FISHERY RESEARCH

DWORSHAK RESERVOIR
NUTRIENT ENHANCEMENT RESEARCH, 2007-2011

DWORSHAK DAM RESIDENT FISH MITIGATION PROJECT

PROGRESS REPORT
March 1, 2007 – February 28, 2012

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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 supplementation as a means to restore declining reservoir productivity and improve fisheries in Dworshak Reservoir. Data were collected from 2004 through 2011, and nutrients (primarily nitrogen as ammonium nitrate) were added from 2007 through 2010. Water quality standards set by the Idaho Department of Environmental Quality (IDEQ) were not violated. The mean Secchi depth for the supplementation period was 0.3 m less than the mean for the non-supplementation period. Mean concentrations of nitrogen (N) and phosphorus (P) in the reservoir did not increase following supplementation, indicating rapid biological uptake of added nutrients. On average, heterotrophic bacteria densities were 109% higher during the supplementation period and picocyanobacteria densities were 60% higher. The mean biovolume of phytoplankton was not significantly higher across supplementation years, but the mean biovolume of edible phytoplankton and the proportion of the phytoplankton community that was edible to zooplankton were substantially higher for the supplementation period. The mean density of *Daphnia sp*. large enough to be consumed by kokanee *Oncorhynchus nerka* was 126% higher for the supplementation period as compared to non-supplementation period. Kokanee exhibited a positive growth response during supplementation, including increased weight in all years and increased length in years of higher density. During the fourth year of supplementation, kokanee biomass was estimated to be 2.3 times higher than the non-supplementation mean and 1.4 times higher than the highest non-supplementation estimate. Also, a record high abundance of kokanee were observed spawning in index tributaries in the fourth year. Dworshak Reservoir appears to be responding to nutrient supplementation 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 supplementation projects in Kootenay and Arrow lakes in British Columbia.

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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 *Oncorhynchus clarkii lewisi*, as well as hatchery stocked rainbow trout *Oncorhynchus 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 *Oncorhynchus 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 supplementation 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 supplementation as a management strategy for restoring the Dworshak Reservoir ecosystem and improving the fishing opportunities it provides. 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 supplementation 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 pilot study.

The primary task of IDFG's monitoring program was to evaluate the effectiveness of the nutrient supplementation program at improving the flow of carbon to the kokanee population in Dworshak Reservoir without adversely affecting water quality. 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 presupplementation conditions to determine the biological effects of the project, including changes to the plankton communities. In supplementation years, data were provided to the consultant to actively manage the nutrient applications. In addition to limnological monitoring, surveys were conducted to monitor the kokanee population. An effective nutrient supplementation 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 from 2004 through 2011, which includes both supplementation and non-supplementation years. These data were used to assess both the limnological and fishery responses to N supplementation and evaluate whether nutrient supplementation should be implemented in Dworshak Reservoir long-term.

STUDY SITE

Dworshak Reservoir was impounded after the construction of Dworshak Dam in 1972 on the North Fork Clearwater River approximately 2.4 km from its confluence with the mainstem Clearwater River. The reservoir is narrow, steeply sloped, and primarily surrounded by coniferous forests. The North Fork Clearwater River and its tributaries drain nearly 632,000 ha, which is composed primarily of montane forests in steeply sloped terrain (Falter et al. 1977). The underlying geology is composed of Columbia River basalt and metamorphic sediments with granitic intrusions covered by shallow soils (Falter et al. 1977). Most of the North Fork Clearwater watershed above the reservoir lies within the Clearwater National Forest. The reservoir is immediately surrounded by land managed by the USACE, but much of the lower watershed is privately owned. 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 2001-2010 was 142 m^3/s (http://www.cbr.washington.edu/dart/; accessed 6/14/12). 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).

OBJECTIVE

1. Maintain a kokanee population that can sustain a catch rate of 0.7 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 3/6/12).

Physical and Chemical Limnology

Sample Collection

Limnological sampling was conducted at seven stations on the reservoir and one station on the North Fork Clearwater River (NFC) below Dworshak Dam (Figure 1). Five stations on the main reservoir were designated as RK-2, RK-31, RK-56, RK-66, 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. Only TP, TDP, N+N, TDS, DOC and Chl *a* were analyzed for NFC.

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) model 58 meter with a 60 m cable and probe assembly with a high sensitivity membrane. The probe was calibrated at each site 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 on the datasheet and plankton were rinsed from the net into the collection bucket, then rinsed into a collection jar and preserved in 70% ethanol. Collection jars were labeled with station, date, and depth of tow. Prior to the field season, several tows were performed with no net and the number of revolutions recorded to serve as a reference point. 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).

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:

$$x = Ln\left[100\left(\frac{l_D}{l_S}\right)\right]$$

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 JMP 9.0 from Statistical Analysis Software (SAS). Means were reported for data that were normally distributed and medians were reported for data that were not normally distributed. In the case of normally distributed data for which a median value was stipulated in the Consent Order issued by IDEQ, both a mean and median value were reported.

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. Presupplementation data were collected from a depth that was twice the Secchi depth to the surface. Since this depth was, on average, similar to the current depth strata, it was compared directly to the data collected from 2008 through 2011 taken from 10 m to the surface. Since data from 2007 was 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 sp*. 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 sp*., 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 sp*. 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 sp*. 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 sp*. 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 sp*. for a given tow was multiplied by the density for that tow to estimate the biomass of available forage for kokanee.

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 supplementation and non-supplementation periods were weighted by year to account for interannual differences in sampling intensity. For data that was not normally distributed, we used a bootstrap technique to derive 95% confidence intervals (Chernick 1999; Efron and Tibshirani 1994). For this, the original data was resampled with replacement using JMP 9.0. For each year, 1000 iterations were performed in which a bootstrap mean was calculated. Confidence intervals were derived using the percentile method, in which 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 then looked up 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. All fish were measured to the nearest mm total length (TL) and a subsample was weighed to the nearest gram. Scales were collected from ten fish from every 1 cm length class from each section. Scales were later examined by two independent readers to determine age (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 = i^th^ 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 for 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 N supplementation, we compared mean size for years with similar abundance.

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 22-23. 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

From 2004 through 2011, inflow to Dworshak Reservoir averaged 151 m^3/s. The highest annual mean (mean = 221 m^3/s) occurred in 2011 and the lowest (mean = 113 m^3/s) occurred in 2010. Mean inflow was higher during the non-supplementation period (mean = 164 m^3/s) than the supplementation period (mean = 138 m^3/s). Reservoir elevation typically reached full pool at 488 m above mean sea level in late June to early July from spring runoff. In early July, hypolimnetic water was evacuated from the reservoir. A typical low pool elevation of 463 m was reached by mid-September and maintained until the following spring. In years of heavy snowpack, additional water was released in the spring in order to capture a larger volume of runoff. The pool elevation was dropped below 460 m in two years during the study period. On May 2, 2011 the pool elevation reached a low of 441 m and on May 4, 2008 pool elevation fell to a low of 449 m.

Physical and Chemical Limnology

Temperature

Water temperatures at 1 m were compared between years using the multiyear sampling frame. Mean temperatures ranged from 17.4 to 19.0°C. Mean temperatures were identical for both the supplementation and non-supplementation period.

A thermocline first developed as early as April in some years and not until June in others. Thermal stratification typically lasted through September on the upper end of the reservoir and through November on the lower end. The mean length of stratification was similar for the non-supplementation (mean = 130 days) and supplementation (mean = 136) period.

Dissolved Oxygen

In all years, DO concentrations remained near saturation for most of the season. However, DO levels below 5 ppm were frequently observed in the metalimnion and hypolimnion late in the season for all years. Low DO readings (≤5 ppm) were typically observed at stations on the upper end of the reservoir. The proportion of sites with a low DO reading ranged from 0 to 20% during the non-supplementation period and from 2 to 20% during the supplementation period.

Water Clarity

Secchi depths were compared between years using a modified multiyear sampling frame (June – November). Mean Secchi depth tended to decline during the study period (Figure 2). Secchi depths were highest in 2004 and 2005, and were similar from 2006 on, with the lowest mean occurring in 2011. Mean Secchi depth was lower for the supplementation period (mean = 3.9 m) than the non-supplementation period (mean = 4.2 m). Bootstrap confidence intervals for this difference (0.3 m) ranged from 0.1 to 0.4 m. Mean Secchi depths for individual supplementation years did not fall outside the range of means for non-supplementation years (Table 1). Additional summaries of Secchi depths for 2011 can be found in Brandt (2012).

Compensation depths were calculated beginning in 2007, the year that nutrient supplementation was initiated. Annual means were compared using data from all treated areas of the reservoir from June through November. Mean compensation depths were similar for all years and the confidence intervals overlapped significantly (Table 1).

Phosphorus

Mean values for TP were compared between years by first adjusting the MDL to 0.010 mg/L. Means for the epilimnion trended downward during the study period (Figure 3). Mean TP values tended to be higher for non-supplementation years than for supplementation years. However, non-supplementation years occurred earlier in the time series, with the exception of 2011, which was one of the lowest means observed for TP. Mean TP values for the hypolimnion and the river were similar to those for the epilimnion and exhibited similar trends.

No adjustments were made when comparing mean values for TDP. As with TP, means for both depth strata and the river trended downward during the study period (Figure 3). Mean TDP also tended to be higher during non-supplementation years than for supplementation years, although the final year in the series (2011) was both a non-supplementation year and the lowest mean TP for both reservoir strata and tied for the lowest mean for the river. Additional summaries of phosphorus data for this study can be found in Brandt (2012).

Nitrogen

Data for TN were only available for 2011. Mean TN values for the epilimnion, hypolimnion, and the river were similar and bootstrap confidence intervals overlapped considerably for all three locations.

Data for TA were also only available for 2011. Detectable levels of TA were rarely observed after May. Since TA was rarely detectable, annual means were similar for both depth strata from the reservoir and the river. Mean TA values for May, when TA was usually detectable, were similar for both reservoir strata (mean = 0.066 mg/L) and lowest in the river (mean = 0.012 mg/L).

Mean values for N+N were compared between years by first adjusting the MDL to 0.010 mg/L. Means for the epilimnion exhibited a high degree of inter-annual variability, but no temporal trend (Figure 3). Mean N+N values for the epilimnion were similar for supplementation and non-supplementation years. Mean N+N values for the hypolimnion, on the other hand, declined during the study period. As with TP and TDP, mean N+N values tended to be higher for non-supplementation years than for supplementation years. However, non-supplementation years occurred earlier in the time series, with the exception of 2011, which had the lowest observed annual mean N+N.

