From: John Canning
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Subject: Comment on document ISRP 2007-9

We thank the Northwest Power and Conservation Council for the opportunity to provide further comment on the ISRPs review of proposal 200753900 - Promote Kokanee Repopulation in Lake Pend Oreille using Autonomous Underwater Vehicles (AUVs) for Location and Verification of Lake Trout Spawning Areas. As the authors of the proposal, we would like to respond to several issues brought up in the ISRP review.

First, we would like to address the statement that *"Causes of the Lake Pend Oreille kokanee declines are not fully known, so controlling lake trout spawning may or may not be the "silver bullet" that will facilitate kokanee recovery. The presumed issue is that lake trout are limiting kokanee populations by predation, and the autonomous underwater vehicles (AUVs) will help identify lake trout spawning grounds so that adults can be netted before they can reproduce successfully."* We feel it has been well established that lake trout are a cause of the recent kokanee declines. Maiolie et al (2006, see attached report) concluded that the kokanee population of Lake Pend Oreille was under severe predation stress. They based this finding on low survival rates in the older year classes of kokanee. These survival rates were measured by both annual trawl sampling and with hydroacoustics. This report is attached for your review. Maiolie et al (2007, in press) also shows that survival rates of kokanee in older age classes have continued to decline to record low levels in 2006. Although egg-to-fry survival has been greatly improved by good lake level management, predation losses are preventing the recovery of the kokanee population, and are in fact driving them to complete extirpation from the lake.

Other recent work estimated that the lake's 42,000 lake trout over age 3, consumed 120 metric tons of kokanee annually. This population estimate of lake trout was completed in 2006 using mark-and-recapture technique and bioenergetics modeling to determine consumption. This work is currently being written as a BPA report. A very recent population estimate of rainbow trout (completed this past spring) estimated their population at 19,000 fish over 16". Bioenergetics modeling estimated they consumed 108 metric tons of kokanee annually. In addition, predation from bull trout (8 tons of kokanee), pikeminnow, and other natural mortality of kokanee, have exceeded the total production of the kokanee population (207 tons produced). Currently, lake trout are the most numerous predator in the system and consume the most kokanee. Benefits to kokanee recovery could be made if lake trout abundance were reduced by locating and netting lake trout from their spawning areas.

Bonneville Power Administration, Avista Power Company, and Idaho Department of Fish and Game are working together in other ways to reduce both lake trout and rainbow trout in the lake. Commerical fisherman have been hired to harvest lake trout using trap nets and gillnets. Anglers can receive $15 for every rainbow or lake trout head turned in. Also fishing regulations have been changed to allow unlimited harvest of rainbow trout and lake trout from the lake and its tributaries even during the rainbow trout spawning season.   The point being that this proposal would be part of a much larger program to reduce predation on kokanee. Lake trout control alone is not a “silver bullet” toward solving the problem, but it is an important part of the equation to recover kokanee.

A second issue raised by the ISRPs review was a question regarding the use of this technology for other purposes and areas other than kokannee recovery in Lake Pend O’reille. Although this technology was proposed specifically for locating lake trout spawning beds in Lake Pend O’reille, underwater imagery can be a very useful and valuable component of exploratory, monitoring and evaluation aspects of many fisheries projects. This technology can provide valuable habitat, ecological, and/or fisheries information that is otherwise unattainable.

A camera equipped AUV can be instrumental in replacing indirect inferences about small scale ecological and fisheries phenomena in large water bodies with preferable quantitative, empirical imagery. In fact, favorable application of this technology could be very widespread, and could be effectively used in virtually any fisheries or aquatic ecology projects or programs that involve suitable submergent hydraulic conditions for recording underwater imagery (exceptions being waters with excessive depth, turbidity, or turbulence). Thus, when suitable waters are involved, creativity on the part of researchers or managers may be the limiting factor for successful implementation of this proposed technology.

FISHERY RESEARCH

LAKE PEND OREILLE FISHERY RECOVERY PROJECT

ANNUAL PROGRESS REPORT
March 1, 2004—February 28, 2005

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IDFG Report Number 06-25
August 2006

Lake Pend Oreille Fishery Recovery Project

Project Progress Report

2004 Annual Report

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TABLE OF CONTENTS

	Page
ABSTRACT	1
INTRODUCTION	2
STUDY AREA	2
PROJECT GOAL	3
PROJECT OBJECTIVES	3
METHODS	3
Kokanee Population	3
Hydroacoustic Population Sampling	3
Hydroacoustic Estimates of Biomass, Production, and Yield	5
Midwater Trawling	6
Fry Netting	8
Hatchery Fry Marking and Stocking	8
Spawner Counts and Surveys	9
Kokanee Spawning Habitat	9
Artificial Spawning Areas	10
Pelagic Predators	11
Abundance and Distribution	11
Target Identification	12
Biomass	13
Other Biotic and Abiotic Factors	13
Opossum Shrimp Abundance	13
Limnology	14
RESULTS	14
Kokanee Population	14
Hydroacoustic Population Sampling	14
Hydroacoustic Estimate of Biomass, Production, and Yield	15
Midwater Trawling	15
Fry Netting	16
Spawner Counts and Surveys	16
Kokanee Spawning Habitat	16
Artificial Spawning Areas	17
Pelagic Predators	17
Abundance	17
Distribution	17
Target Identification	18
Biomass	18
Other Biotic and Abiotic Factors	19
Opossum Shrimp Abundance	19
Limnology	19
DISCUSSION	19
Kokanee Population	19
Kokanee Spawning Habitat	19
Egg-to-fry Survival of Kokanee	19
Kokanee Population Status	20
Monitoring Methods	21

Table of Contents, continued.

Page

Spawner Counts and Surveys 21
Artificial Spawning Areas 21
Pelagic Predators 22
Hydroacoustic methodology 22
Pelagic Predator Biomass 22
Other Biotic and Abiotic Factors 23
Opossum Shrimp Abundance 23
Limnology 23
CONCLUSIONS 24
RECOMMENDATIONS 24
ACKNOWLEDGEMENTS 25
LITERATURE CITED 58
APPENDICES 61

LIST OF TABLES

Table 1. Population estimates of kokanee fry (millions) based on hydroacoustic surveys of Lake Pend Oreille, Idaho in 2004. Percentage of wild fry was based on the proportion of wild fry caught during fry netting. 26

Table 2. Population estimates of kokanee age classes (millions) excluding young-of-the-year, in Lake Pend Oreille, Idaho, August 2004. Estimates were made based on hydroacoustic surveys and partitioned into age classes based on the percent of each age class in the catch of a midwater trawl. 26

Table 3. Survival rates (%) between kokanee year classes estimated by midwater trawling and hydroacoustics, 1990-2004. Hydroacoustic estimates started in 1996. Year refers to the year that the older age class was collected. 27

Table 4. Comparison of kokanee reproductive success in Lake Pend Oreille, Idaho in 2003 and 2004. During the winter of 2002-03, the lake elevation was held above 626.4 m (2055 ft), and in 2003-04 the winter elevation was held above 625.1 m (2051 ft). 27

Table 5. Biomass, production, and yield (metric tons) of kokanee in Lake Pend Oreille, Idaho 1996-2004. 28

Table 6. Kokanee population statistics for trawling on Lake Pend Oreille, Idaho during August 2004 based on geometric means. 28

Table 7. Counts of kokanee spawning along the shorelines of Lake Pend Oreille, Idaho. The numbers shown indicate the highest weekly count. 29

List of Tables, continued.

Page

Table 8. Counts of kokanee spawning in tributaries of Lake Pend Oreille, Idaho. The numbers shown indicate the highest weekly counts at each site. 30

Table 9. Numbers of kokanee fry that were trapped during May 2004 after emergence from artificial spawning boxes placed near the Eagle Boat Ramp on Lake Pend Oreille, Idaho. 30

Table 10. Density estimates of large (>-33 dB) pelagic (water depth >70 m) fish in Lake Pend Oreille, Idaho, during 2003 and 2004. Geometric mean densities were based on log transformed data (log [x+1]). Transect locations for 2003 were described in Bassista et al. (2004). 31

Table 11. Fish implanted with sonic transmitters and tracked during 2003 and/or 2004. Rainbow trout (Rbt), lake trout (Lkt), and bull trout (Blt) were captured either by monofilament gillnets (gillnet), large trap nets (trap net), boat electrofishing (electrofish), or by a combined use of seines and gillnets (seine/gillnet). 32

Table 12. Mean depth and temperature at the location of sonic tagged rainbow trout, lake trout, and bull trout. All observations were made at night during the summers of 2003 and 2004. 33

Table 13. Habitat used by 8 rainbow trout, 10 bull trout, and 11 lake trout during the summers of 2003 and 2004 as determined by sonic tracking. Fish were classified into three groups. A fish was considered pelagic if it was in water >70 m and further than 10 m from the bottom. Fish found in water <70 m and not within 10 m of the bottom was classified as nearshore. A fish was considered benthic if it was found within 10 m of the bottom, regardless of depth. 33

Table 14. Densities (per m^2) of shrimp in Lake Pend Oreille, Idaho, June 15-21, 2004. Sections are shown in Figure 1. 34

Table 15. Secchi transparencies (m) at a mid-lake location (Figure 1) in Lake Pend Oreille, Idaho, 2004, for the period April through October. 35

LIST OF FIGURES

Page

Figure 1. Map of Lake Pend Oreille, Idaho showing prominent landmarks, limnology station, and the three lake sections. The dark lines mark the location of hydroacoustic transects in 2004. Inserted table depicts the area of kokanee habitat in each section. 36

Figure 2. Daily surface elevation of Lake Pend Oreille, Idaho during 2003 and 2004. 37

Figure 3. Map of Lake Pend Oreille, Idaho, showing the locations of transects used for kokanee trawling in 2004. Transects started at the dot and proceeded in the direction of the line. 38

Figure 4. Map of Lake Pend Oreille, Idaho, showing the locations of transects used for kokanee fry trawling in 2004. Transects started at the dot and proceeded in the direction of the line. 39

Figure 5. Design of the fry trap developed to capture emerging kokanee fry from the artificial spawning boxes in Lake Pend Oreille, Idaho during the 2003/2004 spawning season. 40

Figure 6. Map of Lake Pend Oreille, Idaho showing the locations used for shrimp sampling from June 15-21, 2004. 41

Figure 7. Distribution of target strengths from 14,206 pings on fish recorded during hydroacoustic surveys on Lake Pend Oreille, Idaho in August 2004. 42

Figure 8. Total biomass of kokanee in Lake Pend Oreille, Idaho 1995 to 2004. Biomass was estimated based on hydroacoustic surveys. 42

Figure 9. Stock-recruitment curves for the most recent generation (5 year classes) of kokanee in Lake Pend Oreille, Idaho. Figure A was based on trawling and B was based on hydroacoustics. 43

Figure 10. Survival rate for kokanee in Lake Pend Oreille, Idaho from age-1 to age-2 based on hydroacoustic estimates of abundance. 44

Figure 11. Kokanee biomass, production, and yield (metric tonnes) from Lake Pend Oreille, Idaho 1996-2004, excluding 1997 due to 100 year flood. Lines were fitted to all data points except 2004 to illustrate possible change. 44

Figure 12. Length-frequency distribution of kokanee caught by midwater trawling in Lake Pend Oreille, Idaho in August 2004. Abbreviations in the legend include Hatch = late spawning kokanee reared at the Cabinet Gorge Hatchery, Hat-E = early spawning kokanee reared at the Cabinet Gorge Hatchery, Wild = kokanee produced naturally in the lake and its tributaries. Numeral denotes age class. 45

Figure 13. Abundance of kokanee fry in Lake Pend Oreille, Idaho, as estimated using trawling and hydroacoustics. 46

List of Figures, continued.

Page

Figure 14. Comparison of gravel composition before and after the lake was filled to summer pool level at the beach south of Evans Landing and in Kilroy Bay, Lake Pend Oreille, Idaho 2004. 47

Figure 15. Comparison of gravel composition before and after the lake was filled to summer pool level at Ellisport Bay and the south side of Ellisport Bay, Lake Pend Oreille, Idaho 2004. 48

Figure 16. Comparison of gravel composition before and after the lake was filled to summer pool level at Twin Creek and Green Bay Lake Pend Oreille, Idaho 2004. 49

Figure 17. Depth distribution of hydroacoustic targets >-33 dB during August 2003 and 2004 in Lake Pend Oreille, Idaho used for our large pelagic fish population estimate. Fish in water shallower than 75 m deep, or fish at water depths below 35 m deep, were not included. 50

Figure 18. Nighttime depth distribution of pelagic hydroacoustic targets >-33 dB and sonic tracked rainbow trout, bull trout, and lake trout during the summers of 2003 and 2004. Marks located on the y-axis represent fish located on the lake bottom. 51

Figure 19. Biomass estimates of kokanee and large pelagic predators in Lake Pend Oreille based on hydroacoustic surveys during 2003 and 2004. Predator to prey ratio by these estimates are above each bar. 52

Figure 20. Length-frequency distribution of opossum shrimp during June 2004 in Lake Pend Oreille, Idaho. 53

Figure 21. Relationship between the egg-to-fry survival rate of wild kokanee in Lake Pend Oreille, Idaho, and the number of female kokanee spawning that year. Data were divided into years when the winter lake elevation was held higher (626.4 m) (dots) and years when the lake was drawn down (625.1 m) (diamonds). Survival rate in 2004 was labeled for clarity. 54

Figure 22. Annual mean density of opossum shrimp in Lake Pend Oreille, Idaho, 1973-2004. Data collected before 1989 were obtained from Bowles et al. (1991), and data from 1995 and 1996 were from Chipps (1997). Shrimp densities from 1992 and earlier were converted from Miller sampler estimates to vertical tow estimates by using the equation $y = 0.5814x$ (Maiolie et al. 2002). Gaps in the bar chart indicate no data were collected that year. 55

Figure 23. Density estimates of immature and adult shrimp in Lake Pend Oreille, Idaho for the past ten years (1995-2004). Ninety percent confidence limits were placed on the last three estimates, and a linear trend line was fitted to the data points. 56

List of Figures, continued.

Page

Figure 24. Correlation between opossum shrimp densities and the survival rate from kokanee eggs to fry in Lake Pend Oreille, Idaho 1995-2003. Correlation coefficient of 0.00004 indicates little correlation. 57

LIST OF APPENDICES

Appendix A. Location of areas surveyed for shoreline spawning kokanee in Lake Pend Oreille since 1972. 62

Appendix B. Estimated weights of large (>-33 dB) pelagic (water >70 m deep) fish that were at depths <30 m in Lake Pend Oreille, Idaho in 2004. Weights were based on Irving's (1986) length-weight regression for Kamloops rainbow trout. 63

ABSTRACT

The winter elevation of Lake Pend Oreille, Idaho was experimentally lowered during the winter of 2003-04 as part of a multiyear study to improve the spawning and incubation success of kokanee *Oncorhynchus nerka.* During the winter of 2003-04, the lake was drawn down to near minimum pool to allow wave action to clean and re-sort spawning gravels. An additional 25,155 m^2 of spawning gravel appeared to have been created along the shoreline that would be available for spawning kokanee for the following year by keeping the winter lake level 1.2 m higher in future years. However, kokanee egg-to-fry survival dropped to an estimated 2%, because adults were forced to crowd into limited areas where superimposition of redds occurred. These results demonstrated a contrasting range of benefits that could be achieved with proper lake level management.

We estimated kokanee biomass in Lake Pend Oreille declined from 11.4 kg/ha in 2003 to 7.0 kg/ha in 2004, the second lowest recorded for this lake. Kokanee production dropped for the second straight year to 9.6 kg/ha while yield of kokanee increased to 14.5 kg/ha between 2003 and 2004. These findings indicated that the predator/prey imbalance first noted in 1999 was continuing to worsen. We also monitored the opossum shrimp *Mysis relicta* population to help identify other factors that may affect kokanee. A long-term decline in shrimp density continued in 2004 with total shrimp densities at 413 shrimp/m^2. Shrimp densities were not well correlated to the egg-to-fry survival rate of kokanee (r^2 = 0.00004), strengthening the argument that shrimp abundance does not currently determine kokanee survival.

We attempted to develop a hydroacoustic technique to estimate the abundance of rainbow trout *Oncorhynchus mykiss* larger than 415 mm total length (TL) within the limnetic zone of Lake Pend Oreille. Knowing their abundance could help managers balance populations of predator and prey and maintain good fisheries. During the summers of 2003 and 2004, we used sonic tracking to search for eight rainbow trout, 11 lake trout *Salvelinus namaycush*, and 10 bull trout *S. confluentus* to determine the nighttime habitat used by these species. Bull trout and lake trout were mainly found along nearshore benthic areas and used mean depths of 23 and 27 m, respectively. Both species were occasionally located in the limnetic zone. Rainbow trout were exclusively located in the limnetic zone between the lake's surface and 25 m (mean depth = 8 m). We conducted mobile hydroacoustic surveys during August to estimate the abundance of pelagic fish >415 mm TL based on target strengths. We then compared the nighttime location of acoustic targets to the distributions of sonic tracked fish. On the echograms, fish >415 mm TL in the limnetic region were located between the 12 m and 35 m depths (mean = 23 m), and so overlapped the habitat used by all three predatory species. No fish >415 mm TL were detected by hydroacoustics in water <12 m deep. Therefore, our current downlooking hydroacoustic technique would appear to miss many of the shallow rainbow trout and include some lake trout and bull trout in the abundance estimates.

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INTRODUCTION

The kokanee population in Lake Pend Oreille once provided harvests of over a million fish, but is now approaching record low densities (Maiolie and Elam 1993). Beginning in 1996, the U.S. Army Corps of Engineers experimentally changed the winter lake levels of Lake Pend Oreille to improve the habitat for kokanee *Oncorhynchus nerka* spawning along the shorelines. Since then, winter lake levels have fluctuated from the low pool elevation of 625.1 m (2,051 ft) above mean sea level (MSL) to a higher winter elevation of 626.4 m (2,055 ft) MSL. Wave action was found to build clean gravel bars along some shorelines during the winters of full drawdown. Then during winters of higher water levels, kokanee could use these gravel bars for spawning. Lake Pend Oreille was lowered to its low pool elevation of 625.1 m during the winter of 2003-04 to allow wave action to improve the quality of shoreline spawning areas. We documented the effect on spawning habitat as well as the egg-to-fry survival rate during this year as part of this long-term experiment.

Maiolie et al. (2002) recommended developing a hydroacoustic method to estimate rainbow trout *Oncorhynchus mykiss* abundance. By having the ability to monitor kokanee and pelagic predator abundance annually, we may be able to implement management actions designed to help balance predator and prey populations and to improve kokanee survival rates. A proper balance between predator and prey populations is one component necessary to recover the kokanee population and fishery in Lake Pend Oreille, and it would compliment improvements in spawning habitat that were shown to increase egg-to-fry survival (Maiolie et al. 2002). During 2004, we compared the depth distribution of large hydroacoustic targets with the depths of sonic tracked rainbow, lake, and bull trout to determine the effectiveness of surveys.

STUDY AREA

Lake Pend Oreille is located in the northern panhandle of Idaho (Figure 1). It is the largest lake in Idaho and has a surface area of 38,300 ha, a mean depth of 164 m, and a maximum depth of 351 m. Pelagic habitat used by kokanee is considered to be 22,646 ha (Figure 1) (Bowler 1978). Summer pool elevation of Lake Pend Oreille is 628.7 m. Operation of Albeni Falls Dam on the Pend Oreille River keeps the lake level high and stable at the summer pool level (June-September) followed by a drawdown of the lake to 625.1 m or 626.4 m during fall and winter (Figure 2). The Clark Fork River is the largest tributary to the lake. Outflow from the lake forms the Pend Oreille River.

Lake Pend Oreille is a temperate, oligomesotrophic lake. Summer temperatures (May to October) averaged approximately 9°C in the upper 45 m (Rieman 1977; Bowles et al. 1987, 1988, 1989). Thermal stratification typically occurs from late June through September.

A diverse assemblage of fish species is present in Lake Pend Oreille. Native game fish include bull trout *Salvelinus confluentus***,** westslope cutthroat trout *O. clarkii lewisi*, and mountain whitefish *Prosopium williamsoni.* Native nongame fish include pygmy whitefish *P. coulterii*, five cyprinids, two catastomids, and one cottid. Kokanee entered the lake in the early 1930s as downstream migrants from Flathead Lake, Montana and were well established by the 1940s. The estimated peak harvest of kokanee was 1.3 million fish in 1953 (Jeppson 1953). Other introduced game fish include Gerrard rainbow trout, lake whitefish *Coregonus clupeaformis*, and lake trout *Salvelinus namaycush,* in addition to several other cold, cool, and warmwater species.

PROJECT GOAL

The Lake Pend Oreille Fishery Recovery Project's goal is to recover the sport fisheries of the lake that have been impacted by the federal hydropower system and to improve the Lake Pend Oreille ecosystem to the benefit of fish and wildlife, thereby enhancing fishing, recreational opportunities, and other resource values. This is to be accomplished while managing the lake levels for the balanced benefit of fish, wildlife, flood control, and power production.

PROJECT OBJECTIVES

Objective 1. Recover kokanee abundance so that a harvest of 750,000 fish can be maintained on an annual basis.

Objective 2. Have no net change in the amount of shoreline spawning gravel (maintain 160,000 m^2) due to erosion or siltation during this experiment.

Objective 3. Monitor baseline limnological factors that could influence the lake's fish populations.

