FISHERY RESEARCH

LAKE PEND OREILLE RESEARCH, 2019
LAKE PEND OREILLE FISHERY RECOVERY PROJECT

ANNUAL PROGRESS REPORT
January 1, 2019—December 31, 2019

Prepared by:

Pete Rust, Senior Fishery Research Biologist
Sean M. Wilson, Principal Fishery Research Biologist
Nicole G. Mucciarone, PSMFC Fishery Biologist
Ryan Hardy, Principal Fishery Research Biologist
Matthew P. Corsi, Principal Fishery Research Biologist
Jeff Strait, PSMFC Fishery Biologist
and
William H. Harryman, Senior Fishery Technician

IDFG Report Number 22-04
March 2022

LAKE PEND OREILLE RESEARCH 2019

LAKE PEND OREILLE FISHERY RECOVERY PROJECT

Annual Progress Report

January 1, 2019—December 31, 2019

By

Pete Rust
Sean M. Wilson
Nicole G. Mucciarone
Ryan S. Hardy
Matthew P. Corsi
Jeff Strait
and
William H. 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 Numbers 64992, 69290

IDFG Report Number 22-04
March 2022

TABLE OF CONTENTS

Page

INTRODUCTION

Lake Pend Oreille is a natural oligotrophic lake located in northern Idaho. It is the largest (36,000 ha) and deepest (>360 m) lake in Idaho. Historically, the lake provided important recreational fisheries for kokanee *Oncorhynchus nerka,* Bull Trout *Salvelinus confluentus*, Gerrard-strain Rainbow Trout *O. mykiss*, and westslope cutthroat trout *O. clarkii lewisi*. Lake Pend Oreille produced the current world record Bull Trout (32 pounds) and former world record Rainbow Trout (37 pounds). The Lake Pend Oreille fishery is one of the most popular fisheries in the state and has a high economic impact for surrounding communities (Bouwens and Jakubowski 2016).

Kokanee are the backbone of the Lake Pend Oreille fishery, historically supporting a fishery that generated over half of all angler effort and serving as the primary prey source for Bull Trout and Rainbow Trout. Kokanee were introduced in the 1930s by downstream dispersal from Flathead Lake, Montana. They quickly became established and provided an important fishery from the 1940s to the early 1970s (Simpson and Wallace 1982; Bowles et al. 1991). Recreational and commercial fisheries averaged over 1 million kokanee harvested annually from 1951 to 1965 (Simpson and Wallace 1982; Paragamian and Bowles 1995). Starting in the mid-1960s, the kokanee population rapidly declined, which at the time was thought to be a direct result of full drawdowns (11 feet) of the lake that reduced the quantity and quality of shoreline spawning habitat. Beginning in 1996, winter lake level manipulations designed to improve kokanee spawning success were implemented and evaluated. This strategy was believed to be working effectively for a number of years, but research later showed that fluctuations in water levels did not benefit kokanee recruitment (Whitlock et al. 2018). This same project showed that downwelling currents provide a survival advantage to incubating kokanee eggs (Whitlock et al. 2014). Using this new information, we implemented a spawning habitat enhancement project in Idlewilde Bay near the Farragut State Park boat ramp (Rust et al. 2019). We mechanically added suitable-sized spawning substrate in a shoreline reach that has downwelling currents present, but formerly had substrate too large for kokanee to use for spawning. Although the four-foot winter water level strategy has not benefited kokanee as intended, this approach has provided more flexibility for hydrosystem operations.

Another limiting factor for kokanee emerged in the late 1990s. Nonnative Lake Trout, which are voracious predators, became abundant as a delayed response to Mysid shrimp introduction (Ellis et al. 2011; Martinez et al. 2009; Schoen et al. 2012). The Lake Trout population was growing exponentially and nearly collapsed the kokanee population. This not only affects the kokanee fishery, but also had implications for Bull Trout recovery as Lake Trout and Bull Trout can directly compete for food (Guy et al. 2011). Kokanee are also a primary food resource for Gerrard-strain Rainbow Trout (Vidergar 2000; Clarke et al. 2005), which comprise the traditional trophy fishery in Lake Pend Oreille. Kokanee production in Lake Pend Oreille is also heavily influenced by *Mysis diluviana,* which directly competes with kokanee for food. To ensure that total predation does not exceed production and lead to kokanee population collapse (Corsi et al. 2019), an aggressive Lake Trout suppression program was initiated in 2006 to reduce their abundance. This program has demonstrated remarkable success, with the Lake Trout population now at low density and the kokanee population now at high density in response to effective predation management (Dux et al. 2019). Additionally, the rebound of kokanee allowed a harvest fishery to be re-opened in 2013 for the first time since 1999. This fishery has been sustained and is popular with anglers. However, continued, ongoing management is required to maintain ecosystem balance to conserve the diversity of the fish assemblage and these economically important fisheries.

While long-term sustainable management of the kokanee population as a keystone species remains the core goal of this project, some emerging issues related to the entire ecosystem require assessment. In particular, increasing densities of and potential predation by Walleye *Sander vitreus* and Northern Pike *Esox lucius* may affect the nearshore food web. Depletion of forage fish in the littoral areas has the potential to negatively impact Westslope Cutthroat Trout, Bull Trout, Rainbow Trout, and Smallmouth Bass *Micropterus dolomieu* as predators switch prey. Additionally, Walleye and Northern Pike occupy migratory corridors for adfluvial salmonids, especially the Clark Fork River. While trend information for Cutthroat Trout and Bull Trout do not currently suggest predation is a limiting factor, the abundance, distribution, and diet of Walleye and Northern Pike requires continued monitoring and evaluation.

Public support for the aggressive but highly successful predator suppression programs in Lake Pend Oreille has hinged on commitments to the public that we will work for the long-term sustainability of Westslope Cutthroat Trout, Bull Trout, kokanee, Rainbow Trout, and bass populations. This assemblage of sportfishes has been compatible in this system and currently produces world-class fishing opportunity. However, due to the diversity of apex predators in the system, the potential for predatory inertia to collapse the fishery remains a real risk. Therefore, the primary focus of this project continues to be science-based with adaptive predator management and robust monitoring of key fish populations.

STUDY AREA

Lake Pend Oreille is located in the northern panhandle region of Idaho (Figure 1). The Clark Fork River, located on the northeast portion of the lake, is the largest tributary. Outflow from the lake near Sandpoint forms the Pend Oreille River. 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 surface elevation high and stable at 628.7 m above mean sea level (MSL) during summer (June-September), followed by surface elevations of 626.4 m to 625.1 m during fall and winter. Littoral areas are limited and most shorelines are steeply sloped. Detailed maps of tributaries, landmarks, and shoreline areas referenced in this report can be found in Appendix A.

A diverse fish assemblage is present in Lake Pend Oreille. Native game fish include Bull Trout**,** Westslope Cutthroat Trout, and Mountain Whitefish *Prosopium williamsoni.* Native nongame fishes include Pygmy Whitefish *P. coulterii*, Slimy Sculpin *Cottus cognatus*, five cyprinid species, and two catostomid species. The most abundant nonnative game fish is kokanee (landlocked form of Sockeye Salmon) with both early-run (August-September spawn) and late-run (November-December spawn) strains present. Mature kokanee from both runs spawn in tributaries and the more numerous late-run kokanee also spawn along the lake shoreline. Other abundant nonnative game fish include Rainbow Trout, Lake Trout, Lake Whitefish *Coregonus clupeaformis*, and Smallmouth Bass. Less abundant nonnative game fishes include Northern Pike, Brown Trout *Salmo trutta*, Largemouth Bass *M. salmoides*, Yellow Perch *Perca flavescens*, and Walleye.

Historically, Bull Trout and Northern Pikeminnow *Ptychocheilus oregonensis* were the primary native predators 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. Maintain kokanee fishery that can support catch rates of 1.5 fish per hour and ages 1-3 kokanee abundances at or above five million fish to support growth of adfluvial Bull Trout and Rainbow Trout.

2. Suppress Lake Trout populations and maintain them at or below pre-1999 levels.

3. Maintain robust population of Rainbow Trout that consistently produces trophy class fish greater than 20 lbs.

4. Minimize predation and competition by Lake Trout, Walleye, and Northern Pike to ensure these factors do not become limiting for Bull Trout, Westslope Cutthroat Trout, Kokanee, Rainbow Trout, and bass.

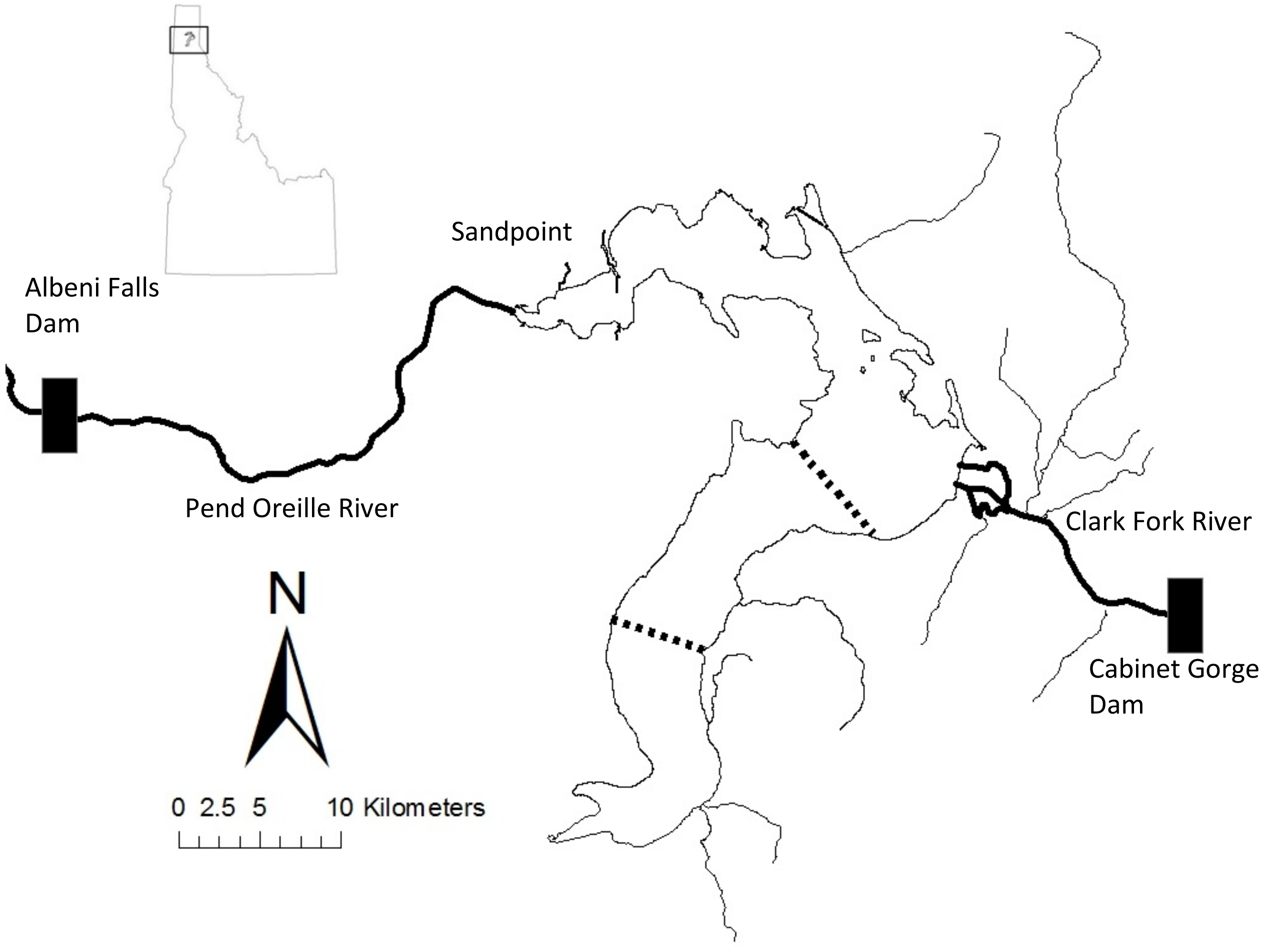

Figure 1. Map of Lake Pend Oreille, Idaho showing the three lake sections (separated by dashed lines) and primary kokanee spawning tributaries. The main inflow and outflow rivers (Clark Fork River and Pend Oreille River) and dams (Cabinet Gorge Dam and Albeni Falls Dam) are shown.

CHAPTER 1: LIMNOLOGICAL MONITORING

ABSTRACT

Limnological monitoring was conducted on Lake Pend Oreille during 2019 to characterize the limnology of the lake and monitor trends in zooplankton and mysid shrimp due to their importance in the food web. Thermal stratification began to establish in May, was well established in June, and remained so into September. Stratification was weak in October and absent by November. Cladoceran zooplankton were present in the epilimnion during stratification. The mean biomass of *Daphnia* consumable by kokanee was 5.1 µg/L from May through November. Biomass peaked in July (mean = 13.8 µg/L) and August (mean = 16.5 µg/L). The total density of mysid shrimp (mean = 225 individuals/L) continues to fluctuate at a post-crash level. The general decline in mysid shrimp appears to be due to a decrease in survival of young-of-the-year mysids, and is less likely due to recruitment. Continued limnological monitoring is crucial to understanding the Lake Pend Oreille food web and informing management of the fishery.

Authors:

Sean M. Wilson
Principal Fishery Research Biologist

Pete Rust
Senior Fishery Research Biologist

Matthew P. Corsi
Principal Fishery Research Biologist

William H. Harryman
Senior Fishery Technician

INTRODUCTION

Fish populations are shaped by complex ecological interactions, including environmental conditions, prey availability, competition, and predation. An in-depth understanding of an aquatic food web requires some basic knowledge of the limnology of the system. Basic physical factors, like temperature and dissolved oxygen (DO), play an important role in determining the distribution, growth, and survival of aquatic species. Plankton communities form the foundation of aquatic food webs. Zooplankton communities are regulated from the bottom up, by both the quantity and quality of food (phytoplankton) resources (Hessen 2008). At the same time, both zooplankton abundance and species composition are controlled from the top down by predation (Carpenter et al. 2001).

Zooplankton provide an important food resource for fish communities. Many fish species depend on zooplankton prey during early life stages, while others, such as kokanee, are obligate planktivores (Schneidervin and Hubert 1987). Species composition, size, and abundance are all important in determining the value of zooplankton as prey for kokanee (Klein et al. 2020; Wilson et al. 2021). Older kokanee depend on large cladocerans as a prey source (Klein et al. 2020), and large *Daphnia* are particularly important (Johnson and Martinez 2012; Wilson et al. 2021). Understanding the factors that influences zooplankton communities, and the size and abundance of large cladocerans, is critical to understanding kokanee production.

Mysid shrimp were introduced to Lake Pend Oreille in the 1960s and have had broad influences on the food web (Bowles et al. 1991). Mysids exert strong top-down control on zooplankton communities and reduce the availability of large cladocerans (Rieman and Falter 1981; Ellis et al 2011), which are an important prey for adult kokanee (Klein et al. 2020). Furthermore, mysids provide an abundant prey source for juvenile Lake Trout, thereby eliminating a recruitment bottleneck and causing a subsequent increase in Lake Trout abundance (Ellis et al. 2011). Competition from mysids limits the productivity of the kokanee population and the amount of predation it can withstand (Corsi et al. 2019). Monitoring trends in mysid abundance is crucial to managing the Lake Pend Oreille fishery and ultimately understanding drivers of the mysid population.

An understanding of how the limnology of Lake Pend Oreille influences the food web is important for the effective management of the lake and fishery. The goal of the limnological monitoring component of this project is to characterize the limnological conditions, plankton communities, and mysid population in order to provide information needed to understand how the food web functions. These data will be used to provide trends in the population of important species, such as mysids and large cladocerans. They will further provide a basis for future needs in modeling ecological interactions.

METHODS

Sampling Design

Limnological surveys were conducted on a monthly basis from May through November. Five sites were sampled in each of three lake sections, for a total of 15 sites throughout the lake (Figure 2). However, sampling could not be conducted effectively during excessive wind. Some sites were not sampled in a given month due to prolonged periods of wind during the portion of the month that sampling was scheduled. A summary of the number of sites sampled each month can be found in (Table 1).

Physical Limnology

Profile data for water temperature, dissolved oxygen (DO), and pH were recorded with a Hydrolab® HL4 sonde configured with a 200 m depth sensor, temperature sensor, luminescent dissolved oxygen (LDO) sensor, and pH sensor with standard reference. The HL4 was programed to record data at two s intervals and was connected to a downrigger with 120 m of cable. The instrument was then lowered at a speed ≤0.3 m/s for the first 100 m, and then increased to a speed ≤2 m/s until reaching 120 m or the bottom. The HL4 was then retrieved and the data downloaded and exported for analysis. If the HL4 was not operational, water temperature and DO were recorded at the surface, 1 m, and every even m to 60 m using an YSI Pro20 with a polarography DO sensor.

Secchi depths were measured from the shaded side of the boat using a standard 20 cm Secchi disc. The re-appearance depth was recorded to the nearest 0.1 m, and observers did not wear sunglasses.

Photosynthetically active radiation (PAR) profile data were recorded with a LI-COR® LI-1500 data logger. The logger recorded 15 s averages taken concurrently with a model LI-192SA underwater quantum sensor and a LI-190R quantum sensor for dry measurements. Measurements were taken at the surface, and every m until the wet measurement dropped below 1% of the surface measurement, or 20 m.

Compensation depth (CD) is the depth where PAR intensity is 1% of the light intensity at 0 m. Before calculating compensation depth, the PAR intensity at depth was adjusted according to the ratio of the concurrent air measurement divided by the air measurement concurrent with the surface reading. Compensation depths were then calculated from the adjusted light intensity profiles by transforming the data as follows:

$$x = Ln\left[100\left(\frac{I_D}{I_S}\right)\right]$$

Where: Ln = natural logarithm
I_D = light intensity at depth
I_S = light intensity at 0 m

A linear model was fitted using the transformed data as the independent variable and the depth (m) at which the measurement was taken as the dependent variable. The resulting equation was solved for x = Ln(1) = 0 to determine the compensation depth.

Biological Limnology

Zooplankton were captured using a Wisconsin style net with a 0.5 m diameter opening and 80 µm mesh. When operational, an Ocean Test Equipment electronic flowmeter (model EF 325) was mounted across the net opening. To reset the meter at depth, a magnet was affixed over the reset position using a rubber band. A length of braided fishing line was attached to the magnet and a release block attached to the rope for retrieving the net. The release block was set to hold the net above the bridle, effectively shortening the line to the bridle. The net was slowly lowered to a depth of 18.3 m. A messenger was then used to trip the release, lengthening the retrieval line, and pulling the magnet free from the reset point on the flow meter. The net was then retrieved at a speed of approximately 0.5 m/s. After retrieving the net, the number of revolutions on the flow meter was recorded. Plankton were rinsed down the net into the collection bucket.

The bucket was swirled to remove excess water, and then the contents were poured through an 80 µm mesh sieve to remove the remainder of the lake water. Plankton were then rinsed into a collection jar and preserved with 95% ethanol.

Zooplankton samples were sent to Aquatic Eco-Solutions for processing. Counts were performed following the methods from Britton and Greeson (1987). Density was estimated as the expanded number of each taxa in the sample divided by the volume of water sampled. The volume was calculated as a cylinder with the diameter of the net and height of the tow length. Total length was measured for up to 20 *Daphnia* and 20 *Bosmina* from each sample using an ocular micrometer.

The weights of individual *Daphnia* were calculated using the following formula (McCauley 1984):

$$lnw = lna + b \times lnL$$

Where: *lnw* = natural log of weight in µg
lna = estimated intercept
b = estimated slope
lnL = natural log of length in mm

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

lna = 2.64
b = 2.54

Biomass was calculated by multiplying the mean weight of *Daphnia* in a sample by the density. *Daphnia* ≥0.8 mm were considered consumable by kokanee (Wilson and Corsi 2016). The density of consumable *Daphnia* was estimated by multiplying the density of all *Daphnia* by the proportion that were consumable. The biomass of consumable *Daphnia* was calculated by multiplying the mean weight of consumable *Daphnia* by the density of consumable *Daphnia*.

Mysids shrimp were sampled during June 4-6, 2019. All sampling occurred at night during the dark phase of the moon, when mysid shrimp are found at shallower depths (Boscarino 2009). We collected mysids at eight randomly chosen sites per lake section (24 sites total) using a 1 m hoop net. Further details on methods can be found in Wahl et al. (2011a).

During laboratory analysis, mysid shrimp were classified and enumerated as either young-of-the-year (YOY) or immature and adults (IA). We estimated density by the number of mysid shrimp enumerated in each sample per volume of water filtered. We calculated a mean density with 90% confidence intervals for each portion of the population. Confidence intervals were estimated similar to those used for kokanee abundance above.

Data Analysis

Weighted means were reported for each metric to account for unequal sample sizes in some months and lake sections. Annual means for lake sections, used for comparative purposes, did not include months for which data were not available for one or more sections. Monthly means, and the whole-lake annual mean, included all available data.

The magnitude of the change in mysid abundance post 2011 was assessed by first calculating the mean abundance for the period from 2003 to 2010 (pre-crash), and 2011 through

2019 (post-crash). These means were then used to calculate to percent decline from the first period to the second. Confidence intervals for the decline were calculated using bootstrap techniques.

To assess changes in the survival of YOY, the abundance of IA was plotted as a function of YOY abundance during the previous year. The data were fit to simple linear models, both with and without period as a covariate, and the fit of each was compared using Akaike's Information Criteria corrected for sample size (AIC_c).

To assess the relative importance of YOY recruitment for mysis, Ricker spawner/recruit (S/R) models were fit using the abundance of YOY in a given year and the abundance of IA during the previous year. Two models were fit to the entire dataset, both with and without period as a covariate, and the fit was compared using AIC_c.

RESULTS

Physical Limnology

Mean water temperature at approximately 1 m increased from 11.2°C in May, to a peak of 20.8°C in August, and then decreased to a low of 5.0°C in December (Figure 3). Mean temperatures did vary between sections by more than 0.6°C with the exception of June. In June, Section 3 was the warmest (mean = 18.2°C), followed by section 2 (mean = 14.7°C) and section 1 (mean = 13.4°C).

A thermocline was detected in five of 15 sites sampled in May, 43 of 45 sites sampled from June through September, 3 of 8 sites sampled in October, and none after then. During maximum stratification (June-September), the mean thermocline depth was 11.9 m (Table 2). Mean depth decreased from May (mean = 8.5 m) through July (mean = 7.9), then increased through September (mean = 11.7 m), and was highest in October (mean = 21.8) when present. During this period, thermocline depths tended to be deepest in section 2 (mean = 14.1 m), shallower in section 1 (mean = 11.19 m), and shallowest in section 3 (mean = 10.6 m).

Lake Pend Oreille remained well oxygenated throughout the year. At depths ≤50 m, the mean DO concentration was 10.6 mg/L, and all DO readings were ≥8.1 mg/L. The mean DO concentration at these depths was similar from May through July and November through December (means = 11 mg/L), and from August through October (mean = 10 mg/L). DO concentrations were typically similar throughout the lake at a given time, with the exception that DO was lower in section 3 (mean = 10.4 mg/L) than sections 1 and 2 (mean = 11.3 mg/L) in June.

The mean pH at depths ≤50 m deep was 7.9 (Table 3). The pH lowest in June (mean = 7.6), higher in May and August (means = 7.8), higher still in November (mean = 8.0), and highest in July (mean = 8.2). The pH tended to decrease with depth (Figure 4). Annual means for depths >11 m were ≥8, whereas the annual means for depths below 11 m were ≤8. However, the depth of this threshold also changed seasonally, with pH values ≥8 at depths ≥8 m in May, 7 m in June, 21 m in July, and 35 m in November. Mean pH was ≤8 for all depths in August. The mean pH was similar for all three lake sections (range = 7.7-8.0).

The mean annual Secchi depth for the entire lake was 6.7 m (Table 4). Secchi depth was lowest in June (mean = 3.1 m), increased through August (mean = 8.5 m), decreased to <8 m from September through November, and was greatest in December (mean = 10.0 m). Secchi depths were greatest in section 1 (mean = 7.1 m), less in section 2 (mean = 6.8 m), and lowest in section 3 (mean = 6.1 m).

The mean annual CD for the entire lake was 16.5 m (Table 5). CD was lowest in May (mean = 10.8 m), increased through September (mean = 19.5 m), decreased through November, and was greatest in December (mean = 26.7 m). CD was greatest in section 2 (mean = 17.6 m), less in section 1 (mean = 16.7 m), and lowest in section 3 (mean = 15.2 m).

Biological Limnology

Zooplankton

The total density of zooplankton varied seasonally, and to a lesser extent, spatially (Table 6). Excluding July, due to the lack of data from section 2, annual means were highest in section 2 (mean = 22.4 individuals/L), followed by section 1 (mean = 19.1 individuals/L), and lowest in section 3 (mean = 17.2 individuals/L). Mean densities for the whole lake were similarly low in May (mean = 15.0 individuals/L) and June (mean = 16.9 individuals/L), highest in July (mean = 63.6 individual/L, no data from section 2), and declined steady through November (mean = 10.6 individuals/L).

The zooplankton community was dominated by cyclopoid copepods, which accounted for 69% of all samples, and calanoid copepods, which accounted for 24% (Figure 5). The remainder of the zooplankton community was composed of cladocerans. *Bosmina* accounted for 3% of all samples, followed by *Diaphanosoma*, which accounted for 2%. *Daphnia* accounted for 1% of all samples. Cladocerans were extremely rare in May, accounting for <1% of the zooplankton community. The proportion of cladocerans increased in June (3%), and peaked in July (11%), then declined steadily through November (<1%).

The lake-wide mean density of *Daphnia* was low in May (mean = 0.003 individuals/L), peaked in July (mean = 2.1 individuals/L; no section 2 data; Table 6), and declined steadily through October (mean = 0.008 individuals/L; Table 6). No *Daphnia* were found in November samples. Excluding July samples, *Daphnia* densities were similar in section 1 and 3 (means = 0.2 individuals/L), and lowest in section 2 (mean = 0.1 individuals/L).

The biomass of consumable *Daphnia* exhibited similar patterns to density (Table 6). No consumable *Daphnia* were sampled in May. Mean biomass was low in June (mean = 0.08 µg/L), increased in July (mean = 13.8 µg/L), peaked in August (mean = 16.5 µg/L), and declined steadily through October (mean = 0.03 µg/L). No consumable *Daphnia* were sampled in November. Mean biomass of consumable *Daphnia* (excluding July samples) was highest in section 1 (mean = 4.7 µg/L), similar in section 2 (mean = 4.4 µg/L), and lowest in section 2 (mean = 3.3 µg/L).

Mysis

The lake-wide mean density of mysids was 225 individuals/m^2 (90% CI of $\pm$ 14.3%) in June of 2019 (Table 7). The mean density of YOY mysids was 125 individuals/m^2 (90% CI of $\pm$ 18.6%), while the density of immature and adults was 99 individuals/m^2 (90% CI of $\pm$ 15.3%). The mean density of total mysids was highest in section 2 (mean = 264 individuals/m^2), followed by section 1 (mean = 222 individuals/m^2), and lowest in section 3 (mean = 191 individuals/m^2).

