FISHERY RESEARCH

LAKE PEND OREILLE RESEARCH, 2011

LAKE PEND OREILLE FISHERY RECOVERY PROJECT

ANNUAL PROGRESS REPORT
March 1, 2011—February 28, 2012

Prepared by:

Nicholas C. Wahl, Senior Fishery Research Biologist
Andrew M. Dux, Principal Fishery Research Biologist
William J. Ament, Senior Fishery Technician
and
William Harryman, Senior Fishery Technician

IDFG Report Number 13-22
November 2013

LAKE PEND OREILLE RESEARCH, 2011

LAKE PEND OREILLE FISHERY RECOVERY PROJECT

Annual Progress Report

March 1, 2011—February 28, 2012

By

Nicholas C. Wahl
Andrew M. Dux
William J. Ament
and
William Harryman

Idaho Department of Fish and Game
600 South Walnut Street
P.O. Box 25
Boise, ID 83707

To

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

Project Number 1994-047-00
Contract Number 52380

IDFG Report Number 13-22
November 2013

TABLE OF CONTENTS

Page

INTRODUCTION 1
STUDY AREA 1
PROJECT OBJECTIVES 2
CHAPTER 1: KOKANEE RESEARCH 4
ABSTRACT 4
INTRODUCTION 5
METHODS 5
  Kokanee Population Dynamics 5
    Abundance and Survival 5
    Hatchery and Wild Abundance 6
    Biomass, Production, and Mortality by Weight 6
    Spawner Counts 7
    Fry Release Study 7
  Kokanee Spawning Habitat Quality 7
  Mysid Research 8
    Mysid Abundance 8
RESULTS 8
  Kokanee Population Dynamics 8
    Abundance and Survival 8
    Hatchery and Wild Abundance 8
    Biomass, Production, and Mortality by Weight 9
    Spawner Counts 9
    Fry Release Study 9
  Kokanee Spawning Habitat Quality 9
  Mysid Research 9
    Mysid Abundance 9
DISCUSSION 10
  Kokanee Population Dynamics 10
  Kokanee Spawning Habitat Quality 11
  Mysid Research 12
RECOMMENDATIONS 12
CHAPTER 2: LAKE TROUT RESEARCH 25
ABSTRACT 25
INTRODUCTION 26
METHODS 26
  Lake Trout Telemetry 26
  Lake Trout Spawning Site Assessment 27
  Lake Trout Population Characteristics 27
RESULTS 28
  Lake Trout Telemetry 28
  Lake Trout Spawning Site Assessment 29
  Lake Trout Population Characteristics 29

Table of Contents, continued.

Page

DISCUSSION....29
Lake Trout Telemetry....29
Lake Trout Spawning Assessment....30
Lake Trout Population Characteristics....31
RECOMMENDATIONS....31
CHAPTER 3: RAINBOW TROUT RESEARCH....41
ABSTRACT....41
INTRODUCTION....42
METHODS....42
Rainbow Trout Population and Exploitation....42
Rainbow Trout Population Characteristics....43
RESULTS....43
Rainbow Trout Population and Exploitation....43
Rainbow Trout Population Characteristics....44
DISCUSSION....44
RECOMMENDATIONS....45
CHAPTER 4: PREDATOR REMOVAL....51
ABSTRACT....51
INTRODUCTION....52
METHODS....52
RESULTS....53
DISCUSSION....54
RECOMMENDATIONS....55
ACKNOWLEDGMENTS....59
LITERATURE CITED....60
APPENDICES....65

INTRODUCTION

Lake Pend Oreille once provided the largest kokanee *Oncorhynchus nerka* fishery in the state of Idaho. Between 1952 and 1966, harvests of kokanee averaged 1 million kokanee/yr with up to 523,000 angler-hours of fishing pressure (Jeppson 1953; Maiolie and Elam 1993). Kokanee harvest dramatically declined after 1966, and by 1985 the annual harvest was only 71,200 kokanee with 179,000 angler hours (Bowles et al. 1987; Maiolie and Elam 1993). In 2000, Idaho Department of Fish and Game (IDFG) closed the kokanee fishery because of low adult kokanee abundance. Fall and winter drawdowns of the lake for flood control and power production were responsible for much of the early kokanee decline (Maiolie and Elam 1993). High predation on the kokanee stocks led to continued kokanee declines after 2000, mainly due to an increase in the lake trout *Salvelinus namaycush* population (Maiolie et al. 2002; Maiolie et al. 2006a).

Two primary strategies have been implemented to recover the kokanee population. Since 1996, the U.S. Army Corps of Engineers has manipulated the winter drawdown of Lake Pend Oreille to either 625.1 or 626.4 m above mean sea level (MSL) to enhance kokanee spawning and egg incubation success. In an attempt to reduce predation on kokanee, IDFG changed regulations to reduce predator abundance. In 2000, IDFG removed all bag limits on lake trout, followed by the removal of rainbow trout *O. mykiss* limits in 2006. In addition to regulation changes, IDFG implemented an Angler Incentive Program (AIP), which pays anglers to harvest lake trout and rainbow trout. To further reduce lake trout abundance, IDFG has contracted with Hickey Brothers, LLC (Bailey's Harbor, Wisconsin) since 2006 to fish gill and trap nets in Lake Pend Oreille. Since reaching a record low in 2007, kokanee abundance increased moderately through 2010 (Wahl et al. 2011b).

During 2011, research focused on evaluating the effects of recovery actions. We examined kokanee population responses to both lake level manipulations and predator removals. We also assessed changes in kokanee spawning habitat due to lake level manipulations. Lake trout research was conducted to determine the influence that removals from angling and netting have had on the population and to help improve the efficiency of lake trout netting operations. We also completed the final year of a two-year rainbow trout study to better assess status of this population.

STUDY AREA

Lake Pend Oreille is located in the northern panhandle region of Idaho (Figure 1). It is the state's largest and deepest lake, with a surface area of 32,900 ha, a mean depth of 164 m, and a maximum depth of 357 m. Only four other lakes in the United States have a greater maximum depth. The Clark Fork River, located on the northeast shore, is the largest tributary to the lake. Outflow from the lake forms the Pend Oreille River, on the northwest shore. Lake Pend Oreille is a temperate, oligotrophic lake in which thermal stratification typically occurs from late June to September (Maiolie et al. 2002) with epilimnetic temperatures averaging about 9°C (Rieman 1977). Operation of Albeni Falls Dam on the Pend Oreille River keeps the lake level high and stable at 628.7 m above MSL during summer (June-September), followed by lower lake levels of 626.4 m to 625.1 m during fall and winter. Littoral areas are limited and most shoreline areas have steep slopes.

A diverse assemblage of fish species is present in Lake Pend Oreille. Native game fish include bull trout *S. confluentus*, westslope cutthroat trout *O. clarkii lewisi*, mountain whitefish

Prosopium williamsoni, and pygmy whitefish *P. coulterii.* Native nongame fishes include slimy sculpin *Cottus cognatus*, five cyprinid species, and two catostomid species. The most abundant nonnative sport fishes are kokanee, rainbow trout, lake trout, lake whitefish *Coregonus clupeaformis*, and smallmouth bass *Micropterus dolomieu*. Less abundant introduced sport fishes include northern pike *Esox lucius*, brown trout *Salmo trutta*, largemouth bass *M. salmoides*, yellow perch *Perca flavescens*, and walleye *Sander vitreus* (Hoelscher 1992).

Historically, bull trout and northern pikeminnow *Ptychocheilus oregonensis* were the primary native predatory fish in Lake Pend Oreille (Hoelscher 1992). The historical native prey population included mountain whitefish, pygmy whitefish, slimy sculpin, suckers *Catostomus spp*., peamouth *Mylocheilus caurinus*, and redside shiner *Richardsonius balteatus*, as well as juvenile salmonids (bull trout and westslope cutthroat trout). Presently, the predominant pelagic predatory species are lake trout, rainbow trout, and bull trout.

PROJECT OBJECTIVES

1. Recover kokanee abundance to a population level that can support an average annual harvest of 300,000 fish and catch rates of 1.5 fish per hour by 2015.

2. Provide kokanee with adequate spawning habitat to allow for population recovery.

3. Reduce the lake trout population to pre-1999 abundance and ensure long-term suppression keeps the population below this level. Below this abundance threshold, negative influences of lake trout on the kokanee and bull trout populations are expected to be minimal.

4. Reduce the rainbow trout population to decrease predation on kokanee until predation no longer limits kokanee recovery.

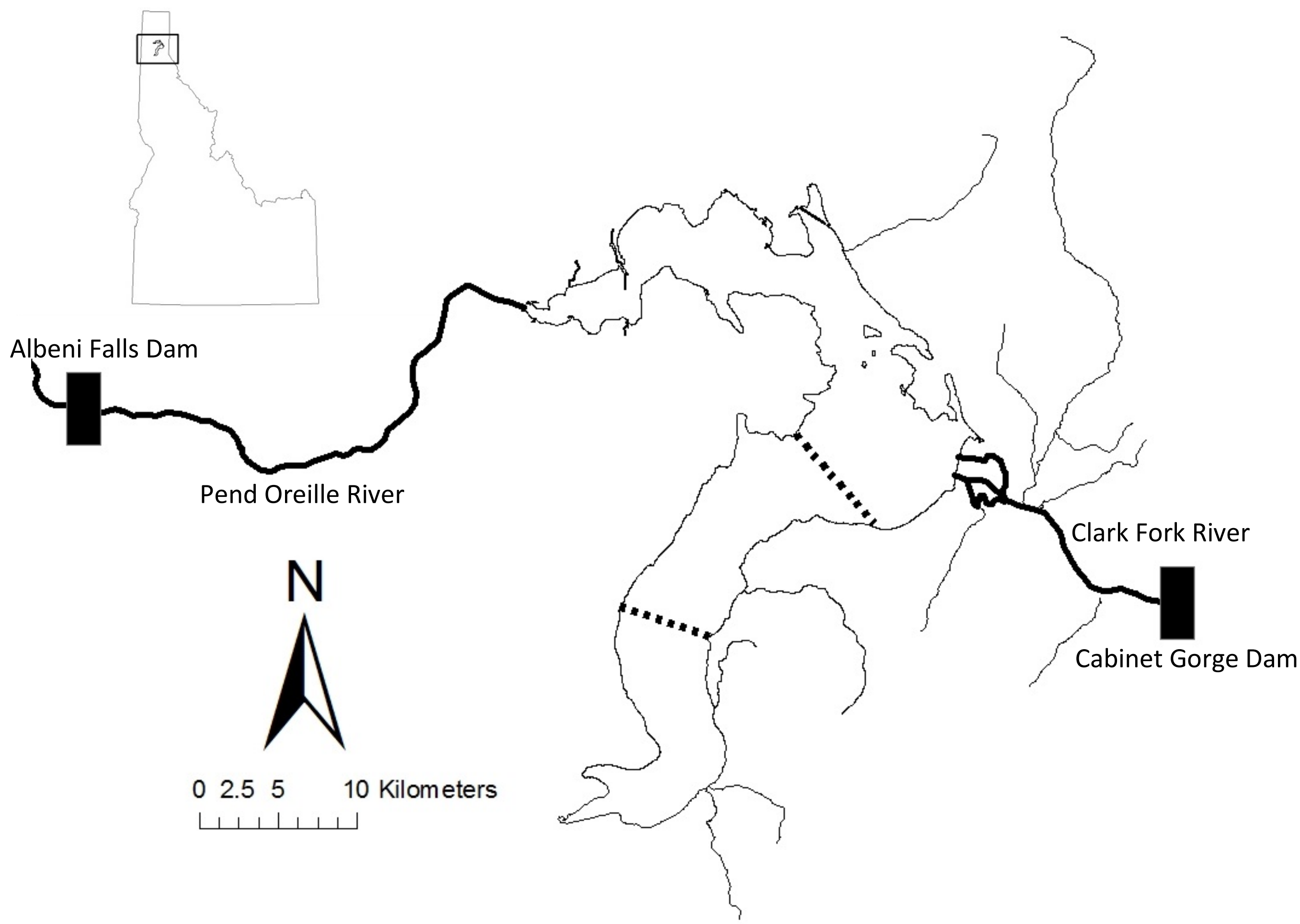


Figure 1. Map of Lake Pend Oreille, Idaho showing the three lake sections (separated by dashed lines) and primary kokanee spawning tributaries. The main inflow and outflow rivers (Clark Fork River and Pend Oreille River) and dams (Cabinet Gorge Dam and Albeni Falls Dam) are shown.

CHAPTER 1: KOKANEE RESEARCH

ABSTRACT

During 2011, we examined the response of kokanee *Oncorhynchus nerka* to a winter water level manipulation strategy designed to improve spawning and egg incubation success for wild kokanee and to a large-scale predator reduction program aimed at reducing predation by lake trout *Salvelinus namaycush* and rainbow trout *Oncorhynchus mykiss*. We conducted hydroacoustic surveys and trawling during August 2011 to assess the kokanee population and determine the impacts of these recovery actions. Total kokanee abundance was 13.9 million (612 kokanee/ha), including 5.8 million wild fry and 4.7 million hatchery fry. Kokanee biomass was 157 metric tonnes (t), with annual kokanee production at 212 t, resulting in a production to biomass ratio of 1.4:1. Survival from age-1 to age-2 was 26%. Substrate assessment indicated no change in gravel composition for wild shoreline-spawning kokanee following the high pool during the winter of 2010-11. Peak visual index counts of wild-spawning kokanee were 5,893 fish on the shoreline, 8,837 early-run tributary spawners, and 9,138 late-run tributary spawners. With the exception of 2010, the counts of shoreline and early-run kokanee were the highest recorded since 1975. Despite the increase in kokanee abundance and biomass, age-1 to age-2 survival declined; however, entrainment downriver during high spring runoff may have contributed to this decline. A major reason kokanee have persisted despite low abundance is that production to biomass ratios have been high. While improved kokanee abundance is promising, most of the increase has occurred in young age classes, and weak cohorts produced from low spawner returns in 2007 and 2008 are still present in the lake and will need to be overcome for bigger gains in abundance and biomass to occur. Overall, results from the past year suggest that kokanee are responding favorably to reduced predation from lake trout. The influence of water level manipulations on higher kokanee recruitment was less clear.

Authors:

Nicholas C. Wahl
Senior Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

William J. Ament
Senior Fishery Technician

William Harryman
Senior Fishery Technician

INTRODUCTION

Numerous factors have contributed to the dramatic decline of kokanee *Oncorhynchus nerka* from their historical abundance levels. However, the extent and timing of winter lake drawdowns has been implicated as most detrimental (Maiolie and Elam 1993). In the 1990s, a strategy was developed to address the problems associated with lake drawdowns. Since 1996, the winter lake level of Lake Pend Oreille has been manipulated to test the ability of a higher winter level to improve kokanee spawning and egg incubation success. With rare exceptions, the U.S. Army Corps of Engineers has set the winter lake elevation at either 625.1 or 626.4 m above mean sea level (MSL; Figure 2).

Benefits from lake level manipulations have been documented, including habitat improvement (substrate redistribution) following winters at 625.1 MSL (Maiolie et al. 2004) and higher kokanee egg-to-fry survival following winters at 626.4 MSL (Maiolie et al. 2006b). Additionally, modeling work conducted in 2009 further corroborated the increased egg-to-fry survival at 626.4 MSL (Wahl et al. 2011b). However, conditions have not yet allowed the expected full benefits of lake level manipulations to occur. Since starting experimental manipulations, mature kokanee density has been low. Initially, kokanee suffered major mortality from a record flood in 1997 (Maiolie 2006b). By the early 2000s, high predation levels created by a rapidly expanding lake trout *Salvelinus namaycush* population surpassed spawning habitat (i.e., winter lake level) as the primary limiting factor for kokanee (Maiolie et al. 2006b).

Since reaching a record low abundance in 2007, kokanee abundance and biomass have increased in response to predator reduction (Wahl et al. 2011b). Continued success of predator reduction efforts will allow for increased kokanee abundance and the opportunity for lake level manipulations to provide greater benefit to kokanee. Additionally, hatchery kokanee fry production has been important in maintaining this population, especially during the years of record low wild adult abundance, and when low numbers of kokanee return to the Sullivan Springs Creek weir for egg collection, IDFG supplements stocking with fry collected from other lakes (e.g., Lake Whatcom, Washington).

During the 2011-12 contract period, we evaluated the response of the kokanee population to both lake level manipulations and predator reduction. Additionally, we examined the quality of kokanee spawning habitat with respect to the winter lake level. Finally, we estimated mysid abundance to determine whether there was a population response to predator reduction and changes in kokanee abundance.

METHODS

Kokanee Population Dynamics

Abundance and Survival

We conducted a lakewide hydroacoustic survey on Lake Pend Oreille to estimate the abundance and survival rate of kokanee. Surveys were performed at night between August 21 and 25, 2011 following the same protocol described in detail by Wahl et al. (2011a). Prior to the surveys, we calibrated the echo sounder for signal attenuation to the sides of the acoustic axis using Simrad's EK60 software. Analysis of hydroacoustic data to derive kokanee density estimates and associated confidence intervals followed the protocol described in Wahl et al. (2010).

We were able to partition out kokanee fry from older age classes during the analysis. However, to partition out hydroacoustics data based on older kokanee age classes (age-1 thru age-5), we sampled kokanee using midwater trawling from August 24 to 31, 2011. These dates were during the dark phase of the moon, which optimized the capture efficiency of the trawl (Bowler et al. 1979). Details of the sampling procedures for midwater trawling have been described in previous reports (Rieman 1992; Wahl et al. 2011a). We also calculate abundance estimates from trawling strictly for comparisons with historic data (kokanee abundance was estimated using trawling alone until 1995), and these results can be seen in Appendix A.

We collected kokanee from each trawl transect and placed them on ice until morning when they were processed. We counted fish from each transect, recorded total length (mm) and weight (g), and checked all kokanee over 180 mm for sexual maturity. Two independent readers aged fish using scales collected from 10-15 fish in each 10 mm size interval. We used the proportion of age-1 thru age-4 kokanee captured by trawling in each section of the lake to partition hydroacoustics data and generate lakewide age-specific abundance estimates. From these estimates, we calculated annual survival between age classes.

To sample kokanee fry for assessing origin (hatchery or wild), we also conducted a midwater trawl survey using a smaller mesh trawl net. Sampling with the fry net began in 1999 and detailed methods have been previously described (Wahl et al. 2011a). 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 until processed. Fish were later thawed, length and weight were measured, and otoliths were removed.

Hatchery and Wild Abundance

All kokanee produced at the Cabinet Gorge Fish Hatchery since 1997 have been marked using thermal mass-marking techniques (or cold branding) described by Volk et al. (1990). Therefore, hatchery kokanee of all ages contain distinct thermal marks. Hatchery personnel initiated thermal treatments five to ten days after fry entered their respective raceways and sacrificed ten fry from each raceway to verify the thermal marking. To determine hatchery and wild kokanee abundance, we sent otoliths from kokanee captured during the midwater trawl surveys (10-15 per 10 mm size interval) to the Washington Department of Fish and Wildlife (WDFW) Otolith Laboratory where personnel checked them for hatchery thermal marks. Methodologies for checking thermal marks are described in Wahl et al. (2010).

We calculated the proportion of wild and hatchery kokanee within each 10 mm length group to estimate the overall proportion of wild and hatchery fry in each section. We then multiplied the proportion of wild fish by the hydroacoustic population estimate for fry in that section. Finally, we summed these values to estimate the abundance of wild fish in the lake.

Biomass, Production, and Mortality by Weight

We calculated the biomass, production, and mortality by weight of the kokanee population in Lake Pend Oreille to assess the effects of predation. Biomass was the total weight of kokanee within Lake Pend Oreille at the time of our population estimate, calculated by multiplying the population estimate of each kokanee year class by the mean weight of kokanee in that year class. Finally, we summed the year class weights to obtain total kokanee biomass in the lake.

Production is 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). Mortality by weight refers to the total biomass lost from the population due to all forms of mortality (e.g., natural, predation) between years (Ricker 1975). Hayes et al. (2007) and Wahl et al. (2011a) provide additional details on methods for estimating production and mortality by weight.

Spawner Counts

We counted spawning kokanee in standard tributaries and shoreline areas (Appendix B) to continue time-series data dating back to 1972. All areas surveyed are historic spawning sites (Jeppson 1960). Tributary streams were surveyed by walking upstream from their mouth to the highest point utilized by kokanee. Surveys for early-run kokanee occurred in September in Trestle Creek, South Gold Creek, North Gold Creek, and Cedar Creek. In addition, surveys for late-run kokanee occurred in November in the same four tributaries as well as Johnson Creek, Twin Creek, and Spring Creek. Shoreline counts for late-run kokanee occurred at nine standardized sites approximately once per week in November and December. For all counts, we counted all kokanee, either alive or dead.

We removed otoliths from early- and late-run kokanee carcasses to determine hatchery and wild proportions of the run, as well as the age of hatchery fish. Methods for otolith removal, preparation, and reading were similar to those described previously. We removed 80 otoliths from early-run kokanee (20 each from South Gold Creek, Granite Creek, Sullivan Springs Creek, and Cabinet Gorge Hatchery ladder) and 80 from late-run kokanee (Sullivan Springs Creek 60, South Gold Creek 20).

Fry Release Study

Kokanee fry released in 2011 received one of four different thermal marks to distinguish specific release groups. First, we marked two groups of fry released in Sullivan Springs Creek to determine whether hatchery kokanee fry experienced differential survival whether they were produced from Lake Pend Oreille (5.2 million released) or from Lake Whatcom, Washington (2.6 million released) kokanee stocks. Additionally, we marked two groups of fry released at Talache Landing on the west shore of Lake Pend Oreille to assess whether kokanee experienced differential survival based on release timing. Kokanee fry were released on June 21 (1.4 million), the usual release timing, and July 11 (1.6 million), which is a later release than normal.

Calculations to estimate fry abundance within each of these groups is identical to those described above. For survival calculations, we generated a simple proportion of the number released that was still in the lake during fall surveys.

Kokanee Spawning Habitat Quality

We have sampled six standardized sites annually since 2004 to assess changes in kokanee spawning substrate composition and assess the effectiveness of the winter-pool manipulation strategy. These sites included Twin Creek, Green Bay, Ellisport Bay, Kilroy Bay, south of Evans Landing, and the south side of Ellisport Bay. In August 2010, divers collected six randomly located samples from a gravel band between elevations 624.8 and 625.8 MSL at each site. We air-dried samples before screening each through a series of soil sieves (sizes 31.5 mm, 6.3 mm, 4.0 mm, and 2.0 mm). Finally, we weighed the substrate from each sieve and the substrate that fell through the finest sieve. We defined “cobble” as substrates that were 31.5 mm and larger, “gravel” as substrates between 31.5 and 4.0 mm, and “fines” as the substrate smaller than 4.0 mm. We modified these size breaks from several other studies (Chapman and McLeod 1987; Cochnauer and Horton 1979; Irving and Bjornn 1984). Differences in the percent of each substrate class were detected using a general linear model (ANOVA).

Mysid Research

Mysid Abundance

We sampled mysids on June 1 to 3, 2011 to estimate their density within Lake Pend Oreille. All sampling occurred at night during the dark phase of the moon. We collected mysids at eight sites per lake section using a 1 m hoop net. Further details can be found in Wahl et al. (2011a).

During laboratory analysis, mysids were classified as either young-of-the-year (YOY) or immature and adults and counted for each sample. We based density estimates on the number of mysids collected in each sample and the volume of water filtered. We calculated the arithmetic means and 90% confidence intervals for the immature and adult portion of the mysid population and for the YOY portion.

RESULTS

Kokanee Population Dynamics

Abundance and Survival

In 2011, we estimated 13.9 million kokanee (12.3-15.7 million, 90% CI) or 612 fish/ha in Lake Pend Oreille, based on our standard hydroacoustic survey. This included 10.5 million kokanee fry (9.1-12.2 million, 90% CI; Table 1, Figure 3), 2.5 million age-1, 420,000 age-2, 290,000 age-3 kokanee, and 120,000 age-4 kokanee (Table 2, Figure 3). Kokanee captured by midwater trawling varied in length from 28-315 mm (Figure 4) and weight from 0.1-231 g. We estimated kokanee survival at 25% from fry to age-1, 26% from age-1 to age-2, 68% from age-2 to age-3, and 61% from age-3 to age-4 (Table 3).

