FISHERY RESEARCH

DWORSHAK RESERVOIR NUTRIENT ENHANCEMENT RESEARCH, 2008

DWORSHAK DAM RESIDENT FISH MITIGATION PROJECT

ANNUAL PROGRESS REPORT
March 1, 2008 – February 28, 2009

Prepared by:

Sean M. Wilson, Fishery Research Biologist
Andrew M. Dux, Principal Fishery Research Biologist
Richard J. Downing, Senior Fishery Technician
Idaho Department of Fish and Game
and
Ben Scofield, Aquatic Ecologist
TG Eco-Logic, LLC

IDFG Report Number 10-05
April 2010

DWORSHAK RESERVOIR
NUTRIENT ENHANCEMENT RESEARCH, 2008

Dworshak Dam Resident Fish Mitigation Project

Annual Progress Report

March 1, 2008—February 28, 2009

By

Sean M. Wilson
Andrew M. Dux
Richard J. Downing
Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707
USA

and

Ben Scofield
TG Eco-Logic, LLC
10905 E. Montgomery Dr., Suite 3
Spokane Valley, WA 99206
USA

To

U.S. Department of Energy
Bonneville Power Administration
Division of Fish and Wildlife
P.O. Box 3621
Portland, OR 97283-3621

Project Number 2007-003-00
Contract Number 36670

IDFG Report Number 10-05
April 2010

TABLE OF CONTENTS

Page

ABSTRACT....1
INTRODUCTION....2
STUDY SITE....3
OBJECTIVES....4
METHODS....4
- Environmental Conditions....4
- Physical and Chemical Limnology....4
  - Sample Collection....4
  - Laboratory Analysis....5
  - Data Analysis....6
  - Quality Assurance....6
- Kokanee Surveys....7
  - Abundance....7
  - Age and Growth....7
  - Production....8
  - Spawner Counts....8

RESULTS....9
- Environmental Conditions....9
- Physical and Chemical Limnology....9
  - Temperature....9
  - Dissolved Oxygen....9
  - Water Clarity....9
  - Phosphorous....10
  - Nitrogen....11
  - Total Dissolved Solids....11
  - Dissolved Organic Carbon....11
  - Precision....11
- Biological Indicators....12
  - Chlorophyll *a*....12
  - Picoplankton....12
  - Phytoplankton....12
  - Zooplankton....13
- Kokanee Population....14
  - Abundance and Density....14
  - Age and Growth....14
  - Production....15
  - Spawner Counts....15

DISCUSSION....15
- Water Quality....15
- Reservoir Productivity....18
- Kokanee Population....19

CONCLUSIONS....20
RECOMMENDATIONS....20
ACKNOWLEDGMENTS....22
LITERATURE CITED....23

LIST OF TABLES

Page

Table 1. Summary of methods used by AM Test Labs to analyze the chemical composition of water samples collected from seven limnological stations throughout Dworshak Reservoir from March through November 2007. 25

Table 2. Summary of methods used by TG Ecologic to analyze biological samples collected from seven limnological stations throughout Dworshak Reservoir from March through November 2007.....25

Table 3. Concentration of dissolved organic carbon (DOC) measured from the epilimnion at two limnological stations on Dworshak Reservoir from March through September 2007. Samples were not collected at RK-72 prior to June due to extremely low reservoir levels.....25

Table 4. Median phytoplankton densities (NCU/ml) from the epilimnion of Dworshak Reservoir in 2008. Densities were measured at seven limnological stations from March through November. Densities are broken out by the five taxonomic classes present and reported as reservoir-wide medians for each month or annual medians for each station.....26

Table 5. Median phytoplankton biovolume (mm^3/L) from the epilimnion of Dworshak Reservoir in 2008. Biovolumes were measured at seven limnological stations from March through November. Biovolumes are broken out by the five taxonomic classes present and reported as reservoir-wide medians for each month or annual medians for each station. 27

Table 6. Density of edible phytoplankton (NCU/L) measured at seven limnological sampling stations on Dworshak Reservoir from March through November of 2008. The median density, median percentage of edible density, and median percentage of the overall density for which edibility could be determined from the literature are given. Medians are either reservoir wide median for each month or annual medians for each station. 28

Table 7. Biovolume of edible phytoplankton measured at seven limnological sampling stations on Dworshak Reservoir from March through November of 2008. The median biovolume, median percentage of edible biovolume, and median percentage of the overall biovolume for which edibility could be determined from the literature are given. Medians are either reservoir wide median for each month or annual medians for each station. 29

Table 8. Ranges of total length (mm) and corrected target strength (Db) for three ages of kokanee surveyed by acoustic methods on Dworshak Reservoir during July 16-18, 2007.....29

Table 9. Abundance of kokanee, given in thousands of fish, in Dworshak Reservoir during July 2008. Estimates were derived from a hydroacoustic surveys and age breakdowns were derived from a fixed-frame trawl survey. Estimates are broken down by age class and reservoir section. 30

Table 10. Density of kokanee in Dworshak Reservoir during July 2008. Estimates were derived from a hydroacoustic surveys and age breakdowns were derived from a fixed-frame trawl survey. Estimates are broken down by age class and reservoir section.....30

List of Tables, continued.

Page

Table 11. Summary of total lengths of kokanee captured during mid-water trawl surveys on Dworshak Reservoir during April, July, and October 2007. Statistics include number of observations, minimum and maximum observations, mean, and standard deviation. Growth is given as the increase in mean length (mm) observed in each age class between surveys. 30

Table 12. Relative weights of kokanee captured during mid-water trawl surveys on Dworshak Reservoir during April and July 2007. Statistics include number of observations, minimum and maximum observations, mean, and standard deviation. 31

LIST OF FIGURES

Figure 1. Map of Dworshak Reservoir depicting the locations of seven limnological sampling stations on the reservoir and one on the North Fork Clearwater below Dworshak Dam. Boundaries of reservoir sections used in statistical stratification are also shown. 32

Figure 2. Map of the North Fork Clearwater River immediately above Dworshak Reservoir showing the four index streams that are surveyed for spawning kokanee. 33

Figure 3. Mean daily inflow, outflow and pool elevation for Dworshak Reservoir during 2008 along with the 10 year mean (1998-2007). Data provided by the U.S. Army Corps of Engineers through the Columbia River Dart website (http://www.cbr.washington.edu/dart/). 34

Figure 4. Seasonal temperature profiles at four reservoir stations on Dworshak Reservoir from March through November 2008. Temperatures are from depths of 1, 30 and 60 meters. Station RK-56 is used in lieu of RK-72 for the 30 and 60 m profiles because it was the uppermost station for which depths in excess of 30 m were encountered throughout the sampling season. 35

Figure 5. Depth of the thermocline, as defined by a change of 1°C over 1 m in depth, measured at three limnological sampling stations on Dworshak Reservoir from March through November 2008. 36

Figure 6. Mean annual Secchi depth (m) measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Error bars represent 95% confidence intervals around the mean. 36

Figure 7. Mean monthly Secchi depths (m) for treated and untreated areas of Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean. 37

Figure 8. Mean annual compensation depths (m) for seven limnological stations throughout Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean. 37

List of Figures, continued.

Page

Figure 9. Mean monthly compensation depth (m), as calculated from readings of photosynthetically active radiation (PAR), for treated and untreated areas of Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean.....38

Figure 10. Box plots representing the distribution of Total Dissolved Phosphorous (TDP) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month. 39

Figure 11. Box plots representing the distribution of Total Phosphorous (TP) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.....40

Figure 12. Box plots representing the distribution of Nitrite + Nitrate Nitrogen (N+N) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.....41

Figure 13. Box plots representing the distribution of Total Dissolved Solids (TDS) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.....42

Figure 14. Box plots representing the distribution of Chlorophyll a (Chl a) concentrations (µg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.....43

Figure 15. Mean density (cells/ml) of picocyanobacteria in the epilimnion for treated and untreated areas of Dworshak Reservoir, from March through November 2007. Error bars represent 95% confidence intervals around the mean.....44

Figure 16. Mean density (cells/ml) of heterotrophic bacteria in the epilimnion for treated and untreated areas of Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean.....45

List of Figures, continued.

Page

Figure 17. Box plots representing the annual distribution of phytoplankton densities from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Densities are given both in terms of natural counting units (NCU) and biovolume (mm^3/L). 46

Figure 18. Box plots representing the annual distribution of phytoplankton densities from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Densities are given both in terms of natural counting units (NCU) and biovolume (mm^3/L). 47

Figure 19. Mean annual composition of the phytoplankton community sampled at seven limnological stations on Dworshak Reservoir from March through November 2008. Mean compositions reflect the mean percentage, based on natural counting units (NCU/ml), that each class contributed to the overall abundance throughout the entire sampling season....48

Figure 20. Mean annual composition of the phytoplankton community sampled at seven limnological stations on Dworshak Reservoir from March through November 2008. Mean compositions reflect the mean percentage, based on natural counting units (NCU/ml), that each class contributed to the overall abundance throughout the entire sampling season....48

Figure 21. Seasonal composition of the phytoplankton community in Dworshak Reservoir. Monthly compositions reflect the mean density, based on natural counting units (NCU/ml), of each class, as measured from March through November 2008 at seven limnological stations throughout Dworshak Reservoir....49

Figure 22. Box plots representing the distribution of edible phytoplankton densities, based on natural counting units (NCU/ml). Graphs either represent all measurements observed at each of seven limnological stations on Dworshak Reservoir, from March through November of 2008, or measurements from all stations during a given month....50

Figure 23. Box plots representing the distribution of edible phytoplankton densities, based on biovolume (mm^3/L). Graphs either represent all measurements observed at each of seven limnological stations on Dworshak Reservoir, from March through November of 2008, or measurements from all stations during a given month. 51

Figure 24. Seasonal density of each class of zooplankton collected from March through November of 2008 at seven limnological stations throughout Dworshak Reservoir. Densities reflect the median density from all seven stations for a given month. 52

Figure 25. Mean reservoir wide monthly zooplankton composition from seven stations on Dworshak Reservoir, collected March through November 2008. Stacked data represents the contribution by percent of each of six major zooplankton taxonomic groups to the total zooplankton assemblage for each month. 53

List of Figures, continued.

Page

Figure 26. Mean annual zooplankton composition from seven limnological stations on Dworshak Reservoir, collected March through November 2008. Stacked data represents the contribution by percent of each of six major zooplankton taxonomic groups to the total zooplankton assemblage for each station. 54

Figure 27. Monthly mean lengths (mm) of *Daphnia sp.* and *Bosmina sp.* from seven limnological stations on Dworshak Reservoir, collected March through November 2008. Error bars represent 95% confidence intervals around each mean. 55

Figure 28. Annual mean lengths (mm) of *Daphnia sp.* and *Bosmina sp.* from seven limnological stations on Dworshak Reservoir, collected March through November 2008. Error bars represent 95% confidence intervals around each mean. 56

Figure 29. Abundance of kokanee, given in thousands of fish, in Dworshak Reservoir during July 2008. Estimates were derived from a hydro-acoustic survey and age composition was determined from a fixed-frame trawl survey. Estimates are broken down by age and reservoir section. 57

Figure 30. Length distribution of kokanee captured by fixed-frame trawl surveys conducted on Dworshak Reservoir during April 2008. Ages were determined by scale analysis. 58

Figure 31. Length distribution of kokanee captured by fixed-frame trawl surveys conducted on Dworshak Reservoir during July 2008. Ages were determined by scale analysis. 59

Figure 32. Length distribution of kokanee captured by fixed-frame trawl surveys conducted on Dworshak Reservoir during October 2008. Ages were determined by scale analysis. 60

Figure 33. Growth, in terms of seasonal changes in mean total length (mm), of kokanee in Dworshak Reservoir. Mean lengths were determined from fixed-frame trawl surveys conducted during 2008. Ages were determined by scale analysis. 61

Figure 34. Length distribution of post-spawn kokanee collected from tributaries to the North Fork Clearwater River on September 24-25 2008. Lengths were measured as total length (mm). 62

LIST OF APPENDICES

Page

Appendix A. Depth and temperature profiles for seven sampling stations on Dworshak Reservoir from March through November 2008. Isopleths indicate water temperature in degrees Celsius at 5 degree intervals.....64

Appendix B. Depth of the thermocline measured at each of seven sampling station on Dworshak Reservoir from March through November 2008. The thermocline was defined as a change in temperature of one degree C over a depth of one meter.....66

Appendix C. Depth and dissolved oxygen for seven sampling stations on Dworshak Reservoir from March through November 2008. Isopleths indicate dissolved oxygen levels in mg/L at 5 mg/L intervals.....67

Appendix D. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Secchi readings taken at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).....69

Appendix E. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for compensation depth at seven sampling stations on Dworshak Reservoir from March through November 2008. Compensation depths were calculated as the depth at which 1% of the photosynthetically active radiation measured at the surface was still present. Statistics are presented by month (all stations combined) and by station (entire year).....70

Appendix F. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Total Dissolved Phosphorous measured at seven sampling stations on Dworshak Reservoir from March through November 2008. For calculation purposes, values that were below the detection limit (0.001 mg/L) were considered to be 0.001 mg/L. Statistics are presented by month (all stations combined) and by station (entire year).....71

Appendix G. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Total Phosphorous measured at seven sampling stations on Dworshak Reservoir from March through November 2008. For calculation purposes, values that were below the detection limit (0.001 mg/L) were considered to be 0.001 mg/L. Statistics are presented by month (all stations combined) and by station (entire year).....72

Appendix H. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for nitrite plus nitrate nitrogen measured at seven sampling stations on Dworshak Reservoir from March through November 2008. For calculation purposes, values that were below the detection limit (0.001 mg/L) were considered to be 0.001 mg/L. Statistics are presented by month (all stations combined) and by station (entire year).....73

List of Appendices, continued.

Page

Appendix I. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Total Dissolved solids measured at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 74

Appendix J. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for chlorophyll *a* measured at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 75

Appendix K. Summary of the relative percent difference and difference between original and duplicate samples for six water quality parameters measured at seven sampling stations on Dworshak Reservoir from March through November 2008. 75

Appendix L. Summary of picoplankton collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 76

Appendix M. Density of phytoplankton collected from the epilimnion at seven sampling stations on Dworshak Reservoir from March through November 2008. Density is given in terms of natural counting units (NCU) per ml, which is typically the number of cells but is the number of colonies for some species. 77

Appendix N. Mean monthly density (NCU/ml) of phytoplankton sampled from the epilimnion at seven sampling stations on Dworshak Reservoir from March through November 2008. Density is given in terms of natural counting units (NCU) per ml, which is typically the number of cells but is the number of colonies for some species. 79

Appendix O. Median zooplankton density from 10 m of water depth to the surface, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 81

Appendix P. Median zooplankton density from 30 m to 10 m of water depth, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 82

Appendix Q. Mean zooplankton density from 10 m of water depth to the surface, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 83

List of Appendices, continued.

Page

Appendix R. Mean zooplankton density from 30 m to 10 m of water depth, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 84

Appendix S. Length statistics for *Daphnia sp.* and *Bosmina sp.* collected between 10 m and the surface at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year). 85

Appendix T. Length statistics for *Daphnia sp.* and *Bosmina sp.* collected between 30 and 10 m below the surface at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).....86

Appendix U. Estimates of kokanee abundance and adult (age-2 and up) densities for Dworshak Reservoir.....87

ABSTRACT

Dworshak Reservoir was identified as a good candidate for nutrient supplementation as a means to restore declining reservoir productivity and benefit fisheries. In 2007, Idaho Fish and Game (IDFG) and the U.S. Army Corps of Engineers (USACE) began a cooperative nutrient supplementation experiment on the reservoir, wherein USACE applied nutrients, IDFG monitored the results using a combination of limnological and fish surveys, and TG Eco-Logic provided the application schedule and limnological data analyses. This report provides results from 2008, the second year of the project.

In 2008, the snowpack and resulting runoff were above average. A thermocline developed later and dissipated earlier than usual. Dissolved oxygen minima, which are typically observed during late summer and fall, were less severe than previous years. None of the water quality standards set forth in the Consent Order issued by the Idaho Department of Environmental Quality (IDEQ) were violated. The median Secchi depth of 3.0 m equaled, but did not exceed, the specified limit. Measurements of total dissolved phosphorus (TDP) and chlorophyll *a* (Chl *a*) in the epilimnion were well below upper limits specified in the Consent Order.

Picoplankton densities in 2008 declined from 2007, but were greater than 2006. This decline may be due in part to an increase in flagellates and other edible phytoplankton, both of which were more prevalent in 2008 than in previous years. The size and biomass of Daphnia increased over pretreatment years. Kokanee were larger in 2008 than in previous years and exhibited better growth than in 2004; however, kokanee densities were lower in 2008 than any other year for which comparisons were made. Therefore, the effect of nutrient enhancement on kokanee growth is currently unclear.

Overall, Dworshak Reservoir appears to be responding similarly to British Columbia lakes and reservoirs that have undergone similar treatments. This is evidenced by a dramatic increase in picoplankton observed during the first year of the experiment, followed by increases in edible phytoplankton during the second year. We expect to see increases in zooplankton production during the third year. Increased fish growth is unlikely to fully occur until zooplankton production improves.

Authors:

Sean M. Wilson
Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

Richard J. Downing
Senior Fishery Technician

Ben Scofield
Aquatic Ecologist

INTRODUCTION

Dworshak Reservoir is the most popular fishing destination in Clearwater County and the third most popular destination in the Clearwater region, based on total angler trips in 2003 (IDFG 2003a). It provides a multispecies fishery for naturally reproducing kokanee *Oncorhynchus nerka*, smallmouth bass *Micropterus dolomieu,* and cutthroat trout *Oncorhynchus clarkii*, as well as hatchery stocked rainbow trout *Oncorhynchus mykiss*. Furthermore, the reservoir provides important habitat for Endangered Species Act (ESA) listed bull trout *Salvelinus confluentus*.

Kokanee provide the most popular fishery on the reservoir, with annual effort levels that have exceeded 140,000 angler hours and annual harvests of over 200,000 fish (Mauser et al. 1989). The pelagic nature and planktivorous feeding habits of kokanee make them well suited for an oligotrophic reservoir with fluctuating water levels, such as Dworshak (Stark and Stockner 2006). Kokanee were first stocked into Dworshak Reservoir in 1972 (Horton 1981). Although two stocks were originally introduced (early spawners from Anderson Ranch and late spawners from Lake Whatcom), the early spawning variety soon dominated (Horton 1981).

Entrainment and oligotrophication have been identified as the primary factors limiting the kokanee population in Dworshak (Stark and Stockner 2006). With the exception of abnormally high runoff years, entrainment was significantly reduced beginning in the early 1990s when drawdown began occurring during the summer and early autumn to provide cool water for Chinook salmon *Oncorhynchus tshawytscha* in the Snake River. Kokanee tend to congregate in the forebay of the dam during the winter and are more susceptible to entrainment during drawdown at this time (Maiolie and Elam 1997). Declining productivity was identified by Bennett (1997) as a critical factor limiting the kokanee fishery. Furthermore, Bennett (1997) recommended that productivity be addressed before implementing intensive fisheries management practices.

To address oligotrophication, Stockner and Brandt (2005) provided a detailed assessment of the reservoir and recommendations for a nutrient supplementation program. Based on phosphorous loading and mean chlorophyll densities, they classified Dworshak as borderline oligo-mesotrophic. However, they found that the phytoplankton communities and associated food web present during the spring were dominated by microbial communities typical of ultraoligotrophic lakes and reservoirs. Dworshak becomes nitrogen limited by mid-summer, leading to a dominance of nitrogen fixing blue-green algae. Blue-green algae are typically abundant from mid-summer to early fall and, because they are inedible to zooplankton, represent a considerable carbon sink. These inefficiencies in the food web result in suboptimal fish production.

The Idaho Department of Fish and Game (IDFG) and the U.S. Army Corps of Engineers (USACE) initiated a five-year nutrient supplementation experiment in 2007. This report covers results of the second year of supplementation. The USACE applied ammonium nitrate to the reservoir on a weekly basis from April through September, and IDFG conducted surveys to monitor changes to the limnology and kokanee populations. TG Eco-Logic, a private consulting company, was contracted to interpret the results of the limnological data and adjust the nutrient prescriptions as necessary. The goal of the program is to restore the system productivity by improving the nitrogen (N) to phosphorous (P) ratios in the reservoir, thereby promoting the growth of desirable (i.e. edible) phytoplankton. Increased abundance of edible phytoplankton is expected to lead to an increased abundance of zooplankton, therefore providing an improved

forage base for fish. Stockner and Brandt (2005) anticipated that a moderate N nutrient supplementation would benefit fish populations without degrading water quality.

The goal of the monitoring program carried out by IDFG was to evaluate the effectiveness of the nutrient supplementation program at improving the flow of carbon to the kokanee population in Dworshak Reservoir without adversely affecting water quality. Limnological surveys were conducted to meet three major objectives. The first was to ensure that water quality standards, as stipulated in the Consent Order issued by the Idaho Department of Environmental Quality (IDEQ), were maintained. Secondly, limnological data were collected in order to make comparisons with presupplementation conditions to determine the biological effects of the project, including changes to the plankton communities. Finally, data were provided to TG Eco-Logic to actively manage the nutrient applications. In addition to limnological monitoring, surveys were conducted to monitor the kokanee population. The objectives laid out in the IDFG Fisheries Management Plan for the kokanee fishery on Dworshak are to maintain a catch rate of 0.7 fish per hour with an average size of 254 mm (IDFG 2003b). An effective nutrient supplementation program is expected to increase the average size of kokanee at any given population density. Kokanee surveys were conducted to determine whether this occurred and if nutrient supplementation will allow for management plan objectives to be achieved.

STUDY SITE

Dworshak Reservoir was impounded after the construction of Dworshak Dam in 1972 on the North Fork Clearwater River approximately 2.4 km from its confluence with the mainstem Clearwater River. The reservoir is narrow, steeply sloped, and primarily surrounded by coniferous forests. The North Fork Clearwater River and its tributaries drain nearly 632,000 ha, which is composed primarily of montane forests in steeply sloped terrain (Falter et al. 1977). The underlying geology is composed of Columbia River basalt and metamorphic sediments with granitic intrusions covered by shallow soils (Falter et al. 1977). Most of the North Fork Clearwater watershed above the reservoir lies within the Clearwater National Forest. The reservoir is immediately surrounded by land managed by the USACE, but much of the lower watershed is privately owned. The primary commercial activity is timber harvest, although there is some agriculture in the lower watershed.

At full pool, Dworshak Reservoir is 86.3 km long with a surface area of 6,916 ha and a volume of 4.3 billion m^3 (Falter 1982). A typical annual drawdown lowers the pool elevation by 24 m and reduces the surface area by 27%. Peak pool elevation is typically reached by late June and drawdown begins after the first week of July, with winter levels reached by the second week of September. The mean hydraulic retention time is 10.2 months (Falter 1982) and the mean daily discharge from 1998-2007 was 0.15 m^3/s (DART).

As part of our sampling design, the reservoir was stratified into three sections (Fig 1). Section 1 extended from the dam to Dent Bridge at river kilometer 27.0, while section 2 extended from Dent Bridge to Grandad Bridge at river kilometer 65.2. Section 3 encompassed the reservoir above Grandad Bridge. This stratified design was used for the kokanee population estimate and for allocating nutrient applications.

Limnological sampling was conducted at seven stations on the reservoir and one station on the North Fork Clearwater (NFC) below Dworshak Dam (Figure 1). Five stations on the main reservoir were designated by river kilometer. These stations were located at RK-2, RK-31, RK-

56, RK-66 and RK-72. Additional stations were located at river kilometer six of the Elk Creek arm (EC-6) and at river kilometer three of the Little North Fork arm (LNF-3). The last two stations were in untreated areas of the reservoir.

OBJECTIVES

1. Restore reservoir productivity and food web efficiency that has declined over time due to oligotrophication.

2. Provide a kokanee fishery that can sustain a catch rate of 0.7 fish per hour with an average size of 254 mm total length.

METHODS

Environmental Conditions

Daily mean reservoir inflow, discharge and pool elevation data provided by the USACE was acquired through the Columbia River Data Access in Real Time (DART) website.

Physical and Chemical Limnology

Sample Collection

Limnological sampling was conducted twice monthly from April through September and once monthly during March, October and November. Because all seven reservoir stations and the river station could not be sampled in one day, samples were collected over a two-day period. Stations RK-66, RK-72 and LNF-3 were not sampled prior to April 21 due to ice. In addition, RK-72 and LNF-3 were not sampled in May due to extremely low pool elevations, which created riverine conditions.

Physical parameters measured included water depth, Secchi depth, water temperature, dissolved oxygen (DO), and photosynthetically active radiation (PAR). Chemical parameters included total phosphorus (TP), total dissolved phosphorus (TDP), nitrate plus nitrite nitrogen (N+N), total dissolved solids (TDS), and dissolved organic carbon (DOC). Biological parameters included chlorophyll *a* (Chl *a*), picoplankton, phytoplankton, and zooplankton. Sampling for DOC was only conducted at RK-31 and RK-72 during the first event each month from April through September. Only TP, TDP, N+N, TDS and Chl *a* were analyzed for NFC.

Water depth was measured using a Furuno™ Model FCV-582 depth sounder. Secchi depth was measured using a standard 20 cm Secchi disc, which was lowered from the shaded side of the boat until no longer visible, then raised until it reappeared. Water temperature and dissolved oxygen measurements were taken concurrently with a Yellow Springs Instruments model 58 meter with a 60 m cable and probe assembly with a high sensitivity membrane. The probe was calibrated at the beginning of each day following the manufacturer's instructions. After recording air temperature, both water temperature and DO measurements were recorded at the surface, 1 m, 2 m, and every 2 m thereafter to 60 m or the reservoir bottom. The depth of the thermocline, defined as a one-degree change in temperature over a one-meter change in depth, was determined and recorded.

Photosynthetically active radiation (PAR) was measured using a Li-Cor® model LI-250A light meter and 400-700 µm quantum sensor (model LI-192SA). The sensor was mounted on a frame and weighted with a lead weight. A 15-second average PAR reading was taken at the water surface and at one meter intervals to 15 m or a reading of zero. A second meter and dry sensor were used to take air readings concurrently with the wet readings.

Water samples were collected from the epilimnion (EPI) and hypolimnion (HYPO) at each station using a 2.2 L Kemmerer bottle. EPI samples consisted of a composite of water from 1, 3, 5, and 7 m, regardless of the presence or depth of a thermocline. One liter of water from each depth was mixed in a splitter bucket. HYPO samples consisted of a single 'grab' from 25 m. For water depths less than 28 m, HYPO samples were taken 3 m above the bottom and the depth noted on the field datasheet. Two 250 ml polyethylene sample bottles were filled from each sample depth (EPI and HYPO). One bottle (unfiltered sample) was pretreated with sulfuric acid (H_2SO_4) by the contracting lab as a preservative. The other bottle (filtered sample) was filled with water filtered through a 47 mm filtering manifold and a 0.45 µm cellulose acetate filter. A vacuum of up to 38 cm of mercury (Hg) was applied using a hand operated pump. The DOC samples were collected by filling a 40 ml glass vial, leaving no headspace, with the EPI composite water. All bottles were labeled with station, date, time, depth (EPI or HYPO), and filtered or unfiltered. Sample bottles were stored on ice while in the field and transferred to a refrigerator until shipping to the contracting lab.

A Chl *a* sample was collected by filtering 500 ml of the EPI composite water through a 0.45 µm glass fiber filter using a similar filtering manifold and hand pump, also taking care not to exceed a vacuum of 38 cm Hg. The filter was removed from the manifold and folded in half on a 15 by 15 cm piece of aluminum foil. The foil was folded around the filter, placed in a Ziploc™ bag and kept on ice until returning to the field office. After returning to the field office, Chl *a* samples were placed in a freezer until shipping.

Picoplankton samples were collected by filling a 60 ml amber polyethylene bottle with the EPI composite water and preserved with six drops of 50% glutaraldehyde. Phytoplankton samples were collected by filling a 125 ml amber polyethylene bottle with sample water, one each for EPI and HYPO. Samples were preserved with fifteen drops of Lugol's solution. All sample bottles were labeled with station, date, time, and depth (EPI or HYPO).

Zooplankton were collected from two depth strata using a 50 cm diameter, 80 µm mesh Wisconsin style net fitted with a flow meter. One tow was performed at each station from 10 m to the surface (upper strata). During the first sampling event each month, an additional tow was performed from 30 m to 10 m (lower strata). Vertical tows were completed by lowering the net to depth and retrieving at a rate of 0.5 m/s. For the lower strata, a messenger was used to close the net at 10 m. The number of revolutions on the flow meter was recorded on the datasheet and plankton were rinsed from the net into the collection bucket, then rinsed into a collection jar and preserved in 70% ethanol. Collection jars were labeled with station, date, and depth of tow. Prior to the field season, several tows were performed with no net and the number of revolutions recorded to serve as a reference point.

Laboratory Analysis

Water samples for chemical analysis were sent to AM Test Labs of Kirkland, Washington. Analytical methods used for each parameter are listed in Table 1.

Biological samples were sent to TG Eco-Logic of Spokane, Washington for analysis. Analytical methods used for each parameter are listed in Table 2.

Data Analysis

The compensation depth is the depth where light intensity is 1% of the light intensity at 0 m. Compensation depths were calculated from the vertical light intensity profiles by first transforming the data as follows:

$$x = \mathrm{Ln}\,[100\,(I_D/I_S)]$$

Where: I_D = light intensity at depth
I_S = light intensity at 0 m

A regression was then developed using the transformed data as the independent variable and the depth (m) at which the measurement was taken as the dependent variable. The resulting equation was solved for x = Ln(1) = 0 to determine the compensation depth.

When summarizing the results of chemical analyses, numerous measurements were below the detection limit of a given assay. In order to calculate descriptive statistics, the detection limit for a given chemical analysis was used whenever the true value was below the detection limit.

Descriptive statistics were computed using JMP 8.0 from SAS. Means were reported for data that were normally distributed and medians were reported for data that were not normally distributed. In the case of normally distributed data for which a median value was stipulated in the Consent Order issued by IDEQ, both a mean and median value were reported. Boxplots were generated using SigmaPlot 11.0 where the 25th and 75th percentiles and median are represented by the box, the 10th and 90th percentiles are represented by error bars, and outliers are represented as individual points.

Quality Assurance

All equipment was rinsed in ethanol, followed by a triple rinse with distilled water, prior to each sampling event. The Kemmerer and splitter bucker were rinsed in surface water at each site prior to sample collection. Vacuum manifolds were rinsed in distilled water prior to installation of a new filter. For each sampling event, a station was randomly chosen to collect field duplicates, rinsates, and blanks. Field duplicates for chemical analysis were collected by filling additional sample bottles (one each for filtered and unfiltered) with EPI water. Rinsates were collected by transferring water provided by the analytical lab from the Kemmerer to the splitter bucket and the filtering manifold (filtered sample only) before filling additional sample bottles (one each for filtered and unfiltered). Blanks were obtained by filling additional sample bottles (one each for filtered and unfiltered) with water provided by the analytical lab. Additionally, a duplicate chlorophyll sample was obtained by filtering an additional aliquot of EPI water as previously described.