The mean densities of all age classes of mysids were lower post-crash than pre-crash (Figure 6). The mean density of YOY mysids decreased by 60% (95% CI = 52–67%), from pre-crash (mean = 422 individuals/m^2) to post-crash (mean = 168 individuals/m^2). The mean density of IA mysids decreased by 72% (95% CI = 67–73%), from pre-crash (mean = 278 individuals/m^2) to post-crash (mean = 78 individuals/m^2). The mean density of total mysids decreased by 65% (95% CI = 60–69%), from pre-crash (mean = 700 individuals/m^2) to post-crash (mean = 246 individuals/m^2, Figure 7).

The decline in mysids appears to be primarily due to a reduction in survival from YOY to IA, rather than a shift in the S/R function. The density of IA was more dependent on period than the density of YOY the previous year. The most parsimonious model (AIC_c = 188.9) included period and an intercept, but not YOY density. This model predicts that survival is generally higher during the pre-crash period, but inconsistent within periods.

Median survival was 77% for the pre-crash period and 47% for the post-crash period (Figure 8). The model including YOY and YOYx period predicted that survival would be constant during each period, but higher during the pre-crash period (Figure 7). This was the next best model (AIC_c = 196.1), but not well supported compared to the best model. The model with YOY alone predicted constant survival regardless of period (Figure 7), and had the least support (AIC_c = 205.8). In contrast, the S/R function may not have shifted between periods (Figure 9). The most parsimonious S/R model did not include period (AIC_c = 57.4). However, there is still support for the second best model, which included period (AIC_c = 58.1), so the role of recruitment is less certain. Of further note, while YOY densities overlapped between periods (Figure 7), IA densities were always lower during the post-crash period (Figure 9).

DISCUSSION

In an earlier study, Lake Pend Oreille was characterized as mesotrophic in terms of water chemistry and primary production, but oligotrophic in terms of plankton communities and hypolimnetic DO levels, likely because of its depth (Rieman 1976). The lake is still characterized by DO levels that are generally near saturation, typical of deep oligotrophic lakes. Surface pH was similar to measurements taken in 1974 and 1975, and consistent with mesotrophic conditions (Rieman 1976). Secchi depth was indicative of oligotrophic conditions most of the year, but mesotrophic during May and June. Secchi depths for the north end of the lake were negatively influenced by run-off from the Clark Fork River during this time, but were equally low in the southern end of the lake in June due to phytoplankton. Anecdotally, zooplankton was difficult to sieve during these months due to the abundance of large phytoplankton that did not easily pass through the mesh. *Asterionella*, a colonial diatom, increased in abundance in 1975, concurrent with an increase in mysid abundance (Rieman 1976). Because *Asterionella* is difficult for large cladocerans like *Daphnia* to consume, it is not grazed down effectively. The dominance of large, inedible phytoplankton will likely result in trophic inefficiencies, which could limit fish production. To assess this, additional data on the composition of the phytoplankton community need to be collected, particularly during this period.

Mysid shrimp have broad effects on the Lake Pend Oreille food web (Bowles et al. 1987; Klein et al. 2020). The abundance of mysid shrimp has historically undergone cycles similar to other western lakes following their introduction (Beattie and Clancey 1991; Richards et al. 1991). However, a dramatic decline in mysid abundance began after 2011, with a nadir in YOY abundance occurring in 2012, followed by a low in IA abundance in 2013 (Wahl et al. 2015a). Afterwards, mysid abundance again cycled, but at a much lower long-term mean (Rust et al. 2020). Modeling suggests that the decline in mysid abundance is a result of lower survival from YOY to IA. While highly variable, survival from YOY to IA was significantly lower during the post-crash period. It is difficult to discern pre-crash and post-crash differences in the stock/recruitment function because adult abundance was distinctly different between these periods. It is most likely that recruitment was stabile across both periods, although, there is some evidence of a shift. It should also be noted that these models are imperfect, as they used combined densities of IA, rather than survival from YOY to immature, and production of YOY from adults. Therefore, the possibility that declines in the mysid abundance are caused in part by poor recruitment should not be entirely discounted. Still, efforts should be concentrated on investigating factors that affect survival of YOY to better understand mysid dynamics in Lake Pend Oreille.

Cladocerans are an important prey resource for adult kokanee (Klein et al. 2020). In particular, *Daphnia* biomass has been shown to be the proximal driver of kokanee growth in Dworshak Reservoir, Idaho (Wilson and Corsi 2016) and a good predictor of kokanee length in Lake Granby, Colorado (Johnson and Martinez 2012). The mean length of age-3 kokanee in Lake Pend Oreille increased post-crash despite an increase in kokanee abundance. This is likely due to an increase in cladoceran prey concurrent with the decline in mysids (Klein et al. 2020). Continued monitoring of the zooplankton community will provide valuable data to understand how the kokanee population will respond to changes to the ecology of the system.

Temperature is a critical environmental factor in determining the distribution of organisms in aquatic systems. The formation of a strong thermocline, along with the depth and temperature of the epilimnion, have been shown to limit the distribution of mysid shrimp, and consequently the abundance and distribution of cladocerans (Martinez and Bergersen 1991). Temperature data are also necessary for a variety of purposes, such as bioenergetics modeling and some methods of estimating mortality for fish species. Long-term datasets for temperature and other key environmental metrics are critical for improving our knowledge of the Lake Pend Oreille ecosystem.

RECOMMENDATIONS

1. Continue to monitor basic limnological metrics to build datasets that can be used to answer questions about the Lake Pend Oreille food web and direct management actions.

2. Continue to monitor mysid shrimp abundance to determine if the collapse documented in 2012 persists.

3. Research factors that could potentially affect survival of YOY mysid shrimp and begin monitoring trends of these factors if not already being done.

Table 1. The number of sites sampled by lake section and month for several limnological parameters. Parameters include water temperature (Temp), dissolved oxygen (DO), and pH profiles, Secchi depth, and zooplankton (Zoop). No pH data was collected in the months of September, October, and December due to problems with the instrument.

	Temp, DO & pH			Secchi			Zoop		
Month	Sec 1	Sec 2	Sec 3	Sec 1	Sec 2	Sec 3	Sec 1	Sec 2	Sec 3
May	5	5	5	5	5	5	5	5	5
Jun	5	5	5	5	5	5	5	5	5
Jul	2	0	5	2	0	5	2	0	5
Aug	5	5	5	5	5	5	5	5	5
Sep	4	2	2	5	2	2	5	2	2
Oct	3	2	3	3	2	3	3	2	3
Nov	2	2	2	0	2	3	0	2	3
Dec	1	1	1	1	1	1	1	1	1

Table 2. The mean depth (m) of the thermocline, when detected, for each section of Lake Pend Oreille, and the whole lake. Months and sections for which no data were available are designated with ND. Months and section for which temperature data were available, but there was no thermocline were designated as NT. For comparative purposes, annual means were calculated for each section using only data from months for which data was available for all three sections. Means were weighted to give each section equal weight within a month and each month equal weight for the year.

Month	Sec 1	Sec 2	Sec 3	Lake
May	22.7	5.4	4.5	10.9
Jun	5.9	13.0	7.5	8.8
Jul	6.6	ND	9.2	7.9
Aug	7.0	9.4	11.0	9.1
Sep	8.9	14.6	14.4	12.7
Oct	NT	28.0	15.5	21.8
Annual	11.1	14.1	10.6	11.9

Table 3. The mean pH of the upper 50 m Lake Pend Oreille by month, lake section, and the whole lake. Months and sections for which no data were available are designated with ND. For comparative purposes, annual means were calculated for each section using only data from months for which data was available for all three sections. Means were weighted to give each section equal weight within a month and each month equal weight for the year.

Month	**Sec 1**	**Sec 2**	**Sec 3**	**Lake**
May	8.0	7.8	7.6	7.8
Jun	7.5	7.7	7.6	7.6
Jul	8.3	ND	8.0	8.2
Aug	7.4	8.3	7.8	7.8
Nov	8.0	7.9	8.0	8.0
Annual	7.7	8.0	7.8	7.9

Table 4. Weighted mean Secchi depth (m) for each section of Lake Pend Oreille, and the whole lake, by month. Months and sections for which no data were available are designated with ND.

Month	**Sec 1**	**Sec 2**	**Sec 3**	**Lake**
May	5.0	4.1	2.6	3.9
June	3.0	3.2	2.9	3.1
July	5.7	ND	6.4	6.1
Aug	9.2	8.2	8.1	8.5
Sept	8.0	6.0	6.7	6.9
Oct	7.8	8.3	7.1	7.7
Nov	ND	8.9	6.4	7.6
Dec	10.0	11.0	9.0	10.0
Annual	7.1	6.8	6.1	6.7

Table 5. Mean compensation depth (m) for each section of Lake Pend Oreille, and the whole lake, by month. Months and sections for which no data were available are designated with ND. For comparative purposes, annual means were calculated for each section using only data from months for which data was available for all three sections. Means were weighted to give each section equal weight within a month and each month equal weight for the year.

Month	**Sec 1**	**Sec 2**	**Sec 3**	**Lake**
May	12.1	10.7	9.6	10.8
June	14.3	11.2	10.5	12.0
July	14.8	ND	18.3	16.6
Aug	15.5	16.4	14.9	15.6
Sept	19.1	20.2	19.1	19.5
Oct	14.9	14.6	15.2	14.9
Nov	16.4	17.6	13.5	15.8
Dec	24.2	32.6	23.3	26.7
Annual	16.7	17.6	15.2	16.5

Table 6. Mean density of total zooplankton, mean density of Daphnia, and biomass of Daphnia large enough to be consumed by kokanee (≥0.8 mm TL). All metrics presented by month, and for each lake section and the whole lake. Months and sections for which no data were available are designated with ND. For comparison, annual means were calculated for each section using only data for month in which all sections were sampled. Means were weighted to give each section equal weight within a month and each month equal weight for the year.

Total zooplankton density				
Month	Sec 1	Sec 2	Sec 3	Lake
May	11.1	26.1	7.9	15.0
Jun	17.5	17.9	15.4	16.9
Jul	85.8	ND	41.3	63.6
Aug	39.1	38.2	32.0	36.4
Sep	23.9	27.3	23.0	24.7
Oct	13.6	13.8	13.4	13.6
Nov	9.1	11.0	11.7	10.6
Annual	19.1	22.4	17.2	25.8
Daphnia density				
Month	Sec 1	Sec 2	Sec 3	Lake
May	0.0	0.0	0.0	0.0
Jun	0.0	0.0	0.0	0.0
Jul	2.3	ND	1.8	2.1
Aug	1.1	0.6	0.6	0.8
Sep	0.1	0.2	0.5	0.3
Oct	0.0	0.0	0.0	0.0
Nov	0.0	0.0	0.0	0.0
Annual	0.2	0.1	0.2	0.4
Consumable *Daphnia* biomass				
Month	Sec 1	Sec 2	Sec 3	Lake
May	0.0	0.0	0.0	0.0
Jun	0.1	0.0	0.1	0.1
Jul	13.8	ND	13.8	13.8
Aug	21.6	13.1	14.9	16.5
Sep	0.8	2.1	12.6	5.2
Oct	0.1	0.0	0.0	0.0
Nov	0.0	0.0	0.0	0.0
Annual	3.8	2.5	4.6	5.1

Table 7. Mean density of mysis shrimp (shrimp/m^2) for three lake sections and the lake-wide mean. Mean densities are given for young-of-the-year (YOY) mysis only, immature and adult (IA) mysis only, and all age classes combined (Total).

	Sec 1	**Sec 2**	**Sec 3**	**Lake**
YOY	129	154	96	125
IA	94	110	94	99
Total	222	264	190	225

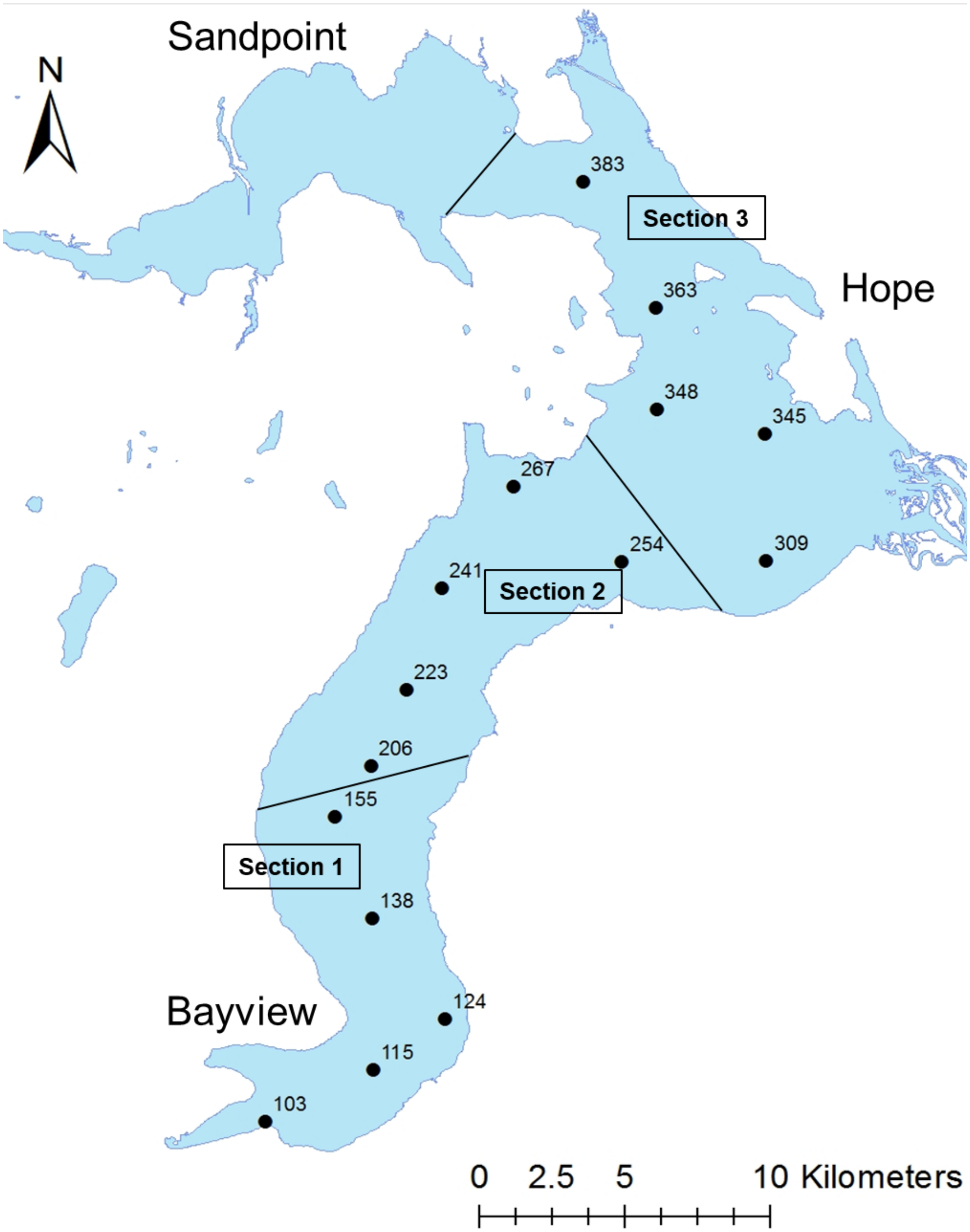

Figure 2. Map of Lake Pend Oreille showing 15 sites used for limnological sampling in 2019.

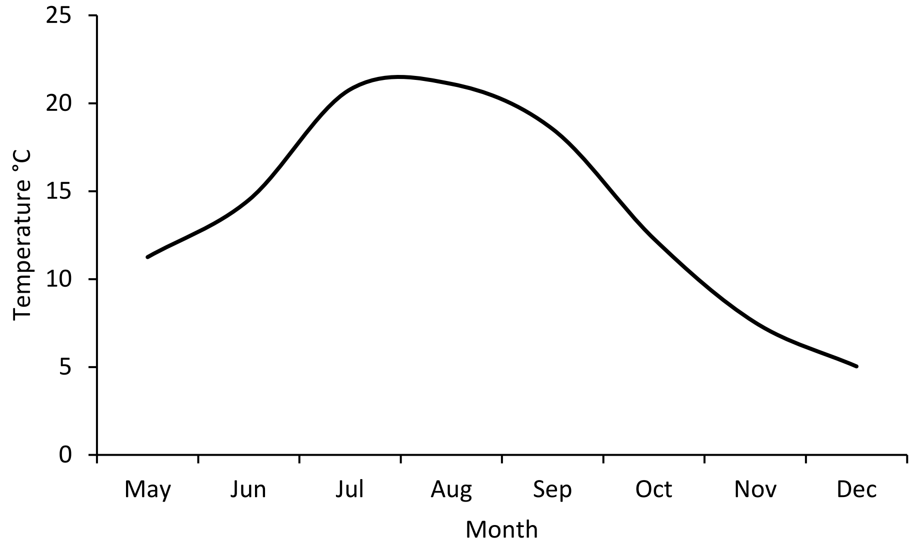

Figure 3. Mean water temperature (°C) at a depth of 1 m for Lake Pend Oreille.

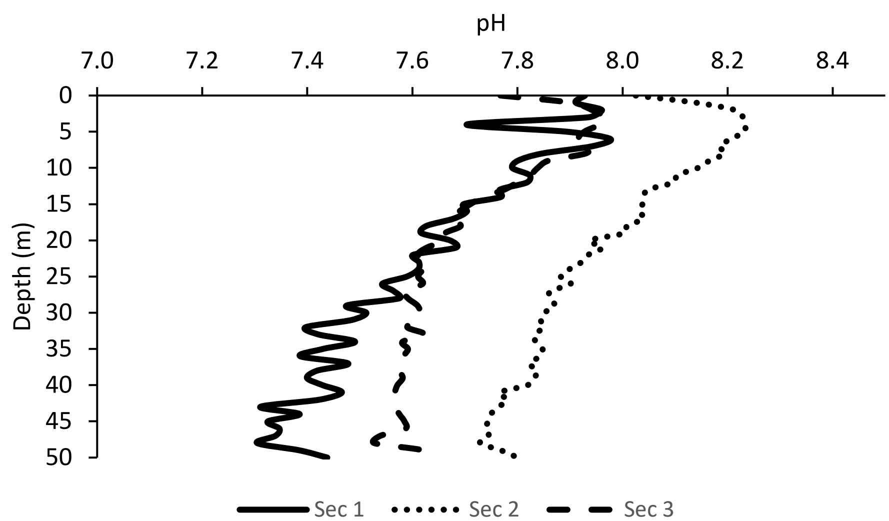

Figure 4. Profiles of mean pH by depth for Lake Pend Oreille by lake section.

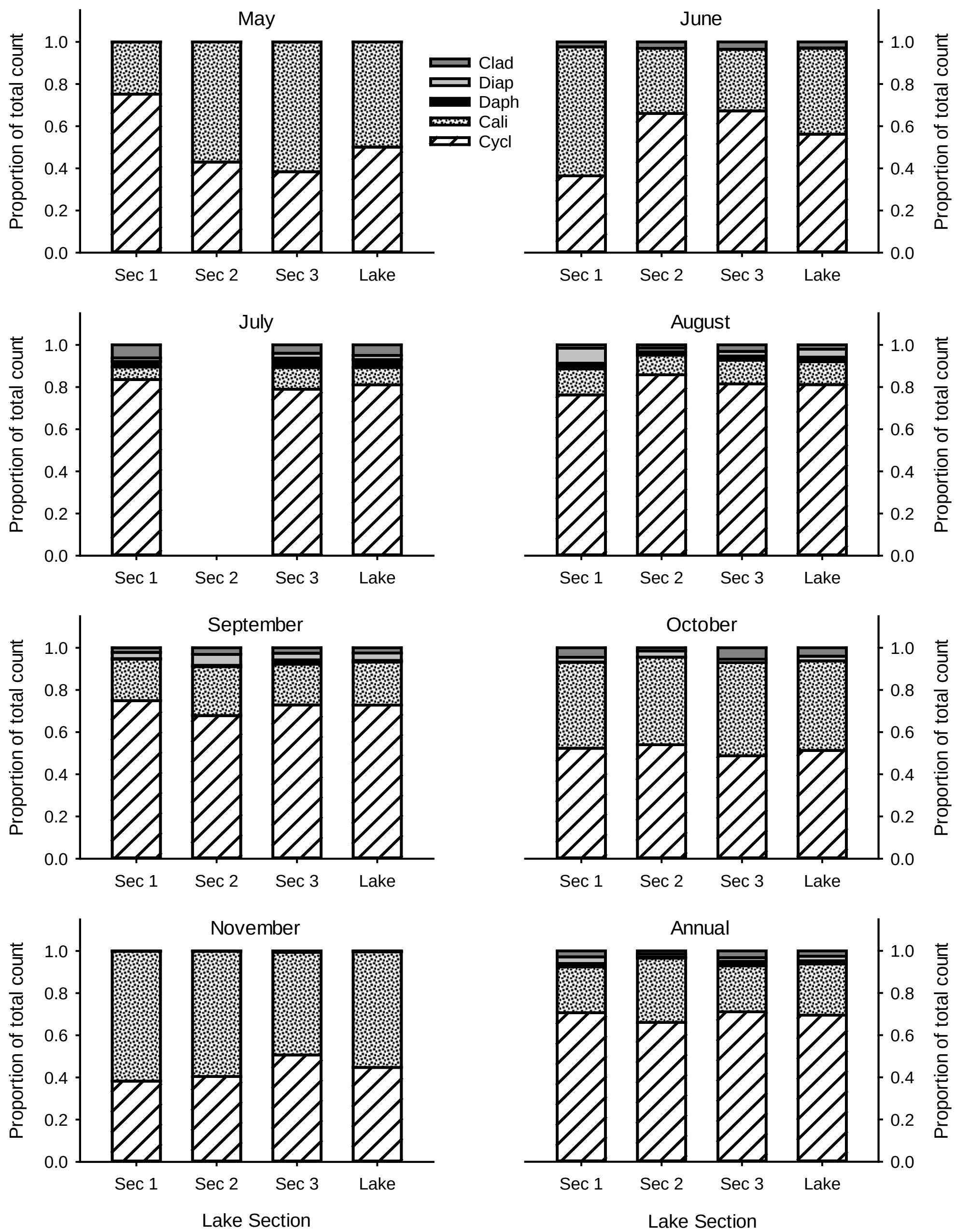

Figure 5. The proportion of the zooplankton community represented by cyclopoid copepods (Cycl), calinoid copepods (Cali), Daphnia (Daph), Diaphanosoma (Diap), and other cladocerans (Clad). Composition is shown separately for each of three lake sections, and the entire lake, by month from May through November.

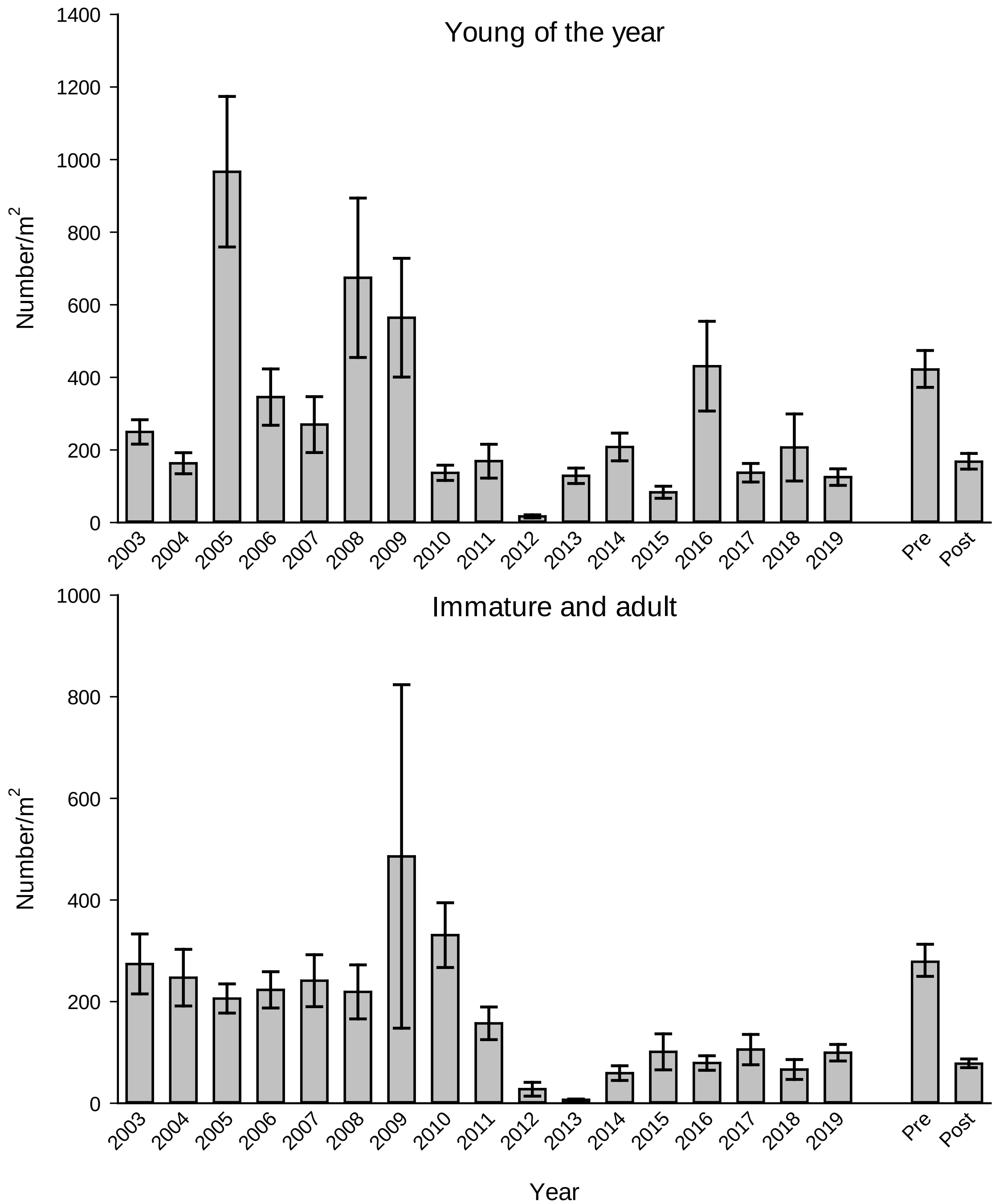

Figure 6. Mean densities (number/m^2) of mysis shrimp estimated from surveys conducted within five days of the new moon in June, along with means for pre-crash (Pre, prior to 2011) and post-crash (Post, 2011 and after). Error bars show 95% confidence intervals.

