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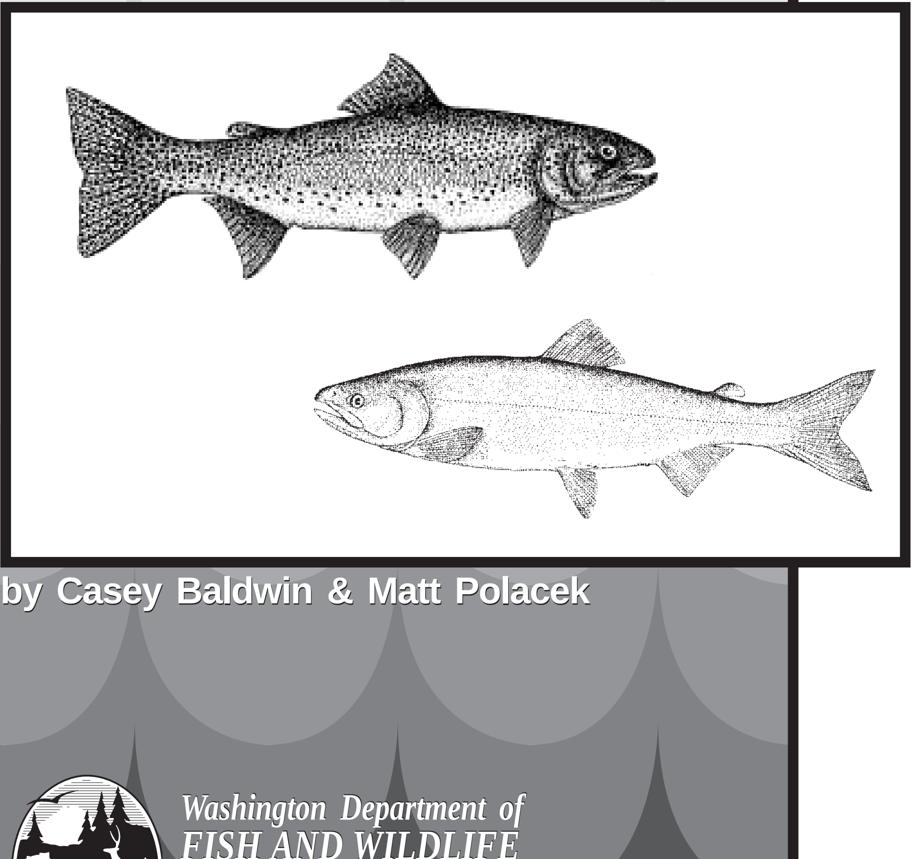
Evaluation of Limiting Factors for Stocked Kokanee and Rainbow Trout in Lake Roosevelt, WA



by Casey Baldwin & Matt Polacek

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Evaluation of Limiting Factors for Stocked Kokanee and Rainbow Trout In Lake Roosevelt, Washington, 1999

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Abstract

Hatchery supplementation of kokanee *Oncorhynchus nerka* and rainbow trout *O. mykiss* has been the primary mitigation provided by Bonneville Power Administration for loss of anadromous fish to the waters above Grand Coulee Dam (GCD). The hatchery program for rainbow trout has consistently met management goals and provided a substantial contribution to the fishery; however, spawner returns and creel survey results for kokanee have been below management goals. Our objective was to identify factors that limit limnetic fish production in Lake Roosevelt by evaluating abiotic conditions, food limitations, piscivory, and entrainment. Dissolved oxygen concentration was adequate throughout most of the year; however, levels dropped to near 6 mg/L in late July. For kokanee, warm water temperatures during mid-late summer limited their nocturnal distribution to 80-100 m in the lower section of the reservoir. Kokanee spawner length was consistently several centimeters longer than in other Pacific Northwest systems, and the relative weights of rainbow trout and large kokanee were comparable to national averages. Large bodied daphnia (> 1.7 mm) were present in the zooplankton community during all seasons indicating that top down effects were not limiting secondary productivity. Walleye *Stizostedion vitreum* were the primary piscivore of salmonids in 1998 and 1999. Burbot *Lota lota* smallmouth bass *Micropterus dolomieui*, and northern pikeminnow *Ptychocheilus oregonensis* preyed on salmonids to a lesser degree. Age 3 and 4 walleye were responsible for the majority (65%) of the total walleye consumption of salmonids. Bioenergetics modeling indicated that reservoir wide consumption by walleye could account for a 31-39% loss of stocked kokanee but only 6-12% of rainbow trout. Size at release was the primary reason for differential mortality rates due to predation. Entrainment ranged from 2% to 16% of the monthly abundance estimates of limnetic fish, and could account for 30% of total mortality of limnetic fishes, depending on the contribution of littoral zone fishes. Inflow to GCD forebay showed the strongest negative relationship with entrainment whereas reservoir elevation and fish vertical distribution had no direct relationship with entrainment. Our results indicate that kokanee and rainbow trout in Lake Roosevelt were limited by top down impacts including predation and entrainment, whereas bottom up effects and abiotic conditions were not limiting.

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Introduction

Project History

The Lake Roosevelt Monitoring/Data Collection Project has been collecting physical, chemical, biotic, and abiotic data since 1988 (Peone et al. 1990; Cichosz et al. 1997; McLellan et al. 2001; McLellan et al. 2002). During this project it became clear that efforts to stock kokanee into Lake Roosevelt were not meeting the creel and spawner return goals of managers (Keith Underwood, personal communication). Data gaps also existed because most monitoring efforts focused on the littoral zone and were missing the limnetic oriented fish including kokanee, rainbow trout, burbot, and lake whitefish *Coregonus clupeaformis*. Thus, in 1998 the Washington Department of Fish and Wildlife (WDFW) began a limnetic sampling regime for Lake Roosevelt to address specific questions regarding limiting factors to limnetic fish populations. Additionally, we combined littoral and limnetic data on fish diet, growth, and thermal experience and used a bioenergetics model to quantify trophic interactions that focused on food limitation for planktivores and the impact of piscivory to stocking efforts.

Limiting Factors

Many factors can contribute to poor survival of fish populations in a reservoir. Typical lake abiotic conditions and biological interactions are altered and exacerbated by reservoir fluctuations. Potential factors affecting survival include inadequate spawning habitat and rearing habitat, poor egg to fry survival, low food supply, high predation, over-exploitation, emigration, entrainment, and unfavorable physical and chemical conditions. The primary management goal for Lake Roosevelt fisheries was the successful recruitment of hatchery-reared salmonids to the fishery. Additionally, kokanee were to return at age-3 or -4 to egg collection facilities to establish a self-sustaining hatchery program. We did not address spawning and early life history survival because the hatcheries were producing yearling fish. Previous studies have shown low exploitation of stocked salmonids, although harvest goals have been achieved for rainbow trout on a regular basis (Cichosz et al. 1997). Therefore, we focused our limiting factors analysis on physical and chemical conditions, food limitation, predation, and entrainment.

Fish distribution and habitat use are restricted by fixed physiological constraints, which limit the geographical distribution of particular species. Fish can cope with sub-optimal conditions in certain systems using behavioral adaptations such as occupying a thermal refuge or foraging for short periods in lethal environments (Rahel and Nutzman 1994; Snucins and Gunn 1995). It is important to relate fish distribution to the physical and chemical domain in which they are operating to identify spatial or temporal stresses. Conversely, if fish are occupying physical zones that are sub-optimal, then behavioral mechanisms to maximize feeding or avoid predation may be identified (Clark and Levy 1988; Luecke and Teuscher 1994).

Food limitation and competition can limit fish populations in lakes and reservoirs (Schneidervin and Hubert 1987; Griffith 1988; Persson and Grenberg 1990; Tabor et al. 1996). Rainbow trout and kokanee commonly rely on zooplankton, specifically large daphnia, as a major food source in many western lakes and reservoirs (Galbraith 1967; Eggers 1982; Schneidervin and Hubert 1987; Beauchamp 1990; Beauchamp et al. 1995; Paragamian and Bowles 1995; Teuscher and Luecke 1996; Luecke and Teuscher 1994; Tabor et al. 1996; Cichosz et al. 1997). When oligotrophic systems such as Lake Roosevelt are artificially supplemented with large numbers of planktivores, there is potential to overexploit zooplankton biomass (Dettmers and Stein 1996). Several approaches have been used to evaluate food limitations in fish populations. Fish expressing slow growth and low relative weight, when compared to a regional standard, were considered food limited in many studies (Wege and Anderson 1978; Murphy et al. 1991; Marwitz and Hubert 1997). Small invertebrate prey size has also been used to indicate food limitation for fish predators (Mills and Forney 1983; Crowder et al. 1987). However, in large reservoirs averages and standards may not apply due to geographic and biological diversity both within and among systems. Bioenergetics models have been applied to fish populations to estimate fish consumption demand, which is compared to forage supply to evaluate the current and potential exploitation of the food resource (Beauchamp et al. 1995; Baldwin et al. 2000). This method allows researchers to evaluate what proportion of available prey biomass is consumed and how much excess biomass is available for increased fish production.

Top predators such as northern pikeminnow, lake trout *Salvelinus namaycush,* and walleye can have a substantial impact on forage fish populations in many systems (Lyons and Magnuson 1987; Rieman et al. 1991; Vigg et al. 1991; Yule and Luecke 1993; Knight and Vondracek 1993). Bioenergetics modeling has proven effective for quantifying the impact of predators on prey populations (Ney 1990; Yule and Luecke 1993; Beauchamp et al. 1995; Hartman and Brandt 1995). The depletion of fish prey is most common for introduced fish assemblages in reservoir settings where drawdown increases vulnerability of prey fish (McMahon and Bennett 1996).

Entrainment has been identified as a substantial source of lost juvenile fish in many reservoirs (Boreman and Goodyear 1988; Travnichek et al. 1993). Hydroacoustics on dam intakes allows for accurate measurements of total entrainment (Johnson et al. 1994; Ransom and Steig 1994). Several strategies to minimize entrainment have been used including strobe lights, sound impulses, and fish capturing devices (Nemeth and Anderson 1992; Ross et al. 1993; Knudsen et al. 1994). Entrainment was monitored at Grand Coulee Dam (GCD) with an array of hydroacoustic transducers by the Colville Confederated Tribes (CCT) in collaboration with Biosonics Inc. from spring of 1996 to autumn 1999. Entrainment estimates become most relevant when related to in-reservoir abundance. Also, understanding limnetic fish distribution in Lake Roosevelt was important if managers were to minimize entrainment by altering hydro operations.

Objectives

Our goal was to identify which environmental and biological factors limit limnetic fish production in Lake Roosevelt. The possible limiting factors examined were temperature and dissolved oxygen conditions, food limitation, predation, and entrainment. Our objectives were:

1. Determine if temperature and dissolved oxygen limit limnetic fish distribution by comparing vertical temperature and dissolved oxygen profiles with in-reservoir fish distributions and literature values for optimal growth conditions.

2. Examine food limitation as a limiting factor by evaluating relative fish growth, prey size, and bioenergetics modeling of planktivore supply versus demand.

3. Determine losses of juvenile salmonids to various piscivore populations. Evaluate reservoir-wide impacts versus local impacts for particular stocking events.

4. Evaluate losses due to entrainment by comparing limnetic fish abundance and distribution to monthly entrainment estimates through Grand Coulee Dam.

Study Area

Franklin D. Roosevelt Lake (Lake Roosevelt) is a Columbia River reservoir created in 1941 by the construction of Grand Coulee Dam (GCD) at river kilometer 960 (Figure 1). The reservoir covers ~33,000 ha at a full pool elevation of 393 m above mean sea level and is managed as a National Recreation Area by the National Park Service. The dam was built for hydropower generation, flood control, and water storage for irrigation in the Columbia Basin Reclamation Project. The 10-year mean (1990-1999) drawdown was 12 m with a maximum drawdown of 24 m occurring in 1997 (DART 2000). The reservoir reaches 241 km upstream from GCD, is generally 1-3 km wide, and has a maximum depth of 122 m. Water retention times are short (12-80 days) and the zooplankton community is more typical of a large river than a lake or reservoir (R. Black, personal communication).

The fish community of Lake Roosevelt has changed since inundation. Northern pikeminnow were the primary fish captured in historical gill net surveys; comprising 65% of the total sample in 1948 (Gangmark and Fulton 1949), 54% in 1976 (Stober et al. 1977) and 15% from 1980-1983 (Beckman et al. 1985). In recent studies, however, northern pikeminnow have generally comprised less than 5% of the species captured in gill nets (Cichosz et al. 1997, 1999). Burbot *Lota lota* were rarely mentioned in historical surveys but consistently comprise 5-15% of species in recent gill net surveys (Cichosz et al. 1997, 1999; Baldwin et al. 1999). In recent gill net and electrofishing surveys, the fish community in Lake Roosevelt has been dominated by largescale suckers *Catostomus macrocheilus*, lake whitefish, and walleye (Peone et al. 1990; Cichosz et al. 1997, 1999). Walleye were first detected in Lake Roosevelt in the early 1950s and by the early 1980s walleye comprised 30% of the total fish relative abundance (Beckman et al. 1985). Many walleye spawn in the Spokane River arm of Lake Roosevelt and then disperse throughout the reservoir and migrate as far north as Canada (McLellan et al. 2002). The walleye post-spawn migration overlaps temporally and spatially with hatchery kokanee releases at the Sherman Creek Hatchery (SCH).

Grand Coulee Dam is a barrier to historic anadromous salmon and steelhead runs. Mitigation for losses of historical salmon migrations into this portion of the Columbia River have resulted in a hatchery kokanee and rainbow trout stocking program. The Sherman Creek Hatchery (SCH), Spokane Tribal Hatchery (STH) and the Lake Roosevelt Net Pen Program have released approximately 0.75 million kokanee and 0.5 million rainbow trout annually since 1988. Hatchery and net pen releases occur from late May to mid-July depending on reservoir operations, temperature, and fish health. Kokanee have been released at SCH with the intention of collecting eggs from returning age-3 spawners. The number of age-3 spawners returning to egg collection sites has never been adequate for egg takes, so other strategies, such as net pens and yearling releases, have been employed in an attempt to improve survival.

Methods

Abiotic Conditions and Limnetic Fish Distribution

We evaluated potential temperature and dissolved oxygen limitations to limnetic fish production using water quality data obtained by the Spokane Tribe of Indians (STI). We then identified areas of sub-optimal conditions based on literature values for each species (Appendix B). Gill net, trawl, and hydroacoustic fish depth distributions were overlaid on vertical plots of temperature and dissolved oxygen to determine habitat use in relation to abiotic conditions.

Abiotic Conditions

Vertical profiles of temperature (°C) and dissolved oxygen (mg/L) were collected bi-weekly at nine mainstem locations using a Hydrolab Surveyor 4 (McLellan et al. 2003). Water quality parameters were logged at 3-m intervals at the seven upstream sites from 0-33 m. Data were recorded to a depth of 90-m at the two downstream sites, Keller Ferry and Spring Canyon, to characterize deep areas of the lower reservoir.

Limnetic Fish Distribution

Limnetic fish abundance and distribution was determined using a combination of hydroacoustics, gill net, and trawling surveys. Lake Roosevelt was stratified into three regions (upper, middle, and lower) for the surveys that were conducted in June, August, and October of 1999, and February of 2000 (Figure 2.1.1). Midwater trawling was only conducted in June and October of 1999.

Hydroacoustic surveys: We used an HTI model 241 echosounder with a 15E split-beam transducer, pole-mounted 1 m below the surface with a down-looking orientation. Data were logged directly into a computer and unprocessed echoes were recorded on digital audiotapes. The pulse repetition rate varied from 3-5 pings/second and only echoes within 7.5E off-axis, that met the single echo criteria of the software, were included in the analysis. Each region was sampled on a single night each month and 7-8 transects were conducted in an elongated zigzag pattern across the limnetic zone of each region, near the period of the new moon (Luecke and Wurtsbaugh 1993). Limnetic transects were at least 200 m from shore and deeper than 20 m. Transects were 4-9 km long and lasted 0.5-1 hour with a boat speed of 2-3 m/s. Night transects began at least 0.5 hour after sunset and ended at least 0.5 hour before sunrise.

Each transect was sectioned into 10 m vertical strata from 1 m below the transducer (2 m below the surface) to the bottom of the reservoir. Echo counting of target-tracked fish was used to determine mean densities for four size classes of acoustic targets (55-45, 45-39.2, 39.2-33.5, and 33.5-28.8 -dB). Target strengths between were converted to estimate fish lengths using a formula generated by Love (1971, 1977); the respective length classes of the previous target strength size classes were 25-100 mm, 101-200 mm, 201-400 mm, and 400-700 mm. Densities were extrapolated to abundance based on the daily reservoir elevation (at the midpoint of the survey) converted to total reservoir volume. The Bureau of Reclamation at Grand Coulee Dam provided volumes at specific elevations.

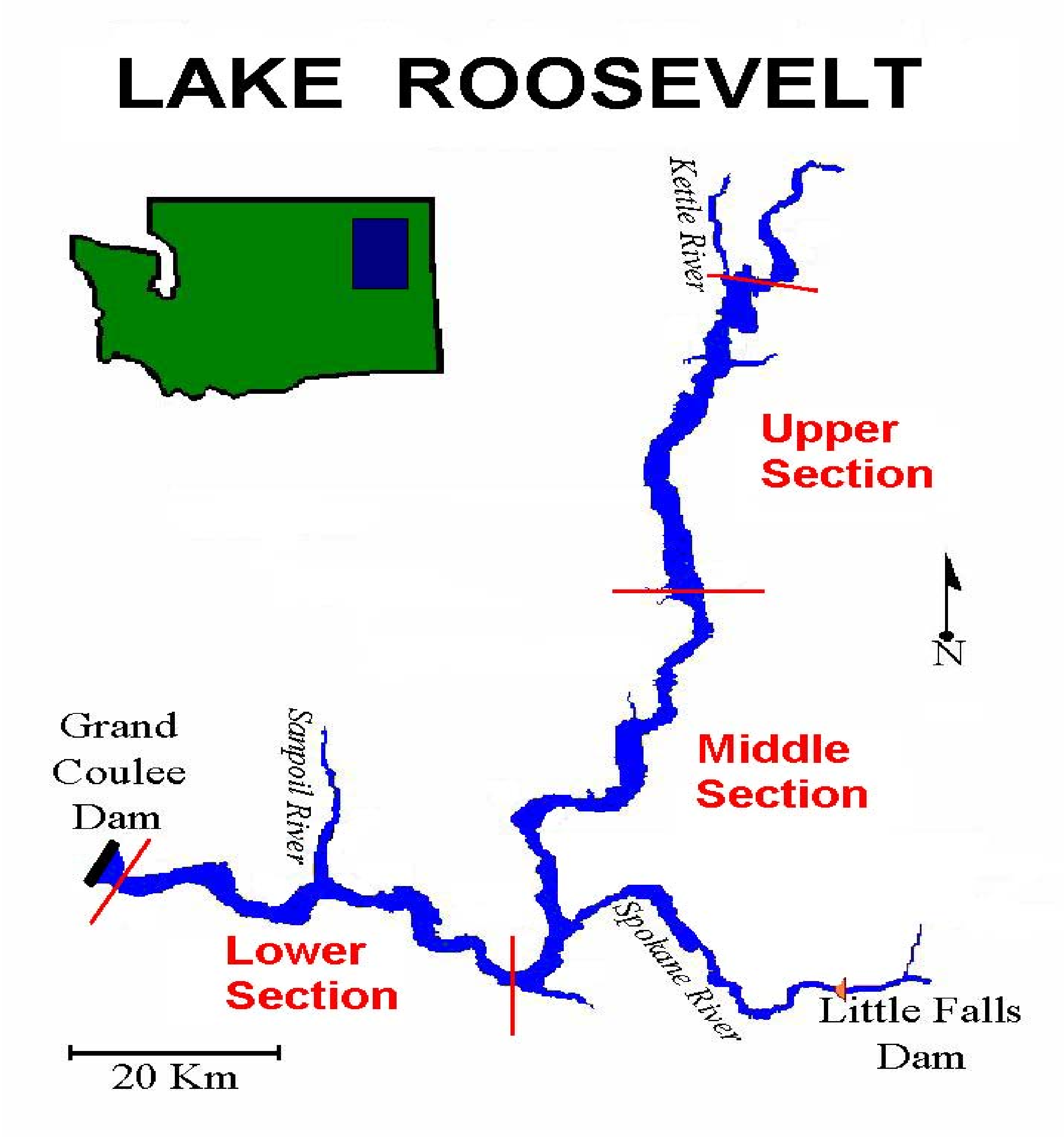

Figure 2.1.1. Map of Lake Roosevelt showing the three sampling regions.

Gill netting and trawling surveys: Gill net and trawl surveys were used to provide species verification, depth distributions, and length frequencies of acoustic targets. We set 3-6 vertical and 4-6 horizontal gill nets overnight in the limnetic zone of each of the three sections for three nights following an acoustic survey (Appendix A, Table A1). Nets were generally placed in the middle third of the shore-to-shore axis and were distributed across several acoustic transects each night. Emphasis was given to areas of high acoustic target abundance. Each vertical gill net was 2.6 m wide, 46 m deep, and consisted of one mesh size throughout (25, 38, 51, 64, 76, 89, or 102 mm stretch). Horizontal nets included floating, suspended, and bottom nets with panels 6.5 m long, 2.6 m deep, and mesh sizes from 25-102 mm in 13 mm increments.

A monofilament trawl with a 47 m^2 opening was used in each region as an active capture technique targeting small fish (< 200 mm) that were less susceptible to gill nets (Murphy and Willis 1996). Trawling transects were conducted on June 15-18 and October 28-30, and generally overlapped four of the eight hydroacoustic transects in each region (Appendix A, Table A2). Depths were chosen to maximize catch rates based on target density information from the hydroacoustic surveys; however, the trawl was limited to a maximum depth of 50 m. The trawl was fished for approximately one hour per haul, and 3-4 tows were conducted each night.

Food Limitation

We used three methods to determine if food limited limnetic fish populations. These included comparing fish growth in Lake Roosevelt with other systems, monitoring the average size and presence of preferred zooplankton in the reservoir, and using bioenergetics modeling to compare fish consumption to available zooplankton biomass.

Spawner Lengths and Relative Weights

Kokanee spawner length-at-age was compared between Lake Roosevelt and other systems in the Pacific Northwest. Kokanee length-at-age is known to increase with increasing aquatic productivity and/or decreased fish density (Rieman and Myers 1992). We used length-at-age of mature kokanee as an indicator of adequate available forage. For immature kokanee and rainbow trout we used the relative weight index (W_r) to evaluate the growth conditions in Lake Roosevelt compared to those in other systems in the United States and Canada (Murphy et al. 1991; Hyatt and Hubert 2000). For kokanee W_r, we distinguished hatchery from wild fish and used data collected between August and October on sexually immature fish. We only reported W_r in October of each year for rainbow trout because of the potential for newly released hatchery fish to skew the results.

Availability of Large Zooplankton

Zooplankton species and size data were provided by STI and collected according to the methods of McLellan et al. (2003). We examined the availability of large (> 1.5 mm) *Daphnia* each month in 1999 to determine if this preferred prey item was present, and if the average size was within the preferred range for salmonid planktivores.

Planktivore Consumption Versus Available *Daphnia* Biomass

We estimated the monthly standing stock biomass of edible size (>1.1 mm) *Daphnia* then determined the number of additional kokanee or rainbow trout that could have been supported by that biomass, i.e., the carrying capacity.

Daphnia Biomass: Total *Daphnia* biomass was reduced to only include the biomass of *Daphnia* larger than 1.1 mm in length. The preferred, or edible size (>1.1 mm) was selected based on observed *Daphnia* in the diet of salmonids from previous Lake Roosevelt studies and with other systems where salmonids were preying upon abundant zooplankton (Galbraith 1967; Schneidervin and Hubert 1987; and Tabor et al. 1996). Total biomass of *Daphnia* was averaged across all twelve sampling sites of the LRFEP to estimate the reservoir wide biomass (Pavlik et al. 2003). The length frequency of *Daphnia* was used each month to estimate the proportion of the population that was larger than 1.1 mm. The weighted mean biomass of the *Daphnia* population > 1.1 mm was calculated as:

$$\frac{\Sigma P_i * B_i}{\Sigma B_i}$$

where P_i = proportion of the population in each 0.1 mm length class
B_i = biomass of individual *Daphnia* within each length class

Finally, we compared the consumption demand of stocked salmonids to the standing stock biomass of *Daphnia*. Consumption estimates for kokanee and rainbow trout were compared on a gram-to-gram basis with available zooplankton forage each month and expressed as the C/B ratio where C = consumption and B = biomass. This provides an index of monthly forage supply relative to the consumptive demand to highlight periods when forage may be limiting.

Planktivore Consumption: The Wisconsin bioenergetics model (Hanson et al. 1997) was used to generate monthly consumption of zooplankton by stocked kokanee and rainbow trout. Model inputs for each fish species included growth, diet, thermal experience, and abundance. Literature values provided in the model were used for prey caloric densities (Hanson et al. 1997).

Growth: Growth was estimated for stocked kokanee using the mean length of known age kokanee captured by Eastern Washington University (EWU) during their fall sampling (McLellan et al. 2001); and rainbow trout by cohort analysis on a semi-annual basis from gill net and electro shocking surveys by WDFW and STI (Appendix B). Length at age was estimated by scale analysis for wild planktivores such as lake whitefish and unmarked kokanee. Then, a length weight regression from a multi-year data set (collected by STI, WDFW, and EWU) was applied to the length-at-age to estimate weight-at-age. This method allowed us generate a more consistent annual growth curve than using the observed weight of fish that were aged, due to small sample sizes of aged fish and high variance of weight-at-age.

Diet: We modeled the average wet weight proportions of each diet item or group. Diet items were categorized into *Daphnia*, *Leptodora*, Copepods, Insects, or Other. STI diet analysis calculated the dry weight proportion of each diet item so a dry to wet weight conversion was used (Hanson et al. 1997). See Cichosz et al. (1997) for a detailed description of STI diet analysis procedures. WDFW and STI diet data were combined and modeled on a seasonal basis, when sample sizes were not adequate (i.e., < 10) then the mean annual diet was used (Appendix B).

Thermal Experience: Thermal experience was estimated from available water temperatures measured by the STI during biweekly or monthly water quality sampling (McLellan et al. 2003)(Appendix B). We assumed fish were occupying their optimal temperature zone for growth, if that temperature was available. When optimal temperatures were not available, we applied the closest available temperature.

Abundance of Planktivores: Kokanee and rainbow trout stocking numbers were obtained from the Lake Roosevelt Net Pen Program, Sherman Creek Hatchery, and Spokane Tribal Hatchery (Combs 1999; Peone 1999; Combs 2000; Peone 2000). We modeled stocked salmonids beginning on their day of release from the net pens or hatchery and started with the 1998 releases to include fish that had survived through at least one winter after stocking (carry-over). In 1998, we modeled kokanee released from the Spokane Tribal Hatchery, Sherman Creek Hatchery, and Lake Roosevelt Net Pen Program totaling 585,272 age-1 (yearlings) and 500,413 fingerlings, along with 541,447 age-1 rainbow trout. In 1999, we modeled 710,078 age-1 kokanee and 578,553 age-1 rainbow trout. A precocity rate of 0.53 was applied to yearling kokanee releases and differential growth and survival was applied based on the mean size of returning spawners for each group, i.e., precocious and non-precocious (Appendix B). Precocity was not estimated in 1998 or 1999; therefore, we used the mean precocity rate from all groups measured in 2000 and 2001 (K. Underwood, personal communication). Survival for kokanee was estimated from the number of age-2 spawners (returning the same year they were released, precocious fish), and the following year for age-3 spawners (McLellan et al. 2001). Monthly mortality was iteratively fit to match the number of survivors and modeled to October of each year using the equation:

$$N_t = N_o e^{-zt}$$

where N_t = the abundance at time t, N_o = the abundance at time t-1, and z = instantaneous mortality (Van Den Avyle and Hayward 1999). Annual survival for rainbow trout was estimated using gill net and electrofishing catch information obtained by the STI standard seasonal surveys using the equation:

$$S = N_1/N_0$$

where survival (S) equals the number of fish in each cohort captured at time t (N_1), divided by the number captured at t-1 year (N_0) (Van Den Avyle and Hayward 1999). For 1998 and 1999, we used both the July sample and the October sample to estimate annual survival of net pen rainbows. Daily mortality was then iteratively fit to match the end number of survivors using the equation for exponential population decline previously described ($N_t = N_o e^{-zt}$). Age-1 kokanee and rainbow trout that survived 1998 were carried over into 1999 and consumption was added to the 1999 cohort. The carrying capacity of the zooplankton population was estimated by dividing total available biomass of edible size *Daphnia* by the consumption of individual kokanee and rainbow trout.

Piscivory on Salmonids by Piscivorous Fishes

We used the Wisconsin bioenergetics model to generate consumption estimates by Lake Roosevelt piscivores (e.g., walleye, burbot, northern pikeminnow, smallmouth bass, and rainbow trout) (Hanson et al. 1997). Model inputs for each fish species included diet, growth, thermal experience, abundance, and spawning (day of year and percent of body weight spawned). Literature values provided in the model were used for predator and prey caloric densities and dry-to-wet weight stomach content conversions for each prey type in the diet analysis (Hanson et al. 1997). Each age class was modeled independently based on the observed annual growth rate for that particular cohort; daily model output was summed into monthly totals. Annual growth was determined from a multi-year scale annuli data set analyzed by both STI and EWU. The back-calculated length-at-age to the most recent annulus was used and a length weight regression was applied to estimate weight-at-age. Sample sizes were too small to facilitate age specific diet, so the average diet of all fish age-2 and older was used for each species.

Relative Impact of Piscivore Species and Age Classes

We identified which species and age class had the greatest potential for impact on recruiting salmonids and estimated monthly consumption to identify the season(s) when piscivory was highest. Relative comparisons were made based on a population of 1000 predators so that results incorporate the age class structure of the population. When small sample sizes or sampling bias provided a skewed age class structure, such as with northern pikeminnow, burbot and smallmouth bass, we averaged the consumption estimates across all age classes (generally age-2 to -7) and expanded to 1000 predators.