As with the epilimnion, mean N+N levels for the river were highly variable and did not exhibit a temporal trend. Mean N+N levels tended to by highest in the river and lowest in the epilimnion. Additional summaries of nitrogen for this study can be found in Brandt (2012).

Total Dissolved Solids

Data for TDS were only available since 2007, the same year that nutrient supplementation was initiated. Mean TDS values for treated areas of the reservoir were similar and traditional confidence intervals overlapped for all supplementation years. Means for untreated areas were similar to treated areas and confidence intervals overlapped considerably within all years. The mean TDS values for both treated and untreated areas was slightly lower in 2011, the only non-supplementation year in the study period, and confidence intervals for both areas did not overlap with previous years. Additional summaries of TDS for this study can be found in Brandt (2012).

Dissolved Organic Carbon

Data for DOC were available since 2007, the same year that nutrient supplementation was initiated. Mean DOC values have trended upwards since 2007, peaking in 2010. The mean DOC value for 2011 was slightly less than 2010, but bootstrap confidence intervals overlap considerably for both years.

Biological Indicators

Chlorophyll *a*

Data for Chl *a* in the epilimnion were compared using the multiyear sampling frame. Annual means exhibited some variability, but did not exhibit an obvious temporal trend (Figure 4). The mean for the supplementation period (mean = 2.30 µg/L) was nearly identical to non-supplementation period (mean = 2.29 µg/L) and the bootstrap confidence interval for the increase included zero.

Data from the river were available since 2007, the year that nutrient supplementation was initiated. Annual means for the river were highly variable and tended to trend downward during the study period. The only two years for which confidence intervals did not overlap were 2008 (mean = 0.79 µg/L) and 2011 (mean = 0.32 µg/L). Annual means for the river were substantially lower than means for the epilimnion and confidence intervals did not overlap (Figure 4). Additional summaries of Chl *a* data can be found in Brandt (2012).

Picoplankton

Data for picoplankton were available since 2006, one year before nutrient supplementation was initiated. Densities of picoplankton were compared between years using a modified multiyear sampling frame (May – October). The mean density of heterotrophic bacteria for the supplementation period (mean = 1,191,000 cells/mL) was 109% higher than for the non-supplementation period (mean = 569,000 cells/mL) and the bootstrap confidence interval for this increase ranged from 94 to 125%. The mean density was much lower in 2006 than all other years and the mean for 2011 was only slightly lower than supplementation years (Figure 5).

The mean density of picocyanobacteria for the supplementation period (mean = 135,000 cells/mL) was 60% higher than for the non-supplementation period (mean = 84,000 cells/mL) and the bootstrap confidence interval for this difference ranged from 32 to 85%. The mean density of picocyanobacteria was also much lower in 2006 than all other years, but the mean density for 2011 was similar to supplementation years and confidence intervals overlapped considerably (Figure 5).

Phytoplankton

Phytoplankton standing crop was compared between years using mean biovolumes for the multiyear sampling frame. Mean biovolumes of total phytoplankton were variable with no apparent temporal trend (Figure 6). The mean biovolume of total phytoplankton for the supplementation period (mean = 0.532 mm^3/L) was 21% higher than for the non-supplementation period (mean = 0.441 mm^3/L), but the bootstrap confidence interval for this increase includes zero (95% CI = -2 to 46%).

Mean biovolume of edible phytoplankton exhibited a similar trend to that of total phytoplankton (Figure 6). The mean biovolume for the supplementation period (mean = 0.33 mm^3/L) was 73% higher than for the non-supplementation period (mean = 0.19 mm^3/L) and the bootstrap confidence interval for this increase ranged from 33 to 126%. The probability that this increase was at least 50% is 0.862.

The proportion of the phytoplankton community that is known to be edible was higher in every supplementation year than for every non-supplementation year (Figure 6). The mean proportion of edible phytoplankton for the supplementation period (mean = 62%) was 22% higher than for the non-supplementation period (mean = 40%) and the bootstrap confidence interval for this difference ranged from 29 to 56%. This represents an increase of 56% in the proportion of edible phytoplankton. The bootstrap confidence interval for this increase ranged from 39 to 77% and the probability that this increase was at least 50% is 0.736.

The dominant taxa of toxigenic cyanobacteria (i.e., blue-green algae) in Dworshak Reservoir have historically been *Anabaena sp.* and *Microcystis sp*. The mean biovolume of *Anabaena sp.* was lower for the supplementation period (mean = 0.03 mm^3/L) than the non-supplementation period (mean = 0.11 mm^3/L). The proportion of the total phytoplankton biovolume that was composed of *Anabaena sp.* for the supplementation period (mean = 5%) was 75% lower than that of the non-supplementation period (mean = 21%) and the bootstrap confidence interval for this decrease ranged from 61 to 82%. In general, the proportion of

Anabaena sp. was much lower for supplementation years, with the exception that 2005 (11%) and 2007 (13%) were similar to presupplementation proportions (Figure 7).

The mean biovolume of *Microcystis sp.* was nearly identical for the supplementation and non-supplementation period (mean = 0.01 mm^3/L). The mean proportion of *Microcystis sp.* was also similar for the supplementation (2%) and non-supplementation period (3%) and bootstrap confidence intervals for this decrease included zero. Based on biovolume, the proportion of times the World Health Organization (WHO) threshold for a low health risk for recreational contact was exceeded during the multiyear sampling frame was lower for the supplementation period (mean = 6%) than for the non-supplementation period (mean = 15%). Additional summaries of phytoplankton data can be found in Brandt (2012).

Zooplankton

Mean zooplankton density was compared between years using a modified multiyear sampling frame (April – November). The mean density of all zooplankters was lowest in 2006 (mean = 9.7 individuals/L) and highest in 2010, the final year of supplementation (mean = 50.9 individuals/L). Means for all other years were similar, with overlapping bootstrap confidence intervals (Figure 8). The mean density for the supplementation period (mean = 30.6 individuals/L) was 62% higher than the mean for the non-supplementation period (mean = 18.9 individuals/L) and bootstrap confidence intervals for this increase ranged from 38 to 91%. The lower confidence limit for the difference in these means was 7.5 individuals/L and the probability that the increase was at least 50% is 0.830.

Mean densities of *Daphnia sp.* were lowest in 2005 and 2006 (range = 2.0 to 2.4 individuals/L) and similar from 2007 to 2011 (range = 3.9 to 5.3 individuals/L). The mean for the supplementation period (mean = 4.7 individuals/L) was 70% higher than that of the non-supplementation period (mean = 2.8 individuals/L) and bootstrap confidence intervals for this increase ranged from 39 to 107%. The probability that the increase was at least 50% was 0.895.

Nearly all *Daphnia sp.* found in kokanee stomachs (99.4%) were ≥0.80 mm in length. The mean densities of *Daphnia sp.* that were ≥0.80 mm in length exhibited similar patterns to densities for *Daphnia sp.* in general. The mean across supplementation years (mean = 3.7 individuals/L) was 76% higher than that of non-supplementation years (mean = 2.1 individuals/L) and bootstrap confidence intervals did not overlap. For 95% of the bootstrap iterations, the mean across supplementation years was at least 1.0 individuals/L more than that of non-supplementation years and the probability that the increase was at least 50% is 0.912.

The mean biomass of *Daphnia sp.* that were ≥0.80 mm tended to be higher in supplementation years than in non-supplementation years. The only exception being that the mean biomass for 2011 was slightly higher than that of 2010 (Figure 8). The mean for the supplementation period (mean = 106 µg/L) was 126% higher than the non-supplementation period (mean = 47 µg/L) and the bootstrap confidence interval for this increase ranged from 75 to 210%. For 95% of the bootstrap iterations, the mean for the supplementation period was at least 44 µg/L more than the non-supplementation period and the probability that the increase was at least 50% is 0.998.

Annual mean lengths of *Daphnia sp.* were lowest in 2005 (mean = 0.83 mm) and highest in 2008 (mean = 1.08 mm). Means were >1.00 mm in three out of four supplementation years and <1.00 in all non-supplementation years. Annual mean lengths of *Bosmina sp.* were lowest in 2006 (mean = 0.33 mm) and highest in 2010 (mean = 0.42 mm). Mean lengths of *Bosmina sp.*

tended to be similar for supplementation and non-supplementation years. Additional summaries of zooplankton data can be found in Brandt (2012).

Kokanee Population Monitoring

Abundance and Density

Kokanee abundance from 2003 through 2011 ranged from 800,000 in 2004 to 4.6 million in 2006, with a mean of 2.3 million and a median of 1.7 million. The abundance of age-1 and older kokanee ranged from 300,000 in 2008 to 2.6 million in 2006, with a mean of 1.0 million and median of 600,000. The mean abundance of age-1 and older fish was almost identical (means = 1.1 million) for supplementation and non-supplementation years for which trawl surveys were performed.

Adult (age-2 and older) density ranged from 14 fish/ha in 2004 to 236 fish/ha in 2006, with a mean of 80 fish/ha and a median of 43 fish/ha. The mean adult density was slightly lower for supplementation (mean = 81 fish/ha) than for non-supplementation years (mean = 91 fish/ha) for which trawl surveys were performed. Revised abundance and density estimates for kokanee are presented in Appendix A.

Size at Age

There were two pairs (non-supplementation versus supplementation) of years that had similar abundance of age-1 and older fish. The years 2004 (347,000) and 2008 (326,000) represent a pair of low density years and 2006 (2.7 million) and 2010 (2.2 million) represent a pair of high density years. The mean TL and estimated L_∞ for age-2 fish in 2004 and 2008 were very similar; however, age-2 fish were almost 20 g heavier in 2008 (Table 2, Figure 9). The mean TL and estimated L_∞ for age-2 fish in 2010 were both nearly 25 mm longer than in 2006, and fish were 35 g, or over 50%, heavier in 2010 as compared to 2006 (Table 2, Figure 9).

Biomass and Production

Kokanee production could only be estimated from one time period that did not coincide with nutrient supplementation, which was 2003-2004. Production estimates for the three time periods that occurred during nutrient supplementation were all higher (Table 3). Two additional time periods, 2006-2007 and 2010-2011, overlap with supplementation and non-supplementation periods.

