Limnetic Fish Surveys and Examination of Some Limiting Factors for Kokanee and Rainbow Trout in Lake Roosevelt, Washington; Annual Report 2005-2006

Prepared by:

Casey Baldwin
Washington Department of Fish and Wildlife
Science Division
Ecological Investigations
Wenatchee, WA 98801

and

Heather Woller
Washington Department of Fish and Wildlife
Science Division
Ecological Investigations
Spokane Valley, WA 99216-1566

Funded by:

The Spokane Tribe of Indians
Lake Roosevelt Fisheries Evaluation Program
Wellpinit, WA 99040

Through a subcontract provided by:

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

Project No. *1994-043-00*
Contract No. 00014804

January 2006

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 goal was to monitor the limnetic fish populations of Lake Roosevelt as a contribution to the multi-agency effort to identify factors that limit the various Lake Roosevelt fisheries. Our objectives were to determine the species composition and vertical and longitudinal distribution of limnetic fishes in relation to abiotic conditions, estimate limnetic fish density and abundance, and evaluate potential food limitation by analyzing relative weight, length at maturity, and diet. The limnetic zone of Lake Roosevelt (from Grand Coulee Dam to Kettle Falls) was surveyed in August and October of 2005 using a combination of gill nets and hydroacoustics. Lake whitefish *Coregonus clupeaformis* (38-43%), walleye *Sander vitreus* (25-34%), kokanee (5-19%), and rainbow trout (9-15%) were the primary species captured in the limnetic zone. Hatchery kokanee only made up 1% of the catch in August, while no hatchery kokanee were collected in October. For kokanee, warm water temperatures during mid-late summer forced them to occupy depth strata with above optimal temperatures (18°C) or deep strata that provided a thermal refuge (15°C) with potentially long vertical migrations (50-80 m) to encounter zooplankton in the photic zone. Fish density was higher in August (21.5 ± 6.3 fish / 10^6 m^3) than October (11.0 ± 3.5 fish / 10^6 m^3). In August, limnetic fish abundance was (115,803 ± 29% CV) for fish between –45 and –30.8 dB (100-550 mm). With 18 % relative abundance in the gill net catch the abundance estimate for wild kokanee in the limnetic zone was 20,845 fish or 0.63 fish/ha. There were no signs of food limitation for kokanee or rainbow trout based on relative weight, mean length of spawners, and the size and species composition of zooplankton.

ACKNOWLEDGEMENTS

We would like to thank the Spokane Tribe of Indians and the Bonneville Power Administration for funding this research. Washington Department of Fish and Wildlife (WDFW) employees who contributed valuable field and lab work and assistance to the project in the form of facilities, equipment, intra-project coordination, fieldwork, review of documents, and administrative support included, Chris Donley, Leslie King, Jason McLellan, Jim Meskan, Curt Vail, John Whalen, and various other Region 1 and Olympia Science Division staff. We thank other agencies and people who provided historical data, facilities, fieldwork, administrative support, and document review including Deanne Pavlik, Chuck Lee, and other Spokane Tribal staff; Dr. Allan Scholz and Holly McLellan of Eastern Washington University, and the National Park Service for parking, camping, and use of boat ramps.

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INTRODUCTION

Project History

The Lake Roosevelt Monitoring/Data Collection Project has been collecting physical, chemical, and biotic data since 1988 (Peone et al. 1990; Scofield et al., in press). 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 (Cichosz et al. 1997). 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. 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. The information in this report should be considered in combination with the efforts of other Lake Roosevelt Fisheries Evaluation Program participants including the Spokane Tribe of Indians (STI), Colville Confederated Tribes (CCT), and Eastern Washington University (EWU). This report will focus on the Lake Roosevelt limnetic surveys from 2005 and a subset of potential limiting factors.

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; Cichosz et al. 1999; McLellan et al. 2003; Scofield et al., in press). Additionally, WDFW has conducted analysis on entrainment, predation, and food limitation (Baldwin et al. 2003). An important component of these analyses was understanding the distribution, abundance, and diet of limnetic fishes.

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 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 sp.*, 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, 1999). 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.

Objectives

Our objectives were:

1. Determine the temporal and spatial characteristics of species composition and vertical distribution in the limnetic zone.

2. 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.

3. Estimate the density and abundance of limnetic fishes including origin specific estimates (hatchery vs. wild) for kokanee.

4. Examine food limitation as a limiting factor for kokanee and rainbow trout by evaluating relative weights, spawner lengths and diet.

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. The reservoir covers approximately 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 based on comparisons with other systems, the reservoir is more typical of a large river than a lake or reservoir (Cooper and Black 1998).

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 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. 2003; Scofield et al., in press). 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 resulted in a hatchery kokanee and rainbow trout stocking program. The 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

Limnetic Fish Distribution and Abundance

Limnetic fish distribution and abundance were determined using a combination of hydroacoustics and gill net surveys. Lake Roosevelt was stratified into 3 regions (upper, middle, and lower) for the surveys that were conducted in August and October of 2005 (Figure 1).

Gill Net Surveys.—Gill net surveys were used to provide species verification, depth distributions, and length frequencies of acoustic targets. We set 6-7 vertical and 5 horizontal gill nets overnight in the limnetic zone of each of the three sections for 3-4 nights following an acoustic survey. 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 6.5 m long, 2.6 m deep panels, and mesh sizes from 25-102 mm in 13 mm increments.

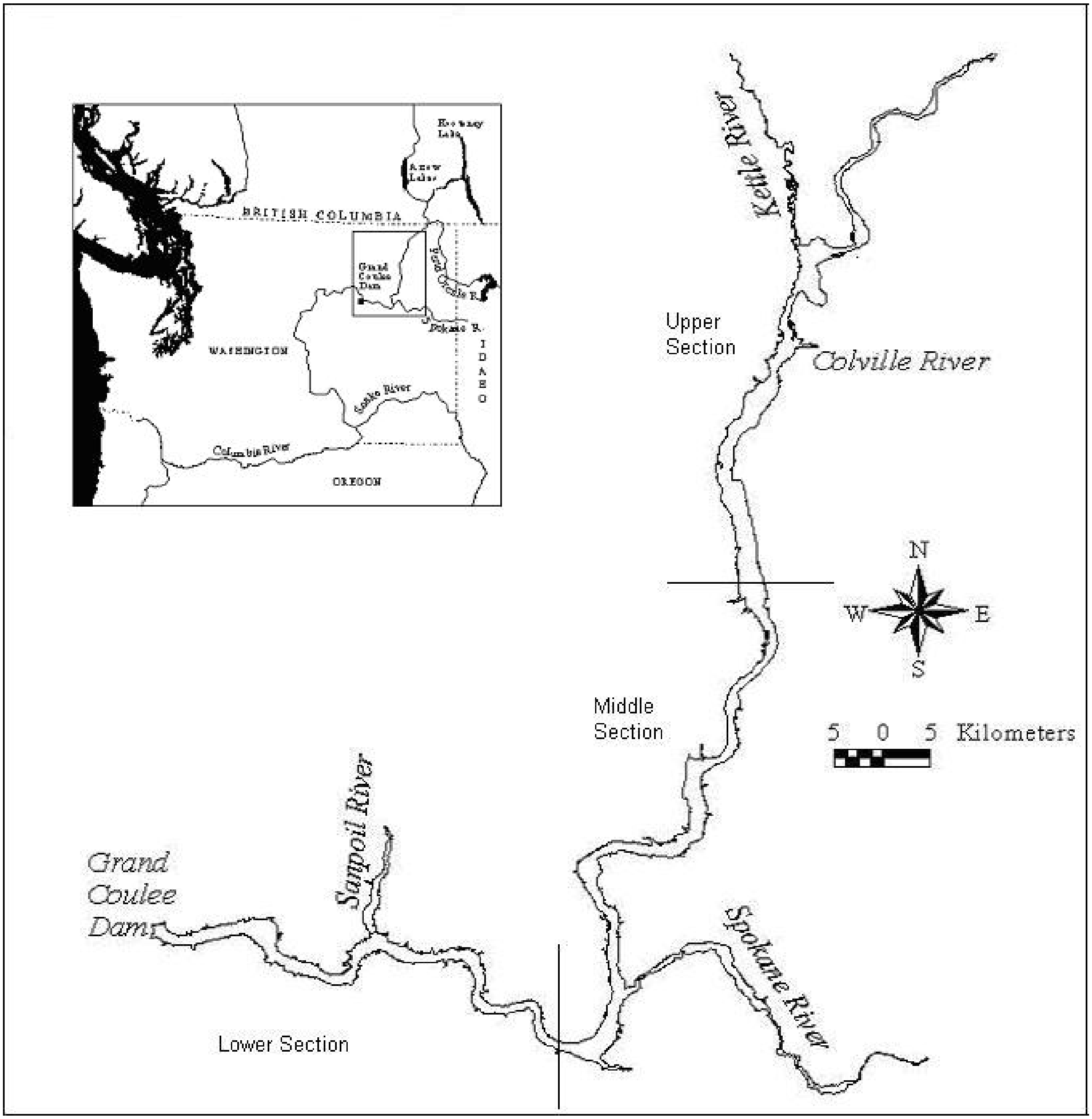

Figure 1. Map of Lake Roosevelt, Washington showing the three (upper, middle, and lower) sampling sections.

Hydroacoustic Density and Distribution.—We used an HTI model 241 echosounder with two pole-mounted 200 kHz transducers; a 15° split-beam transducer in vertical orientation (downlooking) and a 6 x 10° split beam transducer in horizontal orientation (side-scan). Data were logged directly into a computer and unprocessed echoes were recorded on digital audiotapes. A pulse repetition rate of 4 pings/second was multiplexed between the two transducers at a pulse width of 1.25 ms and a 10 kHz pulse width chirp. The horizontal transducer was offset by 7° and surveyed fish targets from 1.5-8 m below the surface. Data within 16 m of the horizontal transducer and 10 m of the vertical transducer were excluded from the analysis due to the near-field effects of a narrow beam and behavioral boat avoidance by the fish (Mous and Kemper 1996; Yule 2000). We only analyzed echoes within 7.5° off-axis (vertical) or 3° off-axis (horizontal), which met the single echo criteria of the software. A series of echoes were considered a fish if tracked for at least three consecutive pings, within 0.3 m/ping, a maximum velocity of 5 ms/ping, and target strengths between –55 and –27.7 dB (approximately 30-800 mm). Target strengths were converted to fish lengths using the formula generated by Love (1971;1977);

$$TL = 2252.1 \bullet \left[EXP\left(0.1204 \bullet TS\right)\right]$$

where TL was the total length (mm) and TS (dB) was the mean target strength of each tracked fish.

Each region was sampled on a single night each month and 7-8 transects were surveyed 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. Transects began at least 0.5 hour after sunset and ended at least 0.5 hour before sunrise.

Density [fish per million cubic meters (10^6 m^3)] was calculated for each transect and then transect densities were averaged together for a reservoir-wide estimate of fish density. For each transect, individually tracked fish were verified as real within the post-processing software (Echoscape v 2.11; HTI 2002). Raw fish counts were adjusted to the effective beam width (*EBW*) within each depth strata by the equation:

$$F_1 = F_0 + \left[F_0 \bullet \left(1 - \frac{EBW}{NBW}\right)\right]$$

where F_1 was the adjusted fish count, F_0 was the original fish count, and *NBW* was the nominal beam width for each transducer. Density was then calculated by dividing the adjusted fish count by the total swept volume for each transect. Swept volume (V) was calculated as:

$$V = \tfrac{1}{2} \cdot b \cdot h \cdot l$$

where (l) was the distance (in meters) of the transect, (h) was the distance (in meters) from the transducer to the end of the stratum (mean bottom depth), and (b) was the beam diameter calculated by:

$$b = 2R \tan\left(\frac{NBW}{2}\right)$$

where R was the range to the end of the stratum (mean bottom depth). Finally, total swept volume was adjusted by subtracting the un-surveyed near-field volume for each transducer (0-8 m for the vertical transducer and 0-10 m for the horizontal transducer). Comparisons of mean density between months and sections were done using two sample t-tests that used separate variances; whereas a paired t-test was used to detect differences between transducers. All statistical tests were conducted with Systat 11 analytical software and a significant p-value of 0.05 (Systat Software Inc. 2004). We described variability using 2 standard errors unless otherwise indicated.

*Abundance.—*Mean fish density was multiplied by reservoir volume to estimate abundance. Two standard errors were used to estimate the 95% confidence interval of the acoustic abundance estimate. Size-specific abundance estimates were determined by applying the percent frequency of each size class from the down-looking transducer to the total abundance estimate. We applied the length frequency from the vertical transducer to the horizontal acoustic targets because fish target echoes in horizontal aspect do not relate to fish length as they do in vertical aspect (Kubecka 1994; Yule 2000). The assumption that fish species composition and size distribution was the same from 1 to 8 m (horizontal acoustics) and from 8 m to lake bottom was validated with netting data. The coefficient of variation from the total abundance estimate was applied to size-specific abundance estimates. Species-specific abundance estimates were calculated by multiplying the species composition from the gill net survey by the acoustic abundance estimates. Fish less than 100 mm long were generally not captured by gill netting in the offshore zone, so no estimate was made for acoustic targets corresponding to this size class.

Abiotic Conditions and Fish Distribution

We evaluated potential temperature and dissolved oxygen limitations to limnetic fish production using water quality data obtained by the STI (Scofield et al., in press). We then identified areas of sub-optimal conditions based on literature values for each species (Appendix A). Vertical and horizontal fish distribution during each season were determined from gill net and hydroacoustic surveys and fish depth distributions were overlaid on vertical plots of temperature and dissolved oxygen to determine habitat use in relation to abiotic conditions.

Monthly (in January and from April-October 2005) vertical temperature (°C) and dissolved oxygen (mg/L) profiles were collected at four mainstem locations (Gifford, Seven Bays, Keller Ferry, and Spring Canyon) by the STI using a Hydrolab Surveyor 4 (Scofield et al., in press). Water quality parameters were logged at 3 m intervals from 0-33 m. Data were recorded every 10 m from 40 m to 90 m at Keller Ferry and Spring Canyon to characterize deep areas of the lower reservoir.

Food Limitation

Relative Weights.— For sexually 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 and rainbow trout W_r, we distinguished hatchery from wild fish and we included fish captured by STI littoral sampling (Scofield et al., in press) to increase sample size and represent reservoir-wide W_r. However, for kokanee, we excluded all sexually mature fish to avoid bias in the estimate of W_r, and because we were using a different method to evaluate sexually mature kokanee.

Kokanee Spawner Lengths.—Kokanee spawner length-at-age was compared between Lake Roosevelt and other systems in the Western United States and Canada. 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. We tested the mean kokanee length-at-age with a two-sample t-test assuming unequal variances.

Diet.—Whole fish stomachs were removed in the field and preserved in 95% ethanol until they could be removed and examined in the laboratory with a dissecting microscope. Stomach contents were sorted by taxon, generally to the nearest order for invertebrates and family for fishes. We determined the wet weights, to the nearest 0.01 g, for each diet taxon. Partially digested fishes were identified using diagnostic bones whenever possible (Hansel et al. 1988). Diet items were also dried at 60°C for 24 hours and dry weights were recorded to the nearest 0.0001 g. Dry weights were recorded for consistency with STI diet protocol, but were not analyzed for this report. We calculated the average wet weight proportion of each prey taxon for each fish species each month to be consistent with bioenergetics modeling protocols in case the data presented here is used in future modeling analyses.

RESULTS

Limnetic Fish Distribution and Abundance

Gill Net Surveys.— In August, 50 horizontal nets and 67 vertical gill nets captured 136 fish throughout the three sections of the reservoir for an overall CPUE of 1.2 fish per gill net night (Table 1; Appendix C). Numerical species composition showed lake whitefish (38%), walleye (25%), and kokanee (19%) as the most abundant species. Most lake whitefish ranged in size between 401-700 mm TL while most walleye ranged between 201-400 mm TL (Table 1). Hatchery and wild kokanee made up 18% and 1% of the catch, respectively, with two size classes collected (401-700 mm TL, 50%; 201-400 mm TL, 41%). One sturgeon was collected measuring approximately 2500 mm TL (~8 feet). Fish were broadly distributed, with most (88%) ranging from 10-60 m. Kokanee, however, were collected from 30 m to as deep as 100 m. In the upper section, one sturgeon was collected in a sinking horizontal net at ~37 m (Table 2; Appendix D).

In October, 55 horizontal and 77 vertical gill nets collected 80 fish throughout the three sections of the reservoir for an overall CPUE of 0.6 fish per gill net night (Table 1; Appendix C). Species composition by number revealed that lake whitefish (43%) and walleye (34%) were the most predominant species with most lake whitefish ranging from 401-700 mm TL and most walleye ranging from 201-400 mm TL. Only wild kokanee (5%) were collected in October with most in the 201-400 mm TL size class (Table 1). Most fish (94%) were distributed between 10-50 m; however, walleye were as deep as 70-80 m in the lower section and burbot and lake whitefish were distributed as deep as 80 m in the middle section. Kokanee were collected in lower numbers than in August and were only distributed between 10-30 m. In the upper section, two sturgeons were collected in a midwater horizontal net at ~38 m and measured 505 mm TL (430 FL) and 516 mm TL (450 FL), respectively (Table 2; Appendix D).

Hydroacoustic Density and Distribution.—Acoustically determined fish density varied by both month (ANOVA; df= 1; f-ratio 30.63; p <0.000) and section (ANOVA; df= 2; f-ratio 47.38; p <0.000) and there was also a significant interaction effect (ANOVA; df= 2; f-ratio 6.24; p = 0.004). Mean fish density (down-looking and side-scan transducers combined) was significantly different between August (21.5 ± 6.3 (2 SE) fish / 10^6 m^3) and October (11.0 ± 3.5 fish / 10^6 m^3) (t Stat= 4.62; df=22; p<0.000)(Table 3). Pair wise comparisons between months within each section indicated significantly higher densities of fish in August in both the lower and upper sections (Table 3). There was a significant difference in total density between sections in August (ANOVA; df=2, f-ratio=27.70; p<0.000) and in October (ANOVA; df=2; f-ratio = 24.25; p<0.000). In August, the upper section had significantly higher fish densities than the lower and middle sections, but there was no difference between the middle and lower sections (Table 4). In October, there was significantly more fish in the upper section than either the middle or lower sections and the middle section also had significantly higher densities than the lower section (Table 4).

There was significantly higher density of fish detected on the vertical (down-looking) transducer (14.1 ± 4.8 fish / 10^6 m^3) than the horizontal (side-scan) transducer (8.1 ± 3.3 fish / 10^6 m^3) in October (df=21; t-stat=3.22; p=0.004), but not in August (df=22; t-stat= 1.69; p=0.105)(Figure 2; Table 5). Acoustic targets had a similar vertical distribution during both months when comparing the percent frequency of range-weighted targets detected within depth bins on the vertical transducer (Figure 3). See Appendix E for more detailed data tables and summaries of hydroacoustic surveys.

Table 1. Species composition and total number of fish caught per size class on Lake Roosevelt, Washington, in August and October 2005.

		Size Classes (mm)						
Month	Species	100-200	201-400	401-700	700+	NA*	n	% n
August	Lake Whitefish	1	15	35	0	1	52	38%
	Walleye	0	28	6	0	0	34	25%
	Kokanee (W)	2	9	11	0	0	22	18%
	Kokanee (H)	0	2	0	0	0	2	1%
	Rainbow Trout	0	14	6	0	1	21	15%
	Longnose Sucker	0	1	1	0	0	2	1%
	Burbot	0	0	1	0	0	1	1%
	Smallmouth Bass	0	1	0	0	0	1	1%
	White Sturgeon	0	0	0	1	0	1	1%
	Total	3	70	60	1	2	136	100%
October	Lake Whitefish	4	10	20	0	0	34	43%
	Walleye	1	22	4	0	0	27	34%
	Rainbow Trout	0	5	2	0	0	7	9%
	Kokanee (W)	1	3	0	0	0	4	5%
	Kokanee (H)	0	0	0	0	0	0	0%
	Burbot	0	1	0	0	1	2	3%
	Smallmouth Bass	0	1	0	0	1	2	3%
	White Sturgeon	0	0	2	0	0	2	3%
	Longnose Sucker	0	1	0	0	0	1	1%
	Largescale Sucker	0	1	0	0	0	1	1%
	Total	6	44	28	0	2	80	100%

*NA indicates no length recorded.

Table 2. Total number of fish caught per 10-meter incremental depths on Lake Roosevelt, Washington in August and October 2005.