Hatchery and Wild Abundance

During the spring of 2011, Cabinet Gorge Fish Hatchery released 10.9 million thermally marked kokanee fry into Lake Pend Oreille. Out of this total, 7.9 million late-run fry were stocked into Sullivan Springs Creek (5.2 million from Lake Pend Oreille and 2.6 million from Lake Whatcom). Additionally, 2.9 million late-run kokanee fry were stocked at Talache Landing along the west shore. Of these fish, 1.4 million were released around June 21, and the remaining 1.6 million were released around July 11.

We sent 203 pairs of otoliths from fry captured in the fry trawl to the WDFW Otolith Laboratory. Additionally, otoliths from 99 kokanee fry and 200 kokanee between ages 1-4 captured in the midwater trawl were sent to the WDFW Otolith Laboratory.

Wild kokanee fry made up 74%, 74%, and 42% of the fry net catch in the southern, middle, and northern sections, respectively (Table 1). Based on these proportions, we estimated the wild fry population at 5.8 million (Table 1). Further, we estimated that wild kokanee comprised 51%, 22%, 30%, and 80% of age-1, age-2, age-3, and age-4 abundance estimates, respectively (Table 2).

Biomass, Production, and Mortality by Weight

Based on the hydroacoustic estimates of kokanee abundance, kokanee biomass was 157 metric tonnes (t) and production was 212 t (Figure 5) for a production to biomass ratio of 1.4:1. Total mortality by weight was 192 t, which was 20 t lower than production (Figure 5).

Spawner Counts

In 2011, we observed a peak of 5,893 kokanee spawning on the lake's shorelines. The majority of these fish (72%; 4,214) were on the shoreline around Bayview in Scenic Bay (Table 4). We observed a peak of 9,138 late-run kokanee spawning in tributaries of Lake Pend Oreille, with 7,057 in South Gold Creek and 1,535 in North Gold Creek (Table 5). Additionally, peak abundance of early-run kokanee was 8,837 with 5,900 in South Gold Creek and 1,737 in North Gold Creek (Table 6).

Early-run kokanee were predominately (70%) of hatchery origin. This pattern held true for the Cabinet Gorge Hatchery ladder and Granite and Sullivan Springs creeks where fish were primarily (≥85%) hatchery origin. However, South Gold Creek early-run kokanee were primarily (95%) wild origin. The age structure of these early-run hatchery fish was 25% age-2, 73% age-3, and 2% age-4. Hatchery fish comprised 76% of late-run kokanee in South Gold and Sullivan Springs creeks and their age structure was 5% age-2, 77% age-3, and 18% age-4.

Fry Release Study

During the fall, we estimated 2.6 million kokanee fry from the Sullivan Springs Creek stock and 0.7 million kokanee fry from the Lake Whatcom stock. Based on the numbers released, survival was estimated to be 49% for Sullivan Springs Creek and 28% for Lake Whatcom. Additionally, we collected an estimated 0.9 million kokanee fry from the early release at Talache Landing and 0.4 million kokanee fry from the late release. Based on the numbers released, survival was estimated to be 69% and 27% for the early and late releases, respectively.

Kokanee Spawning Habitat Quality

Following the high winter lake level during the winter of 2010-11, the mean percent gravel (65% ±15, 90% CI) was not significantly different than the mean percent cobble (28% ±15%, 90% CI; ANOVA; $F_{1,11}$=4.21, p=0.096), but was significantly higher than mean percent fines (7% ±3%, 90% CI; ANOVA; $F_{1,11}$=37.53, p=0.002; Figure 6). There was no difference in substrate composition between 2010 and 2011 (Figure 6).

Mysid Research

Mysid Abundance

We estimated a total mean density of 326 mysids/m^2 during June 2011 (Table 7; Figure 7). This included 157 immature and adult mysids/m^2 (90% CI of $\pm$ 52%) and 167 YOY mysids/m^2 (90% CI of $\pm$ 76%; Table 7; Figure 8).

DISCUSSION

Kokanee Population Dynamics

In the past year, total kokanee abundance increased 11%. Though kokanee abundance was nearly at or above 2010 levels for all age classes, the largest increase was 53% for age-1. This increase was not unexpected as the age-1 cohort was nearly twice as large as the age-2 cohort when they were fry. Survival from age-1 to age-2, the stage when kokanee are most vulnerable to predation, dropped to 26%. Although age-1 to age-2 survival decreased to below desired levels, we are unsure how much of this loss was due to entrainment during the high spring runoff in 2011. Anglers reported large numbers of kokanee in the Pend Oreille River, and biologists below Albeni Falls Dam reported collecting large numbers of kokanee in electrofishing surveys. Both of these occurrences have traditionally been rare and typically only observed in extreme runoff years. However, mean survival was better during 2008-2011 than in 2005-2007 when lake trout were more abundant, suggesting that kokanee survival has increased in response to predator reduction efforts.

While we are encouraged by the increase in age-1 kokanee, multiple consecutive years of strong cohorts are needed to bring this population back to recovery goals. Additionally, comparably strong age-1 cohorts have been recorded as recently as 2005-07, but only 10-32% of these cohorts survived to age-2. We are optimistic that reduced predation pressure on the kokanee population, especially by lake trout, will lead to continued positive trends in survival and higher numbers of kokanee reaching maturity.

Unlike previous years, we did not calculate a kokanee egg-to-fry survival estimate for 2011. Presently, a multiyear graduate study is being conducted by the University of Idaho to more directly measure survival to the emergent fry stage and to better understand some of the mechanisms driving egg incubation success. An additional component of this project, meant to build on the statistical work conducted in 2010 (Wahl et al. 2011b), is to more rigorously evaluate our current egg-to-fry survival metric and the variance associated with the estimate. Results and interpretations of this study will be made available upon completion.

From 1996 to 2011, kokanee production remained relatively consistent, ranging from 174 t to 254 t. However, during 2004-2007, kokanee mortality by weight ($\bar{x}$ = 268 t) was consistently higher than production ($\bar{x}$ = 209 t), leading to decreases in kokanee biomass. Pronounced increases in the production to biomass ratio during this period was vital to slowing the decline of the kokanee population (Wahl et al. 2010). From 2008 to 2011, kokanee production ($\bar{x}$ = 185 t) has been higher than mortality by weight ($\bar{x}$ = 169 t), and biomass in 2011 reached a level not attained since 2004. While we are unsure whether the increase in mortality by weight since 2009 was caused by predation or other factors (e.g., more kokanee reaching maturity before age-4, entrainment during spring runoff), it remained substantially lower than during 2004-2007 when predation potential was highest. Continued implementation of the predator reduction program should further reduce kokanee mortality by weight and, with sustained high production to biomass ratios, lead to increased kokanee biomass.

Spawner counts provide only an index to spawner abundance, but do provide a useful way to coarsely assess trends in spawner escapement. Additionally, it allows the spatial extent of spawning to be evaluated. The upward trend in late-run kokanee escapement since 2007 has been encouraging. Although counts in 2011 were not as high as 2010, spawner count data suggest that spawner escapement during 2009-11 was higher than one generation (five years) earlier. Additionally, late-run tributary counts were the highest since 2004, and with the exception of 2010, shoreline spawner counts in 2011 were the highest recorded since 1975. Additionally, the numbers of kokanee spawners we counted at index sites outside of Scenic Bay during 2010 and 2011 had not been observed since the early 1970s. If kokanee density continues to increase, we anticipate the spatial extent of spawning will further expand to historically used spawning habitats. Additionally, using underwater videography, we documented kokanee spawners at depths of 10-20 m along shorelines in Idlewilde Bay, along Bernard Beach, and near Lakeview. Presently we are unaware of the full extent of this deepwater spawning, but the fish we found were located primarily in areas with frequently recruiting substrate (i.e., gravel slides near Bernard Beach, mouth of Gold Creek).

Early-run kokanee again returned to Granite, Cedar, and North and South Gold creeks where they historically have been uncommon. Most of the early-run kokanee returning to these tributaries have been strays from early-run fry stocked in Sullivan Springs Creek during 2004-09 to bolster the kokanee population when it was at risk of collapse. The exception was South Gold Creek, where otolith analyses have shown that the majority of spawners in this creek have been of wild origin. Previously we stated that early-run kokanee were unlikely to substantially contribute towards recovery goals (Wahl et al. 2011a). Over the long term, we still believe this is the case because redd superimposition by late-run kokanee and bull trout *Salvelinus confluentus* and dynamic flow conditions during egg incubation are threats to sustained fry production. Because stocking of early-run fry was discontinued after 2009, hatchery origin fish will likely only persist through 2012. Afterwards, early-run kokanee are expected to diminish because natural reproduction appears to be largely limited to South Gold Creek.

The differential survival of Sullivan Springs Creek stock and Lake Whatcom stock kokanee fry during 2011 was likely due to size differences. Lake Whatcom fry were smaller when stocked and may have had lower survival due to factors such as gape limitation, fat content, or differential predation. The difference in survival of the early and late release groups was counterintuitive (e.g., late-release fish were larger at the time of stocking, likely had more zooplankton prey available, and fewer days at large in the lake) and the opposite of what has been suggested in the past. Paragamian and Bowles (1995) found that kokanee fry stocked in July had higher survival than those stocked in June due to higher zooplankton abundance, especially *Daphnia*. It is possible that higher than average runoff during June 2011 negatively influenced survival for early-release fry. Repeating this evaluation of hatchery kokanee fry over multiple years will be necessary before drawing conclusions about stocking strategies.

Kokanee Spawning Habitat Quality

During the winter of 2008-09, the full drawdown to 625.1 MSL allowed wave action to redistribute substrates along the shoreline, which led to significantly more shoreline gravels and reduced cobble (Wahl et al. 2011a). We have documented no changes to the overall substrate composition since this drawdown. However drastic changes documented at individual sites (e.g., 63% gravel in 2010 to 37% gravel in 2011 at Evans Landing) suggest that some substrate movement occurred along the lakeshore. While the mean quantity of shoreline gravel remained unchanged, site-specific differences could still be meaningful if they occurred at highly used spawning areas. Previously, we recommended that the lake should be drawn down to a winter elevation of 625.1 MSL once every four years to allow wave action to improve spawning habitat (Maiolie et al. 2002). Substrate data still demonstrate that drawdown to 625.1 MSL effectively re-distributes spawning substrate and makes it more available at elevations above 625.1; however, we believe that substrate sampling methods should be modified to better characterize the annual changes in substrate composition on a lakewide scale and to re-assess how frequently drawdown should occur.

Mysid Research

Mysids in Lake Pend Oreille have gone through a cycle of expansion, decline, and stability. Mysids were introduced in 1966, became fully established by the mid-1970s, and rapidly expanded until 1980. Since 1980, they declined from their peak abundance and have remained relatively stable since 1997. A similar pattern of population fluctuation occurred in other western lakes after mysid introductions (Richards et al. 1991; Beattie and Clancey 1991). While immature and adult mysid (the segments of the population most likely to compete with kokanee) densities have been relatively stable since 1997, YOY mysid densities have periodically increased by up to an order of magnitude. The reason for these increases in YOY densities is unclear, but they have not been correlated with immature and adult mysid densities. Additionally, we have not documented any changes in mysid abundance since 2006 that could be linked to lake trout removal. The lower density of immature and adult mysids in 2011 may or may not be noteworthy. It may simply be a natural fluctuation that is larger than we have observed since the population stabilized, or it could be a decline that indicates instability in the population. Peak runoff conditions were high in 2011 and lead us to speculate that either runoff itself or weather conditions that produced high runoff conditions could have created unfavorable environmental conditions for mysids. We recommend continued assessment of mysids given the potential they have to influence both the kokanee and lake trout populations. If further population decline occurs, a more comprehensive evaluation of mysid population dynamics may be warranted.

RECOMMENDATIONS

1. Continue to assess the kokanee population response to lake level manipulations and predator removal.

2. Coordinate with the U.S. Army Corps of Engineers, Bonneville Power Administration, and other agencies to set a winter lake level that provides adequate spawning habitat for kokanee to the extent possible.

3. Continue to reduce predator abundance to further increase kokanee survival.

4. Evaluate the statistical methods used to estimate kokanee egg-to-fry survival and modify methods if appropriate to provide more robust estimates.

5. Repeat the two kokanee fry releases strategies at Talache Landing to better understand how fry release timing affects survival.

Table 1. Population estimates of kokanee fry (millions) based on hydroacoustic surveys of Lake Pend Oreille, Idaho in 2011. Percentage of wild and late-run hatchery (KL-H) fry was based on the proportions of fry caught using a fry net.

	Southern	Middle	Northern	Lake-wide Total	90% CI
Total kokanee fry abundance estimate	1.3	3.1	6.1	10.5	9.1-12.2
Percent wild fry in fry trawl	74	74	42	—	
Percent KL-H in fry trawl	26	26	58	—	
Wild fry abundance estimate	1.0	2.3	2.5	5.8	

Table 2. Population estimates for kokanee age classes 1 through 4 in Lake Pend Oreille, Idaho, 2011. Estimates were generated from hydroacoustic data that were partitioned into age classes based on the percent of each age class sampled by midwater trawling. Percentage of wild, early-run hatchery (KE-H), and late-run hatchery (KL-H) were based on the proportions of each caught in the trawl net.

Area	Age-1	Age-2	Age-3	Age-4	Total
Southern Section					
Percent of age class by trawling	36.0	25.1	26.6	12.3	
Population estimate (millions)	0.20	0.14	0.15	0.07	0.55
Middle Section					
Percent of age class by trawling	70.8	18.0	7.7	3.4	
Population estimate (millions)	0.47	0.12	0.05	0.02	0.67
Northern Section					
Percent of age class by trawling	86.6	7.7	4.3	1.4	
Population estimate (millions)	1.84	0.16	0.09	0.03	2.12
Total population estimate for lake (millions)	2.51	0.42	0.29	0.12	3.34
90% confidence interval (millions)					2.89-3.87
Percent wild	50	22	29	82	
Percent KE-H	0	3	0	0	
Percent KL-H	50	75	71	18	

Table 3. Survival rates (%) between kokanee year classes estimated by hydroacoustics, 1996-2011. Year refers to the year the older age class in the survival estimate was collected.

	Age Class			
Year	**Fry to 1**	**1 to 2**	**2 to 3**	**3 to 4**
2011 [a]	25	26	68	61
2010[a]	31	35	22	17
2009[a]	26	69	52	7
2008[a]	14	32	40	84
2007[a]	20	10	—[b]	—[b]
2006[a]	23	13	—[b]	—[b]
2005[a]	46	15	26	28
2004[a]	21	33	28	18
2003[a]	35	55	65	—[b]
2002[a]	30	43	—[b]	—[b]
2001	28	27	6	17
2000	52	22	66	40
1999	24	18	71	49
1998	37	28	94	26
1997	42	59	29	17
1996	44	79	40	46

[a] Data from 2002 to 2010 were based on geometric means transformed by log(x+1).
[b] Too few kokanee caught to estimate survival.

Table 4. Counts of kokanee spawning along the shorelines of Lake Pend Oreille, Idaho. The numbers shown indicate the highest weekly count and should be interpreted as an index rather than a total estimate of spawner abundance.

Year	Bayview	Farragut Ramp	Idlewilde Bay	Lakeview	Hope	Trestle Cr. Area	Sunnyside	Garfield Bay	Camp Bay	Anderson Point	Total
2011	4,214	35	124	1,500	0	0	0	20	0	—	5,893
2010	4,865	0	0	3,500	0	0	0	113	0	—	8,478
2009	2,635	36	1	0	0	6	0	9	0	—	2,687
2008	663	6	0	0	0	0	0	0	0	—	669
2007	325	0	0	0	0	0	0	0	0	—	325
2006	1,752	0	0	0	17	0	0	12	0	—	1,781
2005	1,565	0	5	1	0	1	0	66	0	—	1,638
2004	2,342	0	100	1	0	0	0	34	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 5. Counts of late-run kokanee spawning in tributaries of Lake Pend Oreille, Idaho. The numbers shown indicate the highest weekly count and should be interpreted as an index rather than a total estimate of spawner abundance.

Year	S. Gold	N. Gold	Cedar	Johnson	Twin	Mosquito	Lightning	Spring	Cascade	Trestle	Total
2011	7,057	1,536	91	0	0	—	—	440	—	14	9,138
2010	3,115	1,121	26	1	64	—	—	3,522	—	0	7,849
2009	1,257	227	10	0	93	—	—	301	—	15	1,903
2008	278	0	2	0	3	—	—	8	—	0	291
2007	0	0	0	0	0	—	—	0	—	0	0
2006	414	61	21	0	0	—	—	60	—	14	570
2005	5,463	615	1	0	1,244	—	—	—[a]	—	76	7,399
2004	721	2,334	600	16	6,012	—	—	3,331[a]	—	0	9,683
2003	591	0	0	0	—	—	—	626	—	9	1,226
2002	79	0	0	0	0	—	—	0	—	0	79
2001	72	275	50	0	0	—	—	17	—	0	414
2000	17	37	38	0	2	0	0	0	0	0	94
1999	1,884	434	435	26	2,378	—	—	9,701	5	423	15,286
1998	4,123	623	86	0	268	—	—	3,688	—	578	9,366
1997	0	20	6	0	0	—	—	3	—	0	29
1996	0	42	7	0	0	—	—	17	—	0	66
1995	166	154	350	66	61	—	0	4,720	108	21	5,646
1994	569	471	12	2	0	—	0	4,124	72	0	5,250
1992	479	559	—	0	20	—	200	4,343	600	17	6,218
1991	120	550	—	0	0	—	0	2,710	0	62	3,442
1990	834	458	—	0	0	—	0	4,400	45	0	5,737
1989	830	448	—	0	0	—	0	2,400	48	0	3,726
1988	2,390	880	—	0	0	—	6	9,000	119	0	12,395
1987	2,761	2,750	—	0	0	—	75	1,500	0	0	7,086
1986	1,550	1,200	—	182	0	—	165	14,000	0	0	17,097
1985	235	696	—	0	5	—	127	5,284	0	0	6,347
1978	0	0	0	0	0	0	44	4,020	0	0	4,064
1977	30	426	0	0	0	0	1,300	3,390	0	40	5,186
1976	0	130	11	0	0	0	2,240	910	0	0	3,291
1975	440	668	16	0	1	0	995	3,055	0	15	5,190
1974	1,050	1,068	44	1	135	0	2,350	9,450	0	1,210	15,308
1973	1,875	1,383	267	0	0	503	500	4,025	0	18	8,571
1972	1,030	744	0	0	0	0	350	2,610	0	1,293	6,027

[a] Cabinet Gorge Hatchery transferred 3,000 spawners from the hatchery ladder to Spring Creek.

Table 6. Counts of early-run kokanee spawning in tributaries of Lake Pend Oreille, Idaho. The numbers shown indicate the highest weekly count and should be interpreted as an index rather than a total estimate of spawner abundance. Early-run kokanee counts in east shore tributaries began in 2008; prior to this, only Trestle Creek was counted.

Year	S. Gold	N. Gold	Cedar	Trestle	Total
2011	5,900	1,737	328	872	8,837
2010	6,240	2,169	1,352	3,817	13,578
2009	2,231	631	13	362	3,237
2008	592	181	27	50	850
2007	—	—	—	124	124
2006	—	—	—	327	327
2005	—	—	—	427	427
2004	—	—	—	682	682
2003	—	—	—	2,251	2,251
2002	—	—	—	1,412	1,412
2001	—	—	—	301	301
2000	—	—	—	1,230	1,230
1999	—	—	—	1,160	1,160
1998	—	—	—	348	348
1997	—	—	—	615	615
1996	—	—	—	753	753
1995	—	—	—	615	615
1994	—	—	—	170	170
1992	—	—	—	660	660
1991	—	—	—	995	995
1990	—	—	—	525	525
1989	—	—	—	466	466
1988	—	—	—	422	422
1987	—	—	—	410	410
1986	—	—	—	1,034	1,034
1985	—	—	—	208	208
1978	—	—	—	1,589	1,589
1977	—	—	—	865	865
1976	—	—	—	1,486	1,486
1975	—	—	—	14,555	14,555
1974	—	—	—	217	217
1973	—	—	—	1,100	1,100
1972	—	—	—	0	0

Table 7. Densities of mysids (per m^2), by life stage (young of year [YOY], and immature and adult), in Lake Pend Oreille, Idaho June 1-3, 2011.

Section	YOY/m^2	Immature & Adults/m^2	Total mysids/m^2
Section 1	261	143	404
Section 2	167	189	356
Section 3	100	138	239
Whole lake means	169	157	326

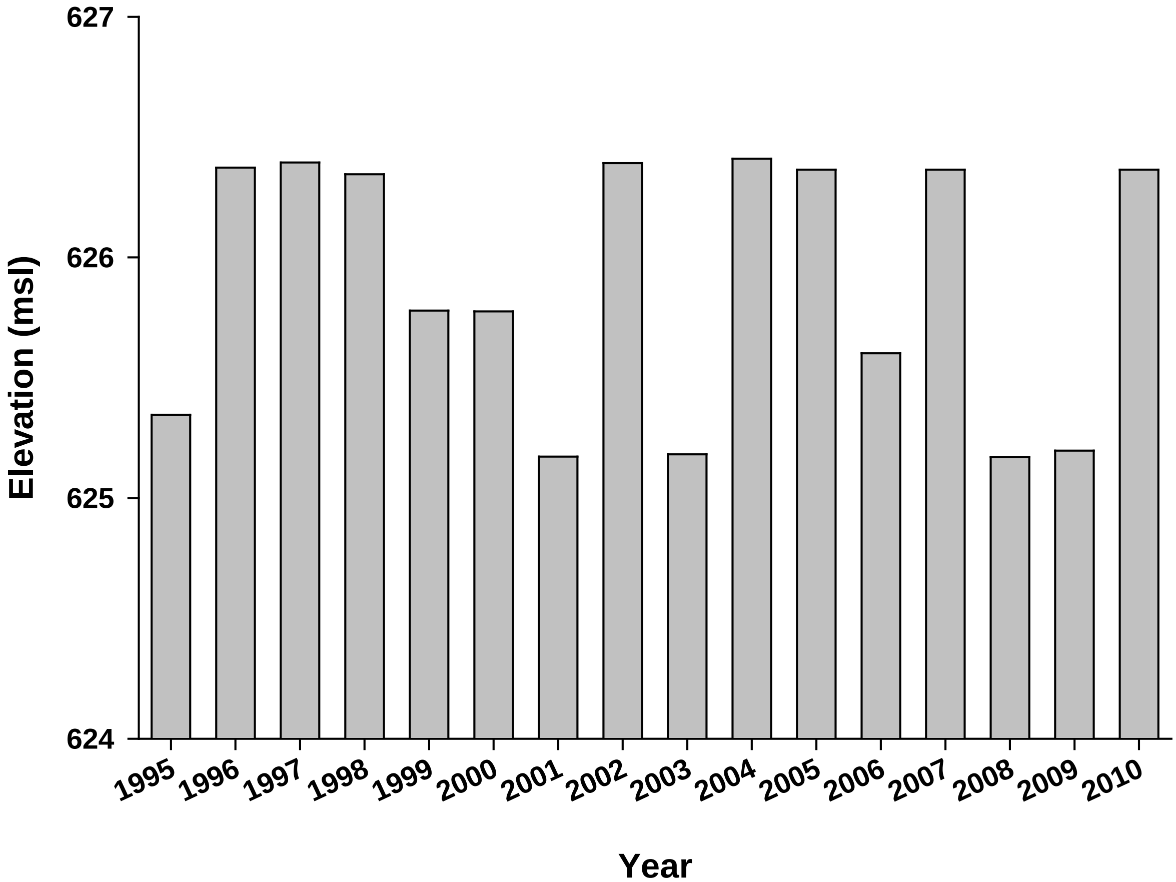


Figure 2. Winter pool surface elevation in meters above mean sea level (MSL) during years of lake level experiment in Lake Pend Oreille, Idaho. Year shown represents the year the lake was drawn down (i.e., 1995 for winter of 1995-1996).