Estimates of kokanee biomass for the first three years of nutrient supplementation were similar to those for non-supplementation years. The biomass estimate for the fourth year of nutrient supplementation was 43% higher than the highest biomass estimates for a non-supplementation year and 2.3 times the mean biomass for the non-supplementation period (Table 3, Figure 10).

Spawner Counts

Peak counts of spawning kokanee observed during the study period were quite variable and counts for the first three years of nutrient supplementation were similar to those for non-supplementation years. However, the peak count for 2010, the fourth year of supplementation, was the highest on record and nearly twice that of any other count for the study period (Figure

11). The mean total length of spawning kokanee for 2010 was below the ten year average, but similar to mean lengths for other years for which spawner counts were nearly half.

The estimated abundance of mature fish in July tracks closely with peak spawner counts (Figure 12). The mean abundance of mature fish for the supplementation period (mean = 416,000) was 59% higher than the mean for the non-supplementation period (mean = 261,000). Likewise, the mean biomass of mature fish for the supplementation period (mean = 48.4 MT) was 56% greater than the mean for the non-supplementation period (mean = 31.1 MT). Historical spawner count data are shown in Appendix B.

DISCUSSION

Water Quality

While the goal of the nutrient supplementation project is to restore lost productivity to the reservoir, it is imperative to do so without degrading overall water quality. DO is an important water quality parameter that the project has the potential to affect negatively. Dworshak Reservoir typically experiences low DO levels during late summer and early fall. These minima are presumed to be caused by phytoplankton that senesce, settle out of the epilimnion, and collect in the metalimnion where they begin to decay (TG Eco-Logic 2008). Although these metalimnetic DO minima occurred prior to the nutrient enhancement project, it is possible that the addition of nutrients and the increased productivity of the system could intensify this phenomenon (TG Eco-Logic 2008). The intensity of this phenomenon appears to be related to reservoir inflow, and presumably the length of thermal stratification. Comparisons of DO concentrations across years did not provide any evidence that nitrogen supplementation is intensifying the late season DO minima (Scofield et al. 2011).

Water clarity is another common metric for water quality. The Consent Order issued by the IDEQ stipulated that the median Secchi depth not fall below 3 m due to nutrient supplementation. Secchi depth is influence by a variety of factors. Two of the most important of these are suspended solids from spring runoff and chlorophyll concentration due to summer algal blooms. In order to examine the effects of algal production on water clarity, we concentrated on data from June through November, when the effect of runoff should be minimal. Although the mean Secchi depth was greater for the non-supplementation period, means for supplementation years were within the range observed for non-supplementation years. The higher mean Secchi depth across non-supplementation years was driven by high Secchi measurements in 2004 and 2005. Mean Secchi depths for supplementation and non-supplementation years after 2005 are very similar. The lowest mean Secchi depth was observed in 2011, the year following suspension of the nutrient applications. It should also be noted that the only year in which the median Secchi depth was below the minimum stipulated by the Consent Order (2011) was a year in which no N was applied to the reservoir. Therefore, nutrient supplementation may be resulting in reduced water clarity, but not to the extent that it has been degraded for recreational purposes.

While nutrients are essential to sustaining aquatic life, it is important not to introduce excessive amounts of nutrients into surface waters. Eutrophication is a common problem in surface waters that results from excessive nutrients (Smith et al. 2006). Mean concentrations of N and P as measured in Dworshak Reservoir have not increased despite supplementation. It is not surprising that the addition of N has not resulted in a detectable increase. Dworshak Reservoir was found to be N limited (Stockner and Brandt 2006) and N in the form of ammonia is absorbed rapidly by the phytoplankton community, usually in 24 hours or less (Stockner 1995). The theoretical concentration of N applied to the reservoir, once fully mixed into the epilimnion, was only 8 µg/L during the heaviest applications. Therefore, there is no evidence that the amount of N being added to the reservoir is excessive.

Since P has not been added to the reservoir since the second year, and then only in very small amounts, the project is not expected to have an effect on P concentrations. However, mean concentrations of P have declined since the beginning of supplementation. This could be due to more efficient uptake of P as a result of more balanced N:P ratios, a reduction in P inputs to the reservoir, or improved analytical procedures.

There have been concerns that nutrients added to the reservoir would be discharged through the dam into the North Fork Clearwater River, causing nuisance algal growth and adversely affecting water quality for anadromous fish hatcheries. The lower reservoir is typically thermally stratified by the time nutrient supplementation is implemented in the spring. N is added to the epilimnion, while dam discharge occurs primarily from the hypolimnion. Furthermore, with the exception of the first year, N additions have not occurred within 8 km of the dam. Therefore, it is unlikely for supplemented N to be discharged directly into the river. Any increase in the nutrient loading to the river would likely be as a result of increased nutrient cycling to the hypolimnion. Nutrient levels in the North Fork Clearwater River below the dam were not measured until 2007, the first year of nutrient supplementation. Since that time, there has been no observable increase in N or P concentrations in the river. While measurements from the river were not taken prior to supplementation, nutrient levels in the reservoir hypolimnion have not increased. Since this is the source for the river, it is unlikely that nutrient loading to the river has increased.

Nutrient supplementation has generated public concerns about whether or not toxigenic cyanobacteria (blue-green algae) have become more prevalent in the reservoir. *Anabaena sp.* and *Microcystis sp.* are the two predominant taxa that have been documented in the reservoir. These taxa typically become prevalent in late summer and fall after available N has been exhausted. Prior to 2008, densities of these taxa were counted in terms of colonies. Beginning in 2008, the counting methodology was changed to cell counts for as many taxa as possible, including *Anabaena sp.* and *Microcystis sp*. Since then, densities of *Microcystis* in excess of the threshold that the WHO determined were a mild health concern (20,000 cells/mL; Falconer et al. 1999) have been observed on several occasions in most years. Since this was not monitored closely prior to nutrient supplementation, there has been a perception that the project has resulted in an increase of toxigenic taxa that were previously absent or present only at very low levels. While the mean biovolume of *Microcystis sp.* in samples collected from the same times and locations was similar for both the supplementation and non-supplementation period, it was three times more likely for the biovolume to exceed that corresponding with the WHO threshold (0.04 mm^3/L) in non-supplementation years than in supplementation years. Therefore, there is no evidence that nutrient supplementation has resulted in any increase of *Microcystis sp.* blooms.

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 supplementation would reduce the prevalence of *Anabaena sp*. (Stockner and Brandt 2006). While *Anabaena sp*. blooms have been observed during supplementation years, both the mean biovolume and the percent contribution of *Anabaena sp*. in samples taken at consistent times and locations was over three times lower for the supplementation period than the non-supplementation period. Similar observations have been made in other North American lakes (Stockner and Shortreed 1988; Schindler et al 2008). These observations, along with our understanding of the ecology of these organisms, strongly supports the idea that N supplementation has reduced the prevalence of *Anabaena sp*. in the reservoir.

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 N supplementation, 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.

Densities of picoplankton were substantially higher for supplementation years than for 2006, the only presupplementation year for which picoplankton were collected. The initial picoplankton response in Dworshak Reservoir was similar in magnitude to that observed during the first years of nutrient supplementation in BC lakes and reservoirs (Pieters et al. 2003; Stockner and MacIsaac 1996; Stockner and Shortreed 1994). However, picoplankton densities did not drop off to 2006 levels following the suspension of nutrient application in 2011. The reason that picoplankton did not return to 2006 levels following the suspension of N supplementation is unclear. It is possible that 2006 was an anomalously low year, or that reservoir productivity did not decline as fast as anticipated.

The annual mean biovolume of total phytoplankton was quite variable over the course of the study period. While the mean standing biovolume of phytoplankton was higher across supplementation years than non-supplementation years, this difference was neither great nor can it be confirmed to a high degree of statistical probability. Furthermore, the mean standing biovolume for three out of four years of supplementation were all within the range observed for non-supplementation years. The high degree of variability in mean biovolume supports the idea that environmental factors are the key drivers of standing stock.

The greatest effect of N supplementation on the phytoplankton community appears to be shifts in the community structure. The trend for the annual mean biovolumes of edible phytoplankton was similar to that of total phytoplankton biovolume. However, these data represent standing biovolume only, and do not indicate whether or not production has increased. Increased productivity in edible species can be masked by increased grazing from zooplankton. While standing biovolume of edible phytoplankton was variable across years, the proportion of the overall biovolume of edible species was higher in every supplementation year than in any non-supplementation year. While supplemented N can be used by edible and inedible species alike, some inedible species (i.e., *Anabaena sp.*) have a competitive advantage when N is nearly exhausted, and tend to dominant the phytoplankton community during the late summer and fall in non-supplementation years. These species were less prevalent during supplementation years, which likely led to the increased proportion of edible species. These observations support the hypothesis that N supplementation is leading to shifts in the phytoplankton community that will result in more efficient transfer of C to the zooplankton community.

The observed shifts in the phytoplankton community structure are believed to be translating into increased forage for kokanee. Densities of *Daphnia sp.*, the preferred forage of kokanee (Stark and Stockner 2006), were higher for the supplementation period than for the non-supplementation period. *Daphnia sp.* were also larger during the supplementation period. Both of these results combined yielded 126% greater biomass of *Daphnia sp*. available as forage for kokanee. This is similar to the response for BC lakes reported by Stockner (1995). However, changes in zooplankton production do not always translate into increases in standing biomass. The mean biomass of *Daphnia sp.* in Upper Arrow Lake increased by only 45% over the first four years of fertilization and the mean for the first eight years dropped to be nearly identical to the presupplementation mean. Despite the lack of a measurable increase in *Daphnia sp.* biomass over the first eight years, average biomass of kokanee increased by three fold during nutrient supplementation (Schindler et al. 2009a).

Kokanee Population Monitoring

Improved kokanee growth is a key indicator of whether or not nutrient supplementation is having desirable effects. Since kokanee typically exhibit density dependent growth, it is important to consider densities when evaluating growth. To account for the effects of density on fish growth, we compared mean sizes for years with 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.