Objective 4. Balance the pelagic predator and prey populations at a ratio of less than 1 kg predator to 6 kg prey. This ratio is a starting point for predator-prey balancing; other objectives will help to define this ratio more specifically for Lake Pend Oreille.

Objective 5. Redefine the point of balance for predators and prey in Lake Pend Oreille where kokanee survival drops below 50% for any year class.

Objective 6. Research and implement methods for the removal of predatory fish that will not impact bull trout. Adjust the predator:prey ratio until the balance point is reached.

Objective 7. Minimize the competition between bull trout and other predatory fish. Reduction in other predators and improvements in kokanee abundance would minimize competition for forage.

METHODS

<u>Kokanee Population</u>

Hydroacoustic Population Sampling

We conducted lakewide hydroacoustic surveys on Lake Pend Oreille to estimate the abundance of kokanee and large pelagic fish >410 mm total length (TL) (> -33 dB; Love 1971). Surveys were performed at night between August 23 and August 30, 2004. Surveys were only performed during night hours (noncrepuscular), because we previously determined that daytime hydroacoustic surveys in Lake Pend Oreille did not detect as many large targets (> -33 dB) as night surveys, and kokanee schooled during daylight and were more difficult to enumerate (Bassista and Maiolie 2004; Bassista et al. 2005).

A Simrad EK60 portable scientific echo sounder equipped with a 120 kHz split beam transducer set to ping at 0.6 s intervals was used to perform mobile hydroacoustic surveys. The transducer was located 0.5 m under the lake surface and placed in a downlooking position off the port side of the boat. Based on this position, the hydroacoustic beam had a diameter of 1.2 m and 3.5 m at depths of 10 m and 30 m below the transducer, respectively. The echo sounder was calibrated annually for signal attenuation to the sides of the acoustic axis using Simrad's Lobe program.

A stratified systematic sampling design was used in our survey. We used a uniformly spaced, zigzag pattern of transects going from shoreline to shoreline as described by MacLennan and Simmonds (1992). The starting point of the zigzag pattern was chosen randomly so transect locations varied annually. Thirty transects were completed in the lake with ten transects in each of the southern (section 1), middle (section 2), and northern sections (section 3) of the lake (Figure 1). Transect lengths ranged from 3.5 km to 8.2 km and were located using a global positioning system (GPS). For all transects we utilized a 7.3 m boat and maintained a speed of approximately 1.3 m/s (boat speed did not affect our calculations of fish density).

We determined kokanee abundance using the echo integration techniques within Echoview software version 3.10.135.03. Targets were included if they met a set of specific criteria. Hydroacoustic traces (a single returned echo from a fish) were accepted if they were over –60 dB and the echo length was between 30% and 180% of the original pulse length at the point of 6 dB below the peak echo value. Additionally, the correction value returned from the transducer gain model could not exceed a two-way maximum gain compensation of 6.0 dB (therefore, this includes all targets within the 3 dB beam width). The targets were accepted if the maximum standard deviation of the minor and major axis angles was less than 0.6 degrees. Targets also had to be aggregated within a layer of fish from about 12 to 50 m to be considered a kokanee.

Once kokanee targets found throughout an echogram met the above criteria, density estimates of all kokanee in each transect were calculated. A box was drawn around the kokanee layer on each echogram to define the area sampled (usually between the 12 m and 50 m depths). We then echo integrated the area in the box to obtain the nautical area scattering coefficient (NASC) and analyzed the box to obtain the mean target strength of all returned echoes. Densities were then calculated by the equation:

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

where: NASC is the total backscattering in m^2/nautical mile^2
TS is the mean target strength in dB for the area sampled

This integration accounted for fish that were too close together to be detected as a single target (MacLennan and Simmonds 1992). The geometric mean density of kokanee was calculated for each lake section by first log transforming the transect densities (log [x+1]). Separate density estimates were made for fry and older aged kokanee. We then multiplied the geometric mean density of kokanee within each lake section by the area of that section.

We used *in situ* target strengths to split fry from the older age classes of fish using Echoview software version 3.10.135.03. Fish traces (a single returned echo off a single fish) were plotted on a bar graph of target strength versus frequency. We used the low point on the distribution curve to define the size break between fry and older age classes of kokanee and checked this size against the sizes of kokanee caught in our midwater trawl samples. Kokanee of ages 1 to 4 were not separated based on their target strengths.

Once we established density estimates for kokanee and pelagic fish >-33 dB on each transect, we calculated ninety percent confidence intervals for lakewide abundance estimates by standard expansion formulas for stratified sampling designs using log transformed data (Scheaffer et al. 1979):

$$\bar{x} \pm t_{n-1}^{90} \sqrt{\frac{1}{N_{total}^{2}} \sum_{i=1}^{3} N_i^{2} \left(\frac{N_i - n_i}{N_i} \right) \frac{s_i^{2}}{n_i}}$$

where:

$\bar{x}$ = the estimated mean number of kokanee in the lake,
t = the Student's t value,
N_i = the number of possible samples in a section i,
n_i = the number of samples collected in a section i,
s_i = the standard deviation of the samples in strata i,

To estimate abundance of hatchery and wild fry, we used two different methods to ensure data were comparable to historic methods and to utilize a potentially more accurate technique. For the first method, we multiplied the total hydroacoustic estimate of fry in each section of the lake by the proportion of wild and hatchery fry collected in midwater trawl samples for that section (trawling described below). For our second method, hydroacoustic fry abundance was multiplied by the proportion of wild and hatchery fry collected in small-mesh fry net for each section of the lake (described below). For both methods, lake section totals were summed to get lakewide abundance estimates of fry. Pelagic targets between -57.0 and -45.0 dB were considered kokanee fry. Hatchery fry were identified based on the presence of cold-brand marks on otoliths verified by Washington Department of Fish and Wildlife.

To estimate the abundance of mature kokanee in Lake Pend Oreille, we multiplied the acoustic estimate of age-1-4 kokanee (-46 dB to –33 dB) in each lake section by the percentage of mature kokanee caught in the midwater trawl within that section. This estimate was divided by 2 to obtain an estimate of mature female kokanee. The number of mature female kokanee collected by hatchery crews was subtracted from the population estimate of mature female kokanee to obtain the number of wild female spawners. The wild spawner estimate was then multiplied by kokanee fecundity to obtain wild potential egg deposition (wild PED). The number of wild fry was divided by last year's wild PED to estimate wild egg-to-fry survival.

Hydroacoustic Estimates of Biomass, Production, and Yield

We calculated the biomass, production, and yield of the kokanee population in Lake Pend Oreille to look for possible evidence of high predation. Hydroacoustic population estimates, along with kokanee weights gathered from the trawl catch, were used for these calculations. Biomass was the total weight of kokanee within Lake Pend Oreille at the time of our population estimate. It was calculated by multiplying the population estimate of each kokanee year class by the mean weight of kokanee in that year class. The year class weights were then summed for the lake's overall kokanee biomass.

Production was defined as the growth in weight of the kokanee population regardless of whether the fish was alive or dead at the end of the year (Ricker 1975). To determine production of an age class of kokanee between two years, we used a three-step equation for each age class. First, we subtracted the mean weight of kokanee in each year class of the previous year from the current year's mean weight of the same cohort (to get the increase in weight of each year class). Second, we averaged the population estimates between the two years. Lastly, we multiplied the increase in mean weight by the average population estimate for each age class. We then summed the results for all of the year classes to determine the production for the entire population. These calculations assume a linear rate of growth throughout the year.

Yield refers to the total weight of kokanee lost from the population due to all forms of mortality (Ricker 1975). To determine annual yield for each age class, we calculated the mean weight per fish between the current and previous year. We then subtracted the population estimate of the current year from the previous year (for each age class) to determine the number of fish that died. Lastly, we multiplied the mean weight times the number that died to estimate the yield for each age class. Results were summed across all year classes to estimate total yield for the kokanee population. Calculations assumed a linear rate of mortality throughout the year.

We regressed both production and yield against kokanee biomass to determine where these two lines cross. At that point, production and yield were equal and biomass would stay stable, which could indicate predator and prey were in balance. Data from 1996 to 2003 were used to plot the trend lines, with the exception of 1997, which was a flood year (due to high mortality that was likely not predator related). Data from 2004 were added to the graph to see if it indicated a change in the predation level in the lake.

Midwater Trawling

We conducted midwater trawling in Lake Pend Oreille from August 10 to August 14, 2004. These dates were during the dark phase of the moon, which optimized the capture efficiency of the trawl (Bowler et al. 1979).

The lake was divided into three sections (Figure 3), and a stratified random sampling scheme was used to estimate kokanee abundance and density. We randomly selected 12 locations within each section and one haul was made in a randomly selected direction at that location. We located each trawl site using the GPS.

Rieman (1992) described in detail the sampling procedures for midwater trawling. However, the net used in our study was slightly different. For the second year, a fixed frame net (10.5 m long with a 3.01 m tall x 2.2 m wide mouth) was used. This net had a rigid steel frame that kept the mouth of the net open and, therefore, did not have otter boards preceding the net mouth. Mesh sizes (stretch measure) graduated from 32, 25, 19, and 13 mm in the body of the net to 6 mm in the cod end. We towed the net through the water at a speed of 1.62 m/s by an 8.8 m boat. We determined the vertical distribution of kokanee by using a Furuno Model FCV-582 depth sounder with a 10° transom mounted transducer. A stepwise oblique tow was conducted along each transect to sample the entire vertical distribution of kokanee, with each step lasting for 3 min (a step corresponded to a 3 m depth strata).

Kokanee from each trawl sample were counted and placed on ice until the next morning when they were analyzed (fry were placed on dry ice to quickly freeze them). Age-1 to -4 kokanee were processed the next day without being frozen. Fry were kept frozen until analyzed. Length and weight were recorded for individual fish, and all kokanee over 180 mm were checked for maturity. Scales and otoliths were taken from 10 to 15 fish in each 10 mm size interval for aging, if available. The otoliths from 105 fry and 137 kokanee between the ages of 1 and 4 were sent to the Washington Department of Fisheries Otolith Laboratory for aging and identification of cold brands to detect hatchery fish.

Kokanee catch per trawl haul was divided by the volume of water filtered by the net to obtain density of kokanee caught. The age-specific density estimate for each section was expanded into a total population estimate using standard expansion formulas for stratified sampling designs (Scheaffer et al. 1979). Kokanee abundance was estimated using geometric (log [x+1]) and arithmetic means (the geometric means probably provide a more accurate estimate of kokanee abundance; however, arithmetic means were calculated for comparisons to past data). The area of the southern and middle sections was calculated inside the 91.5 m contour, and the area of the northern section was calculated inside the 36.6 m contour because of shallower water. Area inside these contours represented the pelagic area of the lake where kokanee were found during late summer (Bowler 1978). For consistency, these same areas have been used each year since 1978; a total of 22,646 ha (Figure 3). Ninety percent confidence intervals (CI) were calculated for kokanee abundance estimates (see equation under Hydroacoustic Population Sampling).

The number of wild and hatchery fish, identified by otolith examination, was used to calculate the percentage of each group within each 10 mm length group. Percent wild fish was multiplied by the population estimate within each length group and then summed to determine the abundance of wild fish.

Potential egg deposition was also calculated based on midwater trawl catch. Percent maturity within each 10 mm length group was multiplied by the population estimate for that length group (based on arithmetic means for consistency to past data) and then summed across length groups. We divided the estimate of mature kokanee by two to obtain an estimate of mature female kokanee (actual trawl catch was 15 mature males : 11 mature females). The number of mature females in the lake was then multiplied by the mean fecundity seen at the Sullivan Springs spawning station to estimate potential egg deposition. Mean fecundity was determined by dissecting 20 female kokanee from the beginning, middle, and end of the spawning run (n = 60). We subtracted the number of females spawned by hatchery personnel at the Sullivan Springs egg-take station and trap mortalities to determine the number of eggs spawned by wild fish (wild PED) based on trawling.

A stock-recruitment curve was drawn for the last generation of kokanee based on trawl data. The number of mature kokanee was graphed against the number of mature kokanee they produced and fitted with a Ricker type curve (Haddon 2001).

Fry Netting

We sampled Lake Pend Oreille with a small mesh net as an additional method to estimate kokanee fry abundance. Sampling with the fry net began on Lake Pend Oreille in 1999 and has continued annually thereafter. Net hauls were made during the same new moon period as that year's midwater trawling to make the results comparable. Ten net hauls were made in each lake section from August 16 to August 18, 2004 (Figure 4).

The fry net was 1.27 m high by 1.57 m wide across the mouth (2 m^2) and 5.5 m in length. Bar mesh size for the net was 0.8 mm by 1.6 mm. The sampling bucket on the cod end of the net contained panels of 1 mm mesh.

Stepwise oblique tows were made through the layer of kokanee seen on the boat's echo sounder. Fry net depths ranged from 15 m to 43 m. The fry net was towed for three minutes at each "step" (a step corresponded to a 3 m depth strata or a 15 m length of cable) until the entire kokanee layer had been sampled. The average boat speed was 1.7 m/s.

All kokanee caught in the fry net were immediately frozen on dry ice. Upon return to the dock, the fry were stored in a freezer for later analysis. The fish were later thawed and measured for length and weight. Total length of each fry was rounded down to the nearest whole mm. Otoliths were removed from kokanee fry (n = 101) caught in the fry net and sent to the Washington Department of Fish and Wildlife Otolith Lab for analysis.

Density of fry (fish/ha) in the kokanee layer was calculated for each net tow based on the volume of water sampled by the net (boat speed [m/s] x time [s] x the area of the net mouth [m^2]) as it passed through the kokanee layer, multiplied by the thickness of the kokanee layer (m), and multiplied by 10,000 to convert estimates to fish/ha. Density estimates were averaged per section and expanded by the suitable area of the section. Estimates of fry within each section were summed to determine the lakewide population estimate of fry.

Hatchery Fry Marking and Stocking

All kokanee released from Cabinet Gorge Fish Hatchery since 1997 have been marked by "thermal mass marking" techniques (or cold branding) described by Volk et al. (1990). Therefore, hatchery kokanee of any age should contain thermal marks. The intent of this marking was to be able to separate hatchery and wild kokanee throughout their lifecycle to determine survival rates.

Thermal marking of the otoliths was done at the Cabinet Gorge Fish Hatchery. Thermal treatments were initiated five to ten days after fry hatched and entered their respective raceways. Fry released in 2004 (brood year 2003) received a 10 day pattern created by four cool water events. The first and second events and the third and fourth events were separated by one day. The second and third events were separated by four days.

Ten fry from each raceway were sacrificed to verify the thermal marking. Recognizable otolith marks were verified on all thermally treated individuals. On March 25, 2004, approximately 232,000 unfed late kokanee fry were released in Spring Creek. The following day an additional 174,000 unfed late kokanee fry were released in Garfield Bay. On May 25, 1,182,613 early run kokanee were released into Sullivan Springs followed by 326,882 late kokanee fry the next day. The next release occurred on June 8, 2004 when 975,331 late kokanee fry were released into Spring Creek. On the next day, 928,808 late kokanee fry were placed in the Clark Fork River (Foster Bar side channel). On June 10, 977,008 late kokanee fry were placed in Twin Creek. The final release of the year occurred from June 15-18, 2004 when 8,463,556 late kokanee fry were released into Sullivan Springs.

We sent 343 otoliths from all kokanee age classes collected during the August trawling to the Washington Department of Fish and Wildlife lab to determine origin. Before shipment, we catalogued each fish, recorded total length and weight, and removed, cleaned and numbered the otoliths. Washington Department of Fish and Wildlife personnel removed one otolith from each of the 343 vials and oriented it on a glass plate labeled to associate the otolith with the specimen vial. Under a fume hood, otoliths were positioned on a glass plate and surrounded with a preformed rubber mold. Rubber molds were then filled with clear fiberglass resin and warmed in an oven for approximately 1 h for curing. The resulting blocks of resin containing the otoliths were cut into groups of four otoliths per block for sectioning and polishing. Blocks of four otoliths were lapped on a rotating disc of 500 grit carborundum paper until the nucleus of each otolith was clearly visible. The otoliths were then polished using a rotating polishing cloth saturated with one micron deagglomerated alpha alumina and water slurry. After lapping and polishing, the otoliths were examined with a compound microscope at 200 power and/or 400 power magnification. Patterns within the otolith were compared to those reference samples taken from the hatchery during fry rearing since 1996. For accuracy, two independent agers examined each otolith. Differences between the readers were settled by re-examination.

Spawner Counts and Surveys

We counted spawning kokanee in standard shoreline areas (Appendix A) and tributaries to continue this time-series data set dating back to 1972. All areas surveyed have been documented as historic spawning sites (Jeppson 1960). Nine shoreline areas and seven tributary streams were surveyed once a week for three straight weeks beginning the third week of November 2003. All kokanee, either alive or dead, were counted. We then summed the highest count at each site to calculate a total spawner count.

Seven tributary streams were surveyed during the same period by walking upstream from their mouth to the highest point utilized by kokanee. Streams included South Gold, North Gold, Cedar, Johnson, Twin, Spring, and Trestle creeks (Trestle Creek supports both an early and late run of kokanee). Trestle Creek was also surveyed on September 16, 2004 to assess the early spawning kokanee stock. We also surveyed the Foster Rapids side channel of the Clark Fork River on November 30 to see if kokanee were utilizing the channel as spawning habitat.

Kokanee Spawning Habitat

Substrate samples were collected during both March and August of 2004 from potential spawning beaches that could be used by kokanee. We sampled shoreline substrate during March, before spring refill covered the exposed materials, to see if composition (percent fines, gravel, and cobble) changed once the substrate was inundated. Potential spawning areas were determined by visually surveying the entire shoreline to locate areas between lake elevations of 624.8 m and 625.8 m that had exposed gravel bars. These areas would be available to spawning kokanee during the winter of 2004-05 when the winter lake level was expected to be above 626.4 m MSL. At each identified location, we measured the length and width of available gravel below elevation 625.8 m, then calculated the total area of potential spawning habitat. Elevations were determined using a carpenter's laser level mounted on a tripod and set a fixed distance above the lake's surface level. One sample was collected at each site and then screened using soil sieves (sizes 31.5 mm, 6.3 mm, 4.0 mm, and 2.0 mm). Sieved samples were weighed to determine the composition. We defined "cobble" as substrates that were 31.5 mm and larger, "gravel" as substrates between 31.5 and 4.0 mm (changed from 6 mm this year), and "fines" as the substrate smaller than 4.0 mm. The reduction in the size of "fines" was based on our judgment that kokanee could successfully use 6 mm material for spawning.

Six sites were sampled during August to monitor changes in substrate composition after being inundated by higher summer pool levels. Scuba divers identified the same gravel band between elevation 624.8 m and 625.8 m and collected four to five samples from each of the six sites. Samples were allowed to drain and then composition was determined using the same methods as above.

Artificial Spawning Areas

Four types of artificial spawning boxes were in Lake Pend Oreille during the 2003-04 spawning season. Two large wooden frames, 2.4 m x 1.2 m x 0.2 m, were placed in the lake during the fall of 2001. Both had stainless steel perforated plate bottoms, lined with fiberglass window screen to contain any emerging fry, and were filled with 6-16 mm diameter gravel (gravel of this size was thought to be usable by kokanee). Each of these boxes was divided into eight equal compartments using 18 x 190 mm boards. One of the boxes had 4 cm ribs along the bottom in an attempt to provide better water circulation under the spawning box and through the gravel. Both of these boxes were placed on the southern side of Leiberg Point on a sand and gravel spit near Eagle boat ramp in Farragut State Park (47° 57.871' N, 116° 32.553' W).

Four other 1 m x 1 m x 0.2 m undivided wooden frames with stainless steel plate and screen mesh bottoms were filled with the same size gravel as above. Two of these had 4 cm ribs along the bottom, while two others had no ribs and lay directly on the lake bottom. These four frames were placed in the lake in October of 2001 and positioned by scuba divers. One frame with ribs and one frame without ribs were placed in close proximity to each other at each site to determine if the ribs were a benefit. A pair of these smaller boxes was placed on the southern side of Leiberg Point near the large boxes (47° 57.870' N, 116° 32.506' W), and a pair was placed near the tip of Leiberg Point (47° 58.156' N, 116° 32.250' W). We also designed fry traps for the tops of the spawning boxes to enumerate emerging fry. The fry traps were secured to the top of the spawning box to prevent fry from escaping (Figure 5).

In the fall of 2002, six additional 1 m x 1 m x 0.2 m boxes were placed in the lake. At each location, one box with bottom ribs and one without were placed together. A pair was placed at each end of Bernard Beach (47° 56.947' N, 116° 30.064' W and 47° 56.960' N, 116° 30.550' W) and one pair was placed just south of the Farragut swim area (47° 57.217' N, by 116° 34.343' W). All boxes were placed at a minimum depth of five feet below the minimum winter lake level.

We attempted to determine if the frame was causing kokanee to avoid the spawning boxes. Therefore, in the fall of 2002, three gravel patches approximately 2 m x 2 m were placed directly on the lake bottom with no supporting frame. Gravel, of the same size as before, was placed to a depth of about 10 to 15 cm on mostly cobble bottom areas. These gravel patches were placed on either side of the boxes set at Bernard Beach and on the shore near the Farragut Park swimming area.