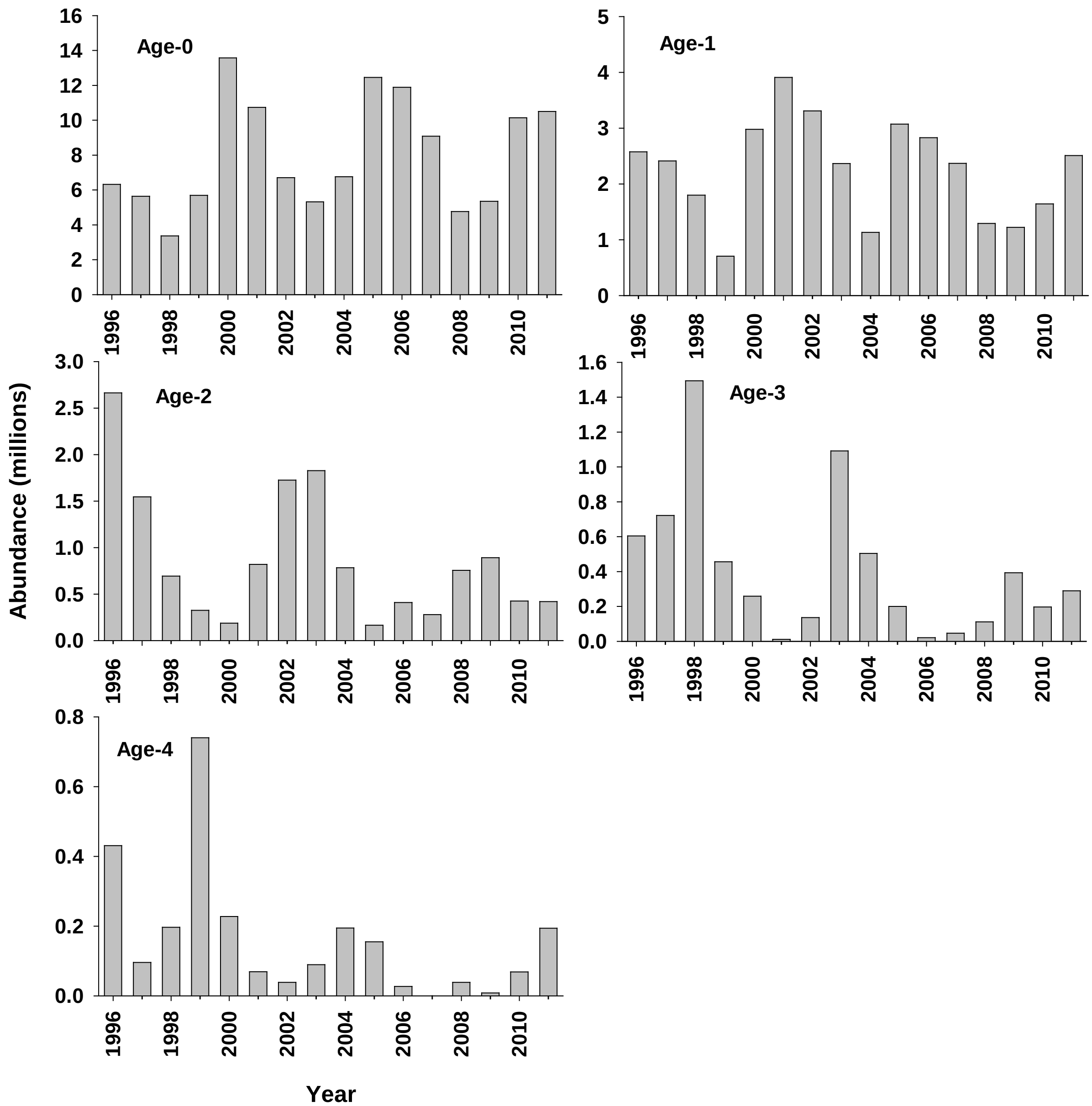


Figure 3. Kokanee age-specific population estimates based on hydroacoustics during 1996-2011.

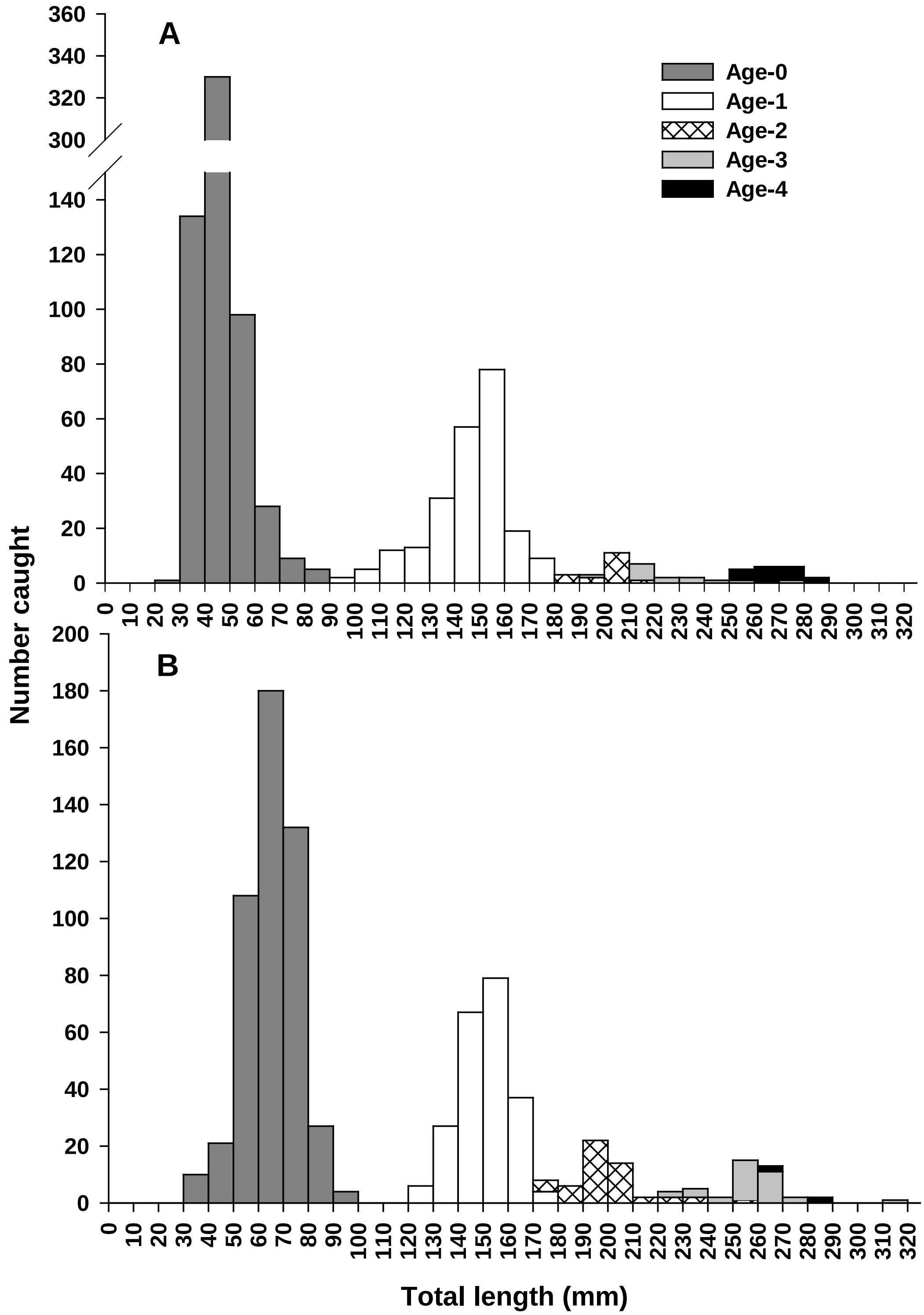


Figure 4. Length-frequency distribution of individual age classes of wild (A) and hatchery (B) kokanee caught by midwater trawling in Lake Pend Oreille, Idaho during August 2011.

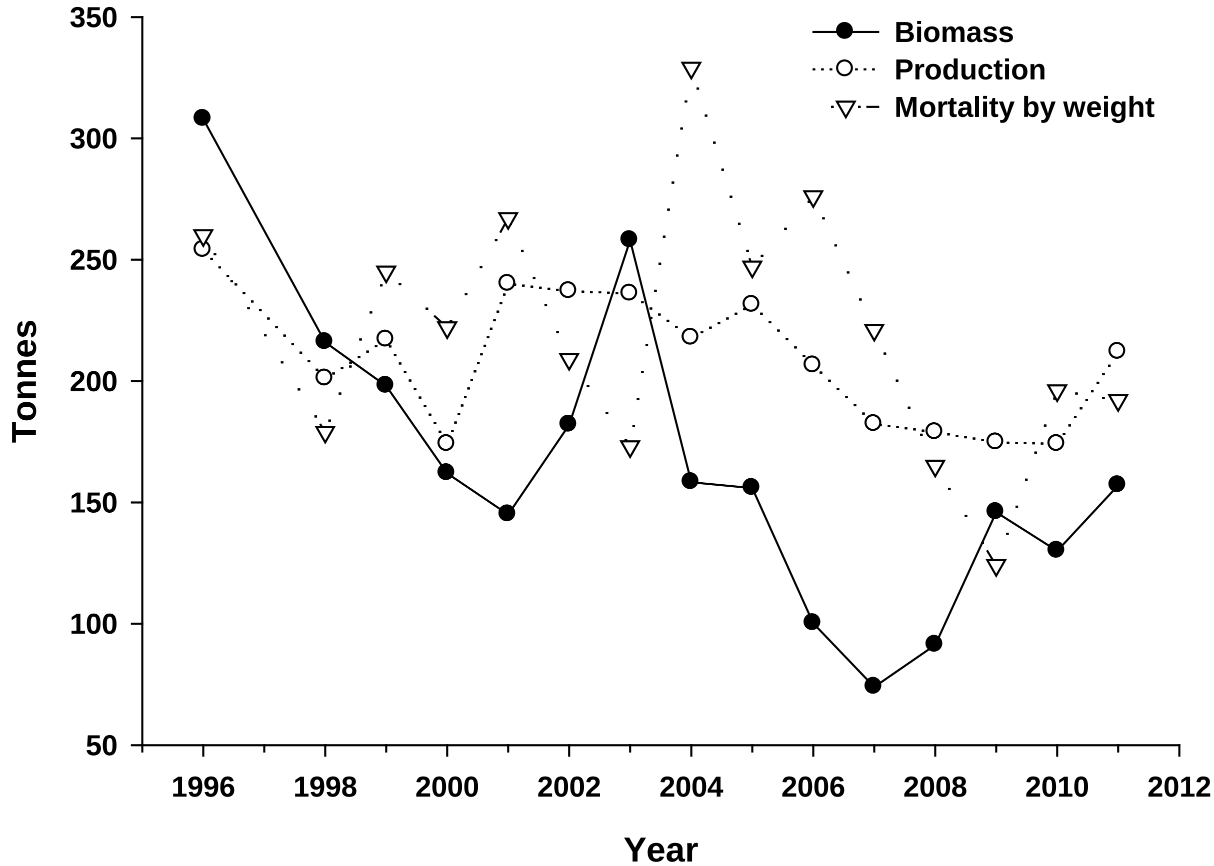


Figure 5. Kokanee biomass, production, and mortality by weight (metric tonnes) in Lake Pend Oreille, Idaho from 1996-2011, excluding 1997 due to 100-year flood.

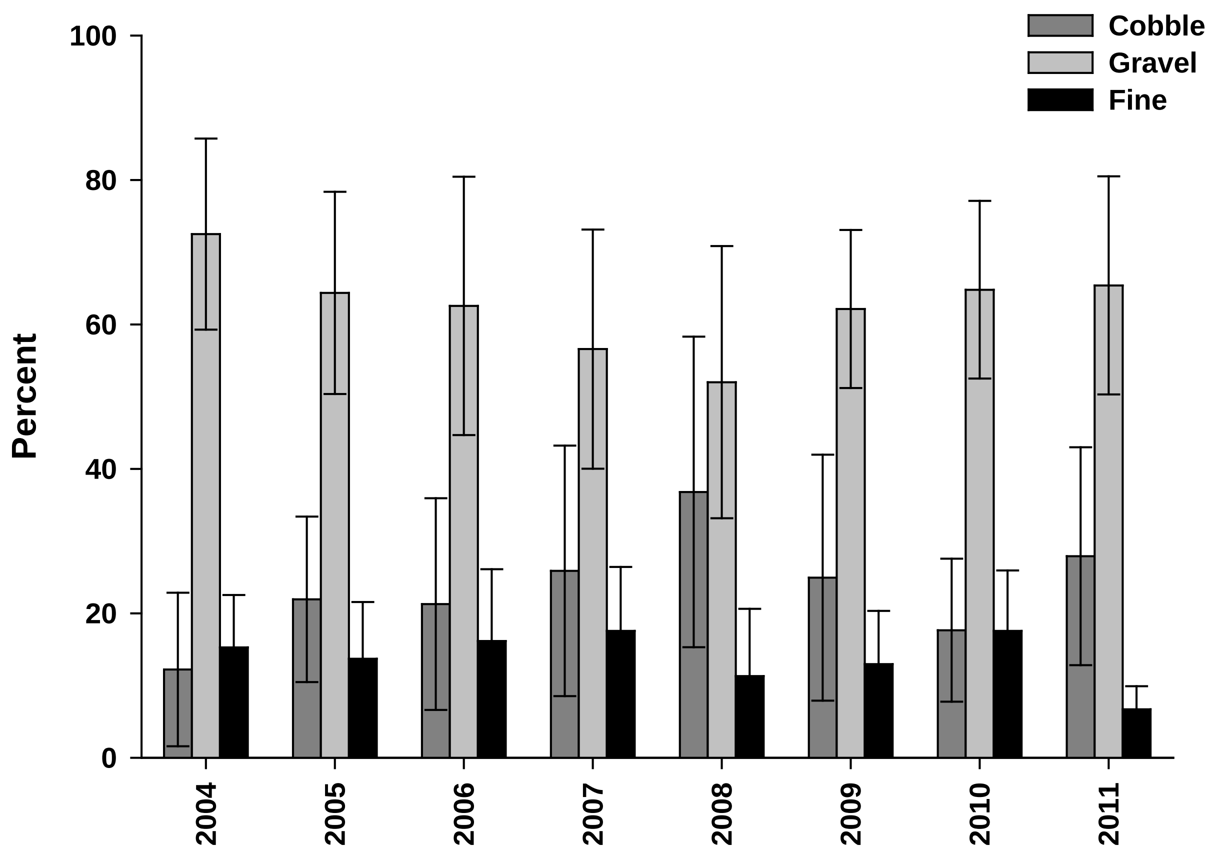


Figure 6. Mean substrate composition (± 90% CI) in Lake Pend Oreille, Idaho during summer 2004-2011. Full winter drawdowns to 625.1 MSL took place during the winters of 2003-04, 2008-09, and 2009-10. Winter pool remained above 626.6 MSL during all other winters.

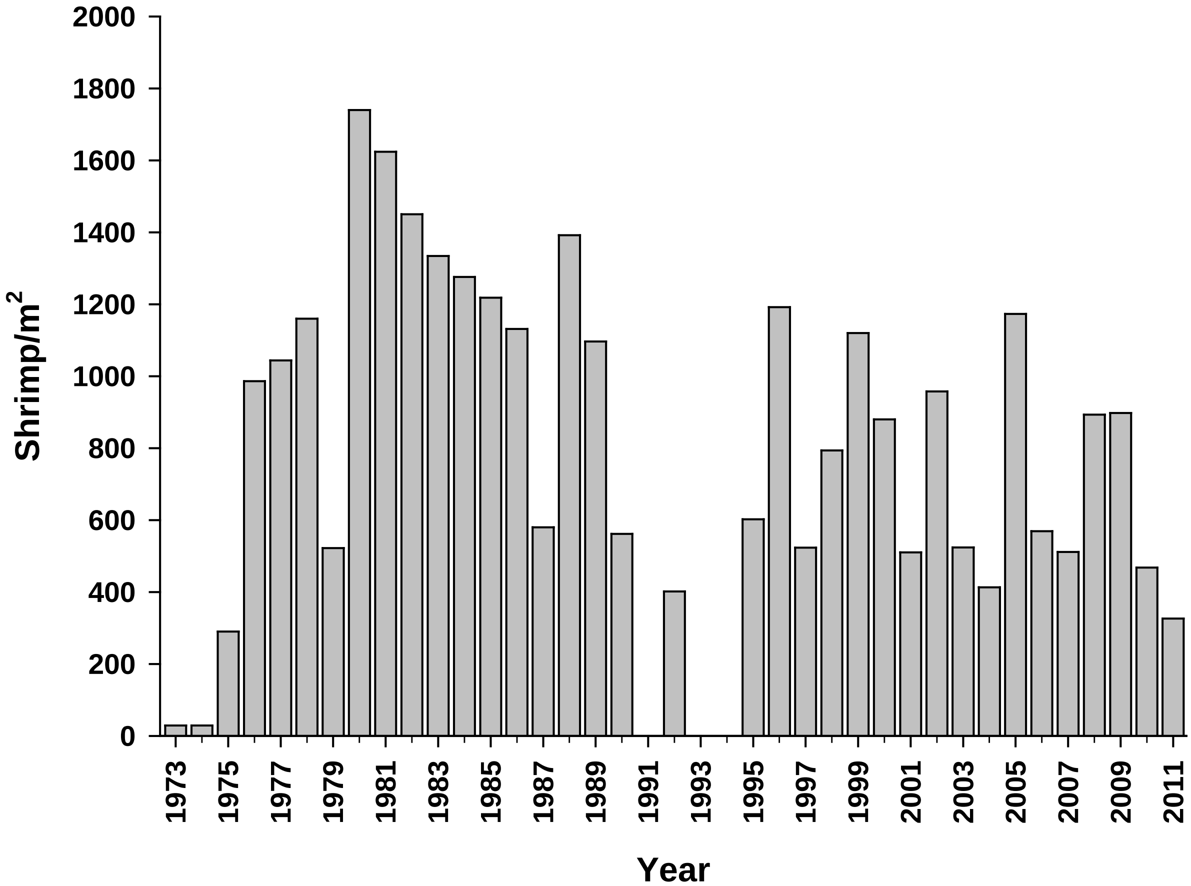


Figure 7. Annual mean density of mysids in Lake Pend Oreille, Idaho from 1973-2011. Data collected before 1989 were obtained from Bowles et al. (1991), and data from 1995 and 1996 were from Chipps (1997). Mysid densities from 1992 and earlier were converted from Miller sampler estimates to vertical tow estimates by using the equation y = 0.5814x (Maiolie et al. 2002). Gaps in the histogram indicate no data were collected that year. Mysids were first introduced in 1966.

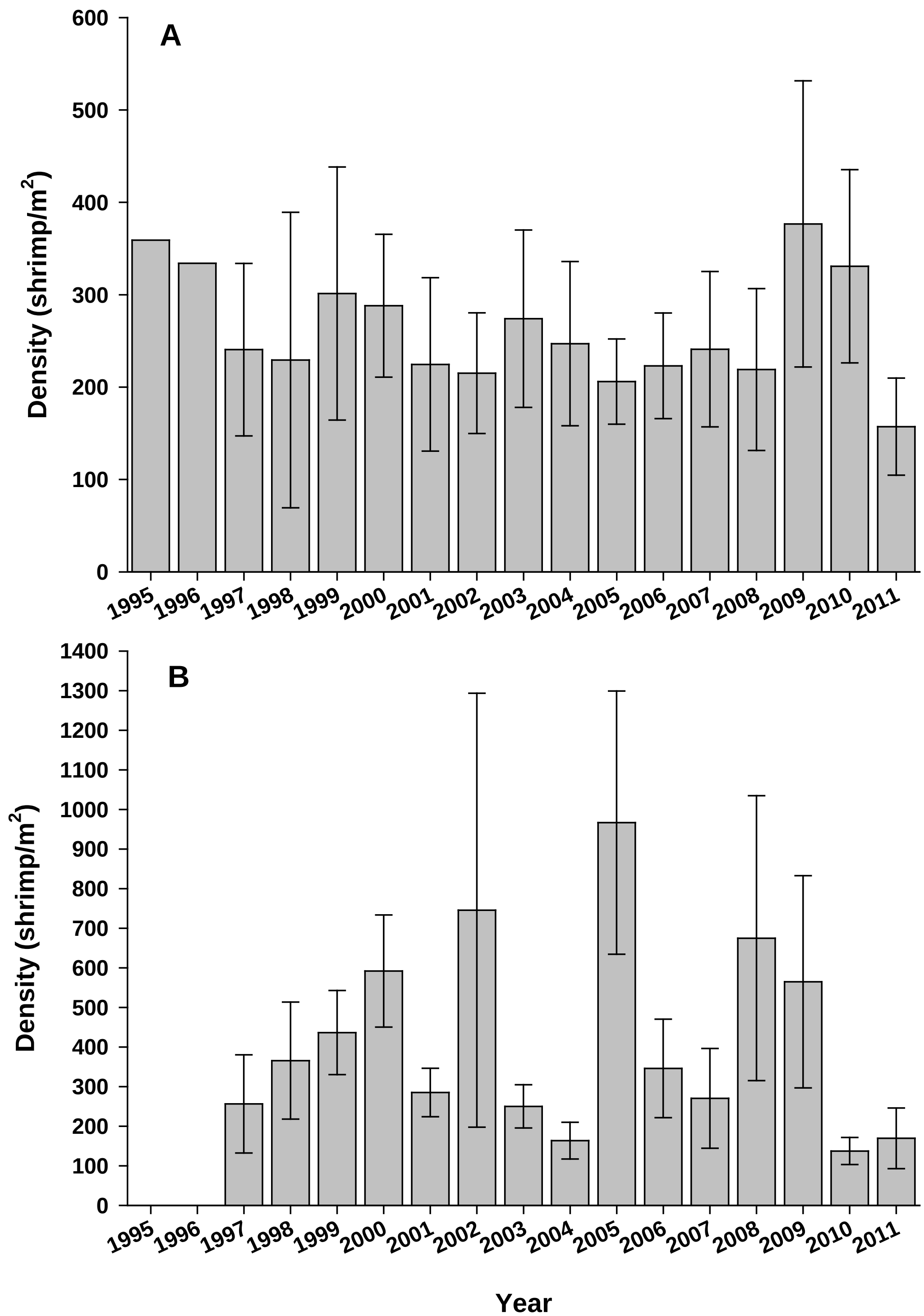


Figure 8. Density estimates of immature and adult (A) and young-of-the-year (B) mysids in Lake Pend Oreille, Idaho 1995-2011. Error bounds identify 90% confidence intervals around the estimate. Immature and adult densities from 1995 and 1996 were obtained from Chipps (1997).

CHAPTER 2: LAKE TROUT RESEARCH

ABSTRACT

The kokanee *Oncorhynchus nerka* population in Lake Pend Oreille has been threatened by high levels of predation over the past decade and was on the verge of total collapse in 2007. To increase kokanee survival, extensive predator (lake trout *Salvelinus namaycush* and rainbow trout *O. mykiss*) removal actions have been implemented, including commercial netting and an angler incentive program. To maximize lake trout removal efficiency, we used acoustic transmitters equipped with depth and temperature sensors to follow mature lake trout to spawning sites. During August through October, we conducted lake trout tracking events to relocate lake trout tagged in late 2010 every other week, and increased tracking frequency to at least once per week during the spawning period (September and October). During October 2011, we tagged 29 adult lake trout ranging from 660 to 940 mm total length ($\bar{x}$ = 825 mm) for 2012 telemetry research. Additionally, we used three stationary receivers (one at each spawning site) to document spawning site fidelity and movement among spawning sites. Although 71% of lake trout exhibited spawning site fidelity between 2010 and 2011, 67% also visited multiple sites in 2011. We examined 1,892 lake trout caught in gill nets from the three spawning sites and found 1,636 (86%) were mature. Lake trout in Lake Pend Oreille have not exhibited any changes to growth or fecundity during the removal efforts, a characteristic that suggests the population was still expanding at the beginning of the removal and is not being regulated by density-dependent mechanisms.

Authors:

Nicholas C. Wahl
Senior Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

INTRODUCTION

Lake trout *Salvelinus namaycush* were stocked in numerous lakes throughout western North America during the late 1800s and early 1900s (Crossman 1995), including Lake Pend Oreille in 1925. Lake trout present a threat to native salmonids, including kokanee *Oncorhynchus nerka* and bull trout *S. confluentus*. Bull trout are particularly susceptible to negative interactions with lake trout, and bull trout populations cannot be sustained after lake trout introduction (Donald and Alger 1993; Fredenberg 2002) without human intervention. Nearby Priest and Flathead lakes share similar characteristics with Lake Pend Oreille and exemplify the impact lake trout can have on bull trout and kokanee populations. In both of these lakes, bull trout were reduced to a small fraction of their historical abundance and kokanee suffered complete collapse after lake trout introduction (Bowles et al. 1991; Stafford et al. 2002). Other western United States lakes have experienced similar detrimental effects to native fish and valued sport fish populations following lake trout introductions (Martinez et al. 2009). Lake trout population modeling conducted in 2006 indicated that the lake trout population in Lake Pend Oreille was doubling every 1.6 years and would reach 131,000 adult fish by 2010 (Hansen et al. 2008). This modeling suggested that changes similar to those seen in Flathead and Priest lakes were eminent without immediate management action. This led IDFG to implement aggressive predator removal actions (netting and incentivized angling) in 2006 in an attempt to substantially reduce or collapse the lake trout population in Lake Pend Oreille (see Wahl and Dux 2010 for details). Although unintentional, commercial overharvest has led to collapse of various lake trout populations throughout their native range, including the Great Lakes and Great Slave Lake (Keleher 1972; Healey 1978; Hansen 1999).