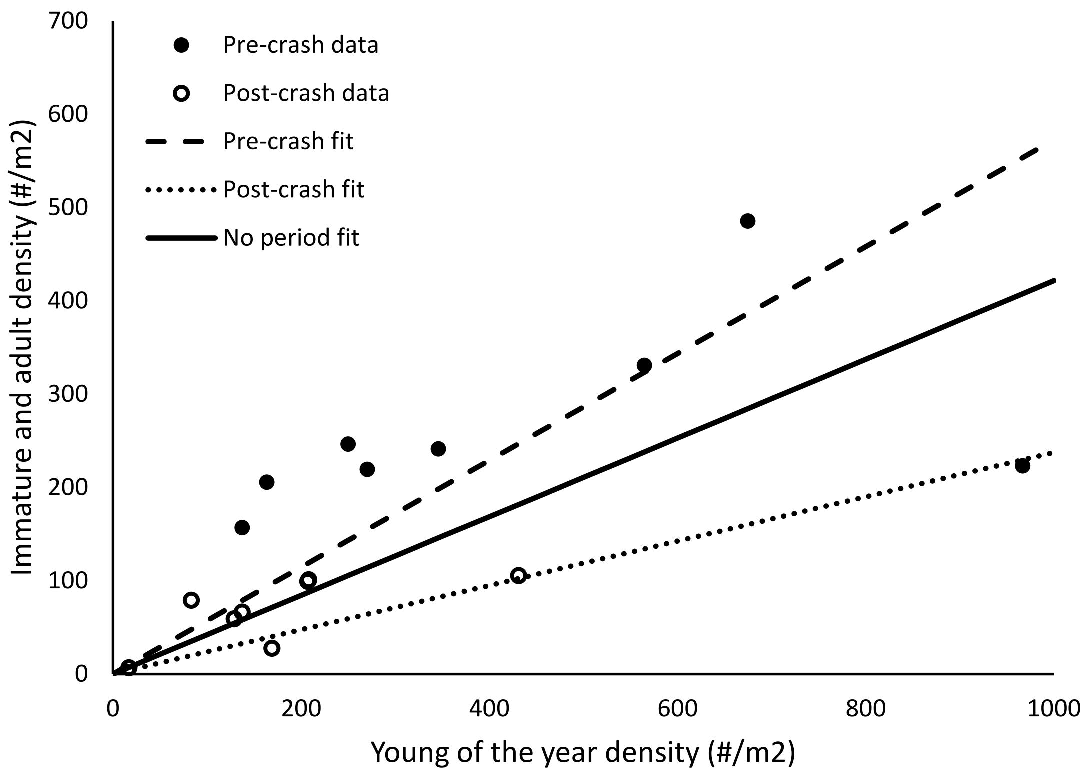

Figure 7. Mean density of immature and adult mysis plotted as a function of the density of young-of-the-year the previous year. Linear models were fitted to the dataset as a whole, and using period (pre,post-crash) as a covariate.

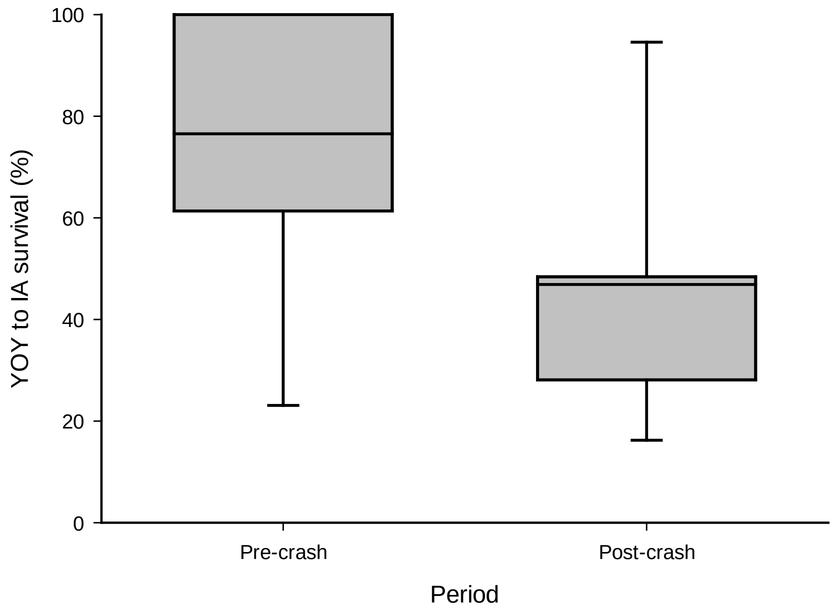

Figure 8. Distributions of percent survival of mysid shrimp from YOY to IA in Lake Pend Oreille during the pre-crash (prior to 2011) and post- crash (after 2011) periods.

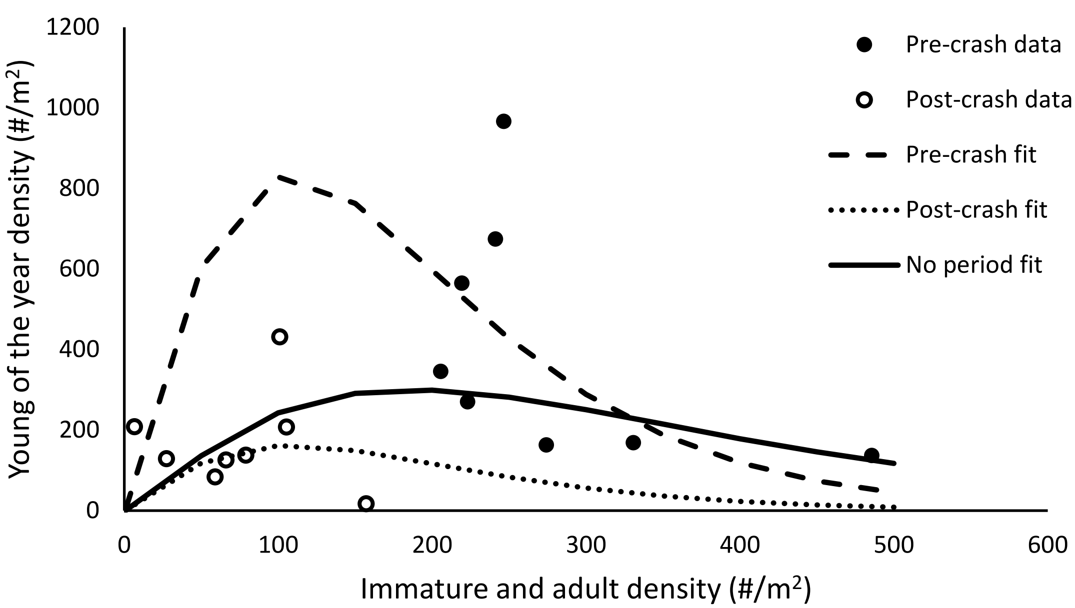

Figure 9. Mean density of young-of-the-year mysis plotted as a function the density of immature and adult mysis the previous year. Ricker spawner/recruit models were fit to the dataset as a whole (no period), and independently to the pre and post-crash periods.

CHAPTER 2: KOKANEE RESEARCH

ABSTRACT

Kokanee are a keystone species in the Lake Pend Oreille fishery. Hydro-acoustic and mid-water trawl surveys, along with index counts of spawning fish, were continued in 2019 to evaluate restoration efforts. Total kokanee abundance during August and September was 18.1 million, including 6.9 million age-0, 2.7 million age-1, 6.0 million age-2, 2.2 million age-3, and 0.3 million age-4. The abundance of age-0 was similar to 2018, and both years marked the lowest in 10 years. The abundances of age-2 and older age classes were all the highest in the past 20 years. Survival from 2018 to 2019 was high for age-1 (99%) and age-2 (93%) kokanee. The mean length of age-2 was 191 mm, the mean length of age-3 kokanee was 220 mm, and the mean length of age-3 kokanee was 240 mm. Survival for these age classes from 2011 through 2019 was nearly double that of survival from 1999 through 2011. Kokanee biomass was estimated at 677 t, which was the highest estimate since 2000. Production was estimated at 437 t, which was the third highest estimate since 2000. Production has remained higher since 2012 than prior to 2012. A slight increase was observed in the number of shore spawning kokanee in Scenic Bay, and the number of early-run kokanee counted in Trestle Creek was the highest since 1975. If survival remains consistent, the low number of age-0 kokanee observed for the past two years should still produce adequate numbers of adults for the harvest fishery. Age-3 and older kokanee were large enough in August of 2019 to recruit to angling gear and provide a sport fishery. Furthermore, the record number of age-2 kokanee were large enough that they should recruit to the fishery as age-3. Efforts continue to be effective for restoring the Lake Pend Oreille kokanee population and production should remain at the current level as long as mysid densities remain low and predators are effectively suppressed.

Authors:

Sean M. Wilson
Principal Fishery Research Biologist

Pete Rust
Senior Fishery Research Biologist

Matthew P. Corsi
Principal Fishery Research Biologist

William H. Harryman
Senior Fishery Technician

INTRODUCTION

Kokanee (lacustrine Sockeye Salmon) *Oncorhynchus nerka* are the keystone of the Lake Pend Oreille fishery. They not only provide a popular sport fishery, with up to 477,000 angler-hours of recreational angling, of which kokanee made up 85% of the catch (Jeppson 1953), but also provide an important prey resource for trophy species, such as Gerrard Rainbow Trout *O. mykiss*, and native species such as Bull Trout *Salvelinus confluentus*. In the 1950s and 1960s, Lake Pend Oreille provided the most popular fishery in the state (Corsi et al. 2019). However, kokanee populations began to decline in the mid-1960s and continued to decline to the point where the fishery was closed in 2000.

Numerous factors contributed to the decline of kokanee from their historical abundance. Most recently, predation and mysid shrimp *Mysis diluviana* were identified as primary limiting factors (Corsi et al. 2019; Klein et al. 2020). Mysid shrimp were introduced in the 1960s and have been implicated as a cause of declining kokanee populations in other systems (Nesler and Bergersen 1991). Mysids likely affect Lake Pend Oreille kokanee in multiple ways, including competition for food that resulted in reduced size of adult kokanee (Klein et al. 2020) and fueling the population growth of predatory Lake Trout (Hansen et al. 2019).

Lake Trout emerged as a threat to kokanee in the 1990s when the population began increasing rapidly (Hansen et al. 2008) and predation threatened to extirpate the kokanee population in the early 2000s (Maiolie et al. 2006b). An aggressive predator removal program was initiated in 2006 to address this issue (Hansen et al. 2008), and the abundance of adult Lake Trout declined by 64% from the peak in 2007 to 2016 (Dux et al. 2019).

Since reaching record lows in 2007, kokanee abundance and biomass have increased annually in response to predator reduction and an unexplained mysid shrimp collapse in 2012 may have accelerated observed kokanee increases (Corsi et al. 2019). With kokanee biomass at its highest since the mid-1990s, a limited harvest fishery (six fish daily limit) was opened in 2013, and in 2014 the daily limit was increased to 15 (the standard for other regional lakes). The more robust kokanee population will provide opportunities for investigating mysid shrimp and kokanee competition and evaluation of hatchery stocking practices. Monitoring the kokanee population is critical to understanding the Lake Pend Oreille food web and informing management of the fishery.

METHODS

Abundance and Survival

We conducted a hydroacoustic survey on Lake Pend Oreille to estimate the abundance and survival rate of kokanee. Hydroacoustic surveys were performed at night within seven days of the trawl survey, with four survey transects in each lake section (see Figure 1). Further protocol details have been described 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 (Simrad Fisheries, Lynnwood, WA). We estimated kokanee abundance with echo integration techniques using Echoview software version 6.1.60.27483 (Echoview Software Pty Ltd, Hobart, Tasmania). This technique calculated densities along each transect using the following equation (see Parker-Stetter et al. 2009):

$$\rho = \left(\frac{NASC}{4\pi 10^{\frac{TS}{10}}}\right)0.00292$$

where ρ is density (number of fish per hectare), *NASC* is the total backscattering (m^2/nautical mile^2), and *TS* is the mean target strength in decibels for the area sampled. To estimate lakewide kokanee abundance, we calculated a mean kokanee density estimate for each section. We then multiplied the mean density in each lake section by the area therein to obtain an abundance estimate for each section. Finally, we summed abundance in each of the three sections to estimate the total kokanee abundance. Further descriptions on the criteria used to analyze the hydroacoustics data can be found in Wahl et al. (2010).

Once density estimates for kokanee were determined, we calculated 90% confidence intervals (CI) for using standard formulas for stratified sampling designs (Scheaffer et al. 1979):

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

where $\bar{x}$ is the estimated mean density of kokanee in the lake (fish/ha), t is the Student's t value, N_i is the number of possible samples in section i, n_i is the number of samples collected in section i, and s_i is the standard deviation of the samples in section i. Confidence intervals were then converted to total abundance based on the total area of the three lake sections.

We were able to separate kokanee fry (<100 mm) from the older age-classes using the Echoview software. A target-strength frequency histogram was established, and the low point was used as the break between fry and larger kokanee. To separate hydroacoustic estimates of larger kokanee into age-classes (age-1 through age-4), we used the results of midwater trawling. Trawling occurred during July 29–31, 2019. These dates were during the dark phase of the moon, which optimized the capture efficiency of the trawl (Bowler et al. 1979). The trawl net had graduated mesh increments ranging from 13 to 32 mm stretch, and sampling procedures for midwater trawling have been described by Rieman (1992) and Wahl et al. (2011a). To sample kokanee fry for assessing origin (hatchery or wild), we also conducted a midwater trawl survey during the 2019 time window using a smaller mesh trawl net (0.8 x 1.6 mm bar) previously described (Wahl et al. 2011a). The fry trawl was discontinued in 2018.

We collected kokanee from each trawl transect, placed them on ice, then placed them in a freezer for storage. To process kokanee, we thawed out sample bags corresponding to each transect, counted the fish, recorded total length (mm) and weight (g), and checked for sexual maturity. We removed scales and otoliths from 10-15 fish in each 10 mm size interval, and otoliths from all fry. Two independent readers aged the scales, and otoliths were used to determine hatchery or wild origin (see below). From these data, we created an age/origin-length key to assign an age and origin to every fish captured. Next, we estimated the mean density of each kokanee age-class within a lake section using the assigned ages and origins of fish. We then used these proportions of each age-class of kokanee in a lake section to separate the age-1 through age-4 hydroacoustics data in that section. After repeating this process for each section, we totaled the values to generate lakewide age-specific abundance estimates. From these age-specific abundance estimates, we calculated annual survival for each age-class (i.e., from one age class to the next) by comparing to the previous year's estimates.

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, all hatchery-origin kokanee otoliths had distinct thermal marks that were used to identify brood year, stock (early vs. late), and origin (hatchery vs. wild). Fish with an identifiable thermal mark were designated as either early run hatchery (KE-H) or late-run hatchery (KL-H). Fish without a thermal mark were designated as wild. Hatchery personnel initiated thermal treatments five to ten days after fry entered their respective raceways and sacrificed ten fry from each raceway to verify thermal marking success. Methodologies for evaluating thermal marks are described in Wahl et al. (2010).

To estimate the proportion of wild and hatchery kokanee, we first calculated the proportion of wild and hatchery kokanee fry within each 10 mm length group to estimate the overall proportion of wild and hatchery fry in each lake 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 entire 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 age-class by the mean weight of kokanee assigned to that age-class. Finally, we summed the calculated weights of age-classes to obtain estimates of total kokanee biomass in the lake.

Production was the growth in weight of the kokanee population regardless of whether the fish was alive or dead at the end of the year (Ricker 1975). To determine production of a kokanee age-class between years, we first calculated the increase in mean weight of a cohort since the previous year and averaged the abundance estimates for that cohort between the two years. Next, we multiplied the increase in mean weight by the average cohort abundance. This process was repeated for all cohorts, and we summed the results for all of the age-classes to determine population-wide production (i.e., within the entire lake). Production *P* for year *t* is estimated using the formula:

$$P_t = \sum (w_{it+1} - w_{it}) \times \left(\frac{n_{it+1} + n_{it}}{2}\right)$$

where *w* is the weight and *n* is the abundance estimate of cohort *i* in year *t*. These calculations assumed linear rates of growth and mortality throughout the year. Hayes et al. (2007) provided additional details on methods for estimating production.

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). To estimate annual mortality by weight for an age-class, we calculated the mean weight of fish in a cohort between years. We then subtracted that cohort's population estimate in the current year from the previous year to determine the number of fish lost. Finally, we multiplied the mean weight by the number of fish lost to estimate the mortality by weight for each age-class. Results were summed across all age-classes to estimate total yield for the kokanee population. Mortality by weight *Y* for year *t* is estimated using the formula:

$$Y_t = \sum (n_{it+1} - n_{it}) \times \left(\frac{w_{it+1} + w_{it}}{2} \right)$$

where *n* is the abundance estimate and *w* is the weight of cohort *i* in year *t*. Linear rates of growth and mortality throughout the year were assumed.

Spawning Kokanee Index Counts

Spawning kokanee were counted at standardized tributary and shoreline index transects where spawning was documented historically (Jeppson 1960). Surveys at index transects built upon annual trend data dating back to 1972. Surveys for late-run kokanee occurred along the shoreline at several locations in Scenic Bay.

RESULTS

Abundance

A total of 18.1 million kokanee (15.1–21.0 million, 90% CI) or 798 fish/ha were estimated to reside in Lake Pend Oreille during 2019, based on the hydroacoustic survey. This included 6.9 million kokanee fry (6.0–7.8 million, 90% CI; Table 8; Figure 10), 2.7 million age-1, 6.0 million age-2, 2.2 million age-3, and 330,000 age-4 kokanee (Table 8; Figure 10). During the midwater trawl survey, 1,168 kokanee were sampled, ranging from 31 to 272 mm TL (Figure 11) and from 0.2 to 183 g. The mean length of age-2 was 191 mm, the mean length of age-3 kokanee was 220 mm, and the mean length of age-3 kokanee was 240 mm.

Hatchery and Wild Abundance

During the spring of 2019, the Cabinet Gorge Fish Hatchery released 4.9 million fry, 4.8 million KLs at Sullivan Springs, 64,000 Lake Whatcom KLs at CGH Ladder, and 47,000 KEs at Trestle Creek. KLs made up 59% of the fry in the lake-wide trawl catch. No KE fry were encountered in the trawl. Based on fixed frame trawling, KLs made up 42% of the age-1, 3% of age-2, 11% of age-3, and 8% of age-4 kokanee lake wide. When applied to acoustic estimates, these proportions yield estimates of 1.1 million age-1, 0.3 million age-2, 0.2 million age-3, and 26,000 age-4 KLs lake wide (Table 8).

During 2019, wild kokanee accounted for 41% of the fry in the lake-wide trawl catch, including 49% in section 1, 38% in section 2, and 30% in section 3. These proportions yielded an estimate of 2.8 million wild fry in the lake; 0.9 million in each sections 1 and 2, and 0.8 million in section 3 (Table 8). Wild kokanee comprised 58%, 95%, 89%, and 92% of age-1, age-2, age-3, and age-4 abundance estimates based on the fixed frame trawl in 2019. These proportions yielded estimates of 1.5 million age-1, 5.7 million age-2, 1.9 million age-3, and 0.3 million age-4 wild kokanee for the lake (Table 8).

Biomass, Production, and Mortality by Weight

Based on the hydroacoustic estimates of kokanee abundance, kokanee biomass during 2019 was 677 metric tonnes (t) and production (from 2018 to 2019) was 437 t (Figure 12). Total mortality by weight was 56 t.

Spawning Kokanee Index Counts

In 2019, we observed 6,410 KLs spawning on the shoreline near the town of Bayview in Scenic Bay (Figure 13). Additionally, 2,331 KEs were counted in Trestle Creek, 2,909 in North Gold Creek, and 4,860 in South Gold Creek, for a total of 10,100 (Figure 13).

DISCUSSION

For the past two years, kokanee fry abundance has remained the lowest in ten years. However, kokanee populations are typically cyclical, and recent fry abundance has not been lower than observed prior to the previous ten-year period. Furthermore, trends in abundance suggest high survival. Survival from age-1 to age-2 for the past 8 years has been approximately double that of the preceding 12 years. Should survival remain relatively high, the fry abundance we have observed recently should produce adequate numbers of adult kokanee to provide a harvest fishery, but at a larger size than recent years (Klein et al. 2020). The abundance of age-1 kokanee suggests that these smaller cohorts of fry are surviving well and should produce adequate numbers of adults in future years. It should be noted that the abundance of age-2 kokanee in 2019 was estimated to be greater than the abundance of age-1 kokanee in 2018, and the abundance of age-4 kokanee in 2019 was estimated to be greater than the abundance of age-3 kokanee in 2018. These estimates resulted in a survival estimates greater than 100%. However, confidence intervals for these estimates overlapped, survival above 100% is nonsensical, and 100% survival is unlikely. Therefore, these were estimates were reported as 99%. Although these estimates are likely greater than the actual survival for these cohorts, the actual survival was likely high.

While fry abundance has declined, the abundance of each age class from age-2 through age-4 was the highest in the past 20 years. However, higher abundance of older age classes has not always lead to improvements in the sport fishery. Catch rates in 2017 were much lower than 2016, likely due to a decrease in the length of age-3 kokanee during 2017 (Rust et al. 2020). In 2019, most age-3 and older kokanee were large enough to recruit to angling gear and provide a fishery. Furthermore, the size distribution of age-2 kokanee suggests that they will be large enough to recruit to angling gear in 2020, despite the high abundance.

Due to the cyclical nature and density dependence typical of kokanee populations, production remains one of the best metrics for evaluating management actions. Production began trending upward in 2012 concurrent with declines in the mysid shrimp population and continued reduction of Lake Trout (Corsi et al. 2019). Production peaked in 2013, but remained higher on average through 2019 than it was prior to 2012. Mysid shrimp limit kokanee production (Corsi et al. 2019); therefore, we expect that production will remain at this higher level as long as the mysid populations remains in decline. Should mysids rebound, predator control will be of even greater importance to maintain the balance between kokanee production and predation and prevent another collapse of the kokanee population. Continued monitoring of kokanee production will be essential for informed management of the fishery.

Index counts of both stream spawning KEs and shore spawning KLs increased in 2019 compared to the previous two years. This is particularly encouraging for KEs, as index counts have been declining for several years (Rust et al. 2020). The count in 2019 was the highest since 1975, and second highest on record. Index counts should be continued; as this is the only method we currently have to assess the performance of these stocks relative to one another.

RECOMMENDATIONS

1. Continue to reduce Lake Trout abundance using targeted gill and trap netting and incentivized angler harvest.

2. Continue to assess the effects of predator removal on kokanee survival, abundance, and growth

3. Resume creel surveys to assess the effects of kokanee size and abundance on the performance of the fishery.

4. Assess optimal levels of hatchery stocking to maintain returns to the hatchery rack for broodstock while maintaining optimal kokanee densities to both satiate predators and provide a harvest fishery.

Table 8. Age-specific abundance estimates for kokanee in Lake Pend Oreille, Idaho, 2019. Abundance estimates were generated from hydroacoustic data and the proportion of age-0 kokanee was determined by target strength. Age-1 and older kokanee were separated into age-classes based on the proportions captured in midwater trawls. Percentage of wild, late-run hatchery (KL-H), and early-run hatchery (KE-H) were also based on the proportions of each caught in the trawl net.

Area	**Age-0**	**Age-1**	**Age-2**	**Age-3**	**Age-4**	**Total**
Section 1 (southern)						
Population estimate	1.86	0.36	2.91	1.78	0.29	7.22
Wild	0.92	0.23	2.82	1.60	0.26	5.83
Hatchery	0.95	0.14	0.09	0.19	0.03	1.39
Section 2 (middle)						
Population estimate	2.31	0.61	1.80	0.31	0.04	5.07
Wild	0.87	0.35	1.73	0.27	0.04	3.27
Hatchery	1.44	0.25	0.07	0.04	0.00	1.80
Section 3 (northern)						
Population estimate	2.69	1.72	1.29	0.09	0	5.79
Wild	0.81	0.98	1.18	0.08	0	3.05
Hatchery	1.88	0.74	0.10	0.02	0	2.74
Total population estimate	6.9	2.7	6.0	2.2	0.3	18.1
90% confidence interval	6.0-7.8	2.2-3.2	4.6-7.4	1.4-3.0	0.2-0.5	15.1-21.0
Wild	2.79	1.55	5.68	1.94	0.30	12.26
Hatchery KL	4.08	1.14	0.20	0.25	0.03	5.69
Hatchery KE	0	0	0.13	0	0	0.13

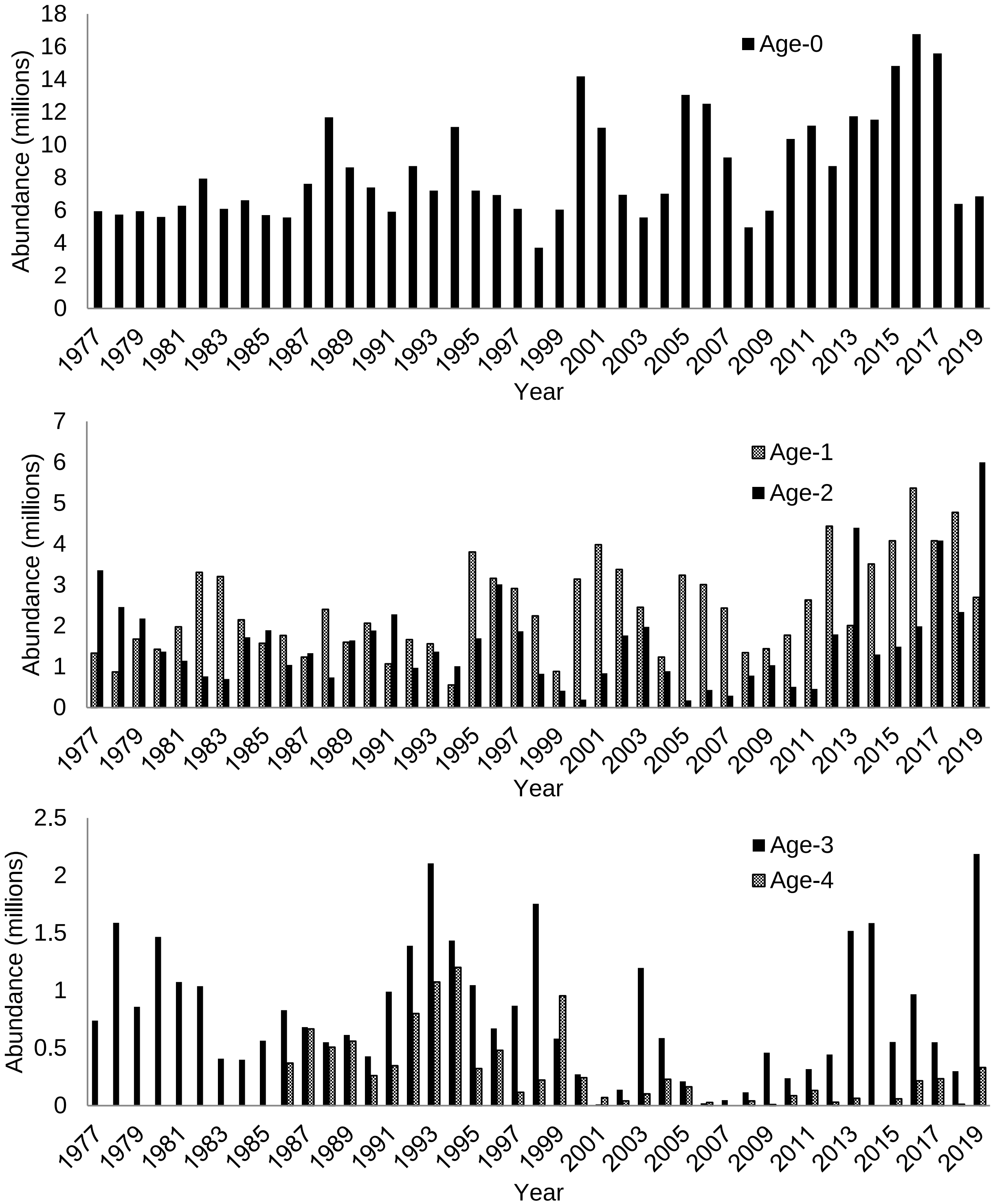

Figure 10. Kokanee age-specific abundance estimates based on hydroacoustic surveys. Estimates prior to 1995 were converted from trawl abundance estimates (Wahl et al. 2016). Age-3 and age-4 kokanee were not separated before 1986.

