



**DWORSHAK RESERVOIR
NUTRIENT RESTORATION RESEARCH, 2012**

**DWORSHAK DAM RESIDENT FISH MITIGATION
PROJECT**

**PROGRESS REPORT
March 1, 2012 – February 28, 2013**



Prepared by:

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**IDFG Report Number 13-20
November 2013**

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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 restoration as a means to restore declining reservoir productivity and improve the Dworshak Reservoir fishery. Under this agreement, the USACE applied nutrients in the form of ammonium nitrate, IDFG monitored the results using a combination of limnological and fish surveys, and Advanced Eco-Solutions provided the application schedule and limnological analysis. This report summarizes the results from 2012, the first year of a second pilot project to assess the effectiveness of nutrient restoration. Water quality standards set by the U.S. Environmental Protection Agency (EPA) and the Idaho Department of Environmental Quality (IDEQ) were not violated. The Secchi depth for 2012 (mean = 4.5 m) was one of the highest in recent years. The chlorophyll concentration (mean = 1.52 µg/L) and phytoplankton biovolume (mean = 0.169 mm³/L) were the lowest in recent history. The proportion of edible phytoplankton (52%) was higher than any non-restoration year. The length (mean = 1.12 mm) and the density (mean = 7.5 individuals/L) of *Daphnia sp.* was the highest in recent years. Together, these resulted in the highest biovolume (mean = 160 µg /L) of *Daphnia sp.* large enough to be consumed by Kokanee (TL ≥0.80 mm) in recent years. The mean age specific length and weight of Kokanee were the highest in recent years, including years of similar fish density. Dworshak Reservoir appears to be responding to nutrient restoration as anticipated and greater improvements to the fishery are possible if results are sustained. Our results to date are consistent with those reported for nutrient restoration projects in Kootenay and Arrow lakes in British Columbia.

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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second most popular destination in the Clearwater region, based on total angler trips in 2011 (Thomas MacArthur, IDFG, unpublished data).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 restoration program. Based on phosphorous (P) loading and mean chlorophyll densities, they classified Dworshak Reservoir as borderline oligo-mesotrophic. However, they found that the phytoplankton communities and associated food web present during the spring were dominated by microbial communities typical of ultraoligotrophic lakes and reservoirs. Dworshak Reservoir becomes nitrogen (N) limited by mid-summer, leading to a dominance of N fixing cyanobacteria (blue-green algae). Blue-green algae are typically abundant from mid-summer to early fall, and because they are inedible to zooplankton, represent a considerable carbon sink. Mid-summer N limitation and the subsequent reduction in zooplankton results in reduced fish production.

The Idaho Department of Fish and Game (IDFG) and the U.S. Army Corps of Engineers (USACE) initiated a five-year pilot project to evaluate nutrient restoration as a management strategy for restoring the Dworshak Reservoir ecosystem and improving the 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 restoration would benefit fish populations without degrading water quality.

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

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

This report summarizes data collected in 2012, the first year of the second pilot study. These data were used to assess both the limnological and fishery responses to nutrient restoration and determine if the biological communities are responding in a positive manner.

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 m³ (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 m³/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).

OBJECTIVES

1. Maintain an annual median Secchi depth of ≥ 3.0 m and an annual median chlorophyll *a* concentration of ≤ 3.0 $\mu\text{g/L}$ for treated areas of the reservoir.
2. Increase densities of picoplankton by twofold in the first year of nutrient restoration.
3. Increase the mean total length of age-2 Kokanee by 20 mm over that observed at a similar pretreatment Kokanee density.
4. Maintain a Kokanee population that can sustain a catch rate of 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 six stations on the reservoir and one station on the North Fork Clearwater River (NFC) below Dworshak Dam (Figure 1). Four stations on the main reservoir were designated as RK-2, RK-31, RK-56, and RK-72, corresponding with the approximate river kilometer (RKM). Two additional stations were located in untreated areas of the reservoir, RKM six of the Elk Creek arm (EC-6) and RKM three of the Little North Fork arm (LNF-3).

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

Physical parameters measured included water depth, water clarity, water temperature, dissolved oxygen (DO), and photosynthetically active radiation (PAR). Chemical parameters included pH, total phosphorus (TP), total dissolved phosphorus (TDP), total nitrogen (TN), nitrate plus nitrite nitrogen (N+N), total ammonia (TA), total dissolved solids (TDS), and

dissolved organic carbon (DOC). Biological parameters included chlorophyll *a* (Chl *a*), picoplankton, phytoplankton, and zooplankton. Sampling for TN, TA and DOC was only conducted during the first event each month. Moreover, DOC samples were only taken at RK-31 and RK-72. 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) Professional Plus multi-parameter meter, polarographic probe and 70 m cable. 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
 l_D = light intensity at depth
 l_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. Pretreatment data were collected from a depth that was twice the Secchi depth to the surface. Since these depths were, on average, similar to the current depth strata, they were compared directly to the data collected from 2008 through 2011 taken from 10 m to the surface. Since data from 2007 were collected from 30 m to the surface, it was first adjusted by calculating the proportion of zooplankton collected in 2008 from 10 to 0 m to the total amount collected in the 10 to 0 m and 30 to 10 m tows (Wilson et al. 2010). The annual mean for this proportion was then applied to the 30 to 0 m data from 2007 to estimate the density of zooplankton from 10 to 0 m. A similar proportion was developed to adjust the estimated biomass of *Daphnia 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):

$$\ln w = \ln a + b \times \ln L$$

Where: $\ln w$ = natural log of weight in µg
 $\ln a$ = estimated intercept
 b = estimated slope
 $\ln L$ = natural log of length in mm

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

$$\ln a = 2.64$$
$$b = 2.54$$

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 treatment and non-treatment periods were weighted by year to account for interannual differences in sampling intensity. For data that were not normally distributed, we used a bootstrap technique to derive

95% confidence intervals (Chernick 1999; Efron and Tibshirani 1994). For this, the original data were resampled with replacement using R 3.0.0. For each year, 1000 iterations were performed in which a bootstrap mean was calculated. Confidence intervals were derived using the percentile method, where the lower confidence limit was equal to the 2.5 percentile of the bootstrap distribution and the upper confidence interval was equal to the 97.5 percentile (Chernick 1999).

Quality Assurance

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

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

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

Where: S_1 = Original sample
 S_2 = Duplicate sample

Kokanee Population Monitoring

Abundance

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

A single hydroacoustic survey was conducted in July concurrent with a trawl survey. The survey was conducted using a Simrad model EK-60 echo sounder and a 120 kHz split beam transducer. The unit was calibrated prior to the survey using a -40.4 decibel (dB) calibration sphere. Kokanee abundance was estimated using a stratified systematic sampling design using the previously described strata. Transects of similar length were laid out in a zigzag pattern across the reservoir, with one transect beginning where the last one ended (Simmonds and MacLennan 2005). Boat speed during the survey averaged 2.0 m/s. The echo sounder was set to ping at 0.6 s intervals with a pulse width of 0.256 milliseconds.

The pelagic region of each echogram was analyzed using Echoview 4.0 software. For the analysis, a maximum beam compensation of 6.0 dB and a minimum and maximum

normalized pulse length of 0.3 and 1.8 were used to distinguish fish from noise. Depths between 10 and 30 m were analyzed using an echo integration technique to calculate the nautical area scattering coefficient (NASC) and mean target strength (TS). Fish densities were calculated as:

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

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 preimpoundment 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 10 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).

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

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 restoration, 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

In 2012, inflow to Dworshak Reservoir averaged 189 m³/s, compared to the 10-year (2002 – 2011) mean of 155 m³/s (Figure 2). Inflow peaked on April 25, 2012 at 1,081 m³/s and a minimum inflow of 14 m³/s was observed on September 3, 2012. Mean discharge through Dworshak Dam was 177 m³/s, compared to the 10-year mean of 155 m³/s. The peak discharge of 552 m³/s occurred on April 21, 2012 and a minimum discharge of 42 m³/s occurred from January 1 through February 26. Pool elevation was similar to the 10-year mean, with the exception of periods in April and December when it typically deviated by 5 m (Figure 2).

Physical and Chemical Limnology

Temperature

The mean water temperature for the multiyear sampling frame at 1 m was 17.9°C for 2012. The mean for 2004-2011 was 17.8°C. The reservoir was completely stratified by May 21, 2012 and remained stratified until August 27, 2012. Thermal stratification lasted for 147 days, which was longer than the mean for 2004-2011 (mean = 133 days).

Dissolved Oxygen

DO concentrations remained near saturation for most of the season. However, DO levels below 5 ppm were frequently observed between August 14 and November 6 at four stations (EC-6, LNF-3, RK-56, and RK-72) and at a mean depth of 31 m and mean temperature of 11°C. Within this date range, 6% of the DO measurements were below 5 ppm.

Water Clarity

The median Secchi depth for the entire reservoir was 3.5 m, whereas the median for the treated area of the reservoir was 3.8 m. Secchi depths were compared between years using a modified multiyear sampling frame (June – November). Mean Secchi depth for this period was 4.3 m for 2012 (Figure 3) compared with 4.1 m for 2004-2011 and 4.2 m for non-restoration years (2004-2006 and 2011). Additional summaries of Secchi depths for 2012 can be found in Brandt (2013).

