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Prepared for the U.S. Army Corps of Engineers, Portland District, under a Government Order with the U.S. Department of Energy Contract DE-AC05-76RL01830

Hydroacoustic Estimates of Fish Density Distributions in Cougar Reservoir, 2011

Final Report

GR Ploskey
SA Zimmerman
MJ Hennen
GW Batten
TD Mitchell

September 2012

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Pacific Northwest National Laboratory
Richland, Washington 99352

Preface

This study was conducted by the Pacific Northwest National Laboratory (PNNL) for the U.S. Army Corps of Engineers, Portland District (USACE). The PNNL project manager was Mr. Gene Ploskey. The USACE technical lead was Scott Fielding and later David Griffith.

The study was designed to assess the density distributions of fish in Cougar Reservoir monthly from April through December 2012.

This report should be cited as follows:

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Executive Summary

The 2008 Willamette Project Biological Opinion requires improvements to operations and structures to reduce impacts on Upper Willamette River Chinook salmon and steelhead, including evaluations of the feasibility of installing new juvenile collection and bypass facilities at three dams on the Willamette River in Oregon: Cougar, Detroit, and Lookout Point dams. Understanding the distribution of juvenile salmonids in the reservoirs will be critical for the development and operation of structures to pass fish safely and efficiently. This report describes results of mobile hydroacoustic surveys of fish distributions in Cougar Reservoir, a 518-ha impoundment behind Cougar Dam on the South Fork of the McKenzie River near Blue River, Oregon.

Day and night mobile hydroacoustic surveys of Cougar Reservoir were conducted once a month from April through December 2011 to quantify the horizontal and vertical distributions of fish. An inflatable pontoon raft, outfitted with a frame holding four 6° split-beam transducers and a global positioning system, was pushed about 4 m ahead of the survey vessel to minimize fish avoidance of the bow wave and boat and maximize detectability. In November and December, transducers were deployed from the front of a pontoon boat with similar results. Two hydroacoustic systems were used to acquire echo trace data to estimate densities at night and during the day. A Precision Acoustic System transceiver controlled three forward-looking split-beams aimed 4°, 11°, and 18° below horizontal to sample fish in three respective depth strata (0−2, 2−4, and 4−6 m) 12.9−15.6 m ahead of the raft. A BioSonics DT-X system controlled one split-beam transducer aimed 10° forward from vertical to sample fish in 2-m strata from 6 to 62 m deep.

The length of the smallest fish that could be detected with the -56 dB threshold was about 35 mm, but given the narrowness of acoustic beams for detecting fish <-53 dB, we only had reasonable detectability for fish >-53 dB (about 50 mm long). We estimated the areal density of fish (fish/hectare) and total numbers of fish in two length classes (50 to 200 mm, and > 200 mm) for the entire reservoir and five reservoir zones by month, and plotted densities on maps of the reservoir for every month surveyed. Surveys were scheduled to coincide with U.S. Geological Survey (USGS) Lampara seine sampling of pelagic areas and Oregon Department of Fish and Wildlife (ODFW) trap-net sampling of littoral areas to obtain concurrent species composition data.

Hydroacoustic estimates of fish densities in pelagic areas were low, as were Lampara seine catches (39 fish in 353 hauls over 9 months; 31 [79.5%] of which were Chinook salmon). Given low catches in the Lampara net, species composition information for pelagic areas was not as robust as that derived from trap netting in littoral areas. The ODFW trap nets caught 1072 fish in 35 trap-net nights over 8 months, and the species composition was 69.2% dace, 24.3% Chinook salmon smolts, 3.6% rainbow trout, and 2.9% cutthroat trout. The smallest dace captured was about 35 mm long. For two time periods (April through August and September through December), we calculated the fraction of fish that were Chinook salmon and its variance from trap net data collected in near-shore areas by the ODFW (within about 30 m of shore) and from USGS Lampara netting data for offshore areas. Those estimates were used with hydroacoustic estimates of the density of 50−200 mm long fish in near-shore and offshore areas and the number of hectares of those two habitats to generate Chinook salmon population estimates and 95% confidence intervals by reservoir zone and month and by month over a 9-month period. According to a paired t-test that had 3645 pairs of day and night samples of fish density in 1-ha cells in the lake, day and night density estimates did not differ significantly. In addition, hydroacoustic estimates of fish density for day and night surveys did not differ significantly in any month for fish 50 to 200 mm long and in 8 out of 9 months for fish >200 mm long. Therefore, we pooled day and night samples to estimate the monthly density of fish in each length class. We plotted composite vertical distributions across months for day and night surveys based on all detected fish and plotted specific vertical distributions that deviated significantly from the composite vertical distributions. Low hydroacoustic density estimates in spring and summer months provided insufficient numbers to obtain robust vertical distribution information for each month.

The highest densities and total numbers of fish 50−200 mm long were measured in December (130.6 ± 8.1 fish/ha[1]; 33037 ± 4013 fish). December estimates of Chinook salmon densities and total numbers were (94.1 ± 9.3 fish/ha; 23797 ± 2363 fish). Densities likely were higher in fall drawdown months than they were from April through August, because fish were larger, more detectable by hydroacoustics, and concentrated by fall drawdown than they were in earlier months. Reservoir volume was inversely correlated with density and total numbers of fish 50−200 mm long, and it was inversely correlated with juvenile Chinook salmon densities and numbers. Volume was the best predictor of densities, but many other environmental variables were highly correlated with volume (e.g., elevation, area, day hours, night hours, Julian day, and month).

If one accepts the premise that there are relatively low densities of fish in Cougar Reservoir, then there are potentially important implications for management decisions to build a downstream collection facility at Cougar Dam. Arguments for or against a downstream passage collector probably depend on the carrying capacity of the reservoir rather than the standing stock that can be estimated at any particular time.

Repeated monthly surveys at Cougar Reservoir provided insight into productive hydroacoustic survey strategies, if additional information is desired for other Willamette Basin reservoirs. Hydroacoustic surveys were clearly most effective after drawdown concentrated the fish and limited their access to headwater areas that are difficult to survey. Consequently, conducting a single monthly survey in late fall or early winter appears to be the most cost-effective and productive strategy for hydroacoustic sampling of flood-control impoundments like Cougar Reservoir that have large pool changes during the year. Focusing survey efforts in a single month would allow many Willamette Basin reservoirs to be sampled within days or weeks of one another using the same equipment. This approach would allow estimates of fish densities and total numbers to be compared among many surveyed reservoirs with no more cost than was required to conduct the 9-month-long study at Cougar Reservoir in 2011.

[1] ± ½ 95% confidence interval

Acknowledgments

This study was the result of hard work by dedicated scientists from the Pacific Northwest National Laboratory (PNNL), Pacific States Marine Fisheries Commission (PSMFC), and the U.S. Army Corps of Engineers, Portland District (USACE). Their teamwork and attention to detail, schedule, and budget were essential for the study to succeed in providing high-quality, timely results to decision-makers.

- USACE: Willamette Valley Project Biologists − Chad Helms, Gregory Taylor, Doug Garletts
  Portland District − Scott Fielding, David Griffith
- USGS: Amy Bratz, Collin Smith, Philip Haner, Matthew Sholtis, Dana Shurtleff, John Beeman
- ODFW: Fred Monzyk and his team
- Confederated Tribes of Warm Springs Oregon: Jeffrey Hogle and their Aquacoustic, Inc. contractors: Anna-Maria Mueller and Donald Degan provided a technical report describing mobile hydroacoustic survey results for Lake Billy Chinook.

Acronyms and Abbreviations

°	degrees (angular)
°C	degree(s) Celsius
ANOVA	analysis of variance
BRZ	boat-restricted zone
cm	centimeter(s)
dB	decibels
DT-X	name of the BioSonics transceiver and transducer system
EBA	effective beam angle
ESA	Endangered Species Act
GPS	global positioning system
h	hour(s)
ha	hectares
km	kilometer(s)
kHz	kilohertz
L	liter(s)
m	meter(s)
mm	millimeter(s)
m/s	meter(s) per second
msl	mean sea level
NMFS	National Marine Fisheries Service
NTU	Nephelometric Turbidity Unit(s)
ODFW	Oregon Department of Fish and Wildlife
µPa	micropascals(s)
PAS	Precision Acoustic Systems
pps	pings per second
PNNL	Pacific Northwest National Laboratory
RM&E	research, monitoring, and evaluation
RPA	Reasonable and Prudent Alternative
µs	microsecond(s)
s	second(s)
TS	target strength
USFWS	U.S. Fish and Wildlife Service
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey
$\widehat{Var}$	estimated variance
WP	Willamette Project

Contents

Figures

Tables

1.0 Introduction

The 2008 Willamette Project (WP) Biological Opinion by the National Marine Fisheries Service (NMFS 2008) requires improvements of operations and structures to reduce impacts on Upper Willamette River Chinook and Upper Willamette River steelhead. Included in the Opinion are requirements for evaluations of the feasibility of installing new juvenile collection and bypass facilities at three WP dams: Cougar, Detroit, and Lookout Point. As a part of these evaluations, the NMFS and the U.S. Fish and Wildlife Service (USFWS) have required that the U.S. Army Corps of Engineers (USACE) develop interim operations and investigate the feasibility of using surface flow outlets or other structures to collect and convey juvenile salmonids past each dam to provide safe passage for downstream-migrating fish. An understanding of when, where, and how juvenile salmonids are distributed in WP reservoirs is important for fisheries managers and the USACE to use to develop operations and structures that collect and pass juvenile salmonids safely and efficiently. Basic information that characterizes juvenile salmonid temporal and spatial distributions in all reservoirs, including forebay areas, is needed for USACE dams in the Willamette Basin (Figure 1.1). The priority projects for research on juvenile salmonid passage, in order from highest to lowest, are Cougar Dam, Detroit Dam, and Lookout Point Dam (NMFS 2008). The evaluation reported herein focuses on Cougar Dam and its reservoir.

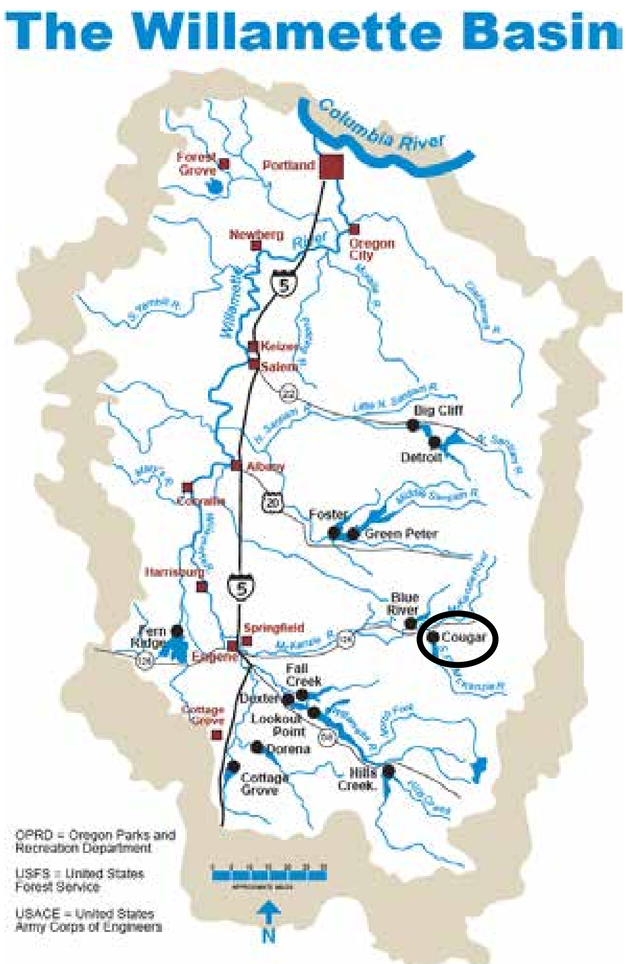

Figure 1.1. Map of the Willamette Basin (USACE Portland District Brochure 2005) with a Black Ellipse around Cougar Reservoir

The USACE Portland District contracted with the Pacific Northwest National Laboratory (PNNL) to conduct mobile hydroacoustic surveys of fish in Cougar Reservoir in 2011. The District also contracted with U.S. Geological Survey (USGS) to conduct acoustic telemetry studies of juvenile Chinook salmon in Cougar Reservoir in 2011. The USGS used a Lampara seine to target juvenile Chinook salmon for tagging, and timed sampling to coincide with most hydroacoustic surveys to provide concurrent species composition data from their total catch so that PNNL could estimate the percent of juvenile Chinook salmon in offshore areas. The USGS also assisted the hydroacoustic survey effort by supplying a survey boat and operator for spring and most summer surveys. The Oregon Department of Fish and Wildlife (ODFW) supplied trap-net data that the PNNL team used to estimate the percent of juvenile Chinook salmon in near-shore areas.

This project is relevant to the 2008 Willamette Project Biological Opinion (NMFS 2008), Reasonable and Prudent Alternative (RPA) 9.3 – Fish Passage Research, Monitoring, and Evaluation (RM&E): "*Develop and carry out RM&E to determine the most effective and efficient means to accomplish safe adult and juvenile fish passage at applicable Willamette Valley Project dams. Specifically, determine downstream fish passage timing through Willamette Valley Project dams.*"

Understanding the spatial and temporal distributions of juvenile salmonids in the reservoir of Cougar Dam will provide critical information to assist in the design of effective long-term fish passage solutions at the dam and elsewhere in the Willamette Basin. Such data will help engineers and biologists decide where to place bypass structures and when to operate them. The data also will serve as baseline information with which post-construction monitoring data can be compared to assess the relative changes and performance of the passage structures. Lessons learned and biological findings at Cougar Dam will be considered for application at other WP dams.

1.1 Reservoir Description

At full pool elevation, Cougar Reservoir is a 518-ha impoundment on the South Fork of the McKenzie River near Blue River, Oregon (Figures 1.1 and 1.2). The reservoir was created in 1963 after the completion of Cougar Dam, a rock-fill hydropower dam that also provides for flood control. The reservoir fluctuates between a low elevation of 466.9 m above mean sea level (msl) that may occur in late fall or winter to a high of about 517.8 m above msl sometime in summer—a total seasonal fluctuation of about 50.9 m. We defined five reservoir zones for describing results: the boat restricted zone (BRZ), the confluence, the east arm, the middle reservoir, and the upper reservoir (Figure 1.2). The deepest areas of the reservoir are in the BRZ and confluence zone; the east arm and upper reservoir have the most area of shallow water when the impoundment is near full pool, but those zones were nearly drained by the pool drawdown in fall. Water is released from the reservoir either through turbines or regulating outlets that have intake structures inside a water control tower located in the northwest corner of the BRZ.

1.2 Goal

The goal of this study was to provide information about juvenile salmonid distribution in the reservoir of Cougar Dam to support decisions on long-term measures and operations to achieve acceptable passage conditions at the dam for Endangered Species Act (ESA)-listed species of fish (NMFS 2008).

1.3 Objectives

Objectives of this hydroacoustic study of Cougar Reservoir from April through December 31, 2011 were to do the following:

1. Estimate the vertical and horizontal distributions of fish in Cougar Reservoir.
2. Evaluate temporal changes in the abundance of fish and juvenile Chinook salmon in Cougar Reservoir.
3. Quantify ambient environmental conditions, and relate them to fish density and the density of juvenile Chinook salmon smolts.

Figure 1.2. Map of Cougar Reservoir Showing Five Zones (right) and a Zoomed Image of the BRZ (left). The background image was from Google Earth.

2.0 Methods

Mobile hydroacoustic methods (Simmonds and MacLennan 2005) were used to sample fish throughout Cougar Reservoir monthly from April through December. The survey team conducted a full survey of the reservoir (when full) during the day and again at night each month except April, when a combination of snow and vessel engine problems limited sampling to a single survey of the entire reservoir that pooled day and night samples. The general approach, hydroacoustic equipment, survey design, data analysis, and related methods are described in the following sections.

2.1 General Approach

Two hydroacoustic transceiver systems were operated simultaneously to control the split-beam transducers used to detect fish during mobile surveys (Figure 2.1). A Precision Acoustic System (PAS) controlled three 6° forward-looking split-beams aimed 4°, 11°, and 18° below horizontal to sample fish 12.9−15.7 m ahead of the transducers in three respective depth zones (0−2, 2−4, and 4−6 m). Transducers were deployed from the front of a shallow draft raft that was pushed by a boat or from the front of a pontoon boat (Figure 2.2). The pontoon devices were used to minimize the bow wave ahead of the survey vessel that might illicit an avoidance response by fish swimming near the water's surface. A BioSonics DT-X system controlled one 7° circular split-beam that was aimed 10° forward from vertical to sample fish from 6 to 62 m deep. For display of vertical distributions, depths were divided into 2-m strata named according to the midpoint depth in meters (i.e., depths 0−2 = 1, 2−4 = 3, … 60−62 = 61). The forward-looking acoustic beams sampled fish in the upper 6 m of the water column that could not be effectively sampled with a down-looking transducer whose beam was too narrow at short range. A battery-powered Trimble GPS Pathfinder® ProXT™ global positioning system (GPS) with an external Hurricane antenna provided sub-meter accuracy position coordinates and highly accurate time data that were fed into the BioSonics data stream. During post-processing, the PAS fish-detection data were time synchronized with the BioSonics data stream.

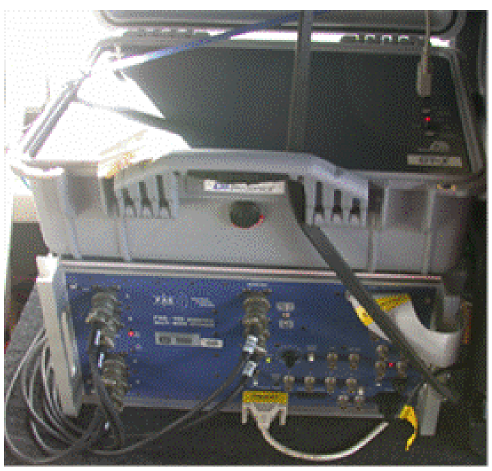

Figure 2.1. Picture of Two Transceivers used to Control Hydroacoustic Transducers for Acoustically d-Detecting Fish in Cougar Reservoir. The upper transceiver was a BioSonics DT-X that controlled one **7**°, circular, 420-kHz, split-beam transducer. The lower transceiver was a PAS Model 103 that controlled three 6° 420-kHz split-beam transducers.