		Depth Bin (m)										
Month	Species	10	20	30	40	50	60	70	80	90	100	Total
August	Lake Whitefish	0	0	**2**	**39**	**10**	**1**	0	0	0	0	52
	Walleye	**1**	**3**	0	**26**	**1**	**3**	0	0	0	0	34
	Kokanee	0	0	**1**	**1**	**3**	**5**	**3**	0	**9**	**2**	24
	Rainbow Trout	**4**	**3**	**5**	**7**	**2**	0	0	0	0	0	21
	Longnose Sucker	0	0	0	**2**	0	0	0	0	0	0	2
	Burbot	0	0	0	0	**1**	0	0	0	0	0	1
	Smallmouth Bass	0	0	0	**1**	0	0	0	0	0	0	1
	White Sturgeon	0	0	0	**1**	0	0	0	0	0	0	1
	Total	5	6	8	77	17	9	3	0	9	2	136
October	Lake Whitefish	**4**	**2**	**7**	**18**	**2**	0	0	**1**	0	0	34
	Walleye	**1**	**1**	**1**	**17**	**4**	0	**2**	**1**	0	0	27
	Rainbow Trout	**6**	0	0	**1**	0	0	0	0	0	0	7
	Kokanee	**2**	0	**2**	0	0	0	0	0	0	0	4
	Burbot	0	0	0	**1**	0	0	0	**1**	0	0	2
	Smallmouth Bass	0	0	0	**2**	0	0	0	0	0	0	2
	White Sturgeon	0	0	0	**2**	0	0	0	0	0	0	2
	Longnose Sucker	0	0	0	0	**1**	0	0	0	0	0	1
	Largescale Sucker	0	0	0	0	**1**	0	0	0	0	0	1
	Total	13	3	10	41	8	0	2	3	0	0	80

Table 3. Statistics results for comparing mean density (fish /10^6 m^3) of acoustically detected fish (~ 30-800 mm) in three sections of Lake Roosevelt, Washington during August and October of 2005.

Section	Transect	Total Density (Fish / 10^6 m^3) August	Total Density (Fish / 10^6 m^3) October		Total Density (Fish / 10^6 m^3) August	Total Density (Fish / 10^6 m^3) October	Pairwise T-test results df	Pairwise T-test results t-stat	Pairwise T-test results p
	L1	5.1	3.5						
	L2	13.6	3.2						
	L3	11.5	1.4						
Lower	L4	10.8	4.0	Mean	12.1	2.9	7	5.27	0.001
	L5	19.3	0.7	SD	4.4	1.3			
	L6	7.9	2.4	SE	1.5	0.4			
	L7	14.1	4.3	2 SE	3.1	0.9			
	L8	14.5	3.5						
	M1	8.3	9.1						
	M2	19.5	4.3						
	M3	17.9	9.4	Mean	14.2	10.9	7	1.47	0.186
Middle	M4	8.7	9.8	SD	5.1	4.6			
	M5	21.7	17.4	SE	1.8	1.6			
	M6	14.6	16.6	2 SE	3.6	3.2			
	M7	11.7	7.1						
	M8	10.9	13.7						
	U1	30.7	8.9						
	U2	29.4	14.9						
	U3	51.2	25.9	Mean	40.6	20.2	6	4.03	0.007
Upper	U4	28.4	21.1	SD	13.0	7.1			
	U5	62.1	16.9	SE	4.9	2.7			
	U6	47.1	24.1	2 SE	9.8	5.4			
	U7	35.2	29.6						
				Mean	21.5	11.0	22.0	4.62	0.000
All Sections				SD	15.1	8.5			
				SE	3.2	1.8			
				2 SE	6.3	3.5			

Table 4. Statistical results for two-sample t-tests comparing mean density (fish / 10^6 m^3) of acoustically detected fish in three sections of Lake Roosevelt, Washington during August and October of 2005.

Month	Parameter	Upper	Middle	Upper	Lower	Middle	Lower
August	Mean	40.6	14.2	40.6	12.1	14.2	12.1
	SD	13.0	5.1	13.0	4.4	5.1	4.4
	df	7.6		7.2		13.7	
	t-Stat	-5.0		-5.52		-0.87	
	p	0.001		0.001		0.398	
October	Mean	20.2	10.9	20.2	2.9	10.9	2.9
	SD	7.1	4.6	7.1	1.3	4.6	1.3
	df	10.0		6.3		8.1	
	t-Stat	-2.95		-6.36		-4.78	
	p	0.014		0.001		0.001	

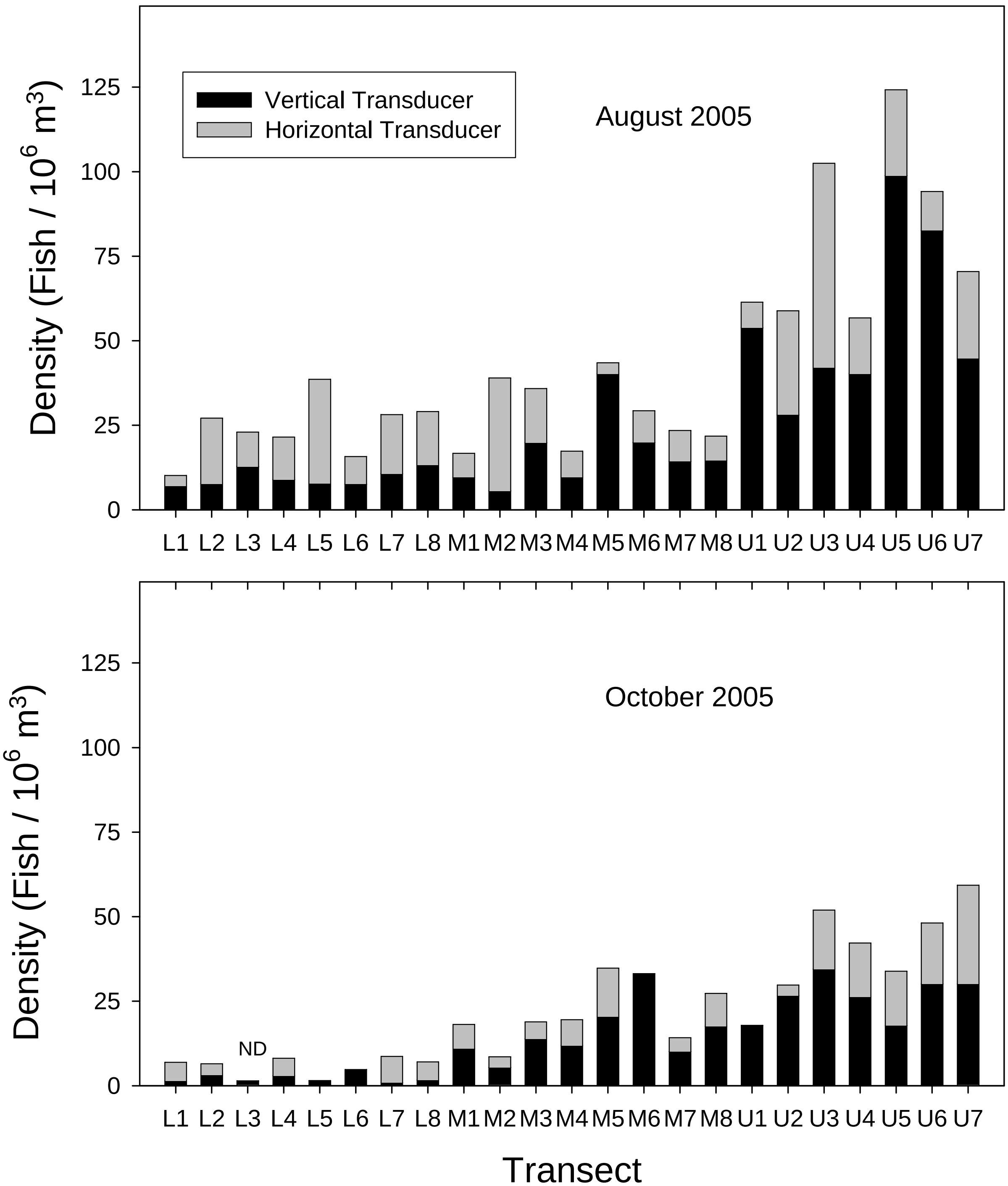

Figure 2. Fish density, estimated with hydroacoustics, for 23 transects on Lake Roosevelt, Washington, in 2005. Transects L1-L8 went from Grand Coulee Dam to Whitestone Rock (42.5 km), transects M1-M8 went from the Lincoln Boat Ramp to Hunters (42.8 km), and transects U1-U7 went from Gifford Ferry to the Kettle Falls Bridge (37.7 km). ND indicates that no data was available for the horizontal transducer due to excessive noise interference.

Table 5. Density (fish /10^6 m^3) of acoustically detected fish targets ($\underset{\sim}{}$ 30-800 mm) on each transducer (down-looking = vertically oriented, side-looking = horizontally oriented) for hydroacoustic surveys conducted on Lake Roosevelt, Washington during August and October of 2005. Summary statistics were for pair-wise comparisons within each month. NA = not applicable for October side-looking transect L3 due to excessive noise interference that prevented data collection.

	August		October	
Transect	Down-looking Density	Side-looking Density	Down-looking Density	Side-looking Density
L1	7.1	3.1	1.3	5.6
L2	7.7	19.4	3.1	3.4
L3	12.8	10.2	1.4	NA
L4	8.9	12.6	2.9	5.2
L5	7.7	30.9	1.5	0.0
L6	7.6	8.2	4.8	0.0
L7	10.7	17.5	0.9	7.7
L8	13.3	15.7	1.7	5.3
M1	9.6	7.1	10.9	7.2
M2	5.6	33.4	5.4	3.1
M3	19.8	16.0	13.8	5.1
M4	9.6	7.7	11.9	7.6
M5	40.2	3.3	20.4	14.3
M6	19.9	9.4	33.1	0.0
M7	14.4	9.1	10.1	4.1
M8	14.7	7.1	17.6	9.7
U1	53.9	7.5	17.9	0.0
U2	28.1	30.8	26.6	3.2
U3	42.1	60.4	34.5	17.4
U4	40.3	16.5	26.3	15.9
U5	98.8	25.4	17.8	16.1
U6	82.6	11.5	30.1	18.0
U7	44.8	25.7	30.1	29.2
Mean	26.1	16.9	14.1	8.1
SD	25.1	13.0	11.5	7.5
SE	5.2	2.8	2.4	1.6
2 SE	10.5	5.7	4.8	3.3
t-stat	1.69		3.22	
df	22		21	
p-value	0.105		0.004	

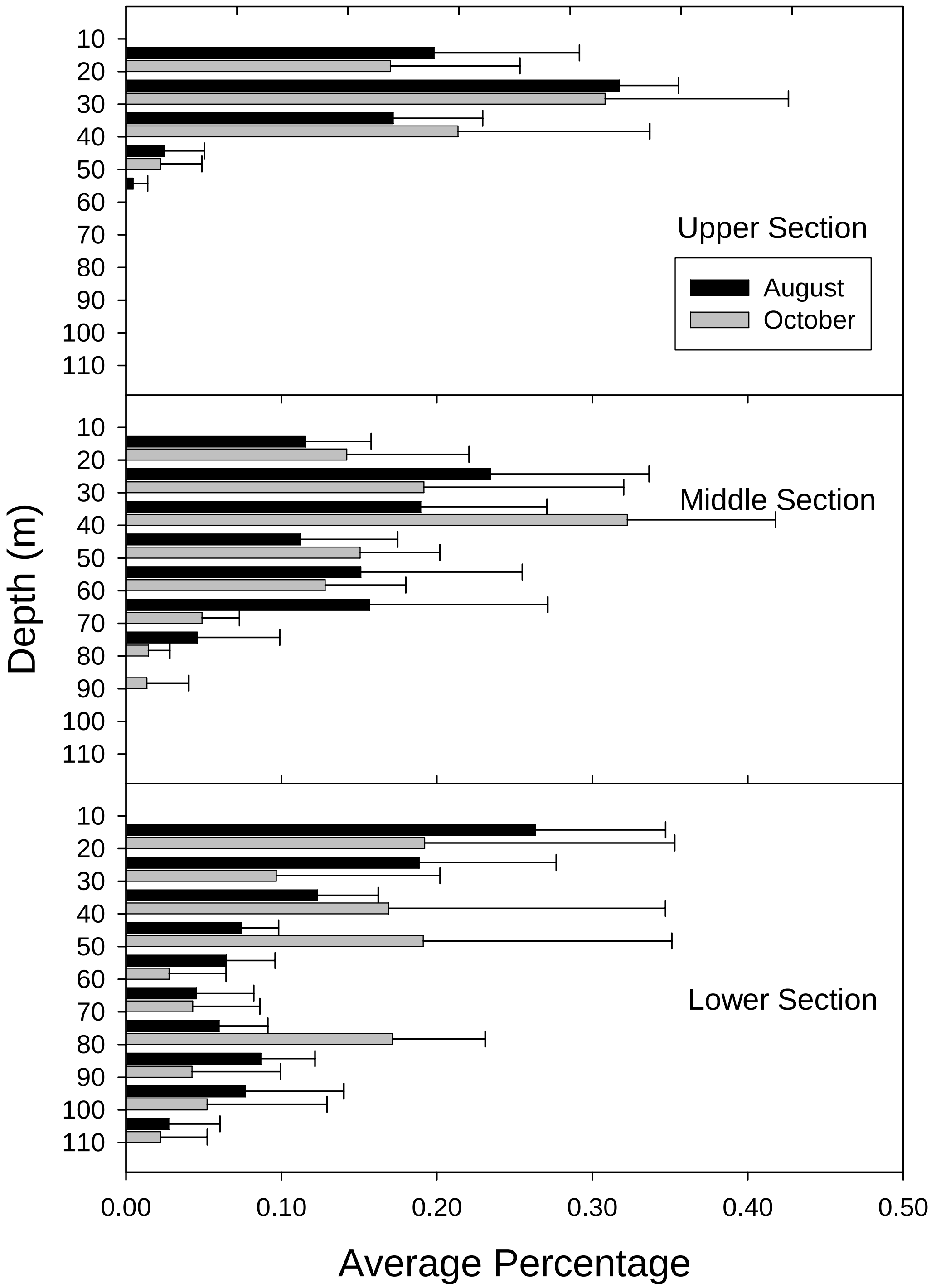

Figure 3. Average percent of fish targets in 10-meter depth bins from a vertically oriented hydroacoustic transducer on Lake Roosevelt, Washington in August of 2005. The error estimate for each mean was ± 2 standard errors.

Abundance.—During the 23 acoustic survey transects in August, 866 fish targets were detected by the vertical transducer and 200 by the horizontal transducer. After adjustments for detectability and volumetric expansion of the acoustic cone, the reservoir-wide acoustic abundance estimate for all fish targets between -55 dB and –28.8 dB (~30-800 mm) was (233,946 ± 68,580 2SE). When multiplied by the proportion of kokanee in the gill net catch, the abundance estimate for wild kokanee between 100-550 mm (based on an estimate from target strength) was 20,845 (± 29% CV and unknown variance from % wild kokanee)(Table 6).

During the 23 acoustic survey transects in October, 438 fish targets were detected by the vertical transducer and 89 by the horizontal transducer. After adjustments for detectability and volumetric expansion of the acoustic cone, the reservoir-wide acoustic abundance estimate for all fish targets between -55 dB and –28.8 dB (~30-800 mm) was 129,388 (± 40,777 2SE). When multiplied by the proportion of kokanee in the gill net catch, the abundance estimate for wild kokanee between 100-550 mm (based on an estimate from acoustic target strength) was 3,668 (± 32% CV and unknown variance from % wild kokanee)(Table 6).

Table 6. Abundance of acoustically detected fish in Lake Roosevelt, Washington during 2005. Acoustic abundance estimates were only expanded to the proportion of kokanee in the gill net catch due to the potential bias from distribution patterns of other species. These estimates would also underestimate the total abundance of kokanee because of higher densities of pre-spawn kokanee in nearshore zones.

	August		October	
	All targets 30-800 mm	Targets ~ 100-550 mm	All targets 30-800 mm	Targets ~ 100-550 mm
% of acoustic targets	100%	49.5%	100%	56.7%
% Hatchery Kokanee		1%		0%
% Wild Kokanee		18%		5%
Total Abundance	233,946	115,803	129,388	73,363
Hatchery Kokanee Abundance		1,158		0
Wild Kokanee Abundance		20,845		3,668
Coefficient of Variation (2 SE)		29%		32%
Hatchery Kokanee / ha		0.04		0.00
Wild Kokanee / ha		0.63		0.11

Abiotic Conditions and Fish Distribution

In August, dissolved oxygen did not fall below 6 mg/L at any of the mainstem sites and depths measured, so it was not analyzed any further as a limiting factor (Figures 4,5; Scofield et al., in press). In August, temperature was above thermal preferences for kokanee, burbot, and rainbow trout in the upper 60 m (Figure 4; Appendix A; Scofield et al., in press). In the lower section, 92% (11 of 12) of the kokanee were captured between 81-100 meters where temperatures were less than 16°C (Figure 4) (Scofield et al., in press). In the upper section, kokanee were captured between 31-50 m (generally in the deepest water available depending on bottom depth) whereas in the middle section all kokanee were captured between 51-70 m again, generally as deep as possible depending on bottom depths (Figure 4). We could not estimate the thermal conditions for fish deeper than 33 m in the middle section because water quality vertical profiles were not extended past 33 m. The lower section captured the most kokanee (50%) with 92% of those being unmarked kokanee. Eighty-eight percent of the kokanee in the middle section and 100% of the kokanee in the upper section were unmarked (Table 7).

In October, dissolved oxygen never dropped below 7 mg/L at the sample locations during the months when we were monitoring limnetic fish distribution. Kokanee were generally captured in water less than 30 m deep during October when temperatures were less than 16°C, however, sample size of kokanee during the October survey was small (n=4) (Table 2; Figure 5).

Rainbow trout were broadly distributed from the surface to 50 m in August (Table 2; Figure 4). In October, the majority (86%) of rainbow trout were captured in the 0-10 m depth bin with one fish captured in the 31-40 m depth bin (Figure 5).

Table 7. Number of marked and unmarked kokanee captured in limnetic gill nets in Lake Roosevelt, Washington 2005. Hatchery kokanee released into Lake Roosevelt were 100% marked, so we assumed that all unmarked fish were of wild origin.

		August				October			
	Mark	Lower	Middle	Upper	Total	Lower	Middle	Upper	Total
Number Captured	Adipose Clip	0	1	1	2	0	0	0	0
	No Mark	12	7	3	22	0	1	3	4
	Total	12	8	4	24	0	1	3	4
Origin Within Each Section	Marked	0%	13%	25%	8%	0%	0%	0%	0%
	Unmarked	100%	88%	75%	92%	0%	100%	100%	100%
Distribution Between Sections	Marked	0%	50%	50%	100%	0%	0%	0%	0%
	Unmarked	55%	32%	14%	100%	0%	25%	75%	100%

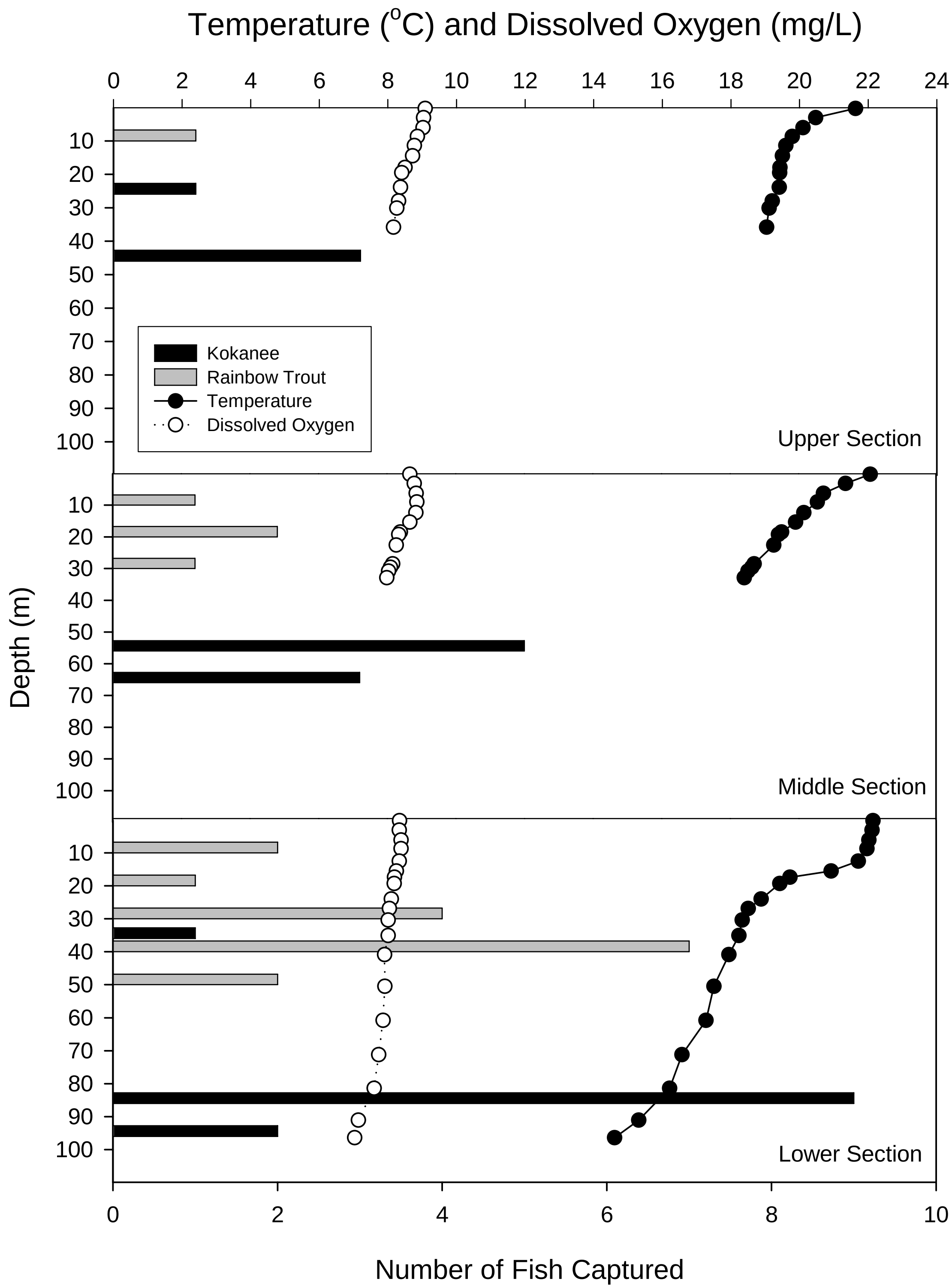

Figure 4. Number of kokanee and rainbow trout captured in 10-meter depth bins and vertical temperature and dissolved oxygen profiles for 3 sections of Lake Roosevelt, Washington in August of 2005. Temperature and dissolved oxygen profiles were from Gifford (upper section, 16 August 2005), Seven Bays (middle section, 16 August 2005), and Spring Canyon (lower section, 17 August 2005) (Scofield et al., in press).