Losses of Juvenile Salmonids to Walleye

We used the bioenergetics model to quantify the consumption of predators and estimate impacts to stocked salmonids. Evaluating impacts through modeling predation rates depended on a walleye abundance estimate made by EWU (McLellan et al. 2002). No abundance estimates were available for other piscivorous species; however, walleye dominate the relative abundance during seasonal monitoring surveys and therefore represent the primary threat to stocking efforts (Cichosz et al 1997; Cichosz et al. 1999; McLellan et al. 2003).

Reservoir-wide impacts: Model estimated consumption for each age cohort was multiplied by the abundance estimate of each cohort to represent total walleye consumption of salmonids. Error bounds were generated by multiplying the coefficient of variation from the abundance estimate by the consumption estimate. We then adjusted total walleye consumption of salmonids for the predator-prey length relationship, growth of stocked salmonids, and for the relative abundance of kokanee and rainbow trout available in the environment. Finally, we divided the number of fish consumed by the number stocked to estimate a percent loss to piscivory.

Consumption by individual age classes of walleye were reduced if their body length did not exceed the minimal length necessary (predator length * 0.5) to feed on the mean length of kokanee or rainbow trout (Appendix C). When various groups of hatchery fish were released at different times we weighted the mean length based on the biomass of total mortality each month.

$$L_m = \left(L1 \bullet \frac{L1}{BL1+BL2}\right) + \left(L2 \bullet \frac{L2}{BL1+BL2}\right)$$

where L_m = weighted mean length
L_1 = length of release group 1
L_2 = length of release group 2
BL_1 = biomass of mortality for length group 1
BL_2 = biomass of mortality for length group 2

The walleye consumption estimate of hatchery salmonids was reduced based on a normal distribution of lengths within two standard deviations (SD) of the mean length for both predator (P_d) and prey (P_y). The lower two SD of prey length was considered the minimum size available and total walleye consumption (C_t) was reduced by the proportion of walleye too small to effectively capture the prey fish (P_s) for each age class of walleye predators:

if: -2 SD of P_y > - 2 SD of P_d * (0.5)
then: $CP_s = C_t * P_s$
where: CP_s was the predator-prey length adjusted consumption of salmonids.

During certain months the sum of walleye consumption of kokanee and rainbow trout exceeded total walleye consumption of salmonids, thereby overestimating the impact to both species. Therefore, we reduced the consumption on each of the species relative to their occurrence in the environment, based on the biomass of individuals lost to mortality each month according to the following equations:

if: $CP_{s(rbt)} + CP_{s(kok)} > C_t$

then: $$MBr_{kok} = \frac{MB_{kok}}{(MB_{kok} + MB_{rbt})}$$

and: $$MBr_{rbt} = \frac{MB_{rbt}}{(MB_{kok} + MB_{rbt})}$$

where MB = Biomass of total mortality and MBr= the ratio of kokanee to rainbow or vice versa.

Final consumption (C_f) of each species was then calculated as:

$$C_{f\,(kok)} = CP_{s(kok)} + [C_t - (CP_{s(rbt)} + CP_{s(kok)})] * MBr_{kok}$$

$$C_{f\,(rbt)} = CP_{s(rbt)} + [C_t - (CP_{s(rbt)} + CP_{s(kok)})] * MBr_{rbt}$$

Reservoir-wide impacts to stocked kokanee and rainbow trout were assessed by determining the percent of the fish released that were lost to predation:

$$\%Loss = \frac{\sum \frac{B_c}{B_i}}{N_s}$$

Where B_c was the total biomass consumed each month, B_i was the mean weight of the individual kokanee or rainbow trout during the month, and N_s was the total number of fish stocked during the year.

Sherman Creek Predation Study: In 1999, we conducted a study to evaluate short-term losses of stocked kokanee following release from the Sherman Creek Hatchery (SCH). This study was written up as a separate manuscript, along with a similar study in 2000. A draft of this manuscript is reported in its entirety in Appendix C. Predation study modeling results from July of 1999 were incorporated into the reservoir-wide consumption estimates to account for the increased rate of consumption using the following formula:

$$C_f = [C_{1*}(A_t - A_P)] + (C_p * A_p)$$

where C_1 was the original reservoir-wide consumption of salmonids, A_t was the reservoir-wide abundance of walleye, A_p was the abundance of walleye during the SCH predation study, and C_p was the consumption of walleye during the SCH predation study.

Entrainment

We evaluated the potential for entrainment to limit limnetic fish abundance by comparing abundance in the reservoir to the abundance entrained and possible causes of entrainment such as elevation, inflow, and vertical distribution of fish in the lower third of the reservoir. The CCT provided monthly entrainment estimates for each of the three GCD powerhouses from January 1996 to September 1999 (LeCaire 2000). We then calculated the E/A ratio by dividing total entrainment (E) by limnetic fish abundance (A). We modeled the E/A ratio over a 12-month period using the average and two SE of September and October 1998, and June and August of 1999 to estimate the annual impact of entrainment.

We compared our abundance estimate for kokanee to the entrainment estimate the month previous to our survey, to determine an indirect qualitative evaluation of the impact of entrainment to the kokanee population. The CCT could not reliably determine species composition of entrained fish targets during their entrainment study, but given the limnetic distribution of kokanee we assumed that there would be a relationship between kokanee abundance and entrainment (LeCaire 2000). The abundance estimate for kokanee was estimated following the methods outlined in section 2.1 of this report.

Next, we compared reservoir elevation and inflow in relation to entrainment to evaluate the conditions when entrainment was highest and determine what factors are likely to effect entrainment. Mean monthly inflow and elevation were taken from the Data Access in Real Time website (www.cqs.washington.edu/dart/river.html). Vertical distribution was determined by averaging the density of acoustic fish targets in 10-m depth bins from the lower eight transects of each survey (June, August, and October). Turbine depth was overlaid on a plot of vertical distribution each month to evaluate entrainment potential based on the natural distribution of fish in the lower third of the reservoir.

Results

Temperature and Dissolved Oxygen Limitations

Limnetic Fish Vertical Distribution

Hydroacoustic surveys revealed a seasonal pattern of vertical distribution, regardless of target strength. In June, fish targets were evenly distributed between 0-20 m,; in August there was a bi-modal distribution with a small mode between 0-10 m and a much broader mode between 70-100 m (Figure 3.1.1). In October, fish targets were spread out between 0-40 m (Figure 3.1.1). Gill net surveys revealed that in June, kokanee and rainbow trout were the predominant species (77%) in the 0-20 m depth zone, whereas lake whitefish and burbot dominated (83%) the 20-60 m depths (Table 3.1.1). In August, all species were broadly distributed but kokanee dominated the species composition (84%) at depths exceeding 60 m (Table 3.1.1). In October, the majority (97%) of fish were captured shallower than 50 m and there was even distribution among depths and species (Table 3.1.1).

Comparison of Fish Distribution with Temperature and Dissolved Oxygen

Reservoir-wide mean temperatures and dissolved Oxygen levels were generally within tolerance limits for kokanee and rainbow trout, with two notable exceptions. First, although monthly means never dropped below 6 mg/L, minimum dissolved oxygen levels were at stressful levels (< 5 mg/L) at some sites and depths (Figure 3.1.2). Second, for kokanee, warm water temperatures during mid- to late summer limited their distribution to the lower half of the water column. This was particularly pronounced in the lower section of the reservoir where most unmarked kokanee were captured at depths with temperatures less than 15°C (Figure 3.1.3).

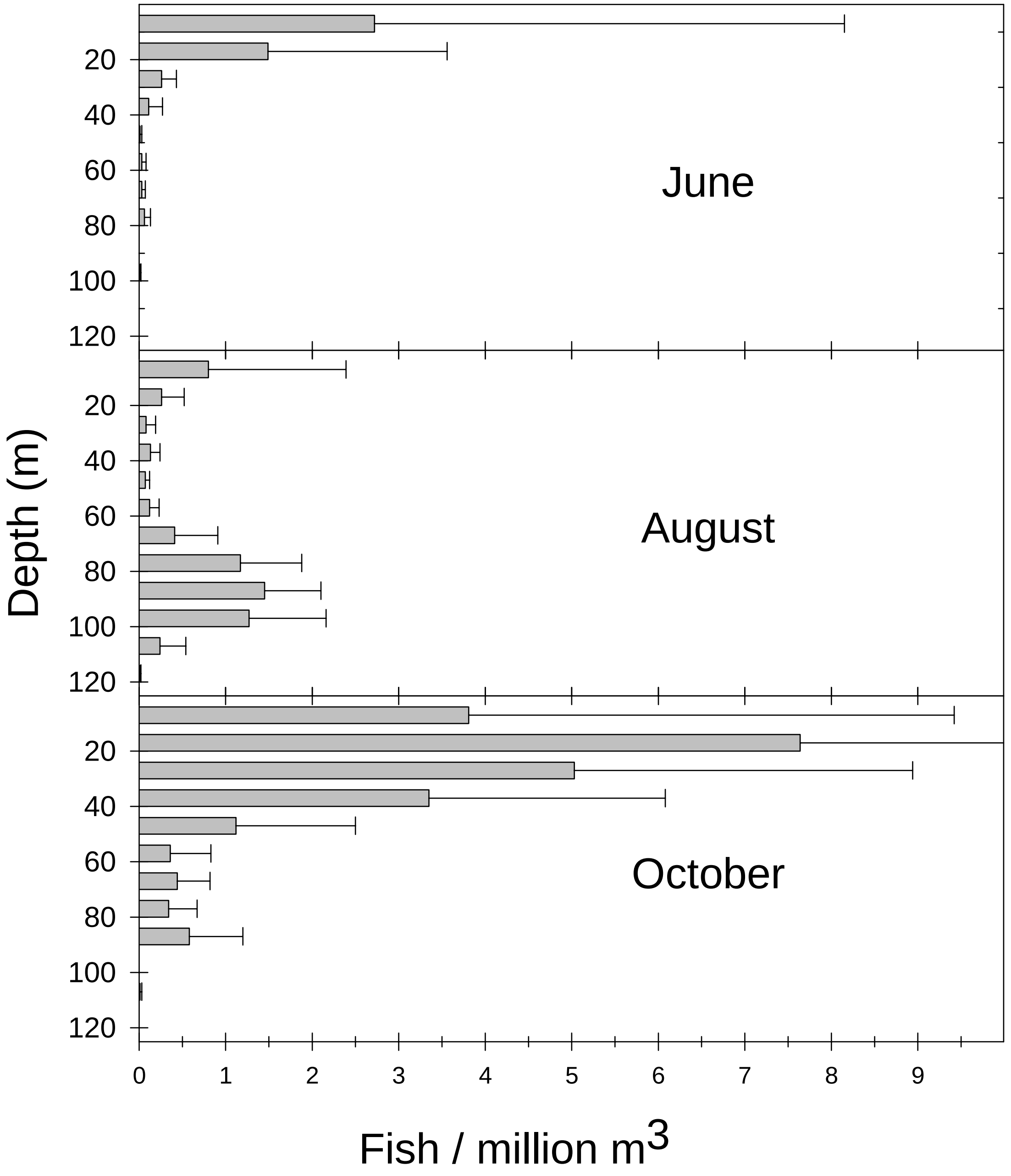

Figure 3.1.1. Vertical distribution of acoustic targets (39.2-33.5 -dB; fish ~ 200-400 mm TL) during various months in 1999 from the lower section of Lake Roosevelt.

Table 3.1.1. Number of each fish species captured in 10 meter depth bins by gill net and trawl surveys on Lake Roosevelt during various months in 1999.

	Depth (m)	Burbot	Kokanee	Lake Whitefish	Rainbow Trout	Walleye	Other Fish	Total
	0-10	0	6	1	9	4	1	21
	10-20	0	7	4	2	0	1	14
	20-30	5	1	10	0	2	0	18
	30-40	2	0	10	0	3	0	15
	40-50	1	1	1	0	0	0	3
June	50-60	4	0	0	0	0	0	4
	60-70	0	0	0	0	0	0	0
	70-80	0	0	0	0	0	0	0
	80-90	0	0	0	0	0	0	0
	90-100	0	0	0	0	0	0	0
	100-110	0	0	0	0	0	0	0
	Total	12	15	26	11	9	2	75
	0-10	0	0	0	2	2	0	4
	10-20	0	1	1	2	1	0	5
	20-30	0	1	3	1	2	0	7
	30-40	1	3	4	0	8	1	17
	40-50	1	4	3	0	1	1	10
August	50-60	1	1	0	0	1	0	3
	60-70	0	3	0	0	0	0	3
	70-80	1	1	0	0	0	0	2
	80-90	0	5	0	0	0	0	5
	90-100	0	11	0	0	0	0	11
	100-110	0	0	1	0	0	0	1
	Total	4	30	12	5	15	2	68
	0-10	0	9	2	5	3	6	25
	10-20	0	8	1	0	1	0	10
	20-30	0	6	13	1	1	1	22
	30-40	0	5	9	0	12	5	31
	40-50	4	3	4	0	4	1	16
October	50-60	0	0	0	0	0	0	0
	60-70	1	1	0	0	0	0	2
	70-80	0	0	0	0	1	0	1
	80-90	0	0	0	0	0	0	0
	90-100	0	0	0	0	0	0	0
	100-110	0	0	0	0	0	0	0
	Total	5	32	29	6	22	13	107

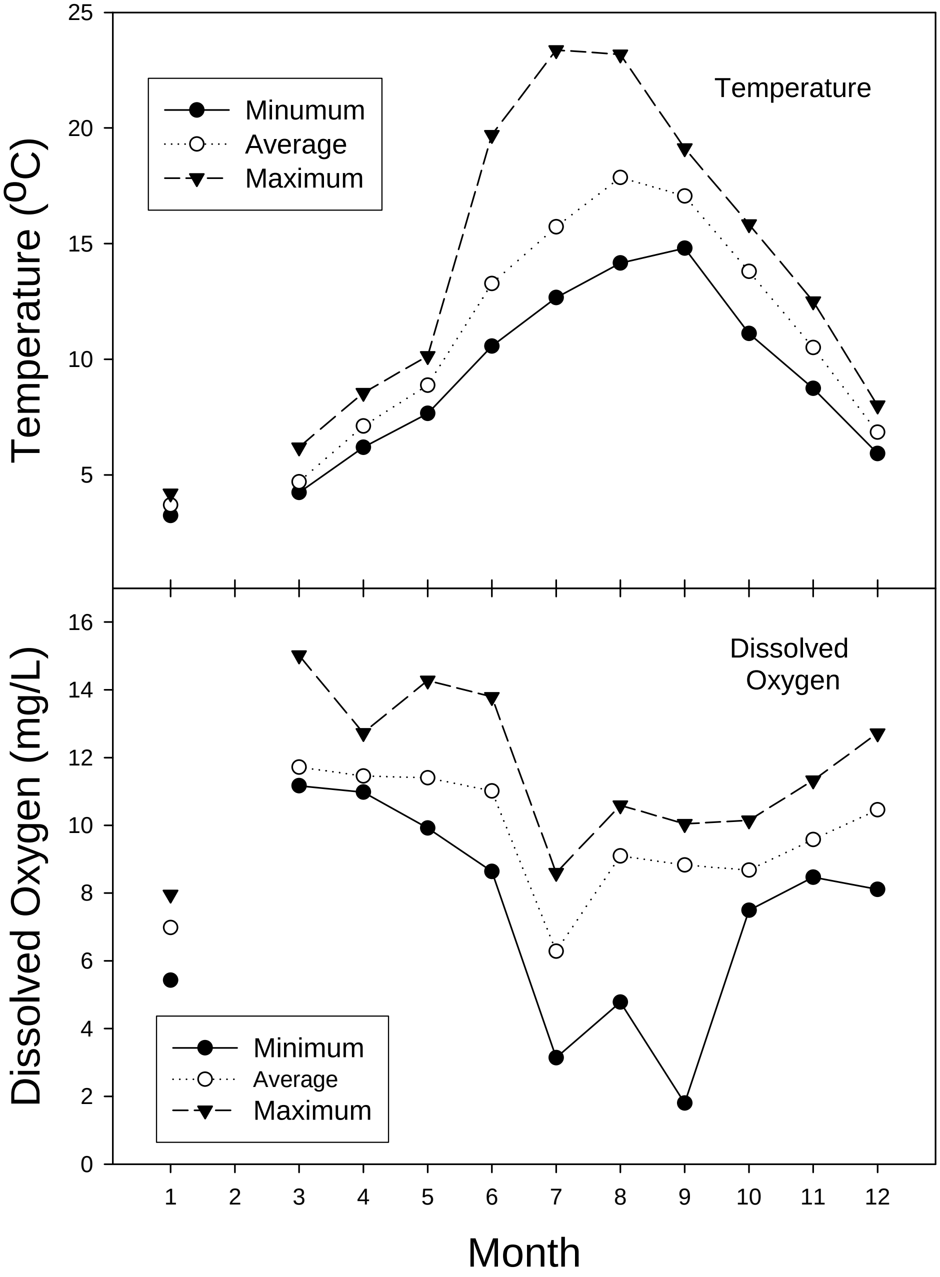

Figure 3.1.2. Mean, minimum, and maximum temperature and dissolved oxygen averaged across all measured depths (0-98 m) from reservoir-wide survey stations. Data were collected by the Spokane Tribe of Indians as part of the Lake Roosevelt Fisheries Evaluation Project (McLellan et al. 2003). No data were collected in February.

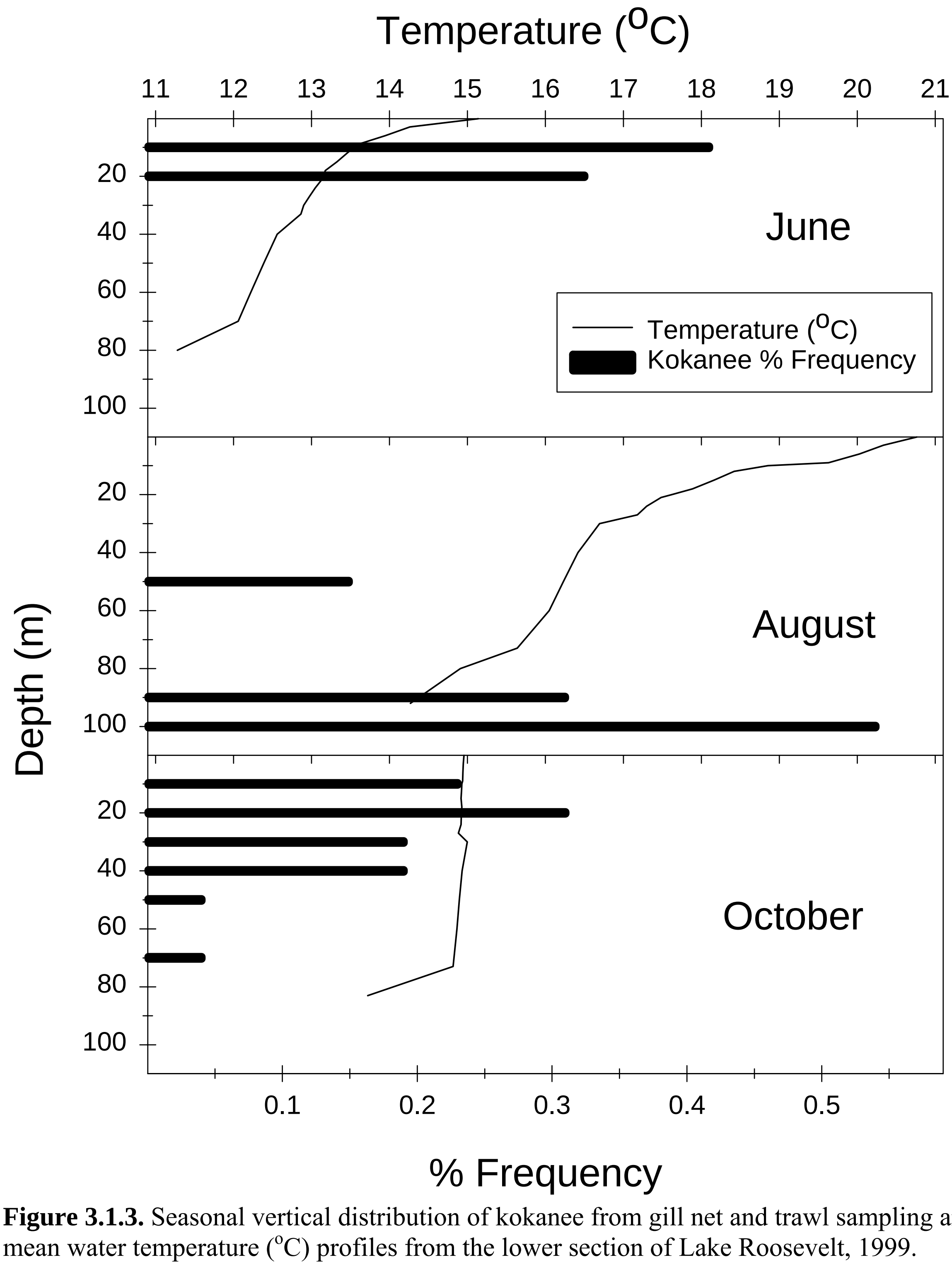

Figure 3.1.3. Seasonal vertical distribution of kokanee from gill net and trawl sampling and mean water temperature (°C) profiles from the lower section of Lake Roosevelt, 1999.

Food Limitation

Spawner Lengths and Relative Weights

We compared the length of kokanee spawners in Lake Roosevelt to previous years and to four water bodies in Idaho. In 1999, age-3 spawners in Lake Roosevelt averaged 352 mm; this was below the 4-year running average on Lake Roosevelt, but 125 mm longer than the average age-3 spawner from the Idaho systems (Table 3.2.1). The W_r of hatchery kokanee was generally low (<100) for kokanee less than 275 mm but high (> 100) for wild kokanee and hatchery kokanee over 275 mm total length during both 1998 and 1999 (Figure 3.2.1). The W_r rainbow trout was consistently near 100 across all sizes for both 1998 and 1999 (Figure 3.2.2).

Availability of Large Zooplankton

Large bodied *Daphnia* were present in Lake Roosevelt during all months of 1999. The average length of *Daphnia* ranged from 0.91-1.37 mm per month; February and March had the smallest mean lengths of 1.05 and 0.91 mm, respectively (Figure 3.2.3) (McLellan et al. 2003). Maximum *Daphnia* lengths ranged from 1.73-3.15 mm with February and April providing the smallest maximum lengths of 1.73 and 1.88 mm, respectively (Figure 3.2.3)(McLellan et al. 2003).

Table 3.2.1. Length at maturity for age-2 to -3 kokanee from Lake Roosevelt and several Lakes in Idaho.

Water Body	Year	Age	Length (mm)	Source
Lake Roosevelt	1996	2	319	Tilson and Scholz 1998a
Lake Roosevelt	1997	2	300	Tilson and Scholz 1998b
Lake Roosevelt	1998	2	299	McLellan et al. 2001
Lake Roosevelt	1999	2	303	McLellan et al. 2001
Average			305	
Lake Roosevelt	1996	3	326	Tilson and Scholz 1998a
Lake Roosevelt	1997	3	443	Tilson and Scholz 1998b
Lake Roosevelt	1998	3	428	McLellan et al. 2001
Lake Roosevelt	1999	3	352	McLellan et al. 2001
Average			387	
Lake Coeur D'Alene	1978-86	2	191	Rieman and Myers 1992
Dworshak Reservoir	1988	2	261	Rieman and Myers 1992
Lake Pend Orielle	1977-88	2	210	Rieman and Myers 1992
Spirit Lake	1981-1988	2	230	Rieman and Myers 1992
Average			223	
Lake Coeur D'Alene	1978-86	3	233	Rieman and Myers 1992
Dworshak Reservoir	1988	3	310	Rieman and Myers 1992
Lake Pend Orielle	1977-88	3	244	Rieman and Myers 1992
Spirit Lake	1981-1988	3	259	Rieman and Myers 1992
Average			262	

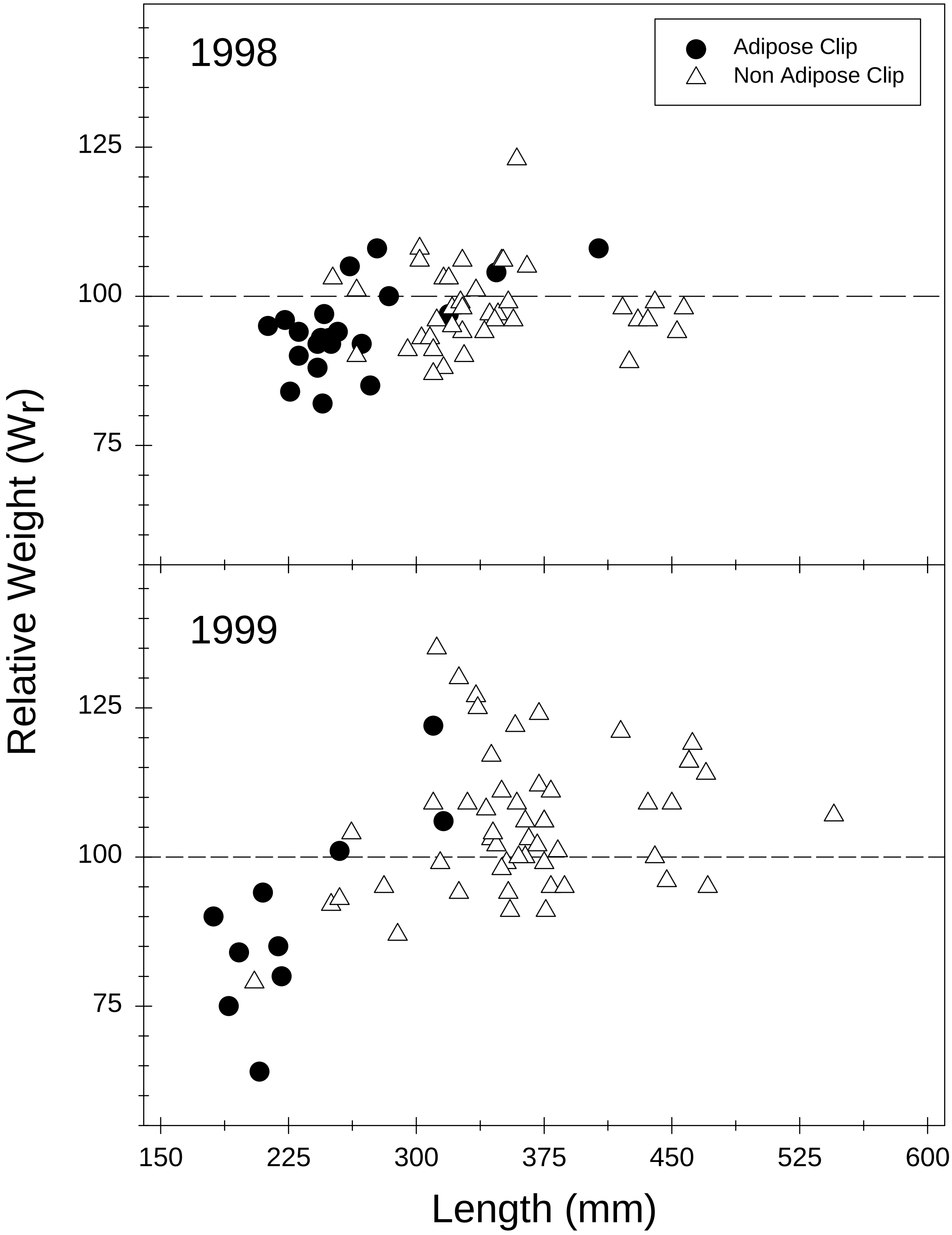

Figure 3.2.1. Relative weights of adipose and non-adipose clipped kokanee from September and October of 1998 and August and October of 1999.

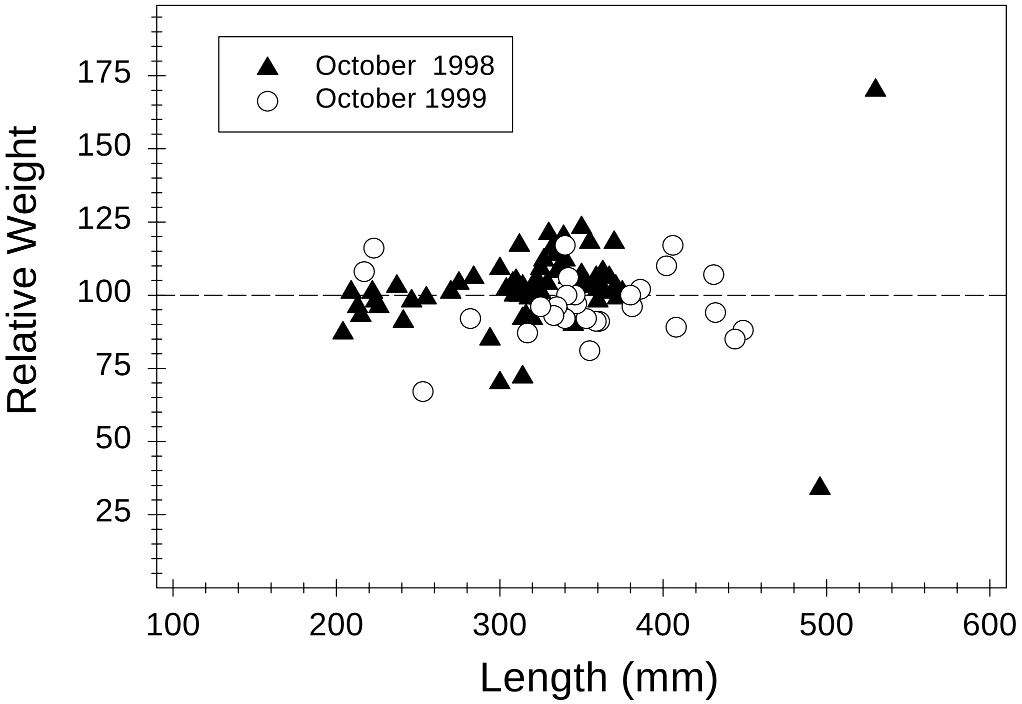

Figure 3.2.2. Relative weights of rainbow trout from October of 1998 and 1999.