For each field duplicate that was collected, the relative percent difference (RPD) between the duplicate and original sample was calculated using the following formula:

$$RPD = \frac{|S_1 - S_2|}{(S_1 + S_2)/2} \times 100$$

Where: S_1 = Original sample
S_2 = Duplicate sample

Kokanee Surveys

Abundance

A single hydroacoustic survey was conducted during the nights of July 22-24. The survey was conducted using a Simrad model EK-60 echo sounder and a 120 kHz split beam transducer. The unit was calibrated prior to the survey using a -40.4 decibel (dB) calibration ball. Kokanee abundance was estimated using a stratified systematic sampling design using the previously described strata. Transects of similar length were laid out in a zigzag pattern across the reservoir, with one transect beginning where the last one ended (Simmonds and MacLennan 2005). Boat speed during the transects averaged 1.6 m/s. The echo sounder was set to ping at 1 s intervals with a pulse width of 0.256 milliseconds.

The pelagic region of each echogram was analyzed using Echoview 4.0 software. For the analysis, a maximum beam compensation of 6.0 dB and a minimum and maximum normalized pulse length of 0.3 and 1.8 were used to distinguish fish from noise. Depths between 10 and 30 m were analyzed using an echo integration technique to calculate the nautical area scattering coefficient (NASC) and mean target strength (TS). The following formula was then used to calculate fish densities:

$$\text{Density (fish/ha)} = (\text{NASC} / 4\pi 10^{TS/10})\ 0.00292$$

Frequency distributions were developed by binning the number of single targets in 1 dB intervals (adjusted target strength) for a given transect. Age breaks were then determined using length at age data from the trawl survey. For this, lengths of trawl caught fish were converted into target strengths using Love's (1971) equation. For each bin, the proportion of trawl caught fish of a given age was applied to determine the number of targets representing each age class. These were then summed by transect and section and used to determine the proportion of fish in each section from each age class. These proportions were then used to apportion the mean overall density for each section by age class. These densities were multiplied by the area of kokanee habitat in each section to arrive at an estimate of age specific abundance for each section.

Age and Growth

Trawl surveys followed the methods described by Rieman (1992). An 8.5 m diesel powered boat was used to tow a fixed-frame midwater trawl. The net was 10.5 m long and attached to a 3.0 m high by 2.2 m wide steel frame. The body of the net consisted of four panels, for which the mesh sizes were 32, 25, 19, and 13 mm. The cod end was composed of 6 mm mesh held open by a 0.8 m steel hoop.

Surveys were conducted on the nights of April 7-9, July 30-31, and October 27-28. The July survey was conducted within two nights of the new moon to maximize capture efficiency (Bowler et al. 1979). For the July trawling, five randomly preselected transects were surveyed in each section. For the April and October trawling, 3-6 transects were conducted per section in sections 1 and 2. Trawling was not performed in Section 3 due to low reservoir levels. All fish

were measured to the nearest mm total length (TL) and a subsample was weighed to the nearest gram. Scales were collected from ten fish from every 1 cm length class from each section. Scales were later examined by two independent readers to determine age (Nielsen and Johnson 1983).

The relative weight (W_r) was calculated for all fish above 119 mm TL. Standard weights (W_s) for kokanee of a given lengths were obtained from Hyatt and Hubert (2000). A W_r for each fish with a known TL and weight (W) was then calculated using the formula from Anderson and Neumann (1996).

In order to estimate the number of fish from each age class caught in the trawl, the proportion of each age class represented in each 1 cm bin was calculated by dividing the number of fish of each age class, as determined from scale analysis, by the total number of fish aged in that bin. These proportions were then applied to the remaining fish in the length bin, which were not aged, in order to estimate the number from each age class within each bin. To calculate the mean TL and W_r for each age class, we first calculated these for each length bin regardless of age. The means for each bin were then multiplied by the estimated number of fish from each age class in that bin, and the products were totaled for each age class to calculate an arithmetic mean. Standard deviations were calculated in a similar manner using the following formula from Zar (1999).

$$s = \sqrt{\frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}}$$

Where: s = standard deviation of the population
X_i = i^{th} individual observation
n = sample size

Production

Production refers to the overall gain in biomass of a fish stock over a specific period, regardless of the fates of the individual fish that make up the stock (Ricker 1975). To estimate kokanee production between July 2006 and July 2007, we adapted a summation method described by Hayes et al. (2007). For this, we first calculated the mean abundance of each cohort using acoustic estimates for each year. We then calculated the mean weight gain for an individual in each cohort based on data from trawling surveys conducted at the same time. The mean weight gain was multiplied by the mean abundance to obtain an estimate of production, assuming linear rates of growth and mortality.

Spawner Counts

Peak spawner counts were conducted on four index streams on the lower North Fork Clearwater River above the reservoir (Figure 2) on September 26. These included Isabella (RK 92), Skull (RK 105), Quartz (RK 109), and Dog (tributary to Isabella at RK 2.6). Each of the index streams were walked from the mouth to the uppermost extent of utilization by spawning kokanee. All spawning kokanee were individually counted when possible or estimated in the case of a deep pool with a large group of fish.

RESULTS

Environmental Conditions

In 2008, inflow to Dworshak Reservoir ranged from 0.02 m^3/s on January 24 to 1.13 m^3/s on May 19 (Figure 3). The mean inflow of 0.17 m^3/s was higher than the ten-year mean (1998-2007) of 0.15 m^3/s. Discharge from Dworshak Dam ranged from 0.03 m^3/s on May 24-25 and June 1 to 0.47 m^3/s on April 3 (Figure 3). The mean discharge of 0.17 m^3/s was higher than the ten-year mean (1998-2007) of 0.15 m^3/s. Pool elevation of Dworshak Reservoir ranged from 449.5 m above mean sea level on May 4 to 487.6 m on July 8. For the most part, pool elevation followed the characteristic pattern of the last ten years, where pool elevation peaks in early July from spring runoff and then drops to 463 m by mid-September. The exception was that the reservoir underwent an extreme drawdown during the spring of 2008 in anticipation of high spring runoff (Figure 3).

Physical and Chemical Limnology

Temperature

Unlike the previous year, water temperature profiles from 1 m below the surface were different at opposite ends of the reservoir. Temperatures were uniformly lowest in March. However, temperatures peaked in early July at the lower and middle portions of the reservoir and in August at the upper end of the reservoir (Figure 4). While the upper end of the reservoir warmed more slowly, it peaked at a higher temperature. Profiles from the lower and middle portions of the reservoir were similar except during the period of rapid refilling after the extreme spring drawdown (Figure 4). Graphic representations of temperature data are presented in Appendix A.

A thermocline developed by May 5 at RK-2 and EC-6, but did not develop until June 8 at all other stations (Figure 5). By September and October, thermal stratification weakened at RK-72, EC-6 and LNF-3, but re-established and deepened through November 10. The duration of the thermocline was inconsistent among stations, as it dissipated as early as September 8 at RK-66 and persisted as late as November 10 at RK-31. Thermocline data are presented in Appendix B.

Dissolved Oxygen

In general, dissolved oxygen (DO) concentrations were near the saturation level throughout the season. As is typical with Dworshak Reservoir, reductions in DO were observed in the metalimnion and hypolimnion late in the year. These reduced DO levels were not as severe as those observed in past years. DO levels below 5 mg/L were only observed at three stations and, with a single exception, near the reservoir bottom. Most of these observations occurred at RK-66, with observations at RK-56 and EC-6 occurring during a single event at each station. Graphic representations of dissolved oxygen data are presented in Appendix C.

Water Clarity

Water clarity, as measured by Secchi depth, ranged from 0.6 m at RK-66 on May 19 to 6.7 m at RK-2 and RK-31 on November 10, with a grand mean and median of 3.0 m. EC-6 had the shallowest Secchi depths (mean = 2.8 m) and RK-72 had the deepest Secchi depths (mean = 3.8 m), although means for other stations were similar (Fig 6). Reservoir-wide Secchi depths

were shallowest in May (mean = 1.8 m) and deepest in November (mean = 6.2 m). Low Secchi depths during the spring coincided with higher than normal spring runoff and lower than normal pool elevations. Water clarity tended to increase in June as pool elevation increased, and decreased again into August as phytoplankton densities increased. Secchi depths from treated areas (mean = 3.2 m) of the reservoir tended to be deeper than those from untreated areas (mean = 2.9 m); however, 95% confidence intervals overlapped in all months (Figure 7). Secchi depths are summarized in Appendix D.

Compensation depths ranged from 2.9 m at RK-66 on May 23 to 14.0 m at RK-2 on November 10. As with Secchi depths, compensation depths were shallowest at EC-6 (mean = 7.3 m) and deepest at RK-2 and RK-72 (mean = 9.7 m). Compensation depths followed a similar seasonal pattern to that of Secchi depths (Figure 8). As with Secchi depths, they also tended to be deeper for treated areas than for untreated areas, however, confidence intervals were overlapping in most months (Figure 9). Compensation depths are summarized in Appendix E.

Phosphorous

TDP levels in the epilimnion ranged from below the detection limit (0.001 mg/L) at multiple times and places to 0.021 mg/L at RK-2 on June 9. The grand median was 0.001 mg/L. RK-56 had the highest TDP (median = 0.003 mg/L) while RK-31 and EC-6 (medians = 0.002 mg/L) were the only other stations with an annual median above the detection limit. Reservoir-wide TDP levels were highest in August (median = 0.004 mg/L) and above the detection limit in only three other months (Figure 10).

Measurements of TDP in the hypolimnion ranged from below the detectable limit (0.001 mg/L) at multiple times and places, to 0.019 mg/L at EC-6 on June 10. The hypolimnetic grand median was 0.003 mg/L. The highest TDP level occurred at EC-6 (median = 0.005 mg/L), and the lowest levels occurred at RK-2 and RK-31 (median = 0.001 mg/L). Reservoir-wide TDP levels were highest in August (median = 0.005 mg/L) and lowest in April, September and October (median = 0.001 mg/L).

Measurements of TDP at NFC ranged from below the detection limit (0.001 mg/L) on multiple occasions to 0.014 mg/L on June 9. The annual median TDP for the river was 0.001 mg/L, which was similar to TDP levels in both the epilimnion and hypolimnion of the reservoir. Measurements of TDP are summarized in Appendix F.

Measurements of TP in the epilimnion ranged from below the detection limit (0.001 mg/L) at multiple times and places, to 0.050 mg/L at RK-56 on April 21 and LNF-3 on June 9 (Figure 11). The epilimnetic grand median was 0.008 mg/L. The highest TP levels were observed at EC-6 and RK-72 (median = 0.009 mg/L), while the lowest TP levels were from RK-2 (median = 0.006 mg/L). Reservoir-wide TP levels were highest in April (median = 0.031 mg/L) and lowest in October and November (median = 0.001 mg/L).

Measurements of TP in the hypolimnion ranged from below the detection limit (0.001 mg/L) at multiple times and places, to 0.066 mg/L at EC-6 on April 22. The hypolimnetic grand median was 0.008 mg/L. The median TP values for a single station ranged from 0.001 mg/L at RK-66, RK-72, and LNF-3 to 0.008 mg/L at RK-56 and EC-6. Reservoir-wide TP levels were lowest in October and November (median = 0.002 mg/L) and highest in April (median = 0.041 mg/L).

Measurements of TP at NFC ranged from below the detection limit (0.001 mg/L) on multiple occasions to 0.086 mg/L on April 7. The annual median TP in the river was 0.006 mg/L, which is similar to TP levels of both the epilimnion and hypolimnion of the reservoir. Measurements of TP are summarized in Appendix G.

Nitrogen

Epilimnetic values for N+N ranged from below the detection limit at multiple times and locations to 0.100 mg/L at RK-66 on May 19 (Figure 12), with a grand median of 0.004 mg/L. RK-56 had the highest N+N levels (median 0.032 mg/L) while RK-2 and RK-72 had the lowest (median = 0.002). Monthly N+N levels were highest in March (median = 0.065 mg/L) and below the detection limit by July (median = 0.001 mg/L).

Hypolimnetic values for N+N ranged from below the detectable limit at multiple locations to 0.140 mg/L at RK-66 on May 19, with a grand median of 0.036 mg/L. RK-72 had the lowest annual N+N levels (median = 0.009 mg/L) while RK-31 had the highest annual levels (median = 0.046 mg/L). Reservoir-wide, hypolimnetic N+N levels were lowest in September (median = 0.007 mg/L) and highest in June (median = 0.076 mg/L).

Measurements of N+N at NFC ranged from 0.005 mg/L on October 9 to 0.100 mg/L on April 23. The annual median N+N value for the river was 0.057 mg/L, which is closest to, but higher than that of hypolimnion. Measurements of N+N are summarized in Appendix H.

Total Dissolved Solids

Measurements of total dissolved solids (TDS) from the epilimnion ranged from 13.0 mg/L at LNF-3 on June 23 to 31.0 mg/L at RK-2 and RK-31 on the same day (Figure 13). The grand median for epilimnetic TDS was 20.0 mg/L. LNF-3 had the lowest TDS levels (median = 19.0 mg/L), while RK-2 and RK-56 had the highest (median = 22.0 mg/L). The reservoir-wide TDS levels were lowest in July (median = 18.5 mg/L) and the highest in November (median = 25.0 mg/L). TDS in the river ranged from 14.0 to 28.0 mg/L, with an annual median of 20.0 mg/L. Measurements of TDS are summarized in Appendix I.

Dissolved Organic Carbon

Dissolved organic carbon (DOC) was measured from the epilimnion at RK-31 and RK-72 during the first sampling event each month. DOC values at both stations ranged from below the detectable limit (0.5 mg/L) to 7.4 mg/L, with a mean value of 1.9 mg/L and a median of 1.0 mg/L (Table 3).

Precision

Precision, based on differences between duplicate and original field samples, was generally high. The mean relative percent difference (RPD) was 69.9% for TDP, 59.8% for TP, 54.8% for N+N, and 3.4 % for TDS. Median RPD values were 28.6% for TDP, 21.1% for TP, 14.8% for N+N and 3.8% for TDS. Mean RDP values were driven by a few instances with high RPD values. While we observed RPD values as high as 200%, these were due to differences of 0.004 mg/L for TDP, 0.008 mg/L for TP and 0.016 mg/L for N+N. While RDP values for TDS were generally lower, they represented differences as high as 2 mg/L. The differences between original and duplicate samples are summarized in Appendix K.

Biological Indicators

Chlorophyll *a*

Chlorophyll *a* (Chl *a*) values from the epilimnion ranged from 0.17 µg/L at RK-72 on June 9 to 8.65 µg/L at EC-6 on July 21 (Figure 14). The epilimnetic grand median was 1.76 µg/L. The highest Chl *a* levels at a station occurred at RK-31 (median = 2.71 µg/L), while the lowest Chl *a* levels were at RK-72 (median = 1.02 µg/L). Monthly reservoir-wide Chl *a* levels were lowest in June (median = 1.00 µg/L) and highest in April (median = 3.24 µg/L). Chl *a* levels at NFC ranged from 0.06 to 3.43 µg/L, with an annual median of 0.54 µg/L. Measurements of Chl *a* are summarized in Appendix J.

Picoplankton

Densities of picocyanobacteria ranged from 265 cells/ml at RK-72 on April 21 to 775 thousand cells/ml at RK-2 on July 7, with a grand median of 33 thousand cells/ml. Annual densities were lowest at RK-72 (median = 24 thousand cells/ml) and highest at RK-2 (median = 56 thousand cells/ml). Reservoir-wide densities (Figure 15) were lowest in May (mean = 5315 cells/ml) and peaked in July (mean = 203 thousand cells/ml).

While heterotrophic bacteria were more numerous than picocyanobacteria, they exhibited similar patterns of abundance. Densities ranged from 114 thousand cells/ml at RK-2 on March 24 to 2.5 million cells/ml at RK-2 on September 22, with a grand median of 750 thousand cells/ml. Reservoir-wide densities (Figure 16) were lowest in March (mean = 179 thousand cells/ml) and highest in October (mean = 1.9 million cells/ml). October densities were substantially lower in untreated areas than in treated areas. Picoplankton data are summarized in Appendix L.

Phytoplankton

Epilimnetic phytoplankton densities ranged from a low of 659 NCU/ml at RK-66 on May 19 to a high of 12122 NCU/ml at LNF-3 on September 8, with a grand median of 2979 NCU/ml (Figure 17). Annual median phytoplankton densities ranged from 2037 NCU/ml at LNF-3 to 3890 NCU/ml at RK-31 (Table 4). When comparing phytoplankton biovolumes, the lowest annual median was 0.15 mm^3/L at RK-72, while the highest was 0.38 mm^3/L at RK-2 (Figure 17; Table 5).

Reservoir-wide phytoplankton densities peaked in April (median = 3558 NCU/ml) and September (median = 5317 NCU/ml; Figure 18; Table 4). August had the highest biovolume (median = 0.44 mm^3/L) followed by April and September (median = 0.33 mm^3/L; Figure 18; Table 5).

Flagellates were the dominant taxa throughout the reservoir, with annual medians for percentage of the overall density (NCU/ml) ranging from 51.5% at RK-31 to 66.7% at LNF-3 (Figure 19). Median densities of flagellates ranged from 1378 NCU/ml at RK-72 to 2048 NCU/ml at RK-31 (Table 4). Blue-greens were the second most abundant taxa, with annual medians ranging from 20.6 to 37.3% of the overall abundance. Median values for blue-green densities ranged from 395 NCU/ml at RK-66 to 1085 NCU/ml at EC-6. Of the remaining groups, diatoms and coccoid greens each typically represented less than 8% of the phytoplankton community by density, while dinoflagellates typically represented less than 0.5% (Figure 19).

Reservoir-wide, flagellates were the dominant taxa in every month except March and October, during which blue-greens were the dominant taxa (Figure 20). Flagellate densities were lowest in March (median = 958 NCU/ml) and highest in August (median = 2406 NCU/ml) and September (median = 2592 NCU/ml; Figure 21). Blue-green densities first peaked in April (median = 1206 NCU/ml), declined, and peaked again in September (median = 1945 NCU/ml) and October (median = 1524 NCU/ml). The early peak consisted primarily of *Synechococcus sp.*, while the late peak was dominated by *Anabaena sp.* and *Microcystis sp.*

Phytoplankton edibility was determined from published research and is a key metric for evaluating the effectiveness of the nutrient supplementation program. The percentage of phytoplankton in a given sample (measured in NCU/ml) for which edibility could be established ranged from 43.3% to 100%, with a grand median of 99.4%. Densities of edible phytoplankton ranged from 354 NCU/ml at LNF-3 on October 6 to 10,582 NCU/ml at RK-31 on May 20, with a grand median of 2497 NCU/ml (Figure 22). Annual medians ranged from 1853 NCU/ml at RK-66 to 3025 NCU/ml at EC-6. Reservoir-wide monthly medians ranged from 1732 NCU/ml in October to 3213 NCU/ml in April (Table 6).

The percent edibility was determined by dividing the density (NCU/ml) of edible phytoplankton by the density of phytoplankton for which edibility could be determined. The percentage that was edible ranged from 13.4% at RK-66 on August 11 to 99.5% at RK-56 on June 23, with an overall median of 80.4%. Annual medians ranged from 61.8% at LNF-3 to 88.3% at RK-31. Reservoir-wide monthly means ranged from 95.1% in June to 31.4% in October (Table 6).

Edibility was also determined based on biovolume (mm^3/L). The percentage of the overall biovolume for which edibility could be established ranged from 7.2% to 100%, with a grand median of 99.0%. The biovolume of edible phytoplankton ranged from 0.01 mm^3/L at LNF-3 on July 21 to 1.03 mm^3/L at RK-31 on May 20, with a grand median of 0.07 mm^3/L. Annual median densities ranged from 0.09 mm^3/L at RK-56 to 0.23 mm^3/L at EC-6. Reservoir-wide monthly medians ranged from 0.06 mm^3/L in November to 0.29 mm^3/L in April (Figure 23; Table 7).

Of that portion of the samples for which edibility was determined, the percentage of edible biovolume ranged from 22.5% at LNF-3 on August 11 to 100% at RK-2 on June 23, with a grand median of 72.5%. The lowest percentage edibility was observed at RK-66 (median = 66.8%) and the highest percentage edibility was at RK-72 (median = 87.9%). Reservoir-wide, percentage edibility was lowest in August (mean = 52.3%) and highest in June (mean = 89.7%). Summaries of phytoplankton data can be found in appendices M and N.

Zooplankton

Zooplankton densities were greater in the upper strata (median = 22.0, mean = 25.7) than the lower strata (median = 1.0, mean = 3.0). Densities in the upper stratum ranged from 0.003 individuals per L at RK-72 on June 9 to 96 individuals per liter at EC-6 on June 23. Annual median densities ranged from 4.0 individuals per liter at RK-72 to 29.8 individuals per liter at EC-6. Reservoir-wide densities were lowest in April (median = 2.7 individuals per liter) and highest in October (median = 32.3 individuals per liter), with a secondary peak in June (Figure 24).

The zooplankton community was composed of two groups, cladocerans and copepods. Copepods were the dominant group in every month, ranging from 56.3% of the individuals

counted in June to 93.1% in March (Figure 25). Cyclops was the prevalent order of copepod throughout the year, comprising 64.8% of all zooplankton counted on average.

Cladoceran densities are of particular interest, as they are the preferred forage of kokanee. The annual mean percentage of cladocerans ranged from 18.9% at EC-6 to 43.4% at RK-72 (Figure 26). Reservoir-wide, the mean percentage of cladocerans ranged from 6.9% in March to 43.7% in June (Figure 25). In general, the percentage of cladocerans was higher in the upper end of the reservoir, in both treated and untreated sections (Figure 26), and during summer months (Figure 25).

Bosmina was the most abundant genera of cladocerans from March through May (Figure 25). *Daphnia* became the most abundant cladoceran from June through November and was the dominant cladoceran at all stations over the course of the sampling season. Other cladocerans represented 5% or less of the zooplankton community in a given month and less than 3% at a given station for the entire year. Zooplankton densities are summarized in Appendices O and P.

Annual mean total lengths of *Daphnia sp.* ranged from 1.08 mm at RK-2 to 1.16 mm at EC-6 (Figure 27). The reservoir-wide mean length ranged from 0.88 mm in May to 1.12 mm in July and October. Annual mean lengths were above 1 mm for all stations (Figure 28) and reservoir wide after May. Annual mean total lengths of *Bosmina sp.* ranged from 0.35 mm at RK-56 to 0.44 mm at RK-2 (Figure 27). The reservoir-wide mean total length ranged from 0.35 mm in September and October to 0.44 mm in April (Figure 28). Zooplankton lengths are summarized in Appendix Q.

Kokanee Population

Abundance and Density

From the hydroacoustic survey conducted on July 22-24, we estimated an overall abundance of 1,523,113 kokanee in Dworshak Reservoir (Table 9). Of these, 1,237,181 were age-0, 200,147 were age-1, 55,117 were age-2, and 30,668 were age 3 (Figure 29). These estimates were based on an overall density of 287 fish/ha. When broken out by age, the densities were 233 fish/ha for age-0, 38 fish/ha for age-1, 10 fish/ha for age-2, and 6 fish/ha for age-3 (Table 10). Age-0 kokanee were most abundant in the lower end of the reservoir and age-2 and age-3 kokanee were most abundant in the upper end of the reservoir (Figure 29). Age-1 kokanee were most abundant in the middle section. Historical abundance estimates for kokanee are presented in Appendix R.

Age and Growth

Midwater trawls were conducted on April 7-9, July 30-31, and October 27-28. A total of 916 kokanee were captured in midwater trawls. Of these, 140 were captured during April trawling, 267 in July, and 509 in October. In April, trawl caught kokanee ranged from 77 to 281 mm total length (TL). These fish were ages 1-3; no age-0 kokanee were encountered in April (Table 11). A total of 111 age-1 kokanee were captured in April, ranging from 77 to 140 mm TL. Age-1 kokanee had a mean TL of 110 mm (Figure 30) and a mean relative weight (W_r) of 64.7 (Table 6). A total of 21 age-2 kokanee were captured, ranging in size from 214 to 281 mm TL. Age-2 kokanee had a mean TL of 245 mm and a mean W_r of 78.0. A total of eight age-3 kokanee were captured, ranging in size from 232 to 262 mm TL. Age-3 kokanee had a mean TL of 251 mm and a mean W_r of 76.8.

In July, trawl caught kokanee ranged from 26 to 328 mm TL. Of these, 119 were age-0 between 26 and 67 mm total length, with a mean TL of 44 mm (Table 5). Another 148 were age 1-3, ranging in size from 159 to 328 mm TL. Of these, ages were verified for 106 through scale analysis. Of these, 67 were age-1 fish ranging in size from 159 to 252 mm TL. Since no other age groups were identified in this size range, all un-aged kokanee in this range were considered age-1. Age-1 kokanee had a mean TL of 209 mm TL (Table 11; Figure 31) and a mean W_r of 85.4 (Table 12). Another 25 were determined to be age-2, ranging in size from 266 to 326 mm TL and 14 were age-3 ranging in size from 282 to 322 mm TL. Age-2 kokanee had a mean TL of 303 mm and a mean W_r of 88.4. Age-3 kokanee had a mean TL of 301 mm and a mean W_r of 91.7.

In October, trawl caught kokanee were between 48 and 305 mm TL. Of these, 437 were age-0 and ranged in size from 48 to 125 mm TL. Age-0 kokanee had a mean TL of 86 mm (Table 11; Figure 32) and a mean W_r of 94.2 (Table 12). Another 69 were determined to be age-1, ranging in size from 193 to 263 mm TL. Age-1 kokanee had a mean TL of 235 mm and a mean W_r of 94.2. Three kokanee were determined to be age-2, ranging in size from 282 to 305 mm TL. Age-2 kokanee had a mean TL of 290 mm and a mean W_r of 93.4.

The mean TL of age-0 kokanee increased by 42 mm from July to October (Table 11; Figure 33). The mean TL of age-1 kokanee increased by 100 mm from April to July and by 25 mm from July to October, for a total of 125 mm. The mean TL of age-2 kokanee increased by 56 mm from April to July and age-3 fish increased by 48 mm over the same period.

Production

Kokanee production from July of 2006 to July of 2007 was estimated to be 140.9 metric tonnes (t). During this period, biomass was estimated to have declined from 81.3 t in 2007 to 39.4 t in 2008. Yield was estimated to be 183.6 t.

Spawner Counts

Peak kokanee spawner counts were performed on September 24-25, during which 7,433 spawning kokanee were counted in four index streams. This included 3,738 in Isabella Creek, 2,160 in Skull Creek, 426 in Quartz Creek, and 1,073 in Dog Creek. Historical spawner count data are shown in Appendix S.

A total of 102 carcasses were sampled during spawner counts. Of these, 21 were female, 46 were male, and 35 were unidentified. Total length could be measured for 31 carcasses, 2 females, 14 males and 15 of unknown sex. The overall mean TL for spawning kokanee was 306 mm (Figure 34). The mid-eye to hypural plate (MEHP) length was recorded for all carcasses. The mean MEHP length of spawning kokanee was 247 mm. Males (mean = 247 mm MEPH) tended to be larger than females (mean = 240 mm MEHP).

DISCUSSION

Water Quality

While a primary goal of the nutrient supplementation project is to restore lost productivity to the reservoir, it is imperative to do so without degrading overall water quality. The Consent

Order issued by IDEQ stipulates a minimum median value for Secchi depth (3.0 m) and maximum median values for epilimnetic TDP (0.025 mg/L) and Chl *a* (3.0 µg/L). These water quality standards were not violated in 2008.

While not addressed in the Consent Order, dissolved oxygen (DO) is another water quality parameter that we considered when assessing the effects of nutrient additions. By late summer and early fall, DO minima are commonly observed in the metalimnion and hypolimnion of Dworshak Reservoir, particularly at the upper end of the reservoir. Metalimnetic DO minima are not uncommon in lakes and reservoirs and have been observed in Dworshak in previous years, including pretreatment years. We believe these DO minima result from the decay of organic material that has a tendency to concentrate in the metalimnion, where the density of the water starts to increase due to the colder water temperatures. As phytoplankton within the epilimnion senesce, they begin to settle and become most concentrated in the metalimnion. There they continue to decay, resulting in reduced DO within the water column. The DO minima observed in 2008 were not as severe as previous years, likely due to the higher runoff and cooler summer, which resulted in a slight delay in stratification. These DO minima appear to be more related to water year and the duration of thermal stratification than to nutrient additions.

Water clarity is a water quality indicator that is important to assess when evaluating a lake or reservoir restoration project (Horne and Goldman 1994). In 2008, water clarity in Dworshak Reservoir was within the range observed from 2004 through 2006, although it was at the extreme low end of this range. However, 2008 was an above average year for both snow pack and resultant runoff. The USACE drew the reservoir down to extreme low levels in May in anticipation of the heavy runoff. This extreme drawdown exposed layers of sediments, which had built up over many years, to erosion by rain and wave action. A combination of the drawdown and higher input of suspended inorganic matter from peak runoff, rather than nutrient additions, caused lower than normal water clarity during the spring. As the reservoir began to reach full pool again, water clarity improved. It is likely that subsequent decreases in water clarity during summer months were due to phytoplankton production. Still, water clarity in 2008 was similar to 2006, a pretreatment year with above average runoff. Therefore, it appears that lower than normal water clarity during 2008 was due more so to high runoff than nutrient supplementation.

Despite regular additions of nutrients to the reservoir, there were not any measurable increases of available nitrogen or phosphorous. This is not surprising, as the amount of phosphorous added was too small to result in a measurable concentration (detection limit = 0.001 mg/L) considering the dilution capacity of the epilimnion. While the amount of nitrogen that was added could have resulted in a measurable increase, nitrogen is typically the limiting nutrient in Dworshak Reservoir and is generally taken up by the biota in less than 24 hours (Stockner and MacIsaac 1996). Since sampling occurs four days after applications, it is unlikely that supplemented nitrogen would remain in the system long enough to be measured. While there is little variation in annual medians for nutrient concentrations, seasonal peaks are typically observed during the spring, coinciding with runoff. The highest concentrations are usually observed in years of above normal runoff, suggesting that runoff has a greater influence on nutrient concentrations than do nutrient applications.

Chlorophyll is another parameter we monitored because chlorophyll concentrations are generally indicative of increased productivity and can be a sign of degraded water quality through excessive or nuisance algal blooms (Horne and Goldman 1994). Chlorophyll concentrations in 2008 were slightly less than previous years when comparing values collected at the same locations (RK-2, RK-31, RK-56 and RK-72) during the same time frame (May

through November). Therefore, nutrient supplementation does not appear to have caused an increase in chlorophyll concentrations through the second year of the project.

In addition to water quality within the reservoir, effects on water quality in the North Fork Clearwater River below the dam were evaluated. Nutrients were applied to the epilimnion, and it is unlikely that supplemental nutrients mixed into the hypolimnion since Dworshak exhibits strong thermal stratification. Understanding which layer of the water column is discharged through the dam will help evaluate the likelihood that supplemented nutrients were discharged into the river. Water can be discharged through the dam by one of two avenues. First, it can be discharged through turbines. In 2008, turbine discharge accounted for 85% of the total discharge through Dworshak Dam. Turbines can be operated in two modes, undershot and overshot. When operated in undershot, turbines always pull water from the hypolimnion. In overshot mode, turbines have the potential of pulling water from either the hypolimnion or epilimnion, depending on pool elevation and the depth of the thermocline. In 2008, spill occurred on a total of 100 days. When spill occurred, it accounted for 27% of the total discharge on average. There are two routes by which spill can be discharged, spill gates and regulating outlets. Regulating outlets always discharge hypolimnetic water. Spill gates have the potential of discharging epilimnetic water depending on pool elevation and depth of the thermocline (Greg Parker, USACE, personal communication).