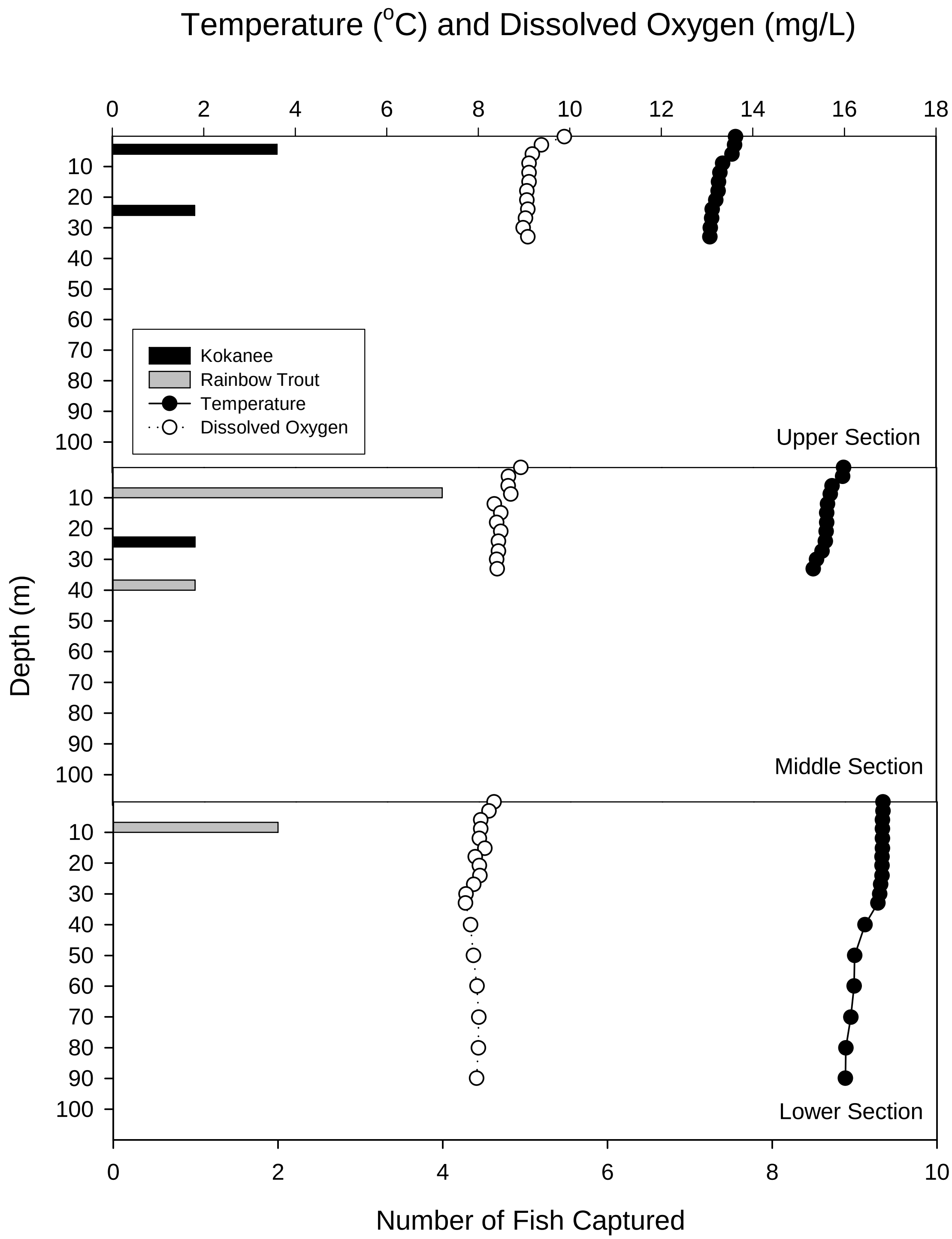

Figure 5. Number of kokanee and rainbow trout captured in 10-meter depth bins and vertical temperature and dissolved oxygen profiles for 3 sections of Lake Roosevelt, Washington in October of 2005. Temperature and dissolved oxygen profiles were from Gifford (upper section, 17 October 2005), Seven Bays (middle section, 17 October 2005), and Spring Canyon (lower section, 18 October 2005) (Scofield et al., in press).

Food Limitation

Relative Weights.— The W_r of hatchery and wild kokanee was generally below 100 (the national average) for fish less than 250 mm but scattered above and below 100 for larger kokanee (Figure 6). The W_r of marked and unmarked rainbow trout was generally near or above 100 for all size classes regardless of origin (Figure 6).

Kokanee Spawner Lengths.—We compared the length of kokanee spawners in Lake Roosevelt to previous years and to other water bodies in the Pacific Northwest, western United States (Table 8; Appendix B), and Canada (Appendix B). In 2005, age-2 spawners in Lake Roosevelt averaged 313 mm (± 25 SD), very similar to the mean from 1996-2004 (306 mm ± 6.5 SE) (Figure 8; Appendix B; McLellan et al. 2001; McLellan and Scholz 2002; EWU unpublished data; McLellan et al. 2006). In 2005, age-3 kokanee averaged 408 mm (± 32 SD), again very similar to the mean from 1996-2004 (412 ± 14.9 SE) (Figure 8; Appendix B; McLellan et al. 2001; McLellan and Scholz 2002; EWU unpublished data; McLellan et al. 2006).

The mean length of age-2 kokanee from Lake Roosevelt (1996-2005) was not significantly longer than age-2 kokanee from Buck Lake, California (Table 8). However, age-2 kokanee in Lake Roosevelt were significantly longer than age-2 kokanee from 4 lakes in Idaho (Table 8). Additionally, age-3 kokanee were significantly longer in Lake Roosevelt (1996-2005) than in either Buck Lake, California or four lakes in Idaho (Table 8). Although statistics could not be conducted (for various reasons related to the format of available information) kokanee in Lake Roosevelt were also considerably larger than in several other water bodies in Washington and British Columbia (Appendix B).

Diet.—We examined 198 fish stomachs from five species captured during limnetic gill net surveys in August (n=140) and October (n=58) 2005 (Table 9, Appendix F). *Daphnia* comprised the greatest mean proportion of the diet for kokanee (98-99%), whereas rainbow trout diets were comprised mostly of *Daphnia* (69%) in August and of both *Daphnia* and various insects (16-26%) in October. Lake whitefish diets consisted of primarily isopods in August (79%) and primarily of isopods (54%), *Daphnia* (26%), and amphipods (14%) in October (Table 9). See Appendix F for a summary of the results of other species (burbot, smallmouth bass, and walleye).

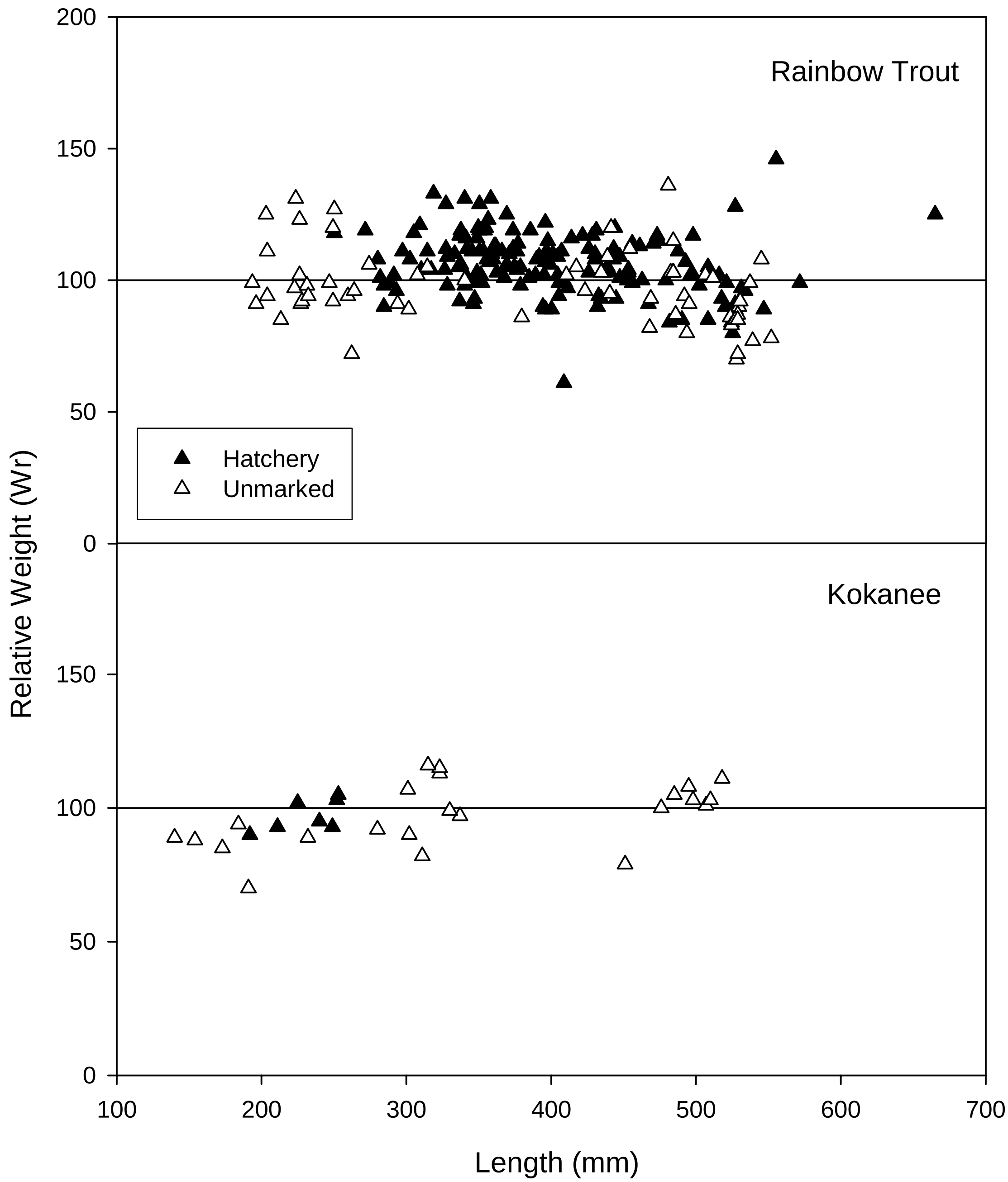

Figure 6. Relative weight of rainbow trout and kokanee in Lake Roosevelt, Washington during 2005. Standard weights for rainbow trout were taken from Murphy et al. (1991) and standard weights for kokanee were taken from Hyatt and Hubert (2000). Rainbow trout and kokanee data from this study were combined with netting and electrofishing catch data from Scofield et al. (in press) and sexually mature kokanee were excluded from the analysis. Hatchery fish were those with any external fin clips or fin deformities commonly observed on net pen origin rainbow trout.

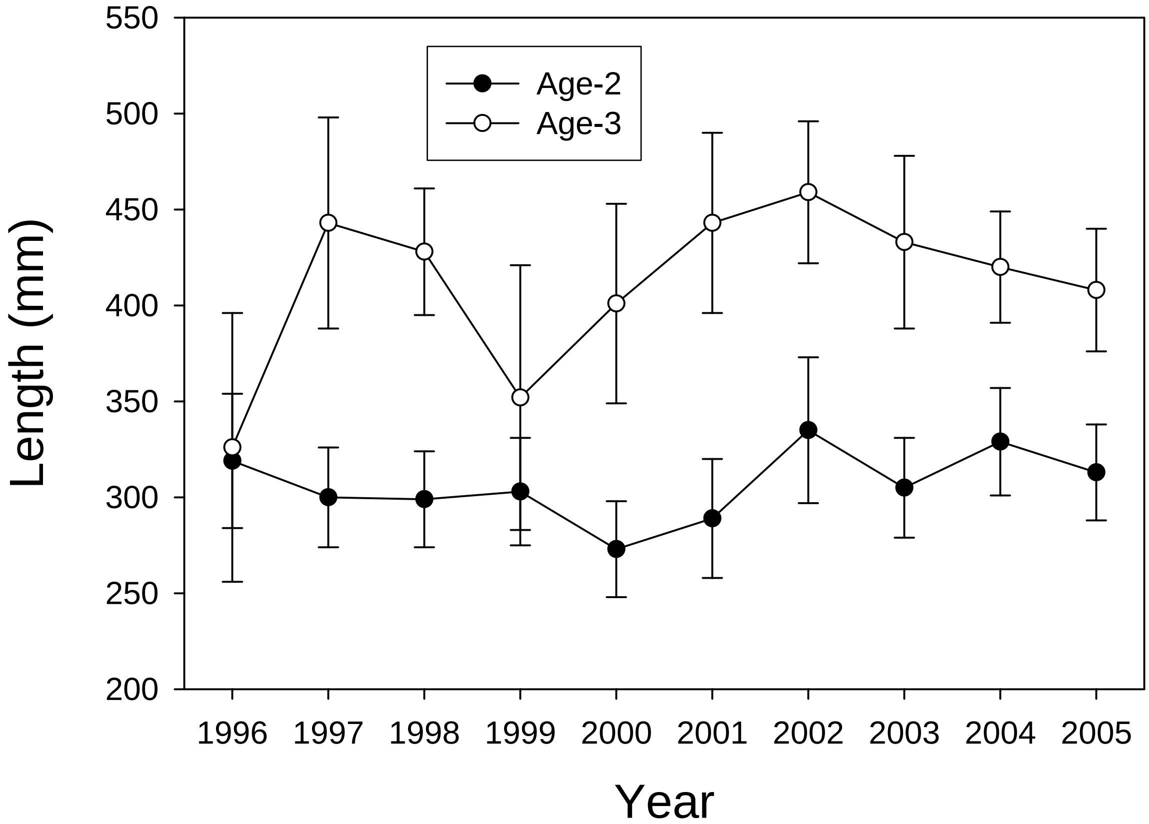

Figure 7. Mean length (± 1 standard deviation) of kokanee in Lake Roosevelt, Washington, 1996-2005. Data were taken from Tilson 1999; McLellan et al. 2001, McLellan and Scholz 2002; H. McLellan, unpublished data, McLellan et al. 2006).

Table 8. Summary of statistics for comparisons of the mean length at maturity for age-2 and age-3 kokanee in Lake Roosevelt, Washington with kokanee in Buck Lake, CA and four Idaho lakes. Tests consisted of two-sample t-tests with separate variances computed in Systat 11 (Systat Software Incorporated 2004). See Appendix B for data and references.

Age Group	Parameter	Lake Roosevelt 1996-2005	Buck Lake	Lake Roosevelt 1996-2005	Idaho Lakes
Age-2	Mean	307	303	307	223
	SD	18	28	18	30
	df	7.7		3.9	
	t-Stat	-0.276		5.20	
	p	0.789		0.007	
Age-3	Mean	411	323	411	261
	SD	42	20	42	34
	df	13.7		11.2	
	t-Stat	-5.62		8.01	
	p	0.000		0.000	

Table 9. Sample size, percent empty stomachs, and monthly average wet weight proportions of various prey taxon for kokanee, rainbow trout and lake whitefish captured in limnetic gill nets in Lake Roosevelt, Washington, 2005.

	Kokanee		Rainbow Trout		Lake Whitefish	
	August	October	August	October	August	October
Number Examined =	24	4	20	7	51	34
% Empty =	54%	25%	35%	0%	12%	3%
Sample Size =	11	3	13	7	45	33
Prey Category						
Daphnia	0.98	0.99	0.69	0.37	-	0.26
Leptodora	0.01	0.01	-	0.00	0.00	0.00
Copepods	-	-	-	-	-	-
Other Cladocerans	-	-	-	-	-	-
Mysids	-	-	-	-	-	-
Diptera	0.01	-	0.05	-	0.05	0.01
Tricoptera	-	-	-	-	0.00	0.00
Plecoptera	-	-	-	-	-	-
Ephemeroptera	-	-	-	-	-	-
Odonata	-	-	0.00	-	0.00	-
Coleoptera	-	-	0.01	0.00	0.00	0.00
Hemiptera	-	-	-	0.16	-	-
Arachnid	-	-	0.03	0.00	0.00	0.00
Bivalve	-	-	-	-	0.05	0.05
Gastropod	-	-	-	-	0.00	0.00
Amphipod	0.00	-	-	0.02	0.05	0.14
Isopod	-	-	-	-	0.79	0.54
Unknown Insect	-	-	0.00	0.26	0.00	0.00
Leech	-	-	0.08	-	0.00	0.00
Nematoda	-	-	-	-	-	-
Decapoda	-	-	-	-	-	-
Hymenoptera	-	-	-	-	-	-
Orthoptera	-	-	0.00	-	-	-
Lepidoptera	-	-	-	-	-	-
Other*	-	-	0.07	0.11	0.01	0.00
Cottid	-	-	-	-	-	-
Catastomid	-	-	-	-	-	-
Cyprinid	-	-	-	-	-	-
Centrarchid	-	-	-	-	-	-
Percid	-	-	-	0.02	-	-
Salmonid	-	-	-	-	-	-
Unknown Osteichthyes	-	-	0.08	0.04	-	-
Vegetation and Inorganics	-	-	0.00	0.02	0.04	0.00

* Terrestrial insects, Bryozoa, or unidentifiable objects

DISCUSSION

In August, it was evident that kokanee were distributed primarily in the cool, deep water of the hypolimnion, except in the upper section where temperatures were nearly isothermic and kokanee were forced to occupy warm waters. The mode in vertical distribution from the August lower section hydroacoustic survey (80-90 m) was similar to the catch depth of kokanee (80-100 m) from that section (Figures 3,4). These fish would have to vertically migrate at least 50-60 meters to find zooplankton in the photic zone. There were some kokanee in the 50-60 m depth zone in the middle section that probably (no measurements available below 33 m) had to endure temperatures (18°C) above their thermal preference (15°C), they would only have to vertically migrate 10-20 meters on a diel cycle to feed in the photic zone during the day. Very little is known about the zooplankton population below the photic zone, or whether zooplankton vertically migrate on a diel cycle in Lake Roosevelt. Understanding the interactions of water temperature, foraging conditions, and prey availability may be important components of fine-tuning a bioenergetics model for kokanee in Lake Roosevelt.

Since 1998, this project has never detected concentrations of sexually immature wild kokanee in the upper section. Given the temperature regime and food concentrations, it seems likely that wild kokanee would remain in the lower section to have access to cool water during summer stratification. Genetic studies have shown that the origin of wild kokanee in Lake Roosevelt was from British Columbia waters (Loxterman and Young 2003; LeCaire et. al. 2000). We know very little about the spatial and temporal dynamics of wild kokanee recruitment into Lake Roosevelt from British Columbia. However, we have documented a consistent population of large, wild kokanee occupying the lower reservoir since 1998, and there has been extensive reports of wild kokanee occupying the lower reservoir for decades, including over 24,000 kokanee purse seined from the forebay of Grand Coulee Dam in 1966 (USNMFS data reported in Stober et. al. 1977; Beckman et. al. 1985; Cichosz et. al. 1997).

In August of 2005, the majority of wild kokanee were caught in the lower (55%) and middle sections and they were fairly evenly distributed across the 200-400 mm and > 400 mm size classes (32%; Table 7). In August of 2004, the majority of wild kokanee were also caught in the middle (50%) and lower sections (31%; Table 7) of the reservoir; however 90% of them were between 200-400 mm (Table 1). The pattern observed in 2005 was most similar to 2000 and 2001 where 75% and 62% of the kokanee were captured in the lower section of the reservoir and 50% and 75% of them exceeded 400 mm, respectively (Baldwin et al. 2005; Baldwin et al. 2006). The 2005 pattern was least similar to 2002 and 2003 when the majority of wild kokanee were captured in the middle and upper sections and the majority of them (73-100%) were less than 400 mm (Baldwin and Woller 2006 a). At this time, no statistical tests have been conducted and small sample sizes are likely to hinder a multi-year analysis of wild kokanee distribution across sections of the reservoir. However, in previous reports we assumed that the majority of the wild kokanee were not occupying the warm upper section of the reservoir during summer periods and that it was used primarily as a migration corridor for fish immigrating from Canada (Baldwin et al. 2006; Baldwin et al. 2005; Baldwin and Polacek 2002). At this time, we cannot make conclusions across multiple years, however, there seems to be some trends that warrant further investigation by conducting a multi-year analysis of hydroacoustic and offshore gill net surveys.