Our comparisons indicated that kokanee were heavier, but not longer, under supplementation at the lower abundance. At higher abundance they were both longer and heavier during supplementation. The increase in mean weight at the high abundance resulted in the highest estimate for overall biomass in recent years (2010). There are two explanations for the greater observed differences in the size of age-2 fish in 2010. The first possibility is that the growth advantage due to N supplementation increases with increasing abundance. In other words, forage availability does not limit growth at low fish densities. The second is that the growth advantage has increased over time. Increases in zooplankton density, particularly in 2010, would support the latter. However, it is difficult to draw conclusions based on two pairings of data. Additional years of data will be needed to determine the real effect of N supplementation on kokanee growth. Future efforts will focus on using mixed-effects models developed by Weisberg et al. (2010) to model growth using back-calculated lengths from scale analyses. This method will allow us to use growth increment data from additional years and test the significance of and account for covariates, such as fish density and forage availability.

Another way to assess benefits to the kokanee population is to assess 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. Since production should be somewhat density independent, it may be a better indicator of how the population responds to increased forage. It should be noted that the method we have used provides an estimate of production from July of the first year to July of the second. Thus, there is only one period that we could estimate production for that did not overlap with a supplementation period (2003-2004) and two estimates (2006-2007, 2010-2011) that coincided with both supplementation and non-supplementation periods. Production estimates for each of the periods that coincided strictly with N supplementation were all higher than the presupplementation estimate. However, our production estimates were also positively correlated ($r^2 = 0.93$) to the abundance of age-1 and older fish at the beginning of the period for which the estimate was calculated. Therefore production is likely not completely density independent. Since we only have one year prior to supplementation for comparison, further caution should be used in interpreting these results.

The most significant effect of N supplementation on the kokanee population appears to be an increase in biomass. As a result of faster growth at a higher fish density, by the fourth year of supplementation kokanee biomass was estimated to be more than double the mean for the non-supplementation period. What remains to be seen is if this level of biomass was an anomaly, or if it will be sustained through continued N supplementation. In Kootenay Lake, BC, kokanee biomass averaged about 5 kg/ha over six years prior to nutrient supplementation. During the first year of supplementation in Kootenay Lake, biomass did not increase above what had been seen previously, but did increase to about 2.5 times the presupplementation mean by the third year. Biomass in Kootenay Lake did not peak until the seventh year of supplementation, at around five times the presupplementation mean (Figure 7.13 in Schindler et al. 2009b). Observations for Dworshak Reservoir are consistent with those from Kootenay Lake, although magnitude of the increase in biomass is yet to be determined. Another uncertainty unique to Dworshak is how kokanee entrainment loss will affect biomass trends under N supplementation. Unusually heavy snowpack and high runoff in the spring of 2011 coincided with a decline in the kokanee population of around 80% (all sources of mortality combined), and entrainment is believed to be the primary source of this mortality. Regular entrainment losses of this magnitude could negate benefits from N supplementation.

There is some evidence that N supplementation may lead to increased abundance and biomass of spawning kokanee in the tributaries above the reservoir. The increase in spawning kokanee is driven largely by 2010 estimates and will need to be sustained over time before definitive conclusions are reached; however, the positive response observed in tributary spawners thus far is encouraging. If the number and biomass of spawners observed in 2010 can be sustained, it would have two effects. First, it would result in increased transfer of nutrients back to the watershed above the reservoir. These recycled nutrients are expected to benefit resident fish communities in the watershed above the reservoir (Grant et al. 1998; Wipfli et al. 1998; Richardson 1993; Wilzbach 1985). Secondly, it should result in an increased number of eggs deposited in the tributaries in a given year and potentially increase kokanee recruitment into the reservoir.

The responses observed following the initial four years of N supplementation, combined with decades of observations from lakes in BC, suggest that continued N supplementation 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 densities of kokanee in the reservoir. As a result, kokanee size is expected to be similar to presupplementation size over the long term, but at higher densities. Higher densities of kokanee in the reservoir of a similar size to presupplementation 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 supplementation in Dworshak Reservoir showed signs of success and similar responses to those observed in several BC lakes and reservoirs following nutrient addition. Water clarity appeared to decrease slightly during nutrient supplementation, but not below the range observed prior to supplementation, or to the point where it was detrimental to recreational uses. The effects of N supplementation 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 body weight at a given density. The increases in both mean length and weight of kokanee at high abundance lead to a substantial increase in overall biomass by the fourth year of supplementation. 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 well beyond the reservoir itself. While it will take additional years of data to confirm that the observed effects are in fact due to supplementation and not natural variation, nutrient supplementation appeared to have a beneficial effect on the ecology of the reservoir and should be continued.

RECOMMENDATIONS

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

2. Conduct primary productivity assays to assess changes to the productivity of the phytoplankton community rather than just standing crop.

3. Conduct controlled and replicated mesocosm experiments to separate environmental effects from N supplementation and determine causation.

ACKNOWLEDGMENTS

The Dworshak Reservoir Nutrient Enhancement 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, John Beck and Ben Perkins, with the U.S. Army Corps of Engineers, made sure that fertilizer was accurately applied. John Bailey, Tim Dykstra, Ann Setter, Steve Juul, and Ben Tice, also with the USACE, all played important roles in this project. Bill Ament and Bill Harryman assisted with trawl, acoustic, and spawner surveys for this project. We also thank the anonymous IDFG personnel from Region 2 who assisted with fieldwork. This project was funded by the Bonneville Power Administration and we thank Jan Brady and Roy Beaty for administering the BPA contract.

LITERATURE CITED

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

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

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

Brandt, D. H. 2012. Dworshak Reservoir nutrient enhancement project: 2011 progress report and data summary. Advanced Eco-Solutions Inc., Newman Lake, WA.

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.

Falconer, I., J. Bartram, I. Chorus, T. Kuiper-Goodman, H. Utkilen, M. Burch, and G. A. Codd. 1999. Safe levels and practices. I. Chorus, and J. Bartram, editors. Toxic cyanobacteria in water: a guide to their public health consequences, monitoring and management. E & FN Spon, London.

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.

Grant, J. W. A., S. O. Steingrimsson, E. R. Keeley, and R. A. Cunjak. 1998. Implications of territory size for the measurement and prediction of salmonid abundance in streams. Canadian Journal of Fisheries and Aquatic Science 55(Suppl. 1):182-190.

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.

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.

Pieters, R., S. Harris, L. C. Thompson, L. Vidmanic, M. Roushorne, G. Lawrence, J. G. Stockner, H. Andrusak, K. I. Ashley, B. Lindsay, K. Hall, and D. Lombard. 2003. Restoration of kokanee salmon in the Arrow Lakes Reservoir, British Columbia: preliminary results of a fertilization experiment. Pages 177-196 in J. G. Stockner, editor. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society, Bethesda, Maryland.

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

Richardson, J. S. 1993. Limits to productivity in streams: evidence from studies of macroinvertebrates. Pages 9-15 in R. J. Gibson and R. E. Cutting, editors, Production of juvenile Atlantic salmon, *Salmo salar*, in natural waters. Canadian Special Publication of Fisheries and Aquatic Sciences 118.

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.

Schindler, E. U., D. Sebastian, L. Vidmanic, H. Andrusak, J. Stockner, M. Bassett, and K. I. Ashley. 2009a. Arrow Lakes Reservoir fertilization experiment, year 8 (2006) report. Ministry of Environment, Nelson, BC.

Schindler, E. U., D. Sebastian, G. F. Andrusak, H. Andrusak, L. Vidmanic, J. Stockner, F. Pick, L. M. Ley, P. B. Hamilton, M. Bassett and K. I. Ashley. 2009b. Kootenay Lake fertilization experiment, year 15 (North Arm) and year 3 (South Arm) (2006) report. Ministry of Environment, Nelson, BC.

Schindler, D. W., R. E. Hecky, D. L. Findlay, M. P. Stainton, B. R. Parker, M. J. Paterson, K. G. Beaty, M. Lyng and S. E. M. Kasian. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole ecosystem experiment. Environmental Sciences 105(32): 11254-11258.

Scofield, B., D. H. Brandt, and J. G. Stockner. 2011. Dworshak Reservoir nutrient enhancement project: 2010 progress report and data summary. TG Eco-Logic, LLC, Spokane, Washington.

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.

Smith, V. H., S. B. Joye, and R. W. Howarth. 2006. Eutrophication of freshwater and marine ecosystems. Limnology and Oceanography 51: 351-355.

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. 1995. Sockeye salmon and kokanee enhancement by lake fertilization: results after two decades of application to lakes of British Columbia, Canada. Marine and Freshwater Habitat Division, Department of Fisheries & Oceans, Vancouver, BC.

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

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

Stockner, J. G., and K. S. Shortreed. 1994. Autotrophic picoplankton community dynamics in a pre-alpine lake in British Columbia, Canada. Hydrobiologia 274:133-142.

Stockner, J. G., and K. S. Shortreed. 1988. Response of Anabaena and Synechococcus to Manipulation of Nitrogen: Phosphorus Ratios in a Lake Fertilization Experiment. Limnology and Oceanography 33(6): 1348-1361.

TG Eco-Logic. 2008. Dworshak Reservoir nutrient enhancement project: 2007 progress report and data summary. TG Eco-Logic, LLC, Spokane, Washington.

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

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.

Wilzbach, M. A. 1985. Relative roles of food abundance and cover in determining the habitat distribution of stream-dwelling cutthroat trout *Salmo clarkii*.

Wipfli, M. S., J. Hudson, and J. Caouette. 1998. Influence of salmon carcass on stream productivity: response of biofilm and benthic macroinvertebrates in southeastern Alaska, U.S.A. Canadian Journal of Fisheries and Aquatic Science 55:1503-1511.

