US Army Corps
of Engineers ®
Portland District

FINAL REPORT

HORIZONTAL AND VERTICAL DISTRIBUTION OF JUVENILE SALMONIDS IN THE COLUMBIA RIVER IN RELATION TO TOTAL DISSOLVED GAS

Prepared by:
U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory

March 2000

HORIZONTAL AND VERTICAL DISTRIBUTION OF JUVENILE SALMONIDS IN THE COLUMBIA RIVER IN RELATION TO TOTAL DISSOLVED GAS

Prepared by:

Dan H. Feil
and
Dennis W. Rondorf

U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501A Cook-Underwood Road
Cook, WA 98605

Prepared for:

U.S. Army Corps of Engineers
Portland District
P.O. Box 2946
333 SW First Ave.
Portland, OR 97208-2946

Project Code DGAS-97(2)-1
Contract Numbers E96960051 and E96970052

March 2000

Table of Contents

Executive Summary

Recently, spill has been provided to expedite the passage of juvenile salmon past hydroelectric dams in the Columbia River basin. Under spill conditions, juvenile salmon are expected to experience less direct mortality due to injury than if they pass through the turbines. However, additional indirect mortality during involuntary spill operations may occur due to the effects of total dissolved gas (TDG) supersaturation. Juvenile salmonids distributed at shallow depths ($\leq$4m) that are exposed to TDG levels ranging up to 140% may develop symptoms of gas bubble disease. The effects of gas supersaturation can be compensated for if juvenile salmonids near the surface are positioned about 1 m deeper for each 10% rise in TDG supersaturation over 100%. Therefore, determining near-surface fish distribution accurately is fundamental to understanding the observed occurrence of gas bubble disease and to modeling exposure and mortality of juvenile salmonids in relation to TDG.

We selected hydroacoustic surveys as our approach because it is a proven technology for determining the distribution of juvenile salmon. However, we were concerned about the precision and accuracy of depth estimates for individual fish in the upper 4 m of the water column because of the importance of the near-surface fish distribution in this particular application. The goals of our research in 1996 were to collect preliminary hydroacoustic data on fish distributions in McNary Reservoir, to evaluate the effects of wind generated surface noise on near-surface depth estimates of standard hydroacoustic targets equivalent in acoustic size to juvenile salmonids, and to evaluate methods of mobile hydroacoustic transducer deployment that would provide resolute near-surface estimates of fish distribution.

Standard hydroacoustic target tests were conducted to determine the near-surface detection rates and the accuracy and precision of depth estimates for two sizes of standard targets (-42 dB $\approx$ 145 mm fish; and -48 dB $\approx$ 69 mm fish) for four wind and wave height conditions. Generally, detection rates declined for standard targets located nearer the surface and as wind speed increased, especially for the smaller standard targets. Acceptable detection rates (80%) for the -42 dB standard target at 0.5 m depth were observed when wind speed was below 5 mph. However, as wind speed increased to 5-10 mph, the detection rate of the -42 dB standard target decreased to 35%. The detection rate of the -48 dB standard target at 0.5 m depth and 5-10 mph wind speed was 8%. A positive bias in the accuracy of standard target depth estimates was observed. This bias was attributed to a miscalculation of bottom depth in the hydroacoustic data acquisition software and was subsequently corrected by the manufacturer. Accuracy of standard target depth estimates for the -42 dB target ranged from +0.21 m to +0.37 m. Accuracy of standard target depth estimates for the -48 dB target ranged from +0.12 m to +0.26 m. Precision of standard target depth estimates for both sizes of targets remained very good under all test conditions, ranging from $\pm$0.04 m to $\pm$0.08 m.

In 1996, we sampled three reaches in McNary Reservoir using a hydroacoustic fish stock assessment system equipped with two transducers deployed in a down-looking/side-looking configuration. Sampling was conducted from June 19 to July 26, 1996, when numbers of migrating juvenile subyearling chinook salmon declined sharply. Distinct diel differences in

the vertical distribution of juvenile salmonids were observed in two of the three reservoir reaches. During daytime sampling of the lower reach of the reservoir, 25% of the fish detected were at ≤4 m in depth. However, during nighttime samples in the same reach, only 5% of the fish detected were at ≤4 m. Similarly, during daytime sampling of the middle reach of the reservoir, 17% of the fish detected were at ≤4 m with only 5% at ≤4 m in nighttime samples. Diel patterns of vertical distribution of juvenile salmonids in the upper reach of McNary Reservoir were significantly different from those observed in the lower and middle reaches. During daytime samples of the upper reach, 3% of the fish detected were at ≤4 m, while 4% were at ≤4 m during nighttime samples. In general, at lower and middle reservoir, sites that are the least riverine, a larger percent of fish were distributed at ≤4 m depth during daytime sampling.

We determined that a remotely operated vehicle (ROV) used as a mobile deployment platform for an up-looking transducer would enable us to collect near-surface fish distribution data with an adequate accuracy and precision to successfully characterize fish distribution in the upper 4 m of the water column. During 1997, our goal was to use the ROV mounted hydroacoustic system developed in 1996 to collect data in McNary Reservoir on the vertical and horizontal distribution of juvenile salmonids, especially near the surface. We also collected TDG data throughout McNary Reservoir to determine the influence elevated levels of TDG may have on juvenile salmonid distribution. Hydroacoustic surveys to determine vertical and horizontal fish distributions were conducted on McNary Reservoir from May 7-30, 1997. The surveys were divided into three time periods: early (May 7-12), middle (May 14-21), and late (May 28-30). We collected hydroacoustic data using stationary point sampling methods during the mid-May sampling period. Juvenile yearling chinook salmon and steelhead were the predominate species present in McNary Reservoir during the early and mid-May sampling periods, while subyearling chinook salmon were the dominate species present in the reservoir during the late-May sampling period.

In general, larger percentages of migrants were observed above the depth of compensation during daytime sampling. During early-May daytime sampling, we found that 23% near the WA shore, 33% near the center (CTR), and 18% of the total fish density near the OR shore was at or above the TDG compensation depth (2.0 m). However, during nighttime sampling, we found that only 14% near the WA shore, 20% at the CTR, and 9% of the total fish density near the OR shore was at or above the TDG compensation depth (2.0 m). During mid-May stationary point sampling, we found that 18% at WA shore, 39% at CTR, and 30% of the total fish density at the OR shore site was at or above the TDG compensation depth (2.0 m WA; 2.5 m OR/CTR) during the daytime. During nighttime sampling, 18% of the total fish density at the WA shore, 23% at the CTR, and 25% at the OR shore site were at or above the TDG compensation depth. During the late-May sampling period, when mostly subyearling chinook salmon were present in the reservoir, we found that 3% near the WA shore, 40% at the CTR, and 24% of the total fish density near the OR shore was at or above the TDG compensation depth (2.0 m). During nighttime sampling, we found that 19% near the WA shore, 23% at the CTR, and 28% of the total fish density near the OR shore was at or above the TDG compensation depth (2.0 m).