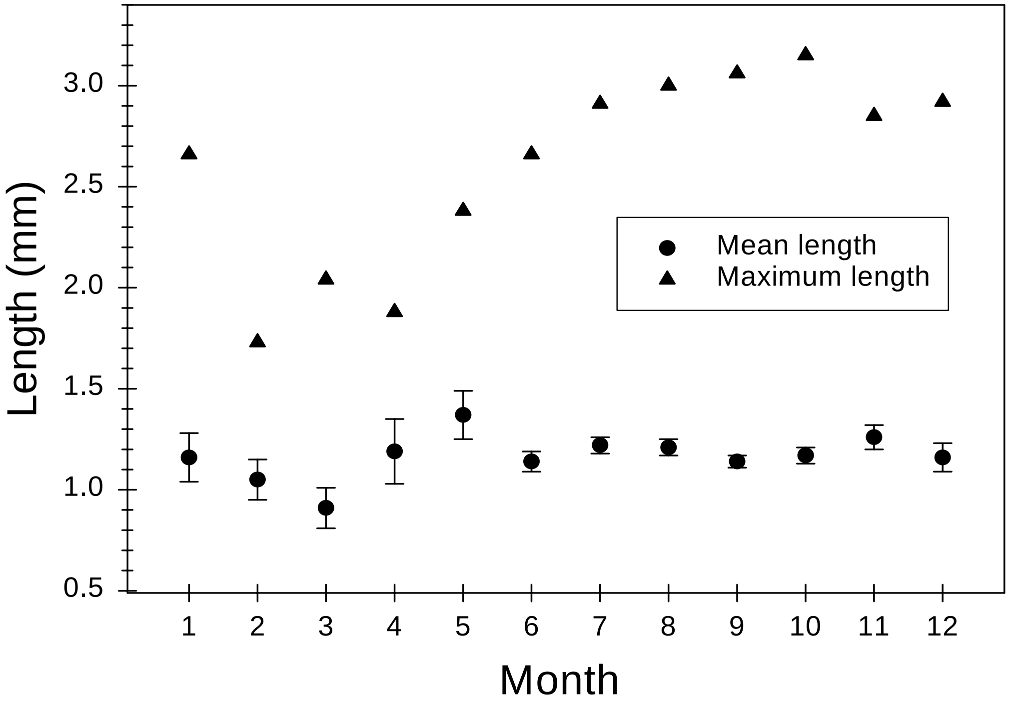

Figure 3.2.3. Mean (+ 2 SE) and maximum *Daphnia* lengths from Lake Roosevelt in 1999. Data provided by the Spokane Tribe of Indians Lake Roosevelt Fisheries Evaluation Program.

Planktivore Consumption Versus Available *Daphnia* Biomass

The standing stock biomass of *Daphnia* > 1.1 mm peaked from August to October (205,891-253,983 kg) and was at its lowest in February (580 kg). The estimated *Daphnia* biomass available during summer and fall months could have supported consumption by millions more rainbow trout or kokanee (Table 3.2.2). In contrast, winter biomass could only have supported as few as 4-5 thousand more age-2 rainbow trout or kokanee (Table 3.2.2).

The consumption to biomass ratio reflected a similar seasonal pattern as the carrying capacity estimates. The ratio was well above 1.0 in January and February, then remained around 1.5 during March and April before dropping to less than 0.5 for the remainder of the year (Figure 3.2.4).

Table 3.2.2. Available *Daphnia* biomass, individual consumption, and the associated carrying capacity (number of additional fish) for Lake Roosevelt during 1999.

		Age 1+ kokanee		**Age 2+ kokanee**	
Month	**Biomass (kg) Daphnia > 1.1 mm**	**(g) Consumption**	**Carrying Capacity**	**(g) Consumption**	**Carrying Capacity**
January	4,182			107	38,980
February	580			100	5,777
March	3,552	6	634,776	122	29,206
April	1,219	19	63,913	140	8,681
May	6,972	26	271,234	178	39,085
June	47,047	57	819,438	202	232,513
July	131,148	107	1,222,961	268	489,031
August	205,891	136	1,512,204	359	572,826
September	253,983	156	1,623,110	330	770,527
October	301,924	169	1,786,165	293	1,029,454
		Age 1+ rainbow trout		**Age 2+ rainbow trout**	
January	4,182			254	16,462
February	580			136	4,257
March	3,552			89	40,028
April	1,219	0	4,666,218	15	81,522
May	6,972	1	8,727,968	3	2,372,586
June	47,047	1	80,483,385	2	25,824,797
July	131,148	15	8,523,183	40	3,281,066
August	205,891	53	3,865,711	122	1,687,593
September	253,983	101	2,506,763	206	1,231,639
October	301,924	155	1,950,898	284	1,062,027

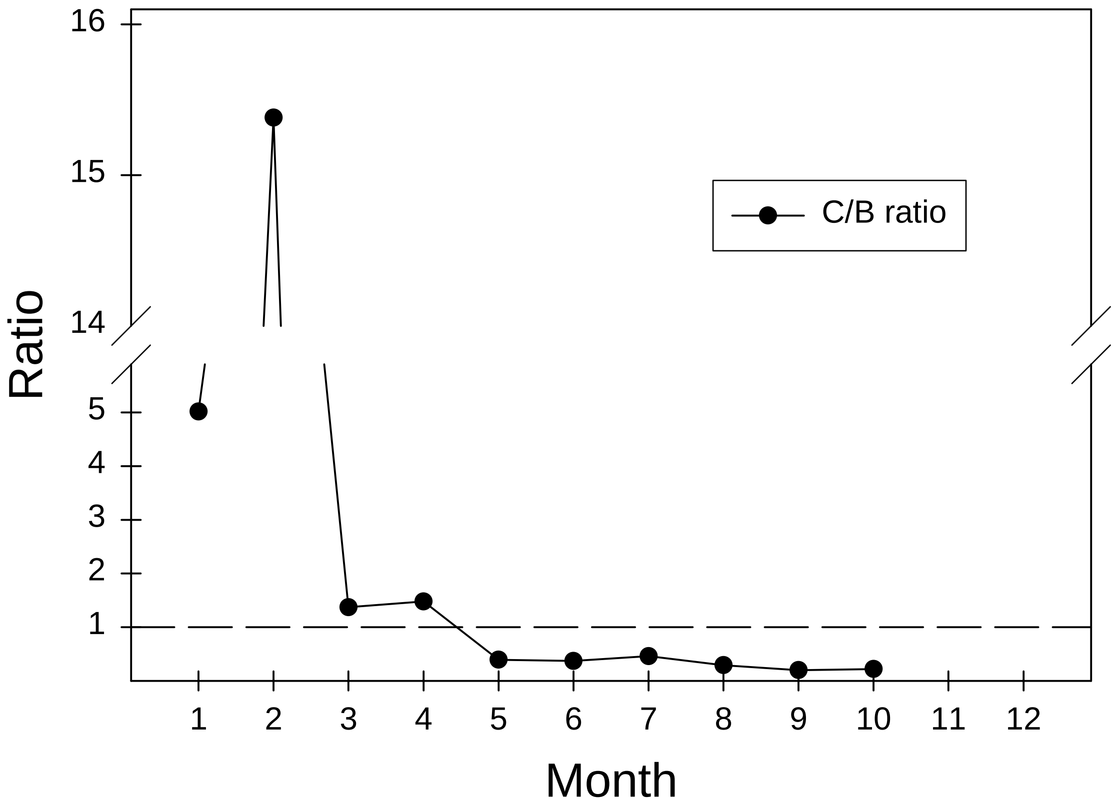

Figure 3.2.4. The ratio of stocked salmonid consumption to the biomass of *Daphnia* larger than 1.1 mm. A ratio > 1.0 indicates that *Daphnia* biomass could not support the level of *Daphnia* consumption estimated from bioenergetic model extrapolations.

Piscivory on Salmonids by Piscivorous Fishes

Relative Impact of Piscivore Species and Age Classes

Walleye, burbot, and smallmouth bass were the only piscivores that had salmonids in their diet contents during the study period (Appendix B). When consumption was scaled to 1000 predators, walleye consumed 588 kg of salmonids during the 17-month study period, whereas burbot consumed 348 kg and smallmouth bass only 83 kg (Table 3.3.1, 3.3.2, 3.3.3). Walleye consumption peaked in August of each year, with 215 and 228 kg of total consumption per 1000 predators in 1998 and 1999, respectively (Table 3.3.1). Walleye consumption of salmonids peaked in October of 1998, and in August and September of 1999, with 44, 78, and 78 kg, respectively. For burbot, consumption peaked in November of 1998 (356 kg) and October of 1999 (402 kg). Burbot consumption of salmonids peaked in July of 1998 with 63 kg per 1000 predators; no salmonids were detected in the diet of burbot in 1999 (Table 3.3.2). Smallmouth bass consumption peaked in August of 1998 (246 kg/1000 predators) and 1999 (173 kg/1000 predators), with consumption of salmonid prey peaking in September of 1998 (16 kg/1000 predators) and 1999 (8 kg/1000 predators) (Table 3.3.3).

Table 3.3.1. Consumption (kg) of various prey categories by 1000 predators age-2 to -8+ for walleye from June 1998 to October of 1999. The Inverts* category consisted of the sum of *Daphnia*, insects, and other categories; Other fish** category was the sum of all non-salmonid fish categories. The osteichthyes category was added to the Salmonid*** category and the Other fish** category based on the proportions of each category to the sum of total fish.

											Summary of Combined Categories			
Month	***Daphnia***	**Insects**	**Other**	**Cotid**	**Catastomid**	**Cyprinid**	**Centrarchid**	**Percid**	**Salmonid**	**Osteichthyes**	**Inverts***	**Other Fish****	**Salmonids*****	**Total**
Jun-98	6	8	17	46	8	12	0	5	8	49	30	115	12	158
Jul-98	7	11	19	63	11	17	0	10	14	62	37	156	21	214
Aug-98	5	12	14	67	12	20	0	19	23	56	30	166	32	228
Sep-98	2	12	7	66	12	22	0	26	30	46	21	164	39	223
Oct-98	0	13	1	66	12	24	0	31	36	38	14	163	44	221
Nov-98	0	12	2	50	8	16	0	21	25	30	14	119	32	164
Dec-98	0	10	3	36	5	10	0	12	16	24	13	83	21	118
Jan-99	0	8	3	25	3	6	0	7	10	18	11	55	14	80
Feb-99	0	8	4	22	2	4	0	4	8	17	12	46	11	68
Mar-99	0	11	6	27	1	4	0	3	8	22	16	53	12	82
Apr-99	0	14	8	33	1	4	0	2	9	28	23	64	14	100
May-99	0	21	13	43	0	4	0	0	11	40	34	80	18	132
Jun-99	0	22	14	31	0	3	0	0	15	45	36	65	28	130
Jul-99	0	31	22	28	0	3	0	0	26	74	52	72	59	183
Aug-99	0	23	22	26	2	4	0	0	28	109	45	91	78	215
Sep-99	0	7	17	19	4	5	0	0	23	125	25	97	78	200
Oct-99	0	0	15	15	5	5	0	0	20	129	15	98	76	189
Total =	21	222	187	663	87	165	0	141	307	912	430	1686	588	2705

Table 3.3.2. Consumption of various prey categories by 1000 predators age-2 to -7+ for burbot from June 1998 to October of 1999. The Inverts* category consisted of the sum of *Daphnia*, insects, and other categories; Other fish** category was the sum of all non-salmonid fish categories. The osteichthyes category was added to the Salmonid*** category and the Other fish** category based on the proportions of each category to the sum of total fish.

										Summary of Combined Categories			
Month	***Daphnia***	**Insects**	**Other**	**Cottid**	**Catastomid**	**Cyprinid**	**Centrarchid**	**Percid**	**Salmonid**	**Osteichthyes**	**Inverts**	**Other Fish**	**Salmonids**	**Total**
Jul-98	0	3	84	86	25	0	3	3	54	27	87	135	63	284
Aug-98	0	9	87	90	24	0	9	9	52	26	96	150	60	305
Sep-98	0	14	78	80	20	0	14	14	43	22	92	144	49	284
Oct-98	0	18	73	72	16	0	17	17	35	19	91	137	40	268
Nov-98	0	29	110	86	18	2	22	20	40	28	139	171	46	356
Dec-98	0	32	116	70	14	4	19	16	32	30	149	147	38	334
Jan-99	0	24	82	37	7	4	10	8	16	22	105	84	20	210
Feb-99	0	22	76	26	5	4	8	5	10	20	99	65	13	177
Mar-99	0	29	96	24	3	6	8	4	8	26	125	67	11	203
Apr-99	0	38	125	21	2	9	8	2	4	34	163	73	8	243
May-99	0	53	170	19	0	13	8	0	1	49	223	89	1	314
Jun-99	0	63	185	22	0	14	3	0	0	74	248	113	0	361
Jul-99	0	58	190	24	0	15	4	0	0	78	248	120	0	368
Aug-99	0	41	198	24	0	18	10	0	0	61	239	113	0	352
Sep-99	0	26	207	24	0	21	17	0	0	46	233	108	0	341
Oct-99	0	15	263	30	0	29	27	0	0	38	277	125	0	402
Total =	0	474	2140	736	135	140	186	98	295	600	2613	1841	348	4803

Table 3.3.3. Consumption of various prey categories by 1000 predators age-2 to -7+ for smallmouth bass from June 1998 to October of 1999. The Inverts* category consisted of the sum of *Daphnia*, insects, and other categories; Other fish** category was the sum of all non-salmonid fish categories. The osteichthyes category was added to the Salmonid*** category and the Other fish** category based on the proportions of each category to the sum of total fish.

											Summary of Combined Categories			
Month	***Daphnia***	**Insects**	**Other**	**Cottid**	**Catastomid**	**Cyprinid**	**Centrarchid**	**Percid**	**Salmonid**	**Osteichthyes**	**Inverts**	**Other Fish**	**Salmonids**	**Total**
Jul-98	7	27	12	31	15	14	0	11	2	60	47	129	4	179
Aug-98	26	44	13	40	27	13	0	10	8	65	83	150	14	246
Sep-98	35	41	7	29	27	5	0	4	11	37	83	98	16	197
Oct-98	35	35	4	21	23	0	0	0	11	19	74	61	15	149
Nov-98	14	14	4	10	9	0	0	0	4	8	32	26	6	64
Dec-98	4	5	3	5	3	0	0	0	1	4	13	11	2	25
Jan-99	1	2	2	2	1	0	0	0	0	2	5	4	1	10
Feb-99	1	1	2	2	1	0	0	0	0	1	4	4	0	8
Mar-99	1	1	3	2	0	0	0	0	0	2	5	5	0	10
Apr-99	1	2	5	4	0	0	0	0	0	3	7	8	0	15
May-99	0	4	10	8	0	0	0	0	0	6	13	14	0	27
Jun-99	0	19	13	13	2	0	0	0	0	14	32	29	0	61
Jul-99	3	42	16	21	7	0	0	0	1	26	61	53	2	116
Aug-99	12	54	18	30	16	0	0	0	4	38	84	82	7	173
Sep-99	15	35	9	22	17	0	0	0	5	29	59	65	8	132
Oct-99	15	20	3	15	16	0	0	0	5	20	38	49	7	95
Total =	171	346	124	256	166	32	0	25	54	336	641	785	83	1508

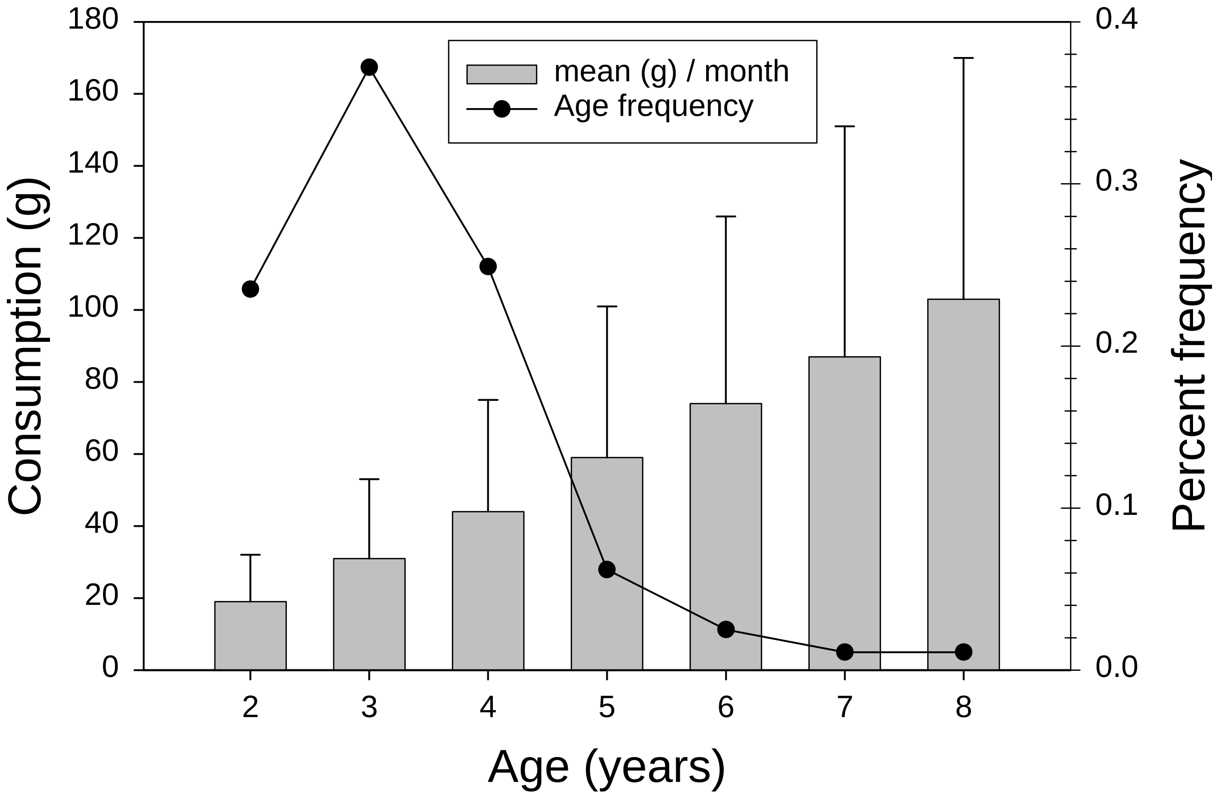

Figure 3.3.1. Mean monthly consumption (g) + 1 SD of salmonid prey by walleye of each age class from June of 1998 to October of 1999 and the age frequency of the walleye population.

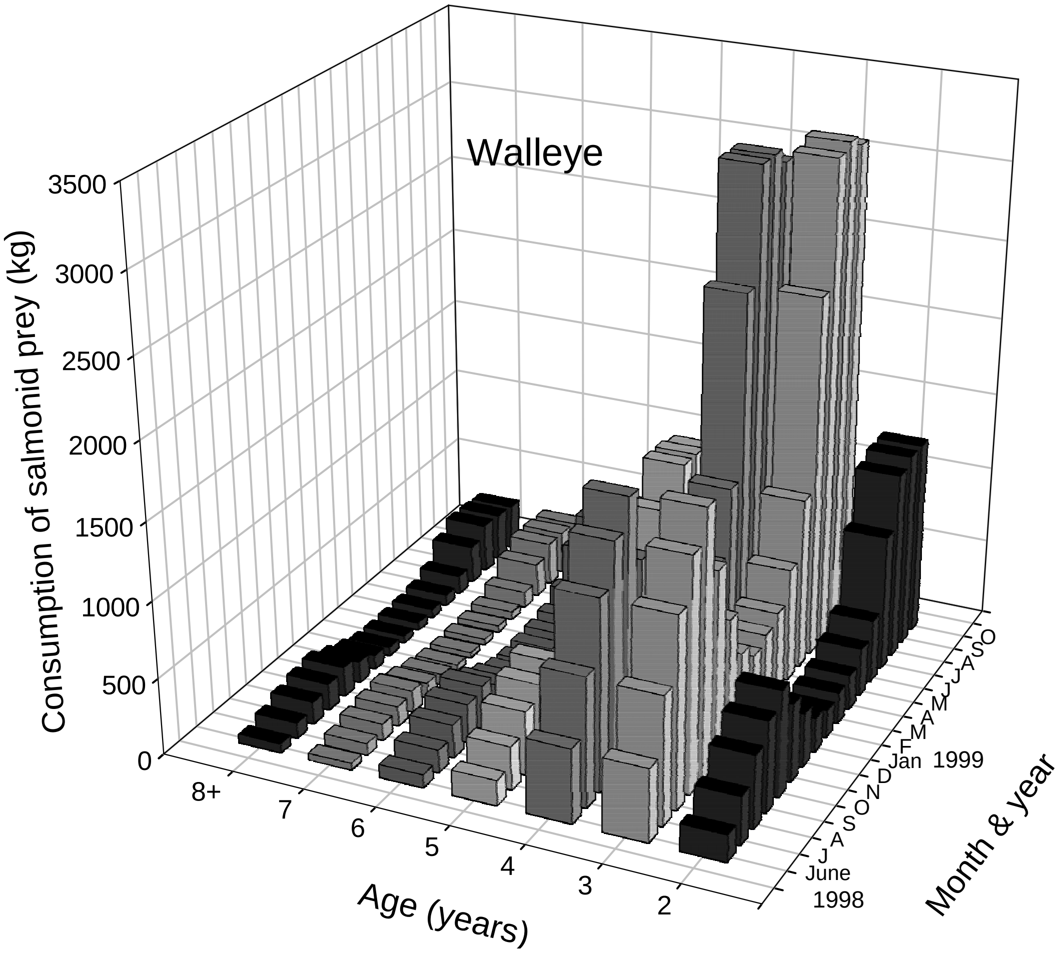

Figure 3.3.2. Consumption of salmonid prey by 1000 walleye predators. Consumption by individual age classes (2-8+) was expanded to the observed age class structure from seasonal monitoring efforts.

Walleye was the only species where data was adequate to facilitate age class consumption comparisons. The consumptive demand of individual walleye increased from age-2 to age-8; however, the age frequency declined rapidly after age-4 (Figure 3.3.1). Consequently, age-3 and age-4 walleye had the greatest relative impact to salmonid prey (Figure 3.3.2).

Losses of Juvenile Salmonids to Walleye

We modeled the consumption of 122,109 (61,491-182,727; 2 SE) walleye based on the recommended abundance estimate from EWU (McLellan et al. 2002) for all walleye longer than 200 mm. Due to the length limitation, the consumption by age-2 to -5 walleye were reduced during various months depending on the size of kokanee or rainbow trout that month. This resulted in a reduction of total walleye consumption of kokanee by 8-61%, depending on the month (Table 3.3.4). Walleye consumption of rainbow trout was reduced by 13-93% per month;

this included reduced consumption for all age classes of walleye during the majority of months (Table 3.3.5).

The sum of consumption of rainbow trout and kokanee exceeded the total consumption by walleye during five of the seventeen months (Table 3.3.6), probably due to the unknown contribution of wild salmonids in the diet. We reduced the consumption by 286-1440 kg according to the respective ratios of biomass lost to mortality each month. This resulted in final monthly consumption estimates ranging from 743-7378 kg for kokanee and 22-2005 kg for rainbow trout.

Walleye consumption of kokanee could account for 31% (15-46%) of the 1998 releases and 39% (20-59%) of the 1999 releases (Table 3.3.7). Walleye consumption of rainbow trout could account for only 3.8% (1.9-5.7%) of total mortality for the 1998 releases and 7.9% (4.0-11.9%) of the 1999 releases (Table 3.3.7).

Entrainment

The entrainment to abundance ratio (E/A) ranged from a low of 0.02 (7104:462,255) in October of 1999 to a high of 0.16 (57804:359,599). The seasonal pattern of E/A ratio followed the general trend in entrainment that peaked in late spring and summer and dropped off by fall (Figure 3.4.1). When the E/A ratio was multiplied by the number of fish stocked in 1999 and modeled through a 1-year period at monthly intervals, the annual mortality for stocked fish due to entrainment was 30% (Figure 3.4.2); assuming that half of entrainment estimates were composed of littoral fishes. Gill net surveys have shown relatively high proportions of littoral fishes in the forebay of Grand Coulee; however no conclusive species composition could be deduced (LeCaire 2000). Therefore, we chose to model the assumption that entrainment was 50% littoral species and 50% limnetic species, but we recognize that the real value could be between 10-90% either way and it could shift temporally. When kokanee abundance from mobile hydroacoustic surveys was regressed against the entrainment estimate for the previous month we found a strong negative relationship that could explain 92% of the variation of reduced kokanee abundance (ANOVA; P=0.01; F=34.9) (Figure 3.4.3). There was no significant relationship between entrainment and elevation at GCD (ANOVA; P=0.44; F=0.61), however, inflow at GCD showed a strong relationship with entrainment (ANOVA; P<0.01; F=60.5) (Figure 3.4.4). Modes in the vertical distribution of acoustic fish targets did not overlap considerably with turbine depth, except during October when the lower half of the peak distribution mode corresponded with the depth of the third powerhouse (Figure 3.4.5).

Table 3.3.4. Outline of the reduction in walleye consumption of kokanee based on the predator prey length relationship where maximum prey length = (predator length * 0.5). The length adjusted walleye consumption column represents the sum of the individual age classes.

Month & Year	Mean Kok Length (mm)	Kok Length - 2 SD	Minimum Walleye Length (mm)	Walleye Age(s)	Reduction per Age Class	Total Walleye Cons. (kg) of Salmonids	Length Adjusted Walleye Cons.(kg)	Reduction of Total Cons.
Jun-98	167	137	273	2	0.65	1,496	1,381	8%
Jul-98	182	149	298	2	0.80	2,618	2,138	18%
				3	0.25			
Aug-98	189	155	310	2	0.90	3,875	3,043	21%
				3	0.30			
Sep-98	186	153	306	2	0.85	4,722	3,719	21%
				3	0.30			
Oct-98	182	149	299	2	0.80	5,343	4,308	19%
				3	0.25			
Nov-98	178	146	291	2	0.70	3,861	3,189	17%
				3	0.20			
Dec-98	192	158	316	2	0.90	2,614	1,933	26%
				3	0.35			
				4	0.05			
Jan-99	208	170	340	2	0.95	1,660	1,079	35%
				3	0.55			
				4	0.10			
Feb-99	221	181	362	2	1.00	1,335	743	44%
				3	0.70			
				4	0.20			
				5	0.05			
Mar-99	210	172	344	2	1.00	1,481	902	39%
				3	0.60			
				4	0.15			
Apr-99	205	168	336	2	0.95	1,651	1,120	32%
				3	0.55			
				4	0.10			
May-99	194	159	318	2	0.90	2,201	1,563	29%
				3	0.40			
				4	0.05			
Jun-99	177	145	291	2	0.80	3,430	2,876	16%
				3	0.20			
Jul-99	201	165	329	2	0.95	9,956	7,378	26%
				3	0.45			

Month & Year	Mean Kok Length (mm)	Kok Length - 2 SD	Minimum Walleye Length (mm)	Walleye Age(s)	Reduction per Age Class	Total Walleye Cons. (kg) of Salmonids	Length Adjusted Walleye Cons.(kg)	Reduction of Total Cons.
				4	0.10			
Aug-99	225	185	369	2	1.00	9,561	5,006	48%
				3	0.80			
				4	0.25			
				5	0.05			
Sep-99	235	193	385	2	1.00	9,625	4,325	55%
				3	0.85			
				4	0.40			
				5	0.10			
Oct-99	243	199	399	2	1.00	9,355	3,641	61%
				3	0.90			
				4	0.50			
				5	0.15			
				6	0.05			

Table 3.3.5. Outline of the reduction in walleye consumption of rainbow trout based on the predator prey length relationship where maximum prey length = (predator length * 0.5). The length adjusted walleye consumption column represents the sum of the individual age classes.

Month & Year	Mean Rbt Length (mm)	Rbt Length - 2 SD	Minimum Walleye Length (mm)	Walleye Age	Reduction per Age Class	Total Walleye Cons. (kg) of Salmonids	Length Adjusted Walleye Cons.(kg)	Reduction of Total Cons.
	200	164	328	2	0.95	1,496	1,057	29%
				3	0.45			
				4	0.90			
Jul-98	229	188	375	2	1.00	2,618	1,334	49%
				3	0.80			
				4	0.30			
				5	0.10			
Aug-98	258	211	423	2-3	1.00	3,875	1,032	73%
				4	0.70			
				5	0.30			
				6	0.10			
				7	0.05			
Sep-98	280	229	459	2-3	1.00	4,722	881	81%
				4	0.90			
				5	0.50			
				6	0.25			
				7	0.10			
Oct-98	297	244	488	2-3	1.00	5,343	731	86%
				4	0.95			
				5	0.70			
				6	0.35			
				7	0.20			
				8+	0.05			
Nov-98	328	269	538	2-4	1.00	3,861	507	87%
				5	0.90			
				6	0.65			
				7	0.40			
				8+	0.15			
Dec-98	361	296	592	2-5	1.00	2,614	87	97%
				6	0.90			
				7	0.65			
				8+	0.55			
Jan-99	380	312	624	2-5	1.00	1,660	33	98%
				6	0.95			

Month & Year	Mean Rbt Length (mm)	Rbt Length - 2 SD	Minimum Walleye Length (mm)	Walleye Age	Reduction per Age Class	Total Walleye Cons. (kg) of Salmonids	Length Adjusted Walleye Cons.(kg)	Reduction of Total Cons.
				7	0.80			
				8+	0.65			
Feb-99	387	317	635	2-6	1.00	1,335	24	98%
				7	0.80			
				8+	0.70			
Mar-99	394	323	646	2-6	1.00	1,481	22	99%
				7	0.85			
				8+	0.75			
Apr-99	166	136	272	2	0.60	1,651	1,442	13%
				3	0.10			
May-99	186	152	304	2	0.85	2,201	1,723	22%
				3	0.25			
Jun-99	216	177	355	2	1.00	3,430	1,994	42%
				3	0.70			
				4	0.20			
				5	0.05			
Jul-99	245	201	402	2	1.00	6,540	2,382	64%
				3	0.95			
				4	0.55			
				5	0.20			
				6	0.05			
Aug-99	273	224	447	2-3	1.00	9,561	2,005	79%
				4	0.85			
				5	0.45			
				6	0.20			
				7	0.10			
Sep-99	299	245	490	2-3	1.00	9,625	1,282	87%
				4	0.95			
				5	0.70			
				6	0.40			
				7	0.20			
				8+	0.05			
Oct-99	324	266	532	2-4	1.00	9,355	701	93%
				5	0.90			
				6	0.60			
				7	0.40			
				8+	0.15			

Table 3.3.6. Final monthly consumption estimates (FC) (kg) after reduction of total walleye consumption of salmonids (C). Reductions occurred when the sum of the length adjusted consumption estimates (CPs) exceeded total walleye consumption. The ratio of biomass lost to total mortality (MBr) for kokanee and rainbow trout was used to determine the extent of reduction for each species.