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

Table 1. 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	9.9	1.2
2008	4.0	3.9	4.2	10.2	2.1
2009	3.8	3.4	4.1	9.6	1.4
2010	3.8	3.6	3.9	9.8	1.5
2011	3.7	3.6	3.9	9.7	1.7

Table 2. Length statistics for two age classes of kokanee from Dworshak Reservoir from three years prior to N supplementation (2003, 2004, and 2006) and four years during N supplementation (2007 – 2010). 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	262.0		1.05	274	278
13-Jul	2004	300.7	317	1.06	318	308
24-Jul	2006	196.3		1.05	206	210
13-Jul	2007	241.0		1.06	255	264
31-Jul	2008	302.2	328	1.05	316	306
20-Jul	2009	271.7	284	1.05	286	285
14-Jul	2010	220.2	227	1.06	233	249
26-Jul	2011	220.0	224	1.05	231	250

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	203.6		1.14	233	
13-Jul	2004	202.5	235	1.19	240	231
24-Jul	2006	144.9		1.16	168	
13-Jul	2007	198.0		1.19	235	
31-Jul	2008	208.7	252	1.14	238	235
20-Jul	2009	168.8	200	1.17	197	190
14-Jul	2010	172.0	193	1.18	204	189[a]
26-Jul	2011	170.8	235	1.15	206	213

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

Table 3. 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**	
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**
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

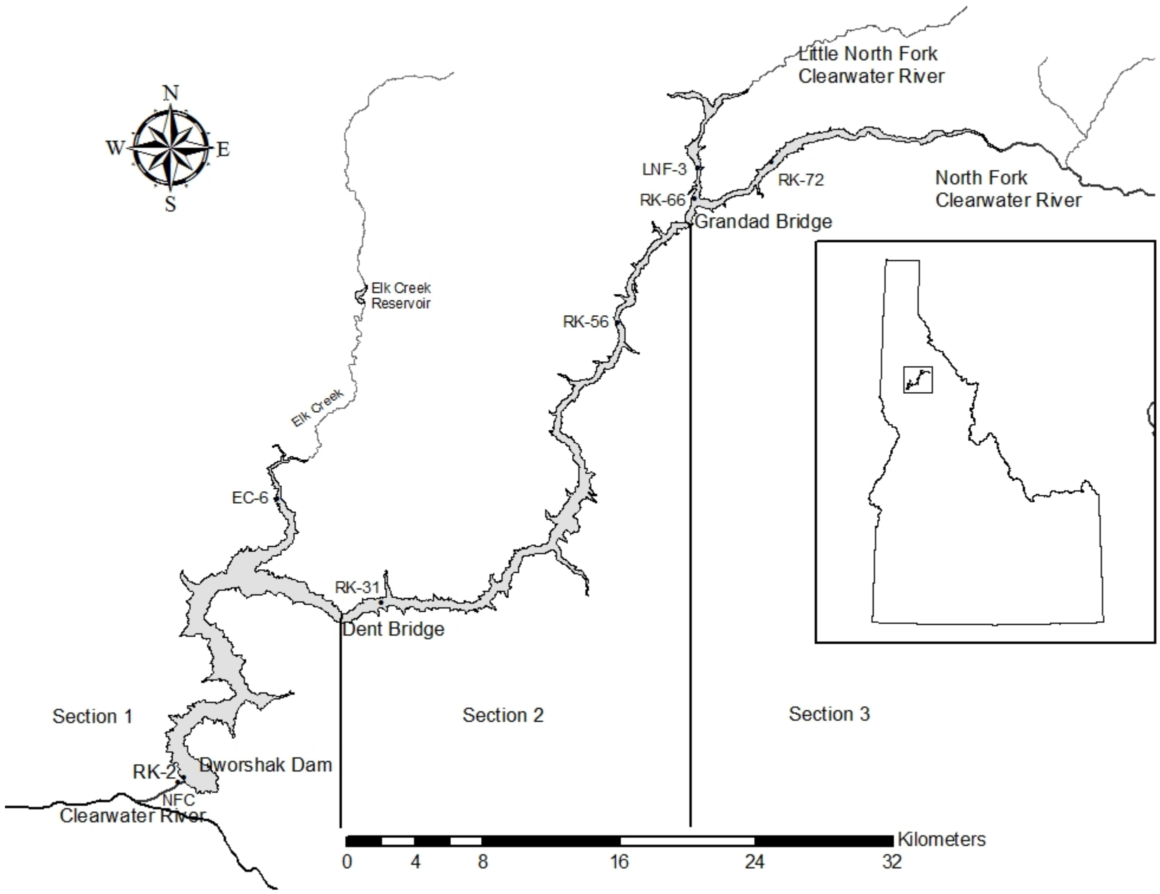

Figure 1. Map of Dworshak Reservoir depicting the locations of seven limnological sampling stations on the reservoir and one on the North Fork Clearwater below Dworshak Dam. Boundaries of reservoir sections used in statistical stratification are also shown.

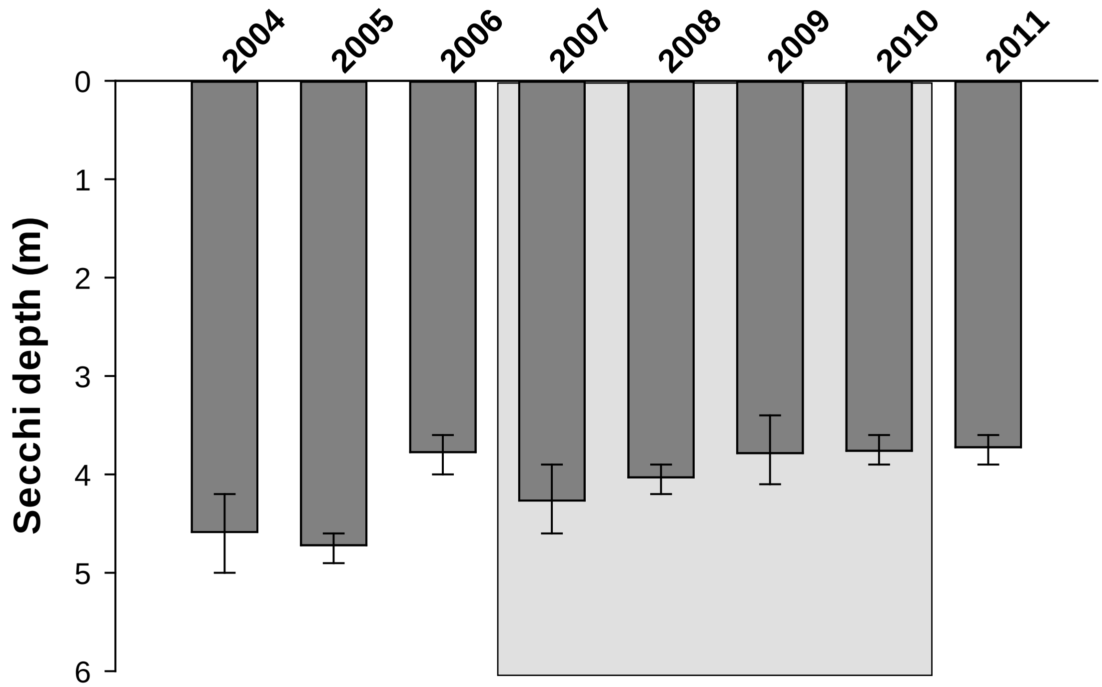

Figure 2. Mean Secchi depth measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from June through November. Error bars represent 95% confidence intervals derived by classical methods. The box indicates the period that nutrients were added to the reservoir.

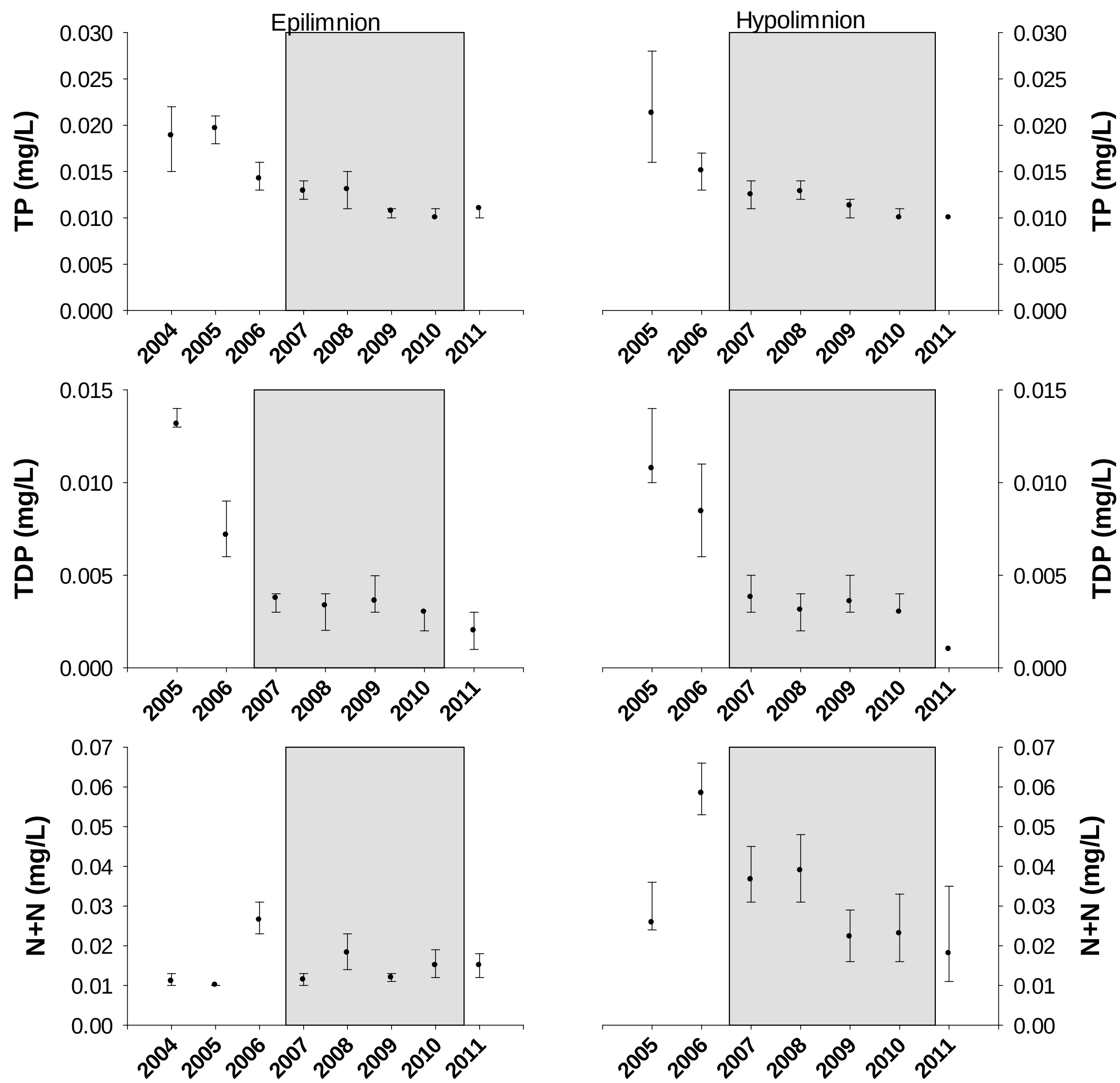

Figure 3. Mean concentration of nutrients measured from two depths at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Nutrients include total phosphate (TP), total dissolved phosphate (TDP), and nitrite plus nitrate nitrogen (N+N). Because detection limits for TP and N+N differed between years, means were calculated from values that were adjusted to reflect the highest detection limit. Error bars represent 95% confidence intervals derived by bootstrapping. Boxes indicate the period of nutrient supplementation.

