Lake Billy Chinook Sockeye Salmon and Kokanee Research Study 1996–2000

PROJECT COMPLETION REPORT

Pelton Round Butte Hydroelectric Project
FERC No. 2030

Prepared for Portland General Electric Company
by

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PREFACE

This report summarizes five years of kokanee salmon Oncorhynchus nerka research on Lake Billy Chinook, Oregon, highlighting new work in 1999–2000. This phase of the study draws heavily from work by Thiesfeld et al. (1999). This report builds on that work without reanalysis of earlier findings.

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EXECUTIVE SUMMARY

An understanding of the dynamics of the current kokanee salmon (*Oncorhynchus nerka)* population in Lake Billy Chinook is critical to evaluate the potential for sockeye salmon introduction (or re-introduction) into the Metolius River basin. Current research has focused on (1) examining the abundance, growth rates, survival, and foraging trends of kokanee in Lake Billy Chinook; (2) defining the characteristics of the spawning population; and (3) trying to determine mechanisms controlling various population attributes. Determining these controlling mechanisms may help managers understand the implications of proposed efforts to shift a portion of the *O. nerka* population from resident kokanee to anadromous sockeye through renewed fish passage at the Pelton Round Butte Project (Project). In conjunction with the proposed reestablishment of fish passage at the Project, conditions in Lake Billy Chinook would also be altered. As part of the proposed new facilities to be constructed for downstream collection of anadromous smolts, water will be drawn from the surface of Lake Billy Chinook rather than from the hypolimnion. This change from deep water withdrawal to surface water withdrawal will result in cooler reservoir temperatures than at present. An understanding of the present conditions and the resulting dynamics of the kokanee population will allow evaluation of the potential effects of these future changes in reservoir habitat conditions on *O. nerka* populations.

Kokanee development from egg deposition through spawning was followed over the study period (1996–2000). Based on water temperature, kokanee eggs in the Metolius River basin hatch from early December through early February, and emergence should occur from early January through early April. Downstream migrating kokanee fry were captured as soon as trapping began in early January and continued through June. Most kokanee fry migrated downstream in late March and early April. Estimated total fry recruitment ranged from a low of 1,898,000 in 1999 to a high of 2,541,000 in 1998. Potential egg deposition ranged from 39,750,000 in brood year 1998 to 67,228,000 in brood year 1997. Therefore, minimum egg-to-fry survival ranged from 3.8 to 4.8% over the course of the study. Abundance of kokanee spawners, potential egg deposition, and fry recruitment in the Deschutes River upstream of Lake Billy Chinook was not estimated. However, even in years of high kokanee spawner abundance, fry recruitment from the Deschutes River is likely only a fraction of overall recruitment into Lake Billy Chinook.

Prior to 1999, kokanee in Lake Billy Chinook grew faster than in most other locations. Age-0 kokanee had exceptional growth in 1996 and 1997. In those years, age-1 kokanee grew well and entered the fishery by late May each year at approximately 250 mm. From 1999–2000 there was a marked decrease in size attained by age-0 kokanee. Average size attained by autumn for age-0 kokanee decreased from 170 mm to less than 120 mm over the course of the study. Throughout the study, kokanee grew slowly after reaching 300 mm.

Rotifers and copepods were the most abundant zooplankton taxa in the reservoir. April to October mean monthly densities of key zooplankton (*Daphnia*, *Bosmina*, calanoids, and

cyclopoids) ranged between 2,000 and 12,000 organisms/m^3 in 1997, and between 6,000 and 30,000 organisms/m^3 in 2000. Zooplankton abundance (standing stock) was usually low during February and March and first increased in the Metolius River arm during April.

Daphnia was the predominant prey item consumed by kokanee in Lake Billy Chinook. Age-0 kokanee consumed mostly *Daphnia* throughout the spring and summer, but Dipterans and cyclopoid copepods were important during various seasons. *Daphnia* were the predominant prey for adult kokanee in most months.

The number of spawning kokanee was estimated only for the Metolius River basin. In the Metolius River basin, spawning kokanee were abundant in 1996, and very abundant in 1999 and 2000. Spawner estimates ranged from a low of 83,471 kokanee in 1996 to a high of 569,201 spawners in 2000. Kokanee were first observed on index sites between 1 September and 1 October, and were last observed between 1 November and 16 November. Mean length of spawning kokanee increased from 241 mm in 1994 to 340 mm in 1998, then decreased to 294 mm in 2000. The percentage of female spawners changed dramatically, ranging from 25% to 65%. Spawner age also changed; whereas 70% of the spawners were age-3 and 30% age-2 in 1997, in 1998, 29–47% were age-1, indicating that kokanee spawn at a younger age when growth rates are good. Conversely, when growth rates were poor, as in 1999 and 2000, no age-1 spawners were sampled. Estimated egg deposition also varied dramatically during the study, ranging from an estimated 13.6 million eggs in 1996 to 67 million eggs in 1997. Finally, redd superimposition (regardless of run size) occurred at several monitored sites, suggesting that it may cause substantial mortality for kokanee eggs.

Kokanee population abundance in Lake Billy Chinook varied greatly over the course of this study. Hydroacoustic estimates suggest that kokanee abundance was low during 1996 and 1997, before increasing in 1998 to 2000. The lowest abundance occurred in February 1998, when approximately 390,000 kokanee were estimated to be in the reservoir. The highest abundance was estimated at 3,900,000 kokanee in August 1999. Age-0 kokanee densities ranged from 52/hectare (52/ha) in February 2000 to 2,200/ha in 1998, while age-1 and older kokanee densities ranged from 31/ha in 1998 to 1,206/ha in April 2000.

It appears that density dependence may be driving these kokanee population fluctuations. The period from egg deposition until the first autumn in the reservoir is when the greatest mortality occurred (approximately 96%); however, losses at this life stage are common and usually high. Losses between age-0 and age-1 were quite variable, ranging from 62% to 92% in Lake Billy Chinook. In 1999, for example, nearly 2 million age-0 kokanee were lost after recruitment to the reservoir. During years of lower population abundance of kokanee (1996–1997), growth for age-0 kokanee was very high. In recent years of high kokanee abundance, growth has declined. Similarly, as the numbers of spawners has increased, average spawner weight and length has decreased significantly, and number of eggs-per-female has decreased. Egg-to-recruitment survival of age-0 kokanee has also declined with increased spawner numbers. While key sources of mortality are difficult to isolate, many factors may contribute to mortality with combined or additive effects from density dependence. The study period may not be long enough to allow the emergence of clear evidence of higher-level population effects from density dependence.

Through intensive year-round sampling, this study has provided better understanding of kokanee biology and ecological interactions in Lake Billy Chinook that will have implications for kokanee, sockeye, and bull trout management in the future. The reservoir will most likely support additional *O. nerka* biomass in the form of sockeye salmon smolts, although kokanee growth rates may continue to decline and populations will continue to fluctuate widely. However, conditions in Lake Billy Chinook are favorable for kokanee production and likely would be favorable for sockeye production.

Current monitoring seems sufficient to identify kokanee trends and demographics. However, additional study would fill in current data gaps and determine changes associated with proposed facilities to alter the reservoir environment and aid fish passage. First, future studies should more intensively evaluate the impact of bull trout consumption on kokanee numbers, especially if the bull trout population is increasing as redd count data suggest. In addition, ecological interactions between these two species remain uncertain. Second, although high age-0 kokanee losses may be due to density-dependent effects, a robust study of numbers of fish passing through Round Butte Dam will be needed as Lake Billy Chinook *O. nerka* are allowed to express an anadromous (sockeye salmon) life history. Finally, estimates of zooplankton standing stock can overestimate or underestimate true production capacity of a reservoir. With the new surface outlet planned to aid fish passage, limnological changes may occur that will change zooplankton dynamics. A future evaluation of zooplankton, including production estimates, would allow a better estimate of *O. nerka* production under proposed new reservoir conditions.

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Chapter 1: Introduction and Study Area

INTRODUCTION

The construction of Round Butte Dam in 1964, near the central Oregon town of Madras, resulted in significant ecological changes to the Deschutes River, including the formation of a large upstream reservoir, Lake Billy Chinook (Figure 1.1). Since the construction of this dam, a wild population of kokanee (*Oncorhynchus nerka*) has become established in the reservoir and contributes to a popular fishery. With respect to other locations in North America, the Lake Billy Chinook kokanee fishery is relatively large and productive in terms of annual catch, angler effort, and yield (Thiesfeld et al. 1995). However, it is unknown what factors control the natural recruitment, survival, and production of this population.

Lake Billy Chinook also serves as a rearing area for several other native fish species, including bull trout (*Salvelinus confluentus*) and rainbow trout (*O. mykiss*). It is likely that kokanee play an important, although yet unexplained, role in the population dynamics of these other species. At various life-history stages, kokanee are an important forage species for bull trout (Beauchamp and Van Tassell 2001).

The kokanee population in Lake Billy Chinook is potentially unique in that it may have originated from the original sockeye salmon population that was native to Suttle Lake in the upper Metolius River basin (Figure 1.1). The population became established without stocking of hatchery kokanee into Lake Billy Chinook, and its origin has not been determined, but the kokanee in Lake Billy Chinook are assumed to have originated from the historic sockeye runs from Suttle Lake (Witty 1999). Kokanee were present in Suttle Lake and Wickiup Reservoir (upper Deschutes River basin) when Round Butte Dam was completed. Some of the kokanee in Suttle Lake may retain the original genetics from the native kokanee and sockeye salmon stock that was present there historically, even though hatchery kokanee have been stocked there in the past (Wallis 1960, Nehlsen 1995).

As part of the Federal Energy Regulatory Commission (FERC) relicensing process, proposals are being examined to reestablish sockeye salmon, chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*) into the basin above Round Butte Dam (Ratliff et al. 2001). The Oregon Fish and Wildlife Commission has adopted administrative rules establishing policies that direct the Oregon Department of Fish and Wildlife (ODFW) to "Restore anadromous and migratory resident fish to their historic range…" (e.g., Stuart et al. 1997). Basin plans adopted for the Metolius, Deschutes, and Crooked rivers direct ODFW to examine the feasibility of restoring anadromous fish upstream of the Pelton Round Butte Project (OAR's 635-500-1820, 635-500-1850, and 635-500-3120).

Although sockeye salmon were once native to this area (Nehlsen 1995), the potential success and impact of reestablishing a sockeye run warrant further investigation. Resource managers believe Lake Billy Chinook has the potential to serve as a rearing area for juvenile sockeye salmon. However, many questions remain regarding the feasibility of reestablishing sockeye salmon in the basin, including production potential and impact on other species. Portland General Electric Company (PGE), ODFW, the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO), other resource management agencies, and other stakeholders have an interest in obtaining a better understanding of the biology of Lake Billy Chinook kokanee salmon.

To learn more about the kokanee population and the potential for rearing sockeye salmon in the reservoir, staff from ODFW, PGE, CTWSRO, and other resource agencies cooperatively developed a study proposal with the following goals (Chilcote 1996):

1. Determine the factors that control kokanee recruitment, growth, and survival in Lake Billy Chinook.

2. Assess the potential ecological relationships of kokanee with other fish species and associated fisheries.

3. Determine the potential for sockeye salmon production in Lake Billy Chinook.

This report summarizes five years of kokanee research that was initiated to address these goals. It also presents a range of potential sockeye salmon production if anadromous fish passage is restored upstream of the Pelton Round Butte Project.

STUDY AREA

The study area includes Lake Billy Chinook, the main rearing area for kokanee, and the three major tributaries to the reservoir: (1) the Metolius River and its tributaries; (2) the lower portion of the Crooked River; and (3) the lower portion of the middle Deschutes Rivers, including Squaw Creek (Figure 1.1). The Pelton Round Butte Hydroelectric Project (Project; FERC No. 2030) is a series of three dams constructed on the Deschutes River. Pelton Dam (River Mile [RM] 102.7), which forms Lake Simtustus, and the Reregulating Dam (RM 100.1) were constructed in 1956–1957 approximately 16 kilometers (km) below the confluence of the Metolius River. Lake Billy Chinook was created by the construction of Round Butte Dam in 1964 at RM 110.4 (Figure 1.1). Lake Billy Chinook has a surface area of 1,619 hectares (ha) and is located in the canyons of the Metolius, Deschutes, and Crooked rivers. The Deschutes River and Crooked River arms run roughly parallel, north and south, whereas the Metolius River arm extends east to west. Lengths of these arms are 13 km, 10 km, and 21 km, respectively. Upstream and downstream passage for both anadromous and fluvial resident fish at the Project was terminated in 1968.

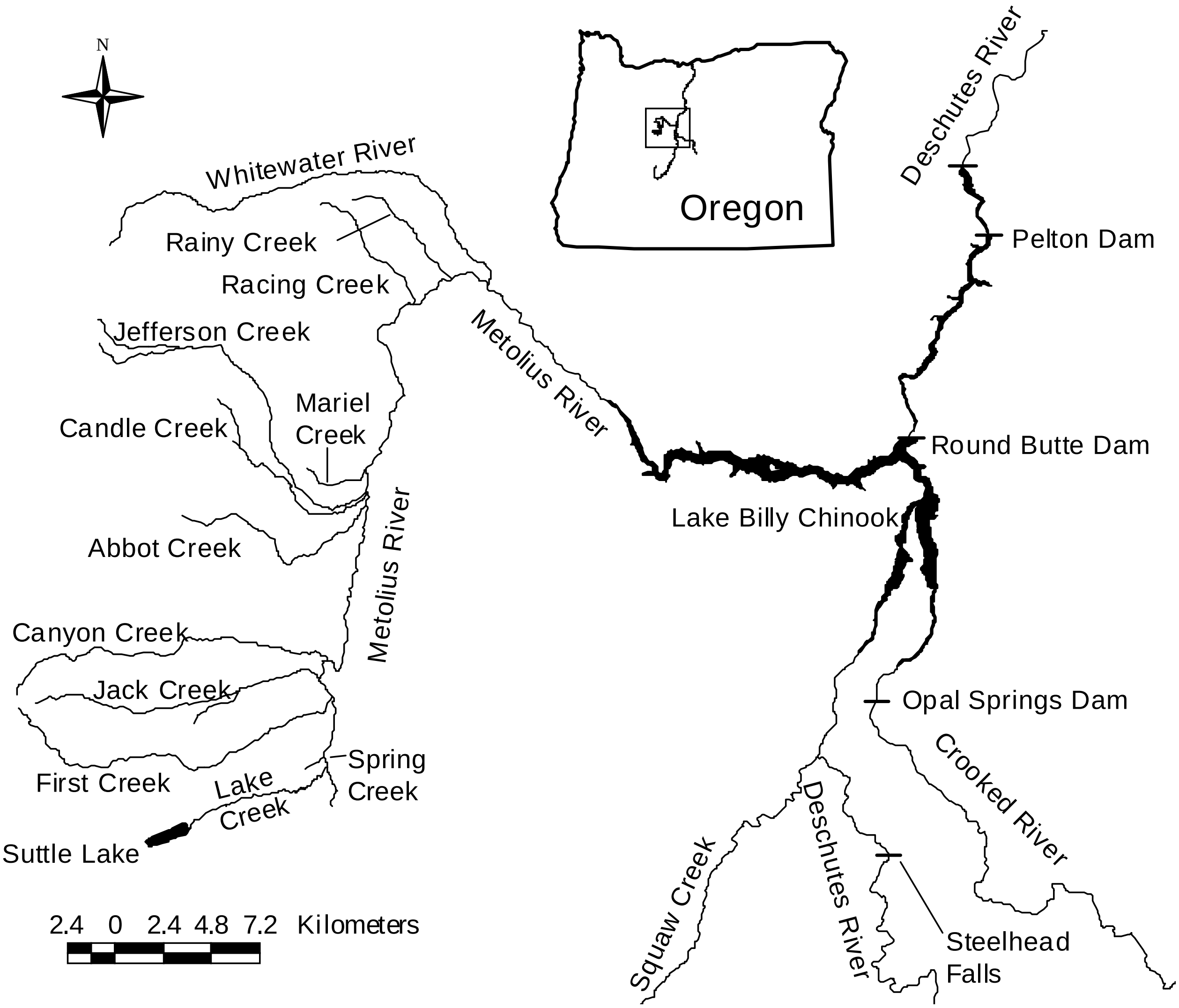

Figure 1.1. Lake Billy Chinook and the Metolius River basin.

The Metolius River originates as a large spring near the base of Black Butte in the Cascade Mountains. From its source it flows north and then east approximately 45 km into Lake Billy Chinook (Figure 1.1). A number of tributaries enter the Metolius River from the west. Progressing downstream from the head of the river, these tributaries are Lake (RM 39.6), Spring (RM 39.4), First (RM 37.2), Jack (RM 36.4), Canyon (RM 35.9), Abbot (RM 29.2), Candle (RM 28.8), Jefferson (RM 28.7), Mariel (RM 28.1), Racing (RM 21.2), and Rainy (RM 19.7) creeks, and Whitewater River (RM 18.4; Figure 1.1). Of these, Spring, Jack, Canyon, Abbot, Candle, and Jefferson creeks are greatly influenced by cold-water springs (approximately 5^{o} C). These springs contribute to the cool temperatures and relatively stable flows in the Metolius River. Whitewater River is a glacially-influenced stream originating on the east slope of Mount Jefferson. The Metolius River and selected tributaries are thought to support the bulk of the kokanee production for Lake Billy Chinook. During years of high abundance, kokanee spawn in most Metolius River tributaries.

Suttle Lake is a 593-ha natural lake located approximately 6.5 km west of the head of the Metolius River. Water from the lake drains into Lake Creek and flows 12.3 km before entering the Metolius River at RM 39.6. Suttle Lake historically served as a rearing environment for sockeye salmon and currently supports an abundant kokanee population.

The Deschutes River originates in the Cascade Mountains southwest of Bend and flows 212 km north to Lake Billy Chinook. Upstream of Lake Billy Chinook, kokanee spawn in the Deschutes River up to Steelhead Falls (RM 127.8), a distance of 13 km. Squaw Creek (RM 123) is the only large tributary below Steelhead Falls. Kokanee have spawned in Squaw Creek, although their distribution and abundance have not been determined. Other juvenile kokanee may migrate downstream from lakes and reservoirs located upstream of Steelhead Falls, such as Wickiup Reservoir.

The Crooked River is the largest eastern tributary to the Deschutes River, originating in the Ochoco Mountains and flowing 249 km west to Lake Billy Chinook. Only the lower 1.2 km of the Crooked River is available to spawning kokanee. The low-head dam at the Opal Springs Hydroelectric Project (RM 7.2) stops upstream passage except during very high river flows. There are no tributaries to the Crooked River between Lake Billy Chinook and the dam at Opal Springs. The Crooked River probably contributes a very small portion of the total reservoir kokanee production.

Native fish in the study area historically included summer steelhead and rainbow trout, chinook salmon, sockeye salmon and kokanee, bull trout, mountain whitefish (*Prosopium williamsoni),* Pacific lamprey (*Lampetra tridentata)*, largescale sucker (*Catostomus macrocheilus)*, bridgelip sucker (*C. columbianus)*, longnose dace (*Rhinichthys cataractae)*, speckled dace (*R. osculus)*, northern pikeminnow (*Ptychocheilus oregonensis),* chiselmouth (*Acrocheilus alutaceus),* shorthead sculpin (*Cottus confusus)*, torrent sculpin (*C. rhotheus)*, slimy sculpin (*C. cognatus),* mottled sculpin (*C. bairdi)* (Fies and Robart 1988), tui chub (*Gila bicolor),* and redside shiner (*Richardsonius balteatus)*. Summer steelhead, anadromous chinook and sockeye salmon, and Pacific lamprey are no longer present because upstream passage was terminated in 1968. Introduced species include brown trout (*Salmo trutta),* brook trout (*S. fontinalis)*, largemouth bass (*Micropterus salmoides),* smallmouth bass (*M. dolomieui),* bluegill (*Lepomis macrochirus),* black crappie (*Pomoxis nigromaculatus),* goldfish (*Carassius auratus),* common carp (*Cyprinus carpio),* and threespine stickleback (*Gasterosteus aculeatus).*

Limnology of Lake Billy Chinook was explained in detail by Raymond et al. (1997). The reservoir is considered eutrophic, stratifying in summer to form a stable epilimnion isolated from the hypolimnion. The thermocline is approximately 10 m deep and the period of stratification generally lasts from May through October. Green algae and nitrogen-fixing blue-green algae are favored by the low nitrogen to phosphorus ratio.

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Chapter 2: Abundance, Age, Growth, and Survival of Kokanee Salmon in Lake Billy Chinook, Oregon

INTRODUCTION

An understanding of the long-term dynamics of the current kokanee salmon (*Oncorhynchus nerka*) population in Lake Billy Chinook is critical to successfully evaluate the potential for sockeye salmon reestablishment in the basin. Kokanee are also an important food source for the threatened bull trout (*Salvelinus confluentus*). Therefore, the majority of the *O. nerka* research has focused on (1) examining abundance, growth rates, survival, and foraging tendencies of kokanee in the reservoir; (2) defining characteristics of the spawning population; and (3) trying to determine some of the mechanisms controlling various population attributes. Determining these controlling mechanisms will help managers understand the implications to the existing *O. nerka* population of having successful fish passage and anadromous *O. nerka* in the ecosystem, and any potential implications to the bull trout population. A three-year study to evaluate kokanee dynamics began in 1996 (Thiesfeld et al. 1999). The research presented in this chapter is an extension of the 1996–1998 study aimed at further identifying key uncertainties and contributing to the long-term data set for this system. This chapter focuses on two years of data (1999–2000). Long-term relationships are discussed in Chapter 4.

METHODS

Fry

Emergence Timing

In 1999, temperature data loggers were deployed at seven spawning locations throughout the Metolius River basin. Regression equations (Murray et al. 1989) were used to estimate hatching and emergence timing for each location. Temperature loggers were not deployed at the study sites in 2000; therefore hatching and emergence was not predicted for that year. At one reference site on the Metolius River, where temperature was monitored, temperature readings were similar in January and February of 1998, 1999, and 2000 ($F = 0.40$, $p = 0.68$).

Kokanee Recruitment to the Reservoir

Downstream migration timing and abundance of kokanee fry entering the reservoir was monitored using screw traps placed just upstream of the influence of Lake Billy Chinook in the Deschutes and Metolius rivers. In the Metolius River, a 2.4 m-diameter screw trap was installed approximately 2 km upstream of the reservoir at Monty Campground, whereas in the Deschutes

River, a 1.5 m-diameter screw trap was fished immediately upstream of the reservoir, allowing access by boat. At both locations, the trap was installed in the thalweg (deepest portion of the river). Fry production from the Crooked River fry was assumed to be very limited (*see* Thiesfeld et al. 1999) and, therefore, fry production from that source was not monitored. In 1999, the screw trap in the Metolius River was operated from 6 January to 3 June. The trap was not operated in the Deschutes River in 1999 because of logistical constraints. In 2000, traps were operated from January through June in the Metolius River and from January through April in the Deschutes River.

Dye marking and recapture of fry were conducted to determine trap efficiency (number of marked recoveries divided by number of marked releases) and to estimate fry recruitment. In 1999 and 2000, kokanee fry were marked with Bismark Brown dye at a concentration of 25 mg/l in a 19-l aerated container. Marked fry were transported approximately 500 m upstream and released along the shoreline at a single location at approximately 1200 hours. In 2000, a subset of marked fry was released at night. Marked fish were captured in the screw trap, enumerated, and released. During periods when the screw trap was not operated, catch was interpolated between dates of operation. In 1999, trap efficiency estimates (n = 16) were averaged weekly and recruitment estimates were calculated with an adjusted Peterson estimate using Chapman's version (Ricker 1975). In 2000, an average trap efficiency (n = 24) was determined. Number of fry captured daily in the screw trap was divided by average trap efficiency, then summed to estimate the total fry outmigration (i.e., recruitment into the reservoir), similar to procedures used by Todd (1994). For comparison, a Peterson estimate, using the Schaefer method (Ricker 1975), was determined based on mark-recapture data from trap efficiency tests (n = 24).

Trap efficiency was not determined for the Deschutes River screw trap. Therefore, an average trap efficiency of 2% (see Results) was used. Efficiency of the Deschutes trap was likely less than Metolius trap efficiency. Total fry outmigration was estimated following procedures described above.

Reservoir Residency

Population Assessment

Kokanee population estimates for 1999–2000 were calculated from hydroacoustic survey data. Thiesfeld et al. (1999) derived kokanee population estimates from trawl data from 1996–1998. Trawl population estimates were often two to five times lower than hydroacoustic-generated population estimates from surveys conducted simultaneously. Therefore, trawl-based population estimates were not determined in 1999–2000. Hydroacoustic targets were verified from concurrent trawl catches and from gill net catch.

Hydroacoustics

Hydroacoustic data were collected from 41 transverse, systematically located transects — 20 in the Metolius River arm, 13 in the Deschutes River arm, and 8 in the Crooked River arm (Figure 2.1). For 2000, 48 transects were surveyed (the original 41 transects plus 3 additional on the Deschutes River arm and 4 additional on the Crooked River arm). Acoustic surveys were conducted within a few days of a new moon, and usually were conducted concurrently with trawling. Hydroacoustic data were collected with a Simrad EY500 transceiver and a 120-kHz, split beam, 7^o transducer. Data were analyzed using the Simrad EP500 post-processing software. In 1999 and 2000, target strength (TS in decibels, dB) was converted to total length (TL in cm) using the formula *TS (dB) = 20 log TL (cm) - 67*. The lower TS cutoff was adjusted seasonally to include newly emerged fry. Targets above -30 dB were eliminated because size separation and the TS-to-size relationship becomes increasingly unreliable as actual fish size increases.

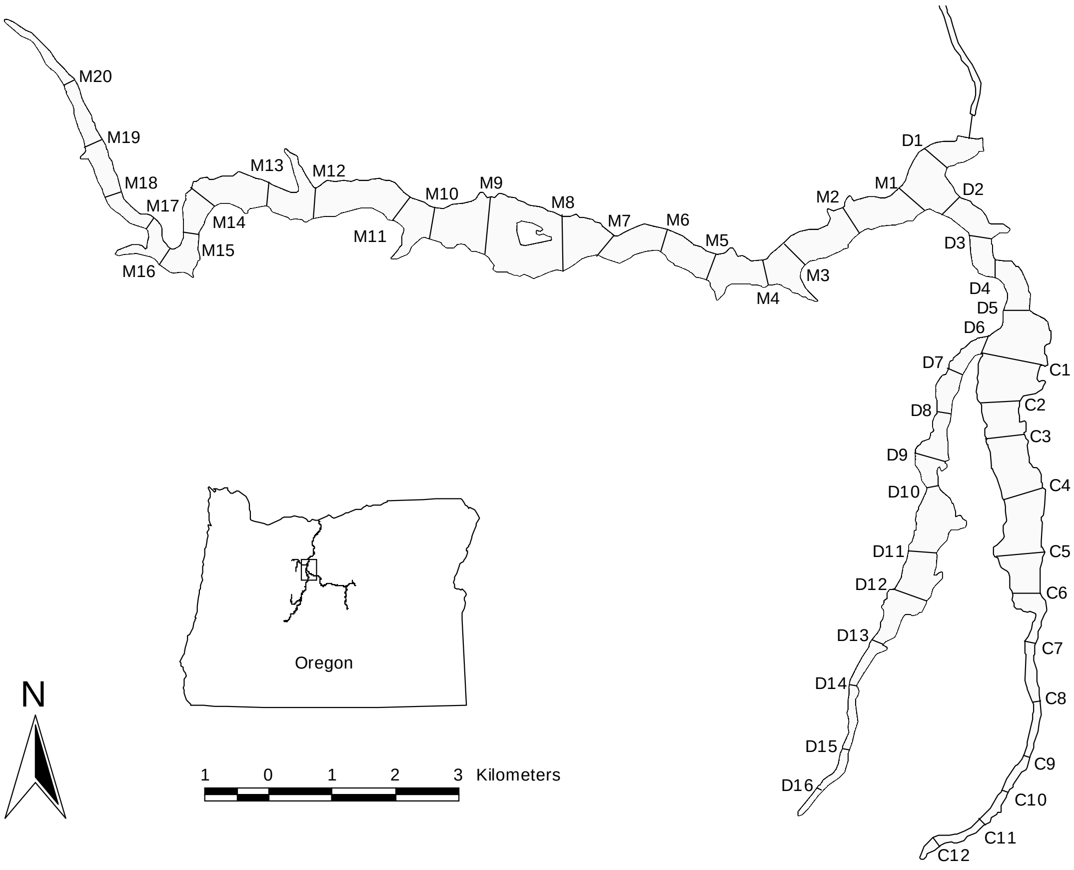

Figure 2.1. Map of Lake Billy Chinook showing locations of hydroacoustic transects.

Trawling

A 3.05-m X 3.05-m otter trawl (Lewis 1973) was fished in the three arms of Lake Billy Chinook at up to 13 transects (Figure 2.2) during February, March, April, July, August and October of 1999, and February, April, July, August, and October of 2000. Trawling was conducted concurrently with hydroacoustic surveys. Number of transects trawled was based on logistical limitations. Trawling occurred just before, during, or just after a new moon to minimize avoidance (Rieman 1992). The trawl was fished at 1.5 m/s with a diesel-powered, 8.5-m boat, at depths corresponding to the kokanee distribution as determined by hydroacoustic surveys, ensuring that most depth intervals were sampled. Total length (nearest mm), weight (nearest 0.1 g), scale, otolith, stomach sample, and depth data were collected from captured kokanee.

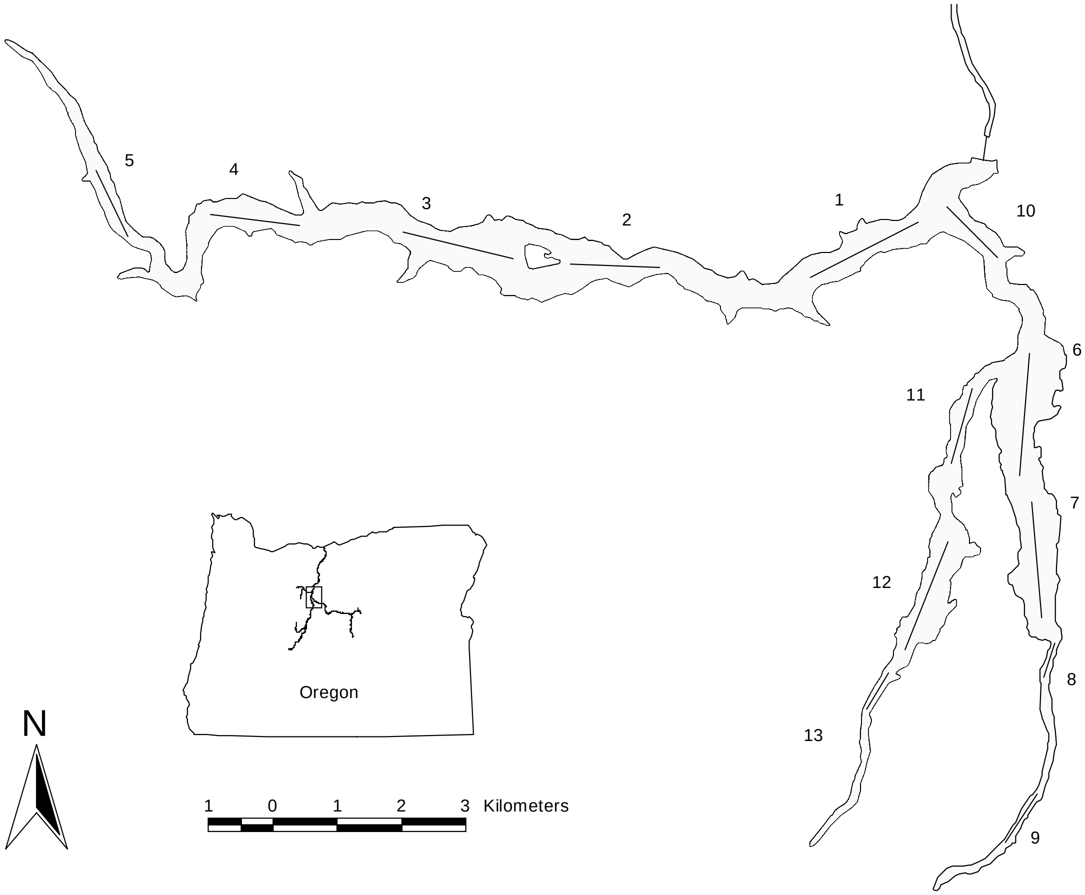

Figure 2.2. Map of Lake Billy Chinook showing locations of trawling surveys.

Gill Netting

A 30-m X 30-m variable mesh gill net was fished overnight near Chinook Island during April and July 1999 and during April, July, and October 2000. Length, weight, otolith, sex, and gonads were collected from netted fish. Depth data was collected in July and October 2000. Data were used to verify trawl catches and acoustic targets. In August 2000, a 1.5-m X 25-m experimental variable mesh gill net was fished at several locations near the reservoir bottom to verify large (> 400 mm) targets detected by hydroacoustics. To verify small targets (< 50 mm), a 0.5-m diameter plankton net (333 µm) was towed vertically from bottom to surface at several locations in August 2000.

Age, Growth, and Condition

Trawled and gill netted kokanee were aged by analysis of otoliths under a microscope. Further growth data was inferred from length frequency data using size-at-age information. Growth rate was calculated as the difference in mean length and weight between two successive sampling periods. Fulton's condition factor ($K = 100 \cdot W/L^3$) was calculated for comparisons and trends.

Diet Analysis

Stomachs were taken from kokanee captured during trawling and were preserved with a 10% formalin solution injected into the stomach. Stomach content volume was measured by displacement in a graduated centrifuge tube. Stomach contents were identified as *Daphnia* spp., *Bosmina* spp., calanoids, cyclopoids, *Leptodora kindtii*, or “other invertebrates.” A subset of organisms was measured (carapace length; using an ocular micrometer) in each sample.

Prey selection was examined using an electivity index comparing proportions of zooplankton found in kokanee diets with proportions of zooplankton found in Lake Billy Chinook ($E = [R1 - P1] / [R1 + P1]$; Ivlev 1961). Only zooplankton taxa found in diets were used in the analysis.

Zooplankton Sampling

Zooplankton were collected monthly at ten locations from February through October, and in December. Zooplankton were sampled with a 10–30 m vertical tow using an 80-µm mesh plankton net, and were preserved in 95% ethyl alcohol. Zooplankton were enumerated and measured (nearest 0.001 mm carapace length). Taxa were identified to species, except for nauplii and copepodites. Counts were used to estimate density (number/m^3) by species.

Spawning

Metolius River Spawner Surveys

Spawning kokanee were counted weekly at 20 index sites in the Metolius River and its tributaries starting on 1 September and continuing until essentially no kokanee were observed. Index sites were chosen in 1994 by locating a small reach (< 100 m) with spawning kokanee in each 1.6 km of river or stream (Ratliff and McCollister 1995). Index sites on the Metolius River started at RM 30 and proceeded upstream to the head of the river. Index sites on the tributaries started at the mouth of each tributary and proceeded upstream every 1.6 km until no spawning kokanee were observed. Index counts were used to determine the peak and duration of the spawning season, and total counts were used as a relative index of spawner abundance. Spawning kokanee were also captured each year from the Metolius River and sometimes from selected tributaries using gill or seine nets. Lengths, weight, sex, and gonads were collected. In 2000, dead spawned-out females were collected to determine egg retention.

Although some kokanee spawning occurs in the Crooked and Deschutes rivers (Thiesfeld et al. 1999; screw trap data, this report), no spawner surveys were conducted in 1999 and 2000 because of logistical constraints.

Additional spawner counts were conducted in the mainstem Metolius River during October 1999 (using a cataraft) and October 2000 (using a canoe) by floating from RM 39.7 (Lake Creek) to RM 35.9 (Canyon Creek). Usually fish were counted while floating; however, when dense aggregations were encountered, floating was stopped while counting fish. Spawner counts were also conducted on Mariel Creek in 1999. In addition, in October 2000, spawners were counted by walking in the Metolius River from RM 40.6 (Riverside Campground) to approximately RM 41.2 (to the head of the Metolius). In all surveys, tagged fish were noted.