Month	Total walleye C (kg)	CPs_k (kokanee)	CPs_r (rainbow trout)	$C-(CPs_k+CPs_r)$	MB (kokanee)	MB (rainbow trout)	MB_r (kok:rbt)	MB_r (rbt:kok)	FC (kokanee)	FC (rainbow trout)
Jun-98	1,496	1,381	1,057	(942)	22,887	14,550	0.61	0.39	1,014	481
Jul-98	2,618	2,138	1,334	(854)	13,949	17,814	0.44	0.56	1,659	959
Aug-98	3,875	3,043	1,119	(286)	7,888	18,078	0.30	0.70	2,843	1,032
Sep-98	4,722	3,719	881	122	4,626	16,260	0.22	0.78	3,719	881
Oct-98	5,343	4,308	731	303	4,789	14,898	0.24	0.76	4,308	731
Nov-98	3,861	3,189	507	164	3,094	13,964	0.18	0.82	3,189	507
Dec-98	2,614	1,933	87	595	2,359	13,886	0.15	0.85	1,933	87
Jan-99	1,660	1,079	33	548	1,335	11,989	0.10	0.90	1,079	33
Feb-99	1,335	743	24	568	1,025	8,714	0.11	0.89	743	24
Mar-99	1,481	902	22	557	1,153	7,765	0.13	0.87	902	22
Apr-99	1,651	1,068	1,442	(859)	1,298	371	0.78	0.22	877	774
May-99	2,201	1,563	1,723	(1,086)	1,918	1,553	0.55	0.45	1,077	1,123
Jun-99	3,430	2,876	1,994	(1,440)	11,478	5,620	0.67	0.33	2,403	1,027
Jul-99	6,540	7,378	2,382	196	25,418	10,352	0.71	0.29	7,378	94
Aug-99	9,561	5,006	2,005	2,550	21,734	11,945	0.65	0.35	5,006	2,005
Sep-99	9,625	4,325	1,282	4,018	6,022	12,804	0.32	0.68	4,325	1,282
Oct-99	9,355	3,641	701	5,012	2,979	14,362	0.17	0.83	3,641	701

Table 3.3.7. Monthly losses of kokanee and rainbow trout to walleye predators in 1998 and 1999. Estimates based on a walleye abundance of 122,109 (61,491-182,727; 2 SE).

	Month & Year	**Biomass Consumed by Walleye (kg)**	**Biomass per Kokanee (g)**	**Numerical Loss**	**Cumulative Loss**	**Lower 95 % CI**	**Upper 95 % CI**
	Jun-98	1014	45	22,650	2.1%	1.0%	3.1%
	Jul-98	1659	58	28,395	4.7%	2.4%	7.1%
Kokanee	Aug-98	2904	66	44,176	8.8%	4.4%	13.2%
Released	Sep-98	3719	63	59,276	14.2%	7.1%	21.3%
in 1998	Oct-98	4308	59	73,378	21.0%	10.5%	31.5%
	Nov-98	3189	54	58,602	26.4%	13.2%	39.6%
	Dec-98	1933	69	27,989	29.0%	14.5%	43.4%
	Jan-99	1079	87	12,439	30.1%	15.1%	45.2%
	Feb-99	743	104	7,117	30.8%	15.4%	46.1%
	Mar-99	902	90	10,042	1.4%	0.7%	2.1%
	Apr-99	877	83	10,545	2.9%	1.4%	4.3%
Kokanee	May-99	1077	71	15,218	5.0%	2.5%	7.6%
Released	Jun-99	2403	54	44,554	11.3%	5.7%	17.0%
in 1999	Jul-99	7378	78	94,183	24.6%	12.3%	36.9%
	Aug-99	5006	110	45,309	31.0%	15.5%	46.4%
	Sep-99	4325	126	34,412	35.8%	17.9%	53.7%
	Oct-99	3641	139	26,170	39.5%	19.7%	59.2%
	Jun-98	487	124	3,917	0.7%	0.4%	1.1%
	Jul-98	959	172	5,564	1.7%	0.9%	2.6%
	Aug-98	1,032	230	4,490	2.5%	1.3%	3.8%
Rainbow	Sep-98	881	279	3,153	3.1%	1.6%	4.7%
Trout	Oct-98	731	324	2,256	3.5%	1.8%	5.3%
Released	Nov-98	507	411	1,234	3.7%	1.9%	5.6%
in 1998	Dec-98	87	517	168	3.8%	1.9%	5.7%
	Jan-99	33	587	56	3.8%	1.9%	5.7%
	Feb-99	24	613	39	3.8%	1.9%	5.7%
	Mar-99	22	639	34	3.8%	1.9%	5.7%
	Apr-99	734	79	9,270	1.8%	0.9%	2.7%
Rainbow	May-99	1,123	104	10,792	3.9%	2.0%	5.9%
Trout	Jun-99	1,027	151	6,821	5.2%	2.6%	7.9%
Released	Jul-99	94	203	465	5.3%	2.7%	8.0%
in 1999	Aug-99	2,005	264	7,609	6.8%	3.4%	10.2%
	Sep-99	1,282	328	3,910	7.6%	3.8%	11.4%
	Oct-99	701	400	1,755	7.9%	4.0%	11.9%

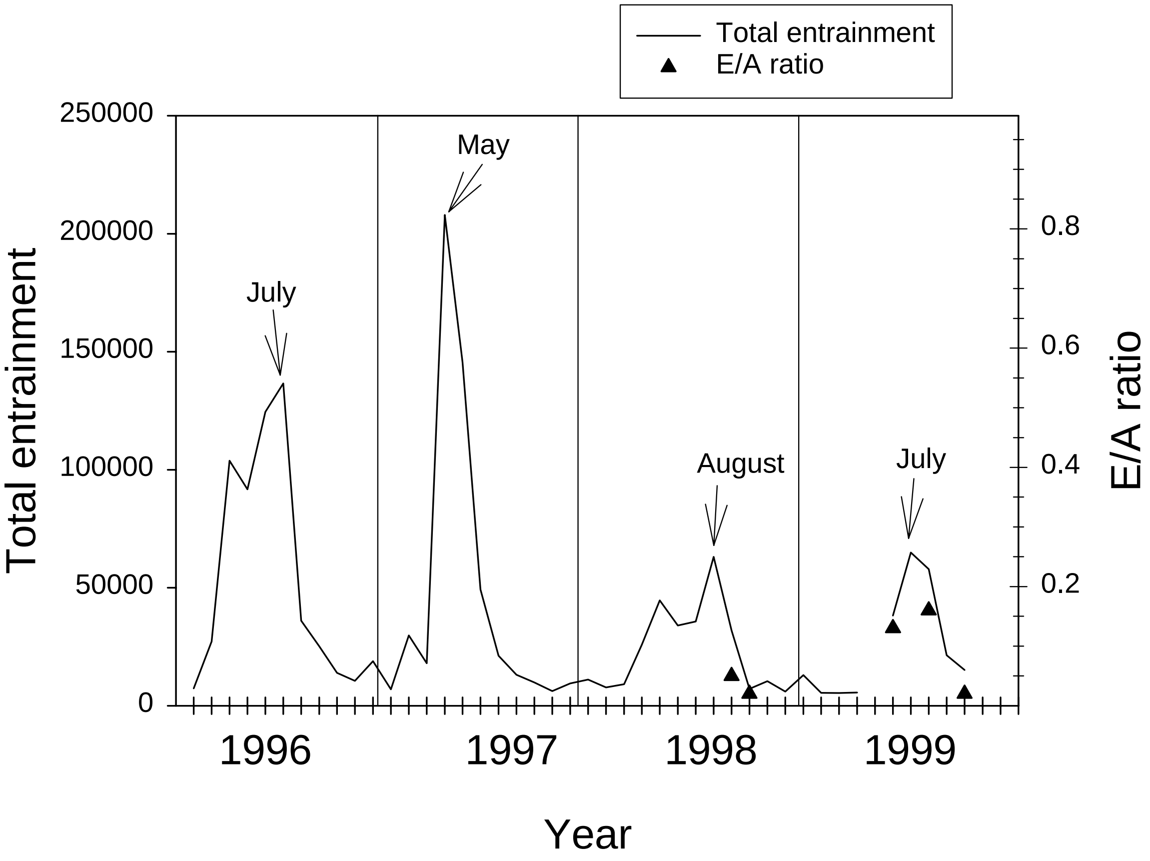

Figure 3.4.1. Total entrainment each month and the E/A ratio 1998 (September and October) and 1999 (June, August, October). Entrainment estimates were taken from LeCaire (2000) and the E/A ratio was the ratio of entrainment (E) to the abundance (A) from the mobile hydroacoustic estimates of total fish abundance.

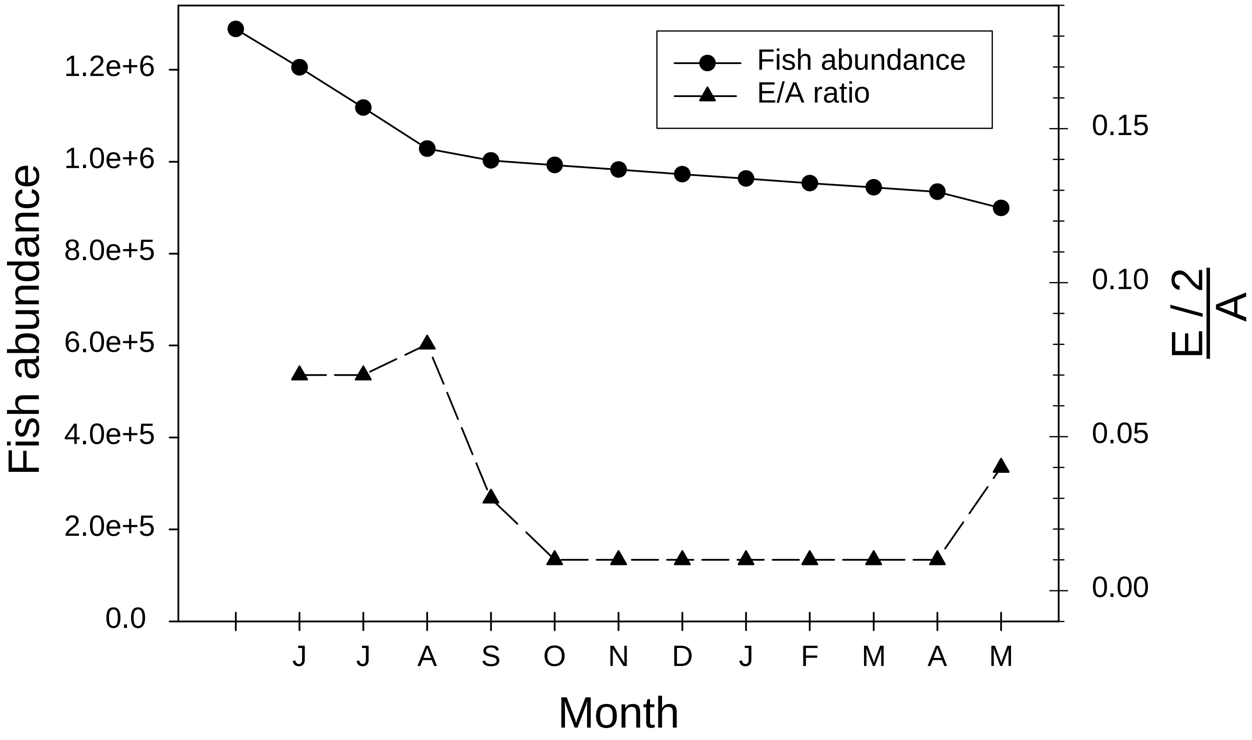

Figure 3.4.2. Fish abundance each month and the E/A ratio. Entrainment (E) was divided by 2 to account for littoral fish contribution. The E/A ratio was estimated in June, August, September, and October based on data from 1998 and 1999. All other months were extrapolated based on seasonal trends in total entrainment. The combined stocking numbers for rainbow trout and kokanee (1,288,631) in 1999 were reduced to 899,277 for an estimated annual entrainment mortality of 30%.

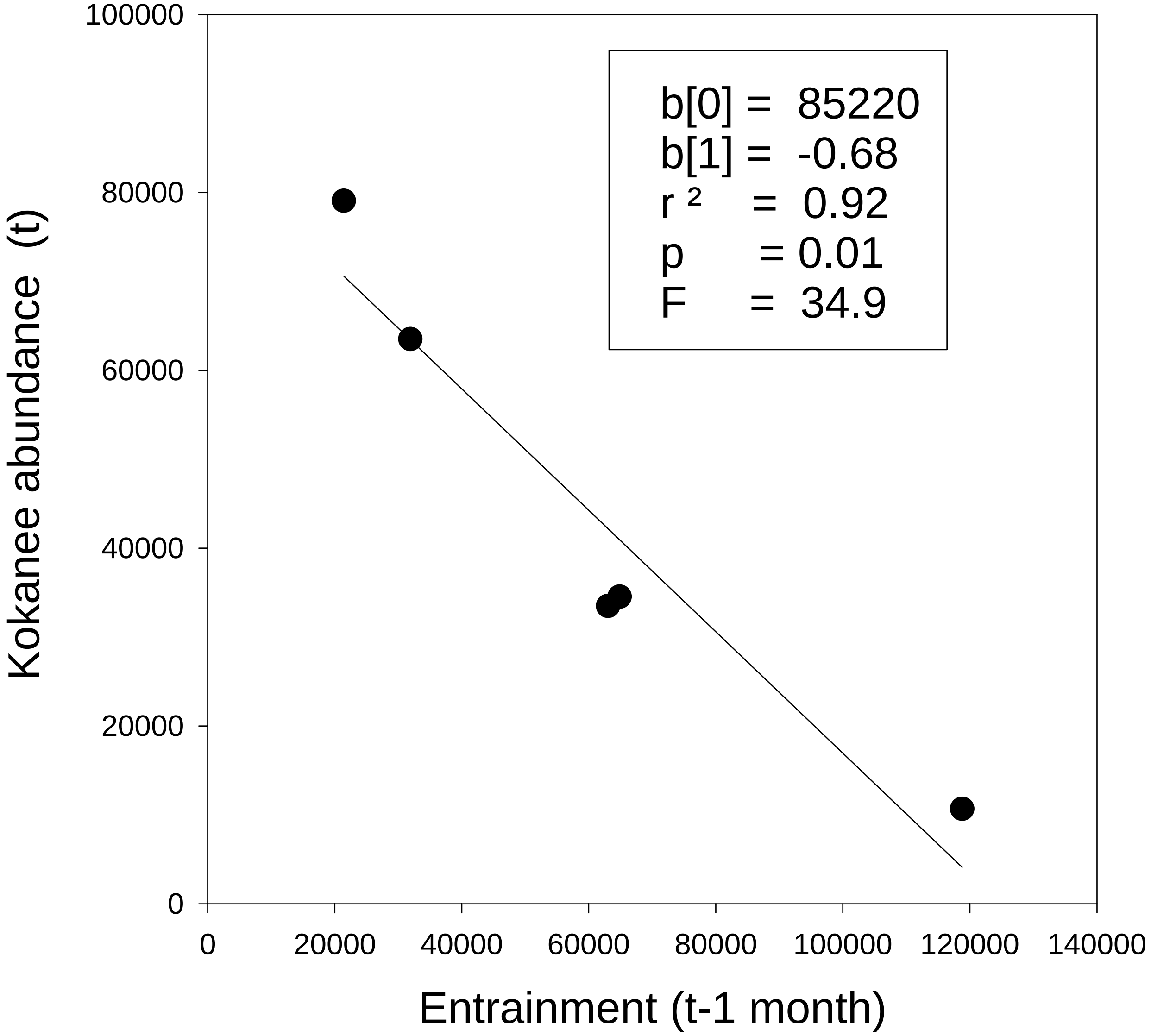

Figure 3.4.3. Reservoir-wide abundance of kokanee 200 mm and larger and total estimated entrainment the previous month. Kokanee abundance estimates were from September 1998, October 1998, June 1999, August 1999, and October 1999.

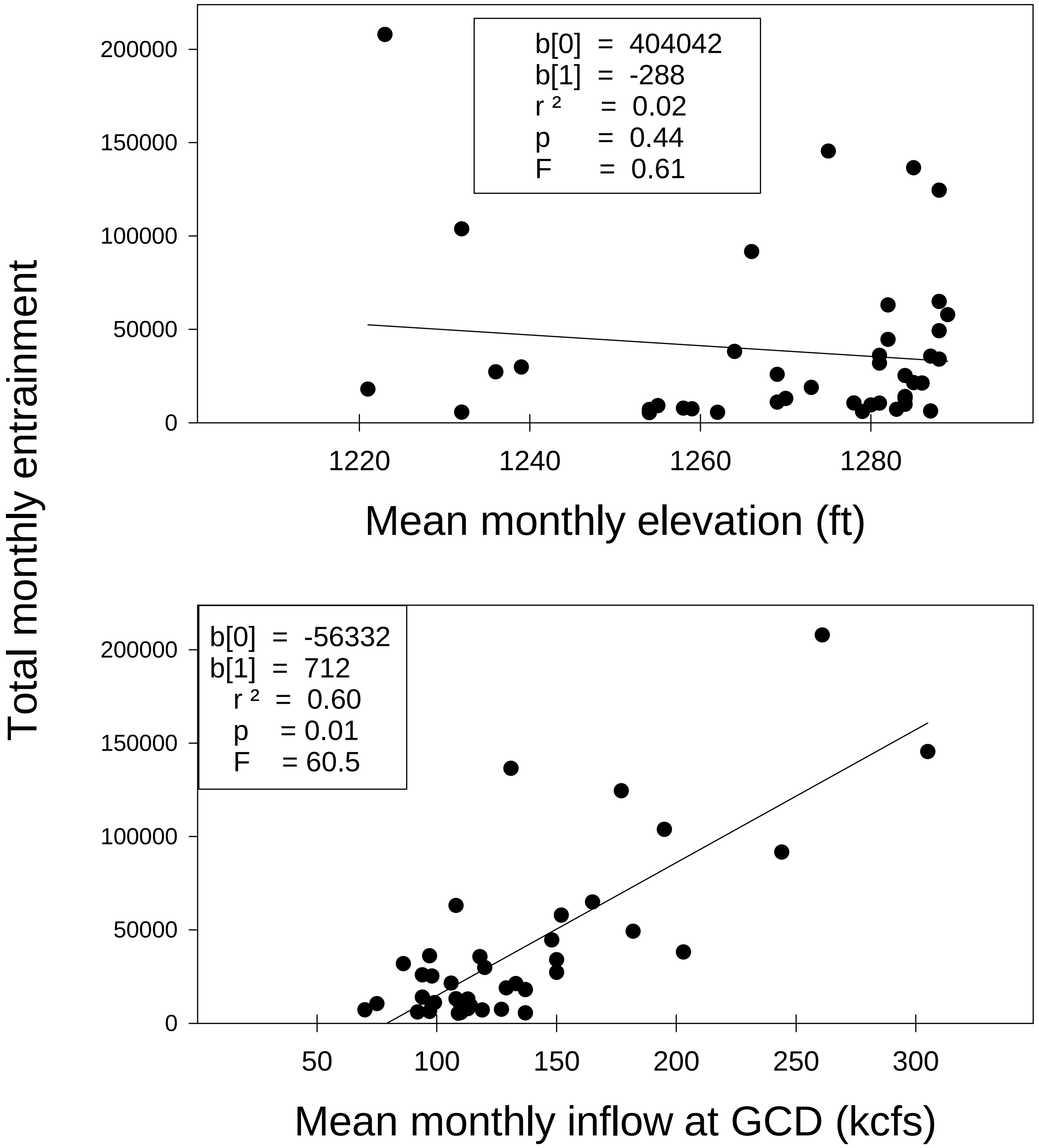

Figure 3.4.4. Factors influencing entrainment at Grand Coulee Dam. Entrainment data taken from R. LeCaire (Colville Confederated Tribes) Chief Joseph Kokanee Enhancement Project, Annual Report 1999. Reservoir elevation and inflow taken from University of Washington, Columbia River Data Access in Real Time (www.cqs.washington.edu/dart).

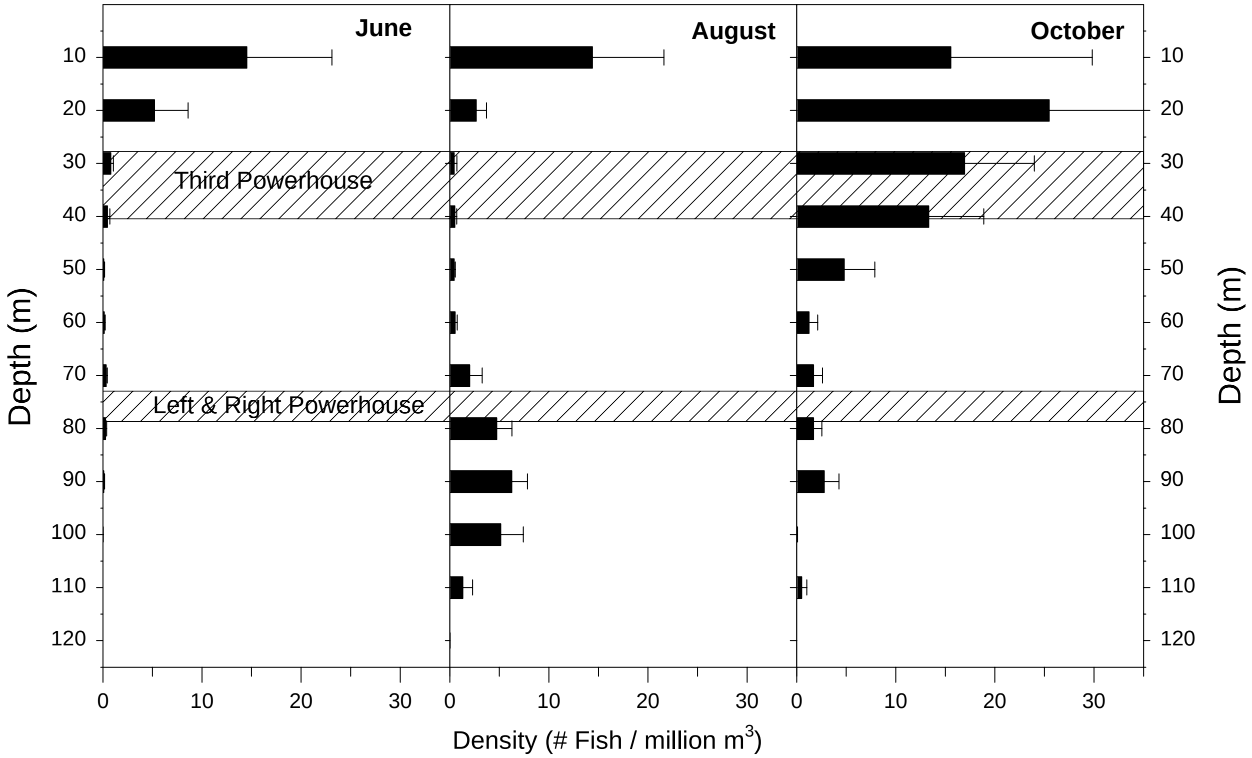

Figure 3.4.5. Mean fish density (± 2 SE) for all acoustic targets -55 to -28.8 dB (30-700 mm TL) from the lower region transects (n=8) in June, August, and October 1999.

Discussion

Temperature and Dissolved Oxygen Limitations

Temperature and dissolved oxygen did not limit kokanee and rainbow trout production on a reservoir-wide basis. Temperatures above the physiological optimum forced kokanee into deeper water, but we were not able to identify negative impacts of this change in distribution. In fact, salmonids can increase their growth rate by moving between optimal and sub-optimal temperature regimes, depending on the availability of forage (Biette and Geen 1980). Given the large size and good condition of kokanee in Lake Roosevelt, it was apparent that they are finding adequate forage, despite their deep nocturnal depth distribution. Kokanee would have to migrate 30-50 meters on a diel cycle to feed in the photic zone during the day. Nothing is known about the zooplankton population below the photic zone. Attempts were made to characterize a diel change in distribution of kokanee using hydroacoustics; however, when kokanee form schools during daylight periods they become problematic for detection using hydroacoustics (Luecke and Wurtsbaugh 1993; Ransom et al. 1999).

Mean dissolved oxygen dropped to near stressful levels (6 mg/L) in late July, with site-specific minimum levels as low as 2 mg / L. This pattern has been observed in Lake Roosevelt in previous years (Cichosz et al. 1997; 1999). Dissolved oxygen was measured to a depth of 90 m and the relatively low levels, combined with warm temperatures may have contributed to the deep depth distribution of kokanee. The mid-summer period of low DO could impose problems for growth and survival of juvenile fish if it becomes more extensive and expands to a longer time period (Warren et al. 1973). We hypothesized that kokanee remaining in the warm waters of upper Lake Roosevelt during summer and early fall experienced lower growth rates or survival than those that occupy lower Lake Roosevelt and vertically migrate to cooler waters available in the deeper lower section. Sample sizes of hatchery kokanee in the lower reservoir were too small (n=1) to facilitate statistical comparisons between sections; however, bioenergetics model simulations showed negative growth rates for kokanee when water temperatures were used from the upper 33 m of the water column. However, kokanee exhibited very good growth because they were able to access cooler water below 33 m. This emphasizes the importance of collecting water quality data to the bottom of the reservoir, regardless of depth.

If fish growth rates or available forage decrease in the future, we may want to reconsider temperature, dissolved oxygen, and other abiotic environmental conditions as possible limiting factors to limnetic fish production. In the future, it will be important for the Lake Roosevelt Fisheries Evaluation Program to collect temperature data at various sites to the bottom of the reservoir, as they did in 1999. This will provide valuable thermal experience data for bioenergetics modeling because fish were distributed much deeper than the standard limnetic sampling depth of 33 m.

Food Limitation

Food was not a limiting factor for limnetic salmonids, based on their high growth rates, early maturity, and the presence of large zooplankton throughout the year. Kokanee spawners were larger in Lake Roosevelt than other systems in the Pacific Northwest. Sexually immature kokanee also had high W_r (> 100) once they were larger than approximately 275 mm. The low W_r values of smaller kokanee may indicate a growth bottleneck that impedes kokanee survival. Most (83%) of the hatchery kokanee less than 275 mm were captured in the upper section of Lake Roosevelt and were therefore exposed to temperatures above their thermal preference.

Rainbow trout W_r was consistently near a value of 100 for all sizes, indicating good growth conditions relative to other populations. We excluded the relative weight of rainbow trout from the July sampling each year because of the inflated value of W_r in July of 1998 (143; 22 SD). Although the value for W_r was lower in July of 1999 (99; 20 SD) we felt that October represented a better time to evaluate W_r because it represented those fish that have acclimated to the reservoir and were no longer affected by hatchery and net pen rearing conditions.

Although large *Daphnia* were present in the reservoir, densities were low (< 1/L) indicating that zooplankton biomass and population structure was limited by cool water temperatures, low phytoplankton productivity, and high flows, rather than zooplanktivory by fish (Brooks and Dodson 1965; Galbraith 1967). There was some evidence of top down effects on the zooplankton community in late winter when the mean size dropped below 1 mm in March and the maximum size dropped below 2 mm in February and April. The reduced length characteristics of the *Daphnia* population coincided with the least available biomass and the highest consumption to biomass ratio. If alternative forage is not available, the carrying capacity for stocked salmonids may be limited in late winter and early spring. Short water retention times in Lake Roosevelt exacerbate the problem since many zooplankton are flushed from the system (Cichosz et al. 1997; 1999).

In the future, it will be important to examine the size of *Daphnia* selected by planktivores in the winter to obtain diet proportions for modeling and to determine if fish are forced to consume smaller *Daphnia* when zooplankton densities are low. The creel survey indicated that most salmonids were caught in the lower region of the reservoir during winter months and zooplankton densities were somewhat higher in the lower region as well (Cichosz et al. 1997, 1999). Therefore, a reservoir-wide comparison of *Daphnia* biomass to fish consumption may not be appropriate during winter and estimates of C/B subdivided by reservoir region may better identify forage availability. Our estimates of hatchery salmonid consumption exceeded the available biomass of edible size *Daphnia* during late winter and early spring months. Model output was based on seasonal diets and was not able to characterize spatial or fine scale temporal shifts in diet composition. For example, the diet of rainbow trout contains high amounts of zooplankton in January (97%) but less than 1% *Daphnia* by May (Appendix B). The model adjusts diet linearly from January 1 to May 1 but the change in diet may occur much more rapidly, therefore we would overestimate rainbow trout consumption of *Daphnia* during the late winter period. Another likely limitation to the late winter C/B ratio analysis was that fish were able to spatially distribute in areas of high zooplankton concentrations and that the standard monitoring sites did not represent the increased zooplankton biomass and density in those areas. This scenario was likely to occur on Lake Roosevelt where high flows and turbulent water flow would cause accumulations of zooplankton in embayments and channel bends.

Piscivory of Salmonids by Piscivorous Fishes

Walleye and burbot were the primary piscivores of salmonids in 1998 and 1999. Walleye had the greatest potential to limit salmonid recruitment due to their high abundance and consistent utilization of salmonid prey. Diet analysis was not adequate to evaluate the contribution of wild salmonids to walleye consumption. We modeled a worst-case scenario for hatchery rainbow trout and kokanee by assuming that walleye first selected hatchery stocked salmonids. There were no data available on the relative abundance of juvenile wild salmonids in Lake Roosevelt.