Pelagic Predators

Abundance and Distribution

We performed lakewide hydroacoustic surveys to determine abundance and depth distribution of large pelagic fish (>-33 dB) using echo counting techniques. Analysis for predators was made on the same downlooking hydroacoustic survey that was used for estimating kokanee density. Surveys were conducted during summer when the lake was stratified, because warmer water temperature might help keep predators deeper in the water column where they were more vulnerable to downlooking echo sounding. Fish were classified into three groups. A fish was considered "pelagic" if it was in water >70 m deep and further than 10 m from the bottom. If a fish was found in water <70 m deep and not within 10 m of the bottom, it was classified as "nearshore." A fish was considered "benthic" if it was found within 10 m of the bottom, regardless of depth. Based on findings by Bassista and Maiolie (2004) and Bassista et al. (2005) we did not include any benthic targets, any targets found below 35 m, or any targets found in aggregations with other targets in our population estimate. We did this to increase the likelihood that we were mostly counting rainbow trout and exclude lake whitefish from the survey.

Echoview software version 3.10.135.03 was used to locate larger fish targets from the hydroacoustic echograms. To distinguish potential pelagic predators, hydroacoustic traces (a single returned echo from a fish) were only examined if they were: 1) >–39 dB (this is smaller than the mean of –33 dB, which allows for individual traces to be below –33 db), 2) the mean of all traces on a fish had to be >-33 dB, 3) the returned echo length at 6 dB below the peak value was between 30% and 180% of the original pulse, 4) the correction value returned from the transducer gain model did not exceed a two-way maximum gain compensation of 6.0 dB (thus all targets within the 3 dB beam width were included), and 5) the maximum standard deviation of the minor and major axis angles was less than 0.6 degrees. Fish with a mean target strength >-33 dB were included as potential predatory fish, which corresponded to a fish with a length of about >415 mm (Love 1971).

Large pelagic fish densities were determined with the same methods used in 2003 (Bassista and Maiolie 2004). Fish density (fish/ha) for each transect was calculated by dividing the number of large pelagic fish by the area sampled at the depth of the fish. Area was calculated by multiplying the number of pings on a transect by the area of a circle at the depth of the fish with a 6.8° cone. Densities were summed (vertically) when more than one large fish was found on a transect. Density estimates were log transformed (log [x+1]) and then averaged for each lake section to obtain a geometric mean density per lake section.

A population estimate was determined for each lake section by taking the geometric mean density (fish/ha) for each section and multiplying it by each section's surface area (ha) inside the lake's 70 m contour line (a total of 21,332.1 ha). Population estimates within each lake section were added together to determine a lakewide population estimate and compared to results from 2003.

We used a scatter plot to represent the depth distribution of large pelagic fish found in 2003 and 2004. Hydroacoustic targets >-33 dB that were at least 10 m from the bottom, found over bottom depths >70 m, and in water depths shallower than 35 m were graphed on the basis of target depth and lake depth below target. We considered these targets potential pelagic predators. We conducted water temperature profiles (1 m intervals) in each lake section prior to hydroacoustic sampling to describe the habitat used by hydroacoustic targets.

Target Identification

We set suspended gillnets in the water column below 35 m to determine the species of large hydroacoustic targets that were detected below this depth in the open water. Based on hydroacoustic data collected during August 2002 and 2003, groups of these fish were concentrated in the northern portion of Lake Pend Oreille west of Warren and Cottage islands (Bassista and Maiolie 2004; Bassista et al. 2005). We suspended monofilament gillnets (6.0 m deep X 60.0 m long) horizontally at depths of 40 to 60 m near where the pelagic fish were observed. The gillnets were composed of two 6.0 m long panels of the following mesh sizes: 50.8 mm, 76.2 mm, 101.6 mm, 127.0 mm, and 152.4 mm, randomly placed throughout the net. Soak time for each net was between two and ten hours, and all sets were at night. Gillnetting was performed during August and September in 2003 and 2004 immediately following our hydroacoustic survey.

Sonic tracking of rainbow, lake, and bull trout was performed during the summer of 2004 to determine their nighttime habitat use and help identify hydroacoustic targets found on the echograms. Tracking data collected during the summer of 2003 on bull trout and lake trout was also used for target identification (Bassista et al. 2005). We collected lake trout and bull trout using various size monofilament gillnets set perpendicular to shore during early morning hours in April and May. Rainbow trout were collected by electrofishing the Clark Fork River in Idaho and by seining in Spring Creek, a tributary of Lightening Creek, during April and May. We used two types of sonic transmitters during the summer of 2004. One type of transmitter, a Sonotronics DT-97, was described in Bassista et al. (2005). The other was a Sonotronics IBT-97 miniature depth transmitter that measured 65 mm in length, had an outside diameter of 11 mm, and weighed 4.0 g underwater. The IBT-97 transmitters had a battery life of 6 months and the DT-97 transmitters lasted at least 12 months (some tags lasted for more than 2 years). Sonic transmitters were surgically implanted in the abdominal cavity of predator fish >415 mm and the methods and calibration techniques were described in Bassista and Maiolie (2004) and Bassista et al. (2005).

Sonic tracking was performed before, during, and after our hydroacoustic surveys while Lake Pend Oreille was thermally stratified. Tracking was limited to nights of low to moderate winds when detection range of the tags was greatest. Tracking was only performed during hours of complete darkness. Crepuscular hours were avoided since we do not conduct hydroacoustic surveys during that time. All tracking was carried out in a 6.3 m boat using directional and omnidirectional hydrophones and a portable receiver (Sonotronics USR96). We utilized a search pattern consisting of a 1.0 km grid based on the detection range of the sonic transmitters (see methods in Bassista et al. 2005).

Habitat information was collected each time a fish was located. Fish depth, water depth, fish's distance from the bottom, and distance from shore were recorded. Scatter plots of fish locations were compared to the locations of echoes in the hydroacoustic surveys to help determine species.

Biomass

We calculated a lakewide biomass estimate of large pelagic fish (>415 mm) that were found at depths ≤35 m. Target strengths of fish >-33 dB were converted into fish length (mm) using the following equation from Love (1971):

$$TS = 19.1 \text{ Log } L + 0.9 \text{ Log } \lambda - 34.2$$

Where:

TS = target strength (dB),
L = fish length in ft, and
λ = acoustic wavelength in ft.

We then converted fish length into weights using the relationship for Kamloops rainbow trout in Irving (1986):

$$W = 0.000126 \times L^{3.385}$$

Where:

W = weight (lbs), and
L = length (inches).

The mean weight of all large pelagic fish was multiplied times the mean density (fish/ha) of these fish, then multiplied by the number of hectares inside the lake's 70 m contour (21,332.1 ha) to obtain an estimate of predator biomass. Predator biomass was compared to kokanee biomass to calculate a predator:prey ratio for the pelagic area of the lake.

Other Biotic and Abiotic Factors

Opossum Shrimp Abundance

We sampled opossum shrimp *Mysis relicta* from June 15-21, 2004 to estimate their density within Lake Pend Oreille. All sampling occurred at night during the dark phase of the moon. The new moon during June has been the standard sampling date for most of the previous work on shrimp and for all of our sampling since 1997. Previously, only ten sites were sampled from each lake section (from 1997-2003); however, this year we selected 15 sampling locations randomly in each of the three lake sections (Figure 6) to improve population estimates and tighten confidence intervals. GPS coordinates were utilized to locate each sample site. We calculated the arithmetic and the geometric means for the immature and adult population of opossum shrimp and used the arithmetic means for young-of-the year (YOY). We also calculated the 90% CI for each estimate.

We collected shrimp using a 1 m hoop net equipped with a Kahl Scientific pygmy flow meter with an antireversing counter. Net mesh and cod end bucket mesh measured 1,000 μm and 500 μm, respectively. The net was lowered to a depth of 45.7 m, allowed to settle for 10-15 seconds, and raised to the surface at a rate of 0.5 m/s using an electric winch. Collected shrimp were placed in denatured ethanol for preservation until laboratory analysis could be performed to determine age and sex data. This methodology has been the standard since 1997.

During lab analysis, opossum shrimp were viewed under a dissecting scope to determine sex, and measured from the tip of the rostrum to the end of the telson, excluding setae. They were then classified into five categories according to sex characteristics: young-of-year (shrimp measuring <11 mm in total length), immature males and females, and mature males and females (Gregg 1976, Pennak 1978).

Limnology

From April through October 2004, we measured water temperature and water clarity (Secchi transparency) monthly. Data were collected at one station at the approximate center of the lake (Figure 4). Sample dates were approximately the middle of each month. We used a Yellow Springs Instrument Company model 57 meter to measure temperature and dissolved oxygen from the surface to a depth of 59 m. The meter was calibrated before each survey using the "water saturated air" method suggested by the manufacturer. Water clarity was monitored using a 20 cm diameter Secchi disc during each survey.

RESULTS

Kokanee Population

Hydroacoustic Population Sampling

In 2004, we estimated the lake contained 9.4 million (8.6 million to 10.1 million, 90% CI) kokanee based on our standard nighttime hydroacoustic surveys (414 kokanee/ha). This included 6.8 million age-0 kokanee (6.2 million to 7.4 million, 90% CI) and 2.6 million (2.3 million to 3.0 million, 90% CI) kokanee of ages 1-4 (Tables 1 and 2). Mean target strengths of kokanee traces showed a separation between kokanee fry and larger fish at the –45 dB level or a fish length of about 100 mm (Figure 7). This corresponded closely to the gap in the length-frequency distribution of trawl samples between fry and age-1 kokanee. Older age classes (ages 1-4) could not be defined based on target strengths alone. These were separated based on the percent frequency of kokanee age classes in trawl samples for each section of the lake (Table 2). The lake contained an estimated 1.1 million age-1, 783,000 age-2, 504,000 age-3, and 195,000 age-4 kokanee. Total biomass of all age classes was estimated at 158 t (Figure 8).

We also split the hydroacoustic estimate of age-1 to age-4 kokanee into the number of mature kokanee based on the percentage of mature fish in the trawl catch within each section. This served as an estimate of mature fish abundance somewhat independent of possible trawl bias. In the trawl, 23%, 15%, and 5% of the catch were mature in the southern, middle, and northern sections, respectively. This yielded an estimate of 397,000 mature kokanee or 198,000 mature female kokanee assuming a 50:50, male:female sex ratio. Fecundity of female kokanee was estimated at the egg-take station at Sullivan Springs to be 406 eggs/female, which yielded an estimated PED of 80.54 million eggs. The hatchery crew collected 50,023 female kokanee, which means the potential wild PED was 60.23 millions eggs (198,364 minus 50,023 females times 406 eggs/female).

A stock-recruitment curve of the previous generation of kokanee showed that three out of the last five year classes had replaced themselves (Figure 9). The two highest year classes, however, did not replace themselves.

Based on hydroacoustics, we calculated the survival rate of each year class of kokanee between 2003 and 2004. Survival was 21% from age-0 to age-1, 33% from age-1 to age-2, 28% from age-2 to age-3, and 18% from age-3 to age-4 (Table 3) (Figure 10).

We estimated wild fry abundance based on the hydroacoustic estimate of fry multiplied by the percent of wild fry in our fry net. Wild fry made up 21.2%, 14.3%, and 21.2% of the fry net catch in the southern, middle, and northern sections, respectively. Based on these numbers we estimated the wild fry population at 1.26 million. The survival of naturally deposited eggs (61.86 million deposited in 2003) to wild fry was estimated to be 2.0% (Table 4).

For comparison, egg-to-fry survival rates were also calculated based on the catch of the midwater trawl that has a larger mesh net. Wild fry made up 11.3%, 12.9%, and 7.7% of the fry caught from the southern, middle, and northern sections of the lake, respectively. These lower percentages indicated the loss of the smaller wild fry through the mesh of the trawl net. Using these percentages, we estimated the population of wild kokanee fry at 717,000. Survival of naturally deposited eggs (61.86 million deposited in 2003) to wild fry was estimated to be 1.2% based on the midwater trawl catch.

Hydroacoustic Estimate of Biomass, Production, and Yield

We estimated kokanee biomass at 158 metric tonnes (t), which was the second lowest biomass estimate in the last ten years (148 t in 2001) (Table 5) (Figure 8). Kokanee production dropped for the second straight year to 218 t (also the second lowest in the last 10 years) (Table 5). Yield of kokanee increased to 329 t between 2003 and 2004, the second highest yield since the lake level experiment began in 1996 (Table 5).

We plotted kokanee production and yield against kokanee biomass to examine trends and correlations (Figure 11). The two trend lines crossed at a point where biomass was approximately 245 t. Yield in 2004 was higher than yield estimates in 2000, 2001, and 2002 when kokanee biomass was similar. Production in 2004 was very near the trend line fitted to the production data from 1996 through 2003.

Midwater Trawling

Population estimates were also made based on midwater trawling. In August 2004, total kokanee abundance based on geometric means was 5.9 million fish (-18% to +22%, 90% CI) with a density of 260 fish/ha (Table 6). This included 5.0 million kokanee fry, 398,000 age-1 kokanee, 258,000 age-2 kokanee, 147,000 age-3 kokanee, and 48,000 age-4 kokanee. The total standing stock of kokanee was 2.36 kg/ha (Table 6). The five age groups ranged in length from 20 mm to 270 mm (Figure 12). Estimates of kokanee fry based on trawling were lower than the estimates based on hydroacoustics (Figure 13).

Based on trawling, the lake contained 205,700 mature fish. Using a 50:50 ratio (previously described), 102,850 were females used to calculate PED. We estimated PED for 2004 at 41.78 million eggs. Wild PED was estimated at 21.4 million eggs (37.84 million less than the estimate based on hydroacoustics). Stock-recruitment curves of mature kokanee show that one year class (the 303,000 adult kokanee in 1995 that produced the 335,000 adult kokanee in 2000) replaced itself in the last generation (Figure 9).

For continuity with past data, we also calculated kokanee abundance based on arithmetic means for 2004. Total kokanee abundance based on the arithmetic mean density of kokanee in each section was estimated at 6.8 million fish (± 12%, 90% CI), with a density of 299 fish/ha. This included 5.0 million kokanee fry (± 16%, 90% CI), 861,000 age-1 kokanee (± 38%), 449,000 age-2 kokanee (± 34%), 265,000 age-3 kokanee (± 35%), and 108,000 age-4 kokanee (± 45%). Total standing stock of kokanee was 4 kg/ha.

Fry Netting

A total of 186 fry were collected using the small-mesh fry net during August 2004. We collected 43 in the southern section, 77 in the middle section, and 66 in the northern section of the lake. Based on the volume of water filtered by the fry net, we estimated 5.2 million kokanee fry were in Lake Pend Oreille. The catches of fry were 21%, 14%, and 21% of wild origin in the southern, middle, and northern sections of the lake, which yielded an estimate of 958,000 wild fry.

Spawner Counts and Surveys

We observed 2,477 kokanee spawning on the shoreline in 2004. We counted 2,342 on the shoreline around Bayview, 100 in Idlewilde Bay, 1 along the shoreline in the Lakeview area, and 34 in Garfield Bay (Table 7).

We observed 13,696 kokanee spawning in tributaries around Lake Pend Oreille (Table 8). Hatchery personnel transplanted approximately 3,000 of the observed kokanee from the Sullivan Springs egg-take station to Spring Creek, since they were in excess of the hatcheries needs. We counted an additional 331 spawners in Spring Creek for a total of 3,331 kokanee. The remaining kokanee were counted in the following tributaries: 721 in South Gold Creek, 2,334 in North Gold Creek, 600 in Cedar Creek, 16 in Johnson Creek, and 6,012 in Twin Creek. An additional 682 kokanee were counted in the September spawning run in Trestle Creek.

Kokanee Spawning Habitat

We collected substrate samples from 68 sites during March and six sites during August. From these samples, we estimated an additional area of 25,155 m^2 of spawning gravel would be made available to kokanee (under at least 0.6 m of water) by raising the winter lake level to 626.4 m MSL in future years. We estimated areas of 4,986 m^2 for the west side, 5,755 m^2 for the south end and east side, 4,489 m^2 for the northeast side, 3,286 m^2 for the north shore, and 6,639 m^2 for the northwest shore.

Among the six sites sampled during both March and August, compositions changed slightly (Figures 14, 15, and 16). At all sites the percent of gravel decreased once water had risen to full summer elevation; however, the samples were still composed of mostly gravel. Areas appeared to be good quality for kokanee spawning based on the percent of gravel and the low incidence of fine material.

Artificial Spawning Areas

Spawning activity was noted in one of our spawning boxes for the first time in 2004. The large spawning box (with 4 cm ribs on bottom) that was located at Leiberg Point was observed to contain redds. SCUBA divers investigated the box and found eyed kokanee eggs present in four of the eight compartments. On March 8-9, 2004, the divers carefully excavated the gravel from one of the compartments and collected all of the eggs. A total of 113 eggs were found. Of these, 109 were alive and eyed-up, and four were dead (Table 9). At the same time, we placed a series of fry traps over the top of the other three sections of the box (Figure 5). We started checking the traps on May 7, 2004 and continued until no fry were observed on two consecutive dives. The first fry were trapped on May 14 and the last on May 28. The traps were removed on June 7, 2004. A total of 146 fry (56, 53, and 37 fry) were collected from these three sections of the spawning box (Table 9). The other large box had a slight amount of disturbance on one end, but extensive investigation revealed only two eggs in that area, so traps were not placed on this box. No activity was observed on any of the smaller boxes.

Pelagic Predators

Abundance

During August 2004, we estimated Lake Pend Oreille had 0.74 large pelagic fish/ha based on our down scanning hydroacoustic survey. Large pelagic fish densities were highest in section 1 (1.0 fish/ha) followed by section 3 (0.91 fish/ha) and lowest in section 2 (0.37 fish/ha) (Table 10). Mean fish density remained stable between 2003 and 2004 for section 1 but increased in 2004 in sections 2 and 3 (Table 10). Overall, the lakewide density estimate of large pelagic fish increased in 2004 (0.55 fish/ha in 2003). The number of transects where we did not detect any large pelagic fish dropped from 13 in 2003 to 11 in 2004.

During August 2004 we estimated Lake Pend Oreille contained 15,800 (90% CI = 10,500 to 21,900) pelagic fish >415 mm in water depths between 12 and 35 m. This estimate was larger than our estimate in 2003 of 11,700 fish (range 7,200 to 17,000 90% CI), though the estimates were not significantly different. Based on our size distribution of hydroacoustic targets and population estimate, the lake contained approximately 11,000 fish between 415 mm and 615 mm (16” to 24”) with the remaining fish up to 970 mm.

Distribution

We detected 294 large fish during our 2004 hydroacoustic survey for pelagic predators. The majority of these fish were located in benthic (119 fish) and nearshore (68 fish) areas and were excluded from our population estimate. The remainder of fish were detected in the pelagic area, of which 56 fish were in water <35 m and were not found in aggregations of other fish. We considered these 56 fish to be potential pelagic predators. The remaining deepwater pelagic fish (46 fish) were typically found in aggregations thought to be characteristic of whitefish and, therefore, not used in population estimates.

The depth distribution of potential pelagic predators shallower than 35 m was similar between 2003 and 2004. During both years the shallowest fish detected was approximately 13 m and mean depth of fish in 2003 was 20 m ± 4.9 m (±1 SD) and in 2004 was 24 m ± 5.43 m

(Figure 17). Based on the hydroacoustic surveys, pelagic fish were located in water temperatures between 6.6°C and 14.4°C in 2003 and between 9.3°C and 20.2°C in 2004.

Target Identification

Based on our hydroacoustic sampling in 2004, we detected 46 pelagic fish estimated to be larger than 415 mm that were deeper than 35 m and were found in aggregations of other fish. These fish were predominantly located in the northern portion of Lake Pend Oreille. In 2004, we gillnetted in this area for 27.5 net hours and captured five lake whitefish (352-468 mm TL), one lake trout (343 mm), and one northern pikeminnow *Ptychocheilus oregonensis* (445 mm). In 2003, we fished our nets for 32 net hours and captured two lake whitefish (404 mm and 396 mm). Based on these results, fish from this area appeared to be mostly lake whitefish with a smaller proportion being predators.

During the summers of 2003 and 2004, we monitored the water depths and temperatures used by 11 lake trout, 10 bull trout, and 8 rainbow trout. Most of the bull trout and lake trout were collected by gillnets in the lake, while most of the rainbow trout were collected by a combination of seining and gillnetting in a spawning tributary (Table 11). Rainbow trout utilized the shallowest depths and warmest temperatures of the three species and were predominantly found in the pelagic area over bottom depths >50 m (Table 12 and Figure 18). On average rainbow trout were located in the top 15 m of the water column and often near the lake surface. Lake trout and bull trout were mostly located in benthic and nearshore areas in depths generally >15 m and in temperatures below 12°C (Table 12 and Figure 18). Both lake trout and bull trout were located in pelagic areas, and this comprised 21% and 16% of total pelagic observations during the summer, respectively (Table 13).

To help determine the species composition of the hydroacoustic targets used in our population estimate, we combined our tracking information with the depth distribution of acoustic targets (Figure 18). Hydroacoustic targets were detected between 12 m and 35 m in the pelagic area of the lake. The majority of rainbow trout depth observations were made in the top 15 m of the water column with several observations made in the 15 to 25 m range. A majority of our sonic tracking observations for bull trout (79%) and lake trout (85%) were made outside the area of pelagic hydroacoustic targets.

Biomass

During August 2004, we estimated there was 36 tonnes of pelagic predator biomass in Lake Pend Oreille (Figure 19). This was an increase from August 2003, when we estimated there was 30 tonnes of pelagic predator biomass. With a biomass of 158 t of kokanee in August 2004, the pelagic predator to kokanee prey ratio was 1 kg of predator to 4 kg of prey. This indicated that there was less kokanee biomass available to predators this year than in August 2003 when the ratio was 1:9 (Bassista et al. 2005) (Figure 19).

