Wood 1992). In Skilak Lake, the predominant zooplankter is *Cyclops columbianus*, which has a 2-year life cycle. Edmundson et al. (2003) concluded that, for Skilak Lake, emergent fry were feeding on the survivors of the previous year's *Cyclops* cohort; heavy predation by sockeye fry on *Cyclops* in the previous year could reduce food availability for the emergent fry, until *Cyclops* recruitment later in the summer. The analyses of Chilkoot Lake zooplankton samples did not include keying *Cyclops* down to species. If the dominant species of *Cyclops* in Chilkoot Lake has a 2-year life cycle, a large cohort of sockeye fry could substantially reduce zooplankton populations, in turn reducing the survival of the next year's sockeye fry cohort.

Chilkoot Lake zooplankton populations are likely influenced by simultaneous ecological processes operating from the bottom-up (algal biomass) and top-down (predation by planktivorous fishes), as was documented for Skilak Lake (Edmundson et al. 2003). Because of uncertainties in our hydroacoustic surveys, I could not draw any definitive conclusions about the effects of the Chilkoot Lake sockeye fry populations on concurrent zooplankton populations for 2001 to 2004. In 2003, EZD, chlorophyll α concentrations and zooplankton biomass were all substantially reduced from 2001 and 2002.

Chilkoot Lake is in transition between being a clear lake, and being a glacial lake. In the spring, and presumably throughout most of the winter, Chilkoot Lake has values consistent with clear lakes. During the summer, Chilkoot Lake becomes more like a glacial lake, as the glaciers melt and feed water and silt into it. The degree of glacial effects appears to be due to the length and heat of the summer. During hot dry summers, the glacial melting is enhanced, and more silt is deposited into the lake. The silt in turn reduces the volume of the lake that can support photosynthetic activity, thereby reducing the phytoplankton population. Reduced photosynthetic activity produces effects at all trophic levels, from phytoplankton to zooplankton, to sockeye fry, and likely to predators further up the food chain. During cooler rainy summers, the amount of food production appears to increase. Thus, the primary productivity of Chilkoot Lake is very dynamic, for reasons beyond our control.

Most glaciers in northern Southeast Alaska are rapidly receding; melting is outpacing snow deposition. The productivity of Chilkoot Lake may have been reduced from what it was in the 1980s, by an increase in ambient temperature. The limnology time series for Chilkoot Lake is too short to make any definitive conclusions. However, in a long-term study of Skilak Lake on the Kenai Peninsula, Edmundson et al. (2003) concluded that there was a trend of increasing glacier melt and water turbidity, and decreasing EZD, consistent with a general warming pattern in air temperatures.

Besides climate-caused annual differences and a (probable) long-term warming trend, intermediate climatic or ecological processes may overlay the long- and short-term weather effects, and further affect Chilkoot Lake's productivity. Medium-term warming and cooling periods likely exacerbate or mitigate the effects of long-term climatic change on lake productivity. In addition, some intermittent factor appears to retard clearing of the lake water over the winter. In 2001 to 2003, the May EZD was about 12 m to 14 m; the 2004 May EZD was less than 8 m. Barto (1995) documented similar decreases in May EZD between 1987 and 1988, and between 1990 and 1991.

It is very likely that the productivity of Chilkoot Lake for sockeye salmon has been reduced from what it was in the 1980s, because of increased annual silt deposition. Short of embarking on massive engineering projects, we cannot alter silt deposition. Trying to increase productivity by lake fertilization or stocking will almost surely fail; geological forces, not biological forces, are causing the reduction in productivity. If the unprecedented turbidity levels of August and

September of 2003 become the norm, adult sockeye returns to Chilkoot Lake will be substantially lower than those seen between 2001 and 2004, possibly on par with 1995.

The glacial effects to Chilkoot Lake are probably finite, because the glaciers that feed Chilkoot Lake are not connected to an icefield. At some point in the future, these glaciers will likely be completely melted, and Chilkoot Lake will then become a clear lake.

The rapidly changing productivity of Chilkoot Lake presents substantial challenges to management of its sockeye stocks. Ideally, management would alter escapement levels to more closely match production of sockeye fry with the productivity of the lake. Unfortunately, the relevant management decisions must be made 10 to 11 months prior to the climatic events affecting lake productivity. Management biologists currently use a static management strategy in the face of a dynamically changing system. Regular limnological monitoring of Chilkoot Lake can provide insight into relative conditions for phytoplankton and zooplankton populations. Hydroacoustic surveys can provide accurate information about sockeye and other pelagic fish populations. The escapement goals and management strategies should be revisited regularly to bring escapement goals into line with long-term changes in Chilkoot Lake's productivity.

RECOMMENDATIONS

Because of the changing glacial influences on Chilkoot Lake's productivity, some monitoring of limnological conditions will be necessary for making informed management decisions concerning the lake's sockeye stocks. The Haines area management biologist is currently using EZD and zooplankton information to refine some of his management decisions, and for general forecasting of success of sockeye fry populations and adult returns to Chilkoot Lake. At a minimum, ADF&G should be taking zooplankton samples, and monitoring temperature and light levels monthly between ice-out (April or May) and late October or November. To obtain the most useful zooplankton information, we need to ensure that the analysis is done properly, and that we consistently use the same laboratory, so that non-sampling errors remain as fixed as is possible.

Hydroacoustic surveys in Southeast Alaska have suffered from deficiencies in sampling design, inclusions of non-fish targets in pelagic fish abundance estimates, and changing equipment without validating the results with estimates developed using previous equipment. At present, the Haines area management staff views Chilkoot Lake hydroacoustic surveys as useful, and continues to request them. ADF&G should consider continuing annual Chilkoot Lake hydroacoustic surveys for a number of years, and then reevaluate them for usefulness of the information. If sampling design or equipment is changed, ADF&G should conduct simultaneous surveys of the lake using the old and new sampling designs or equipment, so that previous years' estimates can be extrapolated for appropriate comparisons with new estimates. If hydroacoustic surveys are found to produce inaccurate estimates of abundance or trends of abundance, ADF&G should terminate the surveys until the technology improves.

A radical shift in annual Chilkoot Lake EZD trends that becomes stable for a number of years may signal a long-term change in lake productivity. More intensive limnological investigations should be conducted at that time, and escapement goal ranges should also be re-evaluated.

For limnological and hydroacoustic investigations to have value, they must be continued over many years. This is especially true for freshwater lakes that change as much as Chilkoot Lake. The original Chilkoot Lake limnology study (1987-1991) was halted about 2 years into documenting a marked downturn in productivity, a fact not fully appreciated until at least 4 years later. Periodic initiation of these studies in response to declines in adult returns virtually guarantees that the relevant data will not be captured, because of the 3-to-5-year lag time between the freshwater life stage and the return of (most) sockeye adults.

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FIGURES AND TABLES

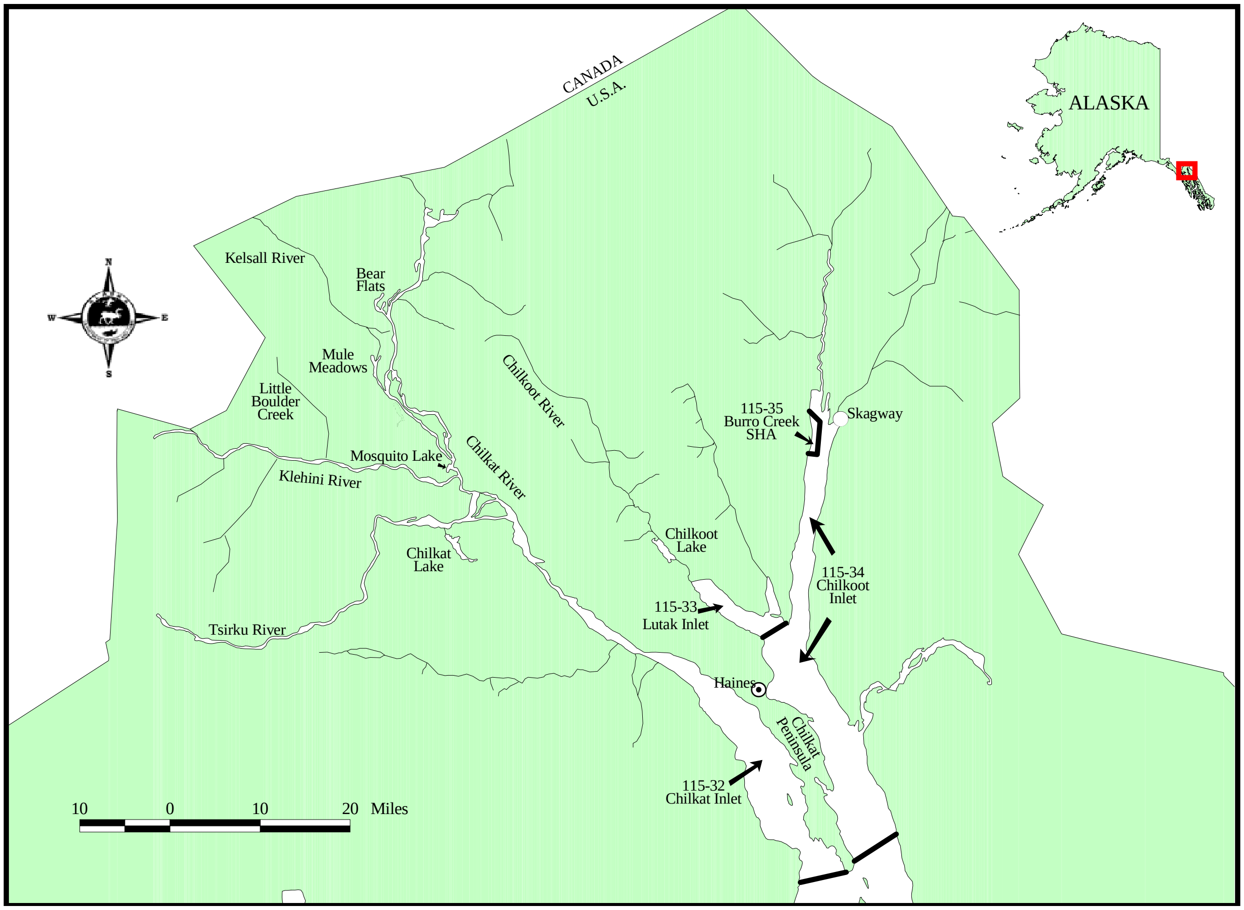

Figure 1.–Map of Upper Lynn Canal, showing fishing sub-districts and major inlet streams.

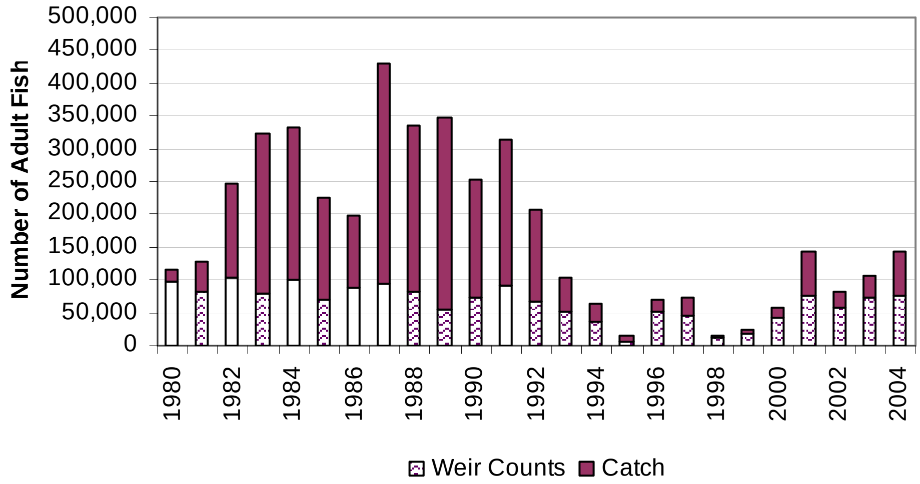

Figure 2.–Estimated total adult sockeye salmon returning to Chilkoot Lake between 1980 and 2004. Returns are separated into fish caught and fish that migrated past Chilkoot weir to spawn.