The only diet data that were identified to species (WDFW, 1999 data) did not reveal whitefish in the diet of walleye or other piscivores. During certain months walleye consumption of salmonids exceeded the biomass of hatchery salmonids lost to total mortality. This excess could be explained by wild salmonids contributing to walleye diets. The annual impact of walleye on kokanee was highly dependent on the abundance estimate of walleye from EWU (McLellan et al. 2002). In fact, the range of impacts for 1998 (15-46%) and 1999 (20-59%) represent the error bounds of the abundance estimate multiplied by the consumption estimate for walleye. The lower end of these ranges (15-20%) might be considered acceptable levels of predation whereas the upper bounds (46-59%) might be considered unacceptable. However, walleye were not the only piscivore, and we did not expand the consumption by burbot, smallmouth bass, or northern pikeminnow. In 1997, salmonid prey constituted 17% of northern pikeminnow diet by weight (Baldwin et al. 1999), and in October of 1999 northern pikeminnow were consuming rainbow trout following a fall release of net pen rainbow trout (WDFW unpublished data). Apparently, the sample size of northern pikeminnow diets was too small in 1998 and 1999 to detect salmonids on a seasonal basis (n=22). Considering consumption by the entire community of piscivores, it was likely that total losses to predation were at least within the 30-50% range. Fine-tuning the abundance estimate and bioenergetics model inputs would certainly allow us to refine our estimate of the impact of piscivores. However, the cost and effort associated with such tasks may be prohibitive. We have proven that predation is one of the primary limiting factors for kokanee and efforts may be better utilized on solutions, rather than model refinement.

The low impact to rainbow trout by piscivores could certainly be one of the primary reasons for their success in Lake Roosevelt. Rainbow trout released from the net pen are generally between 200-225 mm; that reduces the potential predator population by 75-95% when compared to fry releases. The length refuge for rainbow trout exposed to walleye predators has also been quantified under experimental pond conditions, as well as in other western reservoirs (Yule et al. 2000). Kokanee, on the other hand, were released between 150 and 175 mm; that only reduced predation by 15-50% over fry releases. Therefore, size at release and predation could explain much of the difference in success of the rainbow trout program versus the kokanee program.

Entrainment

Entrainment had high potential to limit limnetic fish production in Lake Roosevelt, although we could not directly measure the loss of limnetic fish because we did not know the contribution of littoral fish to total entrainment. Gill net studies conducted by CCT in conjunction with the entrainment study did not provide adequate estimates of species composition thereby limiting the ability of our analysis (LeCaire 2000). Therefore, we assumed that littoral and limnetic fish were equally vulnerable to entrainment and simply divided the entrainment estimate by two before dividing by limnetic fish abundance. Entrainment could still account for 30% of total mortality, even with the rather low entrainment rates of 1-8% / month. We only had four months where reservoir-wide hydroacoustic surveys were conducted simultaneously with hydroacoustic estimates at GCD; however, we used the average of October 1996-1998 to estimate entrainment in October of 1999 to give us a fifth month to estimate the E/A ratio. The October 1999 data did not alter the results since the estimated E/A ratio was the same as October of 1998 (2%).

A more critical extrapolation was made in May of 1999 when we again used the mean from 1996 to 1998 because no data were collected in May of 1999. We compared the reservoir-wide kokanee abundance estimate for June 1999 (t) to the entrainment during May 1999 (t-1) to define the impact of entrainment to kokanee. The regression (Figure 3.4.3) was highly dependent upon this data point and if entrainment in May was considerably lower than the average of the three previous years, then we would have overestimated the impact of entrainment.

We examined three possible factors that directly affect the magnitude of entrainment including reservoir elevation, inflow to GCD, and fish vertical distribution. It was apparent that lowered lake elevation did not directly increase entrainment, but increased inflow did (Figure 3.4.4). Therefore, fish were not being “sucked out” of the reservoir by the draw down, instead they were “pushed out” by the increased flow. However, there is a direct relationship between flood control drawdown and subsequent inflow based on runoff forecast, causing autocorrelation in the analysis. Additionally, drawdown might be indirectly related to entrainment by moving fish downstream and setting them up for the high inflow to push them out of the reservoir. The periods of increased inflow also coincided with hatchery releases and natural recruitment of wild fish such as percids, cyprinids, catostomids, and centrarchids, thereby providing increased abundances of fishes to be entrained throughout the summer months when inflow is higher.

The third powerhouse of GCD was responsible for 89% of total entrainment over the course of the Chief Joseph Kokanee Enhancement Project entrainment study (LeCaire 2000). The difference in entrainment between powerhouses could not be explained by depth of the turbines relative to the vertical distribution of limnetic fishes (Figure 3.4.5). The distribution of fish near the dam would have to be examined much more closely to determine the fine scale movement patterns in relation to the various powerhouses and the pumping station for Banks Lake.

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Appendix A. Gill Net, Trawl, And Hydroacoustic Survey Results

Table A1. Gill net effort on Lake Roosevelt in 1999 following hydroacoustic surveys each month.

						Vertical gill nets						
	Variable mesh			25 mm	38 mm	Mesh size (mm)						
Month	**Floating**	**Sinking**	**Suspended**	**Suspended**	**Suspended**	**25**	**38**	**51**	**64**	**76**	**89**	**102**
June	9	12	16	3	2	3	3	5	2	5	4	5
August	12	15	18	0	11	11	3	11	4	11	2	16
October	9	9	18	0	3	5	3	9	3	9	3	15

Table A2. Effort and depth of midwater trawl tows on Lake Roosevelt in 1999. Lower section was from Grand Coulee Dam to Whitestone Rocks, middle section was from Lincoln to Hunters, and the upper section was from Gifford to Kettle Falls.

Month	Section	# of Tows	Total Time (hrs)	(m) Depth Range
June	lower	4	3.44	15-50
	middle	4	4.08	5-50
	upper	5	5.24	10-25
August	lower	0	0.00	NA
	middle	0	0.00	NA
	upper	0	0.00	NA
October	lower	4	4.80	5-40
	middle	5	4.87	5-40
	upper	2	2.00	11

Table A3. Species composition for size classes of limnetic fish caught in June, August, and October 1999.

		Size Classes				
	Species	**25-100**	**100-200**	**200-400**	**400-700**	**All Sizes**
June	n =	0	6	29	40	75
	Burbot	0%	0%	7%	25%	16%
	Chinook	0%	0%	0%	3%	1%
	Kokanee	0%	83%	24%	8%	20%
	Longnose Sucker	0%	0%	0%	0%	0%
	Largescale Sucker	0%	0%	0%	3%	1%
	Lake Whitefish	0%	0%	21%	50%	35%
	Mountain Whitefish	0%	0%	0%	0%	0%
	Northern Pikeminnow	0%	0%	0%	0%	0%
	Rainbow Trout	0%	0%	24%	10%	15%
	Sculpin	0%	0%	0%	0%	0%
	Smallmouth Bass	0%	0%	0%	0%	0%
	Walleye	0%	17%	24%	3%	12%
August	n =	0	3	41	24	68
	Burbot	0%	0%	5%	8%	6%
	Chinook	0%	0%	0%	0%	0%
	Kokanee	0%	100%	46%	33%	44%
	Longnose Sucker	0%	0%	2%	4%	3%
	Largescale Sucker	0%	0%	0%	0%	0%
	Lake Whitefish	0%	0%	7%	38%	18%
	Mountain Whitefish	0%	0%	0%	0%	0%
	Northern Pikeminnow	0%	0%	0%	0%	0%
	Rainbow Trout	0%	0%	12%	0%	7%
	Sculpin	0%	0%	0%	0%	0%
	Smallmouth Bass	0%	0%	0%	0%	0%
	Walleye	0%	0%	27%	17%	22%
October	n =	6	1	60	41	108
	Burbot	0%	0%	3%	7%	5%
	Chinook	0%	0%	0%	0%	0%
	Kokanee	0%	0%	48%	7%	30%
	Longnose Sucker	0%	0%	2%	2%	2%
	Largescale Sucker	0%	0%	0%	0%	0%
	Lake Whitefish	0%	100%	10%	54%	27%
	Mountain Whitefish	0%	0%	2%	2%	2%
	Northern Pikeminnow	0%	0%	0%	5%	2%
	Rainbow Trout	0%	0%	5%	10%	6%
	Sculpin	83%	0%	0%	0%	5%
	Smallmouth Bass	17%	0%	2%	0%	2%
	Walleye	0%	0%	28%	12%	20%

Table A4. Density for each size class and total density (# / million m^3) of fish within each transect for June, 1999. Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

		Size Class (- dB or cm)						
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**Sub-Total**	**Sub-Total**	**Total**
Transect	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**20-70**	**10-70**	**3-70**
L1		9.6	5.6	4.0	4.5	8.6	14.2	23.8
L2		38.9	1.8	30.0	3.1	33.1	34.9	73.8
L3		0.5	0.4	0.2	0.1	0.3	0.7	1.2
L4		15.2	1.6	0.4	0.1	0.6	2.1	17.3
L5		13.5	0.3	0.1	0.0	0.1	0.4	13.9
L6		2.1	0.9	0.9	0.7	1.7	2.6	4.7
L7		0.3	0.5	0.9	0.3	1.2	1.8	2.1
L8		28.3	9.6	1.0	0.2	1.2	10.8	39.1
M1		1.4	2.3	3.8	0.8	4.6	6.9	8.4
M2		50.1	12.0	20.8	1.2	22.0	34.0	84.0
M3		61.4	4.5	6.8	1.3	8.2	12.7	74.0
M4		41.9	18.8	2.4	0.2	2.7	21.4	63.4
M5		6.7	3.8	4.3	2.5	6.8	10.6	17.3
M6		0.6	33.9	0.0	0.0	0.0	33.9	34.4
M7		4.3	2.6	2.1	1.0	3.1	5.7	9.9
M8		2.8	2.1	2.0	0.7	2.7	4.8	7.5
U1		0.8	0.4	2.1	0.6	2.7	3.1	4.0
U2		15.1	28.4	1.4	0.1	1.5	29.9	45.0
U3		0.6	0.6	2.0	0.9	3.0	3.6	4.2
U4		4.8	4.6	10.0	7.5	17.5	22.1	27.0
U5		57.4	6.3	2.0	1.7	3.7	10.0	67.4
U6		2.2	1.6	1.8	1.1	2.9	4.6	6.8
U7		75.6	16.6	4.7	1.3	6.0	22.6	98.2
mean		18.9	6.9	4.5	1.3	5.8	12.8	31.6
SD		23.4	9.2	7.1	1.7	8.0	11.6	30.4
2 SE		9.7	3.8	3.0	0.7	3.3	4.9	12.7
CV		0.52	0.56	0.66	0.55	0.57	0.38	0.40

Table A5. Density for each size class and total density (# / million m^3) of fish within each transect for August, 1999. Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

		Size Class (- dB or cm)						
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**Sub-Total**	**Sub-Total**	**Total**
Transect	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**20-70**	**10-70**	**3-70**
L1		15.2	6.2	7.9	3.1	11.0	17.2	32.4
L2		21.2	9.0	7.7	1.5	9.3	18.3	39.4
L3		38.9	39.1	6.6	1.8	8.5	47.6	86.5
L4		4.7	17.8	1.7	0.8	2.5	20.4	25.0
L5		45.7	7.9	9.4	3.3	12.7	20.6	66.4
L6		11.1	5.3	5.8	11.8	17.6	22.9	34.0
L7		2.8	2.0	1.9	0.6	2.5	4.5	7.2
L8		2.9	7.2	6.8	0.2	7.0	14.2	17.0
M1		1.9	0.1	19.8	0.0	19.8	20.0	21.9
M2		23.0	1.4	1.0	0.3	1.3	2.7	25.7
M3		14.3	3.6	4.2	0.2	4.4	8.0	22.3
M4		2.4	1.3	1.2	0.2	1.4	2.6	5.1
M5		8.3	1.8	0.2	0.5	0.7	2.5	10.8
M6		23.3	0.8	12.0	0.2	12.2	13.0	36.4
M7		2.2	2.2	1.0	0.0	1.1	3.3	5.5
M8		2.3	1.4	0.4	0.0	0.4	1.8	4.1
M9		3.9	2.9	2.3	0.4	2.6	5.5	9.5
U1		6.0	4.9	3.5	0.3	3.9	8.8	14.8
U2		5.9	4.7	4.3	1.5	5.8	10.5	16.4
U3		5.9	5.2	6.6	1.3	8.0	13.2	19.1
U4		5.4	3.0	4.2	1.2	5.3	8.3	13.8
U5		43.5	12.6	11.3	4.4	15.7	28.3	71.9
U6		51.3	33.7	5.4	2.5	8.0	41.7	93.0
U7		60.8	15.6	4.2	0.9	5.1	20.7	81.5
U8		10.7	4.9	2.2	0.3	2.4	7.3	18.0
mean		16.5	7.8	5.3	1.5	6.8	14.6	31.1
SD		17.6	9.7	4.5	2.4	5.5	11.8	27.0
2 SE		7.2	4.0	1.8	1.0	2.2	4.8	11.0
CV		0.43	0.51	0.35	0.66	0.32	0.33	0.35

Table A6. Density for each size class and total density (# / million m^3) of fish within each transect for October, 1999. Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

			Size Class (- dB or cm)					
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**Sub-Total**	**Sub-Total**	**Total**
Transect	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**20-70**	**10-70**	**3-70**
L1		7.5	2.6	0.4	0.0	0.4	3.0	10.5
L2		4.5	5.3	8.9	2.7	11.6	16.9	21.4
L3		34.1	72.3	52.0	33.5	85.6	157.9	191.9
L4		36.3	43.0	37.6	32.1	69.7	112.7	148.9
L5		5.7	0.9	1.4	0.2	1.6	2.5	8.2
L6		11.4	9.4	15.6	3.0	18.6	28.0	39.4
L7		31.7	16.4	27.1	18.3	45.5	61.9	93.6
L8		47.1	42.2	38.2	31.4	69.6	111.9	159.0
M1		12.2	5.0	9.9	7.2	17.1	22.1	34.3
M2		23.4	2.5	5.3	2.1	7.5	10.0	33.4
M3		34.8	9.3	12.8	2.8	15.6	24.8	59.6
M4		22.8	24.1	7.4	2.4	9.7	33.8	56.5
M5		87.6	23.3	14.9	3.2	18.1	41.3	128.9
M6		32.0	4.6	17.8	1.5	19.3	23.9	55.9
M7		21.1	1.2	0.7	0.3	1.0	2.2	23.3
M8		89.9	14.4	27.9	8.8	36.7	51.0	141.0
U1		50.0	10.3	20.9	9.9	30.8	41.1	91.1
U2		30.6	12.0	18.2	6.5	24.7	36.8	67.4
U3		33.5	22.7	6.4	3.1	9.5	32.2	65.8
U4		21.9	9.1	14.5	5.1	19.6	28.7	50.6
U5		74.5	15.7	12.0	7.9	19.8	35.5	110.1
U6		45.0	6.3	8.0	1.1	9.1	15.4	60.4
U7		195.6	63.3	11.6	5.3	16.8	80.1	275.7
U8		130.3	64.0	10.2	0.0	10.2	74.2	204.6
mean		45.2	20.0	15.8	7.9	23.7	43.7	88.8
SD		44.0	21.2	12.8	10.3	22.6	38.9	68.7
2 SE		18.0	8.7	5.2	4.2	9.2	15.9	28.0
CV		0.4	0.4	0.3	0.5	0.39	0.4	0.3

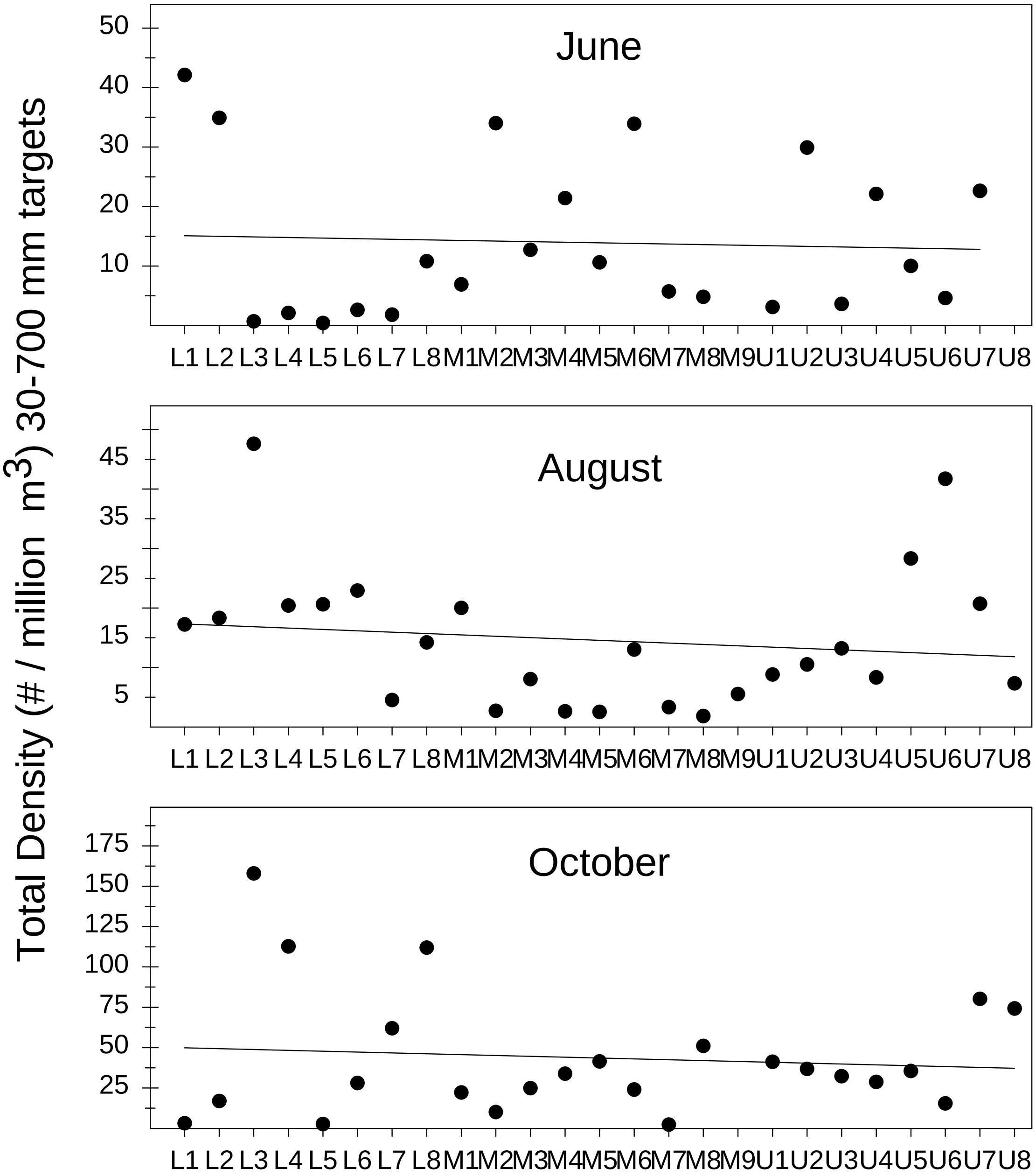

Figure A1. Total density of acoustic targets (55-28.8 -dB; 30-700 mm) from transects on Lake Roosevelt in June, August, and October of 1999. Lines are a simple linear regression, none of which had a significant slope.

Table A7. Mean density (# / million m^3) and standard deviation of acoustic targets for the lower section of Lake Roosevelt for June 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

			Mean Density				**Standard Deviation**		
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**55-45**	**45-39**	**39-34**	**34-29**
Depth (m)	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**3-10**	**10-20**	**20-40**	**40-70**
1-10		10.64	1.17	2.72	0.00	13.36	3.32	7.68	0.00
10-20		1.74	0.94	1.49	1.03	2.67	1.54	2.92	1.74
20-30		0.40	0.11	0.26	0.03	0.50	0.20	0.24	0.06
30-40		0.30	0.06	0.11	0.01	0.47	0.08	0.23	0.02
40-50		0.08	0.01	0.01	0.01	0.11	0.03	0.03	0.02
50-60		0.05	0.05	0.03	0.02	0.09	0.08	0.08	0.04
60-70		0.14	0.14	0.03	0.02	0.12	0.13	0.06	0.02
70-80		0.13	0.07	0.06	0.00	0.22	0.07	0.09	0.00
80-90		0.08	0.02	0.00	0.00	0.12	0.06	0.00	0.00
90-100		0.00	0.02	0.01	0.01	0.00	0.04	0.02	0.02
100-110		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
110-120		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A8. Mean density (# / million m^3) and standard deviation of acoustic targets for the middle section of Lake Roosevelt for June 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

			Mean				**Standard Deviation**		
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**55-45**	**45-39**	**39-34**	**34-29**
Depth (m)	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**3-10**	**10-20**	**20-40**	**40-70**
1-10		14.32	5.97	1.60	0.00	20.33	12.12	4.53	0.00
10-20		3.06	1.12	0.85	0.11	3.37	1.07	0.69	0.21
20-30		1.98	2.05	1.81	0.45	1.73	2.70	1.88	0.48
30-40		0.69	0.60	0.75	0.23	0.63	0.34	0.65	0.32
40-50		0.39	0.14	0.20	0.15	0.39	0.17	0.20	0.31
50-60		0.22	0.10	0.06	0.03	0.32	0.25	0.11	0.06
60-70		0.41	0.01	0.01	0.00	0.57	0.02	0.02	0.00
70-80		0.05	0.00	0.00	0.00	0.14	0.00	0.00	0.00
80-90		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90-100									
100-110									
110-120									

Table A9. Mean density (# / million m^3) and standard deviation of acoustic targets for the upper section of Lake Roosevelt for June 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

		Mean				**Standard Deviation**			
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**55-45**	**45-39**	**39-34**	**34-29**
Depth (m)	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**3-10**	**10-20**	**20-40**	**40-70**
1-10		9.64	5.26	0.00	0.00	20.05	10.51	0.00	0.00
10-20		3.48	1.02	1.00	0.58	5.04	1.20	0.79	0.61
20-30		2.16	0.97	1.76	1.28	2.49	1.07	2.83	2.15
30-40		2.43	0.90	0.25	0.03	4.04	1.23	0.24	0.05
40-50		4.65	0.21	0.43	0.00	12.32	0.57	1.13	0.00
50-60									
60-70									
70-80									
80-90									
90-100									
100-110									
110-120									

Table A10. Mean density (# / million m^3) and standard deviation of acoustic targets for the lower section of Lake Roosevelt for August 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

		Mean				**Standard Deviation**			
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**55-45**	**45-39**	**39-34**	**34-29**
Depth (m)	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**3-10**	**10-20**	**20-40**	**40-70**
1-10		5.58	6.74	0.80	1.29	10.35	11.50	2.25	3.65
10-20		1.83	0.30	0.26	0.27	1.60	0.53	0.36	0.56
20-30		0.19	0.08	0.08	0.09	0.27	0.14	0.15	0.20
30-40		0.17	0.12	0.13	0.09	0.26	0.14	0.15	0.25
40-50		0.20	0.13	0.07	0.04	0.23	0.07	0.08	0.04
50-60		0.29	0.09	0.12	0.04	0.22	0.14	0.15	0.05
60-70		0.99	0.47	0.41	0.16	1.58	0.54	0.70	0.26
70-80		2.30	0.93	1.17	0.34	1.87	0.63	1.01	0.32
80-90		3.20	1.31	1.45	0.30	2.02	0.83	0.92	0.17
90-100		2.35	1.29	1.27	0.23	2.82	1.35	1.27	0.25
100-110		0.70	0.34	0.24	0.04	1.32	0.60	0.42	0.11
110-120		0.01	0.00	0.01	0.00	0.03	0.01	0.02	0.01

Table A11. Mean density (# / million m^3) and standard deviation of acoustic targets for the middle section of Lake Roosevelt for August 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

		Mean				Standard Deviation			
	(-dB)	55-45	45-39	39-34	34-29	55-45	45-39	39-34	34-29
Depth (m)	(cm)	3-10	10-20	20-40	40-70	3-10	10-20	20-40	40-70
1-10		6.11	0.00	3.74	0.00	9.46	0.00	7.27	0.00
10-20		1.32	0.27	0.13	0.06	1.34	0.31	0.27	0.17
20-30		0.50	0.28	0.10	0.03	0.44	0.31	0.20	0.09
30-40		0.29	0.14	0.16	0.00	0.26	0.17	0.27	0.00
40-50		0.26	0.25	0.21	0.06	0.28	0.28	0.20	0.07
50-60		0.61	0.30	0.21	0.03	0.90	0.31	0.27	0.04
60-70		0.55	0.30	0.38	0.01	0.78	0.34	0.68	0.01
70-80		0.08	0.04	0.04	0.00	0.14	0.07	0.05	0.01
80-90		0.00	0.01	0.00	0.00	0.00	0.02	0.01	0.01
90-100									
100-110									
110-120									

Table A12. Mean density (# / million m^3) and standard deviation of acoustic targets for the upper section of Lake Roosevelt for August 1999 (n=7). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

		Mean				Standard Deviation			
	(-dB)	55-45	45-39	39-34	34-29	55-45	45-39	39-34	34-29
Depth (m)	(cm)	3-10	10-20	20-40	40-70	3-10	10-20	20-40	40-70
1-10		1.91	3.81	0.00	0.00	5.04	10.09	0.00	0.00
10-20		5.31	1.05	0.34	0.05	7.57	0.89	0.32	0.14
20-30		4.19	1.28	1.52	0.48	5.19	0.69	1.04	0.50
30-40		2.39	1.72	1.69	0.63	2.79	1.34	1.52	0.93
40-50		3.08	1.53	1.68	0.47	5.13	1.64	1.64	0.50
50-60		0.56	0.18	0.14	0.04	1.02	0.23	0.22	0.11
60-70									
70-80									
80-90									
90-100									
100-110									
110-120									

Table A13. Mean density (# / million m^3) and standard deviation of acoustic targets for the lower section of Lake Roosevelt for October 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

			Mean				**Standard Deviation**		
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**55-45**	**45-39**	**39-34**	**34-29**
Depth (m)	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**3-10**	**10-20**	**20-40**	**40-70**
1-10		2.43	6.56	3.81	2.75	4.56	15.44	7.93	7.79
10-20		5.11	7.22	7.64	5.52	5.49	8.01	7.50	6.25
20-30		4.33	4.39	5.03	3.20	3.67	5.14	5.53	4.01
30-40		4.45	3.15	3.35	2.38	3.43	3.46	3.86	3.36
40-50		1.77	1.34	1.12	0.56	2.22	2.46	1.95	1.17
50-60		0.48	0.24	0.36	0.16	0.84	0.56	0.67	0.24
60-70		0.83	0.37	0.44	0.07	1.09	0.56	0.54	0.11
70-80		1.05	0.23	0.34	0.09	1.24	0.29	0.46	0.22
80-90		1.38	0.43	0.58	0.41	1.92	0.40	0.88	0.69
90-100		0.03	0.01	0.00	0.00	0.09	0.04	0.00	0.00
100-110		0.43	0.06	0.01	0.01	1.21	0.09	0.02	0.03
110-120		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table A14. Mean density (# / million m^3) and standard deviation of acoustic targets for the middle section of Lake Roosevelt for October 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

			Mean				**Standard Deviation**		
	(-dB)	**55-45**	**45-39**	**39-34**	**34-29**	**55-45**	**45-39**	**39-34**	**34-29**
Depth (m)	**(cm)**	**3-10**	**10-20**	**20-40**	**40-70**	**3-10**	**10-20**	**20-40**	**40-70**
1-10		17.75	1.25	2.74	0.00	21.14	3.54	5.08	0.00
10-20		6.11	2.13	2.71	0.00	8.24	2.66	3.26	0.00
20-30		4.36	0.18	0.58	0.38	4.35	0.34	0.92	0.59
30-40		3.87	2.80	3.50	1.17	3.95	3.22	4.33	1.68
40-50		3.74	1.99	1.16	1.39	2.24	3.10	1.10	1.98
50-60		2.83	1.75	0.96	0.36	2.77	1.55	1.03	0.66
60-70		1.41	0.36	0.35	0.25	1.26	0.50	0.51	0.45
70-80		0.23	0.07	0.08	0.00	0.45	0.20	0.22	0.00
80-90		0.17	0.00	0.00	0.00	0.49	0.00	0.00	0.00
90-100		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
100-110									
110-120									

Table A15. Mean density (# / million m^3) and standard deviation of acoustic targets for the upper section of Lake Roosevelt for October 1999 (n=8). Length classes (cm) were estimated from target strength (-dB) using equations from Love (1971,1977).

		Mean				Standard Deviation			
	(-dB)	55-45	45-39	39-34	34-29	55-45	45-39	39-34	34-29
Depth (m)	(cm)	3-10	10-20	20-40	40-70	3-10	10-20	20-40	40-70
1-10		13.14	0.00	0.00	0.00	17.19	0.00	0.00	0.00
10-20		14.52	5.24	1.29	0.64	24.11	9.54	3.41	1.71
20-30		22.63	7.39	4.27	1.79	27.09	10.62	2.98	1.22
30-40		5.84	5.51	5.32	2.15	4.30	2.66	2.67	1.75
40-50		2.97	1.24	1.11	0.36	3.35	1.19	1.95	0.63
50-60									
60-70									
70-80									
80-90									
90-100									
100-110									
110-120									

Table A16. Abundance (a) for all acoustic targets 39.2-28.8 -dB (~200-700 mm fish total length) from mobile hydroacoustic surveys, relative abundance (r) from gill net and mid-water trawl surveys and species-specific abundance estimates. Species-specific estimates were obtained by multiplying the acoustic abundance of all fish targets by the relative abundance of each species. Range equals the lower (and upper) 80% confidence interval multiplied by the lower (and upper) 95% confidence interval of the acoustic abundance estimate. All of the species listed below have a nearshore or benthic aspect to their life history, except kokanee; therefore the abundance estimates listed below should not be construed as total abundance for any species other than kokanee.