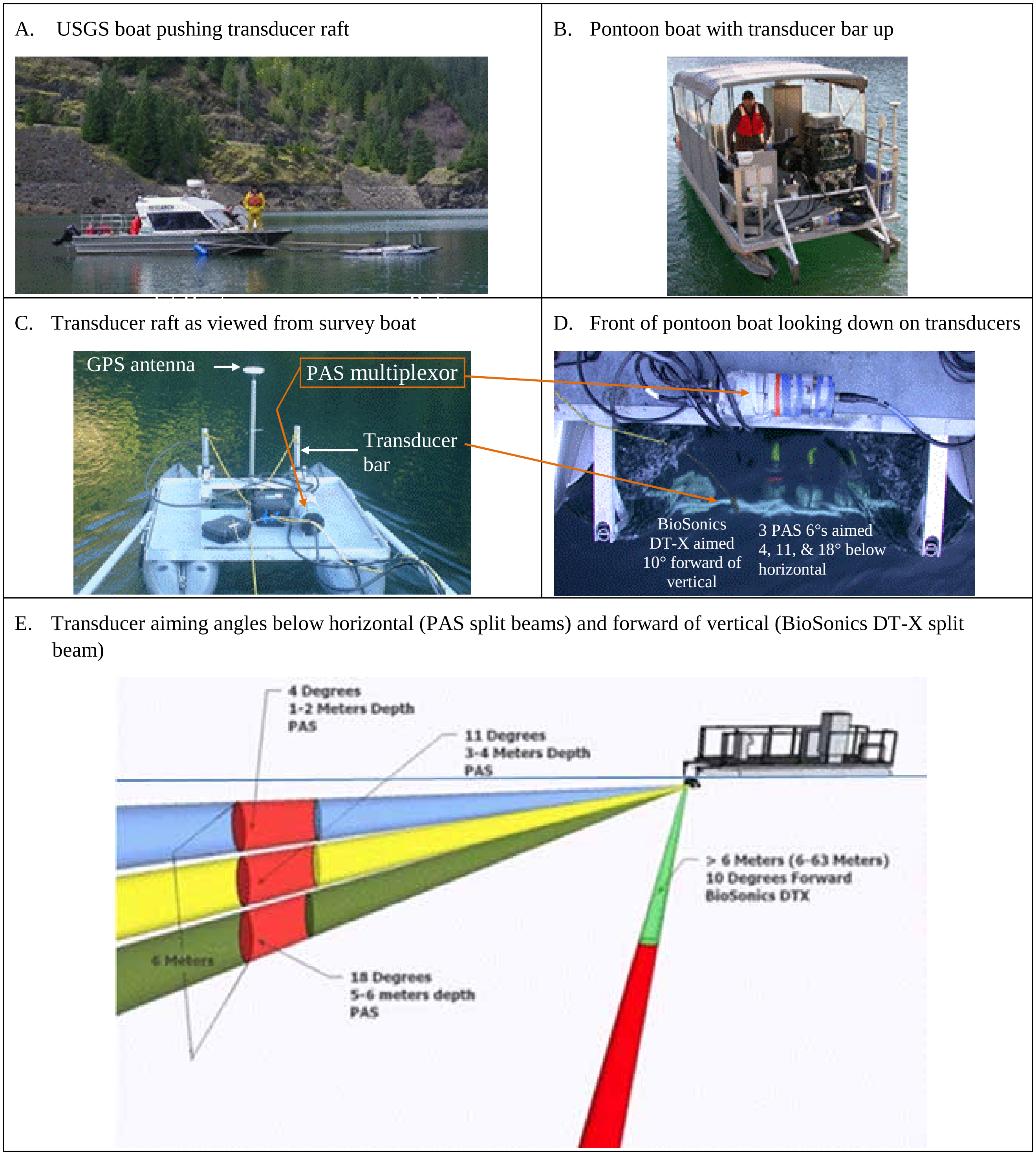

Figure 2.2. Pictures of the Acoustic Sampling Platforms (Panels A−D) used to Survey Fish Distributions in Cougar Reservoir in 2011. Panel E shows a scaled diagram of transducer aiming angles and ensonified acoustic volumes. Red sections of conical beams were the volumes in which fish were counted. Only the first 9 m (out of 56 m) of fish-counting volume is illustrated for the down-looking acoustic beam.

The typical first day of a survey each month involved sampling transects from the BRZ through the east arm before dark, and from the east arm through the BRZ after dark (Figure 2.3), although start and end locations were occasionally reversed. Transects locations were designed to ensure that most of the 1-ha cells in reservoir zones would be sampled. By design, the density of transects was highest in the BRZ. The typical second day involved sampling transects starting in the middle of the confluence zone south toward the upper end of the reservoir before dark, and sampling from the upper end to the confluence again after dark. When the reservoir was full, transects totaled 23 km and required about 8 h to survey. When the pool was rising in April and May, rafts of floating timber and debris had to be avoided and survey times exceeded 8 h. In fall, the pool was lower each successive month and the time required for a full survey was <30% of the time required for full-pool surveys. Areal density and vertical distributions are summarized for the entire reservoir and five zones (Figure 2.3).

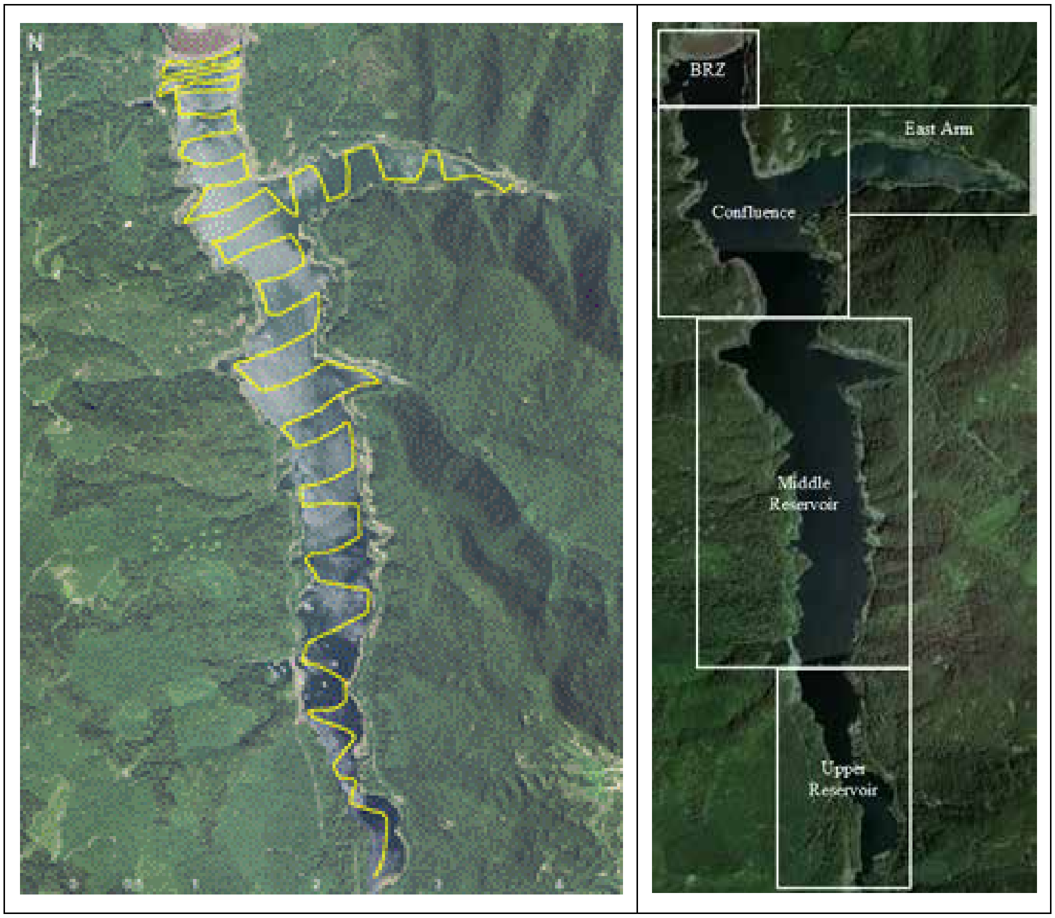

Figure 2.3. Images of Cougar Reservoir Showing Transects Sampled during Mobile Hydroacoustic Surveys (left) and Analysis Zones (right). The dam is at the top of the images.

2.2 Calibrations

BioSonics, Inc., Seattle, Washington, calibrated the DT-X transceiver, cable, and split-beam transducer and provided estimates of source level (218.77 dB || µPa at 1 m), receiver sensitivity (-55.50 dB counts || µPa), beam pattern plots, and beam pattern factors (BPFs). A post-study calibration of the same system provided similar estimates of source level and receiver sensitivity (source level = 218.72 dB and receiver sensitivity = -56.5 dB counts || µPa). The PAS transceiver, cables, multiplexor, and three split-beam transducers were calibrated by PAS, Seattle, Washington (Table 2.1). The hydroacoustic study team verified expected target strengths (TSs) of about -39.5 dB from both systems and every associated transducer by ensonifying a ping pong ball suspended in a 7.3-m-long, 3.7-m-wide, and 1.8-m-deep tank of water. Transducers from each system were mounted in a highly precise rotator about 5 m from the suspended ping pong ball. Results indicated that TS varied <1 dB from the average TS across the acoustic axis of each transducer in both the x and y planes of rotation. The average TS of the ensonified ping pong ball was -39.9 dB for Transducer 415; -39.5 dB for Transducer 418; and -39.8 dB for Transducer 428), and pre- and post-season averages were within 1 dB of each other. The final detection threshold for processing echoes was -56 dB referenced to 1 µPa at 1 m for on-axis fish, which is roughly equivalent to a 35-mm-long fish according to the any-aspect equation of Love (1977). Fine woody debris suspended in the water column, particularly during the pool refill period (April and May) had TSs between -60 and -56 dB, and influenced our choice of a detection threshold because we did not want to inflate counts with non-fish targets. Given the narrowness of the acoustic beam angles for small targets with TS between -56 and -53 dB, we assumed that the systems only had reasonable detectability for fish TS ≥-53 dB (about 50 mm long) where calculated beam angle was at least 4.5° (PAS) or 5° (DT-X). We transmitted a 200-µs pulse on the DT-X system every 7 s (nominal ping rate) and accepted echoes that ranged from 100 to 600 µs in duration from depths of 6 to 62 m. We transmitted a 70-µs pulse at 30 pings per second (pps) (i.e., 10 pps from each of the three fast multiplexed PAS transducers) and accepted echoes that ranged from 0.35 to 210 µs.

Table 2.1. Calibration Data and Calculated Receiver Gains for the Three PAS Split-beam Transducers used to Acoustically Detect Fish in the Upper Water Column in Three 2-m Strata Named by Midpoint Depth (1 m, 3 m, and 5 m). Receiver gains were adjusted to provide equal output voltages for on-axis targets ranging in acoustic size from –56 to –26 dB. Results for split-beam transducers are presented for the x phase, y phase, and the mean of x and y phases.

Echo-Sounder Number and Channel Number	Transducer Number and Phase	Receiver Gain (dB)	Source Level (dB)	Receiver Sensitivity (dB)	Target Strength of Smallest On-Axis Target (dB)	Voltage of Smallest On-Axis Target (dB)
24-00	415 (x)	2.97	215.79	-102.77	-56	60
24-00	415 (y)	3.03	215.73	-102.77	-56	60
24-00	415 mean	3.00	215.76	-102.77	-56	60
24-01	418 (x)	2.68	217.44	-104.12	-56	60
24-01	418 (y)	2.65	217.47	-104.12	-56	60
24-01	418 mean	2.67	217.46	-104.12	-56	60
24-02	428 (x)	3.92	216.10	-104.02	-56	60
24-02	428 (y)	3.99	216.03	-104.02	-56	60
24-02	428 mean	3.95	216.07	-104.02	-56	60

2.3 Fish Tracking

Tracking of fish in BioSonics DT4 echogram files was done in EchoView 5.0, and tracking of PAS echograms was done using PNNL Tracker software Version 2.02. A series of echoes (each >-56 dB threshold) were selected and tracked as a fish if there were four or more echoes in a distinct linear or curvilinear pattern and the echo trace contained a core series of four echoes in five consecutive pings. Echo traces were manually selected using a mouse, and upon selection, processing software wrote out trace statistics to a tracked fish file on a hard disk. Tracked fish statistics included variables like transducer, channel, latitude, longitude, date, time (to the nearest second), start ping, end ping, number of pings, number of echoes, start range, end range, mean TS, standard deviation in TS, slope, linearity, x angle, y angle, noise index, echo strength, mean pulse duration, plunge, target speed, and the standard error of speed. Tracked fish files later were filtered to exclude fish tracked outside a transducer-specific tracking range (Table 2.2).

Table 2.2. Fish Tracking Range for each Transducer

Transducer	Tracking Range (m)
PAS 415 sampling 0−2-m depth stratum	12.9−15.4
PAS 418 sampling 2−4-m depth stratum	13.1−15.5
PAS 428 sampling 4−6-m depth stratum	13.5−15.7
BioSonics DT6-45-420-0615-002 sampling >6 m	6.0–62.0

We classified fish in two size classes according to length based upon split-beam TS data in the tracked fish file, as follows: fish 50−200 mm (-53.00 ≤ TS ≤-41.9 dB); and fish >200 mm (>-41.9 dB). Fish orientation relative to the acoustic axis of the ensonifying acoustic beam has a very strong effect on TS, so a finer definition of fish length classes was not warranted. Classification by TS is problematic because large fish ensonified in tail or head aspect can return echoes with mean TS 10 dB lower than that of the same fish ensonified in side aspect or dorsal aspect. It is reasonable to assume that most single targets with TS >41.86 really were longer than about 200 mm because hydroacoustic systems rarely overestimate TS, although underestimates can easily result from near head- or tail-aspect ensonification. We purposefully transmitted narrow pulse durations to improve range resolution, and we never encountered dense schools of fish where target resolution was questionable. Fish in the 50- to 200-mm length class could very well be larger than 200 mm if they happened to be ensonified in head or tail aspect.

2.4 Bottom Tracking

During echogram processing of DT-X files from the down-looking transducer, operators manually tracked the bottom contour and had the EchoView software write a bottom-track file with variables like date, time to the nearest second, latitude, longitude, and maximum range, which was limited to 62 m or the range to the reservoir bottom in areas ≤62 m deep. Maximum range was limited by the two-way travel time of sound and a need to maintain a pulse repetition rate of at least 7 pps on the DT-X transducer. Bottom tracking was important to identify the number of 2-m- strata sampled at every GPS coordinate along transects. Accurate expansion of fish counts depends upon an accurate accounting of samples without fish as well as samples with fish. The GPS system provided 1-s temporal resolution of spatial coordinates (latitude and longitude), and the spatial resolution of vertical distributions of fish was at each 2-m stratum.

2.5 Detectability and Estimation of Fish Densities

Estimating fish density requires detection of fish in a known sample volume and an accurate estimate of the volume of water sampled. We filtered fish tracks outside of the nominal beam angle for both hydroacoustic systems. For the BioSonics DT4 files, we set maximum beam compensation to 6 dB to limit tracking to echo traces inside of the 7° nominal beam angle. For the PAS files, we excluded echo traces that had an average x- and y-phase beam angle >6° (i.e., (|xangle1| + |xangle2|)/2 > 6°)). We modeled detectability as a function of range from each transducer (Figure 2.4) and used modeled estimates of effective beam diameter to calculate the diameter of the acoustic beam at the mid tracking range for PAS transducers and at the top and bottom of each 2-m stratum sampled by the down-looking BioSonics transducer.

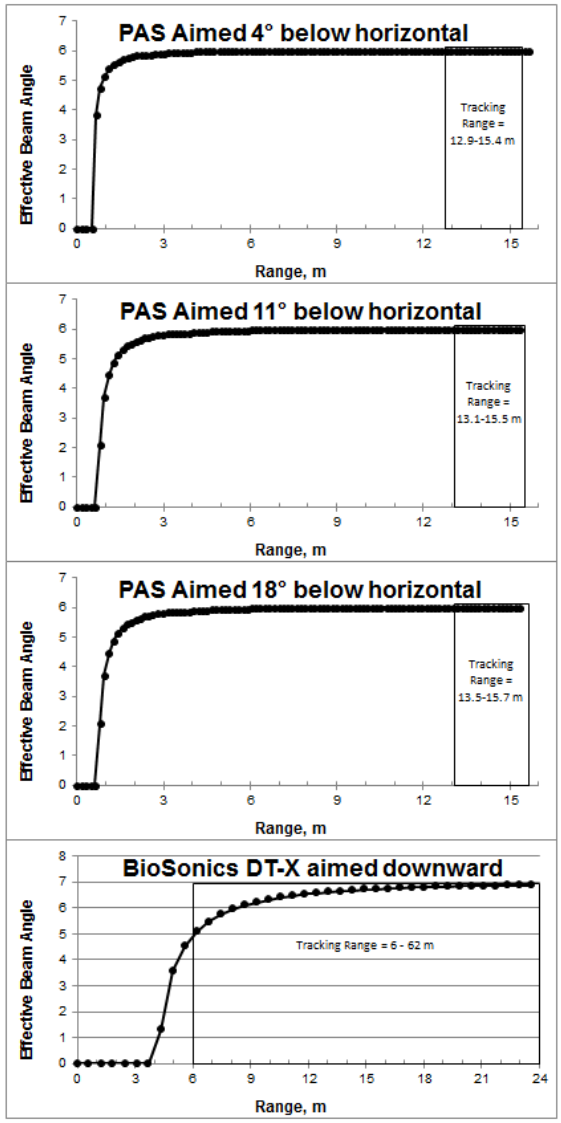

Figure 2.4. Detectability Plots of EBA as a Function of Range from Each Transducer

Detectability modeling and spatial expansions are very important for estimating fish densities without bias introduced by differences in the diameter of an acoustic beam at different ranges from a transducer and the duration of fish in the acoustic beam. Differences in deployments make it very unlikely that equal detectability will occur, and therefore some adjustment is required to improve the assumption of equal detectability. For hydroacoustic sampling, we adjusted for differences in detectability as a function of range from every transducer by modeling effective beam angle as a function of range, which is an index of hydroacoustic detectability.

