FISHERY RESEARCH

KOKANEE RESPONSE TO HIGHER WINTER LAKE LEVELS IN LAKE PEND OREILLE DURING 2005

LAKE PEND OREILLE FISHERY RECOVERY PROJECT

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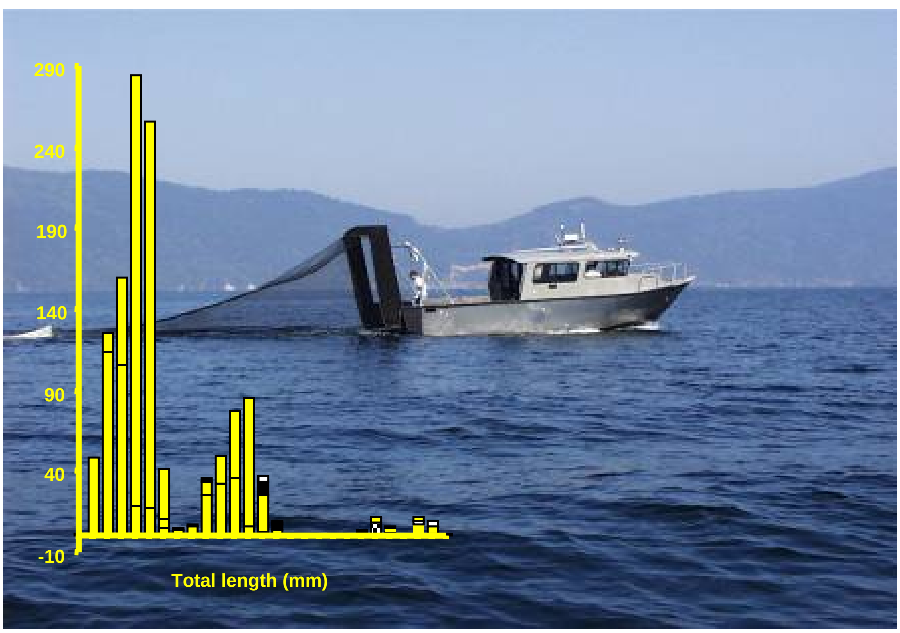

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Kokanee Response to Higher Winter Lake Levels In Lake Pend Oreille During 2005

Lake Pend Oreille Fishery Recovery Project

Project Progress Report, Part 1

2005 Annual Report

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ABSTRACT

Lake Pend Oreille, Idaho was held 1.2 m higher than the previous year in an attempt to improve kokanee *Oncorhynchus nerka* spawning by enhancing shoreline habitat. We estimated that 148,000 female kokanee laid 60.2 million eggs on the lakeshores and in tributary streams during the fall of 2004. From these eggs, an estimated 5.7 million wild fry were produced in 2005 for a survival rate of 9.4%. This was a marked improvement from the 2.0% egg-to-fry survival rate estimated in 2004, when the lake was drawn down to its minimum pool elevation. These results were consistent with past findings and showed the range of benefits attainable by using lake level changes to enhance spawning habitat. Low total biomass of kokanee and poor survival rates between the ages of 1 and 4 indicated this population was in danger of being lost from the lake.

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INTRODUCTION

Lake Pend Oreille, Idaho had been widely known for its kokanee *Oncorhynchus nerka* and trophy trout fishing. Prior to the kokanee fishery closing in 2000, they provided both a popular sport fishery and an abundant prey base for endemic bull trout *Salvelinus confluentus* and trophy Gerrard rainbow trout *Oncorhynchus mykiss*. Since the mid-1960s kokanee numbers have steadily declined, and along with them, the fisheries that relied on them.

During the winter of 2004-05, the water level of Lake Pend Oreille, Idaho was held higher as part of a continuing experiment to enhance kokanee spawning and incubation success (Figure 1). We monitored the kokanee population to evaluate the effect of lake level changes and compare results to previous years. We also estimated abundance of opossum shrimp *Mysis relicta* to determine if they were affecting the outcome of the lake level experiment. Potential spawning areas were monitored by core sampling to see if lake level changes were maintaining spawning habitat. Lastly, we measured zooplankton abundance to determine if it could be limiting the expansion of the kokanee population. These findings were part of a continuing study that was funded by the Bonneville Power Administration to evaluate lake level changes and restore the Lake Pend Oreille fisheries.

STUDY AREA

Lake Pend Oreille is located in the northern panhandle of Idaho (Figure 2). It is the state's largest lake and has a surface area of 38,300 ha, a mean depth of 164 m, and a maximum depth of 351 m. Pelagic habitat used by kokanee is considered to be 22,646 ha (Figure 2) (Bowler 1978). Summer pool elevation of Lake Pend Oreille is 628.7 m. The Clark Fork River is the largest tributary to the lake. Outflow from the lake forms the Pend Oreille River.

Lake Pend Oreille is a temperate, oligotrophic lake. Summer temperatures (May to October) averaged approximately 9°C in the upper 45 m (Rieman 1977; Bowles et al. 1987, 1988, 1989). Thermal stratification typically occurs from late June to September. Operation of Albeni Falls Dam on the Pend Oreille River keeps the lake level high and stable at 628.7 m during summer (June-September) followed by reduced lake levels of 625.1 m during fall and winter (typical dam operation between 1966 and 1996).

A diverse assemblage of fish species is present in Lake Pend Oreille. Native game fish include bull trout**,** westslope cutthroat trout *Oncorhynchus clarkii lewisi*, and mountain whitefish *Prosopium williamsoni.* Native nongame fish include pygmy whitefish *Prosopium coulteri*, 5 cyprinids, 2 catastomids, and one sculpin *Cottus spp*. Kokanee entered the lake in the early 1930s as downstream migrants from Flathead Lake, Montana and were well established by the 1940s. At its peak in 1953, the estimated harvest of kokanee was around 1.3 million fish. Other introduced game fish include Gerrard rainbow trout*,* lake whitefish *Coregonus clupeaformis*, and lake trout *Salvelinus namaycush,* in addition to several other cold-, cool-, and warmwater species.

PROJECT GOAL

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

PROJECT OBJECTIVES

Objective 1. Recover kokanee abundance so that the population could support a harvest of 750,000 fish on an annual basis.

Objective 2. Have no net change in the amount of shoreline spawning gravel (maintain 1.7 million sq. ft.) due to erosion or siltation during this experiment.

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

Objective 4. Improve hatchery stocking program so that it contributes 375,000 kokanee to the harvest.

METHODS

Kokanee Population

Hydroacoustic Population Sampling

We conducted lakewide hydroacoustic surveys on Lake Pend Oreille between August 22 and August 26, 2005 to monitor the kokanee population. Surveys were conducted at night when kokanee are more evenly distributed. A Simrad EK60 portable scientific echo sounder equipped with a 120 kHz split beam transducer set to ping at 0.6 s intervals was used to perform mobile hydroacoustic surveys. The transducer was located 0.5 m under the lake surface and placed in a downlooking position off the port side of the boat. The echo sounder was calibrated for signal attenuation to the sides of the acoustic axis using Simrad's software.

A stratified systematic sampling design was used in our survey. We followed a uniformly spaced, zigzag pattern of transects moving from shoreline to shoreline as described by MacLennan and Simmonds (1992). Twenty-one transects were completed in the lake with eight in the southern section, six in the middle section, and seven in the northern section (Figure 2). Transect lengths ranged from 3.6 km to 7.7 km and were located using a global positioning system (GPS). For all transects we utilized a 7.3 m boat and maintained a speed of approximately 1.3 m/s (boat speed did not affect our calculations of fish density).

We determined kokanee abundance using echo integration techniques. Echoview software version 3.10.135.03 was used to view and analyze the collected data. Hydroacoustic traces (a single returned echo from a fish) were accepted if they were over -60 dB and the echo length was between 30% and 180% of the original pulse length at the point of 6.0 dB below the peak echo value. Additionally, the correction value returned from the transducer gain model could not exceed a two-way maximum gain compensation of 6.0 dB (therefore, it included all targets within the 3.0 dB beam width) and the maximum standard deviation of the minor and major axis angles was less than 0.6 degrees.

Once kokanee targets met the above criteria, we calculated density estimates of kokanee in each transect using the Echoview software. A box was drawn around the kokanee layer on each echogram to define the area sampled (usually between the 10 m and 50 m depths). The area in the box was integrated to obtain the nautical area scattering coefficient (NASC) and analyzed to obtain the mean target strength of all returned echoes. This integration accounted for fish that were too close together to be detected as a single target (MacLennan and Simmonds 1992). Densities were then calculated by the equation:

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

where:

NASC is the total backscattering in m^2/nautical $mile^2$, and
TS is the mean target strength in dB for the area sampled.

To determine a population estimate for kokanee, we first log transformed [log (x+1)] the density estimates to calculate a geometric mean density. We then multiplied the geometric mean density of kokanee for each lake section by the area of each lake section. Abundance in each of the three sections was then summed to estimate the total population.

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

Once density estimates for kokanee were determined, we calculated 90% confidence intervals for lakewide abundance estimates by standard expansion formulas for stratified sampling designs using log transformed data [log (x+1)] (Scheaffer et al. 1979):

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

where:

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

To estimate abundance of hatchery and wild fry, we used two different methods to ensure data were comparable to previous methods and to utilize a potentially more accurate technique. First, we took the total hydroacoustic estimate of fry in each section of the lake and multiplied it by the proportions of wild and hatchery fry collected in midwater trawls (described below) for that section. As a second approach, hydroacoustic fry abundance in each section was multiplied by the proportions of wild and hatchery fry collected with a smaller fry net (described below) in that section. For both methods, estimates of wild and hatchery fry in each lake section were summed to get lakewide abundance estimates of fry. Pelagic targets between -58.0 and -46.0 dB (20 mm to 85 mm based on Love 1971) were considered kokanee fry. Hatchery fry collected by netting were identified based on the presence of cold brand marks on otoliths (described below) verified by Washington Department of Fish and Wildlife.

We also estimated the potential egg deposition (PED) of kokanee using the hydroacoustic data. The acoustic estimate of age 1-4 kokanee (-45.9 dB to –33 dB) in each lake section was multiplied by the percentage of mature kokanee caught in the midwater trawl in that section. We then divided this number by two to obtain the number of females. The number of mature female kokanee collected by hatchery crews was subtracted from the population estimate of mature female kokanee to obtain the number of wild spawners. The wild spawner estimate was then multiplied by kokanee fecundity to obtain wild PED. The number of wild fry was divided by last year's wild PED to estimate wild egg-to-fry survival.

Midwater Trawling

We conducted midwater trawling in Lake Pend Oreille from August 29 to September 2, 2005. These dates were during the dark phase of the moon, which optimized the capture efficiency of the trawl (Bowler et al. 1979).

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

Rieman (1992) described in detail the sampling procedures for midwater trawling. However, the net used in our study was somewhat different. We used a fixed frame that was 10.5 m long, 3.01 m tall and 2.2 m wide at the mouth. This net had a rigid steel frame that kept the mouth of the net open and, therefore, did not have otter boards preceding the net mouth. Mesh sizes (stretch measure) graduated from 32, 25, 19, and 13 mm in the body of the net to 6 mm in the cod end. We towed the net through the water at a speed of 1.72 m/s by an 8.8 m boat. We determined the vertical distribution of kokanee by using a Furuno Model FCV-582 depth sounder with a 10° transom mounted transducer. A stepwise oblique tow was conducted along each transect to sample the entire vertical distribution of kokanee, with each step lasting for 3 min (a step corresponded to a 3 m depth strata).