Metolius River Basin Spawner Estimate and Estimated Egg Deposition

Pre-spawning kokanee were captured with a 100-m boat-deployed beach seine during August and September 1999 and 2000 near the confluence of the Metolius River and Lake Billy Chinook. Adult kokanee were marked with brightly-colored Floy T-bar anchor tags inserted slightly posterior and ventral to the dorsal fin. A subset of kokanee was tagged with double tags to estimate tag retention. Another subsample of seine-captured kokanee was processed in the laboratory, where lengths, weight, and gonads were taken, and number of eggs-per-female was used to determine fecundity. Tagged kokanee were later counted during spawning surveys conducted in the Metolius River and its tributaries for use in a Peterson estimate of total spawners using the Schaefer method (Ricker 1975).

To determine the number of female spawners, the percent of females in the spawning run was multiplied by the estimated spawner abundance. In 1999, eggs-per-female was determined from kokanee collected during beach seining in the reservoir and from females collected on the spawning grounds. In 2000, eggs-per-female and gonad weight (male and female) were determined from kokanee collected during beach seining. Potential egg deposition was estimated by multiplying the average number of eggs per female (less average egg retention) by the number of female spawners.

On 1 November 2000, kokanee redds (n = 27) on the Metolius River and several tributaries were excavated to determine egg deposition and magnitude of superimposition. A 33-cm diameter stream bottom sampler (1 mm mesh net) was pushed into the redd substrate. Redds were agitated and cobble and gravel were carefully removed. Eggs were caught in the collecting net and bucket. This procedure was repeated until cobble could no longer be removed or no more eggs were found. Dissolved oxygen (using Winkler method) and temperature were measured at two excavation sites.

RESULTS

Fry

Emergence

Predicted emergence timing for kokanee fry was similar to the observed downstream migration. Water temperatures in the spawning areas were stable in spring-fed systems and varied between 3°C and 11°C in the other systems. In 1999, hatching was predicted to occur from mid-December through early February, and emergence was predicted to occur from early January through 1 April (Figure 2.3). Jefferson and Candle creeks had predicted hatching and emergence times much later than the mainstem Metolius River or spring spawning sites (Heising Springs and Spring Creek). Predicted hatching times were similar in 1998 (Thiesfeld et al. 1999) and 1999. In 1999, actual downstream migration occurred from January through early June and peaked in April (Figure 2.4). In 2000, outmigration from the Metolius River basin occurred from January through the end of May and peaked in April (Figure 2.5). Fry outmigration from the Deschutes River in 2000 ran from January through April, peaking in late January (Figure 2.5).

Screw trap catches in the Metolius River increased markedly during this study. Kokanee comprised the majority of the 1998 catch (n = 13,735) (Thiesfeld et al. 1999), and kokanee catch increased in 1999 (n = 28,199) and 2000 (n = 56,216). Bull trout were the next highest catch (1998–2000) followed by mountain whitefish and rainbow trout. In 1999, most kokanee fry were captured in late March and early April, and ranged between 25 mm and 40 mm long (Figure 2.6). After May 1999, some kokanee as large as 125 mm were captured. These larger fry may have reared for a short period in the Metolius River, or possibly Suttle Lake, before migrating downstream. In 2000, most kokanee left the Metolius River in late March and early April, and captured kokanee ranged between 20 mm and 40 mm long (Figure 2.7).

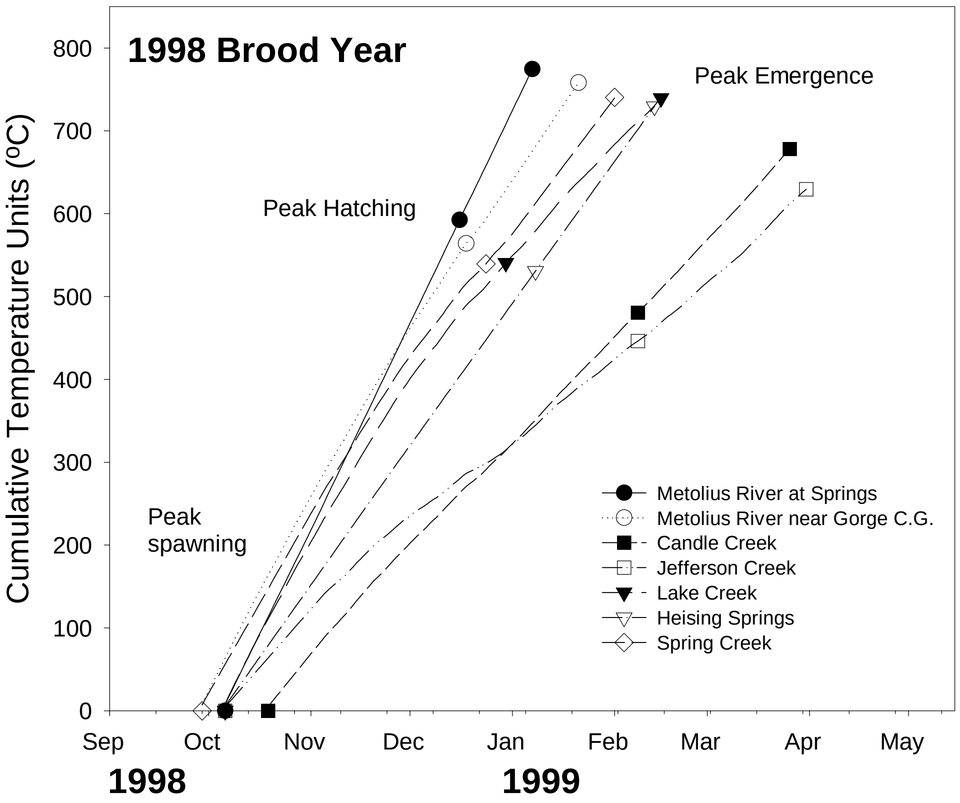

Figure 2.3. Predicted hatching and emergence dates for 1998 brood year (1999 migration year) kokanee predicted by cumulative temperature units from date of peak spawning at seven locations in the Metolius River basin.

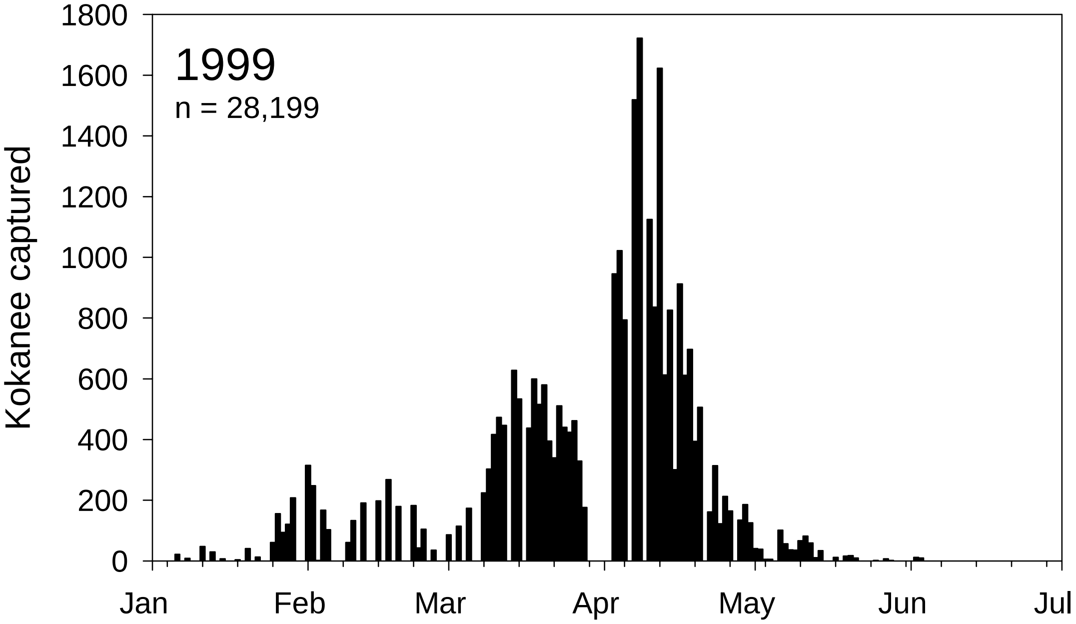

Figure 2.4. Number of juvenile kokanee captured daily in a 2.4 m-diameter screw trap fished just upstream of Lake Billy Chinook in the Metolius River, 1999.

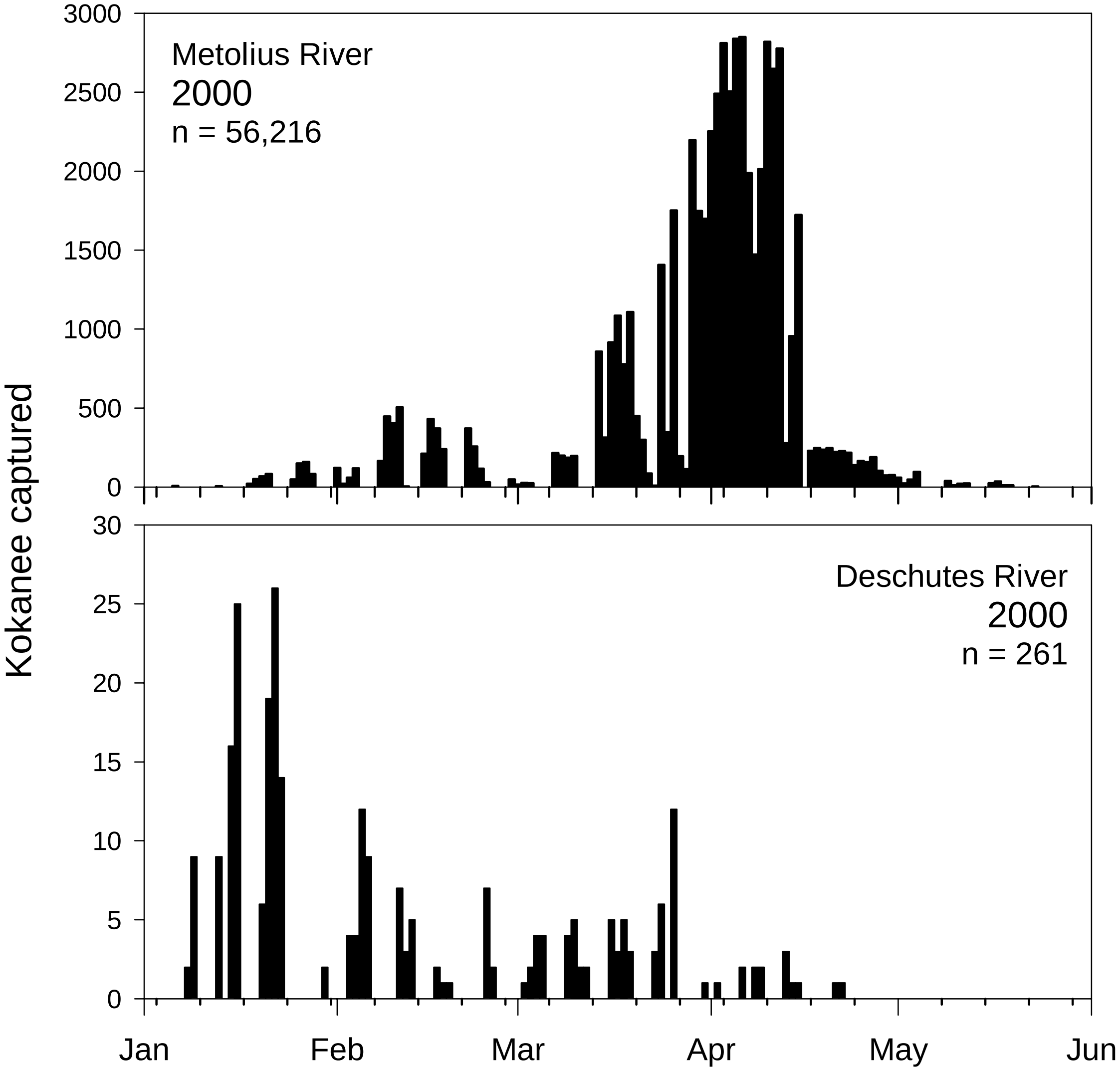

Figure 2.5. Number of juvenile kokanee captured daily in a 2.4 m-diameter screw trap fished just upstream of Lake Billy Chinook in the Metolius River (top panel) and the Deschutes River (bottom panel), 2000.

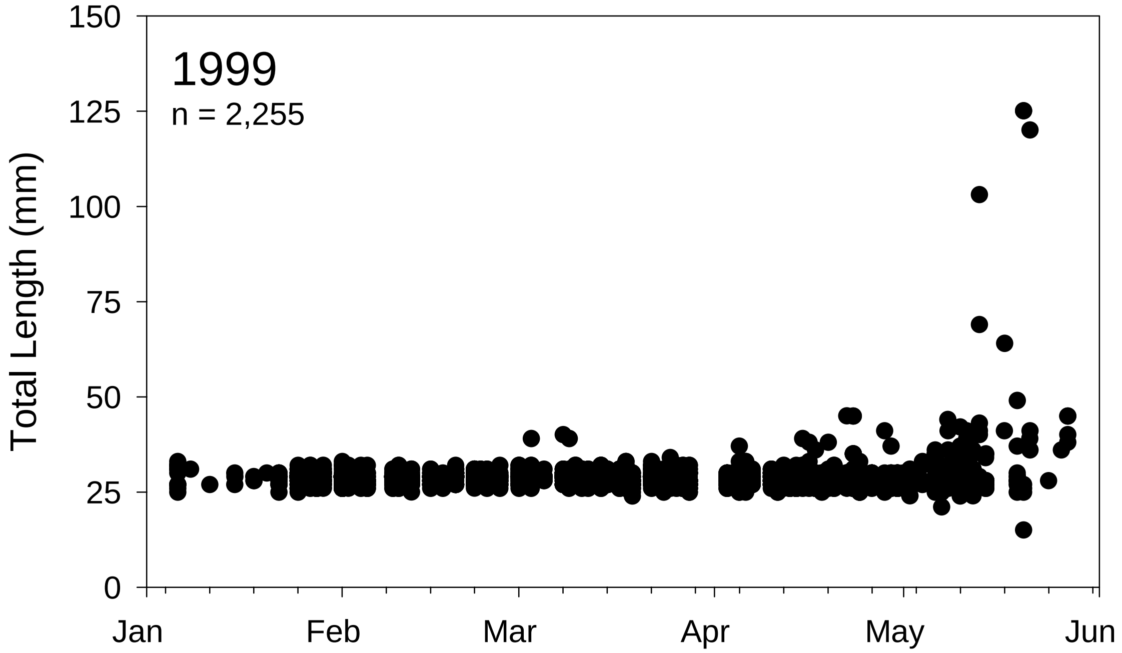

Figure 2.6. Timing and length of kokanee captured in a 2.4 m-diameter screw trap fished just upstream of Lake Billy Chinook in the Metolius River, 1999.

Screw trap efficiency was highly variable, although weekly average trap efficiency was similar between years: 2.1% in 1998 (Thiesfeld et al. 1999), 2.1% in 1999, and 2.8% in 2000. Total fry recruitment from the Metolius River to the reservoir in 1999 was estimated at 1,897,828 (1,645,278 to 2,150,379; 95% confidence interval [CI]) using the Peterson estimate. In 2000, recruitment from the Metolius River was estimated at 2,167,813 fry (1,561,556 to 2,810,800; 95% CI) based on trap efficiency estimate or 2,144,711 fry (1,889,123 to 2,435,311; 95% CI) based on the Schaefer method. These estimates are lower than 1998 fry recruitment estimates of 2,540,963 (1,697,993 to 3,383,932; 95% confidence interval) (Thiesfeld et al. 1999). Although screw trap efficiency was low and never greater than 10%, estimates of age-0 recruitment from the screw trap were similar to recruitment estimates from hydroacoustic analyses.

In 2000, kokanee were the primary catch (n = 261) in the Deschutes River screw trap, followed by brown trout (*Salmo trutta*; n = 140). Most newly emerged kokanee were 20–35 mm long and migrated during January through March (Figures 2.5 and 2.7). Kokanee fry ranging from 80–115 mm were captured in late January. These larger fry may have reared in the river or originated from an upstream reservoir. A number of age-1 kokanee (110–160 mm TL) were also captured in the Deschutes River between mid-April and mid-May 1997 (Thiesfeld et al. 1999). Kokanee recruitment from the Deschutes River in 2000 was estimated to be 27,650 fry, or 1.3% of the estimated Metolius River recruitment for that year.

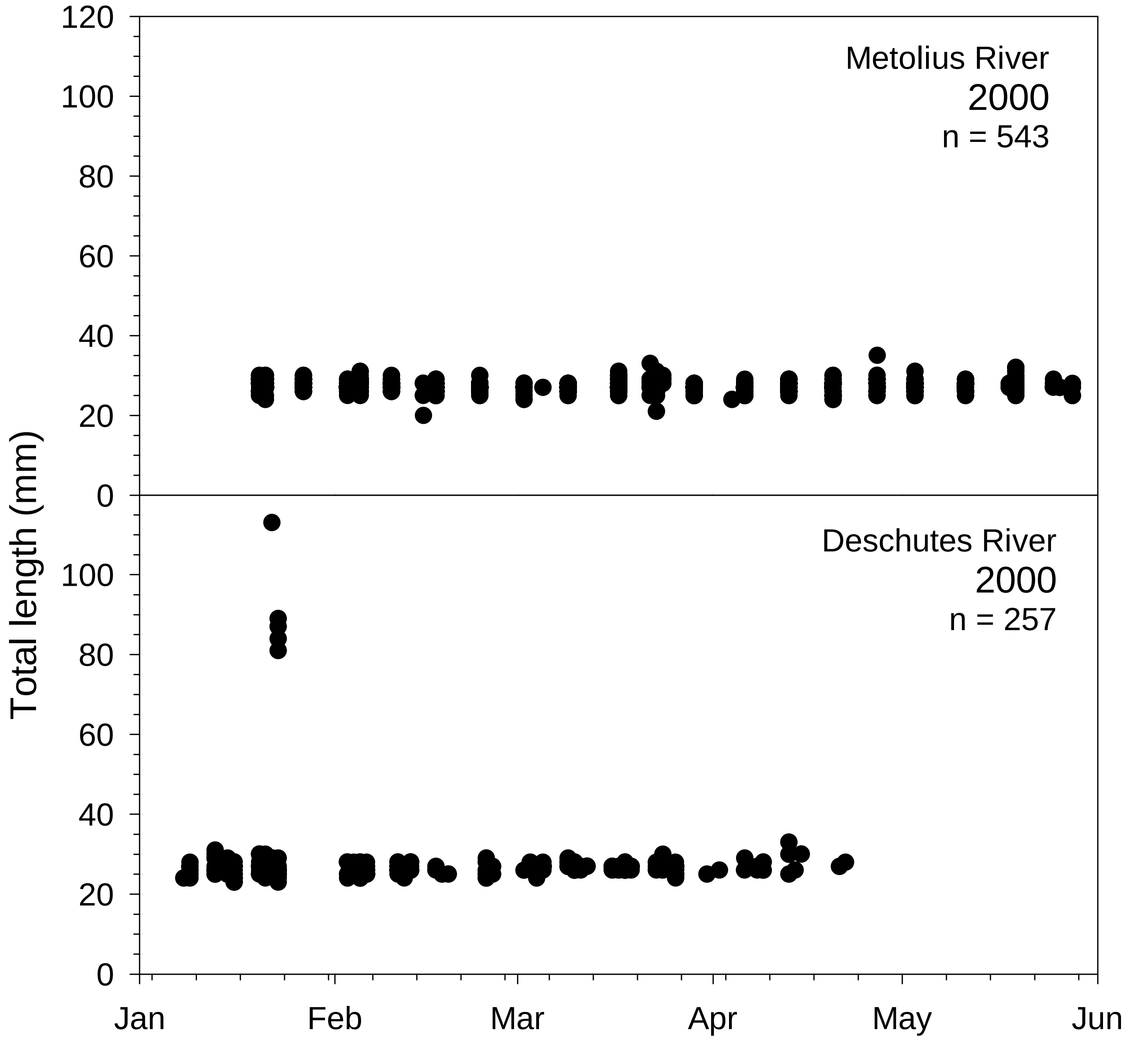

Figure 2.7. Timing and length of kokanee captured in a 2.4 m-diameter screw trap fished just upstream of Lake Billy Chinook in the Metolius River (top panel) and the Deschutes River (bottom panel), 2000.

Reservoir Residency

Population Assessment

The abundance of kokanee in Lake Billy Chinook varied seasonally and annually during the 1999–2000 study period (Figure 2.8). Hydroacoustic estimates show that 1999 kokanee abundance was higher than 2000 abundance, especially for age-0 fish. Overall kokanee population estimates in 1999–2000 were nearly double those during 1996–1998 (Thiesfeld et al. 1999). Kokanee were the predominant catch during trawl surveys (representing >99%) and gill net surveys (>99%, except in October 2000 when 23% were other fish). Therefore acoustic data were not adjusted to account for other species. The lowest abundance in 1999–2000 was in November 2000, when only 712,000 kokanee (about 500/ha) of all ages were estimated. The prior low (since 1996) was in October 1997, when the total population was estimated to be 350,000 kokanee (215/ha). The highest abundance of all five years was estimated in August 1999 (3,864,000 kokanee of all ages, or 2,700/ha).

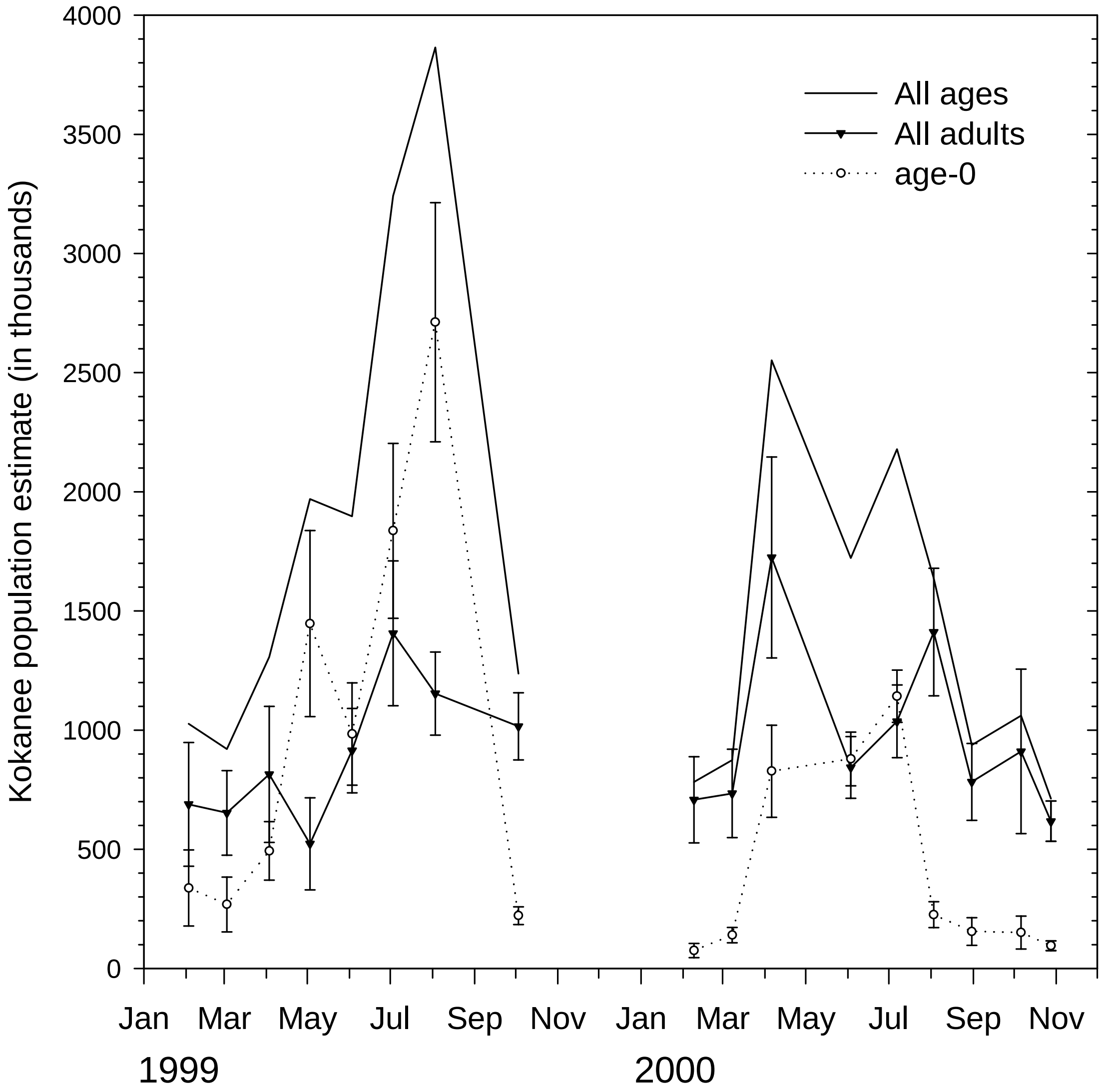

Figure 2.8. Hydroacoustic estimates of kokanee abundance, by age class, in Lake Billy Chinook, 1999–2000. Error bars represent 95% confidence intervals.

Hydroacoustic estimates of age-0 abundance in May of both years were comparable to the screw trap recruitment estimates. Abundance of age-0 kokanee decreased considerably from August through November in 1999 and 2000, similar to trends observed in prior study years (Thiesfeld et al. 1999). Abundance of adult kokanee declined between late July and early October in 1999 and 2000 (Figure 2.8), corresponding with kokanee leaving the reservoir to spawn. Acoustic estimates likely underestimated adult kokanee abundance from April to July in both years.

Abundance of age-0 kokanee in Lake Billy Chinook generally peaked in July or August. Age-0 abundance reached 2,711,000 (about 1,900/ha) in August 1999 and was lowest, 74,500 (52/ha), in February 2000. Prior densities of age-0 kokanee ranged from a low of 159/ha in October 1997 to a high of 2,038/ha in July 1998 (Thiesfeld et al. 1999).

Adult kokanee (age-1 and older) abundance peaked to 1,725,000 (1,206/ha) in April 2000 and was lowest in May 1999 (522,000; 365/ha), far surpassing prior abundance estimates. From 1996–1998, densities of adult kokanee ranged from a low of 31/ha in October 1998 to a high of 187/ha in July 1997 (Thiesfeld et al. 1999).

Although most adults were age-1 kokanee, age-2 and older kokanee averaged 19% (range 9% to 38%) of the population from 1999 to 2000. Abundance of age-2 and older reached 298,000 in August 2000, and was lowest (approximately 56,000) in late October 2000.

Depth distribution of kokanee varied in 2000. Gill net (30 X 30 m) catch of adult kokanee was greatest above 15 m in July, but more adult kokanee moved deeper in October, creating a slightly bimodal distribution (Figure 2.9). Because of low sample sizes of the smallest (< 200 mm) and largest (> 320 mm) kokanee, size-at-depth trends were unattainable.

Depth distribution of kokanee captured in gill nets closely followed acoustic target distributions. No trends were evident from samples of acoustic- or trawl-generated kokanee depth distributions.

Age, Growth, and Condition

Trawling

Growth rates for age-0 kokanee were similar during both 1999 and 2000 but lower than growth rates in prior years (Thiesfeld et al. 1999). In 1999, age-0 kokanee grew from 33 mm total length (mean; range 27 to 46 mm) in April to 175 mm (mean; range 149 to 209 mm) in September, as estimated with length frequency distributions from trawl surveys (Figure 2.10). In 2000, age-0 kokanee grew from a mean of 33 mm (range 27 to 50 mm) in April to a mean of 151 mm (range 122 to 187 mm) by October 2000 (Figure 2.11). Thiesfeld et al. (1999) reported that age-0 kokanee in 1996 and 1997 had reached a mean of 171 and 160 mm by fall, respectively, but grew less in 1998, only reaching 138 mm. Interestingly, the highest ever age-0 abundance occurred in July 1998.

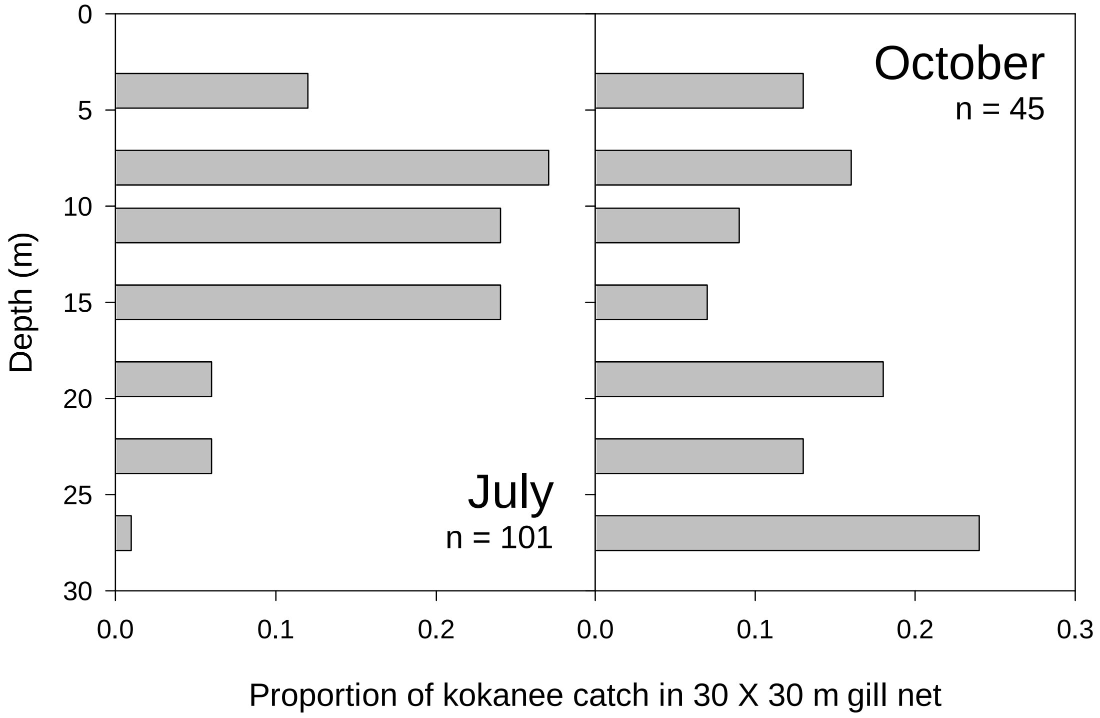

Figure 2.9. Depth distribution of kokanee captured in gill nets (30 X 30 m) set near Chinook Island in Lake Billy Chinook, 2000. Bottom of the reservoir at this site is 30 m.

Size of age-1 kokanee increased from 156 mm (range 105 to 200 mm) in April to 270 mm (range 220 to 281 mm) by September 1999. Mean total length of age-1 kokanee was 165 mm (range 136 to 196 mm) in April and 246 mm (range 214 to 279 mm) in October 2000. By August each year, age-1, age-2, and age-3 kokanee were nearly indistinguishable from each other by size captured in trawls.

Gill Netting

Age-0 kokanee were not captured in the 30 X 30 m gill net set near Chinook Island (Metolius River arm) until July 1999 and October 2000 (Figures 2.12 and 2.13). Mean length of age-0 kokanee reached 162 mm (range 124 to 185 mm) by October 1999 and 149 mm (range 130 to 175) by October 2000. Size of age-1 kokanee increased from 186 mm (range 167 to 202 mm) in April to 231 mm (range 219 to 242) by October 2000.

Additional gill netting was conducted in summer 2000 to verify large targets near the reservoir bottom detected by hydroacoustic surveys. Only kokanee were captured in these bottom sets (mean TL = 256 mm, maximum size was 317 mm).

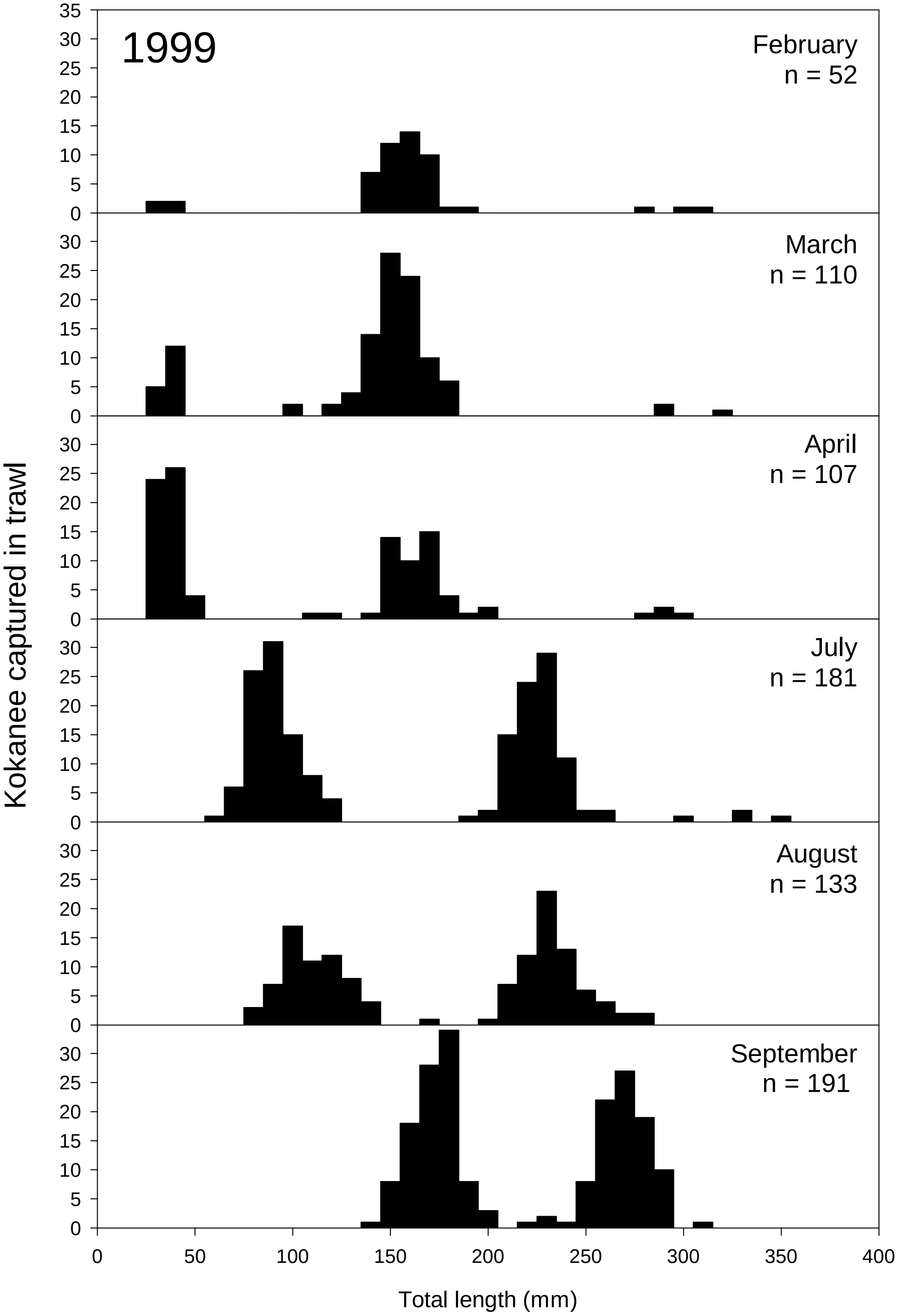

Figure 2.10. Length-frequency distribution of kokanee captured in trawls on Lake Billy Chinook, 1999.