During 2007 and 2008, telemetry research identified two lake trout spawning sites in Lake Pend Oreille (Schoby et al. 2009; Wahl and Dux 2010). Intensive gill netting at these sites since 2008 yielded high numbers of mature lake trout and substantially increased the annual mortality rate on the reproductive segment of the population. In 2010, a third lake trout spawning site was identified. We continued telemetry research in 2011 to further evaluate whether lake trout spawning distribution changed in response to netting. Telemetry research also provided real-time data to guide netting during the spawning period. Along with telemetry, we also examined lake trout population characteristics (i.e., growth and fecundity) to evaluate the response to suppression.

METHODS

Lake Trout Telemetry

To evaluate lake trout spawning distribution, we tracked mature lake trout using acoustic telemetry equipment. We surgically implanted acoustic transmitters (MA-TP16-25, Lotek Wireless Inc., Newmarket, Ontario), equipped with depth and temperature sensors into the abdomen of mature lake trout (see Wahl and Dux 2010 for surgical procedures). Depth sensors were effective to 100 m depths. Additionally, the new tags implanted into lake trout during fall 2011 had custom programming that allowed them to alternate between ping and rest cycles of 13 weeks.

Lake trout tracked during 2011 were captured for tag insertion during fall 2010 (see Wahl et al. 2011b for details). Additionally, we captured and tagged lake trout at spawning sites during the fall 2011 for 2012 telemetry research using gill nets operated by Hickey Brothers, LLC. To ensure sexual maturity, we tagged only lake trout greater than 600 mm (IDFG, unpublished data).

We used paired, boat-mounted, omnidirectional hydrophones and a MAP 600RT P2 receiver to mobile-track tagged lake trout (Lotek Wireless Inc., Newmarket, Ontario). This system incorporated MAPHOST software, which allowed simultaneous decoding of multiple signals and used stereo hydrophones to provide direction of arrival of the transmitters' acoustic signal. Further description of field methodologies for telemetry can be found in Wahl et al. (2011a).

To evaluate spawning site fidelity and movement among the three spawning sites, we submerged a WHS 3050 stationary receiver (Lotek Wireless Inc., Newmarket, Ontario) at each site. The receivers were programmed to run continuously while in the lake (September 6 to October 31).

Lake Trout Spawning Site Assessment

To assess changes in lake trout spawning characteristics (i.e., size and relative abundance of fish), gill nets set by Hickey Brothers, LLC as a part of the removal effort were also used to document the presence of ripe fish. Gill nets used to capture lake trout were 274 m long, 2.0-4.0 m tall and contained a single stretch mesh of 10.2, 11.4, or 12.7 cm. Several nets were tied together to form a long gang that was set in a serpentine pattern that paralleled shore. Gill nets were set around dawn and pulled in the late-morning (typically 4-6 hour sets). We enumerated and measured total length of all lake trout captured in gill nets. Sex and stage of sexual maturity (i.e., ripe) were determined for a subsample of lake trout captured throughout the spawning period.

Lake Trout Population Characteristics

To evaluate age structure of the lake trout population, we removed otoliths from 10 fish in each 50 mm length class during fall netting. We imbedded otoliths in epoxy then sectioned each one across the transverse plane. For accuracy, two independent readers examined each otolith and settled differences by re-examination. To describe the lake trout growth rate, we applied the von Bertalanffy growth model:

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

where L_t = length at time t, L_∞ = the theoretical maximum length, K = the growth coefficient, t = age in years, and t_0 = the time when length theoretically equals 0 mm.

Additionally, we removed ovaries from a subsample of female lake trout captured at the spawning sites during the fall to estimate fecundity. We only removed ovaries from females that had not yet released any eggs. To calculate fecundity for each individual, we weighed the entire ovary, weighed three subsamples of the ovary, and counted the number of eggs in the subsamples. We then calculated the number of eggs per gram for the samples and extrapolated to the entire ovary. A similar approach to estimating fecundity has previously proven effective (O'Gorman et al. 1998).

To gauge the changes in lake trout abundance and the overall effectiveness of the predator removal efforts, a lake trout population estimate was initiated during fall 2011. Lake trout captured in trap nets set by Hickey Brothers, LLC received an individually-numbered spaghetti tag behind the dorsal fin and an individually-numbered coded wire tag in the snout. We used coded wire tags as a secondary mark that would be detectable in the Angler Incentive Program where anglers turn in only the head. Coded wire tags are used to correct for angler compliance (turning in the spaghetti tags) when estimating lake trout angling exploitation. Because the recapture portion of the estimates was not completed at the end this contract period, a full description, analysis, and discussion will appear in the 2012 report.

RESULTS

Lake Trout Telemetry

We tagged 18 mature lake trout from October 7-14, 2010, with six captured at each of the three spawning sites (see Wahl et al. 2011b for details). During fall 2011(October 11-19), we captured and tagged 29 lake trout (to be tracked during 2012) from gill nets set at the three spawning sites with 10 from both Bernard Beach and Evans Landing and nine from Windy Point. These tagged lake trout averaged 825 mm total length (SE = 15, range = 660-940 mm; Figure 9). A complete list of tagged lake trout at-large during the 2011 tracking season is compiled in Appendix C.

Through mobile telemetry, we tracked lake trout once in late March to obtain relocation events of fish and determine which individuals remained at-large. During the fall, we tracked the entire lake roughly once every three weeks from August through October with weekly tracking of the three spawning sites in between. Additionally, the three stationary receivers were in Lake Pend Oreille from September 6 to October 31. Twenty-three tagged lake trout (tagged in 2010) were still at-large at the beginning of fall 2011, and six of these were harvested by the contract netters at the spawning sites. During the fall of 2011, 22 of the 23 at-large lake trout visited at least one of the three spawning sites.

During March 29-30, lake trout were spread throughout the lake, with many concentrated on the north end (Figure 10). During spawning (September 6-October 4), lake trout were concentrated along the Windy Point, Bernard Beach, and Evans Landing spawning sites (Figures 11 and 12). Following spawning (October 24-26), lake trout migrated away from spawning sites and were again widely dispersed throughout the lake (Figure 13).

During their deployment, the stationary receivers recorded 20,319 detections from 18 acoustic-tagged lake trout. From the combination of mobile telemetry and stationary receiver data, we were able to determine that lake trout did exhibit some degree of spawning site fidelity between 2010 and 2011. Of the 17 lake trout that were relocated at a spawning site during both 2010 and 2011, 12 fish (71%) visited the same site both years. However, the same number also visited at least one other site during 2011, and three fish (18%) visited all three sites during 2011. Additionally, of the 18 acoustic-tagged lake trout detected on at least one of the stationary receivers in 2011, 12 were detected on at least two, and nine made multiple trips between spawning sites. Finally, we were able to estimate the minimum amount of time required for fish to travel between each possible pair of spawning sites. The minimum amount of time to travel between two spawning sites ranged from 4.6 to 18.5 hours for distances of 11.4 to 19.1 km (Table 8).

Lake Trout Spawning Site Assessment

During 25 days of the lake trout spawning period, 56,601 m of gill net (206.33 individual nets) was set at the Windy Point spawning area. We captured 1,013 lake trout (4.6 lake trout per 274 m net; 3.5-6.1 = 95% CI) and examined 962 for sexual maturity. Of those fish, 362 were mature females (mean TL = 745 mm, SE = 4.6, range = 492-1110 mm) and 456 were mature males (mean TL = 675 mm, SE = 4.9, range = 370-970 mm). This resulted in a sex ratio of 1.3 mature males per mature female. Length-frequency distributions of fish caught at the Windy Point spawning site are presented in Figure 14.

Over 16 days during lake trout spawning, 39,136 m of gill net (142.67 individual nets) was set at the Bernard Beach spawning site. We captured 501 lake trout (3.1 lake trout per 274 m net; 2.4-4.0 = 95% CI) and examined 459 for sexual maturity. Of those fish, 161 were mature females (mean TL = 765 mm, SE = 6.8, range = 550-1005 mm) and 247 were mature males (mean TL = 711 mm, SE = 6.8, range = 365-1010 mm). This resulted in a sex ratio of 1.5 mature males per mature female. Length-frequency distributions of fish caught at the Bernard Beach spawning site are presented in Figure 14.

Additionally, on ten days during lake trout spawning, 21,031 m of gill net (76.67 individual nets) was set at the Evans Landing spawning site. We captured 492 lake trout (5.5 lake trout per 274 m net; 3.4-8.4 = 95% CI) and examined 471 for sexual maturity. Of those fish, 179 were mature females (mean TL = 757 mm, SE =5.8, range = 490-965 mm) and 231 were mature males (mean TL = 715 mm, SE = 6.6, range = 390-1000 mm). This resulted in a sex ratio of 1.3 mature males per mature female. Length-frequency distributions of fish caught at the Evans Landing spawning site are presented in Figure 14.

Lake Trout Population Characteristics

We aged 158 lake trout (234-1010 mm) that ranged in age from three to 20 years. Lake trout grew from a starting age of t_0 = 1.49 years toward their asymptotic length of L_∞ = 1140 mm at an instantaneous rate of K = 0.110/year (Figure 15).

We estimated the fecundity of 56 female lake trout ranging from 550 to 930 mm ($\bar{x}$ = 743 mm, SE = 12.2). Median fecundity per female was 4,981 eggs, and egg counts ranged from 1,671 to 14,283 (Figure 16).

DISCUSSION

Lake Trout Telemetry

During 2011, lake trout in Lake Pend Oreille used the same three spawning sites (Windy Point, Bernard Beach, and Evans Landing) that have been identified in the past (Wahl et al. 2011b). Although spawning aggregations have become progressively less distinct than in the earlier years of tracking, fish continued to occupy the same shoreline reaches where spawning has occurred in the past, and there was no evidence that fish spawned elsewhere. Gill nets set at spawning sites may have directly prevented aggregations from forming by altering fish behavior, but total effort among three sites in 2011 was only 14% higher than in 2008 netting occurred at only two of the sites. Conversely, netting may have had a slightly more indirect effect on spawning aggregations. Three years of high exploitation may have removed a large enough portion of the spawning lake trout that aggregations are comprised of fewer individuals and fish are more easily disturbed by a similar amount of gill net effort. We do not know whether gill net disturbances negatively influenced spawning success by fish that were not captured and removed, but the apparent influence of gill netting on fish distribution highlights the importance of continued telemetry research. Determining where lake trout are most concentrated within each spawning site will be important for identifying the most productive place to set gill nets as fish shift their distribution during the spawning period. More importantly, continued telemetry research is needed to assess whether disturbances from netting cause fish to seek out new spawning areas, especially given this species' ability to colonize new areas that fit their habitat requirements (Gunn 1995). Additionally, having telemetry data to guide netting efforts increases confidence that netting is occurring in areas of highest fish density and at times when fish are present, which will become more important as lake trout abundance continues to decline and catch rates become low.

In 2009 and 2010, we documented movement of mature lake trout among the three spawning sites. However, the resolution of these data was limited to the frequency with which we tracked (one to two times per week), whereas the stationary receivers deployed in 2011 recorded fish movements continuously throughout the spawning period. During 2011, we documented that several lake trout made repeated, and sometimes very rapid, trips between spawning sites. Lake trout in other systems have been reported to make multiple trips among spawning shoals at minimum speeds of 3 km/h (MacLean et al. 1981). We did not record this pattern during 2007 and 2008, and are unsure of the extent that netting has on the movement we have seen in Lake Pend Oreille in recent years. Although spawning aggregations are less defined and fish are moving more, they are still vulnerable to the nets. Even if they are not at a single spawning site the whole time, they move to other spawning sites where netting also occurs. There is travel time through areas where netting does not occur, but if overall movement rate is higher at the sites than in the past, this might provide a netting advantage where lake trout are more likely to encounter a net.

Lake Trout Spawning Assessment

Over the past four years, we have effectively used data from gill netting at lake trout spawning sites to assess the spawning segment of the population. Length-frequency and sex ratios in 2011 were similar across the three sites, suggesting that the level of effort expended has produced similar effects at each of the sites. This fact is especially important given that the Evans Landing spawning site was not positively identified until 2010 and was not intensively targeted with gill nets until 2011. We have documented a shift in the size structure of lake trout captured at the spawning sites. From 2008 to 2011, the peak of the length-frequency distribution increased from the 600-649 mm length class to the 700-749 mm length class. This shift was due primarily to a reduction in the number of sub-650 mm lake trout being caught and not an increase in larger fish. Lake trout that are first recruiting to maturity (generally around 600 mm) have likely been heavily exploited in previous years through juvenile netting and angling efforts. Also, lake trout ≥850 mm, do not appear to become as entangled in gill net mesh as smaller individuals, so these largest fish in the population may not be exploited at the same rate.

Differences in the duration of time spent at spawning sites, age at maturity, and alternate year spawning in females can skew sex ratios at spawning sites to upwards of 90% males (Martin and Olver 1980; Dux et al. 2011). Though never heavily skewed towards males (2.1 to 1 in 2008; Wahl and Dux 2010), the sex ratio of lake trout captured at spawning sites was nearly even in 2011. This declining ratio suggests that male lake trout have been more vulnerable to removal than females. MacLean et al. (1981) found that female lake trout actually have a higher rate of movement among spawning sites than males; this differential movement pattern may make males more vulnerable to netting by spending fewer days away from the areas netting targets. Telemetry showed that nearly all (96%) lake trout implanted with transmitters at spawning sites in the fall were relocated at a spawning site the following fall. Although we do not know the amount of alternate year spawning occurs, it appears that nearly all fish visit a spawning site each year, and therefore, even alternate year spawning females should be vulnerable to exploitation at the spawning sites.

<u>Lake Trout Population Characteristics</u>

Lake trout age and growth data suggested this population was made up largely of relatively young individuals (<20 years). The growth rate of fish in this population has not changed since 2003-04 (Hansen et al. 2010), providing evidence that lake trout have not had a compensatory growth response to removal efforts. Lake trout abundance was increasing exponentially prior to the removal efforts (Hansen et al. 2010), and the growth rate we documented was among the highest recorded for exploited lake trout populations (Healey 1978). Because growth was already rapid, we expect that the lake trout population should have a minimal compensatory growth response as density continues to decrease.

Surprisingly, lake trout in Lake Pend Oreille have relatively low fecundity compared to other systems in their native range (Healey 1978; Trippel 1993) and nearby Swan Lake, Montana (Cox 2010) and Yellowstone Lake (Syslo et al. 2011). We are unsure as to the reason for the lower fecundity. Beacham and Murray (1993) found Pacific salmon that matured at older ages generally had higher fecundity, but prior to the removal efforts, 50% of female lake trout in Lake Pend Oreille matured at 7.3 years (Hansen et al. 2010), the same age as in Swan Lake (Cox 2010) and one year later than in Yellowstone Lake (Syslo et al. 2011). Data collected during an upcoming population estimate in 2012 will provide insight into whether age-at-maturity has changed since 2004 in response to the removal. However, like the age and growth results, we have documented no changes in lake trout fecundity during the past four years.

RECOMMENDATIONS

1. Use gill nets to remove spawning lake trout from the areas identified in 2011.

2. Tag adult lake trout captured at spawning sites during the fall to better determine sex, investigate spawning site fidelity, and quantify alternate year spawning.

3. Use stationary telemetry receivers to examine movement among the three spawning sites.

4. Continue to periodically evaluate lake trout population dynamics, especially growth, fecundity, and age structure, to determine the response to removal.

5. Complete the recapture portion of the lake trout population and exploitation estimate initiated in 2011, and compare to previous estimates to assess changes in lake trout abundance and the overall effectiveness of the removal program.

Table 8. Minimum amounts of time (top right cells in hours) between detections of acoustic-tagged lake trout at different spawning sites and the straight-line distance (bottom left cells in kilometers) between the sites in Lake Pend Oreille, Idaho during 2010.

	Bernard Beach	**Evans Landing**	**Windy Point**
Bernard Beach	X	4.6	18.5
Evans Landing	11.4	X	10.9
Windy Point	19.1	12.0	X

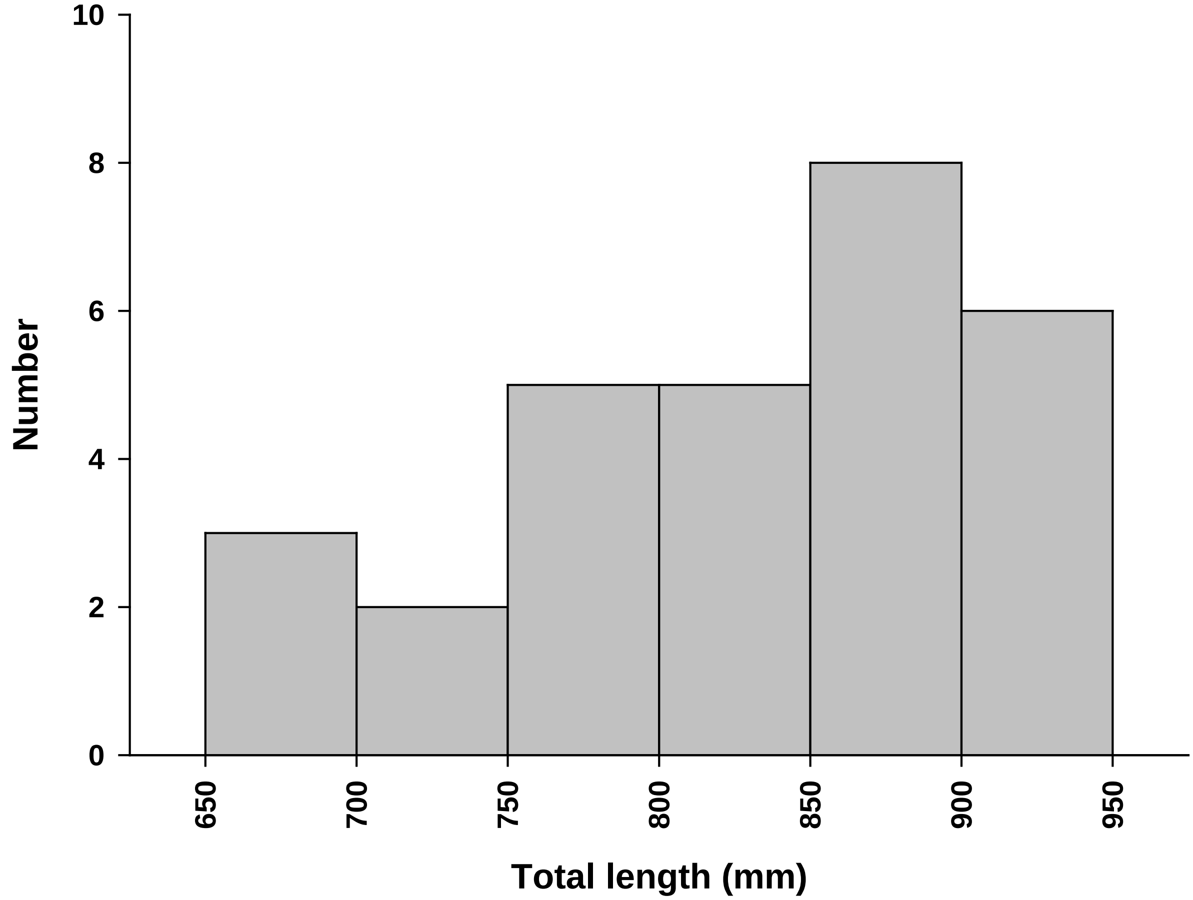


Figure 9. Length frequency of lake trout (n = 29) captured and implanted with acoustic transmitters in Lake Pend Oreille during 2011 for 2012 telemetry research.

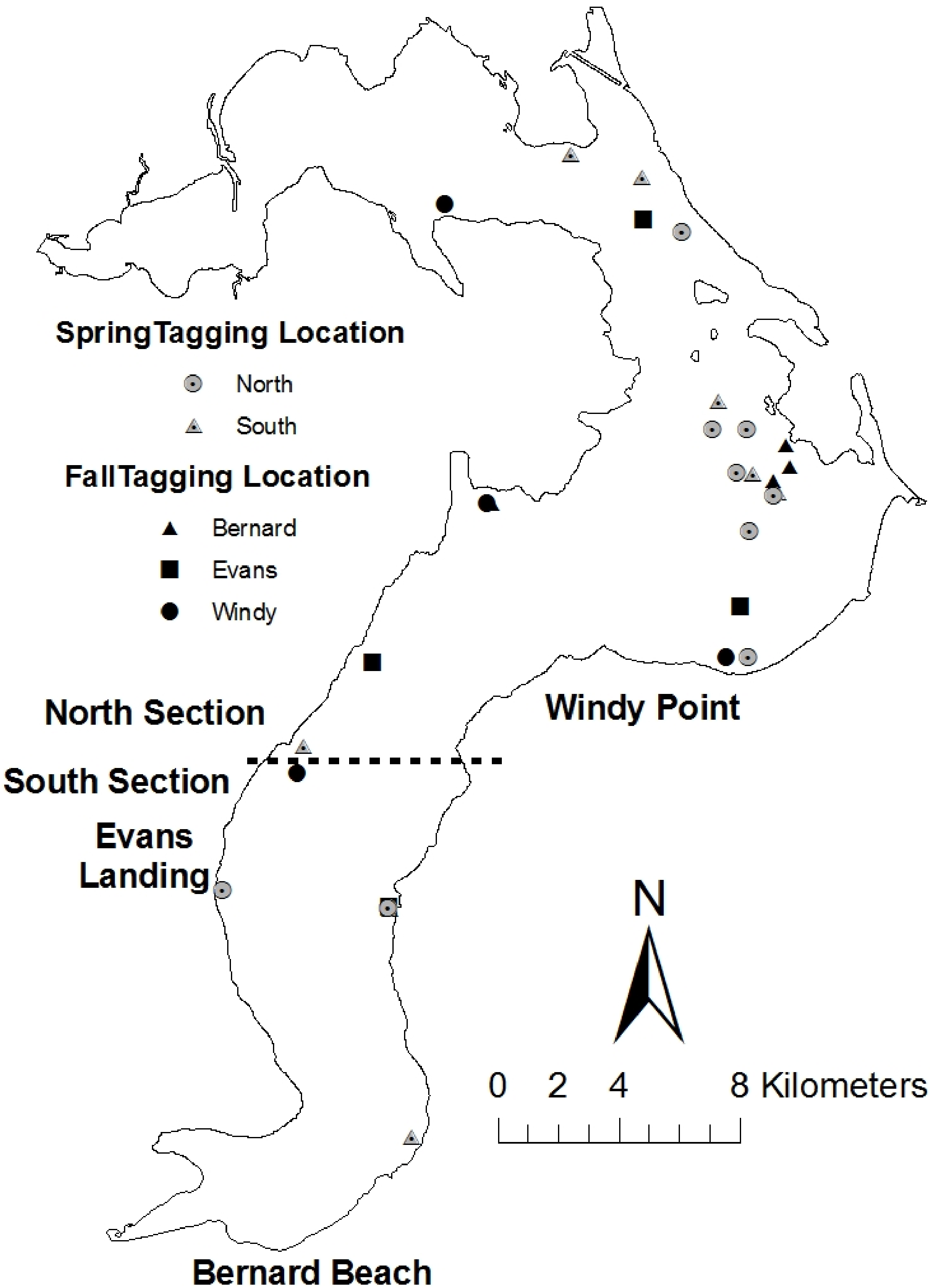


Figure 10. Locations of tagged lake trout during March 28 to 30, 2011 in Lake Pend Oreille, Idaho.