Kokanee from each trawl sample were counted and placed on ice until processed (fry were placed on dry ice to quickly freeze them). Age-1 to -4 kokanee were processed the next day without being frozen. Fry were kept frozen until analyzed. Length and weight were recorded for individual fish, and all kokanee over 180 mm were checked for maturity. Scales and otoliths were taken from 10 to 15 fish in each 10 mm size interval for aging, if available. Otoliths from 112 fry and 132 kokanee between the ages of 1 and 4 were sent to the Washington Department of Fisheries Otolith Laboratory for aging and identification of cold brands to determine the origin of fish (wild or hatchery).

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

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

Potential egg deposition (PED) was also calculated based on midwater trawl catch. Percent maturity within each 10 mm length group was multiplied by the population estimate for that length group and then summed across length groups. We assumed 50% of the mature population was female based on past sampling. The number of mature females in the lake was then multiplied by the mean fecundity seen at the Sullivan Springs Spawning Station to estimate potential egg deposition. Mean fecundity was determined by dissecting 20 female kokanee from three periods (beginning, middle, and end) of the spawning run (n = 60). We subtracted the number of females spawned by hatchery personnel at the Sullivan Springs egg-take station and trap mortalities to determine the number of eggs spawned by wild fish (wild PED) based on trawling.

Fry Netting

We sampled Lake Pend Oreille with a small mesh net as an additional method to estimate kokanee fry abundance. Sampling with the fry net began on Lake Pend Oreille in 1999 and has continued annually thereafter. Net hauls were made during the same new moon period as that year’s midwater trawling to make the results comparable. Ten net hauls were made in each lake section during September 6-8, 2005 (Figure 4).

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

Stepwise oblique tows were made through the layer of kokanee seen on the boat’s echo sounder. Fry net depths ranged from 14 m to 42 m. The fry net was towed for three minutes at each “step” (a step corresponded to a 3 m depth strata) until the entire kokanee layer had been sampled. The average boat speed was 1.7 m/s.

All kokanee caught in the fry net were immediately frozen on dry ice. Upon return to the laboratory, the fry were stored in a freezer for later analysis. The fish were later thawed and measured for length and weight. Otoliths were removed from kokanee fry (n = 99) caught in the fry net and sent to the Washington Department of Fish and Wildlife Otolith Lab for analysis.

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

Hatchery Fry Marking

All kokanee produced at the Cabinet Gorge Fish Hatchery since 1997 have been marked by “thermal mass marking” techniques (or cold branding) described by Volk et al. (1990). Therefore, hatchery kokanee of any age should contain thermal marks. Thermal treatments were initiated five to ten days after fry entered their respective raceways. Fry released in 2005 (brood year 2004) received an 11 day pattern created by four coolwater events. The first, second, and third events were separated by three days and the third and fourth events were separated by one day. Ten fry from each raceway were sacrificed to verify the thermal marking. Recognizable otolith marks were verified on all thermally treated individuals.

During the spring of 2005, Cabinet Gorge Fish Hatchery released 16.27 million thermally marked kokanee fry into Lake Pend Oreille. Of this total, 966,079 fry were of the early spawning strain and the remainder the late spawning strain. We sent 343 otoliths from all kokanee age classes collected during the 2005 trawling to the Washington Department of Fish and Wildlife lab to determine origin. Before shipment, we catalogued each fish; recorded total length and weight; and removed, cleaned and numbered the otoliths. Washington Department of Fish and Wildlife personnel removed one otolith from each of the 343 vials and oriented it on a glass plate labeled to associate the otolith with the specimen vial. Under a fume hood, otoliths were positioned on a glass plate and surrounded with a preformed rubber mold. Rubber molds were then filled with clear fiberglass resin and warmed in an oven for approximately 1 h for curing. The resulting blocks of resin containing the otoliths were cut into groups of four otoliths per block for sectioning and polishing. Blocks of four otoliths were lapped on a rotating disc of 500 grit carborundum paper until the nucleus of each otolith was clearly visible. The otoliths were then polished using a rotating polishing cloth saturated with one micron deagglomerated alpha alumina and water slurry. After lapping and polishing, the otoliths were examined with a compound microscope at 200 power and/or 400 power magnification. Patterns within the otolith were compared to those reference samples taken from the hatchery during fry rearing since 1996. For accuracy, two independent readers examined each otolith. Differences between the readers were settled by re-examination.

Biomass, Production, and Yield

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

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

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

We regressed both production and yield against kokanee biomass to determine where these two lines cross. At that point, production and yield were equal and indicated predator and prey were in balance. Data from 1996 to 2004 were used to plot the trend lines. However, we excluded the flood year of 1997 since significant kokanee mortality occurred that was likely not due to predation. Data from 2005 were added to the graph to see if it indicated a change in the predation level in the lake.

Spawner Counts and Surveys

We counted spawning kokanee in standard shoreline areas (Appendix A) and tributaries to continue this time-series data set dating back to 1972. All areas surveyed have been documented as historic spawning sites (Jeppson 1960). Nine shoreline areas and seven tributary streams were surveyed the first week of December. All kokanee, either alive or dead, were counted.

The seven tributary streams were surveyed by walking upstream, from their mouth to the highest point utilized by kokanee. Streams included South Gold Creek, North Gold Creek, Cedar Creek, Johnson Creek, Twin Creek, Spring Creek, and Trestle Creek (which supports both an early and late run of kokanee). Trestle Creek, which supported a run of early-spawning kokanee, was also surveyed on September 20, 2005 to assess this stock.

Gravel Sampling

We investigated the quality of shoreline substrates around Lake Pend Oreille to determine their suitability for kokanee spawning. Six sites were sampled during mid-July 2005 to monitor changes in substrate composition after being submerged by higher summer pool levels for one year. Scuba divers identified a gravel band between elevation 624.8 msl and 625.8 msl and collected 4-5 randomly located samples from each of the six sites. Divers scooped approximately two liters of substrate into a container and sealed it underwater to eliminate the loss of fine material during transport to the surface. Samples were allowed to dry before each sample was screened using soil sieves (sizes 31.5 mm, 6.3 mm, 4.0 mm, and 2.0 mm). The substrate retained on each screen and the substrate that fell through the finest screen were then weighed and calculated as a percent of the weight of the total sample. We defined "cobble" as substrates that were 31.5 mm and larger, "gravel" as substrates between 31.5 and 4.0 mm, and "fines" as the substrate smaller than 4.0 mm.

Spawning Gravel Cleaning

We cleaned two separate areas of shoreline to observe if clean spawning substrate would attract kokanee spawners. Two 5 m^2 areas were cleaned near the Bayview Resort in Scenic Bay (Figure 2). The areas were at an elevation of 625 m where they would be approximately 1 to 1.5 m below the water surface in years of higher winter lake levels. Substrate in these areas consisted of a high percentage of fine material mixed with gravel suitable for spawning.

A cleaning device was built similar to a large version of an aquarium gravel vacuum using a 1.2 m long x 15 cm diameter polyvinyl chloride (PVC) pipe, 4.6 m of intake hose, 122 m of output hose, and a dredge pump. The 15 cm diameter tube of PVC pipe had two holes cut into it at the lower end covered securely with pieces of clear Plexiglas to serve as windows. These windows allowed the visual observation of silt, sand, and gravel being pulled up into the tube. Suction would pull the sand and gravel up into the pump, but the heavier gravel would drop back out of the intake tube. The 4.6 m intake hose connected the PVC tube to the dredge pump using the appropriate reducers in order to go from 15 cm to 8 cm diameter. The output hose was attached to the dredge pump and extended out 122 m into the lake. With the pump operating, one diver used a 4-tine rake and loosened the substrate while the second diver swept back and forth with the PVC tube vacuuming up the loose fines and sands.

Other Biotic and Abiotic Factors

Shrimp Abundance

We sampled opossum shrimp *Mysis relicta* from June 5-7, 2005 to estimate their abundance within Lake Pend Oreille. All sampling occurred at night during the dark phase of the moon. The new moon during June has been the standard sampling date for our shrimp sampling since 1997. We selected 15 sampling locations randomly in each of the three lake sections, five more than previous years, to improve population estimates and tighten confidence intervals (Figure 5). Global Positioning System coordinates were utilized to locate each sample site.

We collected shrimp using a 1 m hoop net equipped with a Kahl Scientific pygmy flow meter with an antireversing counter. Net mesh and cod-end bucket mesh measured 1,000 μm and 500 μm, respectively. The net was lowered to a depth of 45.7 m (150 ft), allowed to settle for 10-15 seconds, and raised to the surface at a rate of 0.5 m/s using an electric winch. Collected shrimp were placed in denatured ethanol for preservation until laboratory analysis could be performed to determine age and sex data. This methodology has been the standard since 1997.

During lab analysis, Mysids were viewed under a dissecting scope to determine sex and length. Total length was measured from the tip of the rostrum to the end of the telson, excluding setae. Shrimp were classified into five categories according to sex characteristics: young of year (shrimp measuring <11 mm in total length), immature males and females, and mature males and females (Gregg 1976, Pennak 1978). Density of shrimp was based on the number of shrimp in each sample and the amount of water filtered based on the flowmeter reading. We calculated the arithmetic mean density for young-of-the-year shrimp separate from the density estimate of immature and adult shrimp. A 90% confidence interval (CI) was calculated for the overall mean densities.

Limnology

From April through October 2005, we measured water temperature and water clarity (Secchi transparency) monthly. Data were collected at one station at the approximate center of the lake (Figure 2). Sample dates were approximately the middle of each month. We used a Yellow Springs Instrument Company model 57 meter to measure temperature and dissolved oxygen from the surface to a depth of 59 m. The meter was calibrated before each survey using the “water saturated air” method suggested by the manufacturer. Water clarity was monitored using a 20 cm diameter Secchi disc during each survey.

Zooplankton Quality Index

Zooplankton were collected monthly from mid-April through mid-November using two plankton nets with differing mesh sizes (Teuscher 1999). Both nets were 0.5 m in diameter and 1.5 m long with a PVC collection bucket on the cod end. Mesh sizes were 750 micron for the large meshed net, which corresponds to large, “preferred” food items for rainbow trout. The smaller meshed net had 500 micron mesh to collect samples of “available” zooplankton. We collected two vertical tows with each net, from 45.7 meters to the surface, at each of three sampling sites (Figure 2) for 12 samples per month. These samples were stored individually in bottles containing a solution of 50% alcohol and 50% water by volume for a standardized period of two to 10 days as described in Teuscher (1999). The sample was then strained using a 0.15 mm sieve and rinsed with fresh water. The zooplankton were picked from the screen using forceps, blotted dry on filter paper (coffee filters) to remove excess moisture, and weighed to the nearest milligram. The six samples for each mesh size were averaged to obtain a whole lake value.

We then calculated a zooplankton proportion ratio (ZPR) and zooplankton quality index (ZQI). ZPR is a ratio of large zooplankton to smaller zooplankton and represents potential cropping of larger, preferred food items. It is calculated by dividing the mean weight of zooplankton in the 750 micron mesh net by the mean weight of zooplankton in 500 micron net. ZQI combines the ZPR and the weight of both samples to derive an index of the potential of the body of water to support a planktivorous fish population. It was calculated by multiplying ZPR times the sum of the weights of zooplankton in both size nets.