The August acoustic and gill net survey was relatively consistent with results from previous years, though again we were less confident in the October survey results. This was due to the more shallow distribution of kokanee and the very low proportion of kokanee in the net catch. The October vertical distribution appears bi-modal, with fish occupying deeper depths than what was observed in previous years; however, it is just because so few fish were detected on the vertical transducer. For example, in transect L8 the 80 m depth bin shows 30% of the range-weighted fish detections but only five fish were detected on the vertical transducer so the two fish in that deep depth bin were a large proportion of the total (30% rather than 40% was due to the range-weighting algorithm that adjusts for sample volume differences of the acoustic sound cone). We recommend using the August survey for an annual index of abundance for the wild kokanee population.

We assumed equal probability of gill net capture between species; however, this assumption could have overestimated abundance, if a species was more vulnerable to the gill nets. For example, if kokanee were more active than lake whitefish, but just as likely to be retained by the net once it was encountered, then kokanee abundance was overestimated while lake whitefish abundance was underestimated. The gill nets only captured fish greater than 100 mm and larger fish have greater capture probabilities in gill nets (Hamley 1975). We applied the species composition from all fish captured in the gill nets to all acoustic targets greater than –45 dB (~100 mm). If species composition of the smaller fish (<200 mm) was different, then our acoustic estimates would be biased for the smaller size classes. This was the primary reason we did not generate species-specific estimates for acoustic targets smaller than 100 mm; however, densities and abundances for these small targets are reported in Appendix E. Previous studies have employed alternative limnetic sampling methods, such as mid-water trawling, to target smaller fish (Baldwin et. al. 2002). However, catch per unit effort was low and the results did not produce substantial differences in species composition or size distribution of the catch.

We could not determine the volume of water in the limnetic zone independently from the littoral zone. Mean density was extrapolated to reservoir-wide volume; therefore, we assumed that fish density in the littoral zone was equal to the limnetic zone for the species composition observed in limnetic gill nets. We recognize that species composition was much different in the littoral zone and included many more species than we observed in the limnetic zone, particularly in embayments and near creek mouths (McLellan et. al. 2003). We recognized this in the results section and emphasized that the abundance estimates for species other than kokanee do not represent a complete reservoir wide abundance. Additionally, if nearshore densities of kokanee were higher than offshore densities then we underestimated reservoir wide abundance for kokanee; however, the relatively small volume of water in the littoral zone minimized the potential bias from this assumption. The effect of this potential bias was further minimized by using the August estimate, due to the high epilimnetic temperatures that were well above thermal optimum for kokanee. For wild kokanee abundance, we reported the variance around the estimate as the coefficient of variation from the acoustic estimate and did not incorporate error around the proportion of kokanee in the net catch. Therefore, the error bounds around the wild kokanee abundance estimate should be considered a minimum amount of variation.

There were no indications of food limitation for kokanee or rainbow trout, based on the relative weights and the mean spawner length of kokanee (Figures 6-8). The observation from 2001 and

2004 that large rainbow trout had lower relative weights was not apparent in 2005 (Baldwin et al. 2006; Baldwin and Woller 2006c). Additionally, the high mean length of *Daphnia* and presence of large bodied zooplankters reported by Scofield et al. (in press) also indicated that the Lake Roosevelt zooplankton community was not limited by top down influences (i.e. fish consumption) (Brooks and Dodson 1965; Mills and Forney 1983; Crowder et al. 1987). Sexually mature age-2 and age-3 kokanee were of similar size (TL) as the 8-year average from Lake Roosevelt and were significantly larger than in several other systems in the western United States and Canada (Table 8, Appendix B).

This report has summarized the eighth year of limnetic fish sampling on Lake Roosevelt by WDFW. These studies were a supplement to the extensive littoral zone monitoring that has been conducted by the STI, CCT, and EWU and should be considered in context with those studies (McLellan et al. 2006; Scofield et al., in press; CCT unpublished report).

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APPENDIX A. Optimal Growth Temperatures.

Table A1. Optimal growth temperatures for select fish species found in Lake Roosevelt, Washington.

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 1982
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

APPENDIX B. Kokanee length at maturity.

Table B1. Length at maturity for kokanee from Lake Roosevelt, Washington (1996-2005).

Water Body	Year (s)	Age	L_T (mm)	SD	SE	N	Source
Lake Roosevelt	1996	2	319	35		1,201	1
Lake Roosevelt	1997	2	300	26		528	1
Lake Roosevelt	1998	2	299	25		2,423	2
Lake Roosevelt	1999	2	303	28		929	2
Lake Roosevelt	2000	2	273	25		1,672	2
Lake Roosevelt	2001	2	289	31		858	3
Lake Roosevelt	2002	2	335	38		566	4
Lake Roosevelt	2003	2	305	26		2,218	5
Lake Roosevelt	2004	2	329	28		742	5
Lake Roosevelt	2005	2	313	25		777	6
Average/Overall SE			307	18	5.8	10	
Lake Roosevelt	1996	3	326	70		10	1
Lake Roosevelt	1997	3	443	55		3	1
Lake Roosevelt	1998	3	428	33		206	2
Lake Roosevelt	1999	3	352	69		80	2
Lake Roosevelt	2000	3	401	52		6	2
Lake Roosevelt	2001	3	443	47		15	3
Lake Roosevelt	2002	3	459	37		88	4
Lake Roosevelt	2003	3	433	45		55	5
Lake Roosevelt	2004	3	420	29		47	5
Lake Roosevelt	2005	3	408	32		16	6
Average/Overall SE			411	42	13.3	10	

[1] Tilson 1999

[2] McLellan et al. 2001

[3] McLellan and Scholz 2002

[4] McLellan and Scholz 2003

[5] H. McLellan, unpublished data

[6] McLellan et al. 2006

Table B2 (continued). Length at maturity for kokanee in other water bodies in the Pacific Northwest, western United States, and Canada for comparison to kokanee in Lake Roosevelt, Washington.

Water Body	Year (s)	Age	L_T (mm)	SD	SE	N	Source
Lake Coeur D'Alene, ID	1978-86	2	191	-	-	-	1
Dworshak Reservoir, ID	1988	2	261	-	-	-	1
Dworshak Reservoir, ID	2001	2	256-342	-	-	8	2
Lake Pend Orielle, ID	1977-88	2	210	-	-	-	1
Spirit Lake, ID	1981-88	2	230	-	-	-	1
			223		15	4	
Bucks Lake, CA	1999	2 (Female)	320		2.4	50	3
Bucks Lake, CA	1999	2 (Male)	348		2.3	63	3
Bucks Lake, CA	2000	2 (Female)	289		1.7	135	3
Bucks Lake, CA	2000	2 (Male)	303		1.5	148	3
Bucks Lake, CA	2001	2 (Female)	271		3	33	3
Bucks Lake, CA	2001	2 (Male)	287		2.1	67	3
Average/Overall SE			303		11	6	
Lake Coeur D'Alene, ID	1978-85*	3	233	-	-	-	1
Dworshak Reservoir, ID	1988	3	310	-	-	-	1
Lake Pend Orielle, ID	1977-88	3	244	-	-	-	1
Spirit Lake, ID	1981-88	3	259	-	-	-	1
Average/Overall SE			262		17	4	
Bucks Lake, CA	1999	3 (Female)	333		3.8	26	3
Bucks Lake, CA	1999	3 (Male)	357		3	30	3
Bucks Lake, CA	2000	3 (Female)	310		2.2	109	3
Bucks Lake, CA	2000	3 (Male)	322		2.6	53	3
Bucks Lake, CA	2001	3 (Female)	298		2.5	114	3
Bucks Lake, CA	2001	3 (Male)	317		2	105	3
Average/Overall SE			323		8	6	
Kootenay Lake, B.C.	1984-87	2	174 L_F		1.9	175	4
Okanagan Lake, B.C.	1985-87	2	209 L_F		1.5	168	4
Kootenay Lake, B.C.	1985-87	3	184 L_F		1.3	18	4
Okanagan Lake, B.C.	1985-87	3	234 L_F		3.6	139	4
Lake Sammamish, WA (Early-Run)	1981-82; 1993	4	332 L_F		-	51	5
Lake Sammamish, WA (Middle-Run)	2000	4	287 L_F		-	65	5
Lake Sammamish, WA (Late-Run)	2000	4	453 L_F		-	255	5
Upper Arrow Lake, B.C. (Mackenzie Ck.)	1978	Female	199		2.1	25	6
Upper Arrow Lake, B.C. (Mackenzie Ck.)	1978	Male	196		1.7	25	6
Upper Arrow Lake, B.C. (Hill Ck.)	1978	Female	200		1.5	25	6
Upper Arrow Lake, B.C. (Hill Ck.)	1978	Male	198		1.8	25	6

[1] Rieman and Myers 1992
[2] Maiolie et al. 2003
[3] Grover 2005
[4] Parkinson 1988
[5] Berge and Higgins 2003
[6] Murry et al. 1989

* Excluding 1984

Dashes indicate data were unavailable.

L_F (fork lengths) were not included in the average or standard error calculations.

APPENDIX C. Gill net effort and CPUE.

Table C1. Horizontal and vertical gill net effort (nets/night) in each section of Lake Roosevelt, Washington during August and October 2005. Horizontal gill nets with variable mesh included the same array of mesh sizes as the vertical gill nets and suspended nets were set at various depths from 10 m to 110 m.

		Horizontal Gill Nets				Total	Vertical Gill Nets							Total
		Variable Mesh			38 mm	Horizontal	Mesh Size (mm)							Vertical
Month	Section	Floating	Suspended	Sinking	Suspended	Effort	25	38	51	64	76	89	102	Effort
August	Lower	4	8	4	4	20	4	4	4	4	4	4	4	28
	Middle	3	6	3	3	15	2	3	3	3	3	3	3	20
	Upper	3	6	3	3	15	1	3	3	3	3	3	3	19
	Subtotal	10	20	10	10	50	7	10	10	10	10	10	10	67
October	Lower	4	8	4	4	20	4	4	4	4	4	4	4	28
	Middle	4	8	4	4	20	4	4	4	4	4	4	4	28
	Upper	3	6	3	3	15	3	3	3	3	3	3	3	21
	Subtotal	11	22	11	11	55	11	11	11	11	11	11	11	77

Table C2. Horizontal and vertical gill net catch per unit effort (CPUE) in each section of Lake Roosevelt, Washington, during August and October 2005. Horizontal gill nets included the same array of mesh sizes as the vertical gill nets and suspended nets were set at various depths from 10 m to 110 m.

Month	Section	Horizontal Effort	Horizontal Catch	Horizontal CPUE	Vertical Effort	Vertical Catch	Vertical CPUE	Combined CPUE
August	Lower	20	14	0.7	28	17	0.6	0.6
	Middle	15	32	2.1	20	9	0.5	1.2
	Upper	15	56	3.7	19	8	0.4	1.9
	Total	50	102	2.0	67	34	0.5	1.2
October	Lower	20	5	0.3	28	1	0.0	0.1
	Middle	20	35	1.8	28	6	0.2	0.9
	Upper	15	23	1.5	21	10	0.5	0.9
	Total	55	63	1.1	77	17	0.2	0.6

Table C3. Total number of species (n = 136) collected in each section by gear type in August 2005.

Section	Species	Horizontal Gill Nets Variable Mesh Floating	Suspended	Sinking	38 mm Suspended	Total Horizontal Catch	Vertical Gill Nets Mesh Size (mm) 25	38	51	64	76	89	102	Total Vertical Catch
Lower	Kokanee	0	11	0	0	11	0	0	1	0	0	0	0	1
	Lake Whitefish	0	0	0	0	0	0	0	0	0	1	0	0	1
	Rainbow Trout	1	0	0	0	1	0	1	0	5	7	2	0	15
	Walleye	0	0	2	0	2	0	0	0	0	0	0	0	0
	Subtotal	1	11	2	0	14	0	1	1	5	8	2	0	17
Middle	Kokanee	0	5	0	3	8	0	0	0	0	0	0	0	0
	Lake Whitefish	0	1	18	0	19	0	0	0	3	0	0	0	3
	Rainbow Trout	1	0	0	0	1	0	0	0	3	0	0	0	3
	Walleye	0	1	3	0	4	0	0	0	3	0	0	0	3
	Subtotal	1	7	21	3	32	0	0	0	9	0	0	0	9
Upper	Burbot	0	0	0	0	0	0	0	0	0	1	0	0	1
	Kokanee	0	3	0	0	3	0	0	0	0	1	0	0	1
	Longnose Sucker	0	1	1	0	2	0	0	0	0	0	0	0	0
	Lake Whitefish	0	16	10	1	27	0	0	0	0	0	1	1	2
	Rainbow Trout	1	0	0	0	1	0	0	0	0	0	0	0	0
	Smallmouth Bass	0	0	1	0	1	0	0	0	0	0	0	0	0
	Walleye	0	14	7	0	21	0	0	3	0	0	0	1	4
	White Sturgeon	0	0	1	0	1	0	0	0	0	0	0	0	0
	Subtotal	1	34	20	1	56	0	0	3	0	2	1	2	8

Table C4. Total number of species (n = 80) collected in each section by gear type in October 2005.

Section	Species	Horizontal Gill Nets Variable Mesh Floating	Suspended	Sinking	38 mm Suspended	Total Horizontal Catch	Vertical Gill Nets Mesh Size (mm) 25	38	51	64	76	89	102	Total Vertical Catch
Lower	Rainbow Trout	2	0	0	0	2	0	0	0	0	0	0	0	0
	Walleye	0	1	2	0	3	0	0	1	0	0	0	0	1
	Subtotal	2	1	2	0	5	0	0	1	0	0	0	0	1
Middle	Burbot	0	0	1	0	1	0	0	0	0	0	0	0	0
	Kokanee	0	0	0	0	0	0	1	0	0	0	0	0	1
	Lake Whitefish	0	2	15	0	17	0	0	0	0	1	0	1	2
	Rainbow Trout	4	0	0	0	4	0	0	0	1	0	0	0	1
	Smallmouth Bass	0	0	2	0	2	0	0	0	0	0	0	0	0
	Walleye	0	0	10	1	11	0	0	1	0	0	0	1	2
	Subtotal	4	2	28	1	35	0	1	1	1	1	0	2	6
Upper	Burbot	0	1	0	0	1	0	0	0	0	0	0	0	0
	Kokanee	0	0	0	0	0	0	0	1	1	1	0	0	3
	Longnose Sucker	0	1	0	0	1	0	0	0	0	0	0	0	0
	Largescale Sucker	0	0	0	0	0	0	0	0	0	1	0	0	1
	Lake Whitefish	0	3	1	5	9	0	1	1	0	0	0	4	6
	Walleye	0	8	1	1	10	0	0	0	0	0	0	0	0
	White Sturgeon	0	2	0	0	2	0	0	0	0	0	0	0	0
	Subtotal	0	15	2	6	23	0	1	2	1	2	0	4	10

APPENDIX D. Total number of fish caught per section and depth.

Table D1. Total number of fish caught per 10-meter incremental depths per section on Lake Roosevelt, Washington in August 2005.

		Fish Depth										
Section	Species	10	20	30	40	50	60	70	80	90	100	Total
Lower	Kokanee	0	0	0	**1**	0	0	0	0	**9**	**2**	12
	Lake Whitefish	0	0	0	**1**	0	0	0	0	0	0	1
	Rainbow Trout	**2**	**1**	**4**	**7**	**2**	0	0	0	0	0	16
	Walleye	0	0	0	0	0	**2**	0	0	0	0	2
	Total	2	1	4	9	2	2	0	0	9	2	31
Middle	Kokanee	0	0	0	0	0	**5**	**3**	0	0	0	8
	Lake Whitefish	0	0	0	**20**	**1**	**1**	0	0	0	0	22
	Rainbow Trout	**1**	**2**	**1**	0	0	0	0	0	0	0	4
	Walleye	0	**3**	0	**3**	0	**1**	0	0	0	0	7
	Total	1	5	1	23	1	7	3	0	0	0	41
Upper	Burbot	0	0	0	0	**1**	0	0	0	0	0	1
	Kokanee	0	0	**1**	0	**3**	0	0	0	0	0	4
	Longnose Sucker	0	0	0	**2**	0	0	0	0	0	0	2
	Lake Whitefish	0	0	**2**	**18**	**9**	0	0	0	0	0	29
	Rainbow Trout	**1**	0	0	0	0	0	0	0	0	0	1
	Smallmouth Bass	0	0	0	**1**	0	0	0	0	0	0	1
	Walleye	**1**	0	0	**23**	**1**	0	0	0	0	0	25
	White Sturgeon	0	0	0	**1**	0	0	0	0	0	0	1
	Total	2	0	3	45	14	0	0	0	0	0	64
	August Total	5	6	8	77	17	9	3	0	9	2	136

Table D2. Total number of fish caught per 10-meter incremental depths per section on Lake Roosevelt, Washington in October 2005.

		Fish Depth										
Section	Species	10	20	30	40	50	60	70	80	90	100	Total
Lower	Rainbow Trout	**2**	0	0	0	0	0	0	0	0	0	2
	Walleye	0	0	0	**1**	0	0	**2**	**1**	0	0	4
	Total	2	0	0	1	0	0	2	1	0	0	6
Middle	Burbot	0	0	0	0	0	0	0	**1**	0	0	1
	Kokanee	0	0	**1**	0	0	0	0	0	0	0	1
	Lake Whitefish	0	0	**1**	**17**	0	0	0	**1**	0	0	19
	Rainbow Trout	**4**	0	0	**1**	0	0	0	0	0	0	5
	Smallmouth Bass	0	0	0	**2**	0	0	0	0	0	0	2
	Walleye	**1**	**1**	0	**11**	0	0	0	0	0	0	13
	Total	5	1	2	31	0	0	0	2	0	0	41
Upper	Burbot	0	0	0	**1**	0	0	0	0	0	0	1
	Kokanee	**2**	0	**1**	0	0	0	0	0	0	0	3
	Longnose Sucker	0	0	0	0	**1**	0	0	0	0	0	1
	Largescale Sucker	0	0	0	0	**1**	0	0	0	0	0	1
	Lake Whitefish	**4**	**2**	**6**	**1**	**2**	0	0	0	0	0	15
	Walleye	0	0	**1**	**5**	**4**	0	0	0	0	0	10
	White Sturgeon	0	0	0	**2**	0	0	0	0	0	0	2
	Total	6	2	8	9	8	0	0	0	0	0	33
	October Total	13	3	10	41	8	0	2	3	0	0	80

APPENDIX E. Hydroacoustic survey data summaries results.

Table E1. Hydroacoustic survey results and calculations for the vertical transducer on Lake Roosevelt in August 2005. The adjusted count excluded fish in the near-field zone (un-sampled volume from 0-10 m), then expanded the fish count in the remaining sample volume for detectability of fish based on boat speed, ping rate, cone dimensions, and minimum number of pings to be considered a potential fish target. Sample volume was calculated using the algorithms described in the methods section of this report where h=average depth, b= diameter at the average midpoint of the cone, and l was the length of the transect.

Transect	Total Fish Count	Adjusted Fish Count	(h)	b	l	Total Volume (m3)	0-10 m Unsampled Volume (m3)	Adjusted Volume (m3)	(fish / 10^6 m^3) Down-looking Density
L1	19	19.8	75.0	19.7	3862	2856422	50844	2805578	7.1
L2	39	40.4	83.5	22.0	5794	5315792	76279	5239513	7.7
L3	55	56.3	78.8	20.7	5472	4471911	72040	4399870	12.8
L4	54	56.2	80.2	21.1	7564	6402259	99582	6302677	8.9
L5	28	29.9	75.1	19.8	5311	3945421	69921	3875500	7.7
L6	31	33.4	76.9	20.3	5716	4452349	75252	4377097	7.6
L7	37	38.2	70.2	18.5	5633	3653160	74160	3579001	10.7
L8	35	36.7	58.6	15.4	6273	2837569	82580	2754988	13.3
M1	11	11.6	46.2	12.2	4506	1264854	59323	1205531	9.6
M2	15	15.7	58.4	15.4	6437	2888178	84745	2803434	5.6
M3	62	63.5	63.9	16.8	6116	3284718	80519	3204200	19.8
M4	25	24.8	54.4	14.3	6870	2672353	90441	2581912	9.6
M5	45	47.6	46.6	12.3	4345	1242913	57203	1185710	40.2
M6	28	28.1	46.0	12.1	5311	1479073	69921	1409152	19.9
M7	24	24.8	53.9	14.2	4667	1782221	61442	1720778	14.4
M8	32	33.2	50.7	13.3	6964	2353141	91683	2261459	14.7
U1	77	81.7	40.3	10.6	7564	1617419	99582	1517837	53.9
U2	21	22.0	37.7	9.9	4506	844074	59323	784752	28.1
U3	54	58.4	38.6	10.2	7564	1486673	99582	1387091	42.1
U4	18	21.0	30.8	8.1	4667	583285	61442	521843	40.3
U5	65	72.2	32.5	8.6	5794	806737	76279	730458	98.8
U6	63	67.1	38.3	10.1	4506	871496	59323	812174	82.6
U7	32	35.0	36.5	9.6	4828	844763	63562	781201	44.8

Table E2. Hydroacoustic survey results and calculations for the horizontal transducer on Lake Roosevelt in August 2005. The adjusted count excluded fish in the near-field zone (un-sampled volume from 0-16 m), then expanded the fish count in the remaining sample volume for detectability of fish based on boat speed, ping rate, cone dimensions, and minimum number of pings to be considered a potential fish target. Sample volume was calculated using the algorithms described in the methods section of this report where h=average depth, b= diameter at the average midpoint of the cone, and l was the length of the transect.