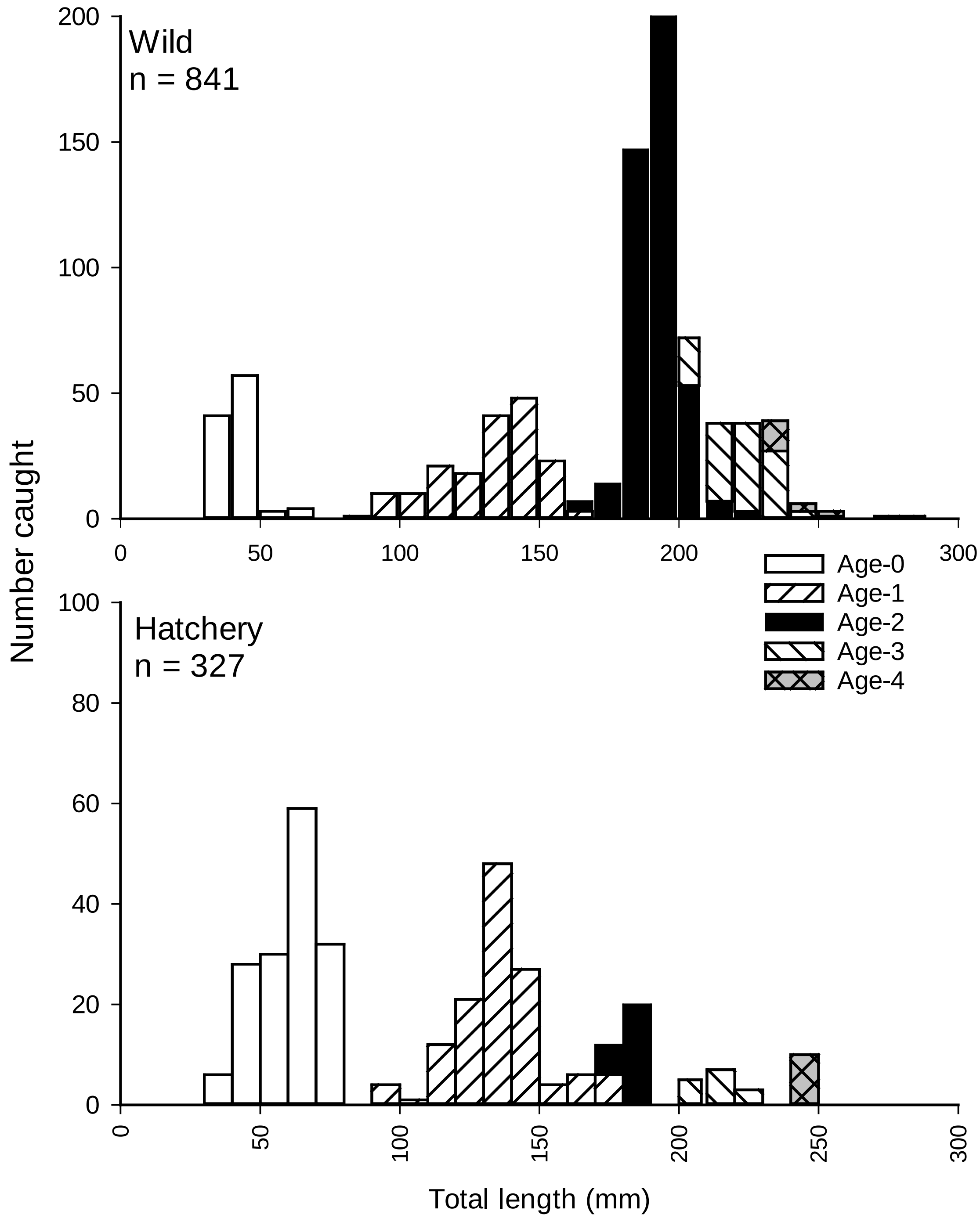

Figure 11. Length-frequency distribution of individual age-classes of wild and hatchery kokanee caught by midwater trawling in Lake Pend Oreille, Idaho during August 2019. Origin and age were determined from a subset of fish from each 1 cm length bin. Proportions of known age and origin were then applied to the remaining fish in each bin to derive theoretic numbers by age and origin for the trawl catch.

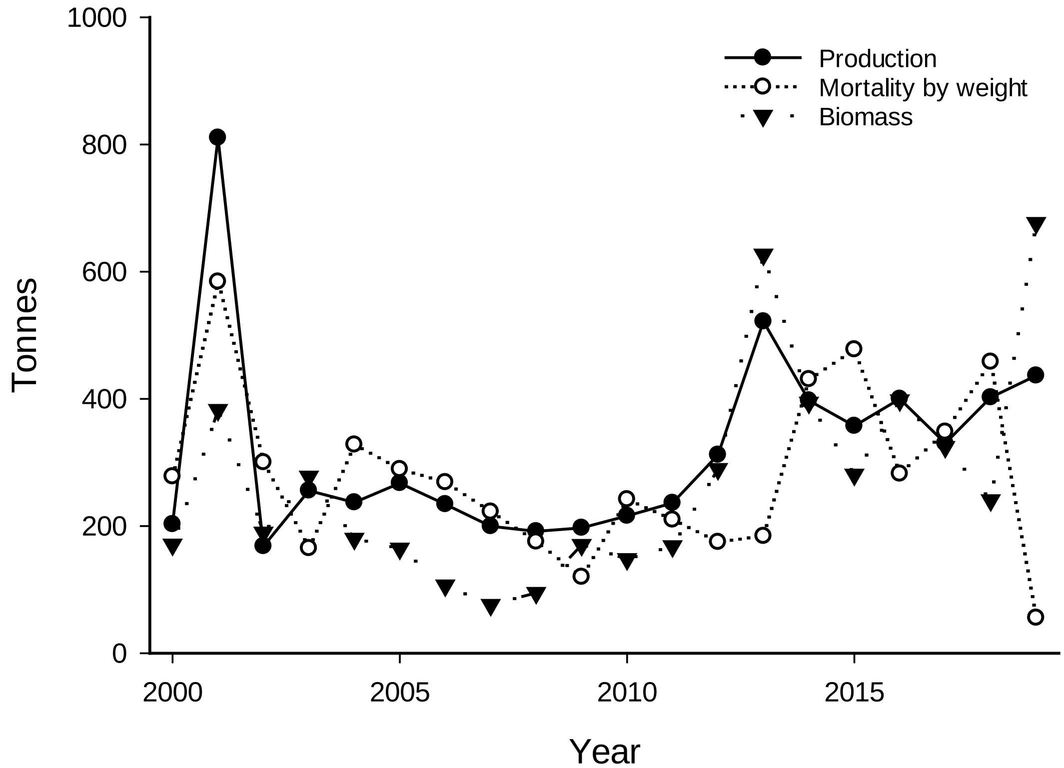

Figure 12. Kokanee biomass, production, and mortality by weight (metric tonnes) in Lake Pend Oreille, Idaho from 2000-2019.

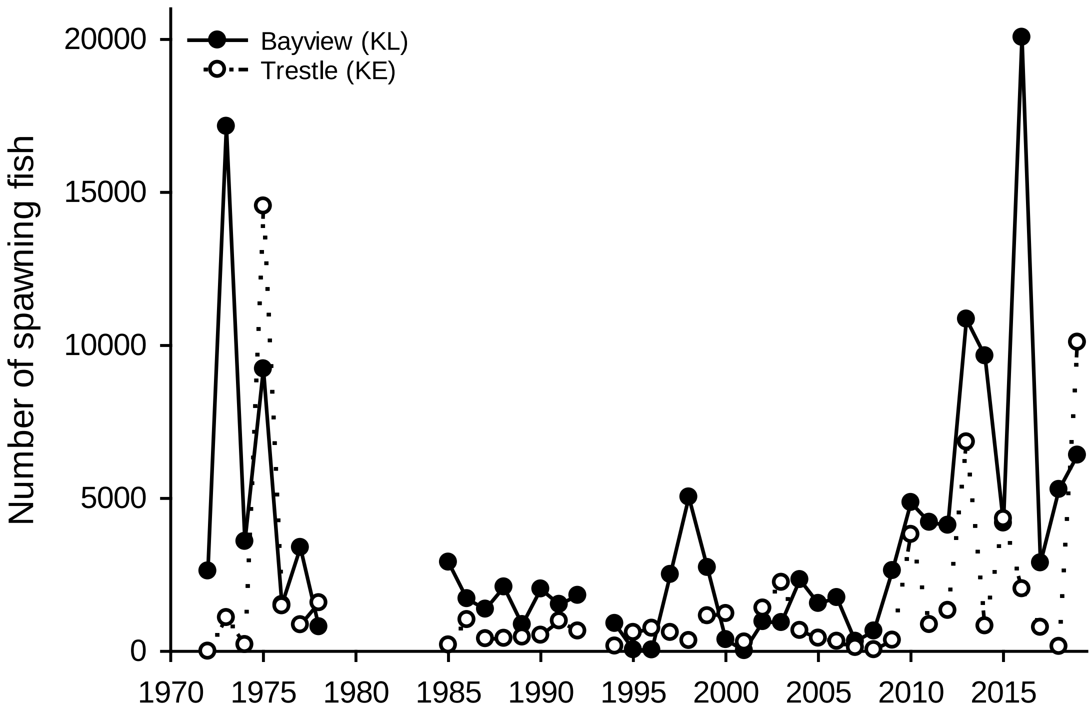

Figure 13. Numbers of early spawning kokanee (KE) counted in Trestle Creek and late-run kokanee (KL) counted along shorelines of Scenic Bay near Bayview, Idaho from 1972-2019. Counts were not available from 1979-1984 and in 1993.

CHAPTER 3: PREDATOR REMOVAL PROGRAM EVALUATION

ABSTRACT

In 2006, the Idaho Department of Fish and Game (IDFG) implemented an aggressive predator removal program aimed at reducing Lake Trout *Salvelinus namaycush* abundance to improve kokanee *Oncorhynchus nerka* recovery in Lake Pend Oreille. First, the IDFG instituted unlimited harvest regulations and a $15 reward for each Lake Trout harvested as part of an angler incentive program (AIP). Secondly, IDFG contracted with Hickey Brothers Research, LLC to remove Lake Trout from Lake Pend Oreille using gill nets and deep-water trap nets. However, due to their relatively high cost per yield, use of trap nets was discontinued in 2018. Instead, three weeks of gillnetting effort was dedicated to assessment sets at stratified random locations throughout the lake in 2018. This randomized assessment netting will be repeated on an annual basis and will serve as a tool for population monitoring and evaluating Lake Trout removal efforts. In 2019, a total of 8,545 Lake Trout were removed during suppression efforts. Of these fish, 6,785 (79%) were removed during targeted gill netting operations. The percent of Bull Trout catch that resulted in direct mortalities during contracted netting operations was slightly higher in 2019 than in 2018 (24.8% vs. 23.0%, respectively). Catch rates during assessment netting averaged 2.15 (±0.21) Lake Trout per 274.3 m net and catch ranged in size from 165 mm to 970 mm. Since predator removal began in 2006, 228,989 Lake Trout have been removed from Lake Pend Oreille. Total Lake Trout catch over the three-week assessment gill netting period in 2019 was more than double that of the total catch from ten weeks of trap netting in 2017. These results suggest that Lake Trout removal and population monitoring via randomized assessment gill netting is an effective and cost efficient alternative to trap nets.

Authors:

Jeff Strait
PSMFC Fishery Biologist

Matthew P. Corsi
Principal Fishery Research Biologist

Pete Rust
Senior Fishery Research Biologist

William H. Harryman
Senior Fishery Technician

INTRODUCTION

Population modeling conducted in 2006 indicated the kokanee *Oncorhynchus nerka* population in Lake Pend Oreille 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). With those conditions, Lake Trout posed a threat to federally threatened Bull Trout *S. confluentus* through predation and competition (Fredenberg 2002; Martinez et al. 2009; Guy et al. 2011). To protect Bull Trout and restore kokanee, IDFG initiated a two-part predator removal program in 2006 aimed at collapsing the Lake Trout population and reducing Rainbow Trout predation. First, IDFG liberalized angling regulations on Lake Trout and Rainbow Trout and initiated an angler incentive program (AIP) which offered a $15 reward for any Lake Trout and Rainbow Trout harvested. Because the program did not decrease Rainbow Trout abundance, the AIP for Rainbow Trout was discontinued after 2012, and harvest regulations were reestablished to rebuild the trophy fishery (Wahl et al. 2015a). Secondly, IDFG contacted Hickey Brothers Research, LLC who had previous experience netting Lake Trout on the Great Lakes to remove Lake Trout from Lake Pend Oreille using gill nets and deep-water trap nets. 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).

Following the implementation of the predator removal program, the population of Lake Trout in Lake Pend Oreille declined nearly 60% from 2006 to 2016 (Dux et al. 2019). In response to this successful reduction in population size, Hansen et al. (2019) conducted a simulation exercise to determine optimal suppression techniques for further population reduction and indefinite maintenance of abundance below a target level (i.e. 10% of the peak abundance in 2006). They found that allocating more effort towards large-mesh gillnets would reduce the amount of time before a target maintenance abundance was reached. The simulation model indicated that the most-effective mesh size combination for reducing both adult and juvenile Lake Trout was comprised of 5.1, 6.4, 12.7, and 14.0 cm mesh. In addition, model predictions showed that if total gillnetting effort was sustained at the 2014 level, it would take between seven and thirteen years of utilizing an optimal mesh size combination to reach the target suppression abundance. However, if effort is reduced to 60% of the 2014 level, it will take twice as long to reach the target abundance. Furthermore, model predictions showed 14 weeks of trap-netting effort could be replaced by one week of gillnetting effort for the same yield.

These findings led to the discontinuation of trap netting following the 2017 season and the implementation of a three-week randomized assessment gillnetting protocol in 2018 (hereafter referred to as assessment netting). This assessment netting protocol will serve as a new monitoring tool for evaluating the status of the Lake Trout population and the success of the predator removal program. As an additional response to these findings, gillnetting effort was increased in 2019 and relied on the four most-effective mesh sizes for targeting adult and juvenile Lake Trout as determined from the simulation model. Our objective was to evaluate and adapt the predator suppression program to most effectively manage predator abundance.

METHODS

In 2019, Hickey Brothers Research, LLC was contracted to remove Lake Trout from Lake Pend Oreille using gill nets for 13 weeks during the winter/spring netting season (January 7-April

11) and for 15 weeks during the fall netting season (September 9-January 10). The last three weeks of fall netting (December 9–Jan 10, 2020) were dedicated to assessment netting. Gill nets mesh sizes ranged from 3.8–14.0 cm (stretch measure). The contract netters set 5.1 and 6.4 cm mesh in the winter/spring (January-April) and late fall (October-November) to target juvenile Lake Trout (i.e. nursery netting) and 12.7 and 14.0 cm mesh in the early fall (September-October) to target adult Lake Trout at spawning sites (i.e. spawner netting). During assessment netting (December 9, 2019–January 10, 2020), gill nets were set along the shoreline in water depths ranging from 18 m to 76 m in randomly selected locations stratified to include approximately 40% of sites from the relatively shallow "north end" and 60% of sites from the remainder of the lake. These gill nets were constructed of 91.4 m panels of translucent stretch mesh ranging from 3.8 cm to 14.0 cm. Each panel contained a single size (cm) mesh (i.e. 3.8, 4.4, 5.1, 6.4, 7.6, 8.9, 10.2, 11.4, 12.7, 14.0) and panels were strung together to create 274.3 m "boxes." Boxes were randomly strung together to create a ten box "gang," and a single gang was set at each randomly selected site. Each gang contained equal effort (274.3 m) of the aforementioned mesh sizes. Lake Whitefish *Coregonus clupeaformis* were enumerated and measured from a stratified random subset of gangs during assessment netting in order to assess current population characteristics.

Lake Trout, Bull Trout, Walleye *Sander vitreus*, Northern Pike *Esox lucius*, kokanee, Smallmouth Bass *Micropterus dolomieu*, Largemouth Bass *M. salmoides*, Yellow Perch *Perca flavescens*, Black Crappie *Pomoxis nigromaculatus*, Rainbow Trout, Brown Trout *Salmo trutta*, Westslope Cutthroat Trout *O. clarkii lewisi* were enumerated and measured for total length upon encounter. Biological samples were opportunistically obtained from a subset of species of interest for use in age and growth analyses. Lake Trout, Walleye, and Northern Pike captured during gill and trap netting efforts were subsequently removed and donated to local food banks, with the exception of Lake Trout or Walleye that were implanted with telemetry transmitters and released alive (see chapters 4 and 6).

For the AIP in 2019, anglers that caught Lake Trout from Lake Pend Oreille turned the heads in to freezers that IDFG had placed around the lake. Heads were collected from freezers weekly, identified to species, and measured from the tip of the snout to the posterior edge of the operculum. Previously developed head-length to total-length relationships for Lake Trout in Lake Pend Oreille (Wahl et al. 2013) were used to extrapolate total length.

RESULTS

In 2019, Hickey Brothers Research, LLC captured a total of 6,785 Lake Trout (Table 9) and 1,251 Bull Trout. Of the total Bull Trout captured during netting operations in 2019, 311 were direct mortalities (24.8%). Gill net effort totaled 740,754 m (89% of 2014 effort). During the Lake Trout spawning period, 768 individual 274.3 m gill nets (210,678 m of net) was set at the spawning sites. We captured 1,231 Lake Trout (1.6 Lake Trout per net; ±0.13 SE) and examined each fish for sex and maturity (Figure 14). Of those fish, 352 were mature females with a mean total length (TL) of 777 mm (SE = 5.69; range = 395-1,030) and 553 were mature males with a mean TL of 680 mm (SE = 4.11; range = 310-1020). The remaining 326 Lake Trout were immature. This resulted in a sex ratio of 1.57 mature males per mature female. During assessment netting, Hickey Brothers Research, LLC set 220 gill nets and captured 516 Lake Trout and 327 Bull Trout. Of the Bull Trout captured, 79 were direct mortalities (24%). Assessment netting catch rates varied by mesh size (Tables 10) and averaged 3.55 (±0.81 SE) Lake Trout per net. Lake Trout captured during assessment netting ranged in size from 170 to 970 mm, with 13% of catch greater than 650 mm (an increase from 4% in 2018).

Gill net catch rates of Lake Trout and Bull Trout varied by mesh size (Table 11). We adjusted mesh-specific effort in 2019 to try to optimize netting efficiency (Figure 15). Effort allocated towards 3.8, 4.4, 7.6, and 11.4 cm mesh in 2019 was similar to 2018, since these meshes were only fished during randomized assessment netting. However, we allocated less effort to 5.1 and 6.4 cm mesh than in 2019 than in 2018, but increased the effort allocated toward 12.7 and 14.0 cm mesh.

Anglers participating in the AIP captured and removed 3,531 Lake Trout in 2017, 2,618 in 2018, and 1,760 in 2019. Although angler harvest has declined over the period, angling is still an important method to capture specific size ranges of Lake Trout that seem to be less vulnerable to netting gear. Estimated total length for Lake Trout caught in the AIP ranged from 235 to 1,065 mm. The size distribution of Lake Trout captured during removal efforts varied by gear type (Figure 16). During suppression efforts, 8,545 Lake Trout were removed in 2019. To date, 228,989 Lake Trout have been removed from Lake Pend Oreille during targeted Lake Trout suppression efforts (Table 9).

DISCUSSION

The predator removal program continues to effectively remove Lake Trout from Lake Pend Oreille in an effort to reach and maintain a target abundance of 10% of the peak estimated abundance in 2006. Since the predator removal program began in 2006, over 55% of the Lake Trout removed have been captured via gill net, 41% via angling, and 3 % via trap nets. Initially, a larger proportion of catch was attributed to angling and trap nets (72% and 10%, respectively, in 2006). However, proportional catch using these methods has declined over time (33% and 2%, respectively, in 2017). While trap nets initially had a substantial influence on fishing mortality, they have been a minor source of mortality relative to gill netting and angling over the course of the removal program (Dux et al. 2019) and were discontinued following the fall of 2017. Despite the change over time in proportional catch by gear type, the use of multiple techniques in combination over the course of the suppression program has resulted in greater fishing mortality than would have been feasible while using only a single suppression technique (Dux et al. 2019). For example, it remains important to use multiple methods in order to exploit all sizes of Lake Trout in the system (Hansen et al. 2010). Angling has shown to have a higher relative selectivity for age-6 and age-7 Lake Trout than the four main mesh sizes utilized in 2019 (i.e. 5.1, 6.4, 12.7 and 14.0 cm; Hansen et al. 2019) and remains an effective method of population suppression when used in concert with netting.

Randomized assessment netting was first implemented in 2018 in place of standardized trap nets and continued to be an effective suppression strategy. While over 100 fewer Lake Trout were caught in 2019 (n = 516) than 2018 (n = 628) assessment netting, this is still over two times the number of Lake Trout caught in trap nets in 2017 (n = 248). Furthermore, we continued to use randomized gillnetting as an opportunity to collect relative abundance and size structure on Lake Whitefish, with the goal of building a dataset to monitor Lake Whitefish population trends over time and provide better insight to population status in Lake Pend Oreille. Finally, we continued to use the assessment period to collect a random sample of otoliths from Lake Trout. We used these structures to assess the age and growth of Lake Trout via a Von Bertalanffy growth model whose parameters are used in a cohort analysis model to obtain age-specific lake-wide abundance estimates (see Dux et al. 2019 for methods). Additional annual information on somatic growth and age specific abundances will supplement the evaluation of the predator removal program and benefit our ability to adapt management strategies in response to population demographics.

The simulation model by Hansen et al. (2019) suggested increasing the total gillnetting effort and allocating most of the efforts toward 5.1, 6.4, 12.7, and 14.0 cm mesh to achieve suppression of the population to the target abundance level in the shortest timeframe. Since this recommendation, we have been making efforts to increase the effort of these mesh sizes to reach the optimal ranges from Hansen et al. (2019). While we did not meet the minimum optimal efforts for 14.0 cm mesh, we met or surpassed these efforts for 5.1, 6.4, and 12.7 cm mesh in both 2018 and 2019. Furthermore, we did increase our use of 12.7 cm mesh, fishing approximately 20,000 meters more of this mesh in 2019 than in 2018. We should continue to push the use of 14.0 cm mesh to reach efforts goals and most effectively target mature Lake Trout.

The overall trends in total catch and catch per unit effort (CPUE) of Lake Trout at spawning sites has been declining since 2008 (Figure 14). In 2019, total catch and CPUE were at lowest levels since 2008. Despite variation in catch over the past few years, the change in length-frequency distribution from 2008 to 2019 indicates that size-classes of mature Lake Trout have been vulnerable to removal efforts. Most importantly, the major reduction of Lake Trout less than 700 mm in the length-frequency distributions compared to those earlier in the program suggest a lack of year-classes recruiting to gill nets set at spawning sites. A large proportion of fish in these cohorts was removed prior to reaching maturity, either through juvenile netting or angler harvest.

Over the past several years, we have effectively used data from gillnetting at Lake Trout spawning sites to assess the spawning segment of the population. Length-frequency distributions since 2013 suggested that the level of effort expended has been sufficient to achieve desired effects at all of the spawning sites. This is particularly important given that the Evans Landing (south end of lake) spawning site has not been targeted for as many years as the other two sites, and we documented fish along more of the Evans Landing shoreline in 2013. The peak of the length-frequency distribution shifted towards smaller Lake Trout during 2012- 2013, which may be related to year classes recruiting to maturity. Over the past five years, we have effectively removed Lake Trout as juveniles, and the shift in size structure of spawning Lake Trout back towards larger individuals should continue. Therefore, we do not expect to see any more large cohorts reaching maturity.

Differences in the duration of time spent at spawning sites, age at maturity, and alternate year spawning in females can skew sex ratios at Lake Trout spawning sites to over 90% males (Martin and Olver 1980; Dux et al. 2011). However, the sex ratio in Lake Pend Oreille has never been highly skewed, ranging from 57% males in 2011 (Wahl et al. 2013) to 67% males in 2008 (Wahl and Dux 2010). In 2019, the sex ratio of adult Lake Trout netted at the spawning sites was 1.57 male to female. We are unsure of the rate of alternate year spawning by females in Lake Pend Oreille, but telemetry has shown that around 90% of the Lake Trout implanted with transmitters visited a spawning site in the fall (Wahl et al. 2013; Wahl et al. 2015a; Wahl et al. 2015b). With nearly all Lake Trout visiting a spawning site each year and 50% of both male and female Lake Trout maturing around age-10 (Wahl et al. 2015a), we would not expect to see a highly skewed sex ratio in Lake Pend Oreille.

Total and proportional Bull Trout mortality was slightly higher in 2019 (24.8%) than in 2018 (23%). As in 2018, we did not find a higher proportional Bull Trout mortality during randomized assessment netting than during all gillnetting efforts during the rest of the year in 2019. Therefore, proportional mortality did not increase with the inclusion of additional mesh sizes during assessment netting.

RECOMMENDATIONS

1. Continue the use of gill nets to remove mature Lake Trout from spawning sites in the fall.

2. Continue the use of small and large mesh gillnets to remove juvenile and mature Lake Trout lake wide throughout the fall, winter, and spring.

3. Continue the use of the AIP to reduce Lake Trout abundance in Lake Pend Oreille.

4. Continue the use of randomized assessment netting in place of trap nets as a tool to monitor the Lake Trout population and assess removal efforts.

5. Increase the amount of effort allocated to 14.0 cm mesh gill nets.

6. Continue to annually evaluate Lake Trout population dynamics, especially growth, fecundity, and age composition, to determine the influence the removals are having on the population.

Table 9. Number of Lake Trout removed during predator suppression efforts from Lake Pend Oreille, Idaho by different gear types from 2006 - 2019.

Year	Angling	Gill nets	Trap nets	Total
2006	11,041	2,774	1,500	15,315
2007	17,665	4,169	1,335	23,169
2008	13,020	10,252	1,509	24,781
2009	7,366	17,186	410	24,962
2010	8,740	17,334	400	26,474
2011	7,324	11,384	150	18,858
2012	7,813	9,500	322	17,635
2013	3,537	10,402	359	14,298
2014	2,511	8,873	259	11,643
2015	3,194	8,634	215	12,043
2016	2,871	6,761	424	10,056
2017	3,531	6,968	248	10,747
2018	2,618	7,845	0	10,463
2019	1,760	6,785	0	8,545
TOTAL	92,991	128,867	7,131	228,989

Table 10. Mean (±SE) catch per unit effort (274.3 m net) by mesh size (cm) for Lake Trout, Bull Trout, and Lake Whitefish caught during assessment netting in 2019. Lake Whitefish catch was derived from the subsample of assessment netting sites where Lake Whitefish were enumerated.