Total dissolved gas supersaturation had little effect on vertical fish distribution throughout the sampling season. Metrics to describe vertical fish distribution included the percent of total fish density at or above the TDG compensation depth, the percent of total fish density at or above 2 m, the percent of total fish density at or above 4 m, the percent of total fish density at or above 8 m, and the depth at which 80 percent of the total fish density occurred. Of 45 linear regressions used to regress metrics of vertical fish distribution on percent TDG supersaturation, only one significant relation was observed. During the early and mid-May sampling periods, a highly significant relation ($P \leq 0.01$) was observed between the 80th percentile fish depth (dependent) and the percent TDG (independent) at the OR shore, resulting in an r^2 of 0.28 (Appendix Table 3). No other relations between metrics describing vertical fish distribution and the percent TDG supersaturation were observed during hydroacoustic sampling in McNary Reservoir.

Seasonal trends in the vertical distribution of fish were evident during the early and mid-May sampling periods (14 days) when mostly yearling chinook salmon and steelhead were present in McNary Reservoir. The 80th percentile of fish depth shifted to shallower depths two of three sites between May 7 and May 21, 1997. Based on the regression of the 80th percentile of fish depth (dependent variable) on day of the month (independent variable) for each site, the predicted 80th percentile fish depth shifted 7 m shallower at the WA shore site and, 8 m shallower at the OR shore site during the two week period as the season progressed ($r^2 = 0.49$, $P < 0.01$ for the WA shore; $r^2 = 0.33$, $P < 0.01$ for the OR shore site). This shift in depth distribution may be concurrent with the progression of the smoltification and an increase in buoyancy of individuals in the smolt population.

Multiple-regression analyses were used to relate the cumulative percent of vertical fish density to the $\log_e(\text{depth}+1)$, diel period, sampling period, and location in the reservoir during the early and mid-May sampling periods in McNary Reservoir. The resulting predictive model was able to explain 84% of the variation in the cumulative percent of vertical fish density.

Acknowledgments

We thank Tom Backman of the Columbia River Inter-Tribal Fish Commission for the invitation to work on research topics related to the distribution of juvenile salmonids and gas supersaturation on the Columbia River. We express our gratitude to Dan Behlin, Tim Darland, Derrek Faber, Ian Jezorek, Tory Mason, Julie Parsons, John Plumb, Rob Reagan, Chris Rooper and our colleagues for their help in conducting experiments and assisting with the preparation of this report. We thank Rock Peters of the Environmental Resources Branch of the U.S. Army Corps of Engineers (COE) for his helpful suggestions concerning this project and its relation to the COE Gas Abatement Program. We are indebted to Randy Harris of the Bureau of Reclamation for his assistance with the remotely operated vehicle (ROV) and to Joe Carroll of the COE's Waterways Experiment Station for his assistance with dissolved gas meters. Funding was provided by the Bonneville Power Administration and the U.S. Army Corps of Engineers, Portland District, under contracts E96960051 and E96970052.

Suggested Citation Formats

Entire Report:

Feil, D.H., and D.W. Rondorf. 2000. Horizontal and vertical distribution of juvenile salmonids in the Columbia River in relation to total dissolved gas. Final report to the U.S. Army Corps of Engineers, Contracts E96960051 and 96970052, Portland, Oregon.

Chapter Within the Report:

Hanks, M.E., D.H. Feil, and D.W. Rondorf. 2000. Distribution of subyearling chinook salmon and total dissolved gas in McNary Reservoir. Pages 16-48 *in* D.H. Feil and D.W. Rondorf. Horizontal and vertical distribution of juvenile salmonids in the Columbia River in relation to total dissolved gas. Final report to the U.S. Army Corps of Engineers, Contracts E96960051 and 96970052, Portland, Oregon.

CHAPTER ONE

Near-Surface Detection and Depth Estimates of
Standard Hydroacoustic Targets Using Up-Looking Deployment Methods

by

Dan H. Feil and Dennis W. Rondorf

U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501A Cook-Underwood Road
Cook, WA 98605

Introduction

Juvenile salmonids distributed at shallow depths ($\leq$4 m) that are exposed to total dissolved gas (TDG) levels ranging up to 140% may develop symptoms of gas bubble disease. The effects of gas supersaturation can be compensated for if juvenile salmonids near the surface are positioned about 1 m deeper for each 10% rise in gas supersaturation (compensation depth). Therefore, determining near-surface fish distribution accurately is fundamental to understanding the observed occurrence of gas bubble disease (Backman et al. 1996) and to modeling exposure and mortality of fish in relation to TDG.

Hydroacoustic methods, used in the past by the U.S. Geological Survey, Biological Resources Division (USGS-BRD) in the Columbia and Snake rivers, are effective in determining the distribution of juvenile salmon. However, concern about the precision and accuracy of the estimated fish distribution in the upper 4 m of the water column was of great importance to this particular application. Although hydroacoustic assessment cannot provide individual exposure histories, it is an appropriate tool to assess the proportion of the smolt population above the compensation depth at any time during the diel period. Hydroacoustic assessments can also provide baseline vertical fish distributions that can be used to calibrate models developed to predict fish distribution and exposure to gas bubble disease. The hydroacoustic system used by USGS-BRD was designed to conduct mobile surveys and consisted of a down-looking dual-beam or split-beam transducer and a side-looking single-beam or split-beam transducer mounted on a towed platform deployed 1 m below the surface. The down-looking transducer sampled an area from 2 m below the surface to the bottom. The side-looking transducer sampled depth strata from 1 to 5 m deep. The multiplexing capability of the echosounder allowed both transducers to operate simultaneously.

The use of down and side-looking transducers, used in previous hydroacoustic surveys by the USGS-BRD, can also result in the fish being ensonified at many different angles or aspects. The aspect may vary from mostly dorsal aspect in the down-looking deployment to lateral or side, anterior, and posterior aspects when ensonified using the side-looking transducers. The maximum side-aspect target strength, reported in decibels (dB), is generally larger than the dorsal-aspect target strength, while posterior/anterior ensonification aspects result in the weakest target strengths (Love 1971). The acoustic scattering pattern, often termed directivity, usually indicates maximum reflectivity from dorsal and ventral aspects and minimum reflectivity from anterior and posterior aspects. The directivity patterns for small salmonids were generally lacking from the literature, although the patterns are well understood and available for larger salmonids (Dahl and Mathisen 1981) and other species. We recognized that the use of side-looking transducers near the surface in many cases results in ensonification of fish at an aspect with minimum reflectivity. Aspects of minimum reflectivity will result in weaker target strengths in the near-surface depth strata where surface “noise” can reduce the probability of identifying small targets as fish. Inasmuch as estimating fish distribution in near-surface depth strata was very important to the understanding of the occurrence of gas bubble disease in juvenile salmonids, we determined that dorsal/ventral ensonification aspects would provide the most reliable and comparable estimates of near-surface fish distribution.

Prior to the start of this study, proposal reviewers correctly indicated that most hydroacoustic systems had limited capability to detect fish near shore, near bottom, and near the surface of the water. This study has addressed some techniques to better assess near boundary distributions. In this case, we were not as concerned with near-bottom distributions because we have assumed the proportion of the juvenile salmonid population distributed near the bottom is small and unless near shore, generally far below the compensation depth for juvenile salmonids exposed to TDG supersaturation. Therefore, improvements in measuring the near-surface distribution of fish were of primary interest.