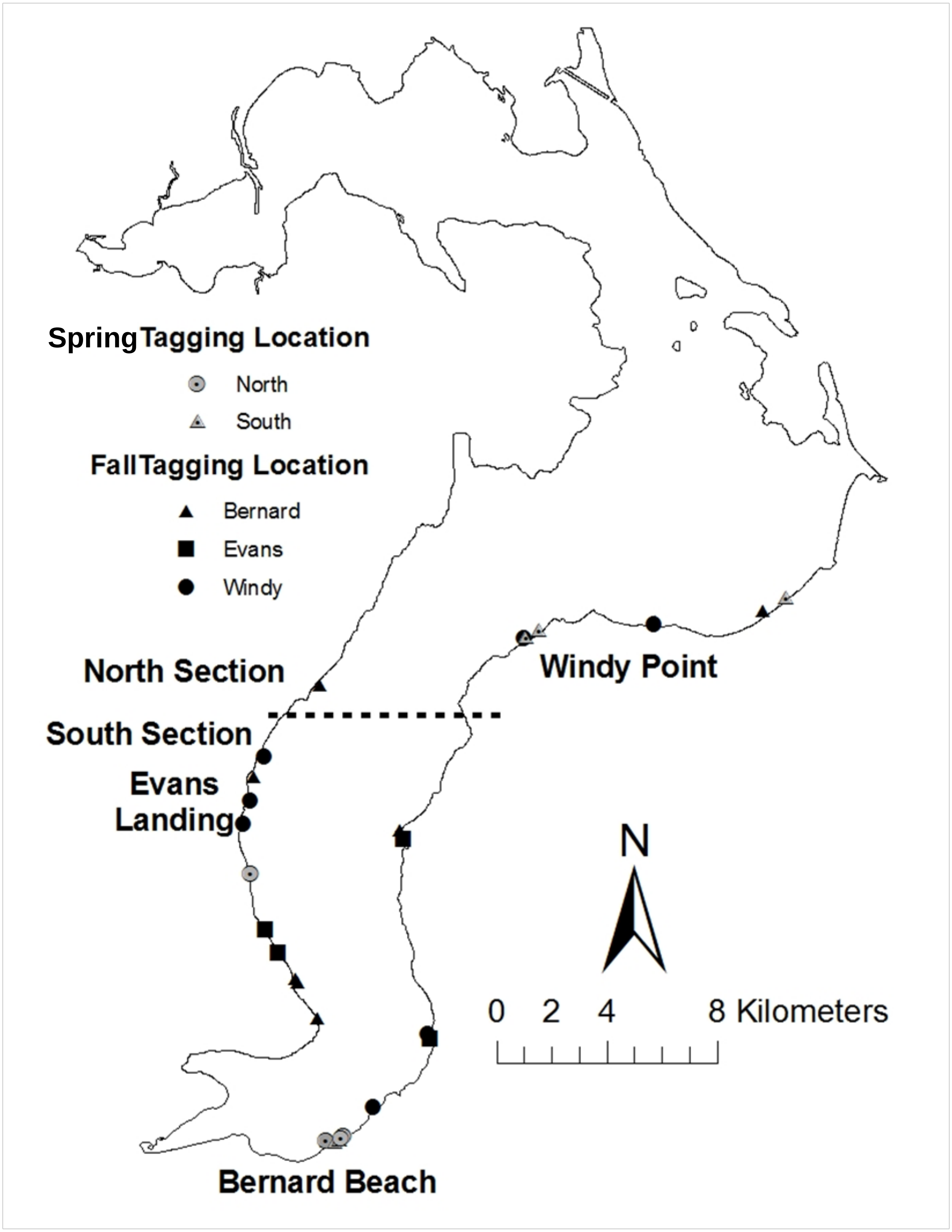


Figure 11. Locations of tagged lake trout during spawning (September 6 to October 4, 2011) in Lake Pend Oreille, Idaho.

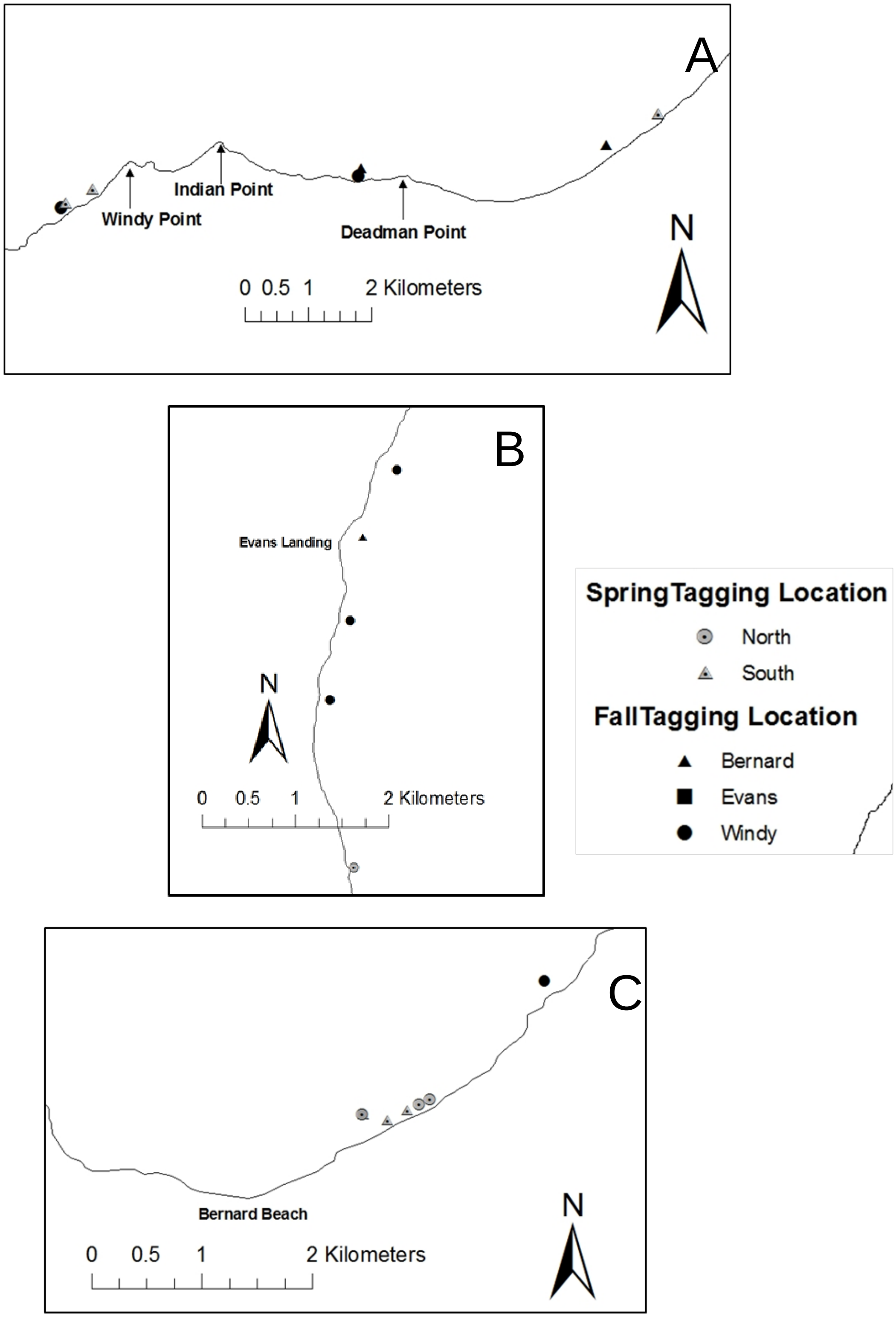


Figure 12. Locations of tagged lake trout at the three spawning sites: Windy Point (A), Evans Landing (B), and Bernard Beach (C) during spawning (September 6 to October 4, 2011) in Lake Pend Oreille, Idaho.

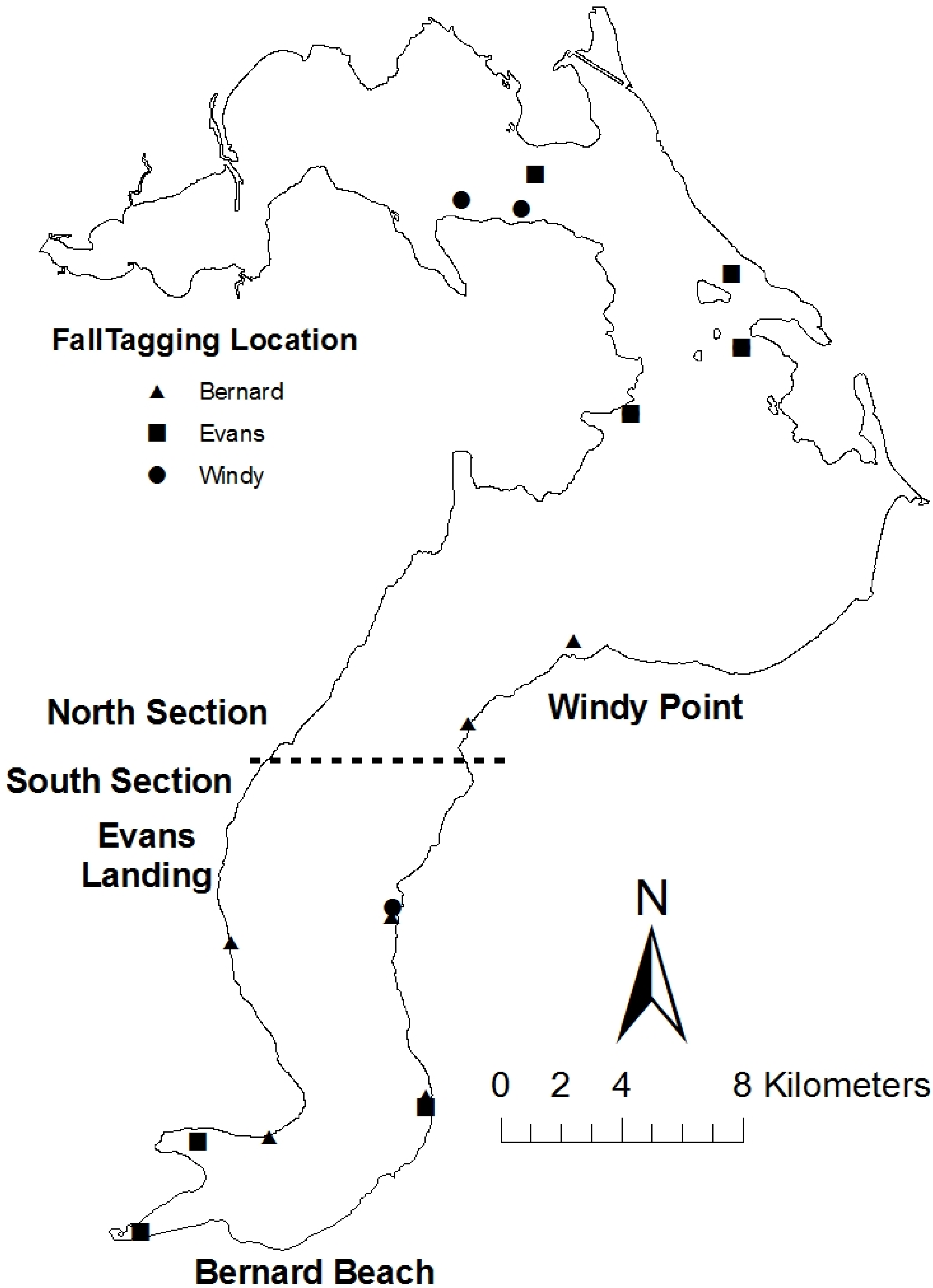


Figure 13. Locations of tagged lake trout during October 24 to 26, 2011 in Lake Pend Oreille, Idaho.

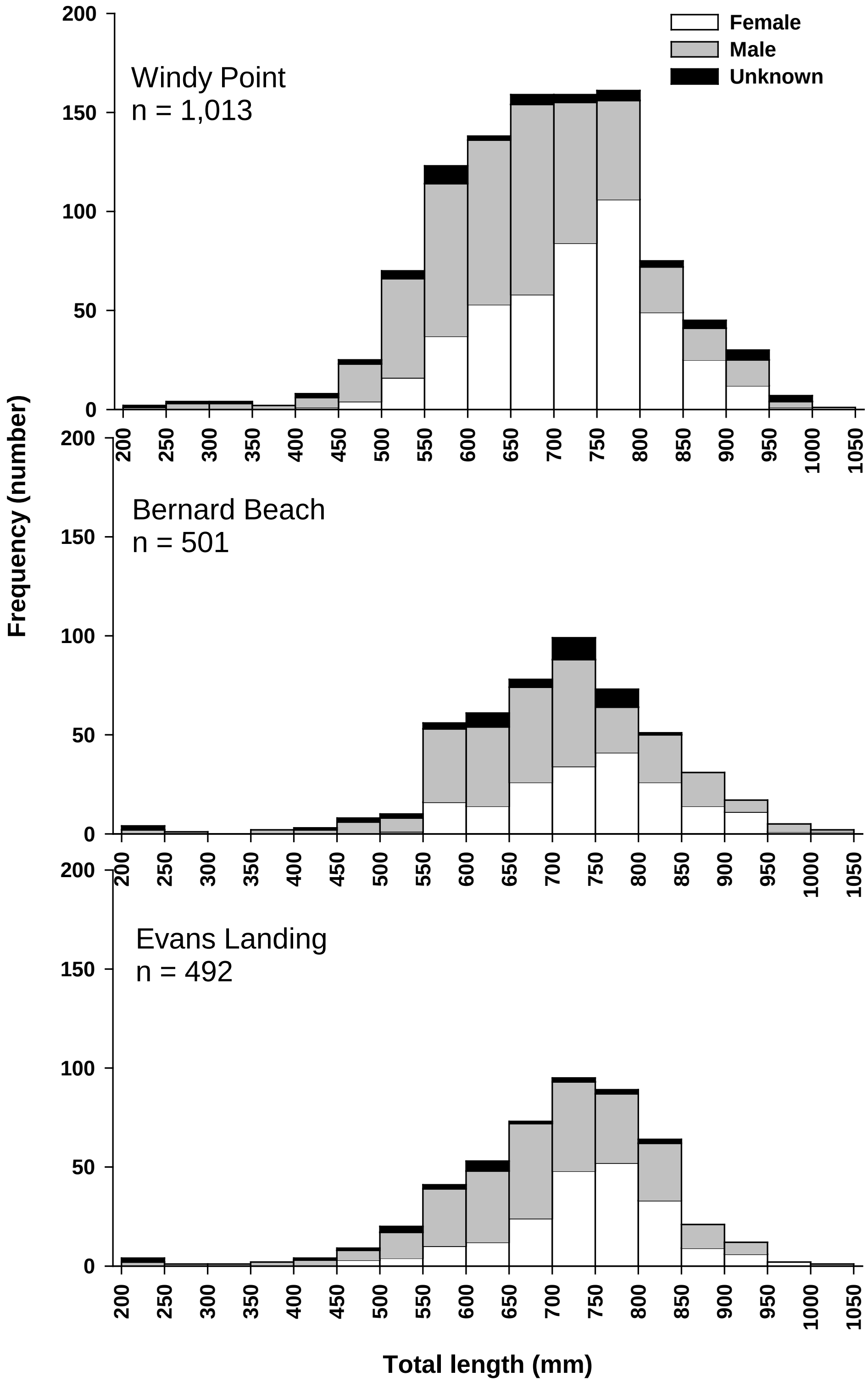


Figure 14. Length frequency histogram of lake trout captured in gill nets at Windy Point, Bernard Beach, and Evans Landing during September 12 to October 20, 2011 in Lake Pend Oreille. “Unknown” fish were not examined for sex.

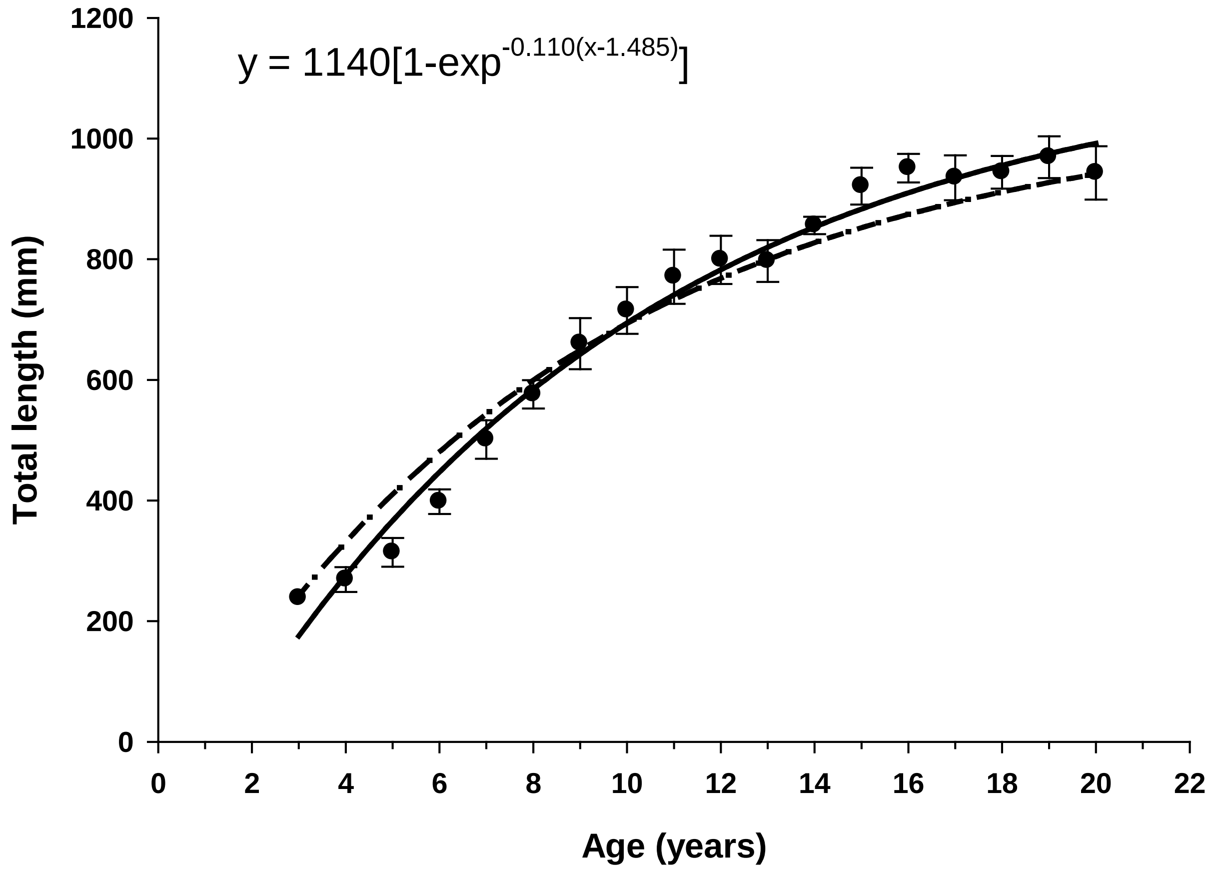


Figure 15. Mean total length-at-age with 95% confidence intervals for lake trout captured during the fall of 2011 in Lake Pend Oreille. Confidence intervals were not calculated for age-3 fish because of low sample size. Growth is described by the fitted von Bertalanffy growth model (solid line), where l_t = total length at time *t*, and *t* = age in years. The dashed line represents the lake trout growth curve developed in 2004.

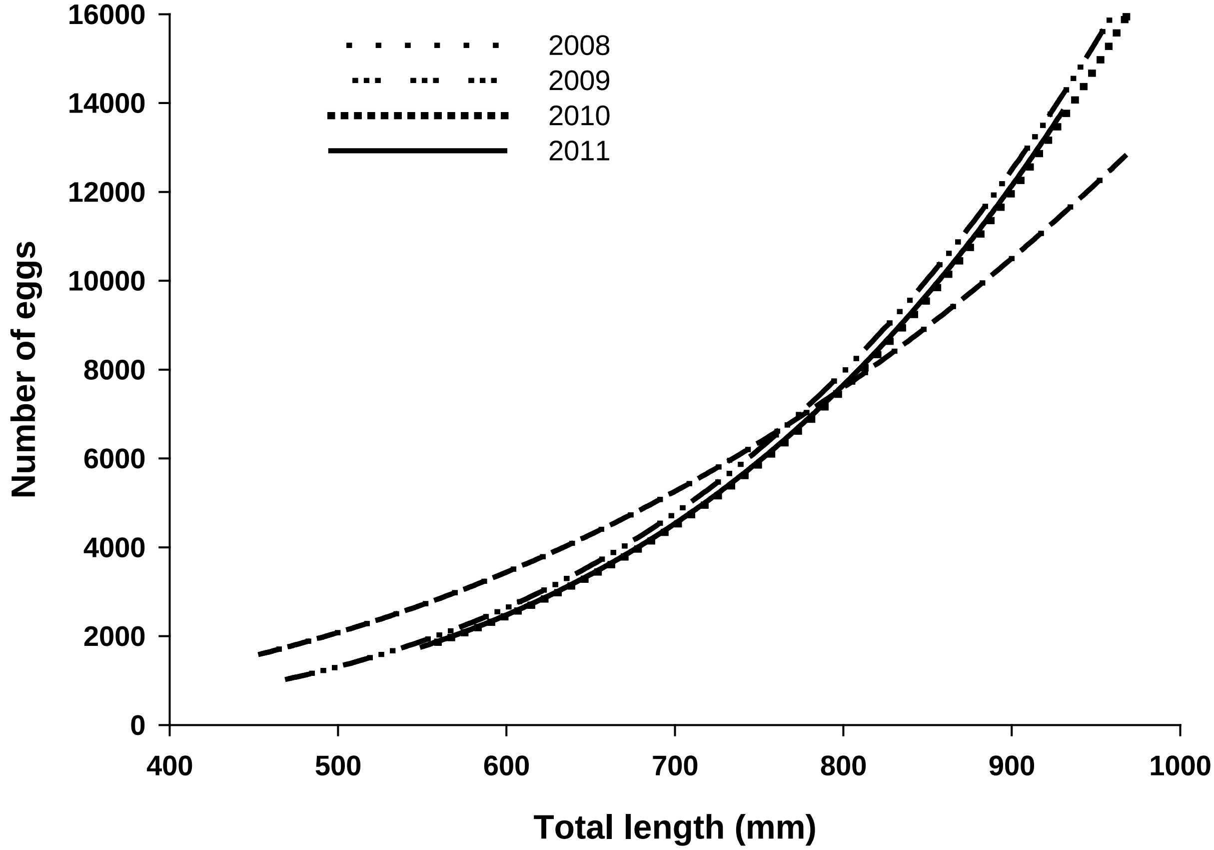


Figure 16. Fecundity-total length relationship for female lake trout captured during the fall of 2008-2011 in Lake Pend Oreille.

CHAPTER 3: RAINBOW TROUT RESEARCH

ABSTRACT

For over a decade, kokanee *Oncorhynchus nerka* recovery in Lake Pend Oreille has been limited by predation, primarily from lake trout *Salvelinus namaycush* and rainbow trout *O. mykiss*. Abundance estimates conducted in 1999 and 2006 for rainbow trout ≥406 mm indicated a stable population, so Idaho Department of Fish and Game implemented an aggressive predator removal strategy aimed at reducing rainbow trout abundance. A population estimate in 2009 suggested the number of rainbow trout ≥406 mm had been reduced despite a low annual exploitation rate. In 2010, we initiated a similar study, but also included all rainbow trout vulnerable to angling (≥300 mm). Following the recapture period, we estimated 34,879 (26,215-47,465 = 95% CI) rainbow trout ≥300 mm in Lake Pend Oreille with 15,237 (10,953-21,860 = 95% CI) ≥406 mm. Annual exploitation was calculated at 19% and 23% for rainbow trout ≥300 mm and ≥406 mm, respectively. Additionally, the mean length at age-5 was 429 mm, 196 mm less than in the 1970s, and mean relative weight for rainbow trout 300-500 mm was below 80.

Authors:

Nicholas C. Wahl
Senior Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

INTRODUCTION

In 1999, the rainbow trout *Oncorhynchus mykiss* population (estimated at 14,607 fish ≥406 mm) consumed an estimated 125 metric tonnes (t) of kokanee *O. nerka* biomass annually in Lake Pend Oreille, while other salmonid predators combined (e.g., lake trout, bull trout *S. confluentus*) only consumed an estimated 25 t of kokanee biomass (Vidergar 2000). Although the lake trout population grew exponentially since 1999 (Hansen et al. 2008), predation from the rainbow trout population (estimated at 19,157 fish ≥406 mm; Maiolie et al. 2008) still threatened the kokanee population in 2006 (Hansen et al. 2010). Population modeling in 2006 suggested exploitation rates were not sufficient to reduce rainbow trout abundance (Hansen et al. 2010). Therefore, Idaho Department of Fish and Game (IDFG) removed all creel limits for rainbow trout, allowed anglers to fish with up to four rods, and initiated an Angler Incentive Program (AIP) that offered anglers a $15 reward per rainbow trout harvested.