	June			**August**			**October**		
		Lower	**Upper**		**Lower**	**Upper**		**Lower**	**Upper**
	(a)	**95 % CI**		**(a)**	**95 % CI**		**(a)**	**95 % CI**	
Acoustic targets	54,098	23,030	85,167	78,273	52,355	104,192	266,783	162,786	370,779
	(r)	80 % CI		(r)	80 % CI		(r)	80 % CI	
Burbot	0.16	0.11	0.23	0.06	0.03	0.10	0.05	0.02	0.08
Kokanee	0.20	0.14	0.27	0.44	0.36	0.53	0.30	0.24	0.36
Lake whitefish	0.34	0.27	0.42	0.18	0.12	0.25	0.27	0.21	0.33
Rainbow trout	0.16	0.11	0.23	0.07	0.04	0.13	0.06	0.04	0.11
Walleye	0.12	0.07	0.18	0.22	0.13	0.30	0.20	0.15	0.27
Other fish	0.03			0.03			0.12		
		Abundance			Abundance			Abundance	
	a * r	range (a * r)		a * r	range (a * r)		a * r	range (a * r)	
Burbot	8,542	2,533	19,588	4,604	1,353	10,711	12,351	3,695	31,250
Kokanee	10,677	3,224	22,995	34,532	18,738	54,990	79,047	38,535	134,436
Lake whitefish	18,507	6,218	35,770	13,813	6,156	26,239	71,636	34,061	123,175
Rainbow trout	8,542	2,533	19,588	5,755	1,895	13,777	17,291	5,915	39,609
Walleye	6,406	1,612	15,330	17,266	7,033	31,263	54,345	24,607	98,357
Other fish	1,424			2,302			32,113		

Appendix B. Bioenergetics Model Parameters and Input

Table B1. Optimal growth temperatures for various fish species. Thermal experience for the bioenergetics model was selected as the closest available temperature to the growth optimum for each age class.

Species	Optimal Growth Temp (^{0}C)	Reference
Kokanee	10 to 15	Scott and Crossman 1973
Juvenile Lake Whitefish	18.5	Edsall 1999
Burbot	15.6 to 18.3	Scott and Crossman 1973
Walleye	20 to 25	Koenst and Smith 1976
Largescale Sucker	18.9	Black 1953
Rainbow Trout	15	Piper 1989
Smallmouth Bass	26.4	Carlander 1977
Juvenile Smallmouth Bass	28.5	Carlander 1977
Yellow Perch	21-24	Scott and Crossman 1973
Northern Pikeminnow	21.5**	Vigg and Burley 1991

** Maximum Consumption Temperature

Table B2. Starting and ending weights for various kokanee release groups in 1998 and 1999, for use in bioenergetics modeling of growth and consumption. End weights were determined from sexually mature kokanee of known age (McLellan et al. 2001) or from WDFW gill net and trawl surveys for wild fish.

Year released		1998				Wild	1999		
Year	Julian Day	Fry	Precocious	Age 1-2	Age 2-3	Age 2-3	Early release	Precocious	Age 1-2
1998	152	5	38	35					
1998	288		301		898	775			
1999	81						25		
1999	166						45	45	35
1999	304	298		481	1253	1104		298	
2000	304								741
p-value		0.51	0.87	0.52	0.46	0.44	0.35	0.88	0.60

Table B3. Rainbow trout growth data used for bioenergetics model. Lengths for hatchery release sizes were estimated using standard equations from Piper et al. (1982) to convert #/pound to millimeters and grams.

		1998 cohort		
Year	**Julian Day**	**Length (mm)**	**Weight (g)**	**Source**
1998	152	210	102	hatchery records
1999	135	401	799	monitoring data
1999	304	483	1090	model prediction
		1999 cohort		
1999	105	187	73	hatchery records
1999	304	335	444	monitoring data

Table B4. Length and weight for specific ages of northern pikeminnow and lake whitefish. A nonlinear regression equation was fit to the fishes length at age data from scale analysis. This was necessary because the mean length at age fluctuated between year classes resulting in negative growth in length between year classes for northern pikeminnow; and because sample size of whitefish age classes were small (n<6). Weight was estimated from the mean length using a log transformed length weight regression. The weight in October was estimated based on the mean growth increment for each species from the multi-year data set.
**nonlinear regression equation (3 parameter sigmoidal): y = a / [1+{e^ -(x-x0)/b}] where: y = length; x = age; and a,b, and X0 were iteratively fit using sigmaplot software version 5.0.

	Age	Estimated* Length	Estimated* Weight (g)	October weight (g)	Length estimate parameters**		Length-weight regression	
Northern pikeminnow	1	58	2	14	a =	588.33	Slope	2.94
	2	154	36	83	b =	-1.71	Intercept	-4.87
	3	245	141	219	x0 =	3.65	R square	0.98
	4	317	301	392			n	359
	5	371	479	570				
	6	412	651	733				
	7	443	805	876				
	8	467	937	998				
	9	485	1050	1102				
	10	499	1145	1189				
	11	511	1225	1262				
	12	521	1293					
	13							
Lake Whitefish	1	179	67	106	a =	589.53	Slope	3.06
	2	238	159	233	b =	2.30	Intercept	-5.07
	3	301	327	443	x0 =	2.90	R square	0.92
	4	364	583	734			n	1071
	5	421	909	1074				
	6	468	1258	1415				
	7	505	1585	1718				
	8	532	1859	1962				
	9	551	2070	2146				
	10	564	2224					

Table B5. Length and weight for specific ages of walleye, burbot, and smallmouth bass. To minimize seasonal growth effects, walleye and bass lengths were back calculated to the most recent annulus. Data were taken from STI and EWU age analysis files from 1996 and 1999. Burbot data were from otolith annuli in 1999 and 2000 conducted by the WDFW otolith lab in Olympia. Weight was estimated from the mean length using a log transformed length weight regression. The weight in October was estimated based on the mean growth increment for each species from the multi-year data set.

	Age	n	Mean Length (mm)	SD	Estimated* Weight (g)	October Weight (g)	Length-weight Regression	
Walleye	1	1358	172	26	40	99	Slope	3.10
	2	1102	261	42	145	242	Intercept	-5.33
	3	756	333	46	307	449	R square	0.96
	4	438	398	48	537	718	n	4156
	5	225	458	59	826	1036		
	6	122	510	69	1157	1392		
	7	50	558	83	1524	1784		
	8	36	602	65	1929	2056		
	9	11	621	77	2123	2861		
	10	13	716	42	3301	3451		
	11	5	731	67	3530	4349		
	12	1	808	NA	4816	5072		
	13	2	829	22	5207			
Burbot	2	6	347	34	252	287	Slope	-4.33
	3	10	381	45	325	407	Intercept	2.65
	4	9	449	43	501	567	R square	0.73
	5	23	492	34	639	701	n	817
	6	14	527	25	767	815		
	7	16	552	30	866	883		
	8	5	560	32	901	900		
	9	1	560	NA	900			
Smallmouth Bass	1	84	94	20	11	23	Slope	3.08
	2	158	130	29	31	71	Intercept	-5.02
	3	169	191	40	101	157	R square	0.97
	4	118	235	37	193	347	n	642
	5	61	310	48	452	479		
	6	23	320	68	494	770		
	7	6	395	16	947	1106		
	8	2	426	18	1195			

Table B6. Mean proportions of kokanee prey categories for use in bioenergetics modeling. When sample size was less than 10 we combined data from all months within the same calendar year (*).

Year	**1998**			**1999**				
Julian Day	**152**	**258**	**288**	**105**	**182**	**227**	**288**	**304**
N	**79***	**13**	**65**	**47***	**47***	**10**	**20**	**20**
Daphnia	0.943	1.000	0.931	0.651	0.651	1.000	0.734	0.734
Insects	0.013	0.000	0.016	0.234	0.234	0.000	0.108	0.108
Other	0.044	0.000	0.053	0.115	0.115	0.000	0.158	0.158
Cottid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Catastomid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Cyprinid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Centrarchid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Percid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Salmonid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Osteichthyes	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table B7. Mean proportions of rainbow trout prey categories for use in bioenergetics modeling. When sample size was less than 10 we combined data from months during the same season (*).

Year	**1998**			**1999**				
Julian Day	**152**	**182**	**274**	**1**	**135**	**181**	**288**	**304**
N	**38***	**38**	**49**	**70**	**25**	**22***	**13**	**13**
Daphnia	0.183	0.183	0.573	0.973	0.004	0.078	0.227	0.227
Insects	0.337	0.337	0.277	0.000	0.510	0.690	0.527	0.527
Other	0.374	0.374	0.110	0.015	0.344	0.233	0.166	0.166
Cottid	0.026	0.026	0.017	0.000	0.041	0.000	0.000	0.000
Catastomid	0.039	0.039	0.000	0.000	0.000	0.000	0.000	0.000
Cyprinid	0.039	0.039	0.000	0.000	0.000	0.000	0.000	0.000
Centrarchid	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000
Percid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Salmonid	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Osteichthyes	0.002	0.002	0.019	0.012	0.100	0.000	0.080	0.080

Table B8. Mean proportions of lake whitefish prey categories for use in bioenergetics modeling. When sample size was less than 10 we combined data from all months within the same calendar year (*).

Year	**1998**				**1999**	
Julian Day	**182**	**244**	**274**	**365**	**152**	**304**
N	**57***	**17**	**40**	**57***	**13**	**24**
Daphnia	0.175	0.176	0.174	0.175	0.000	0.125
Insects	0.176	0.052	0.300	0.176	0.144	0.094
Other	0.648	0.771	0.526	0.648	0.856	0.781
Cottid	0.000	0.000	0.000	0.000	0.000	0.000
Catastomid	0.000	0.000	0.000	0.000	0.000	0.000
Cyprinid	0.000	0.000	0.000	0.000	0.000	0.000
Centrarchid	0.000	0.000	0.000	0.000	0.000	0.000
Percid	0.000	0.000	0.000	0.000	0.000	0.000
Salmonid	0.000	0.000	0.000	0.000	0.000	0.000
Osteichthyes	0.000	0.000	0.000	0.000	0.000	0.000

Table B9. Mean proportions of northern pikeminnow prey categories for use in bioenergetics modeling. Diet data was combined from 1998 and 1999 due to small overall sample size.

Year	**1998**	**1999**
Julian Day	**182**	**304**
N	**22**	**22**
Daphnia	0.000	0.000
Insects	0.319	0.319
Other	0.568	0.568
Cottid	0.113	0.113
Catastomid	0.000	0.000
Cyprinid	0.000	0.000
Centrarchid	0.000	0.000
Percid	0.000	0.000
Salmonid	0.000	0.000
Osteichthyes	0.000	0.000

Table B10. Mean proportions of juvenile walleye (age 1-2) prey categories for use in bioenergetics modeling. When sample size was less than 10 we combined data from all months within the same calendar year (*) or combined similar months among years (**).

Year	**1998**			**1999**		
Julian Day	**152**	**182**	**288**	**135**	**181**	**304**
N	**21**	**21**	**11**	**21***	**12**	**14****
Daphnia	0.038	0.038	0.343	0.000	0.000	0.270
Insects	0.008	0.008	0.013	0.475	0.176	0.010
Other	0.084	0.084	0.164	0.334	0.010	0.129
Cottid	0.506	0.506	0.389	0.000	0.206	0.377
Catastomid	0.110	0.110	0.000	0.000	0.000	0.000
Cyprinid	0.000	0.000	0.091	0.000	0.000	0.071
Centrarchid	0.048	0.048	0.000	0.000	0.044	0.000
Percid	0.033	0.033	0.000	0.000	0.000	0.000
Salmonid	0.003	0.003	0.000	0.000	0.000	0.000
Osteichthyes	0.171	0.171	0.000	0.191	0.564	0.143

Table B11. Mean proportions of adult walleye (age 3 and older) prey categories for use in bioenergetics modeling. When sample size was less than 10 we combined data from months during the same season (*).

Year	**1998**			**1999**			
Julian Day	**152**	**182**	**288**	**135**	**196**	**274**	**304**
N	**63**	**63**	**18**	**60**	**62**	**40**	**40**
Daphnia	0.037	0.037	0.000	0.000	0.000	0.000	0.000
Insects	0.050	0.050	0.056	0.157	0.180	0.000	0.000
Other	0.106	0.106	0.000	0.097	0.122	0.077	0.077
Cottid	0.293	0.293	0.296	0.340	0.146	0.079	0.079
Catastomid	0.053	0.053	0.056	0.000	0.000	0.026	0.026
Cyprinid	0.073	0.073	0.111	0.030	0.016	0.026	0.026
Centrarchid	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Percid	0.032	0.032	0.148	0.000	0.000	0.000	0.000
Salmonid	0.048	0.048	0.167	0.073	0.148	0.105	0.105
Osteichthyes	0.308	0.308	0.167	0.302	0.388	0.686	0.686

Table B12. Mean proportions of smallmouth bass (age 2 and older) prey categories for use in bioenergetics modeling. When sample size was less than 10 we combined data from similar months among years (*).

Year	**1998**		**1999**		
Julian Day	**182**	**288**	**135**	**181**	**304**
N	**14**	**12**	**11**	**27**	**16***
Daphnia	0.000	0.247	0.000	0.000	0.185
Insects	0.130	0.241	0.095	0.392	0.186
Other	0.079	0.017	0.381	0.160	0.013
Cottid	0.178	0.138	0.296	0.183	0.160
Catastomid	0.071	0.164	0.000	0.037	0.186
Cyprinid	0.091	0.000	0.000	0.000	0.000
Centrarchid	0.000	0.000	0.000	0.000	0.000
Percid	0.071	0.000	0.000	0.000	0.000
Salmonid	0.000	0.078	0.000	0.000	0.058
Osteichthyes	0.378	0.115	0.228	0.228	0.212

Table B13. Mean proportions of adult burbot prey categories for use in bioenergetics modeling. When sample size was less than 10 we combined data from all months within the same calendar year (*) or combined months within the same season (**).

Year	**1998**		**1999**		
Julian Day	**182**	**288**	**135**	**181**	**304**
N	**10**	**15***	**36***	**16****	**13**
Daphnia	0.000	0.000	0.000	0.000	0.000
Insects	0.000	0.067	0.171	0.177	0.017
Other	0.300	0.267	0.552	0.494	0.675
Cottid	0.309	0.273	0.056	0.063	0.077
Catastomid	0.091	0.061	0.000	0.000	0.000
Cyprinid	0.000	0.000	0.043	0.035	0.077
Centrarchid	0.000	0.067	0.028	0.000	0.077
Percid	0.000	0.067	0.000	0.000	0.000
Salmonid	0.200	0.133	0.000	0.000	0.000
Osteichthyes	0.100	0.067	0.150	0.231	0.077

Table B14. Thermal experience used for each species modeled in 1998 and 1999. Each species was assumed to occupy its optimal temperature, if available. Available temperatures were determined from STOI bi-weekly monitoring of 11 limnetic stations.

	Julian Day	Burbot	Kokanee	Lake Whitefish	Northern Pikeminnow	Rainbow Trout	Smallmouth Bass	Walleye
1998	152	14.0	12.5	13.7	13.7	13.7	13.7	13.7
	154	14.0	12.5	13.7	13.7	13.7	13.7	13.7
	167	16.0	13.0	16.0	16.3	15.0	16.3	16.3
	182	18.0	13.8	16.0	18.3	15.0	18.3	18.3
	196	17.0	15.2	16.0	19.0	15.0	20.8	20.8
	210	17.0	15.0	16.0	19.0	15.0	23.4	22.5
	223	17.0	14.6	16.0	19.0	15.0	22.7	22.5
	237	17.0	16.0	16.0	19.0	16.5	21.5	21.5
	253	17.0	17.0	16.6	19.0	18.0	20.8	20.8
	266	18.0	17.6	19.2	19.0	18.5	19.7	19.7
	280	19.0	17.0	18.1	18.6	18.5	18.6	18.6
	300	17.0	15.0	16.0	17.3	15.0	17.3	17.3
	321	13.0	12.5	12.9	12.9	12.9	12.9	12.9
	349	9.0	7.7	9.0	9.0	9.0	9.0	9.0
1999	21	4.0	3.7	3.7	3.7	3.7	3.7	3.7
	82	5.0	4.8	4.8	4.8	4.8	4.8	4.8
	111	7.0	7.3	7.3	7.3	7.3	7.3	7.3
	123	9.0	8.7	8.8	8.7	8.7	8.7	8.8
	138	9.0	9.2	9.2	9.2	9.2	9.2	9.2
	151	13.0	12.5	12.5	12.5	10.5	12.4	12.5
	181	15.0	12.5	15.3	15.3	15.0	15.3	15.3
	194	17.0	12.7	16.0	17.1	15.0	17.1	17.1
	208	17.0	13.9	16.0	18.1	15.0	18.1	18.1
	222	17.0	14.4	16.0	19.4	15.0	19.4	19.4
	237	17.0	14.3	16.0	19.4	15.0	19.4	19.4
	251	17.0	16.9	16.8	17.6	16.0	17.6	17.6
	265	17.0	16.6	16.6	17.5	16.9	17.5	17.5
	286	16.0	14.5	15.6	15.6	15.0	15.6	15.6
	300	14.0	12.8	14.4	14.4	14.0	14.4	14.4
	304	14.0	12.8	14.4	14.4	14.0	14.4	14.4

Table B15. Caloric density values used for prey categories in bioenergetics modeling. Values were selected based on literature values summarized in Hanson et al. (1997).

Diet Category	Caloric Density (J/gram)
Daphnia	3860
Insects	3000
Other	3000
Cottid	4186
Catastomid	4186
Cyprinid	4186
Centrarchid	4186
Percid	4186
Salmonid	5500
Osteichthyes	4186

Table B16. Population characteristics for stocked salmonids in Lake Roosevelt in 1998 and 1999 and consumption of *Daphnia*. Mean weight was determined by the bioenergetics model, starting with the mean weight of fish at stocking and ending with the weight of returning spawners. Abundance was reduced using an exponential population decline equation ($Nt = N_oe^{-zt}$). Survival was iteratively fit to the end number of returning fish for each group as determined by EWU adult kokanee collection (McLellan et al. 2001). A precocity rate of 0.53 was applied to the initial stocking numbers for yearling kokanee and differential growth and survival was modeled for the precocious fish (age 2 spawners) and the carryover fish (age 3 spawners).

Release Group	Month	Mean Weight (g)	Mean Length (mm)	Abundance	Consumption of Daphnia (kg)	Number Stocked	Precocity Adjusted Number Stocked
	Jul-98	6	86	500413	1642	500413	NA
	Aug-98	10	102	321793	2980		
	Sep-98	16	118	206930	2799		
1998	Oct-98	23	133	133067	2365		
Kokanee	Nov-98	34	151	85569	1845		
Fry	Dec-98	49	172	55026	1407		
	Jan-99	68	191	35385	946		
	Feb-99	87	208	22754	642		
	Mar-99	109	224	14632	559		
	Apr-99	135	241	9409	461		
	May-99	166	258	6051	415		
	Jun-99	195	272	3891	331		
	Jul-99	223	284	2502	307		
	Aug-99	251	296	1609	288		
	Sep-99	268	303	1035	184		
	Oct-99	284	308	665	114		
	Survival =			0.00500			

Release Group	Month	Mean Weight (g)	Mean Length (mm)	Abundance	Consumption of Daphnia (kg)	Number Stocked	Precocity Adjusted Number Stocked
	Jun-98	56	179	310194	38,819	585272	310194
1998 Precocious Kokanee	Jul-98	98	216	92192	18,901		
	Aug-98	152	250	27400	7,913		
	Sep-98	207	278	8144	2,917		
	Oct-98	265	301	2420	999		
	Survival =			0.00232			
	Jun-98	42	163	275078	17,098	585272	275078
	Jul-98	57	180	151490	12,695		
1998 Carryover Kokanee	Aug-98	72	195	83429	8,539		
	Sep-98	84	205	45946	5,238		
	Oct-98	94	213	25303	3,034		
	Nov-98	112	226	13935	1,660		
	Dec-98	141	244	7674	911		
	Jan-99	173	261	4226	453		
	Feb-99	203	276	2328	233		
	Mar-99	237	290	1282	156		
	Apr-99	278	306	706	99		
	May-99	325	322	389	69		
	Jun-99	369	336	214	43		
	Jul-99	410	348	118	32		
	Aug-99	443	358	65	23		
	Sep-99	456	361	36	12		
	Oct-99	466	364	20	6		
	Survival =			0.00013			
	Mar-99	26	139	13292	84	25080	13292
	Apr-99	31	147	18529	355	25000	13250
1999 Precocious Kokanee	May-99	38	158	28143	1,243	41195	21833
	Jun-99	49	172	140322	8,846	250181	132596
	Jul-99	85	206	176202	30,468	279847	148319
	Aug-99	138	242	67482	17,780	88775	47051
	Sep-99	195	272	7825	2,312		
	Oct-99	259	299	907	288		
	Survival =			0.00156			

Release Group	Month	Mean Weight (g)	Mean Length (mm)	Abundance	Consumption of Daphnia (kg)	Number Stocked	Precocity Adjusted Number Stocked
1999 Carryover Kokanee	Mar-99	26	139	11788	66	25080	11788
	Apr-99	31	147	18629	355	25000	11750
	May-99	38	158	29930	769	41195	19362
	Jun-99	47	170	134037	7696	250181	117585
	Jul-99	67	190	202660	21733	279847	131528
	Aug-99	90	210	145097	19755	88775	41724
	Sep-99	110	225	70763	11073		
	Oct-99	129	237	34511	5834		
	Nov-99	159	254	16831			
	Dec-99	201	275	8208			
	Jan-00	247	294	4003			
	Feb-00	292	311	1952			
	Mar-00	343	328	952			
	Apr-00	403	347	464			
	May-00	472	365	226			
	Jun-00	537	381	110			
	Jul-00	597	395	54			
	Aug-00	654	407	26			
	Sep-00	686	414	13			
	Oct-00	714	419	6			
	Survival =			0.00002			

Table B17. Population characteristics for stocked rainbow trout in Lake Roosevelt in 1998 and 1999 and consumption of *Daphnia*. Mean weight was determined by the bioenergetics model, starting with the mean weight of fish at stocking and ending with the weights determined from monitoring efforts. Abundance was reduced using an exponential population decline equation ($Nt = N_o e^{-zt}$). Annual survival for rainbow trout was estimated using gill net and electrofishing catch information obtained by the LRFEP standard seasonal surveys using the equation S = N1/N0; where survival (S) equals the number of fish in each cohort captured at time t (N_1), divided by the number captured at t-1 year (N_0).

Release Group	Month	Mean Weight (g)	Mean Length (mm)	Abundance	Consumption of Daphnia (kg)	Number Stocked
	Jun-98	124	200	504,782	25,653	504,782
	Jul-98	172	229	380,547	35,209	45,580
	Aug-98	230	258	289,521	51,354	
	Sep-98	279	280	221,197	60,611	
	Oct-98	324	297	169,064	65,442	
	Nov-98	411	328	129,167	61,551	
1998	Dec-98	517	361	98,724	48,346	
Net Pen	Jan-99	587	380	75,109	19,611	
	Feb-99	613	387	57,871	8,038	
	Mar-99	639	394	44,640	4,007	
	Apr-99	682	405	34,106	516	
	May-99	755	422	26,067	78	
	Jun-99	843	442	19,916	37	
	Jul-99	905	455	15,222	617	
	Aug-99	962	467	11,581	1,441	
	Sep-99	1,008	476	8,848	1,862	
	Oct-99	1,052	484	6,763	1,963	
	Annual Survival =			0.04		
	Apr-99	79	166	77,002	21	79,516
	May-99	104	186	122,229	134	97,304
1999	Jun-99	151	216	312,975	284	336,481
Net Pen	Jul-99	203	245	433,238	6,666	
	Aug-99	264	273	385,117	20,557	
	Sep-99	328	299	342,979	34,839	
	Oct-99	400	324	305,474	57,508	
	Annual Survival =			0.25		

Appendix C

Walleye Predation on Hatchery Releases of Kokanee and Rainbow Trout in Lake Roosevelt, Washington

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Abstract

Recruitment failures of stocked kokanee *Oncorhynchus nerka* in Lake Roosevelt have led to examination of various limiting factors. We evaluated the predatory impacts of piscivores on hatchery- and net pen released kokanee and rainbow trout *O. mykiss* from the Sherman Creek Hatchery in 1999 and 2000. We used an angler tournament to mark walleye *Stizostedeon vitreum* for an abundance estimate, and then used gill netting and electrofishing to collect recaptures and monitor the diet of walleye. A bioenergetics model was used to quantify consumption and estimates were extrapolated to walleye abundance to determine a percent loss of hatchery fish. Kokanee averaged 22-100% of walleye (>300 mm Total Length) diet contents, whereas rainbow trout averaged 0-25%, depending on location and timing following release. In 1999, we estimated that 16,610 walleye consumed 15% of the hatchery kokanee within 41 days of release; however, our diet information did not correspond spatially with our population estimate. In 2000, we corrected our spatial bias and estimated that the population of 12,233 walleye consumed 9.4% of the kokanee, and 7.3% of the rainbow trout releases within 41 days of release. We conclude that the walleye population in northern Lake Roosevelt was effectively "swamped" by the biomass of salmonids released at the Sherman Creek Hatchery. However, piscivores may still limit kokanee recruitment depending on long-term predation rates for the reservoir-wide walleye population.

Fish predators can affect prey fish populations in freshwater systems by selecting specific species and size classes (Forney 1974; Stewart et al. 1981; Lyons and Magnuson 1987; Hartman and Margraf 1993; Rieman et al. 1991; Knight and Vondracek 1993; Yule and Luecke 1993). Predation of hatchery-released fishes may also hinder stocking efforts by management agencies (Stein et al. 1981; Baldwin et al. 2000; Yule et al. 2000). High densities of stocked fish can stimulate a predator feeding response, and in some instances result in an abrupt shift in piscivore diet (McMillan 1984; Vigg et al. 1991; Collis and Beaty 1995; Shiveley et al. 1996; Baldwin et al. 2000; Fayram and Sibley 2000). Depletion of fish prey is common for introduced fish assemblages in reservoir settings where drawdown increases vulnerability of prey fish (McMillan 1984; McMahon and Bennett 1996).

Bioenergetics modeling can be used to quantify the effect of predators on prey populations (Stewart et al. 1983; Ney 1990; Yule and Luecke 1993; Beauchamp et al. 1995; Hartman and Brandt 1995; Baldwin et al. 2000). Researchers apply basic biological data on growth, diet and thermal experience to computer models that simulate species- and size-specific physiology to estimate consumption. Individual fish consumption is then expanded to abundance and mortality estimates to quantify population-level effects (Stewart et al. 1981; Hartman and Brandt 1995; Baldwin et al. 2000).

The objective of our study was to assess the impact of predators on hatchery and net pen releases of rainbow trout *Oncorhynchus mykiss* and kokanee *O. nerka* in Lake Roosevelt. After determining the diet, growth, thermal experience, and abundance of piscivores in the vicinity of the Sherman Creek Hatchery (SCH), we used a bioenergetics model to identify which species and age classes had the greatest potential to impact hatchery releases. We estimated the abundance of the dominant piscivore in the system, walleye *Stizostedion vitreum*, then expanded individual consumption to the population of walleye to determine their effect on stocked salmonids.

Study Area

Franklin D. Roosevelt Lake (Lake Roosevelt) is a Columbia River reservoir created in 1941 by the construction of Grand Coulee Dam (GCD) at river kilometer 960 (Figure 1). The reservoir covers ~33,000 ha at a full pool elevation of 393 m above mean sea level and is managed as a National Recreation Area by the National Park Service. The dam was built for hydropower generation, flood control and water storage for irrigation in the Columbia Basin Reclamation Project. The annual hydrologic regime commonly includes spring draw downs of 12-20 m with a maximum operational limit of 25 m. The reservoir reaches 241 km upstream from GCD, is generally 1-3 km wide, and has a maximum depth of 122 m. Water retention times are short (12-80 days) and the zooplankton community is more typical of a large river than a lake or reservoir (R. Black, personal communication).

The fish community of Lake Roosevelt has changed since inundation. Northern pikeminnow *Ptychocheilus oregonensis* were the primary fish captured in historical gill net surveys; comprising 65% of the total sample in 1948 (Gangmark and Fulton 1949), 54% in 1976 (Stober et al. 1977) and 15% from 1980-1983 (Beckman et al. 1985). In recent studies, however, northern pikeminnow have generally comprised less than 5% of the species captured in gill nets (Cichosz et al. 1997, 1999). Burbot *Lota lota* were rarely mentioned in historical surveys but consistently comprise 5-15% of species in recent gill net surveys (Cichosz et al. 1997, 1999; Baldwin et al. 1999; Lake Roosevelt Fisheries Evaluation Project, (LRFEP) unpublished data). In recent gill net and electrofishing surveys, the fish community in Lake Roosevelt has been dominated by largescale suckers *Catostomus macrocheilus*, lake whitefish *Coregonus clupeaformis*, and walleye (Peone et al. 1990; Cichosz et al. 1997, 1999).

Walleye were first detected in Lake Roosevelt in the early 1950s and by the early 1980s walleye comprised 30% of the total fish relative abundance (Beckman et al. 1985). Kokanee and rainbow trout stocking programs were expanded in 1988 to provide a fishery for limnetic planktivores that would experience minimal distribution overlap with walleye (Scholz et al. 1986). The rainbow trout stocking program has been successful in providing a fishery (Cichosz et al. 1997,1999); however, low angler harvest of kokanee and sparse returns of adult kokanee to egg collection sites led to investigations of limiting factors (Tilson and Scholz 1998; Cichosz et al. 1997, 1999). Many walleye spawn in the Spokane River arm of Lake Roosevelt and then migrate north towards Canada (McLellan et al. 2002). The walleye post-spawn migration overlaps temporally and spatially with hatchery kokanee releases at the Sherman Creek Hatchery (SCH). One potential limiting factor for hatchery salmonid success in Lake Roosevelt includes piscivory by walleye or other piscivores including northern pikeminnow and burbot.

Grand Coulee Dam is a barrier to historic anadromous salmon and steelhead runs. Mitigation for losses of historical salmon migrations into this portion of the Columbia River have resulted in a hatchery kokanee and rainbow trout stocking program. The Sherman Creek Hatchery (SCH), Spokane Tribal Hatchery (STH) and the Lake Roosevelt Net Pen Program have released approximately 0.75 million kokanee and 0.5 million rainbow trout annually since 1988. Hatchery and net pen releases occur from late May to mid-July depending on reservoir operations, temperature, and fish health. Kokanee have been released at SCH with the intention of collecting eggs from returning age-3 spawners. The number of age-3 spawners returning to egg collection sites has never been adequate for egg takes, so other strategies, such as net pens and yearling releases, have been employed in an attempt to improve survival.

Sherman Creek Hatchery is located 163 km upstream of GCD and 95 km from the confluence with the Spokane River (Figure 1). At full pool, a 200 m stretch of stream and ~4 hectare cove separates the hatchery from the main reservoir. Fish that disperse from the cove have been recovered in tributary mouth habitats such as the Colville River, shallow embayments throughout the reservoir, and at various depths in the mainstem (Tilson and Scholz 1998; Baldwin et al. 1999; other LRFEP unpublished data).