RESULTS

Kokanee Population

Hydroacoustic Population Sampling

In 2005, we estimated the lake contained 16.1 million (13.9 million to 18.5 million, 90% CI) kokanee, or 709 fish/ha, based on our standard nighttime hydroacoustic surveys. This included 12.5 million age-0 kokanee (10.8 million to 14.3 million, 90% CI) and 3.6 million (3.1 million to 4.2 million, 90% CI) kokanee of ages 1-4 (Tables 1 and 2). Mean target strengths of kokanee traces showed a separation between kokanee fry and larger fish at the –46 dB level or a fish length of about 85 mm (Figure 6). This corresponded closely to the gap in the length-frequency distribution of trawl samples between fry and age-1 kokanee. A second dip in the target strength distribution was found at -40 dB (175 mm), which corresponded to the upper length limit of age-1 kokanee. However, as consistent with past years, we separated kokanee of ages 1 to 4 based on their percent frequency in trawl samples for each section of the lake (Table 2). The lake contained an estimated 3.1 million age-1, 165,000 age-2, 200,000 age-3, 139,000 age-4, and 16,000 age-5 kokanee.

We also split the hydroacoustic estimate of age-1 to age-4 kokanee into the number of mature kokanee based on the percentage of mature fish in the trawl catch within each section. This served as an estimate of mature fish abundance somewhat independent of possible trawl bias. In the trawl, 15.7%, 1.9%, and 7.7% of the catch were mature in the southern, middle, and northern sections, respectively. This yielded an estimate of 269,000 mature kokanee or 134,000 mature female kokanee assuming a 50:50 ratio of males to females. The hatchery crew collected 35,000 female kokanee leaving 99,000 female kokanee to spawn in the lake and tributaries. Fecundity of female kokanee at the egg-take station at Sullivan Springs averaged 511 eggs/female, yielding a wild PED estimate of 50.5 million eggs.

Based on hydroacoustics, we calculated the survival rate of each year class of kokanee between 2004 and 2005. Survival was 46% from age-0 to age-1, 15% from age-1 to age-2, 26% from age-2 to age-3, and 28% from age-3 to age-4 (Table 3). Survival rates were also plotted over recent years. Survival of kokanee from age-1 to age-2 was found to have a downward trend (Figure 7).

The abundance of wild fry was estimated based on the percent caught in our fry net and the hydroacoustic estimate of fry. Wild fry made up 54.6%, 54.6%, and 30.3% of the fry net catch in the southern, middle, and northern sections, respectively (Table 1). Based on these numbers we estimated the wild fry population at 5.67 million. The survival of naturally deposited eggs (60.2 million deposited in 2004) to wild fry was 9.4% (Table 4).

Midwater Trawling

Kokanee population estimates were also made based on midwater trawling. In August 2005, total kokanee abundance based on geometric means was 9.876 million fish (-10% to +11%, 90% CI) with a density of 436 fish/ha (Table 5). This included 7.173 million kokanee fry, 1.870 million age-1 kokanee, 50,000 age-2 kokanee, 61,000 age-3 kokanee, 29,000 age-4 kokanee, and 6,000 age-5 kokanee. The total standing stock of kokanee was 3.04 kg/ha (Table 6). The five age groups ranged in length from 29 mm to 288 mm (Table 5 and Figure 8).

Based on this trawling, the lake contained 202,000 mature kokanee. Using a 50:50 ratio, there were 101,000 females spawning in 2005. Hatchery crews collected 35,000 female kokanee leaving 66,000 to spawn in the lake and tributaries. Fecundity averaged 511 eggs/female at the egg-take station at Sullivan Springs, yielding a wild PED of 33.7 million eggs.

Fry Netting

A total of 275 fry were collected using the small-mesh fry net during September 2005. We collected 89 in the southern section, 121 in the middle section, and 65 in the northern section of the lake. The percentages of wild fry in these sections were 55%, 55%, and 30%, respectively. Based on these methods and using arithmetic means we estimated 7.97 million kokanee fry of which 2.66 million were wild.

Biomass, Production, and Yield

Estimates of kokanee biomass, production, and yield were calculated based on the hydroacoustic data. We estimated kokanee biomass at 156 metric tonnes (t), which was the second lowest biomass estimate in the last ten years (148 t in 2001) (Table 6). Kokanee production remained high at 231 t and yield of kokanee was 247 t.

We plotted kokanee production and yield against kokanee biomass to examine trends and correlations (Figure 9). The two trend lines crossed at a point where biomass was approximately 250 t. Yield in 2005 was slightly higher than production and biomass declined slightly from 2004. Production in 2005 was very near the trend line fitted to the production data from 1996 through 2004.

Spawner Counts and Surveys

In 2005, we observed 1,638 kokanee spawning on the lake's shoreline. We counted 1,565 on the shoreline around Bayview, 5 in Idlewilde Bay, 1 along the shoreline in the Lakeview area, and 66 in Garfield Bay (Table 7).

We observed 7,826 kokanee spawning in tributaries around Lake Pend Oreille (Table 8). Counts included 5,463 in South Gold Creek, 615 in North Gold Creek, 1 in Cedar Creek, 0 in Johnson Creek, 76 in Trestle Creek, and 1,244 in Twin Creek (tributary to the Clark Fork River). An additional 427 kokanee were counted in September as part of the early spawning run that occurs in Trestle Creek.

This year (similar to last year) hatchery personnel transplanted approximately 3,000 kokanee into Spring Creek that had entered the fish ladder at Cabinet Gorge Hatchery egg-take facility. Because of this, a count of naturally spawning kokanee in Spring Creek could not be made.

Gravel Sampling

We collected substrate samples during the month of July from the same six sites where samples were collected in both the spring and summer of 2004. Among four of the sites, gravel compositions changed only slightly from the previous summer (Figure 10), whereas the other two sites gravel composition dropped by an average of 31 percent. At both these sites, cobble replaced the gravel in approximately the same proportion. Fines varied no more than 2.5 percent at four of six locations. At Ellisport and Twin Creek, fines increased by 5.2 percent and 9.4 percent, respectively.

Spawning Gravel Cleaning

Throughout the spawning season, we made periodic checks of the areas cleaned to provide spawning substrate in Scenic Bay. We did not observe any kokanee spawning on or near these areas.

Other Biotic and Abiotic Factors

Shrimp Abundance

The results of the opossum shrimp sampling showed changes in the population from previous years. Total shrimp density increased 184% from last year, from 413 shrimp/m^2 in 2004 to 1,173 shrimp/m^2 in 2005 (Table 9 and Figure 11). However, the number of immature and adult shrimp continued to show a gradual downward trend (Figure 12). Young-of-the-year accounted for 967 shrimp/m^2, and immature and adults made up the remaining 206 shrimp/m^2 (90% CI = $\pm$ 22%). Densities increased in YOY (up 280% from last years 166 shrimp/m^2) and decreased in immature and adults (down 17% from last years 247 shrimp/m^2) within the lake (Table 9). Shrimp length ranged from 3 to 21 mm (Figure 13).

Limnology

Mean summer Secchi transparencies averaged 9.7 m this year in Lake Pend Oreille (Table 10). The lowest reading of 6.7 m was taken in June, whereas the maximum reading was recorded in September at 13.2 m. With the exclusion of winter months (Jan–March and Dec), water temperatures on the lake surface ranged from a low of 5.1°C during April to a high of 21.7°C in August (Figure 14). The lake stratified at approximately the same time as it did in 2004 but only reached to a depth of 14 m by August 18, 2005. Dissolved oxygen levels on the surface of the lake ranged from a high of 10.6 mg/L in April to a low of 8.5 mg/L in August.

Zooplankton Quality Index

ZPR and ZQI values were calculated for July through November 2005 (Table 11). April through June zooplankton densities were too low to calculate the indices. Zooplankton densities increased as summer progressed with peak values of ZPR = 0.402 (September) and ZQI = 0.363 (August). Values declined markedly by November.

DISCUSSION

Kokanee Population Dynamics

Kokanee continued to respond to lake level changes designed to enhance spawning habitat. In 2005, the egg-to-fry survival rate of kokanee spawning in the wild reached a very high 9.4%, and over 5.6 million wild fry were produced (Table 4). This survival rate was similar to the high survival rate estimated in 1998 (9.6%) and 2003 (9.8%) when lake levels were also kept higher during the winter. These rates were considerably better than some years when the water levels were drawn down to the low pool elevation: 1.4% in 1995 and 2.0% in 2004. The high survival in 2002, a full drawdown year with 9.5% survival, was attributable to the very low number of spawners that year that were not believed to be limited by spawning habitat (Maiolie et al. 2004).

In addition to the wild production, hatchery stocking boosted the number of kokanee fry in the lake to 12.5 million or 550 fry/ha. This was the second highest fry density recorded in the last 10 years. For comparison, we measured fry densities in Spirit Lake using the same hydroacoustic gear and software in 2004. Spirit Lake was known for its high densities of kokanee and was the leading producer of kokanee out of 28 lakes in Idaho, Washington, Oregon, Montana, Utah, Colorado, and British Columbia for which yield (kg/ha) was estimated by Rieman and Meyers (1990). Spirit Lake contained 477 fry/ha (lower than Lake Pend Oreille) indicating Lake Pend Oreille was well seeded with kokanee fry.

Fieldwork conducted during 2005 indicated that the Lake Pend Oreille kokanee population was at record lows. Standing stock, as measured by trawling, was estimated at 3.04 kg/ha in 2005 (Table 5). This was well below the 13-17 kg/ha in the late 1970s (Rieman and Bowler 1980) and the 9.71 kg/ha estimated in 1989 (Hoelscher et al. 1990). Even through the recent years of our study, kokanee biomass that was based on hydroacoustics (which give a higher kokanee density) showed a considerable decline. We estimated the lake contained about 350 t (15 kg/ha) of kokanee in 1995 and 1996 by hydroacoustics, but biomass dropped to 156 t (7 kg/ha) by 2005 (Table 6).

Since 1999, we have been concerned that predation will cause the complete loss of kokanee from Lake Pend Oreille (Maiolie et al. 2002). Declines in the survival rates indicated that this situation was worsening (Table 3 and Figure 7). It is unlikely that this population will persist if the current survival rates do not improve. One factor that has kept this population from complete extirpation from the lake has been the pronounced increases in the production:biomass ratio. In 2005, the kokanee population produced 231 t of fish flesh from a population with a biomass of 156 t for a ratio of 1.48:1. This ratio was closer to 1:1 or less in 1996 through 1999. Increases in the production to biomass ratio helped to slow the decline, but with yield exceeding production, continued declines in biomass were observed.

Gravel Sampling

We noticed declines in the quality of shoreline spawning substrate at most locations sampled in 2005. However, the gravel still seemed to be of sufficient quality to support good kokanee spawning during the winter of 2005-06; the second winter in a row of higher lake levels. Previously we had recommended that the lake be drawn down after 3 years of higher winter levels to allow wave action to improve spawning habitat (Maiolie et al. 2002). This recommendation still seemed valid.

Spawning Gravel Cleaning

We had hoped to demonstrate that kokanee would spawn in areas where the lake bottom was recently cleaned. The area chosen was near a historical spawning site in Scenic Bay, which should have made it easily located by spawners. However, we did not observe any kokanee using these areas during the 2005 spawning season. This may have been due to the low abundance of wild kokanee and the fact that adequate gravel was found in many other locations around the lake since the lake was held 1.2 m above minimum pool. With these higher winter lake levels, it was likely that spawning habitat was not limiting.