Effective beam angle (EBA) depends upon the detectability of fish of different sizes in the acoustic beam and is a function of nominal beam width, ping rate, trace criteria, and fish size, aspect, trajectory, velocity, and range. We modeled detectability for every transducer deployment to determine EBA as a function of range from each transducer. We obtained estimates of fish velocity and trajectory by 1-m range strata from manually tracked split-beam data. These data combined with the mean and standard deviation of TS and acquisition data (e.g., ping rate, target-strength threshold, number of echoes, and maximum ping gaps) were entered into a detectability model. Model output consisted of EBA as a function of range from a transducer (see bottom plot in Figure 2.4). Results indicated that some minor adjustment for detectability was required for sample ranges between 6 and 21 m for the BioSonics DT-X transducer. However, no adjustment was needed for the DT-X transducer at greater ranges (21 to 62 m) or for PAS transducers within the tracking range used.

The precise time of the first echo in each fish trace was used to assign the fish to a unique 1-s sample in time, and this prevented counting any fish more than once. Each fish also was assigned to a 2-m-depth stratum named according to its midpoint depth, based on the transducer detecting the fish and the range from the transducer to the fish. For the PAS transducers, 2-m-strata were assigned as follows: Channel 0 = Stratum 1 (0−2 m deep); Channel 1 = Stratum 3 (2−4 m deep); Channel 2 = Stratum 5 (4−6 m deep). For the down-looking BioSonics transducer, fish were assigned to 2-m- strata with midpoint depths ranging from 7 to 61 m according to the average depth of the echo trace, calculated as $\overline{Z} = COS(\theta) \cdot R$, where $\overline{z}$ is mean depth, θ is the transducer aiming angle forward of vertical (10°), and R is the average range of the echo trace from the transducer.

The distance that the boat travelled during each 1-s time interval of each survey was estimated by

$$\sqrt{\left[\left(N_t - N_{t-1}\right)^2 + \left(E_t - E_{t-1}\right)^2\right]}, \tag{2.1}$$

where
N_t = northing coordinate at the end of 1 s
N_{t-1} = northing coordinate 1 s earlier
E_t = easting coordinate at the end of 1 s
E_{t-1} = easting coordinate 1 s earlier.

The median boat speed over all surveys was 1.01 m/s, but it varied depending on environmental conditions during each survey. When the pool was rising in April and May, there was a lot of large timber and other woody debris that had to be avoided. The 1st, 10th, 90th, and 99th percentile speeds were 0.38, 0.83, 1.15, and 1.49 m/s.

The volume of water sampled in each 2-m-depth stratum was estimated differently for the two hydroacoustic systems but can be thought of as extruding two-dimensional shapes over the distance that the boat travelled during each second of the survey. For the forward-looking PAS transducers, we estimated the area of a circle (πr^2) of radius r, where $r = TAN(\theta)R$, θ is effective beam angle, and R is range from the transducer, and multiplied this area by the distance the boat traveled every second. For the down-looking DT-X transducer, we estimated the sample volume in each 2-m stratum as the area of a trapezoid (truncated triangle) times the distance that the boat traveled in each second:

$$Vol = 2\left(\frac{(D_1 + D_2)}{2}\right)D_T, \tag{2.2}$$

where	2	=	the height of a trapezoid in m
	D_1	=	the diameter of the acoustic beam at the top of the trapezoid
	D_2	=	the diameter of the beam at the bottom of the trapezoid
	D_T	=	the distance that the boat travelled in a 1-ha cell.

The diameter of the beam at the top of the trapezoid was calculated as

$$D_1 = TAN\left(\frac{\theta}{2}\right)\cdot(MS - 1)\cdot 2, \tag{2.3}$$

where θ is effective beam angle at the range of detection (from detectability modeling − Figure 2.4) and *MS* is the midpoint depth of the 2-m-depth stratum. The diameter of the beam at the bottom of the trapezoid was calculated as

$$D_2 = TAN\left(\frac{\theta}{2}\right)\cdot(MS + 1)\cdot 2, \tag{2.4}$$

where θ is effective beam angle at the range of detection (from detectability modeling − Figure 2.4 or from the TS and beam pattern factor as described next), *MS* is the midpoint depth of the 2-m-depth stratum. For 1-s sample volumes without fish or with fish that could be detected 6° off the main axis of the acoustic beam (i.e., fish TS > -50 dB (72 mm long according to Love's 1977 any-aspect equation)), the EBA was equal to the nominal 6° for all PAS split-beam samples, and about 7° for the BioSonics split-beam system at ranges >21 m. At shorter ranges from the BioSonics transducer (from 6 to 21 m), EBA was estimated from the detectability curve in Figure 2.4. For small fish (-56 ≤ TS ≤ -50 dB) that could only be detected at an off-axis angle less than the nominal beam angle, the EBA was calculated as two times the half beam angle derived from a transducer's beam pattern factor (BPF; Figure 2.5). For small fish (TS <-50 dB) detected at ranges from 6 to 21 m from the BioSonics transducer, EBA was the smaller of two estimates (i.e., from the top panel of Figure 2.4 or from Figure 2.5).

The BPF of each transducer was calculated from the SONAR equation as follows:

$$BPF = \frac{EL - SL - G_1 - TS - RG}{2}, \tag{2.5}$$

where	EL	=	echo level (dB) expected from for the smallest on-axis target
	SL	=	source level of the transducer
	G_1	=	receiving sensitivity of the system
	TS	=	target strength
	RG	=	receiver gain setting (Table 2.3).

A 40·log10(Range) time-varied gain is not shown because properly calibrated and parameterized hydroacoustic systems apply a 40·log10(Range) time-varied gain to compensate for sound spreading losses as a function of range from the transducer. The systems also correct the echo strength for a targets off-axis angle to provide the TS estimates. Table 2.3 shows calculated BPFs and beam angles for small fish (-56 dB ≤ TS < -50 dB; i.e., between about 35 and 72 mm in length).

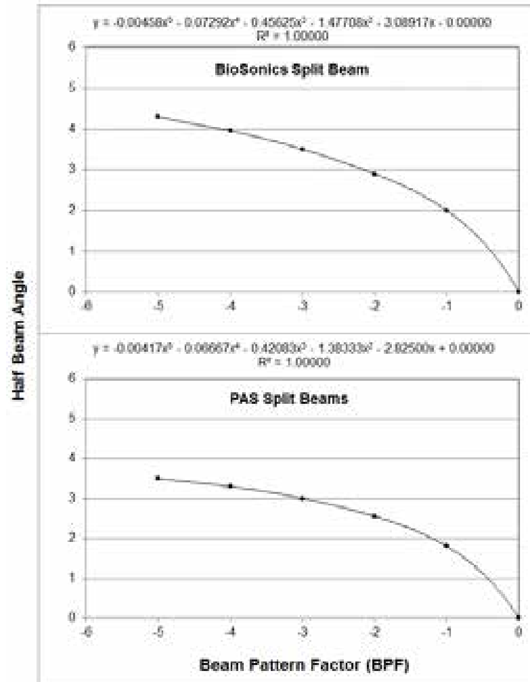

Figure 2.5. Relations between Half Beam Angle and the Beam-pattern Factor

Table 2.3. Calculated Beam Pattern Factors and Effective Beam Angles for Fish TS <-50 dB.

Target Strength	BPF	PAS Beam Angle	BioSonics Beam Angle
-56.00	0.00	0.0	0.0
-55.00	-0.50	2.2	2.5
-54.00	-1.00	3.6	4.0
-53.00	-1.50	4.5	5.0
-52.00	-2.00	5.1	5.8
-51.00	-2.50	5.6	6.4
-50.00	-3.00	6.0	7.0

Fish per cubic meter was calculated by dividing the sum of fish by the sum of volume sampled for every 1-s survey increment and depth stratum. A zero fish/m^3 data set was created by assigning zero fish/m^3 to every possible sample volume and depth stratum. This zero data set was merged with the tracked-fish data set so that fish-density estimates would overwrite zeroes in samples where fish were detected, but sample volumes without fish would retain the zero density estimates. We calculated areal estimates of fish density (fish/m^2) per 1-s survey increment by dividing the sum of fish by the sum of sample volumes at all depths and multiplying those fish/m^3 estimates by maximum depth (m) detected by the down-looking transducer (Z_{max}):

$$\frac{Fish}{m^2} = \frac{Fish}{m^3} \times \frac{Z_{\max}}{1} \qquad (2.6)$$

2.6 Horizontal Distributions

The entire reservoir was divided into a grid of cells that were 20 m from east to west and 500 m from north to south) each defining an area of 1 ha. The mean number of fish/m^2 in each cell was expressed as fish/ha, given that each cell was 1 ha in area. All subsequent calculations of mean density in fish/ha and its variance were based on estimates for individual grid cells in the region of inference (i.e., reservoir zone or the entire reservoir).

After verifying that the fish/ha did not differ between day and night surveys based on 3646 day-and-night pairs of estimates from individual cells sampled during 16 surveys, we pooled day and night density estimates to increase sample volumes per cell and calculated monthly estimates of fish/ha for each cell. For five reservoir zones (Figure 2.3) and for the entire reservoir, we estimated the mean and variance in fish/ha from density estimates for applicable cells. These density estimates were compared with published estimates for other western reservoirs to provide some context for densities in Cougar Reservoir.

For the two length classes of fish studied, we interpolated $\log_{10}$(fish/ha + 1) estimates of fish density among cells using inverse distance weighting and plotted those patterns on areal maps of the reservoir each month. The logarithmic scale allowed us to standardize the range of values on figures, which facilitated comparison of patterns among months.

2.7 Vertical Distributions

Each echo trace sampled was assigned to a 2-m-depth stratum based on the transducer that detected it and, for fish deeper than 6 m, the range from the detecting transducer (Table 2.4). The maximum depth the down-looking beam could effectively sample was 62 m, although no fish were detected >36 m deep. We plotted vertical distributions as fish/m^3 × 10,000 on an x axis versus the midpoint of each 2-m-depth stratum from 1 to 37 m.

Table 2.4. Depth Stratum Assignments

Split-Beam Transducer and Channel	Aiming Angle	Assigned Midpoint of 2-m Stratum[(a)]	Range of Depths Sampled (m)
PAS 6°, Channel 0	4° below horizontal	1	0−2
PAS 6°; Channel 1	11° below horizontal	3	2−4
PAS 6°; Channel 2	18° below horizontal	5	5−6
BioSonics 6°	10° forward of vertical	7, 9, 11,…61 m[(b)]	6−62

(a) See Table 2.1 for fish tracking ranges.

(b) Based on fish depth $= COS(10^{0}) \times R,$ where R is range from the transducer.

2.8 Species Composition from Netting Data

Fish species composition was estimated from Lampara seine data collected by the USGS – Columbia River Research Laboratory concurrently with mobile hydroacoustic surveys and trap-net data collected by the ODFW within 7 days prior to or after mobile surveys within a specific month. The Lampara net was 91.4 m in length and had a (bar) mesh size that tapered from 5.1 to 1.3 cm on the wings and 0.6 cm on the bag. The net was fished by encircling an area and then simultaneously hauling both wings of the net onto the boat deck until the bag was reached (Figure 2.5; C. Smith, United States Geological Survey, personal communication). Pelagic areas along the mobile hydroacoustic transects were netted directly after hydroacoustic sampling during day and night surveys. Near-shore areas were sampled by ODFW using Oneida trap nets (Figure 2.6) set prior to, during, and after hydroacoustic surveys from April to November. The Oneida traps consisted of a 0.64-cm-mesh holding box (2.4 m × 2.4 m × 2.4 m) with a lead net (34.1 m × 3.0 m) extending from shore to the box and two wings (7.2 m × 3.0 m). Oneida traps are a passive capture gear type designed to sample moving fish within 34.1 m of the shoreline and in the upper 3.0 m of the water column. The traps used were effective at capturing and holding fish of approximately 50-mm fork length and greater. All trap nets were fished perpendicular to shore for approximately 24 h at sites selected with a stratified random sampling design (F. Monzyk, Oregon Department of Fish and Wildlife, personal communication).

Figure 2.6. USGS Team Sampling Pelagic Areas with a Lampara Seine

Figure 2.7. Picture of an Oneida Box Trap (described in detail by Monzyk et al. [2011])

2.9 Chinook Salmon Smolt Density and Numbers

The average density of fish between 50 and 200 mm long in near-shore cells averaging ≤12 m of depth was multiplied by the average fraction of fish deemed to be Chinook salmon based on Oneida trap netting of areas within about 30 m of shore during two periods (April through August and September through November). Let $\hat{D}$ be mean fish/ha in near-shore areas and $\hat{F}$ be the fraction of near-shore fish estimated to be Chinook salmon. The adjusted density estimate was written as

$$\tilde{D} = \hat{D}\hat{F} \tag{2.7}$$

Inasmuch as $\hat{D}$ and $\hat{F}$ were estimated independently, the variance of the adjusted density estimate was calculated as

$$\widehat{Var}(\tilde{D}) = (\hat{F}\hat{D})^2 \left[\frac{\widehat{Var}(\hat{D})}{\hat{D}^2} + \frac{\widehat{Var}(\hat{F})}{\hat{F}^2} - \frac{\widehat{Var}(\hat{D}) \times \widehat{Var}(\hat{F})}{\hat{D}^2 \hat{F}^2} \right] \tag{2.8}$$

The average fraction of Chinook salmon was estimated from ODFW trap-net data to be 0.263 ($\widehat{Var}$ =0.0349) from April through August and 0.1425 ($\widehat{Var}$ =0.0227) from September through November. We assumed that the later fraction and variance also applied to December, although trap netting ended in November.

Fish density in offshore cells (mean cell depth >12 m) was multiplied by the fraction of fish deemed to be Chinook salmon based on all Lampera netting of offshore areas from April through August and September through December, analogous to the calculation in Equation (2.7). Variance estimates for fish densities in offshore cells were calculated using an equation similar to Equation (2.8) above. The Chinook salmon fraction for offshore areas was estimated as 0.7750 ($\widehat{Var}$ =0.1906) from April through August and as 0.6250 ($\widehat{Var}$ =0.2292) for the period from September through December. The low catch of fish in offshore areas precluded a reasonable estimation of changes in the Chinook salmon fraction for a finer time increment. The Lampera net caught just 16 fish from April through August and 23 from September through November.

The total number of 50- to 200-mm Chinook salmon in near-shore and offshore areas were estimated for the entire reservoir and five reservoir zones by multiplying adjusted fish/ha by the respective area of near-shore and offshore habitat each month and summing those two products:

$$N = NS_{\hat{D}} \times NS_{\widehat{Ha}} + OS_{\hat{D}} \times OS_{\widehat{Ha}}, \tag{2.9}$$

where N = the total number of 50- to 200-mm Chinook salmon

$NS_{\hat{D}}$ = the near-shore estimate of Chinook salmon density

$NS_{\widehat{Ha}}$ = the number of hectares of near-shore habitat

$OS_{\hat{D}}$ = the offshore estimate of Chinook salmon density

$OS_{\widehat{Ha}}$ = the number of hectares of offshore habitat.

Respective variances also were expanded by multiplying estimated variances in Chinook density by the square of the number of hectares in near-shore and offshore areas each month and summing those two products:

$$\widehat{Var}(N) = \widehat{Var}(NS_{\hat{D}}) \times (NS_{\widehat{Ha}})^2 + \widehat{Var}(OS_{\hat{D}}) \times (OS_{\widehat{Ha}})^2 \tag{2.10}$$

where $\widehat{Var}$ indicated estimated variance and other variables are as defined in Equation (2.9). The number of hectares in near-shore and offshore areas was calculated using ArcGIS Desktop version 10 software, reservoir elevation during each monthly survey, and a rule curve relating surface area to elevation for Cougar Reservoir.

2.10 Population Estimates

We estimated the populations of fish about 50 to 200 mm long, Chinook salmon smolts 50 to 200 mm long, and fish >200 mm long by multiplying estimates of fish density (fish/ha) times the number of hectares in a reservoir zone or the entire reservoir each month. Variances in fish density were multiplied by the square of the number of hectares in a reservoir zone or the entire reservoir each month. We calculated 95% confidence intervals on those estimates as follows:

$$CI_{\alpha=0.05} = \left(\frac{\sqrt{\widehat{Var}}}{\sqrt{n}} \right) \times 1.96 \tag{2.11}$$

We ran a sensitivity analysis on the population estimates of juvenile Chinook salmon in the reservoir in December to determine which input variables had the most effect on results. The analysis was performed using @Risk software by Palisades, and Spearman rank correlation coefficients were used to identify the most critical input variables. Input variables included the fraction of juvenile Chinook salmon in near-shore and offshore areas during the fall drawdown period, associated standard deviations in the Chinook fraction, hydroacoustic estimates of fish densities and standard deviations for near-shore and offshore areas in five reservoir zones, and the number of hectares of area in near-shore and off-shore areas of each zone.

2.11 Relations Between Fish Density and Environmental Variables

We used nonparametric analysis of variance (ANOVA), correlation, and regression models to explore the relationships between independent variables and estimates of fish density. The independent variables included temperature at about 3 m of depth, turbidity, Secchi disk transparency, moon phase, barometric pressure, hours of daylight, hours of darkness, Julian day, and reservoir elevation, area, volume, inflow, and outflow.