Transect	Total Fish Count	Adjusted Fish Count	(h)	b	l	Total Volume (m^3)	0-16 m Unsampled Volume (m^3)	Adjusted Volume (m^3)	(fish / 10^6 m^3) Side-looking Density
L1	1	1.1	48	5.0	3294	398851	44194	354657	3.1
L2	12	11.0	48	5.0	5245	635063	70375	564689	19.4
L3	6	5.5	48	5.0	4959	600540	66535	534005	10.2
L4	7	8.8	46	4.8	7073	790654	94892	695762	12.6
L5	15	15.3	46	4.8	5062	561702	67915	493787	30.9
L6	4	4.4	46	4.8	5556	616357	74545	541813	8.2
L7	8	8.6	46	4.8	5017	556560	67312	489248	17.5
L8	6	6.9	44	4.6	5104	506403	68475	437928	15.7
M1	3	3.3	48	5.1	4243	519902	56926	462977	7.1
M2	20	22.1	48	5.1	6070	743893	81435	662458	33.4
M3	8	9.5	48	5.1	5421	664537	72737	591800	16.0
M4	6	5.6	48	5.1	6702	821136	89914	731222	7.7
M5	1	1.1	48	5.1	2919	357604	39158	318446	3.3
M6	5	5.3	48	5.1	5143	630239	68999	561241	9.4
M7	3	3.3	48	5.1	3353	410916	44981	365935	9.1
M8	3	3.4	48	5.1	4396	538841	58981	479860	7.1
U1	6	5.5	49	5.1	6503	822480	87250	735230	7.5
U2	14	15.7	49	5.1	4506	569738	60454	509283	30.8
U3	47	51.7	49	5.1	7564	956669	101482	855188	60.4
U4	7	7.7	47	5.0	4438	524477	59542	464934	16.5
U5	10	11.3	48	5.0	4189	499914	56205	443709	25.4
U6	5	5.5	48	5.0	4506	537451	60454	476997	11.5
U7	13	13.0	48	5.0	4774	569481	64046	505434	25.7

Table E3. Hydroacoustic survey results summary and expansion to abundance and abundance per size class for Lake Roosevelt, Washington, August 2005.

		Down-looking Density	Side-looking Density	Average Density
		(fish / 10^6 m^3)		
		7.1	3.1	5.1
		7.7	19.4	13.6
		12.8	10.2	11.5
		8.9	12.6	10.8
		7.7	30.9	19.3
		7.6	8.2	7.9
		10.7	17.5	14.1
		13.3	15.7	14.5
		9.6	7.1	8.3
		5.6	33.4	19.5
		19.8	16.0	17.9
		9.6	7.7	8.7
		40.2	3.3	21.7
		19.9	9.4	14.6
		14.4	9.1	11.7
		14.7	7.1	10.9
		53.9	7.5	30.7
		28.1	30.8	29.4
		42.1	60.4	51.2
		40.3	16.5	28.4
		98.8	25.4	62.1
		82.6	11.5	47.1
		44.8	25.7	35.2
	Mean Density =	26.1	16.9	21.5
	SD Density =	25.1	13.0	15.1
	2 SE of density =	10.5	5.4	6.3
	CV =	0.40	0.32	0.29
mean monthly elevation =	1282		Abundance =	233,946
mean monthly volume =	1.0885E+10		SD Abundance =	164,450
			2 SE Abundance =	68,580

	Size Class (mm)			
	30-100	100-200	200-400	400-800
% Frequency =	0.50	0.29	0.18	0.03
Abundance =	116,167	67,495	42,756	7,529
2 SE =	34,054	19,786	12,534	2,207

Table E4. Hydroacoustic survey results and calculations for the vertical transducer on Lake Roosevelt in October 2005. The adjusted count excluded fish in the near-field zone (un-sampled volume from 0-10 m), then expanded the fish count in the remaining sample volume for detectability of fish based on boat speed, ping rate, cone dimensions, and minimum number of pings to be considered a potential fish target. Sample volume was calculated using the algorithms described in the methods section of this report where h=average depth, b= diameter at the average midpoint of the cone, and l was the length of the transect.

Transect	Total Fish Count	Adjusted Fish Count	(h)	b	l	Total Volume (m3)	0-10 m Unsampled Volume (m3)	Adjusted Volume (m3)	Down-looking Density (fish / 10^6 m^3)
L1	4	4.3	80.0	21.1	3862	3257212	50844	3206368	1.3
L2	20	20.7	94.0	24.7	5794	6735184	76279	6658904	3.1
L3	6	6.1	78.5	20.7	5402	4383229	71113	4312116	1.4
L4	18	18.4	82.7	21.8	7147	6436516	94090	6342425	2.9
L5	6	6.4	78.9	20.8	5311	4355078	69921	4285158	1.5
L6	21	22.2	79.9	21.0	5613	4720346	73890	4646456	4.8
L7	3	3.0	72.8	19.2	4686	3267452	61697	3205755	0.9
L8	5	5.1	64.0	16.9	5692	3072221	74943	2997278	1.7
M1	11	11.5	48.3	12.7	3560	1093665	46871	1046794	10.9
M2	16	16.7	61.2	16.1	6437	3173403	84745	3088658	5.4
M3	48	49.9	69.4	18.3	5832	3694217	76774	3617444	13.8
M4	26	27.4	53.4	14.1	6377	2390751	83954	2306798	11.9
M5	23	24.2	47.0	12.4	4266	1241237	56158	1185079	20.4
M6	36	37.4	41.4	10.9	5311	1199644	69921	1129724	33.1
M7	18	18.5	55.5	14.6	4667	1890227	61442	1828785	10.1
M8	42	44.2	52.9	13.9	7081	2610515	93223	2517292	17.6
U1	22	22.3	36.8	9.7	7564	1349876	99582	1250294	17.9
U2	24	24.7	40.8	10.7	4506	987154	59323	927832	26.6
U3	25	27.9	31.0	8.2	7156	904391	94212	810179	34.5
U4	13	13.9	31.6	8.3	4452	586267	58612	527655	26.3
U5	8	9.0	28.0	7.4	5610	580122	73863	506259	17.8
U6	24	25.9	39.4	10.4	4506	921949	59323	862626	30.1
U7	22	24.4	37.5	9.9	4717	874363	62098	812265	30.1

Table E5. Hydroacoustic survey results and calculations for the horizontal transducer on Lake Roosevelt in October 2005. The adjusted count excluded fish in the near-field zone (un-sampled volume from 0-16 m), then expanded the fish count in the remaining sample volume for detectability of fish based on boat speed, ping rate, cone dimensions, and minimum number of pings to be considered a potential fish target. Sample volume was calculated using the algorithms described in the methods section of this report where h=average depth, b= diameter at the average midpoint of the cone, and l was the length of the transect.

							0-16 m		(fish / 10^6 m^3)
Transect	Total Fish Count	Adjusted Fish Count	(h)	b	l	Total Volume (m^3)	Unsampled Volume (m^3)	Adjusted Volume (m^3)	Side-looking Density
L1	2	2.3	49.1	5.1	3623	457158	48604	408554	5.6
L2	2	2.1	49.1	5.1	5632	710600	75559	635041	3.4
L3	1	0.0	49.1	5.1	0	0	0	0	#DIV/0!
L4	3	3.2	49.1	5.1	5514	695875	73976	621899	5.2
L5	1	0.0	49.1	5.1	3285	414881	44072	370809	0.0
L6	1	0.0	49.1	5.1	5794	731798	77735	654063	0.0
L7	4	4.6	49.1	5.1	5322	672451	71399	601052	7.7
L8	2	2.4	49.1	5.1	3935	497054	52791	444263	5.3
M1	3	3.6	49.5	5.2	4407	565797	59123	506674	7.2
M2	2	2.2	49.5	5.2	6019	772869	80750	692119	3.1
M3	3	3.3	49.5	5.2	5691	730836	76358	654478	5.1
M4	5	5.5	49.5	5.2	6283	806613	84289	722324	7.6
M5	3	3.2	49.5	5.2	1942	249419	26051	223368	14.3
M6	1	0.0	49.5	5.2	4269	548155	57280	490875	0.0
M7	1	1.1	49.5	5.2	2323	298288	31167	267122	4.1
M8	6	6.9	49.1	5.1	6226	786711	83528	703183	9.7
U1	1	0.0	48.4	5.1	7564	928198	101482	826716	0.0
U2	1	1.2	48.4	5.1	3418	419186	45858	373328	3.2
U3	14	14.3	48.8	5.1	7378	921754	98983	822771	17.4
U4	7	7.4	49.5	5.2	4064	521383	54522	466861	15.9
U5	9	10.1	48.2	5.1	5794	706350	77735	628616	16.1
U6	8	9.0	49.3	5.2	4392	559340	58931	500409	18.0
U7	15	16.3	49.7	5.2	4828	624537	64774	559762	29.2

Table E6. Hydroacoustic survey results summary and expansion to abundance and abundance per size class for Lake Roosevelt, Washington, October 2005.

		(fish / 10^6 m^3)		
		Down-looking Density	Side-looking Density	Average Density
		1.3	5.6	3.5
		3.1	3.4	3.2
		1.4	NA	1.4
		2.9	5.2	4.0
		1.5	0.0	0.7
		4.8	0.0	2.4
		0.9	7.7	4.3
		1.7	5.3	3.5
		10.9	7.2	9.1
		5.4	3.1	4.3
		13.8	5.1	9.4
		11.9	7.6	9.8
		20.4	14.3	17.4
		33.1	0.0	16.6
		10.1	4.1	7.1
		17.6	9.7	13.7
		17.9	0.0	8.9
		26.6	3.2	14.9
		34.5	17.4	25.9
		26.3	15.9	21.1
		17.8	16.1	16.9
		30.1	18.0	24.1
		30.1	29.2	29.6
	Mean Density =	14.1	8.1	11.4
	SD Density =	11.5	7.5	8.4
	2 SE of density =	4.8	3.2	3.6
	CV =	0.34	0.39	0.32
mean monthly elevation =	1287		Abundance =	129,388
mean monthly volume =	1.1365E+10		SD Abundance =	95,632
			2 SE Abundance =	40,777

	Size Class (mm)			
	30-100	100-200	200-400	400-800
% Frequency =	41%	23%	23%	13%
Abundance =	52518	29,927	30,220	16,724
2 SE =	16551	9,432	9,524	5,271

Table E7. Proportion of fish targets in each depth bin for each hydroacoustic survey transect on Lake Roosevelt, Washington during August 2005. To account for volumetric expansion of the acoustic cone, individual fish targets were converted to weighted fish, following the methods described by Yule (2000).

		Depth Bin (m)										
	Transect	10-20	30	40	50	60	70	80	90	100	110	Sum
	L1	32%	10%	17%	10%	9%	0%	0%	8%	14%	0%	100%
	L2	36%	9%	7%	0%	7%	2%	3%	15%	16%	4%	100%
	L3	18%	4%	13%	10%	6%	2%	1%	13%	23%	9%	100%
	L4	15%	34%	14%	7%	4%	1%	5%	14%	5%	0%	100%
	L5	38%	23%	8%	6%	2%	6%	7%	6%	3%	1%	100%
	L6	42%	25%	5%	9%	0%	8%	10%	1%	0%		100%
	L7	15%	9%	22%	9%	9%	16%	14%	6%	0%		100%
	L8	14%	37%	13%	8%	14%	2%	7%	5%	0%		100%
	M1	22%	30%	10%	8%	6%	16%	9%	0%			100%
	M2	16%	33%	8%	12%	0%	13%	18%	0%			100%
	M3	6%	21%	7%	5%	9%	48%	4%	0%			100%
	M4	14%	13%	21%	15%	9%	28%	0%				100%
	M5	4%	47%	43%	3%	4%	0%	0%				100%
	M6	8%	30%	22%	0%	22%	19%	0%				100%
	M7	15%	0%	20%	20%	42%	3%	0%				100%
	M8	10%	15%	20%	26%	29%	0%					100%
	U1	6%	48%	32%	13%	0%	0%					100%
	U2	32%	43%	22%	3%							100%
	U3	19%	53%	20%	7%	2%						100%
	U4	61%	32%	7%	0%							100%
	U5	33%	48%	18%	1%							100%
	U6	21%	39%	39%	1%							100%
	U7	22%	48%	30%	0%	0%						100%
Lower Section	Mean	26%	19%	12%	7%	6%	5%	6%	9%	8%	2.8%	
	SD	12%	12%	6%	3%	4%	5%	4%	5%	9%	3.7%	
	2 SE	8%	9%	4%	2%	3%	4%	3%	3%	6%	3.3%	
Middle Section	Mean	12%	23%	19%	11%	15%	16%	4.6%	0.0%			
	SD	6%	14%	11%	9%	15%	16%	7.0%	0.0%			
	2 SE	4%	10%	8%	6%	10%	11%	5.3%	0.0%			
Upper Section	Mean	28%	44%	24%	3%	0.7%	0.0%					
	SD	17%	7%	11%	5%	1.1%	#DIV/0!					
	2 SE	13%	5%	8%	4%	1.3%	#DIV/0!					

Table E8. Proportion of fish targets in each depth bin for each hydroacoustic survey transect on Lake Roosevelt, Washington during October 2005. To account for volumetric expansion of the acoustic cone, individual fish targets were converted to weighted fish, following the methods described by Yule (2000).

		Depth Bin (m)										
	Transect	10-20	30	40	50	60	70	80	90	100	110	Sum
	L1	56%	0%	0%	34%	0%	0%	10%	0%	0%	0%	100%
	L2	0%	39%	35%	9%	0%	3%	5%	0%	9%	0%	100%
	L3	0%	0%	71%	0%	0%	0%	21%	0%	0%	8%	100%
	L4	20%	0%	0%	8%	13%	5%	15%	4%	31%	4%	100%
	L5	41%	24%	15%	0%	0%	0%	14%	7%	0%	0%	100%
	L6	37%	15%	15%	0%	10%	8%	14%	0%	2%		100%
	L7	0%	0%	0%	50%	0%	0%	27%	23%	0%		100%
	L8	0%	0%	0%	53%	0%	17%	30%	0%	0%		100%
	M1	0%	54%	20%	0%	17%	5%	0%	4%			100%
	M2	14%	0%	53%	22%	4%	4%	3%	0%	0%		100%
	M3	30%	26%	12%	12%	10%	8%	4%	0%			100%
	M4	29%	0%	41%	17%	12%	0%	2%				100%
	M5	10%	33%	34%	18%	3%	2%	0%				100%
	M6	16%	13%	21%	17%	22%	10%	0%				100%
	M7	0%	9%	39%	22%	22%	7%					100%
	M8	15%	19%	39%	12%	12%	3%					100%
	U1	0%	74%	13%	13%	0%	0%	0%				100%
	U2	13%	45%	36%	6%	0%						100%
	U3	35%	54%	11%	0%	0%	0%	0%				100%
	U4	12%	27%	62%	0%							100%
	U5	38%	62%	0%	0%	0%						100%
	U6	30%	14%	53%	3%							100%
	U7	39%	26%	34%	0%	0%						100%
Lower Section	Mean	19%	10%	17%	19%	3%	4%	17%	4%	5%	2.2%	
	SD	23%	15%	25%	23%	5%	6%	8%	8%	11%	3.4%	
	2 SE	16%	11%	18%	16%	4%	4%	6%	6%	8%	3.0%	
Middle Section	Mean	14%	19%	32%	15%	13%	5%	1.4%	1.3%			
	SD	11%	18%	13%	7%	7%	3%	1.7%	2.3%			
	2 SE	8%	13%	10%	5%	5%	2%	1.4%	2.7%			
Upper Section	Mean	24%	43%	30%	3%	0.0%	0.0%					
	SD	15%	22%	23%	5%	0.0%	0.0%					
	2 SE	12%	17%	17%	4%	0.0%	0.0%					

Table E9. Length frequency of acoustic targets detected on the vertically oriented transducer in Lake Roosevelt, WA in August of 2005. Length (mm) was estimated from target strength (-dB) using equations from Love (1971, 1977).

Bin	*Frequency*	% Frequency	Cumulative % Freq	Cumulative / length bin
50	135	15.5%	15.5%	
75	147	16.9%	32.4%	
100	150	17.2%	49.7%	49.7%
125	93	10.7%	60.3%	
150	51	5.9%	66.2%	
175	58	6.7%	72.9%	
200	49	5.6%	78.5%	28.9%
225	36	4.1%	82.6%	
250	39	4.5%	87.1%	
275	22	2.5%	89.7%	
300	12	1.4%	91.0%	
325	13	1.5%	92.5%	
350	15	1.7%	94.3%	
375	14	1.6%	95.9%	
400	8	0.9%	96.8%	18.3%
425	6	0.7%	97.5%	
450	1	0.1%	97.6%	
475	5	0.6%	98.2%	
500	6	0.7%	98.9%	
525	1	0.1%	99.0%	
550	2	0.2%	99.2%	
575	1	0.1%	99.3%	
600	2	0.2%	99.5%	
625	3	0.3%	99.9%	
650	0	0.0%	99.9%	
675	0	0.0%	99.9%	
700	0	0.0%	99.9%	
725	1	0.1%	100.0%	
750	0	0.0%	100.0%	
775	0	0.0%	100.0%	
800	0	0.0%	100.0%	3.2%
Sum =	870	100.0%		100%

Table E10. Length frequency of acoustic targets detected on the vertically oriented transducer in Lake Roosevelt, WA in October of 2005. Length (mm) was estimated from target strength (-dB) using equations from Love (1971, 1977).

Bin	*Frequency*	% Frequency	Cumulative % Freq	Cumulative / length bin
50	69	15.6%	15.6%	
75	61	13.8%	29.5%	
100	49	11.1%	40.6%	40.6%
125	26	5.9%	46.5%	
150	24	5.4%	51.9%	
175	32	7.3%	59.2%	
200	20	4.5%	63.7%	23.1%
225	21	4.8%	68.5%	
250	15	3.4%	71.9%	
275	11	2.5%	74.4%	
300	17	3.9%	78.2%	
325	9	2.0%	80.3%	
350	6	1.4%	81.6%	
375	12	2.7%	84.4%	
400	12	2.7%	87.1%	23.4%
425	14	3.2%	90.2%	
450	6	1.4%	91.6%	
475	9	2.0%	93.7%	
500	7	1.6%	95.2%	
525	5	1.1%	96.4%	
550	4	0.9%	97.3%	
575	3	0.7%	98.0%	
600	0	0.0%	98.0%	
625	0	0.0%	98.0%	
650	1	0.2%	98.2%	
675	0	0.0%	98.2%	
700	0	0.0%	98.2%	
725	1	0.2%	98.4%	
750	0	0.0%	98.4%	
775	1	0.2%	98.6%	
800	6	1.4%	100.0%	12.9%
Sum =	441	100.0%		100%

APPENDIX F. Diet tables for limnetic fishes.

Table F1. Sample size, percent empty stomachs, and monthly average wet weight proportions of various prey taxon for burbot, smallmouth bass, and walleye captured in limnetic gill nets in Lake Roosevelt, Washington, 2005.

	Burbot		Smallmouth Bass		Walleye	
	August	October	August	October	August	October
Number Examined =	1	1	1	1	31	25
% Empty =	100%	0%	0%	100%	26%	24%
Sample Size =	0	1	1	0	23	19
<u>Prey Category</u>						
Daphnia	-	-	-	-	-	-
Leptodora	-	-	-	-	-	-
Copepods	-	-	-	-	-	-
Other Cladocerans	-	-	-	-	-	-
Mysids	-	-	-	-	0.00	-
Diptera	-	-	-	-	0.01	0.05
Tricoptera	-	-	-	-	-	-
Plecoptera	-	-	-	-	-	-
Ephemeroptera	-	-	-	-	-	-
Odonata	-	-	-	-	-	-
Coleoptera	-	-	-	-	0.00	-
Hemiptera	-	-	-	-	-	-
Arachnid*	-	-	-	-	-	-
Bivalve	-	0.00	-	-	0.00	-
Gastropod	-	-	-	-	-	-
Amphipod	-	0.07	-	-	0.02	-
Isopod	-	0.81	-	-	0.04	0.06
Unknown Insect	-	-	-	-	-	-
Leech	-	0.11	0.50	-	0.20	0.02
Nematoda	-	-	-	-	-	-
Decapoda	-	-	-	-	-	-
Hymenoptera	-	-	-	-	-	-
Orthoptera	-	-	-	-	-	-
Lepidoptera	-	-	-	-	-	-
Other*	-	-	-	-	-	-
Cottid	-	0.00	-	-	0.45	0.43
Catastomid	-	-	-	-	-	-
Cyprinid	-	-	-	-	-	-
Centrarchid	-	-	-	-	0.01	-
Percid	-	-	-	-	-	0.15
Salmonid	-	-	-	-	0.09	0.05
Unknown Osteichthyes	-	-	0.50	-	0.11	0.22
Vegetation and Inorganics	-	0.00	-	-	0.07	0.01

* Terrestrial insects, Bryozoa, or unidentifiable objects

APPENDIX G. Otolith and scale analysis.