While the method of discharge alone cannot tell us the origin of the water, the temperature and chemical makeup of the river water provide clues. By definition, thermal stratification results from differences in temperature between two layers of water. The USACE is required to maintain cool water temperatures in the North Fork Clearwater River to offset warmer water downstream in the Snake River for the benefit of anadromous salmonids. In order to meet temperature requirements, they primarily discharge colder water from the hypolimnion. As a result, the temperature of the river more closely matches that of the hypolimnion. Phytoplankton densities, and resulting chlorophyll concentrations, are highest in the epilimnion where there is sufficient light penetration for photosynthesis. The Chl *a* concentrations at NFC (median = 0.54 µg/L) were generally lower than at RK-2 (median = 2.56 µg/L), suggesting that river water was derived primarily from the hypolimnion. There was, however, a single sampling event on July 21, 2008, for which the Chl *a* concentration in the river (3.43 µg/L) was similar to the concentration in the epilimnion at RK-2 (3.55 µg/L). At the same time, water from the spillway was observed to have a green coloration compared to water discharged from the turbines. The spill water produced a surface foam and a color line was observed for approximately 1 km downstream. This phenomenon lasted several days and had not been observed in the previous ten years (Mark Smith, USACE, personal communication). Together, these observations suggest that epilimnetic water was spilled for several days in late July, but that this is a rare event. As a precautionary measure, nutrient applications were stopped at river km 11 (8 km above the dam) in 2008.

As in 2007, a resident below the dam reported that his irrigation pump became plugged with algae. However, this was a single occurrence in early 2008, following an increase in river flows. This observation occurred before the spill event during which epilimnetic water is believed to have been discharged. The resident reported no further problems for the remainder of the year. Personnel at the Clearwater Fish Hatchery also reported continued periphyton growth in the raceways, but no health issues with fish.

Reservoir Productivity

Climatic conditions are a driving force for growing conditions within the reservoir. In 2008, a higher than normal snowpack and resultant runoff, coupled with a cooler than normal summer, lead to a shortened growing season within the reservoir. Although more outliers in nutrient concentrations were observed during the spring of 2008, annual concentrations of total dissolved phosphorous were lower in 2008 than in 2006, a preapplication year with higher than normal runoff.

Picoplankton densities, both picocyanobacteria and heterotrophic bacteria, were higher than 2006 (preapplication), but lower than 2007. The reduction in densities from the previous year is likely due to two factors. One factor was the delayed spring freshet and cooler summer that lead to a shorter growing season. The other factor was increased grazing pressure from flagellates. The peak in heterotrophic bacteria occurred one month later in 2008 than in 2007, suggesting that the former was a strong influence. However, higher densities of flagellates in 2008 suggest that they had some potential to graze down the picoplankton population. If this was indeed the case, it is an indication that the effects of the nutrient supplementation have progressed upward another trophic level.

Compared to previous years, phytoplankton densities did not appear to be increasing due to nutrient supplementation. However, several shifts in the composition of the phytoplankton community have been observed. Most notable was an increase in flagellate densities coupled with a decrease in diatom densities. The increase in flagellate densities may be in response to increases in picoplankton, as some flagellates are known to graze on picocyanobacteria and heterotrophic bacteria. Flagellates constitute a high quality food source for zooplankton (Sanders and Porter 1990). Although some diatoms provide quality food for zooplankton, the diatom community in 2007 was dominated by *Fragilaria crotonensis*, an inedible species. The lack of inedible diatoms in 2008 has lead, in part, to an increase in overall edibility of the phytoplankton community.

Although blue-green algae densities were not greater than previous years, including preapplication years, a noticeable bloom occurred during the summer and fall. While the spring community was dominated by *Synechococcus sp*., which is edible to zooplankton, the summer and fall bloom was dominated first by *Anabaena circinalis* followed by *Microcystis sp*., both of which are inedible. Furthermore, *Anabaena* and *Microcystis* have the potential to produce neurotoxins, and therefore are a public health concern. Water testing performed by the USACE was negative for the presence of toxins (Paul Pence, USACE, personal communication). Due to the onset of this bloom, applications were suspended as a precaution for three weeks starting on August 7.

Although applications were suspended temporally to allow the blue-green bloom to subside, it is not likely that they caused or exacerbated this bloom. Blue-greens, and *Anabaena* in particular, are not a new occurrence on Dworshak Reservoir. In fact, blue-green densities in 2008 were similar to previous years, including preapplication years. Furthermore, the bloom that began in the summer of 2008 was first apparent in untreated areas of the reservoir. Blue-green blooms are believed to be triggered by a depletion of bio-available nitrogen. In fact, this bloom occurred two weeks after available N+N was depleted in early July. Many blue-greens dominate under these conditions because they are either able to fix atmospheric nitrogen or are able to take up bio-available nitrogen more efficiently at very low concentrations. Therefore, it is generally believed that nitrogen supplementation should reduce densities of blue-greens by removing their competitive advantage (Smith 1983). However, this has not been tested

experimentally. If this hypothesis is tested and supported, careful nutrient additions may actually serve as an effective tool for preventing blue-green blooms. Due to the rapid onset and short duration of these blooms, it is critical to maintain semi-monthly sampling during the experimental phase of this program.

Zooplankton production is a key metric of this project, as increased zooplankton are expected to provide a greater forage base for kokanee. Our sampling methodology for zooplankton was refined in 2008, which allowed for comparisons to be made with past years. In 2007, zooplankton tows were conducted from 30 m to the surface, making them incomparable with previous years. By performing tows from both 30 to 10 m and from 10 m to the surface in 2008, we were able to confirm that zooplankton densities were considerably higher in the upper 10 m of the water column. Prior to 2007, tows were conducted in the photic zone, which was typically between 11 and 12 m. Therefore, the 10 m tows from 2008 are roughly comparable to tows from 2005 and 2006 performed with an 80 µm net.

In 2008, cladoceran densities were similar to previous years where plankton tows were performed with a similar net and tow depths. However, the mean total length of *Daphnia* has consistently been greater than 1 mm during the first two years of nutrient supplementation. *Daphnia* are the preferred forage of kokanee in Dworshak Reservoir (Stark and Stockner 2006). While densities have not increased, this increase in size has also resulted in an increase in *Daphnia* biomass over preapplication years. This increase in size and biomass may be a result of both bottom-up and top-down effects. The increase in flagellate densities should provide *Daphnia* with a high quality forage, allowing them to grow and reproduce at faster rates. Low densities of kokanee may result in reduced cropping and a higher proportion of large *Daphnia* in the population. The size and density of *Daphnia* in years of higher fish density will be important in determining how the zooplankton community is responding to nutrient supplementation.

The complex interactions between climate, hydrology, and food web dynamics result in a system that is difficult to assess. We expect it will take several years before the changes are fully realized, but they should be assessed annually. Data collected in 2008 indicate that Dworshak Reservoir is continuing to respond favorably to nutrient enhancement. If the trends observed during the first two years continue, the improved food web efficiency within the reservoir will result in improved fisheries without negative effecting water quality.

Kokanee Population

A primary goal of the nutrient project is to improve kokanee growth. When comparing total lengths of fish caught in the July trawl surveys, age-2 kokanee were larger in 2008 (mean = 303 mm TL) than in any other recent year, although kokanee lengths were similar in 2004 (mean = 301 mm TL). When comparing increases in mean TL over the course of the year, mean TL of both age-1 and age-2 kokanee increased more during each of the first two years of the project than in 2004, the only preapplication year during which multiple surveys were conducted. In addition to length, kokanee condition appears to have improved since nutrient supplementation began.

When more forage is available, fish may put on more weight relative to body length that they otherwise would. The mean relative weights (W_r) of both age-1 and age-2 kokanee from 2008 were higher than in any recent year for which we have data for comparison, including 2004, when kokanee were similar in TL. As in 2007, mean W_r of trawl caught kokanee increased from April through October, whereas W_r remained essentially constant from May through November in 2004.

Since kokanee typically exhibit density dependent growth (i.e. lower densities result in larger fish and vice versa), it is important to take densities into account when evaluating growth. Based on the hydroacoustic survey, the combined density of age-1 and older kokanee was lower in 2008 than any year since 1998. Therefore, growth should be better than in previous years regardless of nutrient supplementation.

Another way to assess benefits to the kokanee population is to compare production from preapplication and application years. Production has been viewed as a potential method to assess kokanee growth without density dependent effects. The idea being that while the growth of individual kokanee is related both to the availability of forage and the number of fish competing for the available forage (i.e. density dependent), production should be strictly related to forage availability. We predicted that production should be the same whether it resulted from many fish that grew little or few fish that grew a lot. Therefore, comparing production would allow us to make comparisons independent of fish density. However, while growth was slightly better in 2008 than in 2007, production was markedly lower from July 2007 to July 2008 than it was in the previous twelve months. However, mean abundance was much greater during the July 2006 to July 2007 period, suggesting that production is also density dependent in Dworshak Reservoir.

In order to best assess kokanee growth under nutrient supplementation, it will be important to do so under a broad range of population densities. Estimates of kokanee densities were even lower for 2008 than in 2007, which will continue to make the effects of nutrient supplementation on kokanee growth difficult to separate from density dependent growth influences. A year or two of higher densities will be necessary to properly evaluate the effects of fertilization on fish growth. Fortunately, the abundance of age-0 kokanee in 2008 was near the ten-year average. If survival of this year class is good, fish densities should be higher in the coming years, which would greatly aid in assessing growth under nutrient supplementation.

CONCLUSIONS

The nutrient supplementation project has shown early indications of success. Dworshak Reservoir has responded in a similar manner to British Columbia lakes and reservoirs that have undergone nutrient supplementation. The first year of the project brought increases in picoplankton, which may have lead to the increases in flagellates observed during the second year. Flagellates are an excellent source of food for zooplankton, and may lead to increased zooplankton densities and fish production in subsequent years. These increases in productivity have thus far occurred without a negative effect on overall water quality.

While the full influence on fish growth will not be realized for several more years, we have already observed seasonal increases in both length and relative weight. These increases were as good as or better than seasonal increases observed in 2004, which is a year that represents good fish growth prior to nutrient supplementation.

RECOMMENDATIONS

1. The Dworshak Reservoir nutrient enhancement experiment should be continued so that evaluation of the project can continue as the effects of the nutrient applications work their way up through higher trophic levels.

2. Seek funding to continue twice-monthly sampling of the epilimnion during the experimental phase of the project in order to ensure sufficient evaluation of the project, adequately monitor compliance with the IDEQ Consent Order, and provide data for active management of the applications.

ACKNOWLEDGMENTS

The Dworshak Reservoir Nutrient Enhancement Project is a cooperative effort involving many people and several organizations. Paul Pence and Ben Perkins, with the U.S. Army Corps of Engineers, made sure that fertilizer was accurately applied. John Bailey, Tim Dykstra, Steve Juul, and Ben Tice, also with the USACE, all played important roles in this project. We thank the anonymous IDFG personnel who assisted with the fieldwork for this project. This project was funded by the Bonneville Power Administration and we thank Dave Kaplowe and Roy Beaty for administering the BPA contract.

LITERATURE CITED

Anderson, R. O., and R. M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 *in* B. R. Murphy, and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Bennett, D. H. 1997. Evaluation of current environmental conditions and operations at Dworshak Reservoir, Clearwater River, Idaho, and an analysis of fisheries management mitigation alternatives. U.S. Corps of Engineers, Walla Walla, Washington.

Bowler, B., B. E. Rieman, and V. L. Ellis. 1979. Pend Oreille Lake fisheries investigations. Idaho Department of Fish and Game, Job Performance Report. Idaho Department of Fish and Game, Project F-73-R-1, Boise.

DART, C. B. R. Columbia River Data Access in Real Time (DART). Pages Columbia River Data Access in Real Time *in*. University of Washington, Seattle, Washington.

Falter, C. M. 1982. Limnology of Dworshak Reservoir in a low flow year. U.S. Army Corps of Engineers, Walla Walla, Washington.

Falter, C. M., J. M. Leonard, and J. M. Skille. 1977. Part 1. Limnology. Pages 110 *in* Early Limnology of Dworshak Reservoir. U.S. Army Corps of Engineers, Walla Walla, Washington.

Hayes, D. B., J. R. Bence, T. J. Kwak, and B. E. Thompson. 2007. Abundance, biomass, and production. Pages 327-374 *in* C. S. Guy, and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Horne, A. J., and C. R. Goldman. 1994. Limnology, 2nd edition. McGraw-Hill, New York.

Horton, W. D. 1981. Dworshak Reservoir Fisheries Investigations Idaho Department of Fish and Game, Contract No. DACW68-79-C-0034, Boise.

Hyatt, M. H., and W. A. Hubert. 2000. Proposed standard-weight (W-s) equations for kokanee, golden trout and bull trout. Journal of Freshwater Ecology 15(4):559-563.

IDFG. 2003a. 2003 Idaho Sport Fishing Economic Report. Idaho Department of Fish and Game, Boise.

IDFG. 2003b. Fisheries Management Plan 2007-2012. Idaho Department of Fish and Game, Boise.

Love, R. H. 1971. Dorsal-Aspect Target Strength of an Individual Fish. The Journal of the Acoustical Society of America 49(3B):816-823.

Maiolie, M., and S. Elam. 1997. Dworshak Dam impact assessment and fisheries investigation: kokanee depth distribution in Dworshak Reservoir and implications toward minimizing entrainment. Idaho Department of Fish and Game, Project 87-99, Boise.

Mauser, G., D. Cannamela, and R. Downing. 1989. Dworshak Dam impact assessment and fishery investigation. Idaho Department of Fish and Game, Project 87-89, Boise.

Nielsen, L. A., and D. L. Johnson. 1983. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

Rieman, B. E. 1992. Kokanee salmon population dynamics-kokanee salmon monitoring guidelines. Idaho Department of Fish and Game, Job Performance Report, Project F-73-R-14, Subproject II, Study II, Boise.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Dept. of the Environment, Fisheries and Marine Service, Ottawa, Ontario.

Sanders, R. W., and K. G. Porter. 1990. Bacterivorous Flagellates as Food Resources for the Freshwater Crustacean Zooplankter Daphnia ambigua. Limnology and Oceanography 35(1):188-191.

Simmonds, E. J., and D. N. MacLennan. 2005. Fisheries acoustics: theory and practice, 2nd edition. Blackwell Science, Oxford ; Ames, Iowa.

Smith, V. H. 1983. Low Nitrogen to Phosphorus Ratios Favor Dominance by Blue-Green Algae in Lake Phytoplankton. Science 221(4611):669-671.

Stark, E. J., and J. G. Stockner. 2006. Dworshak kokanee population and reservoir productivity assessment; Dworshak Dam impacts assessment and fisheries investigations project. Idaho Department of Fish and Game, Report No. 06-35. Idaho Department of Fish and Game, IDFG 06-35, Boise.

Stockner, J. G., and D. H. Brandt. 2005. Dworshak Reservoir: Rationale for Nutrient Supplementation for Fisheries Enhancement. Eco-Logic Ltd. and TerraGraphics Environmental Engineering.

Stockner, J. G., and E. A. MacIsaac. 1996. The British Columbia Lake fertilization program: overview after two decades of salmon enhancement. Regulated Rivers 12:344–356.

Zar, J. H. 1999. Biostatistical analysis, 4th edition. Prentice Hall, Saddle River, New Jersey.

Table 1. Summary of methods used by AM Test Labs to analyze the chemical composition of water samples collected from seven limnological stations throughout Dworshak Reservoir from March through November 2007.

Analyte	Analytical Method	Detection Limit (mg/l)	Practical Quantitation Limit (mg/l)
TDS	EPA 160.2	1	5
Nitrite+Nitrate	EPA 300.0	0.001	0.005
TP	EPA 365.2	0.001	0.005
TDP	EPA 365.2	0.001	0.005
DOC	EPA 415.2	0.50	1.5

Table 2. Summary of methods used by TG Ecologic to analyze biological samples collected from seven limnological stations throughout Dworshak Reservoir from March through November 2007.

Analyte	Analytical Method
Chlorophyll a	EPA 445.0
Phytoplankton	Utermohl (1958)
Picoplankton	MacIsaac and Stockner (1993)
Heterotrophic Bacteria	Porter and Feig (1980)
Zooplankton	TWRI B-2501-85

Table 3. Concentration of dissolved organic carbon (DOC) measured from the epilimnion at two limnological stations on Dworshak Reservoir from March through September 2007. Samples were not collected at RK-72 prior to June due to extremely low reservoir levels.

	Dissolved Organic Carbon mg/L		
Date	RK-31	RK-72	Mean
3/24/2008	<0.5		<0.5
4/7/2008	<0.5		<0.5
5/5/2008	<0.5		<0.5
6/9/2008	1.3	1	1.15
7/7/2008	7.4	<1.0	4.2
8/11/2008	2.2	2.4	2.3
9/8/2008	<0.5	<0.5	<0.5

Table 4. Median phytoplankton densities (NCU/ml) from the epilimnion of Dworshak Reservoir in 2008. Densities were measured at seven limnological stations from March through November. Densities are broken out by the five taxonomic classes present and reported as reservoir-wide medians for each month or annual medians for each station.

	Median Densities (NCU/ml)					
Month	**Blue-greens**	**Coccoid**	**Diatoms**	**Dinoflagellates**	**Flagellates**	**Total**
Mar	887	213	522	5	958	2610
Apr	1206	284	274	101	1652	3558
May	705	122	243	51	1429	2778
Jun	646	71	122	12	1598	2732
Jul	415	128	104	12	1293	1982
Aug	604	85	146	0	2409	3640
Sep	1945	61	268	0	2592	5317
Oct	1524	73	220	0	1171	3159
Nov	476	0	24	0	1488	2049
Station	**Blue-greens**	**Coccoid**	**Diatoms**	**Dinoflagellates**	**Flagellates**	**Total**
RK-2	958	159	207	11	1521	3282
RK-31	1061	122	207	12	2048	3890
RK-56	436	61	220	10	1427	2085
RK-66	395	41	171	10	1500	2134
RK-72	402	61	98	0	1378	2098
EC-6	1085	142	281	12	1659	3558
LNF-3	463	61	110	0	1537	2037

Table 5. Median phytoplankton biovolume (mm^3/L) from the epilimnion of Dworshak Reservoir in 2008. Biovolumes were measured at seven limnological stations from March through November. Biovolumes are broken out by the five taxonomic classes present and reported as reservoir-wide medians for each month or annual medians for each station.

	Median Biovolume					
Month	**Blue-greens**	**Coccoid**	**Diatoms**	**Dinoflagellates**	**Flagellates**	**Total**
Mar	0.01	0.09	0.04	0.00	0.09	0.24
Apr	0.01	0.09	0.05	0.05	0.09	0.33
May	0.01	0.01	0.05	0.03	0.11	0.29
Jun	0.01	0.02	0.02	0.01	0.10	0.23
Jul	0.04	0.03	0.04	0.01	0.08	0.24
Aug	0.13	0.02	0.03	0.00	0.11	0.44
Sep	0.07	0.02	0.09	0.00	0.10	0.31
Oct	0.06	0.05	0.02	0.00	0.09	0.33
Nov	0.01	0.00	0.00	0.00	0.06	0.10
Station	**Blue-greens**	**Coccoid**	**Diatoms**	**Dinoflagellates**	**Flagellates**	**Total**
EC-6	0.03	0.03	0.05	0.01	0.14	0.30
LNF-3	0.05	0.01	0.03	0.00	0.11	0.23
RK-2	0.04	0.05	0.02	0.01	0.08	0.38
RK-31	0.02	0.01	0.03	0.01	0.09	0.33
RK-56	0.02	0.01	0.05	0.00	0.06	0.20
RK-66	0.02	0.00	0.05	0.01	0.09	0.23
RK-72	0.01	0.02	0.01	0.00	0.08	0.15

Table 6. Density of edible phytoplankton (NCU/L) measured at seven limnological sampling stations on Dworshak Reservoir from March through November of 2008. The median density, median percentage of edible density, and median percentage of the overall density for which edibility could be determined from the literature are given. Medians are either reservoir wide median for each month or annual medians for each station.

	Medians		
Month	**Edible Density (NCU/ml)**	**% Edible Density**	**% Known Edibility**
Mar	2316.28	89.26%	99.22%
Apr	3213.40	90.31%	100.00%
May	2671.07	93.10%	100.00%
Jun	2500.11	96.73%	99.46%
Jul	1774.47	87.58%	98.63%
Aug	3012.33	41.37%	97.07%
Sep	3018.42	52.44%	92.90%
Oct	1731.78	31.98%	89.10%
Nov	1939.11	50.54%	100.00%
Station	**Edible Density (NCU/ml)**	**% Edible Density**	**% Known Edibility**
EC-6	3024.52	87.63%	99.59%
LNF-3	1951.30	61.75%	99.46%
RK-2	2576.16	85.41%	97.44%
RK-31	2990.38	88.32%	99.80%
RK-56	1939.11	72.22%	99.70%
RK-66	1853.74	79.03%	99.34%
RK-72	2048.87	74.27%	97.18%

Table 7. Biovolume of edible phytoplankton measured at seven limnological sampling stations on Dworshak Reservoir from March through November of 2008. The median biovolume, median percentage of edible biovolume, and median percentage of the overall biovolume for which edibility could be determined from the literature are given. Medians are either reservoir wide median for each month or annual medians for each station.

	Medians		
Month	**Edible Density (mm^3/L)**	**% Edible Density**	**% Known Edibility**
Mar	0.21	0.85	0.97
Apr	0.29	0.88	1.00
May	0.24	0.82	1.00
Jun	0.17	0.90	0.96
Jul	0.13	0.74	0.93
Aug	0.13	0.52	0.67
Sep	0.13	0.60	0.76
Oct	0.10	0.67	0.53
Nov	0.06	0.87	1.00
Station	**Edible Density (mm^3/L)**	**% Edible Density**	**% Known Edibility**
EC-6	0.23	0.79	0.99
LNF-3	0.13	0.82	0.98
RK-2	0.18	0.81	0.82
RK-31	0.15	0.87	0.99
RK-56	0.09	0.69	0.95
RK-66	0.10	0.67	0.94
RK-72	0.11	0.88	0.96

Table 8. Ranges of total length (mm) and corrected target strength (Db) for three ages of kokanee surveyed by acoustic methods on Dworshak Reservoir during July 16-18, 2007.

Age	Length Range	Decibel Range
0+	26-67	-60.0-45.0
1+	159-252	-44.9-37.0
2+	266-326	-36.9-30.0

Table 9. Abundance of kokanee, given in thousands of fish, in Dworshak Reservoir during July 2008. Estimates were derived from a hydroacoustic surveys and age breakdowns were derived from a fixed-frame trawl survey. Estimates are broken down by age class and reservoir section.

Section	Age 0	Age 1	Age 2	Age 3	All Ages
Section 1	816	59	6	0	881
Section 2	309	96	10	10	425
Section 3	112	45	40	21	217
Whole reservoir	1237	200	55	31	1523

Table 10. Density of kokanee in Dworshak Reservoir during July 2008. Estimates were derived from a hydroacoustic surveys and age breakdowns were derived from a fixed-frame trawl survey. Estimates are broken down by age class and reservoir section.

Section	Area (ha)	Age 0	Age 1	Age 2	Age 3	All Ages
Section 1	2963	275	20	2	0	297
Section 2	1755	176	55	5	5	242
Section 3	589	190	76	67	36	369
Whole reservoir	5307	233	38	10	6	287

Table 11. Summary of total lengths of kokanee captured during mid-water trawl surveys on Dworshak Reservoir during April, July, and October 2007. Statistics include number of observations, minimum and maximum observations, mean, and standard deviation. Growth is given as the increase in mean length (mm) observed in each age class between surveys.

		Total Length (mm)					Growth
Month	Age	N	Min	Mean	Max	SD	(mm)
Apr	1	103	77	110	140	15.7	
	2	21	214	245	281	18.5	
	3	8	232	251	262	11.8	
Jul	0	119	26	44	67	4.5	
	1	67	159	209	252	18.3	100
	2	25	266	303	326	12.0	56
	3	14	282	301	322	9.3	48
Oct	0	435	48	86	125	14.8	42
	1	69	193	235	263	13.4	25
	3	3	282	290	305	13.0	

Table 12. Relative weights of kokanee captured during mid-water trawl surveys on Dworshak Reservoir during April and July 2007. Statistics include number of observations, minimum and maximum observations, mean, and standard deviation.

		Relative Weight				
Month	**Age**	**N**	**Min**	**Mean**	**Max**	**SD**
Apr	1	32	58.2	64.7	70.9	3.5
	2	21	68.6	78.0	88.0	5.2
	3	8	71.0	76.8	83.3	4.7
Jul	1	50	56.5	85.4	105.1	7.7
	2	23	76.2	88.4	100.3	6.1
	3	12	85.1	91.7	99.1	4.6
Oct	1	69	67.4	94.2	111.0	7.8
	2	3	88.0	93.4	102.3	7.8

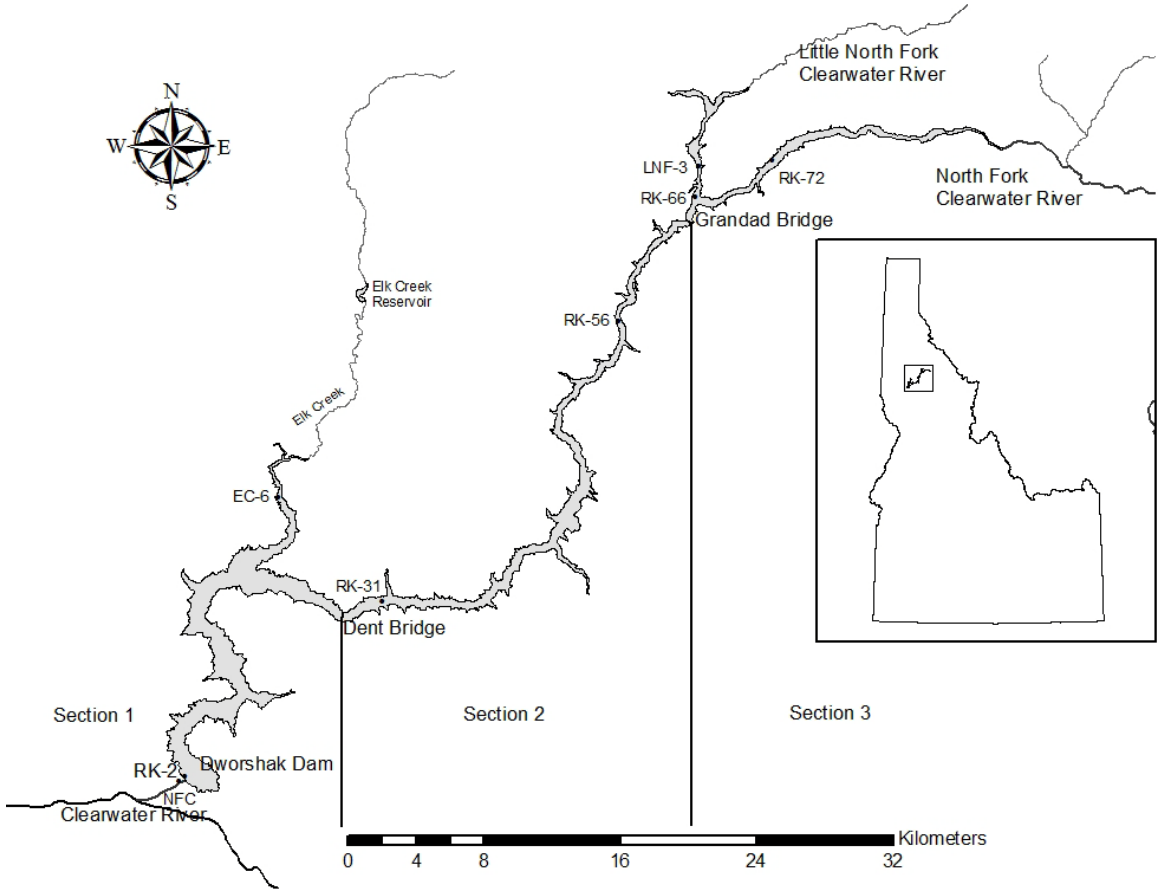


Figure 1. Map of Dworshak Reservoir depicting the locations of seven limnological sampling stations on the reservoir and one on the North Fork Clearwater below Dworshak Dam. Boundaries of reservoir sections used in statistical stratification are also shown.

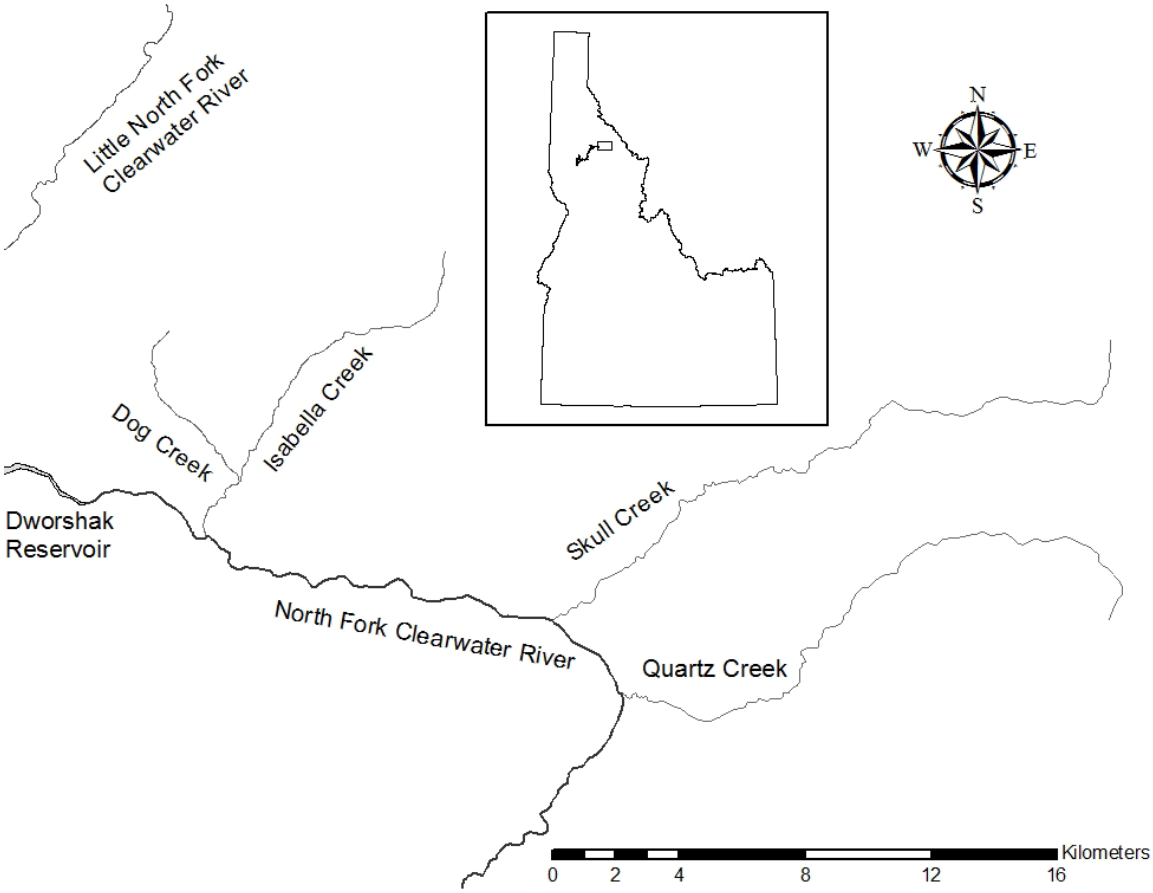


Figure 2. Map of the North Fork Clearwater River immediately above Dworshak Reservoir showing the four index streams that are surveyed for spawning kokanee.