Hourly water temperature data were collected in the forebay of the water control tower (see Figure 1.2) by the USACE (http://www.nwd-wc.usace.army.mil/tmt/documents/ops/temp/string_by_project.html). For our purposes, we looked at the reservoir elevation at the time of hydroacoustic sampling and collated the hourly temperature information from approximately 2.4 to 4.8 m below the surface during the entire sampling period. The temperature at this depth was used to approximate the midpoint in the water column (<6 m) where the majority of the targets were detected. Average temperature differences during day and night survey periods in any given month were less than 2°C, so temperatures were pooled within a month. Temperature data were not available for part of the May survey. Reservoir inflow estimates were obtained from http://waterdata.usgs.gov/usa/nwis/uv?14159200, and outflow estimates were obtained from http://waterdata.usgs.gov/nwis/uv?site_no=14162200.

Turbidity data were taken by USGS during hydroacoustic surveys using both a Secchi disk and a Hach 2100P Turbidimeter. Measurements of turbidity were taken in Nephelometric Turbidity Units (NTU). Daily moon phase, hours of daylight, and mean barometric pressure data were obtained for Blue River, Oregon (the closest available location), from a National Weather Service historical database (http://www.wunderground.com). The assigned moon phase for the sample date was based upon the nearest quarter moon phase (0.25 = first quarter, 1.00 = full moon, 0.75 = last quarter, 0 = new moon). The hours of daylight and dark were calculated from civil twilight for the Cougar Reservoir location. Ordinal dates also were used in models.

3.0 Results

The results cover environmental conditions, trends in TS distributions, a comparison of day and night density estimates, trends in fish and Chinook salmon density and their numbers in reservoir zones and the entire reservoir, and relationships between fish density trends and environmental variables.

3.1 Environmental Conditions

Trends in reservoir elevation, area, and volume were the most obvious environmental changes during the study. Reservoir surface elevation peaked in early June, and project operations reduced reservoir surface area by 49.1% and volume by 68% by early December (Figure 3.1).

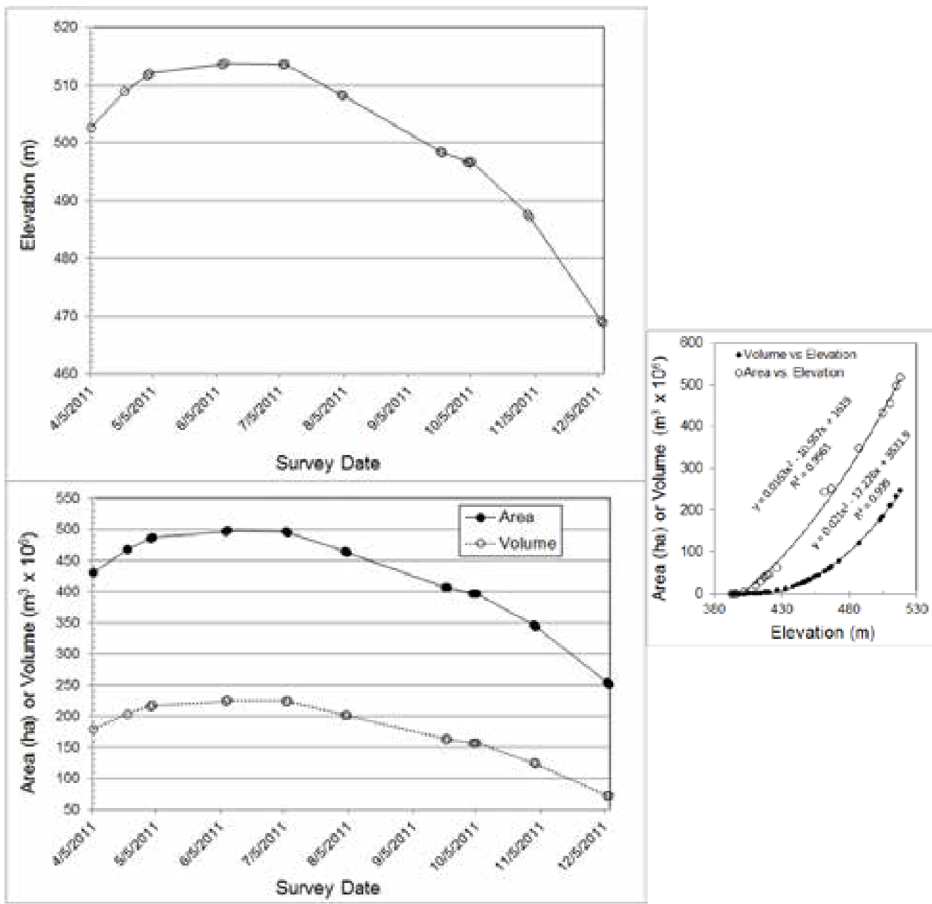

Figure 3.1. Plots of Reservoir Elevation over Nine Months (top), Relationships between Area and Elevation and Volume and Elevation (right), and Trends in Area and Volume over Nine Months (bottom). Regression curves in the right plot were fitted to points taken from Table 2-6 in the *Cougar Dam Downstream Passage Alternatives Study* (USACE Portland District 2010).

Other environmental variables and their monthly values are presented in Table 3.1, and trends during the 9-month study are shown in Figure 3.2. Reservoir elevation, area, and volume, which are highly correlated (Figure 3.1), increased from April through June and declined thereafter. Other variables with generally downward trends included inflow, flow difference (inflow-discharge), turbidity, and daylight hours. Variables that had general upward trends included Julian day, secchi disk transparency (April through November), the number of nighttime hours per day. Water temperature rose through September and then declined through December.

As the previous paragraph suggests, correlations between environmental variables were common (Table 3.2). Correlations and 9 months of data limited the number and choice of independent variables that could be used together in multivariate models to explain trends in estimates of fish density, as described later in this report.

Table 3.1. Table of Environmental Variables and Their Values by Month

	Month								
Variable and (Abbreviation)	4	5	6	7	8	9	10	11	12
Julian date (JDAY)	103	122	158	187	215	263	277	305	340
Elevation, m (Elev)	508.8	512.0	513.9	513.6	508.2	498.3	496.7	487.1	468.8
Area, ha (Area)	449.5	486.0	497.7	496.5	464.4	406.2	396.9	345.3	253.1
Volume, $m^3 \times 10^6$ (Vol)	203.8	217.6	225.7	224.0	201.4	162.8	157.3	123.8	71.8
Inflow, m^3/s (Inflow)[a]	23.9	27.2	43.0	17.2	8.7	6.5	6.9	6.5	9.0
Outflow, m^3/s (Outflow)[b]	19.2	24.4	40.0	26.1	25.4	12.7	13.5	30.4	24.6
Inflow - outflow, m^3/s (FlowDif)	4.7	2.7	3.0	-8.9	-16.7	-6.1	-6.6	-23.9	-15.7
Temperature, °C (Temp)[c]	6.7	7.9	7.9	13.1	13.8	15.5	14.4	10.4	5.3
Barometric Pressure, cm Hg (Baro)	76.2	76.9	76.3	76.4	76.2	76.6	75.3	76.9	77.0
Daylight hours (Day_h)	14.4	15.3	16.6	16.6	15.6	13.2	12.5	11.2	10.1
Night Hours (Night_h)	9.7	8.7	7.4	7.5	8.4	10.8	11.5	12.8	13.9
Secchi Disk, m (Secchi)[d]	3.4	4.1	5.4	5.1	8.2	9.2	8.1	9.1	6.1
Turbidity, NTU (Turbid)[d]	2.44	1.98	1.96	1.12	1.17	1.36	0.91	0.86	1.47
Moon phase (Moon)	0.25	0.00	0.25	0.25	0.25	0.75	0.25	0.25	1.00

(a) Gauging station at USGS 14159200 South Fork Mckenzie River above Cougar Lake.
(b) Gauging station at USGS 14159500 South Fork Mckenzie River near Rainbow, Oregon.
(c) Measured at about 3 m of depth near the water control tower.
(d) Measured by the USGS netting team.

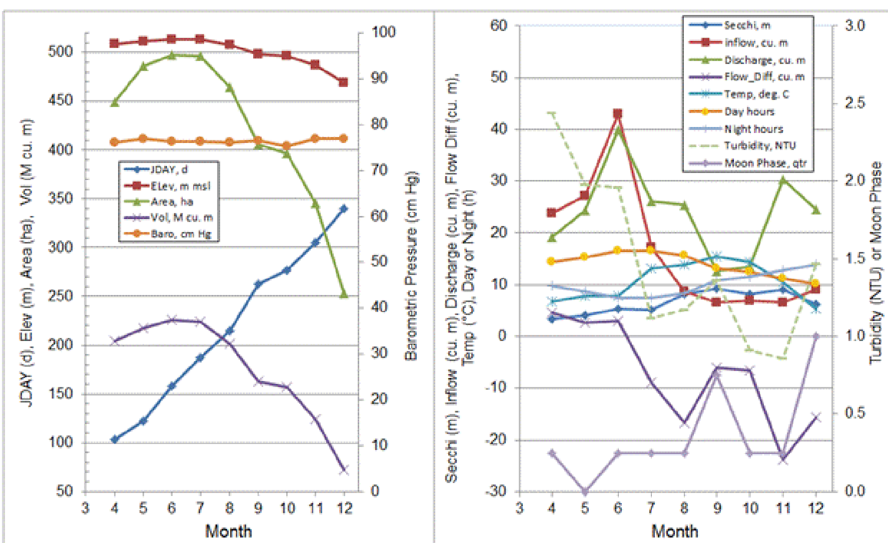

Figure 3.2. Plots of Trends in Environmental Variables Listed in Table 3.1

Table 3.2. Correlations between Environmental Variables Described in Table 3.1 (n=9). For each environmental variable listed in the left column there are three rows of information including a correlate variable abbreviation (Row 1), Pearson Correlation Coefficient (Row 2), and significance probability (Row 3).

Month	JDAY	Vol	Elev	Area	FlowDif	Day_h	Night_h	Turbid	Moon
	0.997	-0.876	-0.862	-0.839	-0.817	-0.801	0.797	-0.766	0.669
	<0.0001	0.0019	0.0028	0.0047	0.0071	0.0094	0.0101	0.0161	0.0487
JDAY	Month	Vol	Elev	Area	Day_h	Night_h	FlowDif	Secchi	
	0.997	-0.882	-0.866	-0.846	-0.809	0.805	-0.798	0.751	
	<0.0001	0.0016	0.0025	0.0040	0.0083	0.0089	0.0100	0.0198	
Elev	Vol	Area	Day_h	Night_h	JDAY	Month	Moon		
	0.997	0.997	0.951	-0.950	-0.866	-0.862	-0.754		
	<0.0001	<0.0001	<0.0001	<0.0001	0.0025	0.0028	0.0189		
Area	Elev	Vol	Day_h	Night_h	JDAY	Month	Moon		
	0.997	0.997	0.966	-0.966	-0.846	-0.839	-0.746		
	<0.0001	<0.0001	<0.0001	<0.0001	0.0040	0.0047	0.0211		
Vol	Elev	Area	Day_h	Night_h	JDAY	Month	Moon		
	0.997	0.997	0.968	-0.967	-0.882	-0.876	-0.737		
	<0.0001	<0.0001	<0.0001	<0.0001	0.0016	0.0019	0.0234		
Inflow	FlowDif	JDAY	Month	Turbid	Secchi	Night_h			
	0.747	-0.747	-0.738	0.734	-0.714	-0.654			
	0.0206	0.0207	0.0232	0.0243	0.0307	0.0559			
Outflow	Inflow	Temp	Baro	Night_h	Day_h	Moon			
	0.621	-0.458	0.344	-0.337	0.333	-0.257			
	0.0741	0.2154	0.3643	0.3746	0.3808	0.5048			
FlowDif	Month	Turbid	JDAY	Inflow	Secchi	Vol			
	-0.817	0.808	-0.798	0.747	-0.703	0.638			
	0.0071	0.0085	0.0100	0.0206	0.0345	0.0644			
Temp	Secchi	Turbid	Inflow	Baro	Outflow	FlowDif			
	0.676	-0.667	-0.516	-0.471	-0.458	-0.266			
	0.0458	0.0498	0.1550	0.2008	0.2154	0.4889			
Baro	Temp	Outflow	Elev	Moon	Area	Vol			
	-0.471	0.344	-0.330	0.311	-0.306	-0.298			
	0.2008	0.3643	0.3856	0.4153	0.4226	0.4356			
Day_h	Night_h	Vol	Area	Elev	JDAY	M			
	-1.000	0.968	0.966	0.951	-0.809	-0.801			
	<0.0001	<0.0001	<0.0001	<0.0001	0.0083	0.0094			
Night_h	Day_h	Vol	Area	Elev	JDAY	M			
	-1.000	-0.967	-0.966	-0.950	0.805	0.797			
	<0.0001	<0.0001	<0.0001	<0.0001	0.0089	0.0101			
Secchi	Turbid	JDAY	Month	Inflow	FlowDif	Temp			
	-0.801	0.751	0.740	-0.714	-0.704	0.676			
	0.0095	0.0198	0.0227	0.0307	0.0345	0.0458			
Turbid	FlowDif	Secchi	Month	JDAY	Inflow	Temp			
	0.808	-0.801	-0.766	-0.749	0.734	-0.667			
	0.0085	0.0095	0.0161	0.0202	0.0243	0.0498			
Moon	Elev	Area	Vol	JDAY					
	-0.754	-0.746	-0.737	0.669					
	0.0189	0.0211	0.0234	0.0487					

3.2 Target Strength Distributions

There were too few fish in most 1-dB bins of TS distributions in most single months before September to provide informative distribution plots (Figure 3.3). Monthly distributions revealed that more fish were detected after drawdown began than when the pool was high. To improve the fidelity of the plots, we pooled data from the months of April and May when the pool was refilling, three months of summer when the pool was full, and two autumn months when the drawdown from full pool was underway (Figure 3.4). We detected adequate numbers of fish in November and December to plot distributions for those months. The hydroacoustic systems obviously did not have full and equal detectability for small fish (TS <-50 dB; about 72 mm long; Love 1977) because the EBA was near zero for -56 dB targets and increased to the full nominal beam angle for targets with TS ≥-50 dB. Sample volumes were adjusted for diminished detectability of fish between -53 and -50, so density estimates will be less affected than the TS distributions. As the study progressed, small fish continually grew to a size that could be detected, and fish were lost from the reservoir due to predation and downstream passage. These distributions represent a snapshot of what was present on the days that we sampled. There is some evidence of a bimodal distribution for fish with TS <-41.9 dB in summer, and modes of smaller fish spread out and move toward larger sizes between April and November (Figure 3.4). There was less evidence of changes in the distribution of fish with TS >-41.9 dB during the study.

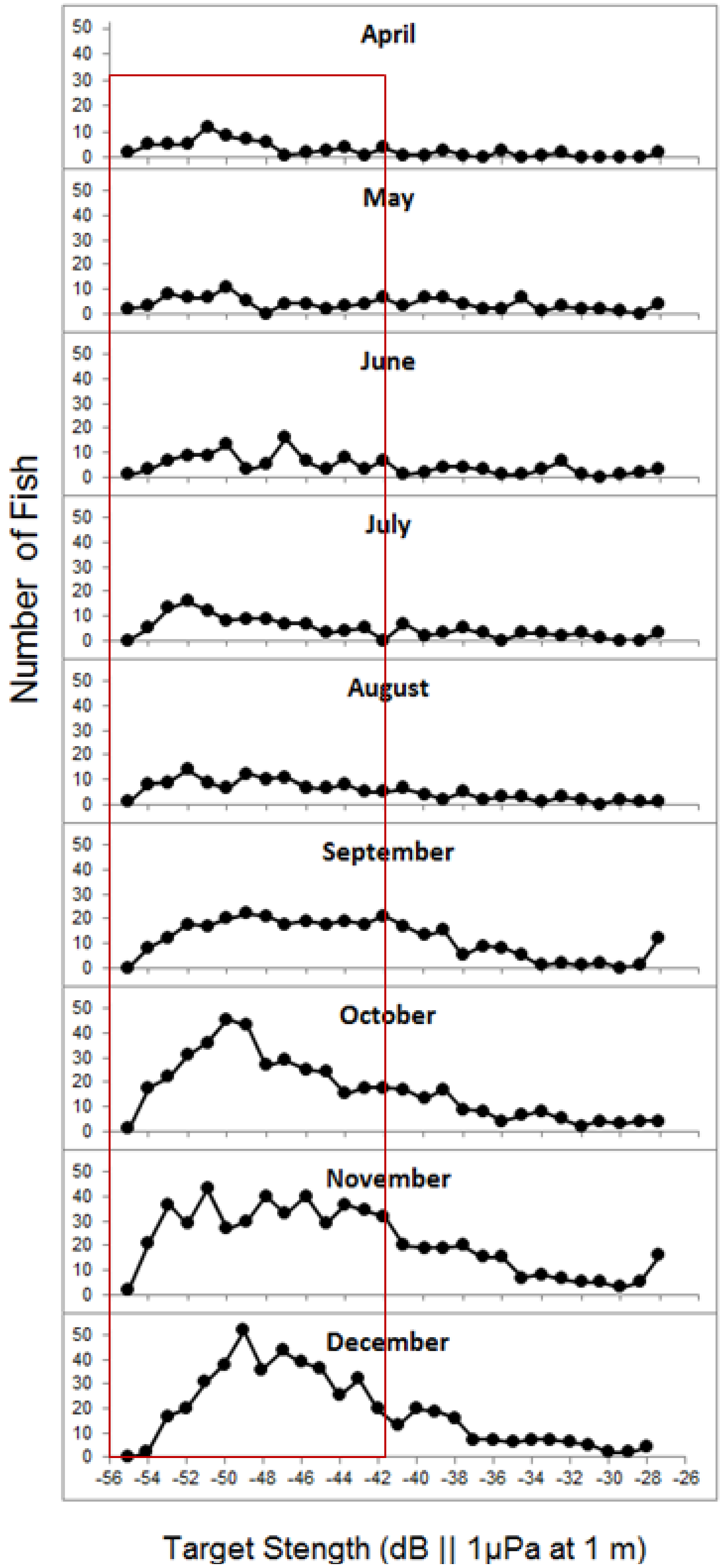

Figure 3.3. Distributions of Average Target Strengths of Detected Fish during Hydroacoustic Surveys. The red box indicates fish with TSs ranging from -56 to -41.9 (about 35 to 200 mm according to Love's any-aspect regression of fish length on acoustic TS [Love 1977]).