In 2005, otoliths were collected from burbot, scales were collected from walleye and both scales and otoliths were collected from kokanee, lake whitefish, and rainbow trout. Walleye otoliths were not taken as both scales and otoliths were taken during the annual Fall Walleye Index Netting survey (Scofield et al., in press), and scales would at least provide a baseline of what was collected limnetically. Otoliths and scales were both taken from kokanee, rainbow trout, and lake whitefish in order to compare and define if age similarities and/or discrepancies existed between both structures. Discrepancies existed when comparing lake whitefish scales and otoliths once fish reached age-3. All age-0, -1, and -2 scales and otoliths matched exactly. All age-3 scales except one (12 of 13) matched exactly with one aged as an age-4 otolith. All age-4 scales and otoliths matched exactly except one (12 of 13,) which was an age-13 otolith. Only one age-5 scale and otolith matched ages exactly (1 of 4), while one otolith was aged as age-6, one as age-7, and one as age-13. None of the scales and otoliths (9) matched for scales aged as age-6 with otoliths being aged as age-7 (2), age-8 (1), age-10 (3), age-11 (1), age-12 (1), and age-18 (1). Two age-7 scales were aged with one otolith matching exactly and the other otolith aged as age-10. One burbot was aged as age-1 and was 354 mm TL. One smallmouth bass was aged at age-2 (scale and otolith) and was 236 mm TL. We collected scales and otoliths from one walleye based on length (743 mm TL). It was aged as age-9 with scales and as age-10 with otoliths. Two longnose suckers (LNS) and one largescale sucker (LRS) were aged using both scales and opercles. One longnose sucker was aged as age-3 by scales and age-8 by opercle (463 mm TL). For the other longnose sucker and the largescale sucker, the scales were inconclusive; however, the opercles were aged as age-2 (318 mm TL; LNS) and age-3 (332 mm TL; LRS), respectively. Kokanee scales and rainbow trout scales and otoliths were not aged at this time. Kokanee otoliths were aged and fish ranged between age-0 and age-3. The WDFW aging laboratory in Olympia, WA aged all scales, otoliths, and opercles.

In 2004 and 2005, the Lake Roosevelt Fisheries Evaluation Program began stocking kokanee fry into tributaries of Lake Roosevelt (Big Sheep Creek, 2004; Onion and Hawk creeks, 2005 along with post-smolts for comparison) (McLellan et al. 2006). All fry planted into Lake Roosevelt were otolith marked either solely by thermal marking or by a combination of thermal and OTC (oxytetracycline) marking. All fry destined for Big Sheep and Onion creeks were marked both thermally and with OTC. All fry destined for Hawk Creek were thermally marked (McLellan et al. 2006). Fifty-nine otolith samples (7 from STI collection; 24 from EWU collection; 28 from WDFW collection) were analyzed for marks by the WDFW otolith laboratory in Olympia, WA. Only one fish was found to have a visible otolith mark (184 mm TL). This fish was collected by the WDFW in the middle section between river mile 654 and 655 (48.04249 N, 118.27348 W). Based on the mark, it was believed to be from the 2004 release at Big Sheep Creek (BSC) (McLellan et al. 2006). For one fish, analysis was inconclusive.

Table G1. Scale ages, otolith ages, and lengths of various fish species per age group collected during limnetic sampling in August 2005.

Species	Scale Age	Mean Length (mm)	Length Range (mm)	n	Otolith Age	Mean Length (mm)	Length Range (mm)	n
Burbot					1	354	354	1
					Total			1
Kokanee	0	*	*	*	0	195	173-232	4
	1	*	*	*	1	309	294-323	2
	2	*	*	*	2	334	280-498	11
	3	*	*	*	3	484	351-520	11
					Total			28
Lake Whitefish	0	198	169-215	10	0	194	160-215	11
	1	351	335-381	18	1	351	335-381	18
	2	441	417-465	15	2	441	417-465	15
	3	507	472-543	13	3	507	472-543	12
	4	541	514-580	12	4	537	505-580	12
	5	551	522-574	4	5	522	522	1
	6	581	545-608	9	6	537	537	1
	7	595	592-598	2	7	583	570-598	4
					8	591	591	1
					10	586	556-608	4
					11	592	592	1
					12	545	545	1
					13	563	551-574	2
					18	585	585	1
	Total			83	Total			84
Smallmouth Bass	2	236	236	1	2	236	236	1
	Total			1	Total			1
Walleye	9	743	743	1	9	~	~	~
					10	743	743	1
	Total			1	Total			1

* Scales not aged at time of publication ~ No data available

Table G2. Number of otoliths collected and examined (by WDFW), and those found to have a visible otolith mark, and the fry release location [Big Sheep Creek (BSC)].

Agency	# Examined	# Marked	Location
EWU	24	0	
STI	7*	0	
WDFW	28	1	BSC
Total	59	1	

*Data inconclusive for 1 fish

APPENDIX H. Walleye reward tagging study.

Introduction and Methods:

The Lake Roosevelt Fisheries Evaluation Program (LRFEP; WDFW, STI, CCT, and EWU), along with the Spokane Walleye Club (SWC), began a two year (2003-2005) walleye tagging study in April 2003. The objectives were to 1) determine how $10 reward tags versus non-reward tags would influence angler response, and consequently, increase tag returns, and 2) add to the previous studies that sought to determine movement and distribution of walleye from the spawning arm.

The Spokane River Arm of Lake Roosevelt between Porcupine Bay (mile 10) and Little Falls Dam (mile 29) was sampled for walleye via boat electrofishing and angling during the walleye spawning run on two occasions in the spring of 2003. Because this area of the Spokane River Arm was closed to allow for walleye spawning, a temporary scientific collection permit was issued to the LRFEP by the WDFW, as well as a temporary tribal permit issued by the STI to the LRFEP, which allowed sampling to take place between April 11-May 3, 2003.

On April 11, 2003 from 08:00-16:00, three electrofishing boats (LRFEP) sampled the Spokane River Arm (from mile 10-mile 29), and on April 19 and May 3, 2003 from 07:00-16:00 members of the LRFEP and ~30 members of the SWC sampled this area by both electrofishing and angling. The goal was to collect, tag, and release 1,000 walleye over the course of the study with approximately 700 walleye to be tagged electrofishing and 300 walleye to be tagged angling. Proportions were estimated based on feasibility of each method. Ideally, we recognize that it would have been most appropriate to mark 50% of the fish with each method. However, the reality of time and financial constraint forced us to set more realistic objectives for the angling portion of the marking events. Due to a failure to mark 1000 fish in the spring on the Spokane Arm, WDFW also attended the Governor's Cup Walleye Tournament (based in Kettle Falls, WA) from June 28-June 29, 2003 and tagged walleye that anglers caught in order to help increase the number of tags used in the study.

In the Spokane Arm, each electrofishing crew was provided a map, data sheets, and marking equipment and were instructed to cover both shorelines in their designated sampling section. If walleye were caught in a specific area, that area could be re-sampled later in the day with low risk of recapture due to high flows and fish movement. Electrofishing effort was ten minutes long unless live well crowding became an issue due to high catch rates.

All walleye caught by anglers were to be taken to a LRFEP boat within one hour of collection to be tagged. All fish, including by-catch, were documented. Species, total length (mm), weight (g), tag number and color, mark or recapture, opercle punch and any other notes were recorded for walleye. Only walleye that were over 200 mm were tagged and hole punched in the left opercle (to determine tag retention). Tagging randomly alternated between reward and non-reward tags to reduce gear bias of the marking event. Walleye were tagged using orange T-anchor style tags that were purchased by the SWC. Reward tags were labeled with “$10 REWARD”, “EWU CHENEY”, the individual tag number, and the EWU phone number to call for reward information. Non-reward tags included the same information minus the statement “$10 REWARD”. Reward tags were numbered from 1-500 and non-reward tags were numbered from 501-1000. All fish recaptured during the study were recorded as a recapture and released. Over the next two years, we intended to recapture walleye using our standard seasonal sampling, Fall Walleye Index Netting, and angler tag returns to both tag boxes and to EWU.

Tag return information was maintained by EWU and held in the comprehensive LRFEP tag return database. On a monthly basis, returned tags were reported by EWU to WDFW, who then notified the SWC of the parties that need to be rewarded. The angler tag return information was analyzed using a two-way contingency table to compare the proportional tag return rate of the two different kinds of tags. We also identified movement and distribution based on where anglers caught walleye.

Results:

A total of 890 walleye were tagged and 121 tags (14%) were returned (Table H1). The percentage of tags returned ranged from 18% for reward tags to 9% for non-reward tags and the difference in return rate was significant (Chi-square= 12.57; df=1; $p < 0.0005$).

Fifty-four reward tags were returned from June 1, 2003-September 15, 2003, 14 reward tags were returned from January 2004-August 29, 2004, and 12 reward tags were returned from February 17, 2005- October 30, 2005 (Table H1). Twenty-five non-reward tags were returned from June 1, 2003-October 12, 2003, 11 non-reward tags were returned from May 11, 2004-September 25, 2004 and 5 non-reward tags were returned from March 11, 2005-August 18, 2005 (Table H1). Two tags were returned from walleye caught in 2006, but were excluded from analysis as they were returned beyond the duration of this study. The number of recaptures and the percentage of tags returned in 2003-2004 were inaccurately reported in the 2004 annual report (Baldwin and Woller 2006c). The corrections are listed below in Table H2.

Table H1. Number and size of walleye tagged, number of recaptures, and percentage of tags returned within each reward category for 2003-2005.

Reward category	Number tagged	Total Length (mm)		Number of	Percent
		Range	Mean (SD)	Recaptures	Returned
$10 REWARD	440	285-813	442 (80) (n = 439)	80	18
Non-reward	450	271-842	443 (88) (n = 449)	41	9
Total	890	271-842	442 (84) (n = 888)	121	14

Table H2. Number and size of walleye tagged, number of recaptures, and percentage of tags returned within each reward category for 2003-2004.

Reward category	Number tagged	Total Length (mm)		Number of	Percent
		Range	Mean (SD)	Recaptures	Returned
$10 REWARD	440	285-813	442 (80) (n = 439)	68	15
Non-reward	450	271-842	443 (88) (n = 449)	36	8
Total	890	271-842	442 (84) (n = 888)	104	12

Table H3. Tag number ranges and number of tags used and not used for reward and non-reward tags.

Reward tags used	n	Non-reward tags used	n	Reward tags not used	n	Non-reward tags not used	n
W015-W0113	99	W0501-W0504	4	W0001-W0014	14	W0505	1
W0115-W0125	11	W0506-W0551	46	W0114	1	W0552	1
W0151-W0169	19	W0553	1	W0126-W0150	25	W0554-W0556	3
W0171-W0174	4	W0557-W0575	19	W0170	1	W0576-W0600	25
W0176-W0245	70	W0601-W0760	160	W0175	1	W0761-W0775	15
W0251-W0460	210	W0776-W0786	11	W0246-W0250	5	W0787	1
W0462-W0467	6	W0788-W0825	38	W0461	1	W0826	1
W0469-W0489	21	W0827-W0846	20	W0468	1	W0847	1
		W0848-W0975	128	W0490-W0500	11	W0976	1
		W0977-W0999	23			W1000	1
Total	440		450		60		50

APPENDIX I. Fish bioenergetics model results and diagnostic checks.

Results for a variety of cases are reported and hope to show that the model is behaving appropriately, and that some diagnostic conclusions can be drawn.

A prescribed mass case, based on fish growth data, is examined at the Spring Canyon monitoring location (upstream of Grand Coulee Dam). The cell of best growth was selected at each timestep, and stomach content was passed on to the other vertical cells. At the end of the day (taken to be midnight), growth was determined and passed on. A similar case was examined at the Porcupine Bay monitoring location (on the Spokane River arm). The Spokane arm is known to have different fish habitat characteristics, and provides a contract with the Columbia River site.

A simple vertical foraging strategy was employed to try to capture some realistic foraging behavior; the best growth strategy predicts a period of minimal consumption in the late summer and fall when prey is abundant. The decision process at each timestep is:

1) Use the cell of best growth if
    a. growth is positive
    b. during nighttime (selects least negative)
2) If daylight (surface lux >1), alternate foraging and "digesting"
    a. Forage at the cell of greatest consumption, C
    b. "Digest" or "rest" at the cell of minimum respiration, R
    c. alternate foraging and digesting timesteps during daylight.

These cases show that fish growth can be reasonable modeled. They also predict that there are periods when foraging at some locations in the reservoir are not practical due to the large metabolic costs associated with warm water. Specifically, near the time of fall turnover, the smallest respiration costs at Spring Canyon exceed the best energy gain from consumption. This indicates that fish are unlikely to a) inhabit that part of the reservoir, and/or b) are utilizing a strategy not modeled. Possibilities include finding cold water inflows, or foraging under more successful techniques such as high prey density littoral regions. The comparison between the two sites suggests the possibility of horizontal migration. When the bioenergetics are poor at Spring Canyon in the late fall and winter, they are more favorable at Porcupine Bay.

The shown runs used a handling time of 0.5 sec. Runs with a 0.33 sec handling time do not greatly influence the results: the positive and negative growth periods are the same, but the magnitude is slightly improved.

The results of the fish bioenergetics model show general agreement with literature values. There is a little difference for a 10-g kokanee (see Figure 16 and subsequent comments and figure).

Base Lake Roosevelt Results at Spring Canyon (LRFEP sta 9.0)

Energy content of prey: a constant of 2420 J/g
Growth method: prescribed function based on data.
Feeding: model output prey densities are used.
Foraging: Best cell at each time-step; growth calculated and passed on to all cells in the segment daily.
Comments: During the warm water periods in roughly July through October, the best place to be for a single time-step is at the bottom of the lake. However, only negligible consumption is then possible. This is unlikely the actual fish behavior to these conditions. Compare with the next section.

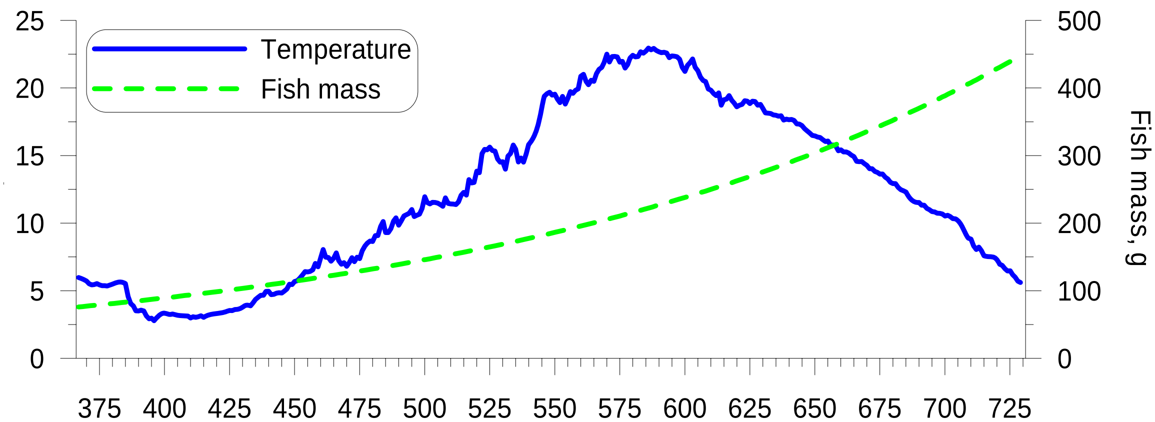

Figure 1. Base case temperature and prescribed fish mass function.

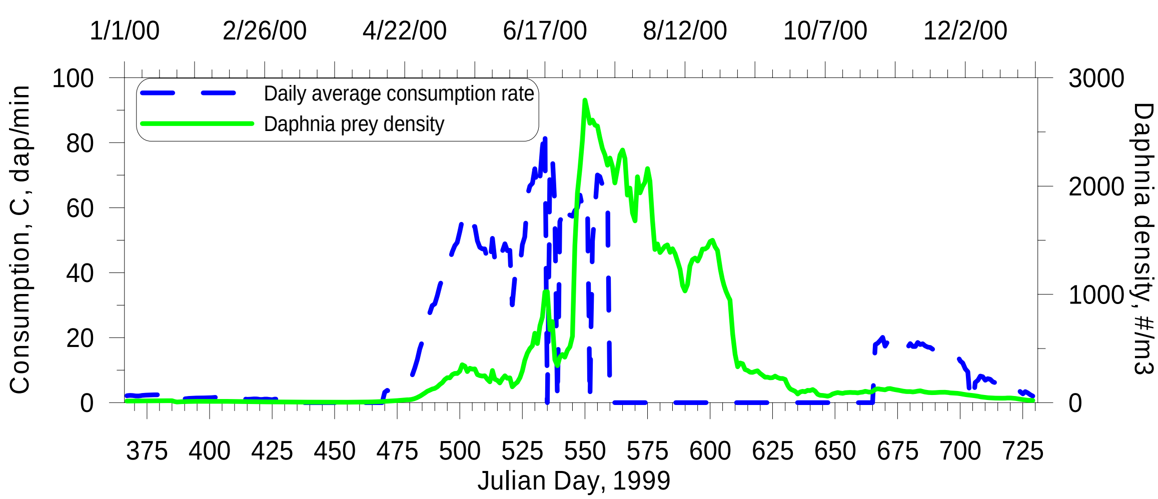

Figure 2. Daily average consumption (includes nighttime) and prey density.

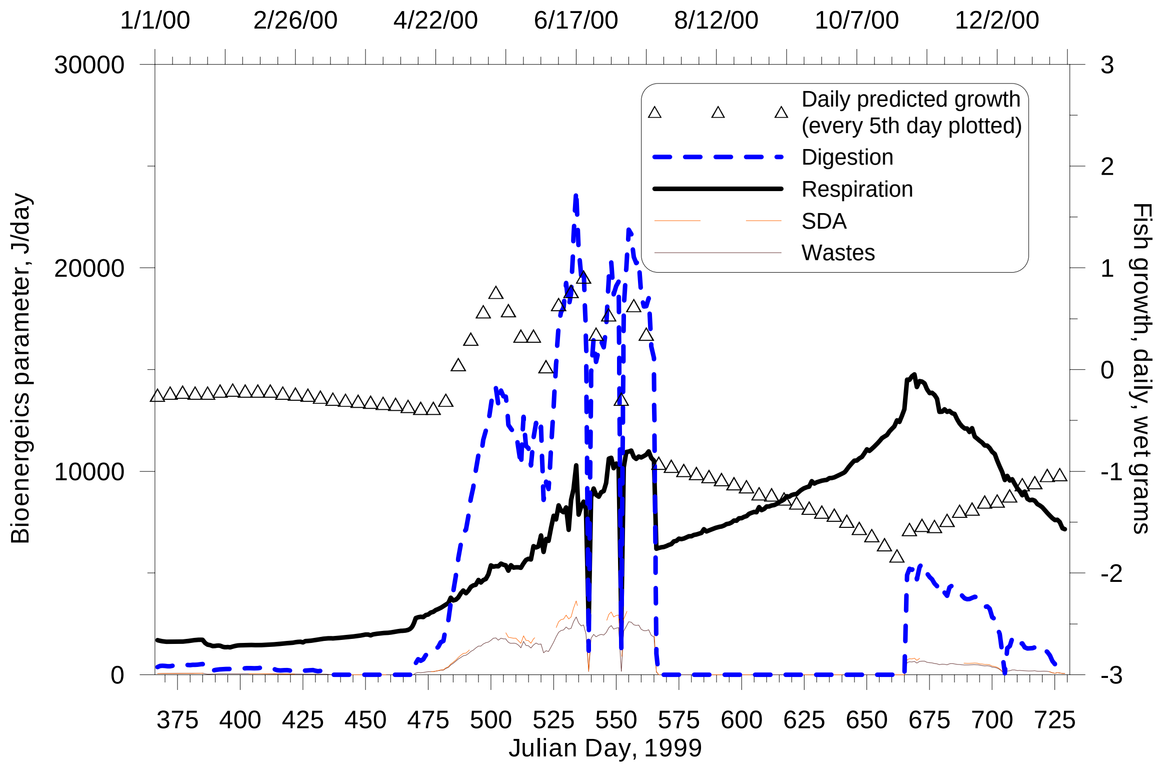

Figure 3. Daily growth and bioenergetic parameters.