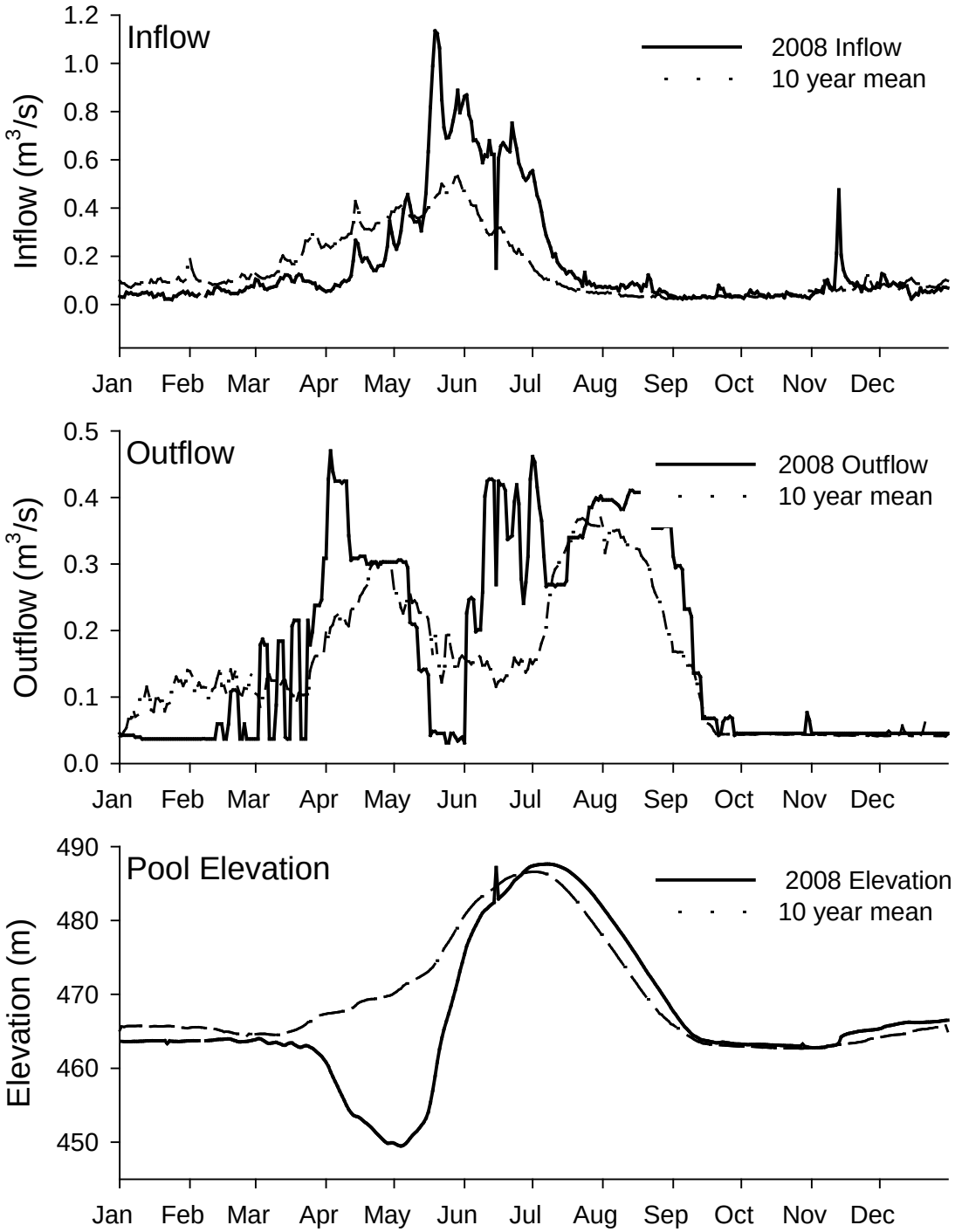


Figure 3. Mean daily inflow, outflow and pool elevation for Dworshak Reservoir during 2008 along with the 10 year mean (1998-2007). Data provided by the U.S. Army Corps of Engineers through the Columbia River Dart website (http://www.cbr.washington.edu/dart/).

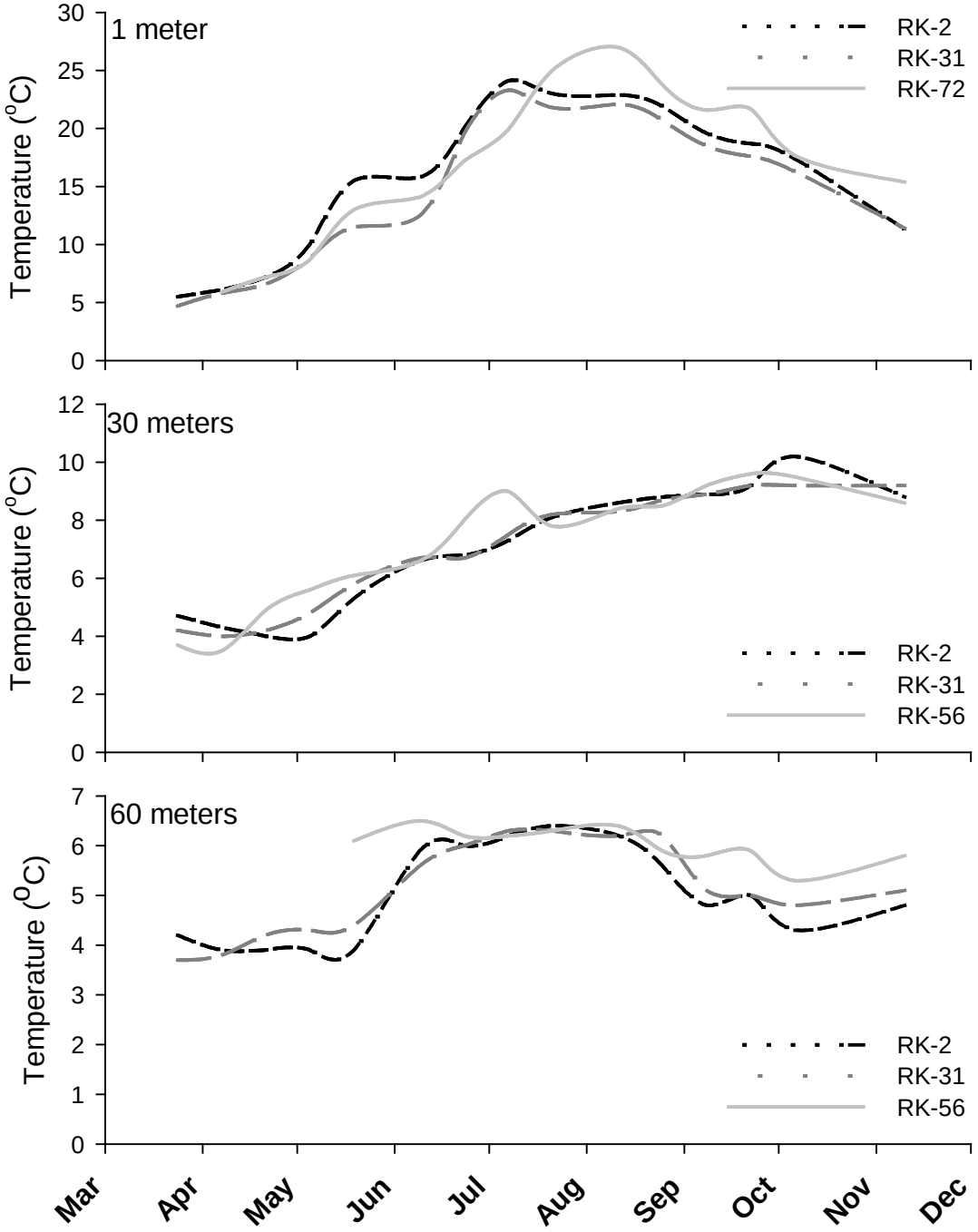


Figure 4. Seasonal temperature profiles at four reservoir stations on Dworshak Reservoir from March through November 2008. Temperatures are from depths of 1, 30 and 60 meters. Station RK-56 is used in lieu of RK-72 for the 30 and 60 m profiles because it was the uppermost station for which depths in excess of 30 m were encountered throughout the sampling season.

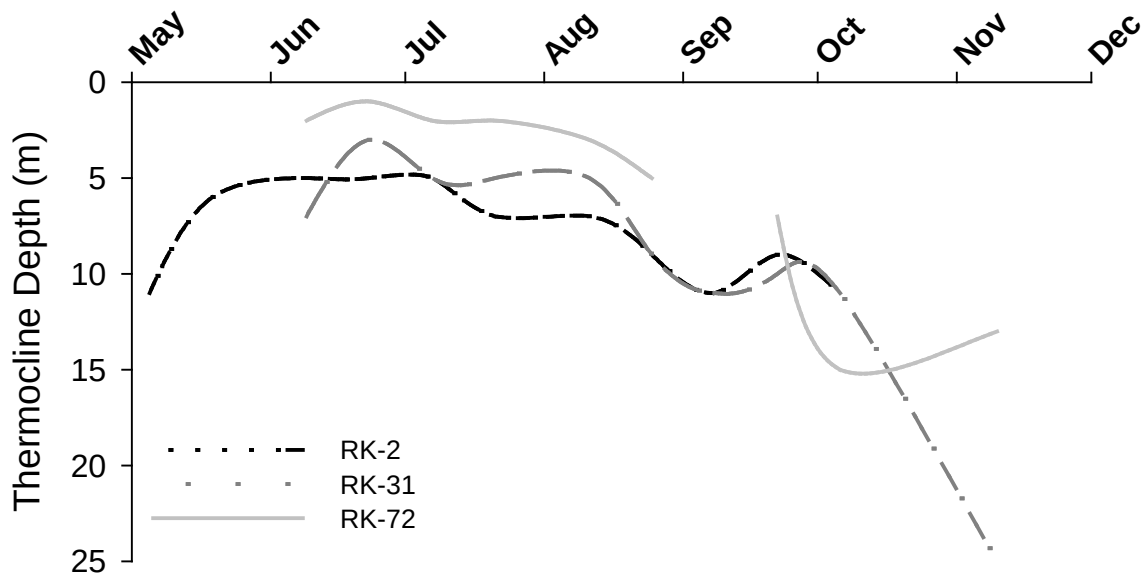


Figure 5. Depth of the thermocline, as defined by a change of 1°C over 1 m in depth, measured at three limnological sampling stations on Dworshak Reservoir from March through November 2008.

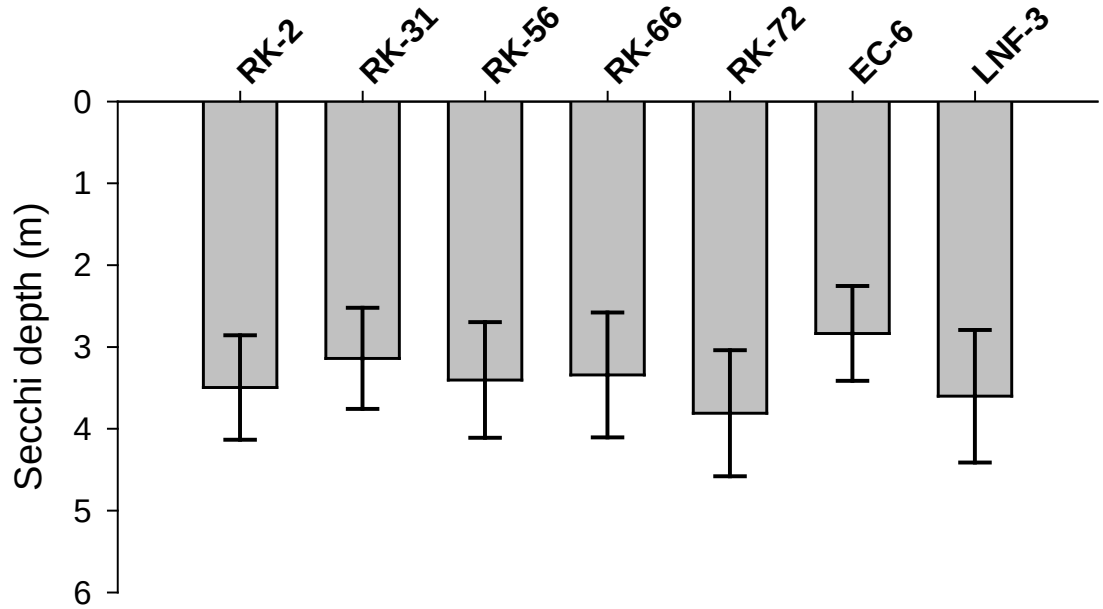


Figure 6. Mean annual Secchi depth (m) measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Error bars represent 95% confidence intervals around the mean.

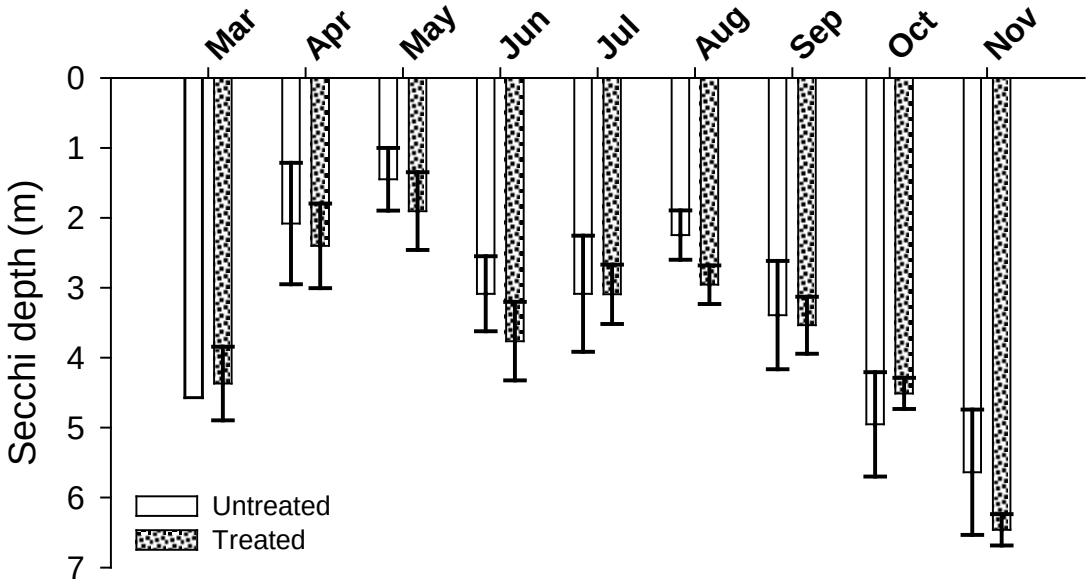


Figure 7. Mean monthly Secchi depths (m) for treated and untreated areas of Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean.

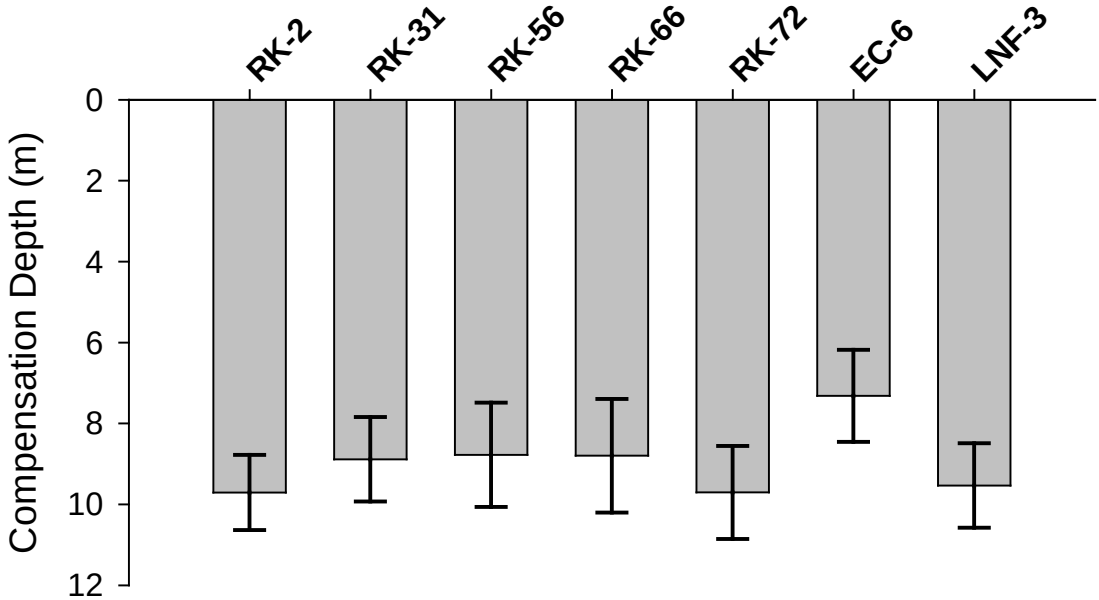


Figure 8. Mean annual compensation depths (m) for seven limnological stations throughout Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean.

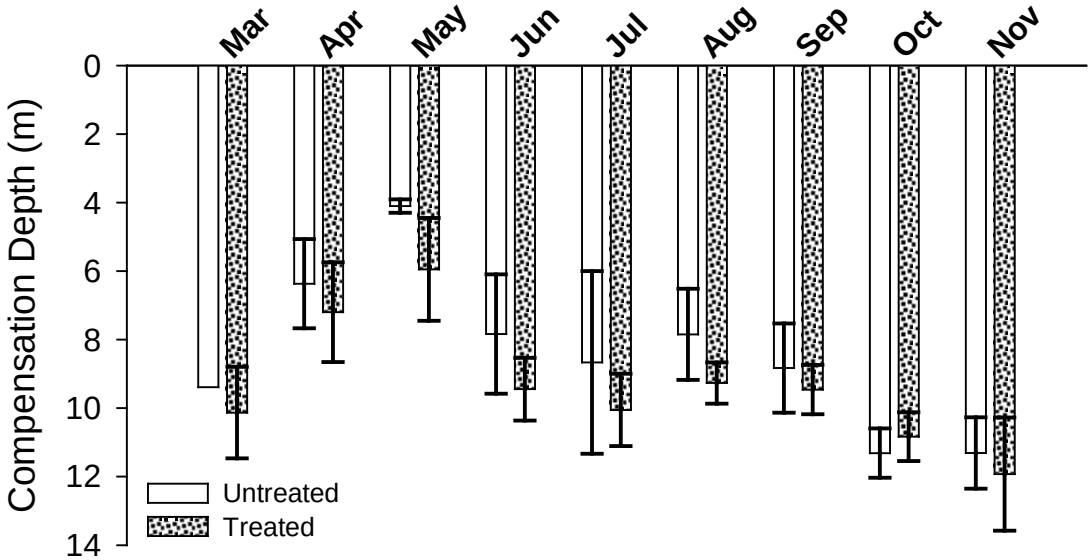


Figure 9. Mean monthly compensation depth (m), as calculated from readings of photosynthetically active radiation (PAR), for treated and untreated areas of Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean.

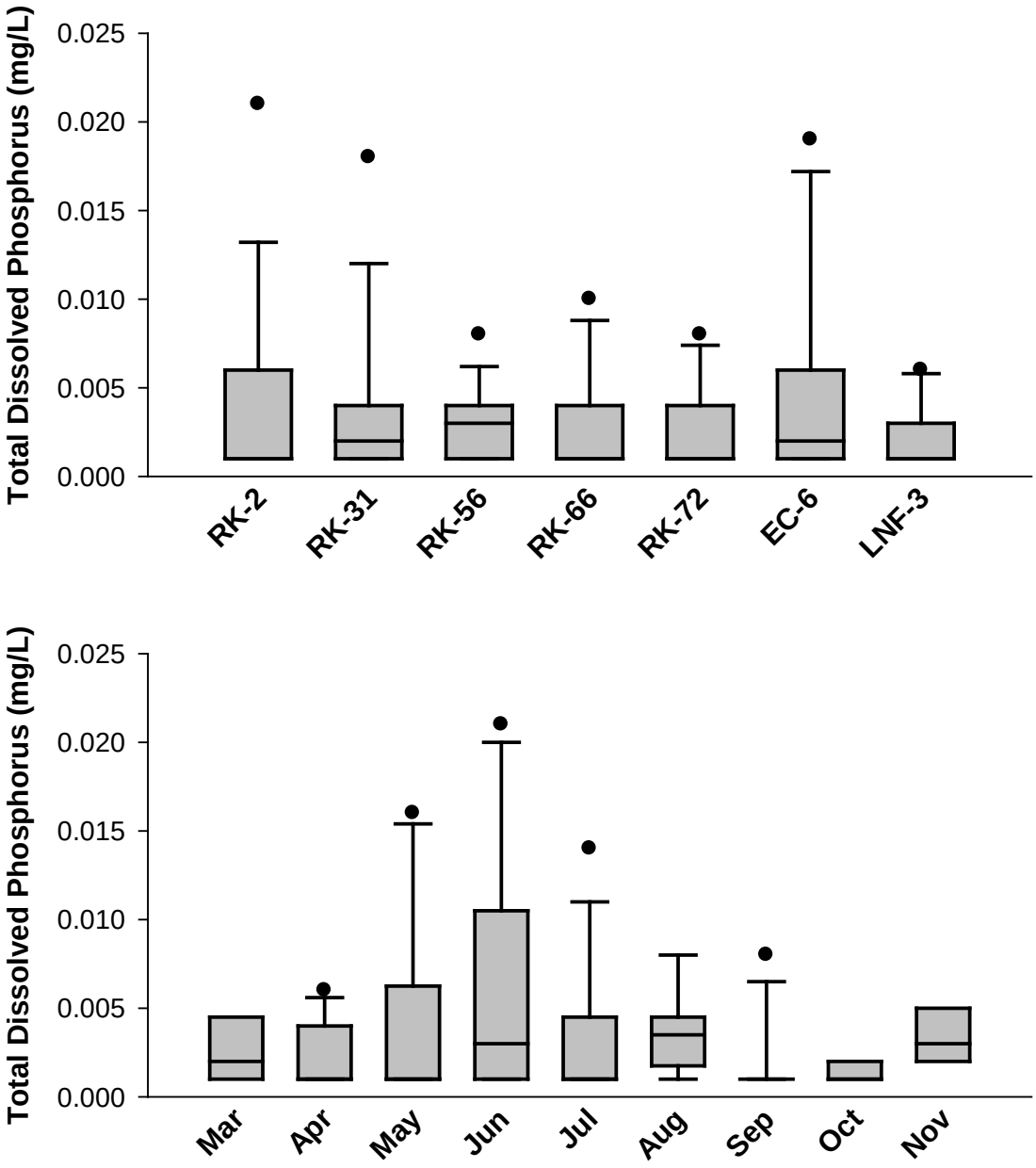


Figure 10. Box plots representing the distribution of Total Dissolved Phosphorous (TDP) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.

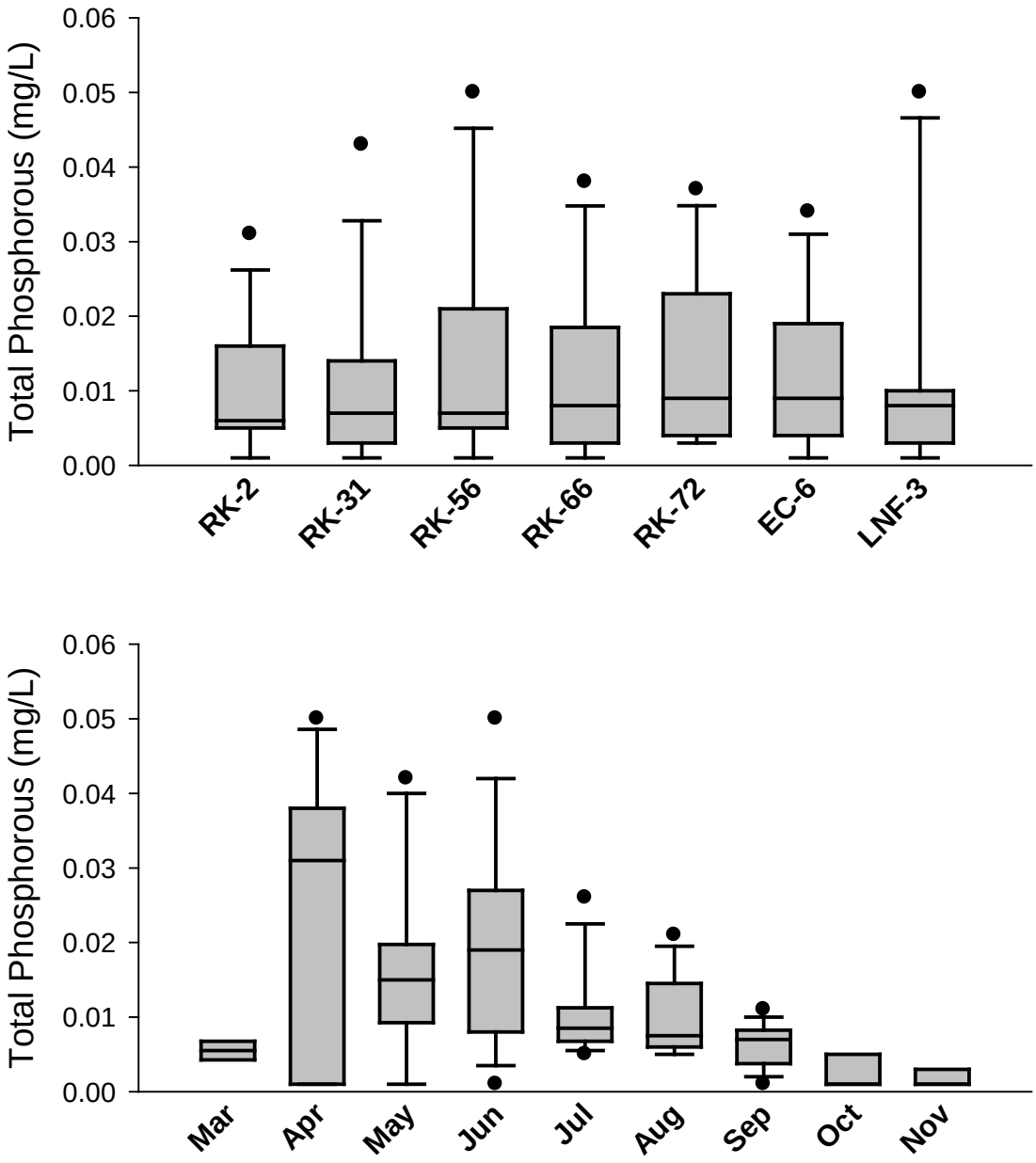


Figure 11. Box plots representing the distribution of Total Phosphorous (TP) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.

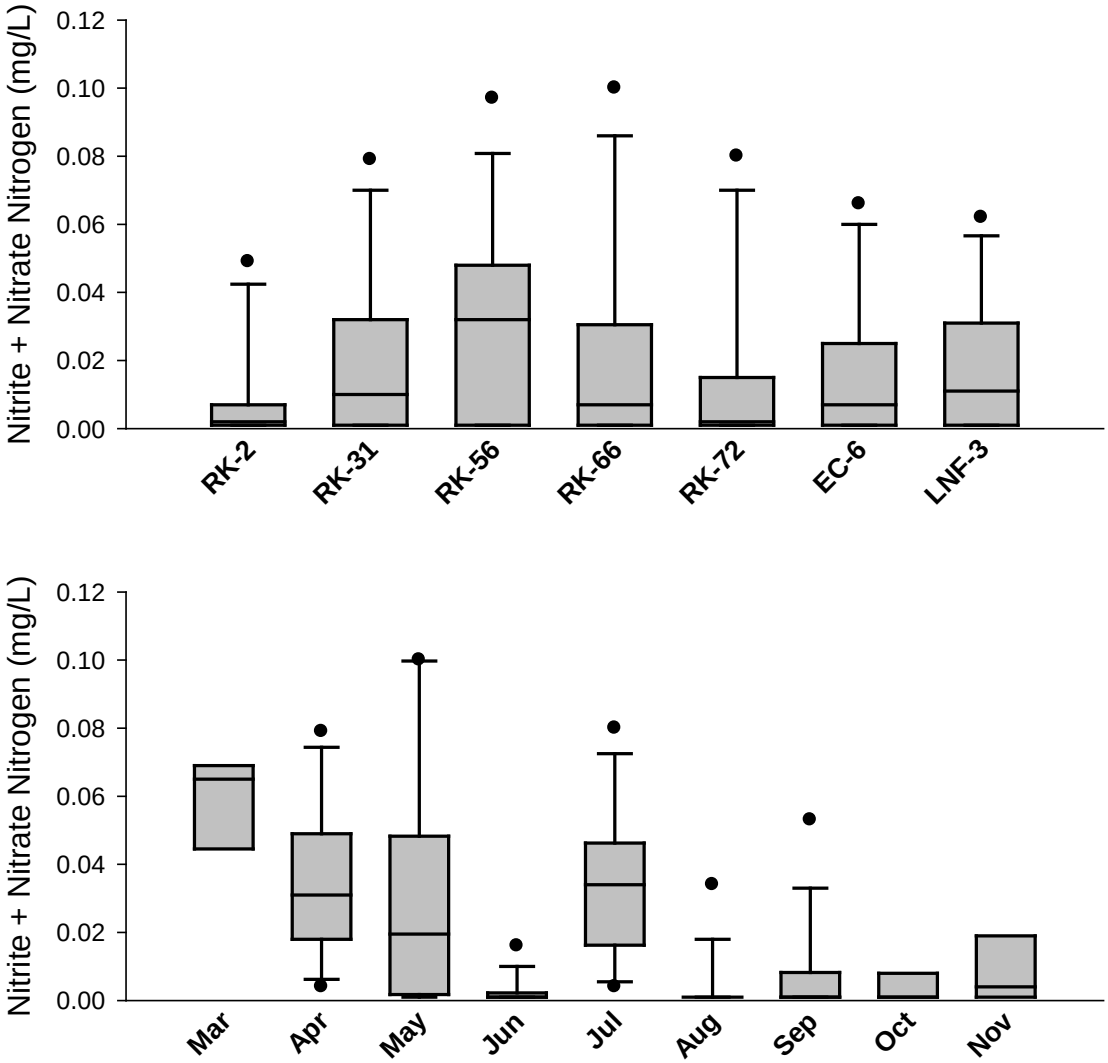


Figure 12. Box plots representing the distribution of Nitrite + Nitrate Nitrogen (N+N) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.