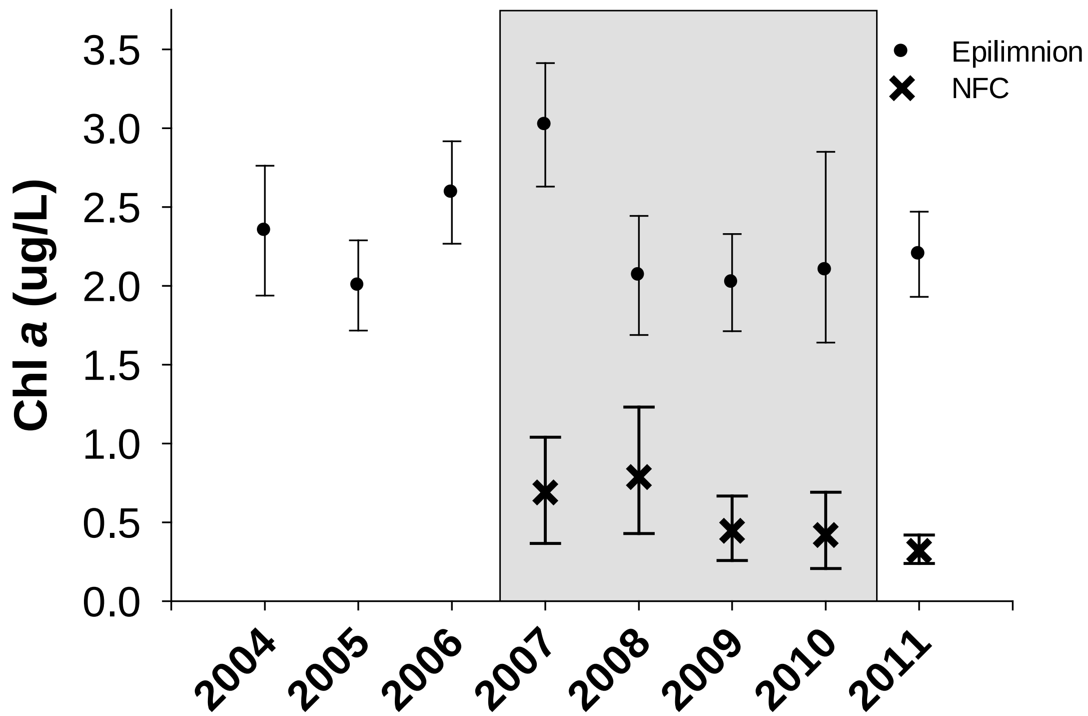

Figure 4. Mean concentration of chlorophyll *a* (Chl *a*) measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) from May through November of 2007–2011 and NFC, the station below Dworshak Dam, for 2007-2011. Error bars represent 95% confidence intervals derived by bootstrapping. The period that nutrients were added to the reservoir is indicated by the box.

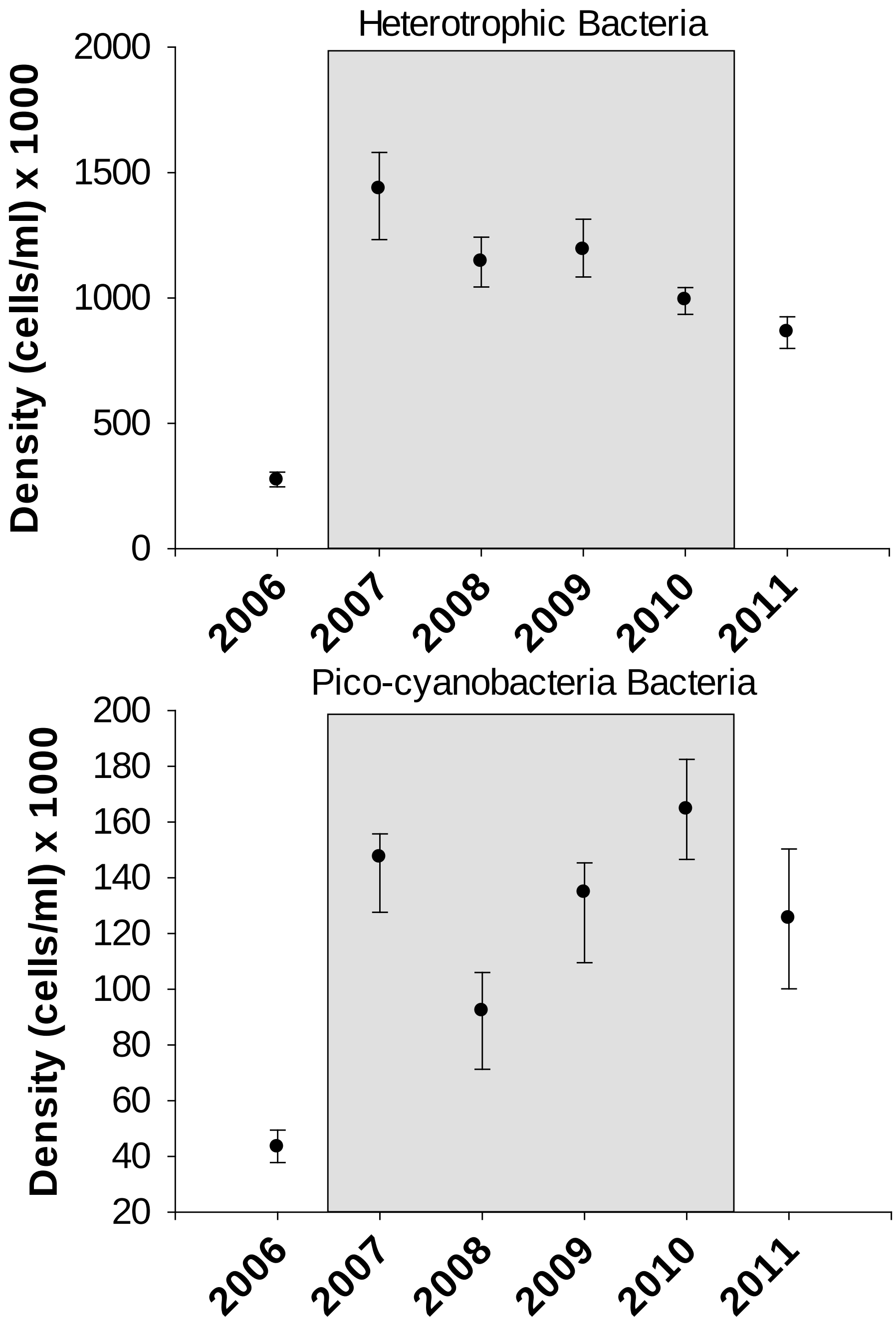

Figure 5. Mean density of picoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Error bars represent 95% confidence intervals derived by bootstrapping. The period that nutrients were added to the reservoir is indicated by the box.

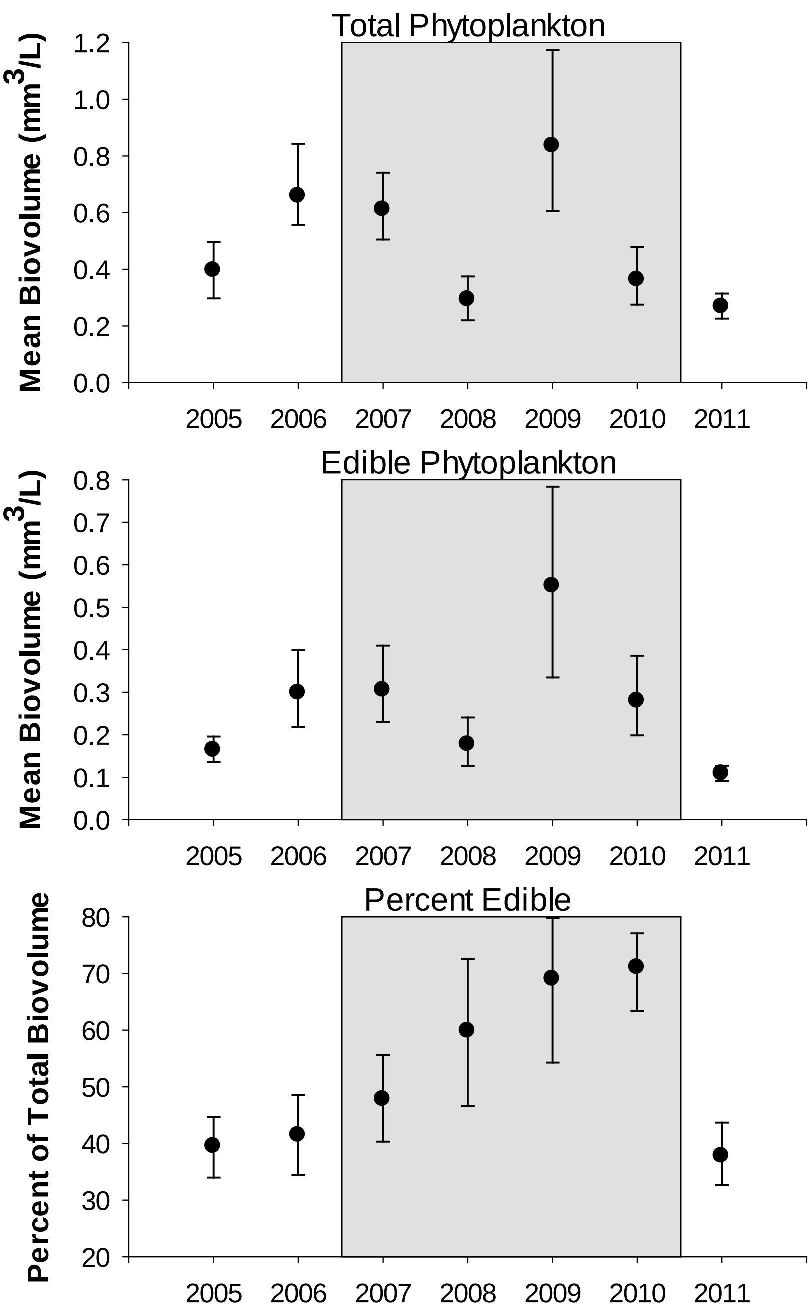

Figure 6. Mean biovolume (mm^3/L) of phytoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Biovolumes are given for total phytoplankton and edible taxa only. The proportion of the total biovolume that was edible is also shown. Error bars represent 95% confidence intervals obtained by bootstrapping. The period that nutrients were added to the reservoir is indicated by the box.