The mean compensation depth for 2012 was 9.7 m, which was similar to other years for which we have data (mean = 9.3 m; 2007-2011). Historical summaries of water clarity can be found in Appendix C.

Phosphorus

The median value for TP in 2012 was 0.007 mg/L for the epilimnion, 0.003 mg/L for the hypolimnion and 0.006 mg/L for the river. Mean values for TP were compared between years by first adjusting the MDL to 0.010 mg/L. Mean epilimnetic TP for the multiyear sample frame in 2012 was 0.011 mg/L, compared to the long-term mean of 0.014 mg/L for 2004-2011 (Figure 4).

The median value for TDP in 2012 (median = 0.001 mg/L) was the same for the epilimnion, hypolimnion and river. No adjustments were made when comparing mean values for TDP. Mean epilimnetic TDP for the multiyear sample frame in 2012 was 0.002 mg/L, compared to the long-term mean of 0.005 mg/L for 2004-2011 (Figure 4). Additional summaries of phosphorus data for this study can be found in Brandt (2013).

Nitrogen

The median value for TN during 2012 was 0.045 mg/L for the epilimnion, 0.020 mg/L for the hypolimnion and 0.060 mg/L for the river. No adjustments were made when comparing mean values for TN. Mean epilimnetic TN for the multiyear sample frame in 2012 was 0.043 mg/L, compared to 0.107 mg/L for 2011.

Concentrations of TA were typically undetectable in 2012. Therefore, the median value (median = 0.005 mg/L) was the same for the epilimnion, hypolimnion and river. No adjustments

were made when comparing mean values for TA. Mean epilimnetic TA for the multiyear sample frame in 2012 was 0.026 mg/L, compared to 0.019 mg/L for 2011.

The median value for N+N during 2012 was 0.001 mg/L for the epilimnion, 0.002 mg/L for the hypolimnion and 0.038 mg/L for the river. Mean values for TP were compared between years by first adjusting the MDL to 0.010 mg/L. Mean epilimnetic N+N for the multiyear sample frame in 2012 was 0.015 mg/L, which was identical to the long-term mean for 2004-2011 (Figure 4). Additional summaries of nitrogen for this study can be found in Brandt (2013).

Total Dissolved Solids

The median value for TDS during 2012 was 17 mg/L for the epilimnion and 14 mg/L for the river. Median TDS values were similar across years. Additional summaries of TDS for this study can be found in Brandt (2013).

Dissolved Organic Carbon

The median value for DOC during 2012 was 2.6 mg/L for the epilimnion. This is similar to the long-term mean of 2.7 mg/L for 2007-2011.

Biological Indicators

Chlorophyll a

The median value for Chl a in the epilimnion was 1.51 µg/L for treated areas of the reservoir and 1.95 µg/L for untreated areas. Chl a was compared between years using the multiyear sampling frame. The mean for this period in 2012 was 1.52 µg/L, compared to the long term-mean of 2.30 µg/L for 2004-2011 (Figure 5). Additional summaries of Chl a data can be found in Brandt (2013).

Picoplankton

The mean density of heterotrophic bacteria in 2012 was 913,000 cells/ml. Densities of picoplankton were compared between years using a modified multiyear sampling frame (May – October). The mean density of heterotrophic bacteria for this period during 2012 was 897,000 cells/mL, compared to the long-term mean of 984,000 cells/mL for 2006-2011 (Figure 6).

The mean density of picocyanobacteria in 2012 was 104,000 cells/ml. The mean density of picocyanobacteria for the multiyear sampling frame during 2012 was 154,000 cells/mL, compared to the long-term mean of 118,000 cells/mL for 2006-2011 (Figure 6). Additional summaries of picoplankton data can be found in Brandt (2013).

Phytoplankton

The mean biovolume of total phytoplankton was 0.180 mm³/L for 2012. The mean biovolume for the multiyear sampling frame was 0.169 mm³/L for 2012, as compared to the long-term mean of 0.489 mm³/L for 2005-2011 (Figure 7). The mean biovolume of total phytoplankton was similar for the restoration (mean = 0.454 mm³/L) and non- restoration (mean = 0.441 mm³/L) period.

The phytoplankton community was composed of five major taxa in 2012. The dominant taxa in 2012 were flagellates, which represented 37% of the total annual biovolume. The next most common taxa were blue-greens, which represented 27% of the biovolume. Diatoms (19%) and Coccioid greens (15%) were less common and Dinoflagellates (2%) were rare.

The mean biovolume of edible phytoplankton was 0.010 mm³/L for 2012. The mean biovolume for the multiyear sampling frame was 0.087 mm³/L for 2012, as compared to the long-term mean of 0.260 mm³/L for 2005-2011. The mean biovolume of edible phytoplankton was higher for the restoration period (mean = 0.276 mm³/L) than the non-restoration period (mean = 0.176 mm³/L).

The proportion of the phytoplankton community that is known to be edible was 52% in 2012. The mean proportion of edible phytoplankton for the multiyear sampling frame for 2012 was also 52% (Figure 7), which represents a 30% increase compared to the mean for non-restoration years (40%; 2005-2006, 2011). For 95% of the bootstrap iterations, this increase was at least 15%.

The mean biovolume of *Anabaena sp.* for the multiyear sampling frame in 2012 was 0.008 mm³/L, which was lower than the mean of non-restoration years (mean = 0.107 mm³/L, Figure 7). The proportion of the total phytoplankton biovolume that was composed of *Anabaena sp.* for the multiyear sampling frame in 2012 (5%) was 77% lower than the mean of non-restoration years (21%). For 95% of the bootstrap iterations, this decrease was at least 67%. Additional summaries of phytoplankton data can be found in Brandt (2013).

Zooplankton

The mean density of all zooplankters was 20.5 individuals/L for the entire reservoir in 2012 (Figure 8). The mean density for the modified multiyear sampling frame (April – November) was 27.9 individuals/L, compared to a mean of 18.9 for non-restoration years (2005-2006, 2011). Cladocerans accounted for 39% of all zooplankton collected in 2012. This proportion was identical for the multiyear sampling frame, compared to the long-term mean of 32% for non-restoration years.

The mean density of *Daphnia sp.* for the modified multiyear sampling frame was 7.5 individuals/L in 2012 (Figure 8). This represents an increase of 168% compared to the mean for non-restoration years (mean = 2.8 individuals/L). For 95% of the bootstrap iterations, this increase was at least 102%.

The mean biomass of *Daphnia sp.* that were ≥0.80 mm (large enough to be eaten by Kokanee) for the modified multiyear sampling frame was 160 µg /L in 2012 (Figure 8). This represents an increase of 242% compared to the mean for non-restoration years (mean = 47 µg/L). For 95% of the bootstrap iterations, this increase was at least 148%.

In 2012, the mean length of *Daphnia sp.* was 1.11 mm for the entire reservoir. The mean length for the multiyear sampling frame was 1.12 mm, compared to 0.97 mm for non-restoration years. The mean length of *Bosmina sp.* was 0.43 mm for both the entire reservoir and the multiyear sampling frame, compared to 0.97 mm for non-restoration years. Additional summaries of zooplankton data can be found in Brandt (2013).

Kokanee Population Monitoring

Abundance and Density

From the hydroacoustic survey conducted on July 16-19, we estimated an overall abundance of 1,251,000 Kokanee in Dworshak Reservoir (Table 1). Of these, 819,000 were age-0, 341,000 were age-1, 85,000 were age-2, and 6,300 were age-3. These estimates were based on an overall density of 241 fish/ha (Table 1). When broken out by age, the densities were 158 fish/ha for age-0, 66 fish/ha for age-1, 16 fish/ha for age-2, and 1 fish/ha for age-3. All age-2 and age-3 fish that were sampled were beginning to mature sexually. Therefore, we estimate 91,000 mature fish in the reservoir during the month of July.

Overall abundance (544,000) was highest in Section 1, while density (406 fish/ha) was highest in Section 3 (Table 1). Overall abundance (240,000) was lowest in Section 3 and density (186 fish/ha) was lowest in Section 1. Abundance of age-0 (374,000) fish was highest in Section 1, age-1 fish (181,000) were most abundant in Section 2 and age-2 fish (56,000) were most abundant in Section 3. Age-3 fish were only found in Section 3 based on trawl surveys. Density of age-0 and age-2 were highest in Section 3, while density of age-1 was highest in Section 2. Revised abundance and density estimates for Kokanee are presented in Appendix B.

Size at Age

Midwater trawls conducted on April 17-18, July 24-26, and October 17-18 sampled a total of 541 Kokanee. Of these, 102 were captured during April trawling, 202 in July, and 237 in October. In April, trawl-caught Kokanee ranged from 74 to 264 mm total length (Figure 9). Only age-1 and age-2 fish were sampled in April; no age-0 Kokanee were encountered. A total of 38 age-1 Kokanee were captured in April, ranging from 74 to 164 mm total length (TL) with a mean of 114 mm (Table 2). A total of 64 age-2 Kokanee were captured, ranging in size from 209 to 264 mm TL. Age-2 Kokanee had a mean TL of 233 mm and a mean W_r of 84.

