FISHERY RESEARCH

DWORSHAK RESERVOIR NUTRIENT RESTORATION RESEARCH, 2013

DWORSHAK DAM RESIDENT FISH MITIGATION PROJECT

PROGRESS REPORT
March 1, 2013 – February 28, 2014

Prepared by:

Sean M. Wilson, Fishery Research Biologist
Andrew M. Dux, Principal Fishery Research Biologist
and
Curtis J. Roth, Fishery Technician
Idaho Department of Fish and Game

IDFG Report Number 15-05
March 2015

DWORSHAK RESERVOIR
NUTRIENT RESTORATION RESEARCH, 2013

Dworshak Dam Resident Fish Mitigation Project

Progress Report

March 1, 2013—February 28, 2014

By

Sean M. Wilson
Andrew M. Dux
and
Curtis J. Roth

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707
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 60349

IDFG Report Number 15-05
March 2015

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

List of Tables, continued.

LIST OF FIGURES

Page

LIST OF APPENDICES

Page

ABSTRACT

The Idaho Department of Fish and Game (IDFG) and the U.S. Army Corps of Engineers (USACE) cooperatively conducted a pilot project to test nutrient restoration as a means to restore declining reservoir productivity and improve the Dworshak Reservoir fishery. Under this agreement, the USACE applied nutrients in the form of ammonium nitrate, IDFG monitored the results using a combination of limnological and fish surveys, and Advanced Eco-Solutions provided the application schedule and limnological analysis. This report summarizes the results from 2013, the second year of a second pilot project to assess the effectiveness of nutrient restoration. Water quality standards set by the U.S. Environmental Protection Agency (EPA) and the Idaho Department of Environmental Quality (IDEQ) were not violated. Secchi depth for 2013 (mean = 4.5 m) was one of the highest in recent years. The chlorophyll concentration (mean = 1.21 µg/L) was the lowest in recent history and phytoplankton biovolume (mean = 0.279 mm^3/L) was below the non-restoration mean (mean = 0.441 mm^3/L). The proportion of edible phytoplankton (44%) was higher than any non-restoration year. The length (mean = 1.07 mm) and the density (mean = 6.2 individuals/L) of *Daphnia* spp. was the second highest in recent years. Together, these resulted in the second highest biovolume (mean = 121 µg /L) of *Daphnia* spp. large enough to be consumed by kokanee (TL ≥0.80 mm) in recent years. The mean length and weight of age-2 kokanee were greater than non-restoration years with similar fish densities. Kokanee growth was influenced by mean biomass of consumable *Daphnia* spp. more than any other factor investigated. Dworshak Reservoir appears to be responding to nutrient restoration as anticipated and greater improvements to the fishery are possible if results are sustained. Our results to date are consistent with those reported for nutrient restoration projects in Kootenay and Arrow lakes in British Columbia.

Authors:

Sean M. Wilson
Senior Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

Curtis J. Roth
Fishery Technician

INTRODUCTION

Dworshak Reservoir is the most popular fishing destination in Clearwater County and the second most popular destination in the Clearwater region, based on total angler trips in 2011 (Thomas MacArthur, IDFG, unpublished data). It provides a multispecies fishery for naturally reproducing kokanee *Oncorhynchus nerka*, Smallmouth Bass *Micropterus dolomieu,* and Westslope Cutthroat Trout *O. clarkii lewisi*, as well as hatchery-stocked Rainbow Trout *O. mykiss*. The reservoir also provides important habitat for Bull Trout *Salvelinus confluentus*, which are listed as Threatened under the Endangered Species Act (ESA).

Kokanee were first stocked into Dworshak Reservoir in 1972 (Horton 1981). Although two stocks were originally introduced (early spawners from Anderson Ranch Reservoir, Idaho and late spawners from Lake Whatcom, Washington), the early spawning variety quickly dominated (Horton 1981). Kokanee provide the most popular fishery on the reservoir, with annual effort levels that have exceeded 140,000 angler hours and annual harvest 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 Reservoir (Maiolie and Elam 1996).

Entrainment and oligotrophication have been identified as the primary factors limiting the kokanee population in Dworshak Reservoir (Stark and Stockner 2006). With the exception of high runoff years, entrainment was reduced beginning in the early 1990s when drawdown began occurring primarily during the summer and early autumn to provide cool water for Chinook Salmon *O. tshawytscha* in the Snake River. During this time period, kokanee are distributed farther from the dam and are less vulnerable to entrainment than during winter (Maiolie and Elam 1997). Bennett (1997) found that discharge from January through March had the highest negative correlation with survival compared to other time periods examined. While entrainment remains a limiting factor for kokanee in some years, oligotrophication is more often the primary limiting factor. Bennett (1997) identified declining productivity as a critical factor limiting the kokanee fishery and recommended it be addressed before implementing intensive fisheries management practices.

Following this recommendation, Stockner and Brandt (2006) conducted a detailed assessment of the reservoir and gave recommendations for a nutrient restoration program. Based on phosphorous (P) loading and mean chlorophyll densities, they classified Dworshak Reservoir 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 Reservoir becomes nitrogen (N) limited by mid-summer, leading to a dominance of N fixing cyanobacteria (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. Mid-summer N limitation and the subsequent reduction in zooplankton results in reduced fish production.

The Idaho Department of Fish and Game (IDFG) and the U.S. Army Corps of Engineers (USACE) initiated a five-year pilot project to evaluate nutrient restoration as a management strategy for restoring the Dworshak Reservoir ecosystem and improving the fishery. The goal of the project is to restore lost productivity by improving the N:P ratios in the reservoir, thereby promoting the growth of desirable phytoplankton (i.e., edible by zooplankton). 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 (2006) anticipated that a moderate N nutrient restoration would benefit fish populations without degrading water quality.

The pilot project began in 2007, with the USACE applying the nutrients and IDFG conducting the monitoring. Advanced Eco-Solutions, a private consulting company, was contracted to assist in designing the monitoring program, interpret the results of the limnological data, and adjust the nutrient prescriptions as necessary. However, nutrient applications were suspended prematurely in late July of 2010 due to a legal challenge. At that time, the project was being conducted under the legal authority of a Consent Order issued by the Idaho Department of Environmental Quality (DEQ). The U.S. Environmental Protection Agency (EPA) then made a determination that a National Pollutant Discharge Elimination System (NPDES) permit would be required for nutrient applications to continue. An NPDES permit was not obtained until October of 2011, which did not allow for nutrient applications in the final year of the original pilot study. A second pilot study was initiated in 2012 and is intended to run through 2017, at which time a determination will be made as to whether or not nutrient restoration should be implemented as a management strategy for the reservoir.

The primary task of IDFG's monitoring program was to evaluate the effectiveness of the nutrient restoration program at improving the flow of carbon to the kokanee population in Dworshak Reservoir without adversely affecting water quality. Thus, limnological surveys were conducted to meet three major requirements. The first requirement was to ensure that water quality standards, as stipulated in the Consent Order permit issued by DEQ, were maintained. Secondly, limnological data were collected to make comparisons with pretreatment conditions to determine the biological effects of the project, including changes to the plankton communities. In treatment years, data were provided to the consultant to actively manage the nutrient applications. Lastly, surveys were conducted to monitor the kokanee population. An effective nutrient restoration program is expected to increase the average size of kokanee at any given population density. Larger kokanee, at a given population density, are expected to produce higher catch rates in the sport fishery (Rieman and Maiolie 1995).

This report summarizes data collected in 2013, the second year of the second pilot study. These data were used to assess both the limnological and fishery responses to nutrient restoration and evaluate the response of biological communities.

STUDY SITE

Dworshak Reservoir was created by 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. Timber harvest is the primary commercial activity, 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). 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 2003-2012 was 154 m^3/s (http://www.cbr.washington.edu/dart/, accessed 3/31/14). Historically, Dworshak Reservoir begins to thermally stratify in April and stratification becomes pronounced from June through September. Destratification begins in the fall and occurs more rapidly at the upper end of the reservoir (Falter 1982).

OBJECTIVES

1. Maintain an annual median Secchi depth of ≥3.0 m and an annual median chlorophyll *a* concentration of ≤3.0 μg/L for treated areas of the reservoir.
2. Increase densities of picoplankton by twofold in the first year of nutrient restoration.
3. Increase the mean total length of age-2 kokanee by 20 mm over that observed at a similar pretreatment kokanee density.
4. Maintain a kokanee population that can sustain a catch rate of 1.2 fish per hour with a minimum average size of 254 mm total length.

METHODS

Environmental Conditions

Daily mean reservoir inflow, discharge, and pool elevation data provided by the USACE were acquired through the Columbia River Data Access in Real Time (DART) website (http://www.cbr.washington.edu/dart/; accessed 3/31/14).

Physical and Chemical Limnology

Sample Collection

Limnological sampling was conducted at six stations on the reservoir and one station on the North Fork Clearwater River (NFC) below Dworshak Dam (Figure 1). Four stations on the main reservoir were designated as RK-2, RK-31, RK-56, and RK-72, corresponding with the approximate river kilometer (RKM). Two additional stations were located in untreated areas of the reservoir, RKM six of the Elk Creek arm (EC-6) and RKM three of the Little North Fork arm (LNF-3).

Limnological sampling was conducted twice monthly from April through September and once monthly during March, October, and November. When all seven reservoir stations and the river station could not be sampled in one day, samples were collected over a two-day period.

Physical parameters measured included water depth, water clarity, water temperature, dissolved oxygen (DO), and photosynthetically active radiation (PAR). Chemical parameters included pH, total phosphorus (TP), total dissolved phosphorus (TDP), total nitrogen (TN), nitrate plus nitrite nitrogen (N+N), total ammonia (TA), total dissolved solids (TDS), and dissolved organic carbon (DOC). Biological parameters included chlorophyll *a* (Chl *a*), picoplankton, phytoplankton, and zooplankton. Sampling for TN, TA, and DOC was only conducted during the first event each month. Moreover, DOC samples were only taken at RK-31 and RK-72.

Water depth was measured using a Garmin™ Model GSD22 depth sounder in conjunction with a GPS MAP 4212 chart plotter. Water clarity was measured using a 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 (DO) measurements were taken concurrently with a Yellow Springs Instruments® (YSI) Professional Plus multi-parameter meter, polarographic probe, and 70 m cable. 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 recorded.

The level of PAR was measured using a Li-Cor® model LI-250A light meter and a 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 were only collected from RK-2 and for the first event each month. They consisted of a single 'grab' from 25 m. 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. Samples were shipped via overnight carrier to the contracting lab within two days of collection. Chemical analyses were performed by AM Test Labs of Kirkland, Washington. Analytical methods used for each parameter can be found in Wilson et al. (2010). While collecting the EPI sample at each station, a 'grab' was collected from 1 m and the pH was measured using a pH10A meter from YSI.

A Chl *a* sample was collected by filtering 250 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 and preserved with 15 drops of Lugol's solution. All sample bottles were labeled with station, date, time, and depth (EPI or HYPO).

Zooplankton were collected using a 50 cm diameter, 80 µm mesh Wisconsin style net fitted with an OceanTest Equipment flow meter. One vertical tow was performed at each station from 10 m to the surface. Tows were completed by lowering the net to depth and retrieving at a rate of 0.5 m/s. The number of revolutions on the flow meter was recorded. Plankton were rinsed from the net into the collection bucket and 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. All plankton and Chl *a* samples were sent to Advanced Eco-Solutions of Newman Lake, Washington for analysis. Analytical methods used for each parameter can be found in Wilson et al. (2010).

Primary production rates were measured by Advanced Eco-Solutions on June 26, July 24, August 21, and September 17 at RK-31. Briefly, water was drawn from five discrete depths spaced throughout the photic zone. Two clear and one opaque BOD bottles were filled for each depth and inoculated with ^{14}C. Bottles were then incubated for approximately four hours at the same depth they were drawn from. After retrieval, aliquots from each bottle were filtered through filters of 20, 2, and 0.2 µm pore size. The filters were then sent to the University of Idaho to measure the amount of ^{14}C, from which daily carbon uptake ($mgC/m^2/day$) could be calculated. For more detail, see Brandt (2014).

Data Analysis

The compensation depth is the depth where light intensity is 1% of the light intensity at 0 m. Before calculating compensation depth, the light intensity at depth was adjusted according to the ratio of the concurrent air measurement divided by the air measurement concurrent with the surface reading. Compensation depths were then calculated from the adjusted light intensity profiles by transforming the data as follows:

$$x = Ln\left[100\left(\frac{I_D}{I_S}\right)\right]$$

Where: *Ln* = natural logarithm
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 R 3.0.1 (www.r-project.org). 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.

Between year comparisons of limnological data were performed using a multiyear sampling frame, which consisted of months and stations that were sampled consistently for all years compared for the metric in question. This sampling frame included data from stations RK-2, RK-31, RK-56, and RK-72 from May through November, unless noted otherwise. When comparing chemical concentrations, in cases where the minimum detection limit was not consistent for all years compared, the minimum was artificially adjusted upward to match the year with the highest minimum level. That is, values in all years below the highest minimum level for any year were considered to be equal to that level for the purposes of calculating descriptive statistics.