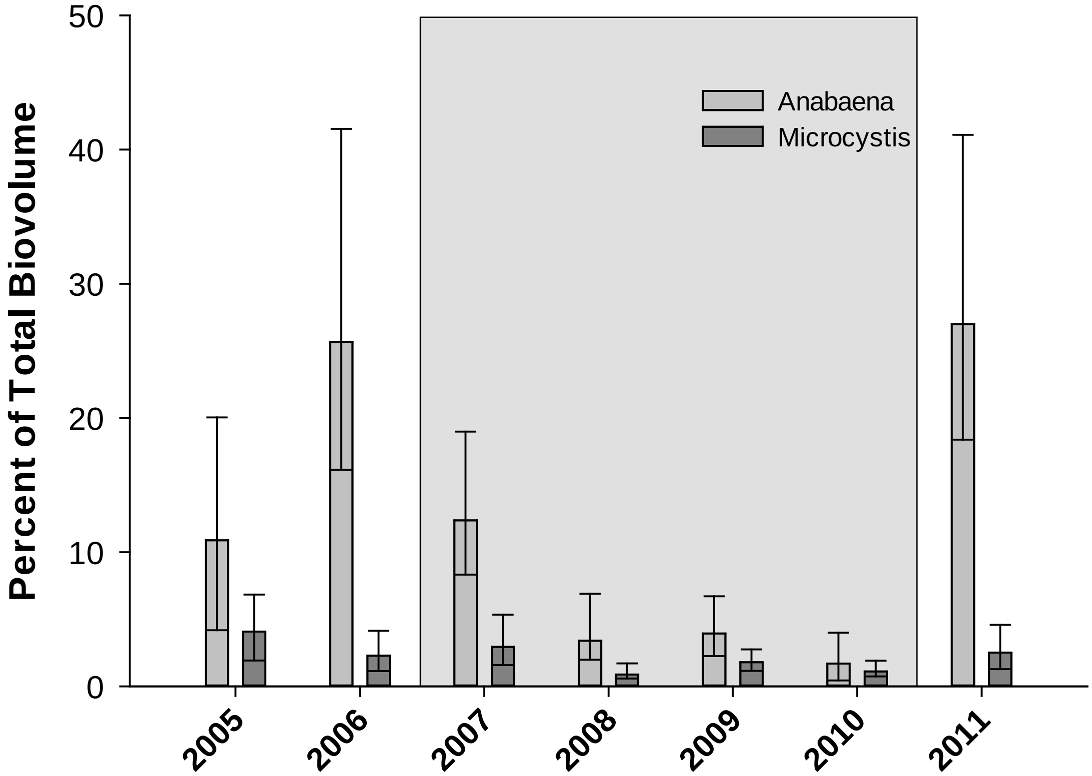

Figure 7. Mean proportion of total phytoplankton biovolume that was composed of toxigenic cyanobacteria (blue-green algae) for three years without N supplementation and four years of N supplementation. Means were taken from samples collected at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from June through November. Error bars represent 95% confidence intervals obtained by bootstrapping. The box indicates the period that N was added to the reservoir.

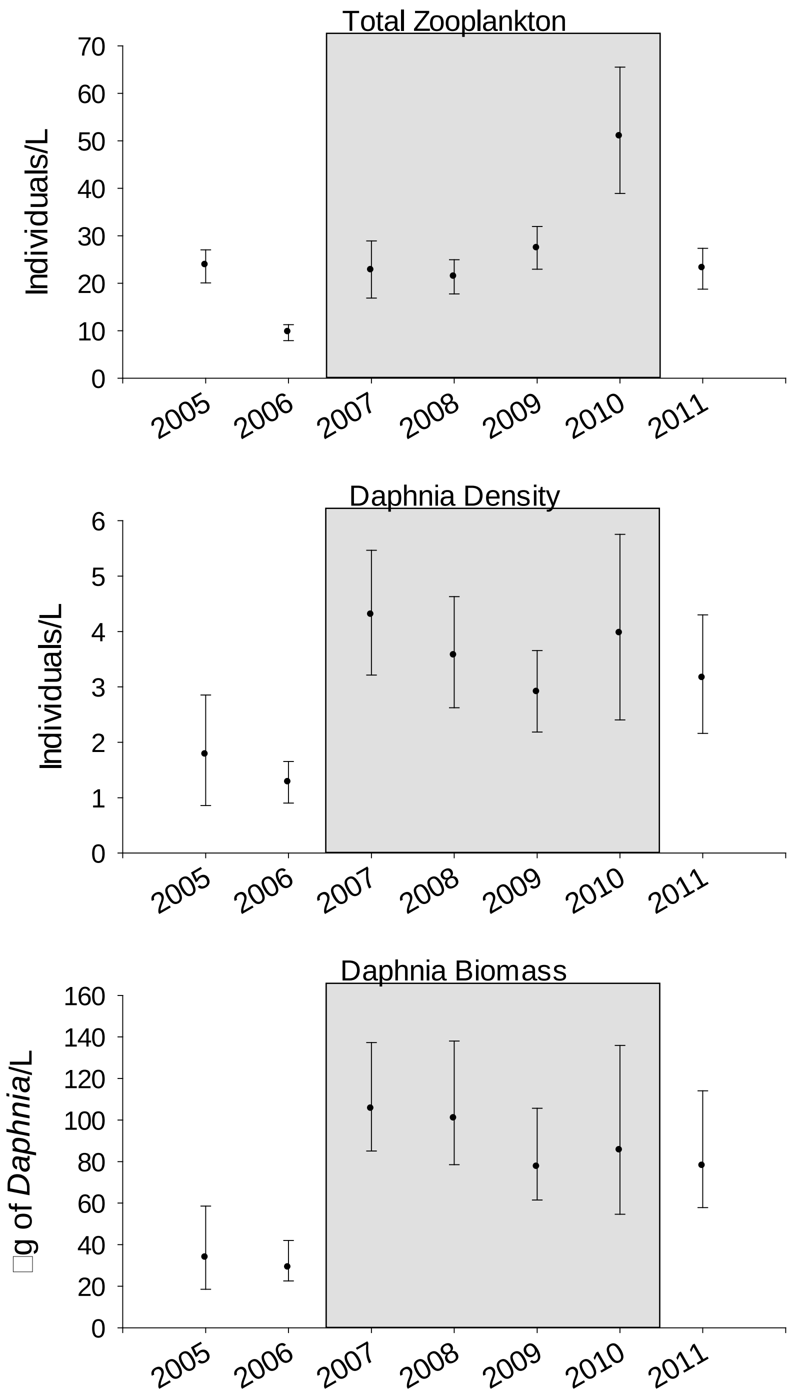

Figure 8. Mean density of zooplankton collected at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from April through November. Densities are presented for three taxonomic groups as well as total zooplankton. Error bars represent 95% confidence intervals obtained by bootstrapping. The box indicates the period that N was added to the reservoir.

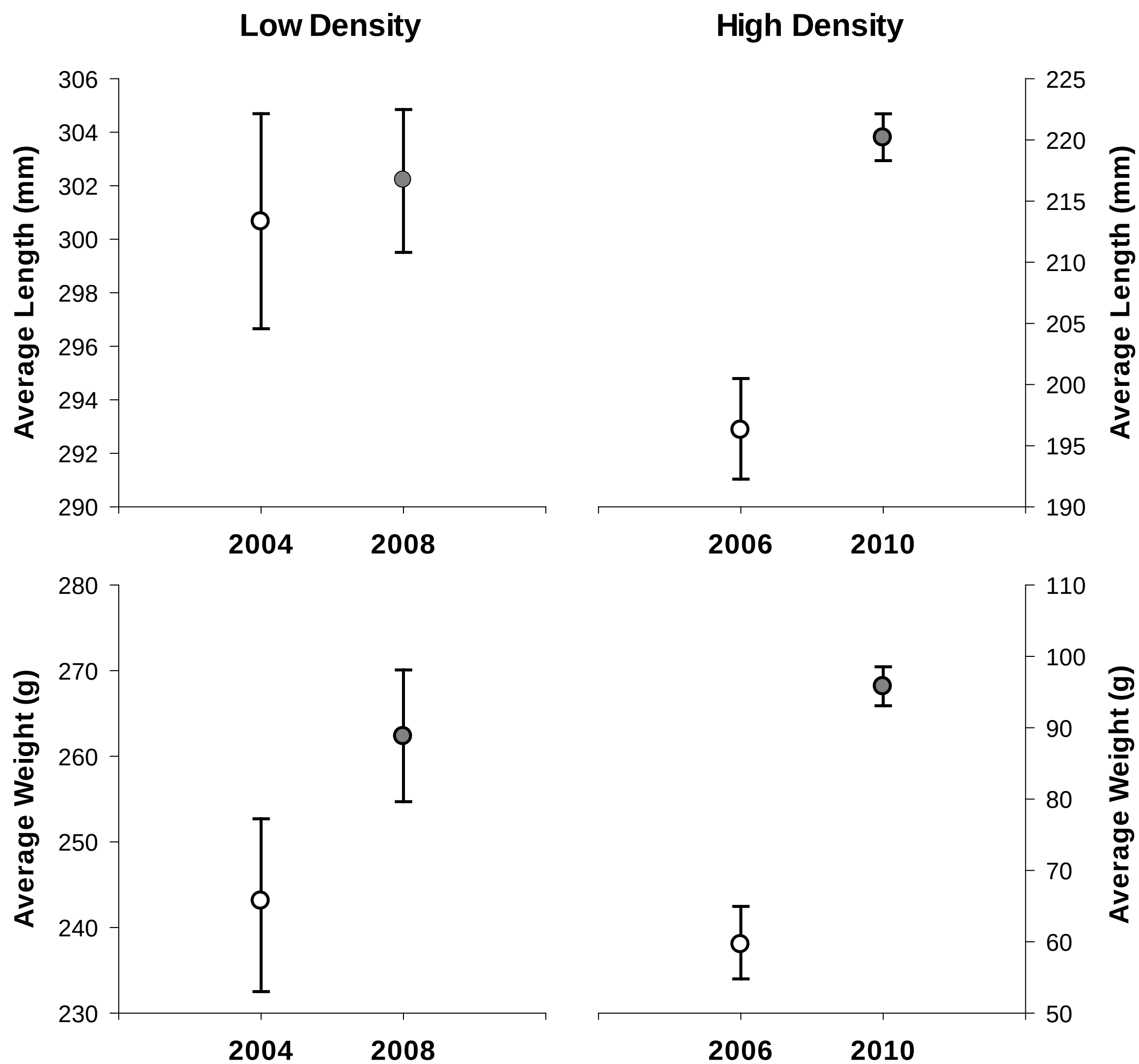

Figure 9. Comparison of mean total length and weight of age-2 kokanee captured during July trawl surveys for two low density years (2004 and 2008) and two high density years (2006 and 2010). Non-supplementation years are indicated by white circles and supplementation years are indicated by grey circles.