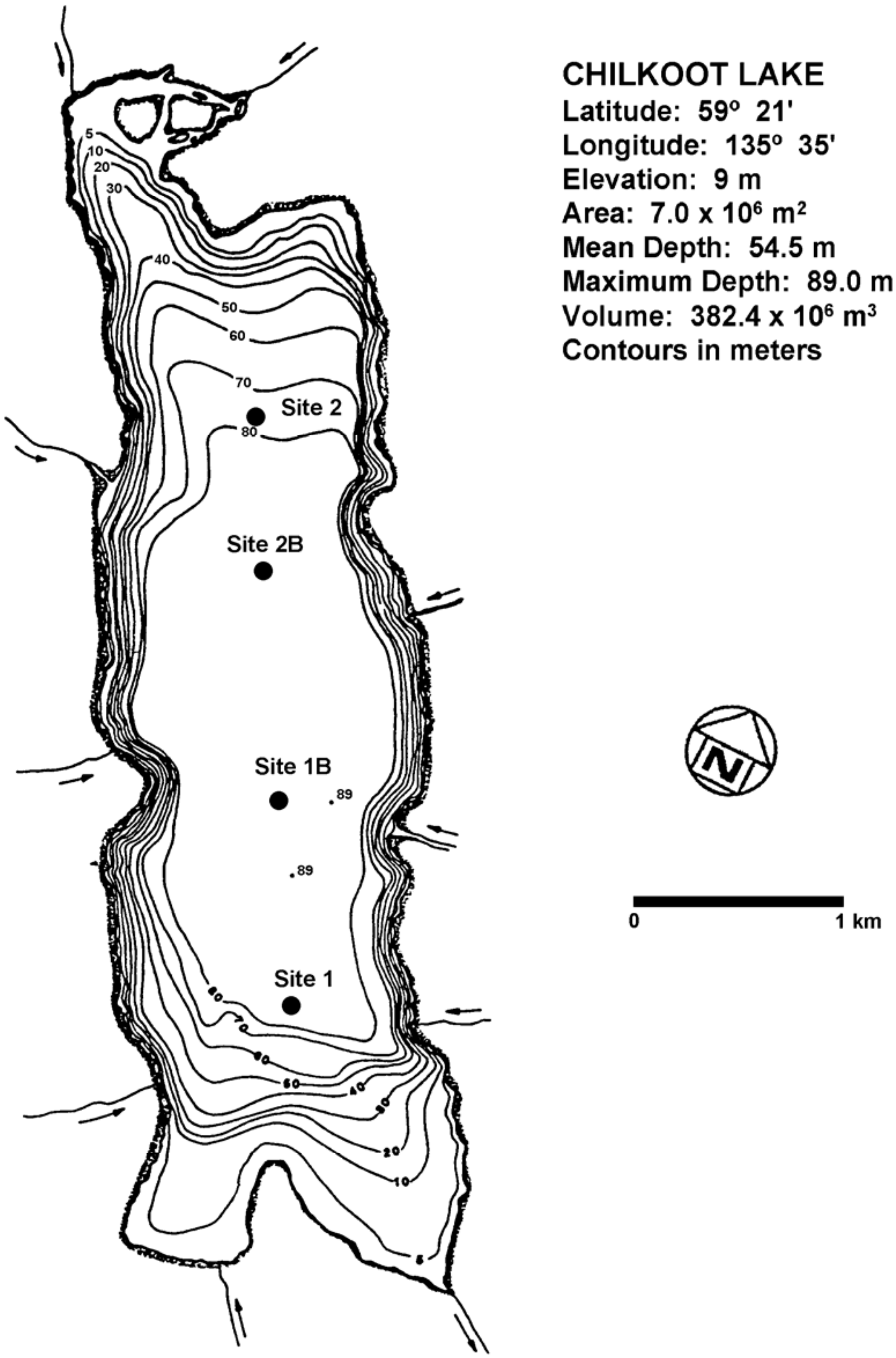

Figure 3.–Bathymetric map of Chilkoot Lake, and location of limnology sampling sites.

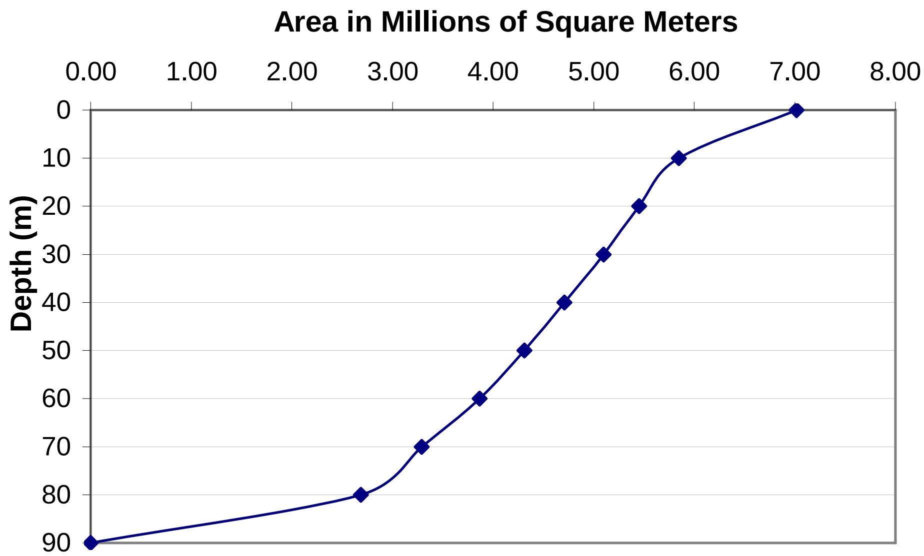

Figure 4.–Hypsometric (depth-area) plot of Chilkoot Lake.

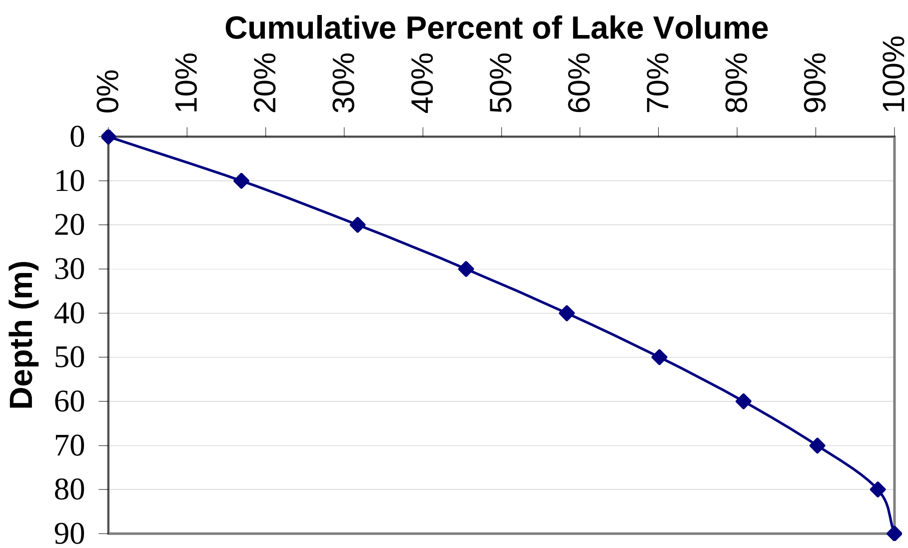

Figure 5.–Depth-volume plot of Chilkoot Lake.

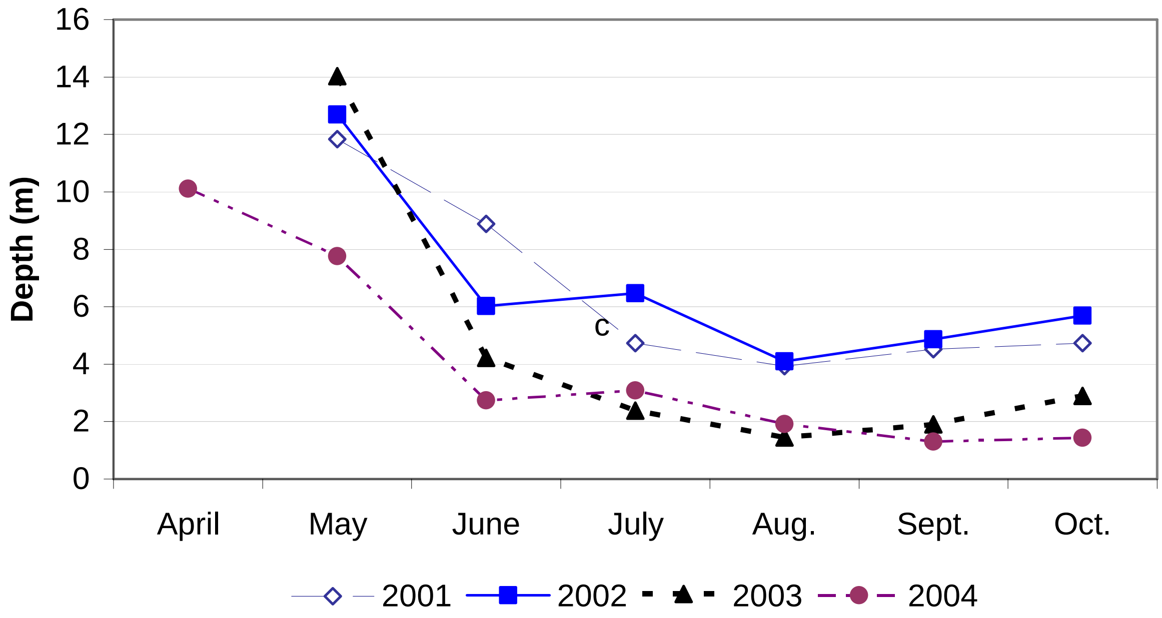

Figure 6.–Euphotic zone depth by month in Chilkoot Lake, between May and October, in years 2001 to 2004.

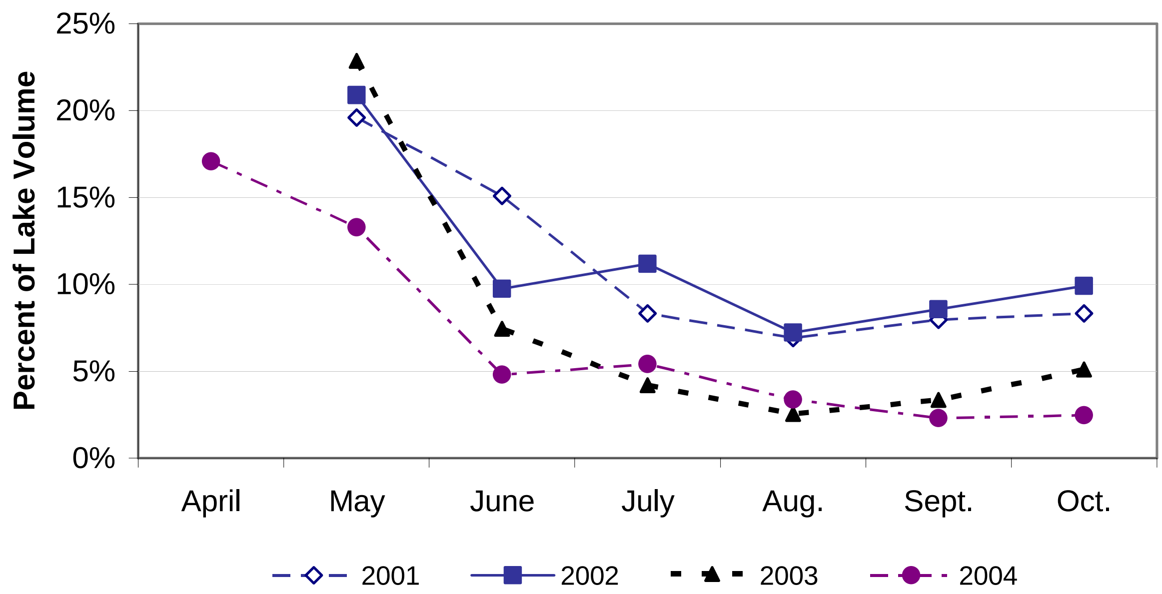

Figure 7.–Estimated percentage of volume of Chilkoot Lake within the euphotic zone depth, by month, between May and October, in years 2001 to 2004.