Shrimp Abundance

Our surveys of opossum shrimp indicated a downward trend in immature and adult shrimp densities over the last 11 years (Figure 12). Lake whitefish were known to eat shrimp, and 41,000 lake whitefish were caught in trap nets in 2004, indicating they were fairly abundant (Peterson and Maiolie 2006). Even so, it was difficult to imagine that whitefish, which were found primarily in areas where the bottom was 30 to 60 m deep, could be controlling shrimp, which inhabited most of the pelagic area within the lake, including the deep central basin. Reasons for the declining trend in shrimp were, therefore, unknown. We recommend continued monitoring of Secchi depth and zooplankton density to see if declines in shrimp were related to declines in overall lake productivity.

Limnology

We found no limnological factors that we felt would influence the results of the lake level experiment. Average Secchi transparency (9.7 m) (Table 10) was clearer than the summer means measured in 1997-2000 (Maiolie et al. 2002). However, Secchi transparencies were quite variable and dependent on the amount of spring runoff. Future monitoring of transparency is recommended to see if this indicates a trend toward declining productivity.

Zooplankton

The ZQI for both August and September on Lake Pend Oreille was in the middle of the 40 waters that Teuscher (1999) compared across Idaho and well above some kokanee waters, such as Ririe, Island Park, and Anderson Ranch Reservoirs. This indicated Lake Pend Oreille had sufficient zooplankton in midsummer to support additional planktivores. The standard ZQI method involved measuring zooplankton in August and September, and therefore, may not have indicated if problems were occurring with zooplankton in spring or fall.

RECOMMENDATIONS

1. Continue to work with the U.S. Army Corps of Engineers to manage water levels for the benefit of kokanee spawning habitat.

2. Reduce predation on kokanee so that the population has a chance to increase in biomass and recover. After this point is reached, predators can once again be increased.

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Table 1. Population estimates of kokanee fry (millions) based on hydroacoustic surveys of Lake Pend Oreille, Idaho in 2005. Percentage of wild fry was based on the proportion of wild fry caught using a fry net and by midwater trawling.

	Southern	Middle	Northern	Total for lake	90% CI
Total kokanee fry abundance by hydroacoustics	2.672	5.137	4.645	12.455	-13.1 to +15.1
Percent wild fry in fry trawl	54.6	54.6	30.3	—	
Wild fry estimate based on acoustics and fry trawling	1.458	2.802	1.408	5.667	
Percent wild fry in midwater trawl	39.0	35.8	13.9	—	
Wild fry estimate based on acoustics and midwater trawling	1.043	1.839	0.644	3.527	

Table 2. Population estimates of kokanee age classes (millions) in Lake Pend Oreille, Idaho, 2005. Estimates were made based on hydroacoustic surveys and partitioned into age classes based on the percent of each age class in the catch of a midwater trawl.

Area	Age-1	Age-2	Age-3	Age-4	Age-5	Total
Southern Section						
Acoustic estimate of kokanee in section (millions)						0.865
Percent of age class in section by trawling	69.2	9.2	13.4	7.0	1.3	
Population estimate in section (millions)	0.599	0.080	0.116	0.061	0.011	0.865
Middle Section						
Acoustic estimate of kokanee in section (millions)						1.341
Percent of age class in section by trawling	95.8	1.6	1.1	1.5	0	
Population estimate in section (millions)	1.286	0.021	0.014	0.020	0.0	1.341
Northern Section						
Acoustic estimate of kokanee in section (millions)						1.383
Percent of age class in section by trawling	85.7	4.7	5.0	4.2	0.4	
Population estimate in section (millions)	1.186	0.065	0.070	0.058	0.005	1.383
Total population estimate for lake (millions)	3.071	0.165	0.200	0.139	0.016	3.591

Table 3. Survival rates (%) between kokanee year classes estimated by midwater trawling and hydroacoustics, 1990-2005. Hydroacoustic estimates started in 1996. Year refers to the year the older age class in the survival estimate was collected.

	Age Class							
	0 to 1		1 to 2		2 to 3		3 to 4	
Year	**Trawl**	**Acoustics**	**Trawl**	**Acoustics**	**Trawl**	**Acoustics**	**Trawl**	**Acoustics**
2005[a]	48	46	16	15	31	26	26	28
2004[a]	35	21	33	33	19	28	14	18
2003[a]	31	35	70	55	54	65	—[b]	—[b]
2002[a]	16	30	13	43	—[b]	—[b]	—[b]	—[b]
2001	44	28	25	27	3	6	13	17
2000	66	52	74	22	168	66	107	40
1999	32	24	16	18	61	71	40	49
1998	40	37	29	28	95	94	25	26
1997	21	42	22	59	12	29	6	17
1996	77	44	101	79	57	40	70	46
1995	46	—	307	—	99	—	21	—
1994	12	—	47	—	76	—	38	—
1993	32	—	98	—	256	—	92	—
1992	67	—	94	—	63	—	83	—
1991	25	—	111	—	53	—	82	—
1990	35	—	124	—	27	—	44	—

[a] Data from 2002 to 2005 were based on geometric means transformed by Log(x+1).
[b] Too few kokanee caught in age class to provide a reliable estimate of survival.

Table 4. Comparison of kokanee reproductive success in Lake Pend Oreille, Idaho in 2004 and 2005. During the winter 2003-04, the lake was held above an elevation of 625.1 m (2051 ft) and in 2004-05, the winter elevation held above 626.4 m (2055 ft).

	2004	**2005**
Number of mature female kokanee in previous year	219,584	198,364
Number of kokanee collected by hatchery crew in previous year	43,351	50,023
Female kokanee spawning in the wild during the previous year	176,233	148,341
Fecundity (eggs/female) in previous year	351	406
Wild spawn eggs in previous year	61.8 m	60.2 m
Number of wild fry produced	1.25 m	5.67 m
Wild egg-to-fry survival (%)	2.0	9.4

Table 5. Kokanee population statistics based on trawling Lake Pend Oreille, Idaho during August 2005.

Age	**0**	**1**	**2**	**3**	**4**	**5**	**Total**
Population estimate (millions)	7.173	1.870	0.050	0.061	0.029	0.006	9.876
± 90% CI (lower & upper limits)	6.4 to 8.0	1.3 to 2.6	0.03 to 0.08	0.04 to 0.09	0.01 to 0.05	0.003 to 0.01	10.2 to 11.4
Density (fish/ha)	316.7	82.6	2.2	2.7	1.3	0.26	436.1
Mean weight (g)	2.31	17.28	99.58	148.55	180.97	174.00	
Standing stock (kg/ha)	0.73	1.41	0.22	0.40	0.24	0.05	3.04
Mean length (mm)	64.3	142.4	223.2	252.8	270.1	265.0	
Length range (mm)	29-92	100-163	166-243	223-274	247-288	267	

Table 6. Biomass, production, and yield (metric tons) of kokanee in Lake Pend Oreille, Idaho 1996-2005 based on hydroacoustic surveys.

Year	Biomass	Production	Yield
2005	155.9	231.3	247.2
2004	158.3	217.8	329.2
2003	258.0	236.0	171.7
2002	188.4	262.6	231.3
2001	148.2	249.0	281.3
2000	169.9	194.2	284.1
1999	249.0	256.0	271.4
1998	253.2	230.3	208.5
1997	228.7	220.7	354.3
1996	352.6	278.4	274.7
1995	343.6		

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

	Bayview	Farragut Ramp	Idlewilde Bay	Lakeview	Hope	Trestle Cr. Area	Sunnyside	Garfield Bay	Camp Bay	Anderson Point	Total
2005	1565	0	5	1	0	1	0	66	0	---	1,638
2004	2,342	0	100	1	0	0	0	34	0	0	2,477
2003	940	0	0	0	0	20	0	0	0	—	960
2002	968	0	0	0	0	0	0	0	0	—	968
2001	22	0	0	0	0	0	0	0	1	—	23
2000	382	0	0	2	0	0	0	0	0	—	384
1999	2,736	4	7	24	285	209	0	275	0	—	3,540
1998	5,040	2	0	0	22	6	0	34	0	—	5,104
1997	2,509	0	0	0	0	7	2	0	0	—	2,518
1996	42	0	0	4	0	0	0	3	0	—	49
1995	51	0	0	0	0	10	0	13	0	—	74
1994	911	2	0	1	0	114	0	0	0	—	1,028
1993	—	—	—	—	—	—	—	—	—	—	—
1992	1,825	0	0	0	0	0	0	34	0	—	1,859
1991	1,530	0	—	0	100	90	0	12	0	—	1,732
1990	2,036	0	—	75	0	80	0	0	0	—	2,191
1989	875	0	—	0	0	0	0	0	0	—	875
1988	2,100	4	—	0	0	2	0	35	0	—	2,141
1987	1,377	0	—	59	0	2	0	0	0	—	1,438
1986	1,720	10	—	127	0	350	0	6	0	—	2,213
1985	2,915	0	—	4	0	2	0	0	0	—	2,921
1978	798	0	0	0	0	138	0	0	0	0	936
1977	3,390	0	0	25	0	75	0	0	0	0	3,490
1976	1,525	0	0	0	0	115	0	0	0	0	1,640
1975	9,231	0	0	0	0	0	0	0	0	0	9,231
1974	3,588	0	25	18	975	2,250	0	20	0	50	6,926
1973	17,156	0	0	200	436	1,000	25	400	617	0	19,834
1972	2,626	25	13	4	1	0	0	0	0	0	2,669

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

Year	S. Gold	N. Gold	Cedar	Johnson	Twin	Mosquito	Lightning	Spring	Cascade	Trestle[a]	Trestle	Total
2005	5,463	615	1	0	1,244	---	---	---[b]	---	427	76	7,826
2004	721	2,334	600	16	6,012	---	---	3,331[b]	---	682	0	13,696
2003	591	0	0	0	—	—	—	626	—	2,251	9	3,477
2002	79	0	0	0	0	—	—	0	—	1412	0	1,491
2001	72	275	50	0	0	—	—	17	—	301	0	715
2000	17	37	38	0	2	0	0	0	0	1,230	0	1,324
1999	1,884	434	435	26	2,378	—	—	9,701	5	1,160	423	16,446
1998	4,123	623	86	0	268	—	—	3,688	—	348	578	9,714
1997	0	20	6	0	0	—	—	3	—	615	0	644
1996	0	42	7	0	0	—	—	17	—	753	0	819
1995	166	154	350	66	61	—	0	4,720	108	615	21	6,261
1994	569	471	12	2	0	—	0	4,124	72	170	0	5,420
1992	479	559	—	0	20	—	200	4,343	600	660	17	6,878
1991	120	550	—	0	0	—	0	2,710	0	995	62	4,437
1990	834	458	—	0	0	—	0	4,400	45	525	0	6,262
1989	830	448	—	0	0	—	0	2,400	48	466	0	4,192
1988	2,390	880	—	0	0	—	6	9,000	119	422	0	12,817
1987	2,761	2,750	—	0	0	—	75	1,500	0	410	0	7,496
1986	1,550	1,200	—	182	0	—	165	14,000	0	1,034	0	18,131
1985	235	696	—	0	5	—	127	5,284	0	208	0	6,555
1978	0	0	0	0	0	0	44	4,020	0	1,589	0	5,653
1977	30	426	0	0	0	0	1,300	3,390	0	865	40	6,051
1976	0	130	11	0	0	0	2,240	910	0	1,486	0	4,777
1975	440	668	16	0	1	0	995	3,055	0	14,555	15	19,740
1974	1,050	1,068	44	1	135	0	2,350	9,450	0	217	1,210	15,525
1973	1,875	1,383	267	0	0	503	500	4,025	0	1,100	18	9,671
1972	1,030	744	0	0	0	0	350	2,610	0	0	1,293	6,027

[a] Trestle Creek early-spawners
[b] Cabinet Gorge Hatchery transferred 3000 spawners from the hatchery ladder to Spring Creek.