In July, trawl caught Kokanee ranged from 33 to 332 mm TL (Figure 9). Of these, 108 were age-0 between 33 and 73 mm TL, with a mean TL of 49 mm (Table 2). Through scale analysis and length distributions, 51 were determined to be age-1, ranging in size from 153 to 240 mm TL. The mean TL of age-1 Kokanee was 206 mm and the mean W_r was 95. Another 39 were determined to be age-2, ranging in size from 255 to 331 mm TL. Age-2 Kokanee had a mean TL of 308 mm and a mean W_r of 97. Another 172 were determined to be age-3, ranging in size from 305 to 332 mm TL. Age-3 Kokanee had a mean TL of 317 mm and a mean W_r of 96.

In October, trawl-caught Kokanee were between 48 and 291 mm TL (Figure 9). Of these, 183 were age-0 and ranged in size from 48 to 119 mm TL (Table 2). Age-0 Kokanee had a mean TL of 92 mm. Another 53 were determined to be age-1, ranging in size from 201 to 262 mm TL. Age-1 Kokanee had a mean TL of 189 mm and a mean W_r of 97. A single Kokanee captured in October was determined to be age-2, and measured 291 mm TL with a W_r of 99.

The mean TL of age-0 Kokanee increased by 37 mm from July to October (Table 2). The mean TL of age-1 Kokanee increased by 92 mm from April to July and by 29 mm from July to November, for a total of 131 mm. The mean TL of age-2 Kokanee increased by 75 mm from April to July. Growth, in terms of increases in mean TL, was slower in 2010 than for any recent year for which data exists, including 2004 (pretreatment). Seasonal increases in W_r were second only to 2008 for age-1 Kokanee, and only slightly less than 2004 for age-2 Kokanee.

Von Bertalanffy growth models were fitted to each year class for each year that we have multiple trawl survey data (2004 and 2008 – 2010). The predicted L_{∞}/L_t for each model resulted in a set of parallel lines for the month of July with no more than 3% difference between years for each year class. Therefore, we used an average value for each day to create a conversion factor, which was used to estimate L_{∞} for all years with July trawl data based on the observed L_t , since there is insufficient data to estimate this value by fitting the model in years with a single trawl survey. Estimates of L_{∞} can be found in Table 3.

The abundance of age-1 and older fish in 2012 (432,000) was similar to that of 2004 (347,000). The mean TL of age-2 fish was longer in 2012 than 2004 and the mean weight was more (Table 3).

Biomass and Production

Kokanee production from July of 2011 to July of 2012 was estimated at 101.3 metric tonnes (t). During this period, biomass was estimated to have increased from 39.4 t in 2011 to 58.3 t in 2012. The biomass of mature fish in the reservoir was estimated to be 27.3 t during July. Mortality by weight was estimated to be 101.3 t. Historical production estimates can be found in Appendix C.

Spawner Counts

On September 17, we captured 49 prespawn Kokanee: 22 from Isabella Creek, 10 from Skull Creek and 17 from Quartz Creek. In addition, we collected 20 post-spawn carcasses during spawner counts on September 26 and 27, for a total of 69 adult Kokanee. Of these, 39 were male and 30 female. Prespawn Kokanee exhibited a unimodal length distribution that ranged from 300 mm to 350 mm (Figure 10). Similar numbers of male (26) and female (23) Kokanee were captured, averaging 324 mm and 329 mm TL, respectively. The mean weight of prespawn Kokanee was 331 g. Assuming negligible mortality from July until spawning results in a biomass estimate of 30.3 t of Kokanee spawning in tributaries to Dworshak Reservoir.

Ovaries or ova were obtained from 15 females. Only 5 of these were preovulatory females, with a mean fecundity of 655 oocytes per female. The mean ova weight was 0.077 g per ova for post ovulatory females. Mean ova weight was positively and significantly related to TL (linear regression, $p = 0.05$, $r^2 = 0.40$). Relationships between TL and fecundity were not tested due to the paucity of data.

Peak Kokanee spawner counts were performed on September 26-27, during which 4,355 spawning Kokanee were counted in four index streams. This included 1,477 in Isabella Creek, 1,676 in Skull Creek, 574 in Quartz Creek, and 658 in Dog Creek. Historical spawner count data are shown in Appendix D.

DISCUSSION

Water Quality

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

The median Secchi depth for the treated portion of the reservoir (Median = 3.8 m) was well above the 3.0 m minimum stipulated by the NPDES permit. In earlier reports, the data suggested a decrease in mean Secchi depth due to nutrient restoration (Wilson et al. 2013). However, the mean Secchi depth for 2012 was one of the highest in recent years. As additional years of data have been collected, it has begun to suggest that any decrease in Secchi depth is smaller than we originally thought. Currently, the observed decrease is only 0.1 m, which is not enough to have a noticeable effect on recreational uses.

The median Chl *a* concentration for the treated portion of the reservoir (Median = 1.51 µg/L) was well below the 3.0 µg/L maximum stipulated by the NPDES permit. The mean Chl *a* concentration for 2012 was the lowest in recent history. Furthermore, our data does not indicate an increase in Chl *a* in response to nutrient restoration.

The median TP concentration for the treated portion of the reservoir (Median = 0.001 mg/L) was well below the 0.025 mg/L maximum stipulated by the NPDES permit. Since the project does not involve adding P to the reservoir, we do not anticipate any increases in either measurement of P except due to variations in natural input.

Another water quality concern is the prevalence of toxigenic cyanobacteria (blue-green algae). Historically, *Anabaena sp.* has been the dominant taxa of toxigenic cyanobacteria. *Anabaena sp.* typically becomes dominant in late summer after available N becomes exhausted. *Anabaena sp.* are known to fix N and believed to have a competitive advantage when fixed N is no longer available (Darren Brandt, Advanced Eco-Solutions, personal communication). Therefore, it was anticipated that N restoration would reduce the prevalence of *Anabaena sp.* (Stockner and Brandt 2006). In 2012, *Anabaena sp.* accounted for only 5% of the total annual biovolume of phytoplankton, which is a substantial reduction from the proportions observed in non-restoration years (mean = 21%, range = 11-27%). On several occasions, visible concentrations of *Anabaena sp.* were observed while conducting routine sampling. These concentrations were only observed on the upper end of the reservoir and were not widespread. Samples were collected from the densest concentrations and no toxins were detected by the contracting lab. No other toxigenic taxa, including *Microcystis sp.*, were detected at high enough densities to cause public health concerns in 2012. Our data does not indicate an increased prevalence of toxigenic cyanobacteria as a result of N additions, and in the case of *Anabaena sp.*, the project is likely resulting in a decreased prevalence.

Reservoir Productivity

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

Picoplankton are generally the first taxa to respond to nutrient additions because they are capable of rapid uptake of nutrients and near exponential growth (Stockner and Antia 1986). Densities of heterotrophic bacteria and pico-cyanobacteria were both many times higher than

2006, the only year prior to nutrient restoration for which we have data. However, picoplankton densities did not drop off substantially in 2011, the year that nutrient restoration was suspended. If densities for 2006 and 2011 are averaged to produce a non-restoration mean, then the increases for 2012 are more modest (58% for heterotrophic bacteria and 83% for picocyanobacteria). In either case, increases in picoplankton represent a positive response at the lowest trophic level. Picoplankton are a food base for nanoflagellates (Jurgens and DeMott 1995), which in turn are a high energy food source for zooplankton (Sanders and Porter 1990).

For 2012, the mean biovolume of total phytoplankton for the multiyear sampling frame was the lowest in recent history. The means for restoration and non-restoration years are very similar, indicating no increase in standing crop due to nutrient restoration. The mean biovolume of edible phytoplankton in 2012 was also the lowest in recent history. However, the percentage of the phytoplankton community that was edible in 2012 was higher than all non-restoration years. This suggests that the greatest effect of nutrient restoration on the phytoplankton community is a shift in the community structure.

The mean density of zooplankters in 2012 was the second highest in recent times and was higher than any non-restoration year. Of greater interest, the mean density of *Daphnia sp.* large enough to be consumed by Kokanee (≥ 0.80 m TL), was higher in 2012 than any other year in recent history. This represents more than a threefold increase over the mean for non-restoration years. Moreover, the mean length of *Daphnia sp.* was longer in 2012 than in any recent year. Together, these factors led to a mean biomass that was also the largest in recent years, and more than three times the mean for non-restoration years. These observations all support the hypothesis that nutrient restoration is leading to greater prey availability for Kokanee.

Kokanee Population Monitoring

Improved Kokanee growth is a key indicator of whether or not nutrient restoration is having desirable effects. Since Kokanee 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 2012 with a non-restoration year of similar abundance. Abundance was used instead of density because density changes with available habitat. The current regime of summer reservoir drawdowns leads to rapid changes in available habitat and therefore fish density. Thus, fish density can be affected by the timing of the survey more so than abundance. Furthermore, we only considered the abundance of age-1 and older fish, as age-0 fish represent a small proportion of the overall biomass and abundance estimates for age-0 fish are less certain.