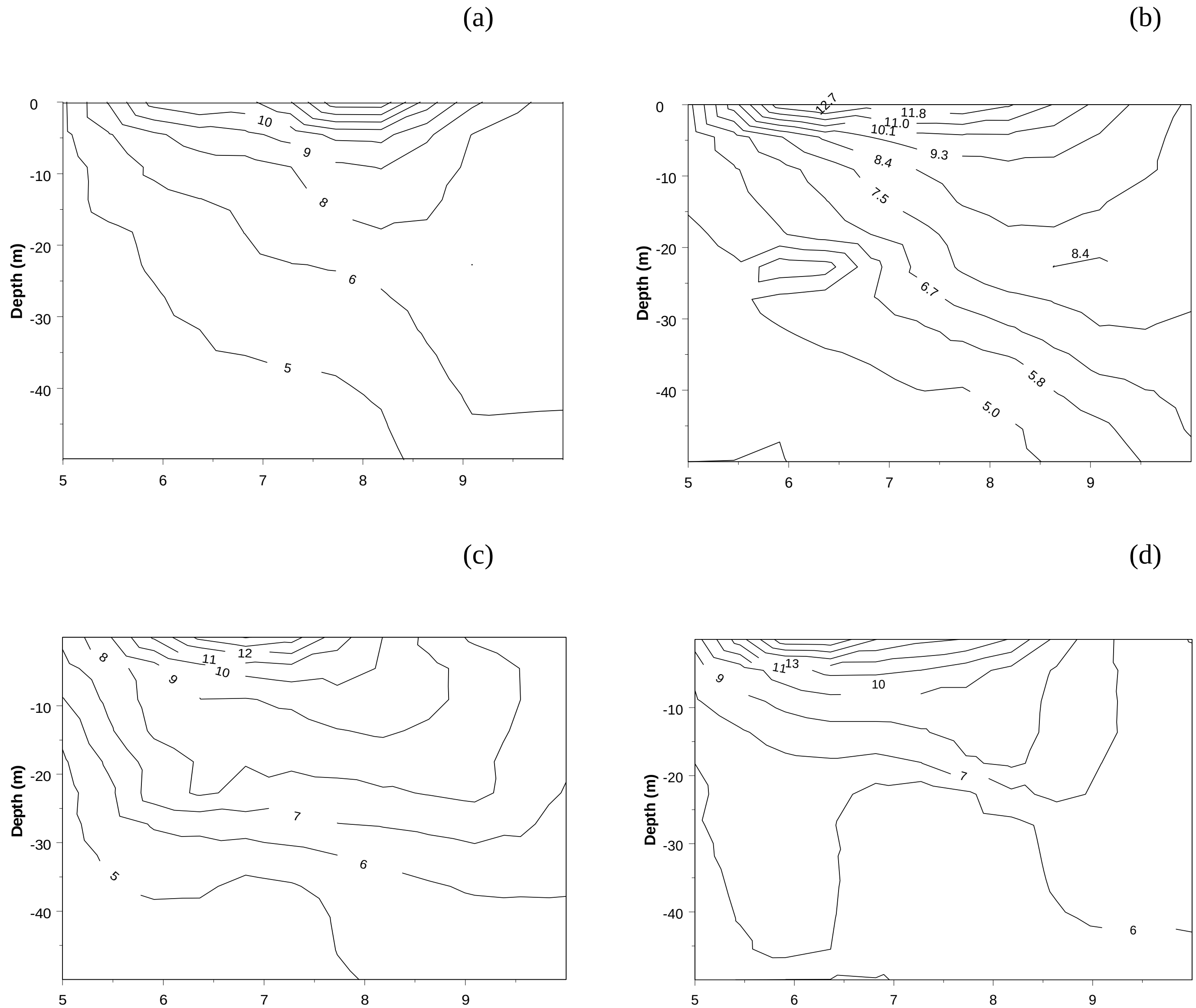

Figure 8.–Depth-time isotherms (ºC) by month for Chilkoot Lake in: (a) 2001, (b) 2002, (c) 2003, (d) 2004. May =5, June=6, July=7, August=8, September=9.

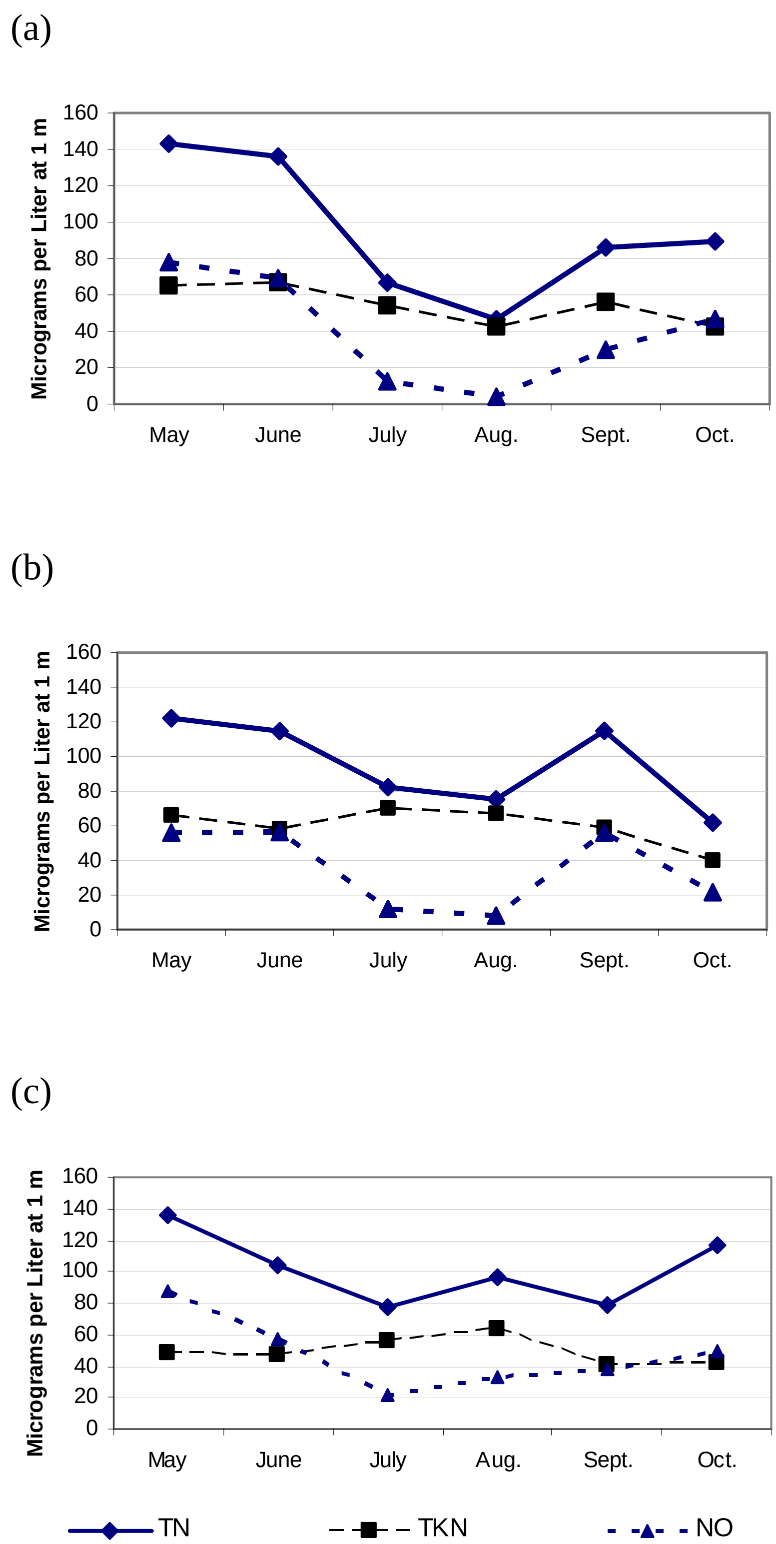

Figure 9.–Seasonal changes in total nitrogen (TN), Kjeldahl (TKN) and nitrate nitrogen (NO) concentrations within the 1-m stratum for Chilkoot Lake in (a) 2001, (b) 2002, and (c) 2003.

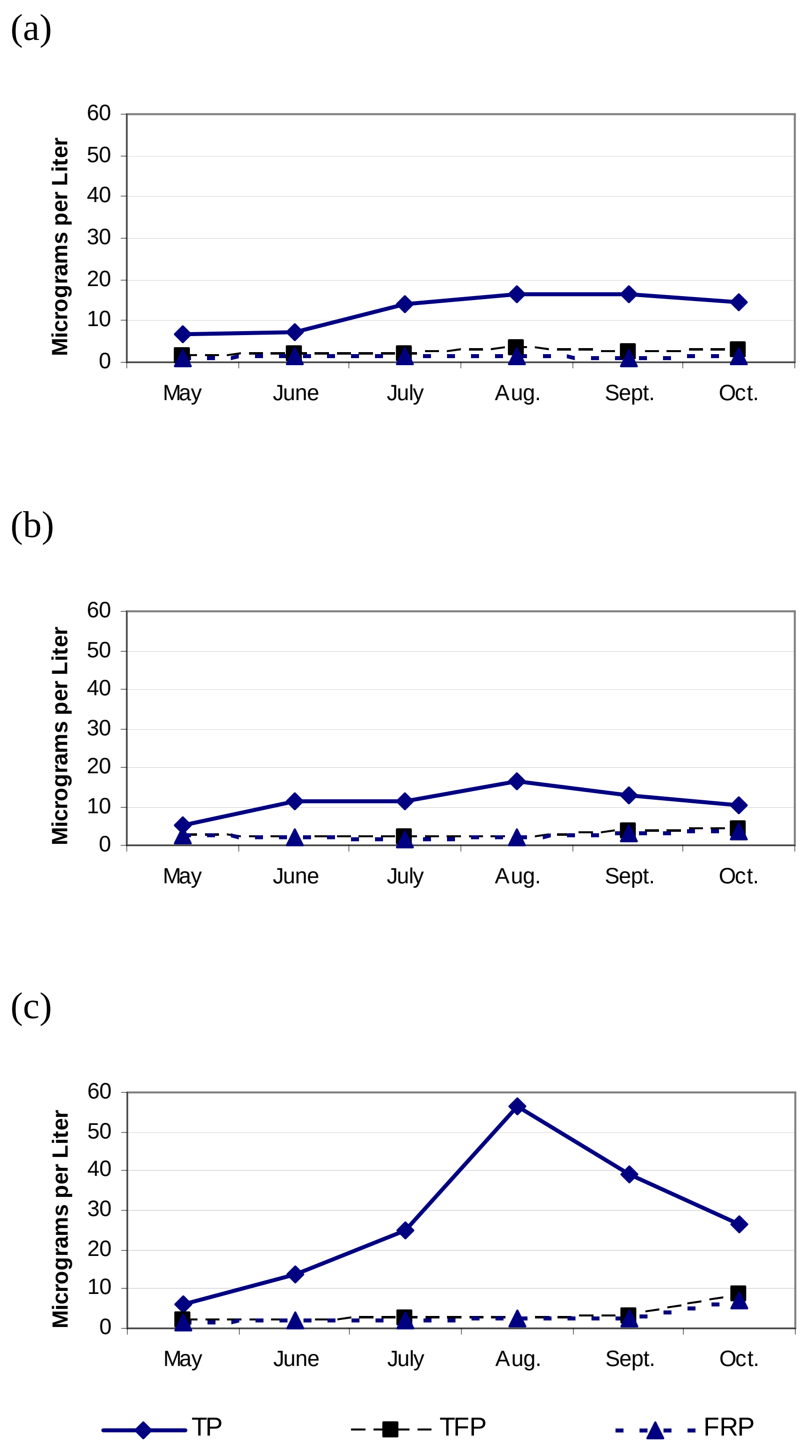

Figure 10.–Seasonal changes in total phosphorus (TP), total filterable phosphorus (TFP), and filterable reactive phosphorus (FRP) concentrations within the 1-m stratum in Chilkoot Lake in (a) 2001, (b) 2002, and (c) 2003.