Mesh Size (cm)	Lake Trout CPUE (±SE)	Bull Trout CPUE (±SE)	Bull Trout Mortality CPUE (±SE)	Lake Whitefish CPUE (±SE)
3.8	6.10 (±1.31)	1.00 (±0.26)	0.17 (±0.17)	118.20 (±60.15)
4.4	3.88 (±0.66)	1.14 (±0.14)	0.14 (±0.14)	95.11 (±54.11)
5.1	4.58 (±0.93)	1.22 (±0.22)	0.33 (±0.17)	117.22 (±60.36)
6.4	4.56 (±0.71)	1.20 (±0.24)	0.67 (±0.16)	40.33 (±11.28)
7.6	2.69 (±0.70)	1.94 (±0.40)	0.81 (±0.28)	17.67 (±3.19)
8.9	3.77 (±0.83)	2.33 (±0.43)	1.28 (±0.43)	28.89 (±7.94)
10.2	1.80 (±0.33)	2.78 (±0.53)	0.78 (±0.25)	13.89 (±3.23)
11.4	2.67 (±0.67)	2.79 (±0.42)	0.43 (±0.23)	4.17 (±1.72)
12.7	2.25 (±0.73)	1.50 (±0.27)	0.43 (±0.17)	1.00 (±0.0)
14.0	3.17 (±1.25)	2.33 (±0.97)	0.22 (±0.15)	1.00 (±0.0)
Average	3.55 (± 0.81)	1.82 (±0.38)	0.53 (±0.22)	43.75 (± 20.20)

Table 11. Annual mean (±SE) catch per unit effort (274.3 m net) by mesh size (cm) for Lake Trout and Bull Trout caught in gill nets during Lake Trout suppression efforts in Lake Pend Oreille during 2019.

Mesh Size (cm)	Effort (m)	Lake Trout CPUE (±SE)	Bull Trout CPUE (±SE)	Bull Trout Mortality CPUE (±SE)	Bull Trout Mortality Rate
3.8	6,035	6.10 (±1.31)	1.00 (±0.26)	0.17 (±0.17)	17 %
4.4	6,035	3.88 (±0.66)	1.14 (±0.14)	0.14 (±0.14)	7 %
5.1	219,547	3.89 (±0.39)	0.35 (±0.05)	0.11 (±0.03)	21 %
6.4	234,269	2.24 (±0.22)	0.52 (±0.07)	0.24 (±0.04)	31 %
7.6	6,035	2.69 (±0.70)	1.94 (±0.40)	0.81 (±0.28)	26 %
8.9	6,035	3.77 (±0.83)	2.33 (±0.43)	1.28 (±0.43)	38 %
10.2	6,035	1.80 (±0.33)	2.78 (±0.53)	0.78 (±0.25)	27 %
11.4	6,035	2.67 (±0.67)	2.79 (±0.42)	0.43 (±0.23)	11 %
12.7	133,868	1.72 (±0.13)	0.65 (±0.06)	0.18 (±0.03)	21 %
14.0	116,860	2.03 (±0.20)	0.73 (±0.12)	0.16 (±0.03)	16 %

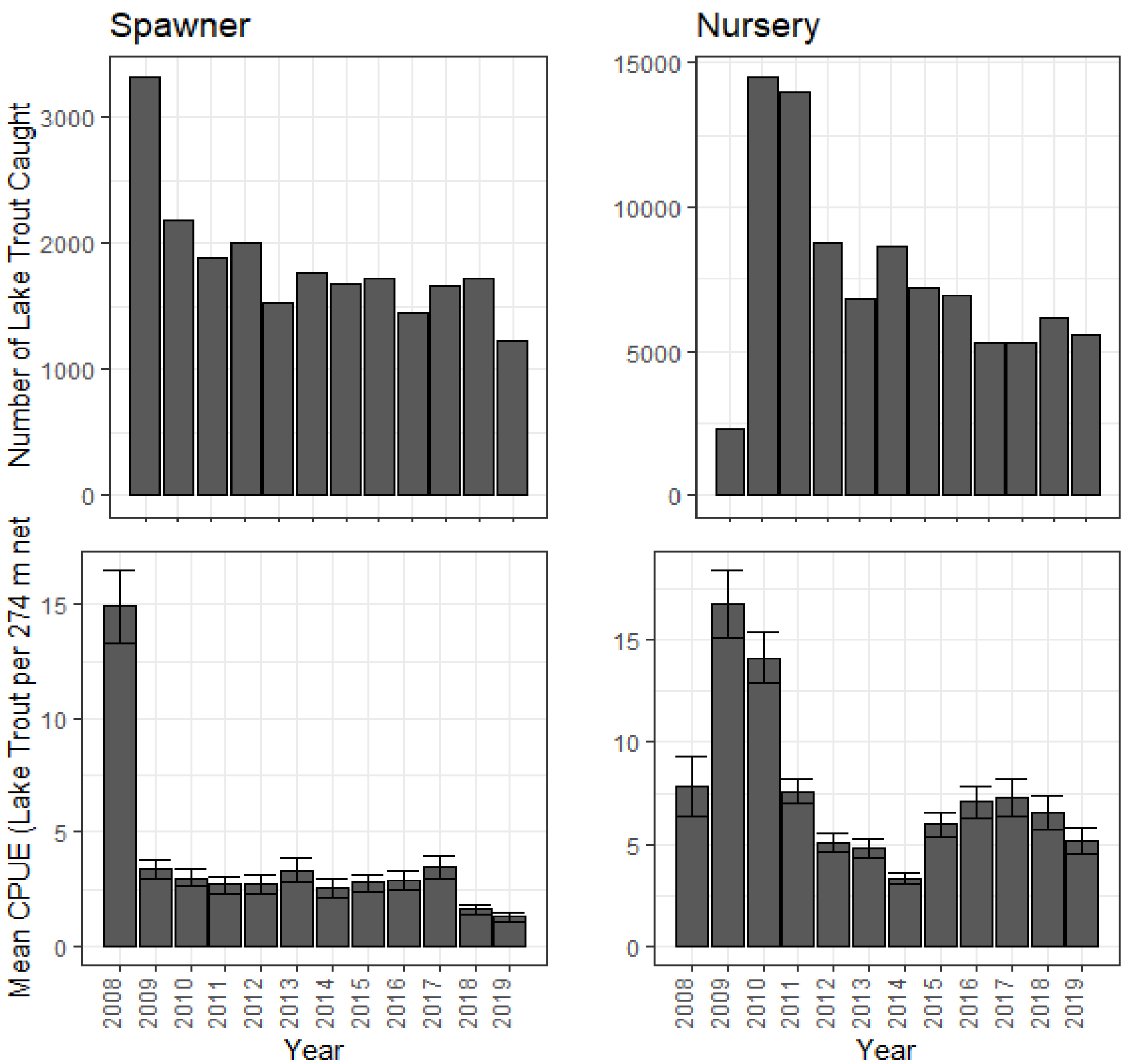

Figure 14. Yearly catch and mean (±SE) catch per unit effort of Lake Trout captured in gillnets during spawner and nursery netting efforts in Lake Pend Oreille, 2008-2019.

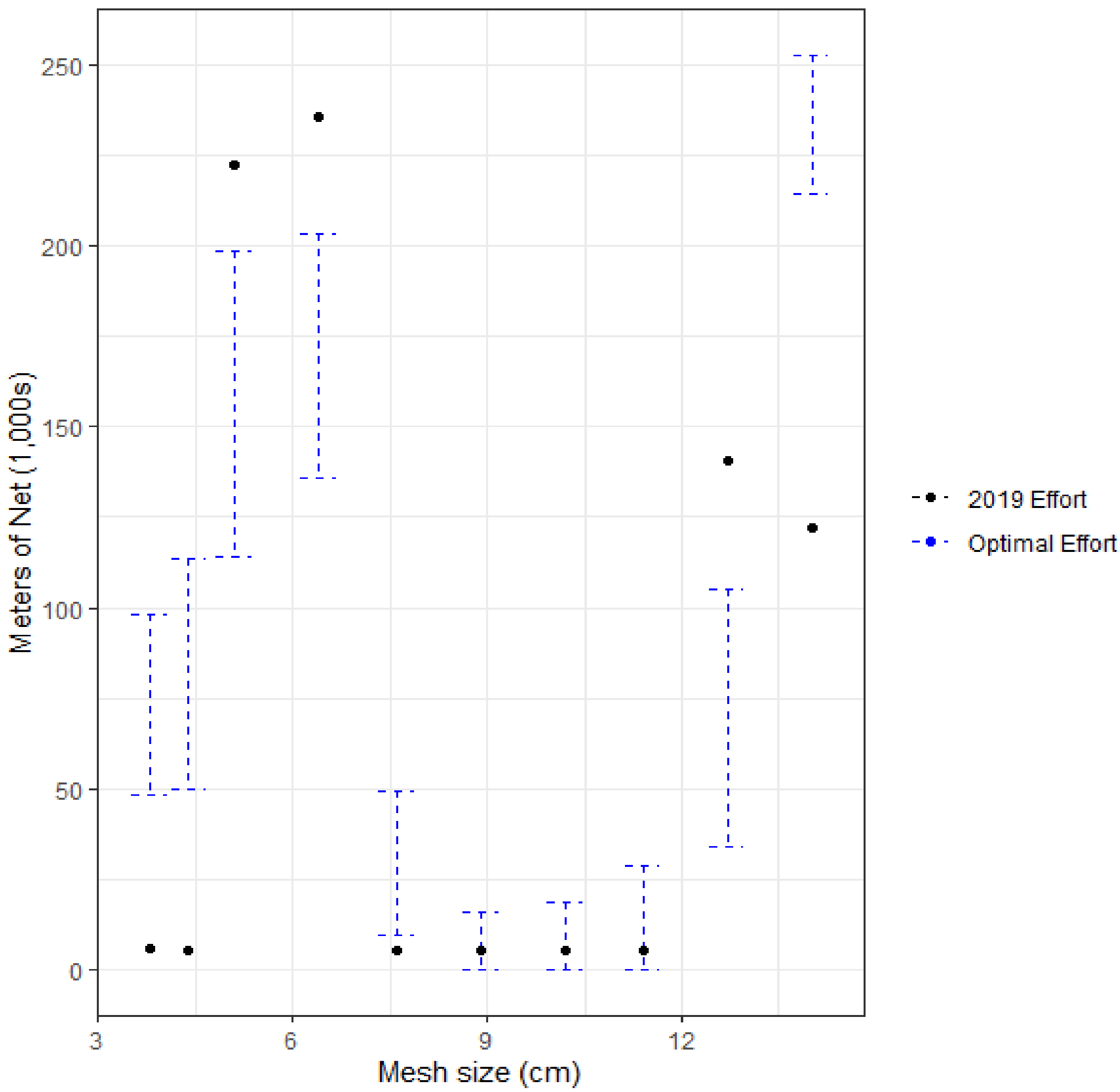

Figure 15. Allocation of gillnetting effort by mesh size in 2019 during Lake Pend Oreille Lake Trout suppression netting. Dotted lines depict the estimated optimal allocation of effort by mesh size in order to achieve target abundance levels in minimal time (Hansen et al. 2019).

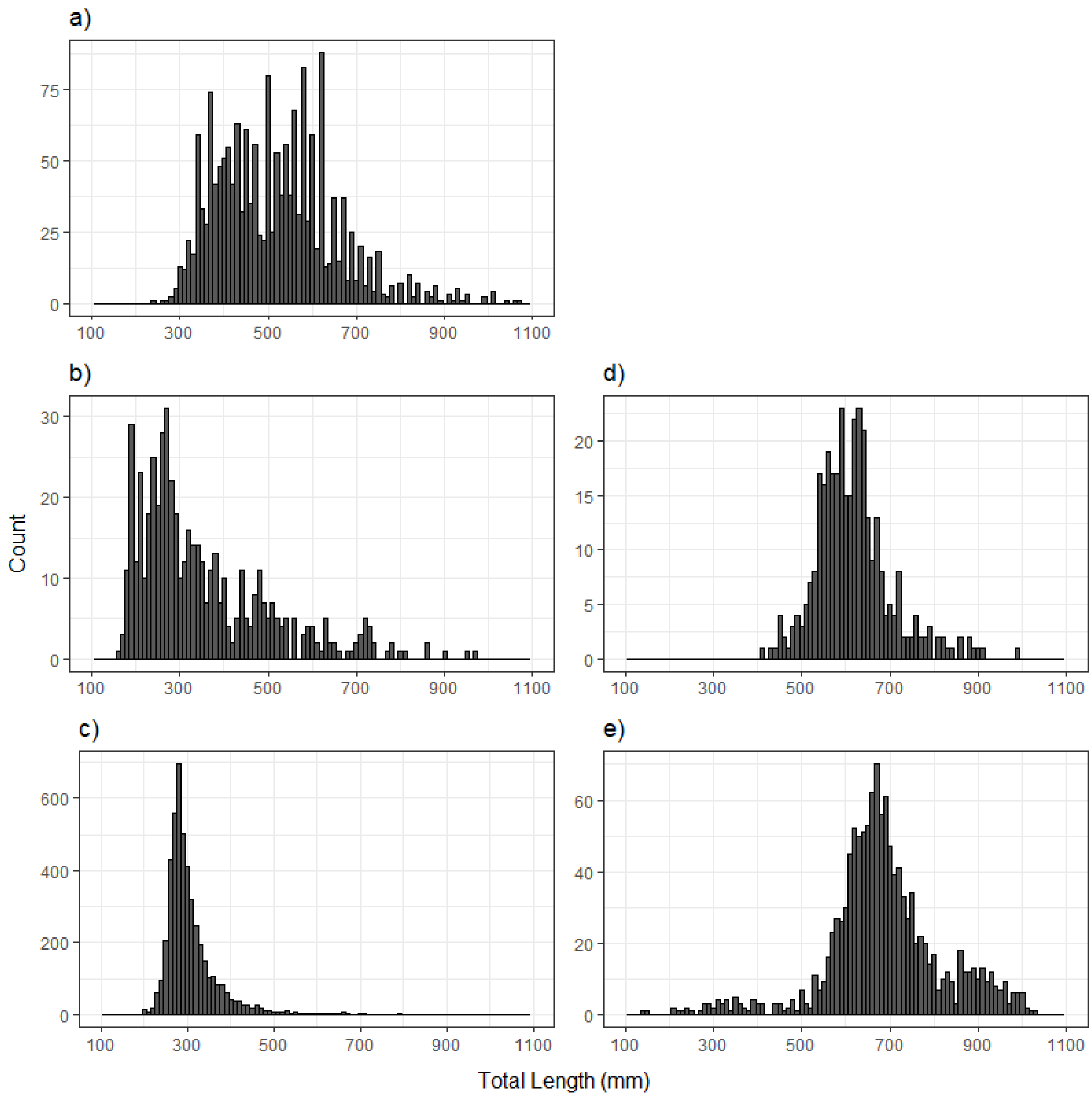

Figure 16. Gear-specific length-frequency histograms for Lake Trout removed during predator suppression efforts (a – angler incentive program, b – randomized assessment gillnets, c – small mesh suppression gillnets, d –large mesh suppression gillnets, e – spawner targeted gillnets) in 2019 in Lake Pend Oreille.

CHAPTER 4: SPAWNING LAKE TROUT RESEARCH

ABSTRACT

We used mobile telemetry to track previously acoustically-tagged mature Lake Trout to spawning sites where we could target spawning aggregations with gill nets and maximize removal efficiency to improve kokanee *Oncorhynchus nerka* and Bill Trout *Salvelinus confluentus* recovery. During September and October 2019, we tracked Lake Trout with mobile telemetry to identify spawning aggregations and provide precise locations of where to set nets. Mobile tracking events occurred along the entire shoreline of the lake, and we used stationary receivers throughout the lake, including the traditional spawning sites, to document movement within and between spawning sites. In 2019, we located seven of 12 acoustically-tagged Lake Trout during telemetry efforts. Six of the seven were located during mobile telemetry and five of the seven were located from stationary receivers. Most of the detections were from the Bernard Beach spawning site followed by the Windy Point site. Relatively few detections were made from the Evans Landing site. Mobile telemetry found concentrations of Lake Trout near the Camp Bay area during the spawning season. In October 2019, 14 more mature Lake Trout ranging in size from 630 to 1000 mm were implanted with Vemco V16-6X (10-year tag life) transmitters for future telemetry studies. A total of 1,231 Lake Trout were caught in gill nets and removed from spawning sites by the contract netters in 2019, including 352 mature females and 553 mature males.

Authors:

Pete Rust
Senior Fishery Research Biologist

Matthew P. Corsi
Principal Fishery Research Biologist

William H. Harryman
Senior Fishery Technician

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 (Figure 1, Appendix A) in 1925. Lake Trout present a threat to other 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 generally cannot be sustained after Lake Trout introduction without human intervention (Donald and Alger 1993; Fredenberg 2002). 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 the introduction of Lake Trout (Bowles et al. 1991; Stafford et al. 2002). Other lakes in the western United States have experienced similar detrimental effects to native fish and valued sportfish populations following Lake Trout introductions (Martinez et al. 2009). Lake Trout population modeling was conducted in 2006 and 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 the Idaho Department of Fish and Game (IDFG) to implement an aggressive predator removal program (netting and incentivized angling) in 2006 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. 2009a; Wahl and Dux 2010). Intensive gill netting at these sites since 2008 has 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 (Wahl et al. 2011b). Telemetry research has continued annually, but the tags deployed for 2012 research all had battery failures prior to data collection (Wahl et al. 2015a). We continued telemetry research in 2019 to further evaluate whether Lake Trout spawning distribution changed in response to netting and used real-time data to guide netting during the spawning period.

METHODS

Lake Trout Telemetry

To evaluate Lake Trout spawning distribution and to improve Lake Trout spawner netting efficiency, we tracked mature Lake Trout during the Lake Trout spawning season (September-October). Fish were captured in fall 2018 during spawner netting operations (Rust et al. 2019) using gill nets operated by Hickey Brothers, LLC. To ensure sexual maturity, we tagged only Lake Trout that were ripe or were greater than 600 mm. Additionally, we captured and tagged Lake Trout during fall 2019 for future telemetry research. Beginning in 2018, we incorporated Vemco telemetry equipment (Vemco Inc., Shad Bay, Nova Scotia) and actively tracked using Vemco receiver (model VR-100) and hydrophone (model VH110). We also incorporated an array of Vemco (model VR2W) passive telemetry receivers throughout the lake and adjoining rivers (see Figure 21 in Chapter 6 for locations of VR2W receivers). All Lake Trout were anesthetized with 30 mg/L of Aqui-S (AquaTactics Fish Health, Kirkland, WA) and transmitters (Vemco model V16H-

6X-69 kHZ) were inserted through a 4.5 cm surgical incision just off the centerline of the abdomen of the fish anterior to the pelvic fins and pushed back to sit on the pelvic girdle. Incisions were closed with non-absorbable sutures.

RESULTS

Lake Trout Telemetry

Twelve mature Lake Trout were implanted with 4-year transmitters in fall 2018. Two of the original 12 transmitters were captured by anglers and removed prior to the spawning season. Three of the tagged Lake Trout remained stationary for several months and were presumed to be dead or shed their tags before the beginning of the 2019 spawning season. Movement data for 2019 are based on seven remaining transmittered Lake Trout.

Six of the seven Lake Trout were located 13 times during the spawning period with active telemetry in the Camp Bay area, just north of Garfield Bay (Figure 17) at depths ranging 9.1 to 84 meters. Two of the seven Lake Trout were located only during active tracking. Five Lake Trout were located on the passive telemetry receivers located near the spawning sites during the spawning season in 2019 (Figure 18). Most of the detections were from the Bernard Beach (near the Cement Plant receiver) and Windy Point spawning sites, with relatively few detections near the Evans Landing site. Detections near the Bernard Beach site increased during the third week (September 23 – September 27) of netting and continued through week seven (October 21 – October 25). Most of the detections near the Windy Point spawning site began increasing during week three, and peaked during week four (September 30 – October 4). Lake Trout used the Windy Point site throughout early November. Few detections were recorded at the Evans Landing spawning site compared to the other two sites, and spawning apparently occurred a few weeks later in the season at that site. Throughout the end of the spawning season, Lake Trout moved further north and began concentrating near Garfield Bay and the Clark Fork delta.

Fourteen mature Lake Trout were implanted with transmitters on October 5 and 6, 2019 for future telemetry studies. All were captured in gill nets (five near the Monarchs and nine near Maiden Rock). Tagged Lake Trout averaged 746 mm total length (range = 630-1000 mm). A complete list of tagged Lake Trout at-large during the 2019 tracking season is provided in Appendix B.

DISCUSSION

During 2017, 2018, and again in 2019, Lake Trout in Lake Pend Oreille primarily used the same three spawning sites that were identified in the past (Wahl et al. 2011b; Wahl et al. 2013; Wahl et al. 2015b). Additionally, we did not document any significant changes in the spatial extent of spawning along these three spawning areas. However, Lake Trout distribution has changed within the stretches of spawning shoreline that have been identified and targeted with gill nets for several years. Since 2016, Lake Trout were located more frequently and for a longer duration at the Bernard Beach and Windy Point spawning sites, and less frequently during a shorter duration at the Evans Landing spawning site. Fish at the Evans Landing site were primarily in small aggregations in sections of shoreline rather than spread out across the entire spawning site, as was the case in previous years (Wahl et al. 2013; Wahl et al. 2015a). Since 2017, several Lake Trout have been located near Camp Bay and were never located at any of the three traditional sites. This suggests some Lake Trout are spawning in new areas of the lake and additional passive telemetry receivers deployed at new sites in addition to continued active telemetry may help locate new spawning areas or additional areas where Lake Trout congregate to focus netting efforts.

During 2007-2009, we observed almost no movement of Lake Trout among the three spawning sites, but since 2010 we documented that several Lake Trout made repeated trips between spawning sites. The use of stationary receivers since 2011 has improved the resolution of these data because of the increased number of detections compared to mobile telemetry alone. We are unsure of the effect that netting has had on the observed movement patterns in Lake Pend Oreille in recent years. Gill nets set at spawning sites may have directly prevented aggregations from forming through the removal of spawning adults or by hindering access to the spawning locations. Additionally, multiple years of high netting exploitation at spawning sites may have removed large enough portions of the spawning Lake Trout that aggregations were comprised of fewer individuals.

Although spawning aggregations have become more dispersed and fish moved between sites more than in the early years of our telemetry research, the fish were still vulnerable to netting at these primary spawning sites. Even if Lake Trout were not at a single spawning site for the duration of the spawning period, they moved to other spawning sites where netting also occurred. There would be travel time through areas where netting did not take place, but if overall Lake Trout travel rate was higher at the sites than in the past, this might provide a netting advantage where Lake Trout were more likely to encounter a net. Additionally, 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 gillnetting 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 effective location to set gill nets as fish shift their distribution during the spawning period. In the future, setting gill nets in more gangs comprised of fewer nets may prove to be more effective than a single long gang if spawning aggregations within each spawning site continue to shrink. Continued telemetry research is needed to assess whether disturbances from netting cause fish to seek new spawning sites, given this species' ability to colonize new areas (Gunn 1995).

Overall, the use of telemetry to guide gill net placement at Lake Trout spawning sites has been a useful tool over the past several years, which has maximized the efficiency of removal efforts. Telemetry has proven to be a successful method for helping increase exploitation of spawning Lake Trout (Wahl et al. 2015a), and increase the effectiveness of the Lake Trout removal program as a whole. With Lake Trout maturing at age-10 and maximum ages in Lake Pend Oreille beyond age-20, it will likely take many more years to fully collapse the population. However, the spawning segment of the population has been drastically reduced since 2008, and netting juveniles has become more effective in the last several years. Although we continue to see signs of a reducing Lake Trout population at all life stages, we must continue removal efforts in a similar fashion to reach collapse, and using telemetry to guide gill net placement on spawning aggregations will be a key component.

RECOMMENDATIONS

1. Continue to use gill nets to remove spawning Lake Trout from the spawning sites identified in the past.

2. Track Lake Trout during spawning using mobile telemetry to verify that traditional spawning sites are being used and new spawning sites are not colonized. Use patterns identified in spawning distribution to guide gill net placement in the future.

3. Use stationary telemetry receivers to examine movement among the three spawning sites and add additional receivers throughout the lake to learn more about system-wide movements to continue to improve netting efficiencies.

Figure 17. Locations of Vemco acoustic tagged Lake Trout determined by active telemetry tracking during spawning period in 2019, Lake Pend Oreille, Idaho.

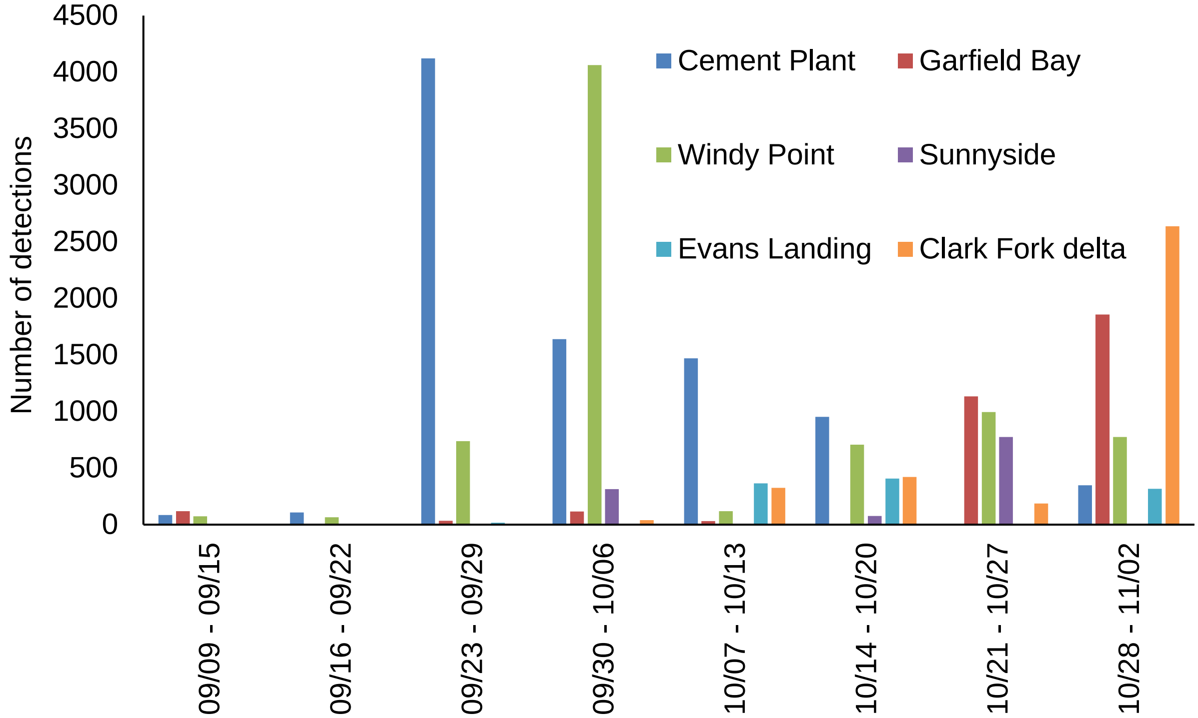

Figure 18. Number of Lake Trout detections by week during spawner netting recorded on stationary receivers between September 9 and November 2 on Lake Pend Oreille, 2019. See Figure 17 for location reference.

CHAPTER 5: RAINBOW TROUT RESEARCH

ABSTRACT

The historic abundance of kokanee *Oncorhynchus nerka* in Lake Pend Oreille provided the forage base necessary for Rainbow Trout *O. mykiss* to grow to world record sizes. However, predation on kokanee by an introduced population of Lake Trout *Salvelinus namaycush* poses a potential threat to the trophy quality of the Rainbow Trout fishery by negatively impacting growth rates and life history traits of this population. In recent years, kokanee abundance has increased following the implementation of a Lake Trout suppression program. The objective of this research is to assess Lake Pend Oreille Rainbow Trout catch rates. Between 2011 and 2019, volunteer anglers have assisted in the collection of Rainbow Trout catch data. Angler catch per unit effort and length frequency of catch was assessed on a yearly basis from 2016 through 2019. Annual catch rates ranged from 0.2 (±0.03) to 0.45 (±0.04) Rainbow Trout per hour and were greatest in 2016. The proportion of annual catch greater than 635 mm ranged from 17 to 24 percent and was greatest in 2018. These findings provide quantitative evidence to validate the biological hypothesis that Rainbow Trout somatic growth is linked to kokanee abundance. This provides further evidence that management actions to improve kokanee abundance benefit and improve the trophy quality of the Rainbow Trout fishery in Lake Pend Oreille.

