Fishery Data Series No. 13-39

Autonomous Lake Mapping and Limnological Assessment of Karluk Lake, 2012

by

Heather Finkle

August 2013

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

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)

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

FISHERY DATA SERIES NO. 13-39

AUTONOMOUS LAKE MAPPING AND LIMNOLOGICAL ASSESSMENT OF KARLUK LAKE, 2012

by
Heather Finkle
Alaska Department of Fish and Game, Kodiak

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

August 2013

This report was prepared by Heather Finkle under award #NA09NMF4380373 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, administered by the Alaska Department of Fish and Game. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric, the U.S. Department of Commerce, or the Alaska Department of Fish and Game.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

Heather Finkle
Alaska Department of Fish and Game, Division of Commercial Fisheries
351 Research Court, Kodiak, Alaska 99615, USA

This document should be cited as:
Finkle, H. 2013. Autonomous salmon lake mapping and limnological assessment of Karluk Lake, 2012. Alaska Department of Fish and Game, Fishery Data Series No. 13-39, Anchorage.

The Alaska Department of Fish and Game (ADF&G) administers all programs and activities free from discrimination based on race, color, national origin, age, sex, religion, marital status, pregnancy, parenthood, or disability. The department administers all programs and activities in compliance with Title VI of the Civil Rights Act of 1964, Section 504 of the Rehabilitation Act of 1973, Title II of the Americans with Disabilities Act (ADA) of 1990, the Age Discrimination Act of 1975, and Title IX of the Education Amendments of 1972.

If you believe you have been discriminated against in any program, activity, or facility please write:
ADF&G ADA Coordinator, P.O. Box 115526, Juneau, AK 99811-5526
U.S. Fish and Wildlife Service, 4401 N. Fairfax Drive, MS 2042, Arlington, VA 22203
Office of Equal Opportunity, U.S. Department of the Interior, 1849 C Street NW MS 5230, Washington DC 20240

The department's ADA Coordinator can be reached via phone at the following numbers:
(VOICE) 907-465-6077, (Statewide Telecommunication Device for the Deaf) 1-800-478-3648, (Juneau TDD) 907-465-3646, or (FAX) 907-465-6078

For information on alternative formats and questions on this publication, please contact:
ADF&G, Division of Sport Fish, Research and Technical Services, 333 Raspberry Road, Anchorage AK 99518 (907)267-2375.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

This report presents the results of limnological data collected to describe abiotic and biotic water quality parameters that influence the growth, survival, and sustainability of wild juvenile sockeye salmon from Karluk Lake on Kodiak Island. During 2012, traditional means of limnological data collection were implemented and an autonomous underwater vehicle (AUV) that collects high-resolution spatial and temporal limnological data was deployed in Karluk Lake. AUV missions were run in Karluk Lake each month between May and September concurrent with traditional means of collecting limnological data. AUV-collected limnological data consisted of pH, chlorophyll, dissolved oxygen, temperature, and turbidity profiles. Depth readings and side-scan sonar imagery were also recorded every second during the AUV missions. Traditionally collected limnological samples consisted of temperature, light penetration, and dissolved oxygen depth profiles, zooplankton, and water samples at depth. Water samples were processed and analyzed in a laboratory for pH, alkalinity, and total phosphorous, filtered reactive phosphorous, total filtered phosphorous, nitrate + nitrite, ammonia, total Kjeldahl nitrogen, chlorophyll-*a*, phaeophytin-*a,* and silicon concentrations. Analysis of AUV data revealed variability in physical conditions over lake area and depth in Karluk Lake. Temperature effects appear to be influenced by lake bathymetry. Similarly, primary production occurs below the epilimnion. For Karluk Lake, low levels of silicon coincided with high zooplankton biomasses indicating silicon was a vital nutrient for lake productivity.

Key words: AUV, Karluk Lake, sockeye salmon, limnology, bathymetry, zooplankton.

INTRODUCTION

Understanding the dynamism of ecological conditions in lake systems over time and space is vital for modeling and predicting types and levels of productivity for a given body of water (Bilby et al. 1996; Kyle 1992; Stockner and MacIsaac 1996). Adult catch and escapement data are often the only data available for modeling salmon productivity. However, these data often lack the contrast to identify factors that influence run failure or success. Similarly, these data are often unable to explain why run size fluctuates over time. Auxiliary data have become increasingly important for managing fisheries because salmonid returns and survival are often affected by habitat conditions. Limnological data are vital for revealing changes in salmon productivity caused by their freshwater rearing environment, where salmon are most susceptible to mortality as juveniles. Few lake systems on Kodiak Island and the Alaska Peninsula, however, possess robust limnological datasets that allow the assessment of the effects of lake rearing conditions upon salmonid survival; Karluk Lake has been intermittently sampled for limnological data since 1979. This report summarizes the Alaska Department of Fish and Game's (ADF&G) efforts to re-establish baseline data and improve data quality of limnological sampling conducted in Karluk Lake (Figure 1).

Limnological sampling includes the collection of temperature, dissolved oxygen, pH, light penetration, nutrient, and zooplankton data. Collection of these data will re-establish a baseline of lake habitat conditions. These data will also eventually allow for comparisons between lake conditions and adult returns. In turn, these analyses may identify rearing conditions that are favorable for juvenile sockeye salmon and why those conditions exist.

This project also sought to enhance the quality of data collected where possible. Although valuable, traditionally-collected data sets, which utilize data from fixed stations, are limited in their scope to describe whole-lake conditions because ecological properties observed on a small spatial scale may not be apparent on larger scales and vice versa (Kiffney et al. 2005). In large or deep lakes, such as Karluk Lake, data from 1 or 2 stations may not accurately reflect the variability of conditions throughout the whole lake (Finkle and Ruhl 2011). A simple way to improve the assessment of whole lake conditions and parameter variability in lakes is by using an autonomous underwater vehicle (AUV) because it can collect limnological data from a substantially greater area in a fraction of the time that traditional methods would require.

The Yellow Springs Instrument (YSI) Ecomapper ™ AUV, acquired by the department with Pacific Coast Salmon Recovery Fund monies in 2009, is a free-swimming robot that collects geo-referenced (latitude, longitude, and depth) water temperature, dissolved oxygen, turbidity, pH, chlorophyll, and blue-green algae data (Figure 2). The AUV possesses an onboard computer that stores and runs a user-plotted mission. Once deployed, the global positioning system unit located in the antenna on top of the AUV guides it along the plotted course when not submerged underwater. On diving missions, which can reach depths as great as 61 m (200 feet), the AUV follows a compass heading to the next waypoint. In addition, the AUV possesses a side-scan sonar system capable of generating bottom profile imagery and detecting fish presence in lakes. The sensor array can be programmed to collect data at varying intervals, recording measurements up to every second for up to a 4-hour mission. As all data points are geo-referenced by location and depth, physical characteristics can be mapped and compared to side-scan sonar imagery of fish presence to help identify preferred habitats. These data maps ultimately allow for relatively quick, high-resolution visual assessments of habitat quality and variability in an entire lake.

Bathymetric data are very useful for assessing salmon productivity. Several quantitative models exist that rely on accurate estimates of lake volume or area to calculate optimal levels of escapement for maximizing production (Koenings and Burkett 1987; Koenings and Kyle 1997). Bathymetric data collected by the AUV since 2009 have been used to remap Karluk Lake (Finkle 2012). The re-estimated lake volume yielded substantially different estimates of optimal salmon escapement in the euphotic volume or zooplankton biomass models (Koenings and Burkett 1987; Koenings and Kyle 1997) used to assess salmon escapement goals for these systems. Continued collection of bathymetric data will further enhance our knowledge of Karluk Lake morphology.

Re-establishing baselines and increasing the spatial and temporal metrics of limnological data for Karluk Lake will eventually lead to better modeling of stock productivity, helping resource managers sustain maximum yields of Alaska's salmon stocks. This report summarizes the traditional limnological data collection and AUV water quality mapping in Karluk Lake during 2012.

METHODS

Karluk Lake was sampled for limnological data from May through October, 2012. The sampling schedule for 2012 is outlined in Table 1. Karluk Lake has 3 stations (Figure 3). Water and zooplankton samples and temperature, dissolved oxygen, and light penetration data were gathered at all stations. Each station's location was logged with a global positioning system and marked with a buoy. Sampling was conducted following protocols established by Thomsen (2008). AUV sampling events were conducted once a month from May through September over the field season. Because of the size of Karluk Lake, multiple missions were required during sampling events to map lake parameters. The timing of AUV missions overlapped with that of traditional limnological sampling.

TRADITIONAL LIMNOLOGICAL SAMPLING

Physical Data - Temperature, Dissolved Oxygen, and Light Penetration

Water temperature (°C) and dissolved oxygen (mg/L) levels were measured with a YSI ProDO™ optical dissolved oxygen and temperature meter. Readings were recorded at 0.5 m intervals to a depth of 5 m, and then increased to 1 m intervals. Upon reaching a depth of 25 m, the intervals were increased to every 5 m up to a depth of 50 m. A mercury thermometer was used to ensure the meter's calibration. Measurements of photosynthetically active radiation were taken with a Li-Cor LI250A photometer equipped with a underwater quantum sensor above the surface, at the surface, and proceeded at 0.5 m intervals until reaching a depth of 5 m. Readings were then continued at 1 m intervals until the lake bottom or to the depth at which one percent subsurface photosynthetically active radiation was reached. The mean euphotic zone depth was determined (Koenings et al. 1987) for the lake and incorporated into a model for estimating sockeye salmon fry production (Koenings and Kyle 1997). Temperature and dissolved oxygen measurements at 1 m were compared to assess the physical conditions in the euphotic zones of the lake. Secchi disc readings were collected from each station to measure water transparency. The depths at which the disc disappears when lowered into the water column and reappeared when raised in the water column were recorded and averaged.

Water Sampling - Nutrients, pH, and Alkalinity

Using a Van Dorn sampler, 4 to 8 L of water were collected from the epilimnion (depth of 1 m) and hypolimnion (depth of 30 m) at each station. Water samples were stored for no more than 72 hours in precleaned polyethylene (poly) carboys and refrigerated until initial processing.

One-liter samples were passed through 4.25 cm diameter 0.7 µm Whatman™ GF/F filters under 15 to 20 psi vacuum pressure for particulate C analyses. For chlorophyll-*a* analysis, 1 L of lake water from each depth sampled was filtered through a 4.25 cm diameter 0.7 µm Whatman™ GF/F filter, adding approximately 5 ml of $MgCO_3$ solution to the last 50 ml of the sample water during the filtration process. Upon completion of filtration, all filters were placed in individual petri dishes, labeled and stored frozen for further processing at the ADF&G Near Island Laboratory (NIL) in Kodiak.

The water chemistry parameters of pH and alkalinity were assessed with a pH meter. One hundred milliliters of refrigerated lake water were warmed to 25°C and titrated with 0.02-N sulfuric acid following the methods of Thomsen (2008).

All filtered and unfiltered water samples were stored and frozen in clean polyetheylene bottles. Water analyses were performed at the ADF&G NIL and Soldotna limnology laboratory for total phosphorous (TP), total ammonia (TA), total filterable phosphorus (TFP), filterable reactive phosphorous (FRP), nitrate + nitrite (N+N), chlorophyll *a*, phaeophytin *a*, and silicon (Si). All laboratory analyses adhered to the methods of Koenings et al. (1987) and Thomsen (2008). Total Kjeldahl nitrogen (TKN) was sent to the University of Georgia Feed & Environmental Water Laboratory for processing. Nutrient data were analyzed via linear regression and compared to published ratio values.

Zooplankton - Abundance, Biomass, and Length

One vertical zooplankton tow was made at each limnology station with a 0.2 m diameter, 153-micron mesh conical net from 50 m. Each sample was placed in a 125 ml polyethylene bottle containing 12.5 ml of buffered formalin to yield a 10% formalin solution. Samples were stored for analysis at the ADF&G NIL. Subsamples of zooplankton were keyed to family or genus and counted on a Sedgewick-Rafter counting slide. This process was replicated 3 times per sample then counts were averaged and extrapolated over the entire sample. For each plankton tow, mean length (±0.01 mm) was measured for each family or genus with a sample size derived from a Student's t-test to achieve a confidence level of 95% (Edmundson et al. 1994). Biomass was calculated via species-specific linear regression equations between dry weight and unweighted- and weighted-average length measurements (Koenings et al. 1987). Zooplankton data were compared to physical and nutrient data via linear regression and published values of length and biomass. Zooplankton biomass data were used to estimate escapement levels by indicating a level of juvenile production that a plankton population can maintain as a forage base following the methods of Koenings and Kyle (1997).

AUV Sampling

In 2012, sampling of Karluk Lake with the AUV consisted of multiple missions in May, June, July, August, and September. The May missions were incomplete in the Middle region and aborted in the Upper region because of software errors. June missions were limited to the Middle region because of a leaking propeller shaft seal. Successful missions were run in July, August, and September. All AUV missions were plotted in VectorMap software on the most recent geo-referenced images available for Karluk Lake (example shown in Figure 4) and then loaded onto the AUV's onboard computer via its own wireless network. Missions were plotted to avoid overlap and increase area coverage to maximize data accuracy for bathymetric mapping. Each deployment and retrieval followed the YSI Ecomapper operation manual (YSI 2009). Physical parameters of temperature (°C), dissolved oxygen (mg/L), pH, turbidity (nephelometric turbidity units; NTUs), and chlorophyll (µg/L) were measured every 1 second along the plotted sampling grid throughout the lake. In addition, bottom profiles and fish presence or absence were obtained with the side-scanning sonar. It should be noted that in assessing fish distribution, species identification was not possible from the side-scan sonar footage. Data were downloaded to a field computer and reviewed following each mission.

AUV Data Analysis

All data were edited for erroneous measurements. Spurious data were omitted from analyses. Traditionally collected limnological data were averaged by month, where applicable, for inseason comparisons. Physical data were plotted against depth for each month.

AUV data for Karluk Lake was divided into 3 regions (Upper, Middle, and Lower; Figure 3) to address homogeneity of lake conditions. Average values for each region were compared within and between months. Maps to display spatial and temporal variability of all AUV data in both lakes were created using the Surfer 9 software package. Bathymetric maps were generated from the depth and coordinate data, also using the Surfer 9 program; lake statistics such as area, volume, and mean and maximum depth were also estimated from the bathymetric data. Side-scanned sonar images were reviewed and fish locations were recorded and plotted on lake maps for each month. Fish locations were also overlain on maps of AUV collected physical and nutrient data.

Traditionally collected limnological and AUV data were compared, where possible, either graphically or statistically by region and month.

Estimates of percent difference of lake volume and area were compared between the 2 methods of data collection. AUV bathymetric data were also employed in an euphotic volume model (Koenings and Burkett 1987) to estimate rearing capacity and optimal escapement for sockeye salmon.

RESULTS

Detailed limnological data for Karluk Lake are presented in Appendix A.

TRADITIONAL LIMNOLOGICAL SAMPLING

Physical Data

The average 1 m temperature in Karluk Lake was 8.8°C (Table 2). The warmest temperature occurred in August (11.3°C) and the coolest was in May (3.9°C; Table 2 and Figure 5). Dissolved oxygen readings taken at a depth of 1 m were the lowest in August (11.5 mg/L) and the greatest in June (13.0 mg/L), averaging between 12.1 mg/L over stations during the sampling season (Table 3; Figure 5). The euphotic zone depth (EZD), estimated from light penetration data, was at its deepest in August (25.1 m) and its shallowest in June (17.0 m; Table 4). The seasonal average of the EZD was 20.5 m (Table 5; Figure 6).

Water Sampling

All data presented in this section were collected from a 1 m depth.

Water chemistry measurements were variable for Karluk Lake during 2012; pH ranged from 7.51 in May to 8.29 in July at Karluk Lake (Table 6). The seasonal pH values averaged 7.8. Seasonal TP averaged between 2.6 µg/L P in July and 4.6 µg/L P in May with a seasonal mean of 3.7 µg/L P (Table 6). Of the photosynthetic pigments, chlorophyll *a* averaged between 0.53 µg/L in May and 1.71 µg/L in October over the sampling season with a seasonal average of 0.99 µg/L (Table 6). Seasonal average total nitrogen (TKN plus NO_3+NO_2) concentrations were greatest in June (815.5 µg/L) and lowest in May (503.2 µg/L; Table 6). Reactive silicon concentrations averaged 370.5 µg/L over the sampling season, ranging between 185.2 (September) and 681.0 (June) µg/L (Table 6).

Zooplankton

The 2012 average abundance of Karluk Lake zooplankton was greatest in June (1,732,307 zooplankton/m^2) with the lowest monthly concentration of 716,737 zooplankton/m^2 in May (Table 7). The species composition was composed predominately of the copepod *Cyclops* throughout the season. *Daphnia* were the most abundant cladoceran, reaching their greatest abundance (251,415 zooplankton/m^2) in September (Table 7). Other zooplankton species present in Karluk Lake were *Epischura*, *Bosmina*, and *Diaptomus*. *Bosmina* had the most ovigerous individuals during a given month (62,588 zooplankton/m^2 in September; Table 7)

The seasonal weighted-average zooplankton biomass for 2012 in Karluk Lake was 2,312 mg/m^2 and ranged from 611 mg/m^2 in May to 3,467 mg/m^2 in July (Table 8). Karluk Lake, with the exception of May, maintained monthly zooplankton biomasses well over 1,000 mg/m^2 during the sampling season (Table 8). *Cyclops* had the greatest biomass (seasonal weighted average of 1,447 mg/m^2) of any species in Karluk Lake during 2012. *Daphnia* and *Cyclops* had similar biomasses of ovigerous individuals throughout the season (Table 8).