(a)

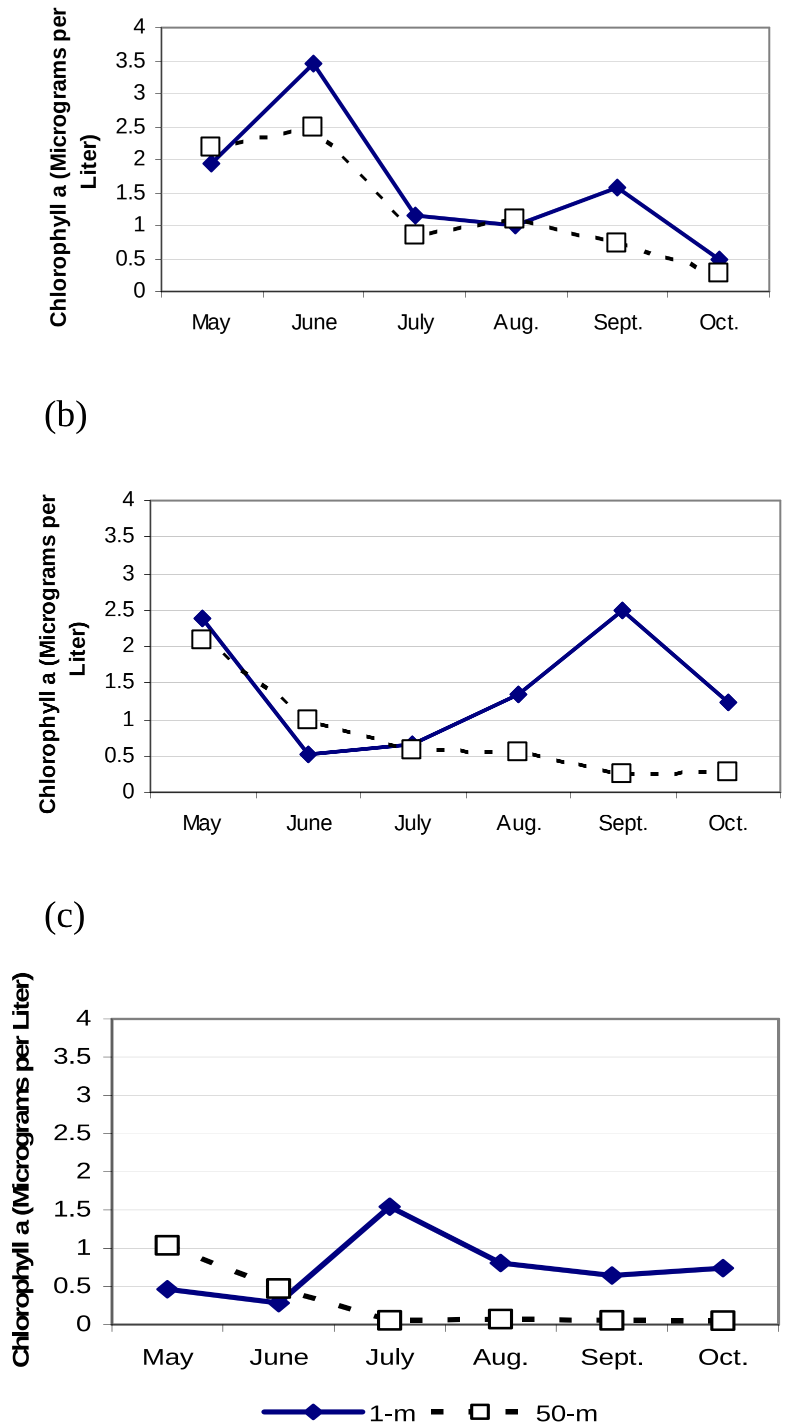

Figure 11.–Seasonal changes in chlorophyll *α* concentrations within the 1-m stratum and 50-m stratum (hypolimnion) in Chilkoot Lake during (a) 2001, (b) 2002, and (c) 2003.

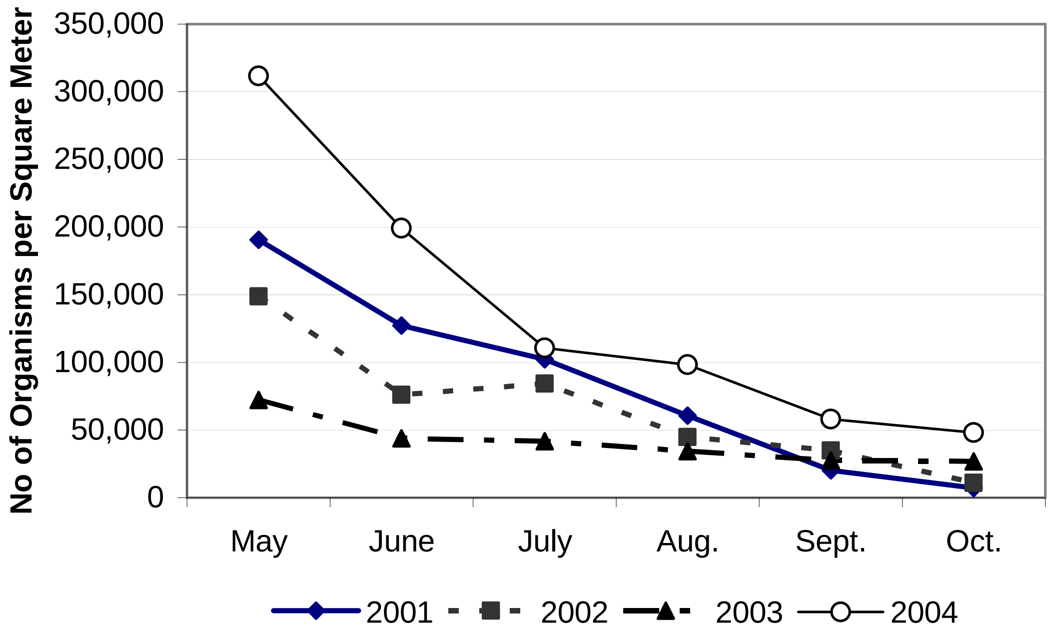

Figure 12.–Seasonal changes in Chilkoot Lake zooplankton density between May and October, 2001 to 2004.

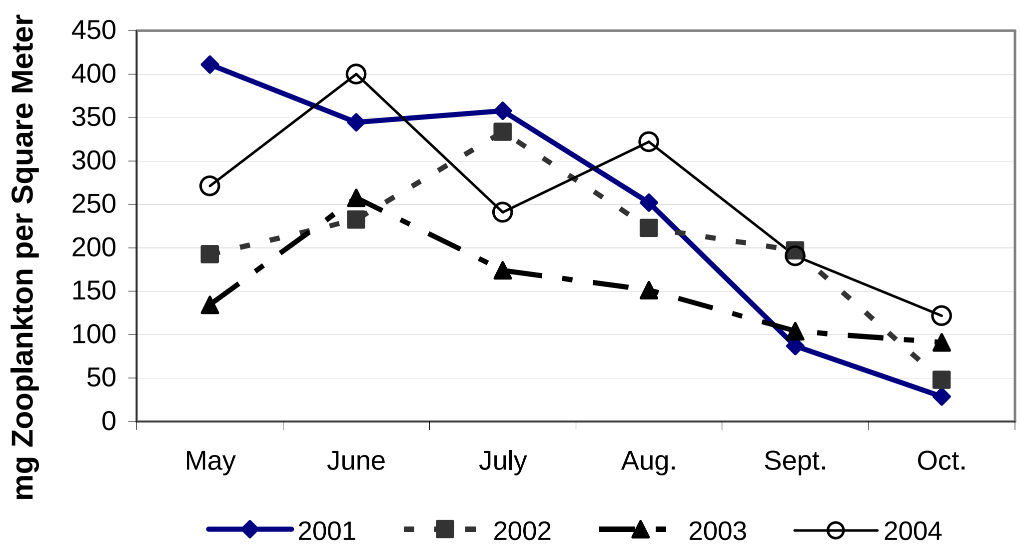

Figure 13.–Seasonal changes in Chilkoot Lake zooplankton weighted biomass between May and October, 2001 to 2004.

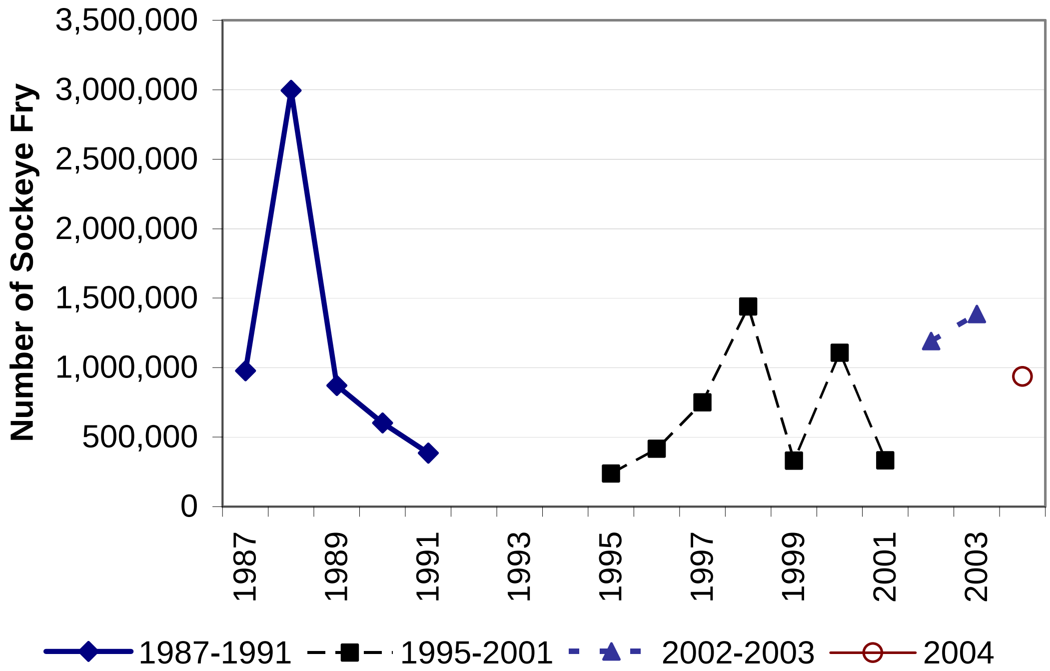

Figure 14.–Estimated abundance of Chilkoot Lake sockeye fry in autumn, as calculated from a series of hydroacoustic surveys conducted from 1987 to 1991, 1995 to 2001, 2002 to 2003, and in 2004.

Table 1.–Estimates of annual escapement, catch, total return, and exploitation rate of returning adult Chilkoot Lake sockeye salmon, from 1980 to 2004.

Year	Weir Counts*	Mark-Recapture Estimates	Catch	Total Return	Estimated Exploitation Rate
1976	71,000		63,000	134,000	46.7%
1977	97,000		113,000	210,000	53.9%
1978	36,000		14,000	50,000	28.7%
1979	96,000		70,000	166,000	42.1%
1980	96,000		21,000	117,000	17.8%
1981	83,000		44,000	127,000	34.4%
1982	103,000		145,000	248,000	58.4%
1983	80,000		242,000	322,000	75.0%
1984	100,000		232,000	332,000	69.8%
1985	69,000		156,000	225,000	69.3%
1986	88,000		110,000	198,000	55.6%
1987	95,000		335,000	430,000	77.9%
1988	81,000		254,000	335,000	75.8%
1989	55,000		292,000	347,000	84.2%
1990	73,000		179,000	252,000	70.9%
1991	91,000		224,000	315,000	71.2%
1992	67,000		141,000	208,000	67.7%
1993	52,000		51,000	103,000	49.8%
1994	37,000		25,000	63,000	40.4%
1995	7,000		8,000	15,000	52.4%
1996	51,000	65,000	19,000	70,000	27.1%
1997	44,000	79,000	29,000	73,000	39.5%
1998	12,000	28,000	2,000	14,000	15.2%
1999	19,000	62,000	4,000	23,000	18.1%
2000	43,000	60,000	15,000	58,000	25.2%
2001	76,000	100,000	67,000	143,000	46.5%
2002	59,000	61,000	24,000	83,000	29.4%
2003	75,000	177,000	32,000	107,000	30.3%
2004	76,000	163,000	66,000	142,000	46.8%

* Weir counts were used in calculating estimates of total return

Table 2.–Descriptive morphometric parameters for Chilkoot Lake.