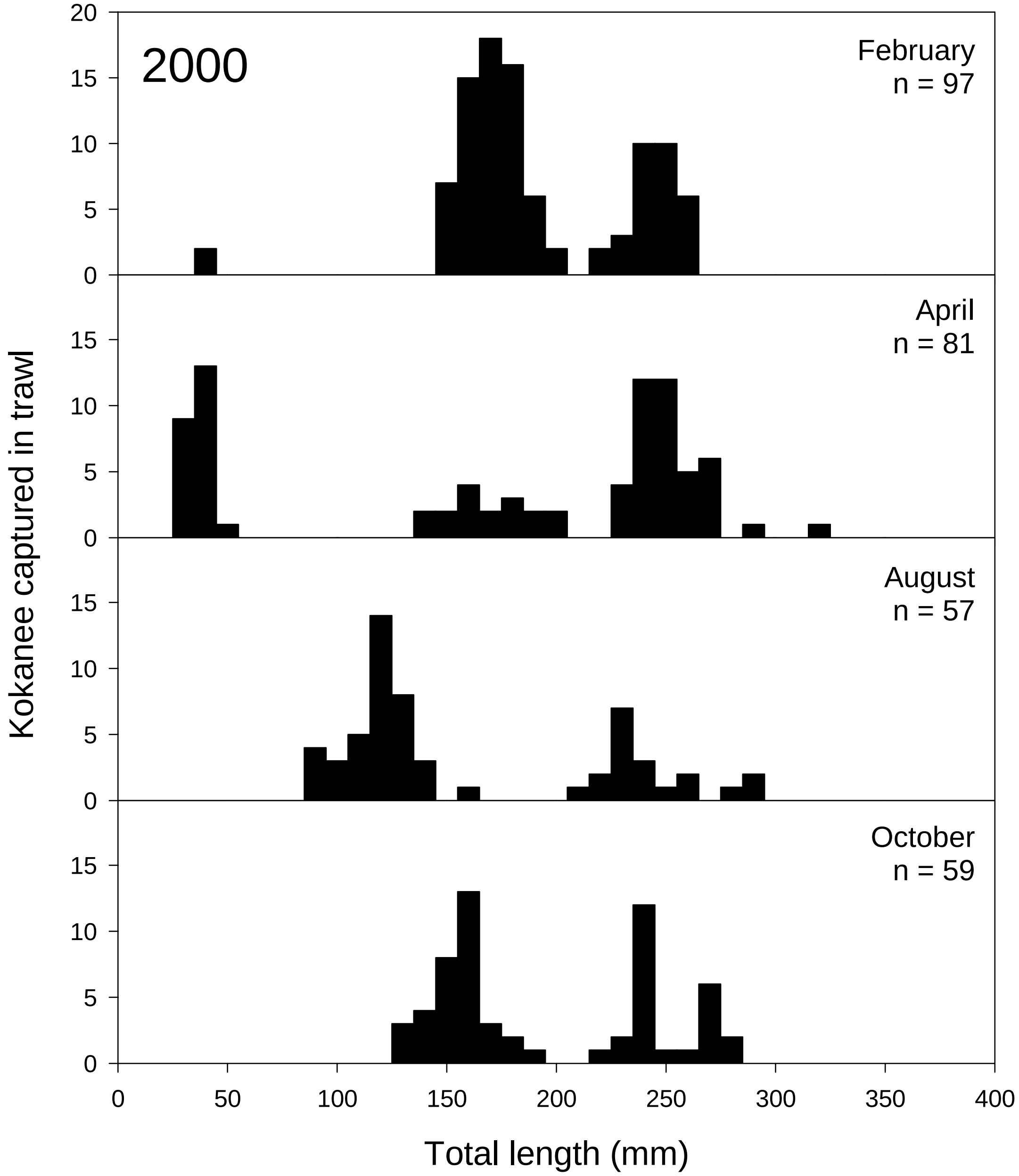

Figure 2.11. Length-frequency distribution of kokanee captured in trawls on Lake Billy Chinook, 2000.

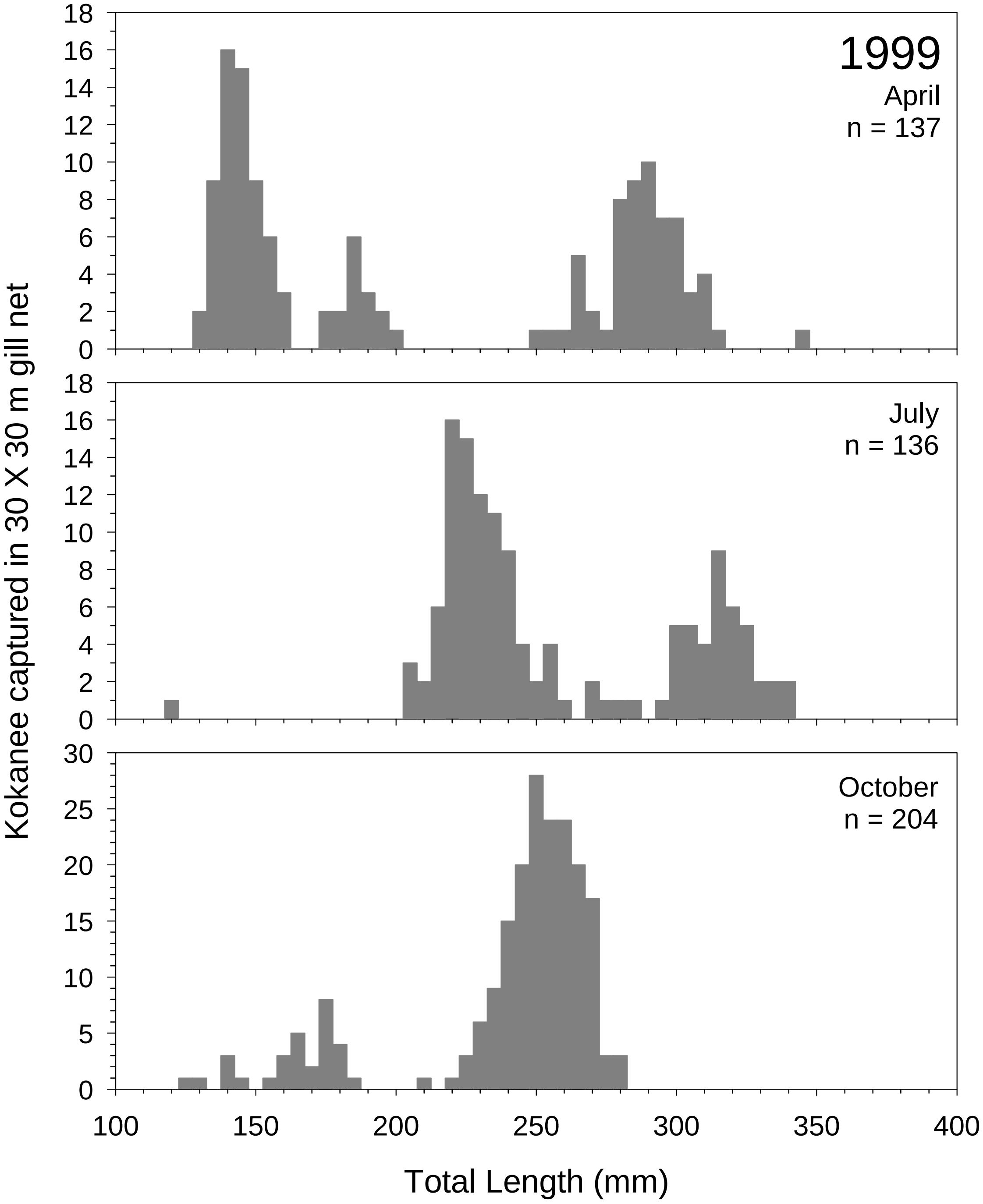

Figure 2.12. Length-frequency distribution of kokanee captured in 30 X 30 m gill net on Lake Billy Chinook, 1999. Note changes in y-axis scale.

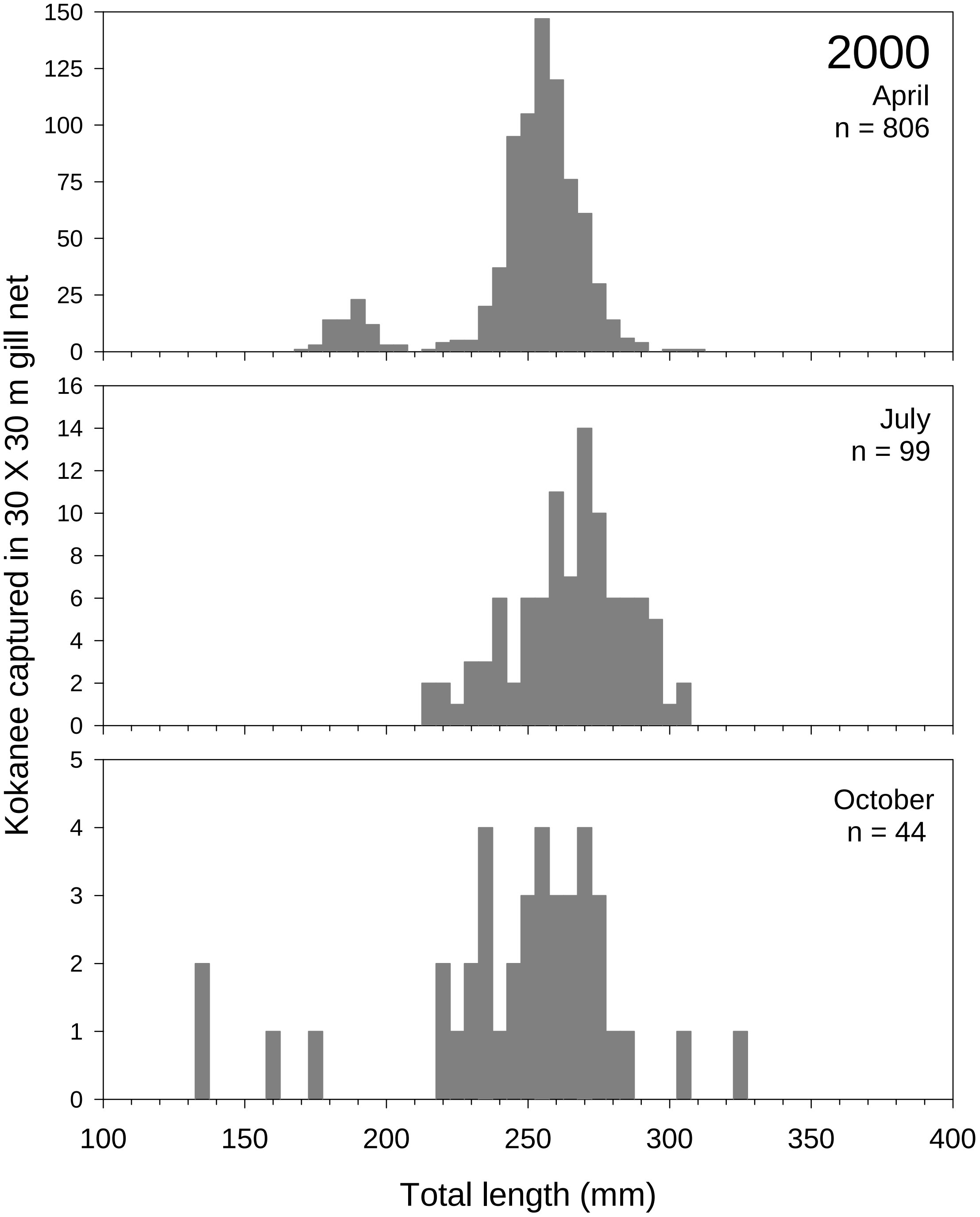

Figure 2.13. Length-frequency distribution of kokanee captured in 30 X 30 m gill net on Lake Billy Chinook, 2000. Note changes in y-axis scale.

Otolith Aging

Data from otolith aging generally corroborated age data from length frequency distributions. Few otoliths from age-0 fish were taken and aged. Generally, it was assumed that fish captured in screw traps and fish less than 100 mm TL were age-0 or young-of-year fish. As with much of the trawl and gill-net data, age-1, age-2, and age-3 kokanee were nearly indistinguishable from each other by size during most seasons (Figure 2.14). In this case, otolith ages provided necessary age and growth resolution (Figure 2.15). Growth rate was highest for age-0, followed by age-1 kokanee, with greatest increases from spring to summer (Figure 2.16). Age-at-length was similar in 1999 and 2000, although 1999 age-2 and age-3 kokanee grew larger (Figure 2.17). Weight of adult kokanee in 1999 was greater than that of adults in 2000 (Figure 2.17). Age-0 kokanee grew rapidly (up to 200 mm), after which growth tapered off. From 1999 to 2000, only one female kokanee was aged at age-4. In 1997, 69% of spawning kokanee (sampled for aging) were age 4.

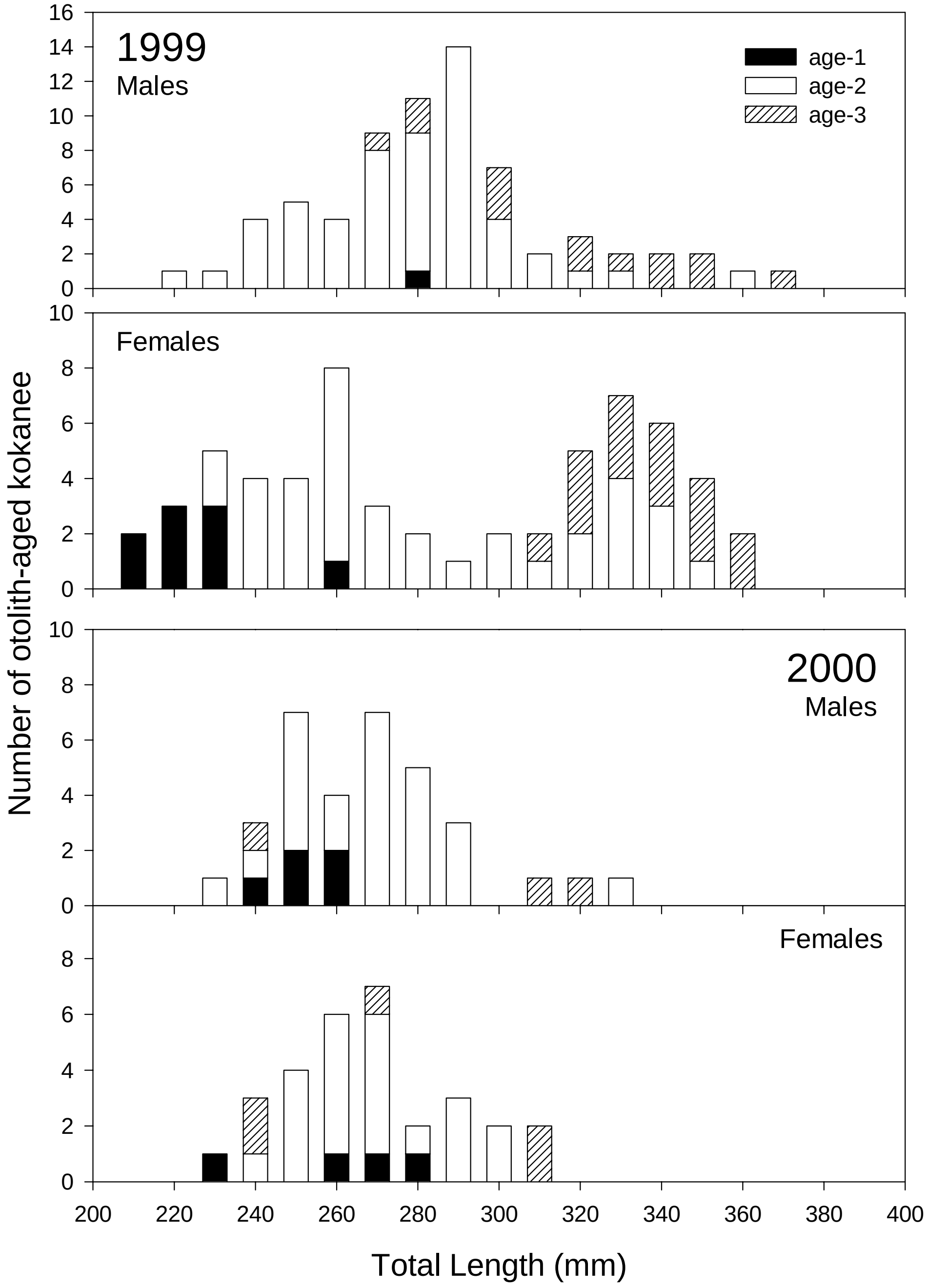

Figure 2.14. Length frequency distributions of otolith-aged kokanee by age separated by sex in Lake Billy Chinook. Kokanee were captured from July to October in 1999, including some spawners. In 2000, kokanee were captured from April to October, no spawners included. Note change in y-axis scale.

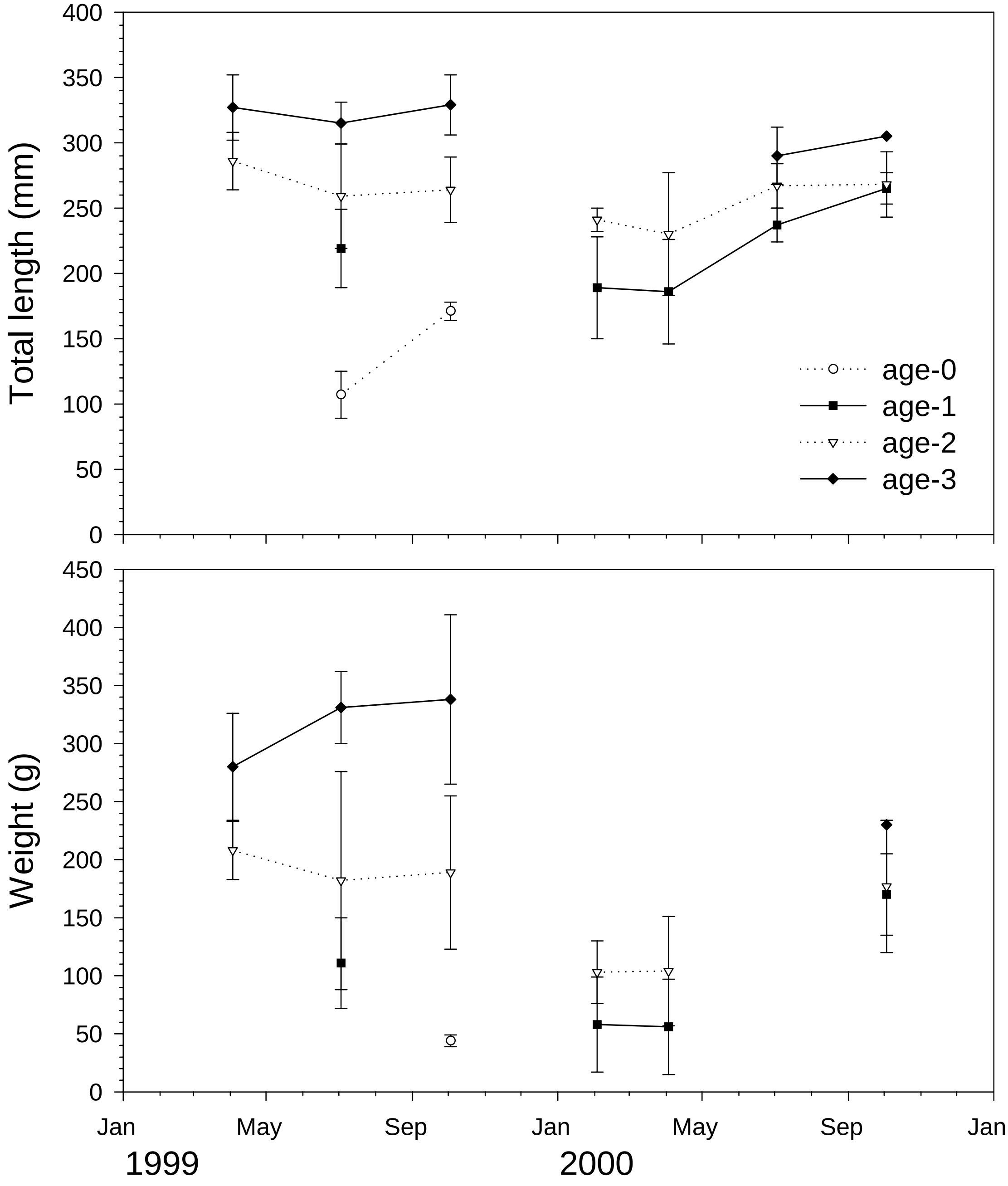

Figure 2.15. Mean lengths and weights for otolith-aged kokanee by month in Lake Billy Chinook, 1999–2000. Error bars represent + 1 Standard Error. Note change in y-axis scale.

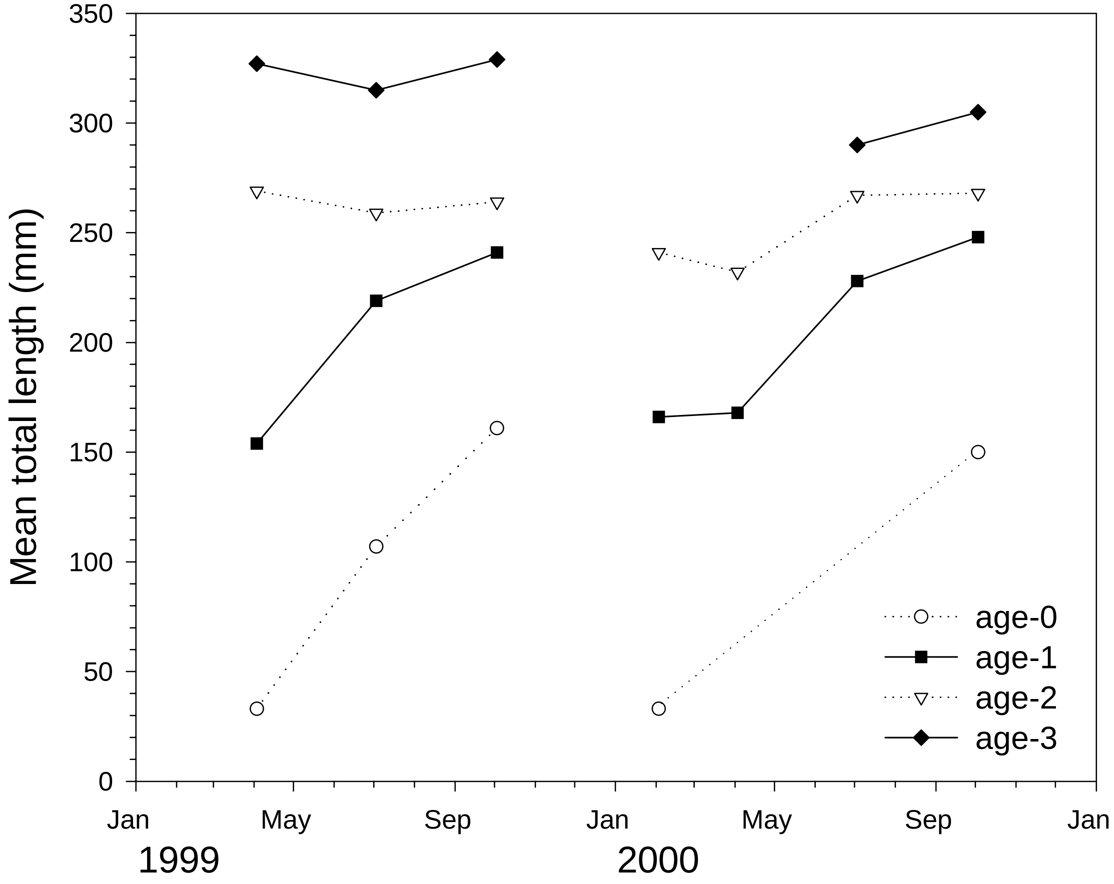

Figure 2.16. Seasonal growth of kokanee by age class in Lake Billy Chinook. Growth data synthesized from all sources: trawling, screw traps, gill netting, and otolith data.

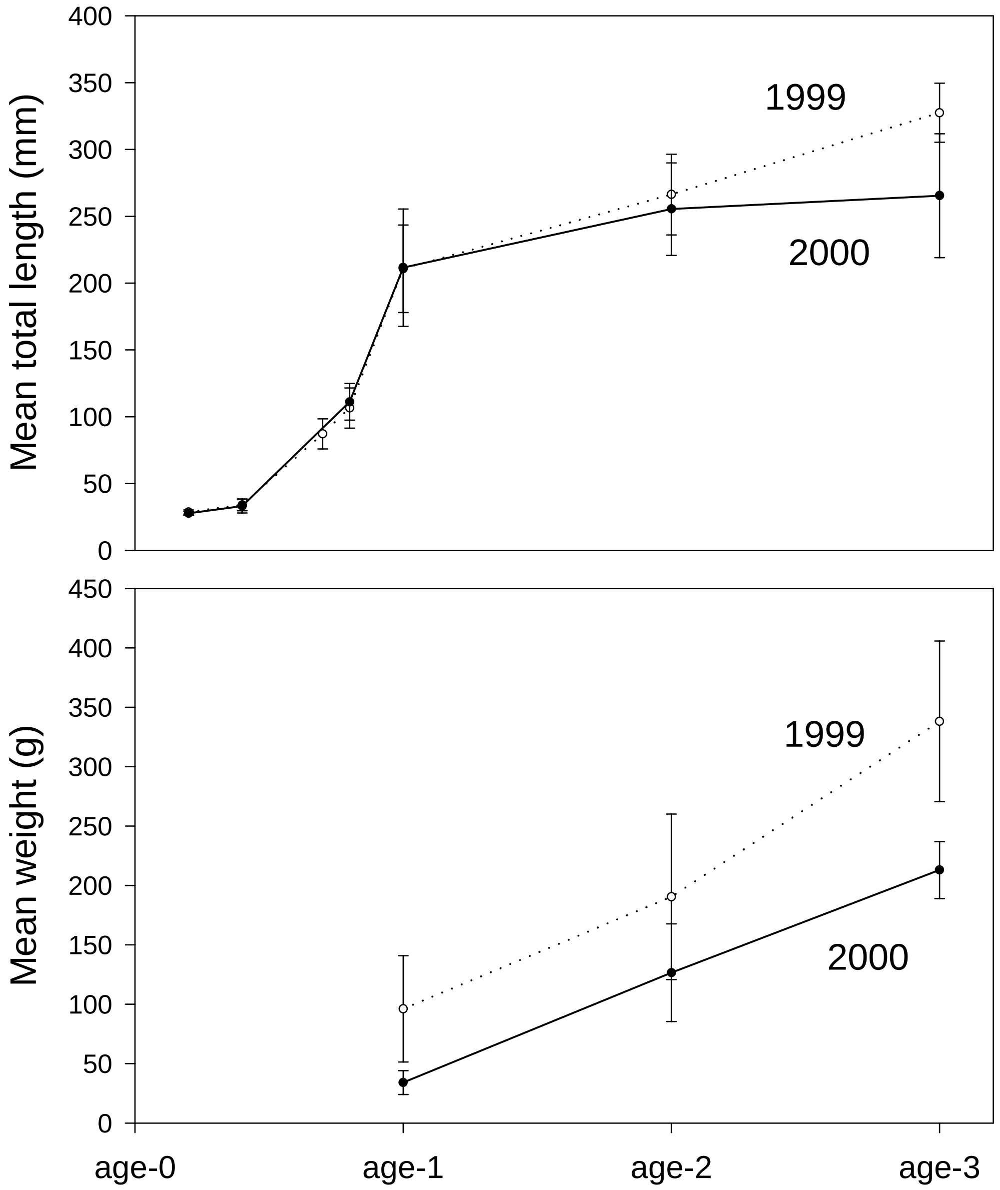

Figure 2.17. Mean length-at-age (top panel) and weight-at-age (bottom panel) for otolith-aged adults and age-0 kokanee in Lake Billy Chinook, 1999–2000. Error bars represent + 1 Standard Deviation (SD).

Condition

Condition index (Fulton's *K*) varied seasonally and by size class (Table 2.1). In general, condition factor was lowest in March and April and highest in July and August during 1999–2000. No information was available regarding condition factor in other kokanee populations, although a decrease in condition through winter and subsequent increase in condition in spring follows trends exhibited by Atlantic salmon (*Salmo salar*) parr (Sutton et al. 2000).

Table 2.1. Fulton condition factor *K* for all age-classes of kokanee in Lake Billy Chinook, 1999–2000. Standard deviation in parentheses.

		Fulton's *K*				
Year	**Season**	**age-0**	**age-1**	**age-2 & -3**	**age-1, -2, -3**	**all kokanee**
1999	March to April	0.797 (0.27)	0.674 (0.27)	0.853 (0.06)		0.729 (0.15)
	July to August	0.764 (0.17)	0.964 (0.07)	0.977 (0.10)		0.899 (0.15)
	October	0.858 (0.07)			0.941 (0.08)	0.898 (0.08)
2000	April		0.760 (0.07)	0.828 (0.06)		0.820 (0.06)
	July to August	0.824 (0.07)			0.924 (0.10)	0.820 (0.06)
	October	0.841 (0.08)			0.893 (0.09)	0.870 (0.11)

Survival and Mortality

Most kokanee mortality occurred prior to recruitment to Lake Billy Chinook (Table 2.2). Mortality from egg deposition to recruitment (to the Metolius River screw trap) was 95% in 1999 (Brood Year [BY] 1998) and 96% in 2000 (BY 1999). In 1999, screw traps appeared to underestimate BY 1998 recruitment. Abundance of age-0 kokanee reached 2,711,299 (± 501,792; 95% confidence interval) according to acoustic estimates, versus the screw trap estimate of 1,897,828 (± 252,551; 95% CI) age-0 kokanee. However, the large confidence intervals indicate that the true difference between these estimates may be less than the point estimates indicate. Survival from egg deposition to autumn was 0.60% for 1999 age-0 kokanee and 0.18% for 2000 age-0 kokanee. This low survival rate was due to a pronounced mortality trend (92% mortality) that occurred from July to October in both 1999 and 2000 (Table 2.2). Winter (November to February in this case) mortality for kokanee was low.

Table 2.2. Abundance estimates for age-0 kokanee at various periods for brood year (BY) 1998 and BY 1999. Percent survival (between estimates) in parentheses. July and October acoustic abundances were obtained in the calendar year following egg deposition (e.g., BY 1998 eggs become age-0 kokanee in Lake Billy Chinook in 1999).

Estimate	Egg deposition	Screw trap recruitment	July acoustic abundance	October acoustic abundance
BY 1998				
Lower 95% CI	30,297,877	1,645,278 (5.4)	2,209,437 (7.3)[a]	183,958 (8.3)
Mean	39,750,116	1,897,828 (4.8)	2,711,229 (6.8)[a]	221,007 (8.2)
Upper 95% CI	53,736,049	2,150,379 (4.0)	3,213,021 (6.0)[a]	258,056 (8.0)
BY 1999				
Lower 95% CI	41,342,108	1,561,556 (3.8)	1,032,027 (66)	74,674 (7.2)
Mean	55,963,097	2,167,813 (3.9)	1,141,686 (53)	94,975 (8.3)
Upper 95% CI	77,516,452	2,810,800 (3.6)	1,251,345 (45)	115,276 (9.2)

[a] Survival calculated from egg deposition to July acoustic estimate.

Adult kokanee mortality was highest from July to late October (Table 2.3), likely due to spawner losses. Mortality for adult kokanee during this period was 60% in 1999 and 56% in 2000, based on hydroacoustic data. Age-1 mortality was 50%, while mortality for age-2 and older fish was 81% from 1 August to 29 October 2000.

Table 2.3. Abundance estimates for adult kokanee at various periods from acoustic and spawner surveys in 1999 and 2000. Percent survival (between estimates) in parentheses.

Estimate	July acoustic abundance	October acoustic abundance	Spawner survey abundance
1999 spawning year			
Lower 95% CI	1,101,967	875,078 (79)	238,572 (22)[a]
Mean	1,405,833	1,015,866 (72)	322,945 (23)[a]
Upper 95% CI	1,709,699	1,156,654 (68)	447,322 (26)[a]
2000 spawning year			
Lower 95% CI	1,143,336	532,812 (47)	414,576 (36)[a]
Mean	1,411,060	617,438 (44)	569,201 (40)[a]
Upper 95% CI	1,678,784	702,064 (42)	806,914 (48)[a]

[a] Survival calculated from July acoustic estimate to spawner survey.

Diet Analysis

The predominant prey consumed by kokanee in Lake Billy Chinook were *Daphnia* spp. (Figure 2.18). Diet varied little between years. Copepods were the predominant prey in February and April, while daphnids dominated diets from July through October. Age-0 kokanee consumed primarily *Daphnia* spp. throughout the year in 1999, but cyclopoid copepods were dominant in age-0 diets in April 1999 and February and April 2000 (Figure 2.19). Diet of adult kokanee was similar. Daphnids were the predominant prey for age-1 kokanee (Figure 2.19). Cyclopoids were predominant in age-1 diets from February through April. Diets of age-2 and age-3 kokanee were nearly identical to age-1 diets. As in past years, *Leptodora kindtii* were important food items in July. Macroinvertebrates were a small proportion of diets for all kokanee in 1999 and 2000, unlike in past years (Thiesfeld et al. 1999).

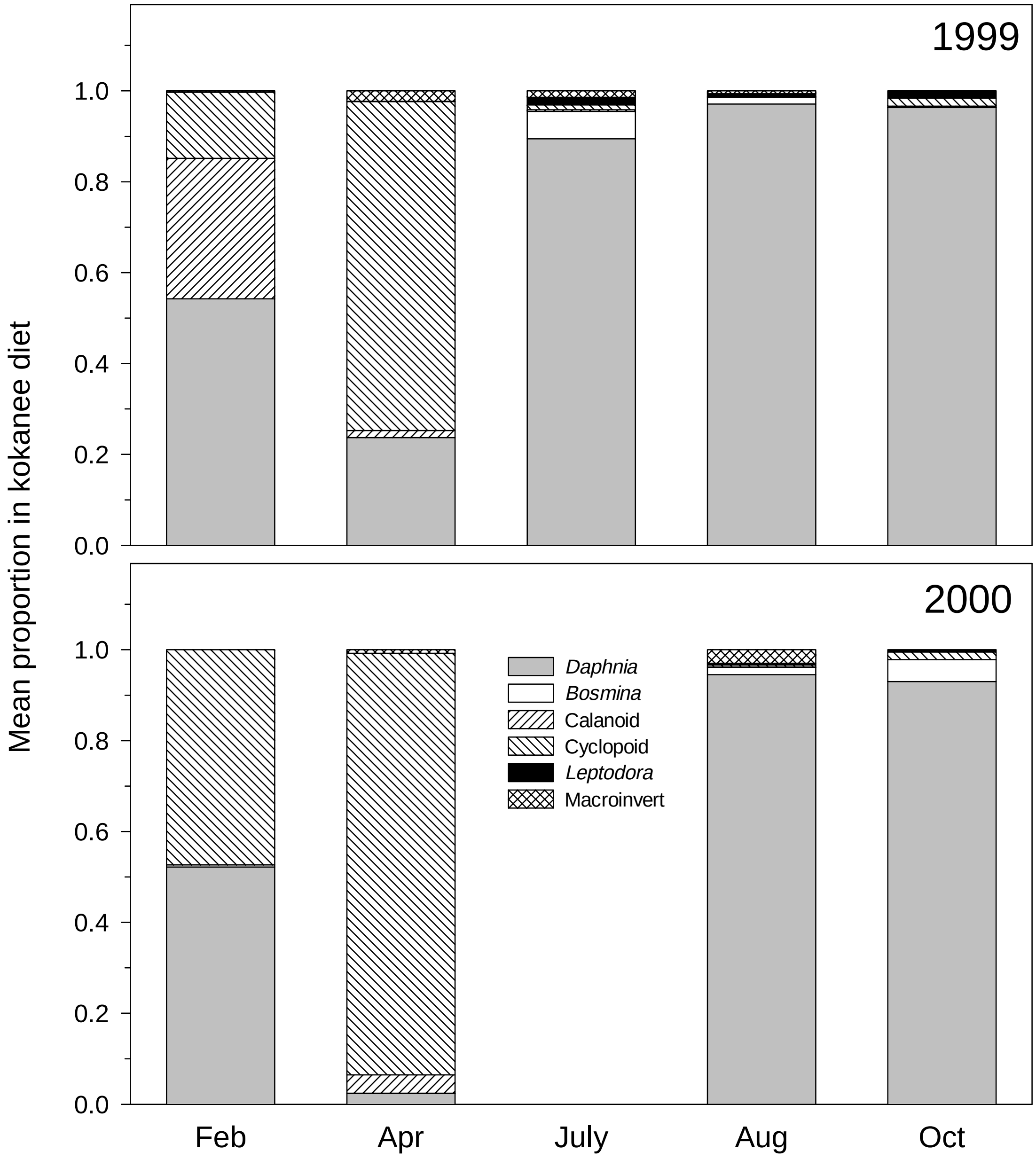

Figure 2.18. Mean proportion by weight of key prey items in kokanee diets (all ages combined) from Lake Billy Chinook, February to October 1999–2000.