Other Biotic and Abiotic Factors

Opossum Shrimp Abundance

We estimated the total abundance of opossum shrimp at 413 shrimp/m^2 in 2004 (Table 14). Young of the year (YOY) density was 166 shrimp/m^2 with a density of 247 immature and adult shrimp /$m^{2.}$ The length-frequency distribution of shrimp cohorts is presented in Figure 20.

The arithmetic mean for the immature and adult shrimp was 247 shrimp/m^2 with 90% CI of ± 36%. The geometric mean estimate was 201 immature and adult shrimp/m^2 with 90% CI of –16% and +19%.

Limnology

Secchi transparencies between April and October 2004 averaged 8.9 m in Lake Pend Oreille (Table 15). The lowest reading of 5.3 m was taken in May, and the maximum reading was recorded in August at 14.6 m. During the same months, water temperatures on the lake surface ranged from a low of 6.8°C during April to a high of 24.2°C in August. The maximum depth of temperature stratification reached 16 m on August 16, 2004. Dissolved oxygen levels on the surface of the lake ranged from a high of 11.1 mg/L in April to a low of 8.3 mg/L in August.

DISCUSSION

Kokanee Population

Kokanee Spawning Habitat

Drawing the lake down to 625.1 m during the winter of 2003-04 had the desired effect of improving shoreline habitat for spawning kokanee. At least 25,155 m^2 of spawning habitat was created during the drawdown. Actual area may have been considerably greater since only large gravel bars were measured and many small pockets of gravel were observed. Bars of gravel were created along the shoreline and remained of good quality after the lake was raised to full pool (Figures 13-15). Allowing 0.1 m^2/spawning pair, this would have provided habitat for about 500,000 mature kokanee, more than enough for the current population of kokanee. If the lake is held 1.2 m higher during 2004-05 as planned, kokanee will have this gravel for spawning plus a substantial amount of deeper habitat at the south end of the lake.

These newly formed gravel areas should be available for the next few years if the water is held higher during winter (Maiolie et al. 2002). We recommend monitoring the quality of the gravel to determine when the next full drawdown is needed to clean and re-sort gravel substrates.

Egg-to-fry Survival of Kokanee

Much of our research since 1997 was to evaluate the potential of changing winter lake levels to enhance kokanee spawning. Egg-to-fry survival declined dramatically from 9.5% in

2002 and 9.7% in 2003 to 2.0% in 2004. This decline was likely the result of the full drawdown during the winter of 2003-2004. The low survival rate was consistent with previous data comparing egg-to-fry survival, winter lake levels, and the abundance of mature female kokanee in the lake (Figure 21). The survival rate of 2.0% was similar to survival rates before the lake level experiment began and comparable to survival in 1978 at 1.3% (Rieman and Bowler 1980) and 1990 at 1.5% (Paragamian et al. 1991) suggesting that a full drawdown resulted in similar losses of kokanee spawning habitat as were previously recorded. The effects of lake level management on kokanee survival will continue to be studied until 2007, at which time final recommendations will be proposed.

Kokanee Population Status

Predatory fish within the lake appear to be limiting the recovery of kokanee by reducing survival rates between fry and adults. Particularly troubling was the drop in survival rates over the last year (Table 3) (Figure 10), indicating increased predation. The downward trend in kokanee biomass over the last 10 years indicated that efforts to reduce predation have not benefited the population (Figure 8). Continued low abundance of the population puts them at risk of complete extirpation from the lake. Stock-recruitment curves (Figure 9) depict a population with little or no harvestable surplus and little resiliency. The trend over the last four decades has been for the stock-recruitment curve to move lower and further to the right (Bowler et al. 1980). Once the curve moves completely to the right of the line of equal replacement, the population would be expected to drop to extinction. Trawl data suggests it is nearly there; however, the hydroacoustics show a slightly better stock-recruitment curve.

The graph of kokanee production and yield versus kokanee biomass also depicted a kokanee population that could be nearing the point of extirpation (Figure 11). This figure shows that as biomass declines, the kokanee population was able to produce fewer kilograms of fish (lower production). However, in recent years the kilograms of kokanee that die (thought to be mainly due to predation) has not only remained high, but has increased in 2004. This graph appeared to show the first stages of depensatory mortality where the rate of decline would accelerate.

Several possible factors could have contributed to an increase in predator abundance. The kokanee fishery was closed during 2000. This eliminated a substantial amount of incidental harvest on rainbow trout smaller than 500 mm, which were shown by Vidergar (2000) to consume more kokanee than other size classes. Bowles et al. (1986) reported a 3.5% incidental catch of other game fish by kokanee fishermen in 1985, and 2,989 rainbows smaller than 432 mm were harvested by anglers seeking species other than rainbows. It is clear that kokanee fishermen caught many of these. Closing the kokanee fishery, therefore, could have reduced mortality on smaller rainbow trout. Another concern was the apparent expansion of the lake trout population. Lake trout were rare in the creel surveys through the mid-1980s (Bowles et al. 1986) but appeared to be expanding with population estimates in 1999 (Vidergar 2000) and 2004 (Peterson and Maiolie 2005). We are concerned that angler harvest of larger lake trout could lead to compensatory increases in smaller lake trout, thus increasing predation pressure. However, three outside lake trout experts with a variety of backgrounds and experience reviewed available Lake Pend Orielle data and did not agree that such a scenario was likely. Because the possibility of increased lake trout exploitation resulting in an undesirable population response is such a minority view, the department has moved forward with the lake trout removal program. A third concern was that stocking kokanee could be keeping predation levels high, thus causing unnaturally high predation levels on the weaker stock of wild kokanee. Each of these issues could be addressed if the current program of direct predator removal proves unsuccessful.

Monitoring Methods

In this study, we combined hydroacoustics and trawling as a method to monitor the kokanee population. This provided a better picture of the kokanee population than either method alone. Trawling has been conducted in Lake Pend Oreille using similar methodology since 1977 and was always done during the dark phase of the moon for consistency and improving the trawl catch (Bowler et al 1979). However, Robinson and Barraclough (1978) compared trawl catch to hydroacoustic estimates for juvenile sockeye salmon in Great Central Lake, British Columbia. They found the catch efficiency for clear sky and dark of the moon was only 47% of that for overcast sky and dark of the moon. This indicated that very low levels of light, even during the dark of the moon, could cause a two-fold change in trawl catch. Our own comparison of trawling to hydroacoustics also produced considerable variability. Kokanee abundance based on trawling ranged from 30% to 90% of hydroacoustic abundance estimates. Ambient light was not measured during our trawling, but might have been a factor in the variability of trawl efficiency. This current approach of partitioning the hydroacoustic estimate with the percent of each age class caught in the trawl seems to provide a more realistic estimate of kokanee abundance than trawling alone.

We also found that species other than kokanee comprised less than 3% of the fish in the trawl catch. Redside shiners *Richardsonius balteatus* were collected in only one trawl that was conducted near the shoreline; therefore, this non-kokanee percentage may not be representative of the pelagic kokanee layer that was used for hydroacoustic analysis. It was also unknown if some of these non-kokanee were captured above the 12 m depth that was the shallowest boundary of the hydroacoustic analysis, since the trawl continued to fish as it was raised or lowered near the surface. Therefore, the influence of non-kokanee on these hydroacoustic population estimates appeared to be minor.

Spawner Counts and Surveys

Numbers of spawning kokanee showed increases in 2004. Counts in tributary streams were the second highest in the last 20 years (Table 8). Shoreline counts were the highest in the last five years (Table 7). We did not consider this a positive trend in the kokanee population because of the problems noted above with survival and yield. Also, it appears spawner counts were not a good index of the adult population since trawling and hydroacoustics indicated low numbers of adults.

Artificial Spawning Areas

For the first time in four spawning seasons, kokanee were found to use one of the 12 spawning boxes placed in the lake. The low use indicated that kokanee did not readily find and utilize this clean substrate as originally hoped. Boxes were placed near known spawning areas, but even this did not result in their use. With the full drawdown during the winter of 2003-04, shoreline spawning habitat was limited, and conditions for the test of these manmade spawning areas were ideal. We cannot recommend at this time building spawning areas to boost kokanee survival during drawdown years. In years of reduced drawdown, egg-to-fry survival approached

10%, spawning habitat was not limited, and, therefore, artificial spawning areas would not be needed.

Pelagic Predators

Hydroacoustic methodology

Sonic tracking showed that rainbow trout in Lake Pend Oreille often utilized the top 12 m of the water column during summer stratification. Thus, our hydroacoustic survey may have missed a large portion of the rainbow trout population in 2004 (and likely in 2003). From July through September we monitored the depth and habitat use of eight rainbow trout >406 mm. Three of these fish had numerous observations (>10) while five were only located five times or less. There was a chance that tagged fish were not representative of the entire Lake Pend Oreille population. However, we do feel confident that a substantial portion of the rainbow trout population utilized the top 12 m of the lake during the summer of 2004. Warner and Quinn (1995) examined the depth distribution of rainbow trout in Lake Washington and found fish using the top 3 m of the water column 90% of the time in water temperatures up to 18.6°C. Our hydroacoustic gear was unsuccessful at detecting large fish above 12 m using downlooking, mobile surveys (Figure 17), likely because of the narrow hydroacoustic beam at shallow depths and fish avoiding the oncoming boat. We recommend future tests including allowing the boat to drift passively while sampling, powering the boat with quiet electric motors, and planing the transducer to the side of the boat to see if these shallow fish can be detected. Additionally, side scanning with a multiplexing system could be used to detect rainbows in the upper water column. However, this method would not have the ability to differentiate large and small fish.

Though the majority of habitat observations of bull trout and lake trout were in benthic and littoral areas, a portion of both populations utilized pelagic areas in Lake Pend Oreille. Although our data supports that this portion was small, it does bring up the problem of estimating the abundance of rainbow trout. Even though there does seem to be distinct temperature and depth preferences by all three species (rainbow trout, lake trout, and bull trout), obtaining a total rainbow trout population estimate using hydroacoustics will be difficult since habitats overlap.

Given the limitations above, we calculated an abundance estimate of large pelagic fish at 15,800 fish >415 mm (90% CI = 10,492 to 21,938). This estimate seemed reasonable considering that the rainbow trout estimate in 1999 was 14,607 fish (Vidergar 2000) and that some of the lake and bull trout would be pelagic. The similarity of results may be coincidental given that rainbow trout were likely underestimated based on sonic tracking results.

Pelagic Predator Biomass

We calculated a predator to prey ratio of 1 kg : 4 kg using the acoustic estimates of large pelagic fish (thought to be predators) and kokanee. Sonic tracking studies indicated that many rainbow trout were likely missed by this population estimate so that the ratio could be even higher on the side of predators. Considering the low survival rate of kokanee, the declining kokanee biomass, and the high kokanee yield, predators and prey would appear to be out of balance.

Other Biotic and Abiotic Factors

Opossum Shrimp Abundance

Opossum shrimp in Lake Pend Oreille have gone through a cycle of expansion and then decline. Shrimp expanded from their introduction in 1966 until 1980, but declined over the last 24 years (Figure 22). Immature and adult shrimp densities (the segment of the population most likely to compete with kokanee) have also shown a downward trend during the current study (Figure 23). A similar pattern of expansion and then decline has been seen in other western lakes after opossum shrimp introductions (Deleray et al. 1999; Richards et al. 1991; Beattie and Clancey 1991).

It is unclear what limits the opossum shrimp population within Lake Pend Oreille. Data collected from the trap net evaluation project in 2003-2004 indicated a substantial lake whitefish population in Lake Pend Oreille (Peterson and Maiolie 2005). Preliminary examination of lake whitefish stomachs showed they fed heavily on opossum shrimp. However, much of the area of Lake Pend Oreille contains water with depths over 300 m and does not contain many whitefish (based on hydroacoustic surveys over deep water). Shrimp in these areas would be fairly isolated from predation.

Lake Pend Oreille appeared to have higher shrimp densities than other lakes in the region. Rumsey (1988) saw densities of opossum shrimp ranging from 5.1 shrimp/m^2 to 223 shrimp/m^2 in six lakes in western Montana using similar methods to collect the shrimp, except that Rumsey only sampled down to 30 m instead of 45.7 m. Though these numbers may not be directly comparable, it still appears that densities of opossum shrimp in Lake Pend Oreille (413 shrimp/m^2) are higher.

One possible reason for higher densities of shrimp may be the depth of the lake. Beattie and Clancey (1991) showed that mysid populations within Flathead Lake have high spatial variability, similar to what we see in Lake Pend Oreille. They suggested that densities of shrimp were higher at sampling stations that were >40 m in depth (>100 shrimp/m^2 at some stations) and considerably lower at shallower sampling stations (<15 shrimp/m^2 in all stations <25 m). Much of Lake Pend Oreille has depths exceeding 40 m.

It appears that opossum shrimp are not limiting kokanee recovery in Lake Pend Oreille. Shrimp densities have continued to decline and kokanee survival has continued to fluctuate over the past several years. Maiolie et al. (2002) found that shrimp densities did not correlate well with survival rates for kokanee between the egg and fry stages. This lack of correlation seems to remain (Figure 24). Continued monitoring of shrimp is recommended.

Limnology

Mean Secchi depth between April and October in Lake Pend Oreille was 8.9 m. Our data from 1997 to 2004 had mean April to October Secchi depths in the 7.0 to 9.3 m range. Data from 1997 to 1999 had mean April to October Secchi depths in the 6.2 to 6.7 m range. From 2000 to 2004, Secchi depths ranged from 8.1 to 8.9 m. An increase in Secchi transparency could indicate a reduction in suspended particulate matter or microbiota and indicates a decline in phytoplankton (Wetzel 1975). Declines in primary production could mean less zooplankton, which is the primary food source of kokanee. However, increases in Secchi depth did not correspond to declines in kokanee egg-to-fry survival since survival rates were at their highest levels observed in 2002 and 2003. Secchi readings were variable between lake sections, months, and years; however, this potential trend toward oligotrophication should be monitored and compared to declines in shrimp abundance.

CONCLUSIONS

During this contract period, we gained additional understanding of the effects of lake level fluctuations on the kokanee population. The winter drawdown in 2003-04 created substantially more spawning habitat for kokanee than would be available for spawning if water were held higher over the next several years. However, the drawdown did reduce the egg-to-fry survival rate during the year of the drawdown. Our monitoring results depicted a kokanee population under severe predation stress. Even with the recent improvements in egg-to-fry survival, the kokanee population has not recovered.

RECOMMENDATIONS

1. Continue to monitor the effects of lake level management on the kokanee population until 2007. At that point, make long-term recommendations for lake level management.

2. Monitor the shoreline gravels if they are inundated for the next several years to identify how long they remain of good quality.

3. Monitor lake productivity and the shrimp population to identify if declines continue to occur in both.

4. Continue to research hydroacoustic methods to estimate the rainbow population by experimenting with uplooking transducers, side scanning, side planning, drifting, and using quiet motors to obtain a more accurate rainbow trout population estimate.

5. Investigate ecological changes that could help to shift the predator:prey ratio more in favor of the prey. The low survival rates and abundance of kokanee indicated that this imbalance continued to exist.

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Table 1. Population estimates of kokanee fry (millions) based on hydroacoustic surveys of Lake Pend Oreille, Idaho in 2004. Percentage of wild fry was based on the proportion of wild fry caught during fry netting.

	Southern	Middle	Northern	Total for lake	90% CI
Total kokanee fry abundance by hydroacoustics	1.828	2.519	2.409	6.756	-8.8% to +9.6%
Percent wild fry in fry trawl	21.2	14.3	21.2	—	
Wild fry population estimate based on hydroacoustic abundance times the percent wild fry in fry trawling	0.388	0.360	0.511	1.259	

Table 2. Population estimates of kokanee age classes (millions) excluding young-of-the-year, in Lake Pend Oreille, Idaho, August 2004. Estimates were made based on hydroacoustic surveys and partitioned into age classes based on the percent of each age class in the catch of a midwater trawl.

Area	Age-1	Age-2	Age-3	Age-4	Total
Southern Section					
Acoustic estimate of kokanee in section (millions)					1.129
Percent of age class in section by trawling	23.61	34.88	29.06	12.45	
Population estimate in section (millions)	0.266	0.394	0.328	0.141	1.129
Middle Section					
Acoustic estimate of kokanee in section (millions)					0.597
Percent of age class in section by trawling	40.21	36.95	19.27	3.58	
Population estimate in section (millions)	0.240	0.221	0.115	0.021	0.597
Northern Section					
Acoustic estimate of kokanee in section (millions)					0.889
Percent of age class in section by trawling	70.49	19.00	6.85	3.67	
Population estimate in section (millions)	0.627	0.169	0.061	0.033	0.889
Total population estimate for lake (millions)	1.133	0.783	0.504	0.195	2.615

Table 3. Survival rates (%) between kokanee year classes estimated by midwater trawling and hydroacoustics, 1990-2004. Hydroacoustic estimates started in 1996. Year refers to the year that the older age class was collected.

	Age Class							
	0 to 1		**1 to 2**		**2 to 3**		**3 to 4**	
Year	**Trawl**	**Acoustics**	**Trawl**	**Acoustics**	**Trawl**	**Acoustics**	**Trawl**	**Acoustics**
2004[a]	35	21	33	33	19	28	14	18
2003[a]	31	35	70	55	54	65	—[b]	—[b]
2002[a]	16	30	13	43	—[b]	—[b]	—[b]	—[b]
2001	44	28	25	27	3	6	13	17
2000	66	52	74	22	168	66	107	40
1999	32	24	16	18	61	71	40	49
1998	40	37	29	28	95	94	25	26
1997	21	42	22	59	12	29	6	17
1996	77	44	101	79	57	40	70	46
1995	46	—	307	—	99	—	21	—
1994	12	—	47	—	76	—	38	—
1993	32	—	98	—	256	—	92	—
1992	67	—	94	—	63	—	83	—
1991	25	—	111	—	53	—	82	—
1990	35	—	124	—	27	—	44	—

[a] Data from 2002 to 2004 were based on geometric means transformed by Log(x+1).
[b] Too few kokanee caught in age class to provide a reliable estimate of survival.

Table 4. Comparison of kokanee reproductive success in Lake Pend Oreille, Idaho in 2003 and 2004. During the winter of 2002-03, the lake elevation was held above 626.4 m (2055 ft), and in 2003-04 the winter elevation was held above 625.1 m (2051 ft).

	2002-03	**2003-04**
Number of mature female kokanee in previous year	53,737	219,584
Number of kokanee collected by hatchery crew in previous year	14,235	43,351
Female kokanee spawning in the wild during the previous year	39,502	176,233
Fecundity (eggs/female) in previous year	320	351
Wild spawn eggs in previous year	12,640,000	61,857,805
Number of wild fry produced	1,228,000	1,258,628
Wild egg-to-fry survival (%)	9.7	2.0

Table 5. Biomass, production, and yield (metric tons) of kokanee in Lake Pend Oreille, Idaho 1996-2004.

Year	Biomass	Production	Yield
2004	158.3	217.8	329.2
2003	258.0	236.0	171.7
2002	188.4	262.6	231.3
2001	148.2	249.0	281.3
2000	169.9	194.2	284.1
1999	249.0	256.0	271.4
1998	253.2	230.3	208.5
1997	228.7	220.7	354.3
1996	352.6	278.4	274.7
1995	343.6		

Table 6. Kokanee population statistics for trawling on Lake Pend Oreille, Idaho during August 2004 based on geometric means.

Age	0	1	2	3	4	Total
Population estimate (millions)	5.031	0.398	0.258	0.147	0.048	5.883
± 90% CI (lower & upper limits)	-28% to +39%	-42% to +70%	-37% to +55%	-37% to +54%	-45% to +62%	-18% to +22%
Density (fish/ha)	222.2	17.6	11.4	6.5	2.1	259.8
Mean weight (g)	1.55	23.85	69.5	87.24	115.14	
Standing stock (kg/ha)	0.34	0.42	0.79	0.57	0.24	2.36
Mean length (mm)	58.6	149.0	205.7	221.2	244.4	
Length range (mm)	26-114	90-194	176-224	204-250	224-270	

Table 7. Counts of kokanee spawning along the shorelines of Lake Pend Oreille, Idaho. The numbers shown indicate the highest weekly count.

	Bayview	Farragut Ramp	Idlewilde Bay	Lakeview	Hope	Trestle Cr. Area	Sunnyside	Garfield Bay	Camp Bay	Anderson Point	Total
2004	2,342	0	100	1	0	0	0	34	0	0	2,477
2003	940	0	0	0	0	20	0	0	0	—	960
2002	968	0	0	0	0	0	0	0	0	—	968
2001	22	0	0	0	0	0	0	0	1	—	23
2000	382	0	0	2	0	0	0	0	0	—	384
1999	2,736	4	7	24	285	209	0	275	0	—	3,540
1998	5,040	2	0	0	22	6	0	34	0	—	5,104
1997	2,509	0	0	0	0	7	2	0	0	—	2,518
1996	42	0	0	4	0	0	0	3	0	—	49
1995	51	0	0	0	0	10	0	13	0	—	74
1994	911	2	0	1	0	114	0	0	0	—	1,028
1993	—	—	—	—	—	—	—	—	—	—	—
1992	1,825	0	0	0	0	0	0	34	0	—	1,859
1991	1,530	0	—	0	100	90	0	12	0	—	1,732
1990	2,036	0	—	75	0	80	0	0	0	—	2,191
1989	875	0	—	0	0	0	0	0	0	—	875
1988	2,100	4	—	0	0	2	0	35	0	—	2,141
1987	1,377	0	—	59	0	2	0	0	0	—	1,438
1986	1,720	10	—	127	0	350	0	6	0	—	2,213
1985	2,915	0	—	4	0	2	0	0	0	—	2,921
1978	798	0	0	0	0	138	0	0	0	0	936
1977	3,390	0	0	25	0	75	0	0	0	0	3,490
1976	1,525	0	0	0	0	115	0	0	0	0	1,640
1975	9,231	0	0	0	0	0	0	0	0	0	9,231
1974	3,588	0	25	18	975	2,250	0	20	0	50	6,926
1973	17,156	0	0	200	436	1,000	25	400	617	0	19,834
1972	2,626	25	13	4	1	0	0	0	0	0	2,669

Table 8. Counts of kokanee spawning in tributaries of Lake Pend Oreille, Idaho. The numbers shown indicate the highest weekly counts at each site.