Phytoplankton densities were recorded both in terms of natural counting units (NCU), which refers to colony numbers for some species and cells for others. Prior to 2008, cells/mL was not recorded for colonial species. Therefore, densities are reported as cells/mL whenever possible, except when making comparisons among years.

Inconsistencies also existed between years in zooplankton collection. To keep comparisons as consistent as possible, only data from collections with an 80 µm mesh net were used. Pretreatment data were collected from a depth that was twice the Secchi depth to the surface. Since these depths were, on average, similar to the current depth strata, they were compared directly to the data collected from 2008 through 2011 taken from 10 m to the surface. Since data from 2007 were collected from 30 m to the surface, it was first adjusted by calculating the proportion of zooplankton collected in 2008 from 10 to 0 m to the total amount collected in the 10 to 0 m and 30 to 10 m tows (Wilson et al. 2010). The annual mean for this proportion was then applied to the 30 to 0 m data from 2007 to estimate the density of zooplankton from 10 to 0 m. A similar proportion was developed to adjust the estimated biomass of *Daphnia* spp. (hereafter referred to as *Daphnia*). These estimates were used when comparing 2007 data to other years.

The forage base for kokanee was evaluated by examining changes in the density and biomass of *Daphnia*, since these are the preferred forage of kokanee and represent the bulk of their diet in most months (Stark and Stockner 2006). The weights of individual *Daphnia* were calculated using the following formula (McCauley 1984):

$$lnw = lna + b \times lnL$$

Where:
- lnw = natural log of weight in µg
- lna = estimated intercept
- b = estimated slope
- lnL = natural log of length in mm

For these calculations, we used estimates from McCauley (1984) for *D. galeata* where:

lna = 2.64
b = 2.54

The minimum size of *Daphnia* available to kokanee as prey was determined by examining the gut contents from kokanee caught during trawl surveys or in angler creels. The number of *Daphnia* measured in a single tow that were equal to or larger than the smallest observed in gut samples was divided by the total measured from that sample to determine the proportion of the overall density that constituted kokanee forage. The mean weight of these *Daphnia* for a given tow was multiplied by the density for that tow to estimate the consumable biomass.

Due to inconsistencies in the data, we chose to make comparisons between years using a graphical analysis of means and confidence intervals rather than attempting more rigorous statistical tests (Johnson 1999). Annual means were weighted by month to account for differences in sampling intensity throughout the year. Likewise, means for the treatment and non-treatment periods were weighted by year to account for interannual differences in sampling intensity. For data that were not non-normally distributed, we used a bootstrap technique to derive 95% confidence intervals (Chernick 1999; Efron and Tibshirani 1994). For this, the original data were resampled with replacement using R 3.0.1. For each year, 1000 iterations were performed in which a bootstrap mean was calculated. Confidence intervals were derived using the percentile method, where the lower confidence limit was equal to the 2.5 percentile of the bootstrap distribution and the upper confidence interval was equal to the 97.5 percentile (Chernick 1999).

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 bucket 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 Population Monitoring

Abundance

As part of our sampling design, the reservoir was stratified into three sections (Figure 1). Section 1 extended from the dam to Dent Bridge at RKM 27.0, while Section 2 extended from Dent Bridge to Grandad Bridge at RKM 65.2. Section 3 encompassed the reservoir above Grandad Bridge.

A single hydroacoustic survey was conducted in July concurrent with a trawl survey. 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 sphere. 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 survey averaged 2.0 m/s. The echo sounder was set to ping at 0.6 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). Fish densities were calculated as:

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

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, length-at-age breaks from trawl caught fish were converted into target strengths using Love's (1971) equation. The proportion of age-0 fish in a particular transect was then determined based on these age breaks and the target strength distribution from that transect. Fish above this age break (age-1 and older) were partitioned based on the proportion of each age class captured in the trawl.

The mean densities were multiplied by the area of kokanee habitat in each section to arrive at an estimate of age-specific abundance for each section. This area was determined by first subtracting the mean depth for single targets in each section from the pool elevation at the time of the survey to determine the mean elevation of the kokanee layer. The reservoir area at this elevation was obtained from a table based on data provided by the USACE (Sam Martin, USACE, personal communication). This table was created using USGS topographic data from pre-impoundment surveys from which the area was calculated at 12.2 m increments between 426.7 and 487.7 m. The areas in the table were then estimated for each 0.3 m increment of elevation using a second order polynomial regression.

Over the course of the study period, calculations used to produce population estimates have been refined. In order to ensure that estimates were comparable between years, we revised earlier estimates so that all estimates used the same methods and reservoir area data to the extent possible.

Age and Growth

Trawl surveys were based on 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 with bar mesh sizes of 32, 25, 19, and 13 mm. The cod end was composed of 6 mm delta mesh held open by a 0.8 m steel hoop.

Three trawl surveys were conducted during most years and occurred in April, July, and October. A November survey was conducted in lieu of an October survey in 2010 due to mechanical difficulties with the trawler. All surveys were conducted within five 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 November trawling, 3-6 transects were conducted per section in Section 1 and 2. Trawling was not performed in Section 3 during spring or fall surveys due to low reservoir levels. Fish were measured to the nearest mm total length (TL) and a subsample was weighed to the nearest gram. When high numbers of fish were encountered (individual trawls with 100 or more fish), a random subsample of at least 20 fish from that size range were selected to be measured and weighed. Remaining fish were tallied by length bin. Scales were collected from 10 fish from every 1 cm length bin from each section for fish that were larger than 100 mm TL in July or 150 mm TL in April or October. Scales were later examined by two independent readers to determine age (Devries and Frie 1996).

The relative weight (W_r) was calculated for all fish above 119 mm TL. Standard weights (W_s) for kokanee of a given length 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 = ith individual observation
n = sample size

The timing of trawl surveys for previous years could potentially vary by up to a month, depending on the timing of the new moon in July. To account for differences in length due to annual differences in the timing of the trawl surveys, we fit length data for individual fish from each age class to the following von Bertalanffy growth model (Isely and Grabowski 2007) for each year in which multiple trawl surveys were performed (2004 and 2008 – 2011).

$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

Where: L_t = The predicted length at time t
t = The Julian date
t_0 = The theoretical date for L = 0
L_∞ = The theoretical maximum mean length
K = Brody growth rate coefficient

Typically, age-2 fish spawned during the fall of the year surveyed, resulting in only two data points (spring and summer). Therefore, we used age-1 fish to estimate K and assumed this value when fitting the model for age-2 fish. Data from the 2007 trawl were not used because individual length data were not available for the fall survey. Models were independently fit to data for each year and age class using JMP 9.0. The L_∞ for each model represents the theoretical maximum mean length that each age class should obtain that year. In order to make adjustments for all years, including those for which we did not have enough data to model, we calculated the mean ratio of L_∞/L_t for each age class for each day in July as a correction factor for that Julian date. The mean TL for trawl caught fish was then multiplied by the correction factor for the Julian date of the trawl survey in order to estimate L_∞ for a given year. This estimate of L_∞ was used to compare age-specific size between years taking the time of year that fish were sampled into account. In order to assess differences in fish size due to nutrient restoration, we compared mean size for years with similar abundance.

To determine the effects of nutrient restoration on kokanee growth, we performed length back-calculations from scales collected from age-1 and older fish in the July trawl surveys between 2003 and 2013. These scales were imaged using a microscope and digital camera. The distance from the focus to each annulus and the margin were measured using either FishBC 3.0.1 or ImageJ 1.46r software. Age-specific TL (mm) was estimated using the following formula (Carlander 1982):

$$TL_a = \left[\frac{(TL_C - 41)}{(D_M)} \times D_a\right] + 41$$

Where:
TL_a = Total length-at-age *a*
TL_C = Total length at capture
DM = The distance from the focus to the margin
Da = The distance from the focus to annulus *a*
41 = The mean TL at scale formation

Annual growth was calculated as:

$$G_a = TL_{a+1} - TL_a$$

Where: G_a = Growth for age *a*

Since most fish spawned as age-2, the length at capture was used as $TL_{(a+1)}$ for age-2 fish.

Growth in terms of length is influenced by a numbers of factors, including environmental conditions present in a specific year and the length (and therefore age) of a fish at that time. Furthermore, since growth is also likely a result of the genetic makeup of an individual fish, the repeated measures from an individual are not likely to be independent. Therefore, back-calculated annual growth was first fit to a mixed effects model in order to separate year effects from those of age and individual fish, (Weisberg et al. 2010).

$$G_{cka} = t_a + y_{c+a-1} + f_{ck} + e_{cka}$$

Where:
G_{cka} = The annual growth of fish *k*, of year class *c*, at age *a*.
t_a = The annual growth of a fish at age *a*.
y_{c+a-1} = The random annual growth effect.
f_{ck} = The random effect for fish *k*.
e_{cka} = Error term.

The year effects estimated from these models were used as the response variable in subsequent linear regression models to determine which measure of fish abundance, total abundance or age-1 and older, was a better predictor of the growth. Finally, year effects were fit to linear models to estimate the importance of factors such as abundance, food availability and nutrient addition on annual growth patterns (Quist and Spiegel 2012). Independent variables for these models included the best measure of abundance, the biomass of consumable *Daphnia*, and nutrient restoration. For this analysis, four candidate models were chosen *a priori* based on our knowledge of kokanee ecology. The best model was determined by the lowest AIC_c value and the relative plausibility of each model was assessed using both the differences in AIC_c (ΔAIC_c) and Akaike weights (w_i) (Burnham and Anderson 2002). Models with ΔAIC_c <2.0 or w_i ≥0.1 were considered to be relatively important.

A separate analysis was conducted by fitting mean age-specific annual growth to a suite of linear models (Isely and Grabowski 2007). As before, models were chosen *a priori* based on our knowledge of kokanee ecology. Predictor variables included the abundance of that age class corresponding to that growth estimate, the biomass of consumable *Daphnia*, whether or not nutrients were added, and interactions of interest.

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 years for which a July trawl survey was performed, 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

Eleven days prior to peak spawning, prespawn fish were collected from four index streams using a seine and dip nets. These included Isabella (RKM 92), Skull (RKM 105), Quartz (RKM 109), and Dog (tributary to Isabella at RKM 2.6) creeks. All fish were measured to the nearest mm TL and weighed to the nearest g. Sex was determined using secondary sexual characteristics or by expressing gametes. Females were euthanized, the ovaries removed and weighed to the nearest g, and preserved in 95% ethanol. Secondary oocytes were later enumerated for each ovary. Mean oocyte weight was calculated by dividing the number of oocytes by the total weight of the ovary (somatic tissue was considered inconsequential). The gonadal somatic index (*GSI*) was calculated for females using the following formula:

$$GSI = \frac{GW}{BW - GW} \times 100$$

Where: *GW* = gonad weight
BW = body weight

Peak spawner counts were conducted on all four index streams on the lower North Fork Clearwater River above the reservoir on September 24-25. Each of the index streams were walked from the mouth to the uppermost extent of kokanee spawning activity. 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 2013, inflow to Dworshak Reservoir averaged 125 m^3/s, compared to the 10-year (2003 – 2012) mean of 155 m^3/s (Figure 2). Inflow peaked on April 13, 2013 at 778 m^3/s and a minimum inflow of 5.7 m^3/s was observed on August 22, 2013. Mean discharge through Dworshak Dam was 137 m^3/s, compared to the 10-year mean of 154 m^3/s. The peak discharge of 368 m^3/s occurred on July 3, 2013 and a minimum discharge of 44.7 m^3/s occurred on December 31, 2013. Pool elevations were higher than normal during the spring of 2013 and full pool was achieved approximately three weeks earlier than normal (Figure 2).

Physical and Chemical Limnology

Temperature

The mean water temperature for the multiyear sampling frame at 1 m was 19.3°C for 2013. The mean for 2004-2012 was 17.8°C. The reservoir was completely stratified by May 21, 2013 and remained stratified through September 9, after which time a thermocline was only consistently present at RK-2. The mean time of thermal stratification was 164 days, which was longer than all but two of the last nine years (range = 110-167 days).

Dissolved Oxygen

DO concentrations remained near saturation for most of the season. However, DO levels below 5 ppm were observed at all stations except RK-2. Most of these were observed during September and at EC-6 and RK-56. Measurements below 5 ppm occurred at a mean depth of 27 m and tended to be observed near the thermocline. Additional summaries of DO for this study can be found in Brandt (2014).

Water Clarity

The median Secchi depth for the entire reservoir was 3.7 m, whereas the median for the treated area of the reservoir was 3.8 m. Secchi depths were compared between years using a modified multiyear sampling frame (June – November). Mean Secchi depth for this period was 4.5 m for 2013 (Figure 3) compared with 4.1 m for 2004-2012 and 4.2 m for non-restoration years (2004-2006 and 2011). Additional summaries of Secchi depths for 2013 can be found in Brandt (2014).