Morphometric Parameter	Value
Lake Elevation	9 m
Lake Area	702 hectares
Watershed Area	33,160 hectares
Lake Volume	382 million m^3
Mean Depth	55 m
Maximum Depth	89 m
Mean Depth/Maximum Depth	0.62
Shoreline Length	15,360 m
Maximum Length (Fetch)	5,400 m
Maximum Width	1600 m
Shoreline Development	1.64
Volume Development	1.82

Table 3.–Estimated surface area by depth zone for Chilkoot Lake.

Depth Zone (m)	Area by Depth (m^2)	Percent of Surface Area
0	7,019,000	100.0%
5	6,472,000	92.2%
10	5,846,000	83.3%
20	5,454,000	77.7%
30	5,100,000	72.7%
40	4,710,000	67.1%
50	4,311,000	61.4%
60	3,868,000	55.1%
70	3,290,000	46.9%
80	2,686,000	38.3%

Table 4.–Estimated volume by depth zone of Chilkoot Lake.

Depth Zone (m)	Volume by Depth (m^3)	Percent of Total Volume
0-5	33,719,000	8.8%
5-10	30,784,000	8.1%
10-20	56,492,000	14.8%
20-30	52,761,000	13.8%
30-40	49,034,000	12.8%
40-50	45,090,000	11.8%
50-60	40,876,000	10.7%
60-70	35,759,000	9.4%
70-80	29,836,000	7.8%
80-89	8,057,000	2.1%
Total	382,408,000	

Table 5.–Calculated euphotic zone depths and vertical extinction coefficients for sampling sites 1 and 2 on Chilkoot Lake between May and October, from 2001 to 2004.

	Euphotic Zone Depth			Vertical Extinction Coefficient		
Year/ Date	**Site 1**	**Site 2**	**Mean**	**Site 1**	**Site 2**	**Mean by Visit**
2001						
5/17	12.93	10.75	11.84	0.36	0.43	0.39
6/15	8.93	8.84	8.89	0.52	0.52	0.52
7/19	4.48	4.99	4.74	1.03	0.93	0.98
8/17	3.81	4.04	3.93	1.21	1.15	1.18
9/19	4.22	4.83	4.53	1.10	0.96	1.03
10/15	4.66	4.80	4.73	0.99	0.96	0.98
Mean	**6.51**	**6.38**	**6.44**	**0.87**	**0.82**	**0.85**
2002						
5/20	12.72	12.67	12.70	0.36	0.37	0.36
6/17	4.66	7.38	6.02	1.08	0.63	0.85
7/19	6.78	6.16	6.47	0.68	0.75	0.72
8/16	4.08	4.12	4.10	1.13	1.12	1.13
9/16	4.99	4.75	4.87	0.93	0.97	0.95
10/16	5.50	5.88	5.69	0.84	0.79	0.81
Mean	**6.46**	**6.83**	**6.64**	**0.84**	**0.77**	**0.80**
2003						
5/19	13.90	14.15	14.03	0.33	0.33	0.33
6/26	4.28	4.17	4.23	10.78	1.11	5.94
7/14	2.39	2.38	2.39	1.94	1.94	1.94
8/19	1.16	1.73	1.45	4.00	2.67	3.33
9/19	1.95	1.86	1.91	2.37	2.49	2.43
10/14	3.01	2.78	2.90	1.54	1.66	1.60
Mean	**4.45**	**4.51**	**4.48**	**3.49**	**1.70**	**2.60**
2004						
4/27	10.45	9.78	10.12	0.44	0.47	0.46
5/27	8.16		8.16	0.57	0.63	0.60
6/25	2.41	3.06	2.74	1.91	1.51	1.71
7/23	2.29	3.87	3.08	2.02	1.19	1.61
8/26	2.00	1.83	1.92	2.31	5.52	3.92
9/29	1.29	1.32	1.31	3.57	3.49	3.53
10/21	1.28	1.60	1.44	3.60	2.89	3.25
Mean	**3.98**	**3.58**	**4.48**	**2.06**	**2.24**	**2.60**

Table 6.–Seasonal mean values for general water quality parameters, metal concentrations, nutrient concentrations, and atom ratios for samples collected at 2 sites, monthly from May to November, at depths of 1 m and 50 m from Chilkoot Lake in 2001.

	at 1 Meter Depth			at 50 Meter Depth			Grand
Analysis Type	**Site 1**	**Site 2**	**Mean**	**Site 1**	**Site 2**	**Mean**	**Mean**
Conductivity (umhos/cm)	33	33	33	42	42	42	30
pH	6.4	6.3	6.4	6.3	6.4	6.3	6.4
Alkalinity (mg/l as Calcium Carbonate)	7.2	6.5	6.8	8.5	8.3	8.4	6.1
Turbidity (NTU)	7.3	6.8	7.0	5.2	4.7	4.9	4.8
Color (Pt units)	4.8	4.7	4.8	7.2	5.5	6.3	4.4
Calcium (mg/L)	4.5	4.5	4.5	5.7	5.6	5.7	4.1
Magnesium (mg/L)	0.4	0.4	0.4	0.4	0.5	0.4	0.3
Iron (ug/L)	163	102	133	98	93	96	91
Total Phosphorus (ug/L)	12.8	12.3	12.5	9.9	9.4	9.7	8.9
Total Filterable Phosphorus (ug/L)	2.5	2.1	2.3	3.0	2.2	2.6	1.9
Filterable Reactive Phosphorus (ug/L)	1.3	1.2	1.3	2.4	1.4	1.9	1.3
Total Kjeldahl Nitrogen (ug/L)	53.1	56.9	55.0	45.6	52.2	48.9	41.6
Ammonia (ug/L)	14.8	8.9	11.9	10.9	10.9	10.9	9.1
Nitrate plus Nitrite (ug/L)	40.8	38.5	39.6	84.2	52.4	68.3	43
Reactive Silicon (ug/L)	1,220	1,214	1,217	1,535	1,505	1,520	1095
Particulate Carbon (ug/L)	212	213	212	133	121	127	136
Nitrogen:Phosphorus Ratio	21:1	24:1	23:1	36:1	31:1	34:1	28:1

Table 7.–Seasonal mean values for general water quality parameters, metal concentrations, nutrient concentrations, and atom ratios for samples collected at 2 sites, monthly from May to November, at depths of 1 m and 50 m from Chilkoot Lake in 2002.

	at 1 Meter Depth			at 50 Meter Depth			Grand
Analysis Type	**Site 1**	**Site 2**	**Mean**	**Site 1**	**Site 2**	**Mean**	**Mean**
Conductivity (umhos/cm)	31	30	31	43	39	41	36
pH	6.4	6.3	6.3	6.4	6.3	6.3	6.3
Alkalinity (mg/l as Calcium Carbonate)	8.1	7.4	7.7	10.3	9.0	9.6	8.7
Turbidity (NTU)	6.6	6.3	6.4	3.0	4.2	3.6	5.0
Color (Pt units)	6.0	4.2	5.1	7.0	5.5	6.3	5.7
Calcium (mg/L)	4.4	4.5	4.4	6.0	5.5	5.8	5.1
Magnesium (mg/L)	0.6	0.6	0.6	0.7	0.7	0.7	0.6
Iron (ug/L)	176	170	173	98	132	115	144
Total Phosphorus (ug/L)	10.9	11.3	11.1	7.2	10.7	8.9	10.0
Total Filterable Phosphorus (ug/L)	3.2	2.5	2.8	2.9	2.6	2.8	2.8
Filterable Reactive Phosphorus (ug/L)	2.7	2.2	2.5	2.5	2.5	2.5	2.5
Total Kjeldahl Nitrogen (ug/L)	56.8	63.6	60.2	42.0	51.6	46.8	53.5
Ammonia (ug/L)	3.7	1.6	2.7	5.4	4.6	5.0	3.8
Nitrate plus Nitrite (ug/L)	46.9	22.9	34.9	62.3	67.1	64.7	49.8
Reactive Silicon (ug/L)	1,284	1,262	1,273	1,611	1,554	1,582	1,428
Particulate Carbon (ug/L)	168	141	154	80	100	90	122
Nitrogen:Phosphorus Ratio	24:1	22:1	23:1	42:1	32:1	37:1	30:1

Table 8.–Seasonal mean values for general water quality parameters, metal concentrations, nutrient concentrations, and atom ratios for samples collected at 2 sites, monthly from May to November, at depths of 1 m and 50 m from Chilkoot Lake in 2003.

		at 1 Meter Depth			at 50 Meter Depth			Grand
Analysis Type		**Site 1**	**Site 2**	**Mean**	**Site 1**	**Site 2**	**Mean**	**Mean**
Conductivity (umhos/cm)		33	33	33	45	46	45	39
pH			6.1	6.2	6.0	6.0	6.0	6.1
Alkalinity (mg/l as Calcium Carbonate)			7.2	8.0	8.9	10.0	9.4	8.7
Turbidity (NTU)	6.3		23.8	23.7	10.7	8.5	9.6	16.6
Color (Pt units)	8.7		4.7	5.2	7.0	5.5	6.3	5.7
Calcium (mg/L)	23.6		4.5	4.6	6.3	6.4	6.3	5.4
Magnesium (mg/L)	5.7		0.4	0.4	0.4	0.4	0.4	0.4
Iron (ug/L)	4.6		356	347	126	113	120	233
Total Phosphorus (ug/L)	0.5		27.6	27.7	20.0	13.5	16.7	22.2
Total Filterable Phosphorus (ug/L)	339		3.2	3.5	4.3	3.4	3.8	3.7
Filterable Reactive Phosphorus (ug/L)	27.9		2.4	2.9	3.3	2.5	2.9	2.9
Total Kjeldahl Nitrogen (ug/L)	3.9		48.3	52.6	44.3	40.3	42.3	47.4
Ammonia (ug/L)	3.3	9.0	7.0	8.0	9.0	6.6	7.8	7.9
Nitrate plus Nitrite (ug/L)	56.9	50.3	47.8	49.1	100.0	100.4	100.2	74.6
Reactive Silicon (ug/L)		1,398	1,377	1,387	1,753	1,774	1,763	1,575
Particulate Carbon (ug/L)		99	111	105	43	58	51	78
Nitrogen:Phosphorus Ratio		19:1	12:1	16:1	31:1	32:1	31:1	23:1

Table 9.–Estimated zooplankton densities in number m^{-2} by site, by collection date, and by species, from samples collected at Chilkoot Lake in 2004. Zero density denotes at least 1 organism counted during the analysis.

Site / Date	4/27	5/27	6/25	7/23	8/26	9/29	10/21	Mean by Site
Site 1								
Cyclops sp	219,307	151,129	55,698	102,565	47,971	37,443	61,979	**96,585**
Bosmina sp.	0	0	0	212	0	0	0	**30**
Site 1B								
Cyclops sp	349,466	214,638	77,942	115,129	44,575	44,575	29,675	**125,143**
Bosmina sp.	0	0	0	340	0	0	0	**49**
Site 2B								
Cyclops sp	361,691	321,617	240,788	78,197	104,176	83,800	23,349	**173,374**
Bosmina sp.	0	0	0	0	0	127	0	**18**
Daphnia longiremis	0	0	0	0	0	127	0	**18**
Site 2								
Cyclops sp	359,314	129,733	82,528	153,846	41,901	75,268	52,641	**127,890**
Bosmina sp.	0	0	0	0	382	0	0	**55**
Mean by Date	**143,309**	**90,791**	**50,773**	**50,032**	**26,556**	**26,816**	**18,627**	**58,129**

Table 10.–Estimated zooplankton densities in number m^{-2} by site, and by collection date, from samples collected at Chilkoot Lake from 2001 to 2004.