We found that an alternative to transducers mounted on boats, towed bodies, and fixed deployments, is to mount a transducer on a remotely operated vehicle (ROV) and ensonify fish near the surface from the ventral aspect. Deploying a transducer with a ROV reduced vessel avoidance, eliminated entanglement problems associated with towed platforms, and deployed the transducer such that the acoustic aspect was consistent for all fish in the sample (i.e., minimized side, anterior/posterior aspects). The objectives of the activities reported in this chapter were to: (1) determine the feasibility of using a ROV for deployment of an up-looking transducer, (2) estimate the probability of detecting small acoustic targets near the water surface, and (3) estimate the accuracy and precision of depth estimates of acoustic targets.

Methods

ROV Testing

Tests were undertaken to examine the feasibility of using a remotely operated vehicle (ROV) as a deployment platform for a hydroacoustic transducer to describe the distribution of juvenile salmonids near the reservoir surface. A Deep Ocean Engineering, Phantom 500 ROV was used to deploy a hydroacoustic transducer in the up-looking position to estimate target depth near the surface. This ROV had 16 kg of forward thrust, a top speed of 2.5 knots, and weighed approximately 35 kg (neutrally buoyant in water). A hydroacoustic transducer weighing 4 kg was attached to the ROV's protective frame with hose clamps. The transducer cable was attached to the ROV control cable and floatation was added to prevent the two cables from sinking to the bottom. Ping-pong balls were used as standard targets (-41 dB) and were suspended at the surface between floats and lead weights. The ROV was either maneuvered beneath the targets or the target arrays were towed over the ROV as it held position. The field trials were conducted in Grand Coulee Reservoir on 10 July 1996 with equipment and assistance (ROV/operator) provided by the Bureau of Reclamation at Grand Coulee Dam.

Standard Target Tests

We estimated the near-surface detection rates, depth, and target strengths of standard hydroacoustic targets under varying wind speeds and water surface conditions. Standard targets were suspended at four depths and data was collected using a hydroacoustic survey system under four wind speed and water surface conditions. These tests were conducted in Drano Lake, Washington adjacent to the Columbia River at river kilometer (Rkm) 261 from October 23 to November 22, 1996.

A net pen frame constructed of aluminum pipe and measuring 3.2 x 4.4 m with floats attached to each corner was deployed as a platform to suspend standard targets at various depths from the surface (Figure 1). This frame was anchored in place using 10 m of 6.4 mm cable attached to each corner of the frame and fastened to concrete anchors on the bottom of the lake, approximately 8 m deep at the location. Cross members equipped with sliding sleeves were placed across the frame to allow positioning of the targets in the acoustic beam.

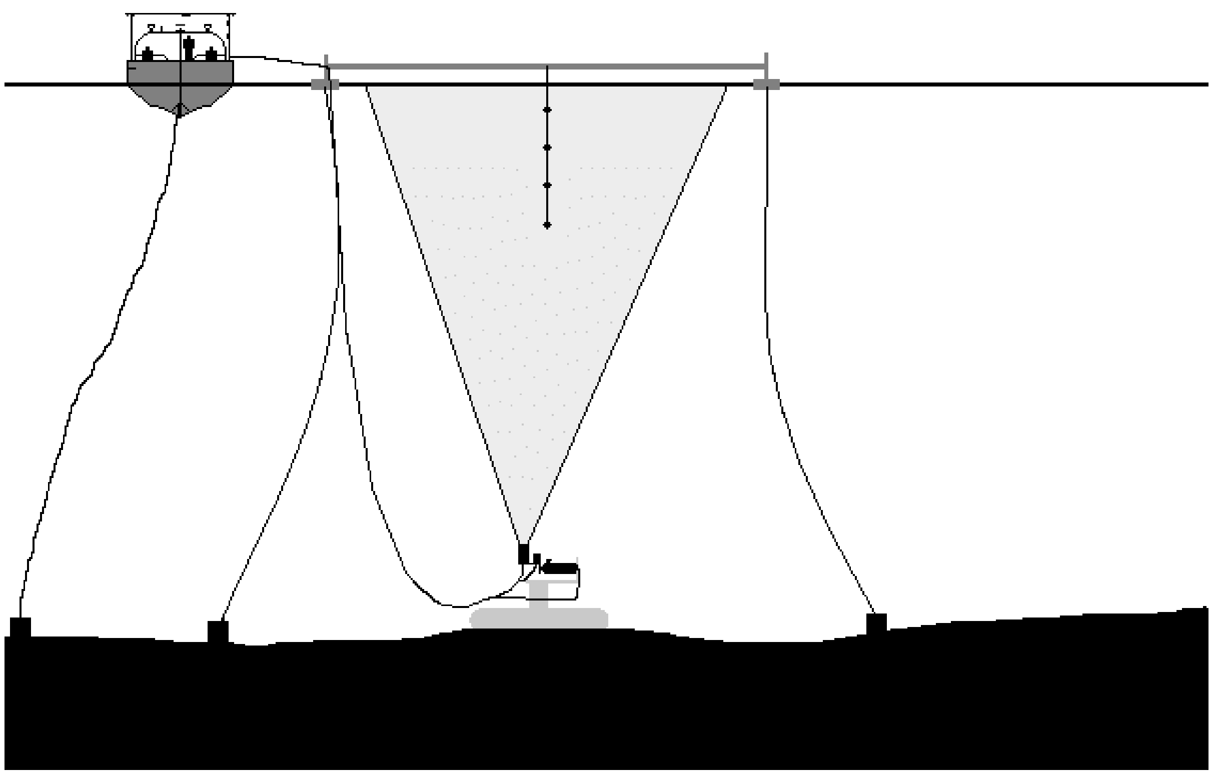


Figure 1.— Diagram of net pen frame and transducer assembly used to conduct detection and depth estimate tests.

High precision stainless steel balls were used as standard hydroacoustic targets for these tests. Balls measuring 25.40 mm in diameter with an approximate target strength of -42.0 dB and balls 12.69 mm in diameter with an approximate target strength of -48.0 dB were selected for the tests. The ball sizes were selected for their relative acoustic size to that of spring and summer migrating juvenile chinook salmon *Oncorhynchus tshawytscha*. At a frequency of 200 kHz, a target strength of -42 dB corresponds to a 145 mm fish, while a target strength of -48 dB corresponds to a 69 mm fish when ensonified in the dorsal aspect (Love 1971). Four balls were suspended 0.5 m apart at 0.5, 1.0, 1.5, and 2.0 m from the surface using a harness constructed of monofilament fishing line (Foote et al. 1987).

A hydroacoustic system was used to estimate depths and target strengths of the standard targets. The system used to make these measurements consisted of the following components: a Hydroacoustic Technology Inc. (HTI) model 243 split-beam digital echosounder operating at a frequency of 200 kHz, a 15° split-beam transducer, a digital audio tape (DAT) recorder and a laptop computer. The echosounder transmitted a signal at 10 pings/s with a 0.2 ms pulse length. Hydroacoustic data were recorded to the computer's hard drive as well as to DAT tape for data backup. Other components independent of the hydroacoustic system included a Remote Ocean Systems pan and tilt rotator used to aim the acoustic transducer and a Jasco Research Ltd. underwater tri-axial attitude measurement unit used to monitor the aiming angle of the transducer. Both of these instruments were controlled with a laptop computer. The transducer, rotator, and attitude measurement unit were all mounted on a stand and lowered to the bottom of the lake directly under the net pen frame. The transducer could then be aimed upward towards the surface using the rotator, while the aiming angle was monitored using the attitude measurement unit.