The mean compensation depth for the entire reservoir was 11.1 m. The mean for the modified multiyear sampling frame (June – November) was 10.9 m, which was the highest in recent years (range = 9.6 to 10.7 m). Historical summaries of water clarity can be found in Appendix A.

Phosphorus

The median value for TP in 2013 was 0.007 mg/L for the epilimnion, 0.003 mg/L for the hypolimnion and 0.004 mg/L for the river. Mean values for TP were compared between years by first adjusting the MDL to 0.010 mg/L. Mean epilimnetic TP for the multiyear sample frame in 2013 was 0.010 mg/L, compared to the long-term mean of 0.014 mg/L for 2004-2012.

The median value for TDP in 2013 was 0.002 mg/L for the epilimnion, 0.001 mg/L for the hypolimnion, and 0.003 mg/L for the river. No adjustments were made when comparing mean values for TDP. Mean epilimnetic TDP for the multiyear sample frame in 2013 was 0.003 mg/L, compared to the long-term mean of 0.005 mg/L for 2005-2012. Additional summaries of phosphorus data for this study can be found in Brandt (2014).

Nitrogen

The median value for TN during 2013 was 0.015 mg/L for the epilimnion, 0.010 mg/L for the hypolimnion and 0.060 mg/L for the river. No adjustments were made when comparing mean values for TN. Mean epilimnetic TN for the multiyear sample frame in 2013 was 0.044 mg/L, compared to 0.109 mg/L for 2011.

Concentrations of TA were typically undetectable in 2013. Therefore, the median value (median = 0.005 mg/L) was the same for the epilimnion, hypolimnion, and river. No adjustments were made when comparing mean values for TA. Mean epilimnetic TA for the multiyear sample frame in 2013 was 0.006 mg/L, compared to 0.019 mg/L for 2011.

The median value for N+N during 2013 was 0.001 mg/L for the epilimnion, 0.005 mg/L for the hypolimnion and 0.048 mg/L for the river. Mean values for TP were compared between years by first adjusting the MDL to 0.010 mg/L. Mean epilimnetic N+N for the multiyear sample frame in 2013 was 0.012 mg/L, which was lower than the long-term mean of 0.015 mg/L for 2004-2011. Additional summaries of nitrogen for this study can be found in Brandt (2014).

Total Dissolved Solids

The median value for TDS during 2013 was 18 mg/L for the epilimnion and 16 mg/L for the river. The median for EPI during the multiyear sampling frame in 2013 (median = 18.0 mg/L) was the second lowest in recent history (range = 16.0 – 31.0) mg/L). Additional summaries of TDS for this study can be found in Brandt (2014).

Dissolved Organic Carbon

The mean value for DOC in the epilimnion during 2013 was 3.4 mg/L. We used a modified multiyear sampling frame (RK-31 only, March – September), for which the mean for 2013 was 4.1 mg/L, which is higher than the long-term mean for 2007-2012 (mean = 2.8 mg/L).

Biological Indicators

Primary Production Rates

In 2013, primary production rates averaged 381 mgC/m^2/day. Mean C uptake at RK-31 in 2013 was equal to 2011 for the month of June, but higher in every other month for which rates were measured (Figure 4). Primary production peaked in August at 695 mgC/m^2/day during

2013. In contrast, productivity at RK-31 peaked in July at 195 $mgC/m^2/day$ and dropped to 91 $mgC/m^2/day$ in August during 2011. Additional summaries and analysis of primary production rates can be found in Brandt (2014).

Chlorophyll *a*

The median value for Chl *a* in the epilimnion was 1.07 µg/L for treated areas of the reservoir and 1.29 µg/L for untreated areas. Chl *a* was compared between years using the multiyear sampling frame. The mean for this period in 2013 was 1.21 µg/L, compared to the long term-mean of 2.17 µg/L for 2004-2012. Additional summaries of Chl *a* data can be found in Brandt (2014).

Picoplankton

The mean density of heterotrophic bacteria in 2013 was 864,000 cells/ml. Densities of picoplankton were compared between years using a modified multiyear sampling frame (May – October). The mean density of heterotrophic bacteria for this period during 2013 was 859,000 cells/mL, compared to the long-term mean of 971,000 cells/mL for 2006-2012.

The mean density of picocyanobacteria in 2013 was 90,000 cells/ml. The mean density of picocyanobacteria for the multiyear sampling frame during 2013 was 116,000 cells/mL, compared to the long-term mean of 123,000 cells/mL for 2006-2012. Additional summaries of picoplankton data can be found in Brandt (2014).

Phytoplankton

The mean biovolume of total phytoplankton was 0.262 mm^3/L for 2013. The mean biovolume for the multiyear sampling frame was 0.279 mm^3/L for 2013, as compared to the long-term mean of 0.449 mm^3/L for 2005-2012 (Figure 5). The mean biovolume of total phytoplankton was similar for the restoration (mean = 0.429 mm^3/L) and non- restoration (mean = 0.441 mm^3/L) periods.

The phytoplankton community was composed of five major taxa in 2013. The dominant taxa in 2013 were blue-greens, which represented 28% of the total annual biovolume. The next most common taxa were diatoms and flagellates, which each represented 25% of the biovolume. Coccoid greens (14%) and Dinoflagellates (8%) were less common.

The mean biovolume of edible phytoplankton was 0.129 mm^3/L for 2013. The mean biovolume for the multiyear sampling frame was 0.126 mm^3/L for 2013, as compared to the long-term mean of 0.246 mm^3/L for 2005-2012. The mean biovolume of edible phytoplankton was higher for the restoration period (mean = 0.254 mm^3/L) than the non-restoration period (mean = 0.190 mm^3/L).

The proportion of the phytoplankton community that is known to be edible was 44% for treated areas of the reservoir in 2013. The mean proportion of edible phytoplankton for the multiyear sampling frame for 2013 was 44% (Figure 5), which represents a 12% increase compared to the mean for non-restoration years (40%; 2005-2006, 2011). The increase was positive in 875 bootstrap iterations.

The mean biovolume of *Anabaena sp.* for the multiyear sampling frame in 2013 was 0.006 mm^3/L, which was lower than the mean of non-restoration years (mean = 0.107 mm^3/L).

The proportion of the total phytoplankton biovolume that was composed of *Anabaena sp.* for the multiyear sampling frame in 2013 (2%) was 89% lower than the mean of non-restoration years (21%). For 95% of the bootstrap iterations, this decrease was at least 76%. Additional summaries of phytoplankton data can be found in Brandt (2014).

Zooplankton

The mean density of all zooplankters was 30.1 individuals/L for the entire reservoir in 2013 (Figure 6). The mean density for the modified multiyear sampling frame (April – November) was 27.3 individuals/L, compared to a mean of 18.9 for non-restoration years (2005-2006, 2011). Cladocerans accounted for 42% of all zooplankton collected in 2013. This proportion was 43% for the multiyear sampling frame, compared to the long-term mean of 37% for non-restoration years.

The mean density of *Daphnia* for the modified multiyear sampling frame was 6.2 individuals/L in 2013 (Figure 6). This represents an increase of 123% compared to the mean for non-restoration years (mean = 2.8 individuals/L). For 95% of the bootstrap iterations, this increase was at least 77%.

The mean biomass of consumable *Daphnia* (TL ≥0.80 mm) for the modified multiyear sampling frame was 121 µg /L in 2013 (Figure 6). This represents an increase of 159% compared to the mean for non-restoration years (mean = 47 µg/L). For 95% of the bootstrap iterations, this increase was at least 83%.

In 2013, the mean length of *Daphnia* was 1.07 mm for both the entire reservoir the multiyear sampling frame. In comparison, the mean for non-restoration years was 0.97 mm. The mean length of *Bosmina* spp. was 0.42 mm for both the entire reservoir and the multiyear sampling frame, compared to 0.36 mm for non-restoration years. Additional summaries of zooplankton data can be found in Brandt (2014).

Kokanee Population Monitoring

Abundance and Density

From the hydroacoustic survey conducted on July 16-19, we estimated an overall abundance of 4,670,000 kokanee in Dworshak Reservoir (Table 1). Of these, 3,975,000 were age-0, 553,000 were age-1, and 143,000 were age-2. These estimates were based on an overall density of 936 fish/ha (Table 1). When broken out by age, the densities were 797 fish/ha for age-0, 111 fish/ha for age-1, and 29 fish/ha for age-2. Of the fish that were captured in the July trawl, 2.4% of the age-1 and 84.6% of the age-2 were beginning to mature sexually. Therefore, we estimate 134,000 mature fish in the reservoir during the month of July.

Overall abundance (2,058,000) was highest in Section 2, while density (1,861 fish/ha) was highest in Section 3 (Table 1). Overall abundance (1,119,000) was lowest in Section 3 and density (536 fish/ha) was lowest in Section 1. Abundance of age-0 (1,838,000) fish was highest in Section 2; age-1 fish (327,000) and age-2 fish (56,000) were most abundant in Section 1. Density of age-0 and age-2 were highest in Section 3, while density of age-1 was highest in Section 1. Revised abundance and density estimates for kokanee are presented in Appendix B.

Size at Age

Midwater trawls conducted on April 10-11, July 9-11, and October 9-10 sampled a total of 2,531 kokanee. Of these, 113 were captured during April trawling, 1169 in July, and 1249 in October. In April, trawl-caught kokanee ranged from 77 to 274 mm total length (Figure 7). Only age-1 and age-2 fish were sampled in April; no age-0 kokanee were encountered. A total of 83 age-1 kokanee were captured in April, ranging from 77 to 155 mm total length (TL) with a mean of 117 mm (Table 2). A total of 30 age-2 kokanee were captured, ranging in size from 220 to 274 mm TL. Age-2 kokanee had a mean TL of 247 mm and a mean W_r of 86.

In July, trawl caught kokanee ranged from 33 to 316 mm TL (Figure 7). Of the 1,058 age-0 that were captured, we subsampled 240. The TL for age-0 was between 33 and 66 mm, with a mean TL of 48 mm (Table 2). Through scale analysis and length distributions, 85 kokanee were determined to be age-1, ranging in size from 160 to 240 mm TL. The mean TL of age-1 kokanee was 201 mm and the mean W_r was 87. Another 26 kokanee were determined to be age-2, ranging in size from 270 to 316 mm TL. Age-2 kokanee had a mean TL of 296 mm and a mean W_r of 89. No age-3 kokanee were encountered in 2013.

In October, trawl-caught kokanee were between 51 and 270 mm TL (Figure 7). Of the 1,194 age-0 fish that were captured, 175 were subsampled. The TL for age-0 fish was between 51 and 113 mm (Table 2). Age-0 kokanee had a mean TL of 84 mm. Another 54 kokanee were determined to be age-1, ranging in size from 166 to 254 mm TL. Age-1 kokanee had a mean TL of 222 mm and a mean W_r of 96. A single kokanee captured in October was determined to be age-2, and measured 270 mm TL with a W_r of 93.

The mean TL of age-0 kokanee increased by 36 mm from July to October (Table 2). The mean TL of age-1 kokanee increased by 83 mm from April to July and by 22 mm from July to November, for a total of 105 mm. The mean TL of age-2 kokanee increased by 50 mm from April to July. Growth of age-2 fish, in terms of increases in mean TL, was higher in 2013 than for all but two years (2008 and 2012), both of which were restoration years. Growth of age-1 fish was similar to both the long-term mean (mean = 104 mm) and both non-restoration years for which data exists.

The mean TL of age 1 fish in July, corrected for the timing of the survey within the month, was 241 mm. When fit to a von Bertalanffy growth model, the L_∞ for age 1 fish was 230 mm. The mean TL of age 2 fish in July, corrected for the timing of the survey within the month, was 314 mm. When fit to a von Bertalanffy growth model, the L_∞ for age 2 fish was 314 mm. Estimates of L_∞ can be found in Table 3.

Growth Comparisons

The abundance of age-1 and older fish in 2013 (696,000) was similar to that of 2003 (638,000). The mean TL of age-2 fish was 34 mm longer in 2013 than 2003 and the mean weight was 83 g more (Table 3). The mean TL and weight of age 1 fish were similar for both years.

Mean age-specific annual growth increments, as calculated from back-calculated length-at-age, were similar to those calculated from mean age-specific length of trawl caught fish for years in which both estimates were available. Based on back-calculated lengths, the mean growth was higher for restoration years than for non-restoration years (Table 4). The mean growth advantage during the restoration period was summed over all age classes, resulting in an age-2 kokanee that is on average 26 mm TL longer in July.