Ovigerous *Diaptomus* were the longest zooplankton (seasonal weighted average of 1.25 mm) collected during 2012 (Table 9). Ovigerous zooplankton were longer than their non-ovigerous counterparts for all identified species. Non-ovigerous *Cyclops* ranged from 0.63 to 0.72 mm and non-ovigerous *Bosmina* did not exceed 0.37 mm in all sampled months. Ovigerous *Bosmina* exceed 0.40 mm in all months except June, when none were present in the sample and in July (Table 9).

AUV SAMPLING

Physical Data

For each month, surface temperature, dissolved oxygen, and turbidity varied minimally from region to region (Tables 10 through 12; Figures 7 and 8). The Lower region had the coolest surface temperatures in May. The Upper region had the warmest surface temperatures, which occurred in August (Table 10; Figure 7). The greatest difference in temperature across regions was 2.2 °C between the Upper and Lower regions during September. Surface dissolved oxygen concentrations were the greatest in June in the Lower region and the lowest in the Lower region during September (Table 11; Figure 8). The greatest difference in dissolved oxygen concentrations across regions was 0.22 mg/L between the Middle and Lower regions during May. Turbidity was greatest in the Upper region of the lake during September and the lowest in the Middle region during May (Table 12). The greatest difference in turbidity across regions in a given month was 911.18 NTUs between the Upper and Middle surface readings during July.

Monthly temperature depth profiles indicated that Karluk Lake was mixing in May and September, stratifying in June, and completely stratified by August with the hypolimnion being deepest (~20 m) during August (Figure 7). The greatest temperature difference between the surface and first 5 m of depth was 1.9 °C in the Upper region during August (Table 10). Dissolved oxygen concentrations generally varied minimally over depth (Figure 8). September dissolved oxygen concentrations showed the most heterogeneity across regions. On average, the Middle region had the greatest variability in turbidity within the first 5 m of depth (85.9 NTUs; Table 12) with the month of August having the greatest seasonal difference of 360.68 NTUs between the surface and 5 m (Table 12).

Water Sampling

The highest pH measurements, ranging from 8.29 to 8.51, occurred in Karluk Lake's Upper region during August (Table 13; Figure 9). The Lower region had the lowest pH measurements (7.50 to 7.74) in May. Average pH values over depth were generally greater in the Middle region during June and July, the Upper region during August, and the Lower region in September (Table 13). Monthly measurements of pH were consistent over depth in each region, with the exception of pH depth profiles from the Lower region during September (Figure 9).

Average surface chlorophyll concentrations were generally higher in June and at their lowest in May (Table 14; Figure 10). September chlorophyll concentrations were the most consistent measurements across regions and depths, ranging from 243.32 to 265.67 μg/L (Table 14; Figure 10). From June through August, chlorophyll concentrations varied among regions and depths.

Bathymetry

The Karluk Lake bathymetric map created with AUV data in 2009 was updated in 2012. The maximum depth of Karluk Lake remained at 139.4 m (Table 15). The average depth increased from the 2009 measurement of 40.5 m to 40.9 m. The volume of Karluk Lake also increased from 1,789 x 10^6 m^3 (2009) to 1,843 x 10^6 m^3 (Table 15).

Sonar Imagery

The lowest densities of fish present in Karluk Lake occurred in May and June with average depths of 15.7 m and 6.3 m respectively. Side-scan sonar imagery indicated fish presence throughout Karluk Lake in August (Figure 11) ranging in depth from 1.6 m to a maximum seasonal depth of 65.2 m. Aggregations of fish in July (average depth 11.1 m) and September (average depth 13.0 m) were detected primarily in the Upper and Middle regions of the lake.

COMPARISON OF SAMPLING METHODS

Comparisons of physical data collected by the AUV to the data collected by traditional methods revealed that Karluk Lake temperatures differed minimally while dissolved oxygen, pH, and chlorophyll concentrations substantially varied over depth, space and time (Tables 10 through 12). Specifically, pH and chlorophyll were generally greater when measured by the AUV; AUV-measured dissolved oxygen concentrations were lower over depth and time (Figures 8 and 10). Region-wide comparisons of averaged AUV to traditional data showed the Lower region differed more from the other regions (Appendix A).

DISCUSSION

PHYSICAL DATA

Traditional and AUV temperature depth profiles indicated a spring turnover event occurred during May. A fall turnover event occurred during September in Karluk Lake. A weak thermocline (the plane of maximum temperature decline relative to depth; Wetzel 1983) developed in June and was strongly defined in July and August. Timing of lake turnover and stratification events greatly affects ecosystem dynamics and will be expounded upon below as it becomes germane to the discussion.

Dissolved oxygen concentrations from the surface to the hypolimnion were at suitable levels (> 6 mg/L) for rearing fishes in Karluk Lake through the sampling season (Michaud 1991). Differences, although not substantial, existed between traditionally-collected data and AUV-collected data. This is likely due to the variability that naturally occurs in systems and the inability of traditional collection methods to accurately represent lake conditions over space and time. Instrument sensitivity should not affect results as both probes are of the same type and from the same manufacturer.

Changes in phytoplankton species composition mediated by physical factors such as reduced water clarity can negatively affect zooplankton consumption and assimilation rates (Wetzel 1983; Kerfoot 1987; Kyle 1996). Cladocerans, which are selective feeders, can have periods of reduced growth or reproduction in the absence of preferred forage (Dodson and Frey 2001). Similarly, Kirk and Gilbert (1990) noted that suspended particles that reduced water clarity dilute food concentrations in the water column reducing cladoceran population growth rates. For Karluk Lake zooplankton, water clarity normally has not been an issue as evidenced by an average summer EZD greater than 20 m (Carlson 1977; Carlson and Simpson 1996). That turbidity increased throughout the season may be equally indicative of phytoplankton production and adequate light for photosynthesis and inflated sensor readings as determined by the manufacturer during post-season servicing; zooplankton production was healthy throughout the summer, however the cladoceran biomass never exceeded the copepod biomss.

WATER SAMPLING

Oligotrophic lakes are preferred habitat for rearing sockeye salmon (Carlson 1977; Carlson and Simpson 1996). Limnological data from traditional and AUV collection methods indicated that Karluk Lake could be classified as having oligotrophic (low) production levels as defined by several trophic-state indices (Carlson 1977; Forsberg and Ryding 1980, Carlson and Simpson 1996).

Nutrient data may be used to indicate limitations in aquatic environments. A comparison of total nitrogen (TN) to total phosphorous (TP) is a simple indicator of aquatic ecosystem health as both are necessary for primary production (Wetzel 1983; UF 2000). Nitrogen-phosphorous ratios of less than 10:1 typically indicate nitrogen limitations in oligotrophic lakes (UF 2000; USEPA 2000). Karluk Lake consistently had TN:TP ratios exceeding 10:1, indicating phosphorous limitations. The TN:TP ratio should, however, be objectively considered as an indicator of lake health. It is unclear if the nutrient concentrations that were measured are what was available or what was left over from photosynthetic processes. It is also uncertain what concentrations of nutrients have precipitated out of the euphotic zone and may be reintroduced during the next turnover event where they can be used. Interestingly, the TN:TP ratio from 1 m samples (175: 1) were on average greater than from samples collected from the hypolimnion (111:1). This suggests that a deep chlorophyll maximum (DCM; Barbiero and Tuchman 2004) exists, holding nutrients just below the thermocline, which when considered in conjunction with other limnological components may help to explain trophic interactions in the lake.

While nitrogen and phosphorous conditions can effect lake primary productivity, primary productivity must also be assessed respective to other lake attributes. Beyond nitrogen and phosphorous, silicon is a vital nutrient for phytoplankton production: diatoms require silicon for bodily structure and reproduction (Vinyard 1979; Wetzel 2001). Primary consumers such as copepods graze upon diatoms (Turner et al. 2001). Thus, if silicon concentrations affect diatom production, they may also influence the abundance of copepods. Average silicon concentrations were relatively low in Karluk Lake and diatoms have been the most abundant taxa of phytoplankton in Karluk Lake (Tables 16 and 17). suggesting that diatoms are utilizing silicon for their metabolic demands and that silicon is an integral nutrient for phytoplankton production. Similary, historical values of silicon from Karluk and other Kodiak Island lakes were inversely related to zooplankton biomass suggesting silicon helps drive zooplankton production (Finkle 2012).

A comparison of the photosynthetic pigment, chlorophyll *a,* to its byproduct, phaeophytin *a,* showed that chlorophyll-*a* concentrations were proportionally high all season (ranging from 2.5 to 21.3 chlorophyll *a* to 1 phaeophytin *a*). Conversely, when primary production is taxed by either overgrazing or poor physical conditions, phaeophytin-*a* levels tend to exceed chlorophyll-*a* levels (COLAP 2001). This signifies that algal levels were generally adequate for supporting primary consumption because the potential for algal (phytoplankton) growth existed as chlorophyll *a* was available for photosynthesis and ahead of its consumption. Lakes with relatively larger chlorophyll-*a* to phaeophytin-*a* ratios and low zooplankton biomasses or small chlorophyll-*a* to phaeophytin-*a* ratios and high zooplankton biomasses, such as Karluk Lake, support this hypothesis. Relative to depth, chlorophyll-*a* was twice as concentrated below the euphotic zone than at 1m when the lake was stratified in July. Because the euphotic zone depth did not exceed 26 m and the nutrient concentrations collected at 30 m were greater than those from 1 m, this supports the hypothesis that a DCM exists and may function as another area of lake productivity beyond the euphotic zone (Barbiero and Tuchman 2004). In light of the traditionally collected data, primary nutrients did not appear to be a limiting factor in Karluk Lake for its levels of primary and zooplankton productivity in 2012. Furthermore, AUV missions located patches of high chlorophyll concentrations, connoting primary production may be greater than indicated from traditional sample collection methods.

Review of the traditionally collected pH data suggested that phytoplankton may influence pH in Karluk Lake more than temperature. Warmer temperatures release hydrogen ions from water molecules, decreasing pH. In contrast, photosynthesis uses dissolved carbon dioxide (CO_2), which acts like carbonic acid (H_2CO_3) in water. The removal of carbon dioxide through photosynthesis, in effect, reduces the acidity of water and therefore pH increases creating a more basic, or alkaline, environment, which is the opposite effect of warming water temperatures (Wetzel 1983). Karluk Lake experienced its highest pH levels concurrent with low levels of useable nitrogen (ammonia and nitrate + nitrite) and phosphorous, and its greatest biomass of phytoplankton, indicative of nutrient consumption during photosynthesis. If temperature had a stronger effect upon pH than phytoplankton, pH would have decreased during the warmest months of July and August, which occurred in August, when the phytoplankton biomass was half of July’s concentration.

In comparison to AUV-collected data, pH values from traditionally-collected methods were generally similar between methods. Because 1 m pH readings were collected in situ from the traditional sampling station using a portable pH meter from the same manufacturer as the AUV, the differences in pH values may be attributed to the spatial variability of lake conditions as opposed to sampling methods.

ZOOPLANKTON

Planktivorous fishes, such as sockeye salmon, can exert top-down pressures on zooplankton communities (Kyle 1996; Stockner and MacIsaac 1996). This type of predation can result in changes to the zooplankton species composition (Helminen and Sarvala 1997; Donald et al. 2001; Thorpe and Covich 2001). Specifically, copepods can enter a state of diapause as an egg or copepodid in response to overcrowding, photoperiod, or predation (Thorpe and Covich 2001). Average monthly biomass estimates for Karluk Lake were high and composed predominately of copepods. The high monthly biomasses were typically well above the satiation level of 1,000 mg/m^2 for rearing salmonids (Mazumder and Edmundson 2002). The cladoceran, *Bosmina*, also serves as an of indicator overgrazing when its length falls below the juvenile sockeye salmon elective feeding threshold size of 0.40 mm (Kyle 1992; Schindler 1992). Respective of physical and nutrient data and the relatively large abundance of ovigerous *Bosmina* >0.40 mm in size, overgrazing seems unlikely to limit zooplankton production.

Silicon concentrations are distinctly tied to zooplankton production in Kodiak lakes (Finkle and Ruhl 2012). Kodiak lakes with low silicon concentrations consistently had high zooplankton biomasses whereas lakes with high silicon concentrations had low zooplankton biomasses.

Phytoplankton species composition and production are dependent on nutrient availability; shifts in plankton species composition are often mediated by changes in nutrient concentrations (Graham et al. 2004). Diatoms require silicon for reproduction and for creating cell walls (Wetzel 2001). Diatoms are also favored forage of copepods, which are abundant in Kodiak lakes with relatively low silicon concentrations. Data collected between 2010 and 2012 indicated that diatoms were highly abundant and had the greatest biomass of phytoplankton species in Karluk Lake (Table 16). This information infers that zooplankton rely upon diatoms to provide the nutrition that facilitates their success in Karluk Lake. Copepods in particular can take advantage of the primary production in the DCM as they can vertically migrate to the hypolimnion to graze upon the concentrated phytoplankton (Barbiero et al. 2000).

AUV IMAGERY AND BATHYMETRY

Side-scan sonar data collected from each month indicated fish presence in Karluk Lake. May and June imagery were limited in their area of coverage because of vehicle malfunctions and therefore are inconclusive. The majority of fish detected each month were located throughout the euphotic zone. Fish observed in July were located mainly in the Upper and Middle regions of the lake and were generally small, which may indicate the presence of sockeye or coho (*O. kisutch*) salmon, Dolly Varden *Salvelinus malma* juveniles or stickleback. Similarly, larger-sized fish were detected near tributary streams and spawning shoals from July through September, which may be adult sockeye salmon or Dolly Varden returning to their spawning locations. Fish detected in September coincided with the influx of adult salmon.

Karluk Lake experienced high water levels extending beyond gravel shorelines into grassy areas throughout the season. Such high water levels may have allowed returning adults to more readily enter tributary streams, reducing the fish presence in the Lower region of the lake during July, August, and September. Similarly, fewer fish would be detected in the Lower region following the outmigration of sockeye salmon juveniles in May and June. Analysis of fish presence relative to a location's conditions cannot be quantified at this time.

It should be noted that detection of fish location was limited to the path that the AUV scanned. Additionally, although individual fish can be discerned in the imagery, species cannot be identified and enumeration is not possible because any overlap of schooling fish precludes accurate counts and the ability to estimate species composition.

Bathymetric data collected in 2012 was added to the Karluk Lake AUV bathymetry data set that has been collected since 2009. There were no substantial changes to the estimates of lake area, volume, mean depth, or maximum depth with the inclusion of 2012 data.

The AUV volume data estimated from this study when limited to the euphotic zone depth showed the greatest volume of water capable of photosynthesis coincided with the lowest biomass of phytoplankton. This event followed the June season-high bloom of zooplankton (>3,400 mg/m^2), which suggests that zooplankton grazing affects phytoplankton production and that phytoplankton biomass can be dense enough to limit light penetration.

CONCLUSIONS

Through the course of this study, numerous patterns of lacustrine productivity have been identified in Karluk Lake. Simplistically, Karluk Lake is deep, clear, and relatively low in nutrients but supports healthy phytoplankton and zooplankton production. These conditions raise the question as to whether the nutrient and zooplankton levels seen in Karluk Lake are what is available or what is left over from consumption. This question is important to ask because changes in nutrient levels can greatly affect trophic cascades (Carpenter et al. 2010) and therefore the success of salmon populations vital to many user groups.

Increases in nutrients levels can intensify trophic cascades, altering the relationships between forage bases and prey (Hansson et al. 1998; Lathrop et al. 2002). After examining relationships among phosphorous and chlorophyll relative to zooplankton, weak trends were apparent that at low phosphorous (R^2=0.28, P=0.01) and chlorophyll (R^2=0.46, P=0.0008) concentrations, higher zooplankton biomasses occurred. These relationships suggest that phosphorous was being utilized for photosynthesis and chlorophyll was being consumed by zooplankton, and because zooplankton were abundant, the nutrient and chlorophyll levels seen may be what was left over.

In light of the AUV chlorophyll data, it is also possible that patchiness of primary production may not be captured by the traditional sampling methods and underestimate available resources. This may be more of an issue, however, when the lake is stratified; AUV data indicated fairly homogenous chlorophyll concentrations across Karluk Lake during known mixing events in May and September.