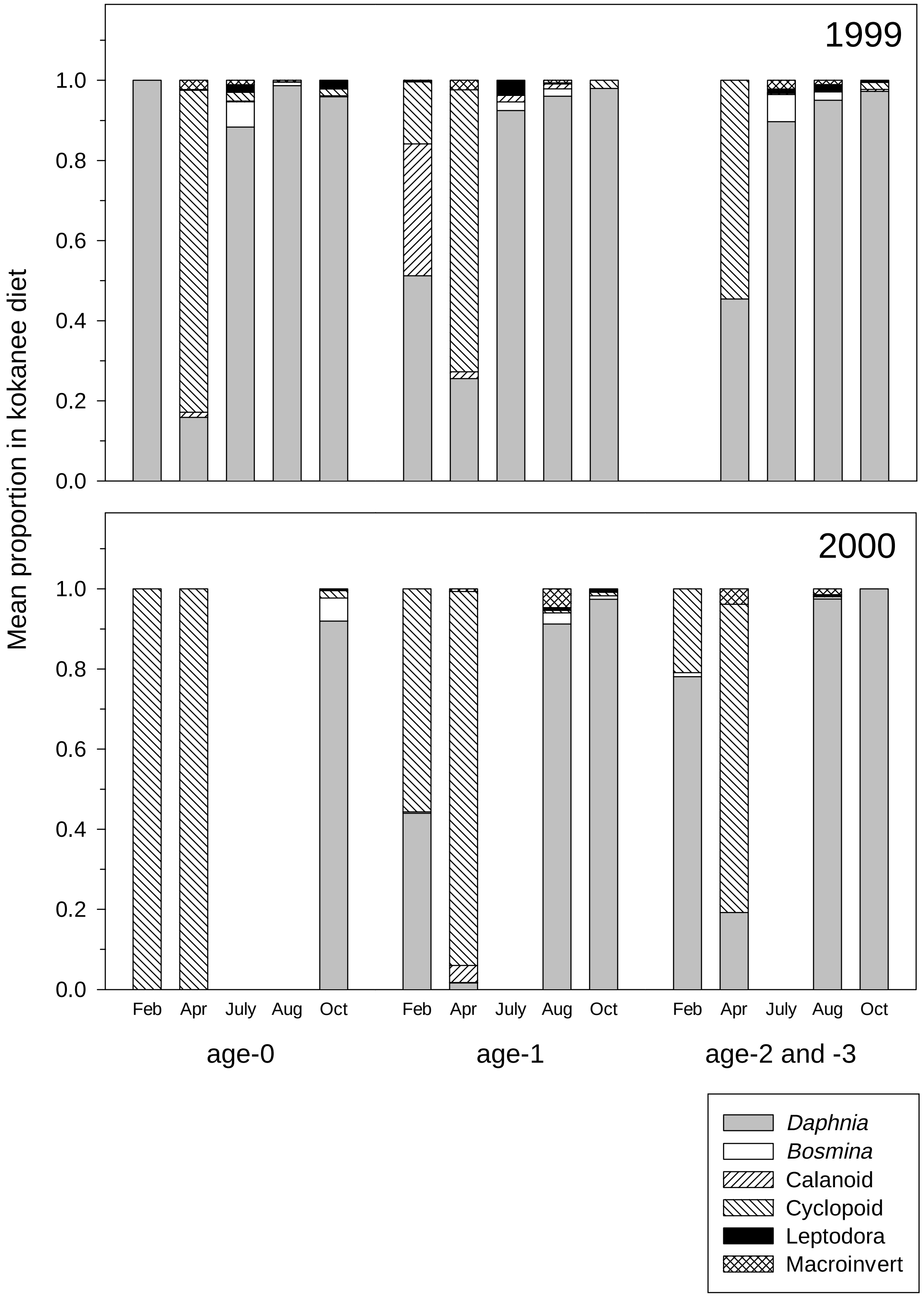

Figure 2.19. Mean proportion by weight of key prey items in kokanee diets separated by age class from Lake Billy Chinook, February to October 1999–2000.

Kokanee clearly selected for *Daphnia* spp. (Table 2.4). Kokanee also showed high preference for *Leptodora*, a large zooplankter. However, this apparent preference may be due to sampling inefficiencies at low abundances of *Leptodora* and patchy distribution. Kokanee selected for cyclopoid copepods in April of each year, corresponding to their dominant proportion of in-lake zooplankton in spring. In 1999, mean daphnid length was 1.08 mm (n = 188; SD = 0.38), mean bosminid length was 0.507 mm (n = 19; SD = 0.23), mean cyclopoid length was 1.02 mm (n = 101; SD = 0.17), and mean calanoid length was 1.27 mm (n = 113; SD = 0.22).

Table 2.4. Ivlev's electivity indices for prey in kokanee diets from Lake Billy Chinook during 1999–2000. Electivity values can range from -1 to 1. A value of zero means proportion of prey in the diet is equal to the proportion in the environment (i.e., neutral selection). Positive values indicate prey selection, while negative values indicate non-selection.

	1999					**2000**				
	Daphnia	*Bosmina*	Calanoid	Cyclopoi	*Leptodor*	*Daphnia*	*Bosmina*	Calanoid	Cyclopoi	*Leptodor*
February	0.861	-1.000	-0.138	-0.064	1.000	0.884	-0.845	-1.000	-0.223	--
April	0.492	-1.000	-0.954	0.728	1.000	-0.772	-0.985	-0.434	0.212	--
August	0.974	-0.910	-0.974	-0.998	-0.650	0.367	0.125	-0.994	-0.963	1.000
October	0.711	-0.917	-0.980	-0.996	1.000	0.568	-0.634	-1.000	-0.800	-0.865

Zooplankton

Rotifers and copepods (especially juveniles) were the most abundant zooplankton during 1999 and 2000 (Figures 2.20 and 2.21). Zooplankton abundance was usually lowest during February and March. Rotifer and juvenile copepod abundance peaked in spring/early summer and again in November. The density of the four important taxa for kokanee (*Daphnia*, *Bosmina*, calanoids, and cyclopoids) was less than 1,800/m^3 during February and March 1999 (Figure 2.20), increasing to about 6,200/m^3 during February 2000 (Figure 2.21). These important prey taxa sustained high densities (greater than 20,000/m^3) from June through November 1999, coinciding with peak age-0 abundances in the reservoir. In 2000, zooplankton taxa important to kokanee peaked in August (approximately 30,000/m^3), later than in 1999, although densities in 2000 were generally higher. Densities of key zooplankton were highest in the Metolius River arm (Figure 2.22), generally three times the densities in the Deschutes and Crooked river arms (Figure 2.23). In 1999 and 2000, densities of key zooplankton were two times higher than in 1997 and comparable to 1998 estimates (Thiesfeld et al. 1999).

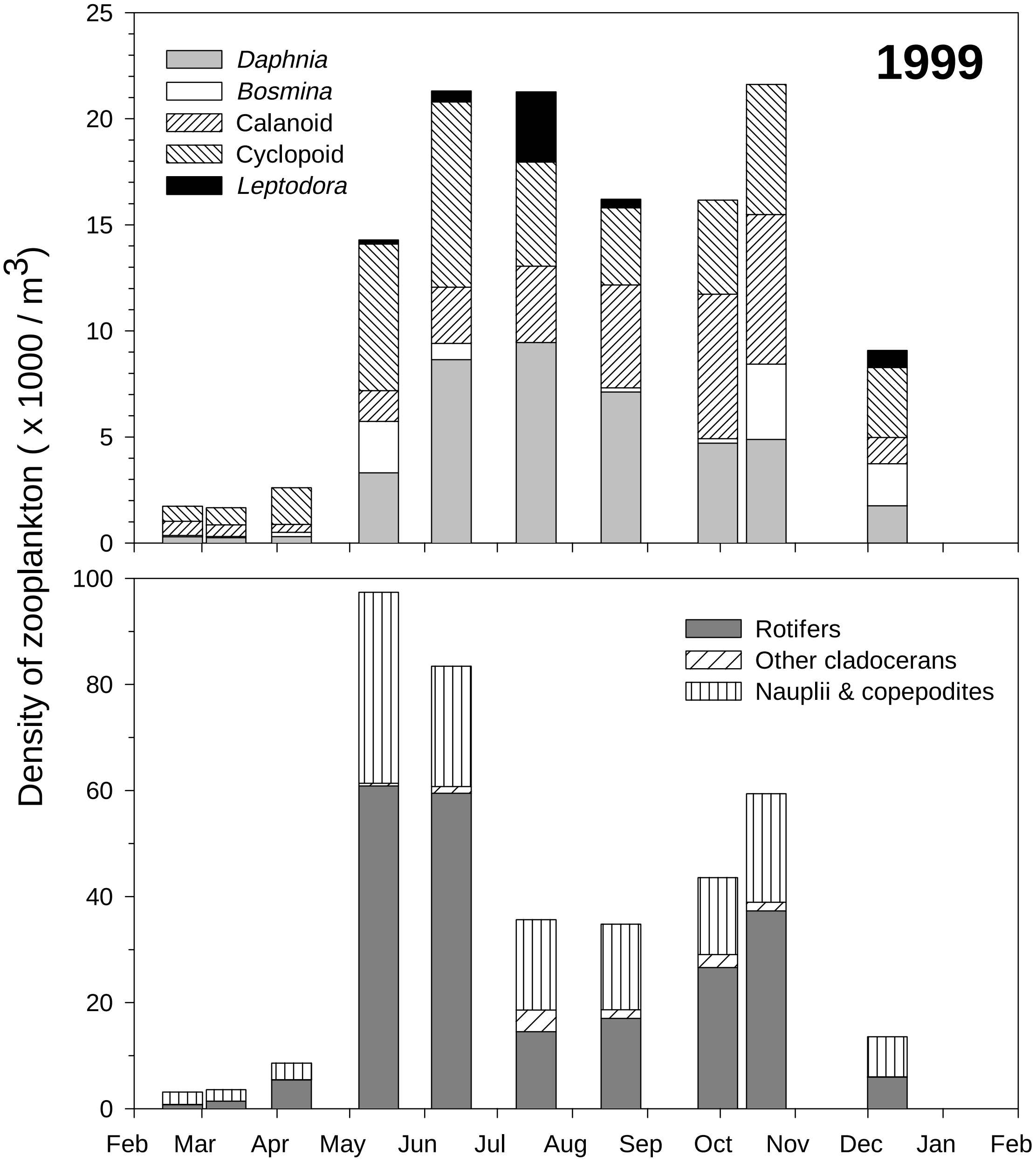

Figure 2.20. Monthly mean density of five key zooplankton taxa in samples collected from Lake Billy Chinook, 1999.

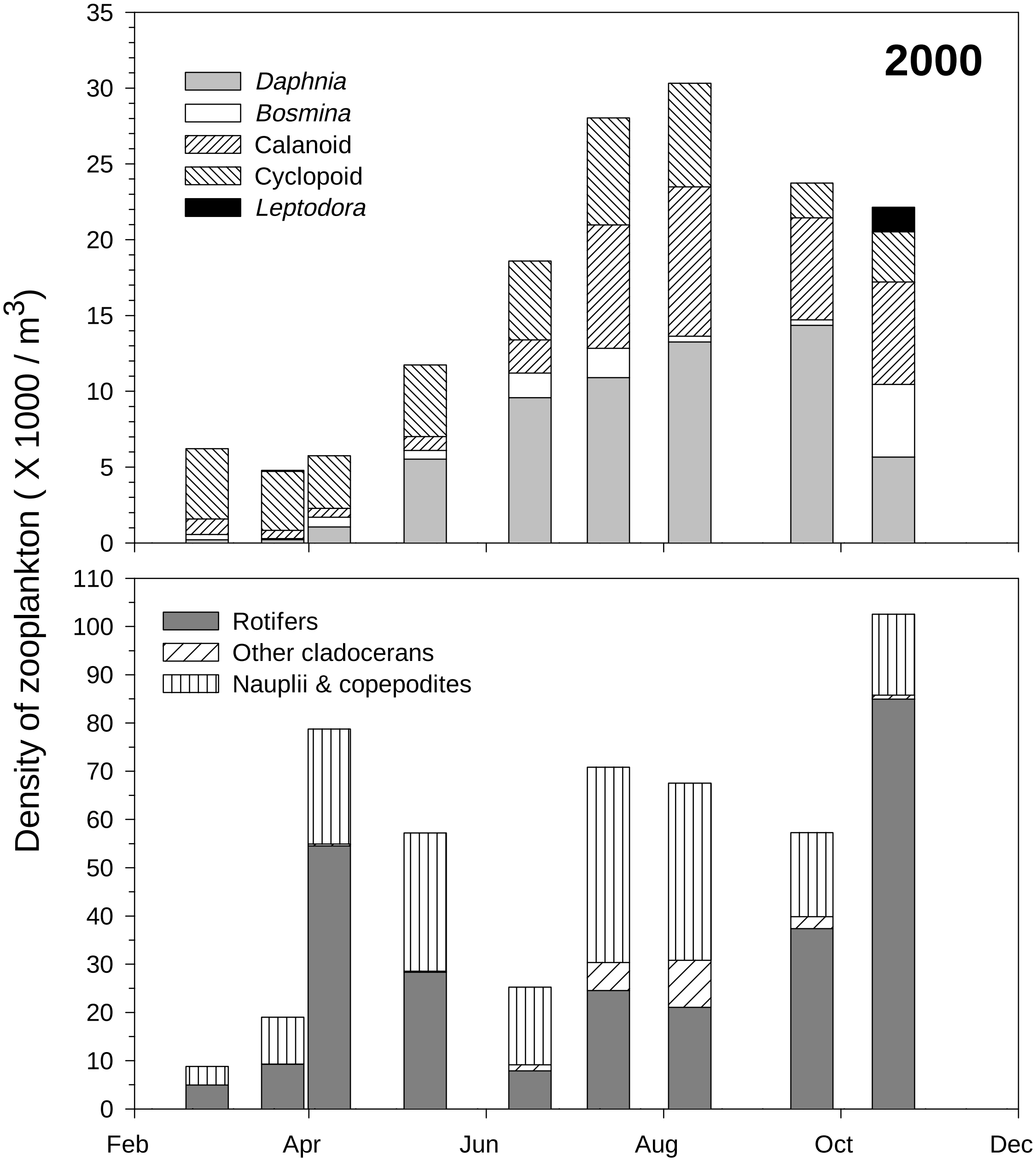

Figure 2.21. Monthly mean density of five key zooplankton taxa in samples collected from Lake Billy Chinook, 2000.

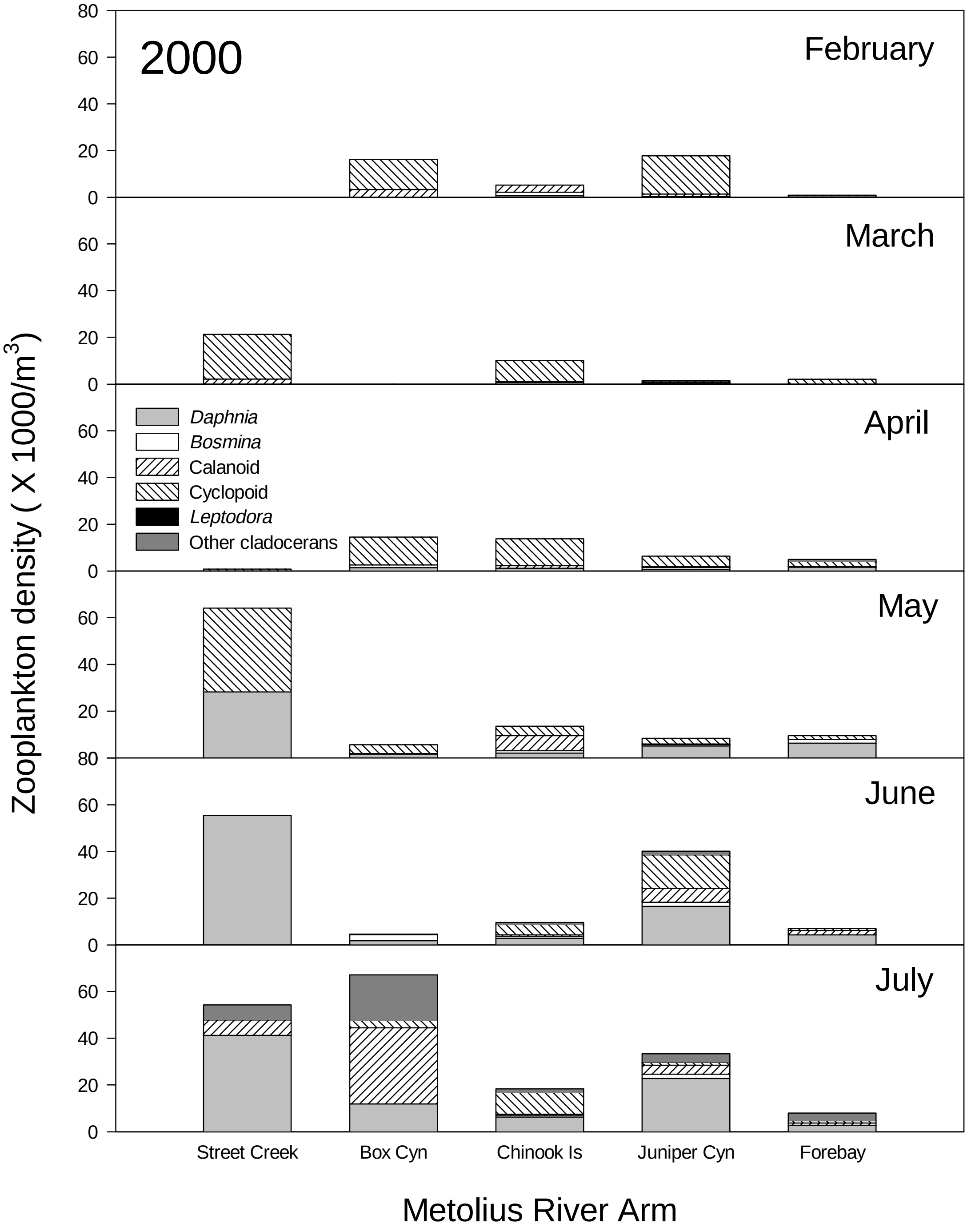

Figure 2.22. Mean zooplankton density for selected taxa in selected areas on the Metolius River arm of Lake Billy Chinook, February to July 2000.

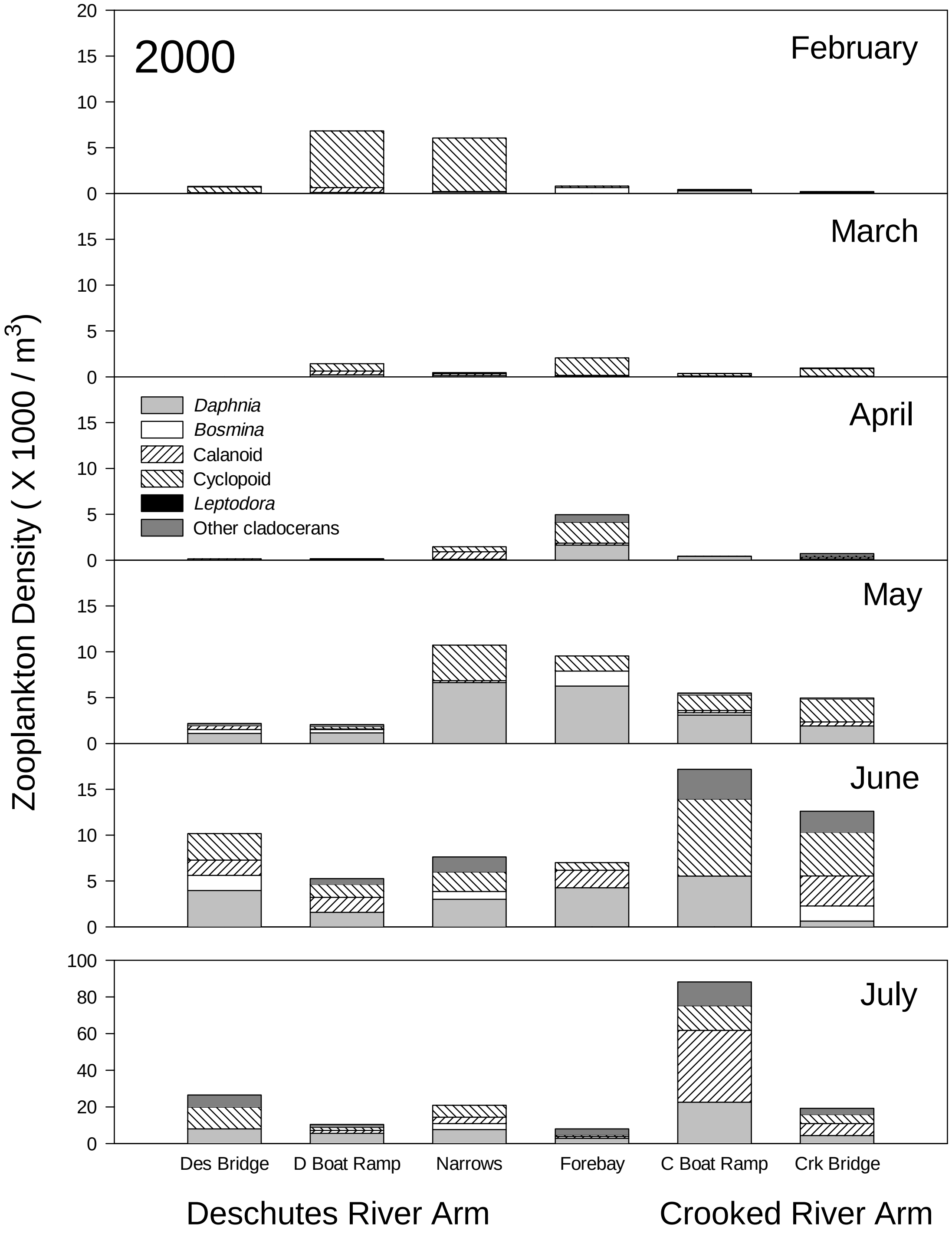

Figure 2.23. Mean zooplankton density for selected taxa in selected areas on the Deschutes and Crooked river arms of Lake Billy Chinook, February to July 2000. Note difference in scale for July.

Zooplankton Abundance and Kokanee Fry Distribution

Correlations between kokanee fry abundance and high zooplankton density were not evident. Zooplankton densities varied by reservoir arm and reach (Figures 2.22 and 2.23). Within the Metolius River arm, zooplankton densities were highest in the upper regions, near Street Creek, advantageous for immigrating fry. In the Deschutes and Crooked arms, zooplankton densities were highest in reaches approaching the forebay. According to acoustic estimates, age-0 abundance was highest in the Metolius River arm from February into July, especially around Chinook Island (Figures 2.24 and 2.25). This is not surprising since approximately 98% of recruitment originates in the Metolius River basin. Kokanee recruitment peaked in July 2000 with an estimated 352,045 age-0 kokanee. Prior to April in the Metolius River arm, and through July in the Deschutes and Crooked river arms, kokanee appeared to be swept toward the forebay, perhaps by wind generated surface currents (Figures 2.24 and 2.25). After March, age-0 kokanee appeared to linger in the Metolius River arm around Chinook Island.

Spawning

Metolius River Spawning Surveys

Kokanee spawned over a two-month period, with a discrete peak spawning time. Kokanee were first observed on index sites during the first two weeks of September and were last observed between 10 and 20 November (Figure 2.26). Spawning peaked on 5 October 1999 and on 16 October 2000. Prior to 2000, spawning generally peaked in the first week of October (Thiesfeld et al. 1999).

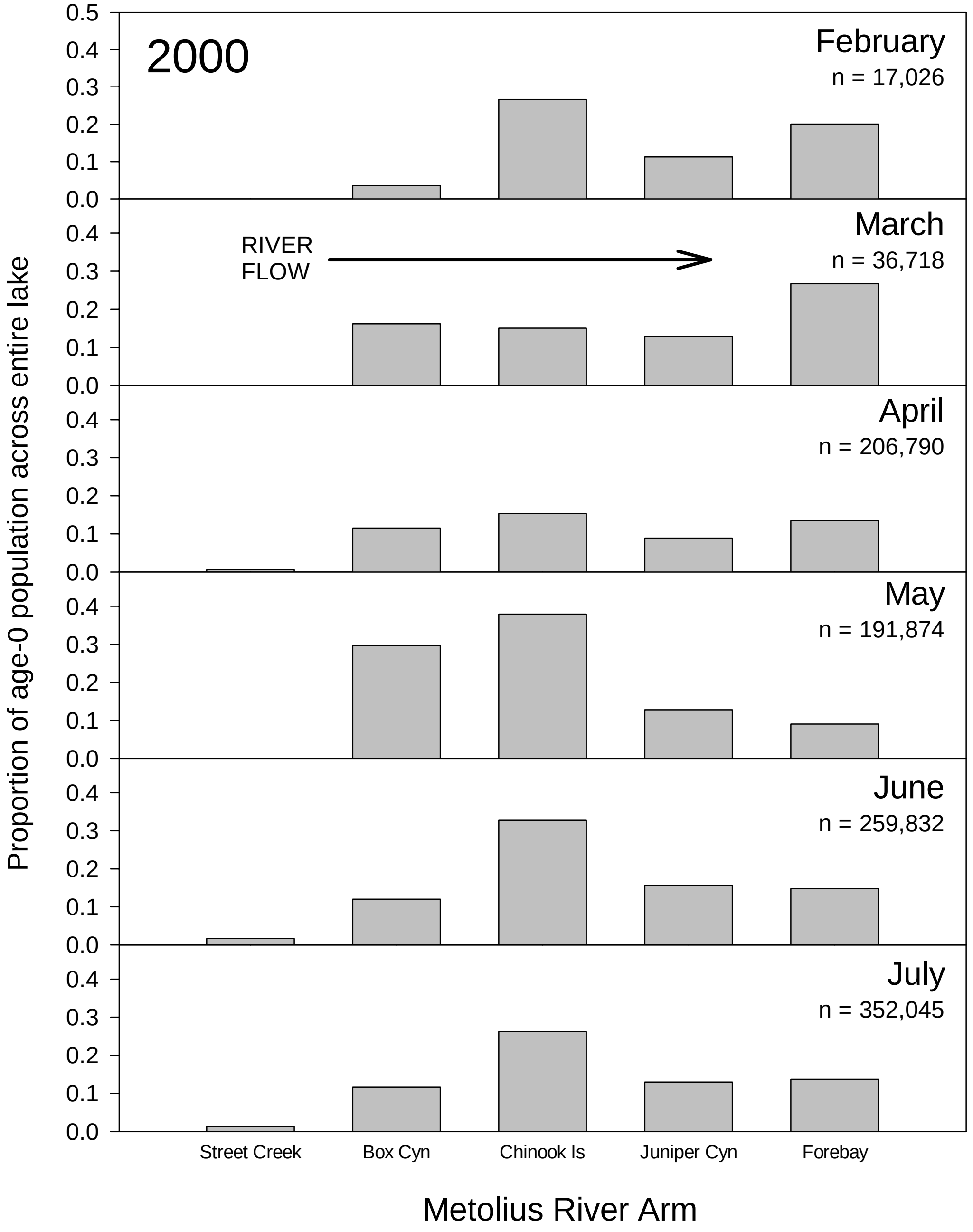

Figure 2.24. Proportion of the age-0 kokanee population by reach (Street Creek, Box Canyon, Chinook Island, Juniper Canyon, and the Forebay) in the Metolius River arm of Lake Billy Chinook, February to July 2000. Sample size is acoustic-estimated population abundance of age-0 kokanee. River flow is designated by arrow, flowing toward the forebay of Round Butte Dam.

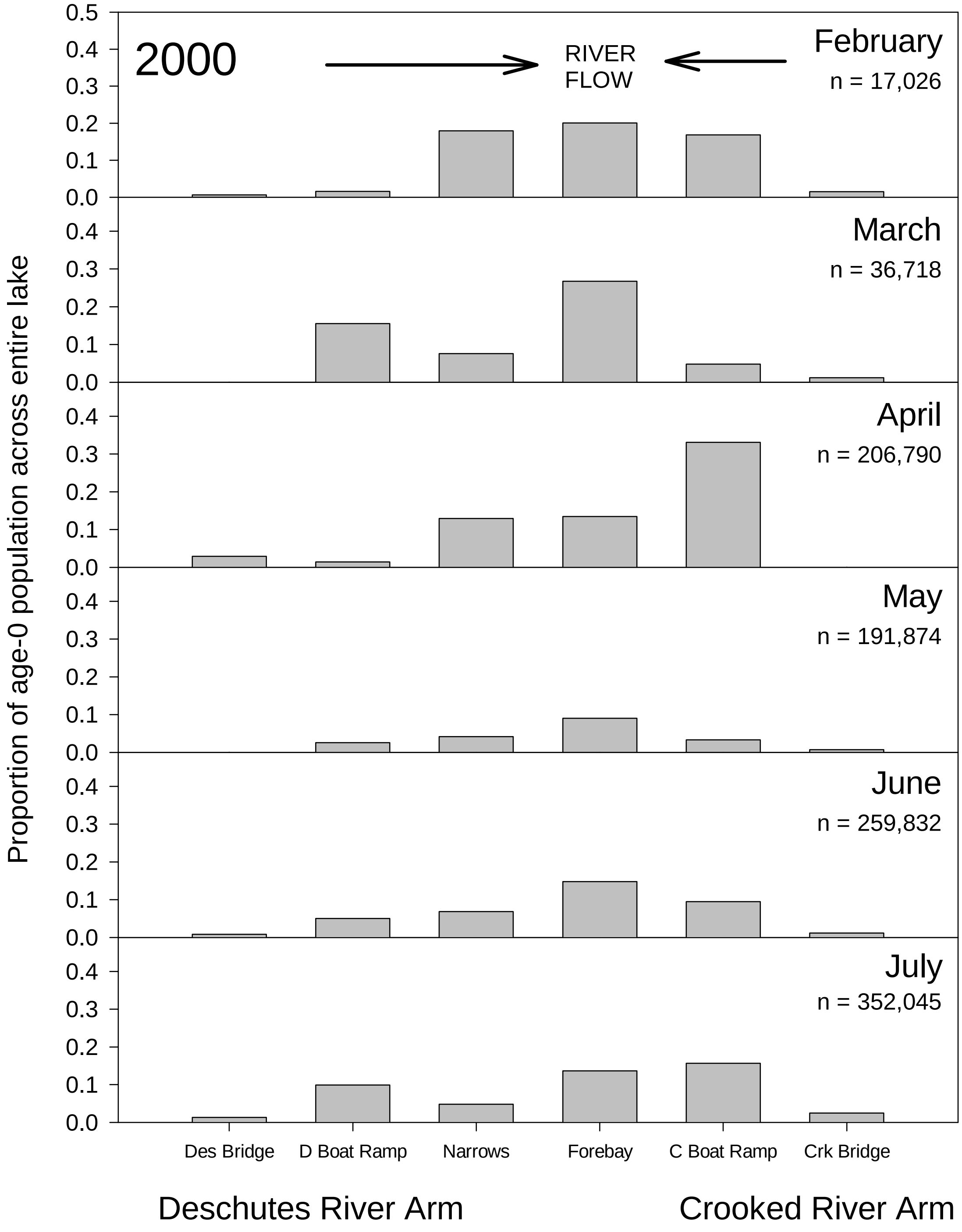

Figure 2.25. Proportion of the age-0 kokanee population by reach (Deschutes River Bridge, Deschutes Boat Ramp, The Narrows, Forebay, Crooked Boat Ramp, Crooked River Bridge) in the Deschutes and Crooked river arms of Lake Billy Chinook, February to July 2000. Sample size is acoustic-estimated population abundance of age-0 kokanee. River flow is designated by arrows flowing toward the forebay of Round Butte Dam.

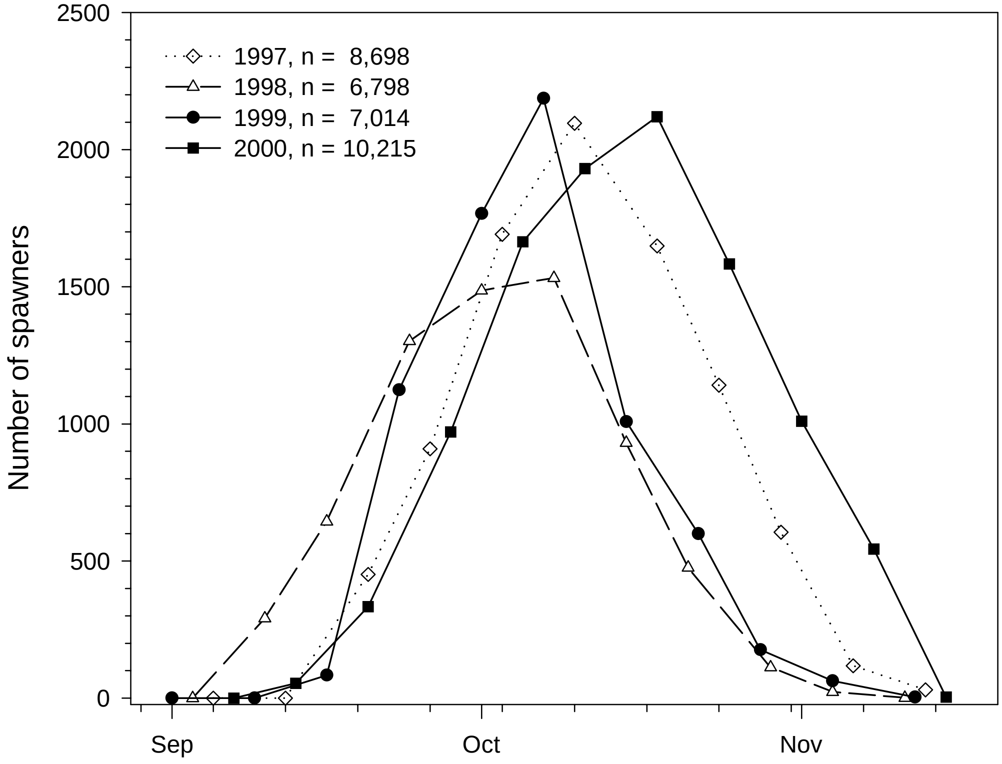

Figure 2.26. Timing of spawning kokanee at Metolius River index sites, 1997–2000. Sample size is total of spawner counts at index sites.

Spawner length decreased in both 1999 and 2000 from previous years (Table 2.5). Mean spawner length was 300 mm TL in 1999 and 294 mm in 2000. Spawner length and weight decreased for both males and females from 1999 to 2000.

Table 2.5. Spawner lengths (TL) and weights (combined, females, and males), 1998–2000. Standard deviation is in parentheses.

Year	TL (mm)	Weight (g)
1998[a]	340 (24.9)	388 (83.7)
Females	343 (22.5)	378 (66.6)
Males	337 (26.1)	396 (93.0)
1999	300 (32.5)	290 (88.6)
Females	329 (23.3)	352 (79.7)
Males	296 (31.7)	282 (86.7)
2000	294 (19.3)	218 (52.1)
Females	290 (16.8)	194 (38.8)
Males	295 (20.1)	229 (53.8)

[a] Data from prior study

Length frequency distributions emphasize the shift in kokanee size (Figure 2.27). Age composition and percent female spawners also varied dramatically (Table 2.6; Thiesfeld et al. 1999). Percentage of spawners that were female was 31% in 2000. Most spawners were age-2 fish in 1999 (74%). In 2000, 61% of the spawning females were age-2, and 81% of male spawners were age-2. Sixty-seven percent of age-2 spawners were male in 1999, while 57% of age-3 spawners were female.