In 2004, the estimated abundance of Kokanee was closest to that for 2012. Kokanee of all age classes were on average both longer and heavier in 2012 than in 2004. This supports the hypothesis that nutrient restoration is resulting in increased growth rates for Kokanee. This is corroborated by data for 2008, a restoration year with similar Kokanee abundance in which fish sizes were also larger than in 2004. However, the best estimate of the increase in mean TL from 2004 to 2012 is only 12 mm using uncorrected TL and 15 mm if correcting based on the timing of the trawl survey, which is short of the objective of a 20 mm TL increase. While 2004 is the closest year in abundance to 2012, the estimated abundance of age-2 and age-3 Kokanee was still 23% higher in 2012 than in 2004, and the biomass was 52% higher. Correcting for these differences in abundance would likely indicate that we were closer to the objective than the simple comparison we employed. Furthermore, this evidence only represents three years of data, of which only a single non-restoration year is represented.

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. Our methodology provides an estimate of production from July of the first year to July of the second. Thus, the 2012 production estimate encompasses both a restoration and non-restoration year, and therefore is difficult to interpret.

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

CONCLUSIONS

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

RECOMMENDATIONS

1. Continue the additional five-year pilot phase to confirm that observed benefits are a result of N restoration and further assess the benefits to the Kokanee population and resultant fishery.
2. Conduct primary productivity assays to assess changes to the productivity of the phytoplankton community rather than just standing crop.

ACKNOWLEDGMENTS

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

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Table 1. Abundance (thousands of fish) and density (fish per ha) of Kokanee in Dworshak Reservoir in July 2012. Estimates were derived from a hydroacoustic survey and age breakdowns were derived from a fixed-frame trawl survey. Estimates are broken down by age class and reservoir section.

Abundance (thousands of fish)						
Section	Age-0	Age-1	Age-2	Age-3	All Ages	
Section 1	374	153	17	0	544	
Section 2	273	181	13	0	467	
Section 3	172	6	56	6	240	
Whole reservoir	819	341	85	6	1,251	
Density (fish per ha)						
Section	Area (ha)	Age-0	Age-1	Age-2	Age-3	All Ages
Section 1	2,923	128	52	6	0	186
Section 2	1,683	162	108	7	0	278
Section 3	592	291	11	94	11	406
Whole reservoir	5,198	158	66	16	1	241

Table 2. Descriptive statistics for total lengths of Kokanee captured during midwater trawl surveys on Dworshak Reservoir on April 17-18, July 24-26, and October 17-18, 2012. Growth is given as the increase in mean length (mm) observed in each age class between surveys. Variance is expressed using standard deviation (SD).

Month	Age	Total Length (mm)					Growth (mm)
		N	Min	Mean	Max	SD	
Apr	1	38	74	114	164	20.2	
	2	64	209	233	264	9.9	
Jul	0	108	33	49	73	7.6	
	1	51	153	206	240	19.3	92
	2	39	255	308	331	13.8	75
	3	4	305	317	332	11.1	
Nov	0	183	48	85	119	16.6	37
	1	53	201	235	262	11.8	29
	2	1	291	291	291		

Table 3.

Length statistics for two age classes of Kokanee from Dworshak Reservoir from three years prior to N restoration (2003, 2004, and 2006) and four years during N restoration (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		CF	L_{∞} from CF	Mean TL (spawners)
		TL (mm)	L_{∞} from model			
30-Jul	2003	262		1.05	274	278
13-Jul	2004	295	317	1.06	312	308
24-Jul	2006	196		1.05	206	210
13-Jul	2007	241		1.06	255	264
31-Jul	2008	303	328	1.05	316	306
20-Jul	2009	272	284	1.05	286	285
14-Jul	2010	219	227	1.06	233	249
26-Jul	2011	220	224	1.05	231	250
10-Jul	2012	308	344	1.06	327	327

Length statistics for Age-1 Kokanee						
Trawl date	Year	Mean		CF	L_{∞} from CF	Mean TL October
		TL (mm)	L_{∞} from model			
30-Jul	2003	204		1.14	233	
13-Jul	2004	203	235	1.19	240	231
24-Jul	2006	145		1.16	168	
13-Jul	2007	198		1.19	235	
31-Jul	2008	209	252	1.14	238	235
20-Jul	2009	169	200	1.17	197	190
14-Jul	2010	172	193	1.18	204	189 ^a
26-Jul	2011	170	235	1.15	196	213
10-Jul	2012	206	255	1.20	247	235

^a 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
2011-12	36.9	56.2	26.4	119.5
2010-11	60.6	37.6		98.1
2009-10	48.6	54.8		103.7
2008-09	52.3	16.4		68.7
2007-08	32.2	21.3	32.7	86.2
2006-07	71.2	99.6		170.8
2005-06				NA
2004-05				NA
2003-04	23.5	30.5		54.1

Biomass (metric tonnes)					
Year	Age-0	Age-1	Age-2	Age-3	Total
2012	0.7	30.3	25.3	2.0	58.3
2011	0.2	16.5	22.8		39.4
2010	1.4	53.2	97.1		151.7
2009	0.7	47.7	21.1		69.6
2008	0.9	19.8	18.6	5.8	45.1
2007	0.3	9.9	57.4		67.5
2006	1.0	40.1	64.5		106.1
2005					NA
2004	0.3	20.1	18.1		38.5
2003	0.3	20.1	56.7		77.1

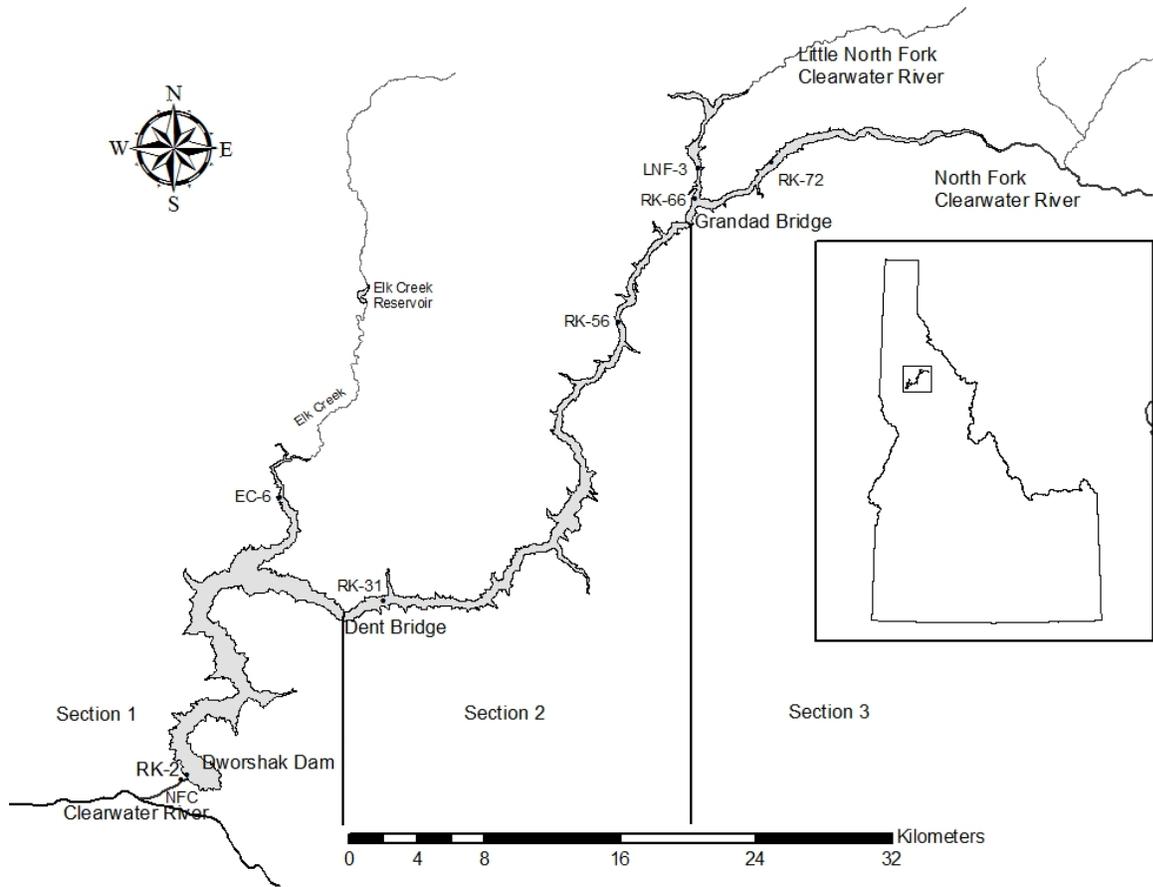


Figure 1. Map of Dworshak Reservoir depicting the locations of seven limnological sampling stations on the reservoir and one on the North Fork Clearwater below Dworshak Dam. Boundaries of reservoir sections used in statistical stratification are also shown.