Similarly, the existence of a DCM in Karluk Lake may also temper any resource limitations as nutrient concentrations below the epilimnion may contribute to lake productivity. A significant relationship exists between phosphorous and chlorophyll (2006, 2009 to 2012 data) in the epilimnion during August stratification (R^2=0.93, P=0.00003). Similar strong relationships also exist below the epilimnion in August (R^2=0.61, P=0.04) and September (R^2=0.95, P=0.0002). With the exception of 2005, no hypolimnion phytoplankton data are available for Karluk Lake to link primary productivity at depth: data are not available to quantify the presence or absence of species better suited to low light conditions or able to migrate between the DCM and epilimnion. Zooplankton data, however, may address DCM productivity to some extent. For example, in Lake Superior, cladocerans such as *Daphnia* and *Bosmina* were confined to the top 20 m of the water column while copepods were found well below the epilimnion (Barbiero and Tuchman 2004). The copepod *Cyclops*, which is a relatively strong swimmer (Thorpe and Covich 2001), has been the predominate zooplankton species in Karluk Lake and thus, may be taking advantage of DCM productivity. Separate plankton tows taken from 50 m and from the bottom of the epilimnion (~20 m) would be needed to validate this hypothesis.

The relationships between variables in Karluk Lake highlights the importance of each factor's ability to influence productivity and, thus, the inherent need for continued study. As primary production is the base of a limnetic food web, any changes in it may significantly impact higher trophic levels such as secondary or tertiary consumers (Milovskaya et al. 1998). In some lake systems, a negative change in rearing conditions at these levels can cause migratory behavior or decreased juvenile sockeye salmon freshwater survival (Parr 1972; Ruggerone 1994; Bouwens and Finkle 2003). Thus, it is important to know and understand patterns of resource abundance and habitat usage to effectively manage a system and conserve its resources. Continued limnological observation of Karluk Lake is necessary for identifying if its rearing habitat may have deleterious effects upon its rearing salmonids.

ACKNOWLEDGEMENTS

Numerous individuals helped make the Karluk Lake Limnology project a success. Darin Ruhl did an outstanding job of scheduling, collecting, and processing samples. Dawn Hunt and Jodi Estrada helped with data collection, analysis, and database development. Melony Lechner provided logistic and field support. Thanks go to Jack Napier for supporting submariner efforts since the 1940s. The Kodiak National Wildlife Refuge provided flight support and use of the Camp Island facilities: particular thanks go to Bill Pyle, Bill Leacock, and Kevin Van Hatten. Cecilia Curtis, Debbie Maas, Molly McCafferty, Teresa Tavel, Robin Gardner, and Lori Ryser provided project and administrative support. Kathy Greer polished this report with her publication expertise. Darin Ruhl, Jodi Estrada, Michelle Moore, Nick Sagalkin, and an anonymous peer insightfully reviewed this document and get superstar status for their help. References to trade names do not imply endorsement by the Alaska Department of Fish and Game.

REFERENCES CITED

Barbiero, R. P., L. L. Stracht, and M. A. Martino. 2000. Effects of the vertical distribution of zooplankton on the estimation abundance and biovolume using deep and shallow tows. U. S. EPA, Great Lakes National Program Office, Chicago, IL.

Barbiero, R. P., and M. L. Tuchman. 2004. The deep chlorophyll maximum in Lake Superior. International Association of Great Lakes Research. Journal of Great Lakes Research 30 (Supplement 1):256-268.

Bilby, R. E., B. R. Frasen, and P. A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of streams: evidence from stable isotopes. Canadian Journal of Fisheries and Aquatic Sciences. 53:164-173.

Bouwens, K. A., and H. Finkle. 2003. Chignik watershed ecological assessment project season report, 2001. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report No. 4K03-10, Kodiak.

Carlson, R. E. 1977. A trophic state index for lakes. Limnology and Oceanography 22(2):361-369.

Carlson, R. E., and J. Simpson. 1996. A coordinator's guide to volunteer lake monitoring methods. North American Lake Management Society.

Carpenter, S. R, J. J. Cole, J. F. Kitchell, and M. L. Pace. 2010. Trophic cascades in lakes: lessons and prospects. Pages 55-69 [*In]* Trophic cascades: predators, prey and the changing dynamics of nature*,* trophic cascades in lakes: lessons and prospects*.* J. Terborgh and J. Estes, editors. Island Press*,* Washington, DC.

COLAP (Congress on Lake and Pond Associations, Inc.). 2001. Standard operating procedures for chlorophyll *a* sampling. Boston, Massachusetts.

Dodson, S. I., and D. G. Frey. 2001. The Cladocera and other Branchiopoda [*In*] Ecology and systematics of North American freshwater invertebrates. 2nd Edition. J. E. Thorpe and A. P. Covich, editors. Academic Press.

Donald, D. B., R. D. Vinebrooke, R. S. Anderson, J. Syrgiannis, and M. D. Graham. 2001. Recovery of zooplankton assemblages in mountain lakes from the effects of introduced sport fish. Canadian Journal of Fisheries and Aquatic Sciences. 58:1822-1830.

Edmundson, J. A., L. E. White, S. G. Honnold and G. B. Kyle. 1994. Assessments of sockeye salmon production in Akalura Lake. Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, Regional Information Report 5J94-17, Juneau.

Finkle, H. 2012. Limnological assessment of Kodiak and Alaska Peninsula salmon lakes, 2011. Alaska Department of Fish and Game, Fishery Data Series No. 12-55, Anchorage.

Finkle, H., and D. C. Ruhl. 2011. Assessment of Kodiak salmon lakes using an autonomous underwater vehicle, 2009. Alaska Department of Fish and Game, Fishery Data Series No. 11-29, Anchorage.

Finkle, H., and D. Ruhl. 2012. Limnological assessment of Kodiak and Alaska Peninsula salmon lakes, 2010. Alaska Department of Fish and Game, Fishery Data Series No. 12-20, Anchorage.

Forsberg, C., and S. O. Ryding. 1980. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. Archiv fur Hydrobiologie 88:189-207.

Graham, J. M., A. D. Kent, G. H. Lauster, A. C. Yannarell, L. E. Graham, and E. W. Triplett. 2004. Seasonal dynamics of phytoplankton and planktonic protozoan communities in a northern temperate humic lake: diversity in a dinoflagellate dominated system. Microbial Ecology 48: 528-540.

Hansson, L. A., H.. Annadotter, E. Bergman, S. F. Hamrin, E. Jeppesen, T. Kairesalo, E. Luokkanen, P. A. Nilsson, M. Sondergaard, and J. Strand. 1998. Biomanipulation as an application of food-chain theory: Constraints, synthesis and recommendations for temperate lakes. Ecosystems 1:558-574.

Helminen, H., and J. Sarvala. 1997. Responses of Lake Pyhäjärvi (southwestern Finland) to variable recruitment of the major planktivorous fish, vendace (*Coregonus albula*). Canadian Journal of Fisheries and Aquatic Sciences. 54:32-40.

REFERENCES CITED (Continued)

Kerfoot, W. C. 1987. Cascading effects and indirect pathways. p. 57-69 [*In*] Predation: Direct and indirect impacts on aquatic communities. Kerfoot, W. C. and A. Sih, editors. University Press of New England. Hanover and London.

Kiffney, P. M., R. E. Bilby, and B. L. Sanderson. 2005. Monitoring the effects of nutrient enrichment on freshwater ecosystems. Pages 237-263 [*In*] Methods for monitoring stream and watershed restoration. P. Roni, editor. American Fisheries Society, Bethesda, Maryland.

Kirk, K. L., and J. J. Gilbert. 1990. Suspended clay and the population dynamics of planktonic rotifers and cladocerans. Ecology 71(5):1741-1755.

Koenings, J. P., and R. D. Burkett. 1987. Population characteristics of sockeye salmon (*Oncorhynchus nerka*) smolts relative to temperature regimes, euphotic volume, fry density, and forge base within Alaskan lakes. Pages 216-234 [*In*] Sockeye salmon (*Oncorhynchus nerka*) population biology and future management. H.D. Smith, L. Margolis, and C. C. Wood, editors. Canadian Special Publications in Fisheries and Aquatic Sciences. Volume 96.

Koenings, J. P., J. A. Edmundson, G. B. Kyle, J. M. Edmundson, and R. B. Burkett. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, Division of Fisheries Rehabilitation, Enhancement, and Development, No. 71. Juneau.

Koenings, J. P., and G. B. Kyle. 1997. Consequences to juvenile sockeye salmon and the zooplankton community resulting from intense predation. Alaska Fisheries Research Bulletin 4(2):120-135.

Kyle, G. B. 1992. Assessment of lacustrine productivity relative to juvenile sockeye salmon *Oncorhynchus nerka* production in Chignik and Black Lakes: results from 1991 surveys. Alaska Department of Fish and Game, FRED Division Report Series 119, Juneau.

Kyle, G. B. 1996. Stocking sockeye salmon (*Oncorhynchus nerka*) in barren lakes of Alaska: effects on the macrozooplankton community. Fisheries Research 28 (1996) 29-44.

Lathrop, R. C., B. M. Johnson, T. B. Johnson, M. T. Vogelsang, S. R. Carpenter, T. R. Hrabik, J. F. Kitchell, J. J. Magnuson, L. G. Rudstam, and R. S. Stewart. 2002. Stocking piscivores to improve fishing and water clarity: A synthesis of the Lake Mendota biomanipulation project. Freshwater Biology 47:2410-2424.

Mazumder, A., and J.A. Edmundson. 2002. Impact of fertilization and stocking on trophic interactions and growth of juvenile sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 59:1361-1373.

Michaud, J. P. 1991. A citizen's guide to understanding and monitoring lakes and streams. Publ. #94-149. Washington State Dept. of Ecology, Publications Office, Olympia, WA, USA.

Milovskaya, L. V., M. M. Selifonov, and S. A. Sinyakov. 1998. Ecological functioning of Lake Kuril relative to sockeye salmon production. North Pacific Anadromous Fish Commission Bulletin. No. 1: 434-442.

Parr, W. H., Jr. 1972. Interactions between sockeye salmon and resident lake fish in the Chignik Lakes, Alaska. M.S. thesis, University of Washington, Seattle.

Ruggerone, G. T. 1994. Investigations of salmon populations, hydrology, and limnology of the Chignik Lakes, Alaska, during 1993. Natural Resources Consultants, Inc. Seattle Wa.

Schindler, D. E. 1992. Nutrient regeneration of sockeye salmon (*Oncorhynchus nerka*) fry and subsequent effects on zooplankton and phytoplankton. Canadian Journal of Fisheries and Aquatic Sciences 49:2498-2506.

Stockner, J. G., and E. A. MacIssac. 1996. British Colombia lake enrichment programme: Two decades of habitat enhancement for sockeye salmon. Regulated Rivers: Research and Management, Vol. 12, 547-561.

Thomsen, S. E. 2008. Kodiak Island lake assessment/limnology project laboratory analysis operational plan. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional information Report 4K08-4, Kodiak.

REFERENCES CITED (Continued)

Thorpe, J. H., and A. P. Covich. 2001. Ecology and classification of North American freshwater invertebrates. Academic Press, San Diego, California.

Turner, J. T., A. Ianora, A. Miralto, M. Laabir, and F. Esposito. 2001. Decoupling of copepod grazing rates, fecundity and egg hatching success on mixed and alternating diatom and dinoflagellate diets. Marine Ecology Progress Series 220:187-199.

UF (University of Florida). 2000. A beginner's guide to water management–nutrients. Department of Fisheries and Aquatic Sciences, Institute of Food and Agricultural Sciences, University of Florida, Gainesville. http://lakewatch.ifas.ufl.edu/LWcirc.html

USEPA (United States Environmental Protection Agency). 2000. Nutrient criteria technical guidance manual: lakes and reservoirs. Washington, D. C.

Vinyard, W. C. 1979. Diatoms of North America. Mad River Press, Inc. Eureka, CA.

Wetzel, R. G. 1983. Limnology. CBS College Publishing. New York.

Wetzel, R. G. 2001. Limnology. Academic Press. San Diego.

YSI (Yellow Springs Instruments). 2009. YSI Ecomapper operation manual. Yellow Springs, OH.

TABLES AND FIGURES

Table 1.–Sampling dates and methods used for Karluk Lake, 2012.

Sample dates	Methods
23-May	W, Z, AUV
24-May	AUV
18-Jun	AUV
19-Jun	AUV
20-Jun	W, Z
24-Jul	AUV
25-Jul	W, Z, AUV
28-Aug	AUV
29-Aug	AUV
30-Aug	W, Z
18-Sep	AUV
20-Sep	W, Z, AUV
17-Oct	W, Z

Note: W = water sampling, Z = zooplankton sampling, AUV = AUV sampling.

Table 2.–Monthly average temperature (°C) measurements from Karluk Lake, 2012.

Depth (m)	Date						Seasonal Average
	23-May	20-Jun	25-Jul	30-Aug	20-Sep	17-Oct	
0.1	4.3	10.1	11.3	11.3	9.7	7.2	9.0
0.5	4.1	9.7	11.2	11.3	9.7	7.3	8.9
1	3.9	9.4	11.2	11.3	9.7	7.3	8.8
1.5	3.9	9.3	11.1	11.3	9.6	7.3	8.8
2	3.9	9.2	11.1	11.3	9.6	7.4	8.7
2.5	3.9	9.1	11.0	11.3	9.6	7.4	8.7
3	3.9	9.0	10.9	11.3	9.6	7.4	8.7
3.5	3.8	8.9	10.9	11.3	9.5	7.4	8.6
4	3.8	8.8	10.8	11.3	9.5	7.4	8.6
4.5	3.8	8.7	10.8	11.3	9.5	7.4	8.6
5	3.8	8.6	10.8	11.3	9.5	7.4	8.6
6	3.7	8.3	10.7	11.3	9.5	7.4	8.5
7	3.7	7.9	10.7	11.3	9.4	7.4	8.4
8	3.7	7.6	10.6	11.3	9.4	7.4	8.3
9	3.7	7.4	10.4	11.3	9.2	7.4	8.2
10	3.7	7.2	10.2	11.2	9.2	7.4	8.1
11	3.7	7.0	10.0	11.2	9.1	7.4	8.0
12	3.7	6.9	9.7	11.1	9.0	7.4	7.9
13	3.7	6.8	9.1	11.0	9.0	7.4	7.8
14	3.7	6.6	8.9	10.8	9.0	7.4	7.7
15	3.7	6.4	8.5	10.3	8.9	7.4	7.5
16	3.7	6.2	8.2	10.0	8.9	7.4	7.4
17	3.7	6.1	8.0	9.7	8.9	7.4	7.3
18	3.7	5.9	7.8	9.6	8.9	7.4	7.2
19	3.7	5.8	7.5	9.4	8.8	7.4	7.1
20	3.7	5.7	7.3	9.3	8.8	7.4	7.0
21	3.7	5.6	7.0	9.1	8.8	7.4	6.9
22	3.7	5.5	6.8	8.7	8.7	7.4	6.8
23	3.7	5.5	6.6	8.4	8.7	7.4	6.7
24	3.7	5.5	6.4	8.0	8.7	7.4	6.6
25	3.7	5.4	6.6	7.7	8.6	7.4	6.6
30	3.7	5.3	6.1	6.9	8.1	7.4	6.2
35	3.7	5.0	5.8	6.5	7.7	7.4	6.0
40	3.7	4.9	5.6	6.3	7.2	7.4	5.8
45	3.7	4.8	5.4	6.0	6.7	7.4	5.7
50	3.7	4.6	5.2	5.8	6.4	7.3	5.5

Table 3.–Monthly average dissolved oxygen (mg/L) measurements from Karluk Lake, 2012.

	Date						Seasonal
Depth (m)	23-May	20-Jun	25-Jul	30-Aug	20-Sep	17-Oct	Average
0.1	12.4	12.9	12.2	11.5	11.6	12.0	12.1
0.5	12.4	12.9	12.2	11.5	11.6	11.9	12.1
1	12.5	13.0	12.2	11.5	11.6	11.9	12.1
1.5	12.5	13.0	12.2	11.5	11.6	11.9	12.1
2	12.5	13.1	12.2	11.5	11.6	11.9	12.1
2.5	12.4	13.1	12.2	11.5	11.6	11.8	12.1
3	12.4	13.1	12.3	11.5	11.6	11.8	12.1
3.5	12.4	13.1	12.3	11.5	11.6	11.8	12.1
4	12.4	13.1	12.3	11.5	11.6	11.8	12.1
4.5	12.4	13.1	12.3	11.5	11.6	11.8	12.1
5	12.4	13.2	12.3	11.5	11.5	11.8	12.1
6	12.4	13.2	12.3	11.5	11.5	11.8	12.1
7	12.4	13.2	12.3	11.5	11.5	11.8	12.1
8	12.4	13.2	12.3	11.4	11.5	11.7	12.1
9	12.4	13.2	12.3	11.4	11.5	11.7	12.1
10	12.3	13.2	12.3	11.4	11.5	11.7	12.1
11	12.3	13.1	12.3	11.4	11.4	11.7	12.0
12	12.3	13.1	12.3	11.4	11.4	11.7	12.0
13	12.3	13.1	12.3	11.4	11.4	11.7	12.0
14	12.3	13.0	12.2	11.4	11.4	11.6	12.0
15	12.3	12.9	12.2	11.4	11.3	11.6	11.9
16	12.2	12.8	12.2	11.4	11.3	11.6	11.9
17	12.2	12.8	12.1	11.3	11.3	11.6	11.9
18	12.2	12.7	12.1	11.3	11.3	11.5	11.9
19	12.2	12.6	12.1	11.3	11.3	11.5	11.8
20	12.2	12.6	12.0	11.3	11.2	11.5	11.8
21	12.1	12.5	12.0	11.3	11.2	11.5	11.8
22	12.1	12.5	11.9	11.3	11.2	11.5	11.8
23	12.1	12.5	11.9	11.3	11.2	11.5	11.7
24	12.1	12.4	11.9	11.3	11.2	11.4	11.7
25	12.1	12.4	11.9	11.2	11.1	11.4	11.7
30	12.0	12.3	11.8	11.1	11.0	11.3	11.6
35	11.9	12.2	11.7	11.0	10.9	11.2	11.5
40	11.8	12.0	11.5	10.9	10.7	11.2	11.4
45	11.7	11.8	11.4	10.8	10.6	11.1	11.2
50	11.6	11.7	11.0	10.6	10.4	10.8	11.0

Table 4.–Monthly average light penetration (µmol s^{-1} m^{-2}) measurements from Karluk Lake, 2012.