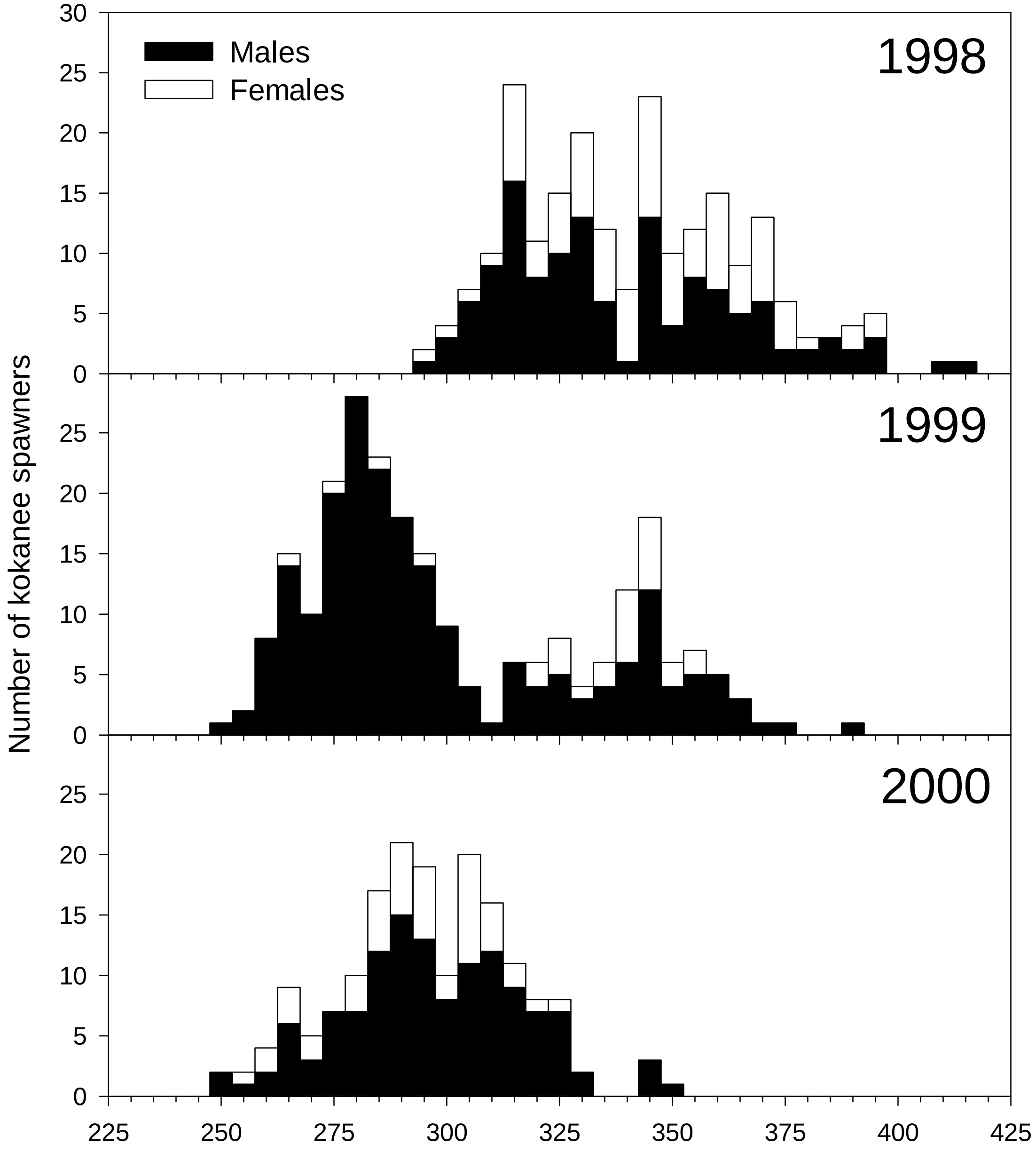

Figure 2.27. Length-frequency distributions of spawning kokanee (males and females) in the Metolius River basin, 1998–2000.

Table 2.6. Estimated number of kokanee spawners, potential egg deposition (PED), percent females, and age composition of spawning kokanee in the Metolius River basin, 1999–2000.

Year	Spawner Estimate	Mean TL (mm)	Mean WT (g)	% age-1	% age-2	% age-3	% Female	% Male	Eggs-per-female	PED
1997 [a]	180,343	335		0	31	69	57	43	654	67,227,891
1998 [a]	153,851	340		29	68	2	38	62	682	39,750,116
1999	322,945	300	290	0	74	26	31[b]	69 [b]	572	55,963,097
2000	569,201	294	218	0	92	8	31	69	335	56,817,667

[a] From Thiesfeld et al. 1999.

[b] Percent female/male estimates from 2000 data. See Spawning Results for reasoning.

Recaptures of double-tagged fish were insufficient to estimate tag retention. Tag loss was assumed to be 25% (Smith et al. 1978). In 1999, spawning kokanee were sampled by herding fish into a gill net stretched across a side channel at one location (near House-on-the-Metolius). Percentage of females at this site was 11%. This same site was sampled again in 2000, and the percentage of females among the spawners was again low, 8%. Therefore, other sites (n = 4) were sampled using a beach seine, and mean percentage of females in the spawning population was determined to be 31%. This number was used for further 1999 and 2000 calculations.

Redd excavations were conducted on 1 November 2000 at five sites on the Metolius River and its tributaries. Number of eggs excavated from redds ranged from 0 to 271 (mean = 14; n = 27; Standard Error = 10). A high degree of redd superimposition was obvious as entire stream reaches were physically disrupted by spawning kokanee. Scattered fish eggs were noticed in all spawning areas, and feeding waterfowl were observed in spawning areas at all times.

Intergravel dissolved oxygen (DO) and temperatures were measured on 1 November 2000 at two spawning sites. At Heising Spring, mean DO was 9.8 mg/l (n = 4; SD = 0.4) at 5 °C. At Riverside Campground, mean DO was 9.7 mg/l (n = 3; SD = 0.5) at 7.5 °C.

Metolius River Basin Spawner Estimate and Potential Egg Deposition

Abundance of spawning kokanee increased markedly in 2000 (Table 2.6). Spawner abundance estimates from various sources were not statistically different because of huge variance around estimates (Figure 2.28).

The kokanee spawning population increased two-fold from 1999 to 2000. Based on mark-recapture population estimates, 323,000 kokanee exited Lake Billy Chinook to spawn in 1999, and a five-year high of 569,000 spawners was estimated in 2000 (Table 2.6). Kokanee fecundity has ranged widely since 1996 (Thiesfeld et al. 1999), reaching an all time low in 2000 with an average 335 eggs-per-female (Table 2.6). Egg retention was low for spawners in 2000 (mean = 13.4; n = 85; SD = 18.4). Concurrent with decreased eggs-per-female, female gonad weight decreased significantly. Mean female gonad weight (± 1 Standard Error) was 44.8 g (± 3.1) in 1998, 46.0 (± 3.5) in 1999, and 13.2 (± 2.1) in 2000. Male gonad weight averaged 8.7 g (± 0.85) in 2000. By comparison, mean gonadal weight for kokanee spawners in Arrow Lake, British Columbia was just over 3 g for testes and approximately 15 g for ovaries (Murray et al. 1989).

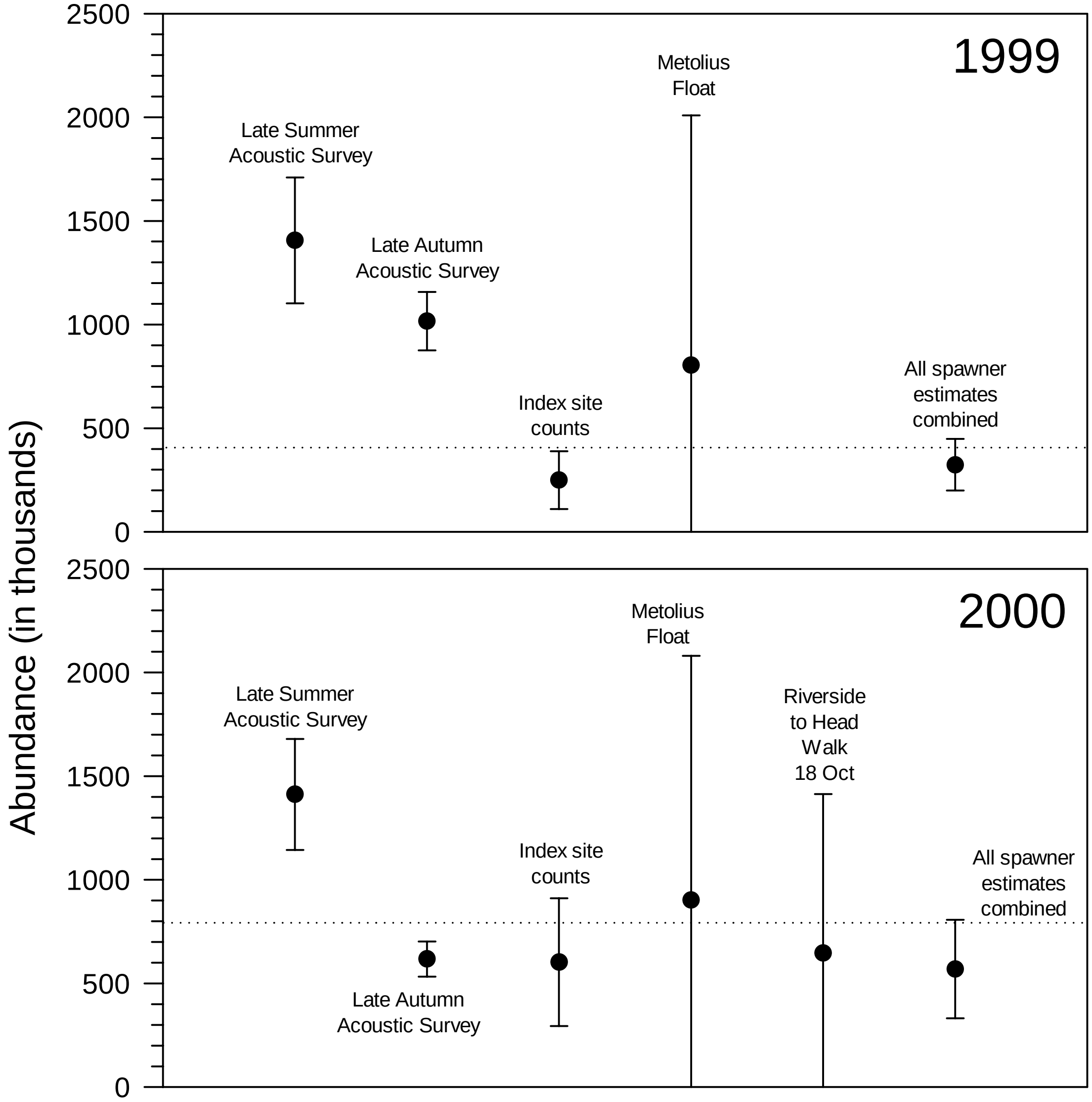

Figure 2.28. Spawner abundance estimates from various surveys, 1999–2000. Dotted line represents loss of adult kokanee from lake (i.e., likely spawner loss) from acoustic-generated estimates. Error bars represent 95% confidence intervals.

As with spawner abundance, potential egg deposition (PED) ranged greatly. Although 2000 spawner estimates were double 1999 estimates, PED was equal because of the lower mean eggs-per-female ratio in 2000. While eggs-per-female (in 2000) was not correlated to female spawner length (Spearman rank correlation; $r_s = 0.20$, $p = 0.17$) or female weight ($r_s = 0.18$, $p = 0.21$), female gonad weight (g) was related to female spawner length ($r_s = 0.47$, $p = 0.0007$) and female weight ($r_s = 0.39$, $p = 0.0032$) in 2000. Male gonad weight was positively correlated with male spawner length ($r_s = 0.73$, $p < 0.0001$) and weight ($r_s = 0.79$, $p < 0.0001$). Thiesfeld et al. (1999) also reported no relationship between eggs/female and kokanee total length in 1997–1998. Long-term (1996–2000) trends and relationships are discussed in Chapter 4.

Disease

Rates of disease and infection varied in Lake Billy Chinook (Table 2.7). Infectious hematopoietic necrosis (IHN) virus stood out in pathogen surveys conducted by ODFW (H. Mark Engelking, personal communication). There was a low prevalence but persistent level of bacterial kidney disease (BKD) and cold-water disease (CWD; incidence of *Flexibacter psyscrophylum* was approximately 25–30%) in moribund and spawning fish. Nearly 100% of the kokanee sampled were infested with a parasitic copepod (likely *Salmincola californiensis*) in summer 2000, and a substantial degree of parasitism by parasitic copepods was seen on the majority of adult kokanee captured by researchers and anglers in summer 2000. Two myxosporean parasites, *Ceratomyxa shasta* (causing ceratomyxosis) and *Myxobolus cerebralis* (causative agent of whirling disease), were not detected in sampled kokanee in 1999 and 2000.

Table 2.7. Incidence of various diseases detected in kokanee sampled in the Metolius River (spawners) and in Lake Billy Chinook (LBC). Unpublished data from ODFW, H. Mark Engelking.

Year	Source	IHN virus	*C. shasta*	*M. cerebralis*	BKD
1999	Metolius R.	63.5	0	0	6.7 (low) 3.3 (high)
	LBC	no samples	0	0	13.3 (low)
2000	Metolius R.	93.4	0	0	no samples
	LBC	31.9	0	0	11.1 (low) 11.1 (med) 19.4 (high)

DISCUSSION

Fisheries management relies heavily on population estimates from various sources. In this study, abundance estimates are derived from several sampling methods, incurring error and bias. Study-specific sampling inadequacies were described in detail by Thiesfeld et al. (1999). While screw traps used during the study proved inefficient, estimates of recruitment derived from screw trap data are conservative and fit reasonably well with acoustic-derived estimates of recruitment. This also applies to estimates of spawner abundance. Spawner estimates based on marking and subsequent "recapture" on spawning grounds are conservative and fit well within the 95% confidence bounds of acoustic estimates of adults lost from the reservoir. Acoustic estimates appear to accurately characterize true population abundance in Lake Billy Chinook. Throughout five years of study, acoustic estimation procedures were modified to decrease variability (e.g., smaller and larger targets eliminated, upper transects removed, and target strength to length calculations refined), thereby making subsequent acoustic-generated population estimates more conservative.

Survival from egg-deposition to recruitment to first autumn (0.60% in 1999 and 0.18% in 2000) appears to be the ultimate factor determining kokanee abundance in Lake Billy Chinook. Although numerous factors affect this mortality rate, key factors in this system include redd superimposition (leading to low potential egg deposition), predation during outmigration and in the reservoir (Beauchamp and Van Tassel 2001), and entrainment (Ratliff and Schulz 1999). Results from this phase of the study and past work (Thiesfeld et al. 1999) suggest that most of the first-year mortality occurred prior to fry recruitment to the reservoir.

Egg-to-fry recruitment survival rates appear low considering the Metolius River basin is heavily influenced by spring upwelling. Estimated egg-to-recruitment survival for Lake Billy Chinook kokanee ranged from 2% to 7% in 1997–2000, comparable to the 3.3% reported by Spaulding (1993) for kokanee in Redfish Lake, Idaho, and data reported by Rieman (1992) for three Idaho lakes (1–4%). However, compared to some systems, survival in the Metolius River basin is quite low. Rieman (1992) reported kokanee egg-to-recruitment survival as high as 10% in Anderson Ranch reservoir, Fraley et al. (1986) reported 20%, and Lindsay and Lewis (1978) reported rates of 18%, 14%, 21%, 25%, and 32% during research on Odell Lake, Oregon. Chapman and Fortune (1963) reported a survival rate of 52% for the earliest work on Odell Lake. Kyle et al. (1988) reported 10% for sockeye salmon, while West and Mason (1987) reported 21% survival. Egg-to-fry survival ranged from 1.5% to 16% for Lake Tahoe kokanee (Gemperle 1998).

During years of high spawner numbers, as in 1999–2000, redd superimposition can lead to physical displacement of eggs and therefore mortality. The spawning season occurs over an 11-week period in the Metolius River basin. Later spawners may superimpose redds on previous redds, displacing eggs causing fry production to be inversely density dependent (Chebanov 1986, 1991; Semenchenko 1988; Parenskiy 1990). If density dependence is truly a factor, mortality rates of emerging fry should vary with spawner density. This is investigated further in Chapter 4. It is plausible that spawners select a limited spawning area that does not change between years (i.e., reaches a carrying capacity) or has not changed during the study. Redd superimposition rate could be an increasing function of spawner or egg density in the stream, such that total number of eggs successfully deposited approaches carrying capacity of the stream as number of spawners increases (McNeil 1964). Final or actual egg deposition may be determined solely by number of late spawners who ultimately displace prior laid eggs. Egg dislodgment increased as the number of spawners, density of eggs in the spawning grounds, and stream discharge increased. Coho salmon (*O. kisutch*) superimposed their redds and destroyed 20–28% of redds constructed by earlier spawners (van den Berghe and Gross 1984). Redd excavations conducted in early November 2000, showed high variability and a low mean eggs per redd. Because this limited survey was conducted late in the spawning run, it may be a good indication of actual egg deposition; that is, actual deposition is far lower than PED. In that case, survival from actual egg deposition to recruitment may be much higher than the 4% reported here.

Available spawning area in the basin may have implications regarding reestablishment of additional *O. nerka* spawners (i.e., sockeye salmon). It appears that capacity of the spawning area may be impaired by increased numbers of spawners owing to a potentially high degree of redd superimposition. While numbers of spawners have increased nearly five-fold over the past several years, recruitment has remained similar. *O. nerka* will, however, spawn on lake beaches and suitable in-lake habitats where upwelling occurs. On two occasions in October 2000, much of the shoreline of Lake Billy Chinook was surveyed for kokanee spawning activity. Although no kokanee were witnessed during these surveys, gravid female kokanee were captured in the reservoir at the end of October, well out of the Metolius River staging area. In Lake Tahoe, in-lake spawning for kokanee occurred months after in-stream spawning ceased (B. Allen, Tahoe Research Group, personal communication).

Kokanee spawning behavior also may have negative impacts on bull trout spawning success in some locations. Bull trout redd counts have increased greatly in recent years (S. Marx, ODFW, personal communication), although actual spawning success of bull trout remains unknown. Bull trout utilize colder spring tributaries to spawn, whereas kokanee generally utilize the warmer spring tributaries and the Metolius River headwater areas more. During high kokanee abundance years, there is some overlap, especially at Heising Spring and the lower reaches of Canyon, Candle, and Jefferson creeks (Ratliff et al. 1996). However, in general bull trout spawn higher in the cold tributaries than kokanee (Ratliff 1992).

Once kokanee abundance is established by the end of their first summer, mortality from July through November and into winter appears to be the most significant loss until spawning. Mortality after peak recruitment (July) into November approached 92% of the age-0 population during 1999–2000 (BY 1998 and BY 1999). Although much of this mortality may be natural, prior mortality estimates in the reservoir were only as high as 30% to 50% (Thiesfeld et al. 1999). After accounting for over-winter mortality, mortality of age-1 kokanee was very low until they entered the fishery at about 250 mm. Thereafter, angling mortality was the predominant mortality source until spawning. In 2000, angler trips and hours fished increased from 1998 and 1999 (see Chapter 3 for angler creel details). Also, according to creel estimates, number of kokanee captured and taken from the reservoir increased nearly two-fold from 1999 to 2000.

The abundance of age-1 kokanee can predict the strength of older age classes in subsequent years and consequently affects growth (Lindsay and Lewis 1978). If the age-1 abundance is relatively high, then density-dependent growth will occur, and by the time the cohort reaches age-2 and age-3, fish will be considerably smaller than during an average density year. This may explain the relatively small average spawner size in 2000. Mean spawner size has decreased steadily since 1998. Female spawners averaged 329 mm (352 g) in 1999, yet averaged 290 mm (194 g) in 2000. Average eggs-per-female also decreased dramatically.

Predation, entrainment, and disease have all been proposed as possible sources of loss or mortality. Beauchamp and Van Tassell (2001) estimated that 1,000 age-3 to -7 (> 200 mm) bull trout could consume 9,362 age-0 kokanee, 398 age-1 kokanee, and 4,116 of age-2 and older kokanee. Based on the 1993 redd counts, they estimated 3,620 bull trout (>200 mm) were in the reservoir and annually consumed 33,703 age-0, 1,434 age-1, and 14,818 age-2 and older kokanee, significantly higher than kokanee losses estimated for winter of 1997–1998 (Thiesfeld et al. 1999). Estimated number of bull trout spawners was similar in 1993 and 1999 (658 and 681 spawners, respectively) (Steve Marx, ODFW, unpublished data). In 2000, an estimated 1,263 bull trout spawned in the Metolius River and tributaries, two to three times more than in years prior. From July to late October, approximately 2.5 million age-0 kokanee were lost from the system in 1999 and over 1 million were lost in 2000. If bull trout consumed 10% of the age-0 kokanee population (n = 2,711,000 age-0 kokanee) in July 1999, over 270,000 would have been lost to predation. Based on a predation rate of 10%, bull trout predation potentially removed 114,000 age-0 kokanee in 2000. If bull trout redd counts accurately reflect greatly increased bull trout numbers in Lake Billy Chinook, predation by bull trout on kokanee will likely become a more important mortality factor in future years.

Piscivorous birds are common to Lake Billy Chinook, however, the effects of this predation on kokanee has not been determined. Double crested cormorants (*Phalacrocorax auritius*) are resident year round, congregating in forebay areas. Mergansers (*Mergus merganser* and *Lophodytes cucullatus*), goldeneye (*Bucephala albeola* and *B. islandica*), gulls (*Larus* spp.), osprey (*Pandion haliaetus*) and bald eagles (*Haliaeetus leucocephalus*) are common especially during autumn in the Metolius River transition zone into Lake Billy Chinook. Modeling suggests that cormorant (*Phalacrocorax auritus*) predation may reduce standing crop for some sport and forage fish by 1–67% (Simmonds et al. 2000). Avian predators consumed 40% of stocked fingerling rainbow trout in a southern Utah reservoir, and sub-adult rainbow trout and cutthroat trout (*O. clarki*) composed 75% of the diet, by biomass, of double-crested cormorants sampled (Modde et al. 1996). Ottenbacher et al. (1994) estimated that consumption of fish by cormorants was as high as 15.8 kg/ha in southwestern Utah reservoirs and lakes. While the impact of avian predators may be highly variable, it is a point to consider given the losses to sub-adult kokanee seen in Lake Billy Chinook in the past three years.

Entrainment of kokanee may explain some losses from Lake Billy Chinook. Only two spill events (February 1982 and 1996) have occurred at Round Butte Dam. Peak entrainment occurs in February and March (Ratliff and Schulz 1999), corresponding with highest annual proportions of the age-0 population in the forebay area. Estimates from gatewell counts and screw trap catch in the tailrace indicated that approximately 136,000 age-1 and older kokanee passed Round Butte Dam in 1999 (Ratliff and Schulz 1999). Peak abundance in the reservoir reached 1,405,833 adult kokanee in July 1999. Therefore, they calculated that entrainment may have removed 10% of the adult population. Further, the number of kokanee in the forebay was positively correlated with the number of kokanee observed in the gatewells, and numbers of age-0 kokanee were greatly under-represented in gatewell counts (Ratliff and Schulz 1999). Skaar et al. (1996) estimated that entrainment removed 19–71% of the kokanee from Libby Reservoir, Montana, the majority of which were age-0. Using these estimates, entrainment potentially removed 270,000 to 730,000 age-0 kokanee from Lake Billy Chinook in 1999, and 114,000 to 308,000 age-0 kokanee in 2000. Estimates from Skaar et al. show the huge variability in entrainment estimates and also demonstrate the potentially high losses due to entrainment. While the adult population in Lake Billy Chinook was subject to losses due to the recreational fishery, a very inconsequential percentage of age-0 kokanee were likely harvested or even captured. To explain current losses after accounting for predation and spring age-1 abundance, entrainment (and natural mortality sources) would need to remove 73% of the age-0 kokanee population to account for the losses seen. Although this estimate may appear unreasonable, Stober et al. (1979) estimated that 60–75% of the adult kokanee population in Banks Lake, Washington, was lost to entrainment in 1976. While operational characteristics vary by hydrosystem, various estimates of entrainment, and large variability in those estimates, warrant consideration with regard to high losses observed in Lake Billy Chinook from 1998 to 2000.

The plan to provide safe downstream passage from a surface withdrawal at Round Butte Dam (Ratliff et al. 2001) is interesting in that active migrants may be passed safely downstream in the future. Some of the few adult sockeye that now return up the Deschutes River have been shown to have had kokanee as their maternal parent (Zimmerman and Ratliff 1999). Fish managers are hoping that enough migrant kokanee will express an anadromous life history to eventually enable the conversion of part of the kokanee population to sockeye (Ratliff et al. 2001).

Losses through Round Butte Dam are likely the only source of Lake Simtustus kokanee recruitment. Lake Simtustus kokanee are larger than Lake Billy Chinook kokanee, likely due to environmental conditions (*see* Raymond et al. 1997) and population density (*see* Kern et al. 1999). Mean total length of kokanee captured in the "jump pool" (presumably escaping to spawn) at Round Butte Dam was 381 mm (SD = 24; n = 28) on 16 August, 358 mm (SD = 29; n = 32) on 14 September, and 369 mm (SD = 29; n = 60) overall (Figure 2.29). Mean female length was 350 mm (SD = 27; n = 18) and mean male length was 367 mm (SD = 29; n = 14).

Total length ranged from 297 to 437 mm, considerably larger than Lake Billy Chinook kokanee. Unfortunately, age data were not collected and abundance of kokanee in Lake Simtustus is unknown. This information could contribute to estimates of entrainment through Round Butte Dam.

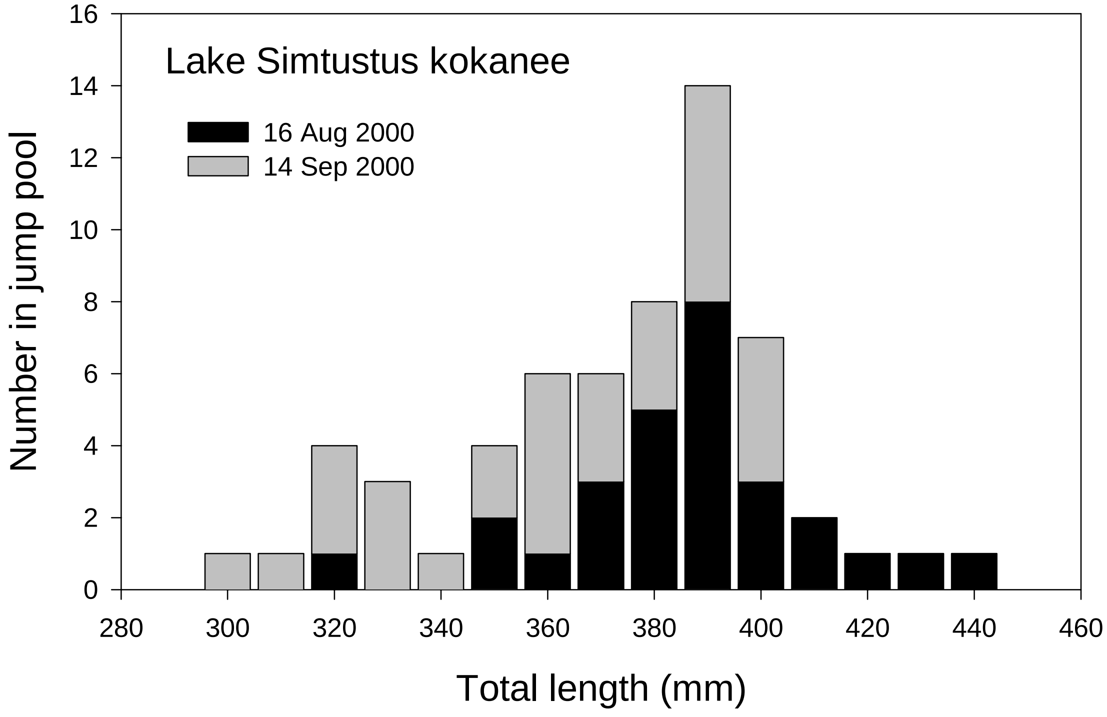

Figure 2.29. Length frequency distribution of kokanee sampled from the jump pool, Lake Simtustus, at the base of Round Butte Dam in August and September 2000. Unpublished data, H. Mark Engelking, ODFW.

Parasites and disease can have direct (i.e., mortality) and indirect (e.g., reduced growth and fecundity, aberrant performance and behavior) effects on host fish. Infectious hematopoietic necrosis (IHN) virus can severely reduce salmon fry survival during the egg-to-fry stage (Williams and Amend 1976), and IHN has been variously associated with occurrence of heavy pre-spawning mortality (Burgner 1991) and may ultimately reduce sockeye salmon runs (Follet and Burton 1995). Concentrations of *Ceratomyxa shasta* are relatively low in Lake Billy Chinook, especially in the Metolius River section (Ratliff 1983), and *C. shasta* was not detected in kokanee in 1999–2000 (H. Mark Engelking, ODFW, personal communication). Infection by *M. cerebralis* often results in high mortality among young fish, but was not detected in sampled kokanee in Lake Billy Chinook (Engelking 2001). The infectious stage of *C. shasta* is found in all three tributaries to Lake Billy Chinook (Ratliff 1983), whereas the infectious stage of *M. cerebralis* has not been demonstrated in the Deschutes River basin (Engelking 2001). Parasitic copepods are rarely present in sufficient numbers to cause serious injury to the host; however, when crowded conditions exist, heavy infections may break out (Pennak 1989). Heavy infestations of these copepods may reduce oxygen exchange in gills and break the external barriers of the fish leading to secondary bacterial and fungal infections. Overall, these stressors can lead to both direct and delayed mortality through immediate and cumulative effects of stress (Wedemeyer et al. 1990). Also, addition of stressors can exacerbate effects of diseases, and addition of multiple stress factors can result in higher mortality and morbidity (Schisler et al. 2000). However, data on the detrimental effects of disease and parasites on the Lake Billy Chinook kokanee population are inconclusive at this point.

Bioenergetics modeling conducted by Thiesfeld et al. (1999) suggested that kokanee consumed a very small proportion of daphnid standing stock in 1998. Further, they estimated that it would require a 40-fold increase in kokanee biomass to consume the entire standing stock of *Daphnia* spp., and kokanee could switch prey if *Daphnia* were not available. In 1998, abundance of age-0 kokanee in Lake Billy Chinook was over 3 million in August, decreasing to nearly 2 million by late October. Usually less than 300,000 adult kokanee were in the reservoir in 1998. Densities of key zooplankton taxa were greater than 20,000/m^3 in spring and autumn 1998. Under this scenario, Lake Billy Chinook kokanee consumed between 1% and 18% (on average 1% or less) of the Daphnia standing stock (Thiesfeld et al. 1999). Beauchamp et al. (1995) estimated that sockeye and kokanee typically consumed considerably less than 1% of *Daphnia* instantaneous production and standing stock in Ozette Lake, Washington. Considering findings from 1998, the following comparisons between years can be made. Seasonal abundances of age-0 kokanee in 1999 were similar to 1998 estimates, and 2000 abundances were half those in 1998 and 1999. Strong recruitment classes in 1998 and 1999 produced high abundances of age-1 kokanee in 1999 and 2000, nearly five times higher than 1998 adult abundance. Key zooplankton densities were similar in 1998, 1999, and 2000, and diets were similar in all years with the exception of decreased macroinvertebrate predation in 1999–2000. Clearly, conditions in the lake have not varied greatly since 1998, except for the increase in adult abundances from 1999–2000. Although adult kokanee have greater potential to deplete zooplankton biomass (Beauchamp et al. 1995, Thiesfeld et al. 1999), it is unlikely that kokanee have impacted available zooplankton resources in the reservoir, even with a five-fold increase in adult abundance (as in 1999 and 2000).

Several factors may influence survival of *O. nerka* fry. Although predation may have major impacts (Beauchamp et al. 1995), zooplankton dynamics are most often associated with fry survival (Foerster 1968, Lindsay and Lewis 1978, Parapamian and Bowles 1995). While density of favorable zooplankton is important, temporal and spatial overlap of zooplankton and fry is critical. Although densities of preferred zooplankton were low from February to April when fry were recruiting to Lake Billy Chinook, zooplankton densities increased substantially in May and peaked by July, concurrently with peak numbers of age-0 kokanee in the reservoir. Surprisingly, highest abundances of kokanee fry were not associated with high zooplankton densities in various areas of the reservoir in 2000, even in areas with the highest densities of the preferred prey, daphnids. Other likely factors that influenced age-0 distribution in Lake Billy Chinook included temperature, flow (especially from February through March), and predation.

Density and growth of *O. nerka* are usually closely related. Growth and survival of kokanee fry is often independent of fry densities (Rieman and Myers 1990, 1992; Beauchamp et al. 1995), although increased density has been shown to be related to reduced growth of young sockeye in several reservoirs (*see review by* Goodlad et al. 1974). High densities of sockeye salmon may also reduce zooplankton abundance and cause a shift in dominant zooplankton taxa (Kyle et al. 1988). Blackett (1979) suggested that impact on the zooplankton community would be avoided at fry densities below 36,000 fry/ha. Peak densities of age-0 kokanee were 2,038 fry/ha in 1998, 1,896 fry/ha in 1999, and 798 fry/ha in 2000. Fry densities in Lake Billy Chinook likely did not inhibit fry growth and survival. Size-at-age for kokanee was usually greater in Lake Billy Chinook compared to other kokanee systems (Janssen 1983, Parkinson et al. 1988, Rieman and Myers 1992, Gemperle 1998). Long-term trends and density dependence are discussed in Chapter 4.

Sex ratios of kokanee captured on spawning grounds varied by sample location. Distortion of sex ratios in *O. nerka* has been attributed to changes in incubation temperature during embryonic development (Craig et al. 1996). The sex ratio of kokanee "spawners" captured from the Lake Simtustus jump pool at the base of Round Butte Dam was 56% female. The sampling method (seine vs. gill net) may have biased the sex ratio in samples from the Metolius River spawning areas. In future sampling, this potential gear-type bias should be investigated.

Suitable intergravel DO levels are critical for embryonic development. Growth response in larval chum salmon (*O. keta*) to deteriorating water quality was to a large extent associated with observed reductions in DO (range 3.5 to 11.3 mg/l; Bams and Lam 1983). Mean length of steelhead trout sac fry (*O. mykiss*) was positively associated with increased DO levels (range 2.6 to 11.2 mg/l; Silver et al. 1963). Steelhead trout embryonic survival was positively correlated with increased DO levels (2.6 to 9.25 mg/l; Coble 1961). The Oregon Department of Environmental Quality has set the minimum DO level for low risk of impairment to salmonid spawning at 6 mg/l (7-day mean of 11 mg/l). Intergravel DO levels in the Metolius River and tributaries meet these criteria, although sampling only occurred at two sites in one day.

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Chapter 3: Angler Surveys on Lake Billy Chinook, Oregon

INTRODUCTION

With respect to other locations in North America, the Lake Billy Chinook kokanee fishery is significant in terms of annual catch, angler effort, and yield. The 1990–1991 average annual harvest for Lake Billy Chinook kokanee was 74,000 fish (Thiesfeld et al. 1995). During the same period of time, the estimated angler effort directed at kokanee averaged 101,111 angler hours per year. Of the 28 lakes compared in a study by Rieman and Myers (1990), only 5 systems had a greater annual catch than that estimated for Lake Billy Chinook. Rieman and Myers (1990) also presented information that demonstrates, in terms of angler effort, that Lake Billy Chinook is comparable to large kokanee fisheries such as Pend Oreille Lake (65,000 to 137,000 angler hours) and Dworshak Reservoir (130,000 to 140,000 angler hours). However, it is in yield per lake surface area that the Lake Billy Chinook kokanee fishery is most notable. Thiesfeld et al. (1995) observed a 1990–1991 average fishery yield of 9.9 kg/ha for Lake Billy Chinook, considerably higher than all but 3 of the 28 lakes examined by Rieman and Myers (1990).