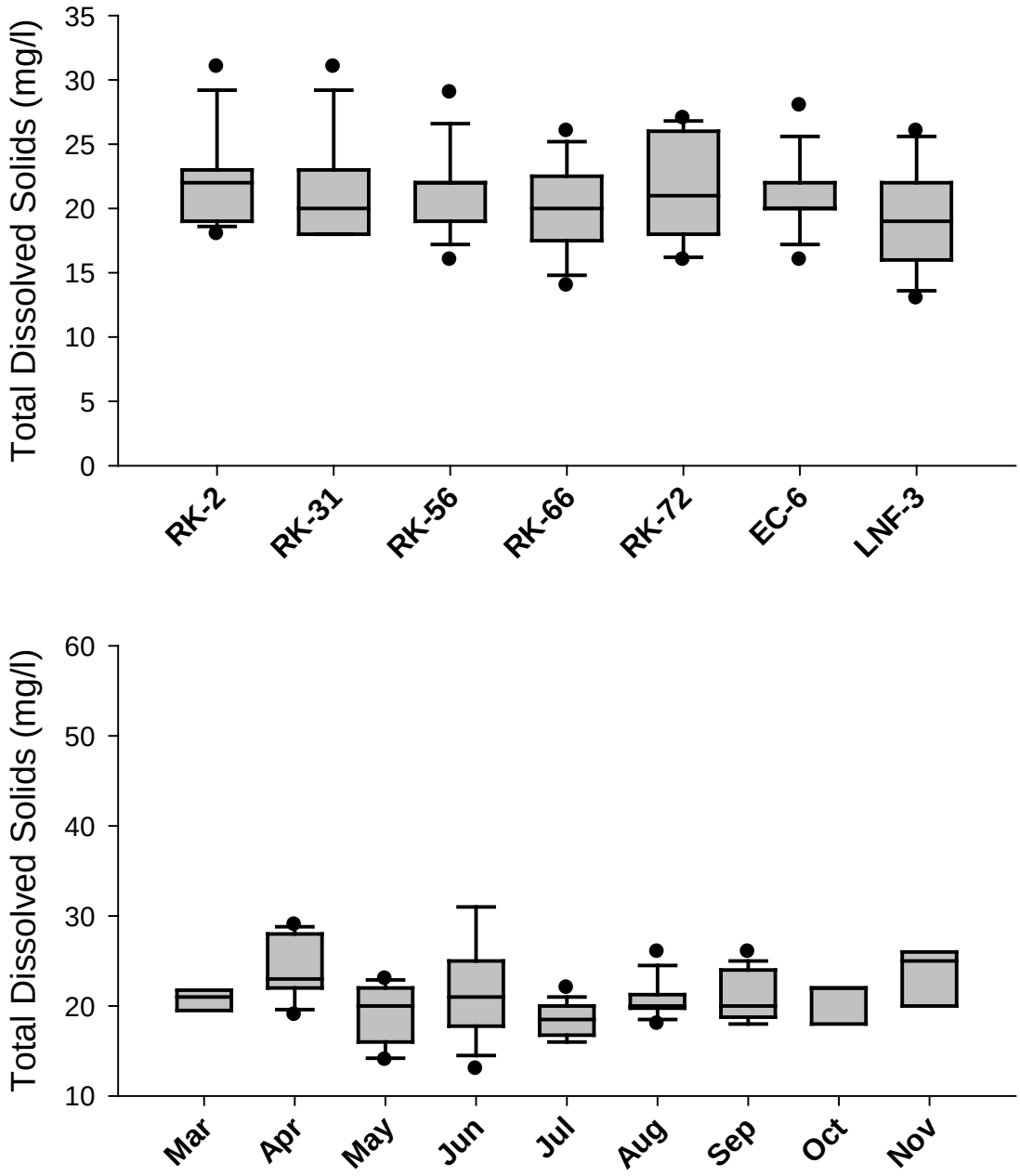


Figure 13. Box plots representing the distribution of Total Dissolved Solids (TDS) concentrations (mg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.

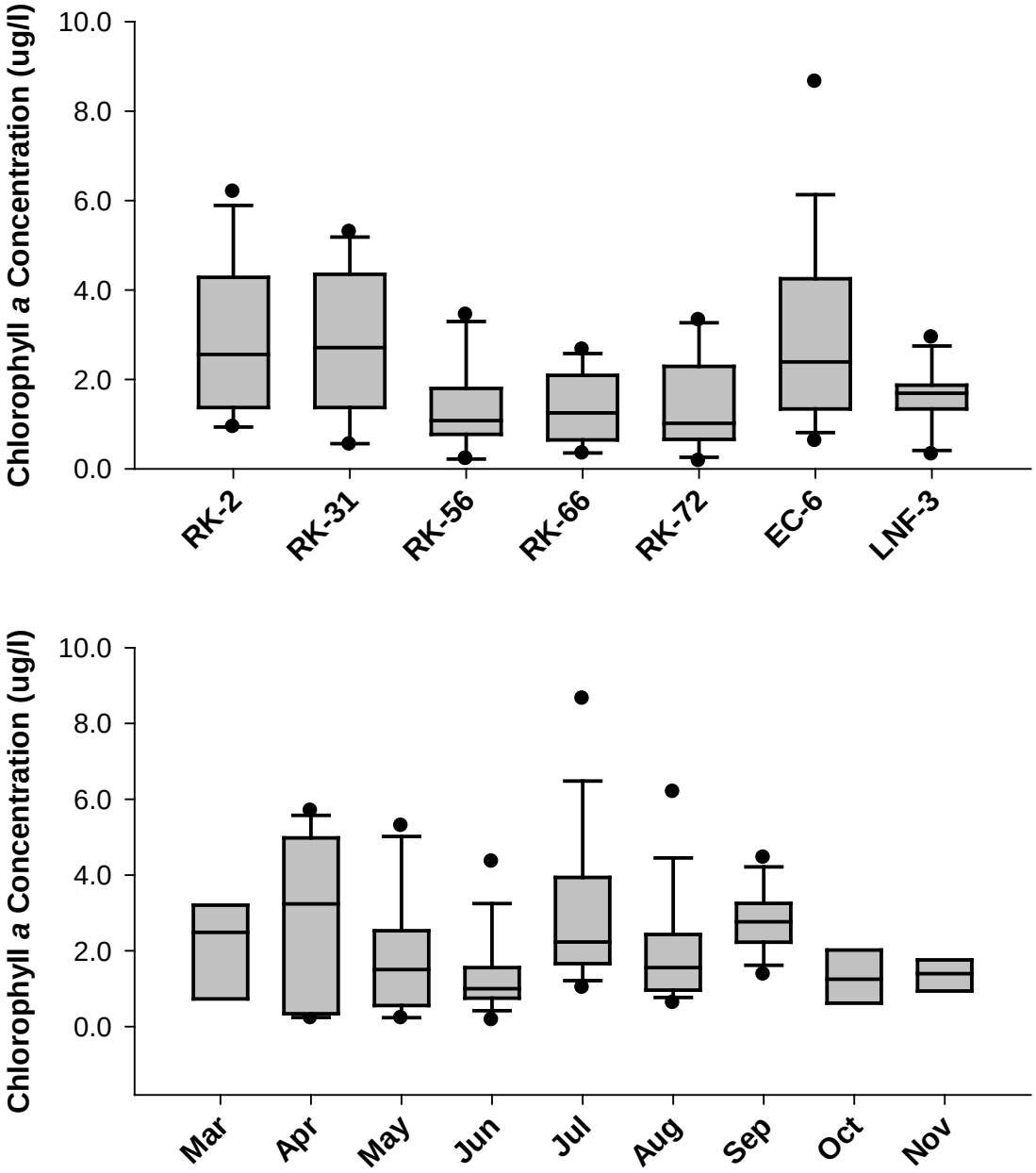


Figure 14. Box plots representing the distribution of Chlorophyll a (Chl a) concentrations (µg/L) from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Graphs represent either all measurements taken at a given station for the entire year, or measurements taken at all stations during each month.

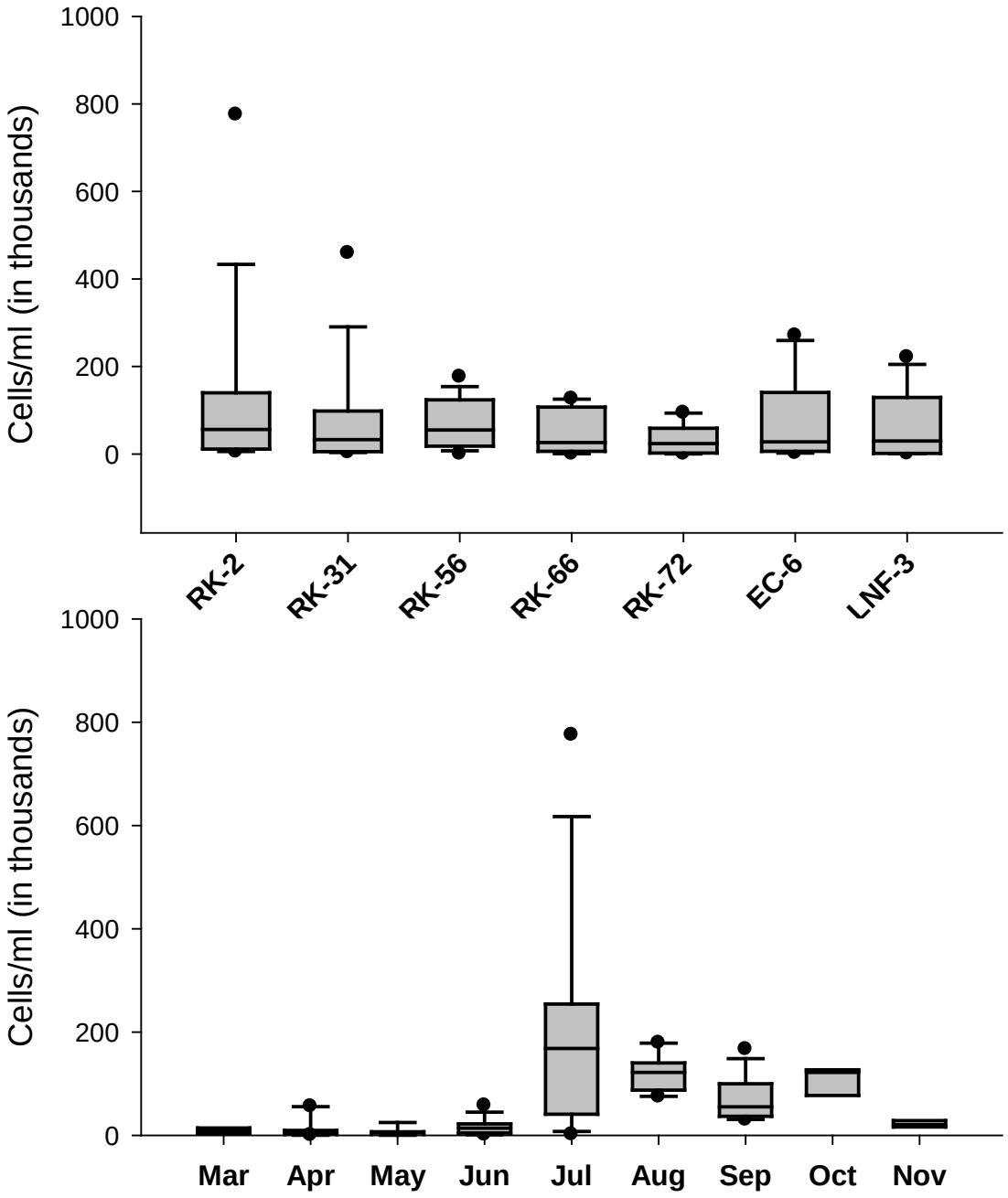


Figure 15. Mean density (cells/ml) of picocyanobacteria in the epilimnion for treated and untreated areas of Dworshak Reservoir, from March through November 2007. Error bars represent 95% confidence intervals around the mean.

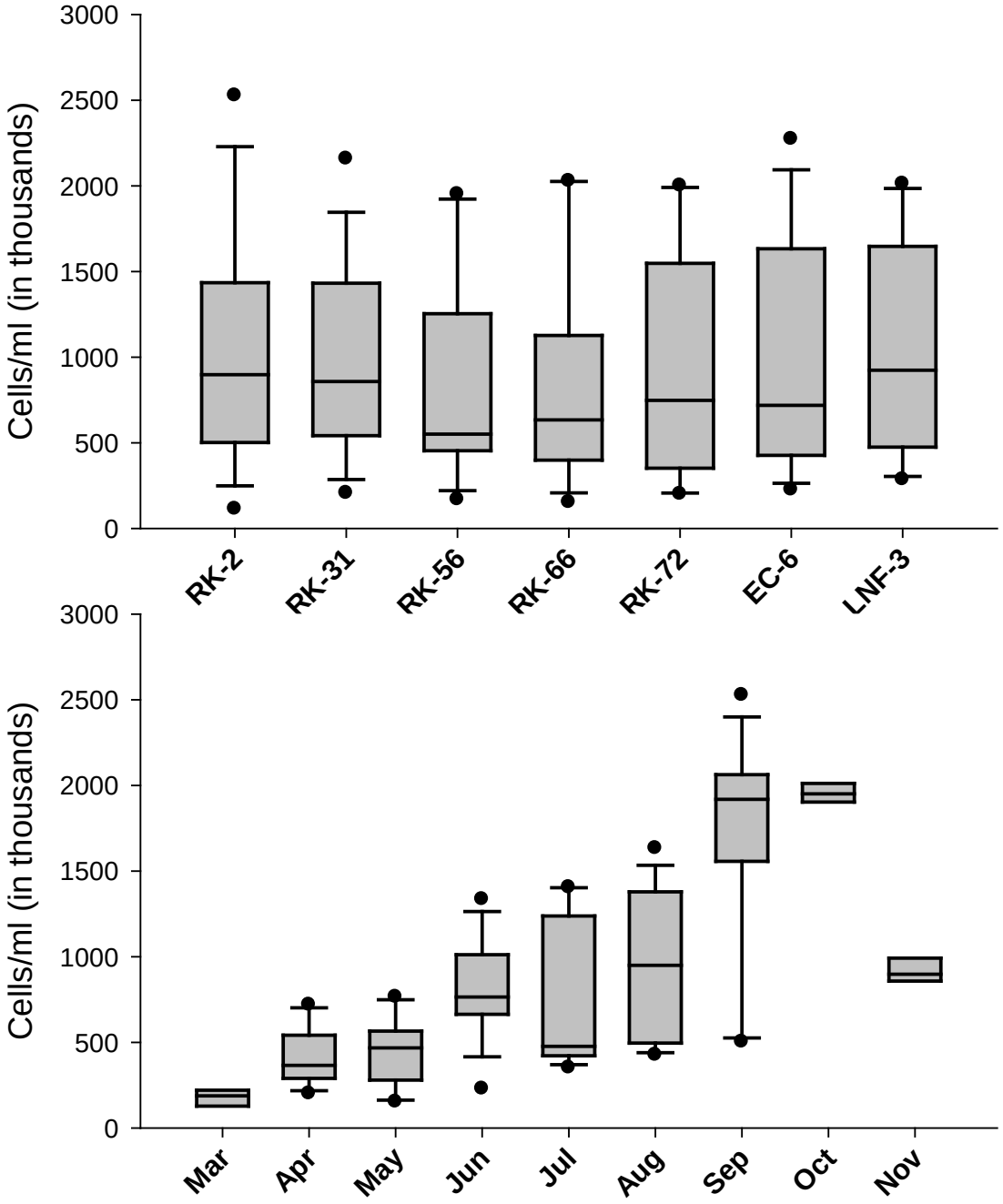


Figure 16. Mean density (cells/ml) of heterotrophic bacteria in the epilimnion for treated and untreated areas of Dworshak Reservoir, from March through November 2008. Error bars represent 95% confidence intervals around the mean.

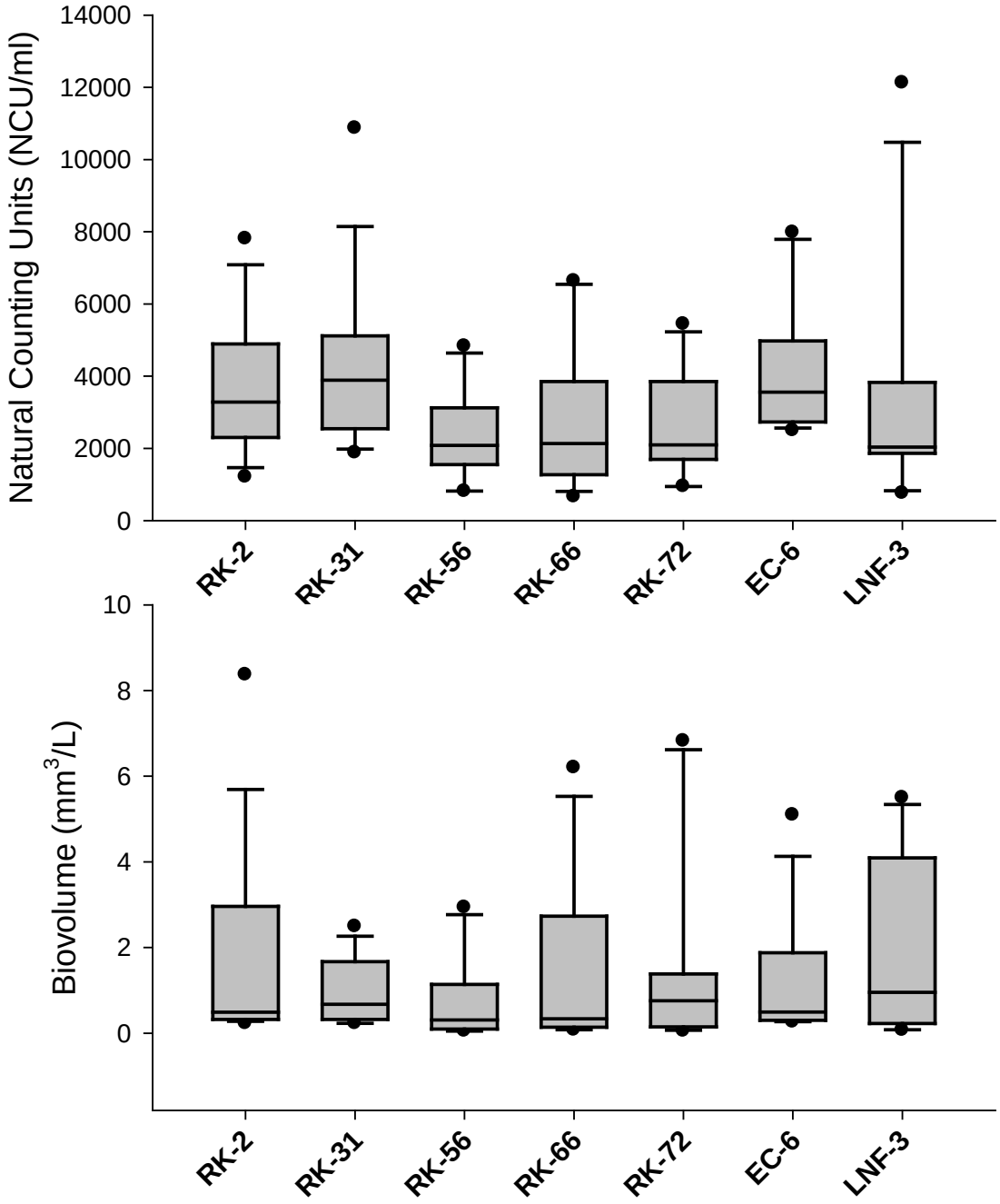


Figure 17. Box plots representing the annual distribution of phytoplankton densities from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Densities are given both in terms of natural counting units (NCU) and biovolume (mm^3/L).

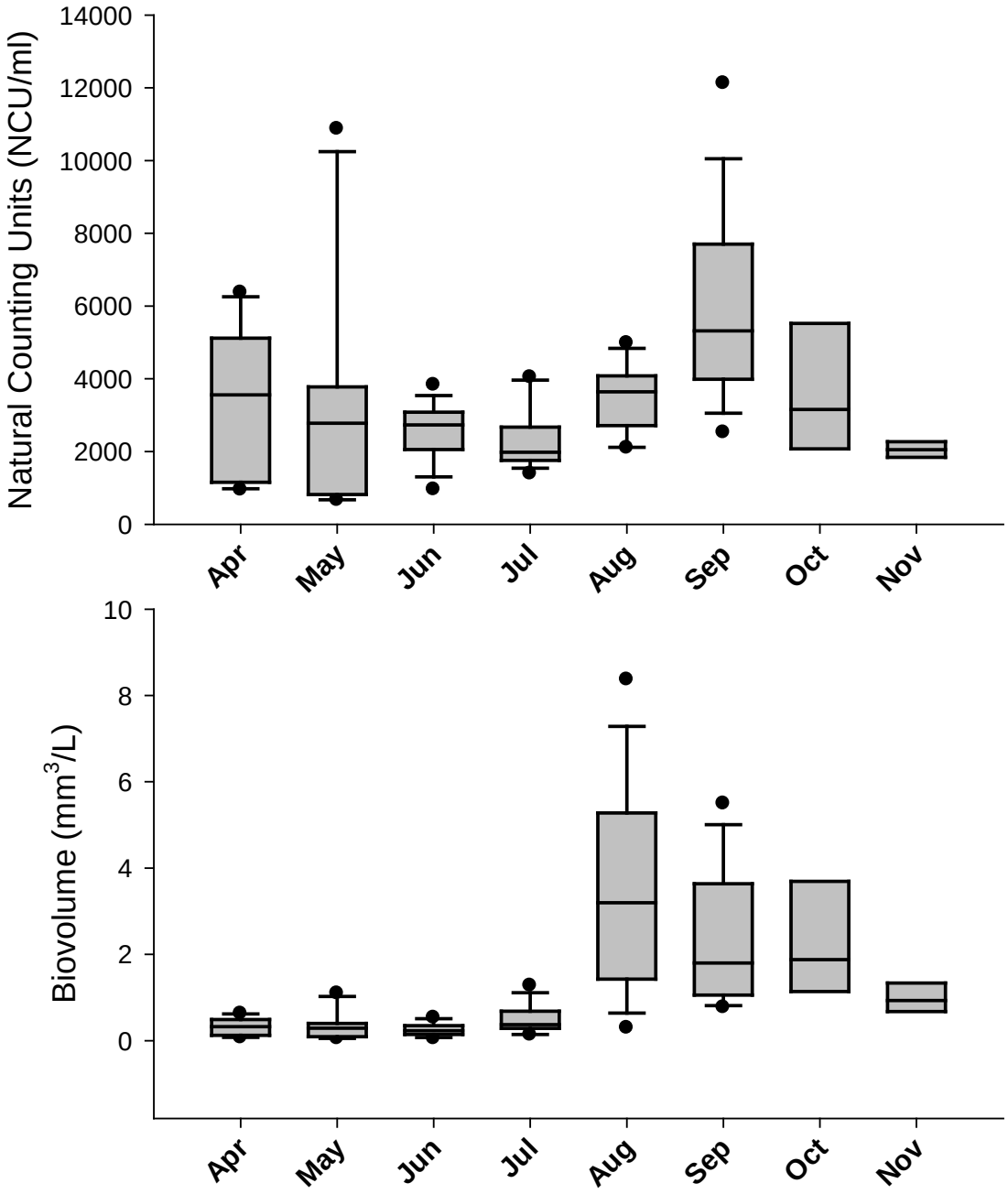


Figure 18. Box plots representing the annual distribution of phytoplankton densities from the epilimnion measured at seven limnological stations throughout Dworshak Reservoir from March through November 2008. Densities are given both in terms of natural counting units (NCU) and biovolume (mm^3/L).

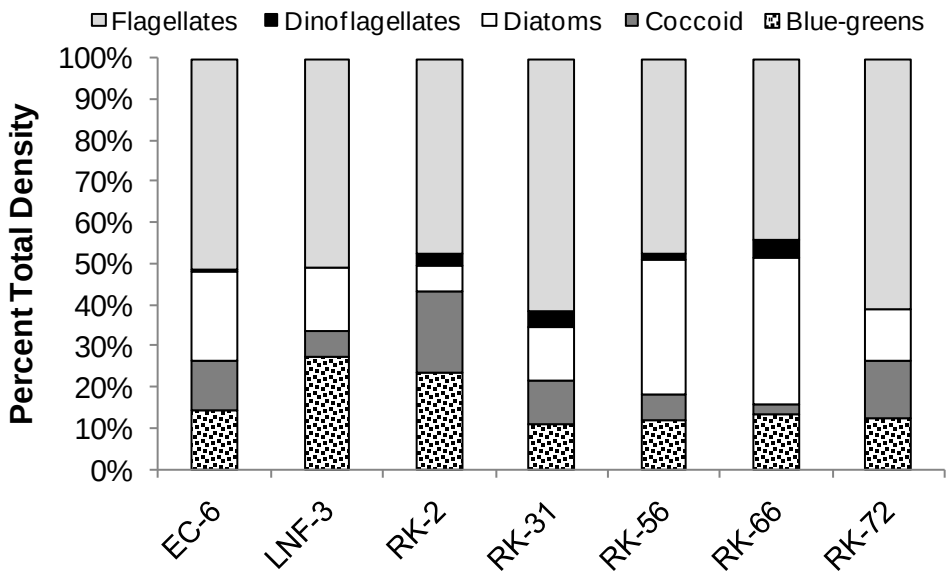


Figure 19. Mean annual composition of the phytoplankton community sampled at seven limnological stations on Dworshak Reservoir from March through November 2008. Mean compositions reflect the mean percentage, based on natural counting units (NCU/ml), that each class contributed to the overall abundance throughout the entire sampling season.

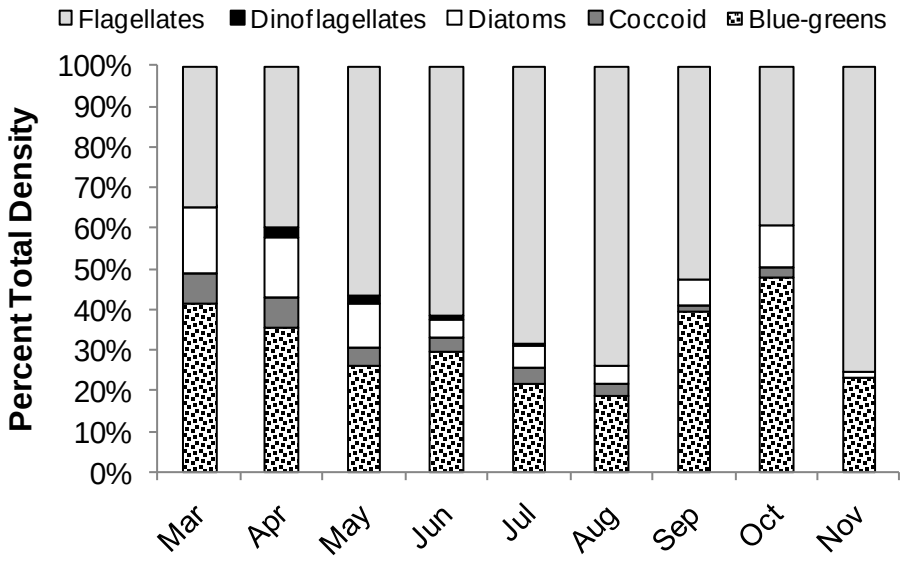


Figure 20. Mean annual composition of the phytoplankton community sampled at seven limnological stations on Dworshak Reservoir from March through November 2008. Mean compositions reflect the mean percentage, based on natural counting units (NCU/ml), that each class contributed to the overall abundance throughout the entire sampling season.

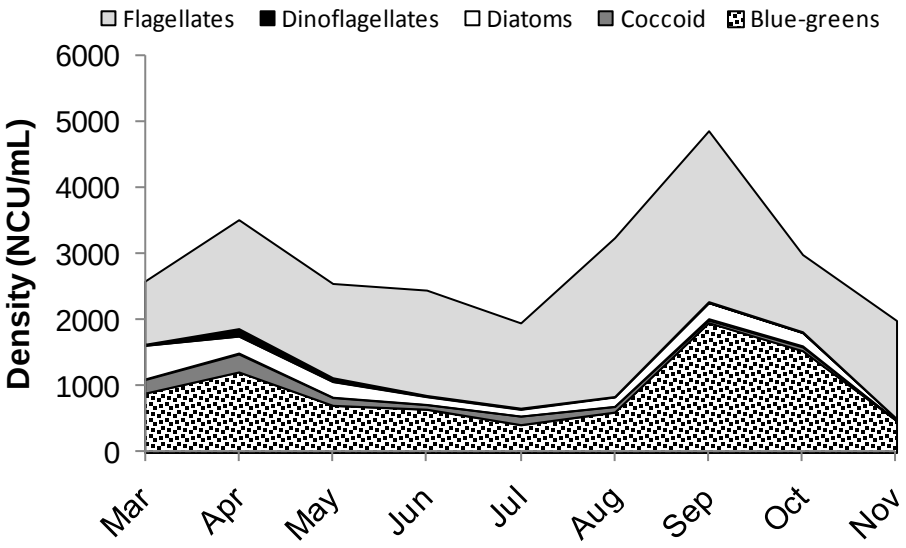


Figure 21. Seasonal composition of the phytoplankton community in Dworshak Reservoir. Monthly compositions reflect the mean density, based on natural counting units (NCU/ml), of each class, as measured from March through November 2008 at seven limnological stations throughout Dworshak Reservoir.