	Date						Seasonal
Depth (m)	23-May	20-Jun	25-Jul	30-Aug	20-Sep	17-Oct	Average
0.1	820.3	1,277.7	759.3	24.4	297.7	218.7	635.9
0.5	698.7	1,058.7	651.7	20.2	258.7	181.7	537.6
1	574.0	940.7	546.3	17.6	216.7	133.7	459.0
1.5	563.7	820.0	394.7	14.1	185.0	104.0	395.5
2	470.7	687.0	306.7	12.1	159.3	94.0	327.2
2.5	409.0	555.7	273.0	11.0	142.0	86.4	278.1
3	297.0	489.3	240.3	10.3	127.3	79.7	232.9
3.5	323.3	419.3	247.0	9.5	112.4	72.3	222.3
4	337.7	401.7	223.3	8.9	102.4	66.9	214.8
4.5	276.0	352.3	211.7	8.4	91.2	58.7	187.9
5	224.7	276.3	187.7	7.8	81.9	53.2	155.7
6	188.0	193.7	149.8	6.6	66.4	44.1	120.9
7	145.5	166.0	115.5	5.7	54.8	35.9	97.5
8	105.8	117.7	86.8	4.8	44.3	28.5	71.9
9	71.6	93.8	65.6	4.1	36.8	23.0	54.4
10	56.7	76.1	54.4	3.4	30.3	18.2	44.2
11	48.2	59.6	44.2	2.9	24.9	14.7	36.0
12	40.4	45.1	37.4	2.4	20.9	11.8	29.2
13	36.2	35.6	31.7	2.0	17.4	9.4	24.6
14	29.0	28.9	26.5	1.7	14.6	7.5	20.1
15	26.2	22.3	22.3	1.4	12.2	5.9	16.9
16	21.2	18.4	18.0	1.2	10.1	4.5	13.8
17	16.1	15.4	14.5	1.0	8.5	3.2	11.1
18	13.6	12.4	11.6	0.8	7.1	2.4	9.1
19	12.7	10.3	8.7	0.7	5.9	1.6	7.7
20	7.7	8.1	6.9	0.6	4.9	1.0	5.6
21	6.7	6.7	5.6	0.5	4.1	0.5	4.7
22	5.4	5.5	4.9	0.4	3.4	0.8	3.9
23	4.1	4.5	4.1	0.3	2.9	0.3	3.2
24		3.8	3.2	0.3	2.4		2.4
25		3.1	2.8	0.2	2.0		2.0
26				0.2	1.8		1.0
27				0.1			0.1
28				0.2			0.2
29							
30							

Table 5.–Monthly average euphotic zone depth and euphotic volume estimates for Karluk Lake, 2012.

Month	Euphotic zone depth (m)	Euphotic volume (x 10^6 m^3)
May	19.38	606
June	17.03	535
July	20.54	640
August	25.09	773
September	22.11	684
October	19.07	596

Table 6.–Monthly and seasonal averages of water chemistry data at depth from Karluk Lake, 2012.

Depth	Sample type	May	June	July	August	September	October	Seasonal average	SE
1 meter									
	pH	7.51	8.23	8.29	7.55	7.64	7.60	7.80	0.06
	Alkalinity (mg/L $CaCO_3$)	22.7	23.8	22.8	22.3	24.3	23.1	23.1	0.12
	Total phosphorous (µg/L P)	4.6	3.3	2.6	3.9	3.4	4.1	3.7	0.12
	Total filterable phosphorous (µg/L P)	2.2	2.3	2.1	2.2	2.6	3.3	2.5	0.07
	Filterable reactive phosphorous (µg/L P)	1.9	0.6	0.5	0.2	0.2	1.3	0.8	0.11
	Total Kjeldahl nitrogen (µg/L N)	442.7	753.0	504.1	471.6	547.9	417.8	522.8	20.28
	Ammonia (µg/L N)	10.1	10.1	9.9	10.6	53.0	17.4	18.5	2.86
	Nitrate + nitrite (µg/L N)	60.6	62.5	66.3	66.3	48.1	98.8	67.1	2.82
	Organic silicon (µg/L)	230.4	681.0	332.6	571.5	185.2	222.2	370.5	34.49
	Chlorophyll *a* (µg/L)	0.53	1.60	0.64	0.69	0.75	1.71	0.99	0.09
	Phaeophytin *a* (µg/L)	0.14	0.27	0.03	0.09	0.15	0.24	0.15	0.01
Hypolimnion									
	pH	7.51	8.12	8.24	7.54	7.67	7.66	7.79	0.05
	Alkalinity (mg/L $CaCO_3$)	22.7	23.8	22.3	22.3	24.2	23.0	23.0	0.13
	Total phosphorous (µg/L P)	6.3	4.8	3.6	4.0	4.5	4.8	4.7	0.15
	Total filterable phosphorous (µg/L P)	2.6	2.7	2.1	2.5	2.9	3.3	2.7	0.07
	Filterable reactive phosphorous (µg/L P)	2.1	1.2	0.6	0.4	0.7	1.4	1.1	0.11
	Total Kjeldahl nitrogen (µg/L N)	509.0	485.6	413.3	454.5	451.5	447.2	456.0	6.87
	Ammonia (µg/L N)	7.4	8.4	8.1	9.7	54.3	17.7	17.6	3.06
	Nitrate + nitrite (µg/L N)	40.9	0.8	4.6	22.3	33.3	128.5	38.4	7.81
	Organic silicon (µg/L)	1651.9	692.1	248.9	379.1	542.7	187.5	617.0	90.02
	Chlorophyll *a* (µg/L)	0.75	1.95	1.28	0.43	0.53	1.55	1.08	0.10
	Phaeophytin *a* (µg/L)	0.19	0.27	0.14	0.17	0.06	0.17	0.17	0.01

Table 7.–Monthly average zooplankton abundance (number/m^2) from Karluk Lake, 2012.

Taxon	Date						Seasonal
	23-May	20-Jun	25-Jul	30-Aug	20-Sep	17-Oct	average
Copepods:							
Epischura	-	18,401	-	1,415	-	-	3,303
Ovig. *Epischura*	-	-	-	-	-	-	-
Diaptomus	23,531	59,625	60,244	95,541	129,600	252,389	103,488
Ovig. *Diaptomus*	-	-	5,750	3,185	12,739	6,104	4,630
Cyclops	366,596	1,492,569	1,465,234	760,350	650,389	765,393	916,755
Ovig. *Cyclops*	-	1,946	24,858	47,417	23,531	13,270	18,504
Harpaticus	-	-	-	-	-	-	-
Nauplii	320,683	144,197	57,148	100,938	149,328	127,123	149,903
Total copepods:	710,810	1,716,737	1,613,234	1,008,846	965,587	965,587	1,196,582
Cladocerans:							
Bosmina	177	-	5,485	18,047	41,667	43,347	18,120
Ovig. *Bosmina*	1,150	-	2,389	21,762	62,588	59,890	24,630
Daphnia longiremis	4,158	4,600	40,340	139,774	251,415	208,333	108,103
Ovig. *Daphnia longiremis*	442	2,123	12,031	60,510	52,725	34,943	27,129
Holopedium	-	-	-	-	-	-	-
Ovig. *Holopedium*	-	-	-	-	-	-	-
Immature cladocerans	-	8,846	21,762	94,657	50,071	23,974	33,218
Total cladocerans:	5,927	15,570	82,006	334,749	458,466	370,488	211,201
Total copepods + cladocerans	716,737	1,732,307	1,695,241	1,343,595	1,424,053	1,336,076	1,407,783

Table 8.–Monthly average zooplankton biomasses (mg/m^2) from Karluk Lake, 2012.

Taxon	Date 23-May	20-Jun	25-Jul	30-Aug	20-Sep	17-Oct	Seasonal average	Seasonal weighted average
Copepods:								
Epischura	-	41	-	11	-	-	9	-
Ovig. *Epischura*	-	-	-	-	-	-	-	-
Diaptomus	66	193	487	440	404	761	392	368
Ovig. *Diaptomus*	-	-	76	40	158	78	59	37
Cyclops	534	2,239	2,606	1,261	855	1,234	1,455	1,447
Ovig. *Cyclops*	-	10	139	257	129	75	102	101
Harpaticus	-	-	-	-	-	-	-	-
Total copepods:	600	2,483	3,307	2,009	1,546	2,148	2,015	1,953
Cladocerans:								
Bosmina	-	-	5	22	42	53	20	20
Ovig. *Bosmina*	3	-	6	54	132	126	53	52
Daphnia longiremis	6	6	74	261	389	389	188	187
Ovig. *Daphnia longiremis*	2	7	75	237	204	133	109	100
Holopedium	-	-	-	-	-	-	-	-
Ovig. *Holopedium*	-	-	-	-	-	-	-	-
Chydorinae	-	-	-	-	-	1	-	-
Total cladocerans:	11	13	160	573	767	703	371	359
Total copepods + cladocerans	611	2,496	3,467	2,582	2,313	2,851	2,386	2,312

Table 9.–Seasonal averages of zooplankton lengths (mm) from Karluk Lake, 2012.

Taxon	Date						Seasonal average length	Weighted average length
	23-May	20-Jun	25-Jul	30-Aug	20-Sep	17-Oct		
Copepods:								
Epischura	-	0.26	-	0.40	-	-	0.33	0.27
Ovig. *Epischura*	-	-	-	-	-	-	-	-
Diaptomus	0.86	0.92	1.16	1.03	0.90	0.88	0.96	0.94
Ovig. *Diaptomus*	-	-	0.99	0.49	1.45	1.47	1.10	1.25
Cyclops	0.66	0.67	0.72	0.69	0.63	0.69	0.68	0.68
Ovig. *Cyclops*	-	1.19	1.22	1.21	1.22	1.22	1.21	1.22
Harpaticus	-	-	-	-	-	-	-	-
Cladocerans:								
Bosmina	0.31	-	0.32	0.36	0.33	0.37	0.34	0.35
Ovig. *Bosmina*	0.54	-	0.34	0.48	0.47	0.48	0.46	0.47
Daphnia longiremis	0.61	0.55	0.60	0.66	0.60	0.66	0.61	0.64
Ovig. *Daphnia longiremis*	0.91	0.86	0.77	0.93	0.92	0.91	0.88	0.90

Table 10.–Karluk Lake AUV and traditionally collected temperature data, by depth, month, and region, 2012.

Region	Depth (m)		May AUV	May Traditional	June AUV	June Traditional	July AUV	July Traditional	August AUV	August Traditional	Sept AUV	Sept Traditional
Upper												
	Surface	°C	ND	4.3	ND	8.6	11.2	11.3	13.7	12.4	10.1	10.0
		SD	ND	-	ND	-	0.10	-	0.66	-	0.05	-
	1-m	°C	ND	4.1	ND	8.3	11.1	11.2	12.6	12.5	10.0	10.0
		SD	ND	-	ND	-	0.16	-	0.43	-	0.11	-
	5-m	°C	ND	4.0	ND	7.5	10.7	10.8	11.8	12.5	9.9	9.9
		SD	ND	-	ND	-	0.18	-	0.29	-	0.03	-
Middle												
	Surface	°C	4.0	4.5	8.4	10.8	10.8	11.2	12.8	11.7	9.4	9.5
		SD	0.69	-	0.61	-	0.58	-	0.81	-	0.19	-
	1-m	°C	ND	3.9	8.4	9.8	10.4	11.0	12.8	10.7	9.8	9.4
		SD	ND	-	0.60	-	0.14	-	0.29	-	0.17	-
	5-m	°C	ND	3.7	8.4	9.0	9.9	10.9	11.7	10.6	9.4	9.2
		SD	ND	-	0.15	-	0.26	-	0.22	-	0.07	-
Lower												
	Surface	°C	3.8	4.0	ND	10.8	9.9	11.4	11.6	10.9	7.9	9.7
		SD	0.13	-	ND	-	0.66	-	0.20	-	0.66	-
	1-m	°C	3.8	3.8	ND	10.1	9.8	11.3	11.7	10.8	7.7	9.7
		SD	0.07	-	ND	-	0.42	-	0.17	-	0.43	-
	5-m	°C	3.8	3.7	ND	9.2	9.1	10.6	11.6	10.8	7.7	9.4
		SD	0.02	-	ND	-	0.39	-	0.15	-	0.50	-

Note: Traditionally collected data values are from a sample size of one precluding SD calculation.

Table 11.–Karluk Lake AUV and traditionally collected dissolved oxygen data, by depth, month, and region, 2012.

			May		June		July		August		Sept	
Region	Depth (m)		AUV	Traditional	AUV	Traditional	AUV	Traditional	AUV	Traditional	AUV	Traditional
Upper												
	Surface	mg/L	ND	12.90	ND	12.82	11.34	12.16	10.12	11.41	10.47	11.59
		SD	ND	-	ND	-	0.03	-	0.05	-	0.02	-
	1-m	mg/L	ND	12.97	ND	12.91	11.37	12.19	10.19	11.40	10.45	11.56
		SD	ND	-	ND	-	0.05	-	0.08	-	0.03	-
	5-m	mg/L	ND	12.95	ND	13.07	11.37	12.23	10.18	11.34	10.45	11.53
		SD	ND	-	ND	-	0.04	-	0.06	-	0.03	-
Middle												
	Surface	mg/L	11.55	12.20	12.43	12.87	11.36	12.15	10.29	11.60	10.31	11.62
		SD	0.31	-	0.26	-	0.10	-	0.11	-	0.10	-
	1-m	mg/L	ND	12.36	12.46	13.00	11.33	12.24	10.22	11.60	10.34	11.64
		SD	ND	-	0.09	-	0.03	-	0.05	-	0.03	-
	5-m	mg/L	ND	12.34	12.44	13.14	11.40	12.21	10.43	11.58	10.20	11.59
		SD	ND	-	0.02	-	0.04	-	0.06	-	0.04	-
Lower												
	Surface	mg/L	11.33	11.90	ND	12.94	11.44	12.16	10.42	11.54	10.11	11.61
		SD	0.16	-	ND	-	0.08	-	0.06	-	0.06	-
	1-m	mg/L	11.25	12.02	ND	13.11	11.45	12.21	10.41	11.56	10.04	11.60
		SD	0.05	-	ND	-	0.04	-	0.03	-	0.04	-
	5-m	mg/L	11.16	11.98	ND	13.27	11.48	12.32	10.40	11.52	10.08	11.48
		SD	0.02	-	ND	-	0.07	-	0.02	-	0.05	-

Note: Traditionally collected data values are from a sample size of one precluding SD calculation.

Table 12.– Karluk Lake AUV turbidity data, by depth, month, and region, 2012.

Region	Depth (m)		May	June	July	August	September
Upper							
	Surface	NTU	ND	ND	1,357.91	1,417.37	1,597.43
		SD	ND	ND	88.13	193.57	1.84
	1-m	NTU	ND	ND	1,307.40	262.80	1,595.83
		SD	ND	ND	220.69	29.57	2.20
	5-m	NTU	ND	ND	1,340.45	1,355.28	1,594.43
		SD	ND	ND	202.02	212.93	2.20
Middle							
	Surface	NTU	54.78	720.89	948.61	1,074.08	1,579.25
		SD	42.86	94.97	351.71	405.92	73.72
	1-m	NTU	ND	733.59	840.31	991.38	1,592.79
		SD	ND	126.41	187.11	230.36	2.73
	5-m	NTU	ND	814.41	1,037.66	713.40	1,587.71
		SD	ND	215.62	307.49	352.31	1.57
Lower							
	Surface	NTU	74.87	ND	446.73	1,271.27	1,567.96
		SD	58.88	ND	260.47	298.10	9.01
	1-m	NTU	47.82	ND	394.96	1,338.34	1,565.81
		SD	27.54	ND	266.54	273.89	6.42
	5-m	NTU	38.03	ND	436.72	1,382.87	1,566.29
		SD	20.56	ND	500.25	123.67	5.90

Note: Turbidity was measured in nephelometric turbidity units (NTU).

Table 13.–Karluk Lake AUV and traditionally collected pH data, by depth, month, and region, 2012.