Each array of -42 dB and -48 dB standard targets were sampled at 5 min intervals over four different wind class categories; 0-5, 5-10, 10-15, and >15 mph. Wind speed was measured at 60 s intervals with a Davis electronic wind speed indicator and mean wind speed was used to categorize 5 min samples into the four wind classes. Wave height was also measured every 60 s. Echoes from each target were screened according to pulse length and distance from the acoustic axis. Due to the conically shaped acoustic beam, we assumed that if the target suspended at a depth of 2 m was in the beam and was detected, the targets suspended at 0.5, 1.0, and 1.5 m should have also been in the beam and been detected under ideal sampling conditions. To minimize detection biases that may have occurred when targets were outside of the acoustic beam, rather than in the beam and not detected, echoes from each ball were only accepted if the 2 m target was detected. The accuracy of standard target depth estimates was determined as the difference between the mean measured depth and the true depth of a standard target. The precision of depth estimates was determined as the standard deviation (SD) of mean depth estimates.

Results

ROV Testing

Target depth information was collected while testing the feasibility of using a ROV deployed acoustic transducer to determine near surface fish distributions. Mean target-to-target distance estimates acquired using the ROV mounted transducer measured 0.97 m ($N = 1102$; SD, 0.10) compared to a true distance of 1.1 m. The ROV used during these tests deployed the transducer sufficiently well to warrant use in hydroacoustic surveys during the spring of 1997 (see Chapter 3). However, a ROV used to determine fish distributions would need to be equipped with a pitch and roll indicator to monitor the attitude of the ROV and possibly a pitch and roll indicator and pan and tilt rotator to monitor and correct the aiming angle of the transducer, independent of the ROV. A ROV deployed from a boat to sample fish populations would also need to be equipped with a position locating system to provide the ROV operator with information about the ROV's position in relation to the deployment boat. Using a ROV locating system would enable the ROV operator to monitor the position of the ROV, keeping it at a known distance ahead or to the side of the deployment boat, while the boat operator locates and navigates transects using a global positioning system (GPS).

Detection of Standard Targets

We expected that as a standard hydroacoustic target was located nearer the surface or as acoustic noise increased due to wind induced turbulence, the targets would be more difficult to detect and become indistinguishable from surface noise. Furthermore, relatively small acoustic targets (i.e., small fish) would be increasingly difficult to separate from noise as target acoustic size and ambient noise converged. This was observed in all but three of the 24 test conditions. The first exception was observed when the detection rate of the -42 dB target at 1.0 m was 3% higher than the detection rate observed for the target at 1.5 m in the 0-5 wind class. The second exception occurred when the detection rate of the -42 dB target at 1.0 m and 10-15 mph had a 5% greater detection rate than the target at 1.0 m and 5-10 mph. The third exception occurred when the detection rate of the -42 dB target at 1.5 m in the 10-15 mph class was 2 and 5% greater than for targets at the same depth at 0-5 and 5-10 mph, respectively (Figure 2A; Table 1).

Detection rates of -42 dB standard hydroacoustic targets generally decreased nearer the surface as wind speed increased. In detection tests performed over the four wind classes, we found that the detection rates of a -42 dB (fish size $\approx$ 145 mm) standard target suspended 1.5 m from the surface ranged from 96% at the 0-5 mph wind class to 53% at >15 mph. Detection rates of a -42 dB target suspended 1.0 m from the surface ranged from 99% at the 0-5 mph wind class to 17% at >15 mph. Detection rates of a -42 dB target 0.5 m from the surface ranged from 80% at the 0-5 mph wind class to 0% at >15 mph (Figure 2A; Table 1).

Detection rates of standard hydroacoustic targets at the relatively small target size of -48 dB (fish size $\approx$ 69 mm) were generally lower than -42 dB targets at a corresponding wind speed and decreased near the surface at all wind conditions. Detection rates of the -48 dB target suspended 1.5 m from the surface ranged from 99% at the 0-5 mph wind class to 0% at >15 mph. Detection rates of a -48 dB target suspended 1.0 m from the surface ranged from 69% at the 0-5 mph wind class to 0% at >15 mph. The -48 dB target suspended 0.5 m from the surface was only detected at the 5-10 mph wind class 8% of the time (Figure 2B; Table 1).

Initially, we believed that the arrangement of the standard targets directly in line with one another may have produced a "shadowing effect", thereby reducing the detection rates of targets farther from the transducer (nearer the surface). The effect of this condition would be indistinguishable from no detection caused by surface noise or movement of the target out of the beam.