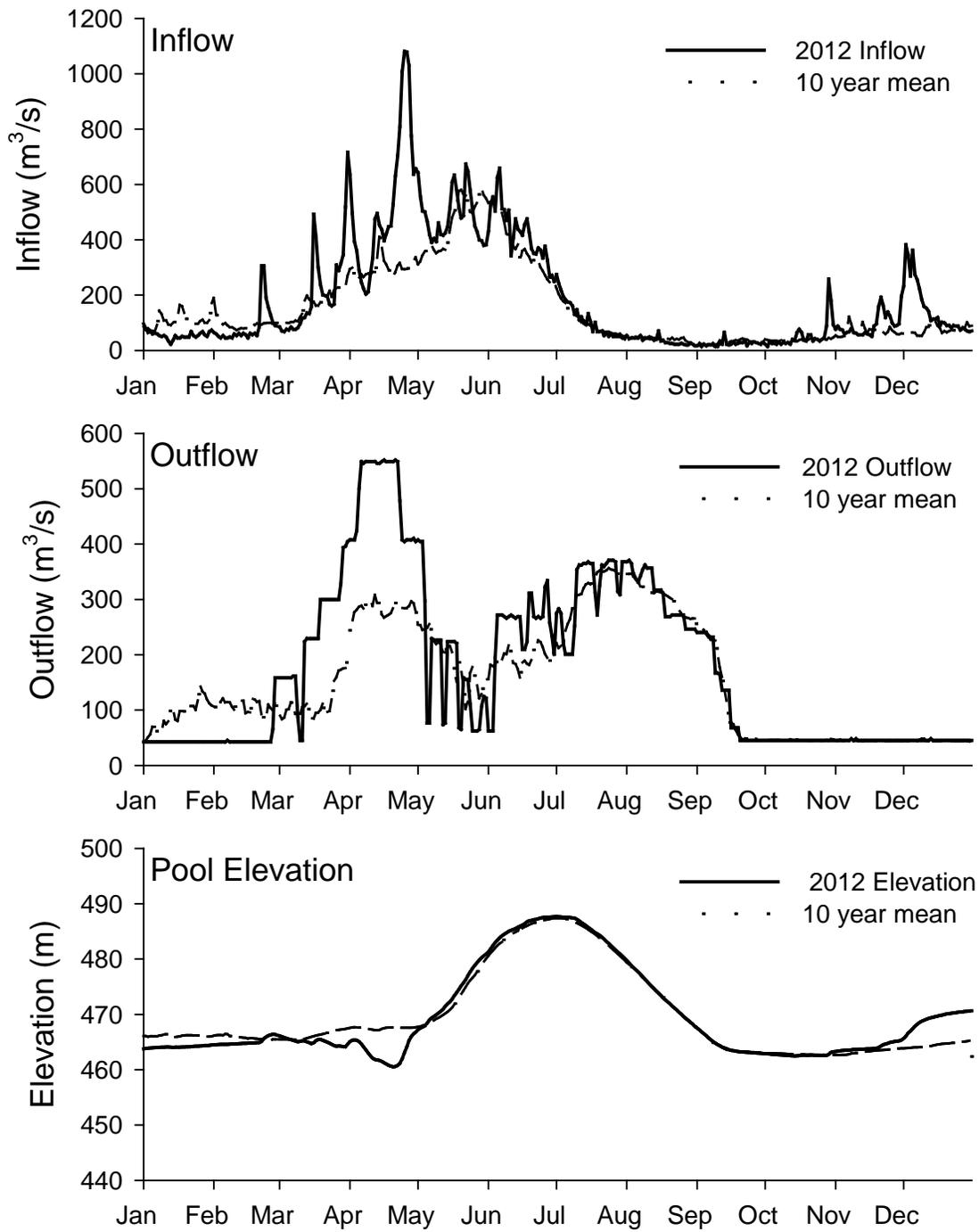


Figure 2. Mean daily inflow, outflow, and pool elevation for Dworshak Reservoir during 2012 along with the 10 year mean (2001-2011). Data provided by the U.S. Army Corps of Engineers through the Columbia River DART website (<http://www.cbr.washington.edu/dart/>; accessed May 2013).

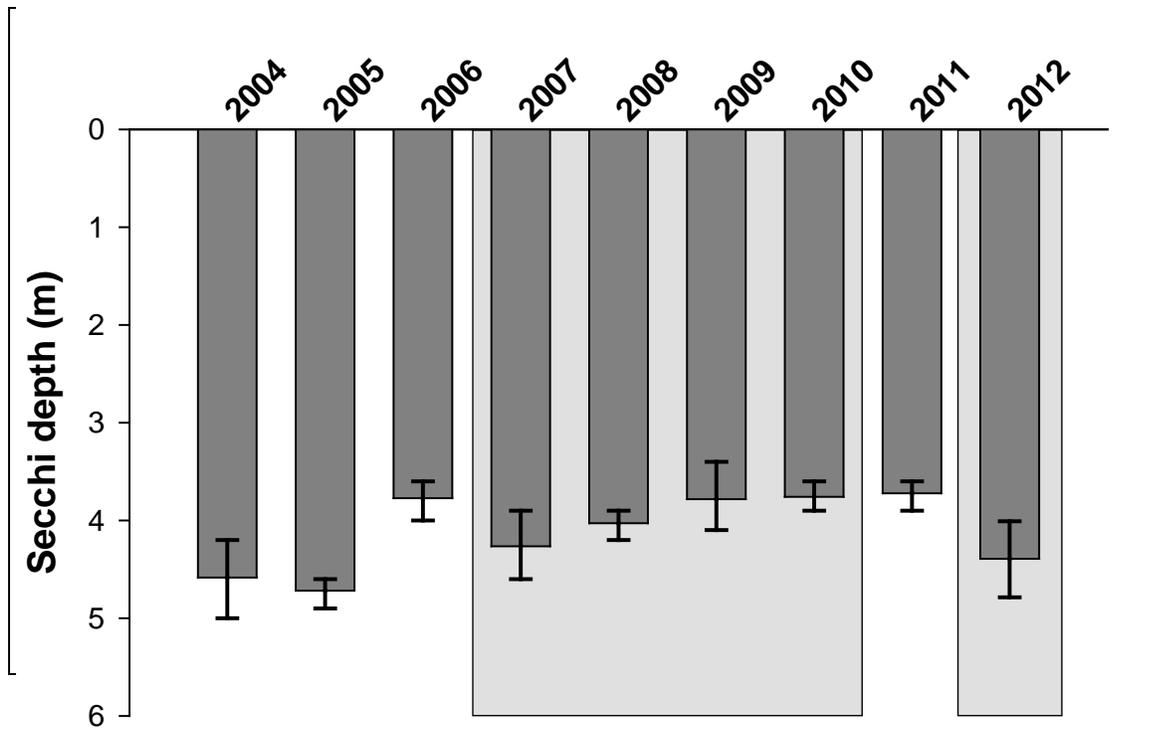


Figure 3. Mean Secchi depth measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from June through November. Error bars represent 95% confidence intervals derived by classical methods. The box indicates the period that nutrients were added to the reservoir.