Rainbow trout population assessments conducted in 2006 and 2009-10 to evaluate responses to removal actions suggested a decrease in the number of rainbow trout ≥406 mm (Wahl et al. 2011b). However, we were unsure how the AIP might have affected the abundance of all rainbow trout vulnerable to angling (≥300 mm). Therefore, we conducted a study to estimate abundance and exploitation rate of rainbow trout ≥300 mm and ≥406 mm to continue to assess the effectiveness of the AIP in reducing rainbow trout predation on kokanee. Additionally, rainbow trout population characteristics (e.g., age and growth, relative weight) in Lake Pend Oreille have not been evaluated for over a decade. Therefore we collected data to better understand rainbow trout population dynamics and determine how to best manage this population into the future.

METHODS

Rainbow Trout Population and Exploitation

To estimate rainbow trout abundance and angling exploitation in Lake Pend Oreille, a mark-recapture study was initiated during the spring of 2010. Because the one-year recapture period had not yet been completed by the end of our 2010 contract, the results of this study are presented here. Tagging methodologies and details were described in previous reports (Wahl et al. 2011a and b). Anglers turned heads in to the AIP freezers, and these heads were used for the capture and recapture portions of the estimate. We assumed that all rainbow trout harvested were turned in for rewards. To estimate abundance of rainbow trout ≥300 mm and ≥406 mm, we derived total length from a head length to total length regression developed during spring 2010 (Wahl et al. 2011b). Estimates of population abundance (*N*) were generated using the Chapman mark-recapture estimate as described by the formula:

$$N = \frac{(M+1) \times (C+1)}{R+1} - 1$$

where *M* is the number of marked fish, *C* is the number of fish sampled, and *R* is the number of fish recaptured. Confidence intervals around the mean were calculated using Poisson distributions of the variable *R* obtained from Ricker (1975). Additionally, we estimated PIT tag and CWT retention over the one-year recapture period.

Rainbow Trout Population Characteristics

To evaluate the population characteristics of rainbow trout in Lake Pend Oreille, we collected fish caught by anglers during October-December 2011. With few exceptions, we recorded total length, weight, maturity, and sex for each fish. In a subsample of fish, we also removed otoliths for ageing and collected a tissue sample to assess the genetic composition of Lake Pend Oreille rainbow trout compared to their parent stock from Kootenay Lake, Canada. The genetic evaluation was performed to assess the extent that hybridization with other hatchery strains of rainbow trout has influenced the population and if any associated changes in growth potential should now be expected. Genetics samples have not yet been analyzed, and a complete description will appear in a future report.

To evaluate the age structure of the rainbow trout population, we imbedded rainbow trout otoliths in epoxy then sectioned each one across the transverse plane. For accuracy, two independent readers examined each otolith and settled differences by re-examination. Additionally, the readers also recorded the number of annuli counted in the middle prior to a wide growth increment (these were assumed to be annuli formed during in-stream rearing). To describe the rainbow trout growth rate, we applied the von Bertalanffy growth model:

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

where L_t = length at time t, L_∞ = the theoretical maximum length, K = the growth coefficient, t = age in years, and t_0 = the time when length theoretically equals 0 mm.

Along with rainbow trout growth, we calculated age and size at maturity, and total annual mortality. Mortality was calculated by developing an age-length key using the population estimate of rainbow trout ≥406 mm, ageing data, and the size structure of rainbow trout ≥406 mm captured from July through November. Finally, we calculated a rainbow trout length-weight relationship and relative weight (W_r) using values for lentic populations (Anderson and Neumann 1996).

RESULTS

Rainbow Trout Population and Exploitation

From June 2010 through May 2011, anglers turned 7,883 rainbow trout heads ≥300 mm in to the AIP. Based on the head length to total length relationship (Wahl et al. 2011b), 4,102 of these were ≥406 mm. At the end of December, we estimated 34,879 (26,215-47,465 = 95% CI) rainbow trout ≥300 mm in Lake Pend Oreille with 15,237 (10,953-21,860 = 95% CI) ≥406 mm (Figure 17). We used the estimated rainbow trout abundance at the end of December for comparison with previous population estimates, and because we believe the population estimate at that point best represents the true abundance (see Wahl et al. 2011b). Annual angling exploitation rate was 19% for rainbow trout ≥300 mm and 23% for those ≥406 mm. A summary of the number of heads in the AIP, recaptures, and population estimates by month is presented in Tables 9 and 10. Of the 53 recaptures, two fish lost a PIT tag, and two different fish lost a CWT. Annual retention rate was 96% for each tag type.

Rainbow Trout Population Characteristics

We aged 150 rainbow trout (213-867 mm) that ranged in age from three to 10 years. Rainbow trout grew from a starting age of t_0 = 1.567 years toward their asymptotic length of L_∞ = 1077 mm at an instantaneous rate of K = 0.173/year (Figure 18). Based on the increments between annuli, rainbow trout appeared to spend an average of three years (range = 2 to 5 years) rearing in streams prior to entering the lake. By subtracting the number of in-stream rearing years from the total age of rainbow trout, we constructed an in-lake growth curve for rainbow trout. This curve described rainbow trout growth from a starting age of t_0 = 0.015 years toward their asymptotic length of L_∞ = 873 mm at an instantaneous rate of K = 0.376/year (Figure 18).

Rainbow trout maturity data suggested that males reached 50% maturity at 563 mm or 5.6 years, and females reached 50% maturity at 570 mm or 6.0 years (Figure 19). Catch curve analysis revealed a total annual mortality of 66% for rainbow trout ages 4 to 10 including fishing and natural mortality rates of 23% and 56%, respectively. The rainbow trout weight-total length relationship exhibited a strong curvilinear relationship with weights ranging from 0.17 to 7.54 kg (Figure 20). Relative weight averaged 92 (median = 92, SE = 1.17, range = 48-131). Mean W_r decreased from the 200 mm size class to the 400 mm size class; all size classes ≥500 mm had mean W_r ranging from 90 to 100 (Figure 20).

DISCUSSION

Based on the population estimate of rainbow trout ≥406 mm generated in 2009, the abundance of these fish had been reduced 46% since the inception of the AIP in 2006 (Wahl et al. 2011b). However, the most recent estimate suggested this segment of the rainbow trout population increased dramatically in one year. These estimates suggest that the AIP has not resulted in substantial overharvest of the sizes of rainbow trout that are most likely to feed on kokanee. Additionally, the estimate of all harvestable-sized rainbow trout (≥300 mm) in 2010 was also similar to the estimate in 2006 (36,209, Maiolie et al. 2008). However, the size structure has shifted slightly with a greater proportion of fish <400 mm and fewer fish 425-600 mm in 2011 compared to 2006.

Annual angling exploitation rates calculated in 2006-07 (19%), 2009-10 (29%), and 2010-11 (23%) were lower than is likely necessary to substantially reduce the rainbow trout population. Average annual exploitation of 33% was not sufficient to reduce stream-dwelling trout over a nine-year period (Gard and Seegrist 1972), whereas 62% exploitation did lead to overharvest of age-4 to age-7 cutthroat trout (Moore and Schill 1984). Additionally, population modeling of rainbow trout in Lake Pend Oreille suggested only a minimal reduction in population abundance with annual fishing exploitation rates of up to 26% (Hansen et al. 2010). Other factors, such as dynamic flow conditions in rainbow trout spawning and rearing tributaries or kokanee abundance may have had more influence on rainbow trout abundance than exploitation through the AIP.

The retention rate of PIT tags in the opercle musculature of rainbow trout that we estimated in Lake Pend Oreille during 2010-11 was higher than during 2009-10 (89%, Wahl et al. 2011b) and retention rates reported elsewhere (89% for bull trout, Baxter et al. 2001; 82% for Yellowstone cutthroat trout *O. clarkii bouvieri*, High et al. 2011). However, we did not have 100% retention for the CWT (96%). This retention rate was not lower than expected as CWT retention is often related to tagger experience (Hale and Gray 1998). The use of CWT to mark rainbow trout was a novel technique to our crew during 2010, and retention rates of nearly 100% should be expected in the future.

The rainbow trout growth curve developed in 2011 suggested slower growth, especially at early in-lake life stages, than previous studies on this population. The mean length at age-5 decreased from 625 mm during 1972-76 (Anderson 1978) to 562 mm in 1983 (Pratt 1984) to 495 mm in 1997-98 (Vidergar 2000) to 429 mm in this study. Mean length at age-3 was only 14 mm different among the four studies. Early in-lake growth rates of rainbow trout have likely declined due to reduced food availability as evidenced by mean W_r below 85 for rainbow trout 300-499 mm. Additionally, mean W_r for rainbow trout ≥500 mm was 97 in this study (Fulton's condition factor = 1.1), whereas Anderson (1978) found that age-5 and age-6 rainbow trout (the two oldest age classes in that study) had a slightly higher mean condition factor of 1.4. Although the current condition factor suggests good fish condition, decreasing kokanee abundance from the 1970s to the 2000s may have led to lower condition and slower rainbow trout growth. We did not calculate growth increments for individual years, but visual inspection suggested rainbow trout that entered the lake in recent years have experienced better growth than those that entered the lake during 2005-07 (years of record low kokanee abundance). Based on the visual inspection of growth increments, the rainbow trout population can still likely achieve some of the large sizes seen historically. Genetics results may provide more insight into the current population's growth potential. Additionally, age-at-maturity was similar to previous studies (Anderson 1978; Pratt 1984; Vidergar 2000), suggesting that gonadal growth and development is not limiting somatic growth of the largest fish in the population.

Previous studies in Lake Pend Oreille have reported total annual mortality for rainbow trout from 25% (Vidergar 2000) to 60% (Ellis and Bowler 1981). The mortality rate we estimated was the highest reported, but we still documented age-10 fish that historically have been rare. The current high mortality rate may actually stem from low recruitment of older age classes due to a flood event in the Lightning Creek drainage during 2006.

RECOMMENDATIONS

1. Consider discontinuation of the AIP for rainbow trout.

2. Examine rainbow trout age structure and growth rates every 2-4 years to assess the population response to differing regulation strategies and changes in kokanee abundance.

3. Complete comparison of Lake Pend Oreille rainbow trout genetics to those of Gerrard-strain rainbow trout in Kootenay Lake, Canada to assess genetic composition and growth potential.

4. Conduct population and exploitation estimates during 2012-13 to evaluate the response of rainbow trout to the AIP program.

Table 9. Monthly summary of rainbow trout heads collected from Lake Pend Oreille, Idaho through the AIP, the number of recaptures, and cumulative population estimates of rainbow trout with 95% confidence intervals. Period covered includes June 2010-May 2011. The estimate as at the end of December was determined to provide the best estimate.

				95% Confidence Interval	
	Number of heads in AIP	**Number of Recaptures**	**Cumulative estimate of rainbow trout ≥300 mm**	**Lower Limit**	**Upper Limit**
June	902	8	28,795	15,426	58,900
July	417	4	29,141	17,220	52,617
August	456	2	33,980	20,805	58,588
September	813	5	37,151	24,282	59,443
October	1,909	16	35,858	25,974	51,025
November	926	9	34,592	25,945	47,172
December	**166**	**1**	**34,876**	**26,215**	**47,465**
January	53	1	34,457	25,996	46,808
February	39	0	34,695	26,176	47,131
March	186	1	35,085	26,522	47,440
April	946	4	37,607	28,736	49,153
May	1,070	2	41,901	32,176	54,501

Table 10. Monthly summary of rainbow trout heads ≥71 mm collected from Lake Pend Oreille, Idaho through the AIP, the number of recaptures, and cumulative population estimates of rainbow trout ≥406 mm with 95% confidence intervals. Period covered includes June 2010-May 2011. The estimate at the end of December was determined to provide the best estimate.

				95% Confidence Interval	
	Number of heads in AIP	**Number of Recaptures**	**Cumulative estimate of rainbow trout ≥406 mm**	**Lower Limit**	**Upper Limit**
June	648	6	16,409	8,147	35,898
July	345	2	19,548	10,473	39,986
August	315	1	23,168	12,801	46,339
September	372	2	24,794	14,374	46,490
October	760	14	16,617	11,430	25,120
November	382	7	15,141	10,839	21,915
December	**104**	**1**	**15,237**	**10,953**	**21,860**
January	34	1	14,973	10,806	21,392
February	22	0	15,084	10,886	21,551
March	95	1	15,133	10,962	21,534
April	475	4	15,721	11,582	21,912
May	550	2	17,290	12,831	23,889

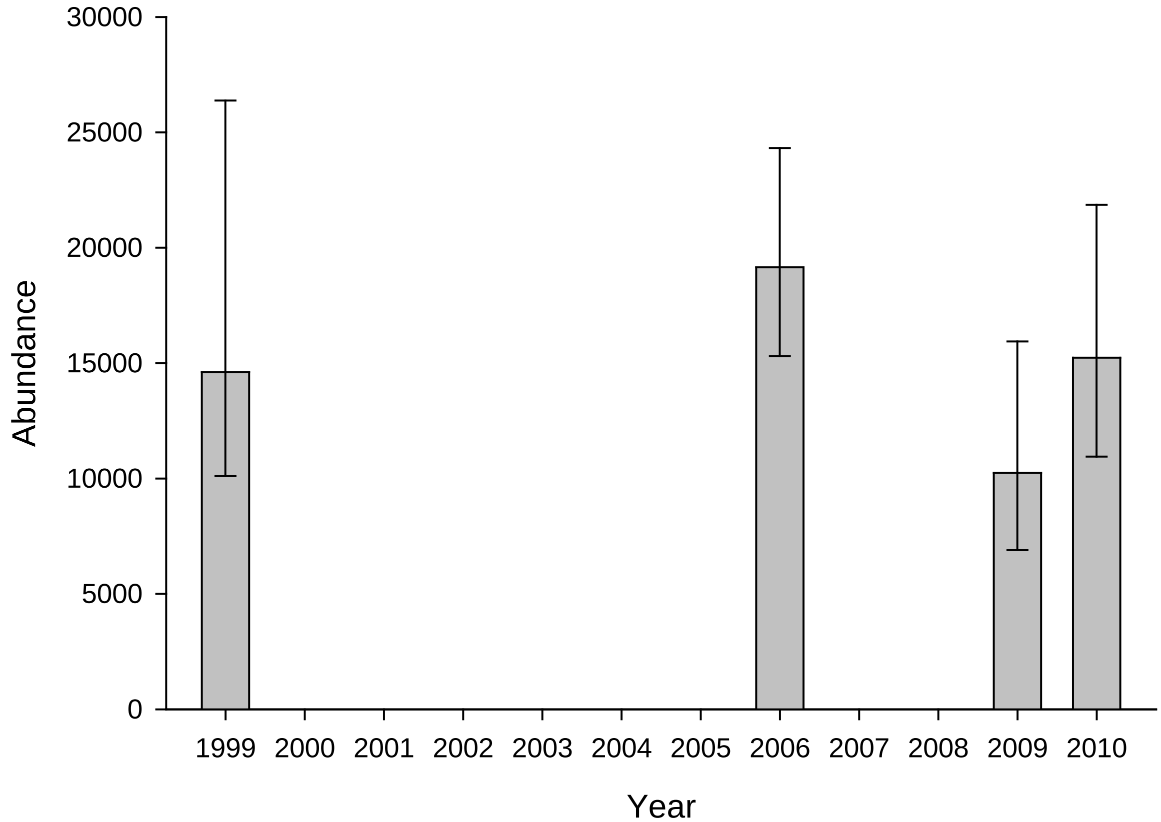


Figure 17. Estimate and 95% confidence intervals of the abundance of rainbow trout ≥406 mm in Lake Pend Oreille.

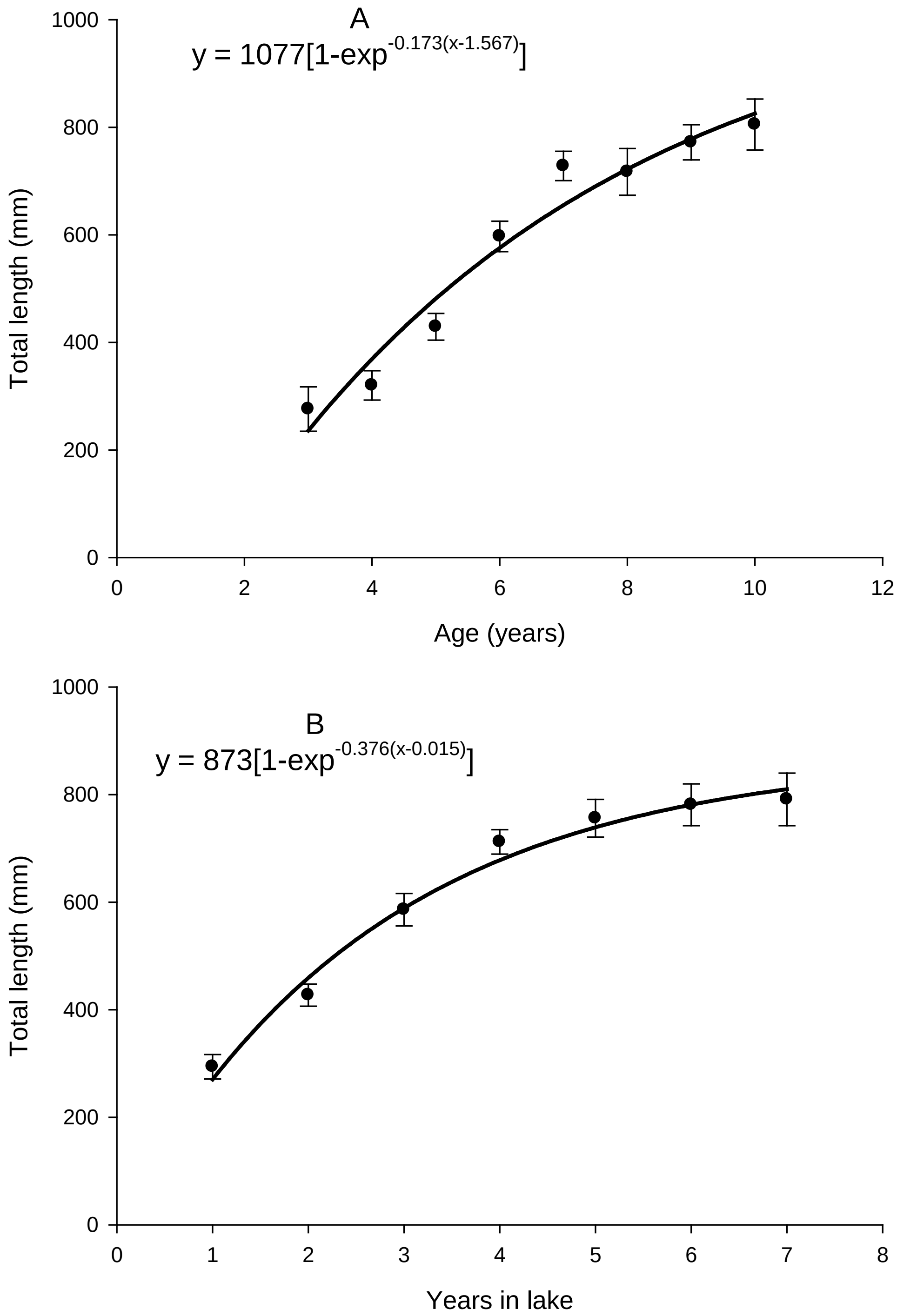


Figure 18. Mean total length-at-age (A) and at years in lake (B) with 95% confidence intervals for rainbow trout captured during the fall of 2011 in Lake Pend Oreille. Growth is described by the fitted von Bertalanffy growth model (solid line).

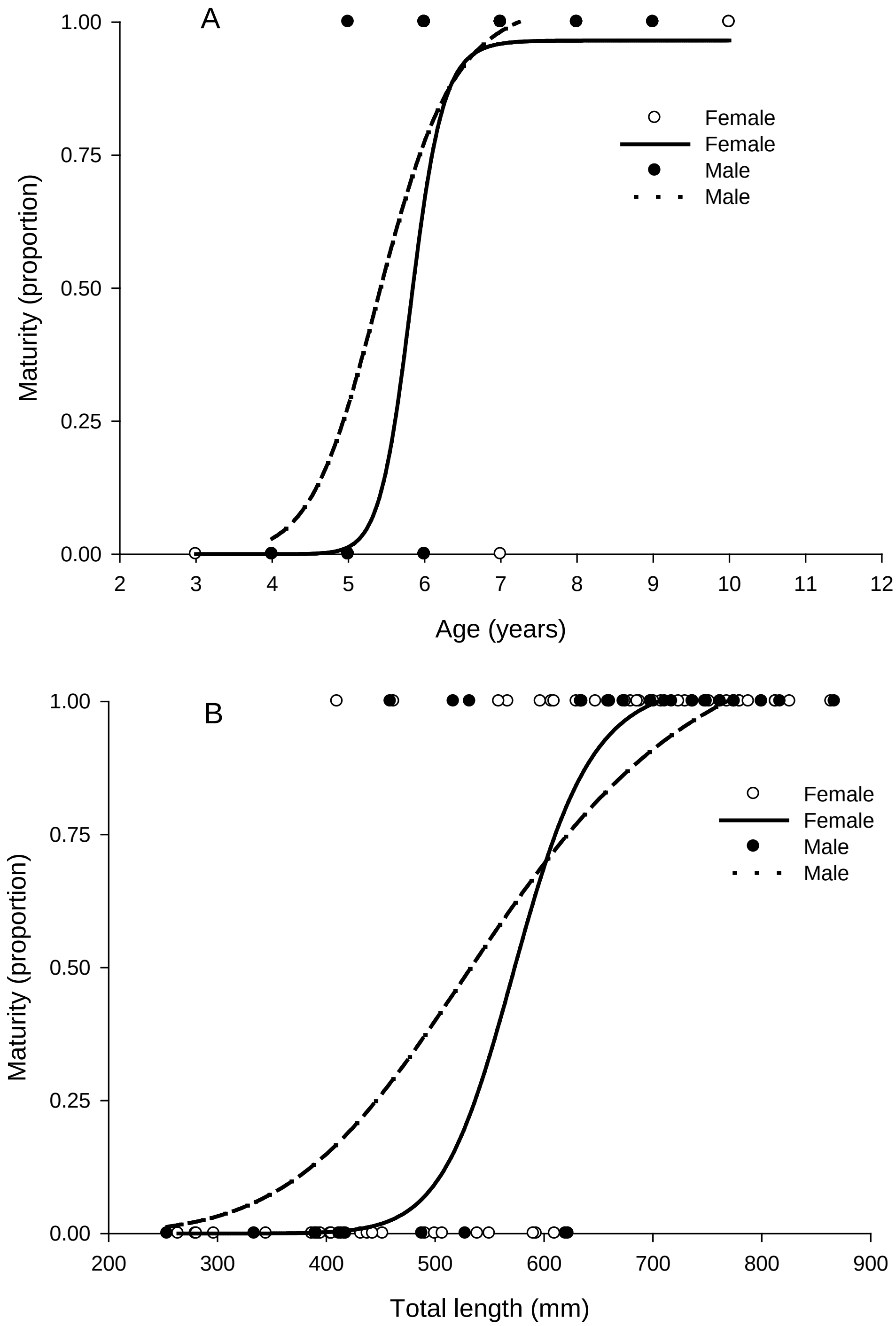


Figure 19. Proportion of mature male and female rainbow trout by age (A) and by total length (B) captured during the fall of 2011 in Lake Pend Oreille. Fifty percent maturity was 5.6 years and 563 mm for males and 6.0 years and 570 mm for females.