Back-calculated growth was further analyzed using a combination of a mixed effects linear model to estimate annual effects, and fixed effects linear models to evaluate influence of other factors on the annual growth effect. Annual growth effects estimated from the mixed effects model (R^2 = 0.601) are shown in Table 5. The best measure of abundance for predicting annual growth effects was total abundance (r^2 = 0.127, Δ AIC_c = 0; Table 6). Although the model using the abundance of age-1 and older fish was plausible by comparison (r^2 = 0.062, Δ AIC_c = 0.94), the former was used in subsequent modeling. Year effects, as estimated from the mixed effects model, were negatively correlated with kokanee abundance, positively correlated with consumable *Daphnia* biomass, and higher for restoration years (Figure 8). Of the linear models we considered, the model using consumable *Daphnia* biomass as an explanatory variable was not only the best fitting model (r^2 = 0.513, Δ AIC_c = 0), but also the only plausible model by comparison (Table 6).

Using a different approach, we also modeled the effects of abundance, food availability, and nutrient addition on the mean age-specific annual growth, as estimated via back-calculation. For age-1 and older kokanee, the relationships between mean age-specific growth and abundance or consumable *Daphnia* biomass were similar to those observed for the annual growth effects. However, these relationships were very weak for age-0 fish (Figure 9). Of the eight a *priori* models we tested, two emerged as plausible (Table 7). Both of these included consumable *Daphnia* biomass as a predictor, while the most parsimonious model included an age by *Daphnia* interaction (r^2 = 0.918, Δ AIC_c = 0, Table 7).

Biomass and Production

Kokanee production from July of 2012 to July of 2013 was estimated at 87.4 metric tonnes (t). During this period, biomass was estimated to have increased from 58.3 t in 2012 to 78.7 t in 2013. The biomass of mature fish in the reservoir was estimated to be 31.3 t during July. Mortality by weight was estimated to be 42.8 t. Historical production estimates can be found in Appendix C.

Spawner Counts

On September 11, we collected 65 adult kokanee: 46 from Isabella Creek and 19 from Skull Creek. Of these, 37 were male and 28 female. Of the females we sampled, seven were partially or completely spawned. Male kokanee exhibited a bimodal length distribution that ranged from 245 mm to 370 mm, with a mean of 317 mm TL. Female kokanee exhibited a unimodal length distribution that ranged from 285 mm to 344 mm, with a mean of 309 mm TL.

Ovaries were obtained from 20 pre-ovulatory females, with a mean fecundity of 644 oocytes per female. Fecundity was positively and significantly related to TL (linear regression, $p = 0.008$, $r^2 = 0.33$).

Peak kokanee spawner counts were performed on September 24-25, during which 12,209 spawning kokanee were counted in four index streams. This included 7,535 in Isabella Creek, 3,507 in Skull Creek, 758 in Quartz Creek, and 409 in Dog Creek. Historical spawner count data are shown in Appendix D.

DISCUSSION

Water Quality

While the goal of the nutrient restoration project is to restore lost productivity to the reservoir, it is imperative to do so without degrading overall water quality. Three metrics are specified in the NPDES permit as indicators of how the project the affects water quality: median Secchi depth, median Chl *a* concentration, and median TP concentration.

The median Secchi depth for the treated portion of the reservoir (Median = 4.2 m) was well above the 3.0 m minimum stipulated by the NPDES permit. In earlier reports, the data suggested a decrease in mean Secchi depth due to nutrient restoration (Wilson et al. 2013). However, the mean Secchi depth for 2012 and 2013 were among the highest in recent years. With these additional years of data, there is no longer any support that nutrient restoration is reducing water clarity.

The median Chl *a* concentration for the treated portion of the reservoir (Median = 1.07 µg/L) was well below the 3.0 µg/L maximum stipulated by the NPDES permit. The mean Chl *a* concentration for 2013 was the lowest in recent history. Furthermore, our data does not indicate an increase in Chl *a* in response to nutrient restoration.

The median TP concentration for the treated portion of the reservoir (Median = 0.007 mg/L) was well below the 0.025 mg/L maximum stipulated by the NPDES permit. Since the project does not involve adding P to the reservoir, we do not anticipate an increase in TP except due to variations in natural input.

Another water quality concern is the prevalence of toxigenic cyanobacteria (blue-green algae). Historically, *Anabaena sp.* has been the dominant taxa of toxigenic cyanobacteria. *Anabaena sp.* typically becomes dominant in late summer after available N becomes exhausted. *Anabaena sp*. are known to fix N and believed to have a competitive advantage when fixed N is no longer available (Darren Brandt, Advanced Eco-Solutions, personal communication). Therefore, it was anticipated that N restoration would reduce the prevalence of *Anabaena sp*. (Stockner and Brandt 2006). In 2013, *Anabaena sp*. accounted for only 2% of the total annual biovolume of phytoplankton, which is a substantial reduction from the proportions observed in non-restoration years (mean = 21%, range = 11-27%). In 2013, no visible concentrations of *Anabaena sp*. were observed while conducting routine sampling. No other toxigenic taxa, including *Microcystis sp.*, were detected at high enough densities to cause public health concerns in 2013. Our data does not indicate an increased prevalence of toxigenic cyanobacteria as a result of N additions, and in the case of *Anabaena sp*., the project is likely resulting in a decreased prevalence.

Reservoir Productivity

Chl *a* is often used as an indicator of productivity in lakes and reservoirs. Mean Chl *a* has not increased in response to nutrient restoration, suggesting that productivity has not increased. However, the relationship between Chl *a* and phytoplankton biovolume is dependent on many variables, including species composition. Furthermore, if the composition of the phytoplankton community has shifted to more edible species, those species may be grazed off by zooplankton at a higher rate, thus masking the increase in productivity (Scofield et al. 2010). Since the overall goal of this project is to increase the amount of carbon (C) that is passed up to higher trophic levels (i.e., fish), rather than the accumulation of C at lower levels (i.e., algae), an increase in Chl *a* should not be viewed as a prerequisite for success.

Picoplankton are generally the first taxa to respond to nutrient additions because they are capable of rapid uptake of nutrients and near exponential growth (Stockner and Antia 1986). Densities of heterotrophic bacteria and picocyanobacteria were both many times higher than 2006, the only year prior to nutrient restoration for which we have data. However, picoplankton densities did not drop off substantially in 2011, the year that nutrient restoration was suspended. If densities for 2006 and 2011 are averaged to produce a non-restoration mean, then the increases for 2013 are more modest (50% for heterotrophic bacteria and 29% for picocyanobacteria). In either case, increases in picoplankton represent a positive response at the lowest trophic level. Picoplankton comprise the food base for nanoflagellates (Jurgens and DeMott 1995), which in turn are a high energy food source for zooplankton (Sanders and Porter 1990).

For 2013, the mean biovolume of total phytoplankton for the multiyear sampling frame was below average. The means for restoration and non-restoration years are very similar, indicating no increase in standing crop due to nutrient restoration. The mean biovolume of edible phytoplankton in 2013 was also below average. However, the percentage of the phytoplankton community that was edible in 2013 was higher than all non-restoration years. This suggests that the greatest effect of nutrient restoration on the phytoplankton community is a shift in the community structure.

It can be misleading to elucidate changes in productivity when looking at standing crop alone. Standing crop is affected both by bottom up factors, such as nutrients, and top down factors (i.e. grazing). Estimates of primary production rates are more informative for determining the effects of nutrient restoration on primary productivity. Primary production rates were higher on average in 2013 than in 2011, a year when N was not added to the reservoir. The difference in production rates were highest in August and September, when rates were observed to drop off in 2011. These results suggest that the addition of N is resulting in increased primary productivity within the system.

The mean density of zooplankters in 2013 was among the highest in recent times and was higher than any non-restoration year. Of greater interest, the mean density of consumable *Daphnia* (≥0.80 m TL), was the second highest in recent history. This represents a 142% increase over the mean for non-restoration years. Moreover, the mean length of *Daphnia* was longer in 2013 than in any non-restoration year. Together, these factors led to a mean biomass that was the second largest in recent years and 159% higher than the mean for non-restoration years. These observations all support the hypothesis that nutrient restoration is leading to greater prey availability for kokanee.

Kokanee Population Monitoring

Improved kokanee growth is a key indicator of whether or not nutrient restoration is having desirable effects. Since kokanee often exhibit density-dependent growth (Rieman and Myers 1992), it is important to consider densities when evaluating growth. To account for the effects of density on fish growth, we compared mean sizes for 2013 with a non-restoration year of similar abundance. Abundance was used instead of density because density changes with available habitat. The current regime of summer reservoir drawdowns leads to rapid changes in available habitat and therefore fish density. Thus, fish density can be affected by the timing of the survey more so than abundance. Furthermore, we only considered the abundance of age-1 and older fish, as age-0 fish represent a small proportion of the overall biomass and abundance estimates for age-0 fish are less certain.

In 2003, the estimated abundance of kokanee was very similar to that for 2013. While age-2 kokanee were on average both longer and heavier in 2013, age-1 kokanee were similar in length but tended to be heavier for a given length. These results are similar to comparisons involving other years of similar abundance, in which fish have been longer and heavier in restoration years. However, the growth of age-2 kokanee, as estimated by back-calculation, was similar for 2013 and 2003, suggesting that the size difference in age-2 fish was primarily due to growth differences of these cohorts as age-1 fish.

The results from modeling back-calculated growth provide the best support that nutrient restoration is resulting in improved growth rates for kokanee. The negative correlation between growth and fish abundance for age-1 and older fish is evidence of density dependent growth due to food limitation for these age classes. Since the data do not support density-dependent growth for age-0 fish, as evidenced by a lack of such correlations, increasing growth for this age class through food web manipulations appears unlikely. However, growth in terms of length is not the only beneficial outcome of an improved food source. For example, increasing food availability may result in increased fat stores instead of length, which could in turn lead to improved survival. Future analysis should be directed toward the effects of nutrient restoration on body weight and survival.

If growth is limited by food, increasing the food supply should increase growth. While nutrient addition was not the best predictor of growth in either analysis, food availability, in terms of the biomass of consumable *Daphnia*, consistently emerged as a top predictor of growth. However, the addition of nutrients is only one factor in determining zooplankton production. Since many factors, including spring inflows, water temperature and solar radiation, determine how much food will be available in a given year, we should not expect annual *Daphnia* production to be driven solely by the amount of N added to the reservoir. Thus, it should not be surprising that the amount of food available is a better predictor of growth than the action taken to increase its availability. Therefore, the increased availability of *Daphnia*, coupled with the relationship between *Daphnia* availability and growth, is evidence that nutrient restoration is resulting in improved kokanee growth.

Another way to assess benefits to the kokanee population is to monitor production. The growth of an individual fish is related to the quantity and quality of forage, as well as the number of fish competing for the available forage. Production, on the other hand, is a measure of how the biomass of the population increased over time, irrespective of the fates of individual fish. Our methodology provides an estimate of production from July of the first year to July of the second year. Unfortunately, we only have one production estimate for this time period from non-restoration years. While we do not know if this estimate is typical for the non-restoration period, all estimates for the restoration period were higher, including the 2012-2013 estimate, which was 70% higher.

The responses observed following the initial years of nutrient restoration, combined with decades of observations from British Columbia lakes, suggest that continued nutrient restoration in Dworshak Reservoir will result in improved growth rates for kokanee. The improved growth rates will likely translate into larger kokanee at a given density, which will result in increased biomass of kokanee in the reservoir. Additionally, the abundance and biomass of kokanee spawning in the tributaries above the reservoir should increase and will likely lead to increased recruitment and subsequently higher densities of kokanee in the reservoir. As a result, kokanee size is expected to be similar to pre-restoration size over the long term, but at higher densities. Higher densities of kokanee in the reservoir of a similar size to pre-restoration should result in higher catch rates and greater angler satisfaction. Furthermore, higher kokanee densities are expected to provide more forage for piscivorous fish, including Bull Trout and Smallmouth Bass.

CONCLUSIONS

Nutrient restoration in Dworshak Reservoir showed signs of success and similar responses to those observed in several British Columbia lakes and reservoirs following nutrient addition. Water clarity appeared to decrease slightly during nutrient restoration, but not below the range observed prior to restoration, or to the point where it was detrimental to recreational uses. The effects of nutrient restoration were observed at all trophic levels. We observed increases in picoplankton, which represent the lowest trophic level, beginning with the first year of nutrient additions. Observed increases in the proportion of edible phytoplankton have resulted in increased zooplankton density and biomass. The increased zooplankton availability was likely responsible for increased kokanee length and weight at a given density. If sustained, the responses observed are expected to provide improved recreational fishing in the reservoir. Furthermore, the increased abundance and biomass of spawning kokanee in the North Fork Clearwater subbasin should benefit resident fish and wildlife beyond the reservoir itself. While it will take additional years of data to confirm that the observed effects are in fact due to restoration and not natural variation, nutrient restoration appears to have had a beneficial effect on the ecology of the reservoir and should be continued.

RECOMMENDATIONS

1. Continue the additional five-year pilot phase to confirm that observed benefits are a result of N restoration and further assess the benefits to the kokanee population and resultant fishery.