Methods

Predator Collection and Diet

The 1999 study included both pelagic and littoral gill netting near the Sherman Creek embayment and Colville River arm of Lake Roosevelt (Figure 1). Sampling occurred on nine occasions over a 40-day period, beginning one day prior to the release of 280,000 kokanee (12,500 kg) from SCH on 28-June (Table 1). A second group of 89,000 (4000 kg) kokanee was released on 29-July (day 33 of the study; Table 1). Kokanee were not fed for one day prior to release and were forced out of the raceways on the day of release; however, thousands of kokanee were observed in the stream for several weeks following release.

Horizontal gill nets included floating, midwater, and bottom nets with 6 m long by 2.6 m deep panels, and mesh sizes from 25 to 102 mm in 13 mm increments. Two of the horizontal gill nets had mesh sizes ranging from 51 to 102 mm to minimize bycatch of hatchery kokanee. Littoral gill nets were oriented perpendicular to the shoreline in water depths from 2 to 12 meters. The smallest mesh size was set closest to shore. Nets were set on nine occasions; June 27, 28, 29, and 30; July 5, 12, 20, and 29; and August 6. On each occasion, three nets were set outside the mouth of Sherman Creek Cove (27 total net nights), two nets were set in Colville River Bay (18 total net nights), and 2-3 nets were set in the offshore mainstem (22 total net nights). Offshore gill nets were set at various depth strata in water depths ranging from 23 to 45 m (maximum depth within the sampling area). Nets were generally set between 1800 and 1900 and retrieved between 2300- and 0200 so piscivores diets represented the crepuscular and night feeding periods. All walleye, northern pikeminnow, and burbot were measured to the nearest mm, weighed to the nearest 5 g, and their stomachs were removed and preserved in 95% ethanol until laboratory examination.

The 2000 study area was expanded to a 55 km stretch of the reservoir from Daisy to North Gorge. This area better represented the spatial heterogeneity of walleye diets following the hatchery release and coincided with the boundaries of the abundance estimate. The 2000 study period was 31 days and began one day prior to a release of 296,000 kokanee from SCH on June 26, 2000. Other groups of kokanee were released prior to, during, and immediately following the study (Table 1). Twelve collection sites were used but only seven were sampled on a particular night. The Sherman Creek (6) and Colville River (7) sites were sampled each night, but all other sites were sampled alternately by sampling odd or even numbered sites. Electrofishing surveys were conducted nine times between June 25 and July 25 (June 25, 26, 27, 28, 29; July 10, 11, 24, 25). Our goal was to collect five non-empty walleye stomachs from each site, but this goal was not achievable at all sample sites due to empty stomachs and low catch rates.

Sites were sampled between 1600 and 2400 with a Smith Root® boat electrofisher with the DC voltage adjusted to produce 3-5 amps, and with a pulse frequency of 120 pulses per second. Piscivores were collected and measured to the nearest mm and stomach contents were removed by gastric lavage for walleye >275 mm (Light et al. 1983). On occasions when stomachs appeared to still contain items after lavaging, fish were sacrificed and the stomach was removed. Stomachs from 30 systematically selected (1 out of every 10) walleye were removed to determine gastric lavage efficacy.

Gill nets were used to increase sample size and supplement electrofishing data on July 10 and July 24, 2000. Horizontal gill nets, previously described, were used at Sherman Creek and at one downstream and one upstream site. The upstream site was in Singer Bay (between sites 4 and 5) and the downstream site was at Martin Beach (between sites 9 and 10) on July 10, and at Barnaby Island (site 11) on July 24.

Stomach contents were examined under a dissecting microscope in the laboratory and sorted by taxon to the nearest order for invertebrates, and family, genus or species for fish. Fish prey were identified using diagnostic bone keys (Hansel et al. 1988), and known example specimens taken from Lake Roosevelt. The blotted-dry wet weight for each prey category of individual predators was recorded to the nearest 0.01 g (Baldwin et al. 2000). Total (TL), standard (SL) or vertebral column (VL) lengths were recorded to the nearest mm for all non-digested prey fish. Standard and vertebral column lengths of partially digested kokanee were converted to total lengths using regression equations developed by Yule and Luecke (1993). We developed similar equations for rainbow trout in this study from the diet of Lake Roosevelt piscivores.

Kokanee	TL = 1.05 * SL + 26.8	N = 30	$r^2 = 0.95$
	TL = 1.49 * VC –19.3	N = 46	$r^2 = 0.99$
Rainbow trout	TL = 1.03 * SL + 14.1	N = 12	$r^2 = 0.89$
	TL = 1.23 * VC + 21.0	N = 12	$r^2 = 0.82$

We used several statistical methods to define predator-to-prey length relationships between walleye and their salmonid prey. Tests were considered significant if P values were less than 0.05. The ratio of prey length to predator length was determined by dividing prey fish length by predator length. The maximum values for the length ratio represented the point of gape limitation for walleye feeding on salmonids. We compared the length distribution of kokanee in the raceway before release to the length distribution of kokanee in walleye stomachs during the study with a Kolmogorov-Smirnov test (SAS Institute 1999); H_o = no difference between the lengths of kokanee in the raceways and in the diet of walleye. We used a simple linear regression model to determine if larger walleye selectively chose larger salmonids (SAS Institute 1999); H_o = no change in prey size with increased predator size. Analysis of variance was performed on the regression points to determine if the slope varied significantly from zero (SAS Institute 1999); H_o = slope was equal to zero. We compared the slopes of the predator length- prey length- regression lines using equations provided in Zar (1984) to determine if data could be pooled for the two years; H_o = no difference between years.

In 2000, we compared the proportions of two different kokanee stocks in the diet contents of walleye. Kokanee eggs from Lake Whatcom, Washington and from Meadow Creek, British Columbia were reared in identical fashion, implanted with a coded-wire tag, and released as a mixed group from SCH. We compared the number of tags recovered from walleye stomachs for each stock, to the number released, using a 2 X 2 contingency table analysis. Our null hypothesis was that there was no difference in the rate of tag recovery from the two stocks of kokanee.

Walleye Abundance

A mark-recapture study was used to estimate walleye abundance in the 55-km stretch of Lake Roosevelt from Daisy to North Gorge. Walleye were initially collected and marked on 19 and 20 June 1999 and 24 and 25 June 2000 in conjunction with the Governor's Cup Walleye Tournament (GCWT) in Kettle Falls. The tournament boundaries were Daisy on the downstream end and North Gorge on the upstream end. Weather during the 1999 tournament was clear and calm on 19 June and partly cloudy and calm on 20 June with surface water temperatures at Kettle Falls ranging from 14 to 16°C, respectively. The weather was partly cloudy and calm on 24 June 2000 and sunny and calm on 25 June 2000 with 13°C surface water temperatures at Kettle Falls.

Tournament rules and organization were designed to minimize walleye mortalities and maximize tagging opportunities for our study. Participants were required to have aerated and re-circulating live wells, and were only allowed to hold five walleyes at a time (even though state regulations allowed eight). Anglers were penalized one fish (out of total of ten) for scoring a dead walleye. A walleye was considered dead if it was unable to maintain an upright position in the live well. Tournament regulations were modified to allow anglers to score all fish, with the ten longest (heaviest) being used for tournament prizes, to increase the probability that they would provide all captured fish for marking and reducing the chance of "high-grading" or holding fish in the live well for long periods until bigger fish were caught. A length-weight regression was used to estimate weights for tournament prizes, thereby avoiding additional handling during weigh in. Weigh boats were located approximately every 3 km between Daisy and North Gorge to minimize holding time and traveling distance in angler's live wells and ensure that releases were relatively close to the capture locations. Walleye were not usually held in contestant's live wells for more than an hour and typically less. When catch rates were high, anglers were filling their live wells quickly and thus scoring them often. When catch rates were low, the weigh boats would move to the contestants to score fish, or contestants would bring one to four walleyes to the weigh boat to avoid the penalty of having to keep a mortality in their live well.

Fish were tagged and released at the weigh boat following scoring for the tournament. Fish were first placed in an aerated live well and held while the remaining fish were being scored from an individual boat. Biologists on the weigh boats affixed each fish with an individually numbered, 20 mm long monofilament "T"- anchor Floy® tag (model FD 94), and immediately released them. Tags were inserted at the posterior base of the first dorsal fin as described by Guy et al. (1996). Walleyes were usually held for ≤10 minutes and no longer than 20 minutes while being tagged.

Walleye were recaptured during the predation gill net sampling at Sherman Creek between 27 June and 09 August 1999, and gill net and electrofishing sampling between 25 June and 25 July 2000. Due to low numbers of walleyes recaptured on each sampling day (low recapture probabilities), data from 27-30 June 1999 and 26-28 June 2000 were pooled to form single recapture occasions for each year (Menkens and Andersen 1988).

We used the computer program CAPTURE and model M_t-Chao to estimate walleye abundances, standard errors, 95% confidence intervals, and capture probabilities, for both years (Otis et al. 1978; White et al. 1982; Chao 1989; Rexstad and Burnham 1991). Model M_t-Chao was used because it reduces to the Lincoln-Petersen estimator when there are two sampling occasions and performs well when capture probabilities are low (Chao 1989; Mitro and Zale 2002). In 1999 and 2000, walleye shorter than 305 mm and 304 mm, respectively, were excluded from the analysis because they were smaller than the fish tagged during the marking periods and thus were not represented in the abundance estimates. Recaptures of fish marked during the recapture period were ignored during analysis. Precision of the estimate was measured by calculating a coefficient of variance (CV), which was defined as the ratio of the standard error of the estimate to the estimate (Hightower and Gilbert 1984). We evaluated heterogeneity due to gear selectivity by comparing the length frequency distributions of fish captured during the mark and recapture occasions in 1999 and 2000 with a Kolmogorov-Smirnov test (SAS Institute 1999); H_o = no difference between the lengths of walleye caught during the mark and recapture occasions. Angler related mortality (harvest), emigration, and immigration were assumed to be minor and were evaluated using volunteer angler tag returns.

Piscivore Consumption Estimates

We used the Wisconsin bioenergetics model (Hanson et al. 1997) to generate daily consumption estimates for each age class of walleye from age-3 to age-7 over the 41-day modeling period in 1999 (June 27-August 6) and 31-day modeling period in 2000 (June 25-July 25). Model inputs specific to Lake Roosevelt included diet (Table 2), growth (Table 3) and thermal experience (Table 4). Literature values, provided in the model software manual, were used for prey caloric densities (Hanson et al. 1997). We modeled the average wet weight proportions of each diet item or category on each sampling day (Table 2). Sample sizes were too small to facilitate age specific diet, so we used the average diet of all walleye over 300 mm on each sampling day for age-3 to -7. In 1999, diet proportions for walleye over 300 mm were applied on nine occasions, whereas in 2000 diet proportions were applied on five occasions; the model extrapolated diet proportions between sampling dates. To achieve adequate sample sizes (10-20 fish) we combined days 2 and 3, days 4 and 5, days 16 and 17, and days 30 and 31 (Table 2). In 2000, we used the diet of walleyes 275-299 mm in length for age-2 fish. Sample size was not large enough to determine the diet on multiple dates for 275-299 mm walleye, so all samples were pooled to provide one diet throughout the study. Walleye less than 300 mm were excluded from model consumption extrapolations because they were not represented in the abundance estimate.

Walleye growth was determined by estimating the mean length- at age from scale analysis, and then adjusting for the duration of the study period. A 4-year (1996-1999) sample of scales was used that we assumed represented average walleye growth in Lake Roosevelt (LRFEP, unpublished data). We estimated growth from June 15 (formation of the annulus) to October 15 (fall gill netting and electrofishing). Mean lengths of each age group (age-2 to -7) were converted to weights using a log transformed length weight regression (SAS Institute 1999). We then estimated the mean daily growth rate from June 15 to October 15 and applied it to the number of days in the study period.

Thermal experience was estimated by averaging water temperature measurements from the top 12 m at three water quality sites collected by the LRFEP during biweekly water quality sampling. Mean water temperature of the entire water column was not used because very few walleye were captured in deep offshore nets, where water temperatures were slightly cooler. Age-specific consumption estimates were adjusted to their relative frequency from reservoir-wide gill net and electrofishing surveys in 1999 (LRFEP, unpublished data; Table 3). Consumption rates were expanded to piscivore abundance estimates to determine the biomass of each fish prey species consumed. Percent loss of each species was calculated by summing the estimated number of fish consumed during the study interval by the number stocked. Salmonid growth during the study period was determined by applying a daily growth rate to the mean size at release. Daily growth for rainbow trout and kokanee was estimated using the bioenergetics model, beginning with the size at stocking and modeling to the mean size at capture in fall gill net surveys (LRFEP, unpublished data). In 2000, kokanee and rainbow trout were released from net pens prior to our study (14 June) and these fish were present in the diet of walleye on our first day of sampling. To estimate consumption of these fish, we back-calculated consumption for ten days from the start of our study (25 June) to 14 June by using the diet, growth and thermal experience from June 25. Although not ideal, this method provides a conservative estimate because diet proportions were likely higher and temperatures were definitely lower during the pre-study period.

Results

Predator Collection and Diet

Walleye represented 89% and 94% of piscivore relative abundance in 1999 and 2000, respectively (Table 5). Burbot comprised 8% of piscivore relative abundance in 1999, but less than 1% in 2000. Northern pikeminnow comprised 3% of piscivore relative abundance in 1999 and 5% in 2000 (Table 5). Salmonid prey were present in burbot (1999) and northern pikeminnow (2000) diets, but the sample size of non-empty stomachs was too small to facilitate further analysis.

Walleyes sampled in 1999 were larger and from a more limited geographic range than in 2000. In 1999, 281 walleyes were captured, with lengths ranging from 196 to 620 mm and a mean of 432 mm (SD 82; Figure 2). Most walleyes were captured in Sherman Creek Mouth (n = 233; 27 net nights) and Colville River Mouth (n = 44; 18 net nights). Only 4 walleye were captured in the 22 net sets from the offshore mainstem sites. In 2000, 585 walleye were captured, with lengths ranging from 115 to 644 mm and a mean of 326 mm (83; Figure 2). Most walleyes (46%) were captured in the Colville River Mouth (site 7), whereas only 3% came from the Sherman Creek Mouth (site 6; Figure 1). Sites 1-5 (upstream) provided 10% of the total walleye catch and downstream (sites 8-12) provided 40% (Figure 1).

Salmonids were an important diet item to walleyes during 1999 and 2000. In 1999, kokanee comprised 75-100% of walleye (>300 mm) diet by weight, and were present in 142 of 174 (82%) non-empty stomachs (Table 2). Forty-six percent of walleye stomachs were empty in 1999 (Table 5). In 2000, kokanee and rainbow trout comprised 25-79% of large (300-644 mm) walleye diets and 8% of small (275-299 mm) walleye diets (Table 2). Salmonid prey fish were present in 72 of 115 non-empty large walleye stomachs and 4 of 26 small walleye stomachs. The lavage technique was successful in removing all diet items in 90% (27:30) of the walleye randomly sub sampled for lavage efficacy. Empty stomachs occurred in 48% of large walleye and 77% of small walleye (Table 5).

The walleye population removed more small salmonids; however, larger walleye tended to consume larger salmonid prey. The length distribution of kokanee consumed by walleye was significantly smaller than those measured in the raceway before release during both 1999 (Kolmogorov-Smirnov test; $X^2 = 12.6$, df = 2, P = 0.004) and 2000 (Kolmogorov-Smirnov test; $X^2 = 34.3$, df = 2, P < 0.001; Figure 3). The sample size of measurable rainbow trout in walleye diet samples was too small (n=6) to facilitate statistical comparison between the size eaten [mean 147 mm (SD 49)] and the size released (208 mm). The mean predator-to-prey length ratio was 0.32 in 1999 and 0.33 in 2000. The maximum predator-to-prey length ratio of 0.53 in 1999 and 0.54 in 2000 indicates that gape limitation occurred at approximately 50% of the predator's body length (Figure 4). Results of the predator-to-prey length ratio were pooled between years because slopes of the regressions were not significantly different (t = -0.118; df= 251; P> 0.50). Prey length increased with predator length by the relationship:

$$\text{kokanee length} = \text{walleye length } (0.20) + 50.58$$

The slope of the regression line was significant (ANOVA; F = 66.10; df = 1, 254; P < 0.001), but the relationship was weak ($r^2 = 0.21$; Figure 4).

The two different strains of kokanee experienced similar rates of predation by walleye, as indicated by coded wire tag recoveries. Twenty coded-wire tags were recovered from 94,518 Lake Whatcom origin kokanee, whereas 24 coded-wire tags were recovered from 105,432 Meadow Creek origin kokanee. The proportions of Lake Whatcom and Meadow Creek kokanee recovered from walleye stomachs did not differ significantly ($X^2 = 0.06$; df = 1; P > 0.75).

Walleye Abundance

In 1999, 1,494 walleye (≥305 mm) were tagged and released during the GCWT. Between 27 and 30 June, 91 walleye were captured during the predation gill net sampling, 8 of which were recaptures (Table 6). The estimated number of walleye ≥305 mm TL was 16,610 with a standard error of 5,266, a coefficient of variation (CV) of 0.32, and 95% confidence interval of 9,296 to 30,864. Capture probabilities during mark and recapture occasions were 0.09 and 0.01, respectively.

In 2000, 714 walleye (≥304 mm) were tagged and released during the GCWT. A total of 146 walleye were collected between 26 and 28 June during the electrofishing and gill net sampling between Daisy and North Gorge. Of the 146 walleye, 7 were recaptures (Table 6). The estimated number of walleye ≥304 mm TL was 12,233 with a standard error of 3,932 (CV = 0.32) and 95% confidence interval of 6,747 to 22,834. Capture probabilities during mark and recapture occasions were 0.06 and 0.01, respectively. Anglers voluntarily returned tags or tag information from 22 walleyes that were originally marked at the 1999 tournament and caught between 3 and 30 July 1999. Of those 22 returns, nine (40.9%) were outside of the study area. All fish caught by anglers outside of the study area were within 10 km of the study area.

Anglers reported catching six walleyes that had been tagged during the 2000 tournament, between 25 June and 21 July 2000. One of the six was caught during the abundance estimate period (25 June) within the study area and was released. One (16.7%) of the six returns was 6 km outside of the study area. The fish that emigrated from the study area in 2000 was caught after the abundance estimate (21 July).

Size selectivity of walleyes varied significantly among gear types used during mark and recapture periods of the abundance estimate. The length distribution of walleye captured by angling was significantly different than those collected by gill netting in 1999 (Kolmogorov-Smirnov test; $X^2 = 36.7$, df = 2, $P < 0.0001$) and electrofishing in 2000 (Kolmogorov-Smirnov test; $X^2 = 33.5$, df = 2, $P < 0.0001$; Figure 5).

Piscivore Consumption

Estimated P-values (proportion of maximum consumption) for walleye were generally low and decreased slightly from age-3 to age-7. P-values were similar in 1999 and 2000, ranging from 0.31 to 0.28 and 0.33 to 0.31 respectively, for age-3 to -7 walleye (Table 3). In 2000, age-2 walleye had a higher p-value (0.65); however, due to their shorter total length they did not have access to as many stocked salmonids as larger walleye (Table 3).

Individual walleye consumption of kokanee ranged from 3.0-12.4 g / day in 1999, and 0.1-8.8 g / day in 2000; depending on age and day of the study. The total daily consumption of kokanee by individual walleye increased with age, but cumulatively, age-3 and -4 walleye [mean lengths 333 mm (46) and 398 mm (48)] had the greatest impact on hatchery releases (Figure 6), because of their high relative abundance (Table 3).

In 1999, walleye consumed 200 kg of kokanee per 1000 individuals 305 mm and larger. Maximum consumption of kokanee by walleye occurred on day 33 (6 kg/1000 walleye; Figure 7) when diet proportions were 100% kokanee following the second hatchery release (Table 2). With a population estimate of 16,610 (9,296-30,864), a total of 3,316 kg of kokanee were consumed from two releases totaling 16,481 kg for a loss of 20% (not adjusted for kokanee growth during the study period). Kokanee growth during the study was 0.9 g/day (27 g/month; 26 mm/month) starting with a mean release size of 166 mm and 45 g. Therefore, the cumulative number of kokanee lost to predation was 54,073 (30,263-100,477) or 15% (8-27%) of the hatchery releases within the study area.

In 2000, walleye consumed 93 kg of kokanee and 14 kg of rainbow trout per 1000 individuals 304 mm and larger. Maximum consumption of kokanee occurred on day 17 (4.2 kg / 1000 walleye) and rainbow trout on day 1 (1.2 kg/1000 walleye; Figure 7). With a population estimate of 12,233 walleye (6,747-22,834), a total of 1,357 kg of kokanee and 313 kg of rainbow trout were consumed. In 2000, we used growth rates of 0.9 g/day and 1.7 g/day for kokanee and rainbow trout, respectively. Therefore, kokanee numerical losses totaled 34,076 (18,794-63,607) for a 9.4% (5.2-17.5%) loss; and rainbow trout numerical losses totaled 4,839 (2,669-9,033) for a 7.3% (4.0-13.6%) loss.

Discussion

Predatory impacts of native and non-native piscivores on native salmonids has been studied extensively in the lower Columbia River basin (Vigg et al. 1991; Tabor et al. 1993; Collis and Beaty 1995; Zimmerman 1999); however, resident fish predator-prey interactions in the upper Columbia River basin have not been investigated. The kokanee-stocking program in Lake Roosevelt was not meeting harvest and spawner return goals and predation was identified as a potential limiting factor (Tilson and Scholz 1998; Cichosz et al. 1999). Reservoir-wide diet studies and bioenergetics modeling revealed inconsistent patterns in predatory impact that resulted in a broad range (0-73%) of possible impacts to hatchery releases (Baldwin et al. 1999).

In 1999, our study was limited because our diet information came from a small portion (3-5 reservoir km) of the geographic range of the abundance estimate (55 reservoir km). Consumption estimates were then expanded to total walleye abundance; however, data collected by LRFEP (July 7-9; n =16) suggested that walleye diets contained much smaller proportions of kokanee (7%) when taken from various locations throughout the study area (LRFEP, unpublished data). This conclusion led us to a different approach for 2000 that allowed us to sample from a broader area. The proportion of kokanee in the diets declined in 2000, but so did the population estimate (by 36%), thereby reducing the impact from 15% to 9.4%. We believe the sampling biases from our 1999 study overestimated the impact of walleye. However, both years are an underestimate of total predation due to some consumption by walleye less than 300 mm and other predators such as burbot and pikeminnow that could not be quantified. Despite the limitations of the 1999 study, the results were quite similar to 2000 and comparing the similarities and differences was helpful in understanding our sampling biases, annual abundance fluctuations, and increasing the sample size of salmonids consumed by walleye predators. Closed population models, including M_t-Chao, have three basic assumptions: 1) the population in the study area remains closed throughout the study; 2) the marked fish do not lose their tags; and 3) all fish in the population have an equal chance of being captured during each sampling occasion (Otis et al. 1978; White et al. 1982; Seber 1982; Pollock et al. 1990).

In short-term studies open populations can sometimes be estimated using closed models because recruitment and mortality can essentially be ignored, as long as there is no significant immigration or emigration (Pollock et al. 1990). Due to the short time period of our estimates, natural mortality and recruitment (growth to a taggable size; 305 mm in 1999 and 304 mm in 2000) were assumed to be negligible. The most likely causes for violating the assumption of closure would have been angler related mortalities, emigration, or immigration. Based on voluntary angler tag returns of 0 for 1999 and 1 for 2000 (the fish was released), there was limited angler harvest during our study. Additionally, angler harvest was low because 45% of the walleye marked at the 1999 tournament and 48% of the walleye tagged during the 2000 tournament were within a protective slot limit of 406 mm to 508 mm.

Short-term delayed mortality as a result of capture by live-release tournament angling could have biased our abundance estimates. Hooking mortality has been demonstrated to be negligible when walleye were released immediately after being caught (Fletcher 1987; Payer et al. 1989; Schaeffer 1989); however, several studies have demonstrated that short-term delayed mortality of tournament caught walleye can be substantial (Goeman 1991; Fielder and Johnson 1994; Hoffman et al. 1996). Increased mortality was generally related to poor weather conditions (high winds and rough water) high water temperatures, high bag limits, non-recirculating livewells, and lack of penalties for dead fish. We believe short-term delayed mortality at the GCWT was negligible due to the tournament structure, optimal temperatures, and weather conditions. The GCWT was designed to minimize mortalities and was very similar to the modified tournament structure that would have resulted from the combined recommendations of Goeman (1991), Fielder and Johnson (1994), and Hoffman et al. (1996).

The main concerns regarding violations of population closure were due to emigration and immigration. Some emigration occurred during both years, as indicated by angler tag returns; however, we minimized the effect of this by reducing our abundance estimate temporally. This suggested that our abundance estimate was low; however, immigration was not evaluated. If mortality, emigration, and immigration all occurred, then abundance was overestimated (Otis et al. 1978; Pollock et al. 1990). We assumed zero tag loss due to the short time period of the estimate. McLellan (1998) held 24 walleye (391 mm to 506 mm), tagged in the same manner as this study, for 60 days in laboratory streams and observed no tag loss.

There are three types of unequal capture probabilities, time, behavior, and heterogeneity, which can act independently or in combination in a population (Otis et al. 1978; White et al. 1982; Pollock et al. 1990). The model we selected, M_t-Chao, accounts for unequal capture probabilities due to time effects. By changing gear types between the marking and recapture occasions, we eliminated a behavioral response (Pollock et al. 1990). Violating the assumption of equal catchability due to heterogeneity may have also biased our abundance estimates. If capture probabilities are heterogeneous in each sample, but independent from sample to sample, then the estimate is not biased (Pollock et al. 1990). The different gear types used in the mark and recapture periods had significantly different size selection in both years, but the size selection was independent, so we contend that our estimates were unbiased by heterogeneity.

During both years, the modeling extended past the end of the recapture period for the abundance estimate. The cut-off date for recaptures was selectively chosen to reduce violation of assumptions of mark-recapture models. We assumed that during the latter half of each predation study, our abundance estimate did not change, even though we have some evidence of walleye moving into and out of the study area. We believe that any error incurred from walleye movement during the study period would not change the abundance estimate to the point of substantially altering the estimated impacts on hatchery releases.

Physical conditions vary annually in Lake Roosevelt (Cichosz et al. 1997, 1999); the timing of reservoir refill, temperature, turbidity, and water retention times are all dependent on spring runoff patterns and corresponding flood control rule curves. The number of walleye in the study area in any given year may depend on these conditions. Although percent impacts on kokanee and rainbow trout were similar in 2000, the Sherman Creek and Kettle Falls rainbow trout releases only represented 16% of the reservoir-wide net-pen program. In contrast, 77% of hatchery- reared kokanee were released in this area in 2000. Therefore, impacts on the overall hatchery program were better represented for kokanee than for rainbow trout.

During both years, consumption of kokanee peaked in the middle to end of the study period. The proportion of salmonids in the diet of walleye remained relatively high, and water temperatures increased, thereby increasing the foraging ability and digestive efficiency of walleye (Swenson and Smith 1973). If walleye continued to feed on hatchery released salmonids until fall, the impact of predation could have been increased by 2- to 3-fold.

The length frequency of walleye was considerably different between years, due primarily to gear selectivity (Hamley 1975; Rudstam et al. 1984; Henderson and Wong 1991). This difference had little effect on the predator-prey length relationship and did not increase the mean prey length consumed.

Management options based on our results would include releasing larger hatchery salmonids, using different release sites that have lower densities of walleye, or reducing total walleye abundance and the mean size of walleye in the population through regulation changes. Releasing bigger fish might increase rainbow trout survival, but rearing larger kokanee would likely increase the rate of precocity, thereby reducing the number of age 3 recruiting to the fishery and returning to egg collection sites (Patterson 1998). Kokanee have been released from other areas in the reservoir, including the Spokane River below Little Falls Dam, Seven Bays near the confluence with the Spokane River, and Lincoln (near Hawk Creek) without substantially better returns than the northern release sites (Tilson and Scholz 1998; McLellan et al. 2001). A change in the walleye regulation has already been submitted to WDFW that will allow harvest of walleye between 406 and 508 mm (previously protected slot limit). Because harvest of smaller walleyes will not be restricted, this regulation should contribute to increased survival of stocked salmonids.