			May		June		July		August		Sept	
Region	Depth (m)		AUV	Traditional	AUV	Traditional	AUV	Traditional	AUV	Traditional	AUV	Traditional
Upper												
	Surface	pH	ND	-	ND	-	8.07	-	8.51	-	7.87	-
		SD	ND	-	ND	-	0.06	-	0.51	-	0.02	-
	1-m	pH	ND	7.59	ND	7.92	8.14	8.25	8.29	7.73	7.89	7.71
		SD	ND	-	ND	-	0.04	-	0.18	-	0.03	-
	5-m	pH	ND	-	ND	-	8.13	-	8.40	-	7.89	-
		SD	ND	-	ND	-	0.05	-	0.26	-	0.03	-
Middle												
	Surface	pH	7.75	-	8.23	-	8.15	-	7.99	-	7.93	-
		SD	0.16	-	0.09	-	0.11	-	0.06	-	0.15	-
	1-m	pH	ND	7.49	8.18	8.29	8.19	8.32	8.00	7.53	7.91	7.59
		SD	ND	-	0.07	-	0.01	-	0.01	-	0.06	-
	5-m	pH	ND	-	8.22	-	8.21	-	7.98	-	7.83	-
		SD	ND	-	0.05	-	0.03	-	0.02	-	0.05	-
Lower												
	Surface	pH	7.74	-	ND	-	8.03	-	8.08	-	8.33	-
		SD	0.30	-	ND	-	0.05	-	0.15	-	0.58	-
	1-m	pH	7.60	7.45	ND	8.47	8.03	8.29	8.06	7.40	8.26	7.63
		SD	0.15	-	ND	-	0.04	-	0.10	-	0.29	-
	5-m	pH	7.50	-	ND	-	8.03	-	8.05	-	8.16	-
		SD	0.12	-	ND	-	0.04	-	0.10	-	0.32	-

Note: Traditionally collected data values are from a sample size of one precluding SD calculation.

Table 14.–Karluk Lake AUV and traditionally collected chlorophyll data, by depth, month, and region, 2012.

Region	Depth (m)		May		June		July		August		Sept	
			AUV	Traditional	AUV	Traditional	AUV	Traditional	AUV	Traditional	AUV	Traditional
Upper												
	Surface	µg/L	ND	-	ND	-	269.94	-	264.85	-	249.00	-
		SD	ND	-	ND	-	21.03	-	42.19	-	15.44	-
	1-m	µg/L	ND	0.64	ND	1.60	261.57	0.64	262.80	0.48	243.32	0.96
		SD	ND	-	ND	-	54.39	-	29.57	-	11.72	-
	5-m	µg/L	ND	-	ND	-	255.62	-	261.48	-	247.45	-
		SD	ND	-	ND	-	62.86	-	37.47	-	15.86	-
Middle												
	Surface	µg/L	17.45	-	375.75	-	143.38	-	175.54	-	253.41	-
		SD	16.67	-	144.12	-	97.92	-	86.25	-	23.76	-
	1-m	µg/L	ND	0.32	345.39	1.83	96.49	0.64	170.54	0.96	250.26	0.32
		SD	ND	-	146.58	-	45.36	-	40.15	-	16.30	-
	5-m	µg/L	ND	-	229.43	-	170.99	-	74.44	-	255.75	-
		SD	ND	-	178.41	-	105.77	-	71.12	-	16.91	-
Lower												
	Surface	µg/L	26.62	-	ND	-	159.26	-	230.77	-	262.47	-
		SD	21.97	-	ND	-	130.03	-	74.24	-	19.05	-
	1-m	µg/L	17.18	0.64	ND	1.37	137.59	0.64	258.02	0.64	265.67	0.96
		SD	10.98	-	ND	-	131.48	-	54.09	-	21.14	-
	5-m	µg/L	16.03	-	ND	-	68.70	-	265.90	-	264.89	-
		SD	7.89	-	ND	-	77.13	-	26.44	-	21.74	-

Table 15.–Karluk Lake bathymetry statistics, 2012.

Bathymetry statistic	
Area (m^2)	38,500,000
Volume (m^3)	184,300,000
Maximum depth (m)	139.4
Average depth (m)	40.9

Table 16.–Annual seasonal average phytoplankton biomasses (mg/m^3) by phylum for Karluk Lake, 2004-2006 and 2010-2012.

	Seasonal average (mg/m^3)						Historical
Phyla	2004	2005[a]	2006	2010[a]	2011	2012	average
Bacillariophyta (Diatoms)	578.5	677.9	99.2	59.7	4,364.7	999.9	1,130.0
Chlorophyta	9.2	68.3	0.8	2.2	4.7	98.4	30.6
Chrysophyta	46.7	41.0	45.2	2.8	60.0	-	32.6
Cryptophyta	11.9	23.0	12.1	0.8	18.3	142.7	34.8
Cyanobacteria	3.1	2.7	0.2	0.2	45.3	5.2	9.4
Dinophyta	-	-	-	-	103.1	-	17.2
Euglenophyta	-	0.2	1.8	-	3.4	60.1	10.9
Haptophyta	6.9	6.6	5.1	-	-	-	3.1
Pyrrhophyta	20.9	58.8	22.8	13.9	-	168.6	47.5
Total	677.3	878.6	187.2	79.5	4,599.8	1,474.9	920.0

[a] May samples were not collected.

Table 17.–Monthly phytoplankton biomasses (mg/m^3) by phylum for Karluk Lake, 2012.

	Month						Seasonal average
Phyla	May	June	July	August	September	October	biomass (mg/m^3)
Bacillariophyta	2,540.9	1,172.7	1,011.3	283.2	396.6	594.5	999.9
Chlorophyta	9.9	38.4	5.1	46.1	162.8	328.1	98.4
Cryptophyta	391.2	270.1	33.0	117.2	7.7	36.9	142.7
Cyanobacteria	0.6	0.8	8.0	2.4	6.0	13.0	5.2
Euglenophyta	13.7	80.0	-	188.3	42.8	36.1	60.1
Pyrrophyta	138.1	200.5	297.2	39.3	277.7	58.9	168.6
Monthly total	3,094.5	1,762.5	1,354.7	676.5	893.5	1,067.5	1474.9

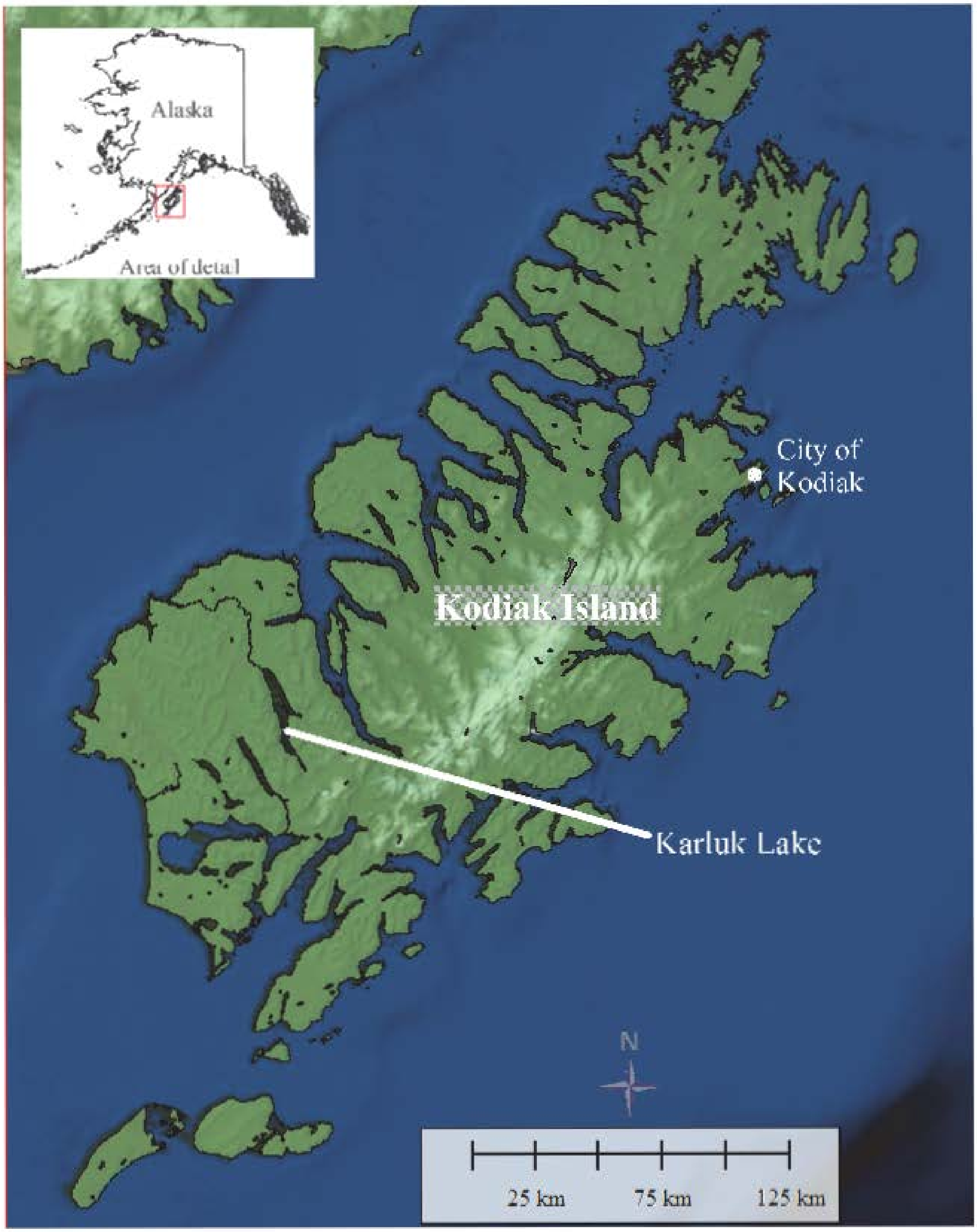


Figure 1.–Map of Kodiak Island, Alaska highlighting Karluk Lake's location.

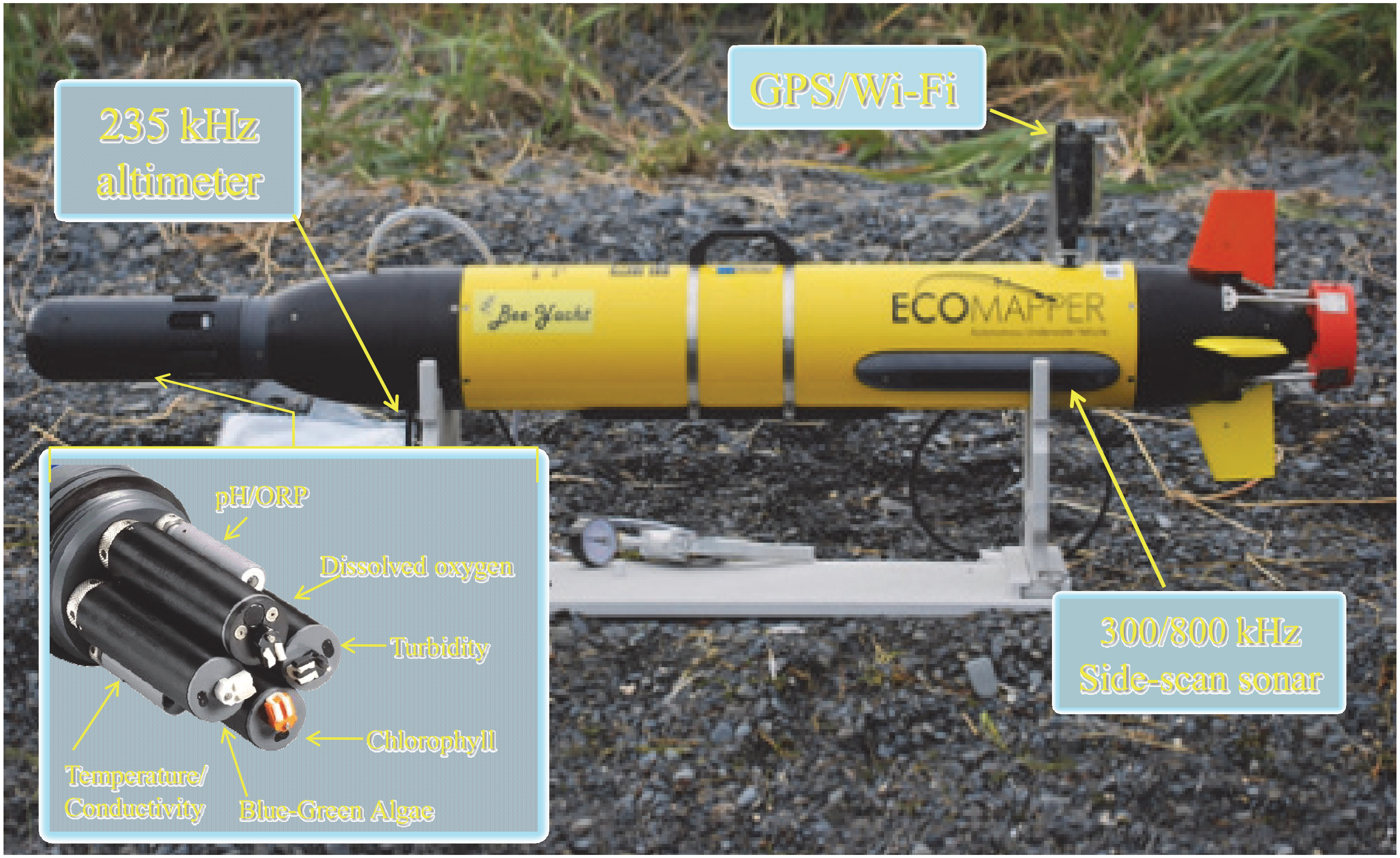


Figure 2.–The AUV and its features.

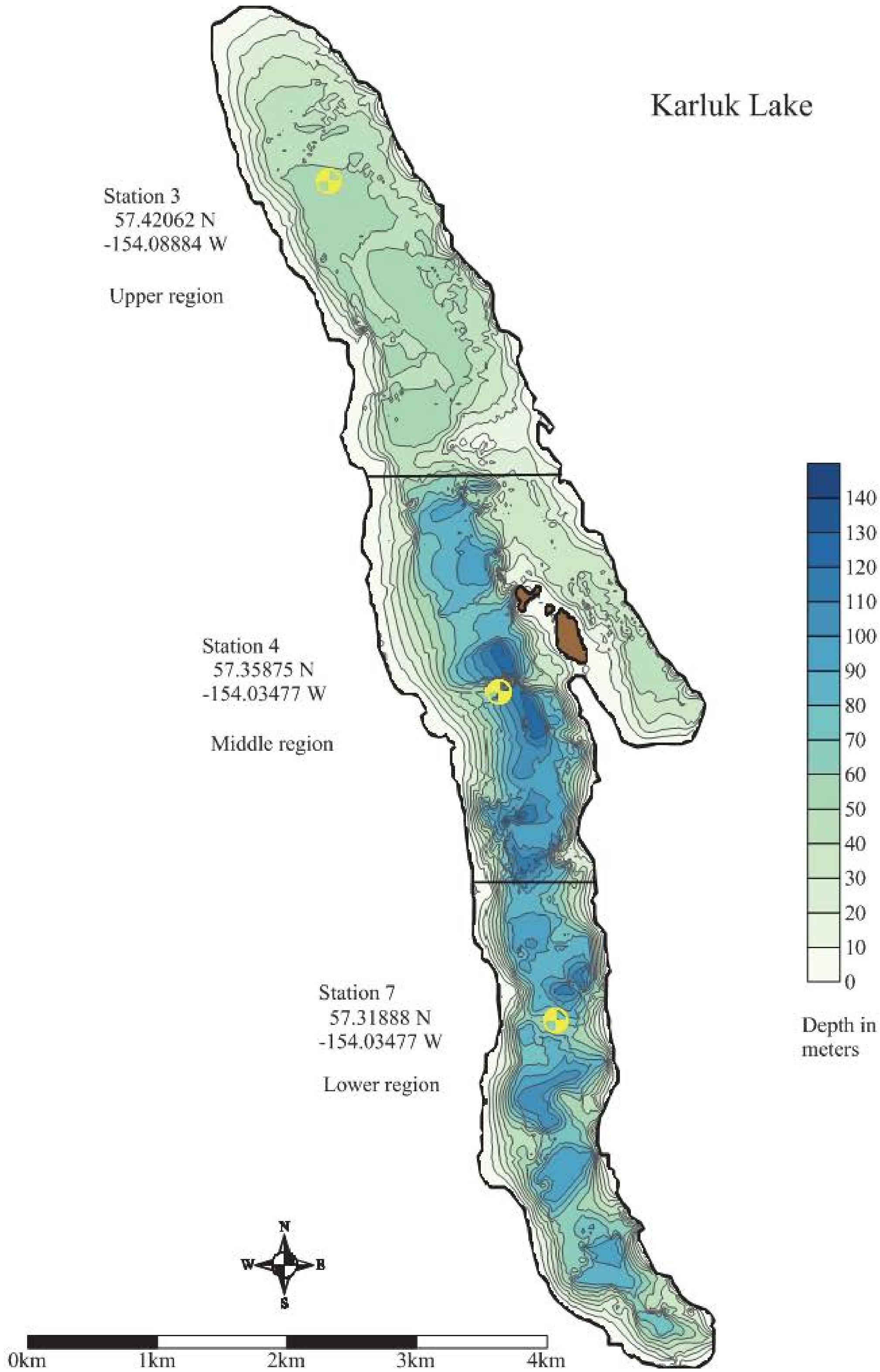


Figure 3.– AUV sampling regions and locations of traditional sampling stations for Karluk Lake, 2012.