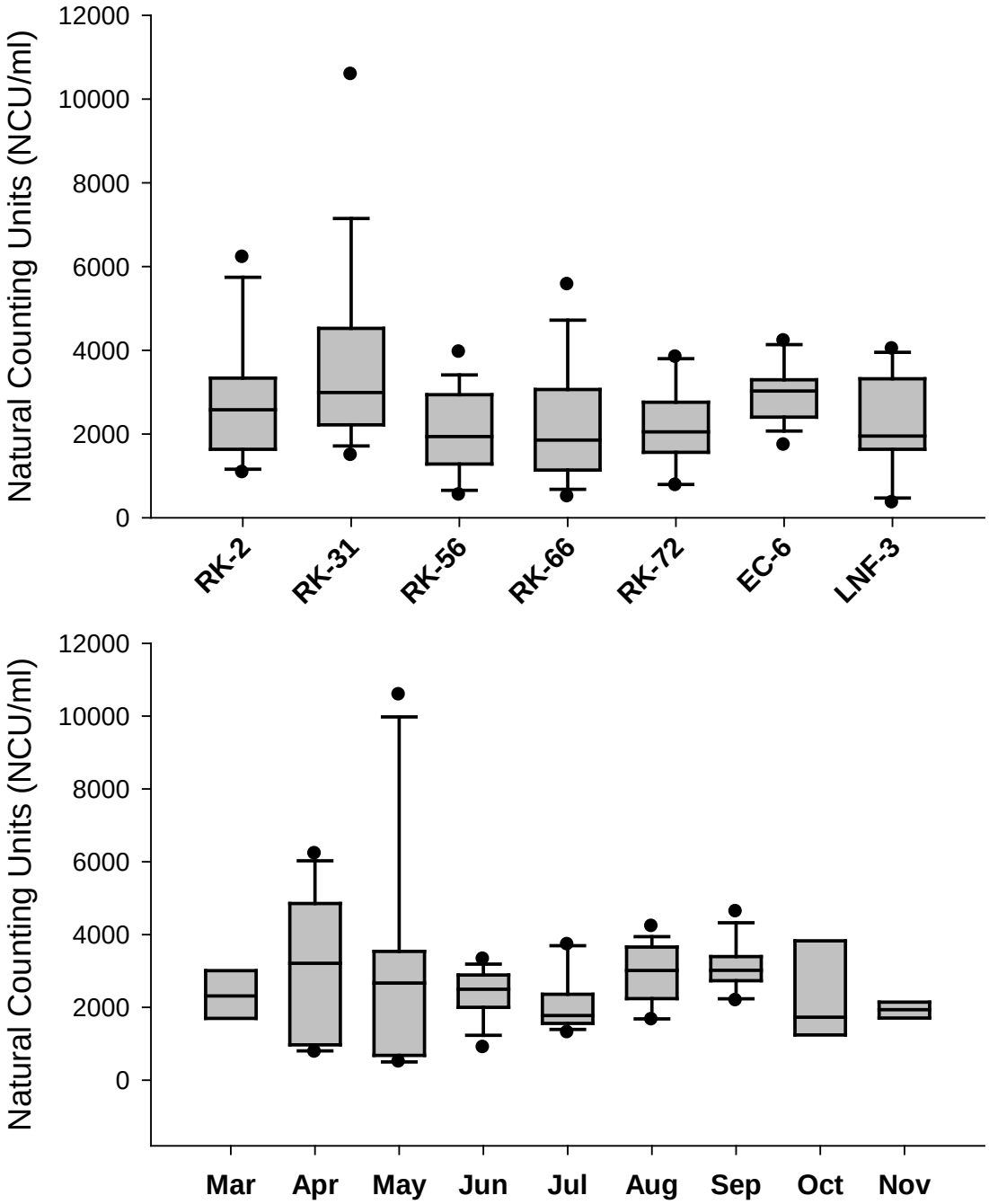


Figure 22. Box plots representing the distribution of edible phytoplankton densities, based on natural counting units (NCU/ml). Graphs either represent all measurements observed at each of seven limnological stations on Dworshak Reservoir, from March through November of 2008, or measurements from all stations during a given month.

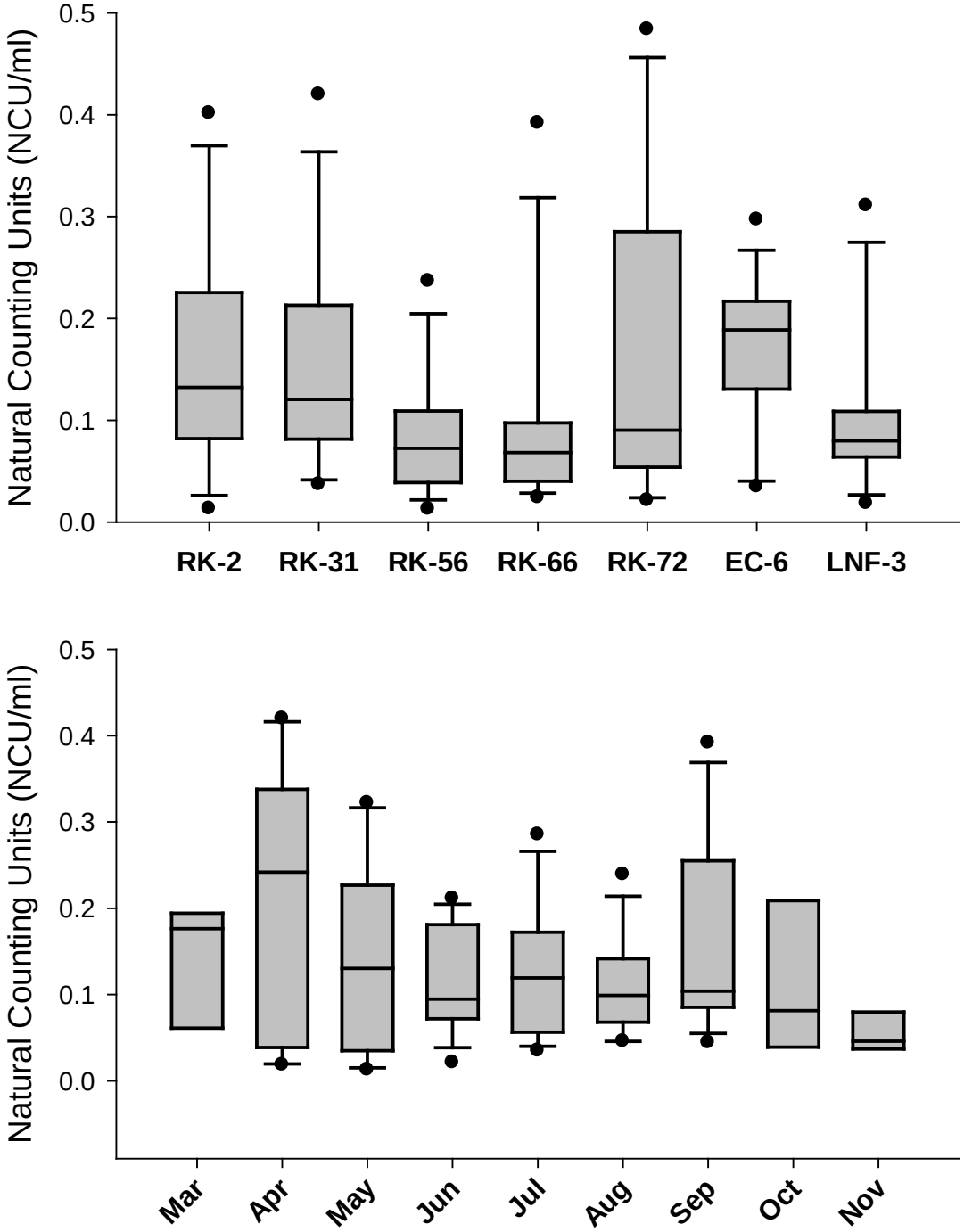


Figure 23. Box plots representing the distribution of edible phytoplankton densities, based on biovolume (mm^3/L). Graphs either represent all measurements observed at each of seven limnological stations on Dworshak Reservoir, from March through November of 2008, or measurements from all stations during a given month.

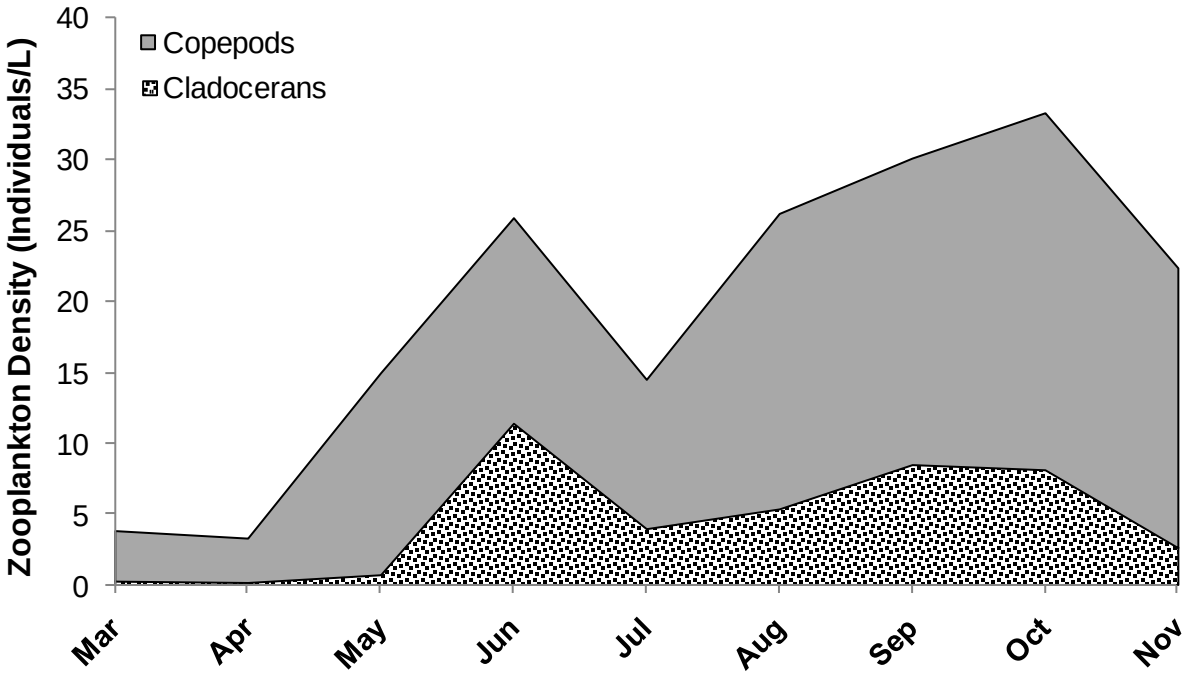


Figure 24. Seasonal density of each class of zooplankton collected from March through November of 2008 at seven limnological stations throughout Dworshak Reservoir. Densities reflect the median density from all seven stations for a given month.

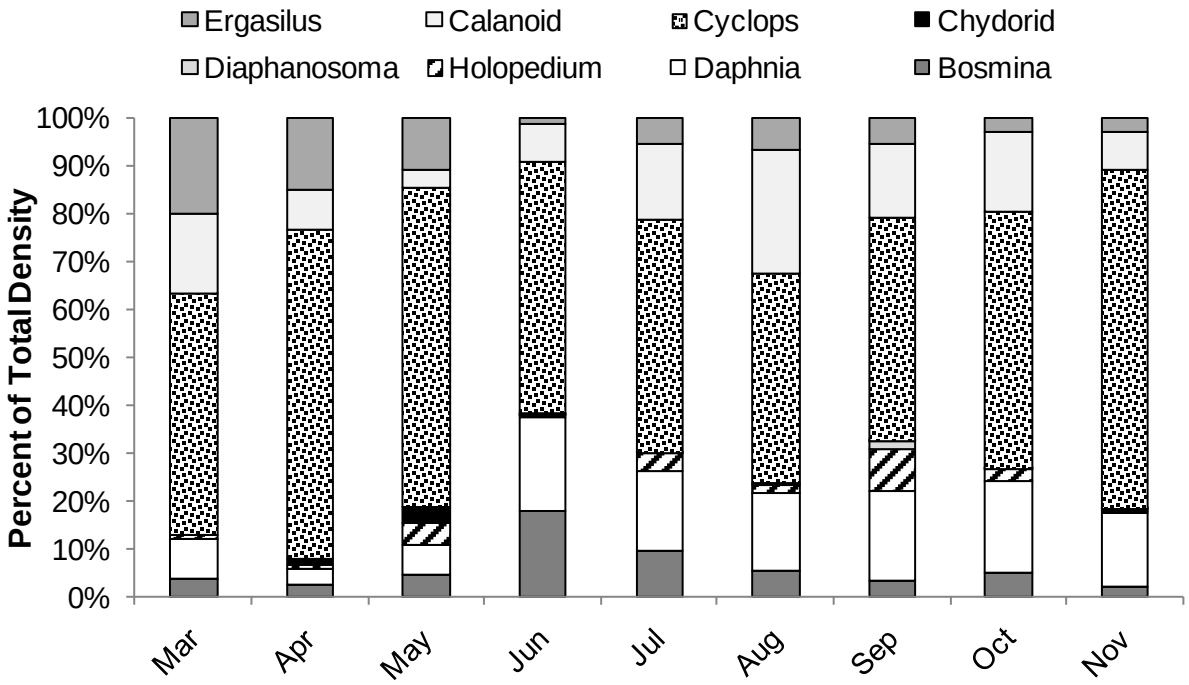


Figure 25. Mean reservoir wide monthly zooplankton composition from seven stations on Dworshak Reservoir, collected March through November 2008. Stacked data represents the contribution by percent of each of six major zooplankton taxonomic groups to the total zooplankton assemblage for each month.

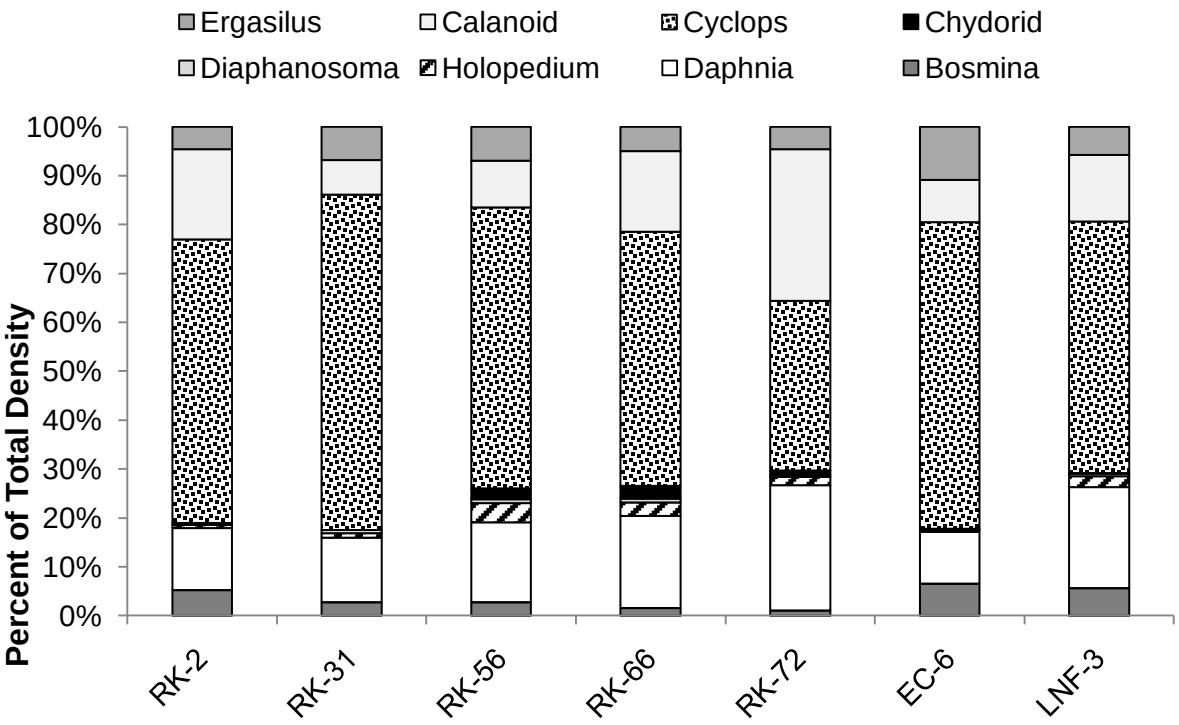


Figure 26. Mean annual zooplankton composition from seven limnological stations on Dworshak Reservoir, collected March through November 2008. Stacked data represents the contribution by percent of each of six major zooplankton taxonomic groups to the total zooplankton assemblage for each station.

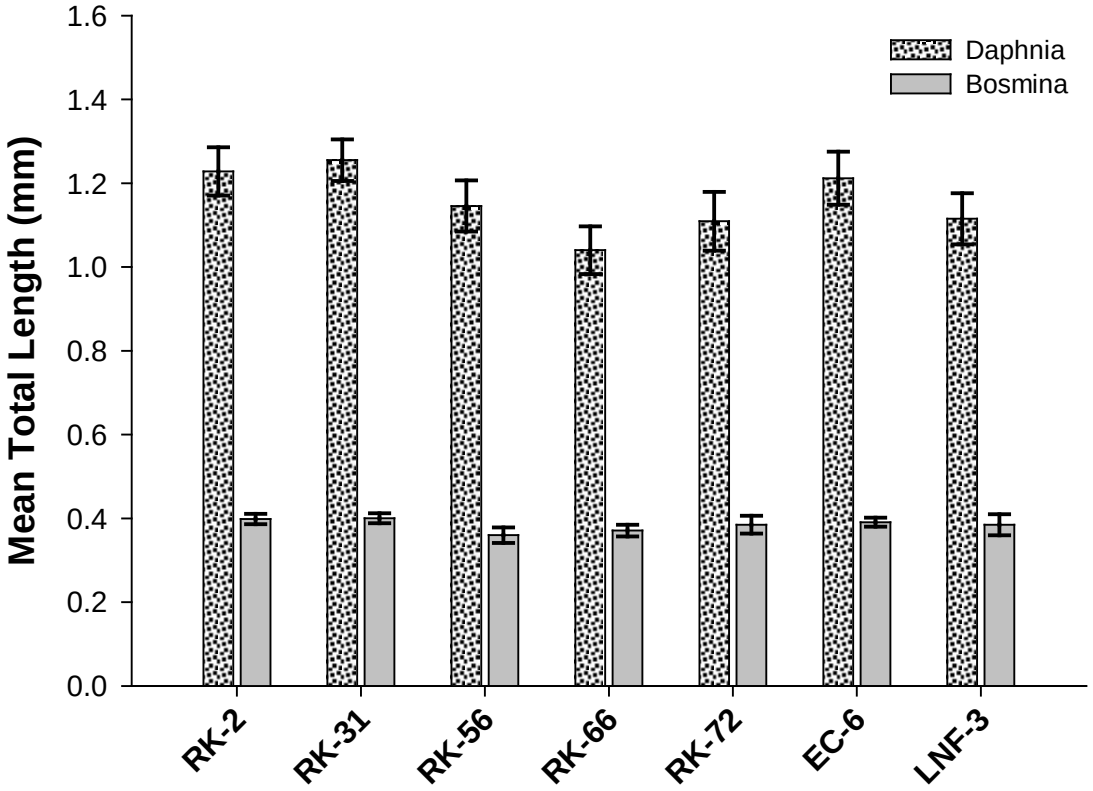


Figure 27. Monthly mean lengths (mm) of *Daphnia sp.* and *Bosmina sp.* from seven limnological stations on Dworshak Reservoir, collected March through November 2008. Error bars represent 95% confidence intervals around each mean.

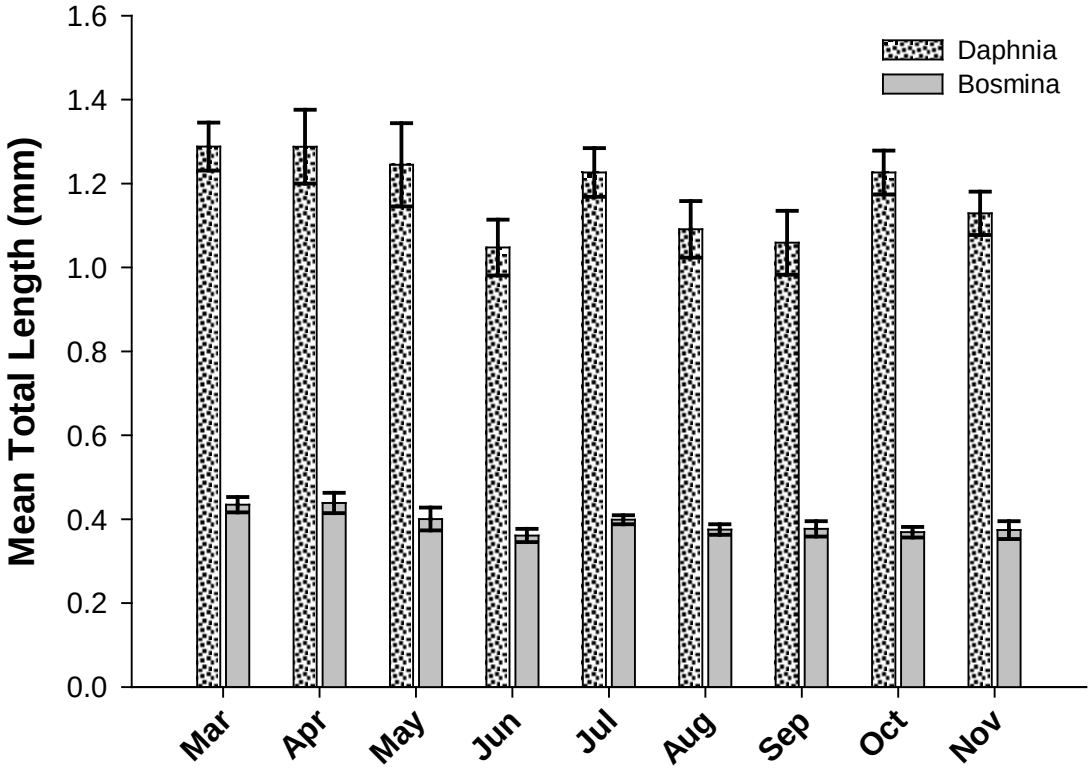


Figure 28. Annual mean lengths (mm) of *Daphnia sp.* and *Bosmina sp.* from seven limnological stations on Dworshak Reservoir, collected March through November 2008. Error bars represent 95% confidence intervals around each mean.

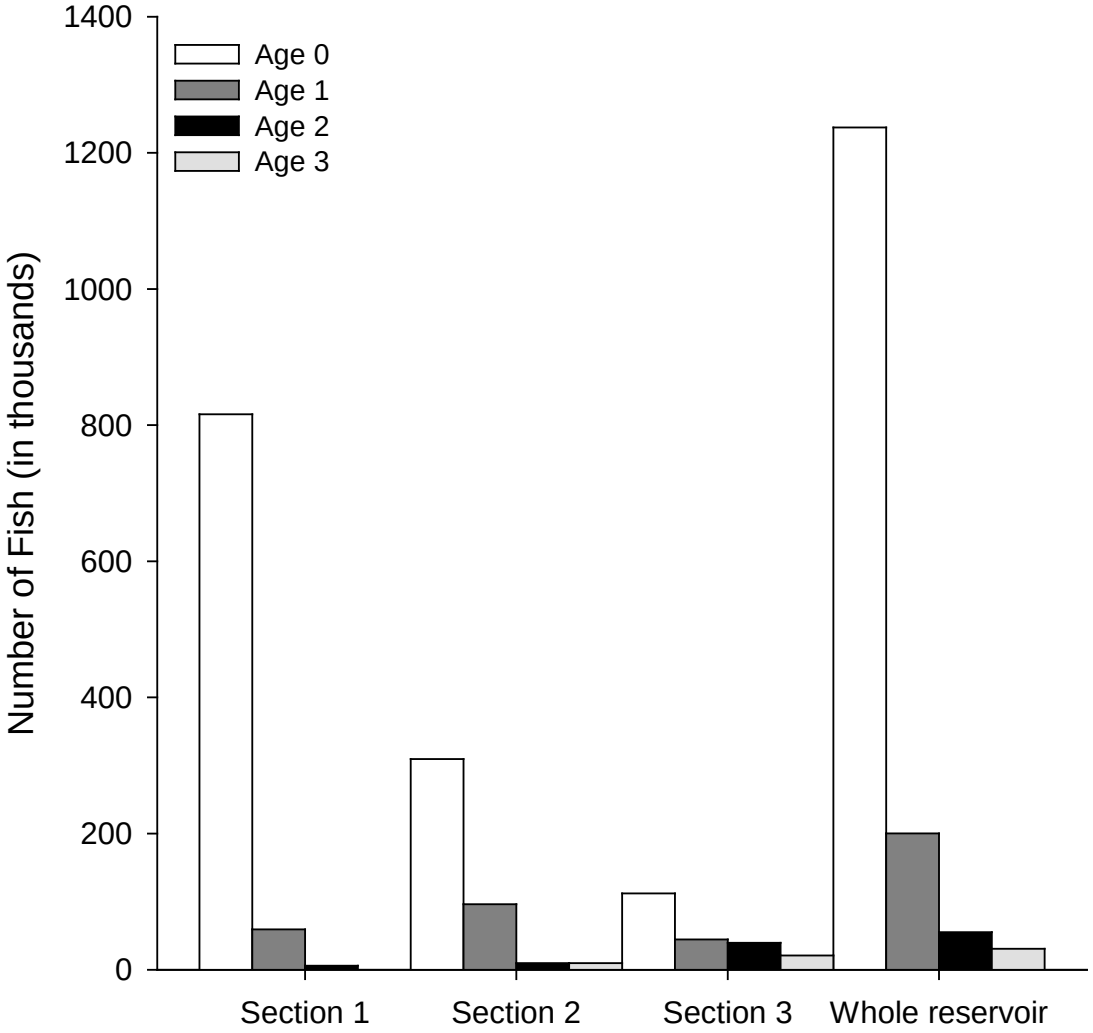


Figure 29. Abundance of kokanee, given in thousands of fish, in Dworshak Reservoir during July 2008. Estimates were derived from a hydroacoustic survey and age composition was determined from a fixed-frame trawl survey. Estimates are broken down by age and reservoir section.

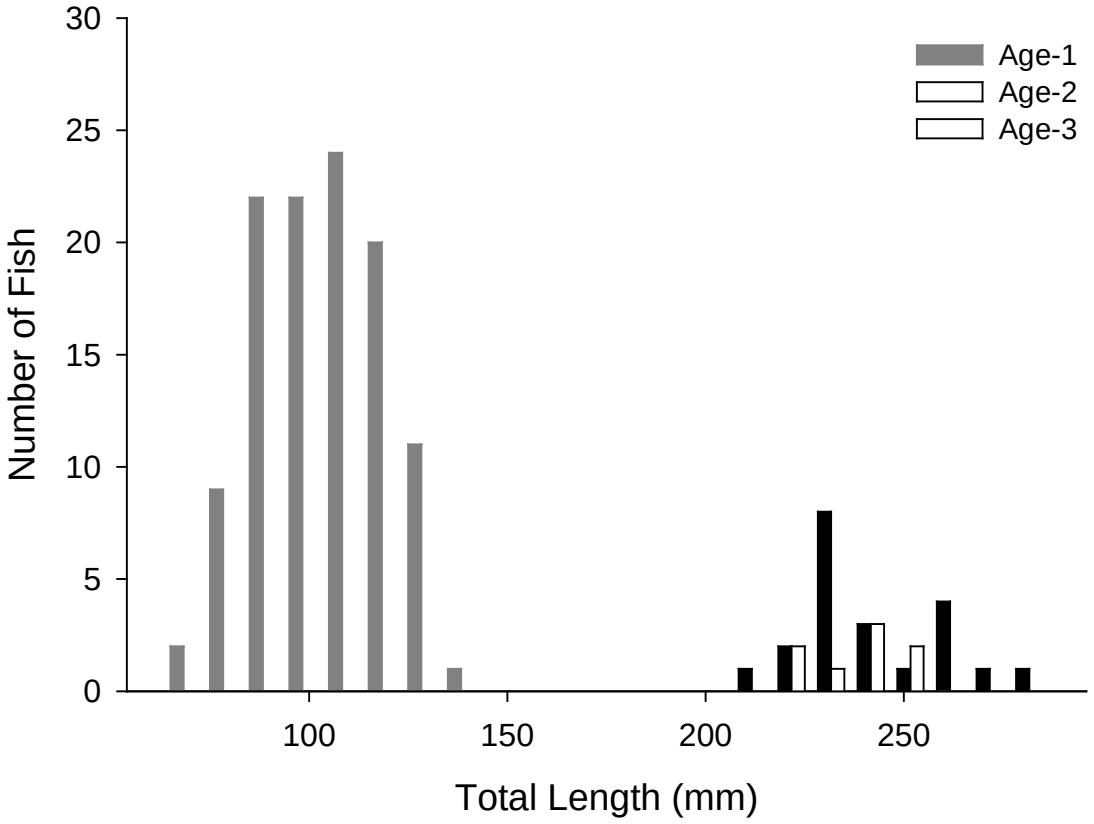


Figure 30. Length distribution of kokanee captured by fixed-frame trawl surveys conducted on Dworshak Reservoir during April 2008. Ages were determined by scale analysis.

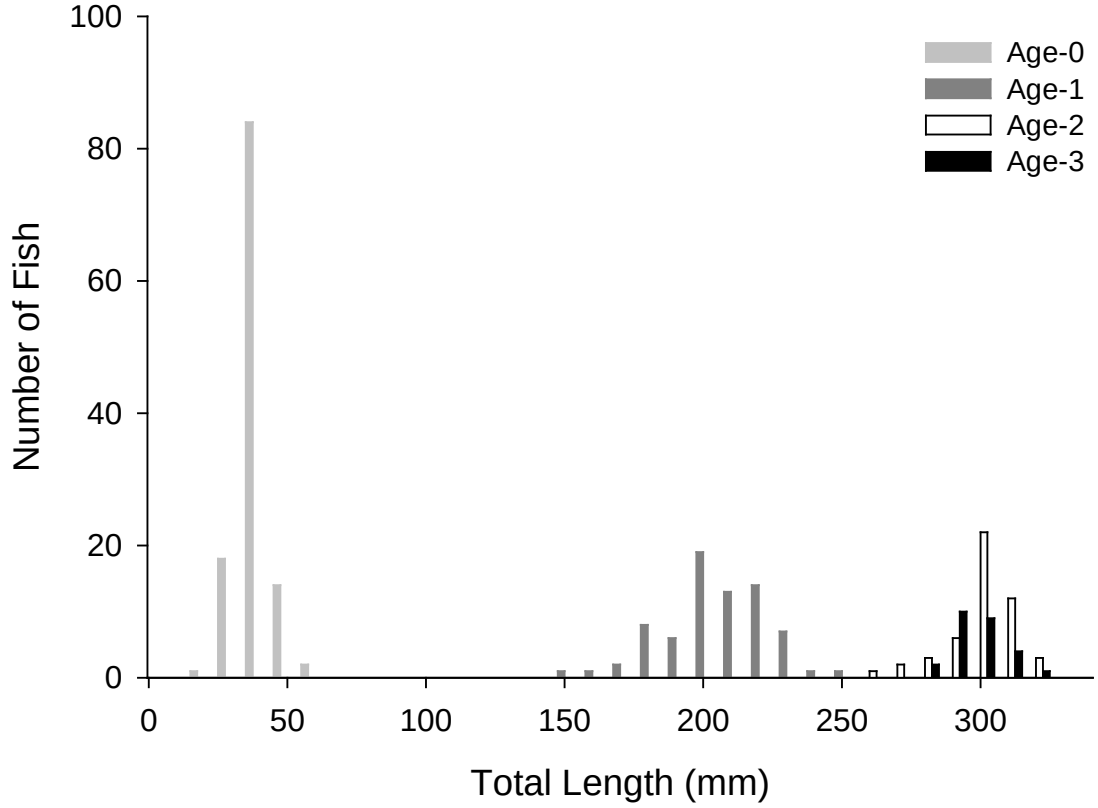


Figure 31. Length distribution of kokanee captured by fixed-frame trawl surveys conducted on Dworshak Reservoir during July 2008. Ages were determined by scale analysis.