Table 9. Densities (per m^2) of shrimp in Lake Pend Oreille, Idaho, June 5-7, 2005. Sections are shown in Figure 1.

Section-Transect	YOY	Immature & Adults	Total Shrimp
1-1	955.9	173.5	1129.4
1-4	1200.9	143.3	1344.2
1-6	565.0	121.4	686.4
1-10	540.0	79.0	619.0
1-19	1791.1	160.8	1951.9
1-21	383.6	118.2	501.8
1-31	951.5	144.8	1096.3
1-36	298.9	175.9	474.7
1-37	910.5	106.7	1017.2
1-39	650.6	125.0	775.7
1-42	1334.9	361.4	1696.3
1-44	1184.8	570.9	1755.7
1-46	1074.4	190.9	1265.4
1-47	570.6	88.2	658.8
1-56	1149.7	228.8	1378.5
Section 1 means	**904.2**	**185.9**	**1090.1**
2-1	1289.5	271.6	1561.1
2-5	1793.3	180.0	1973.4
2-19	888.5	143.3	1031.7
2-21	1826.7	158.2	1984.9
2-22	1246.8	161.2	1408.0
2-29	905.6	138.5	1044.1
2-32	540.3	159.3	699.6
2-35	530.2	464.1	994.3
2-38	622.2	154.5	776.7
2-41	1806.4	298.4	2104.8
2-53	311.5	291.8	603.3
2-56	1448.2	162.2	1610.4
2-62	1308.7	335.7	1644.4
2-70	432.2	28.9	461.1
2-71	5420.5	196.3	5616.7
Section 2 means	**1358.0**	**209.6**	**1567.6**
3-7	603.4	330.3	933.7
3-8	823.6	327.6	1151.2
3-13	722.1	297.3	1019.4
3-14	670.5	246.1	916.6
3-24	292.4	446.1	738.5
3-26	797.3	181.2	978.5
3-29	243.1	158.7	401.8
3-36	417.4	114.9	532.3
3-39	33.2	1.4	34.5
3-44	165.0	163.6	328.6
3-48	601.1	81.5	682.7
3-59	620.3	239.4	859.7
3-69	1265.5	154.1	1419.6
3-71	429.0	208.4	637.3
3-85	2098.3	306.8	2405.1
Section 3 means	**652.2**	**217.1**	**869.3**
Whole lake means	**967.0**	**205.6**	**1172.7**

Table 10. Secchi transparencies (m) at midlake location in Lake Pend Oreille, Idaho, 2005, for the period April through October.

Location	Apr 18	May 13	Jun 21	Jul 15	Aug 18	Sep 15	Oct 18	Summer Mean
Mid-lake station	10.5	8.1	6.7	7.5	11.3	13.2	10.4	9.7

Table 11. Monthly zooplankton size ratio (ZPR) and zooplankton quality index (ZQI) for the 2005 growing season (April – November) for Lake Pend Oreille, Idaho.

Month	ZPR	ZQI
April	<0.001 *	<0.001 *
May	<0.001 *	<0.001 *
June	<0.001 *	<0.001 *
July	0.041 *	0.0014 *
August	0.354	0.363
September	0.402	0.337
October	0.142	0.047
November	0.089 *	0.007 *

* low sample weights prevented calculation of indices

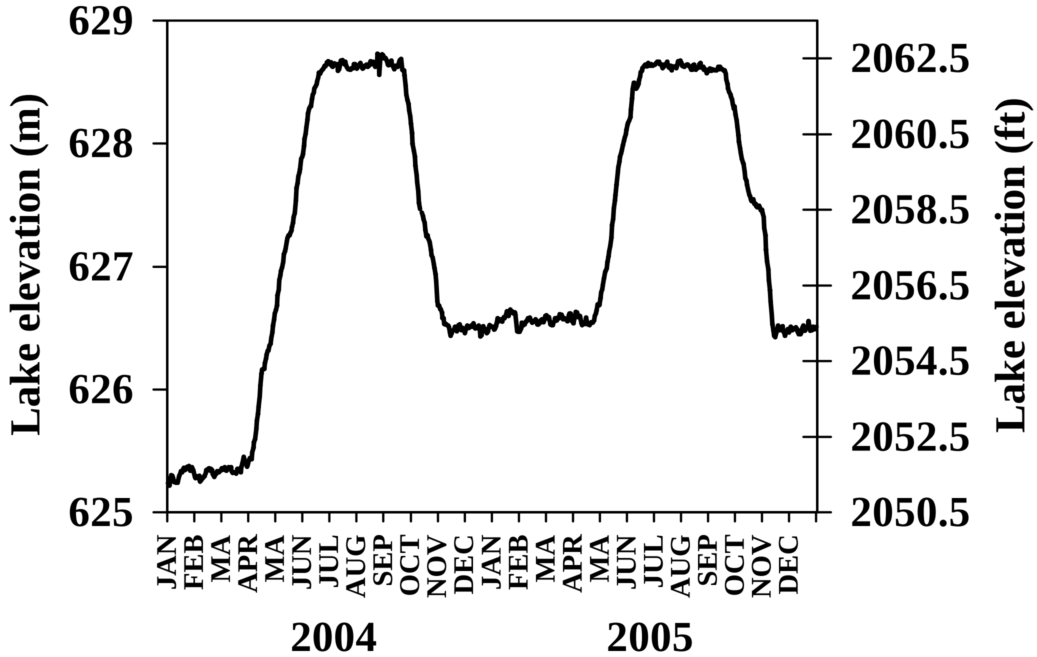
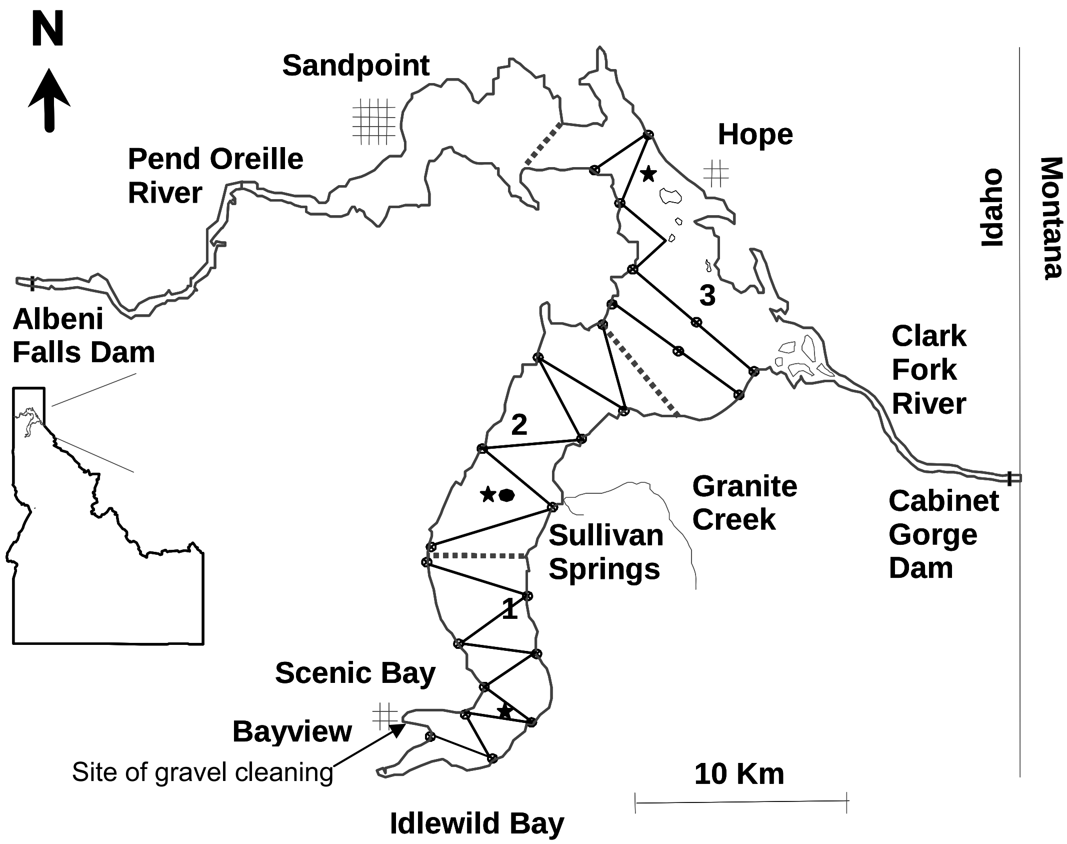


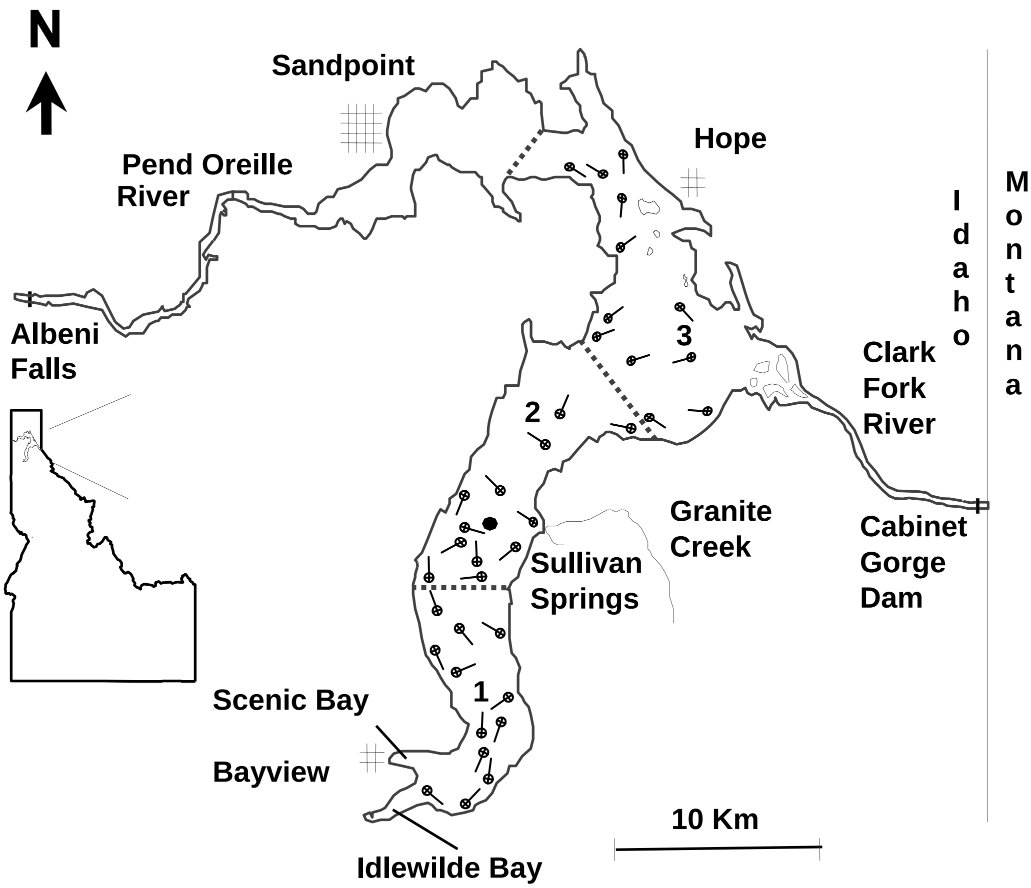
Figure 1. Daily surface elevation of Lake Pend Oreille, Idaho during 2004 and 2005.