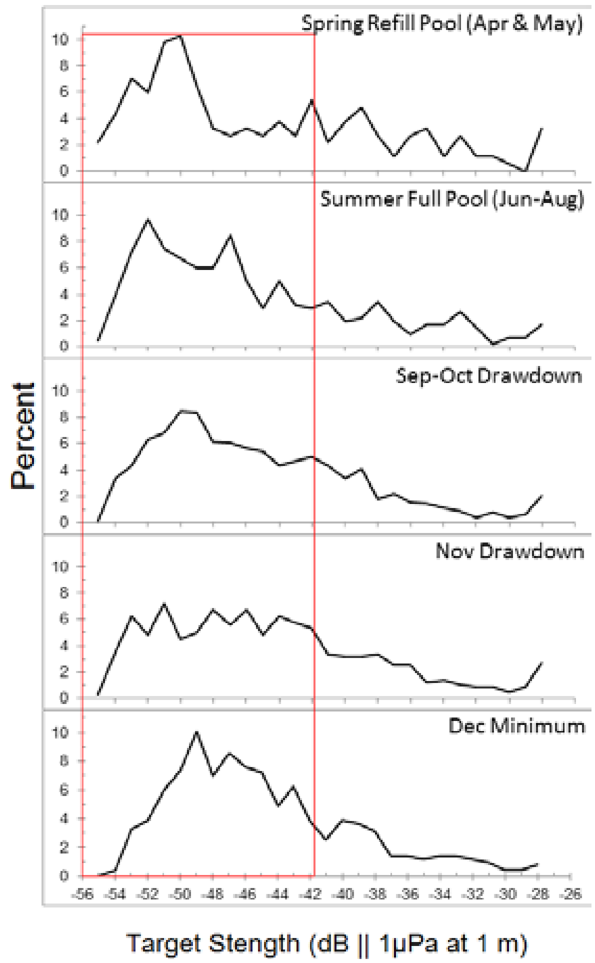

Figure 3.4. Distributions of Average Target Strengths of Detected Fish by Time Period and Reservoir Pool Status. The red box indicates fish with TSs ranging from -56 to -41.9 (about 35 to 200 mm according to Love's any-aspect regression of fish length on acoustic TS [Love 1977]).

3.3 Comparing Day and Night Survey Estimates

We sampled the reservoir once during the day and again at night in every month except April, when only one complete survey was conducted, partly at night and partly during the day. We planned to conduct two surveys in most months because we did not know what to expect at Cougar Reservoir in terms of fish schooling behavior or distributions. Night surveys typically are preferred because fish avoidance of the boat is reduced and fish distributions are more amenable to echo-counting techniques because schools of juvenile salmon tend to disaggregate at night (Johnson et al. 2008). In some reservoirs, fish school tightly during the day but disperse at night, although during 2011 day surveys of Cougar Reservoir, we did not observe large schools of fish that would require an alternative processing method such as echo integration.

We compared day and night estimates of fish density at several spatial levels and found that estimates did not differ significantly, which allowed us to pool day and night survey data and double the number of samples used to estimate fish density per grid cell for every month except April. Our first day-night comparison used pairs of density estimates for every 1-ha cell and provided the largest sample size (n = 3646). Estimated mean densities for the two size groups of fish were similar and had overlapping 95% confidence intervals (Figure 3.5), but in each case, a Shapiro-Wilk normality test failed, so we relied on a nonparametric Wilcoxon signed rank test to verify that the day and night surveys did not differ significantly for fish 50 to 200 mm long (Z = 0.664; P = 0.507) or for fish >200 mm long (Z = -0.0910; P = 0.928). We also compared day and night estimates for the reservoir by month (Figure 3.6). Monthly estimates of fish density were normally distributed for both size groups, and a paired t-test using monthly pairs as replicates revealed no significant differences for small fish (t = -0.442, P = 0.672) or large fish (t = 0.512; P = 0.624), although the power of that test to detect significant differences was low (β < 0.1).

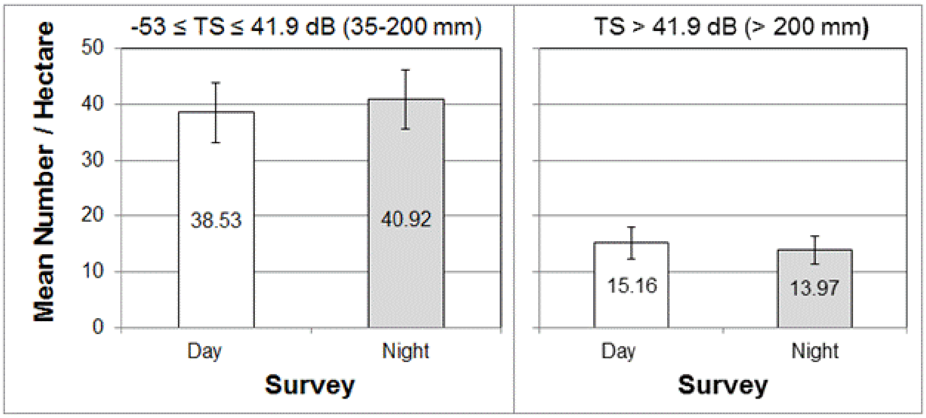

Figure 3.5. Means and 95% Confidence Intervals for Day and Night Density Estimates for Two Size Groups of Fish. There were 3646 pairs of estimates from sampled 1-ha grid cells.

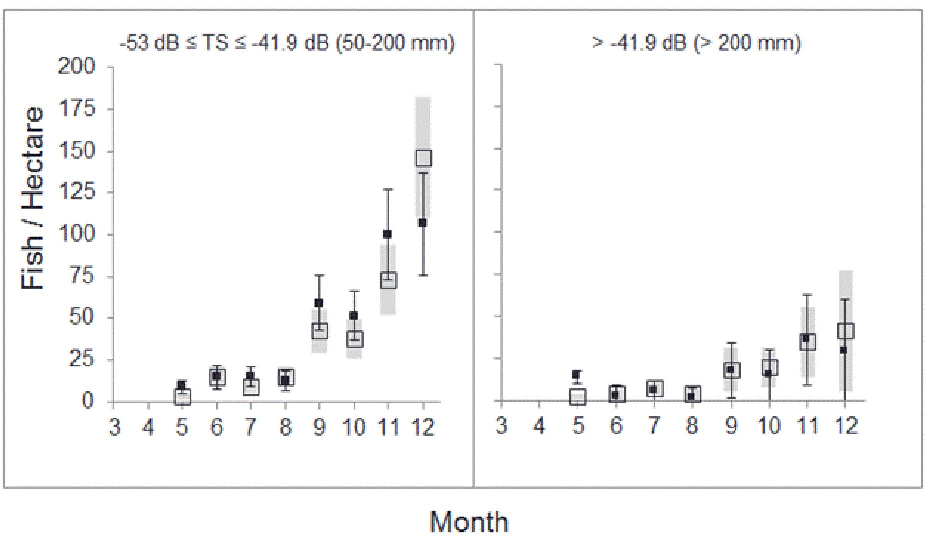

Figure 3.6. Means and 95% Confidence Intervals for Monthly Day and Night Density Estimates for Two Size Groups of Fish. Day estimates are marked by large open squares with wide gray 95% confidence intervals, and night estimates are marked by small solid squares with lines indicating 95% confidence intervals. The 95% confidence intervals for all day and night estimates overlapped in all cases except for fish >200 mm in May when the night estimate was slightly higher than the day estimate.

3.4 Horizontal Distributions in Cougar Reservoir

We made contour plots of fish densities for two size groups of fish on maps of Cougar Reservoir for every month that we surveyed. The distribution of small fish ranging in TS from -53 to -41.9 dB (about 50 to 200 mm long) is illustrated in Figure 3.7. The fixed scale was useful for viewing changes among months. Figure 3.7 shows that densities of small fish increased over time, often were higher in the east arm and in the upper end of the reservoir than in other areas, and were higher in the BRZ in June and from September through December than they were during other months. The plots also hint at concentrations of fish near shore and toward the upper ends of arms of the reservoir before September and a tendency for less near-shore concentration in fall months. The same series of plots with variable scales (Figure 3.8) is better for examining reservoir distributions within months but less useful for illustrating differences among months.

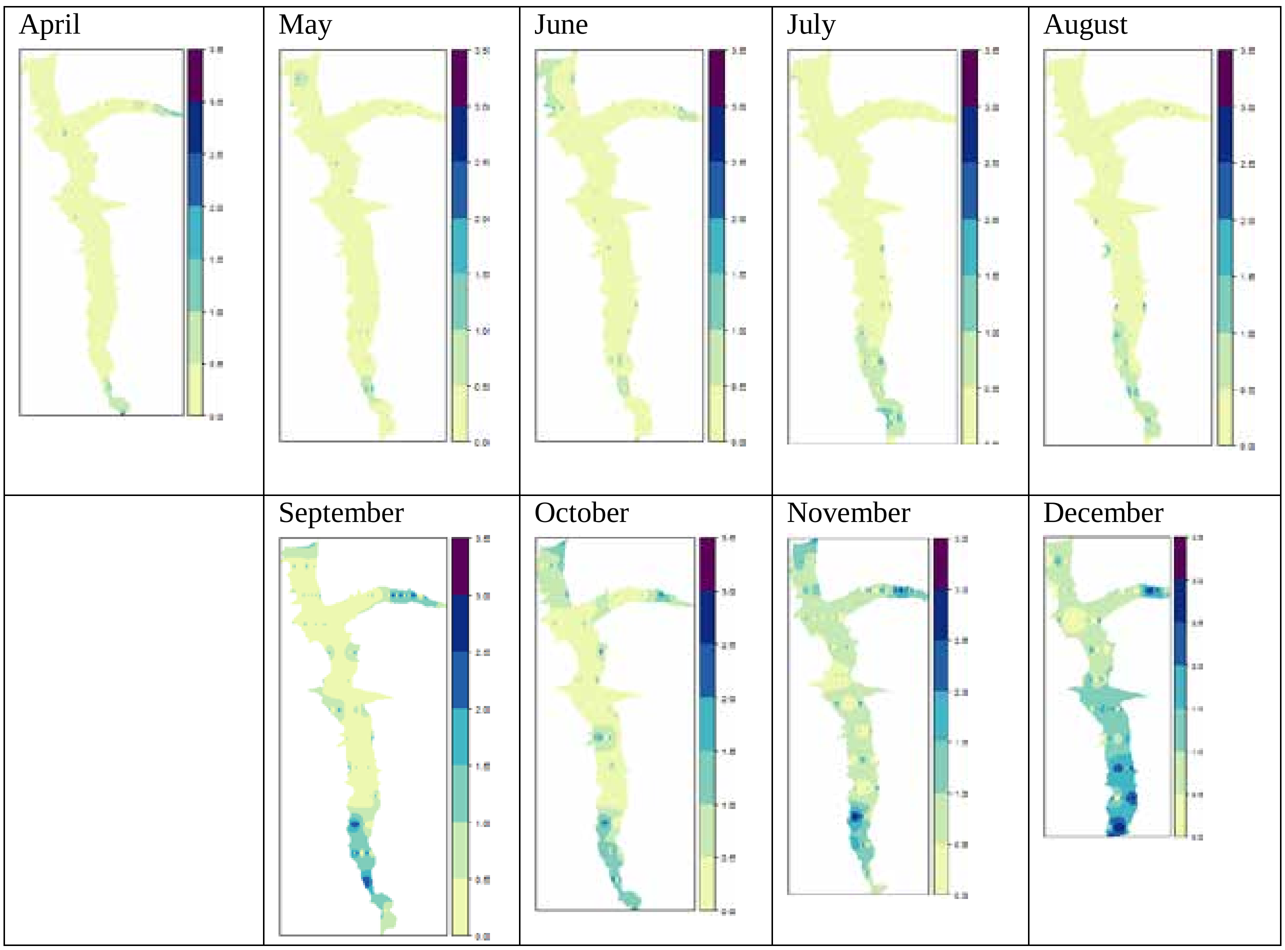

Figure 3.7. Plots of Inverse Weighted Log10(fish/ha) for Fish 50 to 200 mm Long by Month in 2011 using Standardized Contour Scales to Highlight Differences Among Months. Panel sizes reflect areas of the reservoir where mobile surveys could be conducted based on prevailing water surface elevations each month; i.e., not all monthly surveys were exactly the same.

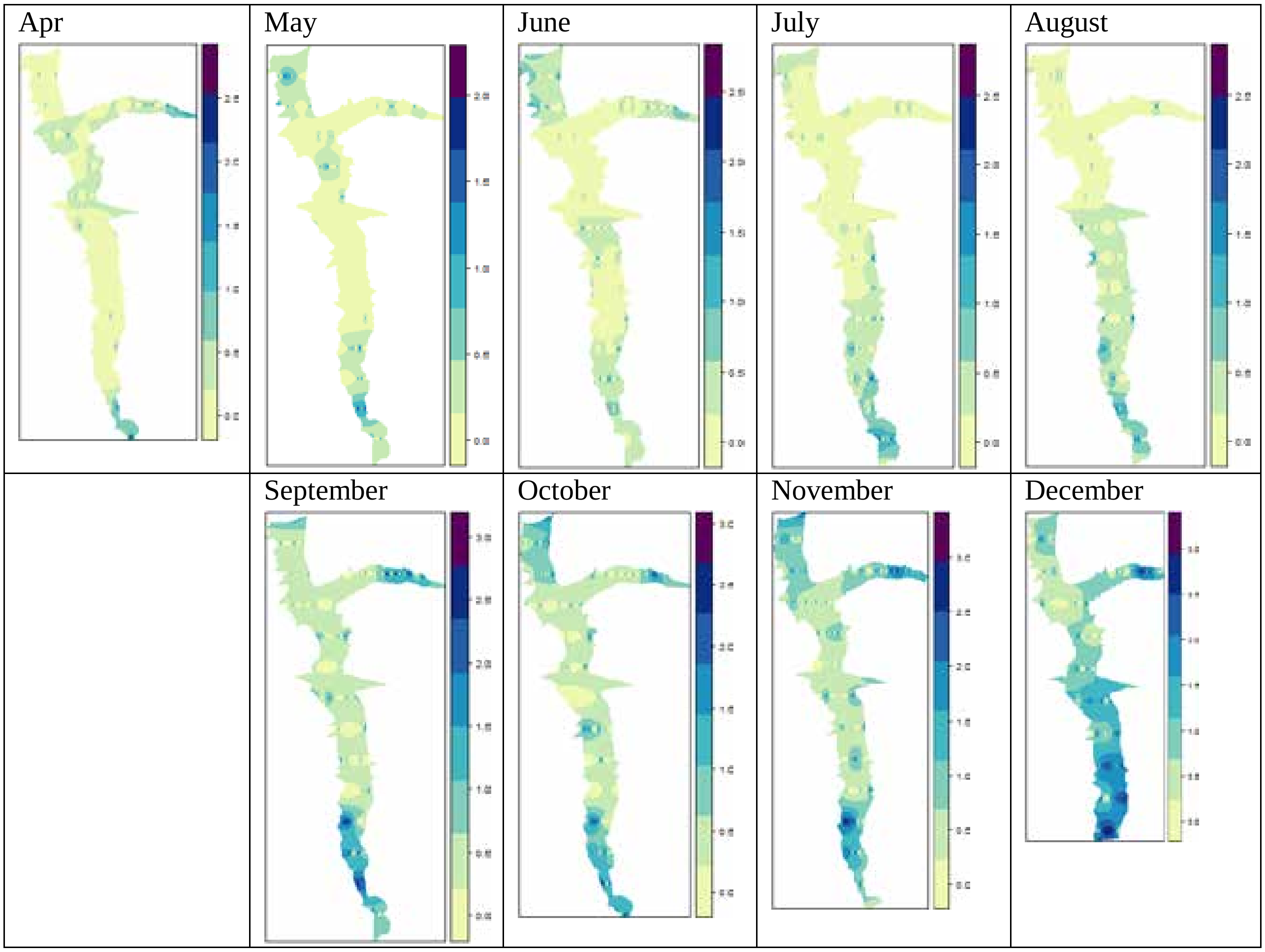

Figure 3.8. Plots of Inverse Weighted Log10(fish/ha) for Fish 50 to 200 mm Long by Month in 2011 using Varying Contour Scales to Highlight Spatial Patterns for Each Month

A fixed-scale plot for fish >200 mm usually showed higher concentrations of larger fish near shore, in the upper east arm, and in the upper half of the reservoir (Figure 3.9). Densities of these fish also increased as the reservoir was drawn down from September through December. Another plot of densities of fish >200 mm with variable scales (Figure 3.10) suggests that the trend of larger fish to be near shore likely was an artifact of the fixed scale. Large fish clearly were distributed in offshore areas in the BRZ in June and from September through December and in the upper half of the reservoir from September through December (Figure 3.10).