Year/ Date	Site 1	Site 1B	Site 2B	Site 2	Mean by Visit
2001					
5/17	212,430	127,356	211,156	211,411	190,588
6/15	284,004	102,012	70,428	52,046	127,123
7/19	100,527	122,601	129,394	56,291	102,203
8/17	51,282	58,499	79,640	52,641	60,516
9/19	12,651	25,267	25,174	17,116	20,052
10/15	8,592	7,438	5,349	7,217	7,149
Annual Mean	**111,581**	**73,862**	**86,857**	**66,120**	**84,605**
2002					
5/20	130,820	243,165	120,530	100,442	148,739
6/17	70,504	128,375	40,075	65,614	76,142
7/19	65,122	91,187	109,696	71,659	84,416
8/16	41,162	41,348	49,924	46,459	44,723
9/16	38,717	24,588	36,068	39,990	34,841
10/16	9,781	9,848	14,468	11,343	11,360
Annual Mean	**59,351**	**89,752**	**61,794**	**55,918**	**66,704**
2003					
5/19	42,078	67,584	100,696	78,146	72,126
6/26	49,924	40,041	--	85,243	58,403
7/14	39,328	31,686	36,678	59,093	41,696
8/19	44,014	31,652	25,539	36,169	34,344
9/19	26,490	31,992	27,237	2,377	22,024
10/14	29,886	25,675	33,724	17,423	26,677
Annual Mean	**38,620**	**38,105**	**44,775**	**46,409**	**41,977**
2004					
4/27	219,307	349,466	361,691	359,314	322,445
5/27	151,129	214,638	321,617	129,733	204,279
6/25	55,698	77,942	240,788	82,528	114,239
7/23	102,565	77,942	78,197	153,846	103,138
8/26	48,183	115,469	104,176	42,286	77,529
9/29	37,443	44,575	85,054	75,268	60,585
10/21	61,979	29,675	23,349	52,641	41,911
Annual Mean	**96,615**	**129,958**	**173,553**	**127,945**	**132,018**

Table 11.–Average length in mm of non-ovigerous *Cyclops* by site and collection date, from zooplankton samples collected at Chilkoot Lake, from 2001 to 2004.

Year/ Date	Site 1	Site 1B	Site 2B	Site 2	Mean by Visit
2001					
5/17	0.90	0.70	0.72	0.78	0.78
6/15	0.89	0.84	0.86	0.89	0.87
7/19	0.99	1.06	0.90	1.01	0.99
8/17	1.05	1.01	1.09	0.98	1.03
9/19	1.07	1.12	1.11	1.04	1.09
10/15	1.02	1.01	1.08	1.05	1.04
Length	**0.99**	**0.96**	**0.96**	**0.96**	**0.97**
Weighted Length	**0.92**	**0.88**	**0.84**	**0.85**	**0.87**
2002					
5/20	0.64	0.57	0.68	0.65	0.64
6/17	0.94	0.92	0.89	0.97	0.93
7/19	1.06	1.06	0.99	1.05	1.04
8/16	1.19	1.13	1.06	1.10	1.12
9/16	1.26	1.19	1.21	1.20	1.22
10/16	1.09	1.07	0.9	1.07	1.03
Length	**1.03**	**0.99**	**0.96**	**1.01**	**1.00**
Weighted Length	**0.86**	**0.79**	**0.89**	**0.87**	**0.85**
2003					
5/19	0.81	0.74	0.71	0.72	0.75
6/26	1.09	1.01		1.13	1.08
7/14	1.00	1.00	1.07	1.09	1.04
8/19	0.95	0.90	0.85	0.96	0.92
9/19	0.86	0.92	0.77	0.83	0.85
10/14	0.82	0.97	0.88	0.94	0.90
Length	**0.92**	**0.92**	**0.86**	**0.95**	**0.91**
Weighted Length	**0.94**	**0.89**	**0.81**	**0.96**	**0.90**
2004					
4/27	0.49	0.55	0.50	0.51	0.51
5/27	0.73	0.75	0.76	0.82	0.77
6/25	0.72	0.63	0.88	0.70	0.73
7/23	0.98	0.97	0.90	0.92	0.94
8/26	0.83	0.78	0.87	0.75	0.81
9/29	0.76	0.87	0.64	0.74	0.75
10/21	0.72	0.79	0.69	0.71	0.73
Length	**0.75**	**0.76**	**0.75**	**0.73**	**0.75**
Weighted Length	**0.69**	**0.69**	**0.71**	**0.68**	**0.69**

Table 12.–Average length in mm of ovigerous *Cyclops* by site and collection date, from zooplankton samples collected at Chilkoot Lake, from 2001 to 2004.

Year/ Date	Site 1	Site 1B	Site 2B	Site 2	Mean by Visit
2001					
5/17	--	--	--	1.16	1.16
6/15	--	--	--	--	--
7/19	1.25	1.23	1.25	1.27	1.25
8/17	1.17	1.12	1.18	1.09	1.14
9/19	1.09	1.08	1.08	1.11	1.09
10/15	1.09	1.10	1.13	1.08	1.10
Length	**1.15**	**1.13**	**1.14**	**1.16**	**1.15**
Weighted Length	**1.15**	**1.11**	**1.10**	**1.16**	**1.13**
2002					
5/20	--	--	--	--	--
6/17	--	--	1.36	1.26	1.31
7/19	1.34	1.23	1.17	--	1.25
8/16	1.23	1.19	1.17	1.19	1.20
9/16	1.25	1.31	1.22	1.22	1.25
10/16	1.23	1.23	1.25	1.22	1.23
Length	**1.26**	**1.24**	**1.23**	**1.22**	**1.24**
Weighted Length	**1.24**	**1.24**	**1.2**	**1.20**	**1.22**
2003					
5/19	--	--	--	--	--
6/26	1.41	1.38	1.37	--	--
7/14	1.40	1.38	1.37	1.33	1.37
8/19	1.27	1.30	1.26	1.33	1.29
9/19	1.29	1.29	1.31	1.29	1.30
10/14	1.30	1.28	1.28	1.21	1.27
Length	**1.33**	**1.33**	**1.32**	**1.29**	**1.32**
Weighted Length	**1.29**	**1.30**	**1.28**	**1.30**	**1.29**
2004					
4/27	--	1.05	--	--	1.05
5/27	--	1.18	1.15	--	1.17
6/25	1.06	1.01	1.14	1.07	1.07
7/23	1.22	1.19	1.18	1.19	1.20
8/26	1.11	1.16	1.11	1.10	1.12
9/29	1.16	1.16	1.14	1.11	1.14
10/21	--	1.08	1.08	1.10	1.09
Length	**1.14**	**1.12**	**1.13**	**1.11**	**1.13**
Weighted Length	**1.15**	**1.15**	**1.12**	**1.12**	**1.14**

Table 13.–Estimated number of targets, number and percentage of fish collected in trawl samples by species, and estimated number of sockeye fry present in Chilkoot Lake in autumn, as calculated from hydroacoustic surveys between 1987 and 2004.

	Tow Net Samples				Percent	Percent	Percent	Est. Number	Est. Number
Year	No. Fish	Sockeye	Stickleback	Other	Sockeye	Stickleback	Other	Targets	Sockeye
1987	194	141	41	12	72.7%	21.1%	6.2%	1,340,000	980,000
1988	85	83	0	2	97.6%	0.0%	2.4%	3,070,000	2,990,000
1989	209	208	1	0	99.5%	0.5%	0.0%	880,000	870,000
1990	240	238	0	2	99.2%	0.0%	0.8%	610,000	600,000
1991	47	38	9	0	80.9%	19.1%	0.0%	480,000	380,000
1992									
1993									
1993									
1995	775	708	52	15	91.4%	6.7%	1.9%	260,000	240,000
1996	174	173	0	1	99.4%	0.0%	0.6%	420,000	420,000
1997	117	116	0	1	99.1%	0.0%	0.9%	760,000	750,000
1998	526	523	0	3	99.4%	0.0%	0.6%	1,450,000	1,440,000
1999	263	248	11	4	94.1%	4.4%	1.5%	350,000	330,000
2000	14	13	0	1	92.9%	0.0%	7.1%	1,190,000	1,110,000
2001	61	29	23	9	47.5%	37.7%	14.8%	700,000	330,000
2002	289	288	0	1	99.7%	0.0%	0.3%	1,200,000	1,200,000
2003	139	138	1	0	99.3%	0.7%	0.0%	1,390,000	1,390,000
2004	199	187	4	8	94.0%	2.0%	4.0%	1,000,000	940,000

APPENDIX A: SUMMARY OF WATER SAMPLE ANALYSIS WITHIN THE EPILIMNION AND HYPOLIMNION OF CHILKOOT LAKE

Appendix A1.–Summary of water sample analysis at site 1 within the epilimnion of Chilkoot Lake during 2001.

	Site 1 at 1 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	46	37	27	24	29	32	33
pH	6.6	6.5	6.2	6.4	6.2	6.7	6.4
Alkalinity (mg/l as Calcium Carbonate)	8.8	7.0	6.2	5.8	6.1	9.0	7.2
Turbidity (NTU)	1	3.2	7.7	12.8	10.5	8.4	7.3
Color (Pt units)	5	6	4	4	4	6	4.8
Calcium (mg/L)	6.3	4.9	3.6	3.1	4.1	4.7	4.5
Magnesium (mg/L)	0.8	0.2	0.4	0.4	0.3	0.4	0.4
Iron (ug/L)	49	103	159	201	243	225	163
Total Phosphorus (ug/L)	8	7.3	16.6	17	13.9	14	12.8
Total Filterable Phosphorus (ug/L)	1.6	1.9	1.7	4.7	2.3	2.7	2.5
Filterable Reactive Phosphorus (ug/L)	0.9	1.3	1.2	1.7	1.2	1.6	1.3
Total Kjeldahl Nitrogen (ug/L)	66.3	68.8	44.5	42.0	49.7	47.1	53.1
Ammonia (ug/L)	15	8.8	5.5	32.9	9.8	16.5	14.8
Nitrate plus Nitrite (ug/L)	82	71.0	13.7	4.1	29	44.2	40.8
Reactive Silicon (ug/L)	1,587	1,250	1,079	879	1,232	1,294	1,220
Particulate Carbon (ug/L)	290	368	195	186	154	76	212
Nitrogen:Phosphorus Ratio	41:1	42:1	8:1	6:1	13:1	10:1	21:1

Appendix A2.–Summary of water sample analysis at site 2 within the epilimnion of Chilkoot Lake during 2001.

	Site 2 at 1 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	46	37	27	23	28	34	33
pH	6.6	6.5	6.3	6.3	6.1	6.2	6.3
Alkalinity (mg/l as Calcium Carbonate)	9.2	6.8	5.8	5.0	5.8	6.6	6.5
Turbidity (NTU)	0.8	3.2	7	12.9	7.7	9.3	6.8
Color (Pt units)	5	6	4	4	4	5	4.7
Calcium (mg/L)	6.4	4.9	3.8	3.3	4	4.6	4.5
Magnesium (mg/L)	0.5	0.2	0.4	0.4	0.4	0.4	0.4
Iron (ug/L)	49	67	138	200	71	87	102
Total Phosphorus (ug/L)	5.3	7.0	11.4	16.0	18.9	15.1	12.3
Total Filterable Phosphorus (ug/L)	1.3	1.9	2.1	1.8	2.4	2.8	2.1
Filterable Reactive Phosphorus (ug/L)	0.8	1.5	1.4	1.1	1	1.3	1.2
Total Kjeldahl Nitrogen (ug/L)	63.8	65.0	63.8	43.2	62.5	43.2	56.9
Ammonia (ug/L)	5	12.2	1.7	22.4	6.8	5.7	8.9
Nitrate plus Nitrite (ug/L)	74	67.3	11.1	4.1	31	44.0	38.5
Reactive Silicon (ug/L)	1,575	1,236	993	925	1,191	1,363	1,214
Particulate Carbon (ug/L)	261	421	186	145	154	110	213
Nitrogen:Phosphorus Ratio	57:1	42:1	15:1	6:1	11:1	13:1	24:1

Appendix A3.–Summary of water sample analysis at site 1 within the hypolimnion of Chilkoot Lake during 2001.