As part of this study to determine the factors limiting the kokanee population in Lake Billy Chinook, an accurate estimate of annual kokanee harvest was necessary. A statistical creel survey was conducted to measure angler effort and harvest of kokanee from 1996 through 2000. This chapter will focus on creel data from 1999 and, more specifically, 2000. Earlier creel data on Lake Billy Chinook is summarized in Thiesfeld et al. (1995, 1999) and, most recently, in Kern et al. (1999). Much of their data is included in tables in this chapter to allow comparisons. Harvest information relating to other fish species such as bull trout (*Salvelinus confluentus*), smallmouth bass (*Micropterus dolomieui*) , rainbow trout (*O. mykiss*), and brown trout (*Salmo trutta*) is also summarized.

METHODS

Surveys were conducted from March through October in 1999 and February through October 2000 following methods by Thiesfeld et al. (1995, 1999). Sampling was randomized within two levels of temporal stratification: month and day type (weekdays and weekends/holidays). In 1999, during March, April, and October, one surveyor covered the entire reservoir. From May through September, the reservoir was divided into two sections: the Metolius River arm, and the combined Deschutes and Crooked river arms. Each section was treated as a separate water body during data analysis. Two surveyors covered the reservoir during this period, one in each section. Two randomly selected weekend or holiday days and two or three randomly selected weekdays were sampled each week. Creel surveyors were on the reservoir 6 to 10 hours on each day sampled. Surveyors were randomly assigned either a morning shift, beginning on the reservoir at daybreak, or an afternoon shift ending at sunset. During all shifts, surveyors were assigned a route to travel to ensure random sampling of the study area.

Angler Interviews

Anglers were interviewed at the completion of their fishing trip or as they were encountered on the reservoir. Angling trips were classified as boat, houseboat, or bank. A representative from each party was asked a standard set of interview questions about the number of anglers, hours fished, area fished, target species, catch (kept and released) of each species, and any fin clips observed. Lengths of a random subset of kept fish were measured.

Angler Counts

Generally, from February through April, counts of fishing boats, bank anglers, and vehicles with boat hauling devices were made at approximately 3–4 hour intervals on scheduled survey days. The number of angling parties (angling pressure) was estimated using only counts of vehicles with trailers at the Cove Palisades State Park boat ramps and Perry South Campground. The State Park campground facilities on the upper and lower Deschutes River arms were not checked for vehicle/trailer combinations, but often boat trailers were parked there and not counted. From May through October, surveyors traversed the reservoir by boat, counting fishing boats and bank anglers (angling pressure) approximately every 2–3 hours. Boat surveys were initiated when the number of non-fishing boats became significant (usually in late April or early May). Surveyors visually determined if a boat was fishing or pursuing other recreation such as water-skiing or cruising.

Analyses

Data for analysis were stratified by reservoir arm, month, day type, and whether the party fished from the bank, boat, or houseboat. Length frequency distributions were determined for each species for each month.

Catch per angler hour (catch rate) for a species, kept or released, was estimated within each stratum as the sum of angler catch divided by the sum of angler hours fished. Catch from both complete and incomplete angler trips was calculated using:

$$C/f_k = \sum_{i=1}^{n} \sum_{j=1}^{m} C_{ijk} / \sum_{i=1}^{n} \sum_{j=1}^{m} H_{ij}$$

where

C/f_k = catch per angler hour (catch rate) of species k,
C_{ijk} = catch of species k by angling party j on day i (i = 1,2,3,...,n) (j = 1,2,3,...,m), and
H_{ij} = hours fished by angler j on day i.

To estimate hours of angler effort, the day was divided into three time periods (prior to 11 a.m., 11 a.m.–4 p.m., and after 4 p.m.) and the average daily boat and bank pressure for each time interval for each stratum was calculated. The time intervals were adjusted slightly throughout the season to accommodate changing day lengths. Average daily angler hours of effort for a stratum were estimated by calculating the area under the curve (AUC) formed by the figure with time on the horizontal axis and angling pressure counts on the vertical axis. Angling pressure was assumed to be zero at the legal start (Time 1) and end (Time 5) of the fishing day.

$$\mathrm{AUC} = 1/2\sum_{h=1}^{5}(T_h - T_{h-1})(E_h + E_{h+1})$$

where

T_h = average time of day of count h during stratum h = 1,2,3,4,5, and
E_h = average stratum count of boats, bank anglers, vehicles at count h.

Total stratum pressure was estimated by multiplying the estimated average daily pressure by the number of days in the time strata.

Average party size was estimated for each time strata for boat anglers. Total boat hours of effort was multiplied by the average party size to estimate total boat angler hours of effort. We estimated catch of kept and released fish of each species, k, as the product of angler hours of effort and catch per angler hour for each stratum.

$$\mathbf{TC_k = AUC * C/f_k}$$

where

TC_k = total catch of species k.

Total number of angler trips was estimated by dividing total estimated hours of effort by the average angler trip. Average length of an angler trip was estimated from completed angler trips for each time stratum. If less than five completed trips were sampled in a time stratum, time strata were successively pooled until at least five completed trips were sampled.

RESULTS AND DISCUSSION

General Trends

Boat anglers expended the greatest amount of fishing effort. The houseboat and bank angler effort (and harvest) accounted for a small fraction of total angler pressure and was frequently zero. Therefore, this report summarizes trends in boat angler effort and harvest.

Total boat angler effort during 1996–2000 ranged from 129,599 to 171,205 hours (Table 3.1). The number of angler trips was fairly constant, between 23,543 and 35,626 trips annually. Effort typically peaked during summer, and the greatest angling effort was directed at kokanee. However, both bull trout and smallmouth bass angling were also popular on the reservoir.

Table 3.1. Estimated number of boat angler trips and angler hours at Lake Billy Chinook, 1996–2000.

	1996		**1997**		**1998**		**1999**		**2000**	
	Trips	**Hours**	**Trips**	**Hours**	**Trips**	**Hours**	**Trips**	**Hours**	**Trips**	**Hours**
Mar	2,077	10,636	2,630	14,122	1,424	9,574	1,643	12,981	2,876	14,335
Apr	2,561	12,364	2,500	13,265	1,715	8,185	1,935	12,701	3,655	18,035
May	4,643	21,498	4,099	20,000	3,727	20,600	3,140	18,121	3,979	14,624
Jun	7,382	38,758	6,046	34,851	5,552	28,533	3,144	22,532	5,556	27,927
Jul	8,177	37,107	6,271	31,793	7,395	26,298	4,970	26,727	7,801	41,851
Aug	6,246	31,798	6,678	27,419	5,968	22,574	5,250	26,503	7,448	35,428
Sep	3,680	15,214	2,543	9,305	3,049	11,823	2,970	13,289	2,851	14,184
Oct	860	3,831	534	2,169	529	2,011	492	2,227	748	4,165
Total	35,626	171,205	31,301	152,923	29,421	129,599	23,543	135,083	34,914	170,549

Kokanee

Harvest

Kokanee harvest from 1996–2000 ranged from 53,410 fish in 1998 to 134,899 fish in 2000 (Table 3.2; Figure 3.1). Prior to this study, the highest harvest previously observed in Lake Billy Chinook creel surveys was in 1991, when 84,296 fish were harvested (Thiesfeld et al. 1995). Relatively few angler-caught kokanee were released, except in 2000 (Table 3.2). However, the large number of estimated released fish during August 2000 was likely exaggerated because of infrequency in sampling. Estimated kokanee harvest (both kept and released) correlated well with the estimated number of spawners over the period 1997–2000 (Figure 3.2).

Table 3.2. Estimated boat angler catch (Kept and released [Rel.]) of kokanee from Lake Billy Chinook, 1996–2000.

	1996		**1997**		**1998**		**1999**		**2000**	
	Kept	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**
Mar	45	13	951	71	1,250	80	1,303	194	5,689	132
Apr	440	181	1,470	87	840	90	2,558	87	5,074	543
May	5,928	816	5,735	46	5,334	7,462	1,320	308	6,235	287
Jun	20,545	1,006	18,191	866	16,075	782	4,643	7,066	26,241	584
Jul	20,562	436	14,804	550	13,873	2,181	20,465	2,828	28,834	3,190
Aug	16,111	587	18,938	2,094	8,776	2,730	25,166	3,956	51,738	35,133
Sep	7,554	414	4,441	897	6,010	1,168	14,925	2,069	8,710	581
Oct	4,085	0	1,067	131	1,251	48	2,509	111	2,277	162
Total	75,270	3,453	65,596	4,742	53,410	14,540	72,889	16,620	134,899	40,612

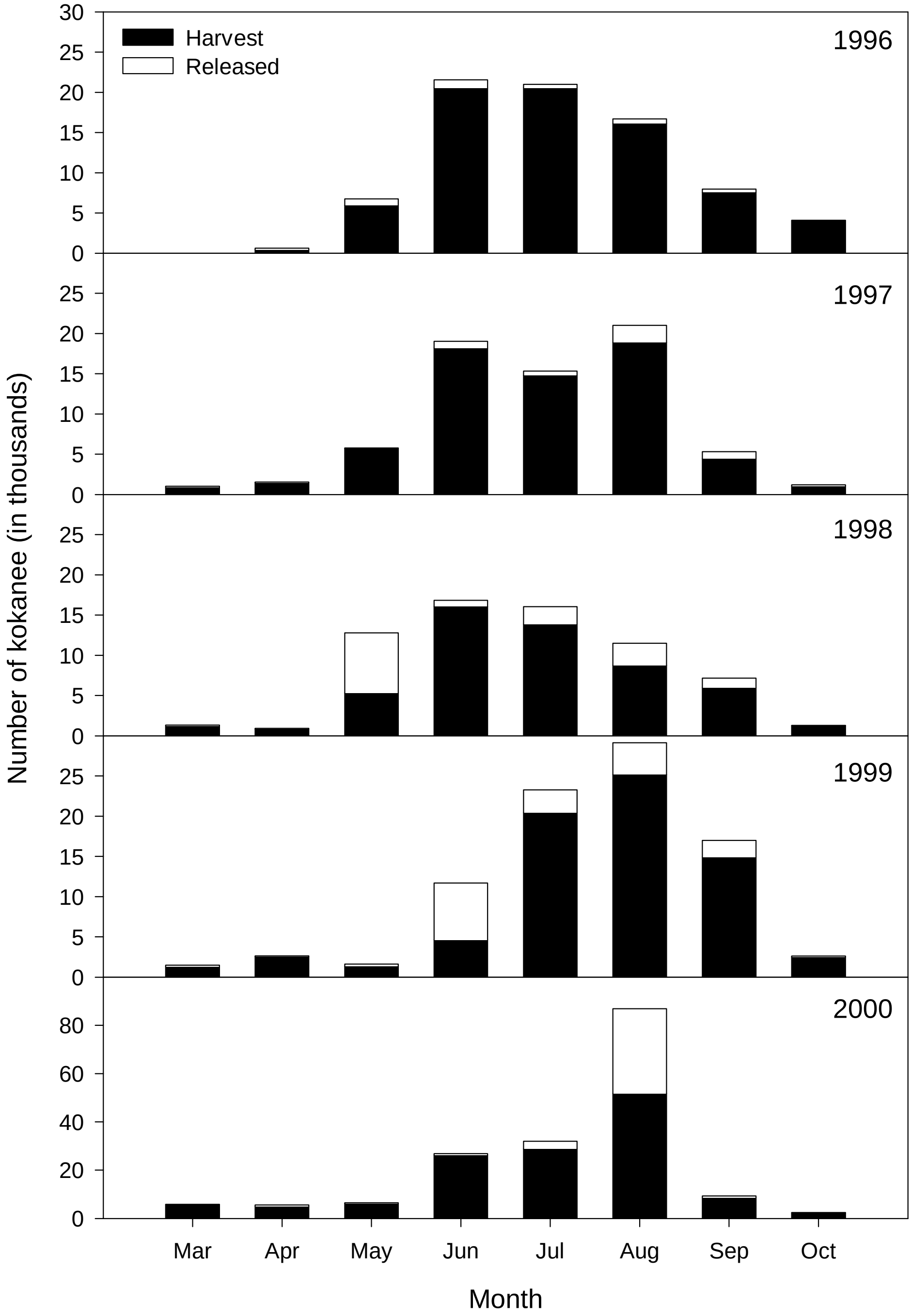

Figure 3.1. Estimated number of kokanee harvested and released by boat anglers by month from creel surveys on Lake Billy Chinook, 1996–2000.

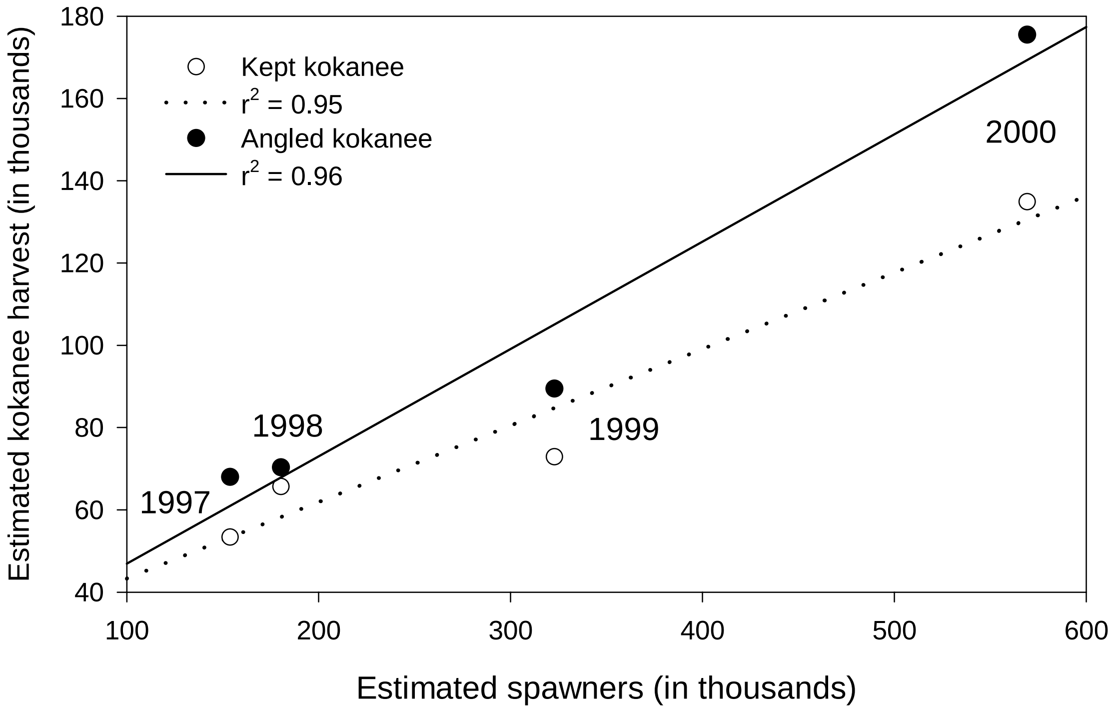

Figure 3.2. Relationship between estimated spawners in the Metolius River and number of kokanee harvested (kept [open circles, dotted line] and total angled [solid circle, solid line; includes kept and released]; March to October) in Lake Billy Chinook, 1997–2000.

Mean annual harvest rates from 1996–2000 have ranged between 0.41 and 0.67 fish-per-angler-hour (Table 3.3). Catch rates were always highest from June to October. The highest monthly catch rates were in late summer, presumably as anglers targeted kokanee preparing to start their spawning migration into the tributaries, particularly the Metolius River.

Table 3.3. Boat angler harvest (kept fish only) per angler hour for kokanee from angler surveys on Lake Billy Chinook, 1996–2000.

	1996	1997	1998	1999	2000
Mar	0.004	0.067	0.131	0.100	0.397
Apr	0.036	0.111	0.103	0.201	0.281
May	0.276	0.287	0.259	0.073	0.426
Jun	0.530	0.522	0.563	0.206	0.940
Jul	0.554	0.466	0.528	0.766	0.689
Aug	0.507	0.691	0.389	0.950	1.460
Sep	0.497	0.477	0.508	1.123	0.614
Oct	1.066	0.492	0.622	1.127	0.547
Mean	0.440	0.429	0.412	0.568	0.669

According to 2000 creel data, sizes of harvested kokanee typically ranged from 200 mm to 350 mm (Figure 3.3). Harvested kokanee were larger on average in 1997 and 1998. Kokanee harvest was mostly composed of age-2 and older fish. By early summer, particularly June, younger fish (age-1) entered the fishery. Larger kokanee entered the creel in August and September as anglers targeted pre-spawning fish as they prepared to migrate up the tributaries, particularly the Metolius River. After September, harvest switched back to younger fish as fewer older, larger fish were available after the annual spawning migration. Overall kokanee harvest and effort declined each year from 1996 through 1998, probably because of declining abundance of kokanee during the same period; however, a strong cohort produced in 1998 began to contribute to the fishery as age-1 fish in 1999, increasing harvest even under reduced angler effort. With increased kokanee abundance in 2000, angler effort and harvest increased markedly. Creel data from 2000 must be viewed cautiously as several logistical constraints limited continuous creel surveying during summer of 2000.

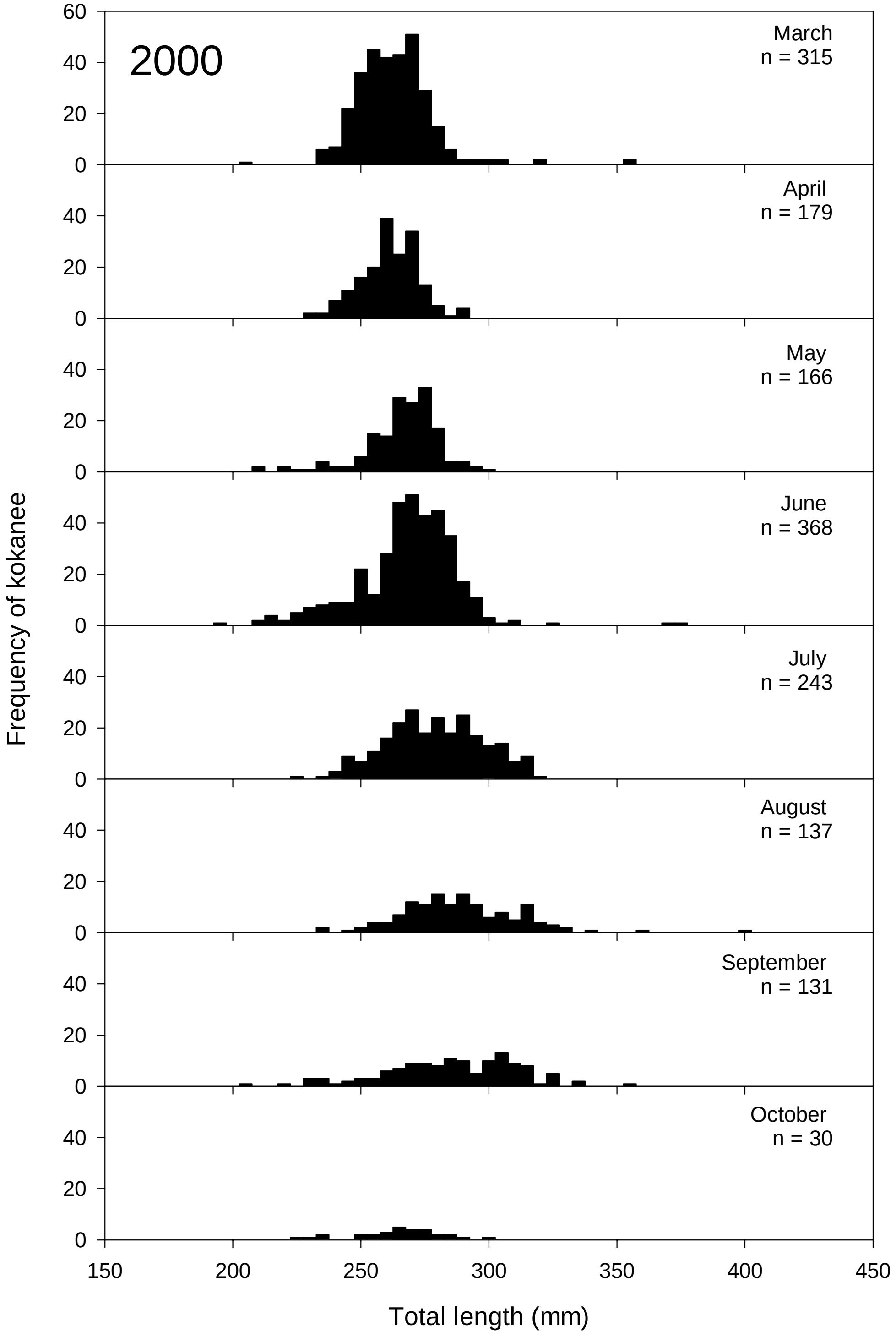

Figure 3.3. Length frequency of kokanee harvested from Lake Billy Chinook, 2000.

Bull Trout

Harvest

In response to increasing concerns about bull trout in Oregon, angling regulations have become more restrictive. In 1997, the minimum harvest size was reduced to 600 mm (24 inches) and a bull trout sanctuary on the Metolius River arm was established. Bull trout harvest from Lake Billy Chinook has consistently decreased from 1996 to 2000 (Table 3.4; Figure 3.4) originally because of in the 1997 regulation reducing minimum harvest size. However, overall catch (harvest and release) and catch rate of bull trout has steadily increased since then (Tables 3.5 and 3.6). Overall bull trout angler effort during 1996–1999 was considerably higher than during 1990–1992 (Thiesfeld et al. 1999). Most of the bull trout caught were released. Bull trout catch and harvest typically peaked during spring, but has been very low in the fall since inception of the 600-mm minimum harvest size and institution of the no fishing sanctuary on the Metolius River arm. In 1996, prior to the inception of the 600-mm minimum limit, very few bull trout greater than 600 mm were harvested after June, a trend that is apparent in 1997 through 2000. The relative lack of larger bull trout caught in the reservoir after June is likely explained by the movement of the bull trout into the Metolius River, where they assemble prior to spawning. A significant number of bull trout < 600 mm were harvested in 1996.

Table 3.4. Estimated boat angler catch (kept and released [Rel.]) of bull trout from Lake Billy Chinook, 1996–2000.

	1996		**1997**		**1998**		**1999**		**2000**	
	Kept	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**
Mar	122	608	84	713	47	747	12	2,480	89	1,612
Apr	168	762	113	620	12	208	28	1,963	30	587
May	198	495	30	240	43	152	21	2,226	13	154
Jun	501	923	31	88	45	774	7	677	27	606
Jul	303	662	33	508	0	1,231	0	1,021	64	3,947
Aug	556	1,507	0	303	9	960	0	3,147	50	3,220
Sep	163	475	0	318	28	835	0	386	23	1,922
Oct	31	17	0	58	0	85	0	152	15	217
Total	1,752	4,079	291	2,849	184	4,996	68	12,055	311	12,265

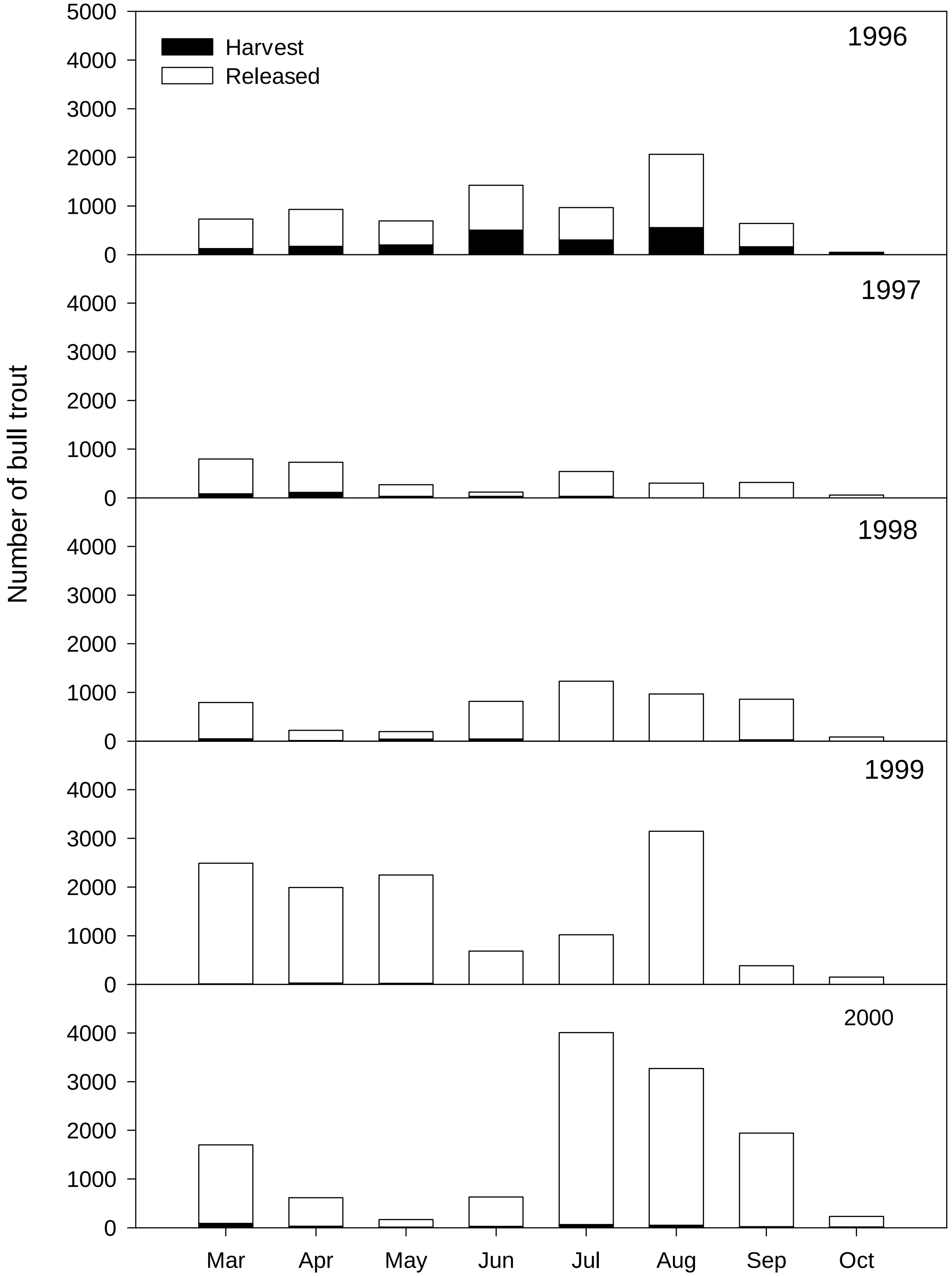

Figure 3.4. Estimated number of bull trout harvested and released by boat anglers by month from creel surveys on Lake Billy Chinook, 1996–2000.

Catch rates of bull trout were typically very low compared to other species (Tables 3.5 and 3.6). However, in 1999, mean angler catch rates of bull trout (harvest and release) were higher than any year since 1996 or in 2000 (this may be due to patchy creel surveys in 2000). Additionally, 1999 catch rates during spring, when bull trout angler effort is greatest, were over twice as high as those in the springs of 1996–1998; catch rates were also high in March and late summer of 2000.

Table 3.5. Boat angler catch (both kept and released) per angler hour for bull trout on Lake Billy Chinook, 1996–2000.

	1996	1997	1998	1999	2000
Mar	0.068	0.056	0.083	0.192	0.119
Apr	0.066	0.055	0.027	0.157	0.034
May	0.032	0.014	0.009	0.018	0.011
Jun	0.037		0.024	0.030	0.023
Jul	0.026	0.017	0.039	0.038	0.096
Aug	0.064	0.011	0.035	0.119	0.092
Sep	0.042	0.034	0.093	0.029	0.137
Oct	0.013	0.027	0.039	0.068	0.056
Mean	0.034	0.021	0.040	0.081	0.071

Table 3.6. Boat angler harvest (kept fish only) per angler hour for bull trout on Lake Billy Chinook, 1996–2000.

	1996	1997	1998	1999	2000
Mar	0.011	0.006	0.005	0.001	0.006
Apr	0.014	0.009	0.001	0.002	0.002
May	0.009	0.002	0.002	0.001	0.001
Jun	0.013	0.001	0.002	0.000	0.001
Jul	0.008	0.001	0.000	0.000	0.002
Aug	0.017	0.000	0.000	0.000	0.001
Sep	0.011	0.000	0.002	0.000	0.002
Oct	0.008	0.000	0.000	0.000	0.004
Mean	0.011	0.002	0.002	0.001	0.002

Most bull trout harvested in 1996 were between 200 mm and 600 mm. After the minimum harvest-size regulation change in 1997, most harvested fish were larger than 600 mm, although some sub-legal fish (< 600 mm) were taken in 1999 and 2000 (Figure 3.5).

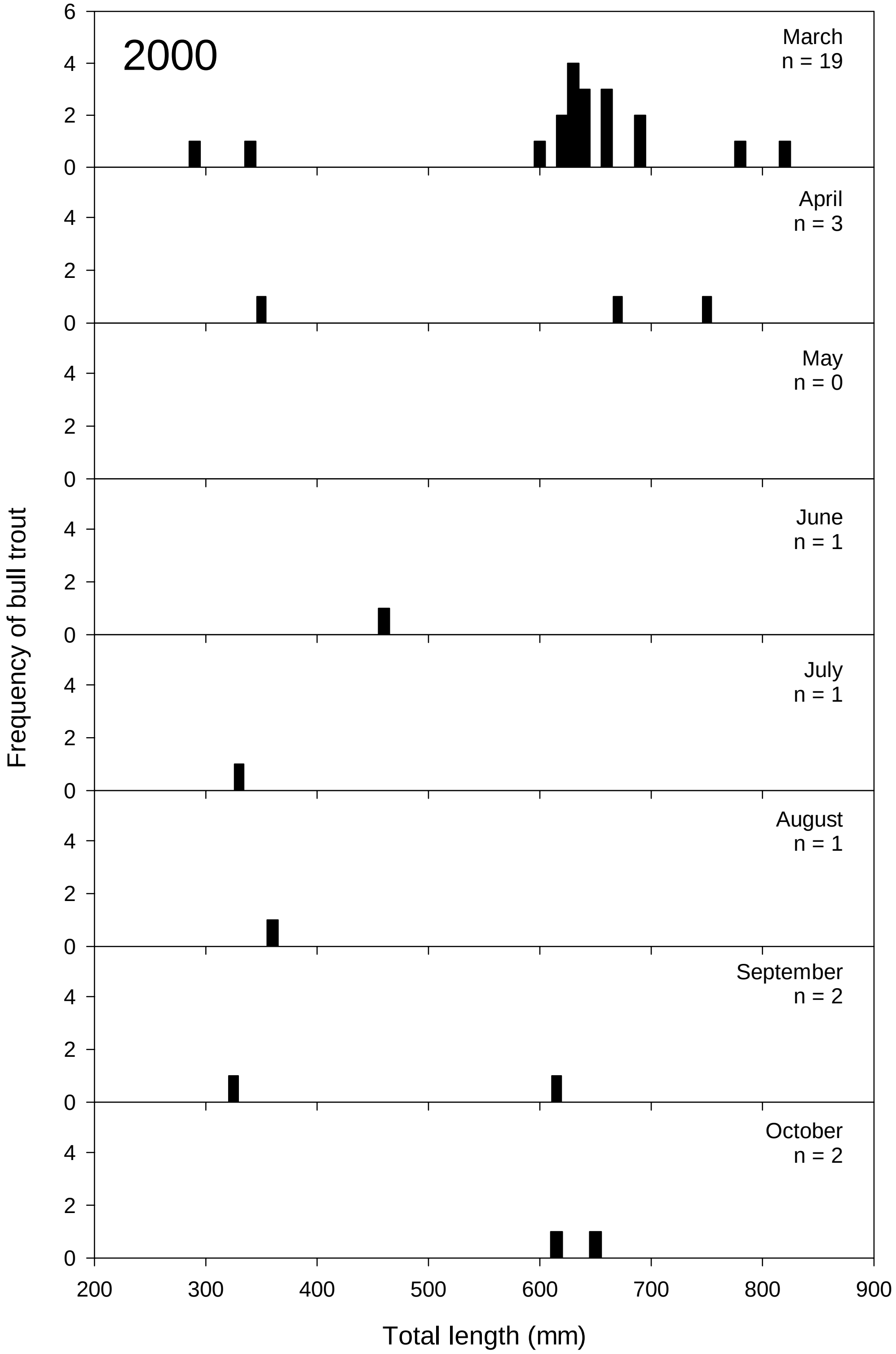

Figure 3.5. Length frequency of bull trout harvested from Lake Billy Chinook, 2000.

Relationship of Harvest to Bull Trout Abundance

In spite of increasing restrictions on harvest after 1996, angling effort directed at bull trout has remained high. Catch of bull trout (harvested and released fish) was higher from 1996–2000 than during 1990–1993 (Thiesfeld et al. 1995). Total catch was highest in 2000, with the catch rate being the highest observed.

The goals of a minimum length limit are to protect the reproductive potential of a fish population, increase angler catch rates (but not always harvest rates), and to promote predation on prey fishes. Thus, the 600-mm minimum length limit for bull trout on Lake Billy Chinook may have increased the abundance of bull trout > 600 mm and spawners; however, without population estimates it is difficult to say whether the bull trout population has increased significantly. It appears that the 600-mm minimum length limit has increased catch rates for bull trout. Without harvest as a controlling factor for the bull trout population, it is conceivable that the availability of prey (i.e., kokanee) will eventually limit the size of this population.

Smallmouth Bass

Harvest

Peak catches of smallmouth bass typically occurred between June and August. Harvest rate was similar during 1996–1998 and 2000 but was much lower in 1999 (Table 3.7). Length frequency distributions for smallmouth bass harvested in 2002 were quite variable (Figure 3.6). Most smallmouth bass harvested ranged from 150 mm to 350 mm, and catches of large bass have been very low.

Table 3.7. Estimated boat angler catch (kept and released [Rel.]) of smallmouth bass from Lake Billy Chinook, 1996–2000.