Authors:

Jeff Strait
PSMFC Fishery Biologist

Pete Rust
Senior Fishery Research Biologist

Matthew P. Corsi
Principal Fishery Research Biologist

William H. Harryman
Senior Fishery Technician

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 per year with up to 523,000 angler-hours of fishing pressure (Jeppson 1953; Maiolie and Elam 1993). In addition to historically providing a popular fishery, kokanee are the forage base that enable Gerrard-strain Rainbow Trout *O. mykiss* in Lake Pend Oreille to reach trophy sizes, including the former world record. However, kokanee abundance substantially declined from historic values, and in the early 2000s the population was at risk of complete collapse (Hansen et al. 2010). High predation rates, primarily created by a rapidly expanding Lake Trout *Salvelinus namaycush* population, were implicated as the primary factor limiting kokanee abundance. In 2006, Lake Trout suppression via commercial netting techniques and an Angler Incentive Program (AIP) was implemented. In order to aid in the recovery of kokanee, Rainbow Trout were added to the AIP program with a $15 bounty and unlimited harvest was allowed during 2006-2012. After kokanee started to rebound following Lake Trout suppression efforts, the management strategy for Rainbow Trout returned to the historical goal of providing a trophy fishery. However, aside from anecdotal evidence from anglers and sporadic creel surveys, there is little data available to advise the management of this population. Standard fishery sampling techniques (i.e. netting, electrofishing, etc.) are not effective capture strategies for Rainbow Trout once they inhabit the pelagic waters of the lake. As a result, Idaho Department of Fish and Game has solicited the help of anglers to record catch and effort data in journals used as a standardized annual monitoring tool to assess the relative abundance and size structure of Rainbow Trout in Lake Pend Oreille. In addition to catch and effort data, anglers also provided pectoral fin rays from Rainbow Trout for use in annual growth analyses. Rust et al. (2018) determined that ages derived from pectoral fin rays sections (non-lethal) were comparable to otoliths for evaluating age and growth parameters. The objectives of this research are to assess Lake Pend Oreille Rainbow Trout catch rates and somatic growth trends and evaluate the impact of kokanee abundance on annual incremental growth.

METHODS

Rainbow Trout catch and effort data were recorded by volunteer anglers from 2016 through 2019. When feasible, anglers provided information on daily catch including total hours fished, number of Rainbow Trout caught, and total length (mm) and weight of each Rainbow Trout caught. These data were used to calculate catch per unit effort (CPUE, # fish /angling hour) and summarizing length frequency distributions of angler catch. Rainbow Trout weight data were not analyzed because available data were limited.

RESULTS

From 2016 to 2019, annual angler catch rates ranged from 0.20 (±0.03) to 0.48 (±0.04) fish per angling hour and the proportion of catch greater than 635 mm has ranged from 17% to 41%. Catch rates were greatest in 2016 and have decreased consistently over the course of the study (Figure 19). However, the proportion of annual catch greater than 635 mm increased from 2016 to 2018, before declining to 28% in 2019 (Figure 20).

DISCUSSION

While angler catch rates in 2019 is the lowest since 2016, the percent of annual angler catch greater than 635 mm (25 inches) remains relatively high. This may indicate an increase in trophy potential of catch, which is a management objective for Rainbow Trout in Lake Pend Oreille.

While the angler catch demographics and predicted mean length at age for this population are promising, these metrics are based on Rainbow Trout total length and do not account for weight information. Fish weight can be an important metric in evaluating trophy potential and condition of fish within a population. In previous years, length-weight ratios have been used to assess the condition of Rainbow Trout in Lake Pend Oreille (Rust et al. 2018; Rust et al. 2019). However, limited sample sizes of weight data in recent years have prevented informative analyses of fish condition. Future analyses of length-weight relationships will provide a more robust indicator of Rainbow Trout trophy potential in Lake Pend Oreille.

Multiple factors such as age, individual specific characteristics (Gjerde 1986), and environmental conditions (Fry 1971; Brett 1979; Sadler and Lynam 1986) can influence yearly somatic growth in fishes. Assessing annual growth using a mixed effects model allows for the influence of these factors on growth to be isolated and evaluated (Weisberg et al. 2010). Therefore, yearly growth specifically attributable to environmental conditions can be assessed. Previous studies have demonstrated the utility in applying this approach to assess factors influencing Salmonid and Catostomid growth (Watkins et al. 2017). In 2018, we applied this approach to assess the influence of kokanee abundance on annual Rainbow Trout growth and found kokanee abundance explains the majority of variation in this element of growth over the timeframe. This finding indicates that availability of this forage base is an important driver of the quality of the trophy Rainbow Trout fishery in Lake Pend Oreille.

Kokanee abundance explains the majority of the variation in Rainbow Trout growth over the course of this study, which is not unexpected as kokanee are the main prey source for piscivorous predators in Lake Pend Oreille. Previous research in Kootenay Lake has also shown that kokanee abundance can be an important predictor of Gerrard Rainbow Trout growth (Andrusak and Andrusak 2015). The impact of kokanee abundance on Rainbow Trout growth demonstrated in this study suggests that management actions that promote abundant kokanee will also likely facilitate the goal of providing a trophy Rainbow Trout fishery in the lake. Additional years of incremental growth data will help validate the magnitude of the relationship between kokanee abundance and Rainbow Trout somatic growth.

RECOMMENDATIONS

1. Increase the sample size of Rainbow Trout weight data and assess condition in 2020.

2. Continue to back-calculate growth increments from Rainbow Trout samples collected in future years and validate the relationship between incremental growth and kokanee abundance.

3. Continue to utilize anglers to collect Rainbow Trout fin rays for annual age and growth analyses.

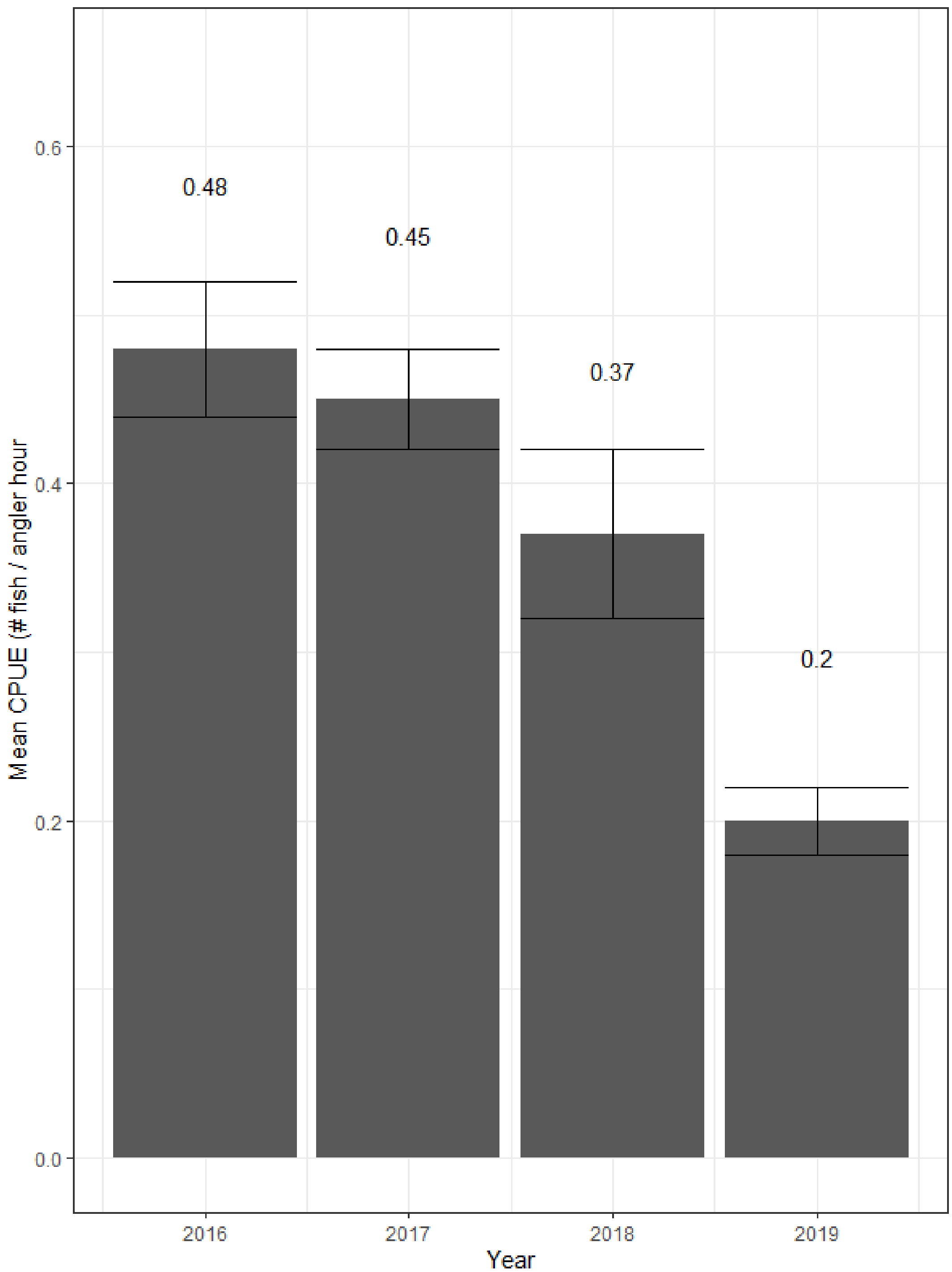

Figure 19. Mean angler catch per unit effort of Rainbow Trout caught per angling hour from 2016 through 2019 in Lake Pend Oreille, Idaho. Error bars denote standard error.

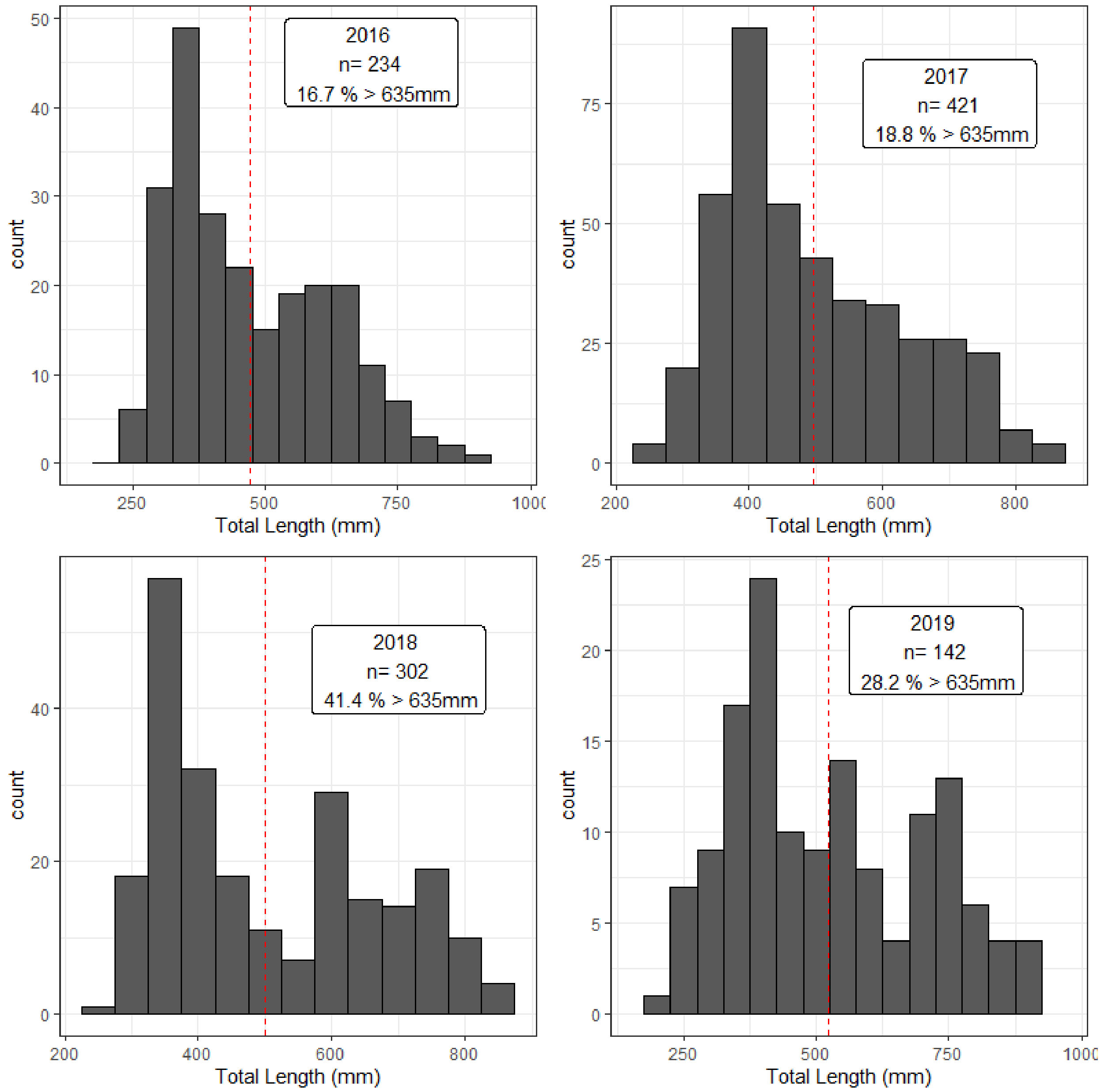

Figure 20. Year-specific length frequency distributions of Rainbow Trout caught by angling from 2016 through 2019 in Lake Pend Oreille, Idaho.

CHAPTER 6: WALLEYE RESEARCH

ABSTRACT

Walleye *Sander vitreus* were illegally introduced into Noxon Reservoir, Montana, upstream of Lake Pend Oreille in the early 1990s. Walleye were established in Lake Pend Oreille at low densities by the mid-2000s and their densities have been steadily increasing. Idaho Department of Fish and Game is concerned about the potential for predation from Walleye to negatively impact the Lake Pend Oreille fish assemblage. As such, we have been investigating opportunities to manage the abundance of Walleye. A tagging study initiated in 2017 suggests that Walleye exploitation is currently around 16%, which is similar to other Walleye fisheries in Idaho, but too low to effectively limit Walleye population expansion without other exploitation alternatives. Walleye in Lake Pend Oreille are believed to be feeding primarily on Kokanee *Oncorhynchus nerka* in the deeper parts of the lake and Yellow Perch *Perca flavescens* and assorted warmwater fish in the shallower areas. We continued the three-week targeted Walleye suppression netting program in spring 2019 and removed 853 Walleyes. This effort will be repeated in 2020, and resulting effects on population parameters will be evaluated in fall 2020 with a standardized Fall Walleye Index Netting program. Telemetry studies initiated in 2017 and continuing through 2019 suggest Walleyes primarily use the northern section of the lake and the Clark Fork and Pend Oreille rivers. Walleyes concentrate seasonally near the Clark Fork and Pack river deltas and other shallow warm bays in the northern sections of the lake but widely redistribute throughout the lake during the summer months. Beginning in fall 2018, we began tagging Walleyes with acoustic transmitters and will begin implementing a passive telemetry receiver array in conjunction with our Lake Trout research to further evaluate Walleye movements and seasonal movement timing throughout the lake-river system. These data will be used to direct anglers to areas where Walleye concentrate, and will help improve netting efficiency for future research studies and management actions.

Pete Rust
Senior Fishery Research Biologist

Matthew P. Corsi
Principal Fishery Research Biologist

INTRODUCTION

Suppression of piscivorous fishes, including Lake Trout *Salvelinus namaycush* and Rainbow Trout *Oncorhynchus mykiss*, has been the focus of the Lake Pend Oreille fishery recovery since 2006. Previous suppression programs have included incentivized sport harvest of Rainbow Trout (ended in 2013) and Lake Trout (ongoing) as well as commercial scale trap net (ended in 2018) and gillnet operations targeting Lake Trout. Through previous research, we had established that reduced kokanee productivity, in concert with an over-abundance of upper trophic level predators had created a predator pit that would have likely led to a complete collapse of kokanee in the system (Hansen et al. 2010, Corsi et al. 2019). The predator suppression program has been a major success and the kokanee population has responded positively.

Walleye, which were illegally introduced into Noxon Reservoir approximately 30 years ago, have become well established throughout Noxon and Cabinet Gorge reservoirs. These reservoirs have provided suitable spawning and rearing habitat for Walleye and downstream drift has led to subsequent invasions into the Idaho portion of the Clark Fork River, Lake Pend Oreille, and downstream into the Pend Oreille River. These fish appeared to have existed in Lake Pend Oreille and the adjoining rivers at low densities in localized habitats for some time. However, more recently walleye collected as by-catch during gillnetting efforts focused on Lake Trout suppression has been increasing throughout the northern and southern basins of the lake. Walleye catch rates during targeted Walleye monitoring efforts (fall Walleye index netting, FWIN) conducted by IDFG Fisheries Management staff in 2011, 2014, and 2017 suggest that densities are doubling about every three years.

An expanding Walleye population has the potential to put several fish populations in Lake Pend Oreille at risk through direct predation and competition. Walleye are prolific piscivores and their establishment in other western lentic systems has led to significant fishery management challenges, particularly where they overlap with salmonid fisheries (MFWP 2016). Lake Pend Oreille represents a critical stronghold for Bull Trout *Salvelinus confluentus* within their native range. Cutthroat Trout *O. clarkii* populations in Lake Pend Oreille are depressed relative to historic abundances, but they appear to be reasonably ubiquitous, thus providing some diversity to the sport fishery as well as life history diversity and conservation value. Rainbow Trout provide a popular world-class trophy fishery that largely depends on abundant kokanee for forage. Kokanee provide a popular yield fishery on the lake and represent a forage base for adfluvial Bull Trout.

Our Walleye population monitoring efforts (netting and telemetry) will establish the necessary baseline information to assess the status of the Walleye population, to evaluate the opportunities for management actions (suppression), and estimate the potential impacts on the current fish community in the Pend Oreille system. In 2019, we implemented an acoustic telemetry program that will allow us to evaluate the number, location, and spatial extent of Walleye spawning aggregations. Using these data, we will be able to target one or several aggregations using commercial gill net gear to collect biological data and assess our fishing power. Additionally, we will continue to evaluate Walleye diet and trophic status in order to determine the scope of their predatory interactions.

Ultimately, this information will be used to establish tolerable management thresholds for Walleye densities and help identify a range of potential management options. Given that burgeoning Walleye populations have a track record of negative fishery consequences in western waters, we will be focusing this project on the efficacy of suppression tools, including physical removal and possible use of emerging suppression technologies.

METHODS

Suppression Netting

To evaluate the feasibility of gill netting as a tool to control Walleye expansion, Hickey Brothers Research LLC was contracted to gill net for three weeks between April 15 and May 3, 2019. Netting effort was focused in areas where concentrations of Walleye were identified from previous telemetry research. Netters used short duration (4-5 hour) gill net sets to target and remove Walleye, while minimizing incidental mortality on other species. Methods are generally similar to those used in Lake Trout suppression netting efforts, which are discussed in detail in Chapter 3 of this report.

Telemetry Research

Beginning in fall 2018, we began tagging Walleyes with acoustic transmitters and implemented a passive telemetry receiver array to further evaluate Walleye movements and seasonal movement timing throughout the lake-river system. These data will be used to direct anglers to areas where Walleye concentrate, and will help improve netting efficiency for future research studies or management actions. To continue to build on our knowledge of general Walleye movements and their life history characteristics in Lake Pend Oreille, we continued our telemetry research in 2019. We surgically implanted Walleye with Vemco transmitters (Vemco Inc., Shad Bay, Nova Scotia, model V16H-4X-69 kHz). Fish were captured during netting operations conducted by Hickey Brothers Research LLC. All Walleye were anesthetized with 30 mg/L of Aqui-S (AquaTactics Fish Health, Kirkland, WA); we only tagged Walleye that were sexually-mature or were greater than 480 mm. Transmitters were inserted through a 2.5 cm surgical incision just off the centerline of the abdomen of the fish anterior to the pelvic fins and pushed back to sit on the pelvic girdle. Incisions were closed with non-absorbable sutures.

Beginning in spring 2019, Walleye were actively tracked using Vemco receiver (model VR-100) and hydrophone (model VH110). We also incorporated an array of 27 Vemco (model VR2W) passive telemetry receivers throughout the lake and adjoining rivers (Figure 21). These (V16p series) tags have a pressure sensor to enable fish depth to be recorded while actively tracking and on stationary receivers. All were captured in gill nets near the Clark Fork delta. A complete list of tagged fish at-large during the 2019 tracking season is provided in Appendices B and C.

To evaluate how Walleyes are distributed throughout the lake and rivers and which areas receive the highest use, we stratified the lake and rivers into five strata (Figure 21). We evaluated the effectiveness of the VR2W array by determining the detection probability of the tagged Walleye among the five strata and among the five seasons. We also evaluated the distribution of detections among the five strata and among the five seasons. Although habitat type has not been classified or quantified on the different areas of Lake Pend Oreille or on the Pend Oreille or Clark Fork rivers, the five strata roughly define the different regions of the lake. Section 1 and 4 represent the Pend Oreille and Clark Fork Rivers, respectively. Section 2 represents the western basin of the lake, and includes relatively shallow water and some of the more productive warmer bays of the lake. Section 3 represents the transition area from the large deeper basin (Section 5) through the Clark Fork River delta (Section 4) to the western section (Section 4 Figure 21). We also evaluated habitat-use metrics based on seasons. These seasons were defined as Prespawn/spring (March 20–May 15), Post-spawn/early summer (May 16–June 20), summer (June 21–September 22), late summer/fall (September 23–November 8), and winter (December 22–March 19).

RESULTS

Suppression Netting

We sampled four sites in 2019 and collected a total of 870 Walleye, of which 853 were removed (Tables 12 and 13). Walleyes were distributed among most of the sampling sites, but the highest catch rates came from the Pack River delta and the Sunnyside area (Table 12). A total of 12 species were collected during the spring sampling, and incidental mortality on Bull Trout and other non-target species was low (<3%;Table 13). Walleye catch rate was similar for males and females. Length of female Walleyes sampled ranged from 345 mm to 815 mm and averaged 563 mm, while males ranged from 325 mm to 710 mm and averaged 487 mm (Figure 22). Over 800 Walleye, Lake Trout, and Northern Pike *Esox lucius* were brought to either the Bonner County Food Bank in Sandpoint or the ABC Food Bank (Athol Gleaners) in Athol for distribution.

Telemetry Research

In the fall of 2018, 20 mature Walleyes ranging from 435 to 910 mm TL and were implanted with Vemco V16p-4X (5-year tag life) sonic transmitters. In the spring and fall of 2019, an additional 40 Walleyes ranging from 575 to 1000 mm TL were implanted with similar transmitters (Appendix C). Tagging occurred between October 16 and November 1, 2018 and between April 15 and May 3, 2019 and again on November 6th, 2019 at three locations (Appendix C).

During 16 days of actively tracking in 2019, we located 15 different Walleye a total of 37 times (Figure 23). Walleye were located primarily in the northern section of the lake near the Clark Fork delta and near Oden Bay and Kootenai Bay (Figure 23). Walleye were also found in Denton Slough and in the shallow water areas in the western basin (Section 2, Figure 23), in areas outside the detection range of passive telemetry receivers. Walleye were also located scattered throughout the Pend Oreille River (Figure 23). No Walleyes were found in the Section 5 during mobile telemetry.

Between March 20 and November 9, 2019, we measured the straight-line distance of 20 individual Walleye as they moved between the stationary VR2W receivers to determine movement extent by season (Figure 24). Mean distance moved during the study period was 366 km (range 61-809 km). Mean weekly distance moved was 13 km (range 1–31 km). Most of the movement occurred during the late summer/fall period and Walleyes moved the least during the prespawn/spring period (Figure 24).

We evaluated the effectiveness of the VR2W array by determining the detection probability of the tagged Walleye among the five strata and among the five seasons. Between 60% and 73% of the tagged Walleye were located on strata 1 through 4 during the season. The probability of Walleye being recorded by receivers in strata 5 were low (Figure 25). Throughout the five seasons, between 60% and 83% of the tagged Walleyes were recorded (Figure 26). The highest probability of detection occurred during late summer/fall and winter. The lowest probability of detection occurred during the post-spawn/early summer period (Figure 26).

We evaluated the distribution of detections among the five strata and among the five seasons. About half of the detections came from strata 4 (Clark Fork River and delta) and strata 1 (Pend Oreille River) had 33% of the detections (Figure 27). Only a few Walleye were located in

Section 5 (Figure 25) and those fish were rarely detected (Figure 27). Most of the Walleye were detected during summer and winter (Figure 28). Only 8% of the detections came during the prespawn/spring and post-spawn/early summer periods (Figure 28).

DISCUSSION

Exploitation studies conducted in 2018 suggest Walleye exploitation rates averaged 16%, which is about average compared to other Walleye fisheries in Idaho (Meyer and Schill 2014). Although Walleye have only been in the system since about the mid-2000s, anglers are targeting them, and learning how to catch them. From the exploitation tags survey questionnaire, anglers reported catching Walleye primarily from the Clark Fork River and the Highway 95 (Sandpoint long-bridge) areas. These areas have been popular with Walleye anglers since at least 2010.

The spring 2017 two-week Walleye netting effort was our first concerted effort to target and tag Walleye. Results from that sampling effort along with results from 2018 and 2019 telemetry studies provided a good foundation for where to target Walleye during the spring. At this point, we have identified three prespawn staging areas at the Clark Fork and Pack River deltas, above the Burlington Northern Railroad Bridge near Sandpoint. We plan to continue spring Walleye suppression netting for three weeks in 2020, and population level effects on density and size structure will be evaluated in fall 2020 with a standardized Fall Walleye Index Netting (FWIN). This FWIN netting has been completed on a three-year rotation beginning in 2011 and is our main tool for tracking system-wide density changes in this Walleye population. Based on results of the previous FWIN surveys, the density has been steadily increasing and doubling about every three years since 2011. The basis for our concerns for this new Walleye population to expand and have negative effects on kokanee and potentially other focal species comes primarily from the FWIN catch metrics. After the 2020 FWIN, we will re-evaluate the effectiveness of relatively small-scale Walleye suppression netting and consider other management actions.

Telemetry studies initiated in 2017 suggested Walleyes primarily used the northern section of the lake and the Clark Fork and Pend Oreille rivers. Walleyes concentrated seasonally near the Clark Fork and Pack river deltas and other shallow warm bays in the northern sections of the lake but appear to widely redistribute throughout the lake and rivers during the summer months, making it difficult to consistently locate Walleye seasonally using active telemetry techniques. Generally, Walleye were shallowest in the water column over the shallowest lake depths in April. Conversely, Walleye were deepest in the water column over the deepest lake depths in May, but depth use varied considerably within and among months. Some Walleye likely suspend in response to kokanee behavior (kokanee layer) after the thermocline forms in June. Evaluating such relationships could provide insight on potential pelagic feeding behavior of Walleye in Lake Pend Oreille.