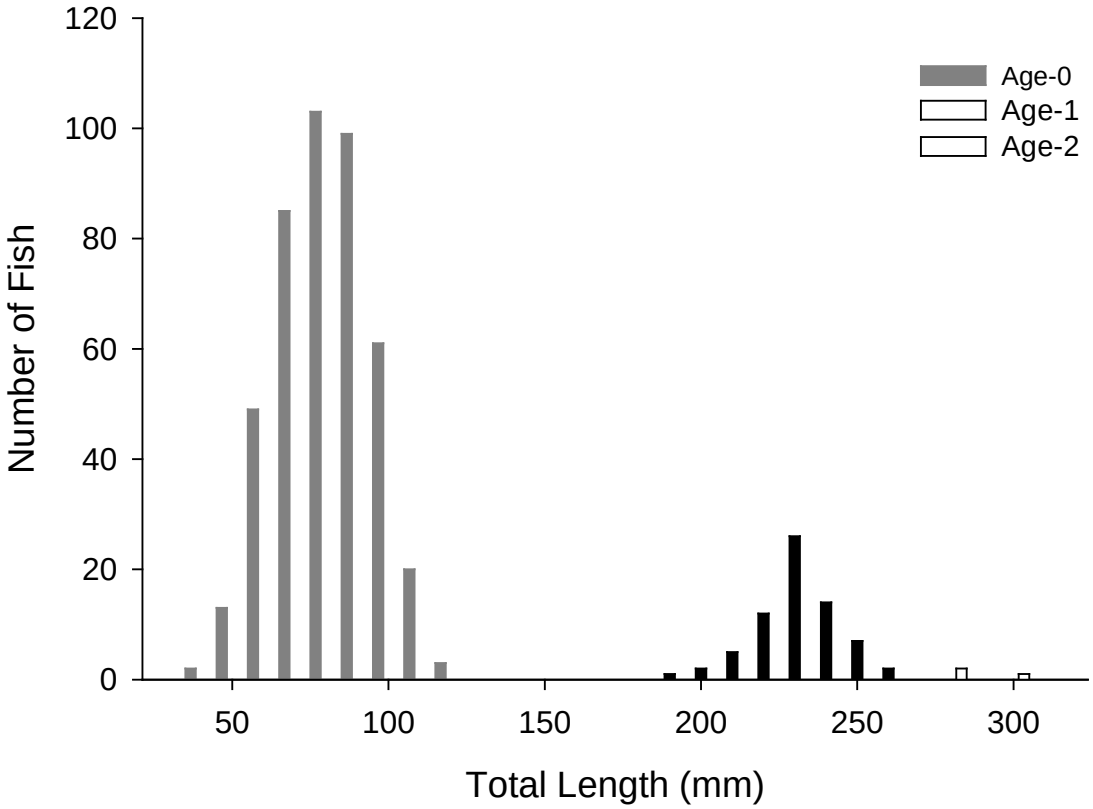


Figure 32. Length distribution of kokanee captured by fixed-frame trawl surveys conducted on Dworshak Reservoir during October 2008. Ages were determined by scale analysis.

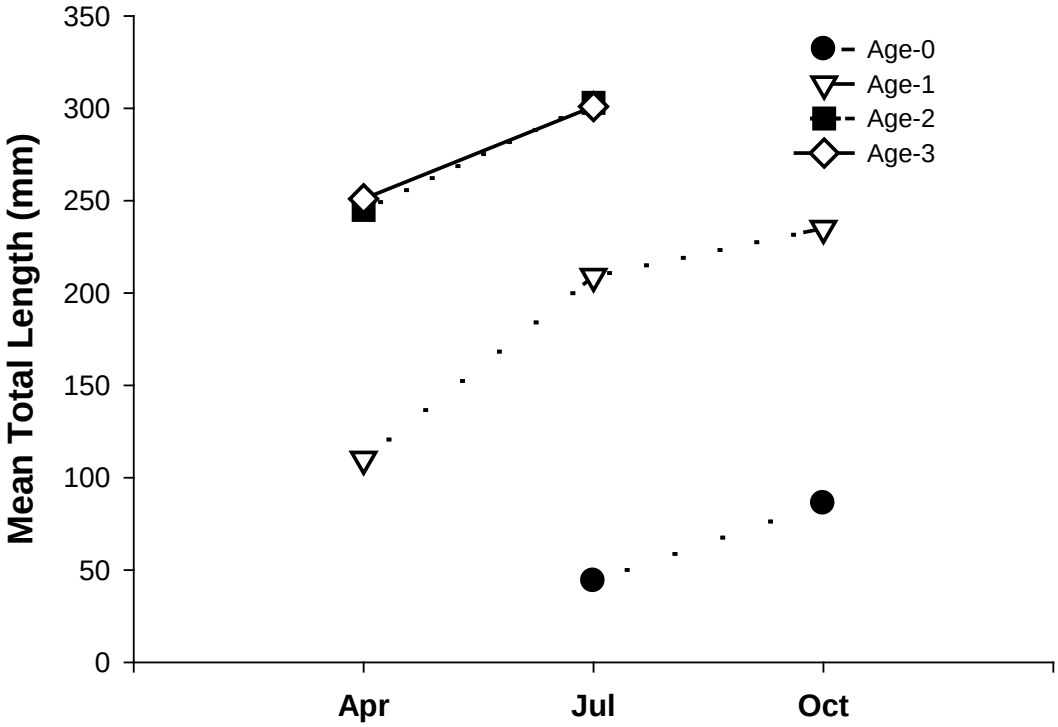


Figure 33. Growth, in terms of seasonal changes in mean total length (mm), of kokanee in Dworshak Reservoir. Mean lengths were determined from fixed-frame trawl surveys conducted during 2008. Ages were determined by scale analysis.

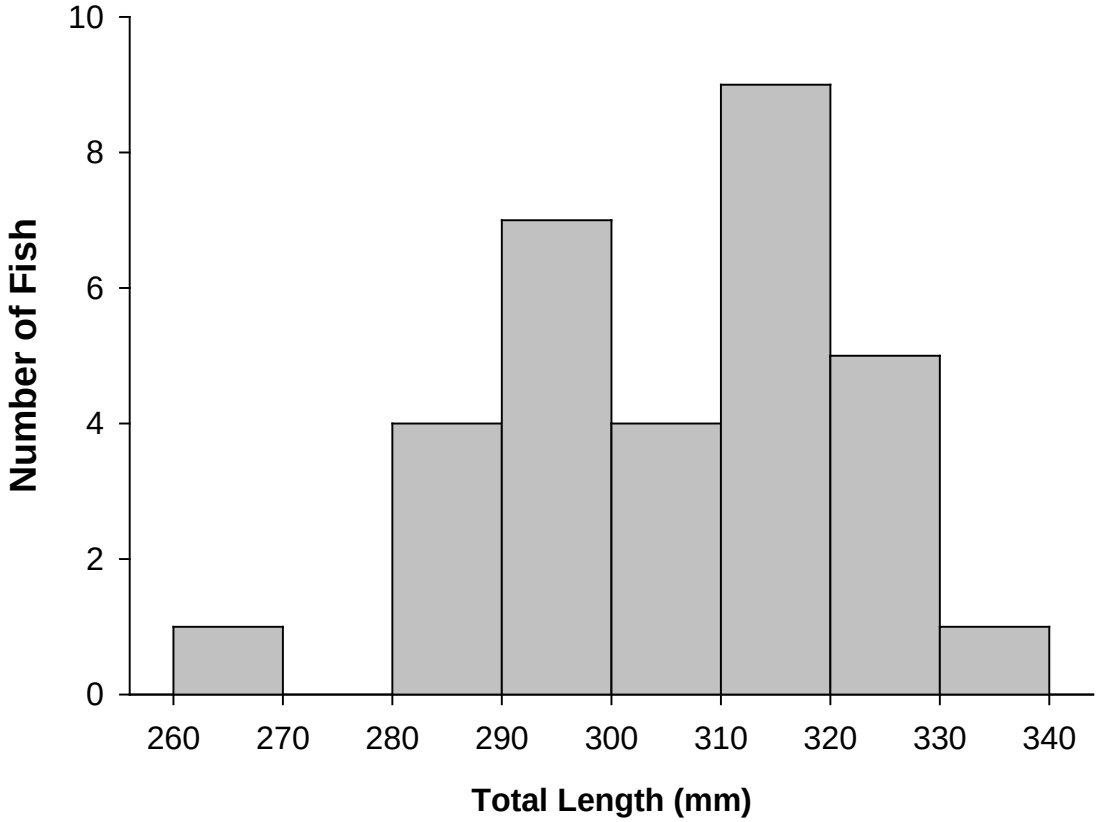
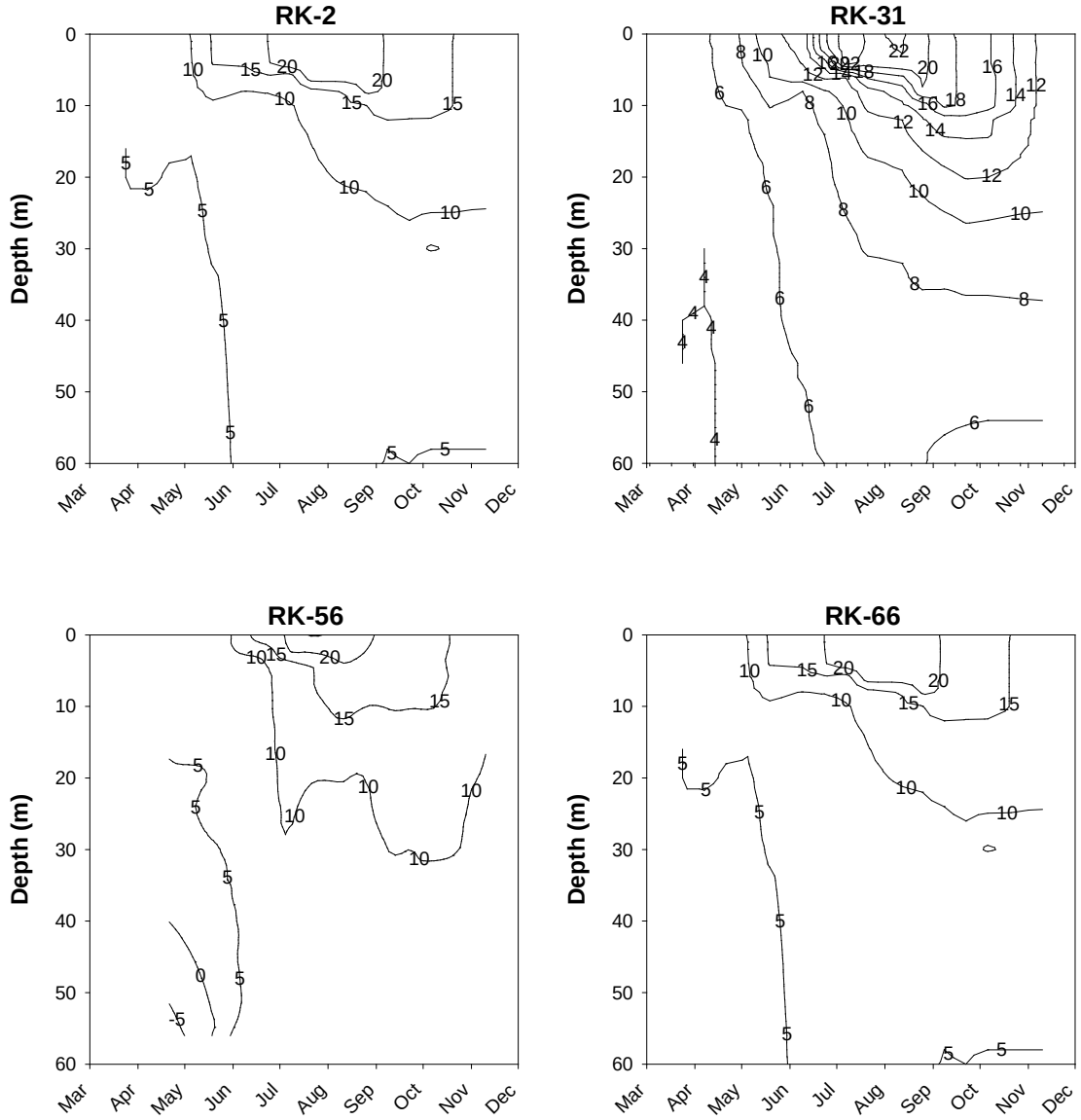


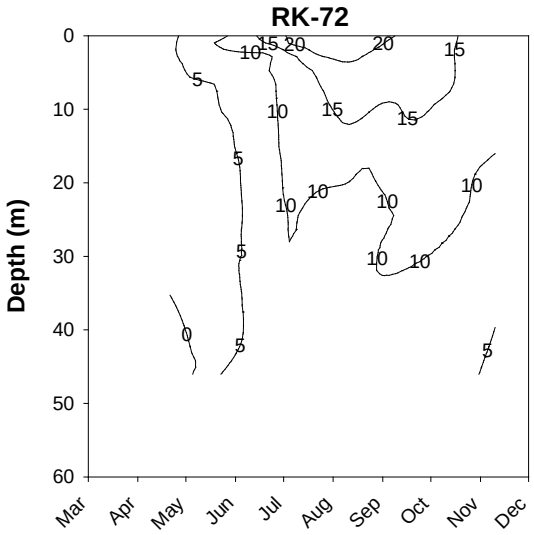
Figure 34. Length distribution of post-spawn kokanee collected from tributaries to the North Fork Clearwater River on September 24-25 2008. Lengths were measured as total length (mm).

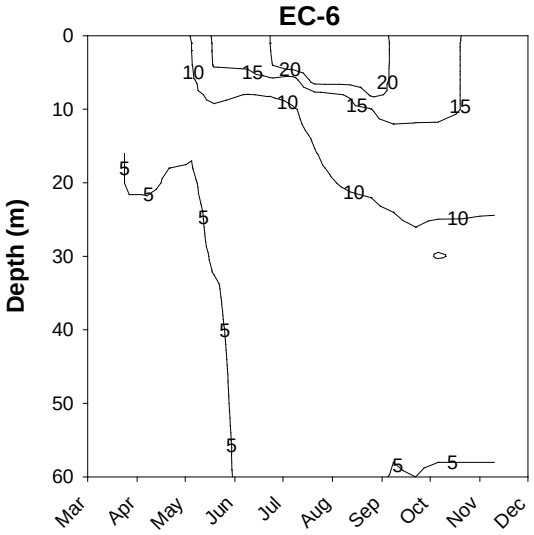
APPENDICES

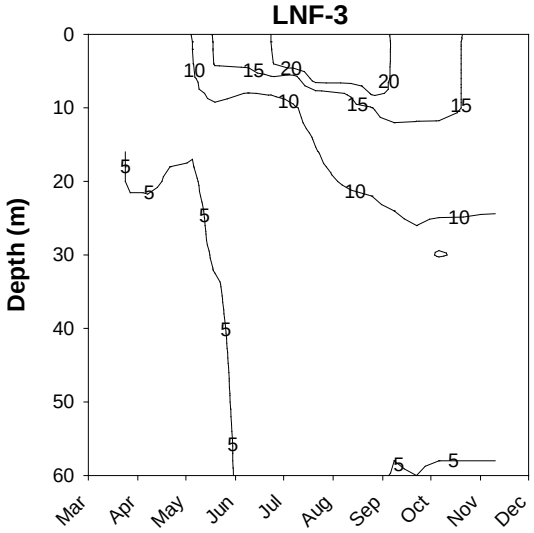
Appendix A. Depth and temperature profiles for seven sampling stations on Dworshak Reservoir from March through November 2008. Isopleths indicate water temperature in degrees Celsius at 5 degree intervals.



Appendix A. Continued.



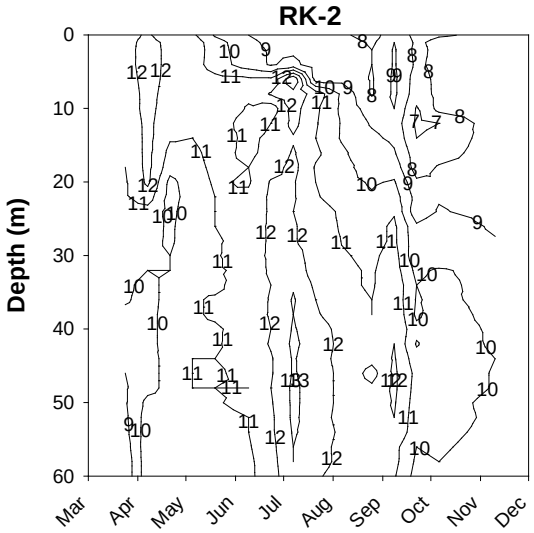


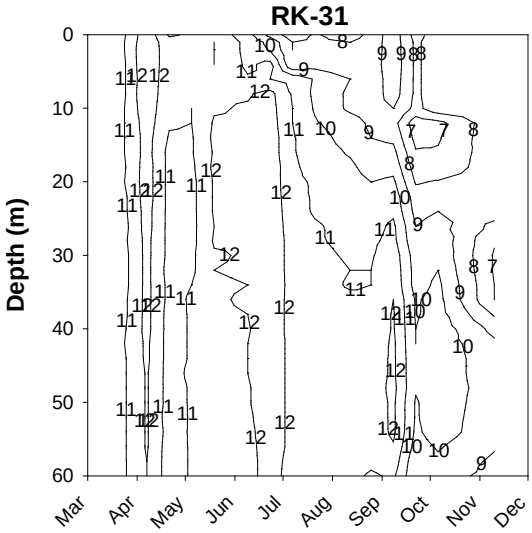


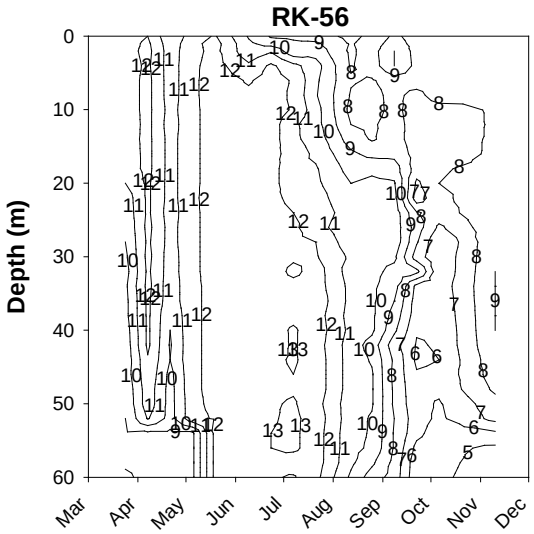
Appendix B. Depth of the thermocline measured at each of seven sampling station on Dworshak Reservoir from March through November 2008. The thermocline was defined as a change in temperature of one degree C over a depth of one meter.

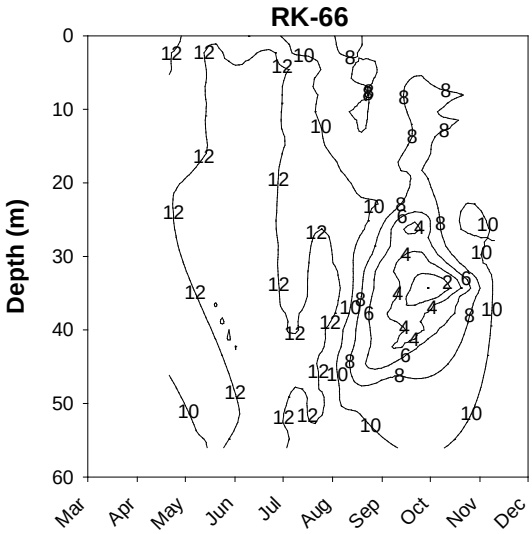
	Depth of Thermocline (m)						
Date	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**	**EC-6**	**LNF-3**
3/24	NS	NS	NS	NS	NS	NS	NS
4/7	NS	NS	NS	NS	NS	NS	NS
4/21	NS	NS	NS	NS	NS	NS	NS
5/5	11.0	NS	NS	NS	NS	2.0	NS
5/19	6.0	NS	NS	NS	NS	2.0	NS
6/9	5.0	7.0	3.0	2.0	2.0	3.0	2.0
6/23	5.0	3.0	3.0	1.0	1.0	2.0	1.0
7/7	5.0	5.0	3.0	3.0	2.0	3.0	2.0
7/21	7.0	5.0	2.0	3.0	2.0	5.0	3.0
8/11	7.0	5.0	5.0	3.0	3.0	5.0	3.0
8/25	9.0	9.0	5.0	3.0	5.0	9.0	2.0
9/8	11.0	11.0	6.0	NS	NS	9.0	7.0
9/22	9.0	10.0	NS	NS	7.0	9.0	NS
10/6	11.0	11.0	NS	NS	15.0	NS	NS
11/10	NS	25.0	NS	NS	13.0	23.0	17.0

Appendix C. Depth and dissolved oxygen for seven sampling stations on Dworshak Reservoir from March through November 2008. Isopleths indicate dissolved oxygen levels in mg/L at 5 mg/L intervals.

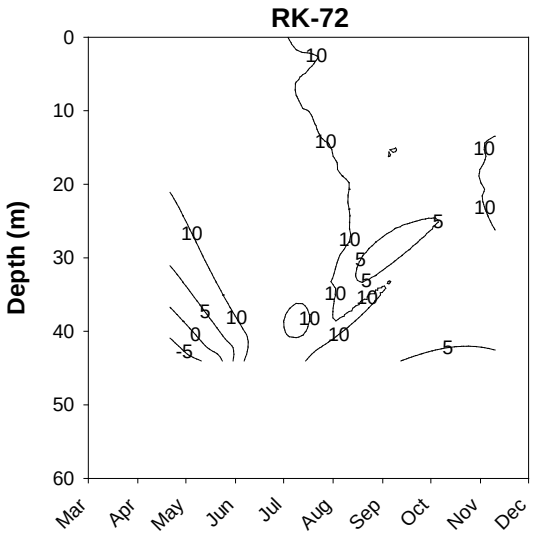


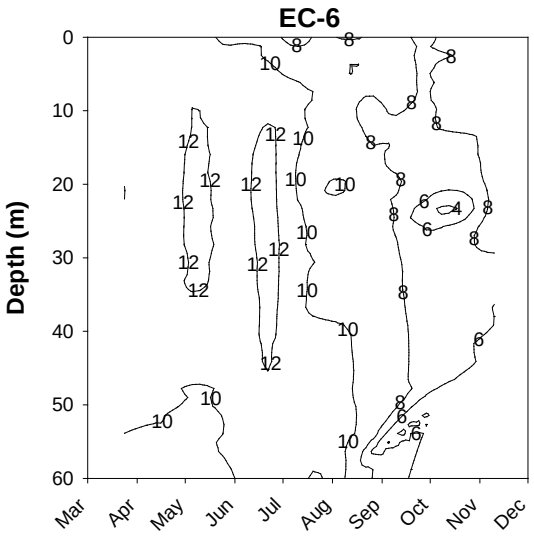


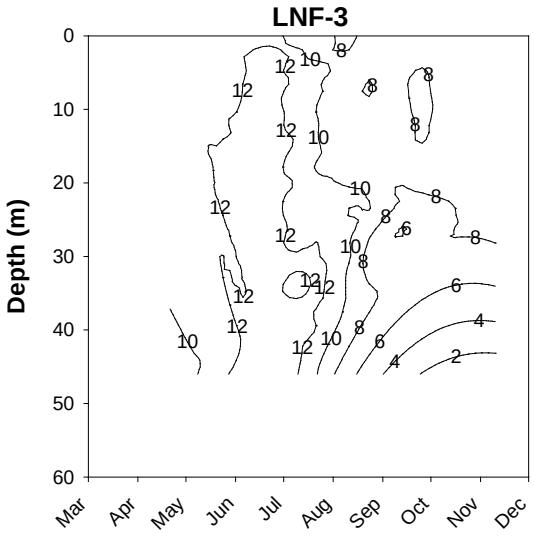




Appendix C. Continued







Appendix D. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Secchi readings taken at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

			Secchi Depth (m)			
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Mar	4	4.0	4.4	4.4	4.9	0.4
Apr	11	1.1	2.3	2.6	3.5	0.8
May	10	0.6	1.8	2.0	2.7	0.7
Jun	14	2.1	3.6	3.4	5.2	0.9
Jul	14	2.1	3.1	3.0	4.3	0.7
Aug	14	2.0	2.8	2.8	3.8	0.5
Sep	14	2.6	3.5	3.3	4.6	0.7
Oct	7	4.3	4.6	4.6	5.3	0.4
Nov	7	5.2	6.2	6.4	6.7	0.5
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	2.1	3.5	3.2	6.7	1.3
RK-31	15	1.8	3.1	2.7	6.7	1.2
RK-56	15	0.8	3.4	3.4	6.4	1.4
RK-66	13	0.6	3.3	3.4	6.1	1.4
RK-72	11	1.7	3.8	4.3	6.4	1.3
EC-6	15	1.2	2.8	2.6	5.2	1.1
LNF- 3	11	1.4	3.6	3.7	6.1	1.4

Appendix E. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for compensation depth at seven sampling stations on Dworshak Reservoir from March through November 2008. Compensation depths were calculated as the depth at which 1% of the photosynthetically active radiation measured at the surface was still present. Statistics are presented by month (all stations combined) and by station (entire year).

		Compensation Depth (m)				
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Mar	4	8.8	9.9	9.9	11.2	1.0
Apr	11	4.5	7.0	7.5	9.8	1.9
May	10	2.9	5.6	5.7	8.9	2.1
Jun	14	6.2	9.0	9.0	11.9	1.7
Jul	14	6.2	9.7	10.7	11.9	2.0
Aug	14	6.4	8.9	9.1	10.5	1.2
Sep	14	7.5	9.3	9.4	10.9	1.2
Oct	7	9.7	11.0	10.9	12.0	0.7
Nov	7	9.7	11.7	11.7	14.0	1.6
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	7.7	9.7	9.4	14.0	1.8
RK-31	15	6.0	8.9	8.8	13.7	2.1
RK-56	15	3.1	8.8	9.7	11.7	2.5
RK-66	13	2.9	8.8	9.4	11.0	2.6
RK-72	11	4.6	9.7	10.2	11.9	1.9
EC-6	15	4.0	7.3	6.4	11.8	2.2
LNF-3	11	5.2	9.5	9.7	11.3	1.8

Appendix F. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Total Dissolved Phosphorous measured at seven sampling stations on Dworshak Reservoir from March through November 2008. For calculation purposes, values that were below the detection limit (0.001 mg/L) were considered to be 0.001 mg/L. Statistics are presented by month (all stations combined) and by station (entire year).

Epilimnion		**Total Dissolved Phosphorus (mg/L)**				
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**St. Dev.**
Mar	4	0.001	0.003	0.002	0.005	0.002
Apr	11	0.001	0.002	0.001	0.006	0.002
May	10	0.001	0.004	0.001	0.016	0.005
Jun	14	0.001	0.006	0.003	0.021	0.007
Jul	14	0.001	0.003	0.001	0.014	0.004
Aug	14	0.001	0.004	0.004	0.008	0.002
Sep	14	0.001	0.002	0.001	0.008	0.002
Oct	7	0.001	0.001	0.001	0.003	0.001
Nov	7	0.001	0.003	0.003	0.006	0.002
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**St. Dev.**
RK-2	15	0.001	0.004	0.001	0.021	0.005
RK-31	15	0.001	0.004	0.002	0.018	0.005
RK-56	15	0.001	0.003	0.003	0.008	0.002
RK-66	13	0.001	0.003	0.001	0.010	0.003
RK-72	11	0.001	0.003	0.001	0.008	0.002
EC-6	15	0.001	0.005	0.002	0.019	0.006
LNF-3	11	0.001	0.002	0.001	0.006	0.002
NFC	15	0.001	0.003	0.001	0.014	0.004
Hypolimnion		**Total Dissolved Phosphorus (mg/L)**				
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**St. Dev.**
Apr	4	0.001	0.003	0.003	0.005	0.002
May	9	0.001	0.004	0.001	0.018	0.006
Jun	10	0.001	0.004	0.002	0.010	0.004
Jul	14	0.001	0.005	0.003	0.019	0.006
Aug	14	0.001	0.004	0.003	0.009	0.003
Sep	14	0.001	0.005	0.005	0.010	0.002
Oct	14	0.001	0.003	0.001	0.008	0.003
Nov	7	0.001	0.002	0.001	0.005	0.002
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**St. Dev.**
RK-2	15	0.001	0.003	0.001	0.015	0.004
RK-31	15	0.001	0.002	0.001	0.008	0.002
RK-56	15	0.001	0.004	0.005	0.008	0.002
RK-66	13	0.001	0.005	0.003	0.018	0.005
RK-72	10	0.001	0.003	0.002	0.008	0.002
EC-6	15	0.001	0.005	0.005	0.019	0.005
LNF-3	10	0.001	0.005	0.004	0.011	0.004

Appendix G. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Total Phosphorous measured at seven sampling stations on Dworshak Reservoir from March through November 2008. For calculation purposes, values that were below the detection limit (0.001 mg/L) were considered to be 0.001 mg/L. Statistics are presented by month (all stations combined) and by station (entire year).

Epilimnion			**Total Phosphorus (mg/L)**			
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Mar	4	0.004	0.006	0.006	0.007	0.001
Apr	11	0.001	0.024	0.031	0.050	0.019
May	10	0.001	0.016	0.015	0.042	0.012
Jun	14	0.001	0.019	0.019	0.050	0.013
Jul	14	0.005	0.010	0.009	0.026	0.006
Aug	14	0.005	0.010	0.008	0.021	0.005
Sep	14	0.001	0.006	0.007	0.011	0.003
Oct	7	0.001	0.003	0.001	0.012	0.004
Nov	7	0.001	0.002	0.001	0.005	0.002
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	0.001	0.010	0.006	0.031	0.009
RK-31	15	0.001	0.010	0.007	0.043	0.011
RK-56	15	0.001	0.014	0.007	0.050	0.015
RK-66	13	0.001	0.012	0.008	0.038	0.011
RK-72	11	0.003	0.013	0.009	0.037	0.011
EC-6	15	0.001	0.012	0.009	0.034	0.010
LNF-3	11	0.001	0.012	0.008	0.050	0.015
NFC	16	0.001	0.016	0.006	0.086	0.024
Hypolimion			**Total Phosphorus (mg/L)**			
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Apr	4	0.004	0.008	0.008	0.011	0.003
May	9	0.001	0.029	0.041	0.066	0.026
Jun	10	0.001	0.022	0.019	0.054	0.019
Jul	14	0.001	0.017	0.018	0.060	0.016
Aug	14	0.005	0.009	0.010	0.016	0.003
Sep	14	0.003	0.010	0.009	0.021	0.006
Oct	14	0.002	0.007	0.007	0.013	0.004
Nov	7	0.001	0.003	0.002	0.007	0.003
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	0.001	0.013	0.006	0.060	0.018
RK-31	15	0.001	0.011	0.006	0.053	0.014
RK-56	15	0.001	0.010	0.008	0.042	0.011
RK-66	13	0.001	0.014	0.010	0.054	0.016
RK-72	10	0.004	0.010	0.010	0.023	0.006
EC-6	15	0.001	0.017	0.008	0.066	0.019
LNF-3	10	0.001	0.010	0.010	0.021	0.008

Appendix H. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for nitrite plus nitrate nitrogen measured at seven sampling stations on Dworshak Reservoir from March through November 2008. For calculation purposes, values that were below the detection limit (0.001 mg/L) were considered to be 0.001 mg/L. Statistics are presented by month (all stations combined) and by station (entire year).