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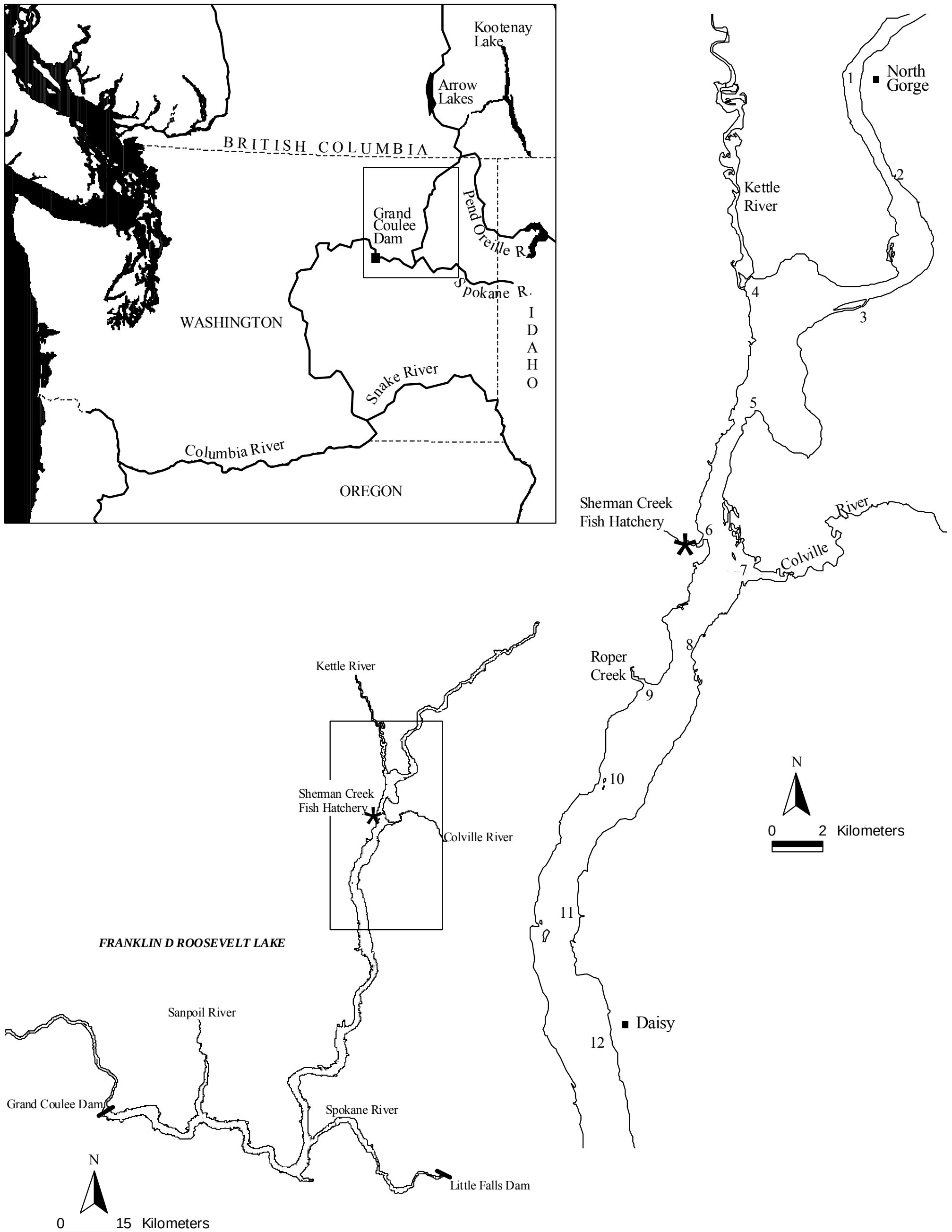

Figure 1. Map showing Lake Roosevelt, Washington on the Columbia River, the location of the study area within Lake Roosevelt, and sampling locations electroshocking and gill net sampling in 1999 and 2000. Numbers correspond to boat ramp locations, bays, or creek mouths in the following order; 1 North Gorge, 2 Evans, 3 Marcus Island, 4 Kettle River, 5 Kettle Falls, 6 Sherman Creek, 7 Colville River, 8 Rickey Point, 9 Roper Creek, 10 French Rocks, 11 Barnaby Island, 12 Daisy.

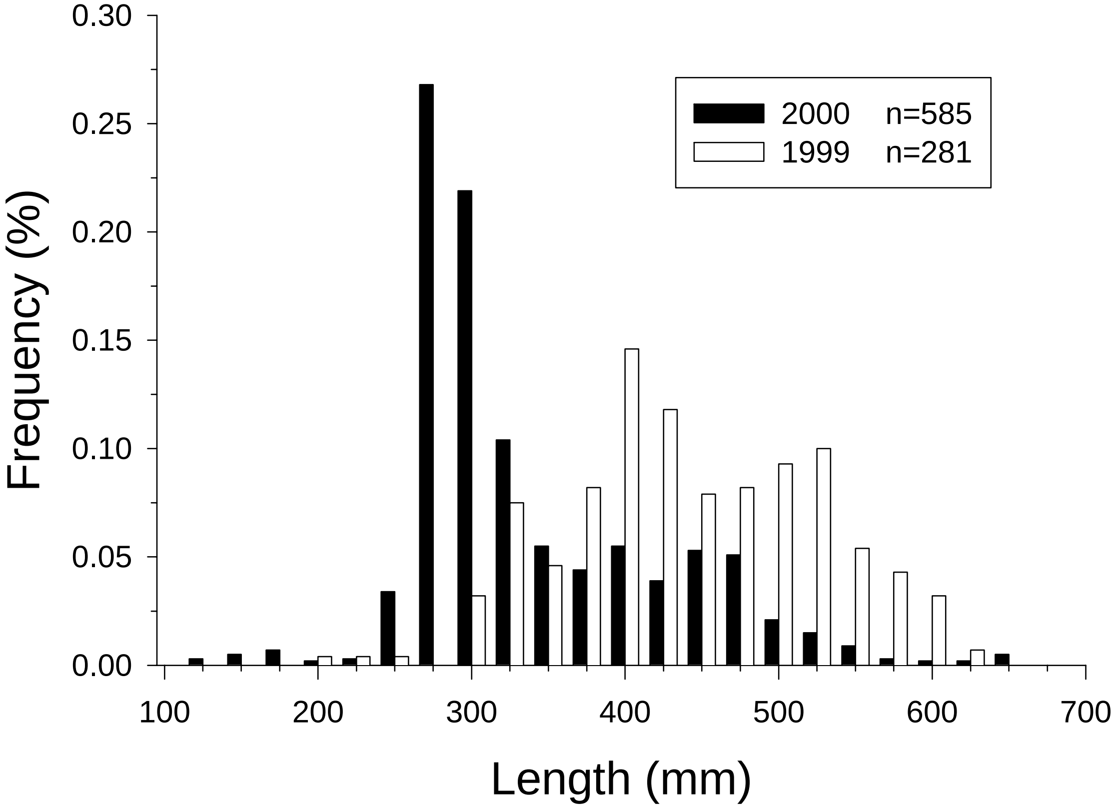

Figure 2. Length frequency of walleye collected in Lake Roosevelt, Washington with experimental mesh gill nets in 1999, and electrofishing and experimental mesh gill nets in 2000.

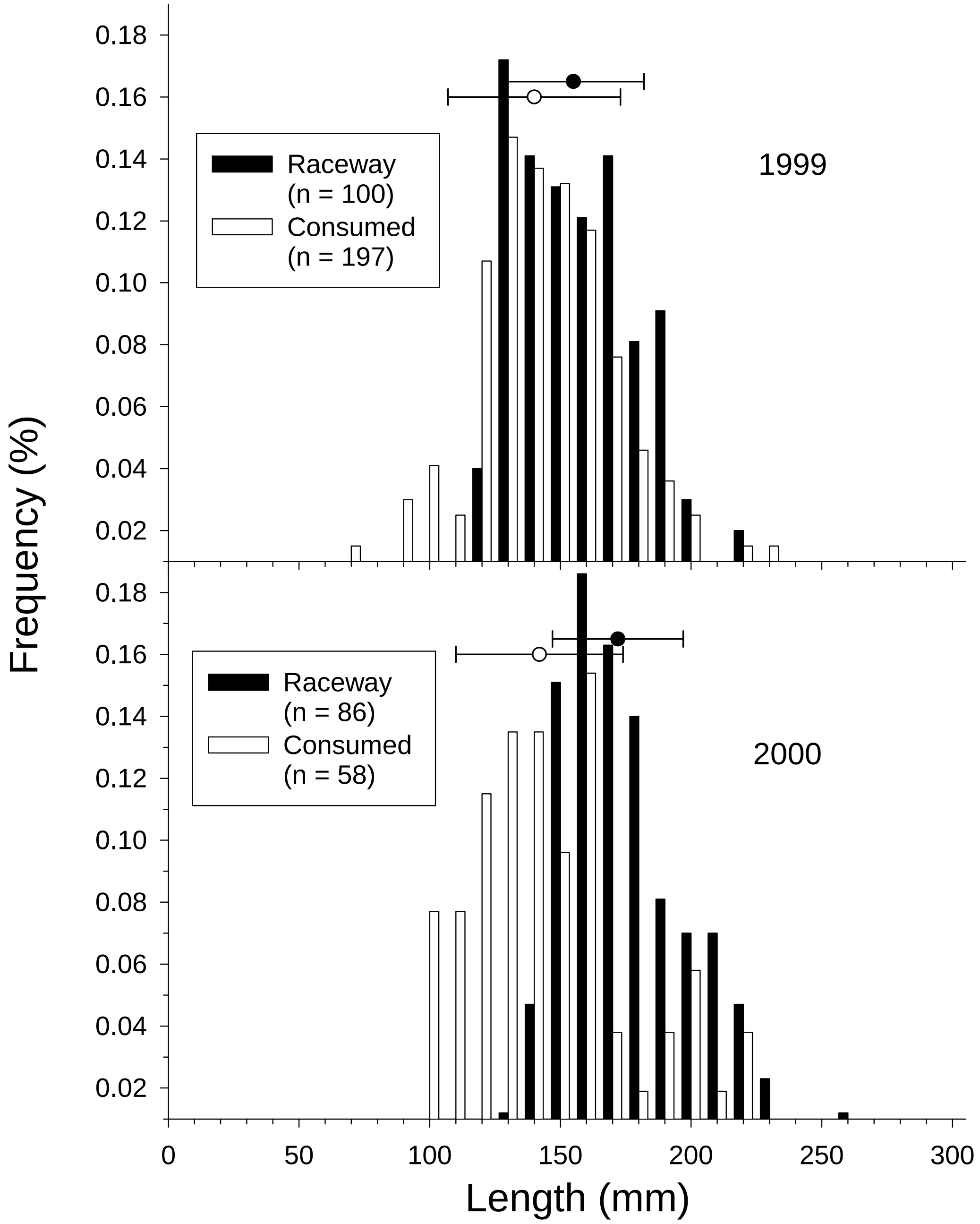

Figure 3. Length frequency (bars) and mean total length (circles; + 1 standard deviation) of kokanee released from the Sherman Creek Hatchery raceways (black) and kokanee consumed by walleye (white) in Lake Roosevelt, Washington during 1999 and 2000.

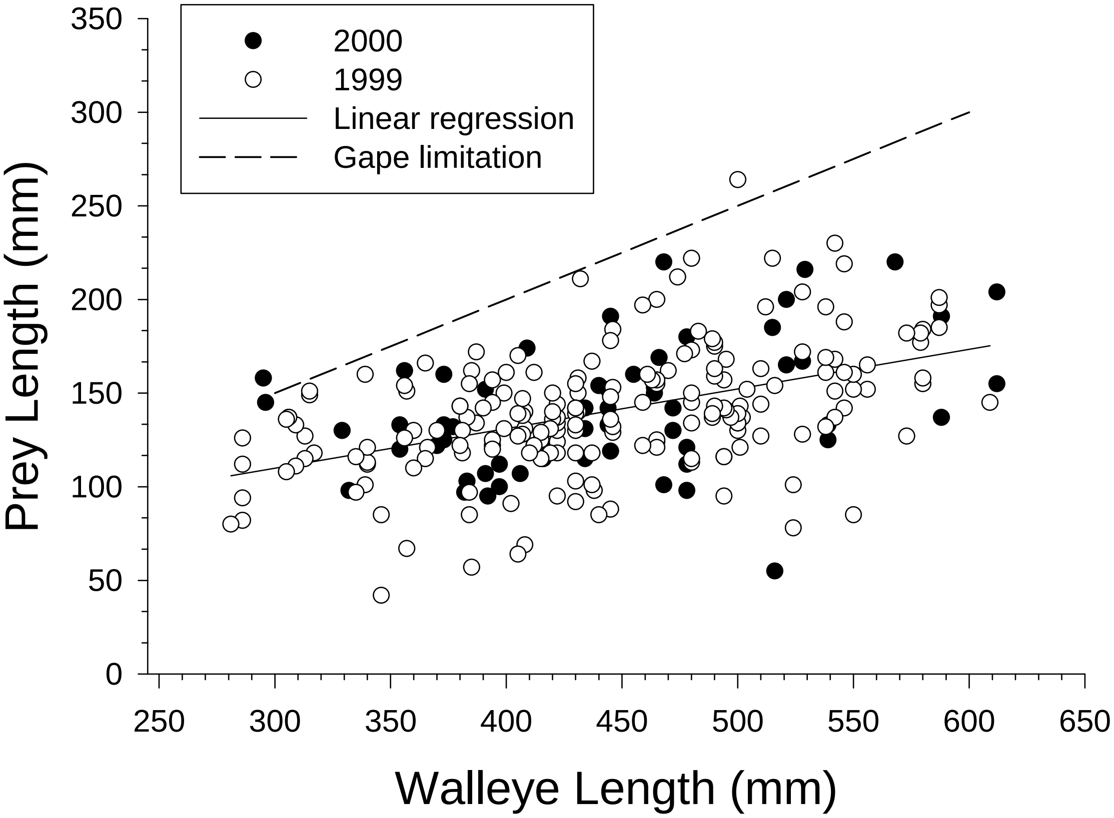

Figure 4. Walleye length and the length of their salmonid prey in lake Roosevelt, Washington during 1999 and 2000. The regression (solid line) represents both years pooled, and was defined by the equation; salmonid length = walleye length (0.20) + 50.58, r2 = 0.21. The dashed line shows a linear relationship of (walleye length * 0.50) and represents gape limitation for the piscivores.

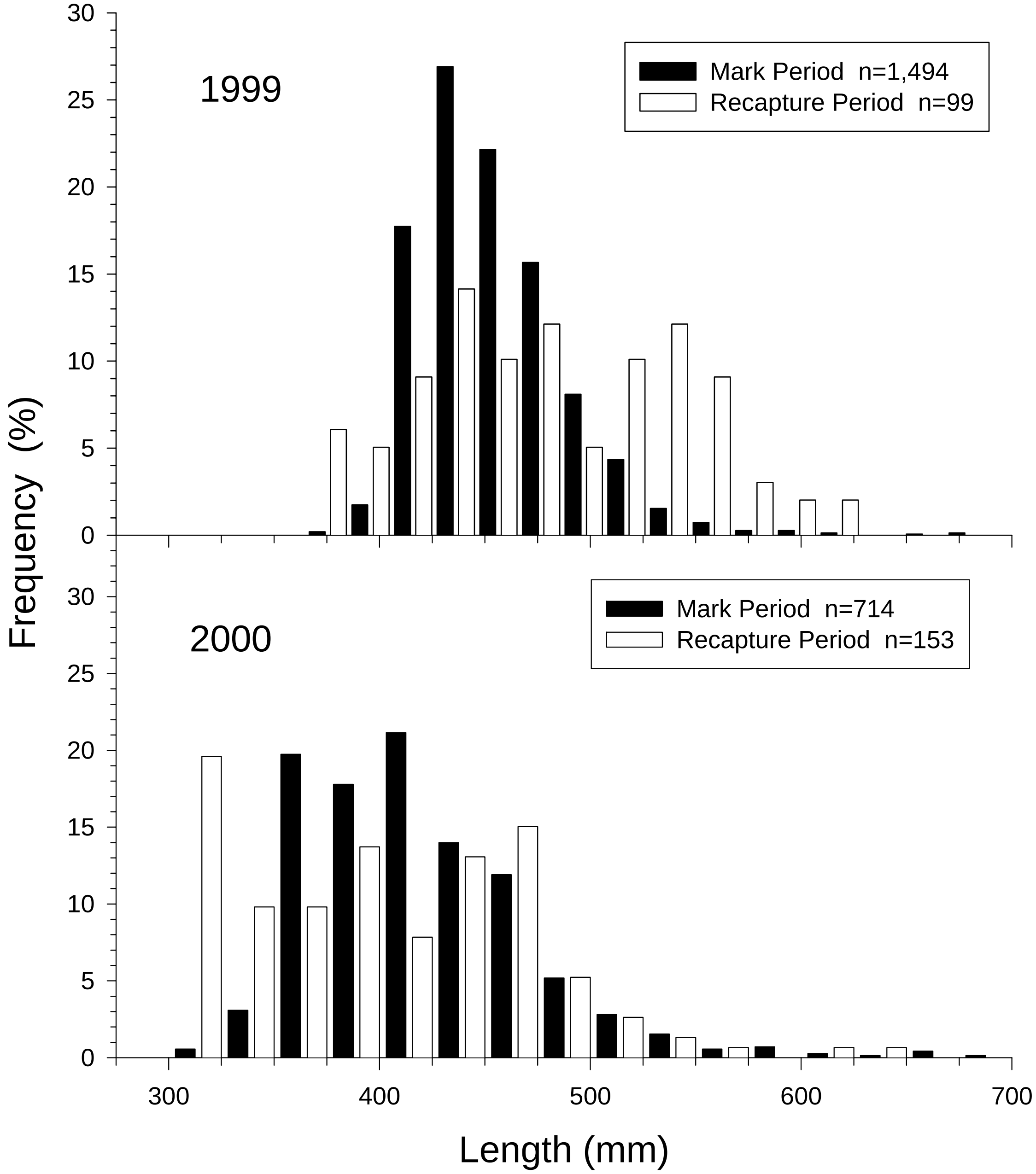

Figure 5. Length frequency of walleye captured in Lake Roosevelt, Washington during the mark- recapture studies in 1999 and 2000. Walleyes were captured by angling during the marking periods on June 19 and 20, 1999 and June 24 and 25, 2000. Walleyes were recaptured by gill netting in 1999 (June 27-30) and electrofishing in 2000 (June 26-28).

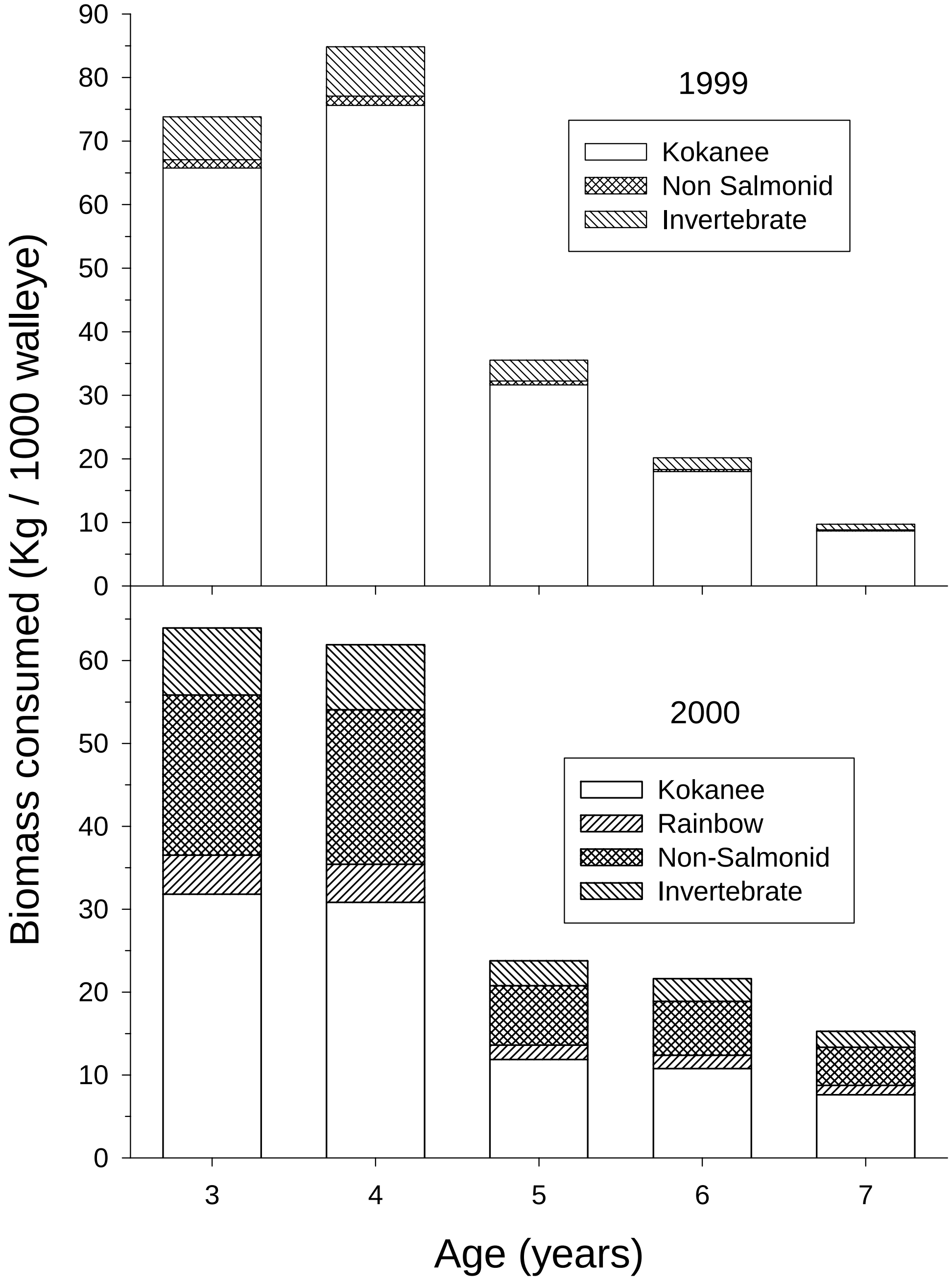

Figure 6. Age specific consumption of various prey types per 1000 walleye in Lake Roosevelt, Washington from June 27 to August 6, 1999 and June 14 to July 25, 2000. The 1000 walleye predators were adjusted to age class structure of 3-7 year old walleye. Age 7 and older fish were modeled as one cohort and reported as age 7+.

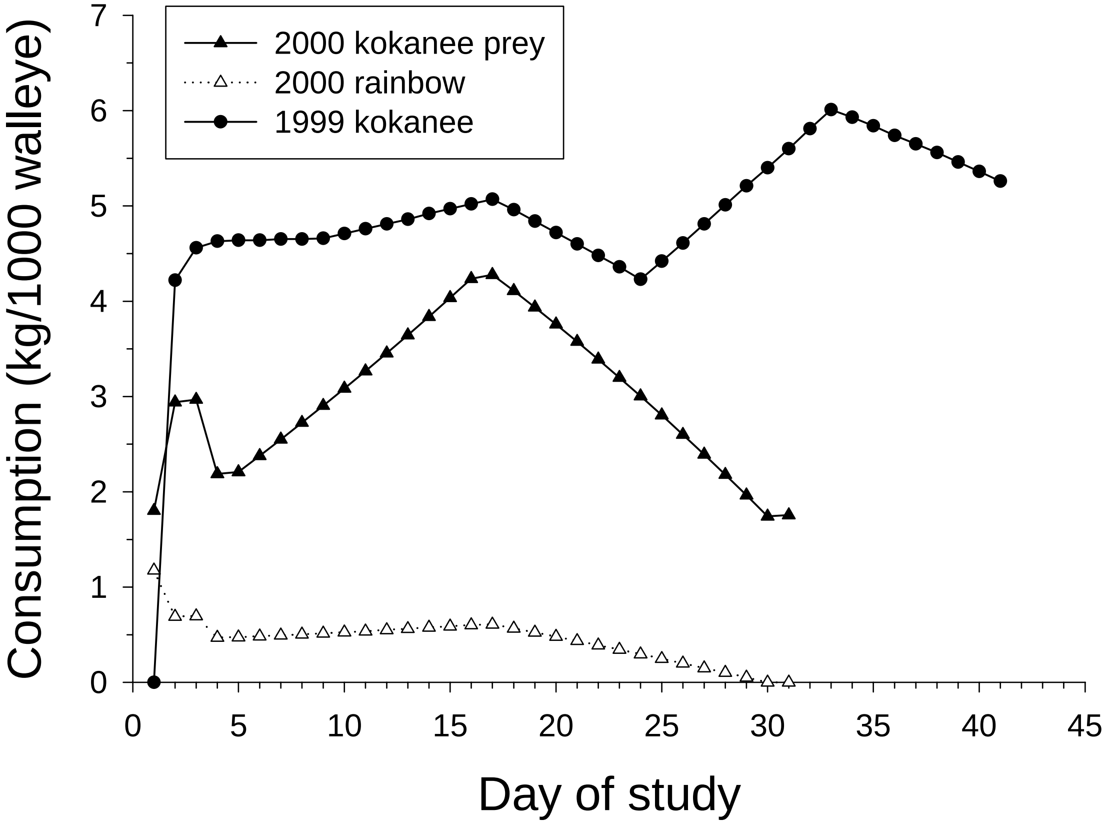

Figure 7. Daily consumption of kokanee and rainbow trout by walleye predators in lake Roosevelt, Washington in 1999 and 2000. The 1000 walleye predators are adjusted to age class structure of walleye age- 3 and older.

Table 1. Salmonid release information for the study area within Lake Roosevelt, Washington, during 1999 and 2000. Mean fish length and standard deviation were determined with 100 fish from the 3 raceways at Sherman Creek Hatchery (SCH). Other fish lengths (*) were calculated from the number of fish/lb (Piper et al. 1982).

Date	Species	Release facility	Location	Number released	Biomass released (kg)	Mean length (± SD (mm))
6/28/99	Kokanee	SCH	SCH	279,847	12,451	155 ± 27
7/29/99	Kokanee	SCH	SCH	88,775	4,030	167*
6/14/00	Rainbow	Net pen	Kettle Falls	37,428	3,657	208*
6/14/00	Kokanee	Net pen	Kettle Falls	197,975	4,563	133*
6/26/00	Kokanee	SCH	SCH	295,610	13,932	172 ± 25
7/14/00	Rainbow	Net pen	Kettle Falls	29,233	1,491	166*

Table 2. Mean wet weight diet proportions used to model consumption of walleyes in Lake Roosevelt, Washington in 1999 and 2000. Caloric densities (joules per gram) for each prey group are shown in parentheses. Sample size of non-empty stomachs is indicated by (n).

Modeling day	**n**	**Kokanee (5,500 J/g)**	**Rainbow (5,500 J/g)**	**Other fish (4,186 J/g)**	**Invertebrates (3,000 J/g)**
			1999 (300-620 mm walleye)		
1	4	0.00	*	0.25	0.75
2	16	0.94	*	0.00	0.06
3	14	1.00	*	0.00	0.00
4	31	1.00	*	0.00	0.00
9	44	0.95	*	0.13	0.05
17	32	0.95	*	0.00	0.05
24	12	0.75	*	0.00	0.25
33	12	1.00	*	0.00	0.00
41	14	0.83	*	0.10	0.07
			2000 (275-299 mm walleye)		
1-31	26	0.04	0.04	0.73	0.20
			2000 (300-644 mm walleye)		
1	9	0.34	0.22	0.44	0.01
2-3	33	0.55	0.13	0.11	0.22
4-5	33	0.40	0.09	0.31	0.20
16-17	28	0.69	0.10	0.11	0.10
30-31	12	0.25	0.00	0.66	0.09

Table 3. Population characteristics of walleye in Lake Roosevelt, Washington in 1999 and 2000. Age frequency was estimated from standardized reservoir-wide gill net and electrofishing surveys. Mean length was back calculated to the nearest annulus from scale-aged walleye 1996-2000 (n=2693). Growth was modeled for 41 days in 1999 and 31 days in 2000 and based on the mean monthly growth rate from July to October 1996-2000. P-values represent the proportion of maximum consumption as predicted by the bioenergetics model.

Year & Cohort	Age Frequency	Mean Length (mm)	SD Length (mm)	Model start Weight (g)	Model end Weight (g)	Model p-values
1999						
2	*	*	*	*	*	*
3	0.45	333	46	307	356	0.31
4	0.36	398	48	537	599	0.30
5	0.11	458	59	826	898	0.29
6	0.05	510	69	1157	1238	0.29
7+	0.02	558	83	1524	1613	0.28
2000						
2		261	42	144	169	0.65
3	0.48	333	46	307	343	0.33
4	0.32	398	48	537	582	0.32
5	0.09	458	59	826	879	0.32
6	0.07	510	69	1157	1216	0.31
7+	0.04	558	83	1524	1589	0.31

Table 4. Mean water temperatures from the upper 12 meters of water averaged across three sites in northern Lake Roosevelt, Washington in 1999 and 2000.

Study date	Modeling day	Water temperature (degrees celsius)
1999		
27-Jun	1	13.3
30-Jun	4	13.8
12-Jul	16	15.2
25-Jul	29	16.3
6-Aug	41	17.1
2000		
25-Jun	1	14.4
5-Jul	11	15.4
25-Jul	31	17.6

Table 5. Total catch of piscivores sampled in Lake Roosevelt, Washington that were longer than 300 mm in 1999 and 275 mm in 2000. Northern pikeminnow (NPM) and burbot consumption were not modeled due to small sample size.

Year	Sampling date	Modeling day	Walleye n	Empty (%)	NPM n	Empty (%)	Burbot	Empty (%)
1999	27-Jun	1	13	69%	0		1	0%
	28-Jun	2	22	27%	3	67%	2	0%
	29-Jun	3	16	13%	2	100%	1	100%
	30-Jun	4	39	21%	1	100%	2	100%
	5-Jul	9	63	30%	2	100%	5	40%
	13-Jul	17	54	43%	1	100%	6	67%
	20-Jul	24	20	40%	0		5	80%
	29-Jul	33	18	33%	0		1	100%
	6-Aug	41	26	46%	0		0	
		Total	271	34%	9	89%	23	61%
		Relative abundance	0.89		0.03		0.08	
2000	25-Jun	1	27	48%	0		1	100%
	26-Jun	2	18	44%	0		0	
	27-Jun	3	124	77%	4	100%	0	
	28-Jun	4	90	79%	7	14%	1	0%
	29-Jun	5	37	41%	1	100%	0	
	10-Jul	16	50	60%	7	14%	0	
	11-Jul	17	15	40%	0		1	100%
	24-Jul	30	32	56%	3	67%	0	
	25-Jul	31	10	60%	0		1	100%
		Total	403	65%	22	41%	4	75%
		Relative abundance	0.94		0.05		0.01	

Table 6. Walleyes captured between Daisy and North Gorge, Lake Roosevelt, Washington in 1999 and 2000. C = the number of unmarked fish, R = the number of recaptures, and Total = the pooled values used to generate the abundance estimates. *Data from these dates not included in the abundance estimates due to pooling.

Year	Sampling Date	C	R
1999	**Marking Period**		
	19-Jun	734	-
	20-Jun	760	-
	Total	**1,494**	**-**
	Recapture Period		
	27-Jun	25	3
	28-Jun	21	1
	29-Jun	13	2
	30-Jun	32	2
	Total	**91**	**8**
	5 Jul*	60	1
	6 Jul*	5	1
	7 Jul*	10	1
	13 Jul*	48	2
	20 Jul*	20	0
	29 Jul*	16	0
	4 Aug*	1	0
	5 Aug*	2	0
	6 Aug*	27	2
2000	**Marking Period**		
	24-Jun	404	-
	25-Jun	310	-
	Total	**714**	**-**
	Recapture Period		
	26-Jun	12	1
	27-Jun	84	5
	28-Jun	50	1
	Total	**146**	**7**
	29 Jun*	18	0
	10 Jul*	32	3
	11 Jul*	14	0
	24 Jul*	12	0
	25 Jul*	10	0