	1996		**1997**		**1998**		**1999**		**2000**	
	Kept	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**
Mar	5	48	0	25	8	2	6	8	7	64
Apr	341	696	0	72	47	568	77	857	346	4,473
May	101	2,517	241	7,398	643	2,295	178	2,263	451	4,004
Jun	1,320	5,367	510	14,821	216	4,522	469	8,834	813	4,224
Jul	819	10,539	994	10,385	1,602	14,031	143	8,321	1,386	14,759
Aug	1,607	8,578	804	6,514	1,522	10,371	193	2,957	1,444	8,693
Sep	58	987	31	226	177	1,892	64	729	56	623
Oct	20	0	0	0	0	5	0	0	0	8
Total	4,271	28,732	2,580	39,441	4,215	33,686	1,131	23,970	4,503	36,847

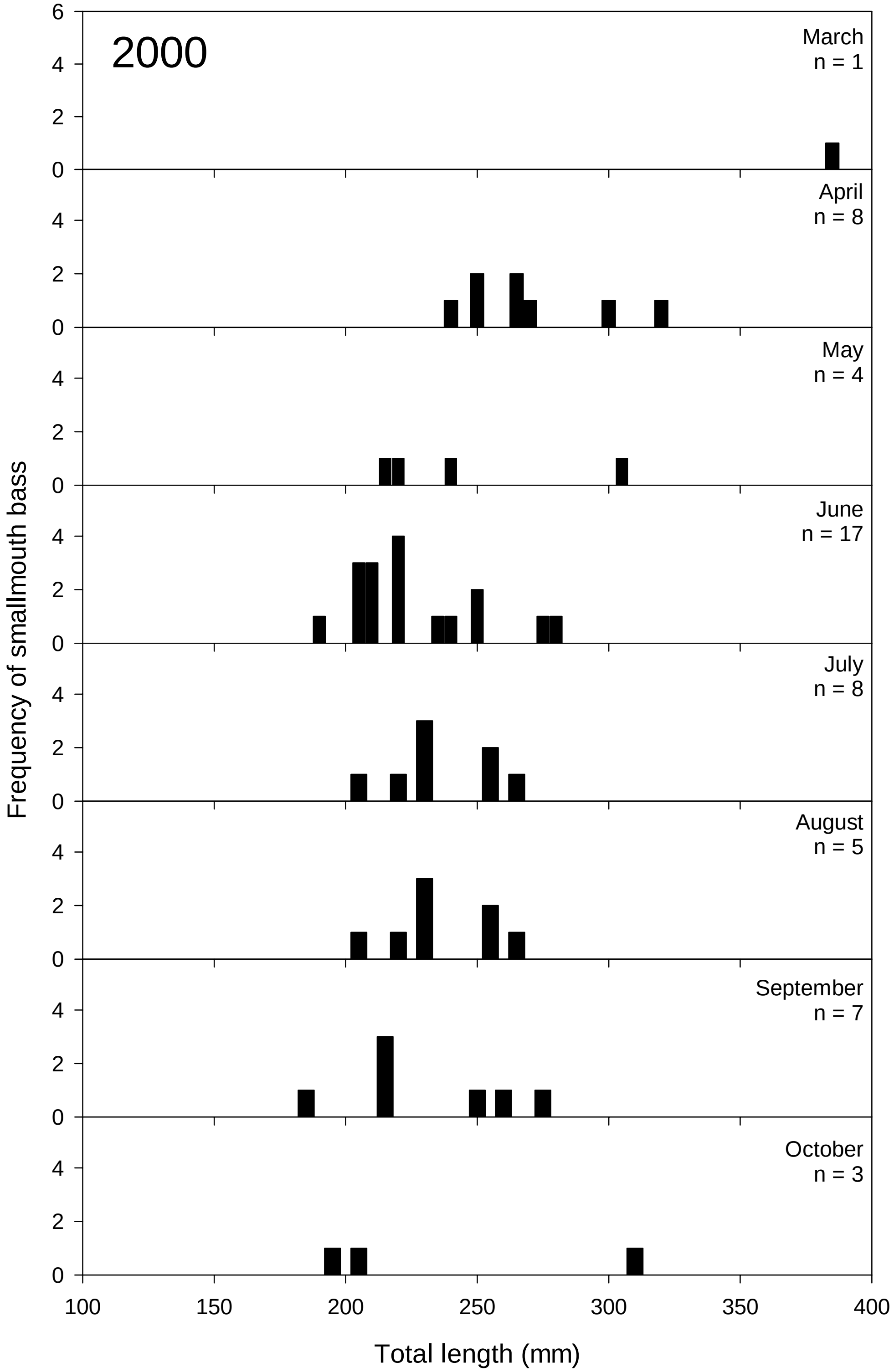

Figure 3.6. Length frequency of smallmouth bass harvested from Lake Billy Chinook, 2000.

Other Species

Rainbow trout and brown trout were also harvested in modest numbers from Lake Billy Chinook (Tables 3.8 and 3.9). Rainbow trout harvested from Lake Billy Chinook typically ranged from 200 mm to -400 mm (Figure 3.7). Harvest and total catch of rainbow trout was highest in 1996, when 4,248 fish were caught and 2,421 were kept (Figure 3.8). The peak of rainbow trout harvest was usually from June through August. In 1999 and 2000, rainbow trout harvest was robust in spring.

Table 3.8. Estimated boat angler catch (kept and released [Rel.]) of rainbow trout from Lake Billy Chinook, 1996–2000.

	1996		**1997**		**1998**		**1999**		**2000**	
	Kept	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**
Mar	147	136	112	60	82	46	225	191	325	170
Apr	143	59	23	69	51	56	292	112	69	304
May	93	112	359	75	115	177	607	250	53	97
Jun	490	414	119	46	196	139	300	318	182	185
Jul	647	389	936	54	356	398	248	869	567	161
Aug	812	675	210	85	313	90	268	0	151	0
Sep	61	0	255	112	81	0	63	11	56	0
Oct	28	42	17	20	11	16	20	60	23	335
Total	2,422	1,828	2,031	531	1,205	920	2,023	1,811	1,426	1,254

Table 3.9. Estimated boat angler catch (kept and released [Rel.]) of brown trout from Lake Billy Chinook, 1996–2000.

	1996		**1997**		**1998**		**1999**		**2000**	
	Kept	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**	**Kept**	**Rel.**
Mar	74	133	131	136	70	32	80	73	143	200
Apr	101	115	24	46	43	52	245	97	61	89
May	140	13	90	15	19	9	14	28	46	0
Jun	418	162	45	60	11	20	21	63	53	0
Jul	231	134	36	106	30	0	0	0	171	0
Aug	65	137	0	14	0	0	0	0	0	0
Sep	0	0	16	16	0	11	63	0	23	0
Oct	14	0	0	0	5	5	0	18	23	31
Total	1,043	694	342	393	178	129	423	278	519	320

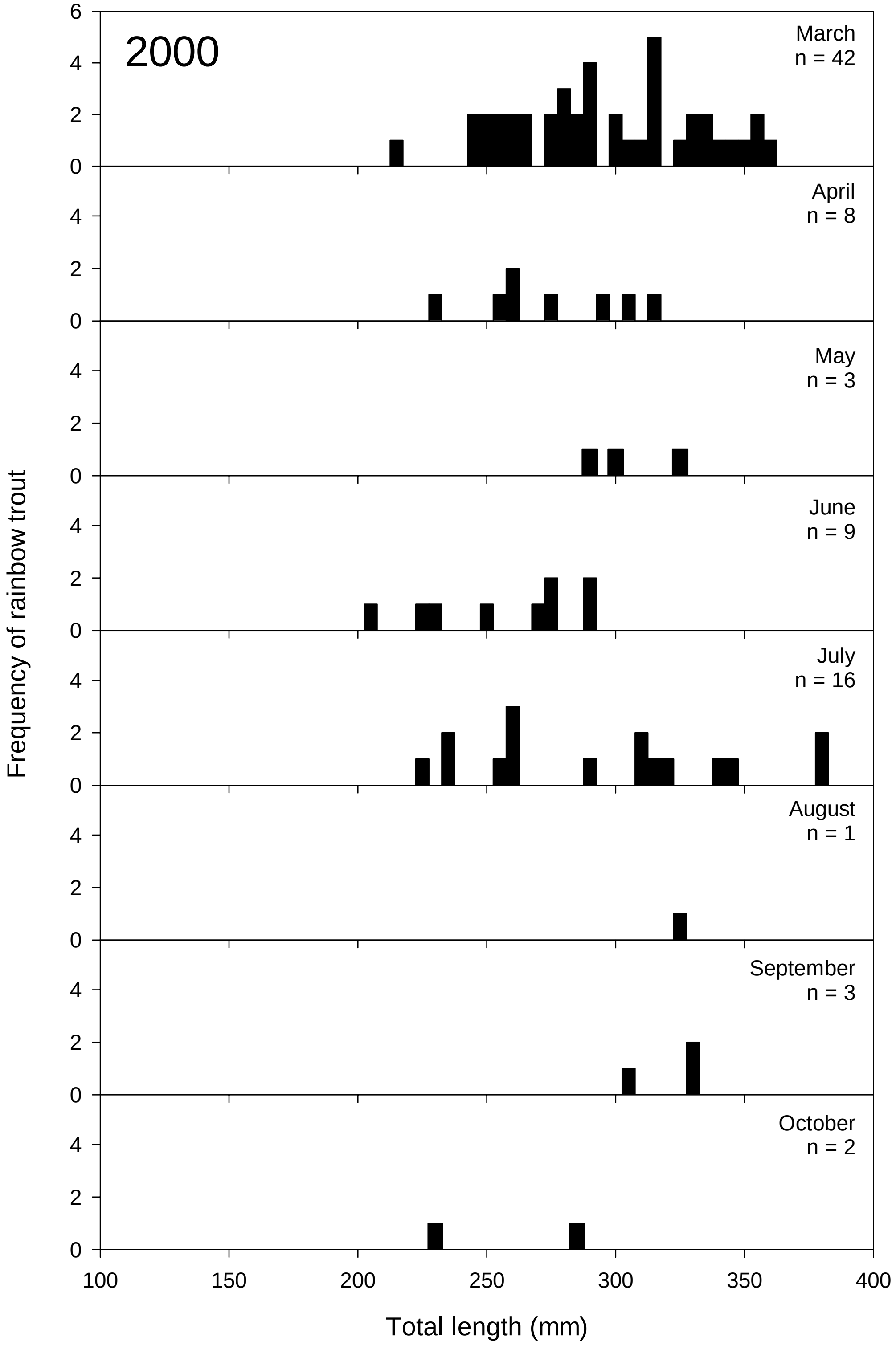

Figure 3.7. Length frequency of rainbow trout harvested from Lake Billy Chinook, 2000.

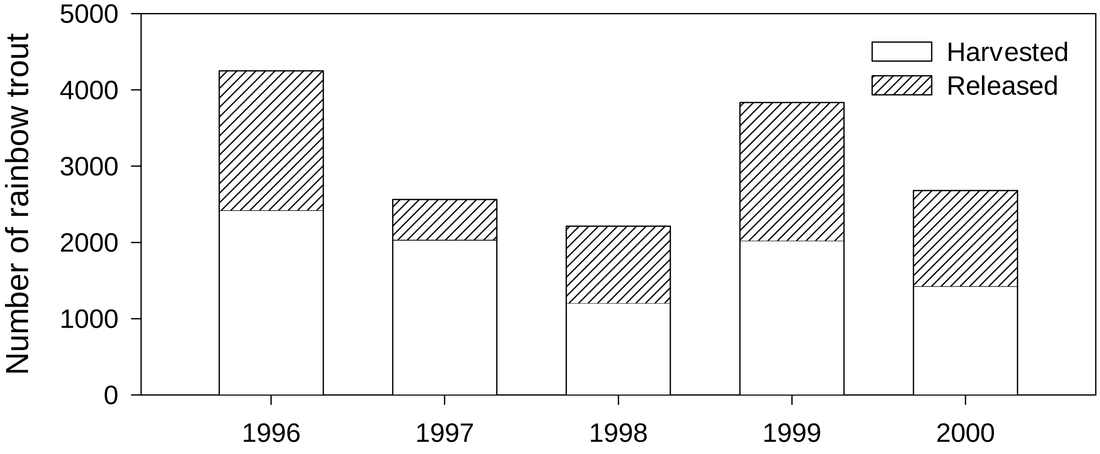

Figure 3.8. Estimated number of rainbow trout harvested and released by boat anglers by month from creel surveys on Lake Billy Chinook, 1996–2000.

Effort targeting brown trout was relatively low (Table 3.9, Figure 3.9). The peak of brown trout harvest was generally between March and June. Brown trout harvested in 2000 generally ranged from 250 mm to 400 mm (Figure 3.10).

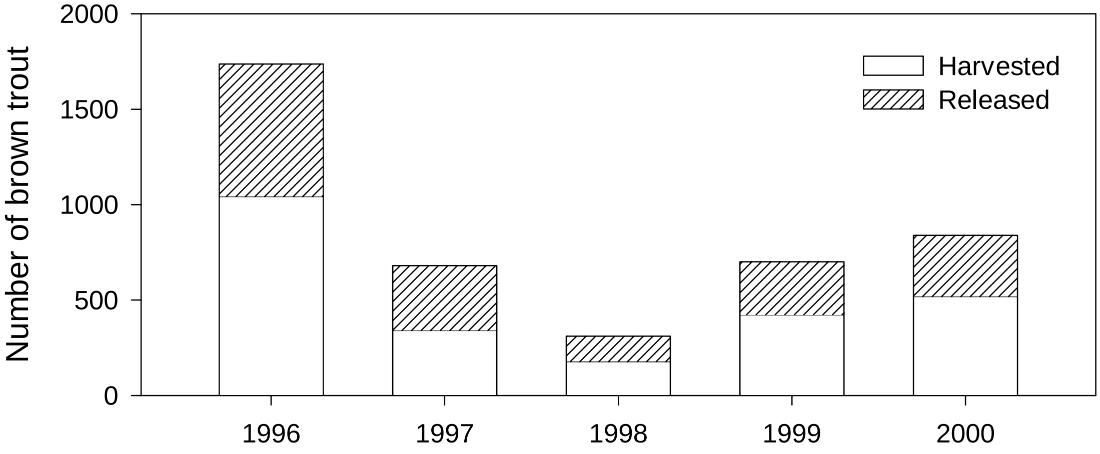

Figure 3.9. Estimated number of brown trout harvested and released by boat anglers by month from creel surveys on Lake Billy Chinook, 1996–2000.

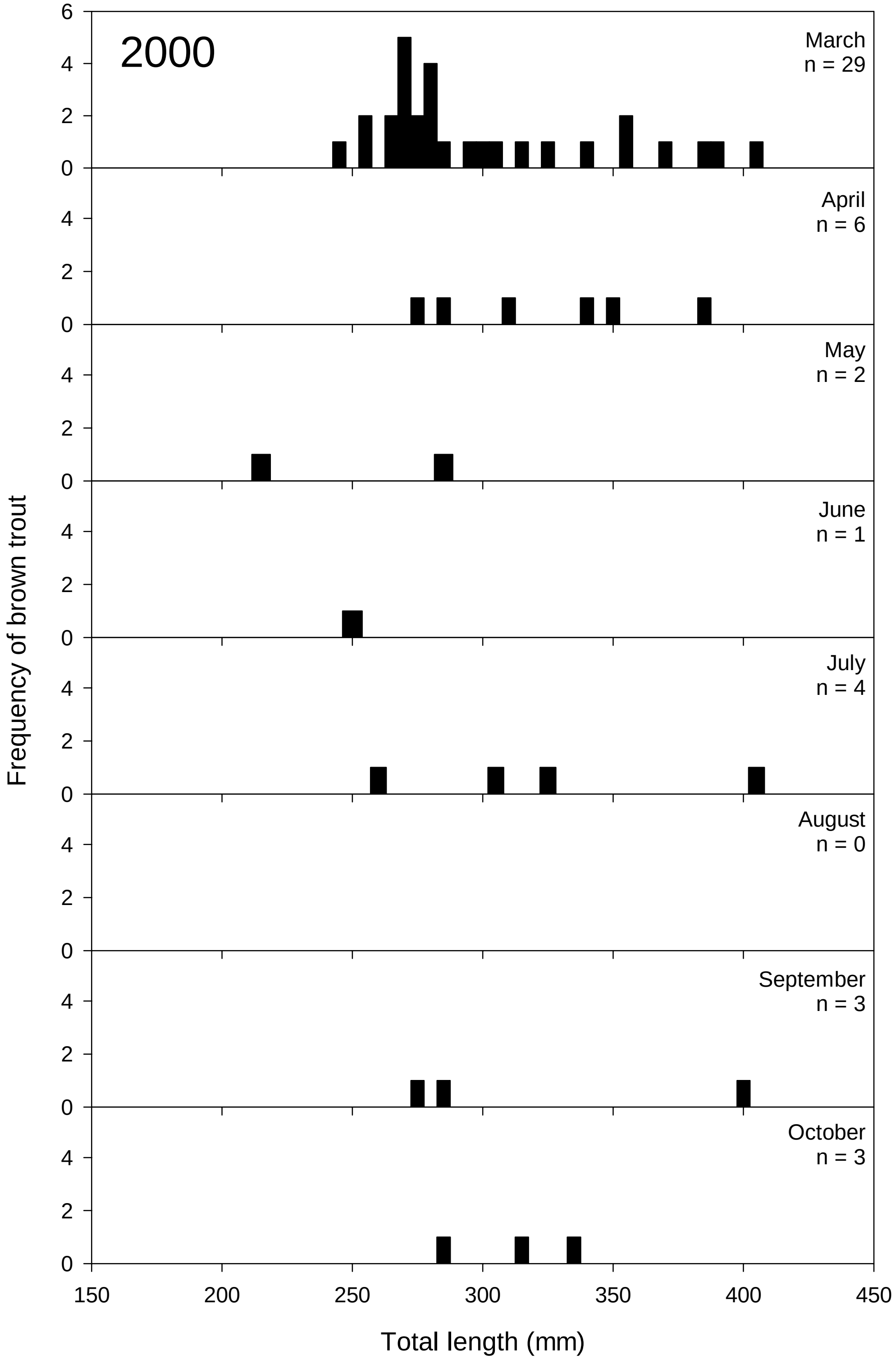

Figure 3.10. Length frequency of brown trout harvested from Lake Billy Chinook, 2000.

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Chapter 4: Population Trends of Kokanee Salmon in Lake Billy Chinook, Oregon: Evidence of Density Dependent Effects?

INTRODUCTION

Abundance of successive year classes of kokanee salmon *Oncorhynchus nerka* fluctuates widely. These fluctuations, and other patterns, can be caused by either variation in the number of eggs deposited each year, or variation in the survival of eggs and age-0 fish following spawning (LeCren 1960). Recruitment variation has also been linked to such factors as spawning stock size (Ricker 1954), environmental conditions (Gulland 1960, Craig and Kipling 1983), or a combination of those factors (Jackson and Noble 2000). Despite considerable research, fundamental factors underlying variable recruitment and subsequent population fluctuations remain unclear, largely because of year-to-year variation in environmental conditions.

The relationship between adult stock and subsequent recruitment can also be highly variable (*see* Gulland 1960). A stock-recruitment relationship in the form of a descending right-hand limb indicates density dependence and suggests instability, and subsequent disturbances may cause large or permanent oscillations (Ricker 1975, *see* Figure 4.8). Given the strong year classes and cyclic behavior of many salmon populations, this density dependent relationship is likely true for kokanee salmon.

Previous successful efforts to predict fish biomass based on productivity of a lake or reservoir were made by Rieman and Myers (1992) and Rieman and Maiolie (1995). Thiesfeld et al. (1999) examined these relationships between kokanee density, age-specific kokanee size, and water transparency. Data for Lake Billy Chinook clearly did not fit developed models, because of several factors: (1) Lake Billy Chinook kokanee exhibited substantially higher growth rates than those in Idaho study lakes; (2) trawl densities in Lake Billy Chinook were lower than Idaho lakes and trawl surveys underrepresented true kokanee densities in the reservoir; and (3) only three years of data were available from Lake Billy Chinook. However, the relationship between mean total length-at-age and secchi disk transparency supports the hypothesis that lake productivity may be the ultimate factor controlling kokanee size (Rieman and Maiolie 1995, Thiesfeld et al. 1999).

Population abundance and life-history information on the kokanee population in Lake Billy Chinook has been collected since the early 1990s. Even though many years of reliable data on population abundance are available, data cover a span of only one continuous cohort, egg deposition in 1997 to spawners in 2000. The purpose of this chapter is to describe variation in population abundance and to investigate mechanisms responsible for these fluctuations with consideration of potential density dependence trends. Relationships between age-specific population abundance, fecundity, survival of new recruits, and biological characteristics were examined.

METHODS

Data were collected following methods described in Chapter 2 (for years 1996–1998, Thiesfeld et al. 1999; for years 1999–2000, this report). Data collection methods are also briefly summarized below. Regression analyses were used to identify significant relationships ($p < 0.05$) between age-specific population abundance, fecundity, survival of new recruits, and other biological and demographic characteristics.

Spawner Abundance

Pre-spawning kokanee were captured with a 100 m boat-deployed beach seine during August and September 1999 and 2000 near the confluence of the Metolius River and Lake Billy Chinook. Adult kokanee were marked with brightly-colored Floy anchor tags inserted slightly posterior and ventral to the dorsal fin. A sample of seine-captured kokanee was processed in the laboratory, where lengths (mm), weight (g), and gonads were taken, and number of eggs per female was used to determine fecundity. Tagged kokanee were later counted during spawning surveys conducted in the Metolius River and its tributaries for use in a Peterson estimate of total spawners using the Schaefer method (Ricker 1975).

To obtain spawner abundance, kokanee were counted weekly at 20 index sites in the Metolius River and its tributaries starting on 1 September and continuing until essentially no kokanee were observed. Spawning kokanee were also captured each year from the Metolius River and on occasion from selected tributaries using nets. Length, weight, sex, and gonads were collected. In 2000, dead spawned-out females were collected to determine egg retention. Comparatively few kokanee spawned in the Crooked and Deschutes rivers (Thiesfeld et al. 1999; *see* Chapter 2 this report); therefore, their contribution was not added to this analysis. Additional spawner counts were conducted in the mainstem Metolius River by floating or walking specific reaches. In all surveys, tagged fish were noted.

Potential Egg Deposition

To determine the number of female spawners, the percent of females in the spawning run was multiplied by the estimated spawner abundance. Eggs-per-female was determined from kokanee collected in the Lake Billy Chinook prior to spawning and on the spawning grounds. Potential egg deposition (PED) was estimated by multiplying the average number of eggs per female (less average egg retention) by the number of female spawners.

Recruitment and Population Assessment

Kokanee recruitment (age-0 abundance) into Lake Billy Chinook was estimated with hydroacoustic surveys. In this study, recruitment was estimated as the peak abundance of age-0 kokanee in the reservoir. This peak abundance occurred in July for all years (1996–2000).

Hydroacoustic data were collected from 41–48 transverse, systematically located transects: 20 in the Metolius River arm, 13–16 in the Deschutes River arm, and 8–12 in the Crooked River arm. Acoustic surveys were conducted just before, during, or after a new moon, and usually were conducted concurrently with trawling. Hydroacoustic data were collected with a Simrad EY500 transceiver and a 120 kHz, split beam, 7^o transducer. Data were analyzed using the Simrad EP500 post-processing software. Target strength (TS in decibels, dB) was converted to total length (cm) using the formula *TS (dB) = 20 log TL (cm) - 67*). The lower TS cutoff was adjusted seasonally to include newly emerged fry. Targets above -30 dB were eliminated because size separation and the TS to size relationship become increasingly unreliable as actual fish size increases.

To verify acoustic targets, a 3.05 m X 3.05 m otter trawl was fished in the three arms of Lake Billy Chinook on up to 13 transects. The trawl was fished at 1.5 m/s pulled behind a diesel-powered, 8.5 m boat, at depths corresponding to the kokanee distribution as determined by hydroacoustic surveys, ensuring that most depth intervals were sampled. Length, weight, age, and gonad data were collected from trawled fish.

Gill netting was also conducted to verify acoustic targets and obtain biological information. A 30 X 30 m variable mesh gill net was fished overnight near Chinook Island, Metolius River arm during April, July, and October. Length, weight, otolith, sex, and gonads were collected from netted fish.

Annual estimates of recruitment (age-0 abundance in the reservoir in July) and spawners were used to compute production, expressed as the natural log of recruits to spawners, *ln*(R/S). Evidence for density-dependence in the relationship of *ln*(R/S) versus spawner abundance was examined by linear regression for the available four years of complete data (1996–1999).

Growth and Survival

Length of age-0 kokanee was measured from trawl and gill net samples obtained in autumn 1996–2000. Survival rate of age-0 kokanee was estimated from potential egg deposition (PED) to peak recruitment of kokanee in July in Lake Billy Chinook for brood years (BY) 1996 to BY 1999.

RESULTS AND DISCUSSION

Kokanee Demographic Trends

Since 1996, annual kokanee population abundance has ranged widely, from a low of about 350,000 in 1997 to a high of nearly 4 million in 1999 (Figure 4.1). Over this short time series, population abundance appears to be increasing. With these large fluctuations, several trends in kokanee demographics emerge, including decreased size and growth of kokanee, decreased fecundity, and decreased survival of age-0 kokanee with increased population abundance.

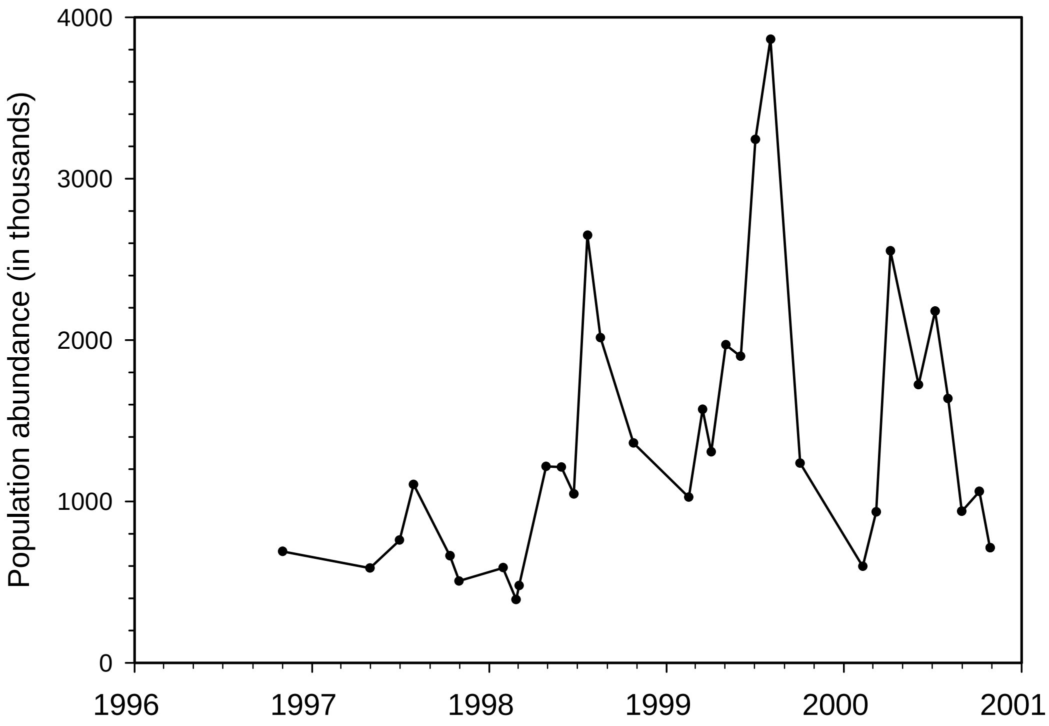

Figure 4.1. Hydroacoustic-generated estimates of kokanee population abundance (all age classes combined) in Lake Billy Chinook, 1996–2000.

Since 1995, the length frequency of the kokanee spawning population has shifted. Mean spawner total length (males and females combined) was 283 mm in 1995, increased to 340 mm in 1998, and decreased to 294 mm in 2000 (Figure 4.2). Spawner length was negatively correlated with several factors: (1) spawner abundance ($r^2 = 0.81$) (Figure 4.3); (2) kokanee abundance (all age classes) in the reservoir ($r^2 = 0.46$, $p = 0.20$); and (3) peak adult abundance in the reservoir ($r^2 = 0.98$). Spawner weight decreased from 388 g in 1998 to 218 g in 2000 and was also negatively correlated with spawner abundance ($r^2 = 0.95$) (Figure 4.3). This same relationship was observed for both female and male spawners. Spawner abundance was inversely correlated with female spawner length (r^2 = 0.97) and weight (r^2 = 0.93). Likewise, spawner abundance was negatively correlated with male spawner length (r^2 = 0.74) and weight (r^2 = 0.93).

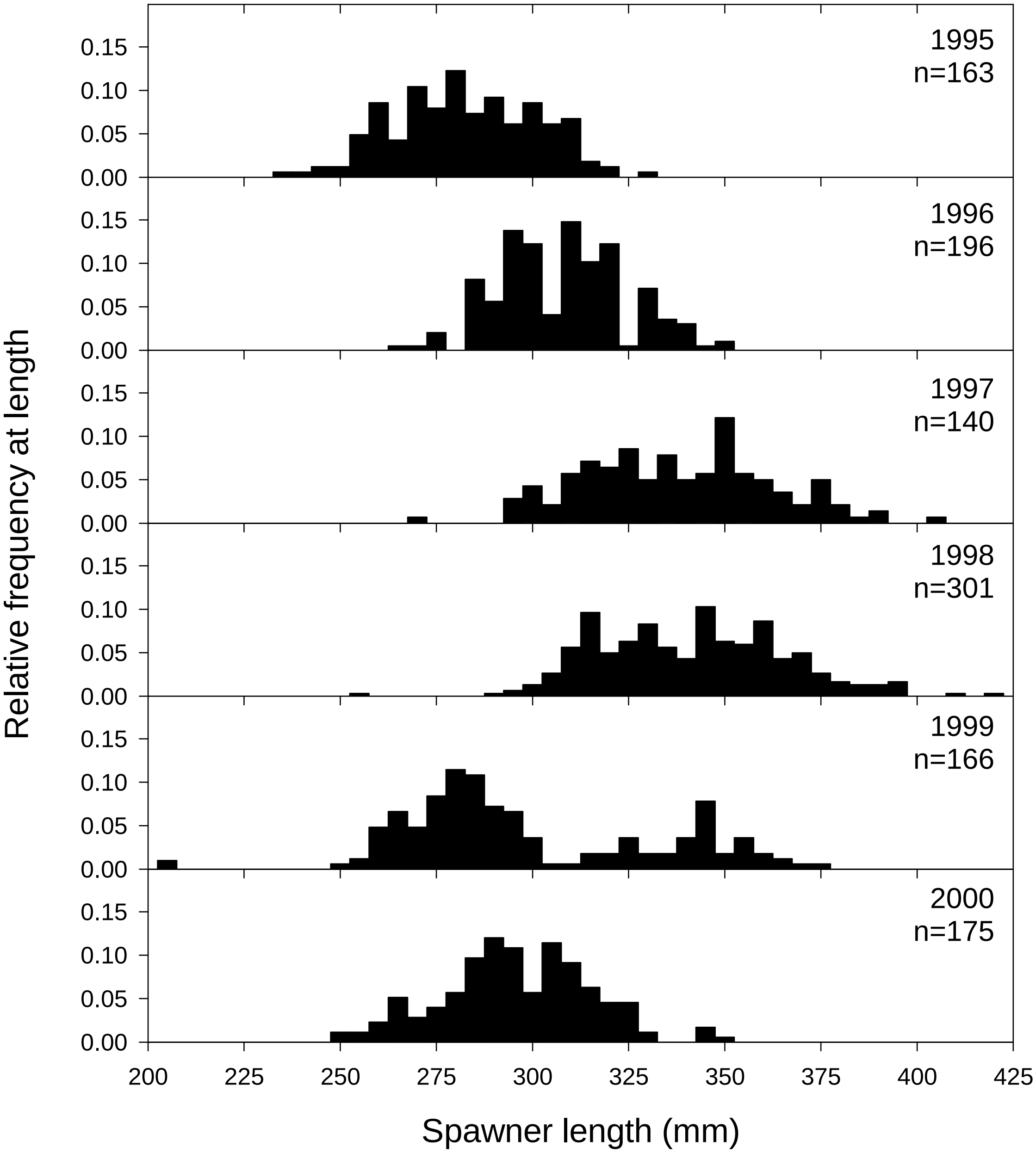

Figure 4.2. Length frequencies of kokanee spawning in the Metolius River from 1995 to 2000.

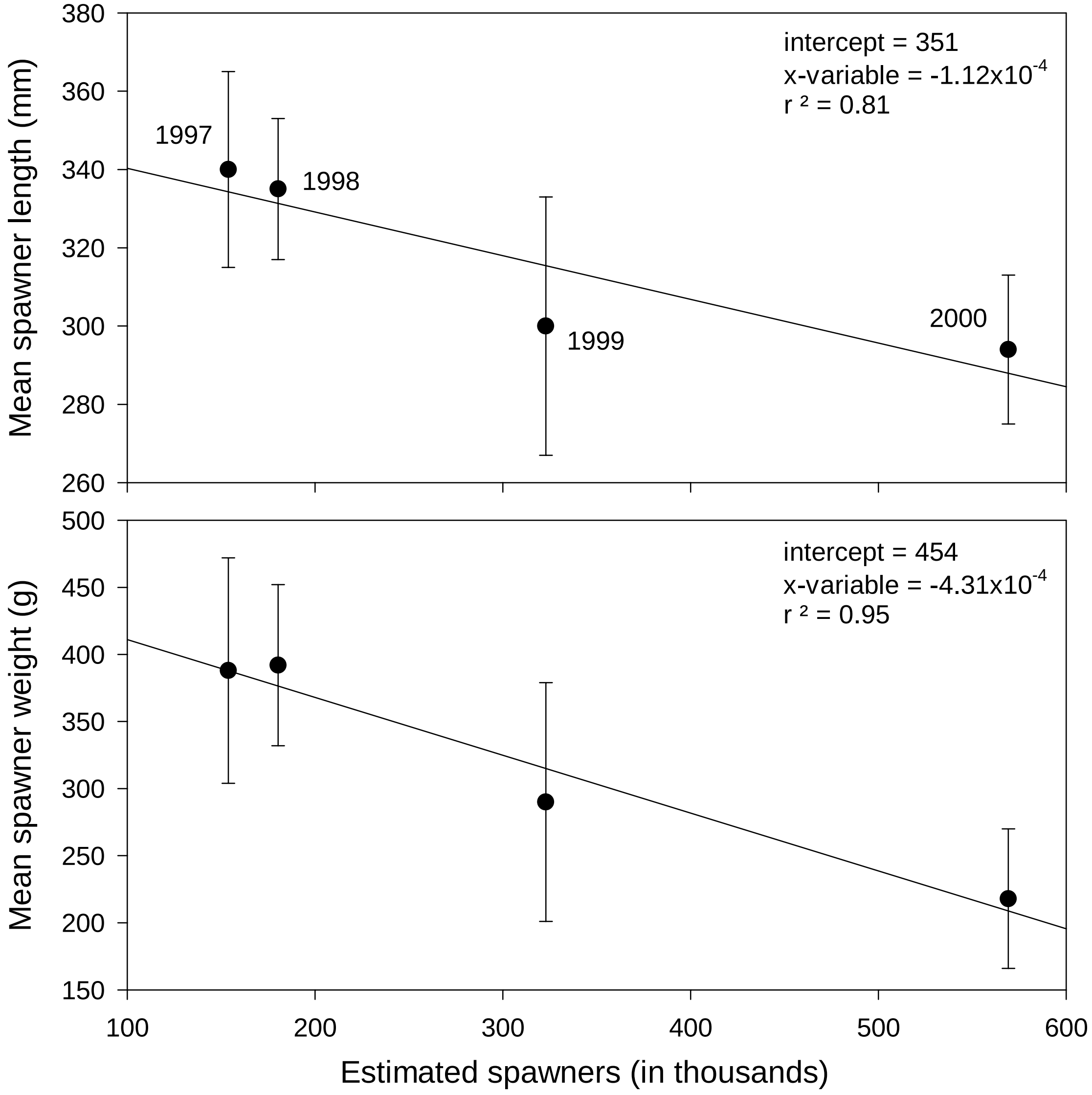

Figure 4.3. Relationship between estimated spawner abundance and mean spawner length (mm; top panel) and mean spawner weight (g; bottom panel) in Lake Billy Chinook. Females and males are combined. Error bars represent one standard deviation around measurement.

Concurrent with increased spawner abundance and decreased female spawner size, the number of eggs-per-female decreased markedly. As mean female spawner size decreased, so did fecundity (Figure 4.4). Number of eggs-per-female was significantly positively correlated with female spawner length (r^2 = 0.997) and weight (r^2 = 0.96; Figure 4.4). Average number of eggs-per-female was 654 in 1997, and by 2000, the average dropped to 335 eggs-per-female. Further, average number of eggs-per-female was significantly negatively correlated with estimated numbers of spawners ($r^2 = 0.99$; Figure 4.5). Therefore, PED was affected. Although spawner numbers in 2000 were nearly double the number of spawners in 1999, PED was nearly identical, about 55 million eggs deposited in both years. Egg size was not evaluated during the study.