2. Conduct creel surveys to monitor changes to the fishery and assess the effects of nutrient restoration on the performance of the fishery.

ACKNOWLEDGMENTS

The Dworshak Reservoir Nutrient Restoration Project is a cooperative effort involving many people and several organizations. Darren Brandt of Advanced Eco-Solutions was responsible for the fertilizer prescriptions and limnological assessments, while Paul Pence and John Beck, with the U.S. Army Corps of Engineers, made sure that fertilizer was applied properly. John Bailey, Ann Setter, and Steve Juul, also with the USACE, all played important roles in this project. Emily Zimmermann was instrumental in accomplishing fieldwork, maintaining databases and conducting data analysis for the project. Bill Ament and Bill Harryman assisted with trawl and acoustic surveys. We also thank the anonymous IDFG personnel from Region 2 who assisted with fieldwork. Matt Corsi and Carson Watkins provided comments that improved the quality of this report. This project was funded by the Bonneville Power Administration and we thank Jan Brady 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.

Brandt, D. H. 2014. Dworshak Reservoir nutrient enhancement project: 2013 progress report and data summary. Advanced Eco-Solutions Inc., Newman Lake, Washington.

Burnham, K. P. and D. R. Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach, 2nd edition. Springer-Verlag, New York.

Carlander, K. D. 1982. Standard intercepts for calculating lengths from scale measurements for some Centrarchid and Percid fishes. Transactions of the American Fisheries Society 111: 332-336.

Chernick, M. R. 1999. Bootstrap methods: a practitioner's guide. Wiley, New York.

Devries, D. R., and R. V. Frie. 1996. Determination of age and growth. Pages 483-512 in B. R. Murphy, and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Efron, B., and R. Tibshirani. 1994. An introduction to the bootstrap. Chapman & Hall, New York.

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.

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.

Isely, J. J., and T. B. Grabowski. 2007. Age and growth. Pages 187-228 *in* C. S. Guy, and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Johnson, D. H. 1999. The insignificance of statistical significance testing. The Journal of Wildlife Management 63(3): 763-772.

Jurgens, K. and W. R. DeMott. 1995. Behavioral flexibility in prey selection by bacterivorous nanoflagellates. Limnology and Oceanography 40: 1503-1507.

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, Report number 97-14, Boise.

Maiolie, M., and S. Elam. 1996. 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, Report number 96-21, 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, Report number 96-21, Boise.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. Pages 228-265 in J. A. Downing and F. H. Rigler, editors. A manual on methods for the assessment of secondary productivity in fresh waters. Blackwell Scientific Publications, Oxford, England.

Quist, M. C. and J. R. Spiegel. 2012. Population demographics of catostomids in large river ecosystems: effects of discharge and temperature on recruitment dynamics and growth. River Research and Applications 28: 1567-1586.

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

Rieman, B. E., and M. A. Maiolie. 1995. Kokanee population density and resulting fisheries. North American Journal of Fisheries Management 15:229-237.

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.

Rieman, B. E., and D. L. Myers. 1992. Influence of fish density and relative productivity on growth of kokanee in ten oligotrophic lakes and reservoirs in Idaho. Transactions of the American Fisheries Society 121(2): 178-191.

Sanders, R. W. and K. G. Porter. 1990. Bacterivorous flagellates as food resources for the freshwater crustacean zooplankter *Daphnia ambigua*. Limnology and Oceanography 35: 188-191.

Scofield, B., D. H. Brandt, and J. G. Stockner. 2010. Dworshak Reservoir nutrient enhancement project: 2009 progress report and data summary. TG Eco-Logic, LLC, Spokane, Washington.

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

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

Stockner, J. G., and N. J. Antia. 1986. Algal picoplankton from marine and freshwater ecosystems: a multidisciplinary perspective. Canadian Journal of Fisheries and Aquatic Science 43: 2472-2503.

Stockner, J. G., and D. H. Brandt. 2006. Dworshak Reservoir: Rationale for Nutrient Supplementation for Fisheries Enhancement. Eco-Logic Ltd. and TerraGraphics Environmental Engineering.

Weisberg, S., G. Spangler and L. S. Richmond. 2010. Mixed effects models for fish growth. Canadian Journal of Fisheries and Aquatic Sciences 67: 269-277.

Wilson, S. M., A. M. Dux, and R. J. Downing. 2013. Dworshak Reservoir nutrient enhancement research, 2007-2011. Dworshak Dam resident fish mitigation project. Idaho Department of Fish and Game, 13-02, Boise.

Wilson, S. M., A. M. Dux, R. J. Downing, and B. Scofield. 2010. Dworshak Reservoir nutrient enhancement research, 2008. Dworshak Dam resident fish mitigation project. Idaho Department of Fish and Game, 10-05, Boise.

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

Table 1. Abundance (thousands of fish) and density (fish per ha) of kokanee in Dworshak Reservoir in July 2013. Estimates were derived from a hydroacoustic survey and age breakdowns were derived from a fixed-frame trawl survey. Estimates are broken down by age class and reservoir section.

Abundance (thousands of fish)						
Section	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**All Ages**	
Section 1	1,110	327	56	0	1,493	
Section 2	1,838	173	48	0	2,058	
Section 3	1,026	54	39	0	1,119	
Whole reservoir	3,975	553	143	0	4,670	
Density (fish per ha)						
Section	**Area (ha)**	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**All Ages**
Section 1	2784	399	117	20	0	536
Section 2	1604	1,146	108	30	0	1,283
Section 3	601	1,706	89	66	0	1,861
Whole reservoir	4990	797	111	29	0	936

Table 2. Descriptive statistics for total lengths of kokanee captured during midwater trawl surveys on Dworshak Reservoir on April 10-11, July 9-11, and October 9-10, 2013. Growth is given as the increase in mean length (mm) observed in each age class between surveys. Variance is expressed using standard deviation (SD).

		Total Length (mm)					Growth
Month	**Age**	**N**	**Min**	**Mean**	**Max**	**SD**	**(mm)**
Apr	1	83	77	117	155	17	
	2	30	220	247	274	14	
Jul	0	240	33	48	66	6	
	1	85	160	201	240	17	83
	2	26	270	296	316	13	50
Nov	0	175	51	84	113	13	36
	1	54	166	222	254	18	22
	2	1	270	270	270		

Table 3. Length statistics for two age classes of kokanee from Dworshak Reservoir from four years without nutrient additions (2003, 2004, 2006, and 2011) and six years with nutrient additions (2007 – 2010, 2012-2013, shaded rows). Statistics include the mean total length (TL), the L_∞ estimated from von Bertalanffy growth models fitted independently to each age class for each year that surveys were performed at multiple times throughout the season, a correction factor (CF) developed by taking the mean proportion of L_∞/L_t for each day in July, an estimate of L_∞ obtained by multiplying the CF for the trawl date by the mean TL, and the mean TL of spawning kokanee (age-2) or age-1 kokanee captured in the fall.

Length statistics for age-2 kokanee						
Trawl date	**Year**	**Mean TL (mm)**	**L_∞ from model**	**CF**	**L_∞ from CF**	**Mean TL (spawners)**
30-Jul	2003	262		1.05	275	278
13-Jul	2004	295	317	1.06	313	308
24-Jul	2006	196		1.05	206	210
13-Jul	2007	241		1.06	255	264
31-Jul	2008	303	328	1.05	318	306
20-Jul	2009	272	284	1.05	286	286
14-Jul	2010	219	227	1.06	232	249
26-Jul	2011	220	224	1.05	231	250
25-Jul	2012	308	344	1.05	323	321
9-Jul	2013	296	314	1.06	314	316
Length statistics for age-1 kokanee						
Trawl date	**Year**	**Mean TL (mm)**	**L_∞ from model**	**CF**	**L_∞ from CF**	**Mean TL October**
30-Jul	2003	204		1.14	233	
13-Jul	2004	203	235	1.19	242	231
24-Jul	2006	145		1.16	168	
13-Jul	2007	198		1.19	236	
31-Jul	2008	209	252	1.14	238	235
20-Jul	2009	169	200	1.17	198	190
14-Jul	2010	172	193	1.18	203	189[a]
26-Jul	2011	170	235	1.15	196	213
25-Jul	2012	206	255	1.15	237	235
9-Jul	2013	201	230	1.20	241	222

The trawl survey for the fall of 2010 was conducted in November rather than October due to mechanical difficulties with the trawler.

Table 4. Annual growth, given as the change in total length (mm) from April of one year to the next for age-0 and age-1 kokanee. Growth of age-2 kokanee is from April to July of the same year. Growth was independently estimated from back-calculation using scales and as the differences in mean length of trawl caught fish at the beginning of each year. Mean growth is reported for each year that data is available, and means are reported for periods of nutrient restoration (Rest, shaded rows) or no nutrient additions (Non).

		Back-calculation			**Trawl**		
Year		**0**	**1**	**2**	**0**	**1**	**2**
2001	Non	101					
2002	Non	112	118				
2003	Non	96	136	40			
2004	Non	113		48			
2005	Non	98	71				
2006	Non	120	91	14	113		
2007	Rest	118	132	49	110	133	46
2008	Rest	109	135	46	107	138	57
2009	Rest	119	89	22	117	91	25
2010	Rest	113	82	28	105	83	21
2011	Non	113	130	17	114	128	20
2012	Rest	113	140	67	117	132	75
2013	Rest			39			50
	Means	110	112	37	112	117	42

Summary statistics for years with trawl data

	Back-calculation			**Trawl**		
	0	1	2	0	1	2
Non	117	130	17	113	128	20
Rest	114	116	42	111	115	46

Summary statistics for all years with back-calculation data

	0	1	2
Non	108	109	30
Rest	114	116	42

Table 5. Annual growth effects for kokanee from Dworshak Reservoir estimated from a mixed effects model. For each year, the best linear unbiased predictor (BLUP), standard error (SE), t statistic (t), degrees of freedom for the denominator (DF), and p-value (p) are given.

Year	BLUP	SE	t	DF	p
2001	74.1	2.53	29.3	1268	<.0001
2002	92.2	2.06	44.7	1208	<.0001
2003	92.4	2.07	44.6	1238	<.0001
2004	90.8	2.96	30.7	1102	<.0001
2005	63.4	1.98	32.1	1267	<.0001
2006	78.9	1.70	46.4	1272	<.0001
2007	96.9	1.54	63.1	1272	<.0001
2008	90.1	1.64	54.8	1241	<.0001
2009	74.1	1.55	47.7	1273	<.0001
2010	77.6	1.46	53.1	1273	<.0001
2011	89.9	1.75	51.3	1273	<.0001
2012	110.6	1.90	58.3	1269	<.0001
2013	91.6	3.57	25.6	1082	<.0001

Table 6. Comparison of linear models used to determine the effect of several factors on annual growth patterns of kokanee from Dworshak Reservoir. The dependent variable was the annual effect previously estimated from a mixed effects model. The first suite of models assessed the best measure of abundance: the total abundance of all age classes or the abundance of age-1 and older kokanee. The second suite of models assessed the effects of consumable *Daphnia* biomass, kokanee abundance, and nutrient addition on annual growth using a set of four a *priori* models. Fit statistics, including the coefficient of determination (R^2), maximized logliklihood (Log$L$), number of parameters (K), Akaike's Information Criterion corrected for sample size (AIC_c), simple differences (ΔAIC_c) and Akaike's weight (w_i) are given. Best approximating models are shaded in gray.

Best Abundance						
Independent variables	R^2	**Log*L***	K	AIC_c	ΔAIC_c	w_i
Total	0.127	-52.79	1	107.94	0.00	0.61
OnePlus	0.062	-53.26	1	108.88	0.94	0.39
Growth Analysis						
Independent variables	R^2	**Log*L***	K	AIC_c	ΔAIC_c	w_i
Daphnia	0.513	-39.67	1	81.84	0.00	0.90
Nutrient	0.134	-42.55	2	87.60	5.76	0.05
Total	0.098	-41.15	1	88.01	6.17	0.04
Nutrient Total	0.165	-41.62	1	93.24	11.40	0.00

Table 7. Comparison of linear models used to determine the effect of several factors on annual growth patterns of kokanee from Dworshak Reservoir. The dependent variable was the mean annual growth for each age class in a given year. Growth was estimated by back-calculation. Independent variables included consumable *Daphnia* biomass, abundance of the corresponding age class in that year, and nutrient addition. Models were selected a *priori* based on existing knowledge. Fit statistics, including the coefficient of determination (R^2), maximized logliklihood (Log$L$), number of parameters (K), Akaike's Information Criterion corrected for sample size (AIC_c), simple differences (ΔAIC_c) and Akaike's weight (w_i) are given. Plausible models, defined as those with an $\Delta AIC_c \leq 2$ or $w_i \geq 1$, are shaded in gray.