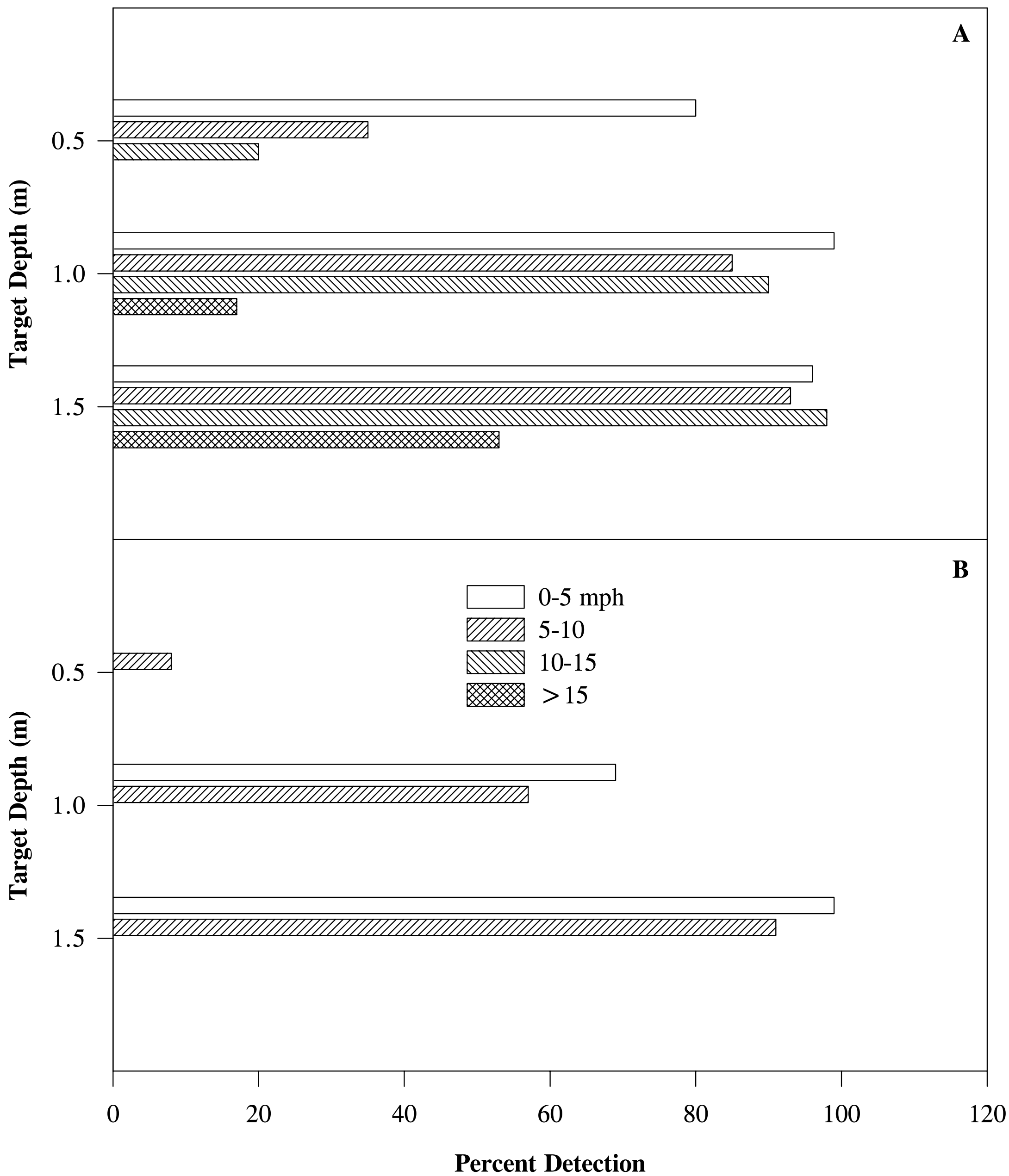


Figure 2.— Percent detection of (A) −42.0 dB targets and (B) −48.0 dB targets placed at 0.5, 1.0, and 1.5 m from the surface under different wind speeds in miles per hour (mph).

In theory, if shadowing did occur, the target strengths of each target should decrease slightly for each target from closest to farthest target from the transducer (MacLennan 1989).

Based on mean target strength results, shadowing could only have occurred with the -42 dB targets at the 0-5 mph wind class (Figure 3A). Target strengths were significantly smaller (ANOVA; $P < 0.05$) at shallower depths for this particular wind speed however, no other example of the shadowing was evident in target strength data for the -42 dB target at other wind speeds or with the smaller -48 dB targets (Figures 3A, 3B). The possibility that shadowing had biased the detection rates was remote, considering that the expected effect was only observed for one target size in one wind class.

Table 1.— Detection rates of –42.0 dB and –48.0 dB standard targets at three depths and four wind speed classes.

True	Wind class (mph)			
depth (m)	0-5	5-10	10-15	>15
		-42 dB percent detection		
0.5	80%	35%	20%	0%
1.0	99%	85%	90%	17%
1.5	96%	93%	98%	53%
		-48 dB percent detection		
0.5	0%	8%	0%	0%
1.0	69%	57%	0%	0%
1.5	99%	91%	0%	0%

Depth Accuracy and Precision

The accuracy of standard target depth estimates was defined as the difference between the mean measured depth and the true depth of a standard target. This difference was expected to become more variable or greater as wind speed increased due to increased wave height. Mean depth estimates of -42 dB standard targets were observed to be greater than the true depth for all test conditions, indicating a positive bias in the estimates. Accuracy of mean depth estimates for -42 dB standard targets suspended at 2.0, 1.5, 1.0, and 0.5 m from the surface for all wind classes ranged from +0.21 m to +0.37 m. Accuracy slightly decreased (larger difference) as wind speed increased from 0-5, 5-10, and 10-15 mph wind classes as expected, however greatest accuracy was observed at the >15 mph wind class (Figure 4A; Table 2).

A positive bias in the accuracy of mean depth estimates was also observed for -48 dB standard targets. Accuracy of mean depth estimates for -48 dB standard targets suspended 2.0, 1.5, 1.0, and 0.5 m from the surface for all wind classes ranged from +0.12 m to +0.26 m . Accuracy did not follow the expected pattern as wind speed increased. Greatest accuracy was observed at the >15 mph wind class (Figure 4B; Table 2).

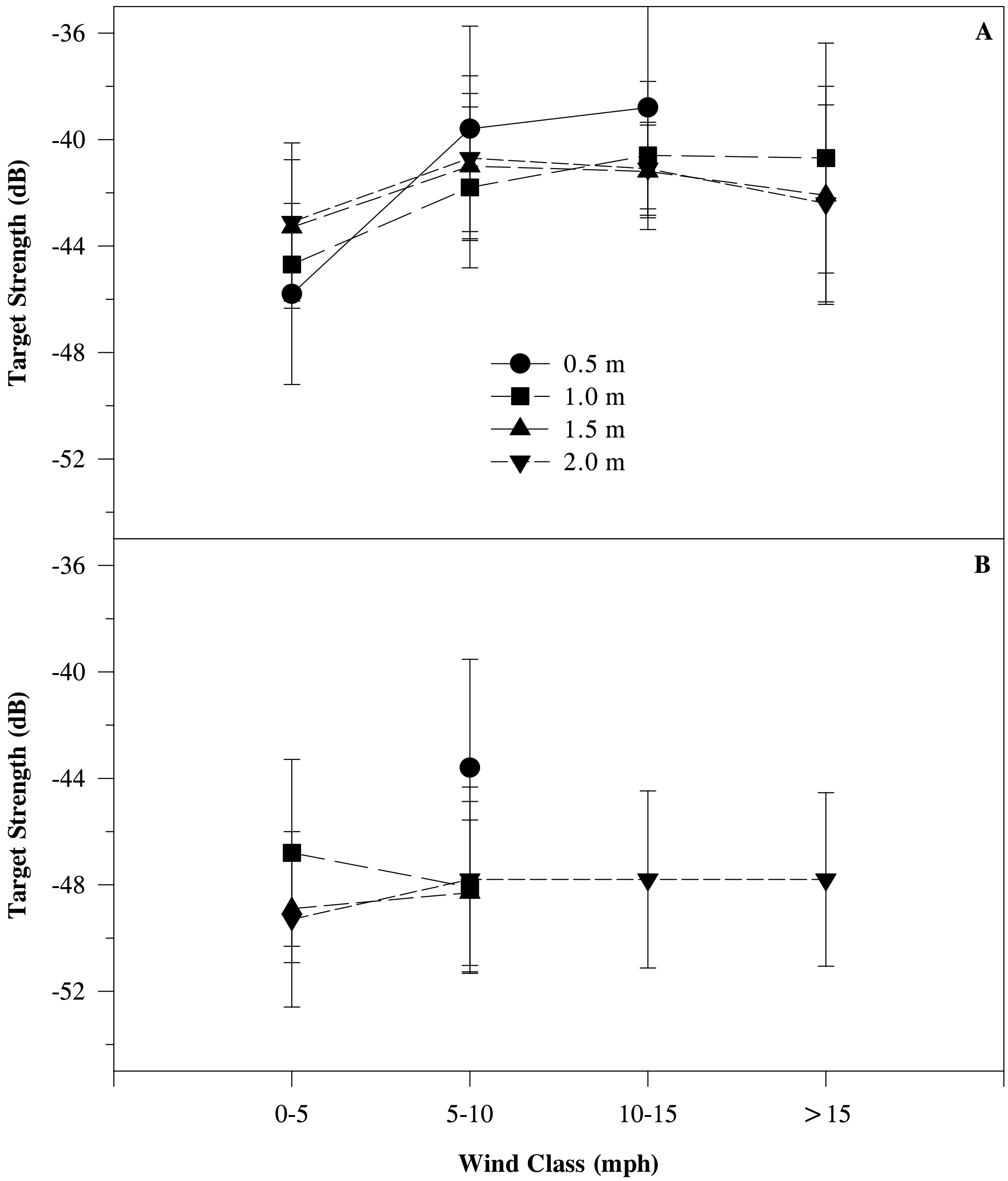


Figure 3.— Mean target strength measurements of (A) -42.0 dB targets and (B) -48.0 dB targets placed at 0.5, 1.0, 1.5, and 2.0 m from the surface under different wind speeds in miles per hour (mph). Symbols represent means and vertical lines represent $\pm$ 1 SD.