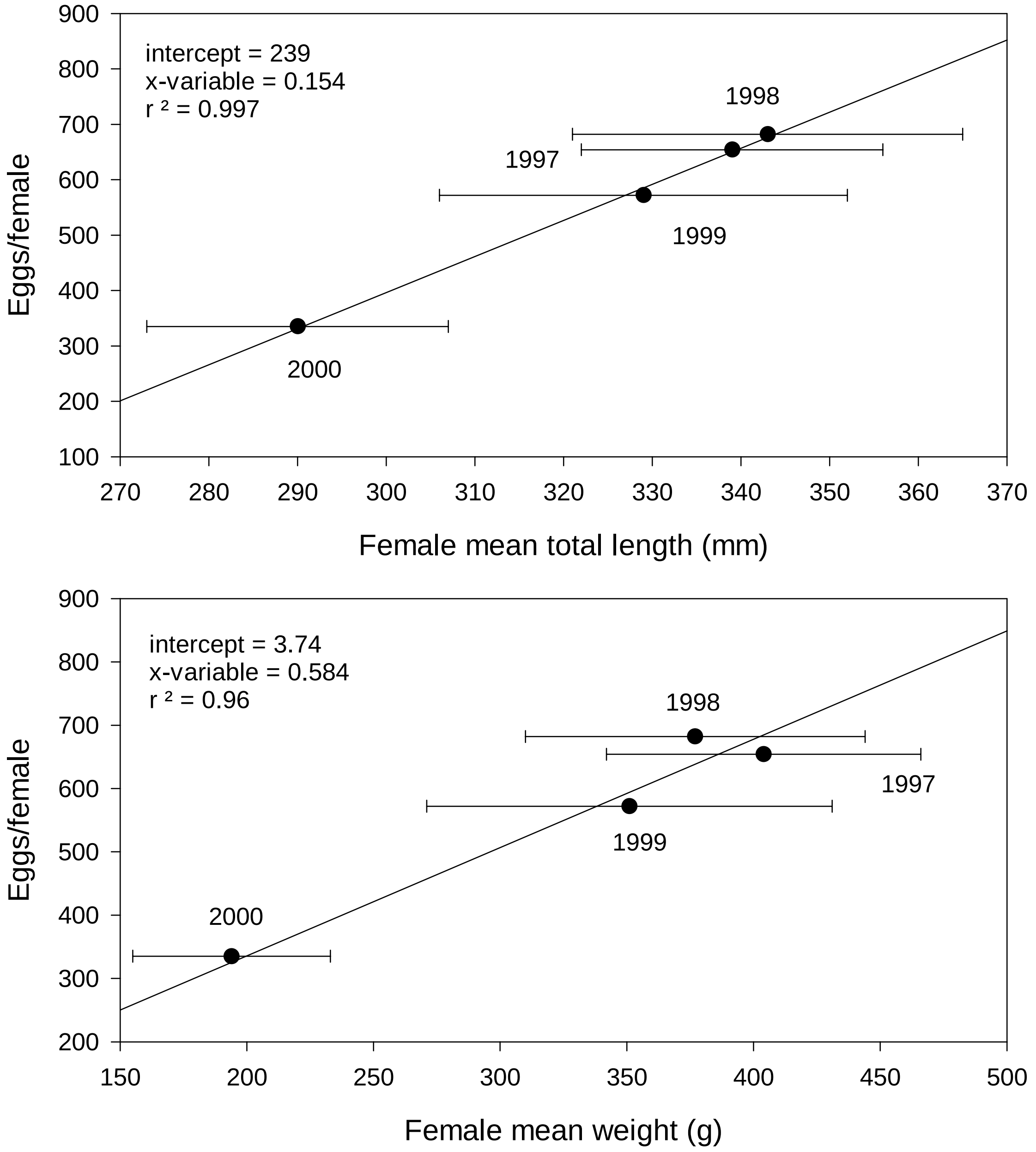

Figure 4.4. Relationship between average number of eggs-per-female and mean female spawner length (top panel) and weight (bottom panel) in Lake Billy Chinook. Error bars represent one standard deviation around measurement.

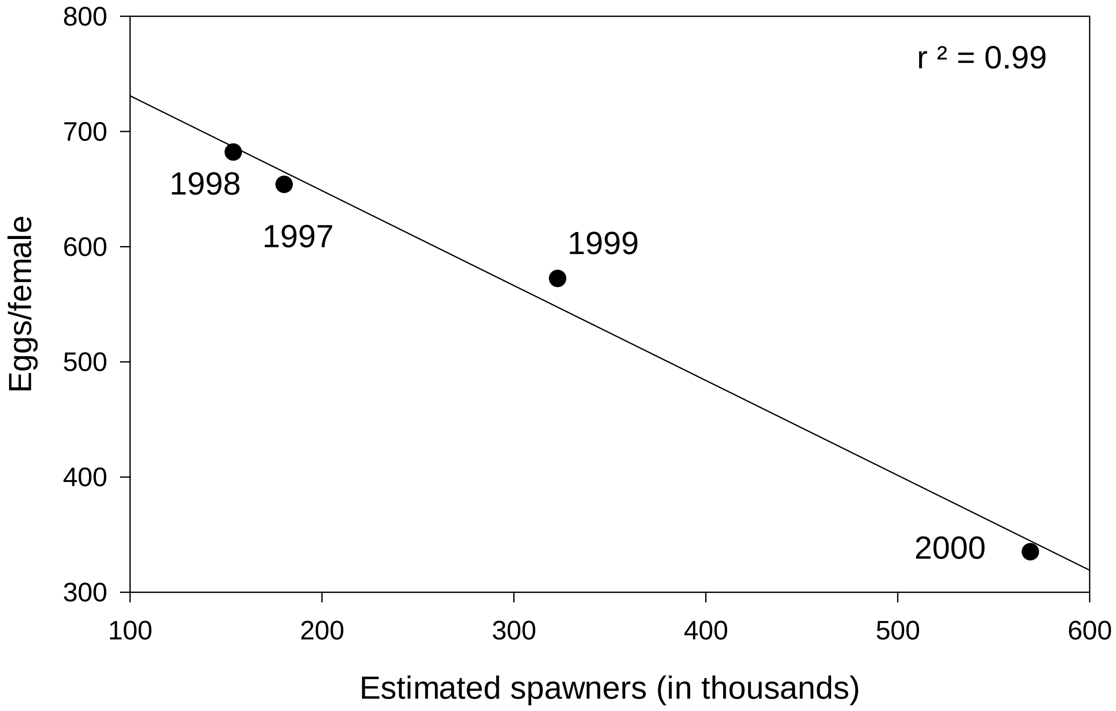

Figure 4.5. Relationship between estimated spawner abundance and average number of eggs-per-female in Lake Billy Chinook.

Density Dependent Trends

There are several theoretical functions used to explain possible spawner-recruit relationships: constant recruitment, recruitment proportional to stock, a density dependent curve with a descending right-hand limb (“Ricker” function), and an ever-increasing yet curved function (“Beverton and Holt”). The Ricker function demonstrates a pattern where the number of recruits or progeny increases up to a carrying capacity, then declines above some threshold number of spawners (Figure 4.6). Although only four years (BY 1996 to BY 1999) of spawner-recruit data are available for Lake Billy Chinook, this Ricker relationship appears to hold in the kokanee population. As numbers of spawners has increased since 1996, subsequent recruitment of age-0 kokanee into the reservoir has risen (up to nearly 3.5 million in BY 1998) then decreased (Figure 4.7). Taking the natural log of recruits-per-spawner (R/S) linearizes this data such that a Ricker function can be fit and evaluated based on a linear regression, demonstrating that recruits-per-spawner is negatively correlated with spawner abundance (adjusted $r^2 = 0.43$, $p = 0.036$; Figure 4.8).

Density dependence is any kind of change in growth, survival, or productivity that occurs at or above certain population levels. From 1996 to 2000 in Lake Billy Chinook, the declines seen in kokanee size, number of eggs-per-female, and age-0 survival as a function of increased spawner numbers and increased peak kokanee abundance may likely be due to density dependent effects. Further, density dependent effects may exacerbate other sources of mortality: food limitation, predation, entrainment, and disease.

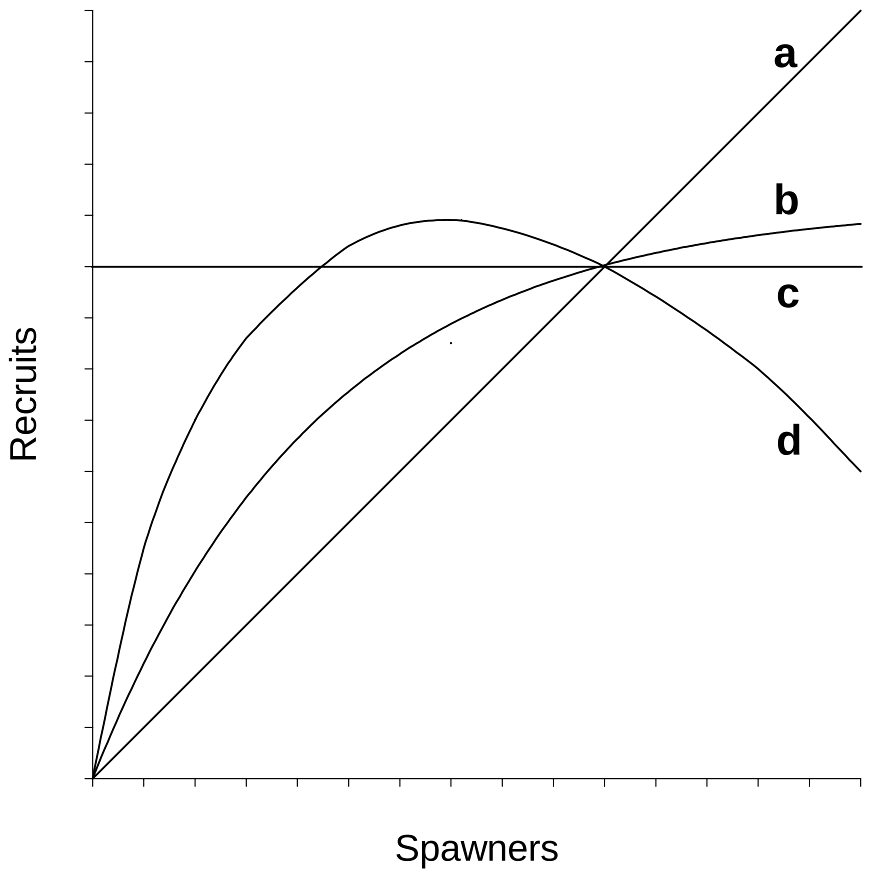

Figure 4.6. Theoretical relationships between spawners and recruits: (a) recruitment proportional to stock, (b) Beverton and Holt function, (c) constant recruitment, and (d) Ricker function.

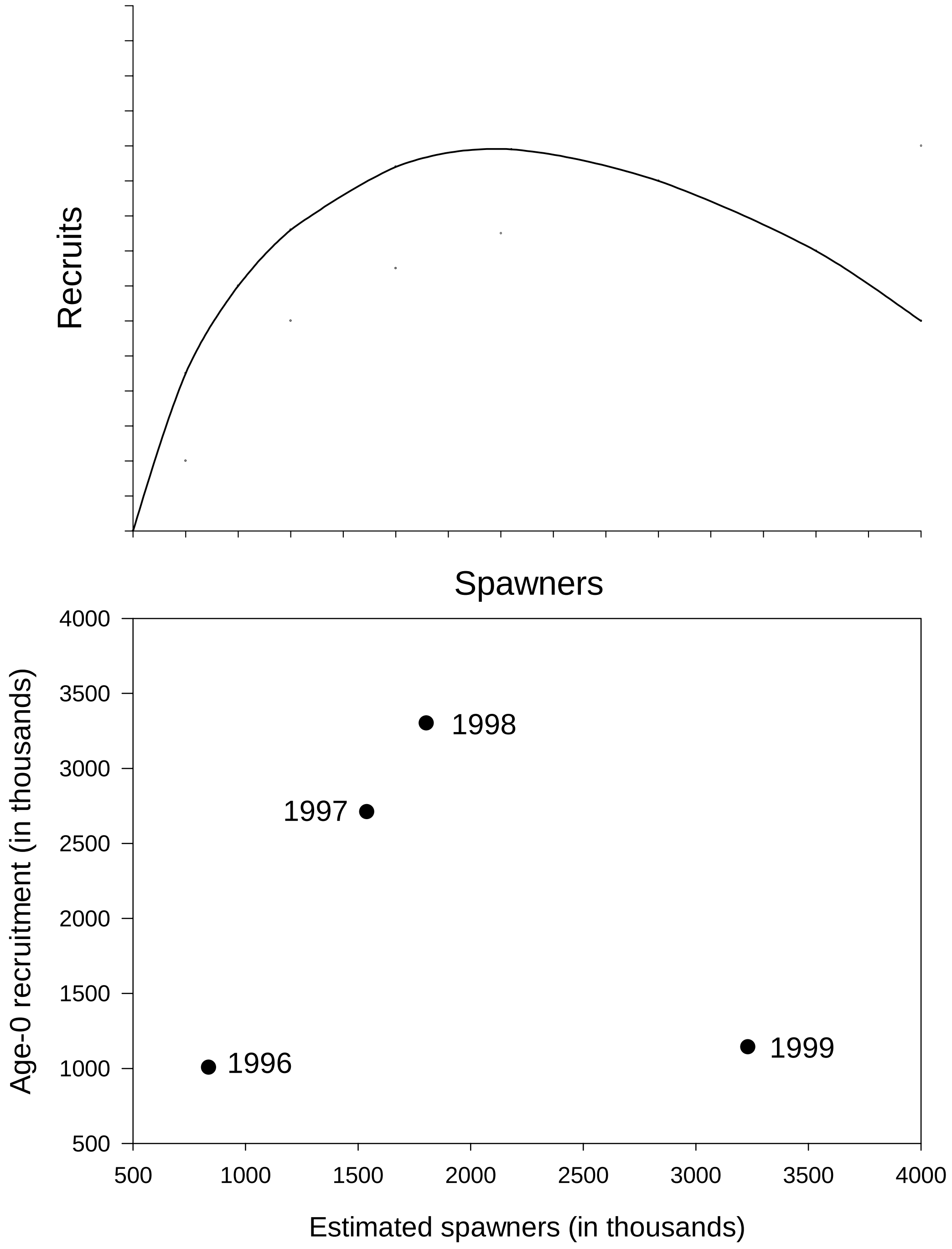

Figure 4.7. Relationship between spawners and recruitment. Top panel depicts theoretical Ricker stock-recruit function. Bottom panel shows relationship between spawners and recruitment (age-0 peak abundance, July) in Lake Billy Chinook, BY 1996 to BY 1999.

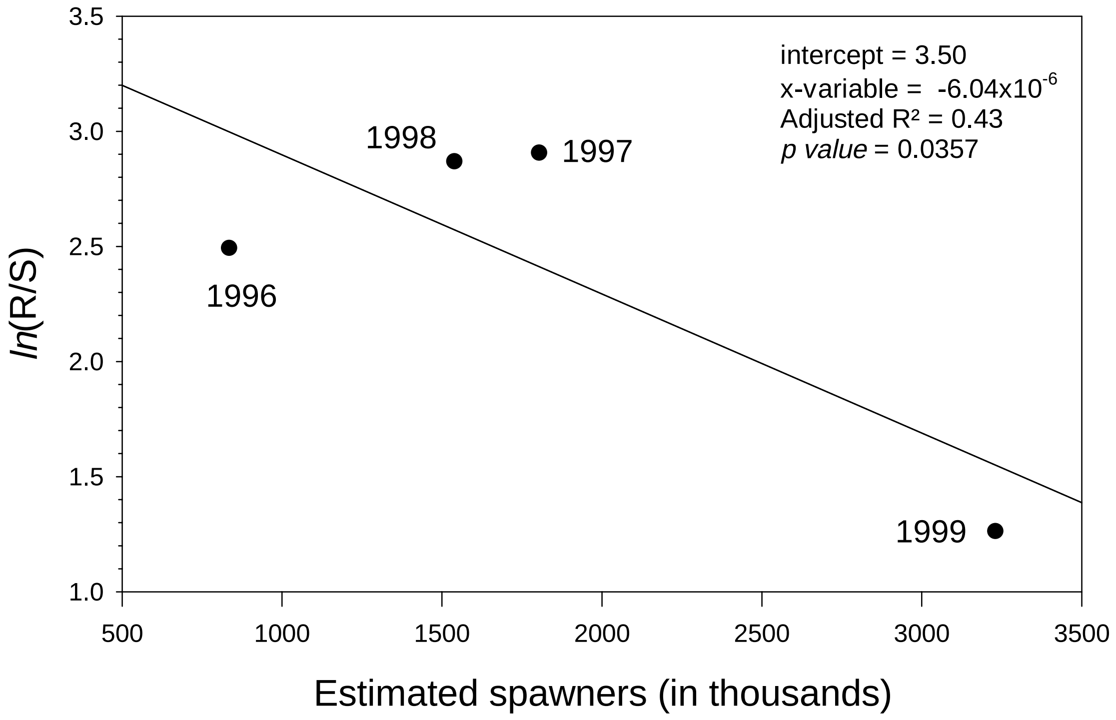

Figure 4.8. Relationship between spawners and production as ln(R/S) in Lake Billy Chinook, BY 1996 to BY 1999.

Kokanee losses

The relationship between spawner numbers and survival of subsequent recruits was highly variable over the study period. Survival of age-0 kokanee, measured from egg deposition to peak recruitment into the reservoir (by July each year), was highest in 1996 (7.4%) and decreased to 2.0% in 1999 (Figure 4.9). Age-0 survival was negatively correlated with spawner abundance from 1996 to 1999 ($r^2 = 0.95$). Estimated numbers of spawners reached an all time high in 2000, almost 570,000 spawning kokanee. If current trends continue, survival of age-0 kokanee into the summer of 2001 may be less than 2%.

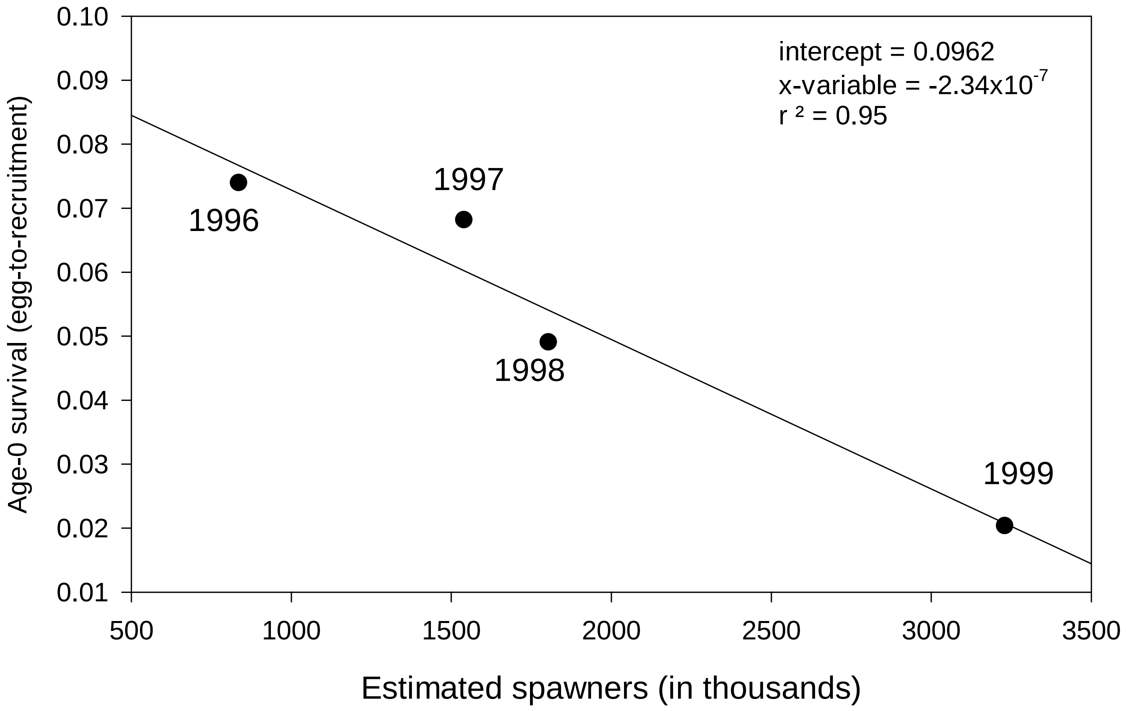

Figure 4.9. Relationship between estimated spawner abundance and age-0 kokanee survival in Lake Billy Chinook, BY 1996 to BY 1999.

Although highest rates of mortality for kokanee over these years occurred between egg deposition and recruitment to the reservoir, intense losses at this life stage are common in fish populations where natural mortality is high (Rieman 1992, Spaulding 1993, see Chapter 2). This mortality is likely due to a high degree of redd superimposition in the Metolius River basin (see Chapter 2, Thiesfeld et al. 1999). However, losses between age-0 and age-1 fish are quite variable, ranging from 60% to 92% in the reservoir from 1996 to 2000. Nearly 2 million of the 1997 brood kokanee (or 92% of this age class) were lost after recruitment to the reservoir (Figure 4.10). Although natural mortality may be common at this life stage, these mortality estimates appear high. Recruitment to the reservoir is defined here as the peak hydroacoustic-generated abundance in the reservoir, which occurs by July each year of the study. If recruitment of age-0 actually does not occur until later in the autumn, survival estimates would be considerably higher. Nonetheless, losses from July to October appear unusually high, especially in 1999 and 2000.

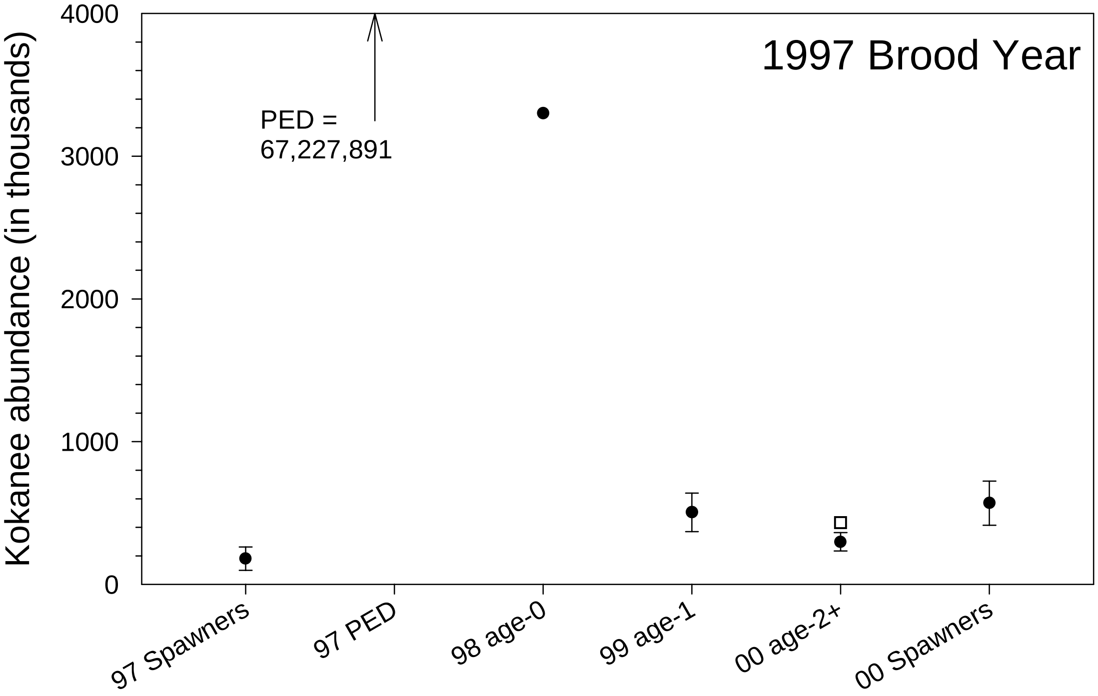

Figure 4.10. Abundance estimated by various methods for each life stage of 1997 brood year kokanee. Square denotes estimate with harvest added to acoustic estimate. Error bars represent 95% confidence intervals.

With increases in peak kokanee population abundance, total length attained by age-0 kokanee by autumn has decreased significantly over time ($r^2 = 0.91$, $p = 0.01$) (Figure 4.11). There are several explanations for this reduced growth, including temperature, food limitation, disease, and density dependence. Mean summer temperatures have remained fairly consistent in the reservoir and do not appear to explain this reduction in growth. Further, zooplankton densities, calculated as mean annual (May to October) number-per-m^3, have actually increased over the study period, 1997–2000. Yet in 2000, when zooplankton densities reached 25,806 zooplankters/m^3, age-0 kokanee only reached 111 mm TL by autumn. Conversely, when zooplankton densities were lowest (5,767/m^3), age-0 kokanee reached 158 mm TL (Figure 4.12).

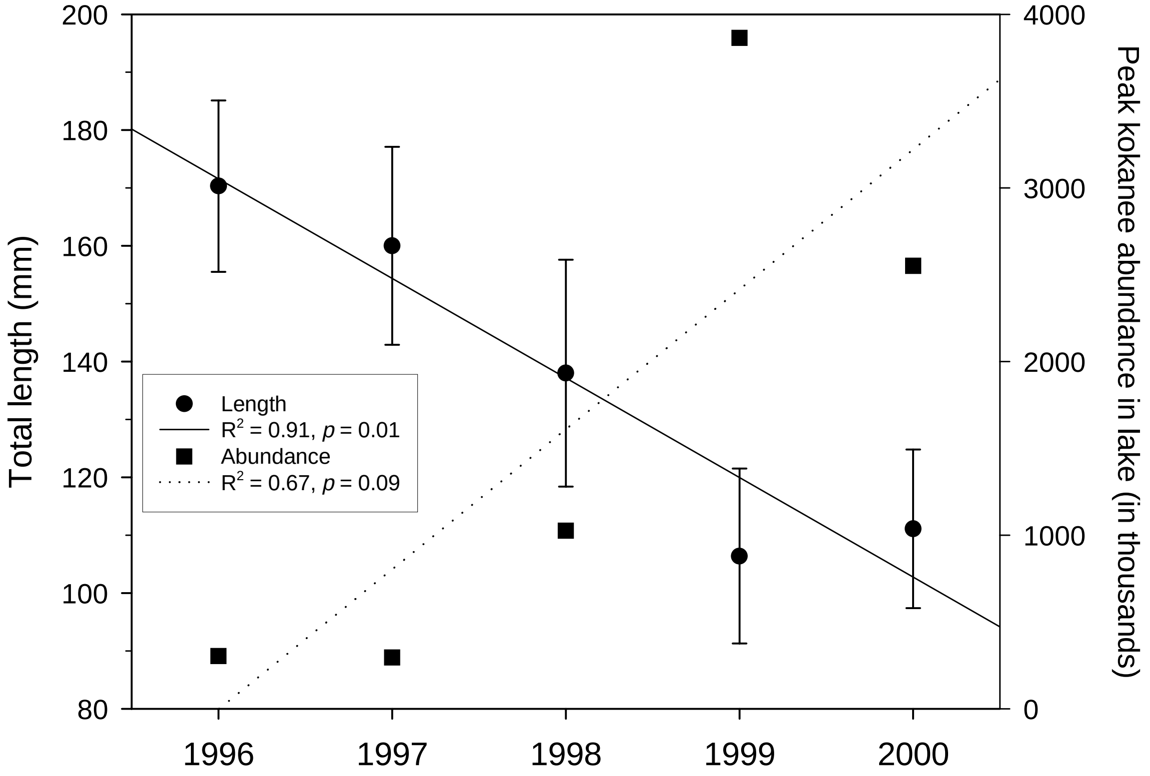

Figure 4.11. Mean total length (black dot) reached by age-0 kokanee by October 1996–2000 (left axis). Error bars depict one standard deviation. Peak kokanee abundance (black square; all age classes) obtained by hydroacoustic-generated estimates, 1996–2000 (right axis).

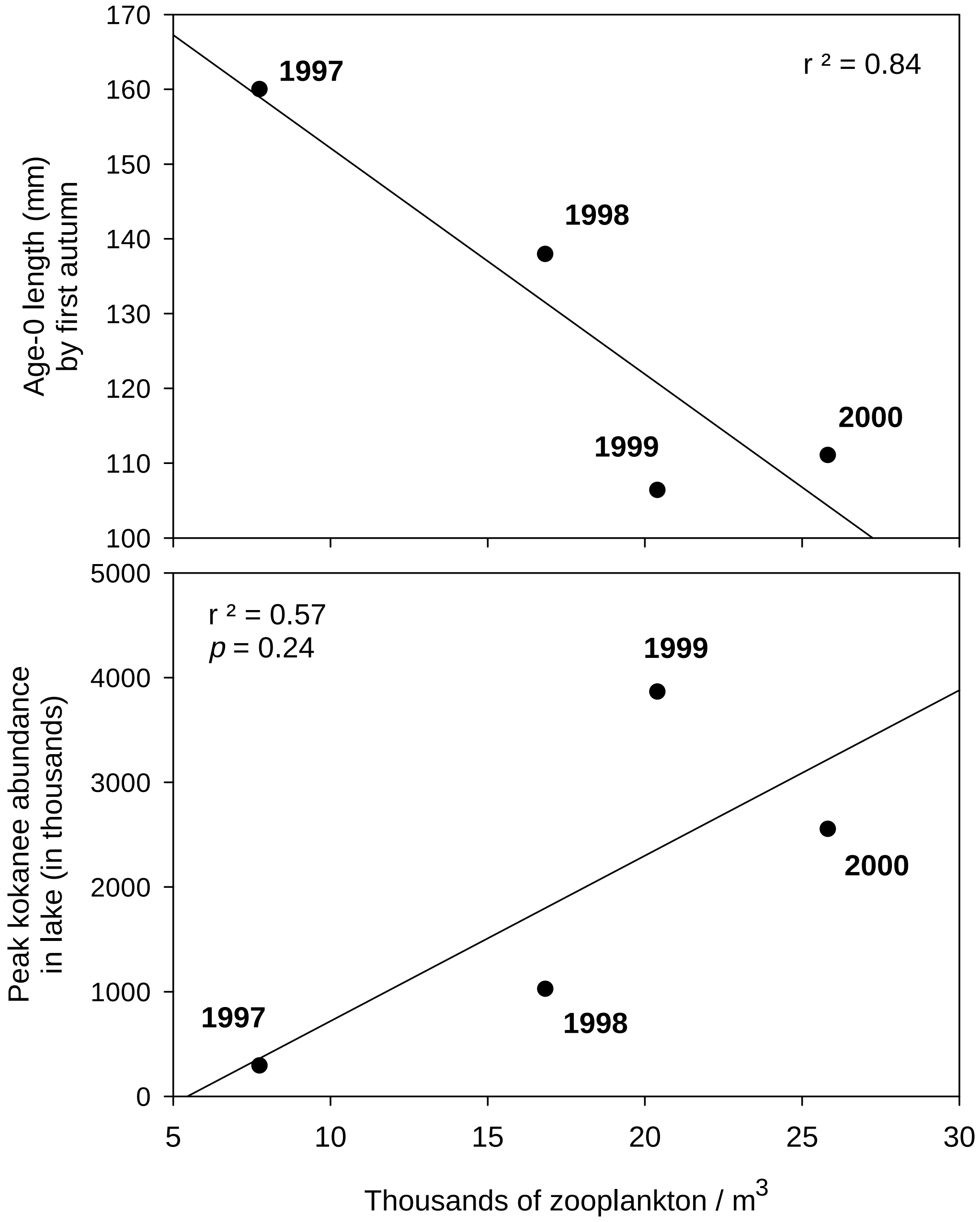

Figure 4.12. Relationship of mean length (mm TL) attained by age-0 kokanee by October and average annual (May to October) zooplankton densities in Lake Billy Chinook, 1996–2000 (top panel). Relationship between peak kokanee abundance (all age classes) and zooplankton density (bottom panel) in Lake Billy Chinook, 1996–2000.

The Future

The kokanee population in Lake Billy Chinook has undergone pronounced cycles. Density dependent effects may explain these observed cycles and fluctuations in kokanee abundance. High rates of mortality for kokanee between age-0 and age-1 are discussed further in Chapter 2. Food limitation, predation, entrainment, and disease have all been proposed as possible sources of loss or mortality. While the key sources of mortality are difficult to isolate, many factors may contribute to mortality with combined or additive effects from density dependence. Also, none of these mortality factors is constant. For instance, during high water events in 1996 and 1997, numbers of kokanee moving out of Lake Billy Chinook through Round Butte Dam were very high (Ratliff and Schulz 1999). In turn, bull trout in the reservoir had reduced condition factor in 1997 and 1998 (Thiesfeld et al. 1999) and reduced bull trout survival was indicated by lower bull trout redd counts during those years compared to the previous four years (Figure 4.13). It appears that higher kokanee survival after 1997 (no high flows, lower kokanee densities, fewer bull trout) allowed for dramatic increases in kokanee numbers to the highest estimated levels of both harvest and spawning in 2000 (*see* Tables 2.6 and 3.2). Following the increase in prey base, bull trout redd counts also showed record numbers in 2000 (Figure 4.13). If bull trout numbers continue to increase, the additional predation on kokanee may lead to significant mortality (Beauchamp and Van Tassel 2001), reducing kokanee numbers and adding to the cyclic nature of both kokanee and bull trout populations.

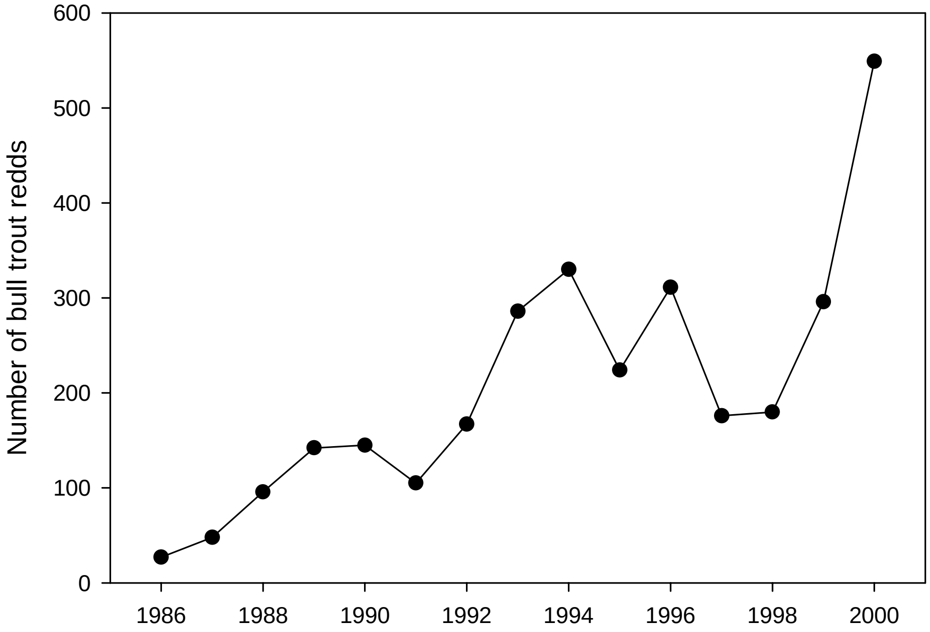

Figure 4.13. Number of bull trout redds counted in the Metolius River, 1986–2000 (Unpublished data from ODFW).

Basic limnological changes are likely to occur in Lake Billy Chinook with the proposed reestablishment of fish passage at Round Butte Dam as a part of the new federal license to operate the Pelton Round Butte Hydroelectric Project (PGE and CTWS 2001). Three-dimensional hydrodynamic modeling of reservoir water currents has indicated that surface withdrawal of generation water is necessary to create surface attraction currents (Yang et al. 2000) that will allow anadromous salmonid smolts to orient to the outlet and emigrate from Lake Billy Chinook (Zabel et al. 1999). Under the current condition, generation water is withdrawn from a depth of 73 m. The bulk of the reservoir is filled down to that depth with water from the Crooked and Deschutes rivers, which is warmer, and thus less dense, than water from the Metolius River. With the proposed new facility and operating procedure, water will be withdrawn from the surface during the winter and spring. Since warmer water from the Crooked and Deschutes rivers will be withdrawn from the surface, the reservoir will essentially be filled from the bottom with colder, denser Metolius River water. The result will be a reservoir that will have a mean spring temperature several degrees cooler than at present (Yang et al. 2000; Khangaonkar et al. 2002). It is difficult to predict what will happen to zooplankton and *O. nerka* production. However, if the future limnology of the Crooked and Deschutes river arms of the reservoir is more like the present Metolius River arm, production should increase (*see* Figures 2.22 and 2.23 comparing zooplankton densities).

As part of the plan to provide safe fish passage, the generation water will be screened, preventing entrainment losses and, feasibly, juvenile *O. nerka* attempting to emigrate from the surface will be passed safely downstream. Kokanee living at depth in the forebay during winter and early spring will no longer be lost. This change has the potential to significantly reduce juvenile mortality, increasing the density of young *O. nerka* in the reservoir.

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