Independent variables				R^2	**Log*L***	***K***	AIC_c	ΔAIC_c	w_i
age	Daph		age:Daph	0.918	-104.79	3	220.43	0.0	0.687
age	Daph			0.884	-103.94	2	222.28	1.8	0.273
age	CA		age:CA	0.893	-102.82	3	227.37	6.9	0.021
age	CA	Nut	age:CA	0.902	-101.82	4	229.48	9.1	0.007
age	CA			0.844	-108.78	2	229.94	9.5	0.006
age	CA	Nut		0.858	-102.82	3	231.05	10.6	0.003
age				0.799	-114.22	1	233.53	13.1	0.001
age	Nut			0.820	-103.82	2	233.68	13.3	0.001

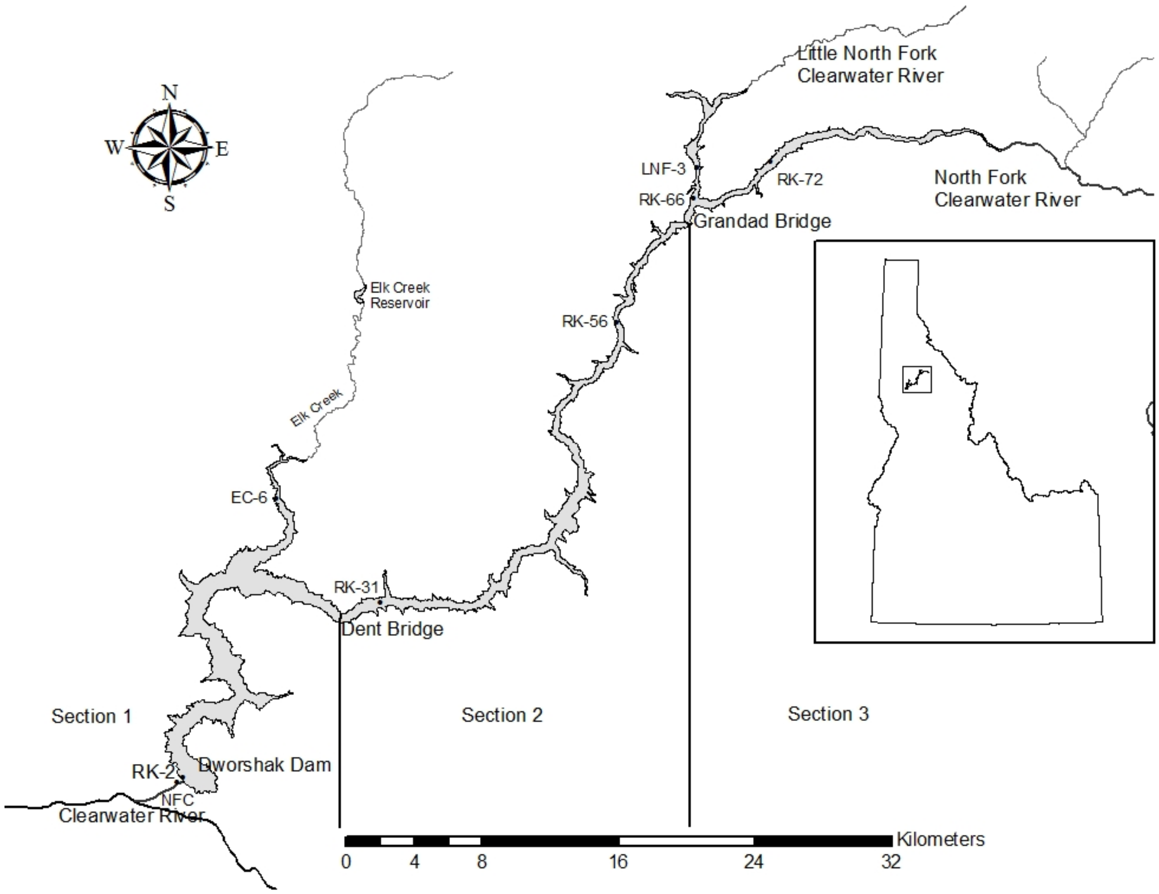

Figure 1. Map of Dworshak Reservoir depicting the locations of seven limnological sampling stations on the reservoir and one on the North Fork Clearwater below Dworshak Dam. Boundaries of reservoir sections used in statistical stratification are also shown.

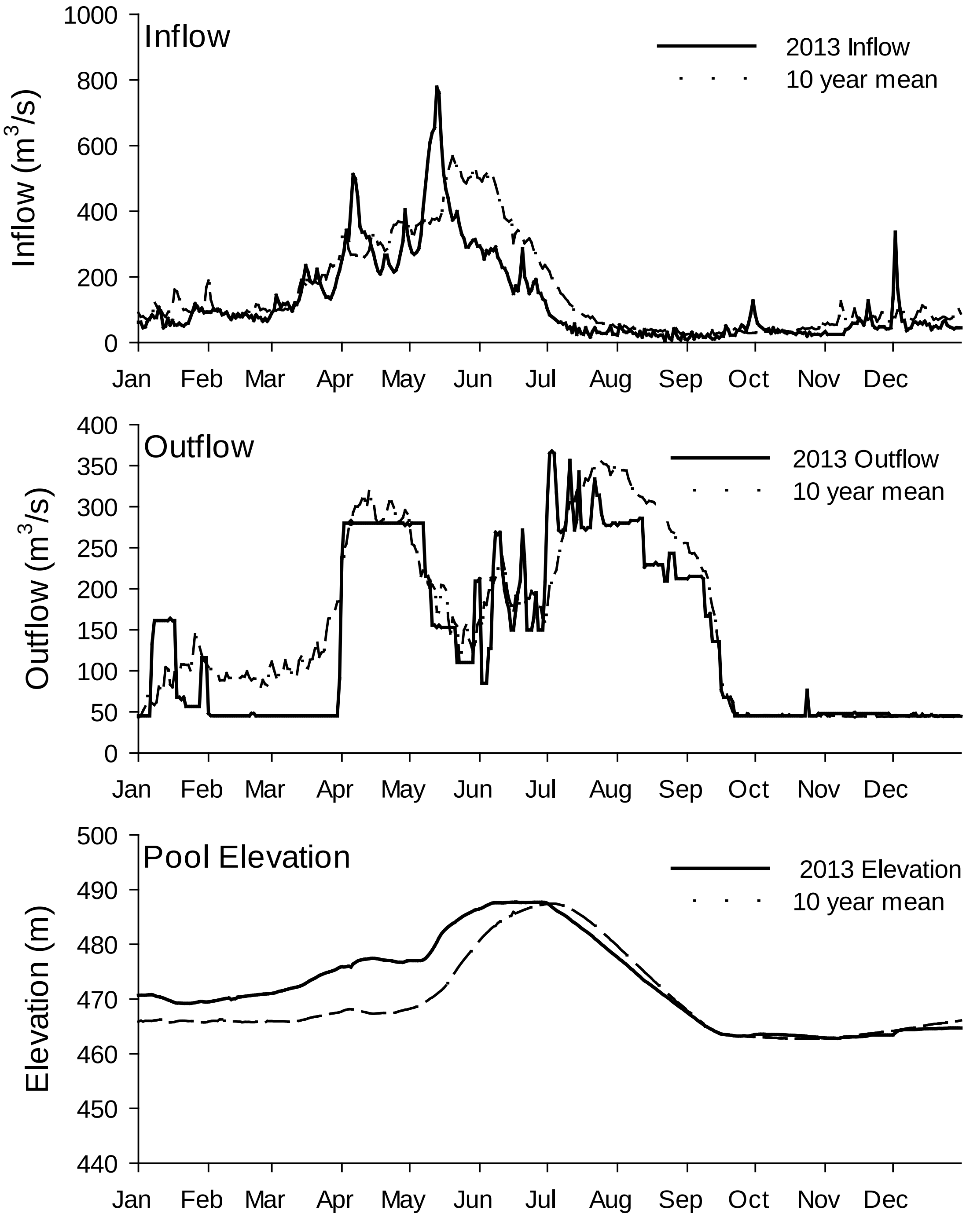

Figure 2. Mean daily inflow, outflow, and pool elevation for Dworshak Reservoir during 2013 along with the 10-year mean (2003-2012). Data provided by the U.S. Army Corps of Engineers through the Columbia River DART website (http://www.cbr.washington.edu/dart/; accessed 3/31/14).

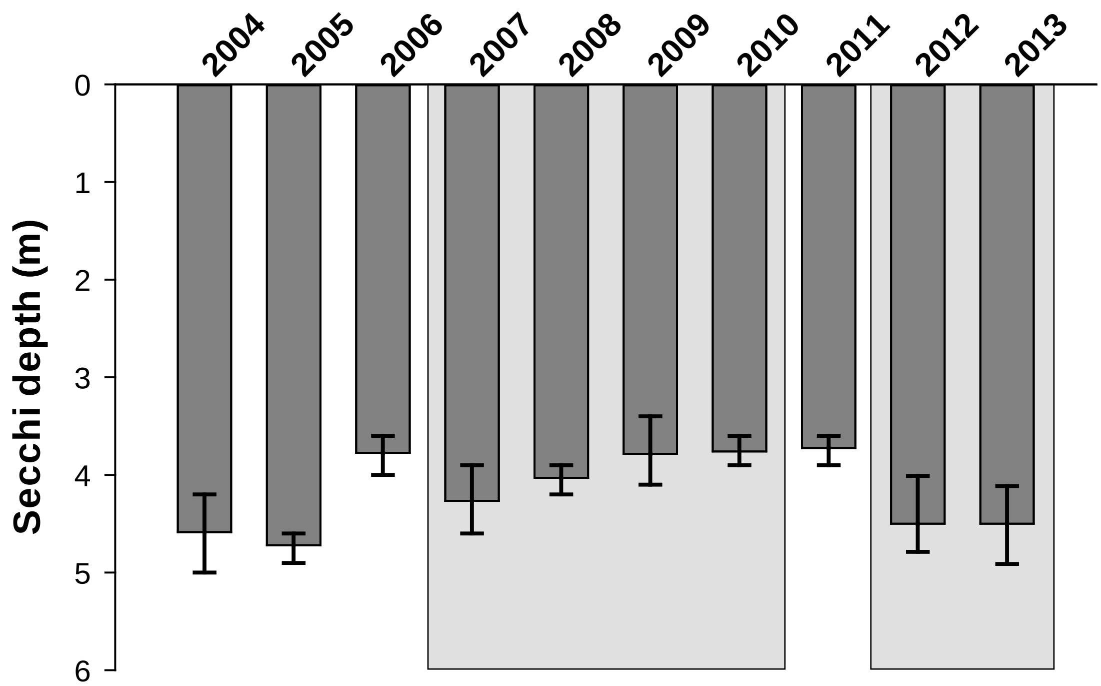

Figure 3. Mean Secchi depth measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from June through November. Error bars represent 95% confidence intervals derived by classical methods. The shaded boxes indicate the period that nutrients were added to the reservoir.

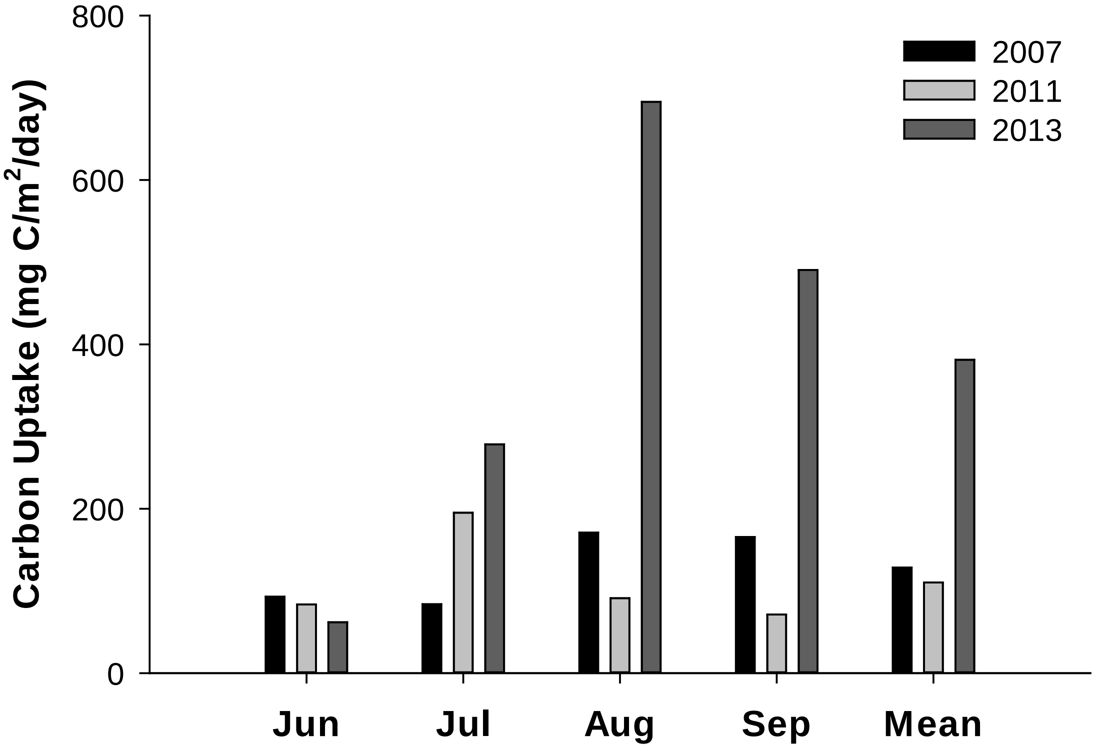

Figure 4. Primary production rates, measured as the uptake of carbon (mg C/m^2/day) into the phytoplankton community, for RK-31. Rates were measured once per month from June through September during three years. Nutrients were added to the reservoir in 2007 and 2013, but not 2011.