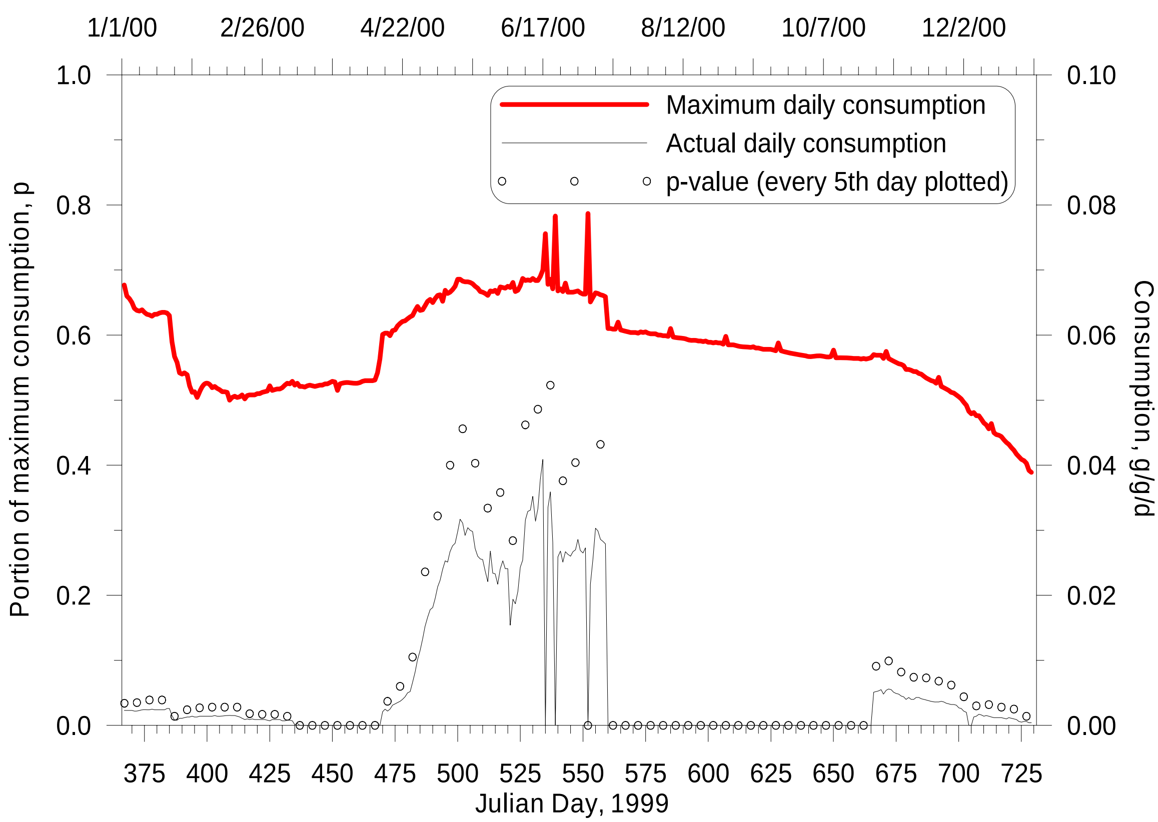

Figure 4. Daily maximum and actual consumption; p-values.

Base Lake Roosevelt Results at Spring Canyon (LRFEP sta 9.0); Simple foraging algorithm

Energy content of prey: a constant of 2420 J/g
Growth method: prescribed function based on data.
Feeding: model output prey densities are used.
Foraging: "Best growth" with conditional vertical foraging during the day. The decision process at each timestep:

3) Use the cell of best growth if
    a. growth is positive
    b. during nighttime (selects least negative)
4) If daylight (surface lux >1), alternate foraging and "digesting"
    a. Forage at the cell of greatest consumption, C
    b. "Digest" or "rest" at the cell of minimum respiration, R
    c. alternate foraging and digesting timesteps during daylight.

Comments: This is an attempt at simple vertical foraging in an attempt to optimize consumption and respiration. Also, when assessing which cell has the best growth, 20% of the consumption is directly added to the digestion parameter to allow for potential digestion (Brett & Groves, 1979). Without this estimate (only used to estimate the best cell, and not for any parameter calculations), the model will pick the most favorable growth locations using the stomach content at the start of the timestep. Since only a small portion of the prey consumed are digested in the same timestep, the model tends to pick the locations of least respiration cost when the waters become warm which in turn leads to empty stomachs.

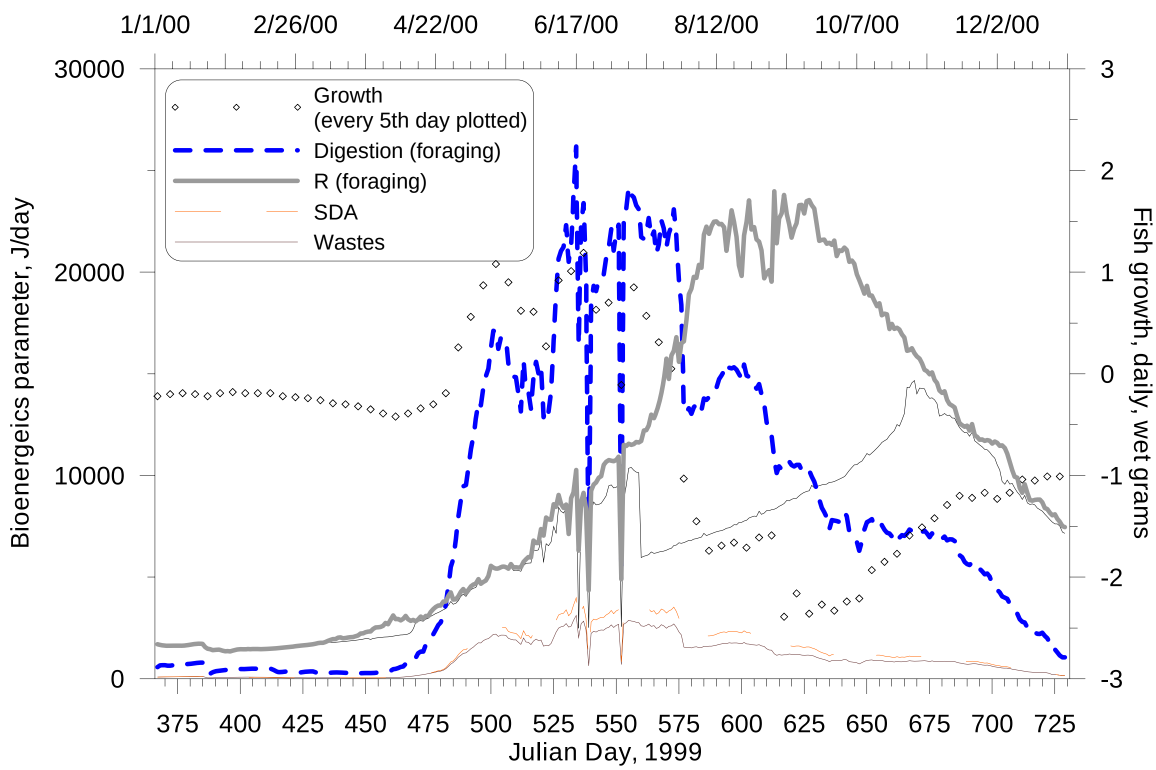

Figure 5. Daily growth and bioenergetic parameters, vertical foraging strategy.

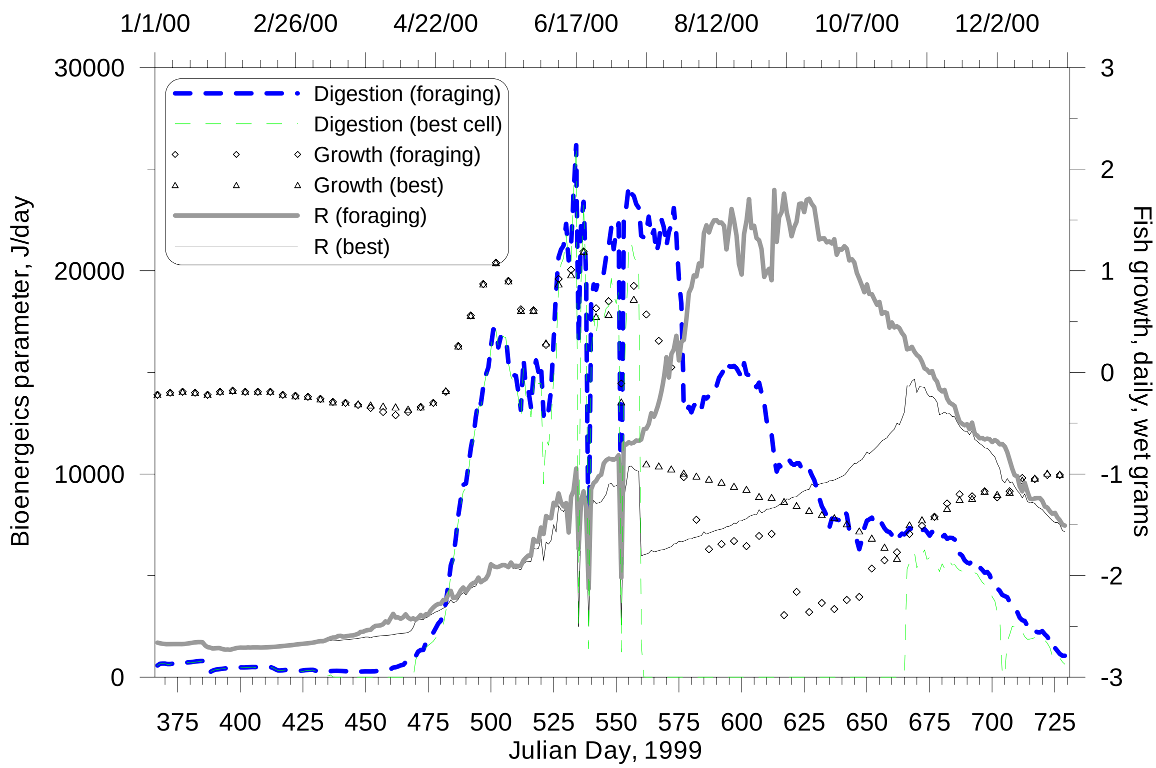

Figure 6. Comparison of fish location optimization strategies: best growth cell and vertical foraging.

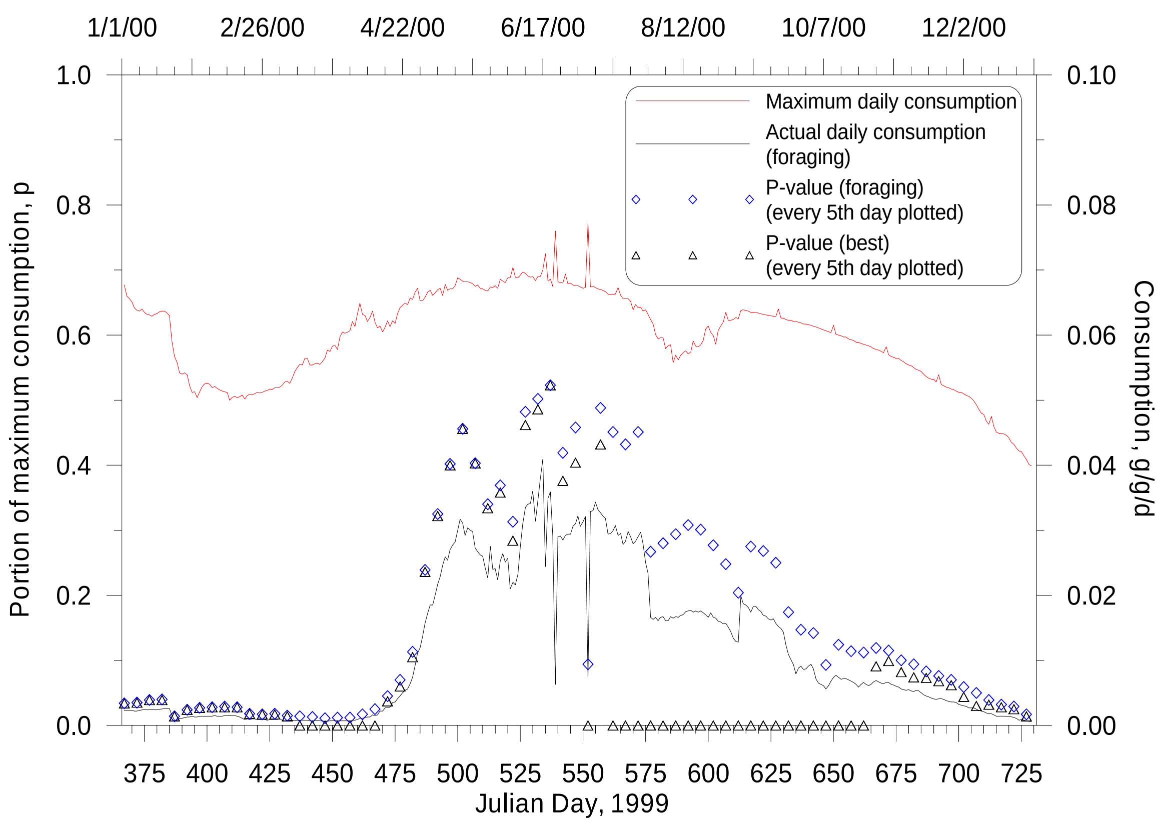

Figure 7. Daily maximum and actual consumption for the foraging model. Comparison of best growth cell and vertical foraging p-values.

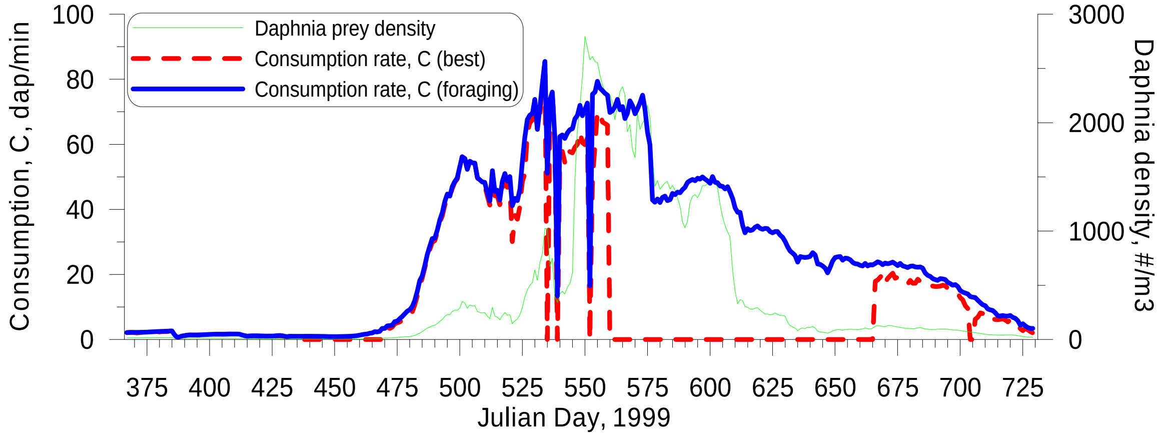

Figure 8. Comparison of daily average consumption rates.

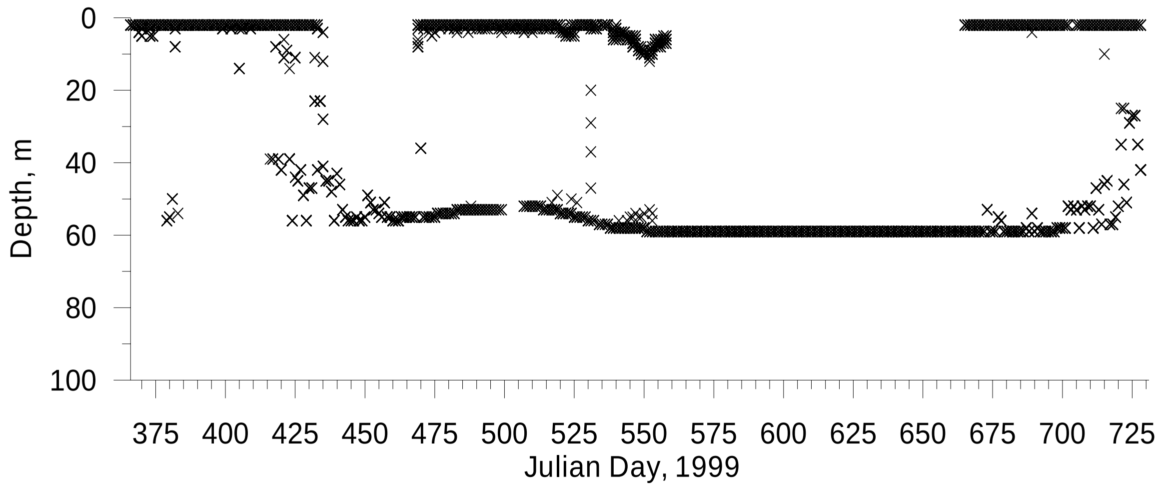

Figure 9. Foraging depths at each timestep, best growth cell method.

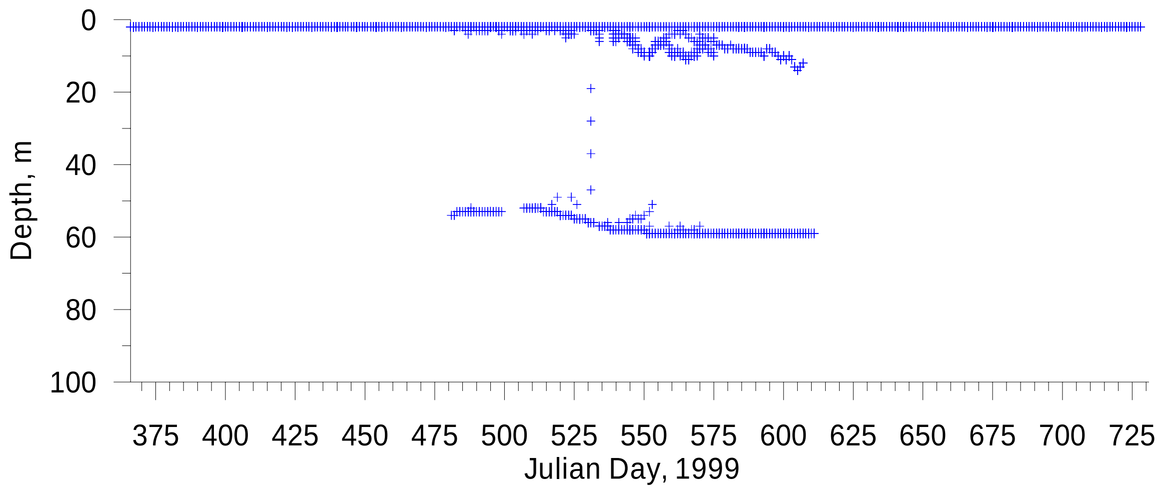

Figure 10. Foraging depths at each timestep, vertical foraging method.

[Figure 9 and Figure 10 were hard to distinguish on the same plot; individual points which look to be the same generally are.]

Comparison of Base Lake Roosevelt Results at Porcupine Bay (Spokane River, LRFEP sta 4.0) with Spring Canyon (Columbia River, LRFEP sta 9.0)

Energy content of prey: a constant of 2420 J/g
Growth method: prescribed function based on data.
Feeding: model output prey densities are used.
Foraging: "Best growth" with conditional vertical foraging during the day. The decision process at each timestep:

5) Use the cell of best growth if
    a. growth is positive
    b. during nighttime (selects least negative)
6) If daylight (surface lux >1), alternate foraging and "digesting"
    a. Forage at the cell of greatest consumption, C
    b. "Digest" or "rest" at the cell of minimum respiration, R
    c. alternate foraging and digesting timesteps during daylight.

Comments: This is the same run as previously reported; a new location is added.

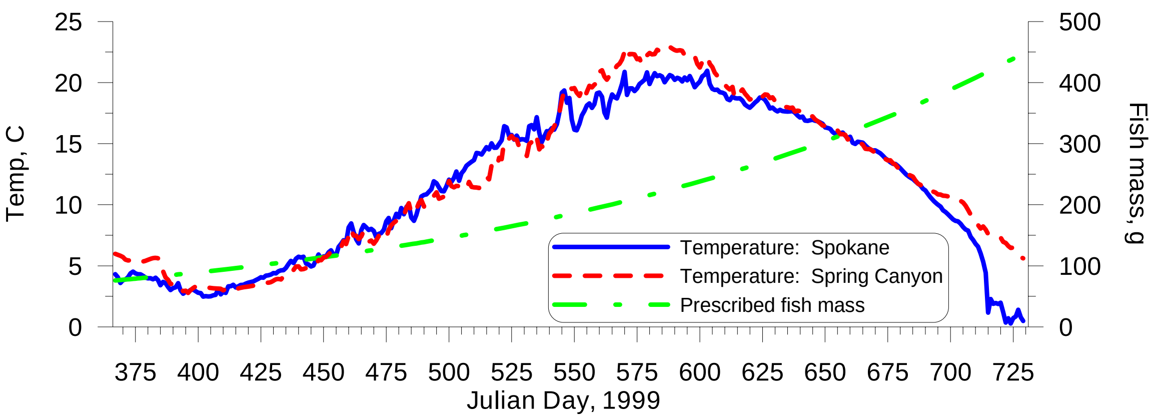

Figure 11. Comparison of water temperatures.

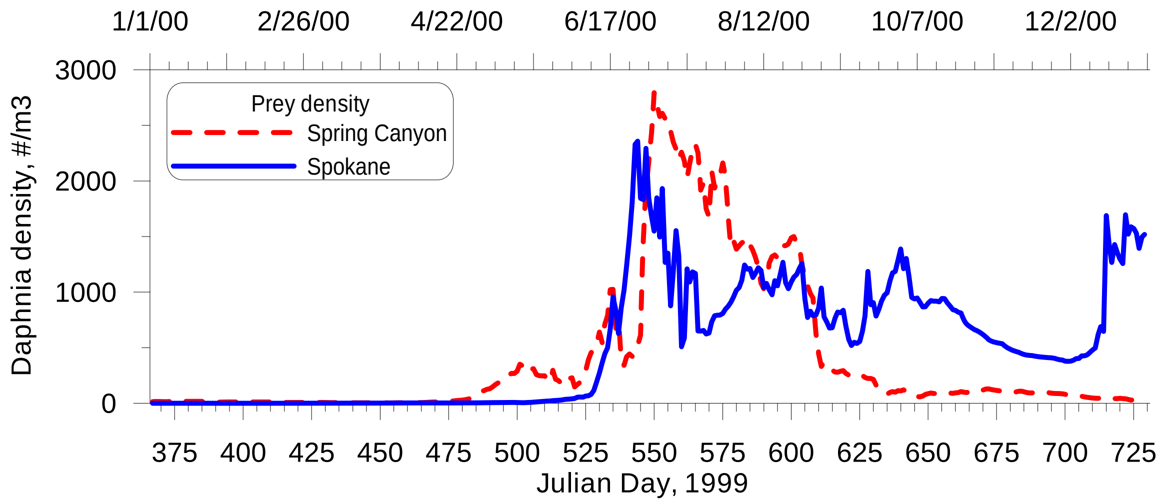

Figure 12. Comparison of prey densities.