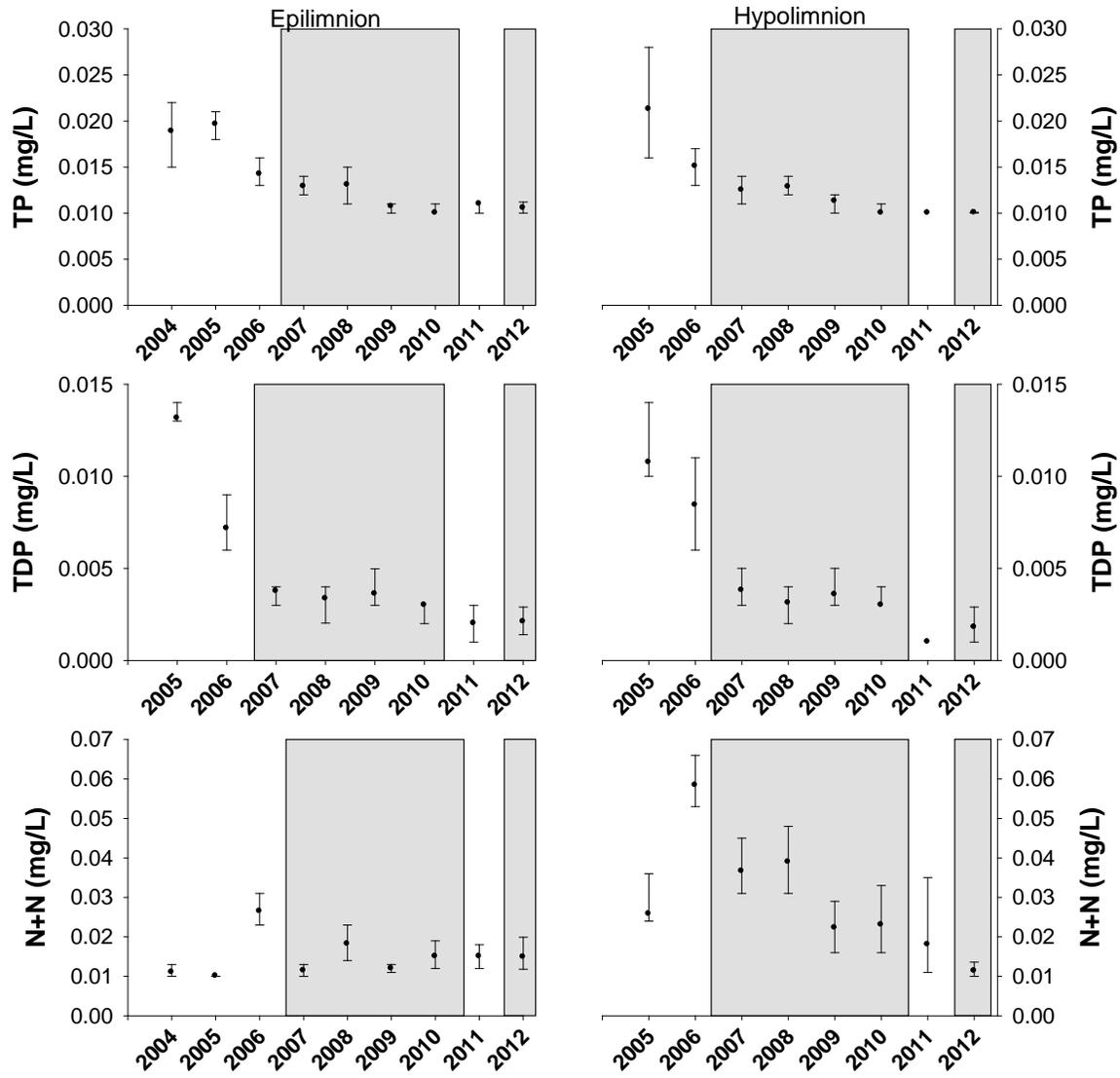


Figure 4. Mean concentration of nutrients measured from two depths at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Nutrients include total phosphate (TP), total dissolved phosphate (TDP), and nitrite plus nitrate nitrogen (N+N). Because detection 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. Shaded boxes indicate periods of nutrient restoration.

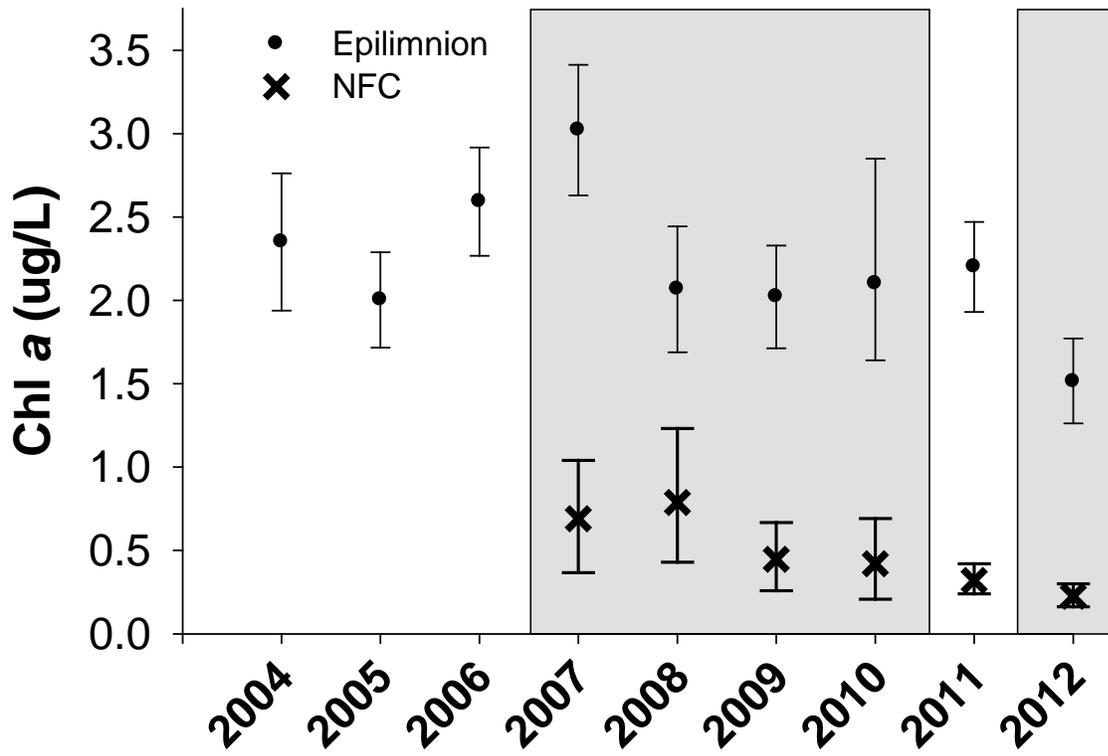


Figure 5. Mean concentration of chlorophyll a (Chl a) measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) from May through November of 2007–2011 and NFC, the station below Dworshak Dam, for 2007-2011. Error bars represent 95% confidence intervals derived by bootstrapping. Treatment periods are indicated by shaded boxes.

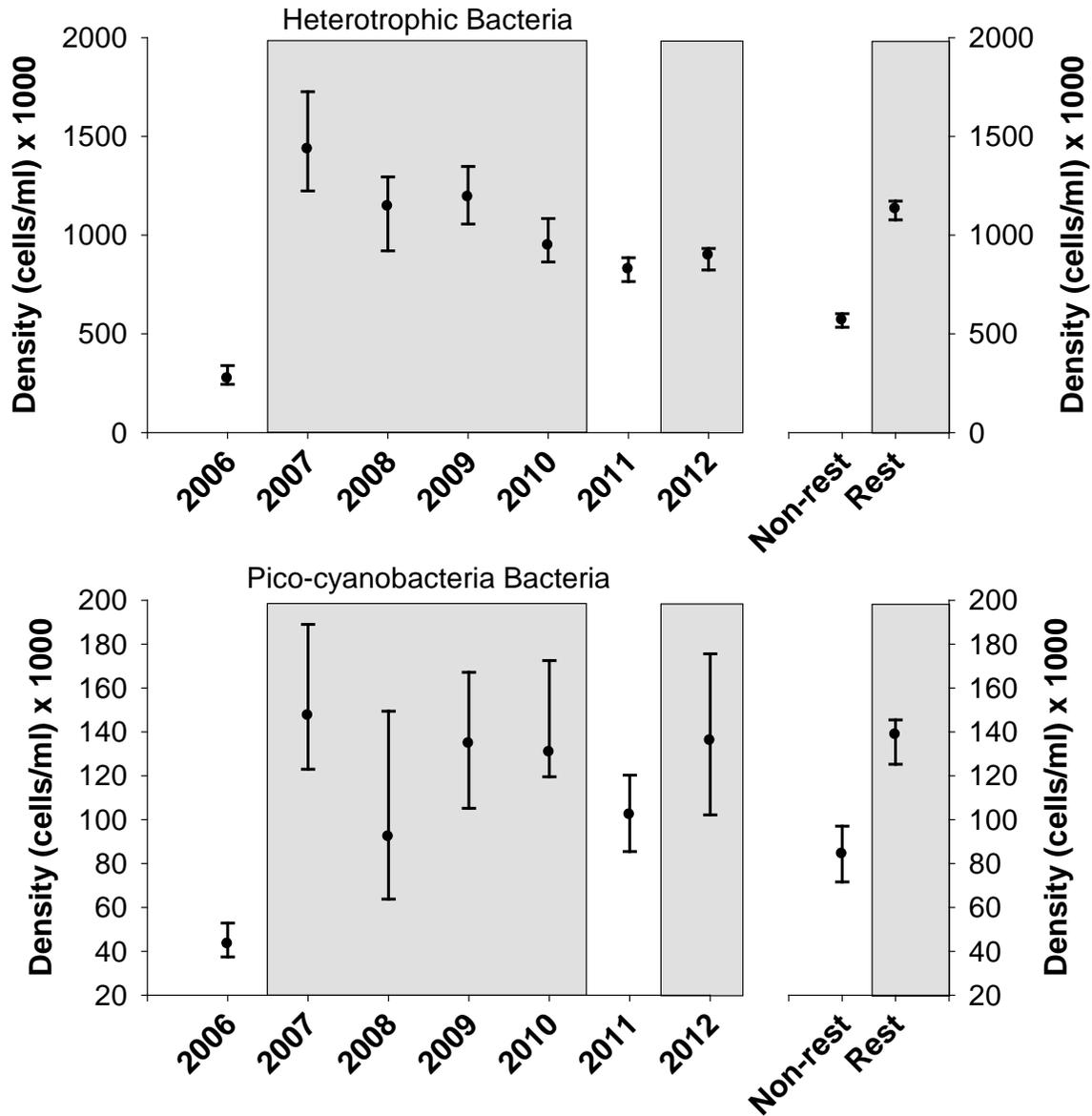


Figure 6. Mean density of picoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Error bars represent 95% confidence intervals derived by bootstrapping. Treatment periods are indicated by shaded boxes.