Year	S. Gold	N. Gold	Cedar	Johnson	Twin	Mosquito	Lightning	Spring	Cascade	Trestle[a]	Trestle	Total
2004	721	2,334	600	16	6,012	---	---	3,331[b]	---	682	0	13,696
2003	591	0	0	0	—	—	—	626	—	2,251	9	3,477
2002	79	0	0	0	0	—	—	0	—	1412	0	1,491
2001	72	275	50	0	0	—	—	17	—	301	0	715
2000	17	37	38	0	2	0	0	0	0	1,230	0	1,324
1999	1,884	434	435	26	2,378	—	—	9,701	5	1,160	423	16,446
1998	4,123	623	86	0	268	—	—	3,688	—	348	578	9,714
1997	0	20	6	0	0	—	—	3	—	615	0	644
1996	0	42	7	0	0	—	—	17	—	753	0	819
1995	166	154	350	66	61	—	0	4,720	108	615	21	6,261
1994	569	471	12	2	0	—	0	4,124	72	170	0	5,420
1992	479	559	—	0	20	—	200	4,343	600	660	17	6,878
1991	120	550	—	0	0	—	0	2,710	0	995	62	4,437
1990	834	458	—	0	0	—	0	4,400	45	525	0	6,262
1989	830	448	—	0	0	—	0	2,400	48	466	0	4,192
1988	2,390	880	—	0	0	—	6	9,000	119	422	0	12,817
1987	2,761	2,750	—	0	0	—	75	1,500	0	410	0	7,496
1986	1,550	1,200	—	182	0	—	165	14,000	0	1,034	0	18,131
1985	235	696	—	0	5	—	127	5,284	0	208	0	6,555
1978	0	0	0	0	0	0	44	4,020	0	1,589	0	5,653
1977	30	426	0	0	0	0	1,300	3,390	0	865	40	6,051
1976	0	130	11	0	0	0	2,240	910	0	1,486	0	4,777
1975	440	668	16	0	1	0	995	3,055	0	14,555	15	19,740
1974	1,050	1,068	44	1	135	0	2,350	9,450	0	217	1,210	15,525
1973	1,875	1,383	267	0	0	503	500	4,025	0	1,100	18	9,671
1972	1,030	744	0	0	0	0	350	2,610	0	0	1,293	6,027

[a] Trestle Creek early-spawners.
[b] Cabinet Gorge Hatchery transferred approximately 3,000 spawners from the hatchery ladder to Spring Creek.

Table 9. Numbers of kokanee fry that were trapped during May 2004 after emergence from artificial spawning boxes placed near the Eagle Boat Ramp on Lake Pend Oreille, Idaho.

Date	Compartment 1	Compartment 2	Compartment 3	Compartment 4	Total
3-8-04	109 eyed eggs 4 dead eggs				
5-7-04		0	0	0	0
5-14-04		5	26	15	46
5-17-04		4	9	9	22
5-20-04		6	3	8	17
5-25-04		39	13	2	54
5-28-04		2	2	3	7
6-1-04		0	0	0	0
6-7-04		0	0	0	0
Total	113 Eggs	56	53	37	146 Fry

Table 10. Density estimates of large (>-33 dB) pelagic (water depth >70 m) fish in Lake Pend Oreille, Idaho, during 2003 and 2004. Geometric mean densities were based on log transformed data (log [x+1]). Transect locations for 2003 were described in Bassista et al. (2004).

Section 1			Section 2			Section 3		
Transect #	**2003 (fish/ha)**	**2004 (fish/ha)**	**Transect #**	**2003 (fish/ha)**	**2004 (fish/ha)**	**Transect #**	**2003 (fish/ha)**	**2004 (fish/ha)**
1-1	0	0.83	2-1	0	1.78	3-1	0.94	1.35
1-2	0.98	0.98	2-2	0	0	3-2	0.85	0
1-3	2.15	0	2-3	0	0.43	3-3	0.14	1.15
1-4	2.69	0.92	2-4	1.49	0	3-4	0.74	3.78
1-5	0	0.66	2-5	0	0	3-5	0	0.81
1-6	0	3.42	2-6	0.26	0.87	3-6	1.76	0
1-7	0	3.26	2-7	0.78	0	3-7	na*	0
1-8	1.47	1.79	2-8	0	0	3-8	na*	0
1-9	1.10	0.16	2-9	0	0.56	3-9	na*	4.03
1-10	5.21	0.46	2-10	0	0.95	3-10	na*	1.74
1-11	2.51	na*				3-11	na*	2.86
1-12	0	na*				3-12	na*	0
Section geometric mean density	0.93	1.00	Section geometric mean density	0.19	0.37	Section geometric mean density	0.64	0.91
Population estimate	5,400	6,400	Population estimate	1,500	2,800	Population estimate	4,800	6,600
Whole-lake population estimate	11,700	15,800						
90% CI	7,197 17,000	10,500-21,900						

* Transects designated “na” were not included as part of the overall survey for that given year.

Table 11. Fish implanted with sonic transmitters and tracked during 2003 and/or 2004. Rainbow trout (Rbt), lake trout (Lkt), and bull trout (Blt) were captured either by monofilament gillnets (gillnet), large trap nets (trap net), boat electrofishing (electrofish), or by a combined use of seines and gillnets (seine/gillnet).

Species	TL(mm)	Wt(kg)	Capture method	Release date	Last observed	Tag ID
Blt	645	2.3	gillnet	6/9/03	8/22/03	4445
Blt	671	5.2	gillnet	6/9/03	9/9/03	4456
Blt	712	3.5	gillnet	6/12/03	8/27/03	4446
Blt	640	2.2	gillnet	6/12/03	9/4/03	4447
Blt	642	2.5	gillnet	6/13/03	8/23/03	4455
Blt	695	3.4	trap net	2/19/04	8/12/04	4476
Blt	725	4.0	trap net	2/20/04	9/10/04	4565
Blt	425	1.5	gillnet	5/12/04	8/31/04	4775
Blt	490	1.4	gillnet	5/13/04	8/16/04	4665
Blt	518	1.1	gillnet	5/20/04	7/28/04	4675
Lkt	625	2.3	gillnet	10/30/02	9/10/04	9999
Lkt	862	6.0	gillnet	1/25/03	8/30/04	7899
Lkt	671	3.0	gillnet	1/25/03	9/11/03	6699
Lkt	835	6.8	gillnet	1/25/03	9/11/04	8888
Lkt	950	6.9	gillnet	5/12/03	9/10/03	4466
Lkt	640	2.3	gillnet	6/5/03	9/10/03	4475
Lkt	700	7.5	gillnet	6/5/03	9/10/03	4465
Lkt	770	4.7	gillnet	6/5/03	9/11/03	4457
Lkt	721	3.4	gillnet	6/9/03	9/11/03	4477
Lkt	435	0.9	gillnet	5/20/04	8/31/04	4686
Lkt	598	1.8	gillnet	5/21/04	9/1/04	4685
Rbt	576	1.6	electrofish	4/6/04	9/17/04	4459
Rbt	625	2.3	seine/gillnet	4/13/04	7/15/04	4449
Rbt	627	2.4	seine/gillnet	4/13/04	9/10/04	4458
Rbt	660	3.5	seine/gillnet	4/23/04	7/23/04	4666
Rbt	571	2.3	seine/gillnet	4/23/04	9/1/04	4647
Rbt	755	4.9	seine/gillnet	4/30/04	8/4/04	4766
Rbt	570	1.6	seine/gillnet	4/30/04	9/11/04	4758
Rbt	468	1.1	seine/gillnet	4/30/04	9/15/04	4768

Table 12. Mean depth and temperature at the location of sonic tagged rainbow trout, lake trout, and bull trout. All observations were made at night during the summers of 2003 and 2004.

Species	Tag ID	Year	# of Observations	Mean Depth (m) (±1 SD)	Mean Temp. (°C) (±1 SD)
Rainbow Trout	4458	2004	29	1 m (±2.5)	21.0°C (±1.8)
	4459		20	10 m (±2.7)	17.6°C (±2.4)
	4647		11	11 m (±3.4)	16.2°C (±1.3)
	4666		5	5 m (±1.9)	19.9°C (±0.2)
	4758		5	1 m (±0.1)	19.0°C (±0.8)
	4768		4	11 m (±6.5)	14.5°C (±1.4)
	4766		2	13 m (±2.7)	15.0°C (±0.1)
	4449		1	11 m	16.5°C
Lake Trout	4477	2003	10	23 m (±2.6)	8.9°C (±0.6)
	7899		8	32 m (±2.6)	6.4°C (±0.3)
	4465		7	24 m (±3.5)	7.9°C (±0.3)
	6699		6	23 m (±5.2)	7.4°C (±1.3)
	9999		4	31 m (±3.1)	7.2°C (±0.8)
	4457		4	26 m (±1.6)	7.7°C (±0.3)
	8888		3	32 m (±16.3)	8.5°C (±5.2)
	4475		3	27 m (±0.8)	7.5°C (±0.4)
	4466		2	23 m (±0.2)	8.1°C (±0.4)
	4685	2004	9	22 m (±2.3)	11.4°C (±2.3)
	4686		9	21 m (±2.4)	11.1°C (±0.7)
	8888		8*	1 m (±0.2)	20.3°C (±1.5)
	9999		5*	37 m (±8.1)	5.9°C (±0.7)
	7899		4*	36 m (±2.2)	5.8°C (±1.3)
Bull Trout	4445	2003	14	19 m (±3.12)	10.7°C (±8.0)
	4446		14	17 m (±2.34)	9.7°C (±0.9)
	4456		14	19 m (±4.53)	10.7°C (±1.3)
	4447		9	20 m (±1.55)	8.6°C (±1.7)
	4455		4	14 m (±15.99)	17.5 (±8.0)
	4565	2004	17	20 m (±3.67)	12.7°C (±3.1)
	4476		7	42 m (±38.1)	11.3 (±6.8)
	4775		4	22 m (±4.1)	12.0°C (±0.9)
	4675		1	75 m	5.2°C
	4665		1	24.0m	10.0°C

*Indicates a fish that was tagged in 2002 or 2003 and tracked for two years.

Table 13. Habitat used by 8 rainbow trout, 10 bull trout, and 11 lake trout during the summers of 2003 and 2004 as determined by sonic tracking. Fish were classified into three groups. A fish was considered pelagic if it was in water >70 m and further than 10 m from the bottom. Fish found in water <70 m and not within 10 m of the bottom was classified as nearshore. A fish was considered benthic if it was found within 10 m of the bottom, regardless of depth.

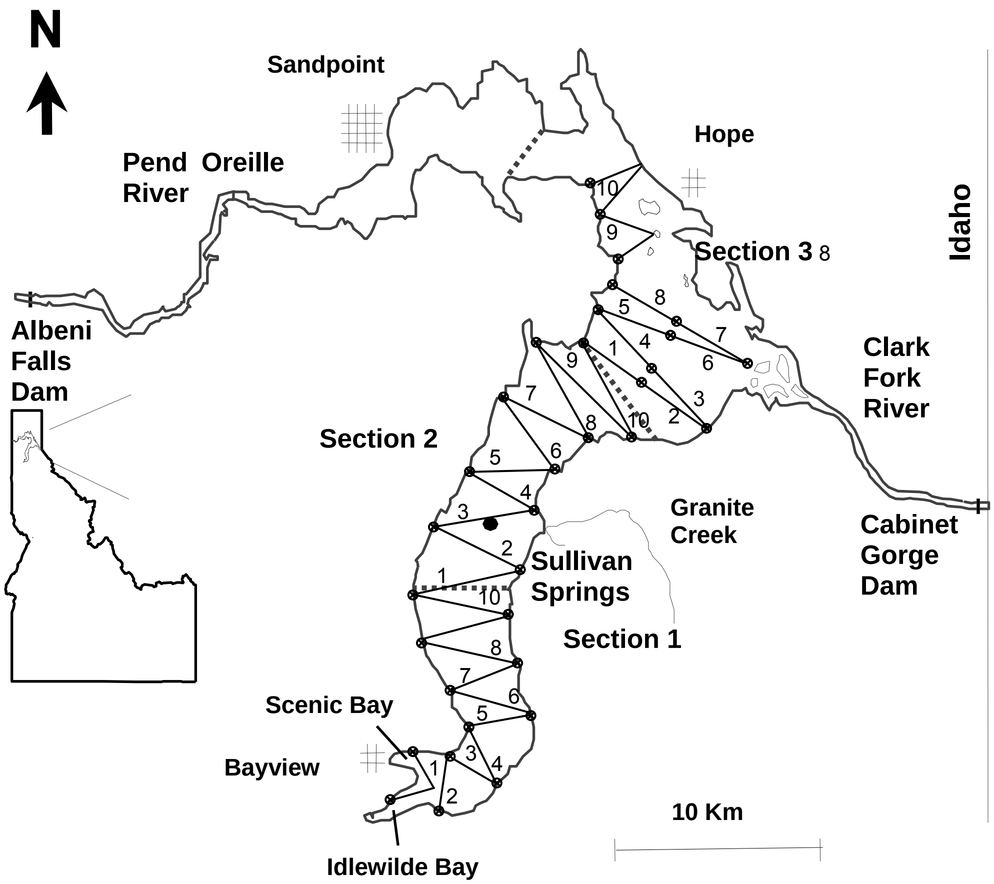
Species	Season	% Observation in Benthic habitat	% Observation in nearshore habitat	% Observation in pelagic habitat
Rainbow Trout	Summer	0%	20%	80%
Bull Trout	Summer	55%	24%	21%
Lake Trout	Summer	60%	24%	16%

Table 14. Densities (per m^2) of shrimp in Lake Pend Oreille, Idaho, June 15-21, 2004. Sections are shown in Figure 1.

Section-Transect	YOY	Immature & Adults	Total Shrimp
1-02	714.8	237.4	952.2
1-04	40.4	119.9	160.3
1-05	79.1	80.4	159.5
1-16	88.8	193.4	282.2
1-19	127.7	107.5	235.2
1-20	129.2	162.9	292.1
1-23	199.0	160.5	359.4
1-34	63.5	143.3	206.8
1-37	223.8	460.3	684.1
1-42	115.5	67.2	182.7
1-43	117.0	208.0	324.9
1-45	307.7	185.8	493.5
1-54	146.6	211.2	357.8
1-56	118.7	115.9	234.6
1-57	136.9	65.0	202.0
Section 1 means	**181.8**	**169.7**	**351.5**
2-04	302.6	447.3	749.8
2-07	152.4	172.9	325.3
2-08	215.9	376.1	592.0
2-12	152.9	203.9	356.8
2-18	226.5	227.8	454.3
2-21	624.3	634.7	1259.0
2-27	195.5	350.8	546.2
2-33	156.1	269.6	425.7
2-35	287.5	399.1	686.6
2-37	174.6	314.5	489.2
2-38	183.1	207.9	391.0
2-43	133.2	176.6	309.8
2-48	371.9	460.6	832.4
2-52	144.0	190.6	334.6
2-54	137.2	319.2	456.4
Section 2 means	**230.5**	**316.8**	**547.3**
3-05	129.3	166.1	295.4
3-08	133.8	158.8	292.5
3-16	80.4	115.0	195.4
3-21	89.2	174.6	263.8
3-31	37.1	148.5	185.7
3-36	66.8	57.3	124.1
3-37	110.5	148.2	258.7
3-48	62.8	120.2	183.0
3-49	98.8	106.7	205.5
3-51	95.4	336.7	432.1
3-52	25.1	56.8	81.9
3-63	86.8	580.4	667.2
3-80	134.3	52.0	186.3
3-84	199.6	136.0	335.6
3-89	49.1	1275.4	1324.5
Section 3 means	**93.3**	**242.2**	**335.4**
Whole lake weight by area means	**165.7**	**247.4**	**413.0**

Table 15. Secchi transparencies (m) at a mid-lake location (Figure 1) in Lake Pend Oreille, Idaho, 2004, for the period April through October.

Location	Apr 16	May 14	Jun 15	Jul 15	Aug 16	Sep 15	Oct 15					Summer Mean
Mid-lake station	6.4	5.3	7.3	8.0	14.6	10.4	10.3					8.9



Area	Section (hectares)
1	6486
2	7776
3	8384

● - Limnology station
⊗ - Start and stop of transects

Figure 1. Map of Lake Pend Oreille, Idaho showing prominent landmarks, limnology station, and the three lake sections. The dark lines mark the location of hydroacoustic transects in 2004. Inserted table depicts the area of kokanee habitat in each section.

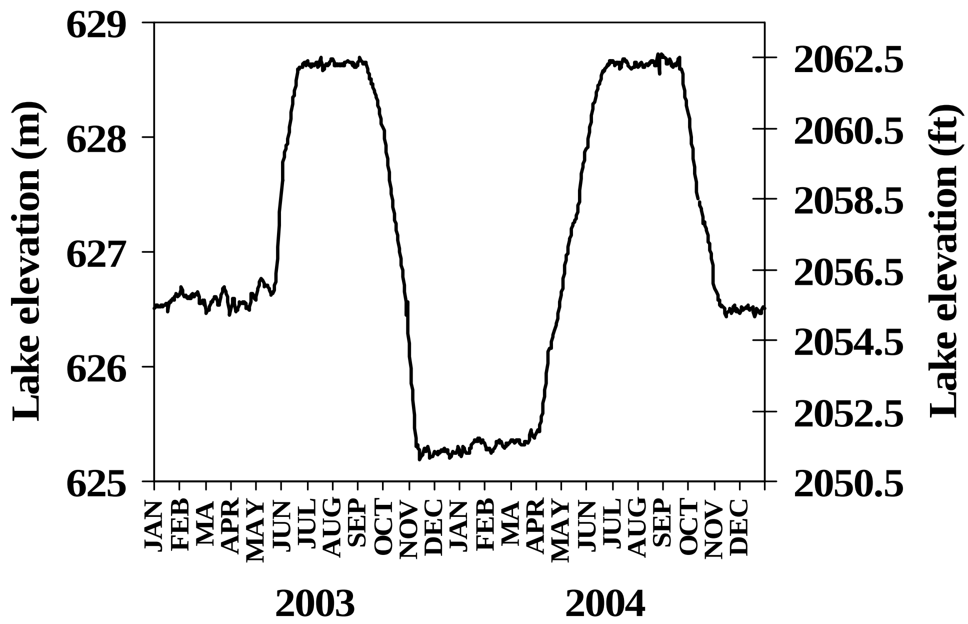
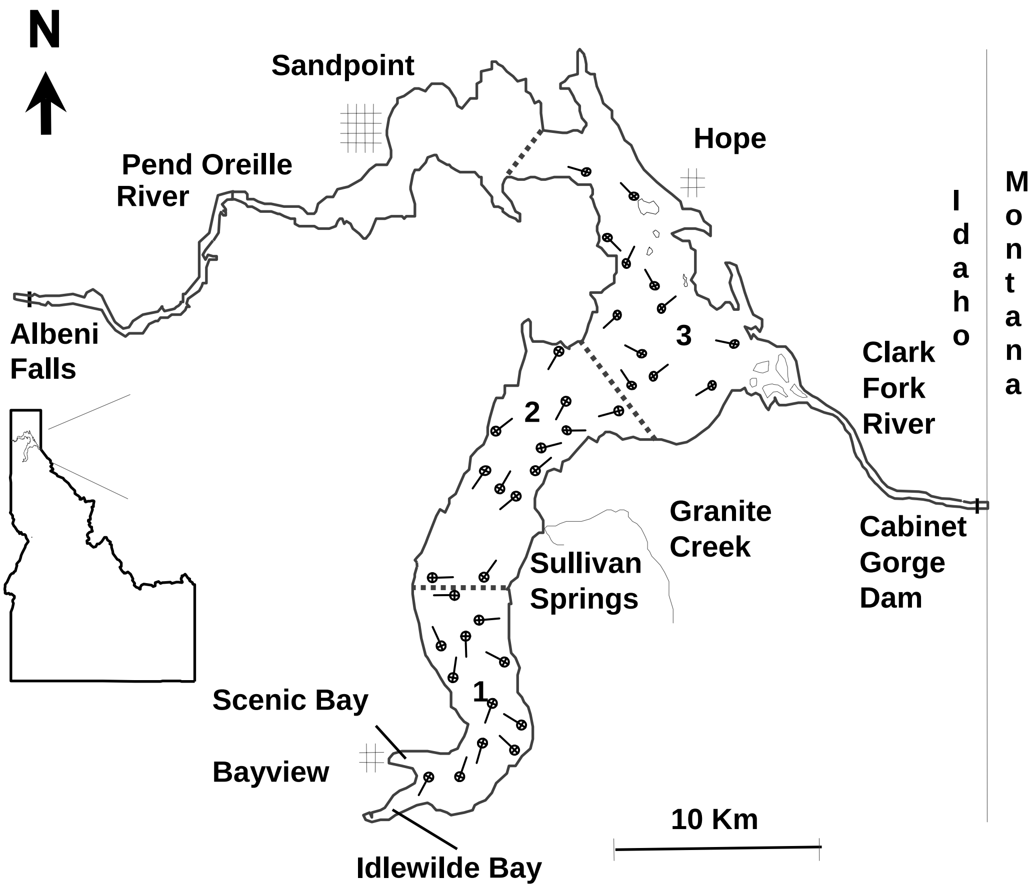


Figure 2. Daily surface elevation of Lake Pend Oreille, Idaho during 2003 and 2004.