	Site 1 at 50 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	46	46	44	47	32	37	42
pH	6.6	6.5	6.2	6.4	6	6.2	6.3
Alkalinity (mg/l as Calcium Carbonate)	9	8.8	8.3	8.9	6.7	9.0	8.5
Turbidity (NTU)	0.8	1.5	2.7	4.0	14.4	7.5	5.2
Color (Pt units)	6	4	6	13	9	5	7.2
Calcium (mg/L)	6	6.3	6.4	6.1	4.7	4.9	5.7
Magnesium (mg/L)	0.5	0.2	0.6	0.4	0.4	0.5	0.4
Iron (ug/L)	53	43	64	61	182	187	98
Total Phosphorus (ug/L)	5.8	4.1	8.1	9.3	20.9	11.4	9.9
Total Filterable Phosphorus (ug/L)	1.6	1.4	1.6	6.5	5.2	1.9	3.0
Filterable Reactive Phosphorus (ug/L)	1.2	1.1	1.1	6.0	4	1.1	2.4
Total Kjeldahl Nitrogen (ug/L)	53.5	49.6	45.8	44.5	42	38.1	45.6
Ammonia (ug/L)	4.9	6.1	6.7	17.4	19.6	10.9	10.9
Nitrate plus Nitrite (ug/L)	66.9	72.7	72.2	78.2	150	65.5	84.2
Reactive Silicon (ug/L)	1,644	1,604	1,587	1,595	1,397	1,383	1,535
Particulate Carbon (ug/L)	208	267	98	79	85	60	133
Nitrogen:Phosphorus Ratio	46:1	66:1	32:1	29:1	20:1	20:1	36:1

Appendix A4.–Summary of water sample analysis at site 2 within the hypolimnion of Chilkoot Lake during 2001.

	Site 2 at 50 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	46	46	44	45	34	35	42
pH	6.6	6.4	6.3	6.3	6.2	6.4	6.4
Alkalinity (mg/l as Calcium Carbonate)	8.8	8.8	8.3	8.7	6.6	8.4	8.3
Turbidity (NTU)	0.8	1.3	2.7	4.4	9.3	9.5	4.7
Color (Pt units)	5	4	5	9	5	5	5.5
Calcium (mg/L)	6.3	5.9	5.8	6.1	4.6	4.7	5.6
Magnesium (mg/L)	0.5	0.2	0.6	0.5	0.4	0.5	0.5
Iron (ug/L)	50	42	61	67	87	251	93
Total Phosphorus (ug/L)	4.7	4.5	8	10.6	15.1	14	9.4
Total Filterable Phosphorus (ug/L)	1.4	2.0	2.2	2.4	2.8	2.1	2.2
Filterable Reactive Phosphorus (ug/L)	0.9	1.4	1.4	1.6	1.3	1.6	1.4
Total Kjeldahl Nitrogen (ug/L)	49.6	50.9	53.5	74.0	43.2	42.0	52.2
Ammonia (ug/L)	7	8.8	15.3	18.5	5.7	10.0	10.9
Nitrate plus Nitrite (ug/L)	76	37.5	33.3	64.9	44	58.6	52.4
Reactive Silicon (ug/L)	1,594	1,649	1,582	1,531	1,363	1,309	1,505
Particulate Carbon (ug/L)	230	167	113	50	110	54	121
Nitrogen:Phosphorus Ratio	59:1	43:1	25:1	29:1	13:1	16:1	31:1

Appendix A5.–Summary of water sample analysis at site 1 within the epilimnion of Chilkoot Lake during 2002**.**

	Site 1 at 1 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	41	34	27	26	26	33	31
pH	6.1	6.2	6.2	6.6	6.4	6.6	6.4
Alkalinity (mg/l as Calcium Carbonate)	10.8	7.9	8.2	7.3	6.4	8.0	8.1
Turbidity (NTU)	1.2	6.0	4.7	10.9	11	5.6	6.6
Color (Pt units)	8	5	5	5	5	8	6
Calcium (mg/L)	6	4.3	4.1	3.4	3.8	4.8	4.4
Magnesium (mg/L)	1	0.5	0.5	0.5	0.5	0.8	0.6
Iron (ug/L)	50	168	152	263	244	181	176
Total Phosphorus (ug/L)	5.7	12.3	7.7	16	13.3	10	10.9
Total Filterable Phosphorus (ug/L)	3.3	2.1	2.2	2.2	3.8	5.6	3.2
Filterable Reactive Phosphorus (ug/L)	3	2.0	2.3	1.4	2.9	4.5	2.7
Total Kjeldahl Nitrogen (ug/L)	72.9	52.1	37.5	76.0	64.7	37.5	56.8
Ammonia (ug/L)	7	1.7	1.7	9.1	1.3	1.7	3.7
Nitrate plus Nitrite (ug/L)	57	64.5	13.6	12.5	104	30.2	46.9
Reactive Silicon (ug/L)	1,642	1,326	1,186	1,118	1,188	1,245	1,284
Particulate Carbon (ug/L)	280	174	116	116	214	106	168
Nitrogen:Phosphorus Ratio	50:1	21:1	15:1	12:1	28:1	15:1	24:1

Appendix A6.–Summary of water sample analysis at site 2 within the epilimnion of Chilkoot Lake during 2002.

	Site 2 at 1 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	39	32	27	24	26	31	30
pH	6	6.2	6.2	6.6	6.4	6.3	6.3
Alkalinity (mg/l as Calcium Carbonate)	9.4	7.7	7.4	6.5	6.4	6.7	7.4
Turbidity (NTU)	1.2	4.2	4.4	10.0	11.2	6.5	6.3
Color (Pt units)	5	5	4	4	3	4	4.2
Calcium (mg/L)	6.2	4.7	3.8	3.5	3.7	4.8	4.5
Magnesium (mg/L)	0.5	0.3	0.6	0.7	0.4	0.8	0.6
Iron (ug/L)	53	112	134	285	233	204	170
Total Phosphorus (ug/L)	4.3	10.4	14.8	16.2	12	10.2	11.3
Total Filterable Phosphorus (ug/L)	2.2	2.4	2.3	2.4	2.9	2.7	2.5
Filterable Reactive Phosphorus (ug/L)	1.9	2.3	1.2	2.7	3	2.3	2.2
Total Kjeldahl Nitrogen (ug/L)		64.6	103.2	58.4	53.2	42.8	63.6
Ammonia (ug/L)	3	0.2	1.7	1.7	1.7	2.0	1.6
	59.4						
Nitrate plus Nitrite (ug/L)	55	48.3	9.6	3.8	8	12.9	22.9
Reactive Silicon (ug/L)	1,626	1,328	1,121	1,113	1,161	1,220	1,262
Particulate Carbon (ug/L)	157	171	119	168	122	109	141
Nitrogen:Phosphorus Ratio	59:1	24:1	17:1	9:1	11:1	12:1	22:1

Appendix A7.–Summary of water sample analysis at site 1 within the hypolimnion of Chilkoot Lake during 2002.

	Site 1 at 50 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	39	44	42	45	41	44	43
pH	6.1	6.3	6.3	6.5	6.4	6.6	6.4
Alkalinity (mg/l as Calcium Carbonate)	9.9	10.3	10.8	10.7	8.9	11.1	10.3
Turbidity (NTU)	1.2	1.0	1	1.6	4.5	8.4	3.0
Color (Pt units)	8	5	5	8	8	8	7
Calcium (mg/L)	6.2	5.8	6.4	5.9	5.5	6.3	6.0
Magnesium (mg/L)	0.6	1.0	0.7	0.5	0.4	0.7	0.7
Iron (ug/L)	54	53	53	43	99	284	98
Total Phosphorus (ug/L)	4.1	4.0	6.5	6.8	7.2	14.3	7.2
Total Filterable Phosphorus (ug/L)	4	1.7	2.3	2.8	2.7	4.0	2.9
Filterable Reactive Phosphorus (ug/L)	3.2	1.7	2	2.3	2.9	3.1	2.5
Total Kjeldahl Nitrogen (ug/L)	60.4	39.6	41.7	46.9	33.3	30.2	42.0
Ammonia (ug/L)	3.6	5.0	7.5	9.2	6.0	1.1	5.4
Nitrate plus Nitrite (ug/L)	86.0	74.4	62.9	61.1	19	70.5	62.3
Reactive Silicon (ug/L)	1,634	1,650	1,655	1,651	1,636	1,439	1,611
Particulate Carbon (ug/L)	119	122	42	53	74	71	80
Nitrogen:Phosphorus Ratio	81:1	63:1	36:1	35:1	16:1	20:1	42:1

Appendix A8.–Summary of water sample analysis at site 2 within the hypolimnion of Chilkoot Lake during 2002.

	Site 2 at 50 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	41	41	35	37	43	37	39
pH	6	6.3	6.3	6.3	6.4	6.3	6.3
Alkalinity (mg/l as Calcium Carbonate)	9	10.1	8.7	8.7	9	8.4	9.0
Turbidity (NTU)	1.3	0.9	2.1	9.0	2.4	9.3	4.2
Color (Pt units)	5	5	6	6	5	6	5.5
Calcium (mg/L)	6.4	5.9	5.1	5.0	5.7	4.9	5.5
Magnesium (mg/L)	0.5	0.9	0.8	0.8	0.5	0.8	0.7
Iron (ug/L)	59	56	59	226	66	327	132
Total Phosphorus (ug/L)	5.6	7.2	8.4	16.0	6.9	20.2	10.7
Total Filterable Phosphorus (ug/L)	1.9	2.3	3.2	2.9	2.4	2.8	2.6
Filterable Reactive Phosphorus (ug/L)	1.7	1.9	3.0	3.2	2.5	2.6	2.5
Total Kjeldahl Nitrogen (ug/L)	54.2	75.0	40.6	54.2	40.6	44.8	51.6
Ammonia (ug/L)	3	6.1	4.3	7.0	5.6	1.0	4.6
Nitrate plus Nitrite (ug/L)	68	96.4	68.5	11.6	75.3	82.3	67.05
Reactive Silicon (ug/L)	1,688	1,661	1,413	1,492	1,658	1,409	1,554
Particulate Carbon (ug/L)	185	108	68	99	50	89	100
Nitrogen:Phosphorus Ratio	48:1	53:1	29:1	9:1	37:1	14:1	32:1

Appendix A9.– Summary of water sample analysis at site 1 within the epilimnion of Chilkoot Lake during 2003.

	Site 1 at 1 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	44	34	28	28	28	33	33
pH	6.3	6.2	6.1	6.0	6.2	6.7	6.3
Alkalinity (mg/l as Calcium Carbonate)	8.8	8.0	14	7.3	7.5	6.8	8.7
Turbidity (NTU)	1.2	12.6	23.2	50.1	37.6	16.7	23.6
Color (Pt units)	5	4	4	4	6	11	5.7
Calcium (mg/L)	6.2	4.8	3.8	4.2	4	4.6	4.6
Magnesium (mg/L)	0.4	0.4	0.4	0.8	0.5	0.2	0.5
Iron (ug/L)	25	177	184	745	644	256	339
Total Phosphorus (ug/L)	3.6	12.7	24.1	66	35.3	26	27.9
Total Filterable Phosphorus (ug/L)	1.7	1.5	2.3	2.4	3.8	11.6	3.9
Filterable Reactive Phosphorus (ug/L)	1.1	1.5	1.9	2.1	3.1	10.0	3.3
Total Kjeldahl Nitrogen (ug/L)	48.1	43.0	49.1	85.2	45	71.0	56.9
Ammonia (ug/L)	2	1.7	13.7	3.5	12.2	20.7	9.0
Nitrate plus Nitrite (ug/L)	83	57.1	26.5	36.5	38	61.7	50.3
Reactive Silicon (ug/L)	1,661	1,410	1,199	1,321	1,324	1,471	1,398
Particulate Carbon (ug/L)	120	91	117	56	149	61	99
Nitrogen:Phosphorus Ratio	80:1	17:1	7:1	4:1	5:1	11:1	21:1

Appendix A10.–Summary of water sample analysis at site 2 within the epilimnion of Chilkoot Lake during 2003.