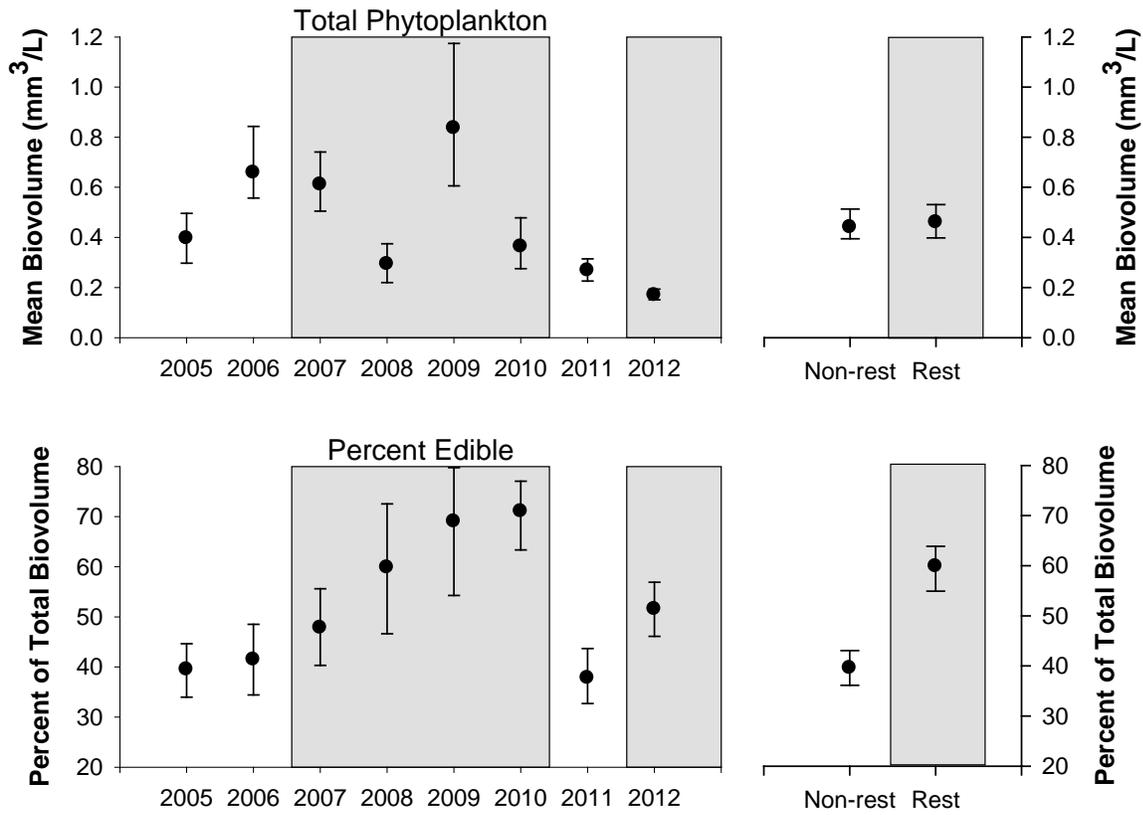


Figure 7. Mean biovolume (mm³/L) of phytoplankton measured at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from May through November. Biovolumes are given for total phytoplankton and edible taxa only. The proportion of the total biovolume that was edible is also shown. Error bars represent 95% confidence intervals obtained by bootstrapping. Treatment periods are indicated by shaded boxes.

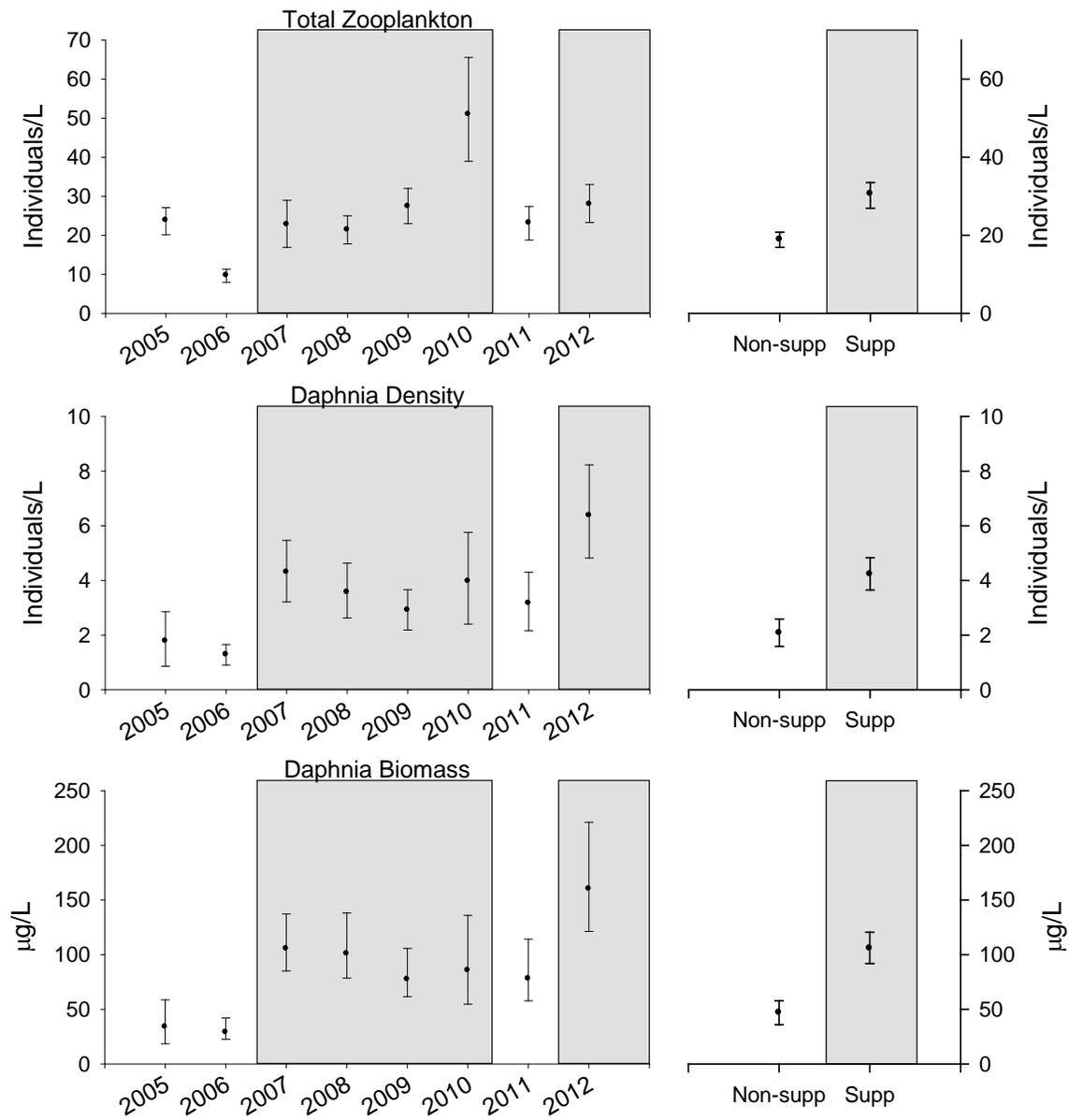


Figure 8. Mean density of zooplankton collected at four sampling stations (RK-2, RK-31, RK-56, and RK-72) on Dworshak Reservoir from April through November. Densities are presented for three taxonomic groups as well as total zooplankton. Error bars represent 95% confidence intervals obtained by bootstrapping. Treatment periods are indicated by shaded boxes.