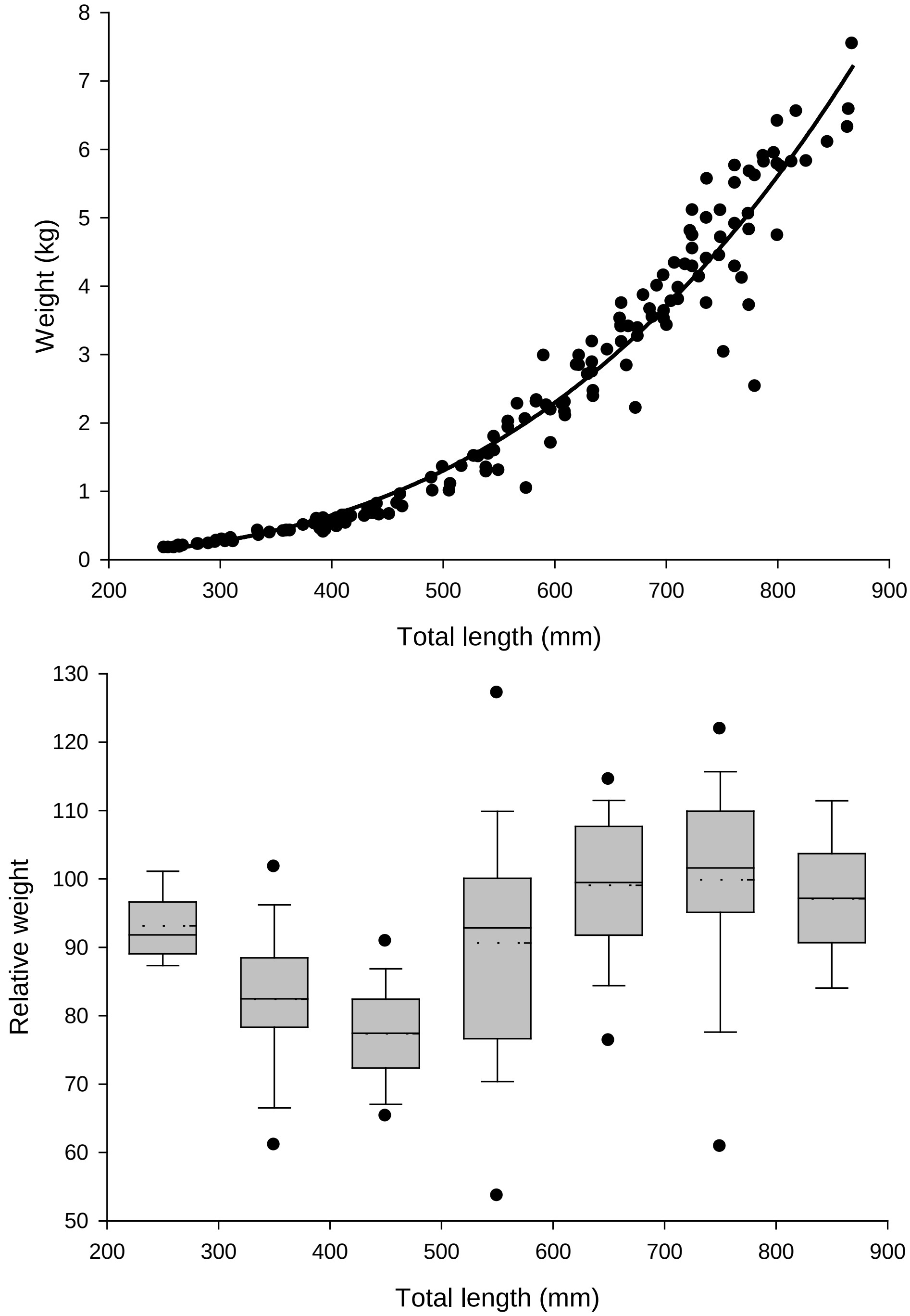


Figure 20. Weight-total length relationship (A) and box and whisker plot of relative weights (W_r) of size classes (B) of rainbow trout captured during the fall of 2011 in Lake Pend Oreille. Within each box, median is indicated by a solid line, mean is indicated by a dashed line, boxes represent 25th and 75th percentiles, whiskers represent 10th and 90th percentiles, and circles represent 5th and 95th percentiles.

CHAPTER 4: PREDATOR REMOVAL

ABSTRACT

For more than a decade, kokanee *Oncorhynchus nerka* recovery in Lake Pend Oreille has been limited by predation from lake trout *Salvelinus namaycush* and rainbow trout *O. mykiss*. To address this issue, Idaho Department of Fish and Game (IDFG) implemented an aggressive predator removal strategy aimed at reducing lake trout and rainbow trout abundance. IDFG instituted unlimited harvest regulations and a $15 reward for each lake trout and rainbow trout harvested as part of the Angler Incentive Program. Additionally, IDFG contracted with Hickey Brothers, LLC to remove lake trout from Lake Pend Oreille using gill nets and deepwater trap nets. During 2011, the netters removed 5,841 and 5,539 lake trout in gill nets during the spring and fall, respectively. The netters removed an additional 150 lake trout in trap nets in the fall. Anglers turned in 7,324 lake trout heads and 8,697 rainbow trout heads. Total biomass removed in 2011 was 20,632 kg of lake trout (0.63 kg/ha) and 7,017 kg of rainbow trout (0.21 kg/ha). Since the predator removal began in 2006, 133,559 lake trout and 41,188 rainbow trout have been removed from Lake Pend Oreille.

Authors:

Nicholas C. Wahl
Senior Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

INTRODUCTION

Population modeling conducted in 2006 suggested the kokanee *Oncorhynchus nerka* population had a 65% chance of complete collapse due to predation, and exploitation rates of lake trout *Salvelinus namaycush* and rainbow trout *O. mykiss* at that time were not sufficient to reduce the risk (Hansen et al. 2010). Additionally, the lake trout population was doubling every 1.6 years and was projected to reach 131,000 adults by 2010 without management intervention (Hansen et al. 2008). In an attempt to collapse the lake trout population and reduce rainbow trout predation until kokanee could recover, the Idaho Department of Fish and Game (IDFG) initiated a two-tiered predator removal program in 2006. First, IDFG liberalized the angling regulations for lake trout and rainbow trout on Lake Pend Oreille (removed creel limits and allowed anglers to fish with up to four rods) and initiated an angler incentive program (AIP) which offered $15 rewards per lake trout or rainbow trout harvested. Recently, the rod limits were removed altogether. Additionally, IDFG contracted with a commercial fishing operation that had prior lake trout netting experience in the Great Lakes (Hickey Brothers, LLC) to remove lake trout with gill nets and deepwater trap nets in Lake Pend Oreille. A combination of gill nets, trap nets, and angling was necessary to maximize the likelihood of exerting high enough annual mortality to sufficiently reduce the lake trout population and prevent kokanee extirpation (Hansen et al. 2010).

METHODS

Hickey Brothers, LLC was contracted to remove lake trout from Lake Pend Oreille using gill nets and deepwater trap nets during 29 weeks (15 weeks in the spring and 14 weeks in the fall) in 2011. Gill nets contained stretch mesh of 5.1-12.7 cm. The contract netters set primarily 5.1-7.0 cm mesh in the spring (January-April) and late fall (October-December) to target juvenile lake trout and 10.2-12.7 cm mesh in the early fall (September-October) to target large lake trout at spawning sites. Methodologies for setting gill nets are described in Chapter 2. Gill nets were typically set around dawn and pulled several hours later, although on occasion were set in the afternoon and pulled the following morning. Four trap nets (described in detail by Peterson and Maiolie 2005) were set during the fall at locations standardized in previous years. Hickey Brothers, LLC set the trap nets during the first week of fall netting and lifted the nets weekly. Because rainbow trout primarily use pelagic habitats (Maiolie et al. 2006a), they are rarely caught in the commercial nets and cannot be effectively targeted.

For the AIP, anglers who caught lake trout and rainbow trout from Lake Pend Oreille turned the heads in to freezers placed around the lake. Heads were collected from freezers weekly, thawed, identified, and measured from the tip of the snout to the posterior edge of the operculum. A head-length to body-length relationship developed in 2010 was used to extrapolate total length. The relationship was produced from 405 lake trout with total lengths ranging from 283 to 950 mm and head lengths ranging from 54 to 210 mm and fit the following linear regression (R^2 = 0.9593) where *TL* is fish total length (mm) and *HL* is head length (mm):

$$TL = 4.2643 \times HL + 64.724$$

As a metric to evaluate the response of lake trout to removals, we used the combined catch rate of trap nets set at four standardized locations during fall 2007-2011 (nets were set at only three of these locations in 2006) to index trends in mature lake trout abundance.

To gauge the changes in lake trout abundance and the overall effectiveness of the predator removal efforts, a lake trout population estimate was initiated during the fall 2011 (described in the Lake Trout Research chapter). Concurrently, we initiated a bull trout population estimate to assess their response to changes in kokanee and lake trout abundance as well as the influence of netting bycatch. Because the recapture portion of these estimates was not completed at the end this contract period, a full description, analysis, and discussion will appear in the 2012 report.

RESULTS

During spring 2011, (from January 17 to April 29), Hickey Brothers, LLC set a total of 357,713 m of gill net (1,304 individual 274 m nets) and captured 5,841 lake trout (2.9 lake trout per net; 2.4-3.5 = 95% CI) and 395 bull trout (0.4 bull trout per net; 0.3-0.4 = 95% CI) with 113 direct mortalities (29%). All the lake trout caught were removed. Weekly catch rates ranged from 1.4 lake trout per net (0.7-2.4 = 95% CI) during March 28-April 1 to 8.8 lake trout per net (5.7-13.5 = 95% CI) during January 22-28. Captured lake trout ranged in size from 200-908 mm, but because the netters set primarily small mesh nets to target small lake trout, 96% of fish caught were <450 mm (Figure 21). Based on the length-weight relationship developed for lake trout in Lake Pend Oreille (Wahl et al. 2011b), the lake trout biomass removed during spring gill netting was 2,228 kg.

During fall 2011, (from September 5 to December 16), Hickey Brothers, LLC set a total of 256,673 m of gill net (935.67 individual 274 m nets) and captured 5,573 lake trout (4.9 lake trout per net; 4.3-5.6 = 95% CI) and 979 bull trout (1.0 bull trout per net; 0.9-1.2 = 95% CI) with 277 direct mortalities (28%). Of the lake trout caught, 5,539 were removed. From September 12 to October 20, when the netters were only fishing at spawning sites, mean catch rate was 4.1 lake trout per net (3.4-4.9 = 95% CI). Afterwards, netting targeted small lake trout, and mean catch rate was 6.4 lake trout per net (5.4-7.6 = 95% CI). Captured lake trout ranged in size from 168-1110 mm (Figure 21). Based on the length-weight relationship (Wahl et al. 2011b), the lake trout biomass removed during fall gill netting was 8,596 kg. Also during the fall (from September 5 to November 16), five trap nets set by Hickey Brothers, LLC captured 367 lake trout (0.9 lake trout per net-night; 0.7-1.2 = 95% CI; Figure 22), and 55 bull trout with nine direct mortalities (16%). Of the lake trout captured, 150 were removed; the remainder were tagged and released for the population estimate. Peak weekly catch rate was 2.3 lake trout per net night (0.9-4.6 = 95% CI) during September 12-18, prior to the lake trout spawning period. Trap net-caught lake trout ranged in size from 324-897 mm. Based on the length-weight relationship (Wahl et al. 2011b), the trap nets removed 331 kg of lake trout biomass during the fall.

During 2011, anglers turned in 7,324 lake trout heads to the AIP program with 79% of these fish turned in during June-October (Table 11). Based on head length-total length and total length-weight relationships developed for lake trout in Lake Pend Oreille (IDFG, unpublished data), anglers removed 9,477 kg of lake trout biomass. Additionally, during 2011, anglers turned in 8,697 rainbow trout heads with 72% turned in during April-June and October-November (Table 12). Based on head length-total length and total length-weight relationships developed for rainbow trout in Lake Pend Oreille (IDFG, unpublished data), anglers removed 7,017 kg of rainbow trout biomass. However, anglers also mistakenly turned in 38 bull trout heads to the AIP program.

The catch rate of the standardized trap nets averaged 1.1 lake trout per net-night (0.7-1.5 = 95% CI) in 2011 (Figure 22).

DISCUSSION

Since the predator removal program began in 2006, 133,559 lake trout have been removed from Lake Pend Oreille (Table 13). However, there has been a dramatic shift in the contribution by capture method, partly because lake trout age- and size-structure has changed in response to removals. Total angler catch and trap net catch rate has declined as larger (>500 mm) lake trout have been removed from the population. In 2006, 72% of the lake trout were removed by angling (Table 13), which is selective for lake trout primarily age-5 to age-9 (Hansen et al. 2010). By 2009, only 30% of lake trout were removed by angling. The proportion has changed slightly to 39% of lake trout removed by anglers, mainly due to a dramatically reduced catch rate of juvenile lake trout in the gill nets. Similarly, trap nets, which effectively target lake trout ≥age-8, have shown an 80% decrease in catch rate since 2006. While angling and trap nets became less effective, gill nets made a bigger contribution. The shift in contribution of each capture method over time demonstrates the importance of using multiple capture methods in a suppression program to exploit all sizes of lake trout (Hansen et al. 2010).

Incidental bycatch of bull trout has been a concern since the lake trout removal using commercial gill nets began. A population estimate conducted in 2008 concluded that there were 8,004 (4,580-15,135 = 95% CI) bull trout in Lake Pend Oreille ≥400 mm (J. McCubbins, Avista Corp. personal communication). During 2011, 212 of the 399 mortalities were ≥400 mm, or roughly 3% of the population. Additionally, only 822 of the 1,429 bull trout captured in gill and trap nets during the year were ≥400 mm, or 10% of the population. Based on these data, incidental bycatch of bull trout in the commercial netting gear has had only minimal, if any, negative effects on this population. This is also corroborated by stable bull trout redd count trends during the years of predator removal (Maiolie et al. 2011). Additionally, netting provides a presumed, although not quantified, benefit to bull trout from reduced lake trout abundance and increased kokanee abundance. The bull trout population estimate currently underway will provide more insight into the status of bull trout in Lake Pend Oreille.

The number of rainbow trout turned in to the AIP was the highest in the six years of this program. We are unsure how angler effort, angler attitude, fishing conditions, and changes in rainbow trout abundance influence annual variation in AIP catch. However, the sustained angler catch for rainbow trout relative to reduced angler catch for lake trout, along with no significant changes in the rainbow trout population estimates, suggests that reduction efforts likely have had a lesser effect on rainbow trout than lake trout.

High densities of juvenile lake trout (≤450 mm) were discovered in relatively shallow (45-90 m) portions of the lake during 2008, and since that time, considerable gill netting effort has been focused on their removal each year. The main area of the lake that is targeted is the northern basin from the islands northwest to Bottle Bay. Over the last four years, the mean annual catch rate of lake trout in this part of the lake has declined 74% from 16.9 lake trout per net (13.9-20.5 = 95% CI) to 4.4 (3.8-5.1 = 95% CI). With an exponentially growing population through 2006, and not exploiting lake trout at spawning sites until 2008, several strong year classes of lake trout may have been produced. Based on the decreasing catch rate, these year classes appear to be reduced drastically, and with progressively smaller spawner numbers since 2008, cohorts and catch rates should continue to decline. Additionally, targeting these fish reduces the numbers that are available to recruit to maturity, thereby further reducing spawning potential. In the coming years, we expect to start seeing the effects of this netting with fewer fish reaching maturity (600 mm) and fewer juvenile fish recruiting to the gear (250 mm).

The catch rate of the standardized trap nets decreased 82% from 2006 to 2009, but has remained consistent since then. Although catch rate has stabilized at a lower level, this may not indicate stability in adult lake trout abundance. Telemetry data suggest that adult lake trout exhibit preferences towards specific habitats, including an area on the north end of the lake in close proximity to three of the standardized trap net sites. We suspect that this concentrated distribution pattern may have resulted in higher trap net catch rates than would be expected with a more uniform fish distribution. If catch rates have been influenced by fish distribution, then we should expect a rapid decline to occur if this segment of the population approaches collapse from overharvest. Despite the consistent catch rates since 2009, standardized trap net catch rates since 2006 continue to suggest that the adult lake trout population has been dramatically reduced in response to removal actions. We are encouraged by the response lake trout have exhibited to removal thus far; however, continued removal actions are necessary to determine the level of population reduction that can be achieved and how much effort is required to keep the population suppressed.

RECOMMENDATIONS

1. Continue the use of gill nets to remove mature lake trout from spawning sites in the fall and immature lake trout during other times of year.

2. Continue the use of the AIP to reduce the numbers of lake trout in Lake Pend Oreille during 2012.

3. As recommended in Chapter 3, consider discontinuation of the AIP for rainbow trout.

4. Complete the recapture portion of the bull trout population estimate initiated in 2011 to assess response to changes in kokanee and lake trout abundance and the influence of netting bycatch.

Table 11. Number of lake trout from Lake Pend Oreille, Idaho turned in to the AIP by month and year.

Month	2006	2007	2008	2009	2010	2011
January	--	415	58	144	330	146
February	--	789	241	156	351	78
March	--	895	363	179	380	105
April	--	1,261	544	263	343	256
May	1,317	2,445	771	1,033	873	347
June	2,136	3,107	2,117	1,321	1,558	2,049
July	1,033	2,809	2,612	1,178	1,354	1,115
August	2,200	1,949	1,878	1,051	988	718
September	1,755	1,864	2,178	969	1,261	940
October	1,561	1,046	862	409	766	930
November	661	831	940	483	330	348
December	250	254	298	180	206	292
TOTAL	**11,041**	**17,665**	**13,020**	**7,366**	**8,740**	**7,324**

Table 12. Number of rainbow trout from Lake Pend Oreille, Idaho turned in to the AIP by month and year.

Month	2006	2007	2008	2009	2010	2011
January	--	124	216	27	42	162
February	--	78	33	45	68	53
March	--	154	96	79	176	182
April	--	1,050	357	241	616	922
May	1,211	1,376	548	948	1,254	930
June	510	1,212	711	602	953	1,161
July	206	396	337	392	461	636
August	375	526	244	369	387	276
September	544	654	391	447	828	561
October	1,561	1,114	644	967	1,696	1,560
November	1,412	1,288	1,073	1,452	1,216	1,684
December	129	171	203	224	217	570
TOTAL	**5,948**	**8,141**	**4,695**	**5,793**	**7,914**	**8,697**

Table 13. Number of lake trout removed from Lake Pend Oreille, Idaho by different gear types each year.

Gear	2006	2007	2008	2009	2010	2011	Total
Angling	11,041	17,665	13,020	7,366	8,740	7,324	65,156
Gill Nets	2,774	4,169	10,252	17,186	17,334	11,384	63,099
Trap Nets	1,500	1,335	1,509	410	400	150	5,304
TOTAL	**15,315**	**23,169**	**24,781**	**24,962**	**26,474**	**18,858**	**133,559**

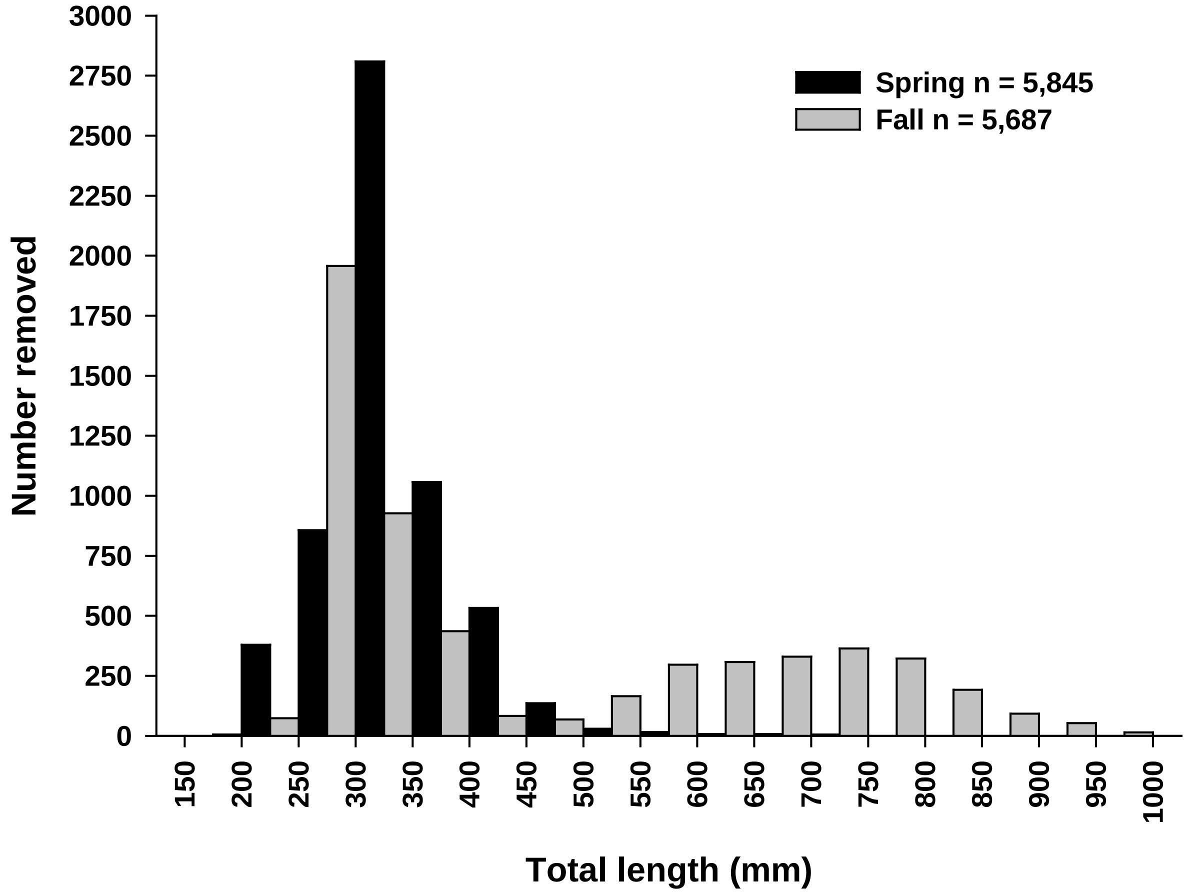


Figure 21. Length frequency histogram of lake trout removed during the spring and fall of 2011 in Lake Pend Oreille.

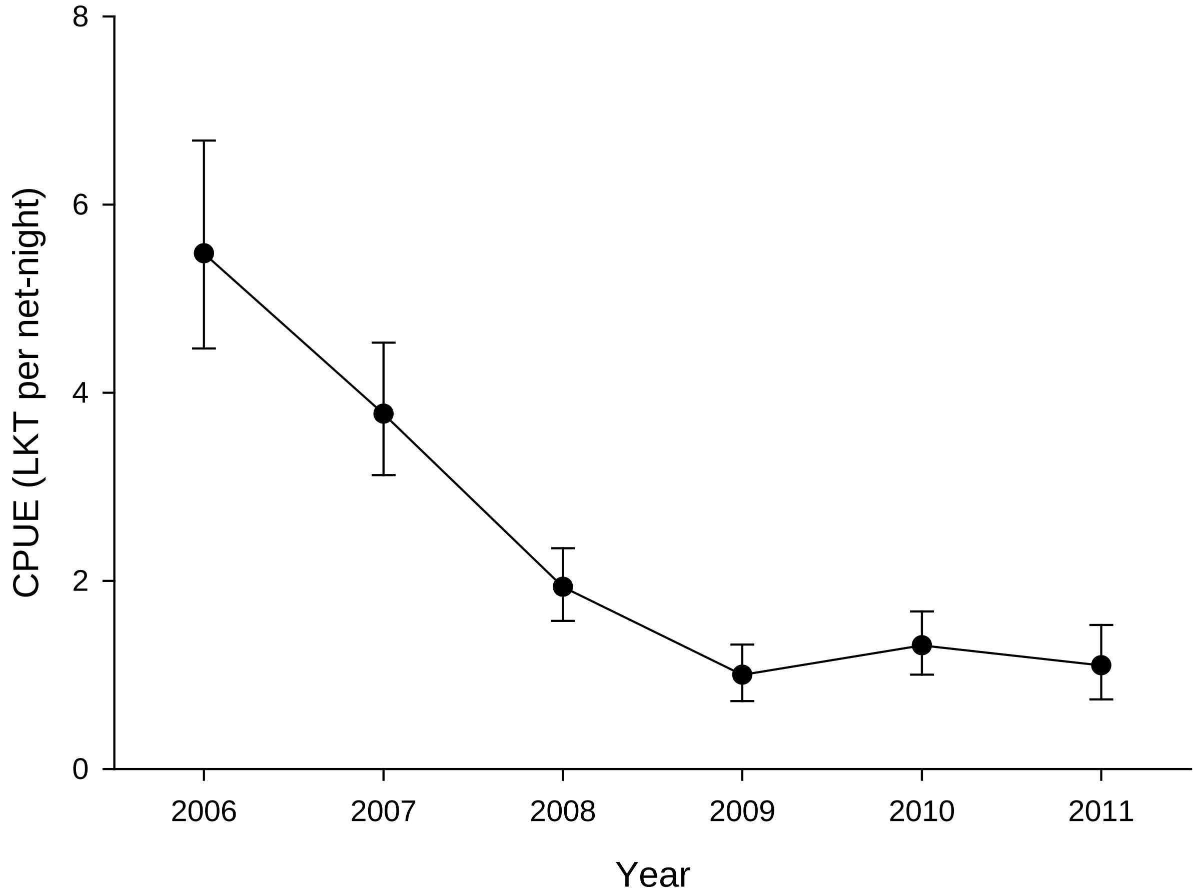


Figure 22. Mean catch rate and 95% confidence intervals of lake trout caught in trap nets set at four standardized locations during fall in Lake Pend Oreille, Idaho. The 2006 catch rate is based on three of the four standardized trap net locations.