Section	Area (hectares)
1	6486
2	7776
3	8384

- Transect location and direction

Figure 3. Map of Lake Pend Oreille, Idaho, showing the locations of transects used for kokanee trawling in 2004. Transects started at the dot and proceeded in the direction of the line.

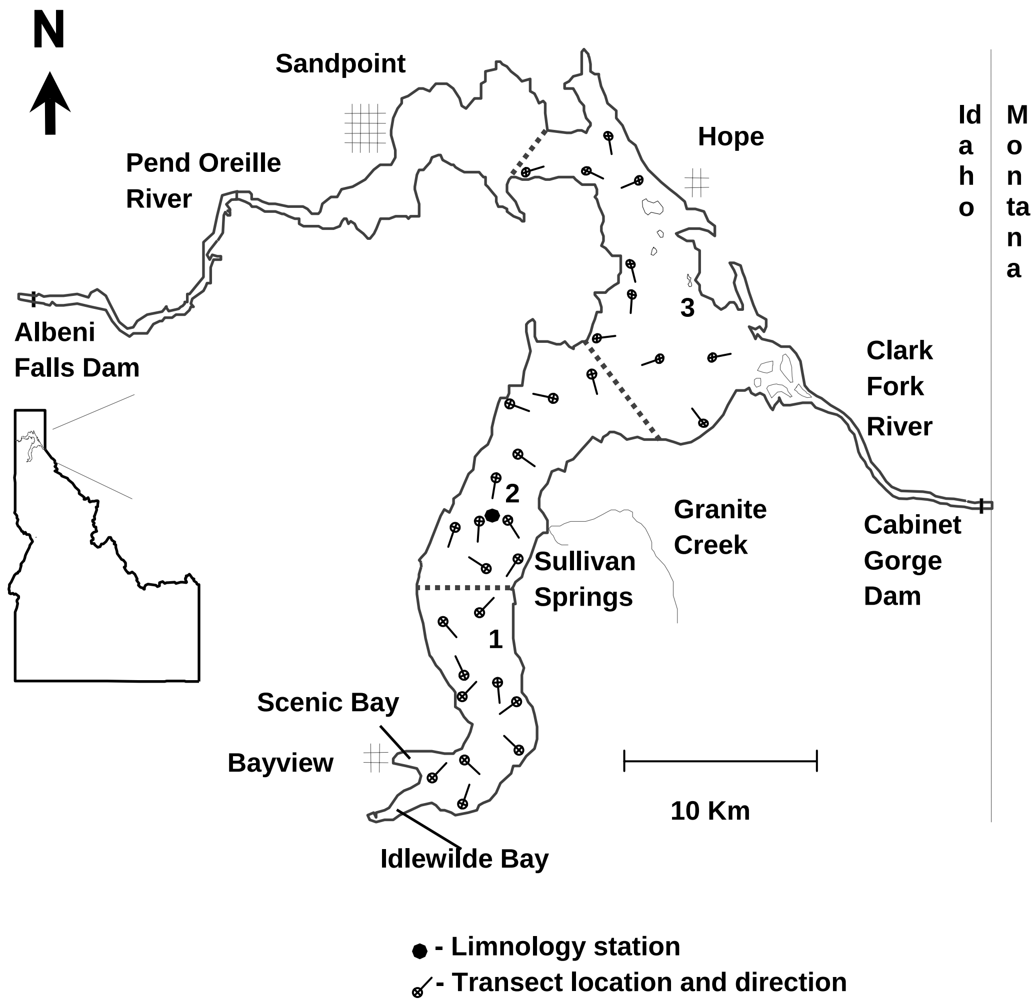


Figure 4. Map of Lake Pend Oreille, Idaho, showing the locations of transects used for kokanee fry trawling in 2004. Transects started at the dot and proceeded in the direction of the line.

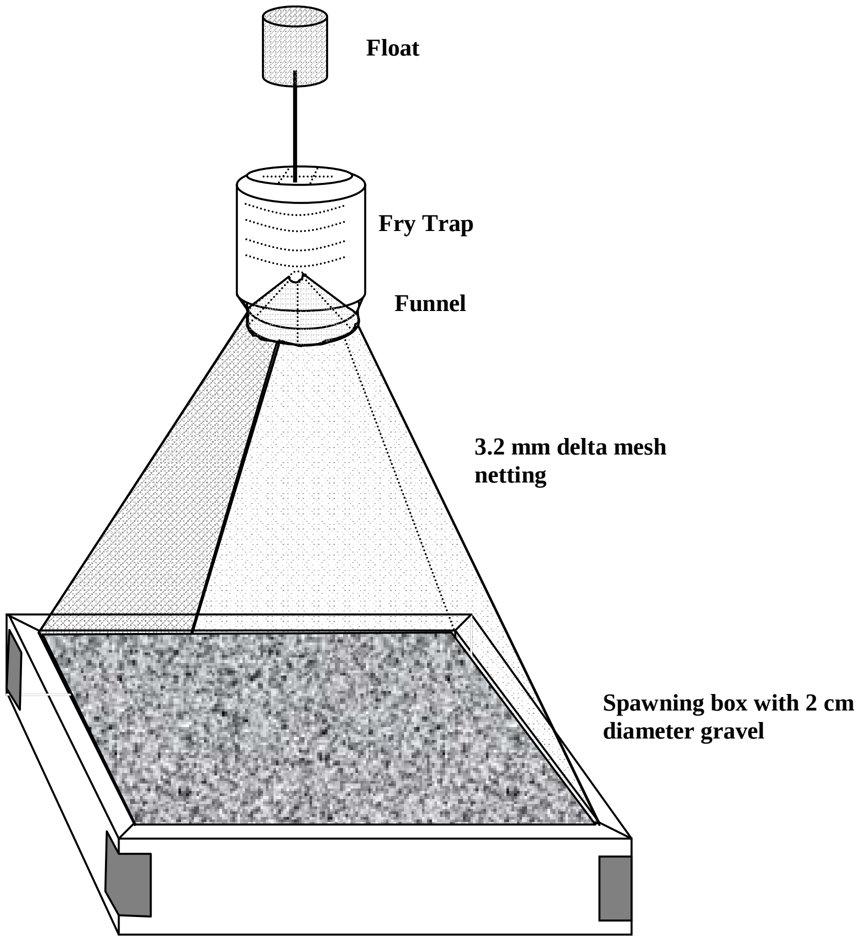


Figure 5. Design of the fry trap developed to capture emerging kokanee fry from the artificial spawning boxes in Lake Pend Oreille, Idaho during the 2003/2004 spawning season.

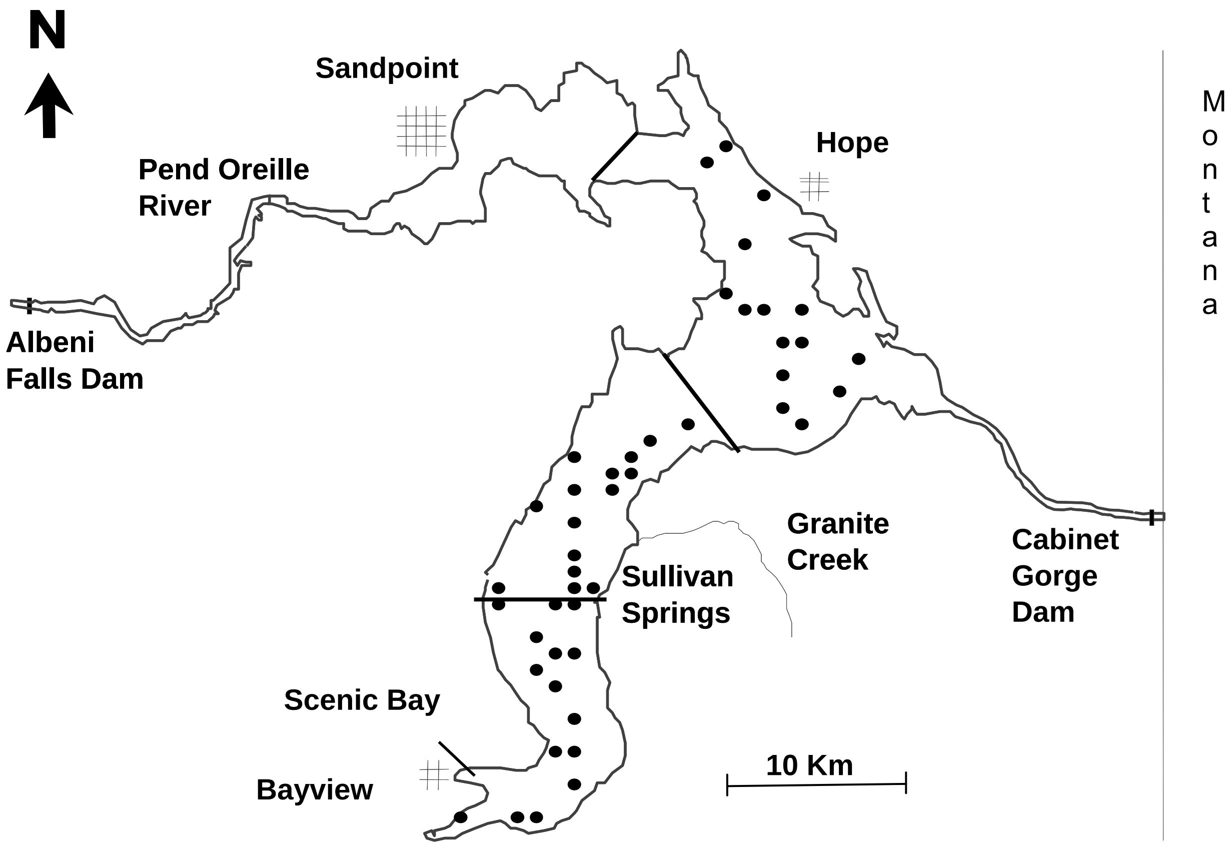


Figure 6. Map of Lake Pend Oreille, Idaho showing the locations used for shrimp sampling from June 15-21, 2004.

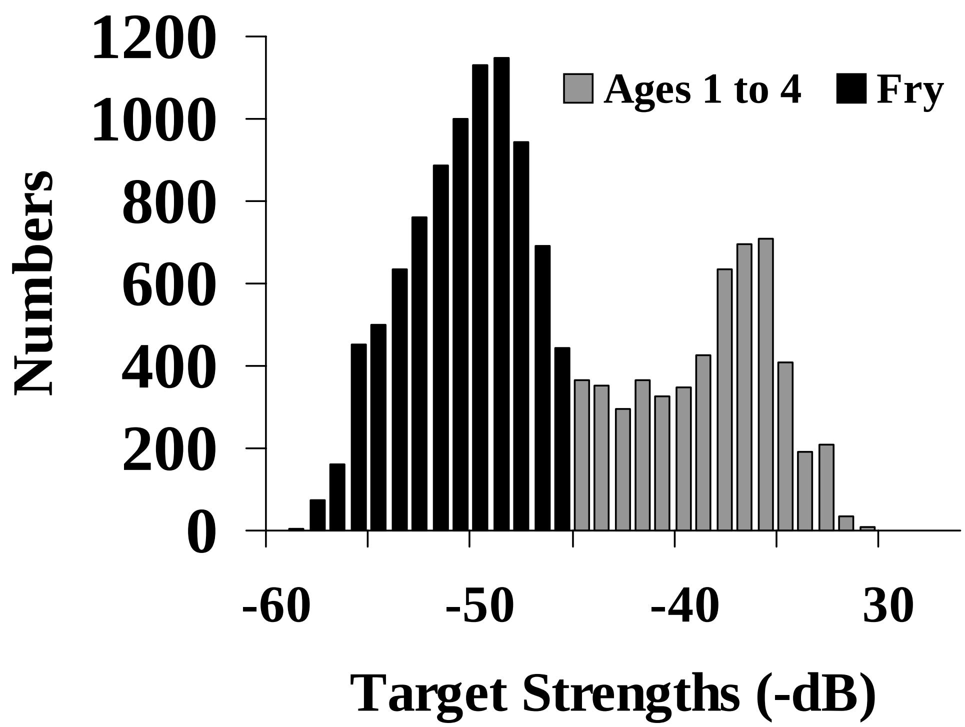


Figure 7. Distribution of target strengths from 14,206 pings on fish recorded during hydroacoustic surveys on Lake Pend Oreille, Idaho in August 2004.

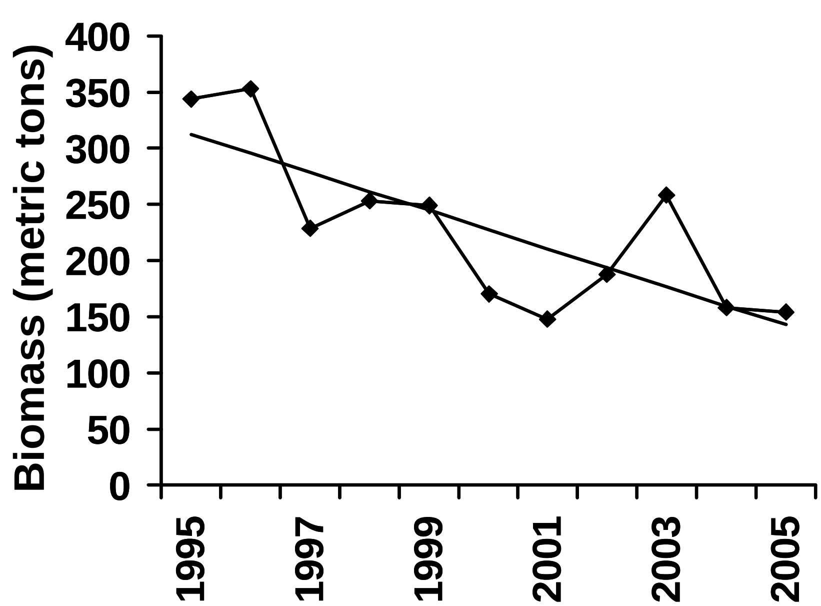


Figure 8. Total biomass of kokanee in Lake Pend Oreille, Idaho 1995 to 2004. Biomass was estimated based on hydroacoustic surveys.

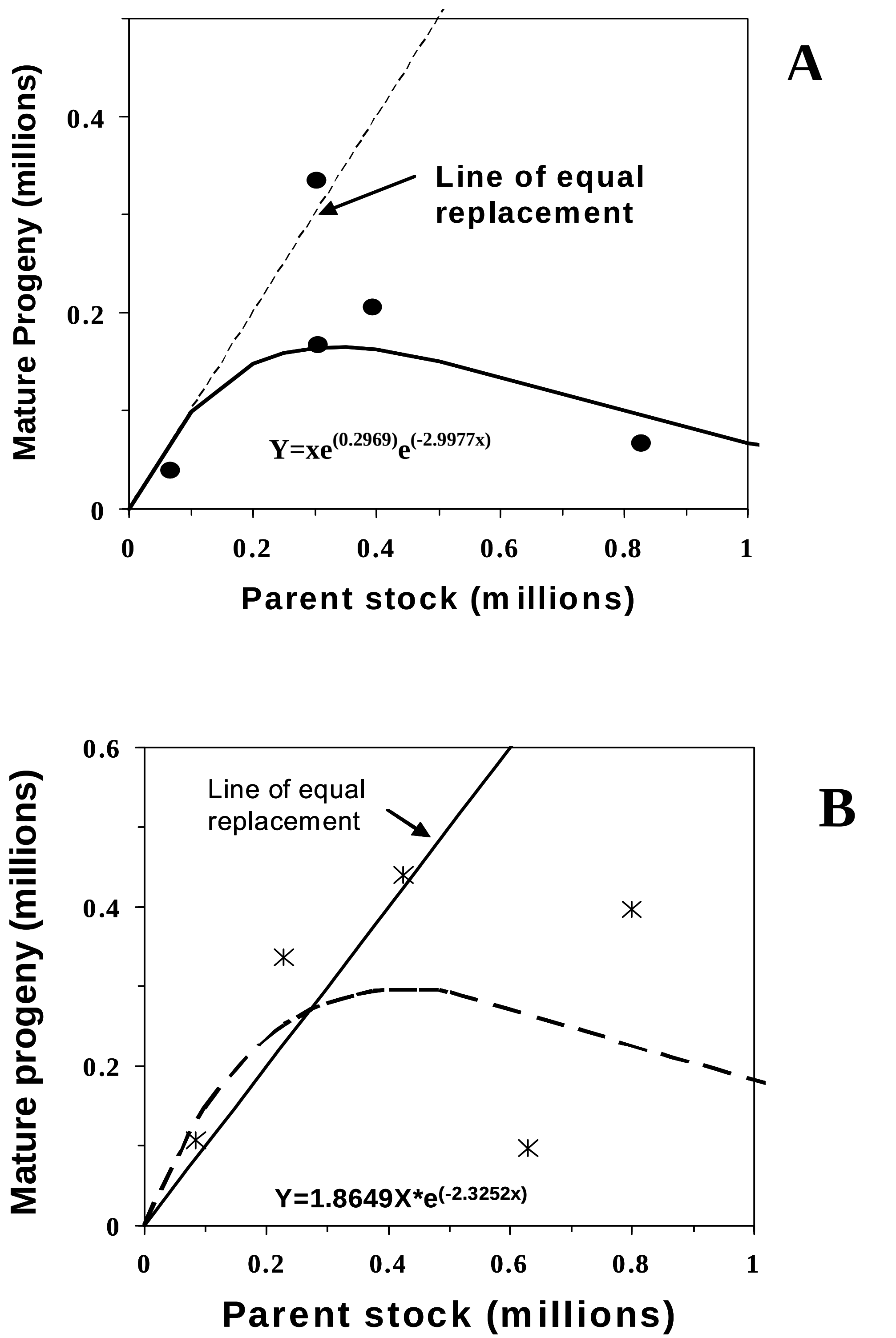


Figure 9. Stock-recruitment curves for the most recent generation (5 year classes) of kokanee in Lake Pend Oreille, Idaho. Figure A was based on trawling and B was based on hydroacoustics.

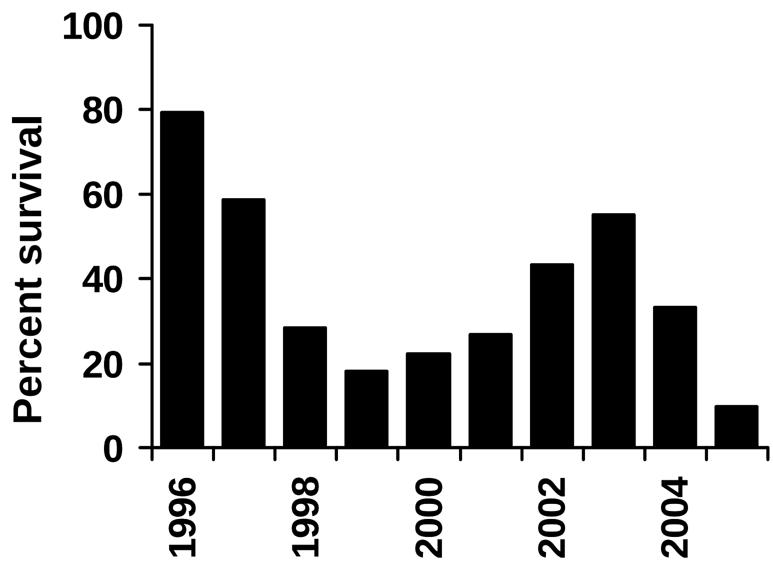


Figure 10. Survival rate for kokanee in Lake Pend Oreille, Idaho from age-1 to age-2 based on hydroacoustic estimates of abundance.