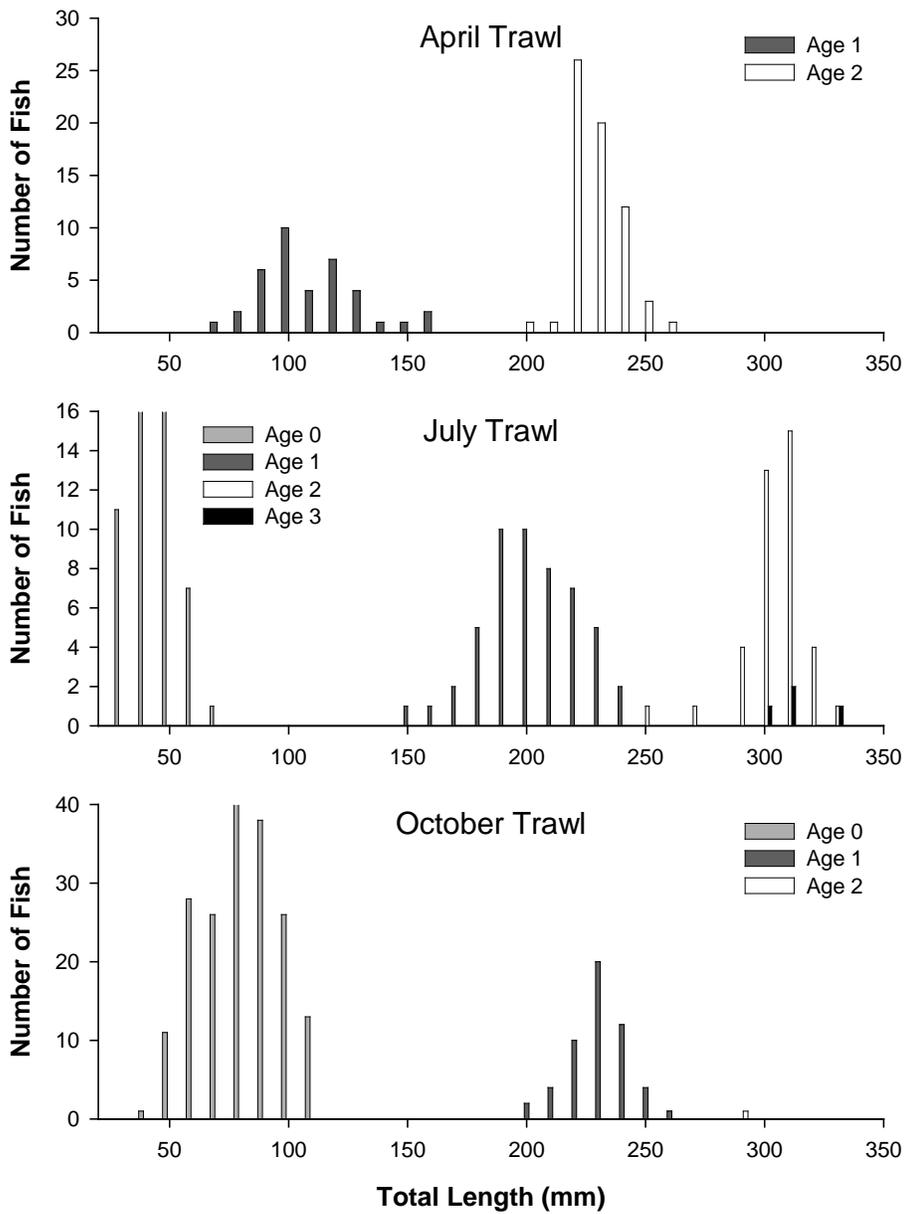


Figure 9. Length frequency of Kokanee captured in mid-water trawl surveys on Dworshak Reservoir on April 17-18, July 24-25, and October 17.

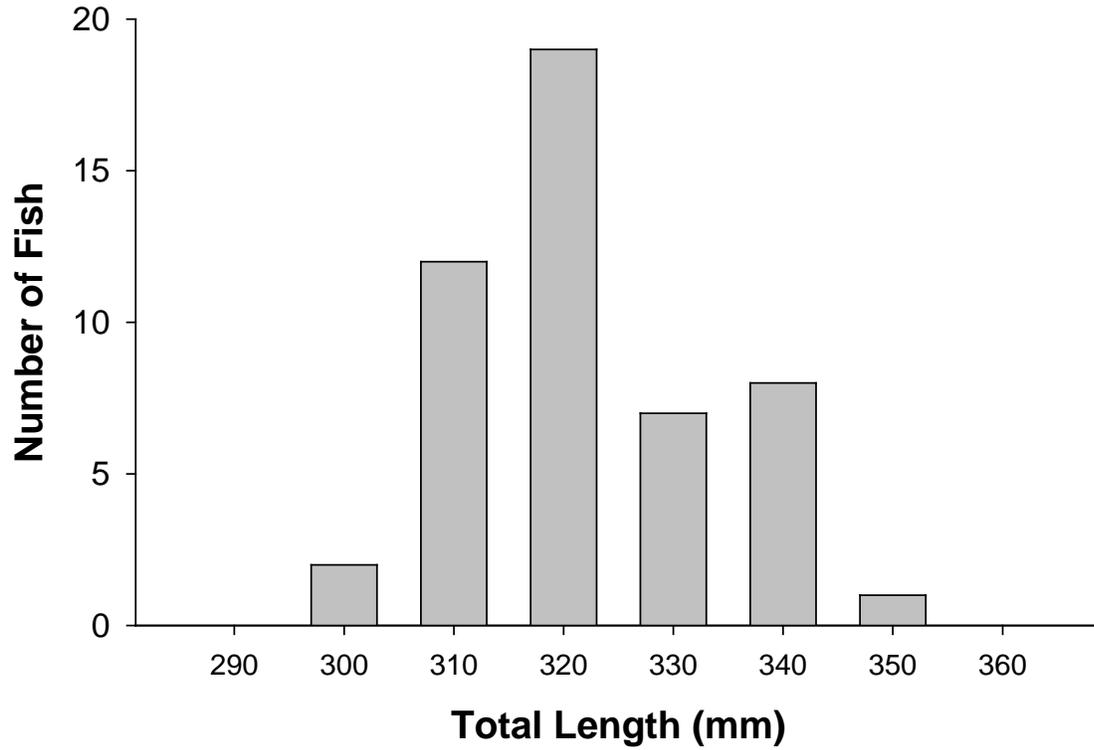


Figure 10. Length-frequency of prespawn Kokanee captured during spawner counts on September 17 from Isabella, Skull, and Quartz creeks.

APPENDICES

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

Year	Secchi Depth			Compensation Depth	
	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	1.7
2009	3.8	3.4	4.1	9.6	1.5
2010	3.8	3.6	3.9	9.8	1.6
2011	3.7	3.6	3.9	9.7	1.8
2012	4.5	4.0	4.8	10.7	10.7

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

Year	Sampling Method	Kokanee Abundance					Adult Density (fish/ha)
		Age-0	Age-1	Age-2	Age-3	Total	
2012	Hydroacoustic	819,012	340,809	85,023	0	1,251,187	18
2011	Hydroacoustic	494,073	361,416	230,670	972	1,087,132	43
2010	Hydroacoustic	2,331,120	1,177,439	1,030,226	1,483	4,538,785	190
2009	Hydroacoustic	1,022,086	1,109,492	118,753	0	2,250,331	15
2008	Hydroacoustic	1,359,430	233,123	71,024	21,986	1,685,563	18
2007	Hydroacoustic	531,703	147,300	457,245	0	1,136,248	93
2006	Hydroacoustic	1,996,987	1,550,134	1,082,431	0	4,629,552	242
2005	Hydroacoustic	2,339,695	696,738	179,734	0	3,216,167	35
2004	Hydroacoustic	448,833	272,802	74,419	0	796,054	14
2003	Hydroacoustic	372,664	281,254	356,434	0	1,010,353	69
2002	Hydroacoustic	1,246,959	1,101,232	127,933	0	2,476,124	24
2001	Hydroacoustic	1,962,000	781,000	405,000	0	3,150,000	75
2000	Hydroacoustic	1,894,857	303,680	199,155	0	2,397,691	37
1999	Hydroacoustic	1,143,634	363,250	38,464	0	1,545,347	7
1998	Hydroacoustic	537,000	73,000	39,000	0	649,000	7
1997	Trawling	65,000	0	0	0	65,000	0
1996	Hydroacoustic	231,000	43,000	29,000	0	303,000	5
1995 ^a	Hydroacoustic	1,630,000	1,300,000	595,000	0	3,539,000	110
1994	Hydroacoustic	156,000	984,000	304,000	9,000	1,457,000	69
1993	Trawling	453,000	556,000	148,000	6,000	1,163,000	33
1992	Trawling	1,040,000	254,000	98,000	0	1,043,000	22
1991	Trawling	132,000	208,000	19,000	6,000	365,000	5
1990 ^a	Trawling	978,000	161,000	11,000	3,000	1,153,000	3
1989 ^b	Trawling	148,000	148,000	175,000	0	471,000	32
1988	Trawling	553,000	501,000	144,000	12,000	1,210,000	29

^a June sampling likely resulted in an underestimate of age-0 Kokanee.

^b September sampling likely resulted in an underestimate of mature Kokanee.

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

Production (metric tonnes)				
Period	Age 0-1	Age 1-2	Age 2-3	Total
2011-12	36.9	56.2	26.4	119.5
2010-11	60.6	37.6		98.1
2009-10	48.6	54.8		103.7
2008-09	52.3	16.4		68.7
2007-08	32.2	21.3	32.7	86.2
2006-07	71.2	99.6		170.8
2005-06				NA
2004-05				NA
2003-04	23.5	30.5		54.1

Biomass (metric tonnes)					
Year	Age-0	Age-1	Age-2	Age-3	Total
2012	0.7	30.3	25.3	2.0	58.3
2011	0.2	16.5	22.8		39.4
2010	1.4	53.2	97.1		151.7
2009	0.7	47.7	21.1		69.6
2008	0.9	19.8	18.6	5.8	45.1
2007	0.3	9.9	57.4		67.5
2006	1.0	40.1	64.5		106.1
2005					NA
2004	0.3	20.1	18.1		38.5
2003	0.3	20.1	56.7		77.1

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

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