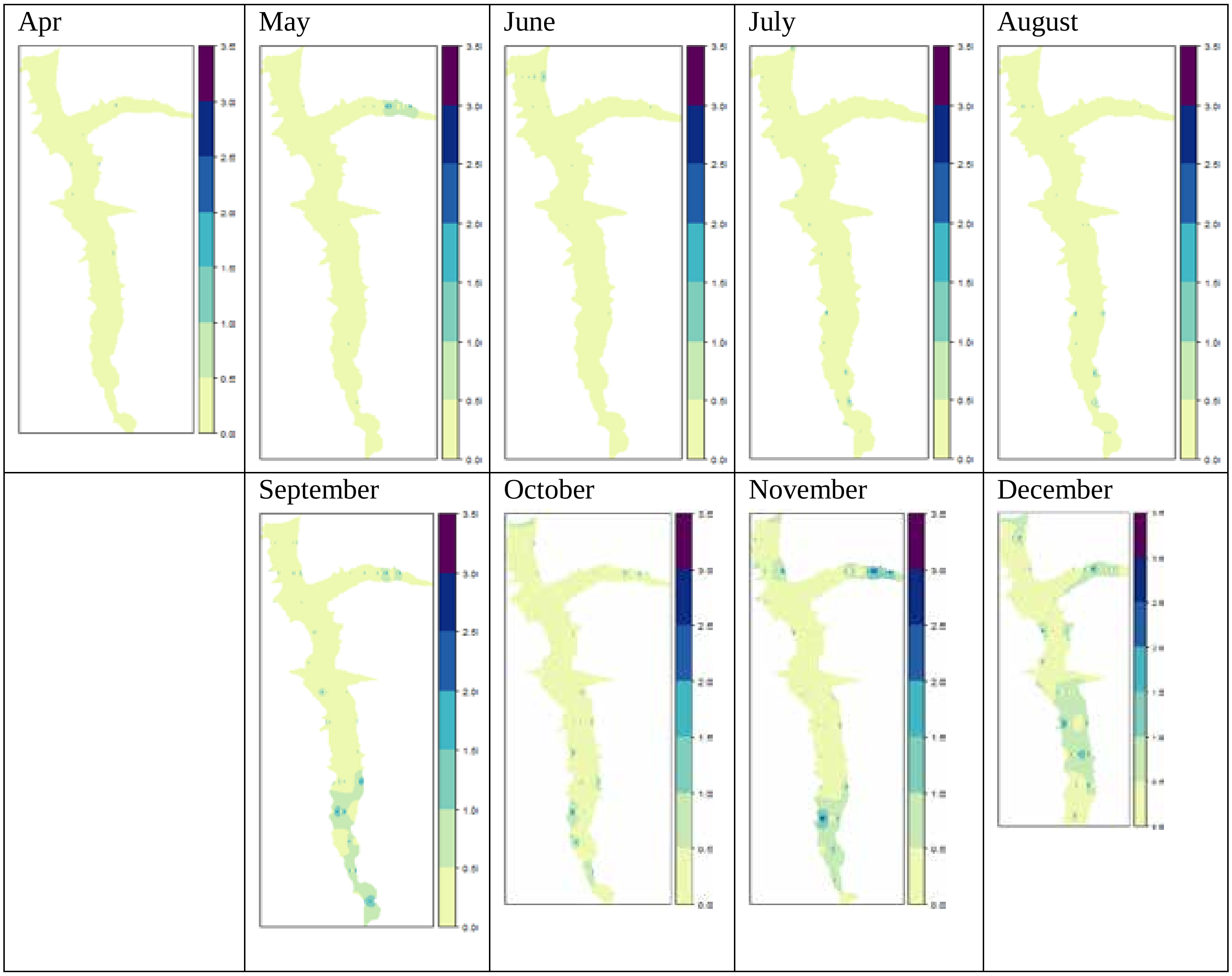

Figure 3.9. Plots of Inverse Weighted Log10(fish/ha) for Fish >200 mm Long by Month in 2011 using Standardized Contour Scales to Highlight Differences among Months

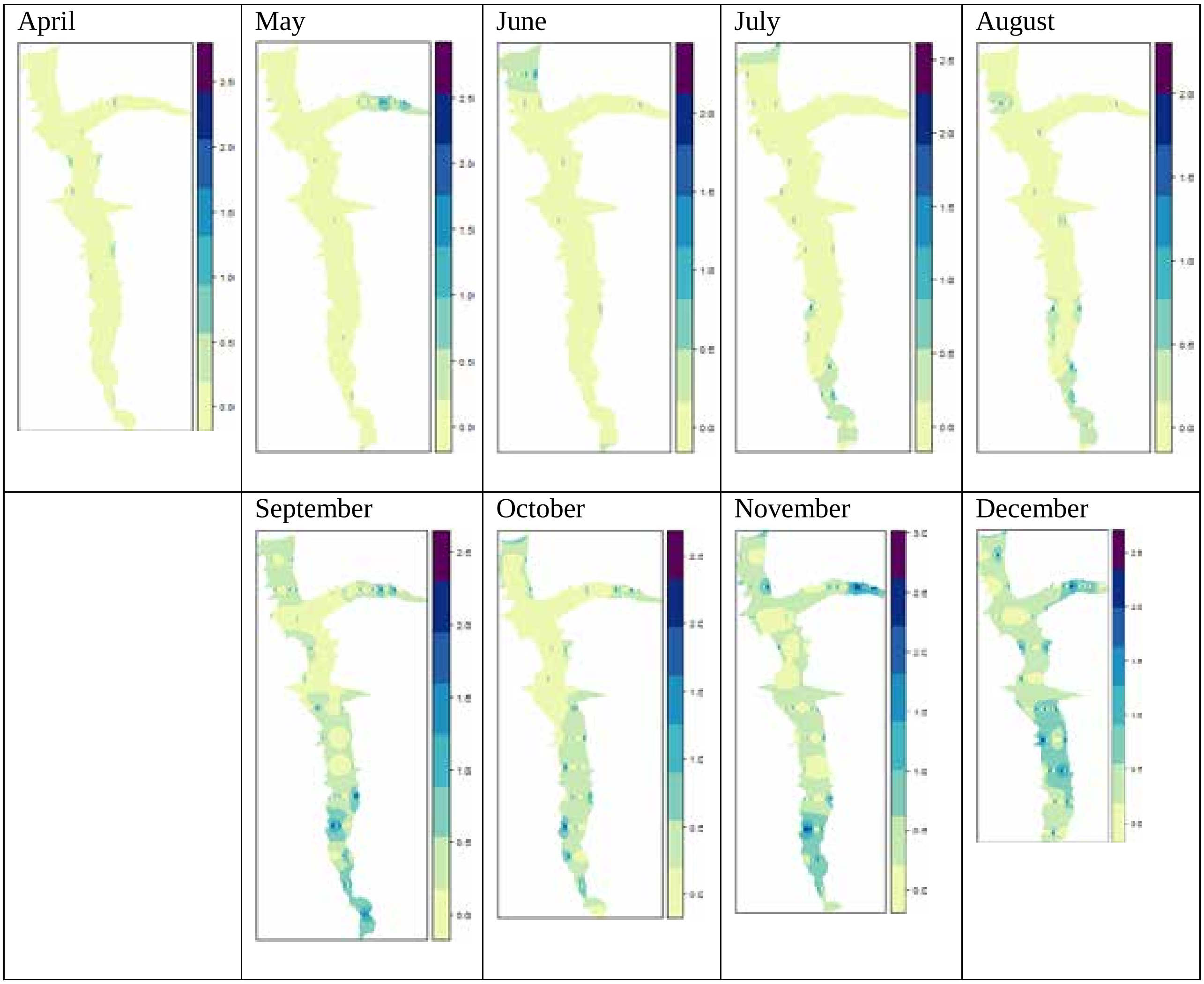

Figure 3.10. Plots of Inverse Weighted Log10(fish/ha) for Fish >200 mm Long by Month in 2011 using Varying Contour Scales to Highlight Spatial Patterns for Each Month

3.5 Vertical Distributions

Over the entire study, the vertical distributions were dominated by detections in the upper 6 m of the water column; the deepest detection was about 36 m deep, and day and night distributions differ slightly, with 64% of targets detected above 6 m during the day and 78% detected above 6 m at night (Figure 3.11). The highest percentage of fish occurred at depths between 2 and 4 m. The percent of detections in midpoint strata 7 and 9 were consistently lower than expected. The only obvious departures from the general pattern in Figure 3.11 occurred in the middle reservoir zone throughout the study and in August and November (Figure 3.12). In those cases, there were obviously higher percentages of fish detected in water >6 m deep.

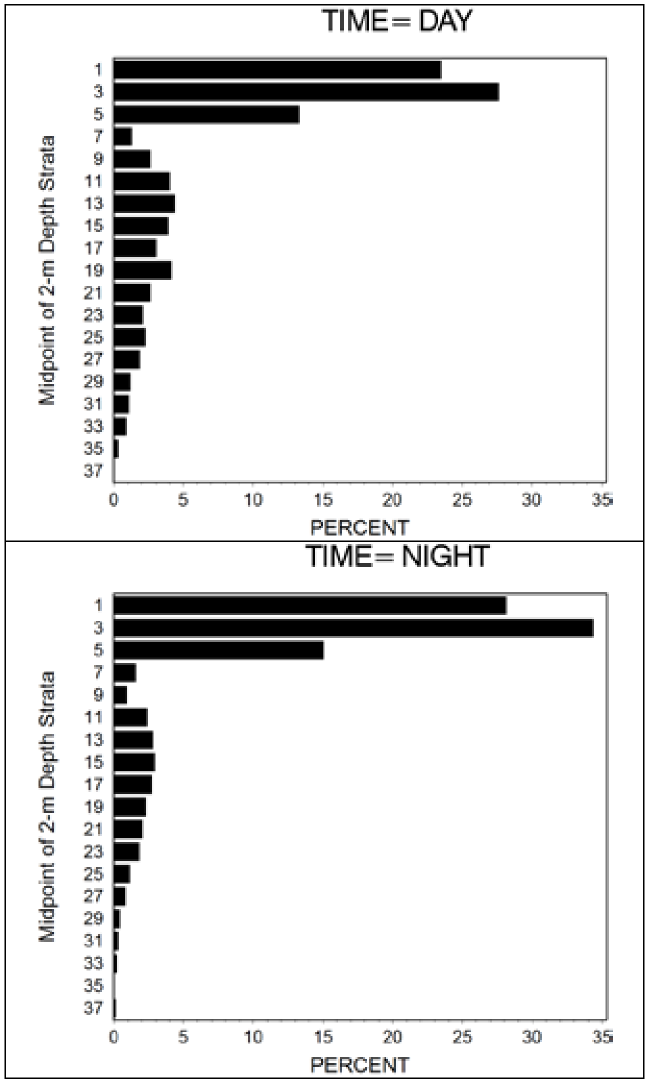

Figure 3.11. Composite Vertical Distribution Fish Sampled using Mobile Hydroacoustics at Cougar Reservoir from April through December 2011

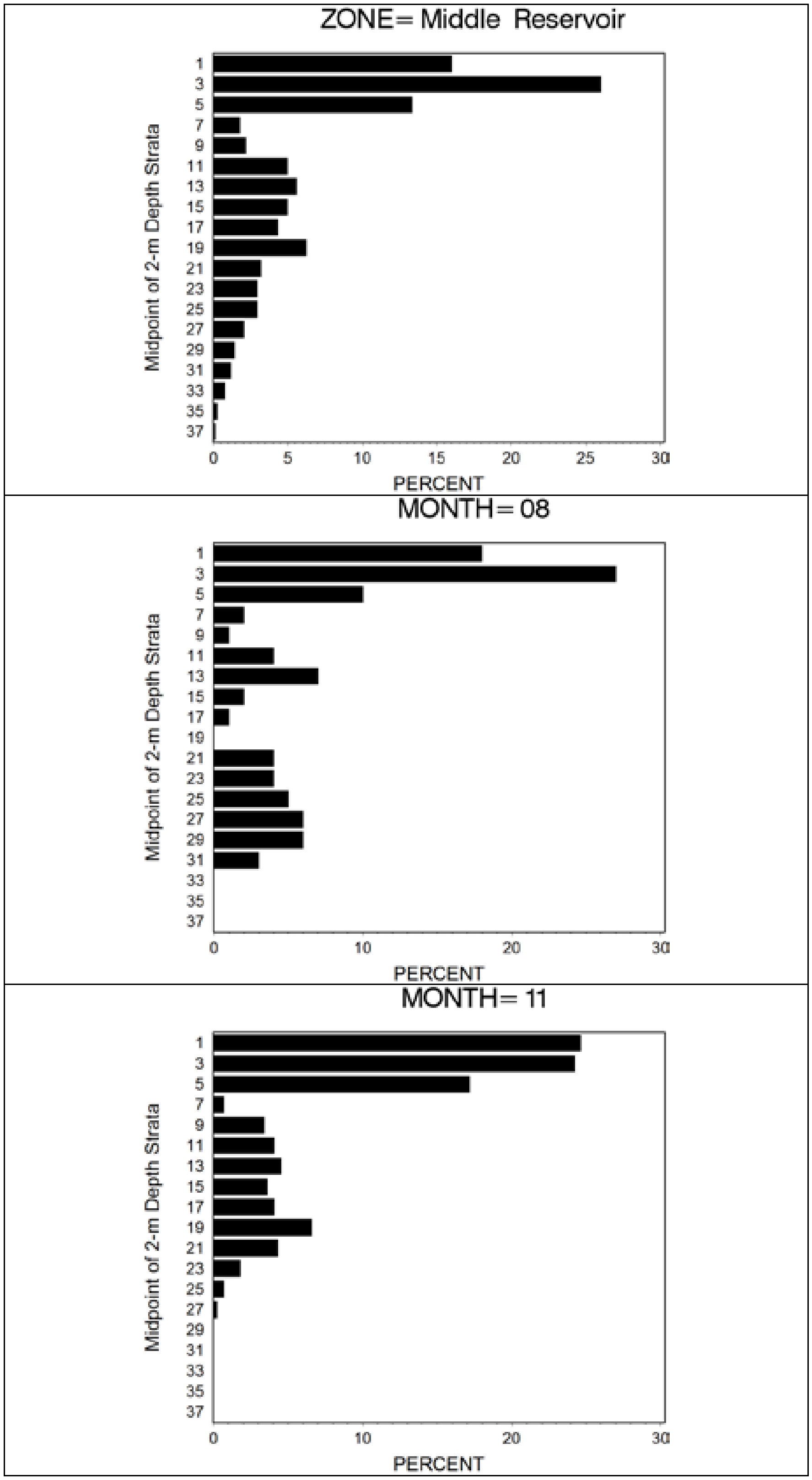

Figure 3.12. Vertical Distributions that Deviated from the Patterns in Figure 3.11 by Having Higher Percentages of Detections at Depths >7 m

3.6 Relations Between Environmental Factors and Density

We explored relationships between a set of monthly environmental variables and the density of fish between 50 and 200 mm in length using nonparametric ANOVA and multiple regression models. The focus of these analyses was primarily limited to small fish to provide information that might be useful to surface collection efforts for juvenile salmonids. The estimated density of Chinook salmon and all targets 50 to 200 mm long were very highly correlated (Figure 3.13) despite very different estimation procedures. The strong correlation indicates that relations between environmental variables and fish 50 to 200 mm long will be similar to those for Chinook salmon smolts of the same size.

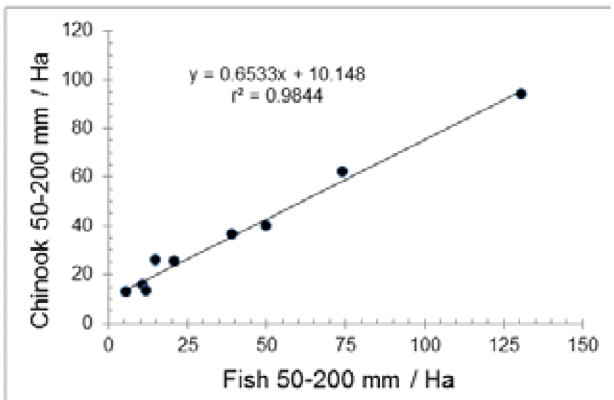

Figure 3.13. Correlation Between Estimated Densities of Chinook Salmon and the Density of all Fish 50 to 200 mm Long. The density of all 50- to 200-mm fish were estimated directly from hydroacoustic surveys, whereas the density of Chinook salmon of the same size was estimated from species composition data from netting data provided by the USGS and ODFW, hydroacoustic survey density estimates, and estimates of surface area within and beyond 30 m of shore every month.

We ran a two-way ANOVA on ranks of fish/ha because density data were not normally distributed, and we determined that there were significant differences in density among months and zones, and that there was a significant interaction between month and zone (Table 3.3). The highest densities of small fish were recorded in most reservoir zones during November and December as illustrated in Figures 3.6 and 3.7. The upper reservoir zone had the highest density ranking in four months (5, 7, 8, 9), the second highest ranking in three months (4, 6, 10), and that zone was drained by drawdown by December (Figure 3.7). The upper east arm had the highest density ranking in two months (April and December), the second highest in two months (September and November), and was in the top three out of five zones in two other months (6 and 10). The BRZ density ranked highest in three months (6, 10, 11), although densities in the BRZ did not differ significantly from those in the upper reservoir in June or from those in the upper reservoir and upper east arm in October and November. The BRZ was ranked second highest out of five zones in two other months (5 and 7) and third highest in three months (8, 9, and 12). For the entire reservoir, the ranking of fish density was higher in December than it was in November, and it was higher in November than it was in September and October, which did not differ significantly (Table 3.4). Other months were mostly similar with only April and May differing significantly. Given the BRZs' importance as a likely collection site for Chinook salmon smolts, we also ran a multiple range test on density ranks among months there, and not surprisingly, autumn months were ranked among the highest (Table 3.5).