The precision of standard target mean depth estimates (i.e., the closeness of repeated measures) was defined as the standard deviation (SD) of mean depth estimates. Standard deviations were expected to become greater or more variable as wind speed and wave height increased. Precision of mean depth estimates for -42 dB standard targets did not follow the expected pattern of becoming more variable as wind speed increased. Precision of mean depth estimates for -42 dB standard targets suspended at 2.0, 1.5, 1.0, and 0.5 m from the surface for all wind classes ranged from 0.04 m to 0.08 m (Figure 4A; Table 2).

Likewise, precision of mean depth estimates for -48 dB standard targets did not increase in variability as wind speed increased. Precision of mean depth estimates for -48 dB standard targets suspended at 2.0, 1.5, 1.0 and 0.5 m from the surface at all wind classes ranged from 0.05 m to 0.08 m (Figure 4B; Table 2).

Table 2.— Mean depth estimates, precision (SD) and accuracy {mean-true} of -42 dB and -48 dB standard targets at four depths and four wind speed classes.

True	Wind class (mph)			
depth (m)	0-5	5-10	10-15	>15
		-42 dB mean depth estimates		
0.5	0.78(0.04){0.28}	0.80(0.07){0.30}	0.84(0.06){0.34}	No detection
1.0	1.30(0.04){0.30}	1.33(0.07){0.33}	1.37(0.05){0.37}	1.23(0.08){0.23}
1.5	1.78(0.04){0.28}	1.80(0.07){0.30}	1.85(0.06){0.35}	1.71(0.07){0.21}
2.0	2.29(0.04){0.29}	2.32(0.07){0.32}	2.36(0.06){0.36}	2.23(0.07){0.23}
		-48 dB mean depth estimates		
0.5	No detection	0.65(0.06){0.15}	No detection	No detection
1.0	1.25(0.08){0.25}	1.16(0.05){0.16}	No detection	No detection
1.5	1.75(0.07){0.25}	1.69(0.05){0.19}	No detection	No detection
2.0	2.26(0.08){0.26}	2.20(0.05){0.20}	2.12(0.05){0.12}	2.12(0.07){0.12}

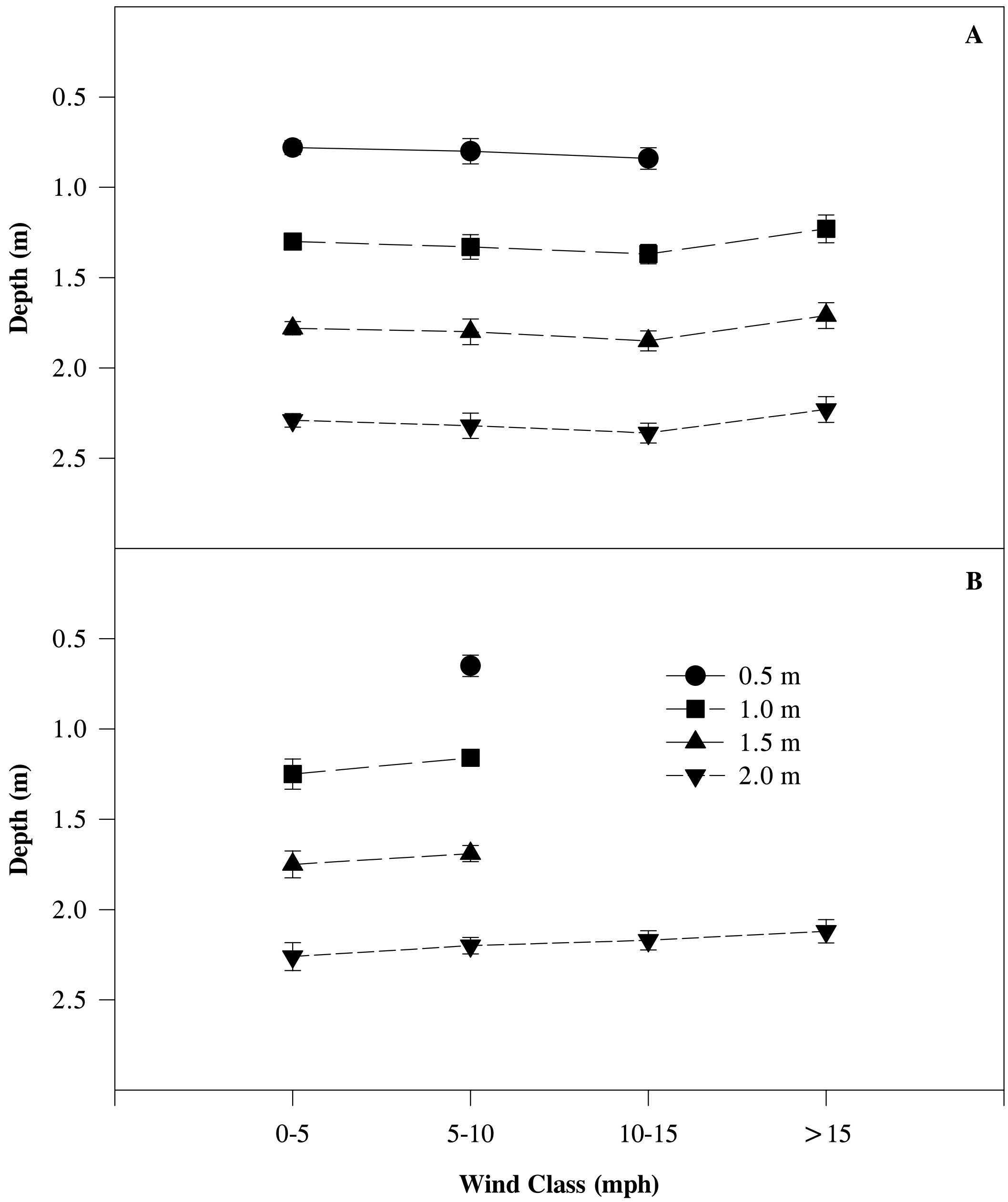


Figure 4.— Mean depth estimates of (A) -42.0 dB targets and (B) -48.0 dB targets placed at 0.5, 1.0, 1.5, and 2.0 m from the surface under different wind speeds in miles per hour (mph). Symbols represent means and vertical lines represent ± 1 SD.