Section	Area (hectares)
1	6486
2	7776
3	8384

● - Limnology station
⊗ - Start and stop of transects
★ - Zooplankton sampling site

Figure 2. Map of Lake Pend Oreille, Idaho showing prominent landmarks, limnology station, zooplankton sampling sites, and the three lake sections. The dark lines mark the location of hydroacoustic transects in 2005. Inserted table depicts the area of kokanee habitat in each section.



Section	Area (hectares)
1	6486
2	7776
3	8384

- Transect location and direction

Figure 3. Map of Lake Pend Oreille, Idaho showing the locations of kokanee trawling transects used in 2005.

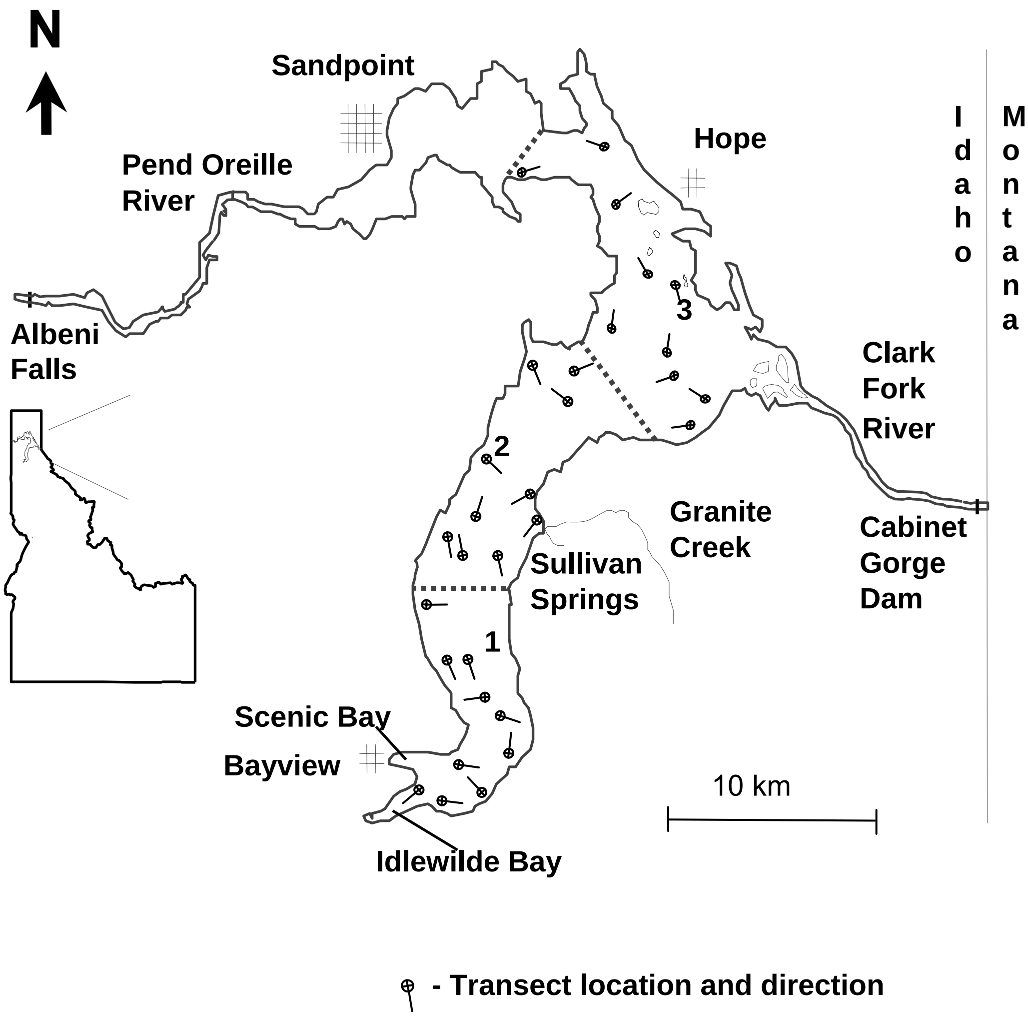


Figure 4. Map of Lake Pend Oreille, Idaho, showing the locations of kokanee fry trawling transects used in 2005.

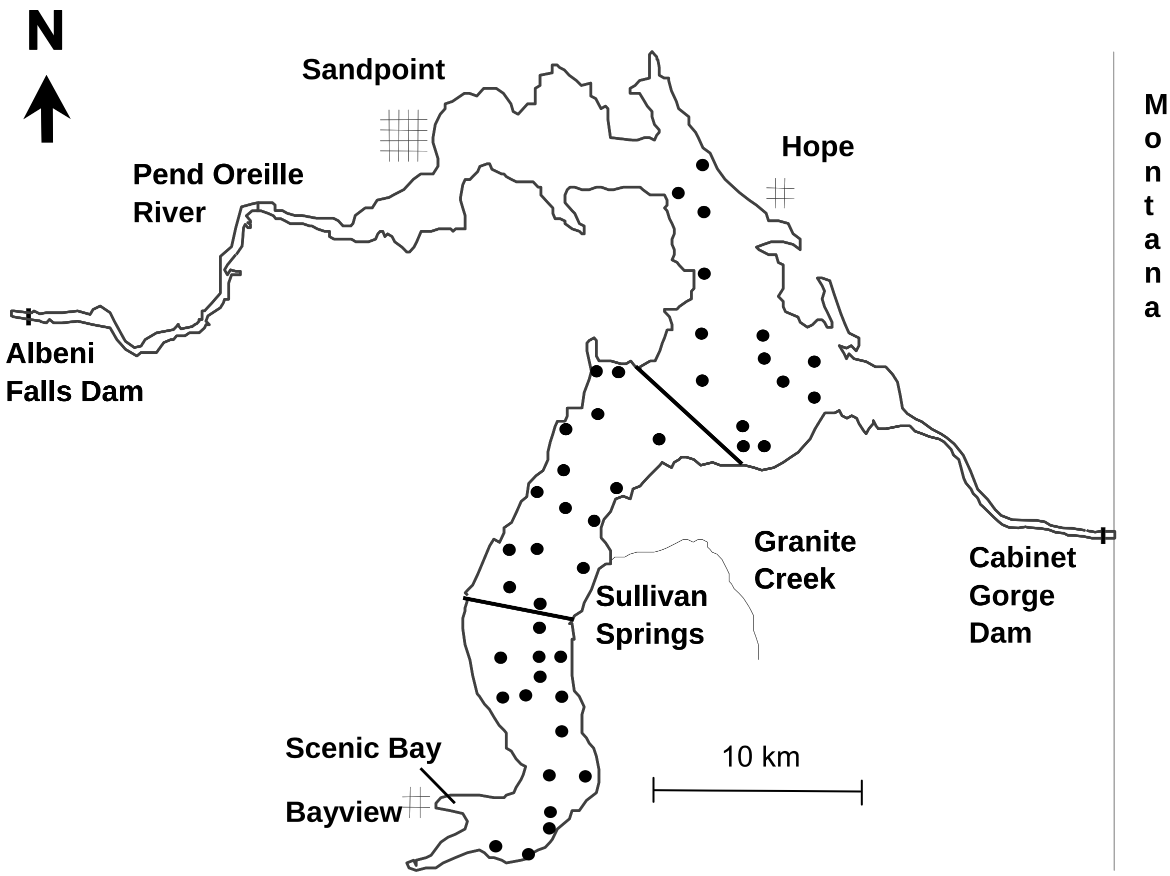


Figure 5. Map of Lake Pend Oreille, Idaho showing the shrimp sampling locations used between June 5-7, 2005.

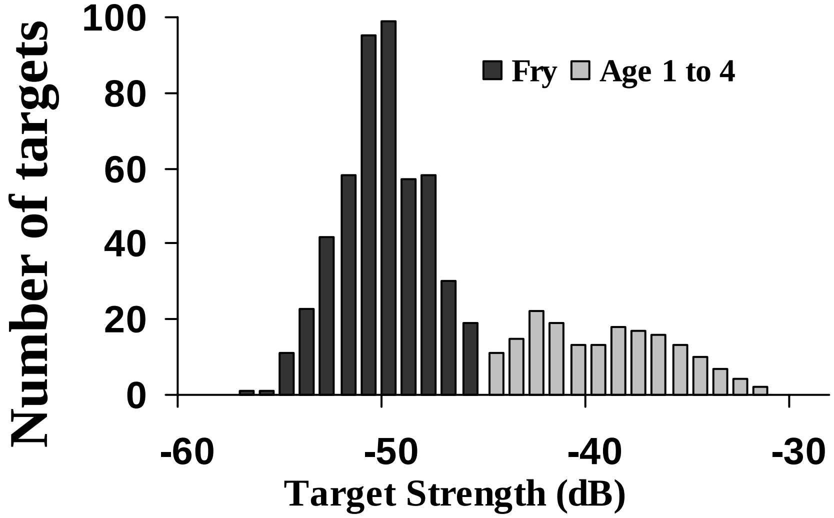


Figure 6. Target strengths of 674 fish in Lake Pend Oreille during surveys between August 29 and September 2, 2005. Distribution was created to define the target strength between kokanee fry and age-1 and older kokanee (>-46 dB).

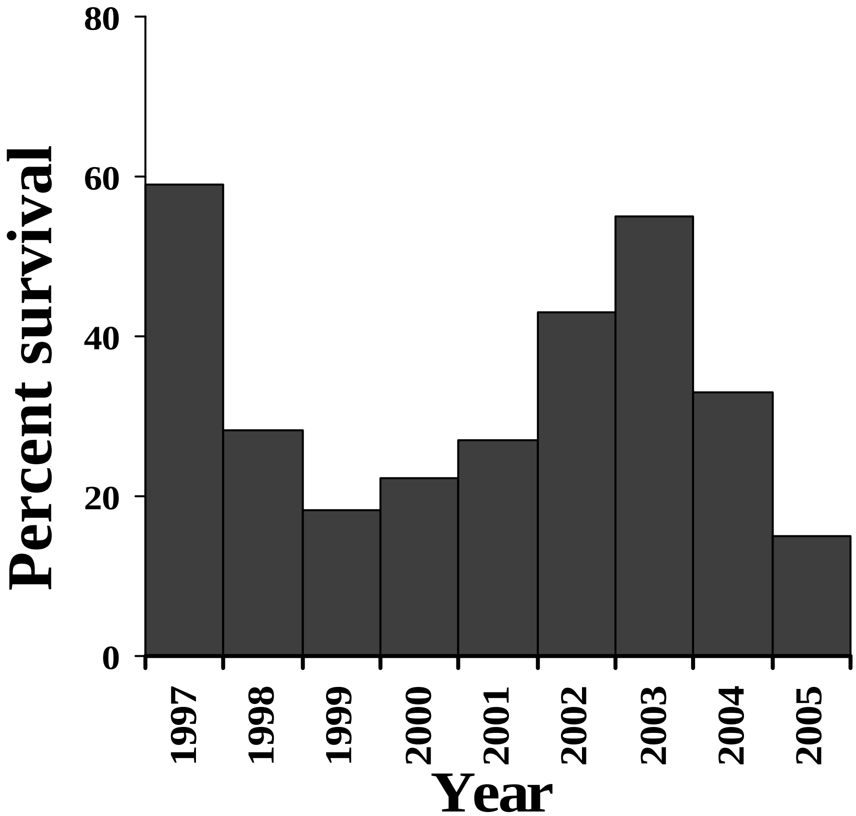


Figure 7. Survival rates of kokanee from age-1 to age-2 in Lake Pend Oreille, Idaho based on hydroacoustic surveys of the lake.