Table 3.3. Output of Proc GLM (http://www.sas.com/;Version 9.3) Showing Results of a Two-way Analysis of Variance on Ranks of the Density of Fish 50 to 200 mm Long in Cougar Reservoir. Variables include month, zone, and the interaction term M*zone.

```
                              NONPARAMETRIC TEST

                             The GLM Procedure
Dependent Variable: RFISH_HA   Rank for Variable FISH_HA
                                          Sum of
Source                      DF           Squares     Mean Square    F Value    Pr > F
Model                       43        1797617844        41805066      24.36    <.0001
Error                     8179       14038583316         1716418
Corrected Total           8222       15836201160

               R-Square     Coeff Var      Root MSE    RFISH_HA Mean
               0.113513      31.86093      1310.121         4112.000

Source                      DF       Type I SS     Mean Square    F Value    Pr > F

Month                        8     877566458.6     109695807.3      63.91    <.0001
ZONE                         4     403671502.4     100917875.6      58.80    <.0001
Month*ZONE                  31     516379883.2      16657415.6       9.70    <.0001

Source                      DF     Type III SS     Mean Square    F Value    Pr > F

Month                        8     823708345.0     102963543.1      59.99    <.0001
ZONE                         4     390660304.6      97665076.2      56.90    <.0001
Month*ZONE                  31     516379883.2      16657415.6       9.70    <.0001
```

Table 3.4. Ryan-Einot-Gabriel-Welsch Multiple Range Test (Proc GLM; SAS Version 9.3) on Ranks of Fish/ha among Months (m). Density estimates were added to link ranks to original unranked estimates.

```
                  NOTE: This test controls the Type I experiment-wise error rate.
                               Alpha                           0.05
                               Error Degrees of Freedom        8214
                               Error Mean Square            1821115
                               Harmonic Mean of Cell Sizes 855.7903

                                 NOTE: Cell sizes are not equal.
Number of Means              2              3              4              5              6
Critical Range       165.23303      178.74055      186.12027      191.12763      194.87923
                             7              8              9
                     197.85914      197.85914      202.40469

                   Means with the same letter are not significantly different.
                        REGWQ Grouping      Mean Rank     N  Month  Fish/ha

                                     A       4780.45    702    12    126.6
                                     B       4585.09    881    11     86.4
                                     C       4295.28    944    9      50.8
                                     C       4253.71    955    10     44.4
                                     D       4003.39    481    4      24.4
                                E    D       3883.73   1015    6      14.8
                                E    D       3851.71   1178    7      12.0
                                E    D       3841.67   1069    8      13.7
                                E            3796.52    998    5       5.7
```

Table 3.5. Ryan-Einot-Gabriel-Welsch Multiple Range Test (Proc GLM; SAS Version 9.3) on Ranks of Fish/ha in the BRZ among Months (m). Density estimates were added to link ranks to original unranked estimates.

```
                  NOTE: This test controls the Type I experiment-wise error rate.
                                Alpha                           0.05
                                Error Degrees of Freedom         879
                                Error Mean Square            2146151
                                Harmonic Mean of Cell Sizes   90.102
                                  NOTE: Cell sizes are not equal.
     Number of Means              2              3              4              5              6
     Critical Range       553.85315      599.23168      624.01166      640.84077      653.43729
                                  7              8              9
                          663.43956      663.43956       678.6895
                    Means with the same letter are not significantly different.
                           REGWQ Grouping      Mean Rank     N  Month     Fish/ha
                                     A         5534.2      79    11      129.6
                                B    A         5154.8      89    10      117.0
                                B    C         4674.7      66    9         56.7
                                D    C         4332.9      82    12        74.5
                                D    C         4312.5     124    6         37.9
                                D              4020.5     125    5          5.9
                                D              3963.8     133    7         15.0
                                D              3746.7     133    8          3.2
                                D              3704.9      57    4          1.3
```

Reservoir elevation, area, and volume were the best predictors of the density of fish 50 to 200 mm long (Figure 3.14), but of course these independent variables are themselves highly correlated (Figure 3.1). A stepwise regression procedure added the number of hours of daylight as the next variable in the model, but the addition only increased variation about 1% over what was explained by elevation.

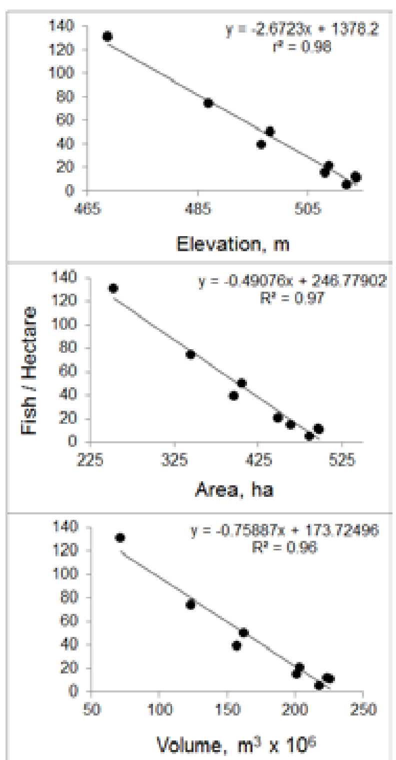

Figure 3.14. Regression of the Density of Fish 50 to 200 mm Long on Reservoir Elevation, Area, and Volume

3.7 Population Estimates

For each of the five reservoir zones and the entire reservoir, we estimated monthly total numbers of fish in three groups: fish 50 to 200 mm long, Chinook salmon smolts 50 to 200 mm long, and fish >200 mm long. Estimates of total numbers and the density estimates from which they were derived are tabled in Appendices A, B, and C.

The best predictor of total numbers of fish 50 to 200 mm long was reservoir volume (Figure 3.15; Table 3.6), but other independent variables also were highly correlated with those monthly estimates (Table 3.6). The same independent variables were significantly correlated with estimated numbers of Chinook salmon (Table 3.6), and again volume was the most highly correlated variable (Figure 3.16), along with other correlated independent variables. Estimated numbers of large fish >200 mm long followed a similar monthly trend (Figure 3.17) and were correlated with many of the same independent variables.

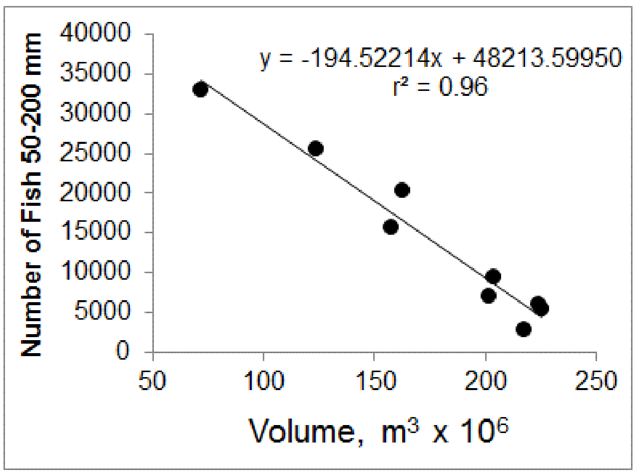

Figure 3.15. Regression of the Total Number of Fish 50 to 200 mm Long on Reservoir Volume

Table 3.6. The Most Significant Correlations between Independent Variables and Estimates of Total Numbers of Fish in Three Size Groups of Fish and Independent Environmental Variables Described in Table 3.1 (n=9). The name of the independent variable, a Pearson Correlation Coefficient, and a probability value are listed in each of three rows adjacent to a dependent variable in the left-side cells.

Dependent Variable	Independent Variable						
Fish	Volume	Area	Elev	Night hours	Day hours	JDAY	Month
50−200 mm	-0.97712	-0.97300	-0.96907	0.94524	0.94502	0.88110	0.86419
	<.0001	<.0001	<.0001	0.0001	0.0001	0.0017	0.0027
Chinook	Volume	Area	Elev	Day hours	Night hours	JDAY	Month
50−200 mm	-0.96618	-0.96095	-0.95080	-0.94490	0.94424	0.87010	0.85813
	<.0001	<.0001	<.0001	0.0001	0.0001	0.0023	0.0031
Fish >200 mm	Night hours	Day hours	Vol	Area	Elev	JDAY	Month
	0.92589	-0.92350	-0.87995	-0.86963	-0.85164	0.79232	0.77715
	0.0003	0.0004	0.0018	0.0023	0.0036	0.0109	0.0137

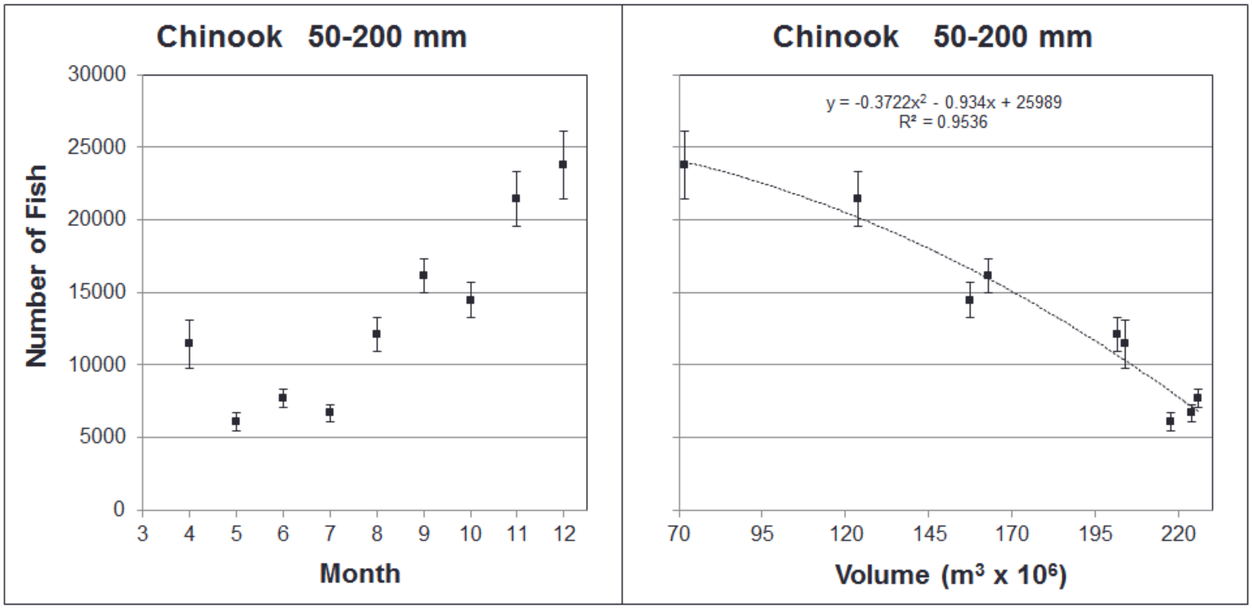

Figure 3.16. Monthly Changes Trends in Estimates of Total Numbers of Chinook Salmon 50 to 200 mm Long (left) and the Relation between Total Numbers and Reservoir Volume (right). Vertical bars are 95% confidence intervals.

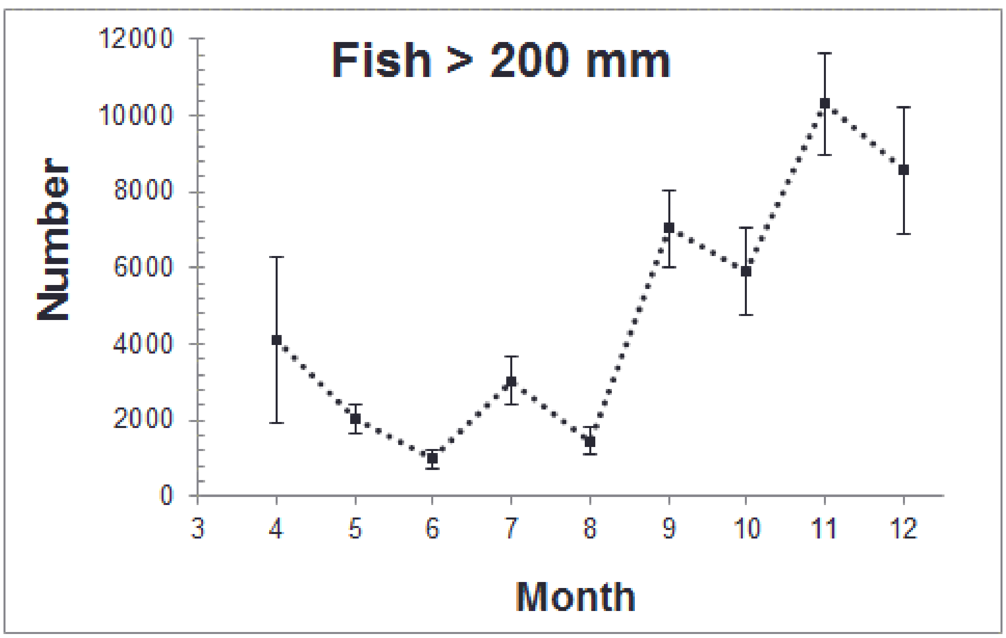

Figure 3.17. Monthly Changes Trends in Estimates of Total Numbers of Fish >200 mm Long. Vertical bars are 95% confidence intervals.

The sensitivity analysis of juvenile Chinook salmon population estimates revealed that the most critical input variables based on Spearman-ranked correlation coefficients were 1) the fraction of Chinook salmon in offshore areas (r = 0.78), the fraction of Chinook salmon in near-shore areas (r = 0.57), and the water surface area over the middle reservoir zone (r = 0.14). No other input variables had correlation coefficients >0.1.

Unlike density estimates that often tended to be higher in the shallower and more productive zones (up-river or east arm), estimates of total numbers usually are highest in zones with the most surface area. These trends are evident in the estimates tabulated in Appendices A, B, and C.

4.0 Discussion

This section discusses temporal and spatial patterns observed in the data, and compares hydroacoustic estimates of fish density with other reported estimates. Finally, we discuss how future survey efforts might be streamlined to reduce costs and improve the comparative value of mobile hydroacoustic survey results to support management decisions and the management implications of the study results.

4.1 Temporal and Spatial Trends

Increasing densities and numbers of fish during the 2011 fall drawdown were the most obvious trends in the 2011 hydroacoustic data. These temporal trends occurred for all five zones of the reservoir and for the entire impoundment. We observed a 10-fold increase in the average density of fish classified as 50 to 200 mm long and a 5-fold increase of fish >200 mm long between August and December. Densities from April through July were similar to the low densities observed in August. Physical concentration alone would only explain a doubling of densities based on the changes in surface area, which decreased 49.1%, or a tripling of densities based on a 68% reduction in reservoir volume. Increases in fish density and total numbers of fish after June were highly and inversely correlated with decreases in reservoir elevation, area, and volume reductions after June, but two other less obvious factors likely contributed to observed trends and relationships exceeding levels expected from physical changes in reservoir surface area and volume alone.

First, fall drawdown laterally displaced fish from shallow, near-shore habitats that are less effectively sampled with hydroacoustics and concentrated those fish in the main body of the reservoir where they were readily detected. The highest densities of fish often were observed in the upper end of the east arm and upper end of the reservoir, and those areas were largely drained by December after the fall drawdown of the reservoir pool (see Figures 3.7 through 3.10). Sampling of shallow areas <2 m deep was difficult because transducers were mounted on the raft or boat at depths of 0.6 m and were vulnerable to collisions with rocks and stumps that could damage them. The diameter of forward-looking acoustic beams 12 to 15 m ahead of the raft are about 1.5 m, so any structure protruding off the bottom truncates the acoustic beams and obscures fish at greater ranges. Trap net catches of fry and parr by ODFW were higher in the upper reservoir areas in summer than farther downstream (Monzyk et al. 2012 [1]).

Second, density estimates should increase as fish grow and recruit to a detectable size by autumn 2011. Most fish that hatched in spring or summer likely would have grown to a fully detectable size (TS ≥-50 dB; length >72 mm) by November or December. The presence of suspended debris, particularly in spring, forced us to process data with a -56 dB detection threshold. We could reliably detect most fish with TS ≥-53 dB (about 50 mm and longer) because the effective beam angle was at least 70% of the nominal beam angle, but smaller fish (TS <-53 dB) down to the -56 dB processing threshold were progressively less detectable. For example, a fish with a -55 dB TS >1.1° off the acoustic axis could not be detected in any beam (see Table 2.2 for EBAs for small fish), and a fish with TS = -56 dB (about 35 mm long) could only be detected if it passed through the center of an acoustic beam. We detected a

[1] Monzyk FR, JD Romer, R Emig, and TA Friesen. 2012. "Distribution of Chinook Fry and Parr Rearing in Willamette Project Reservoirs." Paper presented at the 2011 Willamette Basin Fishery Science Review, Corvallis, Oregon.

few small fish with a TS between -56 and -53 dB (about 35 to 50 mm long, respectively), but given the narrowness of the acoustic beam angles for fish of that size the vast majority would have been missed.

The only sections of the reservoir that we were unable to survey consistently included the uppermost riverine section and within about 75 m of the water control tower (Figure 1.2). The USGS was conducting an acoustic telemetry study throughout 2011 and had deployed numerous rafts in the forebay area around the tower. The rafts were less of an impediment than the many signal cables running between the rafts. In 2010, Khan et al. (2012) reported observing numerous schools of fish within 50 m of the tower from April through June. Schooling behavior was not observed in fall or winter, even though the total number of fish detection events was higher in fall than it was in summer (Khan et al. 2012). In contrast, we observed no evidence of fish schooling during any survey in 2011, but again, we could not sample near the tower where milling of fish was the most common behavior observed in 2010. If the tower is an attractant for fish because of flow cues, it would not be surprising for fish to congregate there, with schooling being a natural consequence.

Vertical distributions varied little among months or between day and night surveys, although there was some evidence that more fish were detected deeper during the day than at night. Most fish were detected in the upper 6 m of the water column and none were detected deeper than about 36 m. These observations contrast with those of Khan et al. (2012), who reported most fish within 50 m of the water control tower detected at depths between 10 and 20 m during two dates (11/14 and 12/07/2011) when they sampled vertical distributions with a BlueView acoustic camera. Khan et al. (2012) observed few fish in the upper 10 m of the water column near the tower. We can only assume that the depth distribution near the tower was unique and highly influenced by the flow regime there. We have no records of higher densities at depths between 10 and 20 m than within the top 6 m of the water column, but again, we did not survey within 75 m of the tower. We observed an abrupt decrease in density between the fifth and seventh 2-m strata in most areas that we surveyed in 2011, and that reduction may be a consequence of reduced detectability of fish at short ranges in the down-looking transducer relative to the high detectability of the forward-looking transducers (see Figure 3.4). We used the EBA to calculate smaller sample volumes in short-range-depth strata sampled by the down-looking beam, but apparently that did not fully compensate for detectability differences as a function of range from the down-looking transducer.

4.2 Context for 2011 Survey Results

The best context for the survey results are other reported hydroacoustic estimates of fish density. Unfortunately, we could not identify estimates for other reservoirs in the Willamette Basin, so we were forced to compare our estimates to those for other reservoirs in the Pacific Northwest. Finding reported estimates for exactly the same size classes of fish was not possible, so we simply compared the density of all fish sampled using hydroacoustic methods. These comparisons require some license because methods vary among the studies and would affect density estimates.