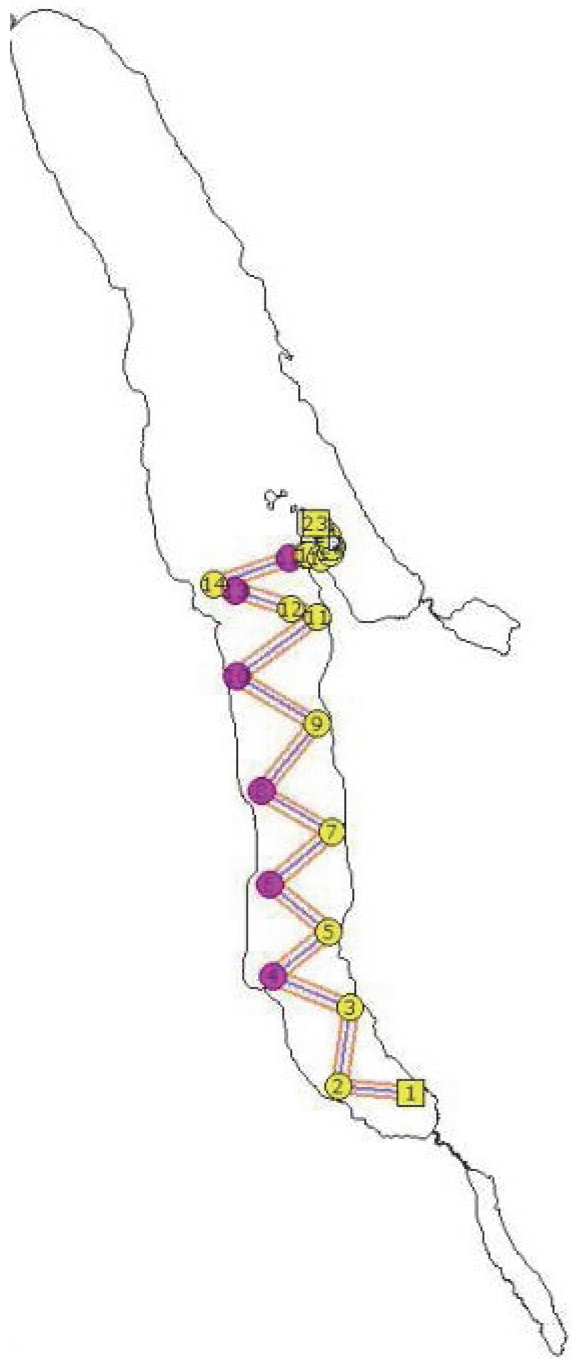


Figure 4.–Example of an AUV mission plotted in Karluk Lake using VectorMap software.

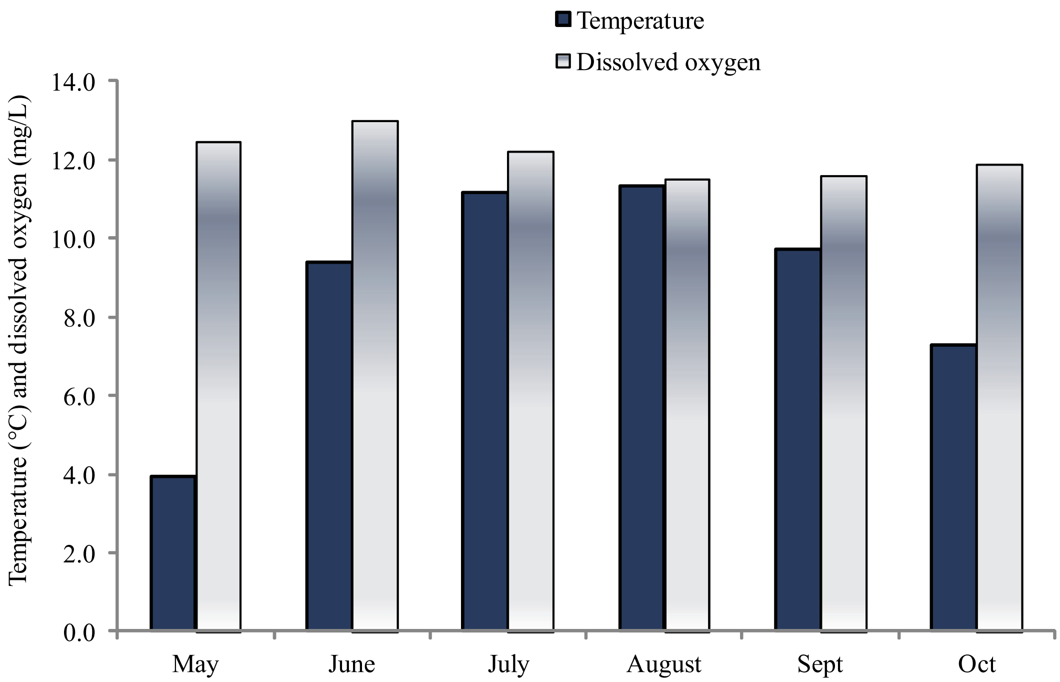


Figure 5.–Seasonal average 1 m temperature and dissolved oxygen measurements from Karluk Lake, 2012.

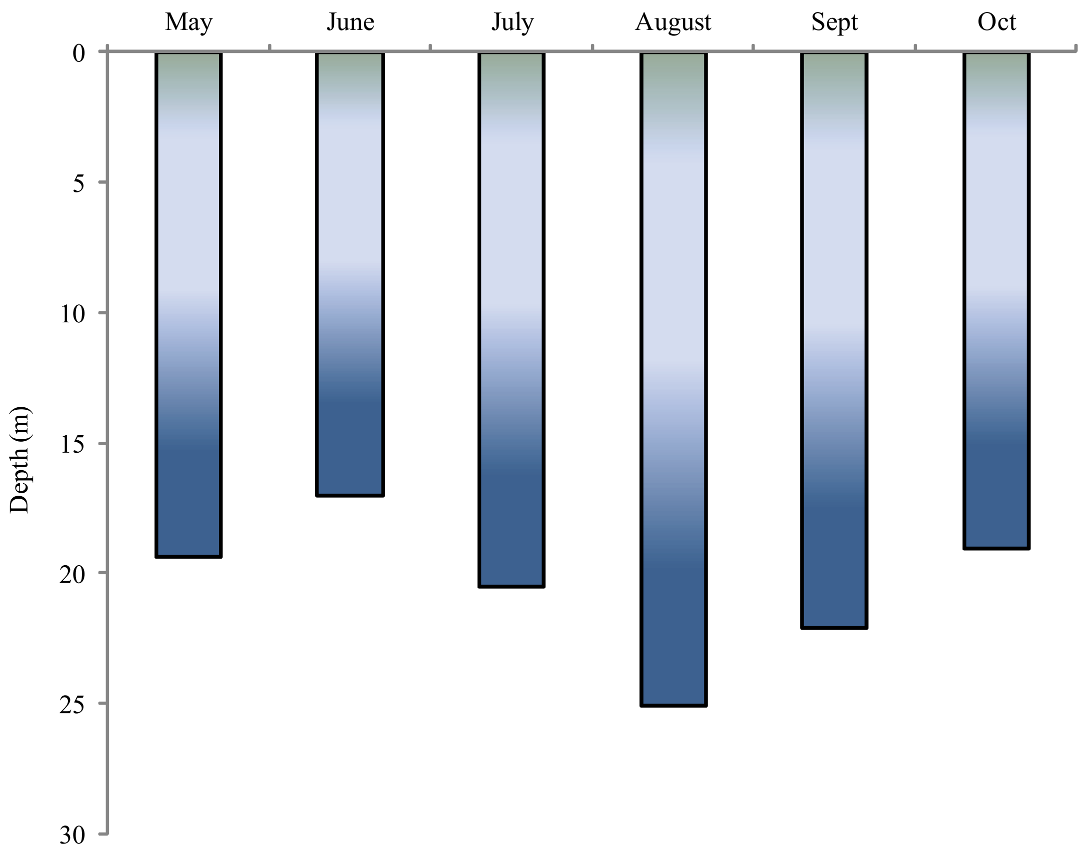


Figure 6.–Seasonal average euphotic zone depth (EZD) for Karluk Lake, 2012.

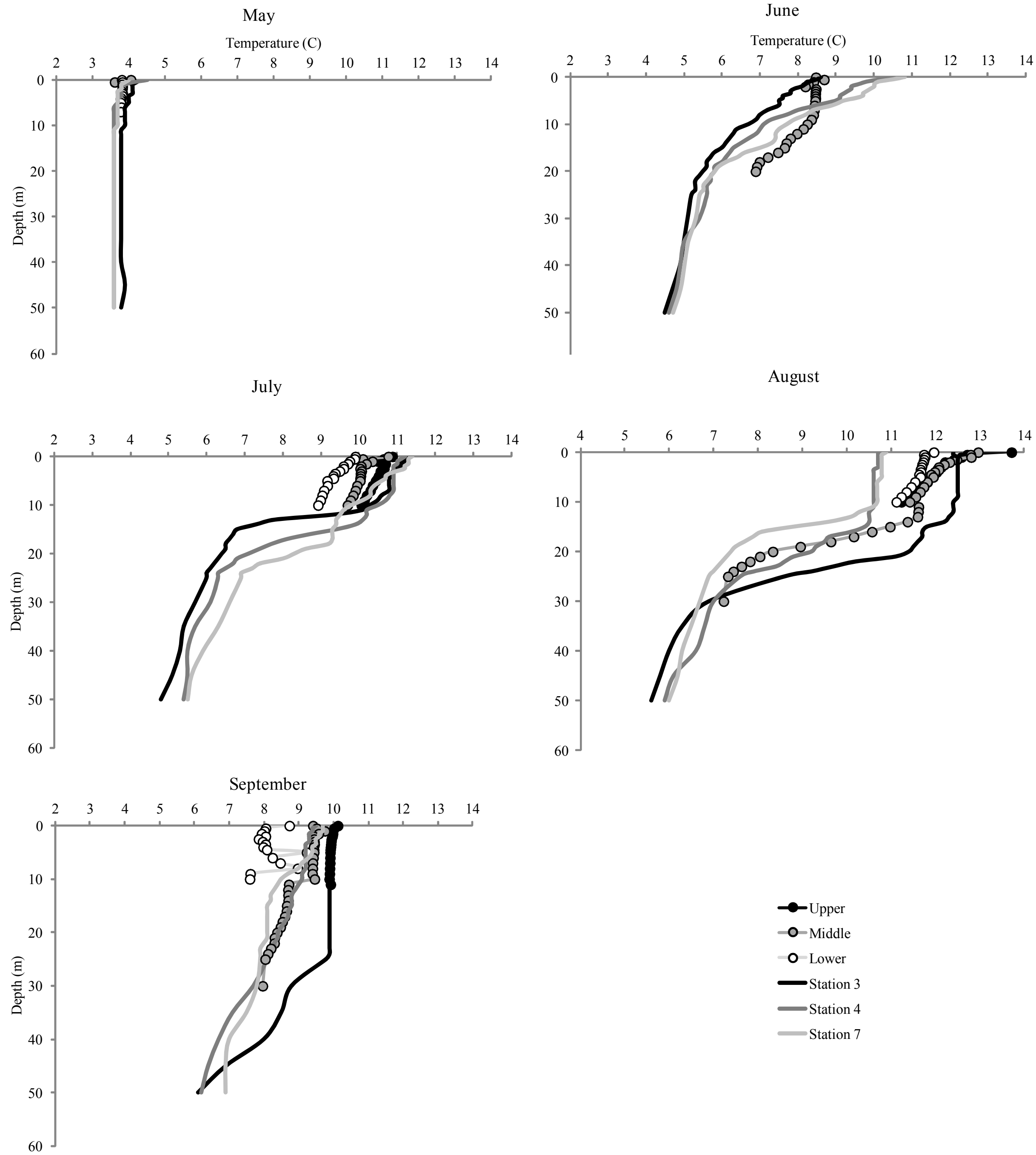


Figure 7.–Karluk Lake AUV (Lower, Middle, Upper) temperature depth profiles by month compared to traditionally collected (Stations 3, 4, and 7) data, 2012.

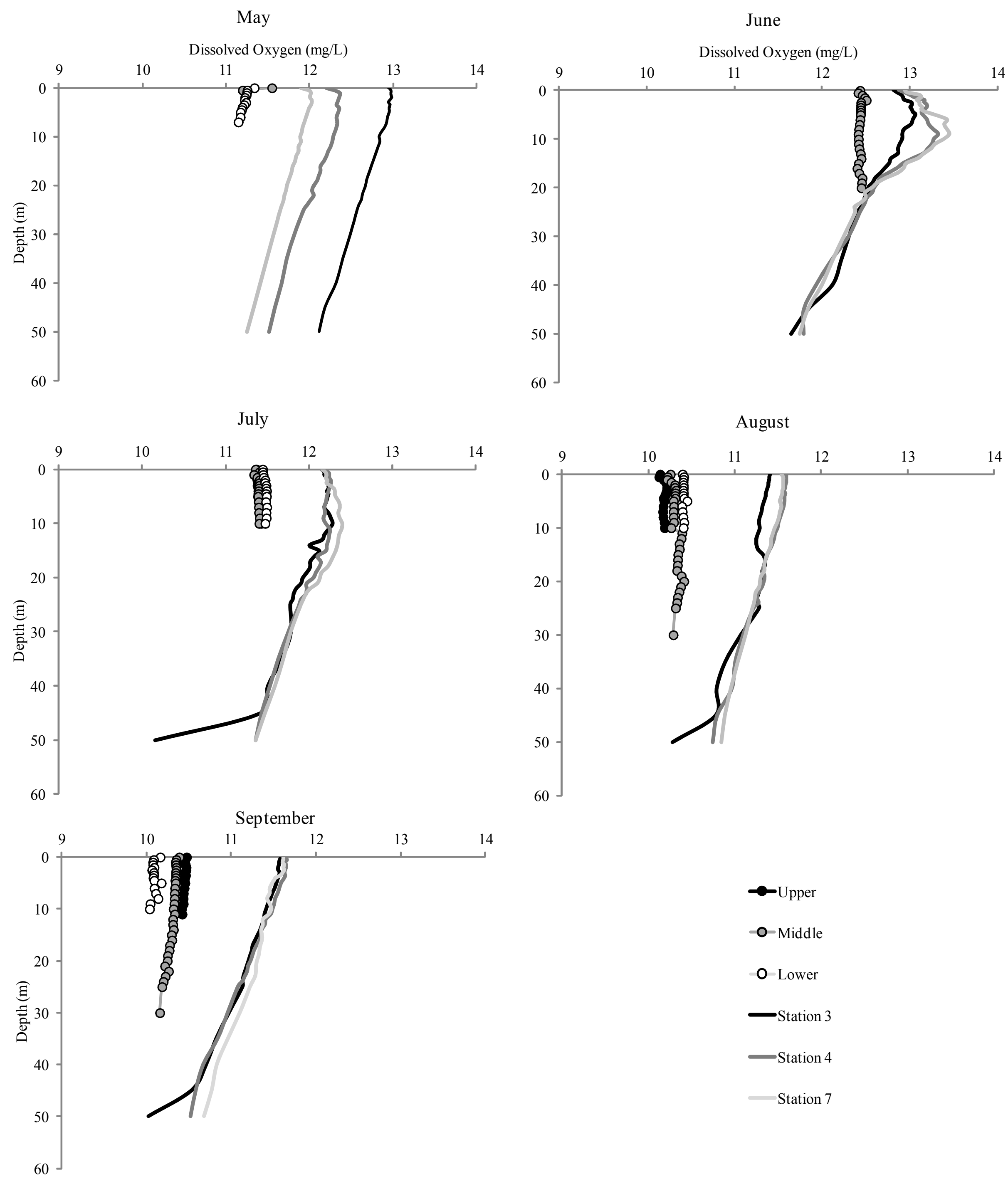


Figure 8.–Karluk Lake AUV (Lower, Middle, Upper) dissolved oxygen depth profiles by month compared to traditionally collected (Stations 3, 4, and 7) data, 2012.