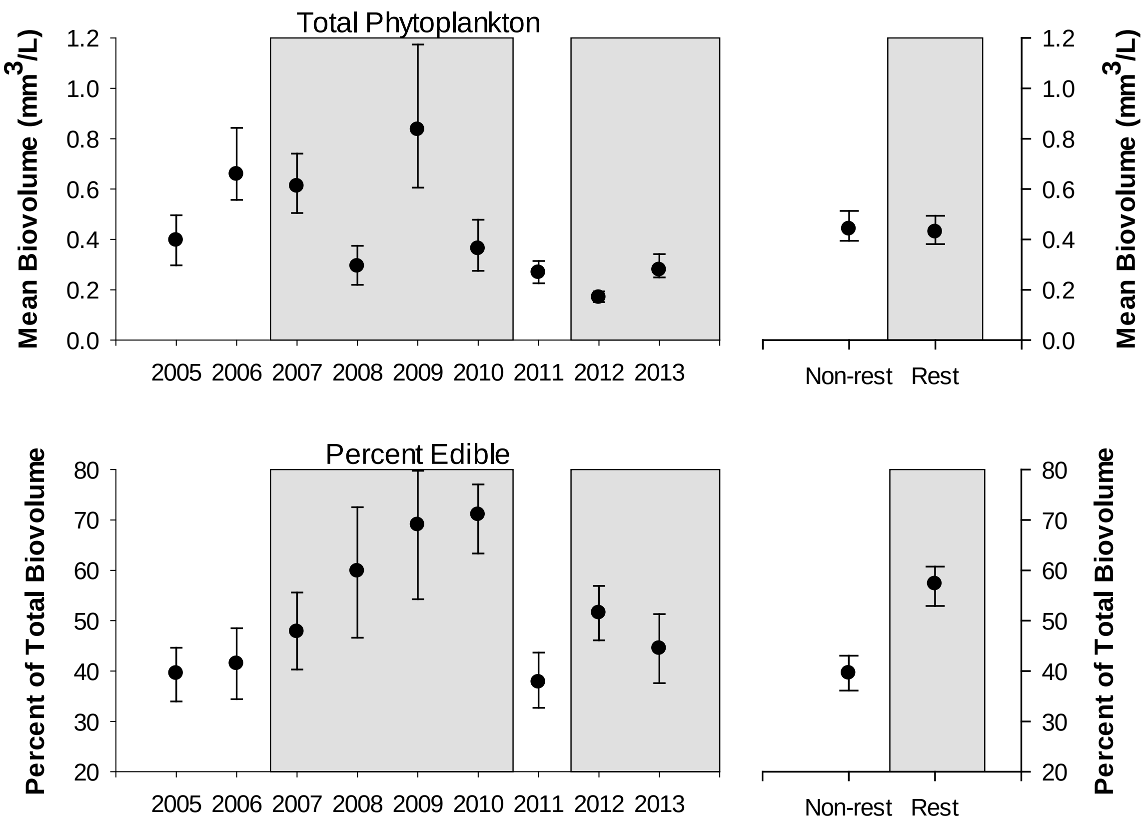

Figure 5. Mean biovolume (mm^3/L) of phytoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Biovolumes are given for total phytoplankton and edible taxa only. The proportion of the total biovolume that was edible is also shown. Error bars represent 95% confidence intervals obtained by bootstrapping. Treatment periods are indicated by shaded boxes.

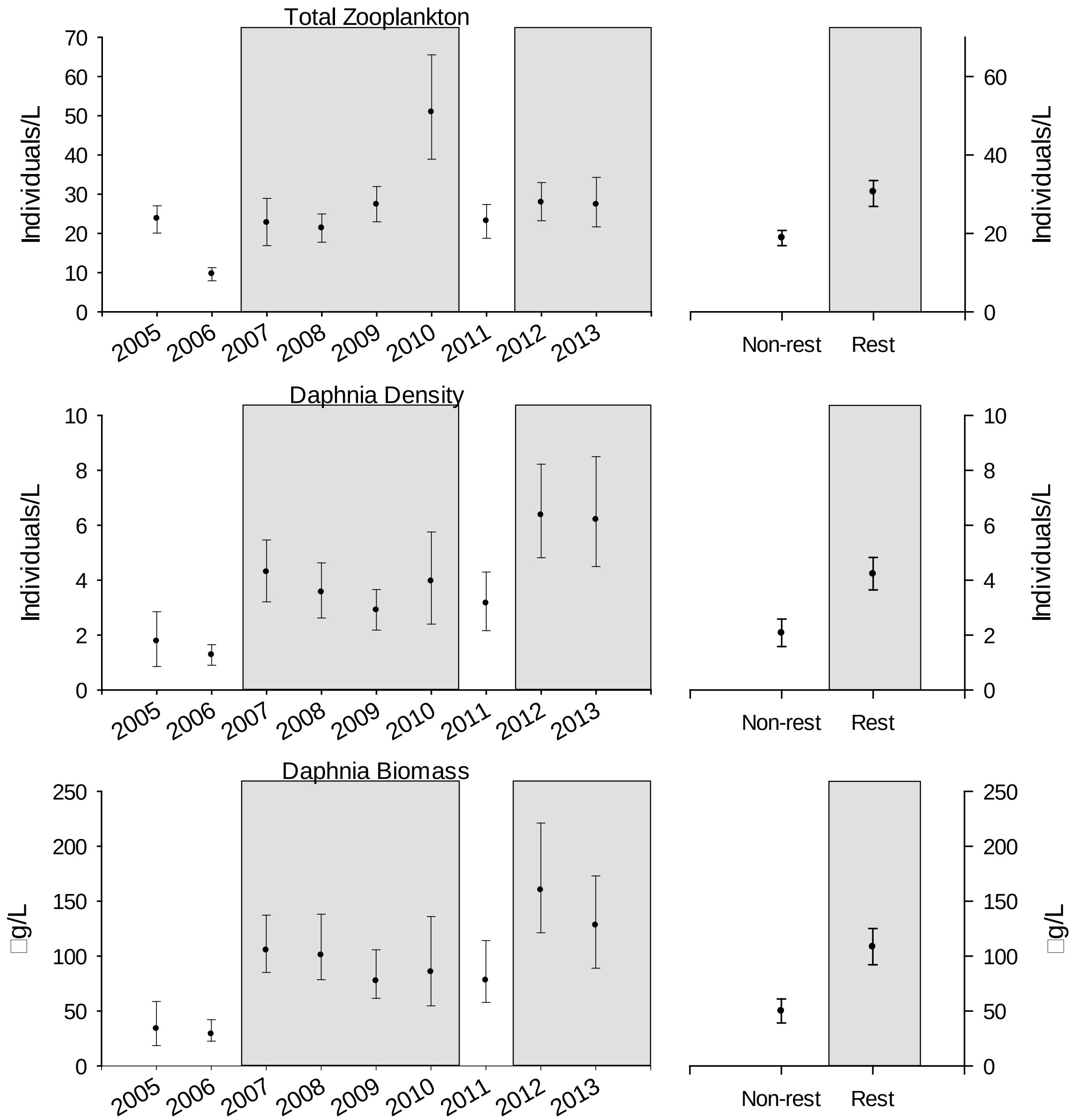

Figure 6. Mean density of zooplankton collected at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from April through November. Densities are presented for three taxonomic groups as well as total zooplankton. Error bars represent 95% confidence intervals obtained by bootstrapping. Treatment periods are indicated by shaded boxes.

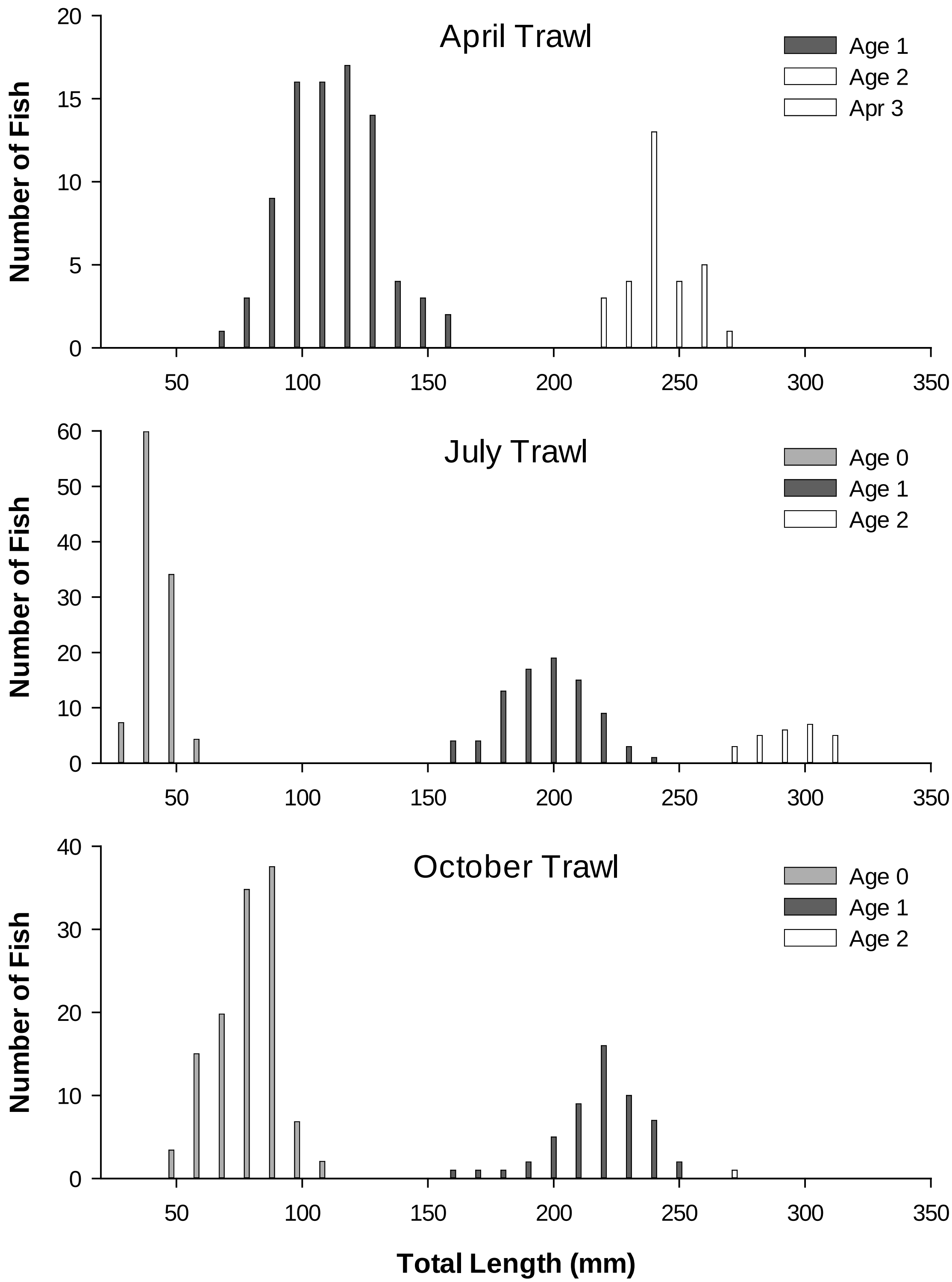

Figure 7. Length frequency of kokanee captured in mid-water trawl surveys on Dworshak Reservoir on April 10-11, July 9-11, and October 10-11. Numbers of age-0 fish represent a subsample of 10% of the total catch.