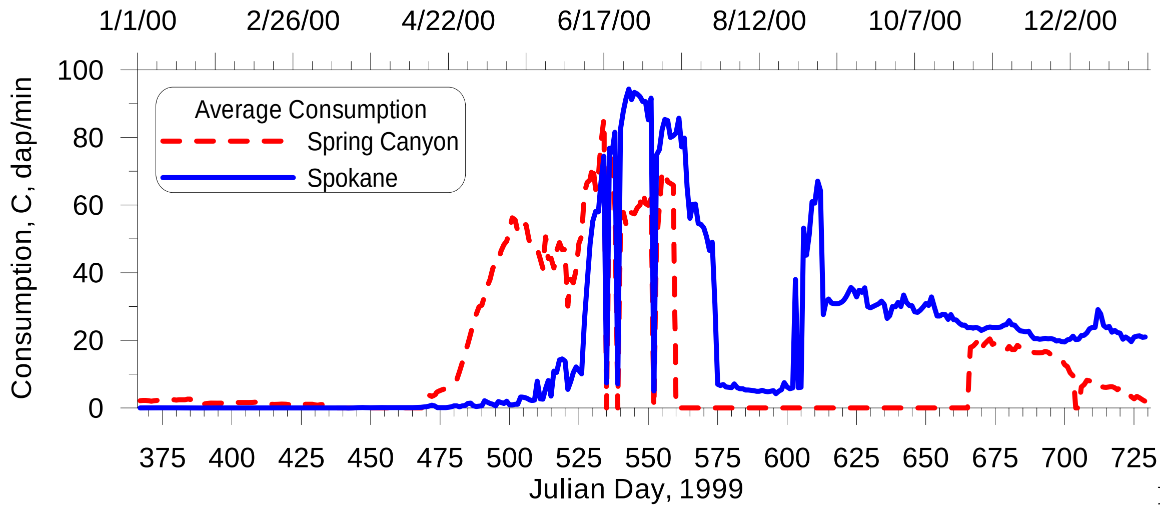

Figure 13. Comparison of consumption rates.

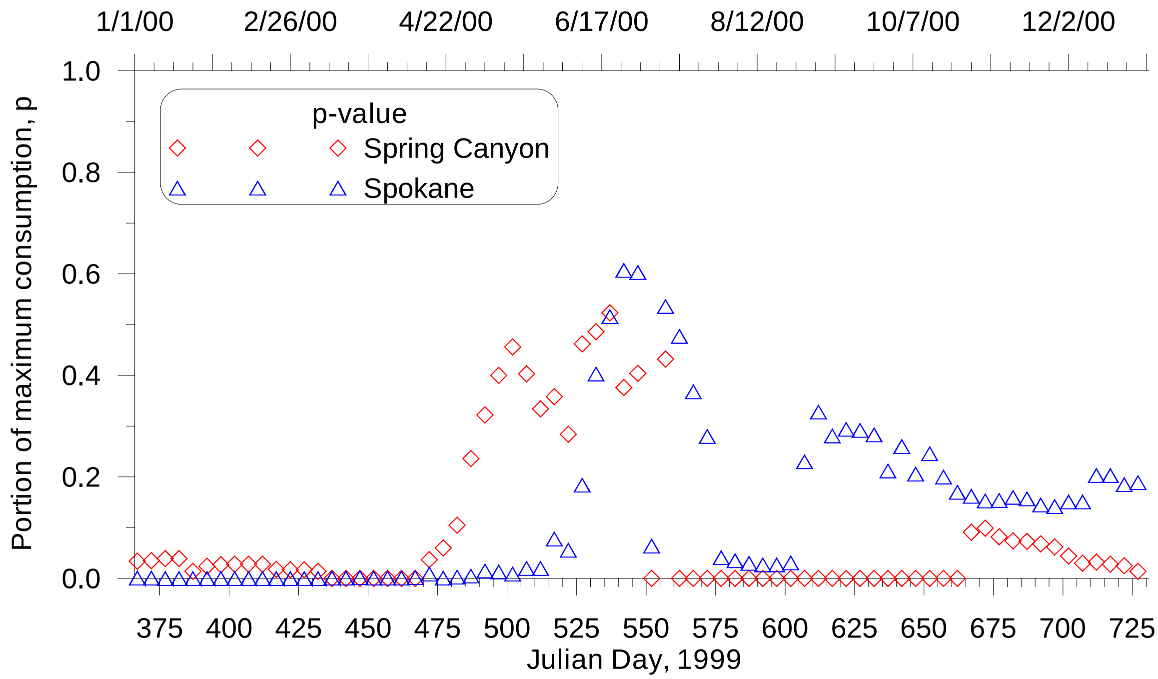

Figure 14. Comparison of p-values.

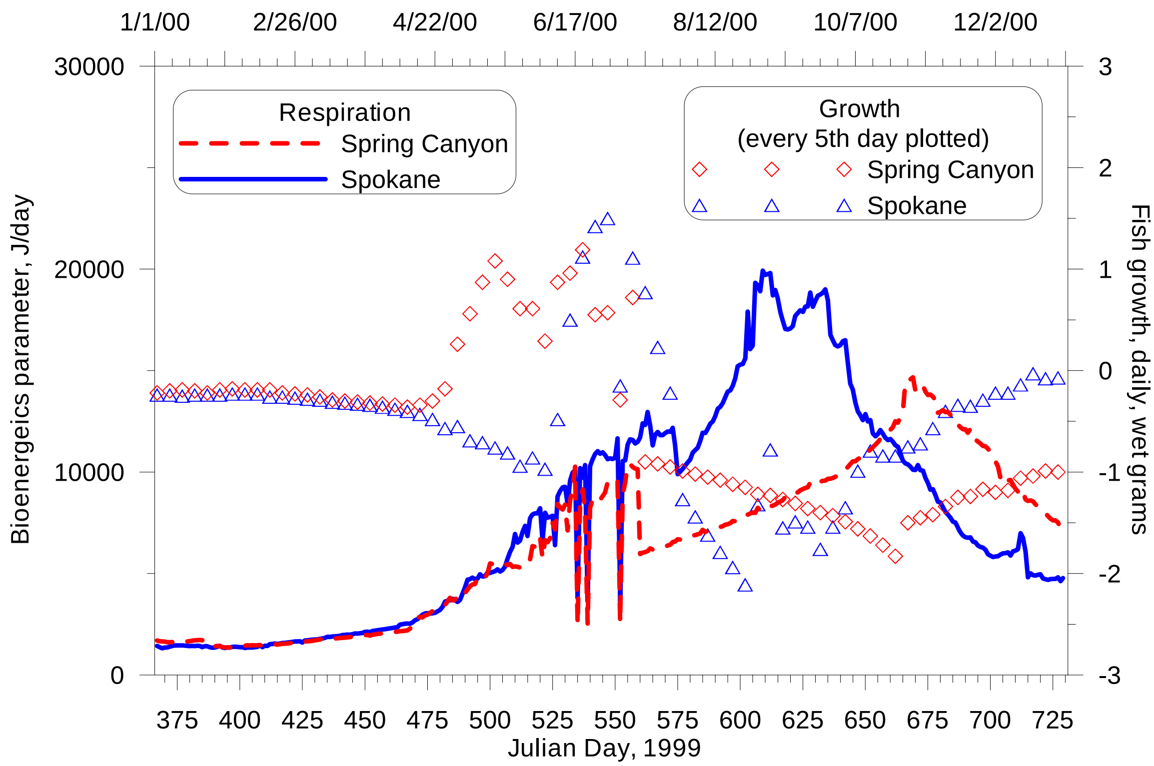

Figure 15. Comparison of respiration and daily growth.

Fixed mass kokanee, diagnostic run at 100% C_{max}.

Energy content of prey: a constant of 2800 J/g
Growth method: no growth: fixed masses of 10 and 100 grams.
Feeding: consumption rate set by Cmax = function (T, mass)
Foraging: Best cell at each time-step.
Comments: Diagnostic run to compare model results to literature results.

C_{max} is formulated using Beachamp, et al. (1989):

$$C_{\max} = 0.303 \cdot M^{-0.275} \cdot TL(temp) \qquad \text{in g/g/d}$$

$$C_{\max} = 0.303 \cdot M^{-0.275} \cdot TL(temp) \cdot M \cdot E_{daphnia} \qquad \text{in J/d}$$

Foraging rate (C, in daphnia/minute) was determined by dividing C_{max} by 1440; thus feeding occured continuously and was only a function of temperature (mass was constant).

The allometric function reported by Hewitt & Johnson (1992) is used for the Kokanee energy density.

$$E_{fish}\left[\tfrac{J}{g}\right] = \begin{cases} 4.1868 \cdot (1.8510 \cdot M + 1250) & \text{for} \quad M \le 196 \text{ g} \\ 4.1868 \cdot (1.1254 \cdot M + 1588) & \text{for} \quad M > 196 \text{ g} \end{cases}$$

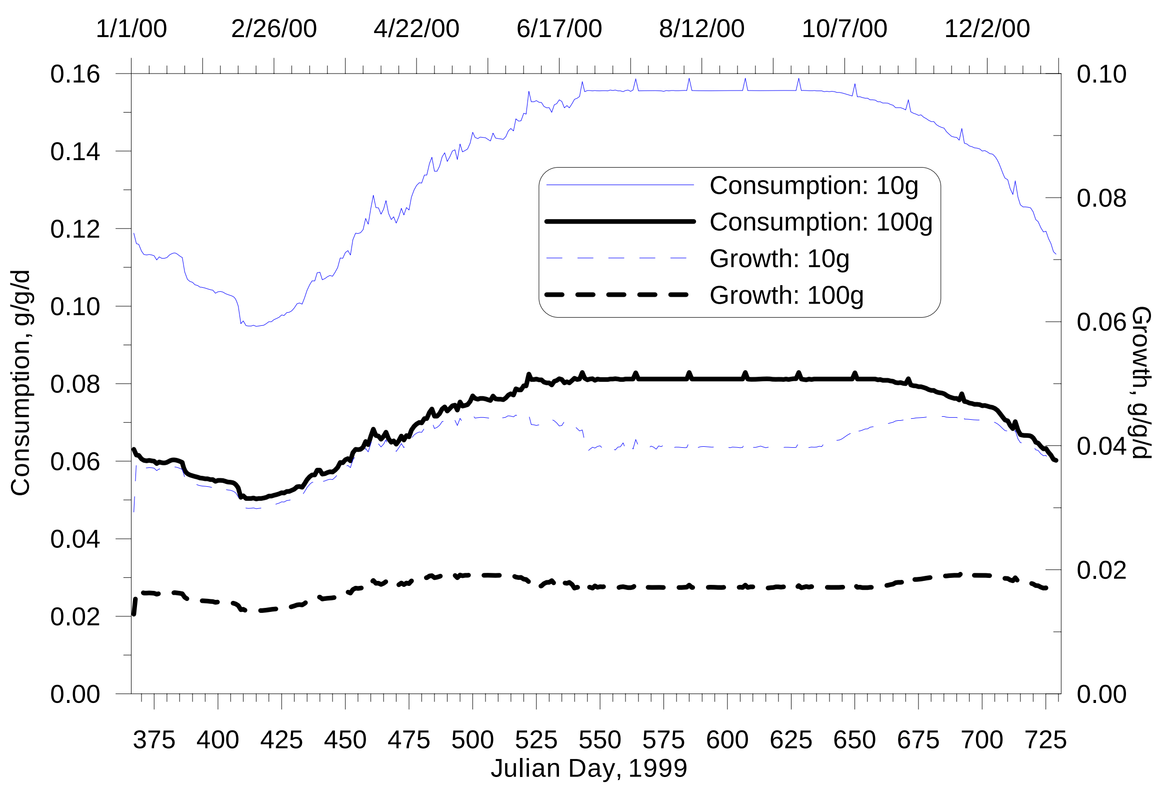

Figure 16. Growth and Consumption rate at C_{max} for a 10 g and 100g kokannee.

Subsequent figure is from Dave....I'm not sure why the 10 g peak growth is higher than those seen below. The first check is to see if we are using the same Fish energy density and the same C_{max} formulation.

I think the differences between your estimated growth and Dave's is simply a difference regarding how Dave produced his graph. I ran the same data in the canned Wisconsin model and came up with a growth rate of 0.056 g/g day using C-max at 14 C with 2800 J/gram. I think the remaining difference is because the canned model assumes all the consumed prey is available for growth while your model relies on the temperature specific digestion rate.

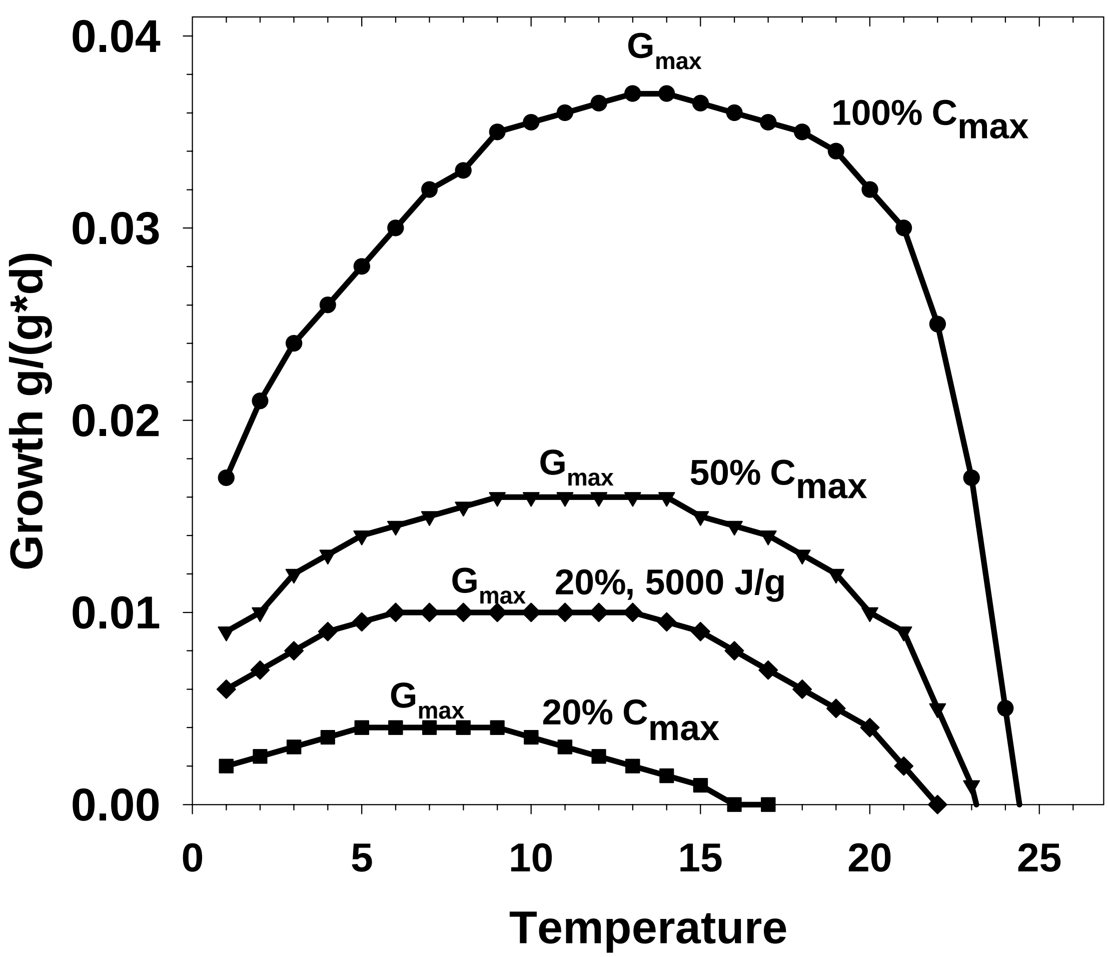

Fig. 3. A comparison of temperature-dependent daily growth rates for 10 g sockeye salmon feeding at different percentages of the maximum daily consumption rate C_{max} on prey containing energy density of 2800 $J \cdot g^{-1}$, except the second lowest curve represents growth at 20% C_{max} with

a diet containing high energy prey (5000 J·g^{-1}). The maximum growth rate for each consumption level is indicated by G_{max}.

Thornton-Lessem function check

A comparison of the Thorton-Lessem function computed in a spreadsheet to that of the Fortran code is shown as Figure 17.

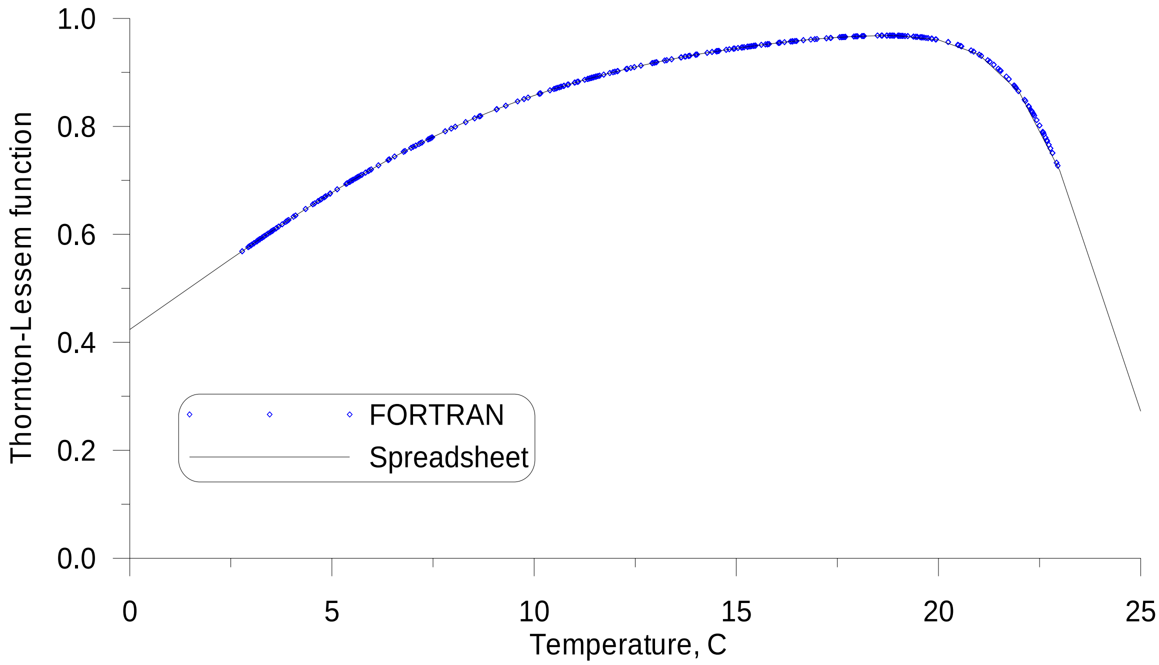

Figure 17. Thornton-Lessem function values; stand alone spreadsheet and Fortran code comparison.

APPENDIX J. Other WDFW Activities Under the STI/BPA Contract Number 94BI32148 August 1, 2005 to July 31, 2006.

Provided quarterly reports to STI project manager via e-mail within 15 days of the end of each quarter.

Provided final reports for all remaining previous contract periods.

Collaborated with STI and other contractors on study designs to answer overall questions relating to limiting factors of littoral and pelagic fish populations.

Attended coordination meetings with Spokane Tribal biologists and other Lake Roosevelt subcontractors to discuss research findings and identify initial management options.

Performed rove and active point creel survey at various boat launches throughout the upper 1/3 of Lake Roosevelt from Gifford to China Bend.

> Collected rove and active point data according to a monthly-randomized schedule created by STI biologists. Creel data was collected from January 2005 through December 2005. The STI, along with a biometrician from WDFW, designed a new creel protocol, which began in September 2004 (Lee et al. 2006, Scofield et al., in press).
>
> Creel clerk attended coordination meetings via conference call among the reservoir wide creel clerks (STI and CCT) and STI staff as required (minimum 1 monthly).
>
> Submitted data collected from creel surveys by FAX within 1 working day and mailed the original data sheets within 1 week of the end of each month to the STI.

Assisted with sturgeon tag retention study for Lake Roosevelt White Sturgeon Project in February 2005.

Attended Resident Fish Conference in Spokane, WA in June 2005.

Attended Hydroacoustic Workshop in Yellowstone WY, in June 2005.

Assisted with Full Census Creel Survey in February, July and October 2005 per new creel protocol implemented in September 2004.

Collaborated with the STI and the CCT in November 2005 to collect data on walleye during the annual Fall Walleye Index Netting (FWIN). All fish data was given to the STI, with the exception of otoliths, which were sent to the WDFW lab for aging. Aging information was completed and sent to the STI.

WDFW biometrician provided edits and analysis for the implementation of the new creel protocol.

WDFW otolith lab analyzed otoliths for thermal marks collected during WDFW, STI, and EWU sampling.

Manuscript final edits and acceptance by Northwest Science for: “Status, Distribution, Diet, and Growth of Burbot in Lake Roosevelt, Washington”.