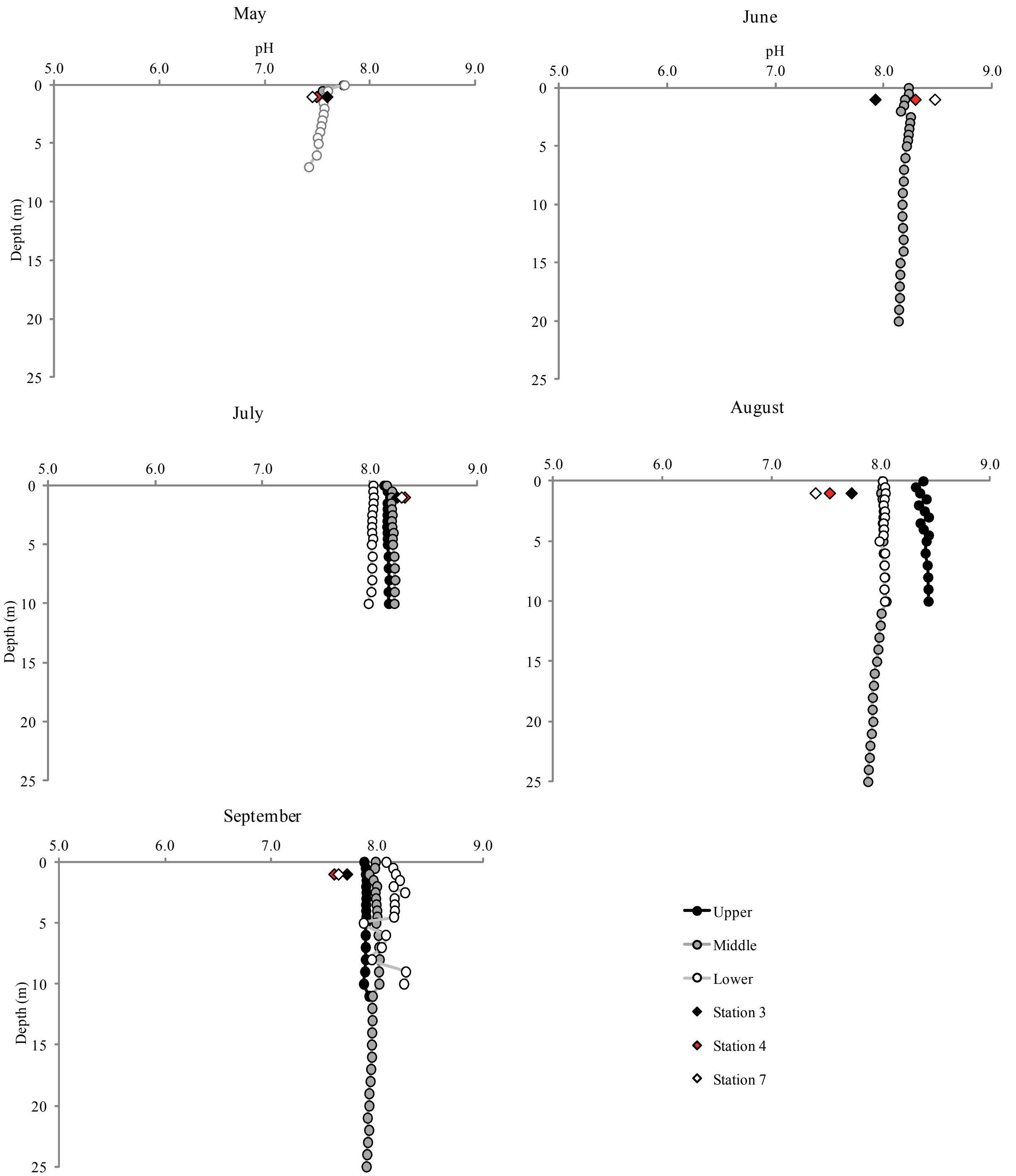


Figure 9.–Karluk Lake AUV (Upper, Middle, Lower) pH depth profiles by month compared to traditionally collected (Stations 3, 4, and 7) data, 2012.

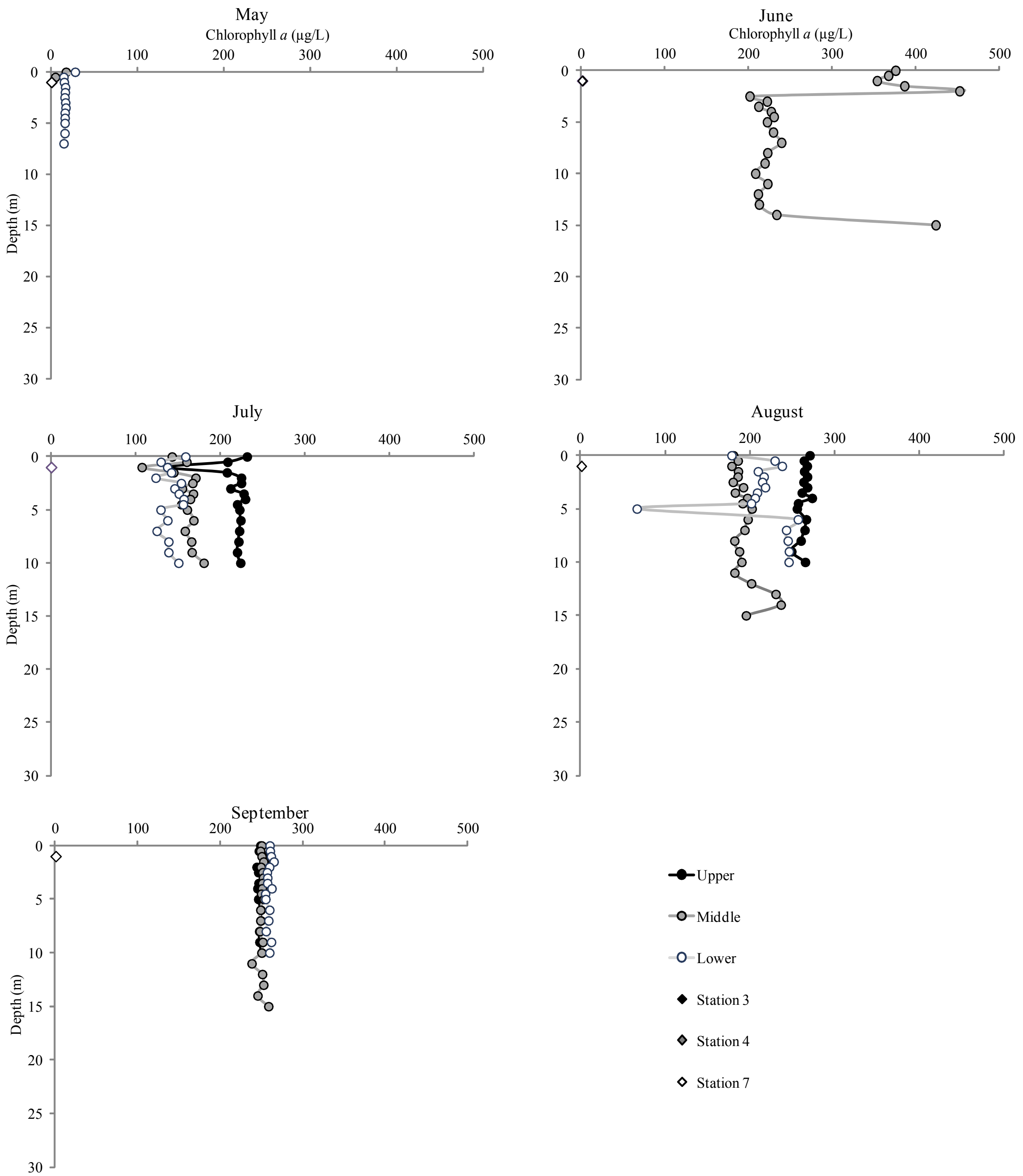


Figure 10.–Karluk Lake AUV (Upper, Middle, Lower) chlorophyll-*a* depth profiles by month compared to traditionally collected (Stations 3, 4, and 7) data for May through September, 2012.

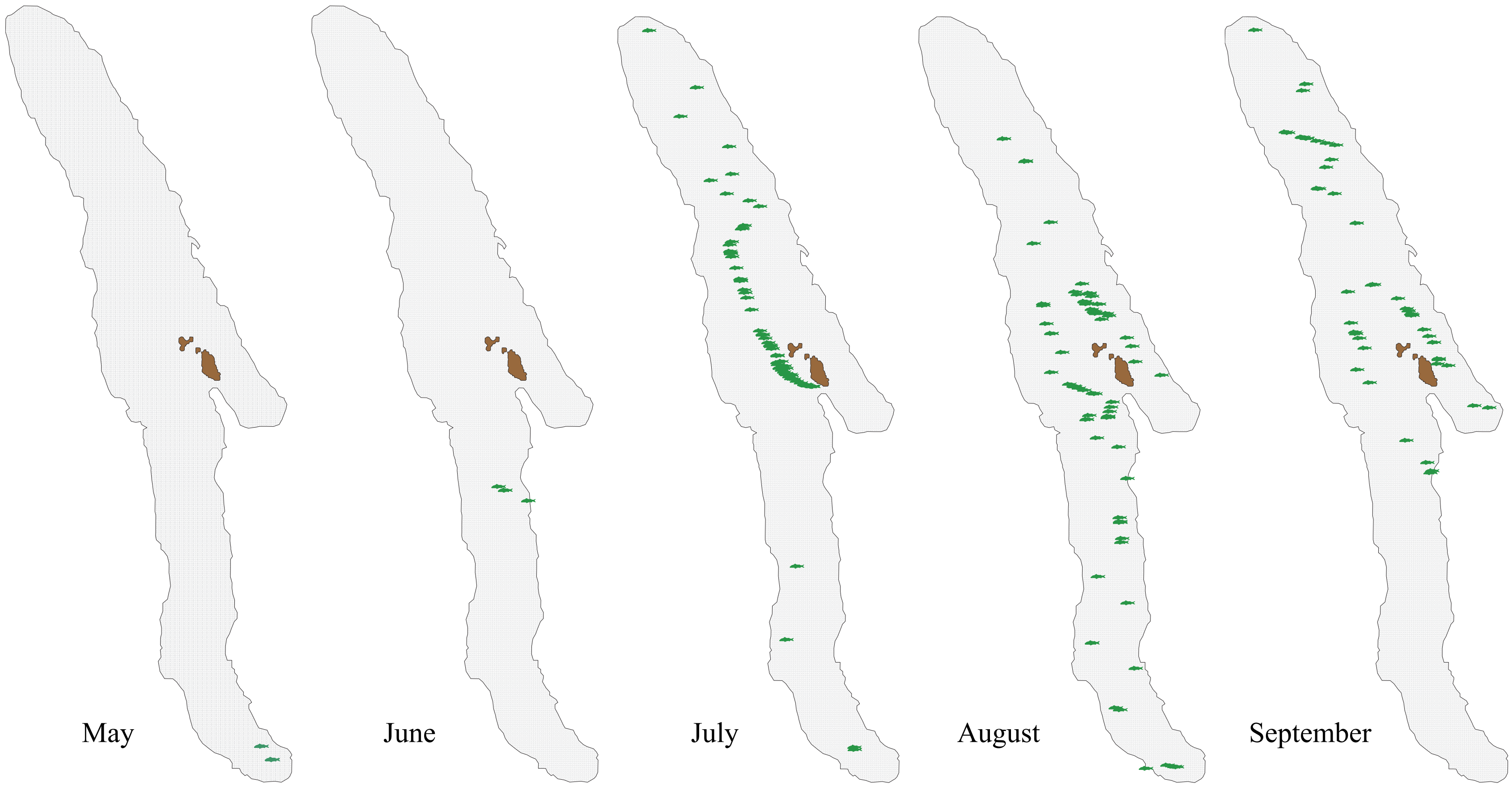


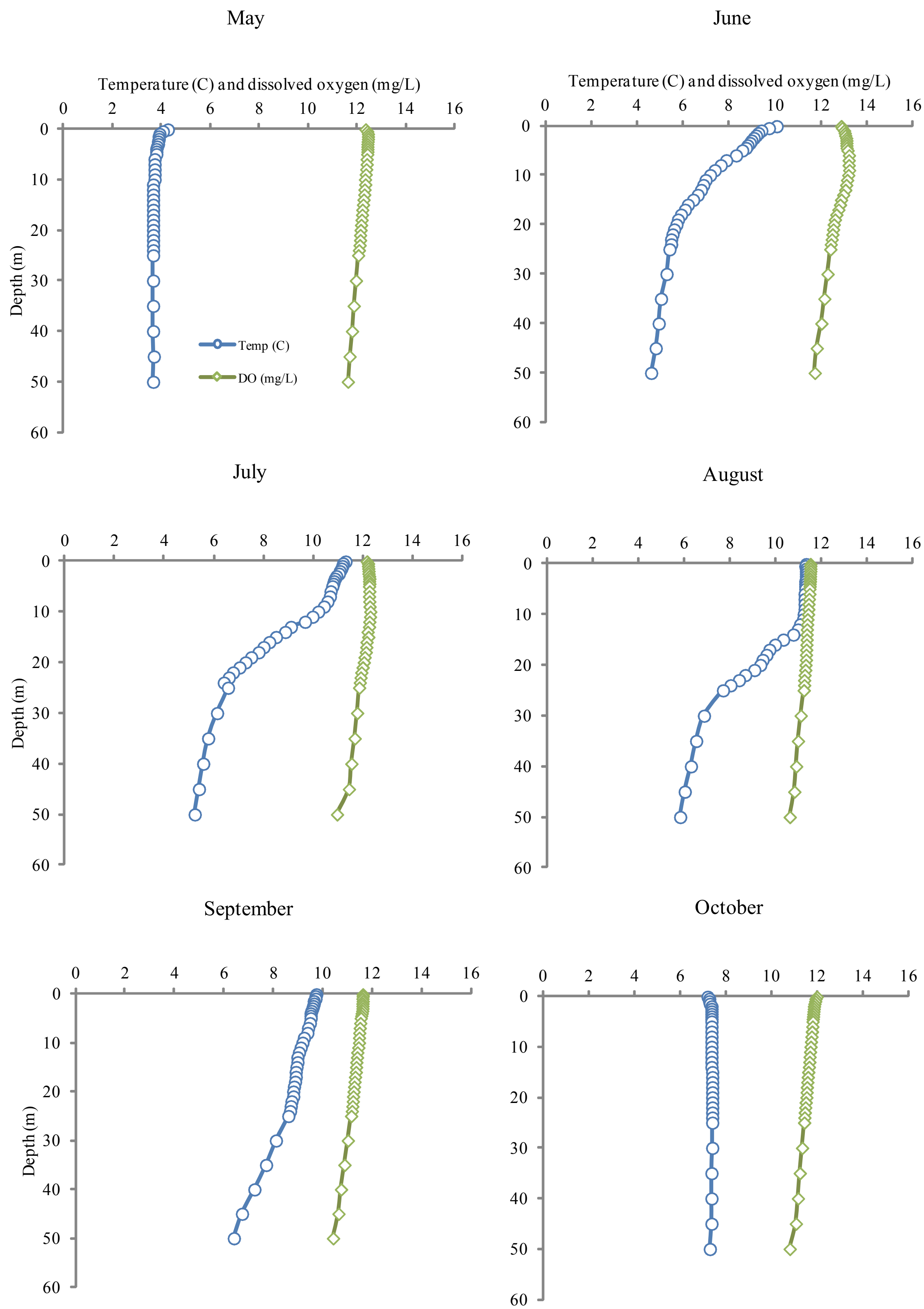
Figure 11.–Map of fish presence by month in Karluk Lake, 2012. May samples were limited to the Middle and Lower regions and June samples were conducted only in the Middle region.

APPENDIX A. KARLUK LAKE MONTHLY LIMNOLOGICAL DATA

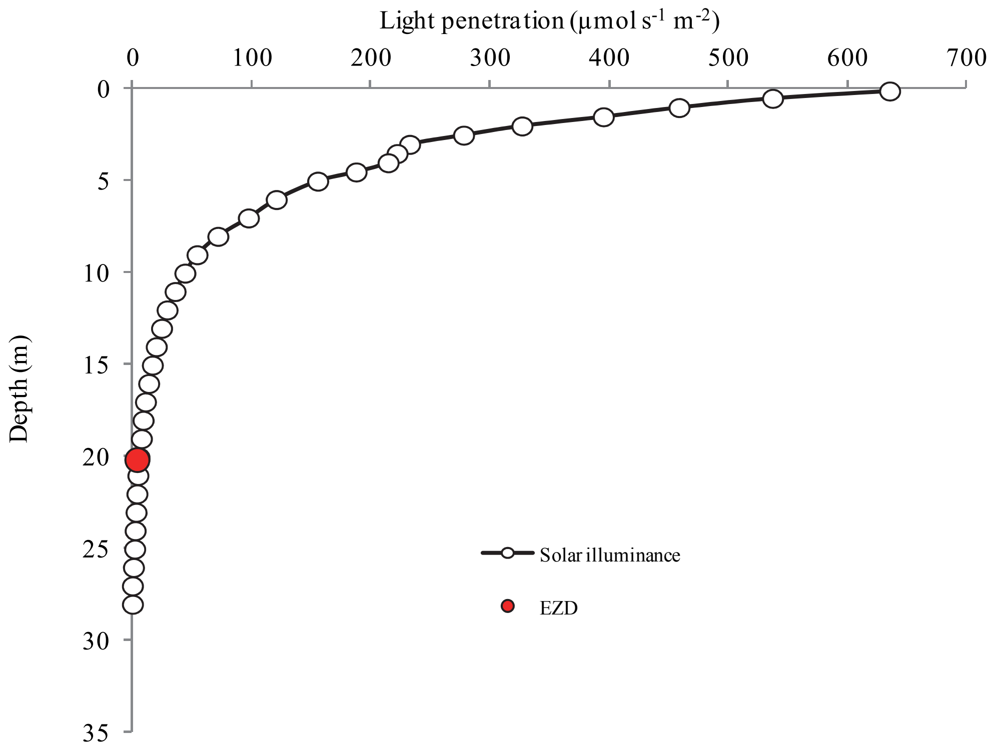
Appendix A1.–Monthly and seasonal averages of 1 m temperature and dissolved oxygen, euphotic zone depth (EZD), and Secchi measurements from Karluk Lake, 2012.