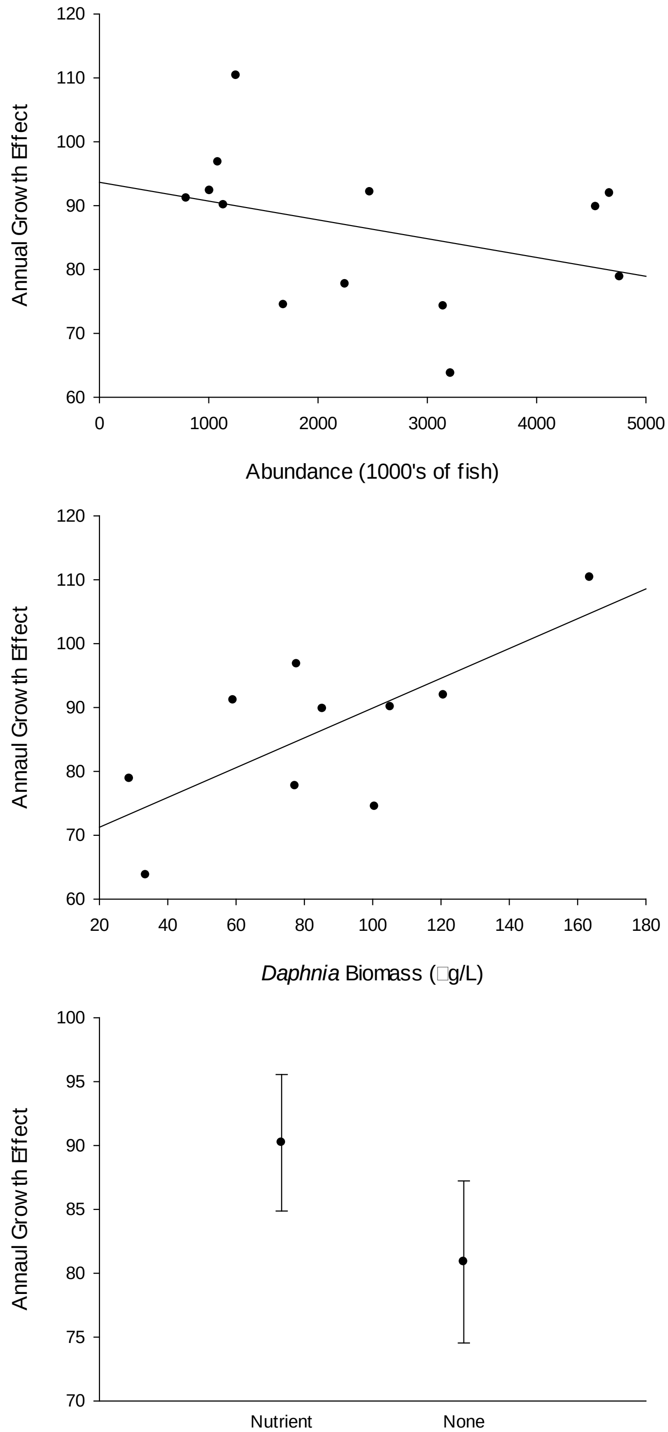

Figure 8. Relationships between annual growth effects estimated from a mixed effects model and three predictor variables, including the total abundance of kokanee for that year, the mean biomass (µg/L) of consumable *Daphnia*, and whether or not nutrients were added to the reservoir.

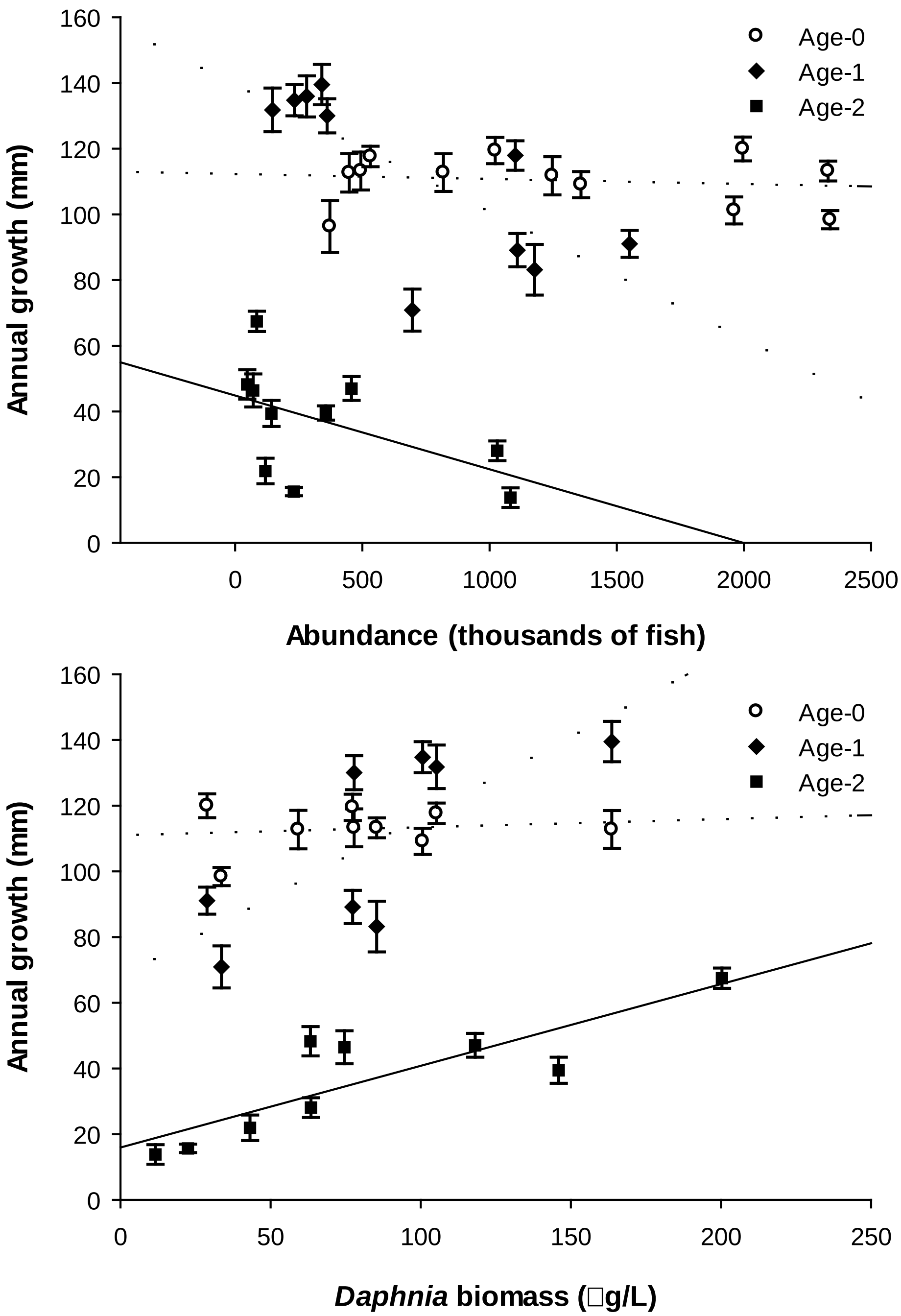

Figure 9. Mean annual growth, in terms of the change in TL (mm), and 95% confidence intervals for three age classes of kokanee plotted against kokanee abundance or mean biomass of consumable *Daphnia*. Lines represent simple regression models for each age class.

APPENDICES

Appendix A. Water clarity statistics, including mean Secchi and compensation depths, for Dworshak Reservoir. Only data from stations RK-2, RK-31, RK-56, and RK-72 from June through November were used. Confidence bounds (LCL = lower confidence limit and UCL = upper confidence limit, 95%) for Secchi depths were obtained by bootstrapping.

	Secchi Depth			**Compensation Depth**	
Year	**mean**	**LCL**	**UCL**	**mean**	**SD**
2004	4.6	4.2	5.0		
2005	4.7	4.6	4.9		
2006	3.8	3.6	4.0		
2007	4.3	3.9	4.6	9.8	1.2
2008	4.0	3.9	4.2	10.2	1.7
2009	3.8	3.4	4.1	9.6	1.5
2010	3.8	3.6	3.9	9.8	1.6
2011	3.7	3.6	3.9	9.7	1.8
2012	4.5	4.0	4.8	10.7	1.5
2013	4.5	4.1	4.9	11.1	1.3

Appendix B. Estimates of kokanee abundance and adult (age-2 and older) densities for Dworshak Reservoir. Estimates from 2003 to present have been revised using estimates of available kokanee habitat from data provided by Sam Martin of the USACE.

		Kokanee Abundance					Adult
Year	Sampling Method	Age-0	Age-1	Age-2	Age-3	Total	Density (fish/ha)
2013	Hydroacoustic	3,975	553	143	0	4,670	29
2012	Hydroacoustic	819,012	340,809	85,023	0	1,251,187	18
2011	Hydroacoustic	494,073	361,416	230,670	972	1,087,132	43
2010	Hydroacoustic	2,331,120	1,177,439	1,030,226	1,483	4,538,785	190
2009	Hydroacoustic	1,022,086	1,109,492	118,753	0	2,250,331	15
2008	Hydroacoustic	1,359,430	233,123	71,024	21,986	1,685,563	18
2007	Hydroacoustic	531,703	147,300	457,245	0	1,136,248	93
2006	Hydroacoustic	1,996,987	1,550,134	1,082,431	0	4,629,552	242
2005	Hydroacoustic	2,339,695	696,738	179,734	0	3,216,167	35
2004	Hydroacoustic	448,833	272,802	74,419	0	796,054	14
2003	Hydroacoustic	372,664	281,254	356,434	0	1,010,353	69
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[a]	Trawling	978,000	161,000	11,000	3,000	1,153,000	3
1989[b]	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] June sampling likely resulted in an underestimate of age-0 kokanee.
[b] September sampling likely resulted in an underestimate of mature kokanee.

Appendix C. Estimates of production and biomass of kokanee in Dworshak Reservoir. Production estimates span the period from July of the first year to July of the second year. Both estimates are based on July acoustic and mid-water trawl surveys. Production estimates could only be obtained when trawl surveys were performed in subsequent years and biomass estimates were obtained for every year that a trawl survey was performed.

	Production (metric tonnes)				
Period	**Age 0-1**	**Age 1-2**	**Age 2-3**	**Total**	
2012-13	50.3	37.1		87.4	
2011-12	36.9	56.2	26.4	119.5	
2010-11	60.6	37.6		98.1	
2009-10	48.6	54.8		103.7	
2008-09	52.3	16.4		68.7	
2007-08	32.2	21.3	32.7	86.2	
2006-07	71.2	99.6		170.8	
2005-06				NA	
2004-05				NA	
2003-04	23.5	30.5		54.1	
	Biomass (metric tonnes)				
Year	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**Total**
2013	3.0	41.0	34.6		78.7
2012	0.7	30.3	25.3	2.0	58.3
2011	0.2	16.5	22.8		39.4
2010	1.4	53.2	97.1		151.7
2009	0.7	47.7	21.1		69.6
2008	0.9	19.8	18.6	5.8	45.1
2007	0.3	9.9	57.4		67.5
2006	1.0	40.1	64.5		106.1
2005					NA
2004	0.3	20.1	18.1		38.5
2003	0.3	20.1	56.7		77.1

Appendix D. Number of kokanee spawners counted in index tributaries to the North Fork Clearwater River above Dworshak Reservoir, Idaho during September 1988-2013. Counts were performed on or near September 25, the historical peak of spawning activity.

Year	Isabella Creek	Skull Creek	Quartz Creek	Dog Creek	Total	Mean TL (mm)
2013	7,535	3,507	758	409	12,209	309
2012	1,447	1,676	574	658	4,355	327
2011	3,598	2,846	773	1,396	8,613	244
2010	26,529	24,212	5,283	3,385	59,409	249
2009	5,366	4,343	918	626	11,253	285
2008	3,738	2,160	462	1,073	7,433	306
2007	11,342	10,913	1,268	1,771	25,294	264
2006	12,604	12,077	2,717	2,345	29,743	210
2005	6,890	3,715	2,137	617	13,359	243
2004	6,922	2,094	450	1,474	10,940	308
2003	12,091	10,225	1,296	1,083	24,695	278
2002	15,933	7,065	2,016	1,367	26,381	267
2001	3,751	1,305	722	301	6,079	305
2000	3,939	402	124	565	5,030	314
1999	10,132	361	827	2,207	13,527	
1998	627	20	13	18	678	
1997	144	0	0	0	144	
1996	2,552	4	13	82	2,651	
1995	12,850		2,780	1,160	16,790	
1994	14,613	12,310	4,501	1,878	33,302	
1993	29,171	7,574	2,476	6,780	46,001	
1992	7,085	4,299	1,808	1,120	14,312	
1991	4,053	1,249	693	590	6,585	
1990	10,535	3,219	1,702	1,875	17,331	
1989	11,830	5,185	2,970	1,720	21,705	290
1988	10,960	5,780	5,080	1,720	23,540	280

Prepared by:

Sean M. Wilson
Fishery Research Biologist
Idaho Department of Fish and Game

Andrew M. Dux
Principal Fishery Research Biologist
Idaho Department of Fish and Game

Curtis J. Roth
Fishery Technician
Idaho Department of Fish and Game

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

Daniel J. Schill
Fisheries Research Manager

James P. Fredericks, Chief
Bureau of Fisheries