Average densities of fish before the fall drawdown in Cougar Reservoir were very low compared to any reported estimates that we could find (Table 4.1). However, after seeing the increase in fish densities during the fall drawdown, it seemed obvious that hydroacoustic sampling was much more effective in November and December than it was before September for reasons described in Section 4.1. Consequently, we decided to compare reservoir-wide average densities for December with reported estimates for other lakes. For comparative purposes, we converted all reported densities to fish/ha. On a fish/ha basis, the highest monthly density in Cougar Reservoir was considerably lower than estimates for other lakes, except Banks Lake, Washington. However, most of the other lakes with higher densities had kokanee populations, which can be very abundant. The other hydroacoustic studies also sampled smaller fish and had less restrictive echo-trace acceptance criteria or used echo integration to count fish.

Table 4.1. Comparison of Hydroacoustic Estimates of Fish Densities in Cougar Reservoir in December with Estimated Densities of all Fish in other Pacific Northwest Reservoirs

Reservoir	Fish/Ha	Standard Deviation	Month	Smallest TS (dB)	Echo-Trace Criteria or Other Method
Cougar Reservoir[(a)]	162	234	December	-53	4 echoes in 5 pings
Lake Billy Chinook (LBC)[(b)]	1190	1290	February	-54	3 echoes in 3 pings
LBC Metolius Arm	1380	960			
LBC Dechutes Arm	1420	1780			
LBC Crook River Arm	450	610			
Sawtooth Valley Lakes[(c)]			September	-59	Echo integration
Redfish Lake	442				
Alturas Lake	762				
Stanley Lake	229				
Yellowbelly Lake	760				
Pettit Lake	616				
Sullivan Lake, WA([d)]	409		September	-55	3 echoes in 3 pings
Pend Oreille, ID[(e)]	670		August	-60	Echo integration
Banks Lake[(f)]	57			-55	3 echoes in 3 pings

(a) This study.
(b) Mueller and Degan (2011).
(c) Beauchamp et al. (1997).
(d) Baldwin and McLellan (2005).
(e) Maiolie et al. (2008).
(f) Polacek (2008).

Other evidence of the relatively low number of fish, including Chinook salmon smolts, comes from the USGS team's capture of only 39 fish (31 Chinook salmon) in 353 hauls with a 91-m-long Lampara seine over 9 months. The trap netting at Cougar Reservoir in 2011 captured more fish: 260 Chinook and 812 fish of other species (742 of which were dace) in 35 net-nights of sampling over 8 months. This is an average of just 23.2 fish (7.4 juvenile Chinook salmon) per trap-net night.

We find it difficult to judge the reasonableness of population estimates presented in Appendices A and B when the only data with which to compare are the rates of apparent passage downstream through the dam, as indexed by ODFW screw-trap data. The 2010 screw-trap data collected by ODFW indicated that juvenile Chinook salmon pass through the dam all year, and preliminary estimates indicate that higher numbers (perhaps several thousands of fish per month) pass downstream in winter (Figure 3.5 in Khan et al. 2012). The 2011 screw-trap catches follow a similar pattern but were not expanded to abundance estimates by ODFW (Figure 14 in Romer et al. 2012). Not being familiar with screw-trap data and assumptions associated with interpreting those data (e.g., trap efficiency, effort, and potential expansion factors), we were uncomfortable extrapolating trap catches to numbers of Chinook salmon that might be passing through the dam in a year. The December juvenile Chinook salmon population estimate was 23,797 (95% confidence interval: $21{,}434 \leq n \leq 26{,}160$), and these numbers would appear sufficient to support the range of dam-passage rates suggested by the 2011 screw-trap data. The population estimate represents a point estimate for early December, not a rate estimate that might be obtained from screw-trap data. Given our limited experience with screw-trap data, we leave it for others to judge the reasonableness of the population estimates in this report. Clearly, the best estimates that could be made were for periods when most fish were large enough to be detected and were distributed where they were vulnerable to acoustic detection (i.e., late fall or early winter).

The sensitivity analysis of juvenile Chinook population estimates indicated the importance of having robust estimates of the fraction of juvenile Chinook in near-shore and offshore areas, because those factors had the most effect on the resulting estimates. The surface area of the middle reservoir zone was the third-most important variable, but it was much less important than estimated fractions of juvenile Chinook salmon. A Monte Carlo simulation with 1000 iterations had an estimated mean population of about 23,776 juvenile Chinook salmon, with 25th and 75th percentiles of 13,392 and 33,911 fish, respectively (Figure 4.1).

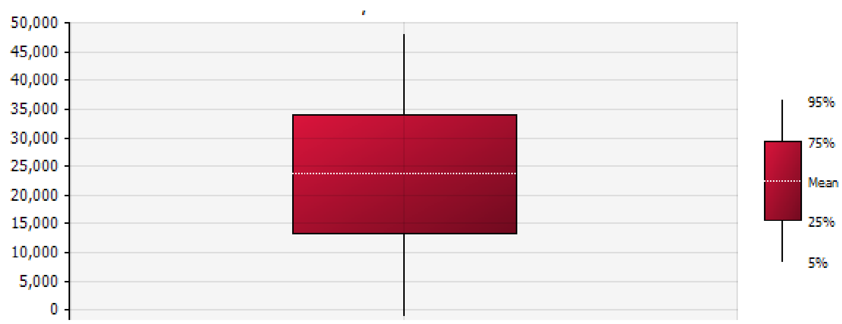

Figure 4.1. Chinook Salmon Population Estimates for December Based on a Monte Carlo Simulation using Estimated Fractions of Chinook in Near-shore and Offshore Areas in Five Reservoir Zones, Standard Deviations in those Estimated Fractions, and Hydroacoustic Estimates of Total Fish Density and its Standard Deviation for those Same Reservoir Zones

4.3 Lessons Learned

Hydroacoustic surveys were clearly most effective after drawdown concentrated fish and limited access of fish to headwater areas that are difficult to survey. Repeated monthly surveys at Cougar Reservoir provided insight into productive hydroacoustic survey strategies, in case additional information is desired for other Willamette Basin reservoirs. Conducting a single monthly survey in late fall or early winter appears to be the most cost-effective and productive strategy for hydroacoustic sampling of flood-control impoundments like Cougar Reservoir that have large pool changes during the year (Figure 3.1). Focusing survey efforts in a single month would allow many Willamette Basin reservoirs to be sampled within days or weeks of one another using the same equipment. This approach would allow estimates of fish densities and total numbers to be compared among many surveyed reservoirs with no more cost than was required to conduct the 9-month long study at Cougar Reservoir in 2011.

4.4 Implications for Management

If one accepts the premise that there are relatively low densities of fish in Cougar Reservoir, then there are potentially important implications for management decisions to build a downstream collection facility at Cougar Dam. Arguments for or against a downstream passage collector probably depend on the carrying capacity of the reservoir rather than the standing stock that can be estimated at any particular time. If the reservoir supports low densities because it lacks carrying capacity to support higher densities, then perhaps the collector would provide greater benefits if it were deployed at another reservoir. However, a collector could be quite beneficial if there is sufficient carrying capacity at Cougar Reservoir and densities only appear low because of continuous downstream movements of fish through the turbines and regulating outlets, as suggested by the ODFW data. If populations of juvenile Chinook salmon are lower in Cougar Reservoir than in other USACE reservoirs in the basin, the collector might provide greater basin-wide benefits if it were deployed elsewhere. However, we also can see how low numbers in Cougar Reservoir can be used to justify adding a surface collection structure there.

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Appendix A

Estimates of Density and Total Numbers of Fish Classified as 50 to 200 mm Long

Table A.1. List of Density Estimates (fish per hectare) and Total Numbers of Fish Acoustically Classified as 50 to 200 mm Long in Five Reservoir Zones. Tabled values are sorted by zone and month.

Zone	Month	Hectares	Fish/Ha	½ 95% CI	Total Number	½ 95% CI
BRZ	4	23	1.31	1.94	30	45
BRZ	5	25	5.93	3.36	148	84
BRZ	6	27	37.93	23.07	1024	623
BRZ	7	27	15.00	10.42	405	281
BRZ	8	25	3.16	2.89	79	72
BRZ	9	21	56.66	35.15	1190	738
BRZ	10	17	116.98	48.98	1989	833
BRZ	11	14	129.62	54.09	1815	757
BRZ	12	12	74.45	55.08	893	661
Confluence	4	165	13.20	9.60	2178	1584
Confluence	5	172	3.22	1.80	554	309
Confluence	6	174	6.12	3.81	1065	662
Confluence	7	172	3.69	3.45	635	593
Confluence	8	164	4.26	4.93	698	808
Confluence	9	146	20.54	7.84	2999	1145
Confluence	10	147	23.86	14.64	3507	2151
Confluence	11	132	32.29	10.46	4262	1381
Confluence	12	108	58.81	25.60	6351	2765
Middle Reservoir	4	204	18.13	12.64	3698	2579
Middle Reservoir	5	212	3.09	2.10	654	445
Middle Reservoir	6	215	4.96	2.83	1066	608
Middle Reservoir	7	213	7.62	3.18	1624	676
Middle Reservoir	8	202	22.29	8.86	4502	1789
Middle Reservoir	9	180	31.67	11.24	5700	2022
Middle Reservoir	10	182	24.01	9.31	4370	1695
Middle Reservoir	11	163	74.32	25.24	12115	4114
Middle Reservoir	12	127	188.76	42.94	23972	5453
Upper East Arm	4	21	94.75	48.85	1990	1026
Upper East Arm	5	24	7.10	7.85	170	188
Upper East Arm	6	26	42.42	27.28	1103	709
Upper East Arm	7	27	18.23	25.16	492	679
Upper East Arm	8	24	7.89	12.05	189	289
Upper East Arm	9	18	188.77	82.04	3398	1477
Upper East Arm	10	19	97.63	43.00	1855	817
Upper East Arm	11	13	338.42	137.32	4399	1785
Upper East Arm	12	6	303.39	169.71	1820	1018
Upper Reservoir	4	37	39.67	27.93	1468	1033
Upper Reservoir	5	52	22.88	14.75	1190	767
Upper Reservoir	6	55	22.35	17.24	1229	948
Upper Reservoir	7	57	49.98	19.57	2849	1115
Upper Reservoir	8	50	29.49	16.87	1474	843
Upper Reservoir	9	41	169.46	70.28	6948	2881
Upper Reservoir	10	33	117.99	57.53	3894	1898
Upper Reservoir	11	23	130.08	80.85	2992	1860

Table A.2. List of Density Estimates (fish per hectare) and Total Numbers of Fish Acoustically Classified as 50 to 200 mm Long by Month

Month	Hectares	Fish/Ha	½ 95% CI	Fish	½ 95% CI
4	450	20.81	2.17	9363	1909
5	485	5.60	0.42	2716	398
6	497	11.04	0.69	5487	676
7	496	12.11	0.69	6004	674
8	465	14.93	1.36	6943	1242
9	406	49.84	2.18	20235	1737
10	398	39.23	2.27	15613	1774
11	345	74.15	4.29	25583	2900
12	253	130.58	8.09	33037	4013

Appendix B

Estimates of Density and Total Numbers of Chinook Salmon 50 to 200 mm Long

Table B.1. List of Chinook Salmon Density Estimates (fish per hectare) and Total Numbers Acoustically Classified as being 50 to 200 mm Long in Five Reservoir Zones. Tabled values are sorted by zone and month.

Zone	Month	Hectares	Fish/Ha	½ 95% CI	Number	½ 95% CI
BRZ	4	23	18.13	15.6	417	359
BRZ	5	25	21.77	10.8	544	270
BRZ	6	27	75.42	23.0	2036	620
BRZ	7	27	31.78	13.6	858	366
BRZ	8	25	22.41	11.4	560	285
BRZ	9	21	46.25	23.9	971	502
BRZ	10	17	90.46	35.2	1538	599
BRZ	11	14	96.99	32.2	1358	450
BRZ	12	12	39.77	24.9	477	299
Confluence	4	165	12.58	7.7	2076	1276
Confluence	5	172	6.80	1.7	1169	294
Confluence	6	174	10.09	3.9	1756	677
Confluence	7	172	7.27	3.3	1250	563
Confluence	8	164	8.50	4.4	1393	720
Confluence	9	146	19.00	4.5	2773	650
Confluence	10	147	33.63	9.6	4944	1414
Confluence	11	132	25.32	6.9	3342	914
Confluence	12	108	44.98	19.4	4857	2091
Middle Reservoir	4	204	28.42	10.9	5798	2232
Middle Reservoir	5	212	10.15	4.4	2152	925
Middle Reservoir	6	215	8.11	2.9	1743	629
Middle Reservoir	7	213	7.77	2.7	1656	586
Middle Reservoir	8	202	41.94	8.1	8471	1634
Middle Reservoir	9	180	24.93	7.1	4486	1281
Middle Reservoir	10	182	18.37	6.1	3343	1110
Middle Reservoir	11	163	57.17	15.5	9319	2527
Middle Reservoir	12	127	125.28	22.0	15911	2799
Upper East Arm	4	21	71.29	55.0	1497	1155
Upper East Arm	5	24	24.65	11.9	592	286
Upper East Arm	6	26	41.92	24.2	1090	629
Upper East Arm	7	27	19.82	20.0	535	540
Upper East Arm	8	24	12.56	14.6	301	350
Upper East Arm	9	18	139.67	77.4	2514	1393
Upper East Arm	10	19	72.79	32.0	1383	609
Upper East Arm	11	13	309.74	198.8	4027	2585
Upper East Arm	12	6	425.16	454.9	2551	2729
Upper Reservoir	4	37	44.56	27.0	1649	1000
Upper Reservoir	5	52	31.93	13.4	1660	695
Upper Reservoir	6	55	19.84	13.7	1091	755
Upper Reservoir	7	57	42.25	15.7	2408	897
Upper Reservoir	8	50	27.67	14.4	1384	721
Upper Reservoir	9	41	131.11	56.5	5376	2317
Upper Reservoir	10	33	98.81	49.8	3261	1645
Upper Reservoir	11	23	147.65	96.8	3396	2227

Table B.2. List of Density Estimates (fish per hectare) and Total Numbers of Chinook Salmon Fish Acoustically Classified as being 50 to 200 mm Long by Month

Month	Hectares	Fish/Ha	½ 95% CI	Total Number	½ 95% CI
4	450	25.42	3.74	11437	1682
5	485	12.61	1.27	6117	617
6	497	15.52	1.32	7716	656
7	496	13.52	1.19	6707	591
8	465	26.04	2.49	12110	1156
9	406	39.71	2.84	16121	1152
10	398	36.35	3.04	14468	1208
11	345	62.15	5.43	21442	1872
12	253	94.06	9.34	23797	2363

Appendix C

Estimates of Density and Total Numbers of Fish Classified as >200 mm Long

Table C.1. List of Density Estimates (fish per hectare) and Total Numbers Acoustically Classified as being >200 mm Long in Five Reservoir Zones. Tabled values are sorted by zone and month.

Zone	Month	Hectares	Fish/Ha	½ 95% CI	Total Number	½ 95% CI
BRZ	4	23	0.0	0.00	0	0.0
BRZ	5	25	1.5	1.90	39	47.6
BRZ	6	27	10.8	7.86	291	212.1
BRZ	7	27	13.7	9.63	371	259.9
BRZ	8	25	0.0	0.00	0	0.0
BRZ	9	21	21.7	31.56	455	662.7
BRZ	10	17	56.4	42.08	959	715.4
BRZ	11	14	31.0	21.77	434	304.8
BRZ	12	12	46.2	31.41	554	376.9
Confluence	4	165	9.4	10.96	1552	1808.4
Confluence	5	172	1.8	1.79	302	308.2
Confluence	6	174	1.2	1.47	210	256.1
Confluence	7	172	2.9	3.21	493	551.6
Confluence	8	164	2.3	2.11	371	345.9
Confluence	9	146	9.5	5.63	1393	821.7
Confluence	10	147	6.5	6.01	957	883.9
Confluence	11	132	15.1	6.79	1994	896.6
Confluence	12	108	32.7	19.67	3529	2123.9
Middle Reservoir	4	204	11.9	14.84	2421	3028.1
Middle Reservoir	5	212	0.8	1.08	165	230.0
Middle Reservoir	6	215	0.3	0.46	72	99.1
Middle Reservoir	7	213	4.1	3.28	881	699.5
Middle Reservoir	8	202	2.9	2.17	577	438.7
Middle Reservoir	9	180	16.2	6.74	2909	1214.0
Middle Reservoir	10	182	15.9	8.34	2893	1517.7
Middle Reservoir	11	163	29.1	10.89	4737	1774.7
Middle Reservoir	12	127	32.5	11.29	4131	1433.7
Upper East Arm	4	21	0.0	0.00	0	0.0
Upper East Arm	5	24	58.4	39.19	1401	940.6
Upper East Arm	6	26	6.4	8.90	167	231.4
Upper East Arm	7	27	9.5	18.69	257	504.6
Upper East Arm	8	24	1.2	2.44	30	58.5
Upper East Arm	9	18	47.7	33.01	858	594.2
Upper East Arm	10	19	25.1	22.85	477	434.1
Upper East Arm	11	13	172.5	84.34	2242	1096.4
Upper East Arm	12	6	57.4	62.66	344	375.9
Upper Reservoir	4	37	4.0	7.90	149	292.4
Upper Reservoir	5	52	2.8	3.94	145	204.8
Upper Reservoir	6	55	4.6	9.03	253	496.6
Upper Reservoir	7	57	18.1	15.04	1029	857.2
Upper Reservoir	8	50	9.3	7.92	466	396.2
Upper Reservoir	9	41	34.7	25.16	1423	1031.7
Upper Reservoir	10	33	18.4	16.57	608	546.9
Upper Reservoir	11	23	38.7	26.95	890	620.0

Table C.2. List of Density Estimates (fish per hectare) and Total Numbers of Fish Acoustically Classified as being >200 mm Long by Month

Month	Hectares	Fish/Ha	½ 95% CI	Fish	½ 95% CI
4	450	9.16	2.46	4122	2166
5	485	4.23	0.40	2052	377
6	497	2.00	0.25	993	242
7	496	6.11	0.64	3031	623
8	465	3.11	0.39	1444	355
9	406	17.34	1.26	7039	1005
10	398	14.81	1.48	5894	1156
11	345	29.85	1.96	10297	1324
12	253	33.83	3.35	8559	1662

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