More recent telemetry studies initiated in 2019 have allowed us to better understand Walleye movement extent or capability as well as seasonal movements and habitat use. This information provides baseline parameters with which we can compare over time as Walleye densities or lake conditions change. We changed telemetry techniques beginning in 2019 from primarily radio telemetry/mobile tracking methods to acoustic telemetry with passive techniques and mobile telemetry options. To date, both techniques have provided the same large-scale view of how Walleye use Lake Pend Oreille and the adjoining river systems. Based on mobile telemetry, the highest-use areas are in the northern and western portions of the lake and include the Clark Fork River and Clark Fork delta, the Pack River delta, Oden and Kootenai Bays, the bridges near Sandpoint, and Denton Slough. There is also high use of the Clark Fork River and

Pend Oreille Rivers seasonally. Results from 2019 suggest Walleye are highly mobile and often move several hundred kilometers throughout the year. Our current VR2W array is effective at detecting Walleyes throughout the year and in all areas of the system except the southern basin. The probability of a Walleye detected in this area is low, likely, because few Walleyes use this area and those that do, only do seasonally. From the passive telemetry array, nearly half of the total Walleye detections in 2019 came from the Clark Fork River and delta area. Although this area likely has the highest densities of Walleyes throughout the year, the locations of receivers in this stratum likely influences the high detection rate. Although active tracking has documented many Walleye in Oden Bay, Kootenai Bay, Denton Slough, and other shallow bays, lack of receivers or poor receiver performance in these shallow areas likely underestimates the percent detection comparisons. Adding additional passive receivers to the array to fill detection gaps will continue to improve system performance moving forward. Focusing active telemetry in shallow, weedy bays where passive receivers function poorly, to fill in the gaps left by the existing VR2W array will provide the best overall picture of how Walleye or other species use Lake Pend Oreille and the adjoining rivers throughout the year.

Table 12. Walleye catch rates (Walleyes per 900 ft. of net) by location from spring 2017, 2018, and 2019-targeted Walleye netting.

Sampling Location	2017		2018		2019	
	Number	CPUE	Number	CPUE	Number	CPUE
Bottle Bay	3	0.8	0	0		
Clark Fork delta			80	6.7	42	1.8
Ellisport Bay	8	2.0	6	0.5		
Fisherman's Is.	93	8.0	31	2.6	68	2.8
Garfield Bay	1	0.1				
Idlewilde Bay	1	0.1				
Kootenai Point			44	3.7	43	1.8
Lees Point	0	0				
Long Beach South	2	0.3				
Martin Bay			1	0.1		
Memaloose Island	4	0.7				
Owens Bay	13	2.2				
Pack River delta	189	9.5	975	11.7	717	7.0
Sandpoint RR bridge	61	5.1	147	16.3		
Sheepherder Point	41	3.7				
Sourdough Point	3	0.8				
Total	419		1284		870	

Table 13. Species caught and numbers removed in gillnets during spring 2019 Walleye netting. Asterisk indicated fish that were dead at time of capture.

Species	Number Caught	Number Released	Number Removed
Walleye	870	17	853
Black Crappie	20	20	0
Brown Trout	25	18	7*
Bull Trout	46	33	13*
Cutthroat Hybrid	4	1	1*
Lake Trout	12	0	12
Largemouth Bass	2	2	0
Northern Pike	72	0	72
Rainbow Trout	24	20	4*
Smallmouth Bass	282	282	0
Westslope Cutthroat Trout	24	21	3*
Yellow Perch	111	111	0

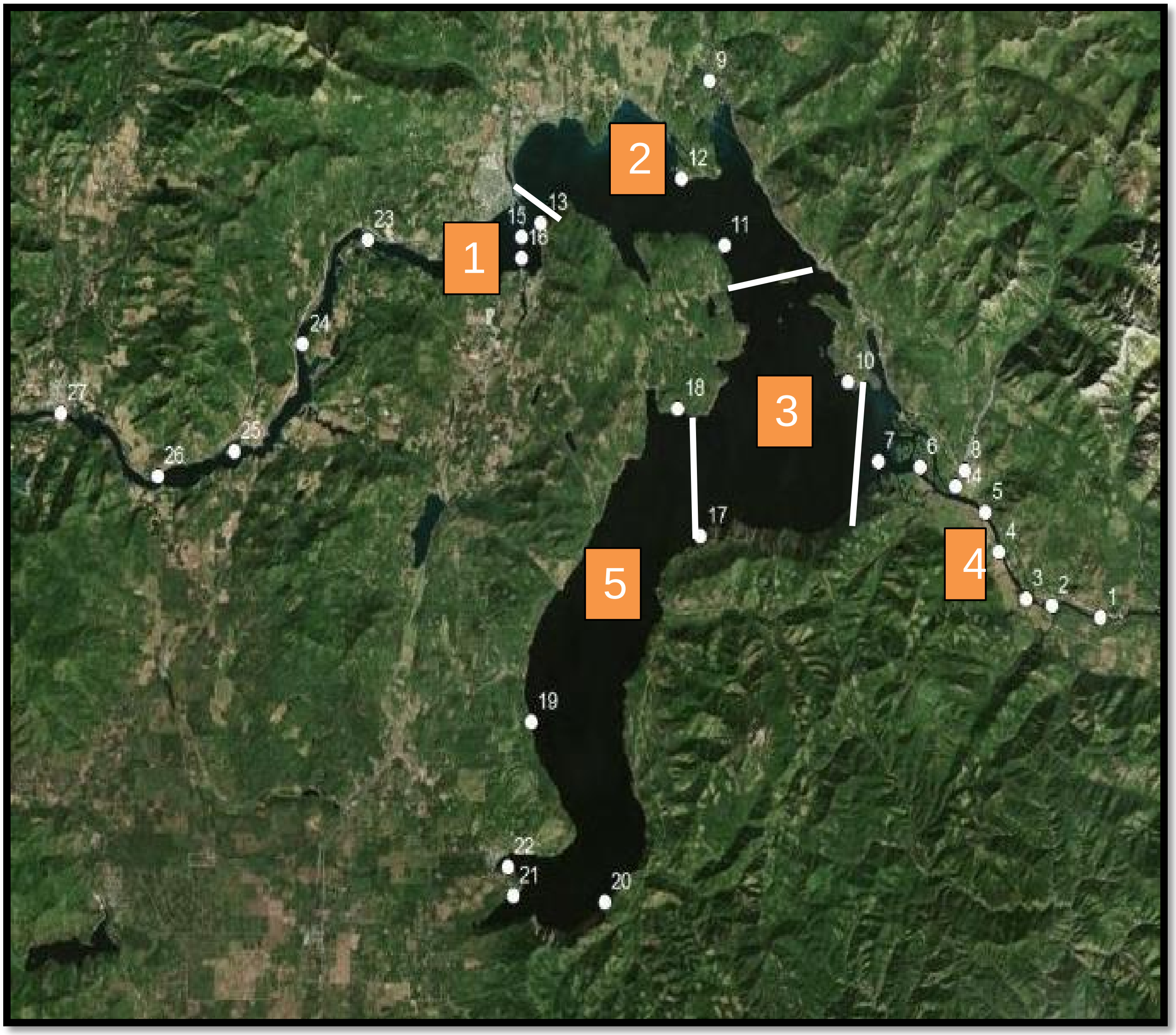

Figure 21. Five habitat strata and locations of 27 Vemco VR2W telemetry receiver in Lake Pend Oreille, and the Clark Fork and Pend Oreille Rivers, 2019.

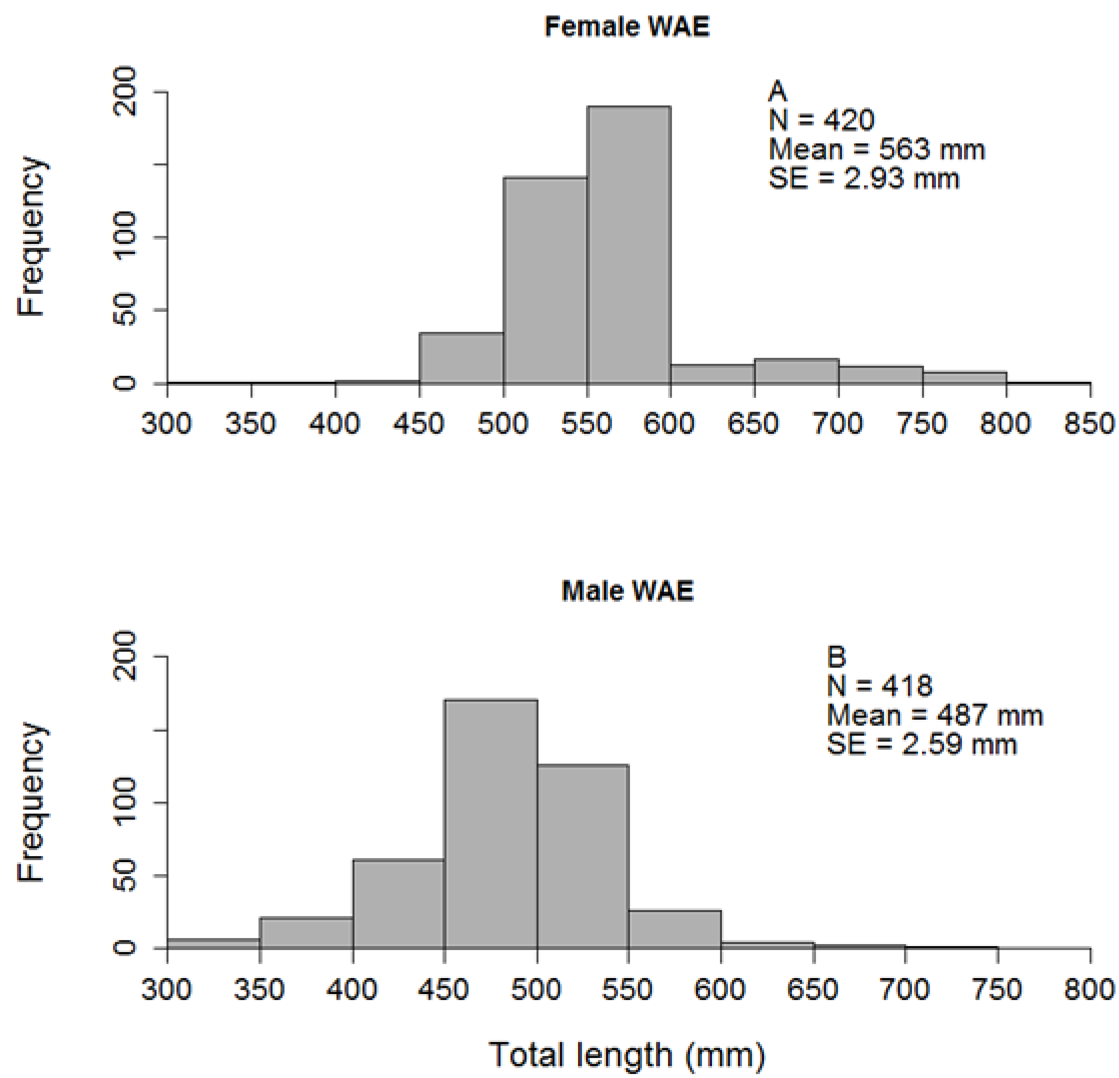

Figure 22. Length-frequency histogram of male and female Walleye captured and removed during targeted suppression netting by Hickey Brothers research LLC with gill nets from April 15–May 3, 2019, Lake Pend Oreille, Idaho.

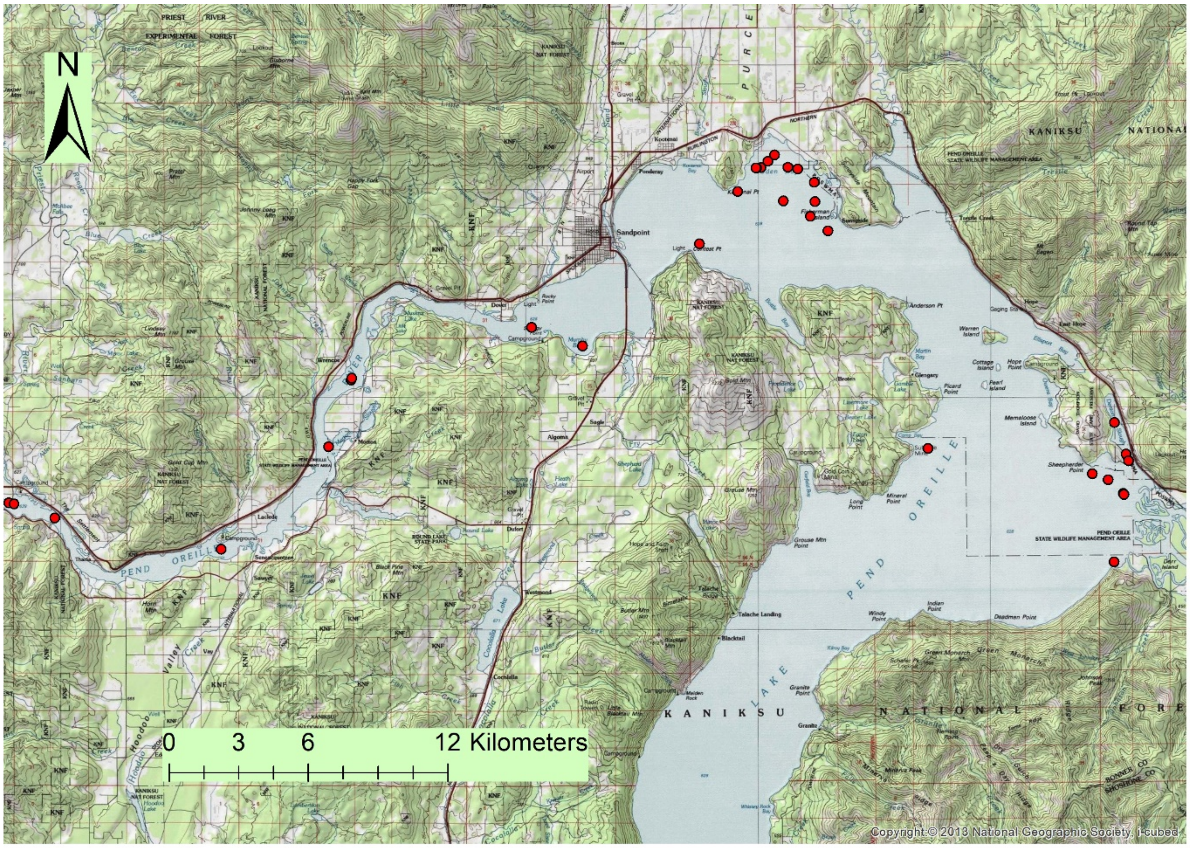

Figure 23. Locations of Walleyes determined by actively tracking in Lake Pend Oreille, and the Clark Fork and Pend Oreille Rivers in 2019.

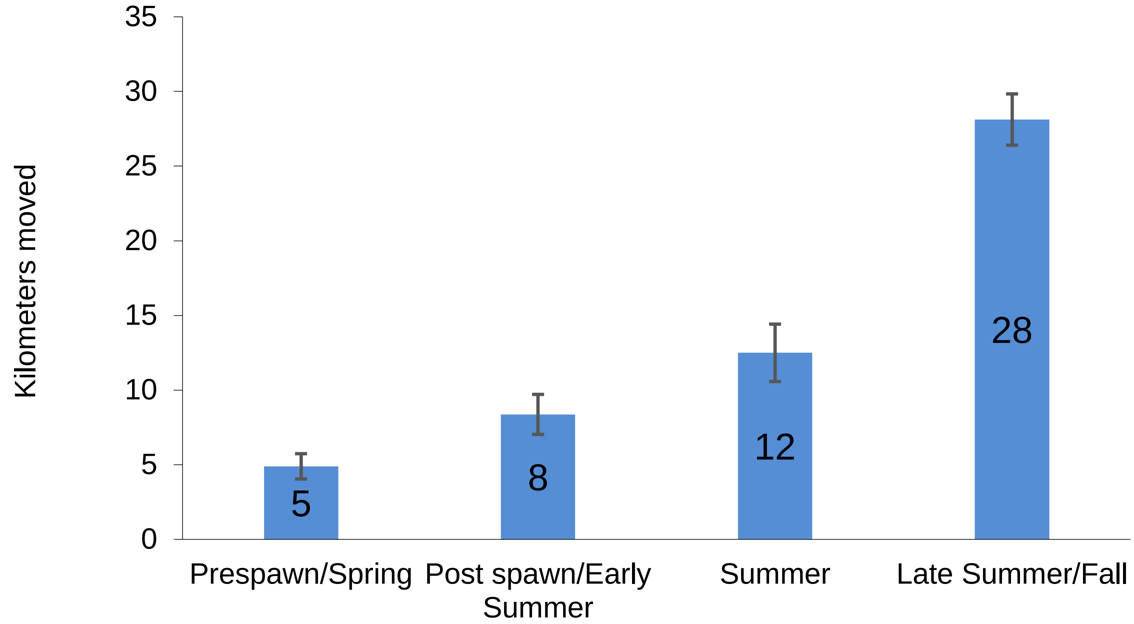

Figure 24. Mean weekly seasonal movement distances of Walleyes in Lake Pend Oreille, 2019.

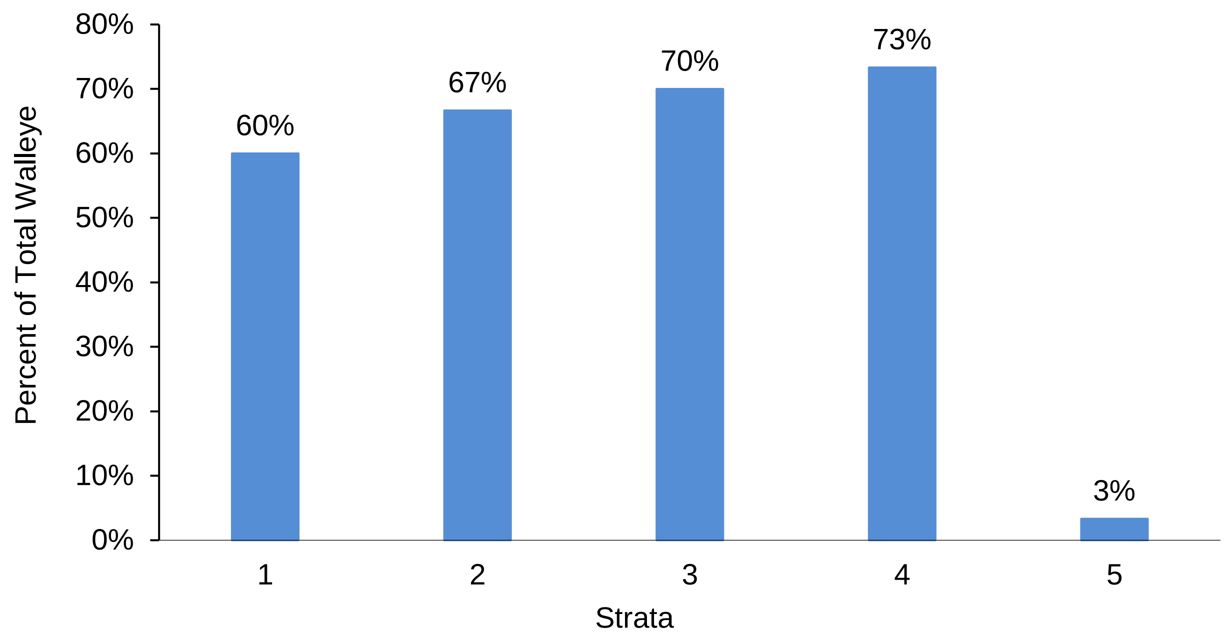

Figure 25. Percentage of tagged Walleye recorded on Vemco VR2W receivers within each strata in Lake Pend Oreille, 2019.

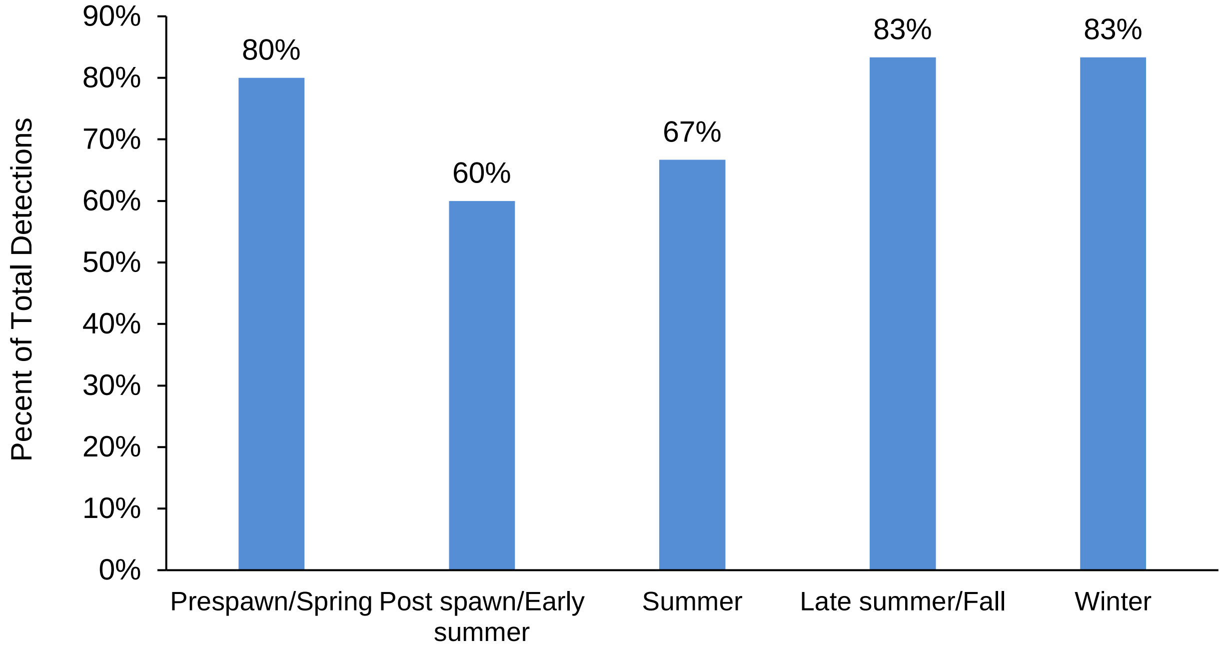

Figure 26. Percentage of tagged Walleye recorded on Vemco VR2W receivers by season in Lake Pend Oreille, 2019.

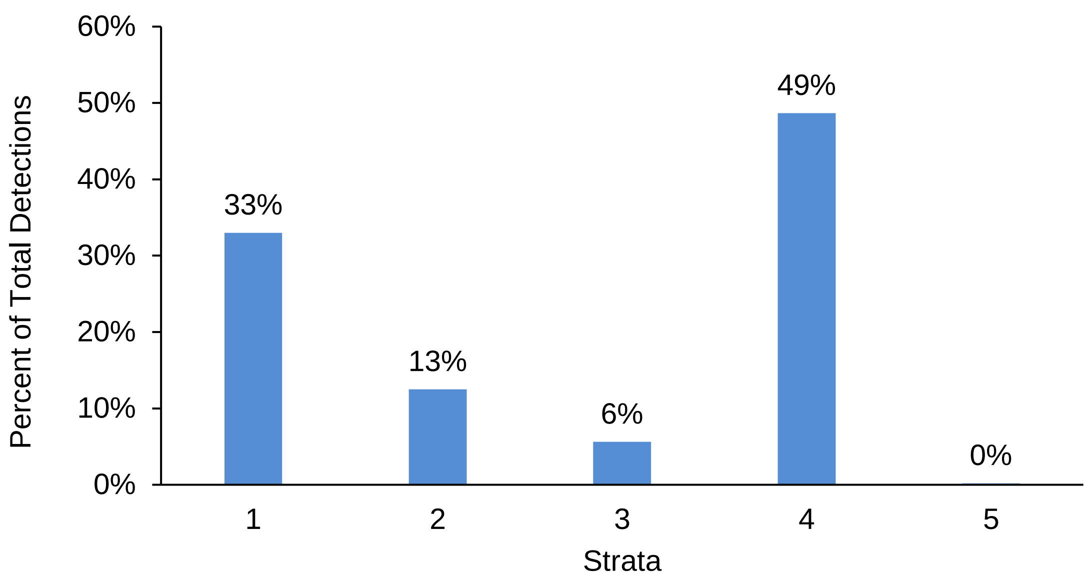

Figure 27. Percentage of total Walleye detections recorded on Vemco VR2W receivers by strata in Lake Pend Oreille, 2019.

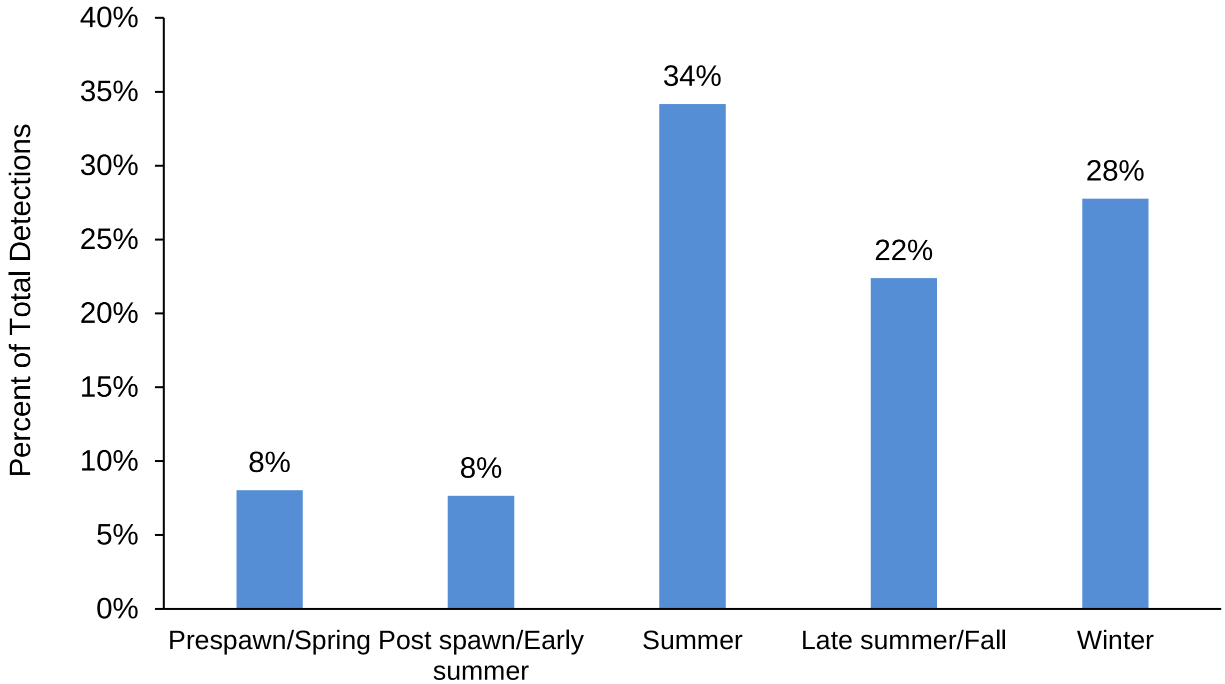

Figure 28. Percentage of total Walleye detections recorded on Vemco VR2W receivers by season in Lake Pend Oreille, 2019.

ACKNOWLEDGMENTS

Many people contributed to making this research project possible. We thank Avista staff Nate Hall, Paul Kusnierz, and Heide Evans for their input and administrative support. This project was funded through Appendix F5 of the Clark Fork Settlement Agreement. Thanks to all the IDFG personnel who volunteered assistance in completing the fieldwork required for this project. Also thanks to the Bonneville Power Administration (BPA) who provided funding for this project and to Cecilia Brown and Jennifer Lord for their help in administering our BPA contract. Additional funding was received from Avista Corporation for the Lake Trout netting and angler incentive programs. The help from these people and agencies was greatly appreciated.