Epilimnion		**Nitrate-Nitrite Nitrogen (mg/L)**				
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Mar	4	0.038	0.060	0.065	0.070	0.015
Apr	11	0.004	0.036	0.031	0.079	0.022
May	10	0.001	0.031	0.020	0.100	0.037
Jun	14	0.004	0.035	0.034	0.080	0.022
Jul	14	0.001	0.003	0.001	0.016	0.004
Aug	14	0.001	0.003	0.001	0.034	0.009
Sep	14	0.001	0.008	0.001	0.053	0.014
Oct	7	0.001	0.004	0.001	0.011	0.004
Nov	7	0.001	0.011	0.004	0.032	0.012
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	0.001	0.009	0.002	0.049	0.015
RK-31	15	0.001	0.019	0.010	0.079	0.025
RK-56	15	0.001	0.030	0.032	0.097	0.030
RK-66	13	0.001	0.022	0.007	0.100	0.030
RK-72	11	0.001	0.013	0.002	0.080	0.024
EC-6	15	0.001	0.016	0.007	0.066	0.021
LNF-3	11	0.001	0.016	0.011	0.062	0.019
NFC	15	0.005	0.059	0.057	0.100	0.029
Hypolimion		**Nitrate-Nitrite Nitrogen (mg/L)**				
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Apr	4	0.048	0.062	0.065	0.071	0.010
May	9	0.030	0.060	0.051	0.094	0.025
Jun	10	0.013	0.063	0.046	0.140	0.043
Jul	14	0.037	0.073	0.076	0.110	0.023
Aug	14	0.001	0.027	0.027	0.051	0.012
Sep	14	0.001	0.027	0.023	0.061	0.017
Oct	14	0.001	0.018	0.007	0.091	0.027
Nov	7	0.001	0.038	0.010	0.120	0.053
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	0.001	0.048	0.039	0.120	0.039
RK-31	15	0.001	0.048	0.046	0.097	0.034
RK-56	15	0.005	0.044	0.037	0.110	0.034
RK-66	13	0.009	0.042	0.039	0.140	0.036
RK-72	10	0.001	0.020	0.009	0.074	0.024
EC-6	15	0.001	0.045	0.041	0.110	0.032
LNF-3	10	0.001	0.034	0.019	0.110	0.034

Appendix I. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for Total Dissolved solids measured at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

Epilimnion		**Total Dissolved Solids (mg/L)**				
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Mar	4	19.0	20.8	21.0	22.0	1.3
Apr	11	19.0	24.2	23.0	29.0	3.4
May	10	14.0	19.1	20.0	23.0	3.0
Jun	14	13.0	21.6	21.0	31.0	5.5
Jul	14	16.0	18.5	18.5	22.0	1.8
Aug	14	18.0	20.6	20.0	26.0	2.0
Sep	14	18.0	20.9	20.0	26.0	2.7
Oct	7	18.0	20.6	22.0	23.0	2.1
Nov	7	20.0	23.6	25.0	27.0	3.1
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	18.0	22.3	22.0	31.0	3.8
RK-31	15	18.0	21.2	20.0	31.0	3.8
RK-56	15	16.0	21.3	22.0	29.0	3.1
RK-66	13	14.0	20.2	20.0	26.0	3.3
RK-72	11	16.0	21.3	21.0	27.0	3.8
EC-6	15	16.0	20.8	20.0	28.0	2.8
LNF-3	11	13.0	19.3	19.0	26.0	3.8
NFC	15	14.0	20.4	20.0	28.0	4.2

Appendix J. Number of observations (n), minimum, mean, median, maximum and standard deviation (SDEV) for chlorophyll *a* measured at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

Epilimnion			**Chlorophyll a (µg/L)**			
Month	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
Mar	4	0.31	2.14	2.49	3.28	1.34
Apr	11	0.22	2.72	3.24	5.69	2.25
May	10	0.22	1.78	1.51	5.29	1.52
Jun	14	0.17	1.31	1.00	4.35	1.03
Jul	14	1.02	2.92	2.24	8.65	1.98
Aug	14	0.62	1.92	1.56	6.19	1.39
Sep	14	1.37	2.78	2.77	4.45	0.82
Oct	7	0.54	1.41	1.25	3.20	0.93
Nov	7	0.58	1.53	1.40	3.32	0.90
Station	**n**	**Min**	**Mean**	**Median**	**Max**	**SDEV**
RK-2	15	0.93	2.90	2.56	6.19	1.66
RK-31	15	0.54	2.95	2.71	5.29	1.60
RK-56	15	0.22	1.42	1.08	3.44	1.08
RK-66	13	0.34	1.34	1.25	2.66	0.79
RK-72	11	0.17	1.46	1.02	3.32	1.05
EC-6	15	0.62	2.82	2.39	8.65	2.03
LNF-3	11	0.32	1.57	1.69	2.93	0.67
NFC	15	0.06	0.79	0.54	3.43	0.87

Appendix K. Summary of the relative percent difference and difference between original and duplicate samples for six water quality parameters measured at seven sampling stations on Dworshak Reservoir from March through November 2008.

	Relative Percent Difference				**Difference**			
Parameter	**mean**	**median**	**min**	**max**	**mean**	**median**	**min**	**max**
N+N (mg/L)	0.0%	49.0%	28.6%	133.3%	0.000	0.002	0.001	0.009
TP (mg/L)	0.0%	43.5%	21.1%	155.6%	0.000	0.004	0.002	0.008
TDP (mg/L)	0.0%	47.9%	14.8%	176.5%	0.000	0.005	0.003	0.018
TDS (mg/L)	0.0%	3.4%	3.8%	11.8%	0.000	0.667	1.000	2.000
DOC (mg/L)	0.0%	19.8%	11.7%	79.5%	0.000	0.427	0.180	1.830
Chl *a* (µg/L)	0.0%	49.0%	28.6%	133.3%	0.000	0.002	0.001	0.009

Appendix L. Summary of picoplankton collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

Heterotrophic Bacteria

		Abundance (Cells/ml)			Biovolume (mm3/L)		
Month	**N**	**Median**	**Mean**	**SD**	**Median**	**Mean**	**SD**
Mar	4	187,515	178,675	49,287	0.075	0.072	0.020
Apr	11	365,232	428,505	161,954	0.146	0.171	0.065
May	10	467,550	447,494	181,124	0.187	0.179	0.073
Jun	14	764,928	819,702	275,842	0.306	0.328	0.110
Jul	13	476,252	756,564	416,598	0.191	0.303	0.167
Aug	14	949,006	963,776	463,657	0.380	0.386	0.186
Sep	14	1,918,148	1,740,110	582,273	0.767	0.696	0.233
Oct	7	1,950,788	1,922,084	131,977	0.780	0.769	0.053
Nov	7	897,820	935,608	92,528	0.359	0.374	0.037
Station	**N**	**Median**	**Mean**	**SD**	**Median**	**Mean**	**SD**
RK-2	15	897,820	1,071,835	686,190	0.359	0.429	0.274
RK-31	15	857,126	988,703	566,267	0.343	0.395	0.227
RK-56	15	550,392	798,524	561,364	0.220	0.319	0.225
RK-66	13	633,307	821,455	618,085	0.253	0.329	0.247
RK-72	11	747,760	951,463	665,889	0.299	0.381	0.266
EC-6	15	718,511	977,909	671,226	0.287	0.391	0.268
LNF-3	10	923,890	1,037,300	602,101	0.370	0.415	0.241

Picocyanobacteria

		Abundance (Cells/ml)			Biovolume (mm3/L)		
Month	**N**	**Median**	**Mean**	**SD**	**Median**	**Mean**	**SD**
Mar	4	8,822	8,849	5,357	0.044	0.044	0.027
Apr	11	3,815	12,927	20,916	0.019	0.065	0.105
May	10	3,974	5,315	7,300	0.020	0.027	0.037
Jun	14	13,936	16,855	14,887	0.070	0.084	0.074
Jul	14	168,288	203,258	205,407	0.841	1.016	1.027
Aug	14	121,871	117,859	34,578	0.609	0.589	0.173
Sep	14	55,107	71,617	41,465	0.276	0.358	0.207
Oct	5	121,871	106,039	30,306	0.609	0.530	0.152
Nov	7	20,453	22,013	7,261	0.102	0.110	0.036
Station	**N**	**Median**	**Mean**	**SD**	**Median**	**Mean**	**SD**
RK-2	15	56,167	116,516	193,789	0.281	0.583	0.969
RK-31	15	33,170	78,237	119,453	0.166	0.391	0.597
RK-56	15	53,920	61,801	55,801	0.270	0.309	0.279
RK-66	13	26,388	50,083	50,295	0.132	0.250	0.252
RK-72	10	23,950	34,083	35,112	0.120	0.170	0.176
EC-6	14	27,871	78,080	94,208	0.139	0.390	0.471
LNF-3	11	29,673	63,717	72,069	0.148	0.319	0.360

Appendix M. Density of phytoplankton collected from the epilimnion at seven sampling stations on Dworshak Reservoir from March through November 2008. Density is given in terms of natural counting units (NCU) per ml, which is typically the number of cells but is the number of colonies for some species.

Blue-greens	**EC-6**	**LNF-3**	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**
Anabaena circinalis	61	50	220	53	16	37	45
Anabaena sp.	98	268	817	305	213	232	
Anabaenopsis sp.	443		28	12			12
Aphanothecae sp.			20	25			
Chroococcus sp.	256	125	319	250	28	105	28
Coelosphaeria sp.	2,805	98	73	232	122	85	
Microcystis sp.	1,102	1,041	462	293	253	544	301
Planktothrix agardhii						12	12
Pseudoanabaena sp.	598	244	165	280	12	61	24
Synechococcus sp. (coccoid)	598	355	645	707	428	819	650
Synechococcus sp. (rod)	364	229	404	576	216	281	204
Synechocystis	488	232	146	518	140	165	122
Coccoid Greens, Desmids, etc.	**EC-6**	**LNF-3**	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**
Ankistrodesmus sp.	39	32	96	47	22	22	30
Ankyra				24		17	
Chlorella	48	19	34	41	23	17	17
Clamydocapsa sp.		49	101		20		68
Coelastrum sp.	49	200	34	54	207	610	281
Cosmarium sp.	115		158	94	22		12
Crucigenia sp.					146		
Dichtyosphaerium		12					
Elakatothrix sp3	55	38	70	68	24		24
Golenkinia sp.	12		12	12			
Monoraphidium	43	61	14	29	37	30	81
Oocystis sp.	71	24	64	38	73	36	67
Pediastrum sp.		12					
Phacus	12		10			24	
Planctonema sp.				10		20	
Planctosphaeria	10	12	25	10	98	98	390
Spondylosium sp.			30			268	
Tetraedron	10			12			
Diatoms	**EC-6**	**LNF-3**	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**
Achnathidium sp.	25	40	33	35	41	37	32
Asterionella formosa var1	179	67	75	85	121	276	264
Aulacoseira granulata	213				49		
Aulacoseira italica	159		30	10			
Aulicoseira distans	30						
Ceratoneis sp.	10	41			18	30	91
Cocconeis sp.					10	16	
Cyclotella comta	37	16	14	12	12	14	11
Cyclotella glomerata	90	24	66	90	30	35	30
Cyclotella stelligera	10					20	
Cymbella sp.	15	16			32	37	26
Diatoma sp.	30				20	15	
Fragilaria acus	39		81	87	27	20	
Fragilaria angustissima	20	22	45	40	19	21	24
Fragilaria capucina	89	25	83	117	26	25	12
Fragilaria construens	51		12	21	38	28	10
Fragilaria crotonensis	137	37	275	387	96	39	85

Appendix M. Continued.

Diatoms	**EC-6**	**LNF-3**	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**
Fragilaria ulna	15			30	10	10	10
Gomphonema sp.					30	10	
Hannea Arcus		10			30	20	20
Navicula sp.	33	20	14	22	31	37	20
Nitzschia sp.	20						
Pinnularia sp.						30	10
Rhizosolenia sp.			12				
Stephanodiscus sp.	15	47	37	28	35	28	49
Synedra	195		244	73		24	
Dinoflagellates	**EC-6**	**LNF-3**	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**
Ceratium		12				12	
Glenodinium sp.							49
Gymnodinium sp1	32	22	43	37	20	13	11
Gymnodinium sp2	13		22	25		11	10
Peridinium spp.	28	10	34	57	15	10	
Flagellates	**EC-6**	**LNF-3**	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**
Bitrichia sp.				12	12		12
Boda sp.	227	205	182	586	143	189	177
Chromulina sp1	40	28	54	48	28	33	29
Chryptomonas sp.	118	73	76	110	53	52	57
Chrysidiastrum				37			
Chrysochromulina sp.	111	44	99	148	60	51	39
Dinobryon sp.	52	46	279		21	61	12
Kephyrion sp.	37	15	50	81	44	14	18
Mallomonas sp2	19		41	25	12	12	10
Ochromonas sp.	23	37	33	42	30	32	30
Paranema			10				
Pseudokephrion sp.	21	12	29	33	16	14	18
Small microflagellates	1,397	1,213	1,033	1,246	1,163	1,157	1,134
Synura	37		49	85			24
Trachelomonas sp.	22			12	20		

Appendix N. Mean monthly density (NCU/ml) of phytoplankton sampled from the epilimnion at seven sampling stations on Dworshak Reservoir from March through November 2008. Density is given in terms of natural counting units (NCU) per ml, which is typically the number of cells but is the number of colonies for some species.

Blue-greens	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Anabaena circinalis				43	30	76	167		12
Anabaena sp					12			356	
Anabaenopsis sp.						30	1,232		
Aphanothecae sp.	20	25							
Chroococcus sp.				215	49	127	366	207	12
Coelosphaeria sp.					152	98	1,004		
Microcystis sp.					122	143	1,567	606	87
Planktothrix agardhii				12	12				
Pseudoanabaena sp.							203		
Synechococcus sp. (coccoid)	813	781	556	488	976	197	146	1,314	307
Synechococcus sp. (rod)	195	423	232	402	362	347	1,055	186	167
Synechocystis							261		
Coccoid Greens, Desmids, etc.	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Ankistrodesmus sp.	10	51	58	30	41				
Ankyra				21	18				
Chlorella	10	38	44	27	35	20	24	24	12
Clamydocapsa sp.				44			49	183	12
Coelastrum sp.	10	18			189	125	349	12	
Cosmarium sp.	189	201	86	14	21		12		
Crucigenia sp.							146		
Dichtyosphaerium								12	
Elakatothrix sp3	37	140	78	23	33	44	24		12
Golenkinia sp.					12			12	
Monoraphidium				58	20	23	54	12	
Oocystis sp.		71	10	41	88	41	28	37	98
Pediastrum sp.				12					
Phacus				10			24	12	
Planctonema sp.		10		20					
Planctosphaeria	10	25		10				149	
Spondylosium sp.	30					268			
Tetraedron				10		12			
Diatoms	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Achnathidium sp.	20	45	56	23	18	27	44	34	
Asterionella formosa var1	10	14	20	49	76	88	246	274	159
Aulacoseira granulata					110		256		
Aulacoseira italica		10	20	159	49				
Aulicoseira distans		30							
Ceratoneis sp.	10	43	20						
Cocconeis sp.	10		20		12				
Cyclotella comta		10	10	18	17	12	12		
Cyclotella glomerata	188	80	57	47	49	38	33		
Cyclotella stelligera				15					
Cymbella sp.	20	45	36	11	12	12			
Diatoma sp.		20	20						
Fragilaria acus	71	88	46	10					
Fragilaria angustissima		41	43	30	24	15	21		
Fragilaria capucina	162	107	39	28	18	12	12		
Fragilaria construens		41	46	20	12				16
Fragilaria crotonensis	355	30	30	41	12	418	216	193	12

Appendix N. Continued

Diatoms	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Fragilaria ulna		10	17	15					
Gomphonema sp.			20						
Hannea Arcus			30	14					
Navicula sp.	10	33	47	20	20	18	12		12
Nitzschia sp.			20						
Pinnularia sp.		20							
Rhizosolenia sp.					12				
Stephanodiscus sp.				12	37	35	29	12	
Synedra							146		
Dinoflagellates									
Ceratium					12	12			
Glenodinium sp.							49		
Gymnodinium sp1		50	29	20	14	12	12		
Gymnodinium sp2		22	20	14	12		12		
Peridinium spp.	10	55	29	14					
Flagellates	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
Bitrichia sp.						12	12		
Boda sp.	124	209	485	232	236	205	240	174	174
Chromulina sp1		42	56	29	42	33	28	49	40
Chryptomonas sp.	76	105	82	112	89	57	68	61	59
Chrysidiastrum					37				
Chrysochromulina sp.	41	133	156	108	78	57	43	38	20
Dinobryon sp		122	355	61	16	28	49		12
Kephyrion sp.	56	30	116	16	12	27	17	12	18
Mallomonas sp2		24	35	20	18	12	15	24	12
Ochromonas sp.	10		112		22	33	20	54	27
Paranema			10						
Pseudokephrion sp.		10	43	15	20	24	16	12	12
Small microflagellates	568	840	582	878	993	1,630	2,282	922	1,078
Synura						49			
Trachelomonas sp.	20					12	24		

Appendix O. Median zooplankton density from 10 m of water depth to the surface, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

			Median Zooplankton Density (individuals/L)						**Grand Median**
Station	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**	**EC-6**	**LNF-3**		**s**
n	15	15	15	13	11	15	11		95
Bosmina	0.61	0.36	0.14	0.13	0.06	0.88	0.19		0.28
Chydorid	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Daphnia	3.69	3.27	4.79	3.85	1.60	1.72	6.08		3.51
Diaphanosoma	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Holopedium	0.10	0.05	0.19	0.13	0.10	0.01	0.51		0.10
Leptodora	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Scapholeberis	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Cladocerans	5.35	3.65	6.52	5.45	1.87	3.00	8.69		4.56
Calanoid	5.61	1.27	2.14	3.31	3.12	1.43	4.38		2.29
Cyclops	14.82	16.55	6.57	9.36	2.38	20.40	11.90		12.63
Ergasilus	1.07	0.95	0.34	0.32	0.32	2.10	1.16		0.76
Copepods	20.78	18.74	7.33	10.49	4.29	25.21	20.94		17.52
Total Zoop	28.90	20.75	16.81	21.39	6.91	34.12	30.94		22.00
Month	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
n	4	11	10	14	14	14	14	7	7
Bosmina	0.14	0.08	0.33	4.47	0.31	0.24	0.17	0.62	0.20
Chydorid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daphnia	0.08	0.05	0.21	5.43	2.67	4.13	6.76	7.04	2.60
Diaphanosoma	0.00	0.00	0.00	0.00	0.00	0.07	0.55	0.09	0.00
Holopedium	0.01	0.00	0.00	0.05	0.25	0.32	0.73	0.19	0.00
Leptodora	0.00	0.00	0.00	0.00	0.02	0.05	0.00	0.00	0.00
Scapholeberis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cladocerans	0.29	0.19	0.74	11.43	3.99	5.39	8.51	8.15	2.65
Calanoid	0.89	0.43	0.10	0.73	4.18	4.80	5.56	3.88	2.44
Cyclops	2.14	1.87	11.90	12.08	6.74	13.19	15.31	21.45	16.20
Ergasilus	0.53	0.25	1.49	0.34	0.90	0.90	1.46	0.76	0.61
Copepods	3.57	3.13	14.26	14.51	10.54	20.86	21.65	25.21	19.76
Total Zoop	3.85	3.32	17.34	25.46	16.69	30.70	32.44	37.94	21.39

Appendix P. Median zooplankton density from 30 m to 10 m of water depth, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

			Median Zooplankton Density (individuals/L)						Grand
Station	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**	**EC-6**	**LNF-3**		**Medians**
n	9	9	9	6	6	9	6		54
Bosmina	0.13	0.07	0.04	0.07	0.00	0.09	0.02		0.04
Chydorid	0.11	0.08	0.03	0.12	0.37	0.07	0.34		0.07
Daphnia	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Diaphanosoma	1.29	0.41	0.42	0.61	0.17	0.79	1.05		0.62
Holopedium	0.06	0.05	0.03	0.05	0.11	0.05	0.13		0.06
Leptodora	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Scapholeberis	0.03	0.05	0.03	0.04	0.07	0.17	0.10		0.06
Cladocerans	0.02	0.00	0.00	0.06	0.00	0.00	0.11		0.01
Calanoid	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Cyclops	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Ergasilus	0.65	0.20	0.23	0.40	0.14	0.26	0.60		0.25
Copepods	1.55	0.64	0.45	0.77	0.59	1.16	1.66		0.79
Total Zoop	2.26	0.85	0.78	1.12	1.53	1.42	2.29		1.01
Month	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
n	4	4	4	7	7	7	7	7	7
Bosmina	0.06	0.01	0.00	0.24	0.32	0.36	0.01	0.06	0.01
Chydorid	0.10	0.10	0.01	0.00	0.02	1.47	0.10	0.25	0.14
Daphnia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diaphanosoma	0.69	0.37	0.08	0.42	0.16	1.29	0.29	1.33	1.45
Holopedium	0.06	0.06	0.02	0.03	0.05	1.06	0.02	0.32	0.10
Leptodora	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scapholeberis	0.22	0.12	0.02	0.01	0.03	0.24	0.03	0.06	0.07
Cladocerans	0.01	0.00	0.00	0.00	0.00	0.09	0.05	0.05	0.00
Calanoid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cyclops	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ergasilus	0.11	0.09	0.03	0.28	0.44	1.55	0.23	0.51	0.11
Copepods	1.05	0.59	0.11	0.44	0.21	4.72	0.43	1.55	1.57
Total Zoop	1.21	0.64	0.16	0.78	0.60	6.28	0.63	2.26	2.31

Appendix Q. Mean zooplankton density from 10 m of water depth to the surface, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

	Mean Zooplankton Density (individuals/L)								Grand
Station	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**	**EC-6**	**LNF-3**		**Means**
n	15	15	15	13	11	15	11		95
Bosmina	2.73	0.94	0.50	0.31	0.09	2.16	1.24		1.20
Chydorid	0.00	0.00	0.00	0.00	0.00	0.00	0.01		0.00
Daphnia	5.51	3.35	3.88	4.52	4.78	4.95	5.77		4.63
Diaphanosoma	0.09	0.16	0.26	0.28	0.09	0.06	0.22		0.17
Holopedium	0.21	0.20	0.32	0.51	0.21	0.16	0.58		0.30
Leptodora	0.04	0.01	0.02	0.02	0.00	0.05	0.02		0.02
Scapholeberis	0.13	0.00	0.00	0.00	0.00	0.00	0.00		0.02
Cladocerans	8.71	4.66	4.99	5.64	5.17	7.38	7.84		6.34
Calanoid	6.89	1.51	2.24	3.57	3.33	2.65	4.17		3.46
Cyclops	18.74	18.94	9.05	10.29	5.46	23.51	13.82		14.73
Ergasilus	1.18	1.16	0.55	0.41	0.52	2.74	1.17		1.14
Copepods	26.81	21.61	11.84	14.27	9.31	28.89	19.16		19.33
Total Zoop	35.52	26.28	16.83	19.90	14.48	36.27	27.00		25.67
Month	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
n	4	11	10	14	14	14	14	7	7
Bosmina	0.16	0.35	1.44	5.07	0.53	0.32	0.27	0.88	0.27
Chydorid	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Daphnia	0.08	0.17	2.05	8.73	3.48	4.35	7.66	7.57	3.62
Diaphanosoma	0.00	0.00	0.00	0.00	0.00	0.22	0.78	0.16	0.08
Holopedium	0.01	0.02	0.14	0.12	0.48	0.33	0.81	0.38	0.02
Leptodora	0.00	0.00	0.00	0.02	0.07	0.05	0.00	0.02	0.00
Scapholeberis	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00
Cladocerans	0.25	0.53	3.63	13.95	4.70	5.27	9.52	9.01	3.98
Calanoid	0.77	0.41	0.56	3.50	4.89	5.49	5.25	4.19	2.55
Cyclops	2.04	5.46	10.18	20.74	18.55	13.32	15.55	21.43	17.84
Ergasilus	0.91	0.87	1.20	0.54	1.29	1.95	1.45	0.76	0.66
Copepods	3.71	6.75	11.94	24.79	24.74	20.76	22.26	26.37	21.04
Total Zoop	3.97	7.28	15.57	38.74	29.44	26.03	31.78	35.38	25.02

Appendix R. Mean zooplankton density from 30 m to 10 m of water depth, given as the number of individuals per L for the nine major taxonomic groups of zooplankters collected at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

	Mean Zooplankton Density (individuals/L)								Grand Medians
Station	**RK-2**	**RK-31**	**RK-56**	**RK-66**	**RK-72**	**EC-6**	**LNF-3**		
n	9	9	9	6	6	9	6		54
Bosmina	0.58	0.11	0.13	0.11	0.06	0.62	0.09		0.27
Chydorid	0.48	0.12	0.16	1.08	0.86	0.12	1.05		0.48
Daphnia	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Diaphanosoma	1.60	0.56	1.03	1.23	0.96	2.39	3.57		1.57
Holopedium	0.42	0.09	0.34	0.58	0.50	0.18	1.38		0.44
Leptodora	0.00	0.00	0.03	0.00	0.00	0.00	0.01		0.01
Scapholeberis	0.06	0.11	0.06	0.13	0.07	0.24	0.22		0.12
Cladocerans	0.03	0.02	0.05	0.15	0.02	0.01	0.20		0.06
Calanoid	0.00	0.00	0.00	0.00	0.01	0.00	0.00		0.00
Cyclops	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00
Ergasilus	1.03	0.22	0.55	0.85	0.60	0.81	1.68		0.78
Copepods	2.14	0.79	1.24	2.43	1.89	2.75	4.84		2.17
Total Zoop	3.17	1.01	1.79	3.28	2.48	3.55	6.52		2.95
Month	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
n	4	4	4	7	7	7	7	7	7
Bosmina	0.05	0.02	0.00	0.91	0.57	0.33	0.05	0.13	0.03
Chydorid	0.16	0.10	0.01	0.30	0.06	2.12	0.08	0.71	0.24
Daphnia	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Diaphanosoma	0.55	0.40	0.23	1.61	2.47	3.47	0.29	0.89	2.71
Holopedium	0.07	0.05	0.03	0.42	0.06	1.98	0.05	0.48	0.35
Leptodora	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00
Scapholeberis	0.27	0.10	0.05	0.04	0.06	0.40	0.04	0.08	0.11
Cladocerans	0.01	0.00	0.00	0.00	0.04	0.15	0.22	0.05	0.01
Calanoid	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
Cyclops	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ergasilus	0.13	0.07	0.04	1.34	0.68	2.50	0.32	0.66	0.40
Copepods	0.97	0.61	0.30	1.95	2.59	5.99	0.41	1.68	3.06
Total Zoop	1.10	0.68	0.33	3.29	3.26	8.49	0.73	2.34	3.45

Appendix S. Length statistics for *Daphnia sp.* and *Bosmina sp.* collected between 10 m and the surface at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

	Daphnia			***Bosmina***		
Month	**n**	**Mean**	**SDEV**	**n**	**Mean**	**SDEV**
Mar	37	0.89	0.30	54	0.41	0.08
Apr	73	0.91	0.29	87	0.44	0.07
May	79	0.88	0.29	99	0.39	0.09
Jun	215	1.11	0.28	213	0.43	0.92
Jul	259	1.21	0.39	109	0.38	0.07
Aug	258	1.15	0.36	105	0.36	0.07
Sep	280	1.19	0.36	59	0.35	0.06
Oct	140	1.21	0.37	70	0.35	0.07
Nov	140	1.01	0.26	52	0.36	0.06
Station	**n**	**Mean**	**SDEV**	**n**	**Mean**	**SDEV**
RK-2	271	1.08	0.36	189	0.44	0.97
RK-31	231	1.14	0.37	174	0.39	0.08
RK-56	207	1.12	0.33	89	0.35	0.07
RK-66	183	1.12	0.34	54	0.37	0.08
RK-72	180	1.11	0.37	47	0.37	0.07
EC-6	209	1.16	0.36	223	0.39	0.08
LNF-3	200	1.13	0.33	72	0.37	0.09

Appendix T. Length statistics for *Daphnia sp.* and *Bosmina sp.* collected between 30 and 10 m below the surface at seven sampling stations on Dworshak Reservoir from March through November 2008. Statistics are presented by month (all stations combined) and by station (entire year).

	Daphnia			***Bosmina***		
Month	**n**	**Mean**	**SDEV**	**n**	**Mean**	**SDEV**
Mar	57	1.288	0.220	65	0.435	0.075
Apr	62	1.288	0.354	39	0.438	0.077
May	42	1.244	0.328	45	0.400	0.093
Jun	75	1.047	0.294	105	0.361	0.083
Jul	108	1.226	0.308	137	0.399	0.065
Aug	106	1.091	0.354	105	0.375	0.066
Sep	99	1.059	0.386	81	0.377	0.084
Oct	127	1.226	0.301	101	0.369	0.065
Nov	113	1.129	0.281	48	0.374	0.075
Station	**n**	**Mean**	**SDEV**	**n**	**Mean**	**SDEV**
RK-2	135	1.228	0.342	143	0.398	0.075
RK-31	146	1.255	0.307	155	0.400	0.075
RK-56	113	1.146	0.332	103	0.360	0.096
RK-66	103	1.040	0.294	76	0.371	0.062
RK-72	91	1.109	0.342	44	0.385	0.072
EC-6	99	1.212	0.321	159	0.391	0.069
LNF-3	102	1.115	0.314	46	0.385	0.087

Appendix U. Estimates of kokanee abundance and adult (age-2 and up) densities for Dworshak Reservoir.

Year	Sampling Method	Kokanee Abundance					Adult Density (fish/ha)
		Age 0	Age 1	Age 2	Age 3	Total	
2008	Hydroacoustic	1,237,181	200,147	55,117	30,668	1,523,113	16
2007	Hydroacoustic	584,547	332,017	235,346	0	1,151,910	48
2006	Hydroacoustic	2,182,983	1,508,780	2,123,631	0	5,815,394	484
2005	Hydroacoustic	2,134,986	769,663	107,466	0	3,011,626	21
2004	Trawling	2,136,892	692,348	90,715	0	3,919,956	14
2003	Hydroacoustic	439,580	434,586	276,055	0	1,150,222	42
2002	Hydroacoustic	1,246,959	1,101,232	127,933	0	2,476,124	24
2001	Hydroacoustic	1,962,000	781,000	405,000	0	3,150,000	75
2000	Hydroacoustic	1,894,857	303,680	199,155	0	2,397,691	37
1999	Hydroacoustic	1,143,634	363,250	38,464	0	1,545,347	7
1998	Hydroacoustic	537,000	73,000	39,000	0	649,000	7
1997	Trawling	65,000	0	0	0	65,000	0
1996	Hydroacoustic	231,000	43,000	29,000	0	303,000	5
1995[a]	Hydroacoustic	1,630,000	1,300,000	595,000	0	3,539,000	110
1994	Hydroacoustic	156,000	984,000	304,000	9,000	1,457,000	69
1993	Trawling	453,000	556,000	148,000	6,000	1,163,000	33
1992	Trawling	1,040,000	254,000	98,000	0	1,043,000	22
1991	Trawling	132,000	208,000	19,000	6,000	365,000	5
1990[b]	Trawling	978,000	161,000	11,000	3,000	1,153,000	3
1989[a]	Trawling	148,000	148,000	175,000	0	471,000	32
1988	Trawling	553,000	501,000	144,000	12,000	1,210,000	29

[a] September trawl survey likely resulted in an underestimate of mature kokanee.
[b] June trawl survey may have resulted in an underestimate of age-0 kokanee.

Prepared by:

Sean M. Wilson
Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

Richard J. Downing
Senior Fishery Technician

Ben Scofield
Aquatic Ecologist
TG Eco-Logic, LLC

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

_____
Daniel J. Schill
Fisheries Research Manager

_____
Edward B. Schriever, Chief
Bureau of Fisheries