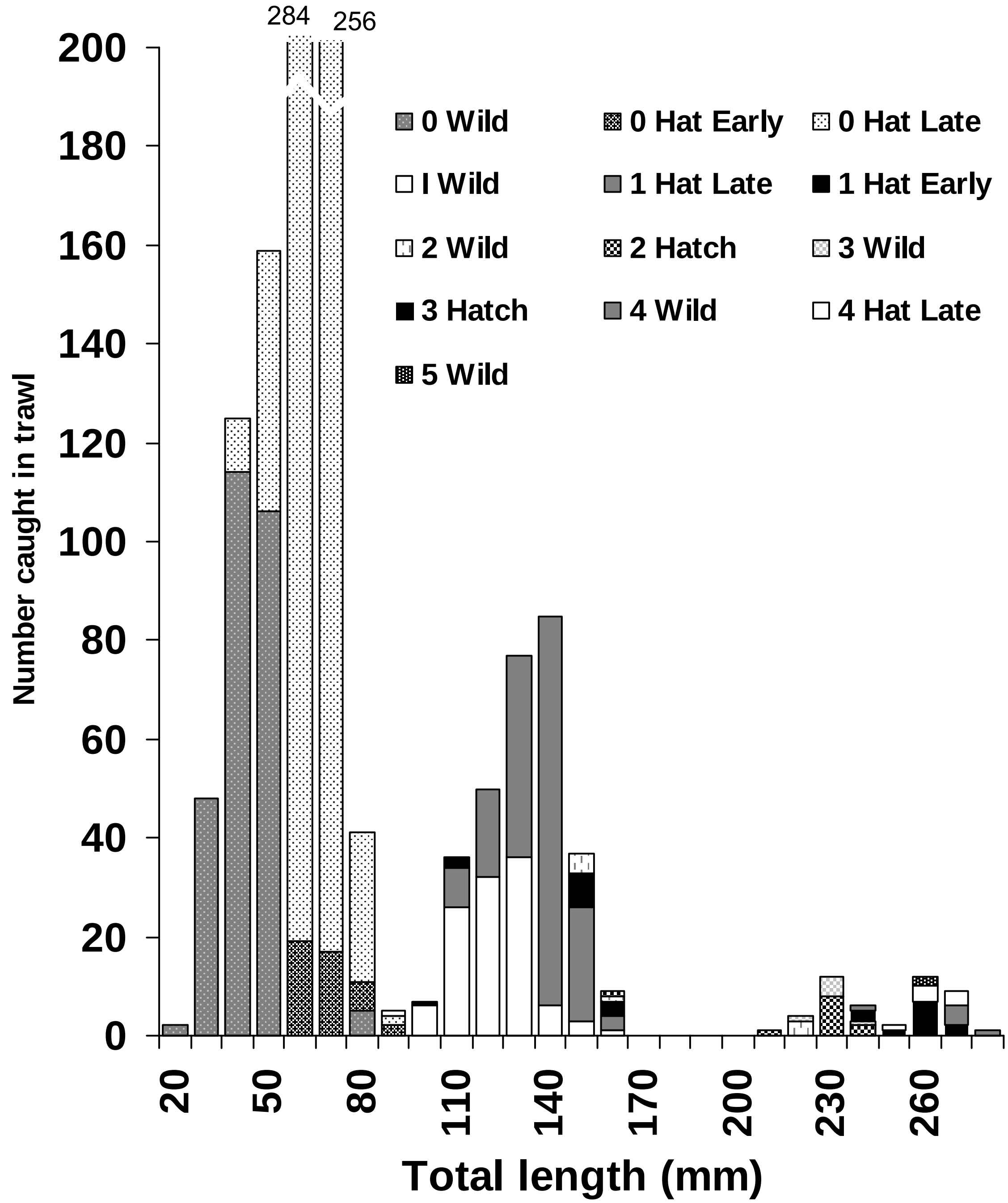


Figure 8. Length-frequency distribution of kokanee caught by midwater trawling in Lake Pend Oreille, Idaho in August 2005. Abbreviations in the legend include Hat Late = late spawning kokanee reared at the Cabinet Gorge Hatchery, Hat Early = early spawning kokanee reared at the Cabinet Gorge Hatchery, Wild = kokanee produced naturally in the lake and its tributaries. Numeral denotes age class.

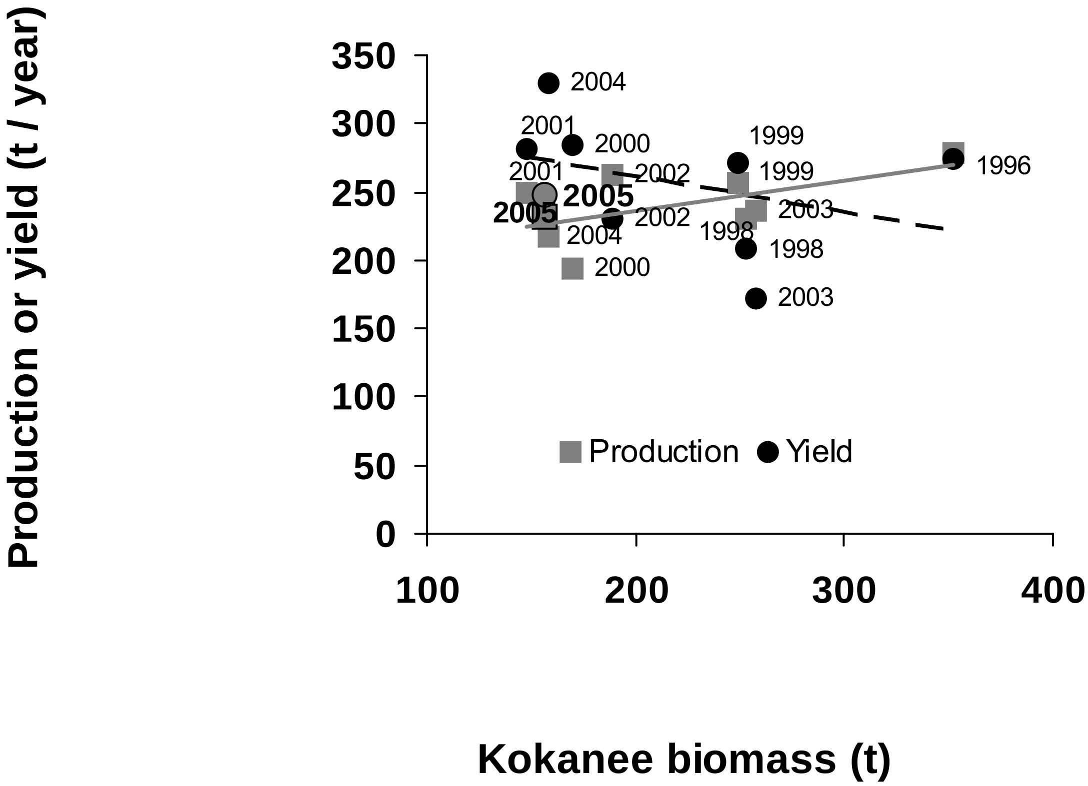


Figure 9. Kokanee biomass, production, and yield (metric tonnes) from Lake Pend Oreille, Idaho 1996-2005, excluding 1997 due to 100 year flood. Lines were fitted to all data points except 2005 to illustrate possible change.

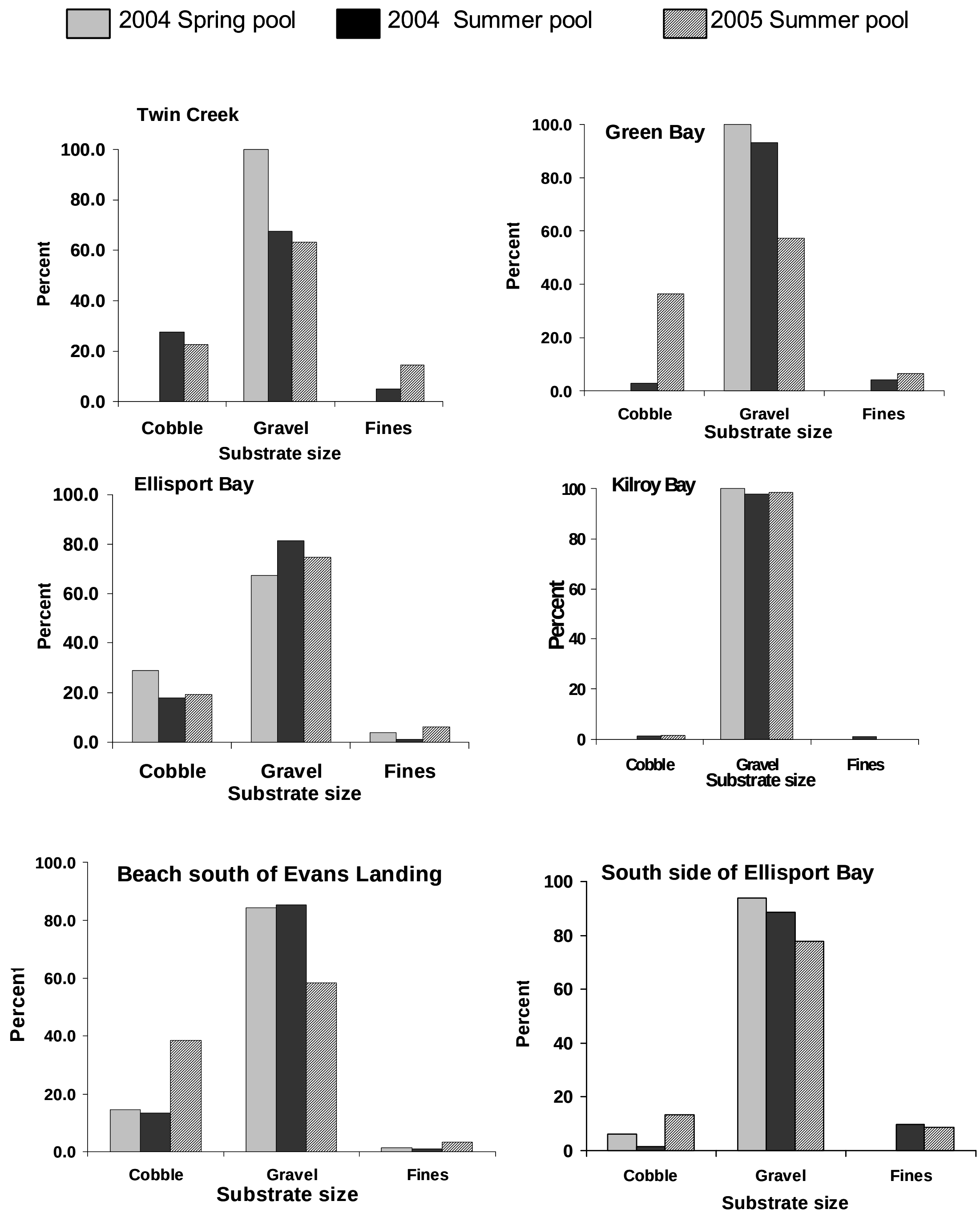


Figure 10. Substrate composition on potential kokanee spawning beaches in Lake Pend Oreille, Idaho. Sampling during spring 2004 was conducted above the water line at an elevation of 625.1 tp 625.4 m while lake was at its low pool level. Other samples were collected at the same elevation by scuba diving during summer.