Discussion

ROV Testing and Recommendations

Feasibility testing of using a ROV as a transducer deployment platform provided insight on the capabilities and limitations of using a ROV to determine near-surface vertical fish distribution. Mean measured target-to-target distance estimates were slightly less than true distances. These slight differences were likely a result of towing the targets over the ROV.

By towing the array of targets, drag imposed on the array caused the assembly to hang at an angle less than 90° vertical, thereby reducing the vertical distance between the ping-pong ball and lead weight. The ROV tested was quite capable of carrying the weight of a single acoustic transducer at speeds suitable for conducting mobile hydroacoustic surveys to determine fish distributions. Water velocities at the test site were comparable to velocities encountered in lower McNary Reservoir (<0.3 m/s), and did not hinder the performance of the ROV. Mounting additional transducers or sampling gear will require a larger, more powerful ROV, as would sampling areas with higher water velocities. Another factor that may limit the ROV's performance is the additional weight and drag of the transducer cable. The ROV umbilical or control cable was neutrally buoyant and did not significantly affect the maneuverability of the ROV, however, attaching the hydroacoustic transducer cable to the umbilical cancels the neutral buoyancy and roughly doubles its diameter. This had a definite effect on performance as the length of cable between boat and ROV increased. A custom built, neutrally buoyant umbilical with sufficient spare conductors to accommodate an acoustic signal was recommended for this application. However, a more expedient approach would be to encase the two cables in a braided cover and add floatation as needed to achieve neutral buoyancy. This option would also provide greater flexibility in terms of adding additional sampling gear to the ROV that require a communication cable.

Detection of Standard Targets

Detection rates generally followed the expected trend of decreasing nearer the surface as wind speed increased or target size decreased. In some cases, -42 dB targets located in shallower depth strata or under conditions of a higher wind class had a higher detection rate than the test condition with more ideal acoustic sampling conditions, but those differences were small, 2 to 5%. The differences in detection rates among targets at the same depth over different wind classes may be attributed to normal variations in surface noise. Surface noise can be highly variable and may not be related as closely to wind speed or direction at one particular moment, as it is to the duration that a given wind speed is sustained over time, giving surface waves and motion time to build. The unexpected result of a -42 dB target at 1.0 m being detected at a higher rate than the -42 dB target at 1.5 m for the same wind speed was not particularly alarming since the difference in detection rates was small, only 3%. Of greater importance were the high detection rates, 99 and 96%, of the 1.0 and 1.5 m targets at the 0-5 mph wind class.

Detection rates of -42 dB targets (fish size = 145 mm) suspended at 0.5 m dropped sharply as wind speed increased compared to targets suspended at 1.0 and 1.5 m. Detection rates of -42 dB targets at 1.0 and 1.5 m for <15 mph wind speeds were acceptable, at or above 85% however, once wind speeds exceeded 15 mph, the detection rate dropped to less than 55%. Targets at 0.5 m were detected at much lower rates (≤80%) for <15 mph wind speeds and not detected at all at the >15 mph wind class. Using up-looking techniques may still provide inaccurate estimates of fish distribution in the top 0.5 m of the water column. The low detection rates of 0.5 m targets points out one of the limitations that exist when using hydroacoustics to sample fish populations; detecting targets near (≤1 m) boundaries is very difficult (although may be remedied to some extent by transmitting at shorter pulse widths). This causes concern, as determining fish distribution in this part of the water column is of great importance in determining fish exposure to TDG. For fish sampling purposes, these results provide valuable information and will help to establish guidelines for making decisions in the field to discontinue sampling as wind speeds increase.

Detection rates of -48 dB targets (fish size ≈ 69 mm) were relatively low. Targets suspended at 0.5 and 1.0 m had detection rates of 69% or less at all wind speeds. At wind speeds >10 mph, none of the targets were detected. Given these detection rates, sampling populations of smaller fish in the upper 1.0 m of the water column equivalent to a -48 dB target could produce indeterminate distribution estimates even under ideal sampling conditions. Conner et al. (1991) found that juvenile fall chinook salmon in the Snake River move offshore and begin migrating downstream at approximately 85 mm in fork length (target strength = -46 dB at 200 kHz). Detection rates of these slightly larger targets, likely to be ensonified during hydroacoustic sampling in McNary reservoir in June and July, may be higher than rates observed for -48 dB targets. Also, some of the problems encountered detecting smaller targets near the surface may be rectified by transmitting at a higher frequency, such as 420 kHz. Using a higher frequency may enable us to separate targets that are nearer each other and increase the detection of smaller targets, though it may also be more susceptible to wind generated surface noise.

Depth Accuracy and Precision

Depth estimate data for both sizes of targets placed the targets deeper in the water column than their actual depth (Figures 4A, 4B). This error in accuracy was attributable to a miscalculation of bottom depth (surface in this case) in the data acquisition software (S.V. Johnston, HTI, personal communication). HTI has updated the software to correct the bottom depth measurement error.

The precision of depth estimates was expected to become more variable as wind speed, and hence wave height increased. The net pen frame was anchored to be vertically immobile and standard targets were suspended from the frame. We expected that as wave height increased, the water surface would be fluctuating up and down, independent of the targets, causing the variability of depth estimate precision to increase with wind speed. Overall, the precision of depth estimates for -42 dB targets was good, ≤ ±0.08 m (SD). Precision of depth estimates for -48 dB targets was also good, $\leq \pm 0.08$ m (SD) (Figures 4A, 4B; Table 2). The precision of depth estimates did not follow the expected pattern of becoming more variable as wind speed increased, in fact no apparent patterns in precision associated with wind speed were observed.

In summary, the tests conducted during this study provided a better understanding of the capabilities and limitations of the equipment that were used to assess near-surface fish distributions in 1997 (see Chapter 3). We recommended that a ROV be considered as a transducer deployment platform to determine near-surface fish distribution for the Dissolved Gas Abatement Study (DGAS) Program. However, for this deployment method to be successful, the ROV will need to be equipped with adequate attitude and positioning instrumentation. It is imperative to recognize that obtaining accurate fish distribution estimates at depths of ≤ 1 m will be difficult regardless of deployment technique. Compared to existing methods for deployment of hydroacoustic transducers, employing a ROV offers the greatest potential to more accurately assess undisturbed near-surface fish distribution using mobile hydroacoustics in reservoirs.

References

Backman, T.W.H., A.F. Evans, and M.A. Hawbecker. 1996. Symptoms of gas bubble trauma induced in salmon by total dissolved gas saturation of the Snake and Columbia Rivers, USA. Draft report contract no. 95BI39861 to the Bonneville Power Administration, Portland, Oregon.

Conner, W. P., H.L. Burge, and W.H. Miller. 1991. Rearing and emigration of naturally produced Snake River fall chinook salmon juveniles, Pages 86-116 *in* D.W. Rondorf and W.H. Miller, editors. Identification of the spawning, rearing and migratory requirements of fall chinook salmon in the Columbia River Basin. Report contract no. DE-AI79-91BP21708 to the Bonneville Power Administration, Portland, Oregon.

Dahl, P.H., and O.A. Mathisen. 1981. Measurements of acoustic backscattering directivity and target strength of salmonids. Final Report to Washington Department of Fisheries, Olympia, Washington.