Sample type	May	June	July	August	September	October	Seasonal average
Station 3							
1-m Temperature (°C)	4.1	8.3	11.2	12.5	10.0	7.2	8.9
1-m Dissolved oxygen (mg/L)	13.0	12.9	12.2	11.4	11.6	11.9	12.2
EZD (m)	21.7	19.1	21.5	25.5	21.3	19.2	21.4
Secchi depth (m)	9.8	9.8	7.8	5.5	9.8	7.75	8.4
Station 4							
1-m Temperature (°C)	3.9	9.8	11.0	10.7	9.4	7.3	8.7
1-m Dissolved oxygen (mg/L)	12.4	13.0	12.2	11.6	11.6	11.9	12.1
EZD (m)	19.1	16.6	22.5	23.7	23.3	19.0	20.7
Secchi depth (m)	11.0	7.3	6.3	5.8	10.5	7.5	8.0
Station 7							
1-m Temperature (°C)	3.8	10.1	11.3	10.8	9.7	7.3	8.8
1-m Dissolved oxygen (mg/L)	12.0	13.1	12.2	11.6	11.6	11.9	12.1
EZD (m)	17.4	15.4	17.7	26.1	21.8	19.0	19.5
Secchi depth (m)	11.0	6.8	6.5	5.3	10.8	8.5	8.1

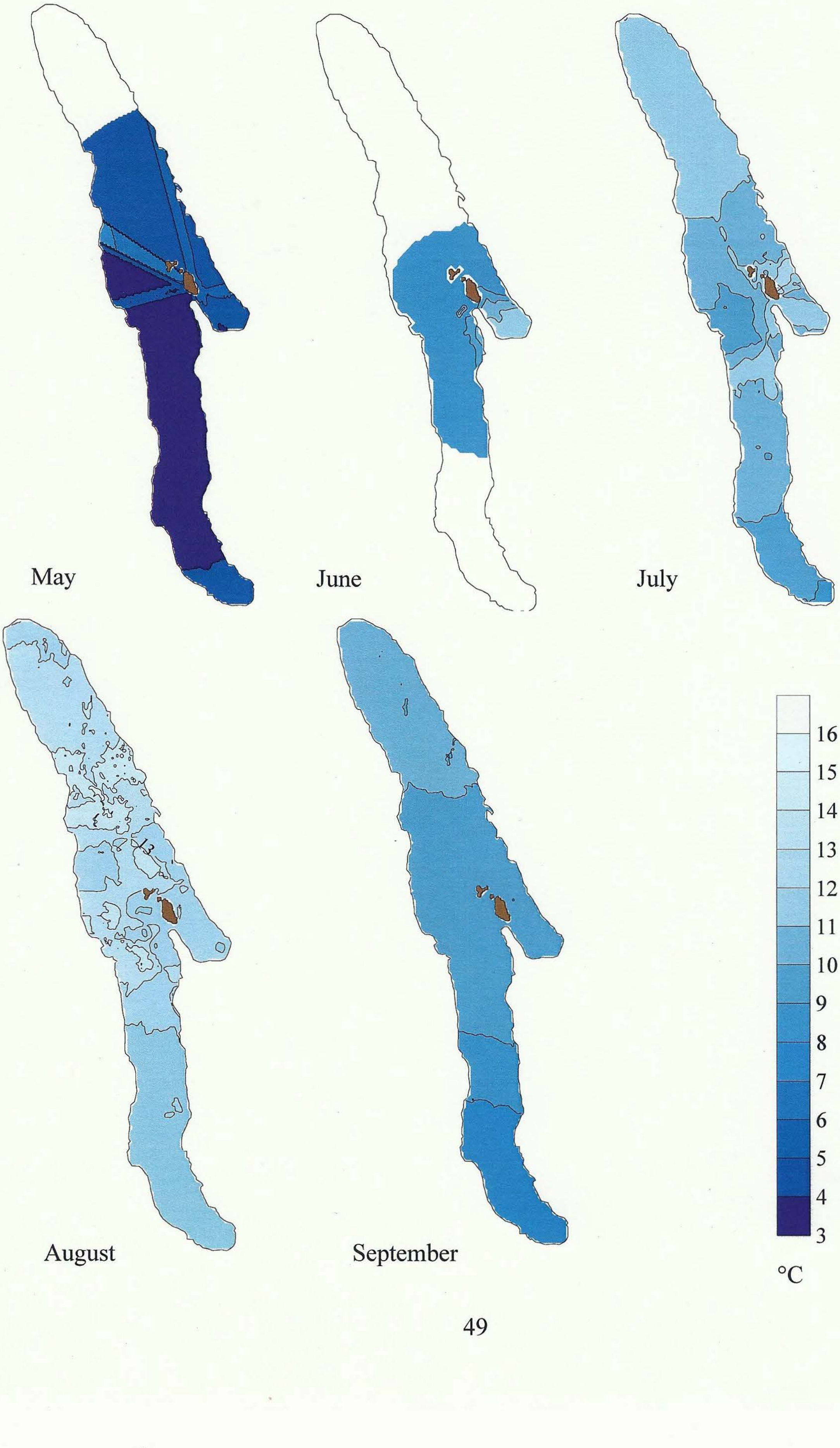
Appendix A2.–Temperature and dissolved oxygen depth profiles by month for Karluk Lake, 2012.



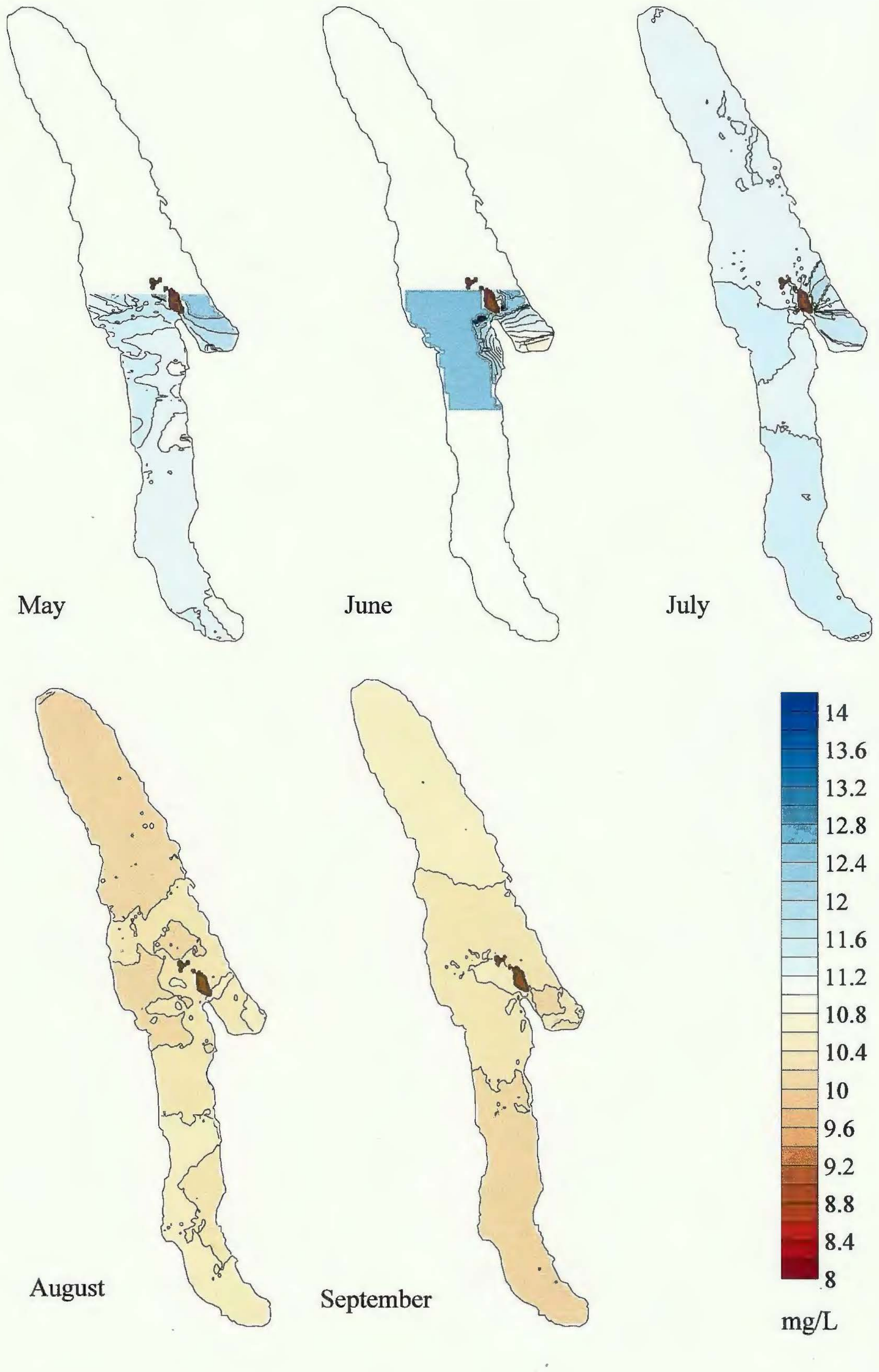
Appendix A3.–Average monthly solar illuminance profile for Karluk Lake, 2012.



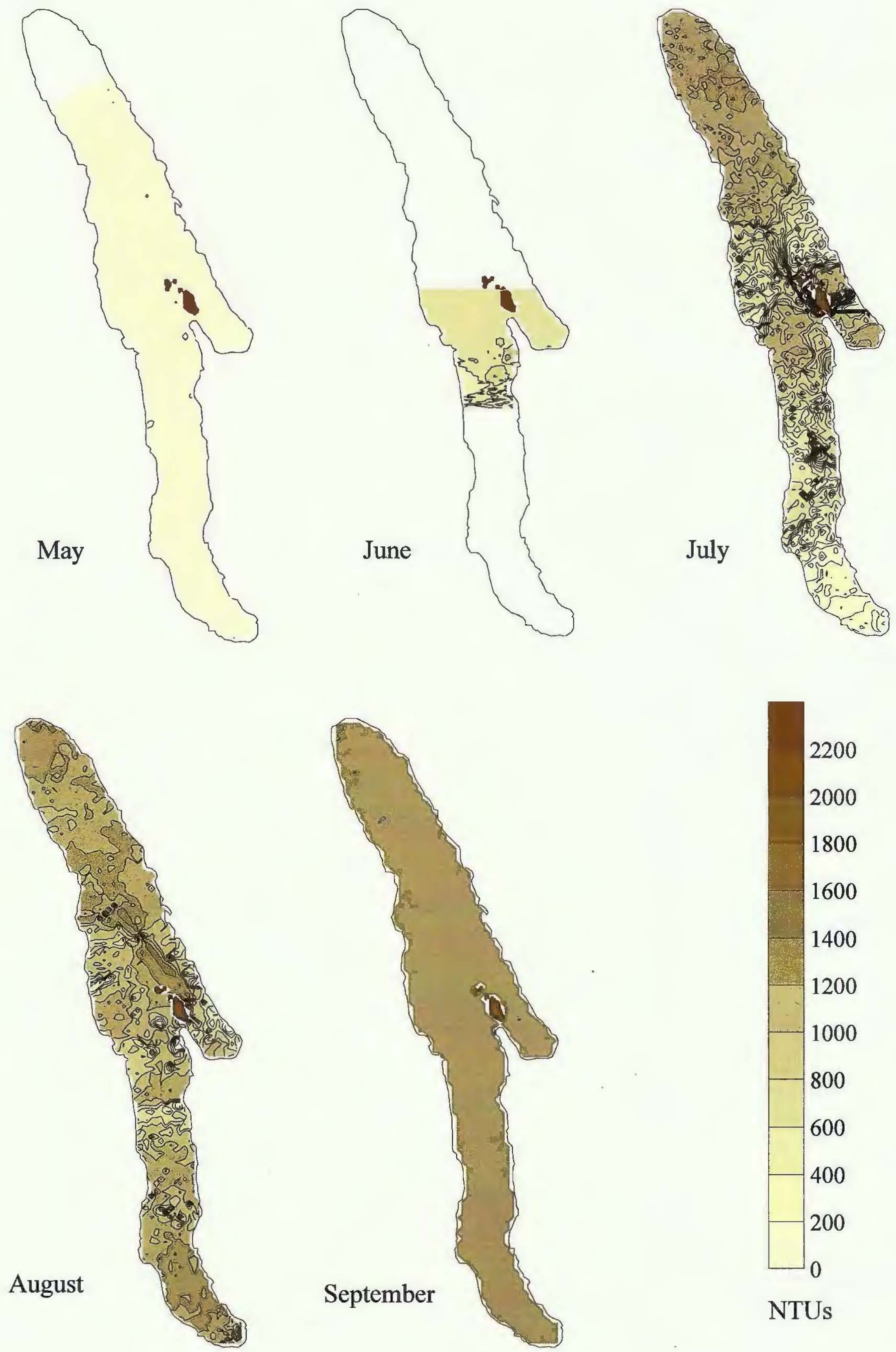
Appendix A4.–Karluk Lake AUV surface temperatures by month, 2012.



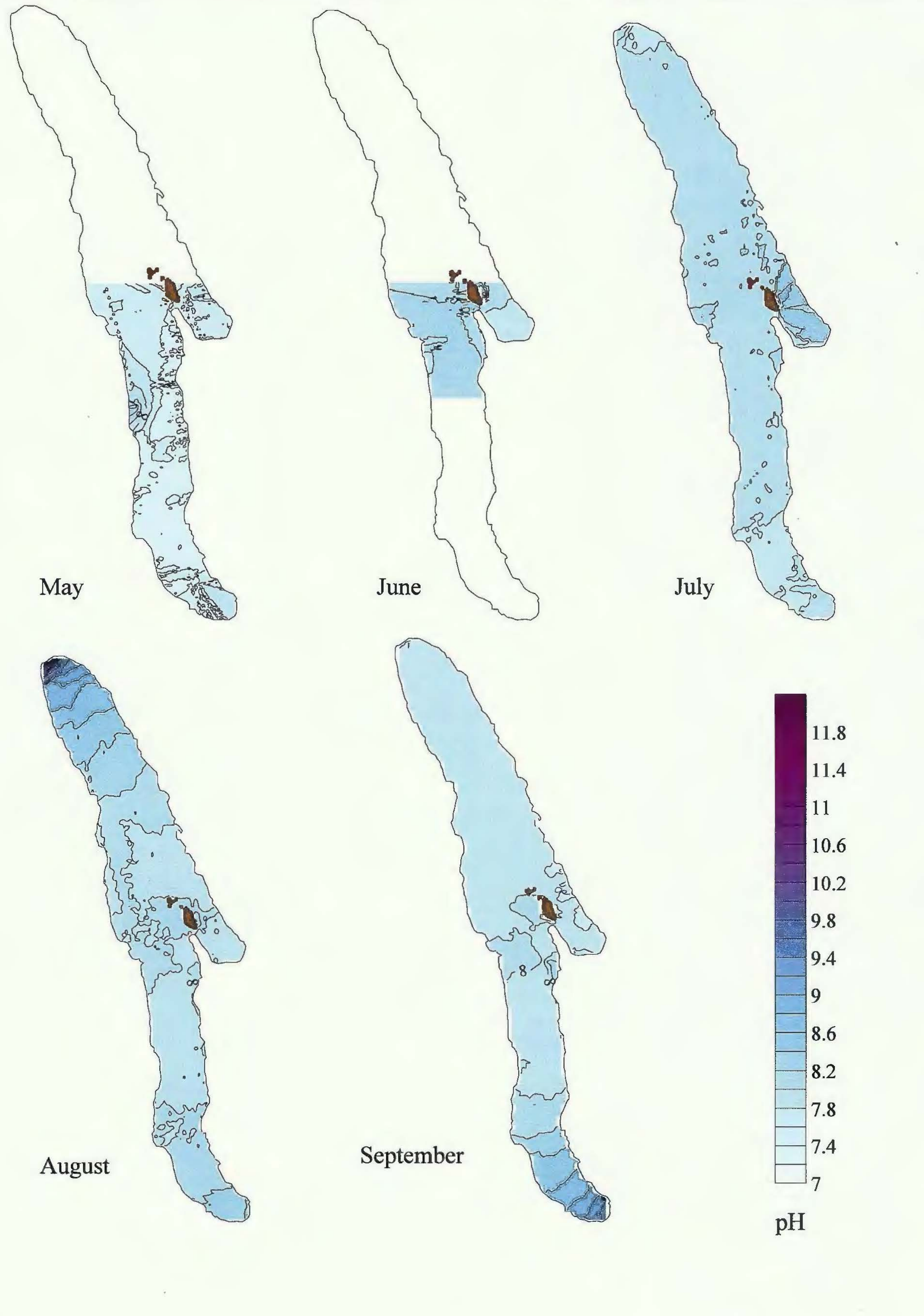
Appendix A5.–Karluk Lake AUV surface dissolved oxygen concentrations by month, 2012.



Appendix A6.–Karluk Lake AUV surface turbidity by month, 2012.



Appendix A7.–Karluk Lake AUV surface pH by month, 2012.



Appendix A8.–Karluk Lake AUV surface chlorophyll concentrations (µg/L) by month, 2012.