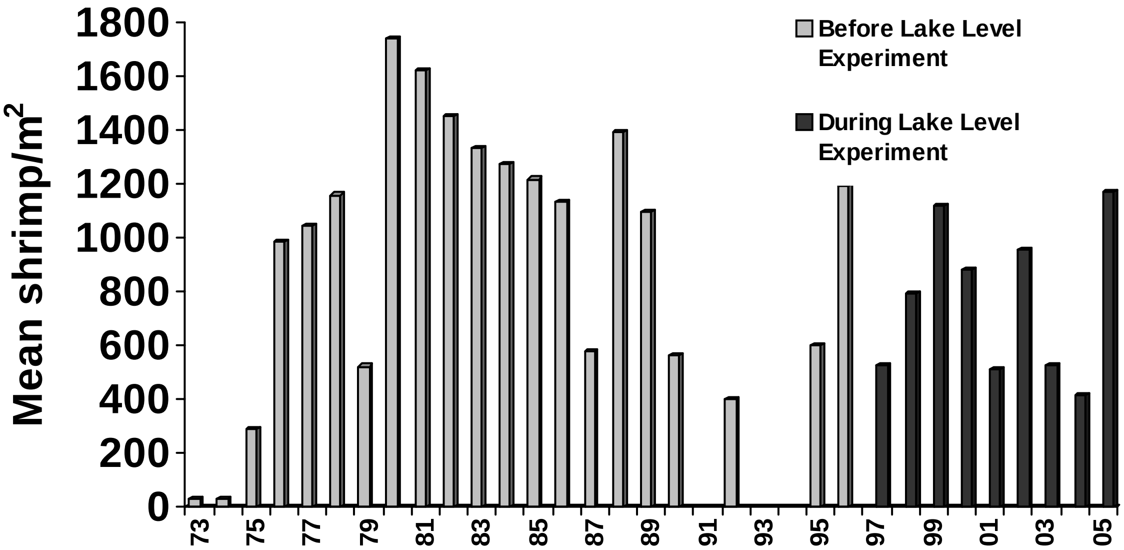


Figure 11. Annual mean density of opossum shrimp in Lake Pend Oreille, Idaho 1973-2005. Data collected before 1989 were obtained from Bowles et al. (1991), and data from 1995 and 1996 were from Chipps (1997). Shrimp densities from 1992 and earlier were converted from Miller sampler estimates to vertical tow estimates by using the equation y = 0.5814x (Maiolie et al. 2002). Gaps in the bar chart indicate no data were collected that year.

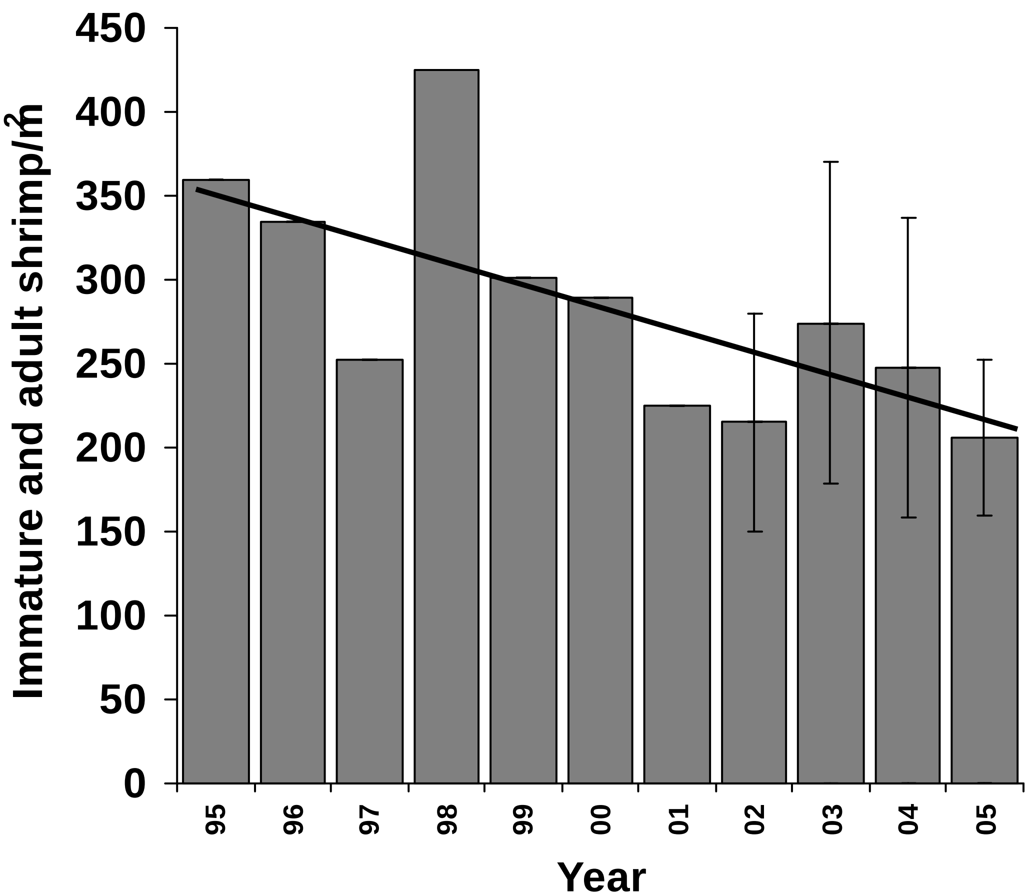


Figure 12. Density estimates of immature and adult shrimp in Lake Pend Oreille, Idaho for the past 11 years (1995-2005). A linear trend line was fit to the data points to show the apparent decline. Error bounds were also added the recent population estimates to identify 90% confidence intervals around the estimate.

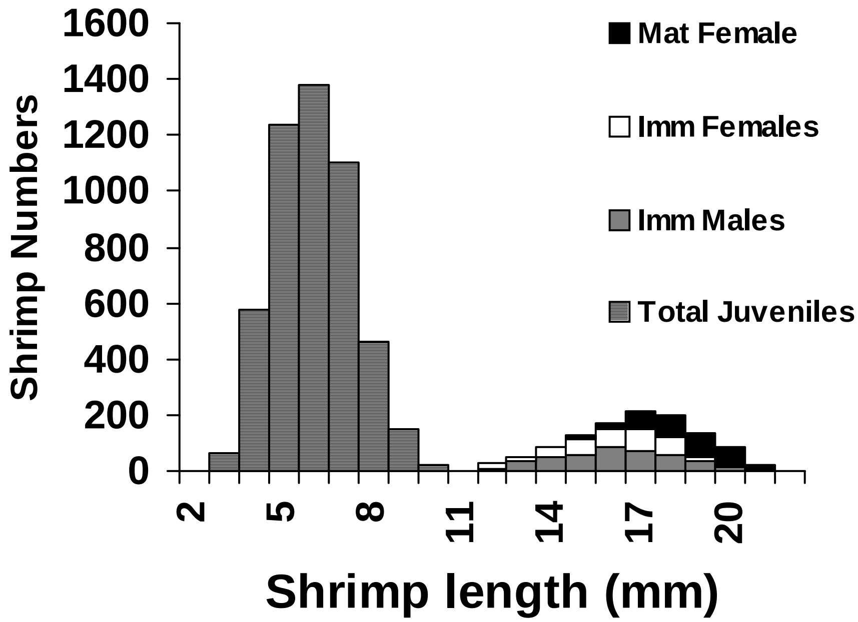


Figure 13. Opossum shrimp length frequency distribution during June 2004 on Lake Pend Oreille, Idaho. Abbreviations are Mat = mature and Imm= immature.

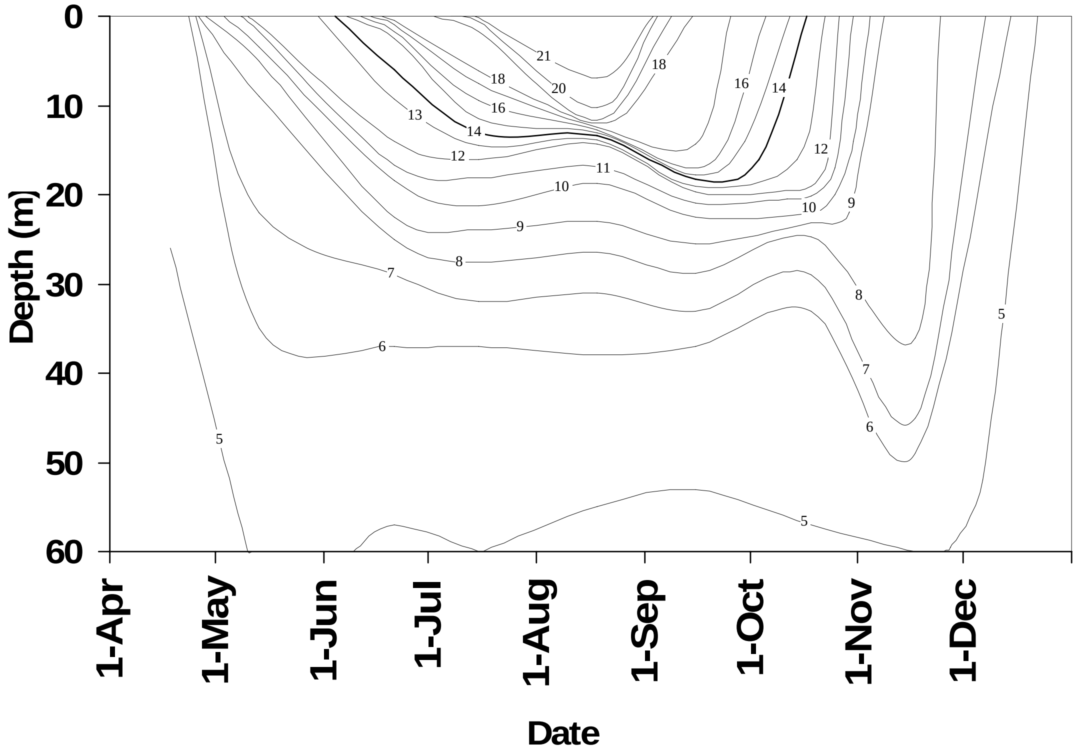


Figure 14. Isotherms (°C) in the top 60 m of water in Lake Pend Oreille, Idaho during 2005. Temperatures were measured at the approximate center of the lake (Figure 2).

APPENDICES

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

Scenic Bay

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

Farragut State Park

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

Lakeview

- From mouth of North Gold Creek go north 100 meters and south 1/2 km.

Hope/East Hope

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

Trestle Creek Area

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

Sunnyside

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

Garfield Bay

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

Camp Bay

- Entire area within confines of Camp Bay.

Fisherman's Island

- Entire Island Shoreline - not surveyed since 1978.

Anderson Point

- Not surveyed since 1978.

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