	Site 2 at 1 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	45	32	28	27	30	33	33
pH	6.2	6.1	6	6.0	6.1	6.1	6.1
Alkalinity (mg/l as Calcium Carbonate)	8.3	7.9	6.6	6.5	6.6	7.2	7.2
Turbidity (NTU)	1.2	14.6	23.7	44.8	38.2	20.2	23.8
Color (Pt units)	6	6	4	4	4	4	4.7
Calcium (mg/L)	6.3	4.9	4.0	3.5	3.9	4.5	4.5
Magnesium (mg/L)	0.4	0.6	0.3	0.4	0.5	0.3	0.4
Iron (ug/L)	25	161	362	654	666	267	356
Total Phosphorus (ug/L)	8.4	14.4	25.6	46.2	43.5	27.2	27.6
Total Filterable Phosphorus (ug/L)	2.2	2.6	3	3.0	2.5	5.7	3.2
Filterable Reactive Phosphorus (ug/L)	1.6	2.3	1.9	2.5	2.1	4.1	2.4
Total Kjeldahl Nitrogen (ug/L)	49.1	51.2	62.5	40.9	36.8	49.0	48.3
Ammonia (ug/L)	1.7	0.5	3.0	18.8	4.9	12.9	7.0
Nitrate plus Nitrite (ug/L)	92	57.2	16.6	30.3	38.3	52.3	47.8
Reactive Silicon (ug/L)	1,598	1,403	1,230	1,276	1,359	1,394	1,377
Particulate Carbon (ug/L)	117	45	170	88	120	128	111
Nitrogen:Phosphorus Ratio	37:1	17:1	7:1	3:1	4:1	8:1	4:1

Appendix A11.–Summary of water sample analysis at site 1 within the hypolimnion of Chilkoot Lake during 2003.

	Site 1 at 50 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	45	46	45	44	44	46	45
pH	6.3	6.1	6	6.0	5.7	6.1	6.0
Alkalinity (mg/l as Calcium Carbonate)	9.9	8.9	9.1	8.7	7.5	9.0	8.9
Turbidity (NTU)	0.9	1.5	5.3	28.6	14.6	13.2	10.7
Color (Pt units)	6	13	4	5	5	9	7.0
Calcium (mg/L)	6.5	6.1	6.4	6.0	6	6.5	6.3
Magnesium (mg/L)	0.4	0.4	0.4	0.4	0.5	0.3	0.4
Iron (ug/L)	25	25	28	373	163	142	126
Total Phosphorus (ug/L)	4.5	6.1	13.4	39.3	30.5	25.9	20.0
Total Filterable Phosphorus (ug/L)	3.0	5.9	2.3	2.6	3	8.9	4.3
Filterable Reactive Phosphorus (ug/L)	1.9	4.8	1.6	2.2	2.3	6.7	3.3
Total Kjeldahl Nitrogen (ug/L)	38.8	39.8	38.8	49.2	42.9	56.3	44.3
Ammonia (ug/L)	1.3	3.8	14.4	12.8	9.1	12.3	9.0
Nitrate plus Nitrite (ug/L)	87.1	109.9	98.5	105.3	95.7	103.2	100.0
Reactive Silicon (ug/L)	1,743	1,752	1,773	1,743	1,752	1,755	1,753
Particulate Carbon (ug/L)	59	27	39	74	48	13	43
Nitrogen:Phosphorus Ratio	62:1	54:1	23:1	9:1	10:1	14:1	29:1

Appendix A12.–Summary of water sample analysis at site 2 within the hypolimnion of Chilkoot Lake during 2003.

	Site 2 at 50 Meter Depth						
Date/Analysis Type	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Mean**
Conductivity (umhos/cm)	46	44	45	50	45	45	46
pH	6.1	6.1	6.1	6.0	6.1	5.8	6.0
Alkalinity (mg/l as Calcium Carbonate)	12.6	8.8	9.6	10.4	9.5	8.8	10.0
Turbidity (NTU)	1.1	2.0	2.5	5.6	19.1	20.4	8.5
Color (Pt units)	6	5	5	8	5	4	5.5
Calcium (mg/L)	6.4	6.6	6.4	6.3	6.6	6.2	6.4
Magnesium (mg/L)	0.4	0.4	0.5	0.4	0.5	0.3	0.4
Iron (ug/L)	25	21	21	335	91	185	113
Total Phosphorus (ug/L)	4.7	4.7	8.5	16.9	21.8	24	13.5
Total Filterable Phosphorus (ug/L)	2.4	2.3	2.6	3.7	4.4	5.0	3.4
Filterable Reactive Phosphorus (ug/L)	1.9	1.8	1.5	3.0	2.9	3.6	2.5
Total Kjeldahl Nitrogen (ug/L)	31	32.6	39.8	37.8	44	56.3	40.3
Ammonia (ug/L)	2.0	7.7	1.8	4.6	11.5	12.1	6.6
Nitrate plus Nitrite (ug/L)	96	112.8	86.3	106.4	115.5	85.0	100.4
Reactive Silicon (ug/L)	1,766	1,782	1,795	1,736	1,846	1,716	1,774
Particulate Carbon (ug/L)	161	53	12	30	33	61	58
Nitrogen:Phosphorus Ratio	60:1	69:1	33:1	19:1	16:1	13:1	35:1

APPENDIX B: SUMMARY OF ALGAL PIGMENT ANALYSIS FOR CHILKOOT LAKE

Appendix B1. Summary of algal pigment analysis (in µg L^{-1}), by sampling visit, site and (euphotic) depth for Chilkoot Lake in 2001.

	1 Meter		**Mid-Euphotic Zone**		**1% Light Level**		**50 Meter (Hypolimnion)**		**Mean**
Date/ Type	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**by Date**
5/17/2001									
Chlorophyll *α*	1.90	2.00	2.18	1.54	2.25	1.52	2.43	1.95	1.97
Phaeophytin *α*	0.92	1.01	0.94	0.87	0.92	0.89	1.05	1.25	0.98
6/15/2001									
Chlorophyll *α*	3.58	3.30	2.98	2.88	4.45	3.90	2.48	2.46	3.25
Phaeophytin *α*	-0.33	0.05	0.18	0.08	-1.07	-0.46	0.08	0.13	-0.17
7/19/2001									
Chlorophyll *α*	0.91	1.39	1.00	1.29	1.00	----	1.16	0.56	1.04
Phaeophytin *α*	0.15	0.31	0.24	0.28	0.18	----	0.51	0.24	0.26
8/17/2001									
Chlorophyll *α*	0.82	1.20	0.51	1.38	0.67	1.03	1.14	1.07	0.98
Phaeophytin *α*	0.11	0.17	0.05	0.18	0.08	0.14	0.17	0.24	0.14
9/19/2001									
Chlorophyll *α*	1.43	1.72	1.40	2.35	0.89	0.80	0.72	0.76	1.15
Phaeophytin *α*	0.21	0.21	0.21	0.04	0.16	0.17	0.14	0.17	0.15
10/15/2001									
Chlorophyll *α*	0.50	0.47	0.44	0.48	0.44	0.46	0.31	0.26	0.42
Phaeophytin *α*	0.15	0.12	0.17	0.08	0.12	0.08	0.11	0.11	0.12
Annual Mean by Site and Depth									
Chlorophyll *α*	**1.52**	**1.68**	**1.42**	**1.65**	**1.62**	**1.54**	**1.37**	**1.18**	**1.47**
Phaeophytin *α*	**0.20**	**0.31**	**0.30**	**0.26**	**0.07**	**0.16**	**0.34**	**0.36**	**0.25**

Appendix B2.–Summary of algal pigment analysis (in $\mu g\ L^{-1}$), by sampling visit, site and (euphotic) depth for Chilkoot Lake in 2002.

	1 Meter		**Mid-Euphotic Zone**		**1% Light Level**		**50 Meter (Hypolimnion)**		**Mean**
Date/ Type	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**by Date**
5/20/2002									
Chlorophyll *α*	1.44	3.30	1.70	2.30	4.00	2.68	2.83	1.35	2.45
Phaeophytin *α*	0.19	0.71	0.31	0.33	0.59	0.37	0.63	0.44	0.45
6/17/2002									
Chlorophyll *α*	0.39	0.67	0.36	1.17	0.32	1.26	0.94	1.03	0.77
Phaeophytin *α*	0.32	0.32	0.39	0.39	0.31	0.31	0.53	0.53	0.39
7/19/2002									
Chlorophyll *α*	0.85	0.46	0.98	1.50	0.55	0.36	0.53	0.64	0.73
Phaeophytin *α*	0.23	0.33	0.27	0.43	0.13	0.18	0.23	0.32	0.27
8/16/2002									
Chlorophyll *α*	0.99	1.71	1.54	2.01	0.73	0.95	0.62	0.47	1.13
Phaeophytin *α*	0.27	0.45	0.38	0.34	0.25	0.27	0.27	0.22	0.31
9/16/2002									
Chlorophyll *α*	3.59	1.41	1.18	1.07	0.83	0.54	0.19	0.29	1.14
Phaeophytin *α*	0.15	0.43	0.42	0.35	0.36	0.21	0.16	0.15	0.28
10/16/2002									
Chlorophyll *α*	1.49	0.97	0.92	0.84	0.64	0.68	0.29	0.28	0.76
Phaeophytin α	0.50	0.34	0.44	0.35	0.33	0.33	0.17	0.14	0.33
Annual Mean by Site									
Chlorophyll *α*	**1.46**	**1.42**	**1.11**	**1.48**	**1.18**	**1.08**	**0.90**	**0.68**	**1.16**
Phaeophytin *α*	**0.28**	**0.43**	**0.37**	**0.37**	**0.33**	**0.28**	**0.33**	**0.30**	**0.33**

Appendix B3.–Summary of algal pigment analysis (in µg L^{-1}), by sampling visit, site and (euphotic) depth for Chilkoot Lake in 2003.

	1 Meter		Mid-Euphotic Zone		1% Light Level		50 Meter (Hypolimnion)		Mean
Date/ Type	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**Site 1**	**Site 2**	**by Date**
5/20/2002									
Chlorophyll *α*	1.44	3.30	1.70	2.30	4.00	2.68	2.83	1.35	2.45
Phaeophytin *α*	0.19	0.71	0.31	0.33	0.59	0.37	0.63	0.44	0.45
6/17/2002									
Chlorophyll *α*	0.39	0.67	0.36	1.17	0.32	1.26	0.94	1.03	0.77
Phaeophytin *α*	0.32	0.32	0.39	0.39	0.31	0.31	0.53	0.53	0.39
7/19/2002									
Chlorophyll *α*	0.85	0.46	0.98	1.50	0.55	0.36	0.53	0.64	0.73
Phaeophytin *α*	0.23	0.33	0.27	0.43	0.13	0.18	0.23	0.32	0.27
8/16/2002									
Chlorophyll *α*	0.99	1.71	1.54	2.01	0.73	0.95	0.62	0.47	1.13
Phaeophytin *α*	0.27	0.45	0.38	0.34	0.25	0.27	0.27	0.22	0.31
9/16/2002									
Chlorophyll *α*	3.59	1.41	1.18	1.07	0.83	0.54	0.19	0.29	1.14
Phaeophytin *α*	0.15	0.43	0.42	0.35	0.36	0.21	0.16	0.15	0.28
10/16/2002									
Chlorophyll *α*	1.49	0.97	0.92	0.84	0.64	0.68	0.29	0.28	0.76
Phaeophytin *α*	0.50	0.34	0.44	0.35	0.33	0.33	0.17	0.14	0.33
Annual Mean by Site									
Chlorophyll *α*	**1.46**	**1.42**	**1.11**	**1.48**	**1.18**	**1.08**	**0.90**	**0.68**	**1.16**
Phaeophytin *α*	**0.28**	**0.43**	**0.37**	**0.37**	**0.33**	**0.28**	**0.33**	**0.30**	**0.33**