ACKNOWLEDGMENTS

Many people contributed to making this study possible. Fisheries technicians Mark Duclos and Brian Hammond assisted with many of the field and laboratory activities and the maintenance of equipment. We would also like to thank the anglers for their assistance in capturing rainbow trout for the ageing and genetics studies. The U.S. Army Corps of Engineers made the necessary lake level changes, and the Bonneville Power Administration provided funding for this study. We wish to thank Cecilia Brown for her help in administering our BPA contract. The help from these people and agencies was greatly appreciated.

LITERATURE CITED

Anderson, R. 1978. Age and growth characteristics of Pend Oreille Lake Kamloops. Idaho Department of Fish and Game, Lake and Reservoir Investigations, Job Performance Report, F-53-R-12 & 13.

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

Baxter, J. S., B. Westover, T. Down, and S. Snelson. 2001. Retention of floy tags and passive integrated transponder tags in a wild bull trout population one and two years after tagging. Pages 177-180 *in* M. K. Brewin, A. J. Paul, and M. Monita, editors. Bull Trout II conference proceedings. Trout Unlimited Canada, Calgary, Alberta.

Beacham, T. D., and C. B. Murray. 1993. Fecundity and egg size variation in North American Pacific salmon (*Oncorhynchus*). Journal of Fish Biology 42:485-508.

Beattie, W. D., and P. T. Clancey. 1991. Effects of *Mysis relicta* on the zooplankton community and kokanee population of Flathead Lake, Montana. American Fisheries Society Symposium 9:39-48.

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

Bowles, E. C., V. L. Ellis, D. Hatch, and D. Irving. 1987. Kokanee stock status and contribution of Cabinet Gorge Hatchery, Lake Pend Oreille, Idaho. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract DE-A179-85BP22493, Project 85-839. Portland, Oregon.

Bowles, E. C., B. E. Rieman, G. R. Mauser, and D. H. Bennett. 1991. Effects of introductions of *Mysis relicta* on fisheries in northern Idaho. American Fisheries Society Symposium 9:65-74.

Chapman, D. W., and K. P. McLeod. 1987. Development of criteria for sediment in the northern Rockies ecoregion. EPA 910/9-87-162. USEPA, Region 10, Seattle, Washington.

Chipps, S. R. 1997. *Mysis relicta* in Lake Pend Oreille: seasonal energy requirements and implications for mysid - cladoceran interactions. Doctoral dissertation, University of Idaho.

Cochnauer, T., and B. Horton. 1979. A reference workbook for use in determining stream resource maintenance flows in the State of Idaho.

Cox, B. S. 2010. Assessment of an invasive lake trout population in Swan Lake, Montana. Master's thesis. Montana State University, Bozeman.

Crossman, E. J. 1995. Introduction of the lake trout (*Salvelinus namaycush*) in areas outside its native distribution: a review. Journal of Great Lakes Research 21 (Supplement 1):17-29.

Donald, D. B., and D. J. Alger. 1993. Geographic distribution, species displacement, and niche overlap for lake trout and bull trout in mountain lakes. Canadian Journal of Zoology 71:238-247.

Dux, A. M., C. S. Guy, and W. A. Fredenberg. 2011. Spatiotemporal distribution and population characteristics of a nonnative lake trout population, with implications for suppression. North American Journal of Fisheries Management 31:187-196.

Ellis, V. and B. Bowler. 1981. Pend Oreille creel census. Idaho Department of Fish and Game, Lake and Reservoir Investigations, Job Performance Report, F-73-R-3.

Fredenberg, W. 2002. Further evidence that lake trout displace bull trout in mountain lakes. Intermountain Journal of Sciences 8(3):143-152.

Gard, R., and D. W. Seegrist. 1972. Abundance and harvest of trout in Sagehen Creek, California. Transactions of the American Fisheries Society 101:463-477.

Gunn, J. M. 1995. Spawning behavior of lake trout: effects on colonization ability. Journal of Great Lakes Research 21 (Supplement 1):323-329.

Hale, R. S., and J. H. Gray. 1998. Retention and detection of coded wire tags and elastomer tags in trout. North American Journal of Fisheries Management 18:197-201.

Hansen, M. J. 1999. Lake trout in the Great Lakes: basin-wide stock collapse and binational restoration. Pages 417-453 in W. W. Taylor and C. P. Ferreri, editors. Great Lakes fishery policy and management: a binational perspective. Michigan State University Press, East Lansing.

Hansen, M. J., N. J. Horner, M. Liter, M. P. Peterson, and M. A. Maiolie. 2008. Dynamics of an increasing lake trout population in Lake Pend Oreille, Idaho. North American Journal of Fisheries Management 28:1160-1171.

Hansen, M. J., D. Schill, J. Fredericks, and A. Dux. 2010. Salmonid predator-prey dynamics in Lake Pend Oreille, Idaho, USA. Hydrobiologia 650:85-100.

Hayes, D. B., J. R. Bence, T. J. Kwak, and B. E. Thompson. 2007. Abundance, biomass, and production. Pages 327-374 in C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Healey, M. C. 1978. The dynamics of exploited lake trout populations and implications for management. Journal of Wildlife Management 42:307-328.

High, B., G. Schoby, D. Keen, and D. Garren. 2011. Fishery management annual report, Upper Snake Region, 2009. Report Number 11-107. Idaho Department of Fish and Game, Boise.

Hoelscher, B. 1992. Pend Oreille Lake fishery assessment 1951 to 1989. Idaho Department of Health and Welfare, Division of Environmental Quality Community Programs. Boise.

Irving, J. S., and T. C. Bjornn. 1984. Effects of substrate size composition on survival of kokanee salmon and cutthroat and rainbow trout embryos. U.S. Department of Agriculture Forest Service. Completion Report, Cooperative Agreement 12-11-204-11, Supplement 87, Boise, Idaho.

Jeppson, P. 1953. Biological and economic survey of fishery resources in Lake Pend Oreille. Idaho Department of Fish and Game, Job Completion Report, Project F 3-R-3. Boise.

Jeppson, P. 1960. Evaluation of kokanee and trout spawning areas in Pend Oreille Lake and tributary streams. Idaho Department of Fish and Game, Job Progress Report, Project F-53-R-10. Boise.

Keleher, J. J. 1972. Great Slave Lake: effects of exploitation on the salmonid community. Journal of the Fisheries Research Board of Canada 11:827-852.

MacLean, J. A., D. O. Evans, N. V. Martin, and R. L. DesJardine. 1981. Survival, growth, spawning distribution, and movements of introduced and native lake trout (*Salvelinus namaycush*) in two inland Ontario lakes. Canadian Journal of Fisheries and Aquatic Sciences 38:1685-1700.

Maiolie, M. A., and S. Elam. 1993. Influence of lake elevation on availability of kokanee spawning gravels in Lake Pend Oreille, Idaho, *in* Dworshak Dam impacts assessment and fisheries investigations. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract DE-AI79-87BP35167, Project 87-99. Portland, Oregon.

Maiolie, M. A., K. Harding, W. J. Ament, and B. Harryman. 2002. Lake Pend Oreille fishery recovery project. Idaho Department of Fish and Game, Completion Report to Bonneville Power Administration, Contract number 1994-047-00, Report number 02-56. Portland, Oregon.

Maiolie, M. A., W. Harryman, and W. J. Ament. 2004. Lake Pend Oreille fishery recovery project. Idaho Department of Fish and Game, Annual Progress Report to Bonneville Power Administration, Contract number 1994-047-00, Report number 04-24. Portland, Oregon.

Maiolie, M. A., T. P. Bassista, M. P. Peterson, W. Harryman, W. J. Ament, and M. A. Duclos. 2006a. Lake Pend Oreille fishery recovery project. Idaho Department of Fish and Game, Completion Report to Bonneville Power Administration, Contract number 1994-047-00, Report number 06-25. Portland, Oregon.

Maiolie, M. A., M. P. Peterson, W. J. Ament, and W. Harryman. 2006b. Kokanee response to higher winter lake levels in Lake Pend Oreille during 2005. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract number 00016828, Report number 06-31. Portland, Oregon.

Maiolie, M. A., G. P. Schoby, W. J. Ament, and W. Harryman. 2008. Kokanee and rainbow trout research efforts, Lake Pend Oreille, 2006. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract number 25744, Report number 08-06. Portland, Oregon.

Maiolie, M., R. Hardy, M. Liter, R. Ryan, K. Carter-Lynn, and J. Fredericks. 2011. Fishery management annual report, Panhandle Region, 2010. Report Number 11-117. Idaho Department of Fish and Game, Boise.

Martin, N. V., and C. H. Olver. 1980. The lake charr. Pages 205-277 *in* E. K. Balon, editor. Charrs: salmonid fishes of the genus *Salvelinus*. Dr. W. Junk, The Hague, Netherlands.

Martinez, P. J., P. E. Bigelow, M. A. Deleray, W. A. Fredenberg, B. S. Hansen, N. J. Horner, S. K. Lehr, R. W. Schneidervin, S. A. Tolentino, and A. E. Viola. 2009. Western lake trout woes. Fisheries 34:424-442.

Moore, V., and D. Schill. 1984. South Fork Snake River fisheries investigations. Idaho Department of Fish and Game, Job Completion Report, Project F-73-R-5, Boise.

O'Gorman, R., J. H. Elrod, and C. P. Schneider. 1998. Reproductive potential and fecundity of lake trout strains in southern and eastern waters of Lake Ontario, 1977-1994. Journal of Great Lakes Research 24:131-144.

Paragamian, V. L. and E. C. Bowles. 1995. Factors affecting survival of kokanees stocked in Lake Pend Oreille, Idaho. North American Journal of Fisheries Management 15:208-219.

Peterson, M. P., and M. A. Maiolie. 2005. Evaluation of large trap nets for lake trout removal in Lake Pend Oreille, Idaho. Idaho Department of Fish and Game, Project Progress Report, Report Number 04-35. Boise.

Pratt, K. I. 1984. Pend Oreille trout and char life history study. Idaho Department of Fish and Game in cooperation with Lake Pend Oreille Idaho Club, Boise.

Richards, R., C. Goldman, E. Byron, and C. Levitan. 1991. The mysids and lake trout of Lake Tahoe: A 25-year history of changes in the fertility, plankton, and fishery of an alpine lake. American Fisheries Society Symposium 9:30-38.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada, Bulletin 191:382. Ottawa, Ontario.

Rieman, B. E. 1977. Lake Pend Oreille limnological studies. Idaho Department of Fish and Game, Job Performance Report, Project F-53-R-12, Job IV-d. Boise.

Rieman, B. E. 1992. Kokanee salmon population dynamics-kokanee salmon monitoring guidelines. Idaho Department of Fish and Game, Job Performance Report, Project F-73-R-14, Subproject II, Study II. Boise.

Schoby, G. P., N. C. Wahl, and A. M. Dux. 2009. Lake trout spawning locations in Lake Pend Oreille, 2007. Idaho Department of Fish and Game, Annual Progress Report to Bonneville Power Administration, Contract Number 25744, Report Number 09-13, Portland, Oregon.

Stafford, C. P., J. A. Stanford, F. R. Hauer, and E. B. Brothers. 2002. Changes in lake trout growth associated with Mysis relicta establishment: a retrospective analysis using otoliths. Transactions of the American Fisheries Society 131:994-1003.

Syslo, J. M., C. S. Guy, P. E. Bigelow, P. D. Doepke, B. D. Ertel, and T. M. Koel. 2011. Response of non-native lake trout (*Salvelinus namaycush*) to 15 years of harvest in Yellowstone Lake, Yellowstone National Park. Canadian Journal of Fisheries and Aquatic Sciences 68:2132-2145.

Trippel, E. A. 1993. Relations of fecundity, maturation, and body size of lake trout, and implications for management in northwestern Ontario lakes. North American Journal of Fisheries Management 13:64-72.

Vidergar, D. T. 2000. Population estimates, food habits and estimates of consumption of selected predatory fishes in Lake Pend Oreille, Idaho. Master's thesis. University of Idaho, Moscow.

Volk, E. C., S. L. Schroder, and K. L. Fresh. 1990. Inducement of unique otolith banding patterns as a practical means to mass-mark juvenile Pacific salmon. American Fisheries Society Symposium 7:203-215.

Wahl, N. C., and A. M. Dux. 2010. Evaluation of lake trout spawning locations in Lake Pend Oreille, 2008. Annual Progress Report to Bonneville Power Administration, Contract Number 25744, Report Number 10-03, Portland, Oregon.

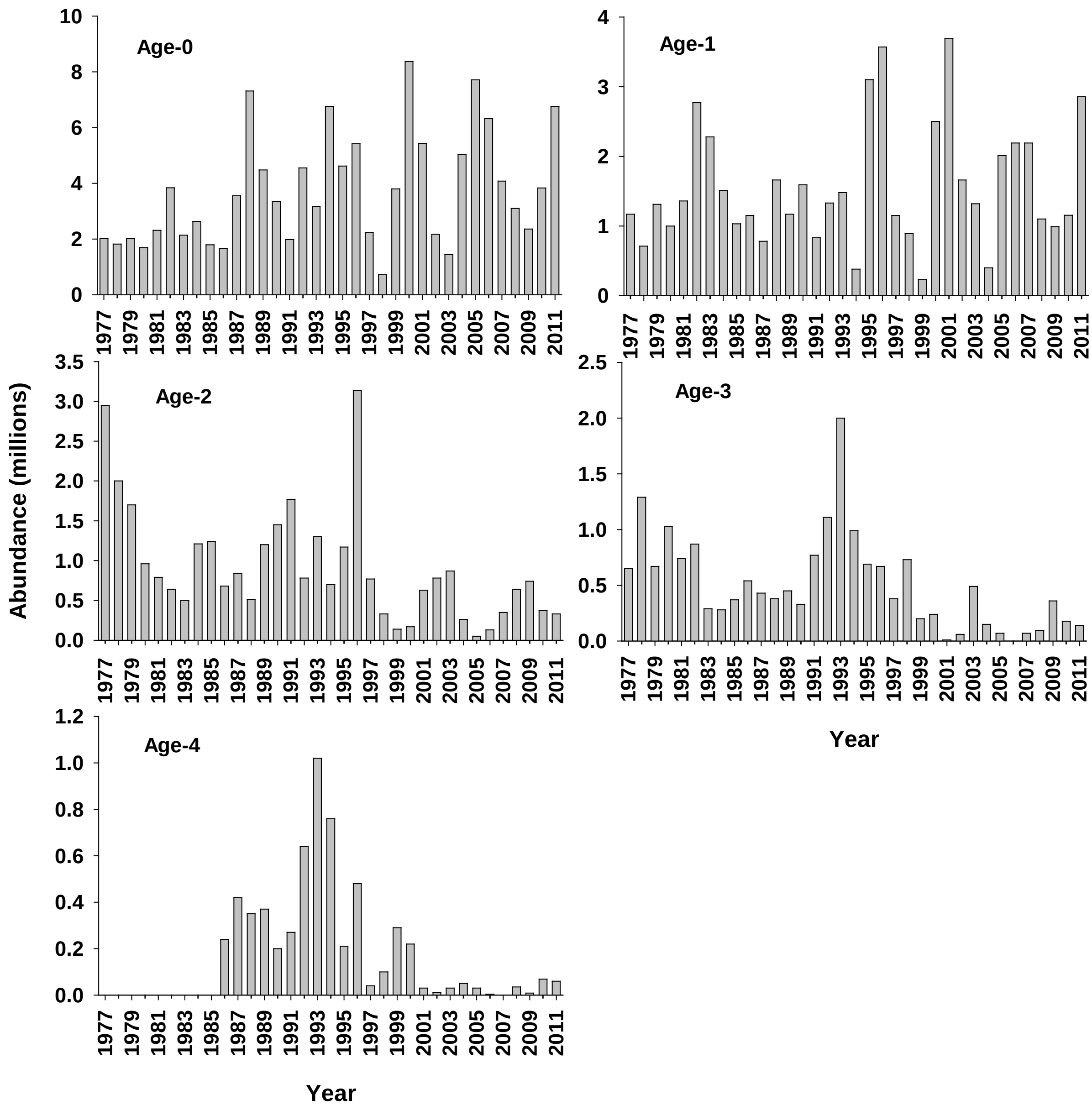
Wahl, N. C., A. M. Dux, W. J. Ament, and W. Harryman. 2010. Kokanee and rainbow trout research, Lake Pend Oreille, 2008. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Number 36475, Report Number 10-02, Portland, Oregon.

Wahl, N. C., A. M. Dux, W. J. Ament, and W. Harryman. 2011a. Lake Pend Oreille Research, 2009. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Number 41509, Report Number 11-08, Portland, Oregon.

Wahl, N. C., A. M. Dux, W. J. Ament, and W. Harryman. 2011b. Lake Pend Oreille Research, 2010. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Number 46612, Report Number 11-22, Portland, Oregon.

APPENDICES

Appendix A. Kokanee age-specific population estimates based on midwater trawling between 1978 and 2011. Age-3 and -4 kokanee were not separated prior to 1986.



Appendix B. 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 1/2 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 boat basin area.

Sunnyside

- From Sunnyside Resort go east approximately 1/2 km.

Garfield Bay

- Along docks at Harbor Marina on east side of bay.
- From the public boat ramp go southwest toward Garfield Creek. Cross Garfield Creek and proceed 1/4 km.
- Survey Garfield Creek up to road culvert.

Camp Bay

- Entire area within confines of Camp Bay.

Fisherman's Island

- Entire Island Shoreline - not surveyed since 1978.

Anderson Point

- Not surveyed since 1978.

Appendix C. Tag number, tag date, capture location, size and sex of lake trout with acoustic transmitters in Lake Pend Oreille, Idaho at-large during the 2011 contract period. Fate of fish was as of the end of February 2011; harvested fish were removed by either anglers (A) or the netters (N).

Tag ID	Date Tagged	Capture Method	Capture Location	Lake Section	Total Length (mm)	Weight (kg)	Sex	Number of Locations via Mobile Tracking	Fate of Fish	Date of Last Record (Tracked, Detected, or Harvested)
40800	5/18/2010	Angling	Granite Bay	North	772	5.14	U	10	Harvested (N)	10/10/2011
41000	4/30/2010	Angling	Longbeach	North	802	4.98	U	7	At-Large	10/9/2011
41100	4/14/2010	Gill Net	Lee’s Point	North	950	9.84	U	14	At-Large	10/9/2011
41400	4/7/2010	Gill Net	Lee’s Point	North	662	3.40	U	8	At-Large	9/18/2011
41600	4/14/2010	Gill Net	Lee’s Point	North	884	8.61	M	13	Harvested (N)	10/13/2011
41900	4/7/2010	Gill Net	Lee’s Point	North	695	3.78	F	7	Harvested (N)	9/28/2011
42200	4/30/2010	Angling	Off Clark Fork River	North	712	3.70	U	11	At-Large	9/19/2011
42300	5/1/2010	Angling	North of Whiskey Rock	South	625	2.35	U	10	Harvested (N)	10/4/2011
42400	5/6/2010	Gill Net	Capehorn	South	843	7.05	U	7	Harvested (N)	10/14/2011
43200	5/13/2010	Angling	South of Whiskey Rock	South	595	2.19	U	11	At-Large	10/26/2011
43300	5/14/2010	Angling	South of Cement Plant	South	650	2.46	F	8	Harvested (N)	9/26/2011
43400	5/12/2010	Angling	North of Capehorn	South	641	1.80	U	5	Harvested (A)	8/5/2011
43700	5/24/2010	Angling	North of Cedar Creek	South	705	3.17	U	11	At-Large	9/6/2011
43800	5/26/2010	Angling	North of Capehorn	South	786	5.33	U	10	At-Large	10/3/2011
43900	5/18/2010	Angling	Lakeview	South	851	6.27	U	12	At-Large	10/8/2011
44000	10/7/2010	Gill Net	Evans Landing	--	724	--	F	5	At-Large	10/30/2011
44100	10/7/2010	Gill Net	Evans Landing	--	917	--	F	8	At-Large	10/24/2011
44600	10/8/2010	Gill Net	Bernard Beach	--	690	--	F	7	At-Large	10/24/2011
44700	10/8/2010	Gill Net	Bernard Beach	--	816	--	M	6	At-Large	10/29/2011
44900	10/8/2010	Gill Net	Bernard Beach	--	817	--	M	5	At-Large	10/31/2011
45100	10/14/2010	Gill Net	Windy Point	--	870	--	F	2	At-Large	10/25/2011
45200	10/14/2010	Gill Net	Windy Point	--	872	--	F	5	At-Large	10/24/2011
45300	10/14/2010	Gill Net	Windy Point	--	912	--	M	7	At-Large	10/25/2011
45500	10/14/2010	Gill Net	Windy Point	--	872	--	F	2	At-Large	10/21/2011
46000	10/11/2011	Gill Net	Bernard Beach	--	796	--	F	0	At-Large	10/31/2011
46100	10/11/2011	Gill Net	Bernard Beach	--	743	--	F	0	At-Large	10/31/2011
46200	10/11/2011	Gill Net	Bernard Beach	--	866	--	M	0	At-Large	10/26/2011
46300	10/11/2011	Gill Net	Bernard Beach	--	930	--	F	1	At-Large	10/26/2011
46400	10/11/2011	Gill Net	Bernard Beach	--	890	--	F	1	At-Large	10/25/2011
46500	10/11/2011	Gill Net	Bernard Beach	--	834	--	M	1	At-Large	10/27/2011
46600	10/11/2011	Gill Net	Bernard Beach	--	669	--	M	1	At-Large	10/28/2011
46700	10/11/2011	Gill Net	Bernard Beach	--	857	--	F	1	At-Large	10/31/2011
46800	10/11/2011	Gill Net	Bernard Beach	--	925	--	F	1	At-Large	10/31/2011
46900	10/11/2011	Gill Net	Bernard Beach	--	724	--	M	0	At-Large	10/31/2011
47000	10/12/2011	Gill Net	Evans Landing	--	810	--	M	0	At-Large	10/25/2011
47100	10/12/2011	Gill Net	Evans Landing	--	698	--	M	0	At-Large	10/29/2011
47200	10/12/2011	Gill Net	Evans Landing	--	865	--	M	1	At-Large	10/25/2011
47300	10/12/2011	Gill Net	Evans Landing	--	815	--	M	0	At-Large	10/26/2011
47400	10/12/2011	Gill Net	Evans Landing	--	800	--	M	1	At-Large	10/30/2011
47500	10/12/2011	Gill Net	Evans Landing	--	817	--	M	0	At-Large	10/27/2011

Appendix C. Continued.

Tag ID	Date Tagged	Capture Method	Capture Location	Lake Section	Total Length (mm)	Weight (kg)	Sex	Number of Locations via Mobile Tracking	Fate of Fish	Date of Last Record (Tracked, Detected, or Harvested)
47600	10/12/2011	Gill Net	Evans Landing	--	904	--	M	1	At-Large	10/24/2011
47700	10/12/2011	Gill Net	Evans Landing	--	794	--	M	1	At-Large	10/25/2011
47800	10/12/2011	Gill Net	Evans Landing	--	858	--	F	1	At-Large	10/25/2011
47900	10/12/2011	Gill Net	Evans Landing	--	750	--	M	0	At-Large	10/26/2011
48000	10/19/2011	Gill Net	Windy Point	--	870	--	F	0	At-Large	10/24/2011
48100	10/14/2011	Gill Net	Windy Point	--	925	--	M	0	At-Large	10/14/2011
48200	10/19/2011	Gill Net	Windy Point	--	878	--	F	0	At-Large	10/30/2011
48300	10/19/2011	Gill Net	Windy Point	--	660	--	M	1	At-Large	10/30/2011
48400	10/19/2011	Gill Net	Windy Point	--	760	--	F	0	At-Large	10/26/2011
48500	10/14/2011	Gill Net	Windy Point	--	940	--	F	1	At-Large	10/25/2011
48600	10/14/2011	Gill Net	Windy Point	--	900	--	F	1	At-Large	10/25/2011
48800	10/14/2011	Gill Net	Windy Point	--	778	--	F	0	At-Large	10/31/2011
48900	10/14/2011	Gill Net	Windy Point	--	872	--	F	0	At-Large	10/29/2011

Prepared by:

Nicholas C. Wahl
Senior Fishery Research Biologist

Andrew M. Dux
Principal Fishery Research Biologist

William J. Ament
Senior Fishery Technician

William Harryman
Senior Fishery Technician

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

Daniel J. Schill
Fisheries Research Manager

Edward B. Schriever, Chief
Bureau of Fisheries