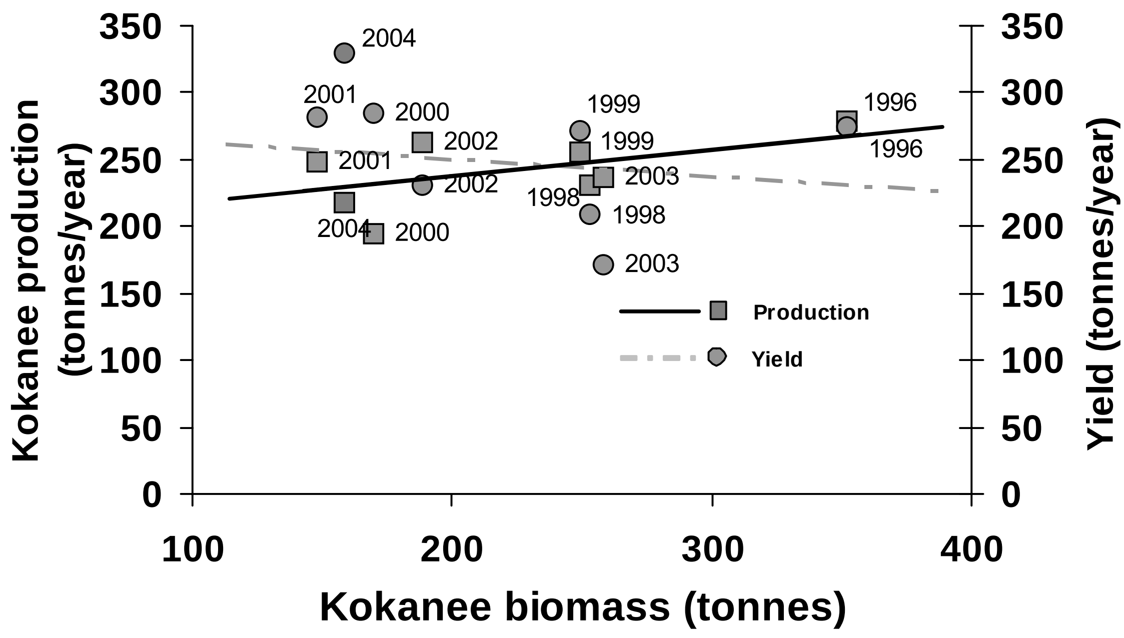


Figure 11. Kokanee biomass, production, and yield (metric tonnes) from Lake Pend Oreille, Idaho 1996-2004, excluding 1997 due to 100 year flood. Lines were fitted to all data points except 2004 to illustrate possible change.

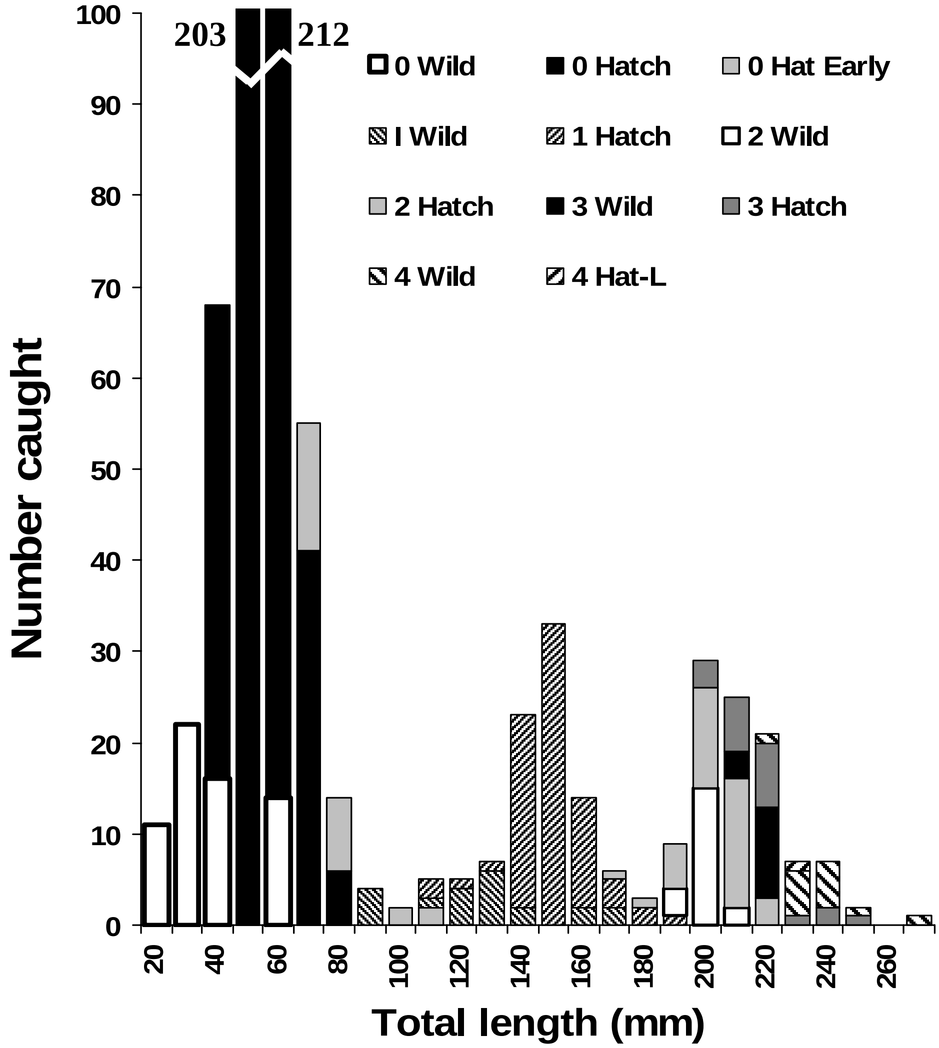


Figure 12. Length-frequency distribution of kokanee caught by midwater trawling in Lake Pend Oreille, Idaho in August 2004. Abbreviations in the legend include Hatch = late spawning kokanee reared at the Cabinet Gorge Hatchery, Hat-E = early spawning kokanee reared at the Cabinet Gorge Hatchery, Wild = kokanee produced naturally in the lake and its tributaries. Numeral denotes age class.

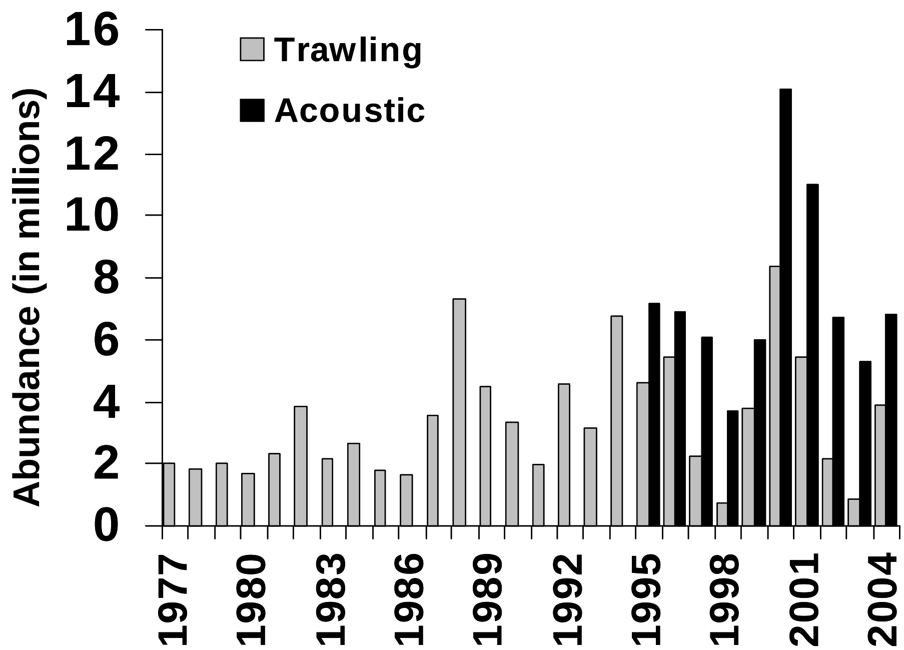


Figure 13. Abundance of kokanee fry in Lake Pend Oreille, Idaho, as estimated using trawling and hydroacoustics.

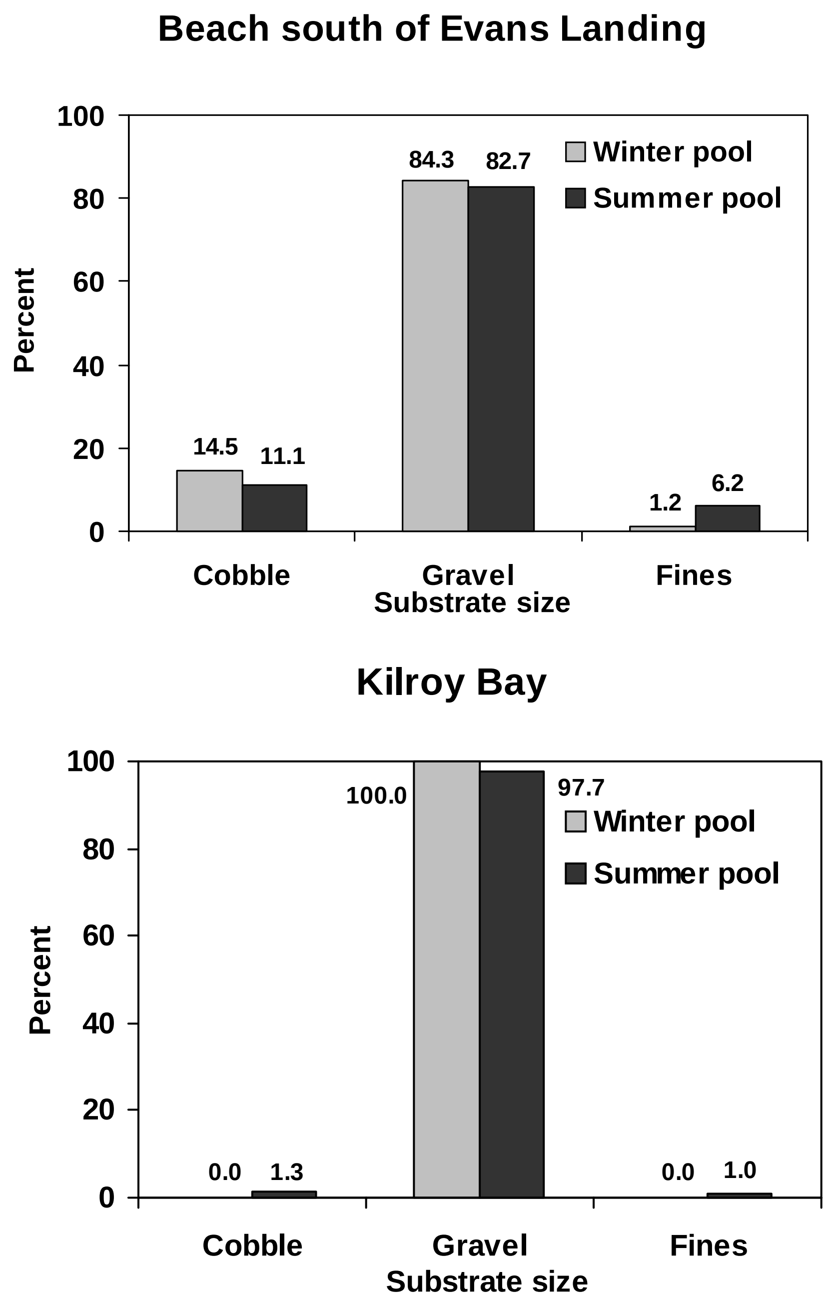


Figure 14. Comparison of gravel composition before and after the lake was filled to summer pool level at the beach south of Evans Landing and in Kilroy Bay, Lake Pend Oreille, Idaho 2004.

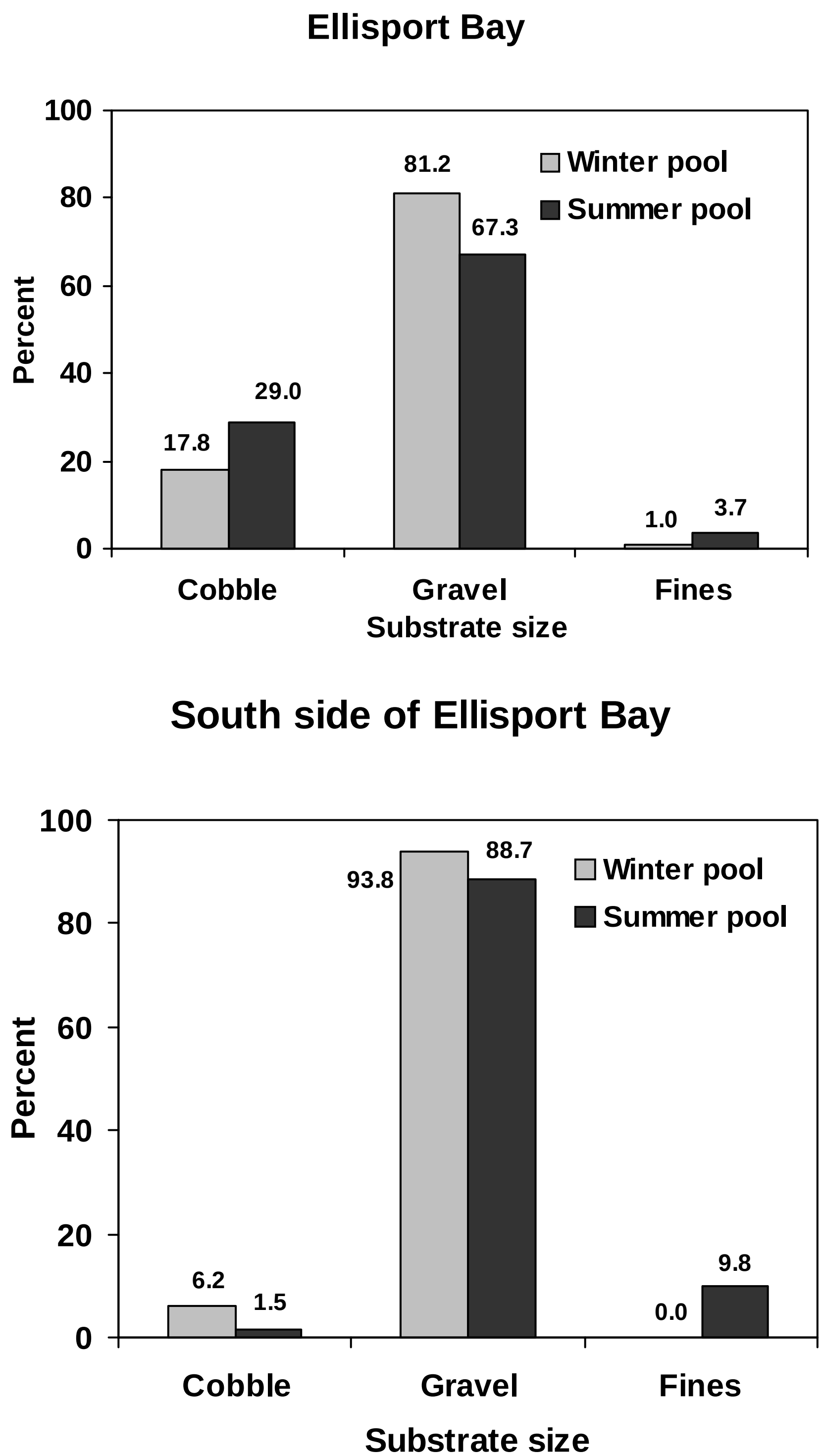


Figure 15. Comparison of gravel composition before and after the lake was filled to summer pool level at Ellisport Bay and the south side of Ellisport Bay, Lake Pend Oreille, Idaho 2004.

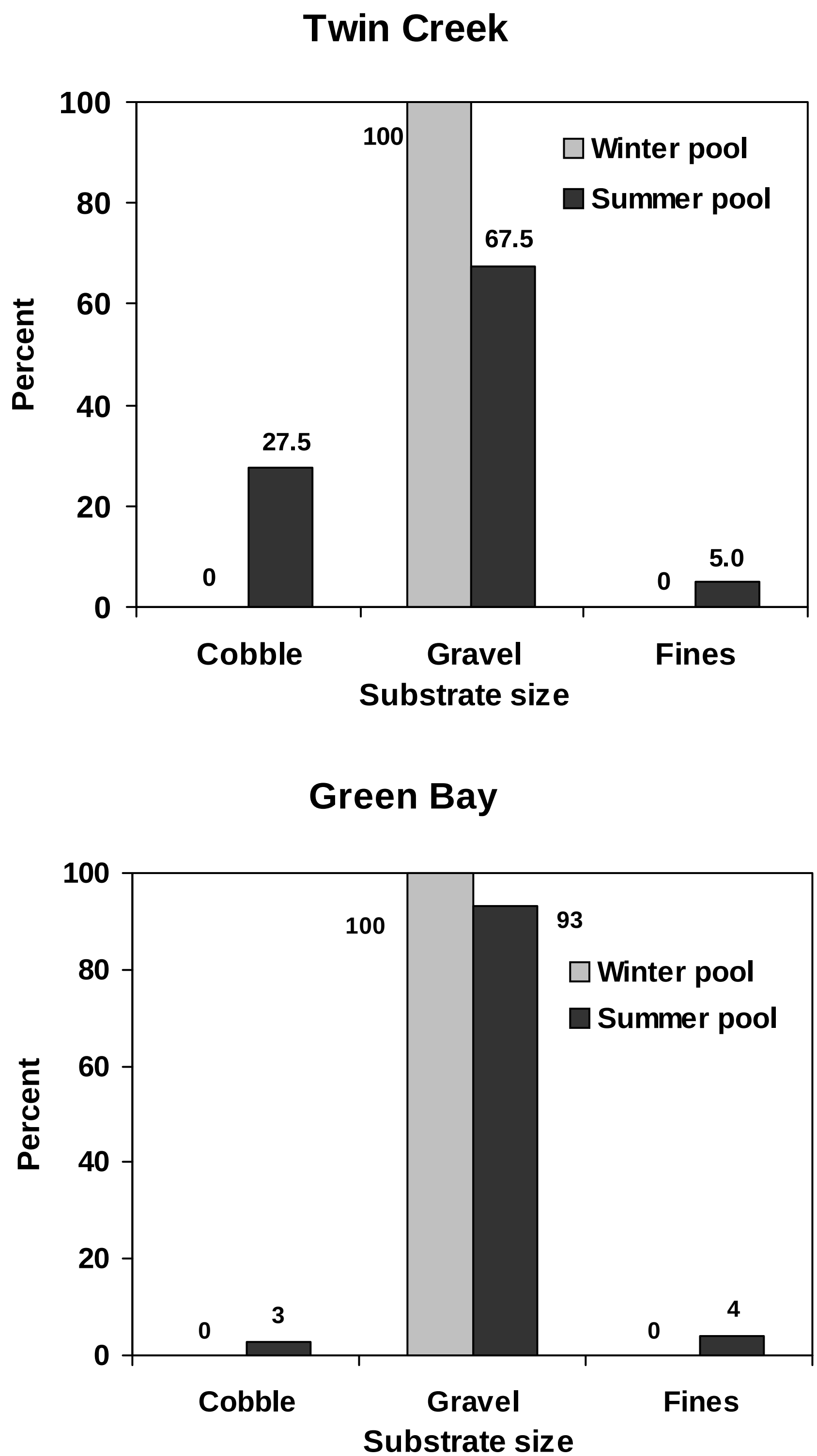


Figure 16. Comparison of gravel composition before and after the lake was filled to summer pool level at Twin Creek and Green Bay Lake Pend Oreille, Idaho 2004.

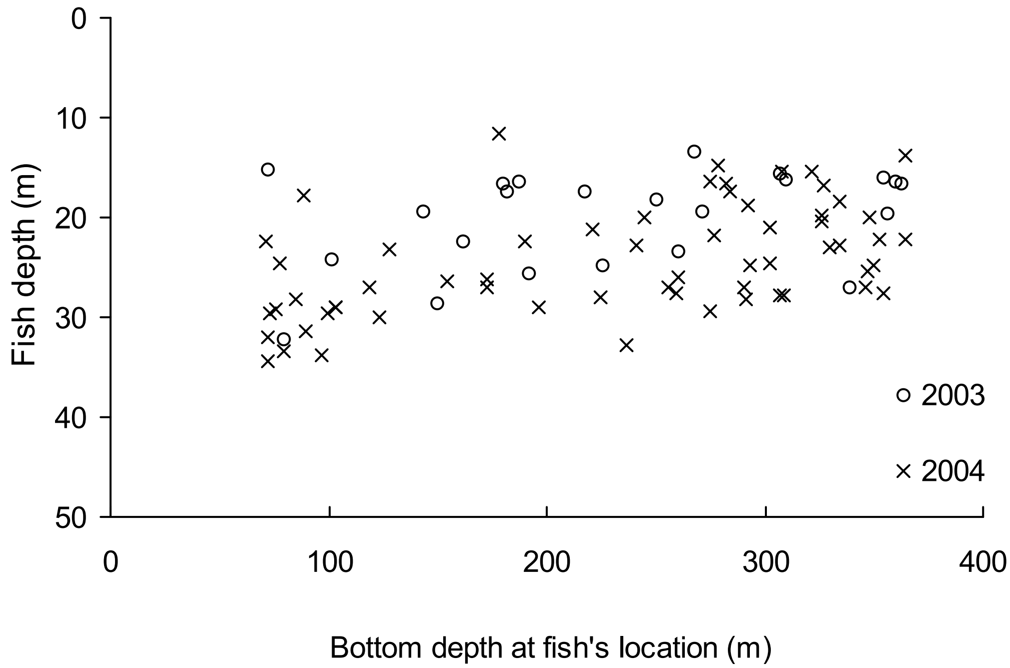


Figure 17. Depth distribution of hydroacoustic targets >-33 dB during August 2003 and 2004 in Lake Pend Oreille, Idaho used for our large pelagic fish population estimate. Fish in water shallower than 75 m deep, or fish at water depths below 35 m deep, were not included.