LITERATURE CITED

Andrusak, G. F., and H. Andrusak. 2015. Gerrard Rainbow Trout Growth and Condition with Kokanee Prey at Low Densities-2015. Report prepared for Fish and Wildlife Compensation Program – Columbia Basin by Redfish Consulting Ltd. FWCP Report No. F-F15-15. 31 pp. +8 app. Nelson, British Columbia.

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.

Boscarino, B. 2009. Effects of light on the feeding interactions and spatial distributions of the opossum shrimp, *Mysis relicta*, and the alewife, *Alosa pseudoharengus*, in Lake Ontario. Doctoral dissertation, Cornell University.

Bouwens, K. A., and R. Jakubowski. 2016. 2014 Lake Pend Oreille creel survey. Avista Corporation, Noxon, Montana.

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.

Brett, J. R. 1979. Environmental factors and growth. Pages 599-675 in W. S. Hoar, D. J. Randall, and J. R. Brett, editors. Fish physiology, volume 8. Academic Press, New York.

Britton, L. J., and P. E. Greeson. (Editors). 1987. Techniques of water-resources investigations of the United States Geological Survey. Reston (VA): U.S. Geological Survey Methods for collection and analysis of aquatic biological and microbiological samples, Chap A4.

Carpenter, S. R., J. J. Cole, J. R. Hodgson, J. F. Kitchell, M. L. Pace, D. Bade, K. L. Cottingham, T. E. Essington, J. N. Houser, and D.E. Schindler. 2001. Trophic cascades, nutrients, and lake productivity: Whole-lake experiments. Ecological Monographs 71(2): 163-186.

Clarke, L. R., D. T. Vidergar, and D. H. Bennett, 2005. Stable isotopes and gut content show diet overlap among native and introduced piscivores in a large oligotrophic lake. Ecology of Freshwater Fish 14:267-277.

Corsi, M., M. Hansen, M. Quist, D. Schill, and A. Dux. 2019. Influences of Lake Trout (*Salvelinus namaycush*) and *Mysis diluviana* on kokanee (*Oncorhynchus nerka*) in Lake Pend Oreille, Idaho. *Hydrobiologia*, 840 (1), pp. 351–362.

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.

Dux, A. M., M. J. Hansen, M. P. Corsi, N. C. Wahl, J. P. Fredericks, C. E. Corsi, D. J. Schill, and N. J. Horner. 2019. Effectiveness of Lake Trout (*Salvelinus namaycush*) Suppression in Lake Pend Oreille, Idaho: 2006-2016. Hydrobiologia 840:319-333.

Ellis, B. K., J. A. Stanford, D. Goodman, C. P. Stafford, D. L. Gustafson, D. Beauchamp, D. W. Chess, J. A. Craft, M. A. Deleray, and B. S. Hansen. 2011. Long-term effects of a trophic cascade in a large lake ecosystem. Proceedings of the National Academy of Sciences 108:1070-1075.

Fredenberg, W. 2002. Further evidence that Lake Trout displace Bull Trout in mountain lakes. Intermountain Journal of Sciences 8:143-152.

Fry, F. E. J. 1971. The effects of environmental factors on the physiology of fish. Pages 1-98 in W. S. Hoar and D. J. Randall, editors. Fish physiology, volume 6. Academic Press, New York.

Gjerde, B. 1986. Growth and reproduction in fish and shellfish. Aquaculture 57:37-55.

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

Guy, C. S., T. E. McMahon, C. J. Smith, B. S. Cox, W. A. Fredenberg, and D. W. Garfield. 2011. Diet overlap of top-level predators in recent sympatry: Bull Trout and nonnative Lake Trout. Journal of Fish and Wildlife Management 2:183-189.

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., M. P. Corsi, and A. M. Dux. 2019. Long-term suppression of the Lake Trout (*Salvelinus namaycush*) population in Lake Pend Oreille, Idaho. Hydrobiologia 840:335-349.

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. 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.

Hessen, D. O. 2008. Efficiency, energy and stoichiometry in pelagic food webs; reciprocal roles of food quality and food quantity. Freshwater Reviews, 1(1): 43-57.

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

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.

Johnson, B. M., and P. J. Martinez. 2012. Hydroclimate mediates effects of a keystone species in a coldwater reservoir. Lake and Reservoir Management 28: 70-83.

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.

Klein, Z. B., M. C. Quist, A. M. Dux, and M. P. Corsi. 2020. Ontogenetic diet shifts with potential ramifications for resource competition in a kokanee-Mysis diluviana system. Hydrobiologia, 847: 3951-3966.

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., 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.

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., and E. P. Bergersen. 1991. Interactions of zooplankton, *Mysis relicta*, and kokanees in Lake Granby, Colorado. American Fisheries Society Symposium 9:49-64.

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.

McCauley, E. 1984. The estimation of the abundance and biomass of zooplankton in samples. In A manual on methods for the assessment of secondary productivity in fresh waters. Edited by J.A. Downing and F.H. Rigler. Blackwell Scientific Publications, Oxford, pp.

Meyer, K. A., and D. J. Schill. 2014. Use of a Statewide Angler Tag Reporting System to Estimate Rates of Exploitation and Total Mortality for Idaho Sport Fisheries, North American Journal of Fisheries Management 34: 1145-1158.

MFWP (Montana Fish, Wildlife, and Parks). 2016. Ecology and Management of Montana Walleye Fisheries. Avista document identification number 2016-0449. Montana Cooperative Fishery Research Unit, Montana State University, Bozeman, Montana, and Montana Fish, Wildlife and Parks, Helena.

Nesler, T. P., and E. P. Bergersen. 1991. Mysids in fisheries: hard lessons from headlong introductions. American Fisheries Society Symposium 9.

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.

Parker-Stetter, S. L., L. G. Rudstam, P. J. Sullivan, and D. M. Warner. 2009. Standard operating procedures for fisheries acoustic surveys in the Great Lakes. Great Lakes Fishery Commission, Special Publication 09-01. Ann Arbor, Michigan.

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. 1976. Limnology of Pend Oreille Lake, Idaho, with emphasis on the macro-zooplankton community. M.S. Thesis. University of Idaho, Moscow.

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.

Rieman, B. E., and C. M. Falter. 1981. Effects of the establishment of Mysis relicta on the macrozooplankton of a large lake. Transactions of the American Fisheries Society 110:613-620

Rust, P. J., N. P. Wahl, M. P. Corsi, J. Ament, and W. Harryman. 2018. Lake Pend Oreille Research, 2015. Idaho Department of Fish and Game, Annual Report to Bonneville Power

Administration, Contract Numbers 64992 and 69290, Report Number 18-01, Portland, Oregon.

Rust, P. J., N. P. Wahl, M. P. Corsi, J. Ament, and W. Harryman. 2019. Lake Pend Oreille Research, 2016. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Numbers 64992 and 69290, Report Number 19-02, Portland, Oregon.

Rust, P. J., N. G. Mucciarone, S. M. Wilson, M. P. Corsi, and W. Harryman. 2020. Lake Pend Oreille Research, 2017 and 2018. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Numbers 64992 and 69290, Report Number 19-18, Portland, Oregon.

Sadler, K., and S. Lynam. 1986. Some effects of low pH and calcium on the growth and tissue mineral content of yearling brown trout, *Salmo trutta*. Journal of Fish Biology 29:313-324.

Scheaffer, R. L., W. Mendenhall, and L. Ott. 1979. Elementary survey sampling, second edition. Duxbury Press. North Scituate, Massachusetts.

Schneidervin, R. W., and W. A. Hubert. 1987. Diet overlap among zooplanktophagous fishes in Flaming Gorge Reservoir, Wyoming-Utah. North American Journal of Fisheries Management 7(3): 379-385.

Schoby, G. P., N. C. Wahl, and A. M. Dux. 2009a. 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.

Schoen, E. R., D. A. Beauchamp, and N. C. Overman. 2012. Quantifying latent impacts of an introduced piscivore: pulsed predatory inertia of Lake Trout and decline of kokanee. Transactions of the American Fisheries Society 141:1191-1206.

Simpson, J., and R. Wallace. 1982. Fishes of Idaho. University of Idaho Press, Moscow.

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.

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.

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.

Wahl, N. C., A. M. Dux, W. J. Ament, and W. Harryman. 2013. Lake Pend Oreille Research, 2011. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Number 52380, Report Number 13-22, Portland, Oregon.

Wahl, N. C., A. M. Dux, W. J. Ament, and W. Harryman. 2015a. Lake Pend Oreille Research, 2012. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Numbers 52380 and 57288, Report Number 15-04, Portland, Oregon.

Wahl, N. C., A. M. Dux, W. J. Ament, and W. Harryman. 2015b. Lake Pend Oreille Research, 2013. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Numbers 57288, and 60656. Report Number 15-13, Portland, Oregon.

Wahl, N. C., M. P. Corsi, J. R. Buchanan, W. J. Ament, and W. Harryman. 2016. Lake Pend Oreille Research, 2014. Idaho Department of Fish and Game, Annual Report to Bonneville Power Administration, Contract Numbers 60656 and 64992. Report Number 16-14, Portland, Oregon.

Watkins, C. J., T. J. Ross, M. C. Quist, and R. S. Hardy. 2017. Response of Fish Population Dynamic to Mitigation Activities in a Large Regulated River. Transactions of the American Fisheries Society 146(4):703-715.

Weisberg, S., G. Spangler, L. S. Richmond. 2010. Mixed effects models for fish growth. Canadian Journal of Fisheries and Aquatic Sciences 67:269-277.

Whitlock, S. L., M. C. Quist, and A. M. Dux. 2014. Influence of Habitat Characteristics on Shore-Spawning Kokanee. Transactions of the American Fisheries Society 143:1404-1418.

Whitlock, S. L. M. C. Quist, and A. M. Dux. 2018. Effects of water-level management and hatchery supplementation on kokanee recruitment in Lake Pend Oreille, Idaho. Northwest Science 92:136-148.

Wilson, S. M., and M. Corsi. 2016. Dworshak Reservoir nutrient enhancement research, 2008. Dworshak Dam resident fish mitigation project. Idaho Department of Fish and Game, 16-22, Boise.

Wilson, S., M. Corsi, D. Brandt, and E.J. Stark. 2021. The response of Daphnia to nutrient additions and kokanee abundance in Dworshak Reservoir, Idaho. Canadian Journal of Fisheries and Aquatic Sciences.

Appendix A. Detailed maps of tributaries and shoreline areas around Lake Pend Oreille.

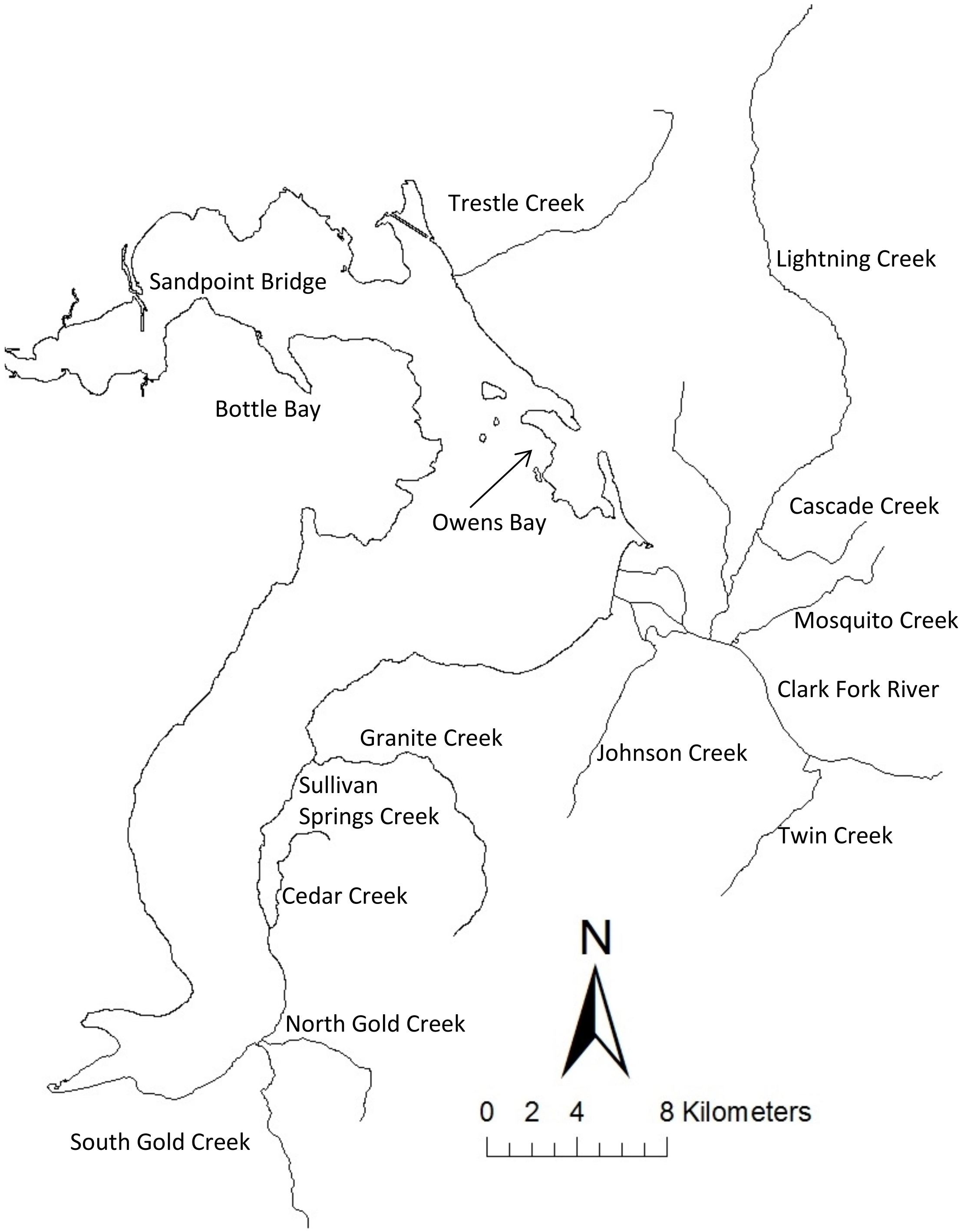

Figure A1. Map of Lake Pend Oreille showing tributaries.

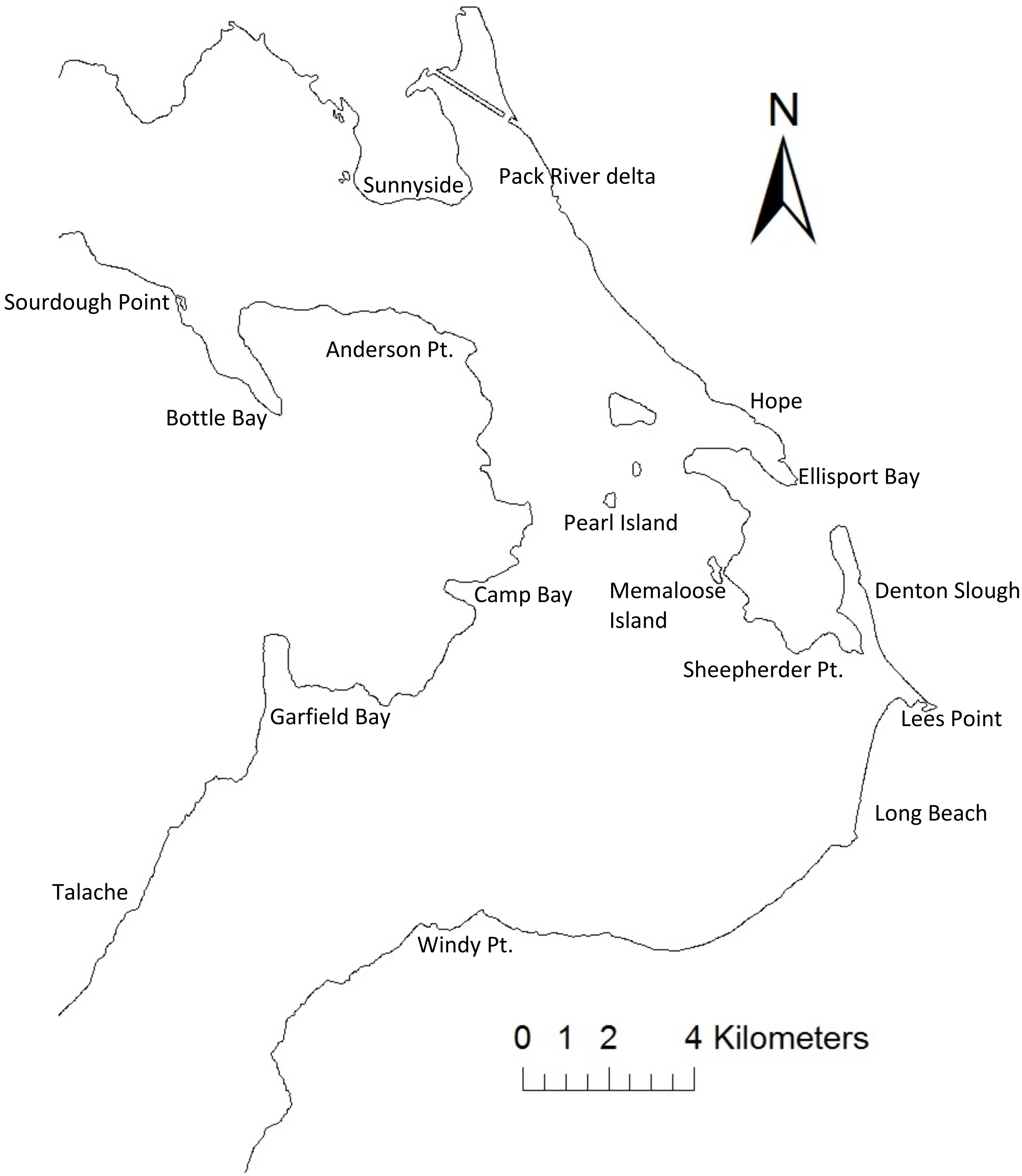

Figure A2. Map of the north half of Lake Pend Oreille showing major landmarks on the lake.

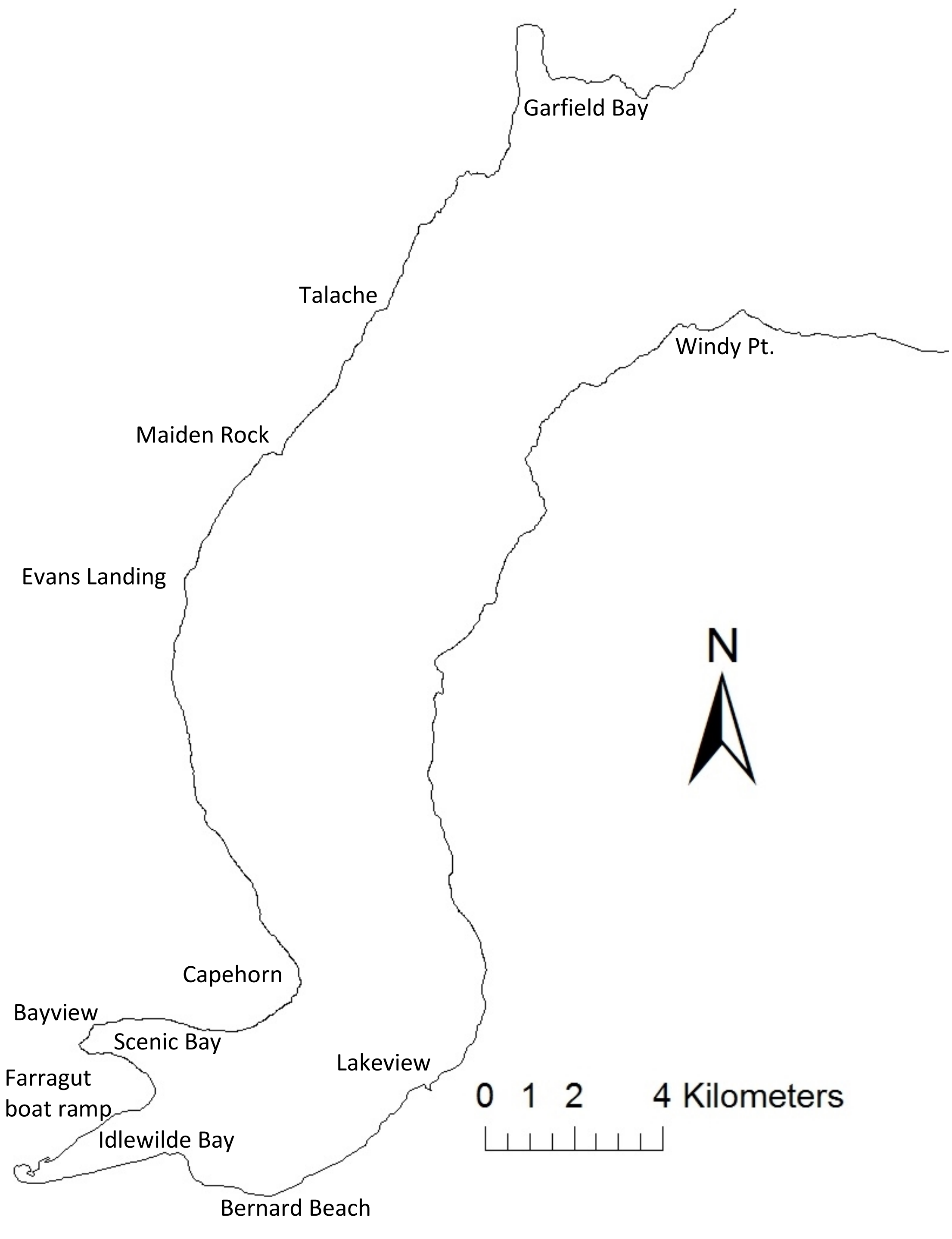

Figure A3. Map of the south half of Lake Pend Oreille showing major landmarks on the lake.

Appendix B. Acoustic telemetry tag specifications for Lake Trout that were active and available for tracking during 2018 and 2019, Lake Pend Oreille, Idaho.

Tag ID	Date Tagged	Transmitter Type	Tag Life (Years)	Capture Location	Total Length (mm)	Sex
8499	10/10/18	Vemco	4	X-slide to plaque rock	795	M
8500	10/10/18	Vemco	4	X-slide to plaque rock	700	M
8501	10/10/18	Vemco	4	X-slide to plaque rock	905	F
8502	10/10/18	Vemco	4	X-slide to plaque rock	750	M
8503	10/10/18	Vemco	4	X-slide to plaque rock	835	F
8504	10/10/18	Vemco	4	X-slide to plaque rock	910	M
8505	10/11/18	Vemco	4	Camp Bay south	871	F
8506	10/11/18	Vemco	4	Camp Bay south	786	F
8507	10/11/18	Vemco	4	Camp Bay south	870	F
8508	10/11/18	Vemco	4	Camp Bay south	623	M
8509	10/11/18	Vemco	4	Camp Bay south	846	M
8510	10/11/18	Vemco	4	Camp Bay south	870	F
5938	10/08/19	Vemco	10	Maiden Rock	1000	M
5939	10/08/19	Vemco	10	Maiden Rock	860	F
5940	10/08/19	Vemco	10	Maiden Rock	695	F
5941	10/08/19	Vemco	10	Maiden Rock	900	F
5946	10/08/19	Vemco	10	Maiden Rock	710	F
5948	10/08/19	Vemco	10	Maiden Rock	840	F
8502-01	10/08/19	Vemco	10	Maiden Rock	730	M
8506-01	10/08/19	Vemco	10	Maiden Rock	650	M
5949	10/08/19	Vemco	10	Maiden Rock	650	F
5942	10/09/19	Vemco	10	Monarchs	690	M
5943	10/09/19	Vemco	10	Monarchs	640	M
5944	10/09/19	Vemco	10	Monarchs	690	M
5945	10/09/19	Vemco	10	Monarchs	630	F
5947	10/09/19	Vemco	10	Monarchs	755	M

Appendix C. Tag ID, tag date, capture location, and size of Walleye with Vemco acoustic tags in Lake Pend Oreille, 2018 and 2019.

Tag ID	Date Tagged	Transmitter Type	Tag Life (Years)	Capture Location	Total Length (mm)	Sex
23128	10/16/18	Vemco	3	LPO River - Dover RR bridge	435	Unk
23125	10/17/18	Vemco	3	LPO River - Dover RR bridge	546	Unk
23123	10/30/18	Vemco	3	LPO River - Dover RR bridge	553	Unk
23126	10/30/18	Vemco	3	LPO River - Dover RR bridge	584	Unk
23132	11/01/18	Vemco	3	Cabinet gorge hatchery	724	F
23124	11/01/18	Vemco	3	Cabinet gorge hatchery	610	Unk
23131	11/01/18	Vemco	3	Cabinet gorge hatchery	597	Unk
23134	11/01/18	Vemco	3	Cabinet gorge hatchery	533	Unk
23133	3/27/19	Vemco	3	Pack River	575	Male
23129	4/10/19	Vemco	3	Pack River	572	Female
21946	4/15/19	Vemco	5	Below Cabinet Gorge	530	Male
21947	4/15/19	Vemco	5	Below Cabinet Gorge	539	Female
21950	4/15/19	Vemco	5	Below Cabinet Gorge	541	Male
21953	4/15/19	Vemco	5	Below Cabinet Gorge	549	Female
21956	4/15/19	Vemco	5	Below Cabinet Gorge	578	Female
21957	4/15/19	Vemco	5	Below Cabinet Gorge	588	Female
21959	4/15/19	Vemco	5	Below Cabinet Gorge	560	Female
23127	4/15/19	Vemco	3	Below Cabinet Gorge	555	Female
23130	4/15/19	Vemco	3	Below Cabinet Gorge	560	Female
21945	5/3/19	Vemco	5	Pack River	542	Male
21948	5/3/19	Vemco	5	Pack River	715	Female
21949	5/3/19	Vemco	5	Pack River	562	Unk
21951	5/3/19	Vemco	5	Pack River	598	Unk
21952	5/3/19	Vemco	5	Pack River	587	Unk
21955	5/3/19	Vemco	5	Pack River	542	Unk
8509-01	5/3/19	Vemco	5	Pack River	710	Female
21955-01	11/6/19	Vemco	5	Clark Fork delta	620	Female
23126-01	11/6/19	Vemco	3	Clark Fork delta	650	Female
5255	11/6/19	Vemco	6	Clark Fork delta	615	Female
5256	11/6/19	Vemco	6	Clark Fork delta	585	Male
5258	11/6/19	Vemco	6	Clark Fork delta	611	Female
5259	11/6/19	Vemco	6	Clark Fork delta	615	Female
5262	11/6/19	Vemco	6	Clark Fork delta	600	Male
5273	11/6/19	Vemco	6	Clark Fork delta	600	Female

Prepared by:

Pete Rust
Senior Fishery Research Biologist

Matthew P. Corsi
Principal Fishery Research Biologist

Ryan S. Hardy
Principal Fishery Research Biologist

Nicole G. Mucciarone
PSMFC Fishery Biologist

Sean M. Wilson
Principal Fishery Research Biologist

William H. Harryman
Senior Fishery Technician

Approved by:

IDAHO DEPARTMENT OF FISH AND GAME

Matthew P. Corsi
Fisheries Research Manager

J. Lance Hebdon
Chief, Bureau of Fisheries