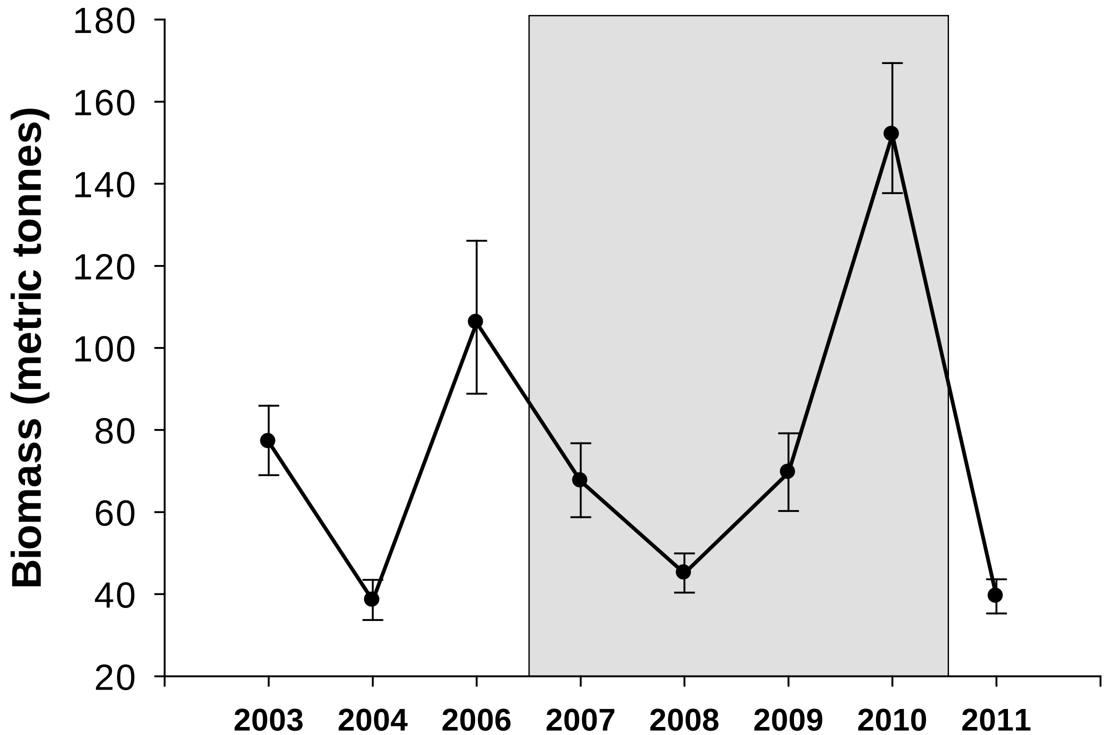

Figure 10. Estimated biomass of kokanee in Dworshak Reservoir derived from July acoustic and trawl surveys. Error bars represent 95% confidence intervals obtained by bootstrapping. The box indicates the period that N was added to the reservoir.

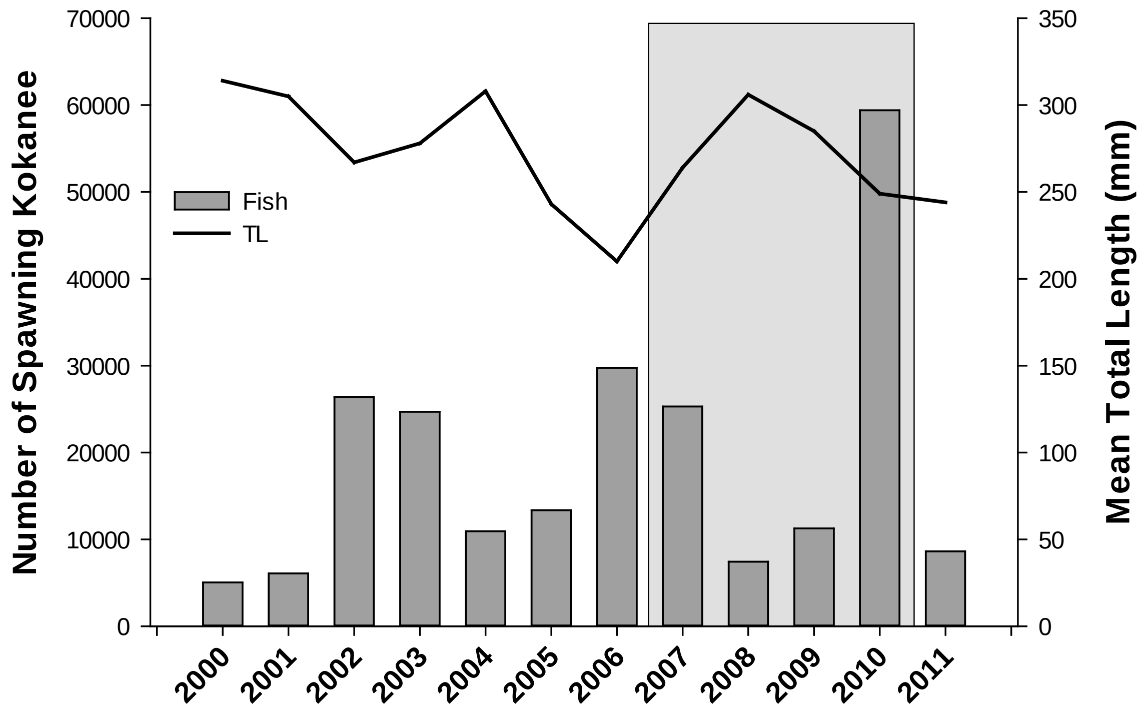

Figure 11. Counts of spawning kokanee from four index streams: Isabella, Dog, Skull, and Quartz Creeks. Counts were performed within three days of the historical peak, September 25. The line indicates the mean total length of spawning fish. The box indicates the period that N was added to the reservoir.

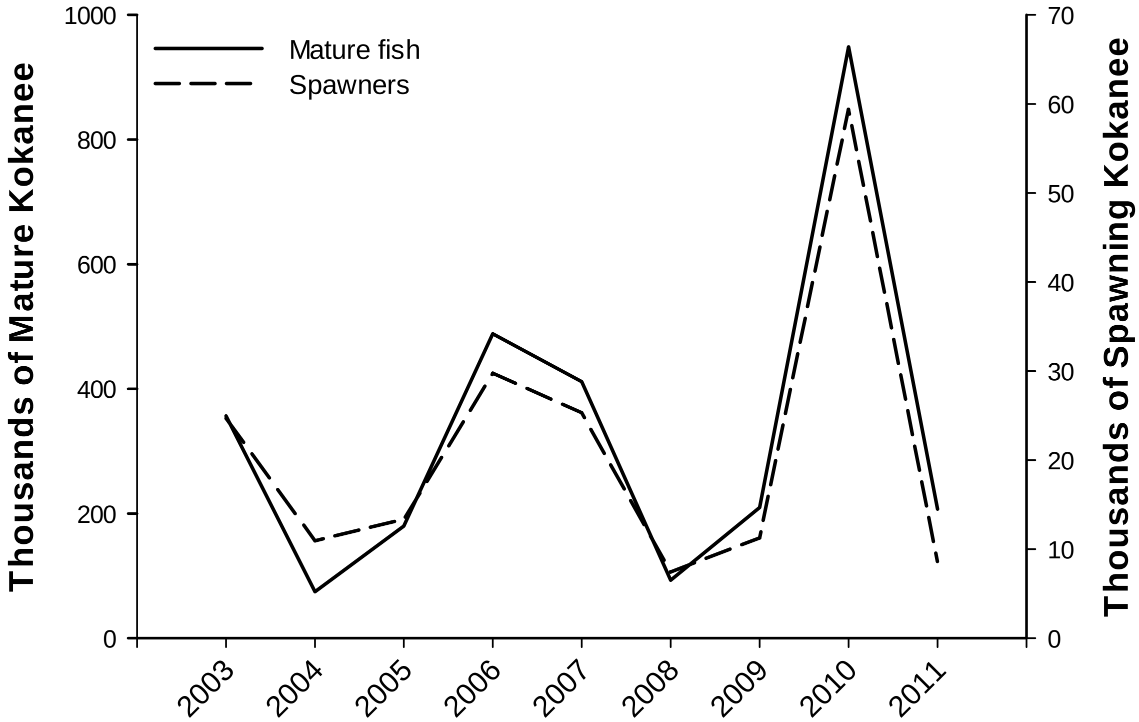

Figure 12. Estimates of mature kokanee in Dworshak Reservoir in July of each year compared to counts of spawning kokanee from four index streams: Isabella, Dog, Skull, and Quartz Creeks. Counts were performed within three days of the historical peak, September 25. The abundance of mature fish was determined by acoustic estimates and the proportion of mature fish captured in concurrent trawl surveys. When trawl caught fish were not examined for maturity, length distributions combined with proportion of mature fish observed within length categories from other years were used to estimate the proportion of mature fish.

APPENDICES

Appendix A. 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 Density (fish/ha)**
Year	**Sampling Method**	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**Total**	
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 B. Number of kokanee spawners counted in index tributaries to the North Fork Clearwater River above Dworshak Reservoir, Idaho during September 1988-2011. 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)**
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

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