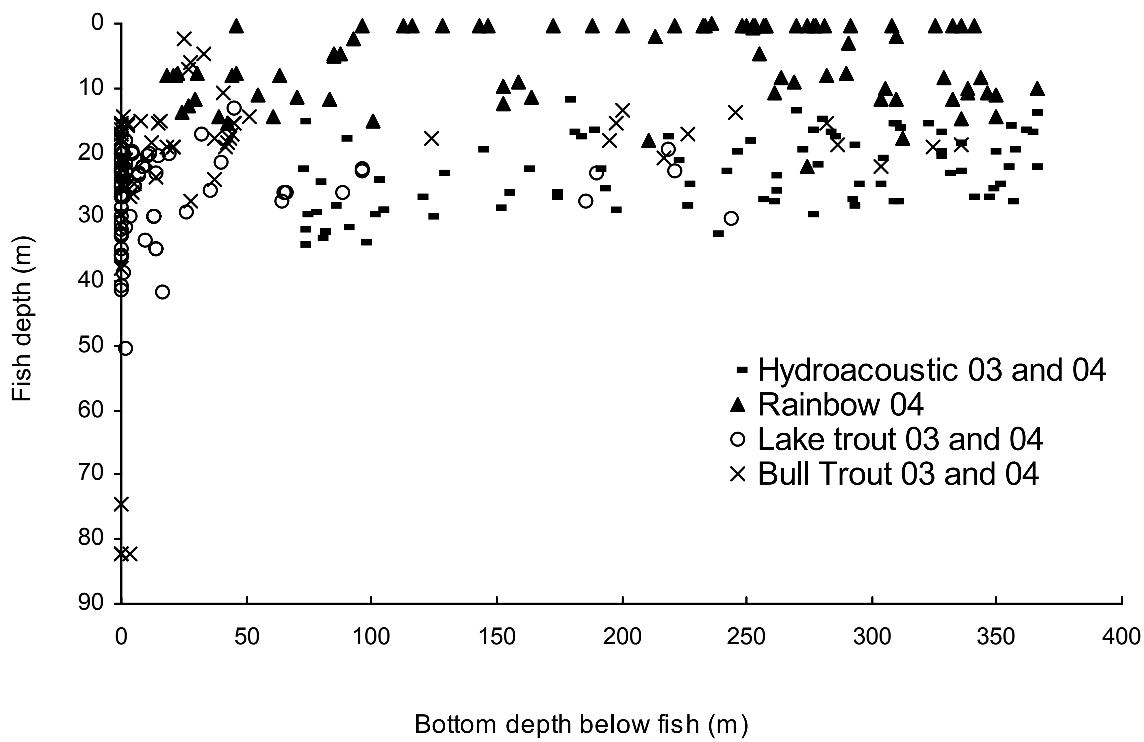


Figure 18. Nighttime depth distribution of pelagic hydroacoustic targets >-33 dB and sonic tracked rainbow trout, bull trout, and lake trout during the summers of 2003 and 2004. Marks located on the y-axis represent fish located on the lake bottom.

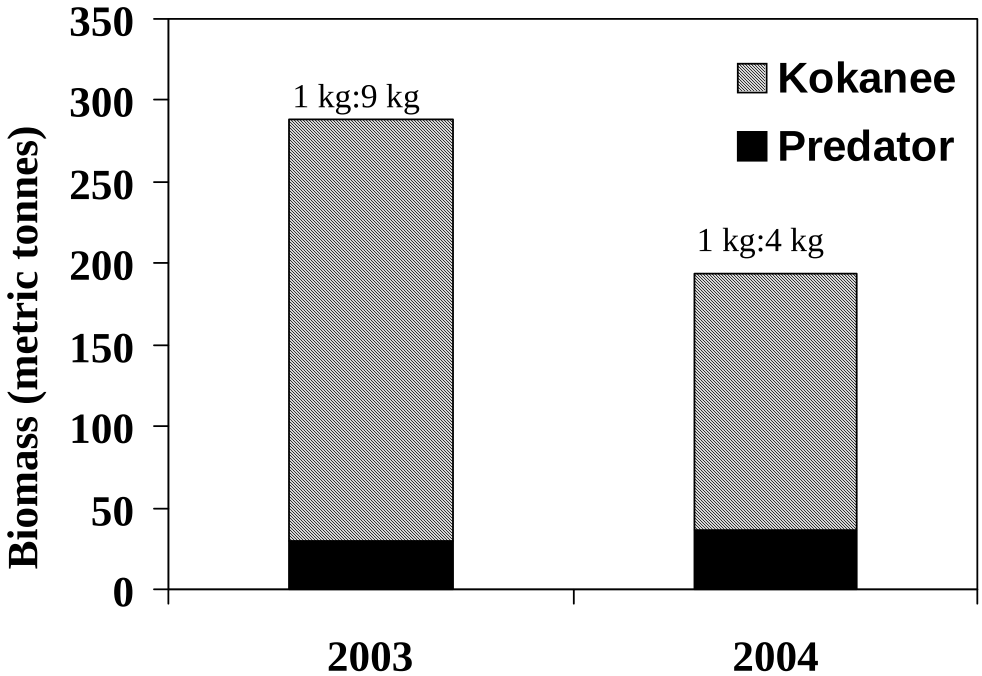


Figure 19. Biomass estimates of kokanee and large pelagic predators in Lake Pend Oreille based on hydroacoustic surveys during 2003 and 2004. Predator to prey ratio by these estimates are above each bar.

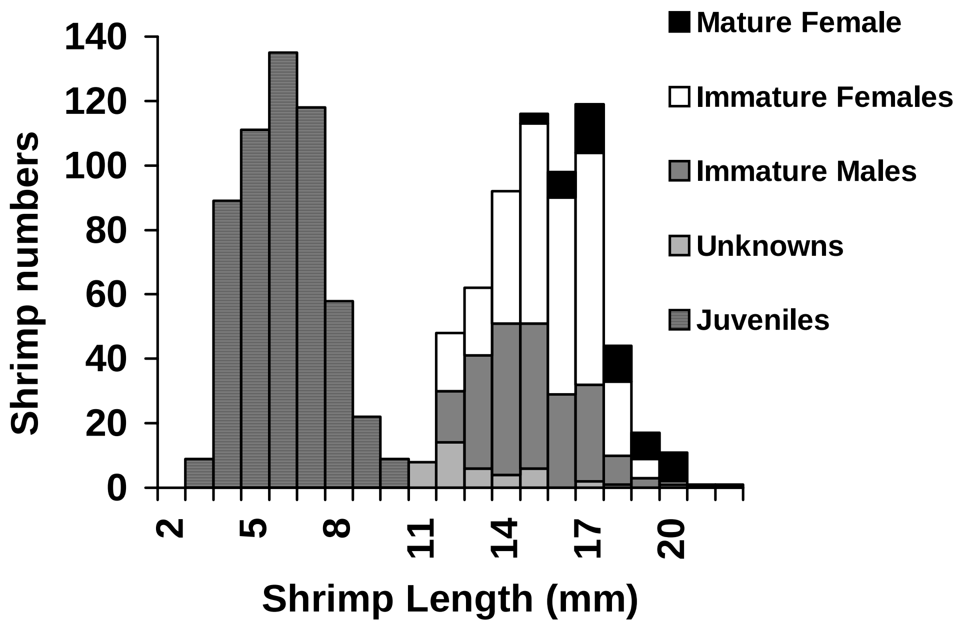


Figure 20. Length-frequency distribution of opossum shrimp during June 2004 in Lake Pend Oreille, Idaho.

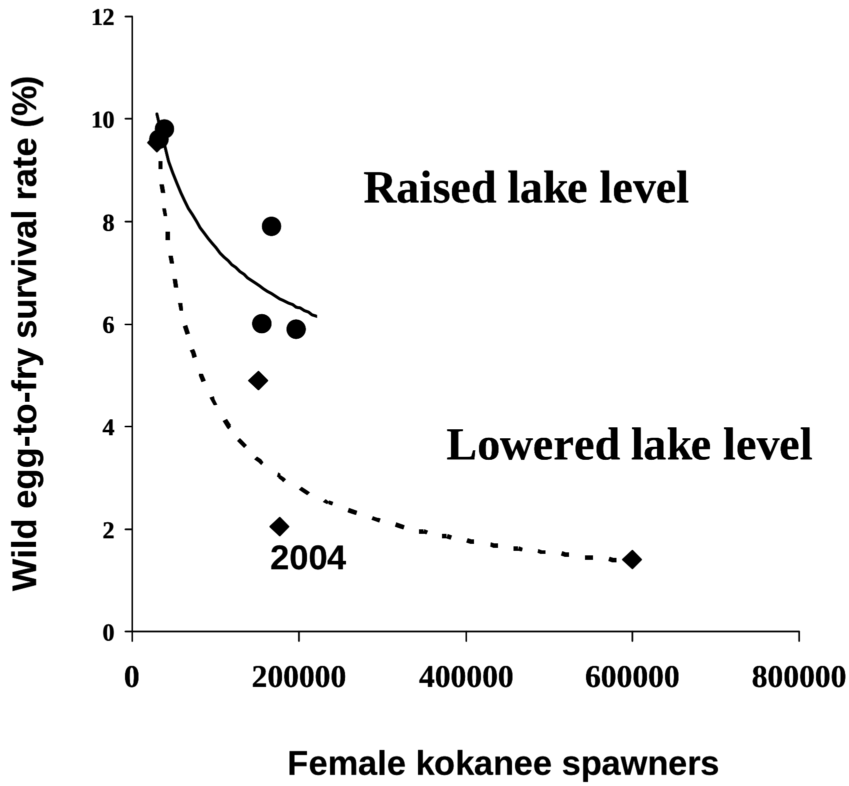


Figure 21. Relationship between the egg-to-fry survival rate of wild kokanee in Lake Pend Oreille, Idaho, and the number of female kokanee spawning that year. Data were divided into years when the winter lake elevation was held higher (626.4 m) (dots) and years when the lake was drawn down (625.1 m) (diamonds). Survival rate in 2004 was labeled for clarity.

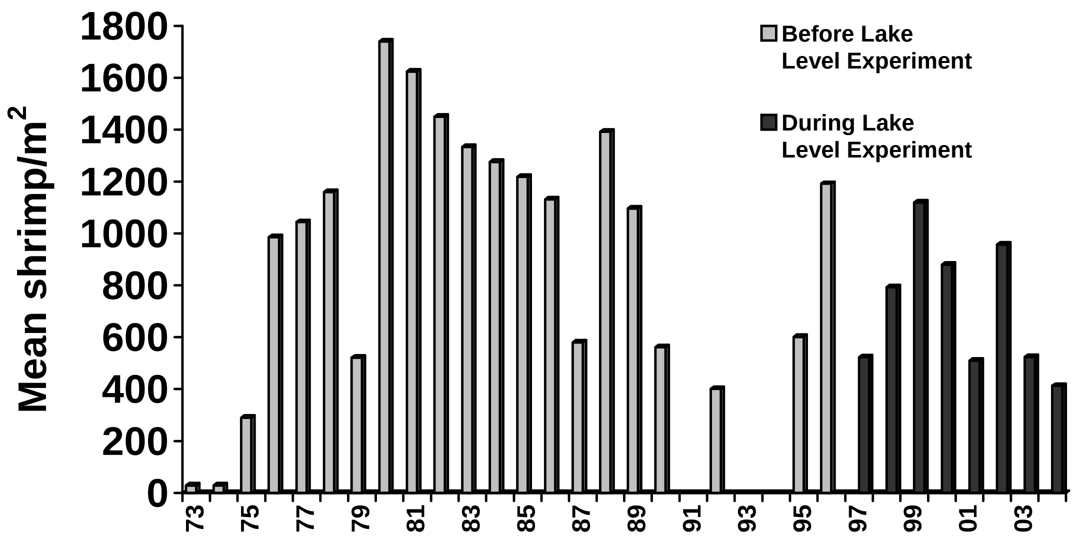


Figure 22. Annual mean density of opossum shrimp in Lake Pend Oreille, Idaho, 1973-2004. Data collected before 1989 were obtained from Bowles et al. (1991), and data from 1995 and 1996 were from Chipps (1997). Shrimp densities from 1992 and earlier were converted from Miller sampler estimates to vertical tow estimates by using the equation y = 0.5814x (Maiolie et al. 2002). Gaps in the bar chart indicate no data were collected that year.

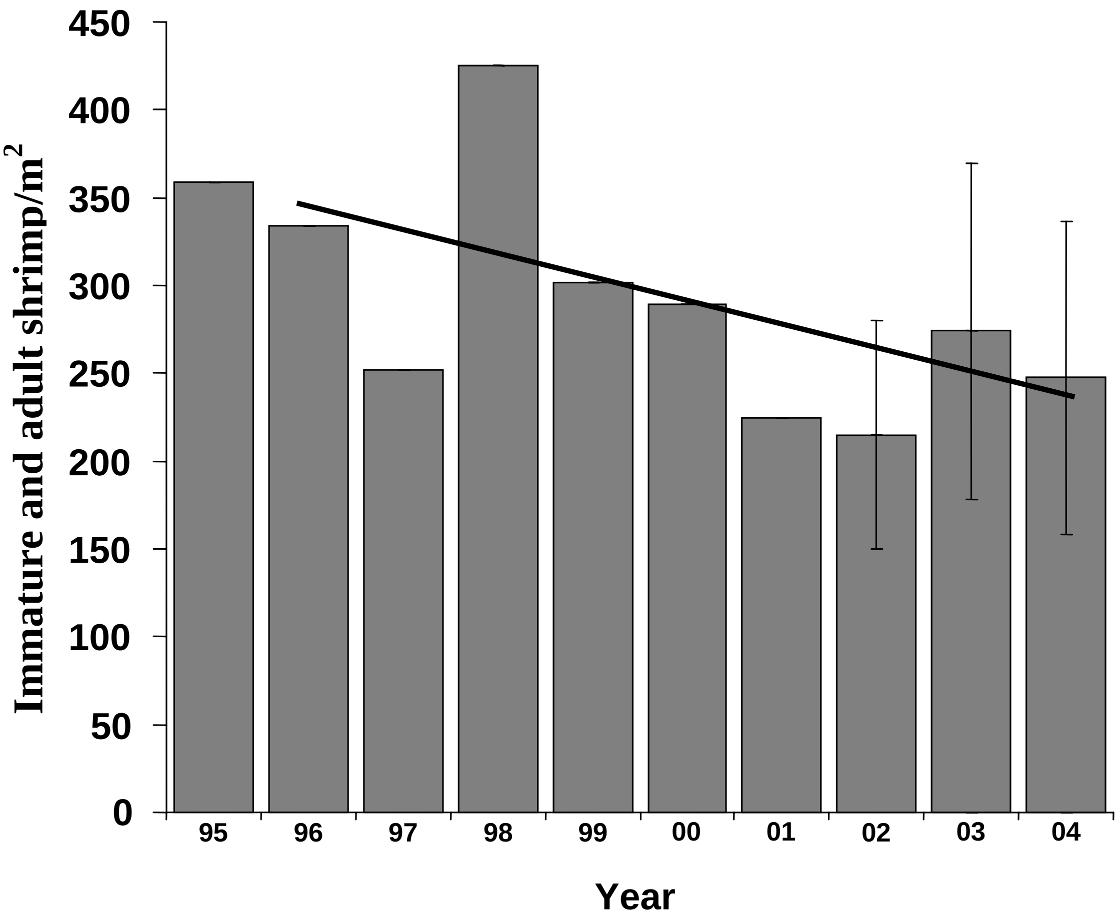


Figure 23. Density estimates of immature and adult shrimp in Lake Pend Oreille, Idaho for the past ten years (1995-2004). Ninety percent confidence limits were placed on the last three estimates, and a linear trend line was fitted to the data points.

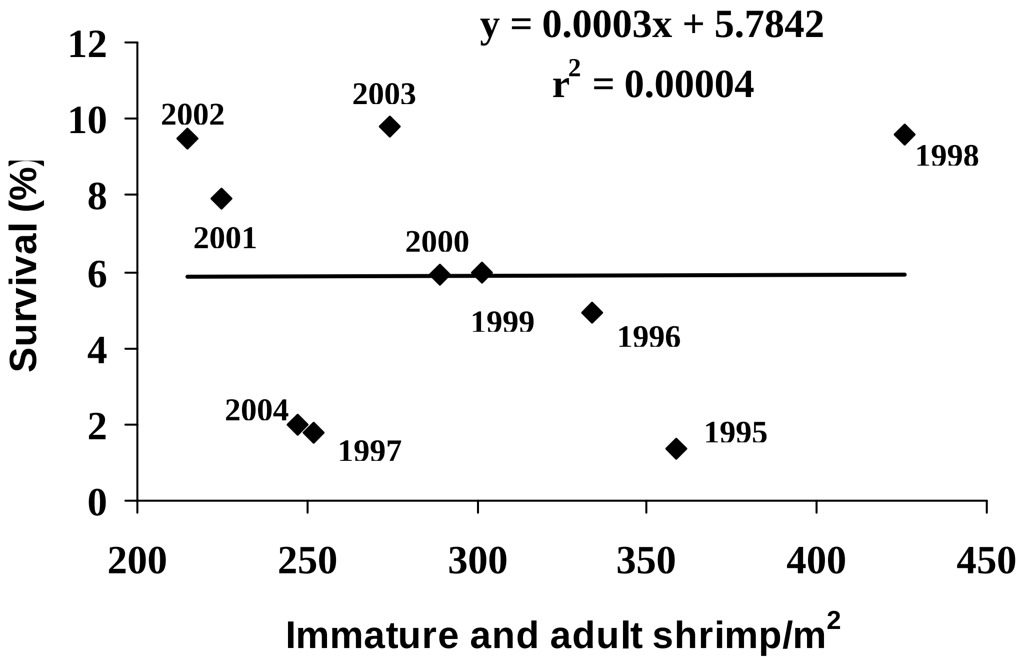


Figure 24. Correlation between opossum shrimp densities and the survival rate from kokanee eggs to fry in Lake Pend Oreille, Idaho 1995-2003. Correlation coefficient of 0.00004 indicates little correlation.

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APPENDICES

Appendix A. Location of areas surveyed for shoreline spawning kokanee in Lake Pend Oreille since 1972.

Scenic Bay

- From Vista Bay Resort to Bitter End Marina (the entire area within the confines of these two marinas and all areas between).

Farragut State Park

- From state park boat ramp go both left and right approximately 1/3 km.
- Idlewilde Bay from Buttonhook Bay north to the north end of the swimming area parking lot.

Lakeview

- From mouth of North Gold Creek go north 100 meters and south ½ km.

Hope/East Hope

- Start at the east end of the boat launch overpass and go west 1/3 km.
- From Strong Creek go west and stop at Highway 200. Go east to Lighthouse Restaurant.
- Start at East Hope Marina and go west stopping at Highway 200.

Trestle Creek Area

- From the Army Corps of Engineers recreational area boat ramp go west to mouth of Trestle Creek, including Jeb and Margaret's RV Park boat basin.

Sunnyside

- From Sunnyside Resort go east approximately ½ km.

Garfield Bay

- Along docks at Harbor Marina on east side of bay.
- From the Idaho Department of Fish and Game managed boat ramp go toward Garfield Creek. Cross Garfield Creek and proceed ¼ km.
- Survey Garfield Creek up to road culvert.

Camp Bay

- Entire area within confines of Camp Bay.

Anderson Point

- Not surveyed since 1978.

Appendix B. Estimated weights of large (>-33 dB) pelagic (water >70 m deep) fish that were at depths <30 m in Lake Pend Oreille, Idaho in 2004. Weights were based on Irving's (1986) length-weight regression for Kamloops rainbow trout.

Fish No #	Lake Section	Target Strength (dB)	Length (mm)	Weight (kg)
1	1	-32.9	420	0.76
2	1	-32.9	421	0.77
3	1	-32.8	425	0.79
4	1	-32.9	422	0.77
5	1	-32.9	419	0.76
6	1	-32.9	420	0.76
7	1	-29.1	662	3.55
8	1	-32.6	435	0.86
9	1	-32.9	420	0.76
10	1	-32.7	430	0.82
11	1	-32.9	420	0.76
12	1	-29.4	640	3.17
13	1	-32.3	450	0.96
14	1	-32.9	420	0.76
15	1	-32.7	430	0.82
16	1	-32.9	420	0.76
17	1	-32.8	425	0.79
18	1	-32.4	445	0.93
19	1	-30.6	550	1.90
20	1	-32.2	455	1.00
21	1	-32.4	445	0.93
22	2	-28.1	750	5.42
23	2	-32.9	420	0.76
24	2	-32.6	435	0.86
25	2	-30.3	575	2.21
26	2	-32.8	425	0.79
27	2	-32	465	1.07
28	2	-32.8	425	0.79
29	2	-25.9	970	12.95
30	2	-30.9	535	1.73
31	2	-32.7	430	0.82
32	2	-28	750	5.42
33	2	-29.9	600	2.55
34	2	-32.8	425	0.79
35	2	-32.9	420	0.76
36	2	-29.4	635	3.09
37	2	-30.5	560	2.02
38	2	-29.6	625	2.92
39	2	-25.1	1070	18.05
40	2	-26.9	860	8.62
41	2	-28.6	700	4.29
42	2	-32.2	455	1.00
43	2	-31.9	470	1.11
44	3	-32.6	435	0.86
45	3	-32.9	420	0.76
46	3	-32.8	425	0.79
47	3	-32.8	425	0.79
48	3	-28.7	690	4.09
49	3	-29.3	645	3.25
50	3	-29.9	600	2.55
51	3	-28.8	685	3.99
52	3	-30.8	540	1.78
53	3	-32.5	440	0.89
54	3	-29.7	615	2.77
55	3	-31.2	515	1.52
56	3	-30.8	540	1.78
Mean				2.27

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