Foote, K.G., H.P. Knudsen, G. Vesines, D.N. MacLennan, and E.J. Simmonds. 1987. Calibration of acoustic instruments for fish density estimation: A practical guide. ICES Coop. Res. Rep. No. 144.

Love, R.H. 1971. Dorsal-aspect target strength of an individual fish. The Journal of the Acoustical Society of America 49:816-823.

MacLennan, D. N. 1990. Acoustical measurement of fish abundance. The Journal of the Acoustical Society of America 87:1-15.

Thorne, R.E. 1983. Hydroacoustics. In: Fisheries Techniques pages 239-259 *in* L.A. Nielsen and D.L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, Maryland.

Thorne, R.E., C.J. McClain, J. Hedgepeth, E. S. Kuehl, and J. Thorne. 1992. Hydroacoustic surveys of the distribution and abundance of fish in Lower Granite Reservoir, 1989-1990. Final report contract no. DACW68-C-0022 to the Corps of Engineers, Walla Walla, Washington.

CHAPTER TWO

Distribution of Subyearling Chinook Salmon
and Total Dissolved Gas in McNary Reservoir

by

Michael E. Hanks, Dan H. Feil, and Dennis W. Rondorf

U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501A Cook-Underwood Road
Cook, WA 98605

Introduction

Uncontrolled spill at lower Snake and Columbia River hydroelectric dams can increase total dissolved gas supersaturation in the water to over 130% in the main stem river. Levels above 130% may result in gas bubble disease and are deleterious to resident fish (Dell et al. 1974; Weitkamp 1974), caged juvenile salmon (Ebel 1969; Ebel 1971; Meekin and Allen 1974; Weitkamp 1976; Blahm et al. 1976; Dawley 1986), and fish held in the laboratory (Weitkamp and Katz 1975). The degree of impact of total dissolved gas (TDG) levels above 110% on the survival of juvenile salmonids in the river remains controversial; higher levels are more harmful (Beiningen and Ebel 1970; Panel 1994), but the amount of additional risk is uncertain. Hydrosystem operators, fishery managers, and fishery researchers wish to identify this relation more precisely.

Gas supersaturation levels greater than 110% exceed the maximum standard for aquatic resources established by the U.S. Environmental Protection Agency, Washington State Department of Ecology, and Oregon State Department of Environmental Quality. The Biological Opinion for the operation of the Federal power system has directed the U.S. Army Corps of Engineers (COE) to implement a gas abatement program as noted in Reasonable and Prudent Alternative number 18 (NMFS 1995). In response, the COE, Portland District has developed a Dissolved Gas Abatement Study (DGAS) Program to modify the spillways at some dams and has identified the study of juvenile salmonid distribution as a part of their implementation of the Opinion. Furthermore, distribution of juvenile salmonids was identified as a priority in the National Marine Fisheries Service's Gas Bubble Disease Research Priorities (NMFS 1996).

The distribution of salmonids in the reservoirs is one of the determinants of the individual exposure history of juvenile salmonids to gas supersaturation and ultimately the development of gas bubble disease in fish. It is not known to what degree and how long the juvenile fish are exposed to elevated levels of dissolved gas, how the fish may compensate by changing depth (not necessarily in direct response to TDG), and how the dose-response physical variables and gas bubble disease are related. Fish can compensate for each 10% in TDG levels over 100% by moving about 1 m deeper in the water column. Therefore, most juvenile salmonids migrating in the Columbia River basin exposed to TDG <140% will have a depth of compensation of <4 m.

The alteration of rivers from riverine to slow-water habitats by the construction of hydroelectric dams has presented migratory salmonids with a different environment during the seaward migration. There is little data on the vertical distribution of juvenile salmonids in these relatively new environments within the Columbia River basin. In the Hanford Reach, a free flowing reach of the Columbia River, juvenile salmon migrated mostly in deep (up to 12 m) channels (Dauble et al. 1989). Smith (1974) found that combined catches at shallow and deep sites in Lower Monumental Reservoir indicated 58% of the juvenile chinook salmon *Oncorhynchus tshawytscha* and 36% of the steelhead *Oncorhynchus mykiss* were migrating in the upper 12 ft of the reservoir. Inferences about behavior and vertical migration cannot be drawn from studies at dams because the diel distribution of juvenile migrants changes as they approach main stem dams (Dawson et al. 1985; Thorne et al. 1992). Diel changes in vertical distribution of juvenile salmonids may be significant if a large percentage of the population of juvenile salmonids is above the depth of compensation.

The occurrence of gas bubble disease is presently being monitored as part of the Smolt Monitoring Program (SMP) at main-stem dams. Collection and bypass facilities may bias the observations for gas bubble disease by reducing bubbles through recompression or increasing gas bubble disease due to holding fish in shallow water prior to observations (Panel 1994). Juvenile fish facilities also include only those fish that are highest in the water column and guided into the juvenile fish collection system at the dam (Giorgi et al. 1988). If the guided fish are not representative of the populations, then the current monitoring program is inadequate for the purposes of determining the incidence of gas bubble disease. A need to compare the occurrence of gas bubble disease among juvenile salmonids in collection facilities at selected dams to fish collected from the river was identified. In response, T.W.H. Backman of the Columbia River Inter-Tribal Fish Commission (CRITFC) proposed to conduct biological sampling to determine the occurrence of gas bubble disease in juvenile salmonids in reservoirs for comparison to monitoring sites (Backman et al. 1996) and invited us to assess the distribution of fish. Implicit in Backman et al. (1996) is the assumption that sampling is representative of the population of juvenile salmonids in the reservoir. The objective of the portion of the study reported in this chapter was to collect preliminary data on fish distribution and TDG levels while Backman et al. (1996) sampled juvenile salmonids in reservoirs for the occurrence of gas bubble disease.

Methods

Hydroacoustic surveys were conducted on McNary Reservoir from June 19 to July 26, 1996 using a hydroacoustic fisheries assessment system and an acoustic Doppler current profiler (ADCP) deployed from a boat. Three reaches of the reservoir were selected for hydroacoustic sampling (lower, river kilometer (Rkm) 474.7-482.8; middle, Rkm 490.8-498.9; upper, Rkm 506.9-515; Figure 1). The lower reach was adjacent to Hat Rock State Park, Oregon and was characterized by a gradually sloping river bottom on the south side of the reservoir, a maximum depth of 40 m, and a moderately sloping bottom on the north side. The middle reach was located between Hat Rock State Park and the Port of Kelly, Washington and had a gradually sloping bottom along the south side, a maximum depth of about 35 m, and a sharply sloping bottom on the north. The upper reach was located between the Port of Kelly, Washington and the confluence of the Snake and Columbia rivers. It was characterized by a shallow shelf (<4 m) that extended about two-thirds of the way across the reservoir from the east side, a maximum depth of about 20 m, and a moderately sloping bottom along the west shore. Because of the bathymetry of the east side of this reach, we only sampled the area between the west shore and the west edge of the shallow shelf.

Locations of transects sampled within a reach were determined by randomly selecting the beginning transect. Cross-sectional transects spaced 161 m apart were sampled, starting at

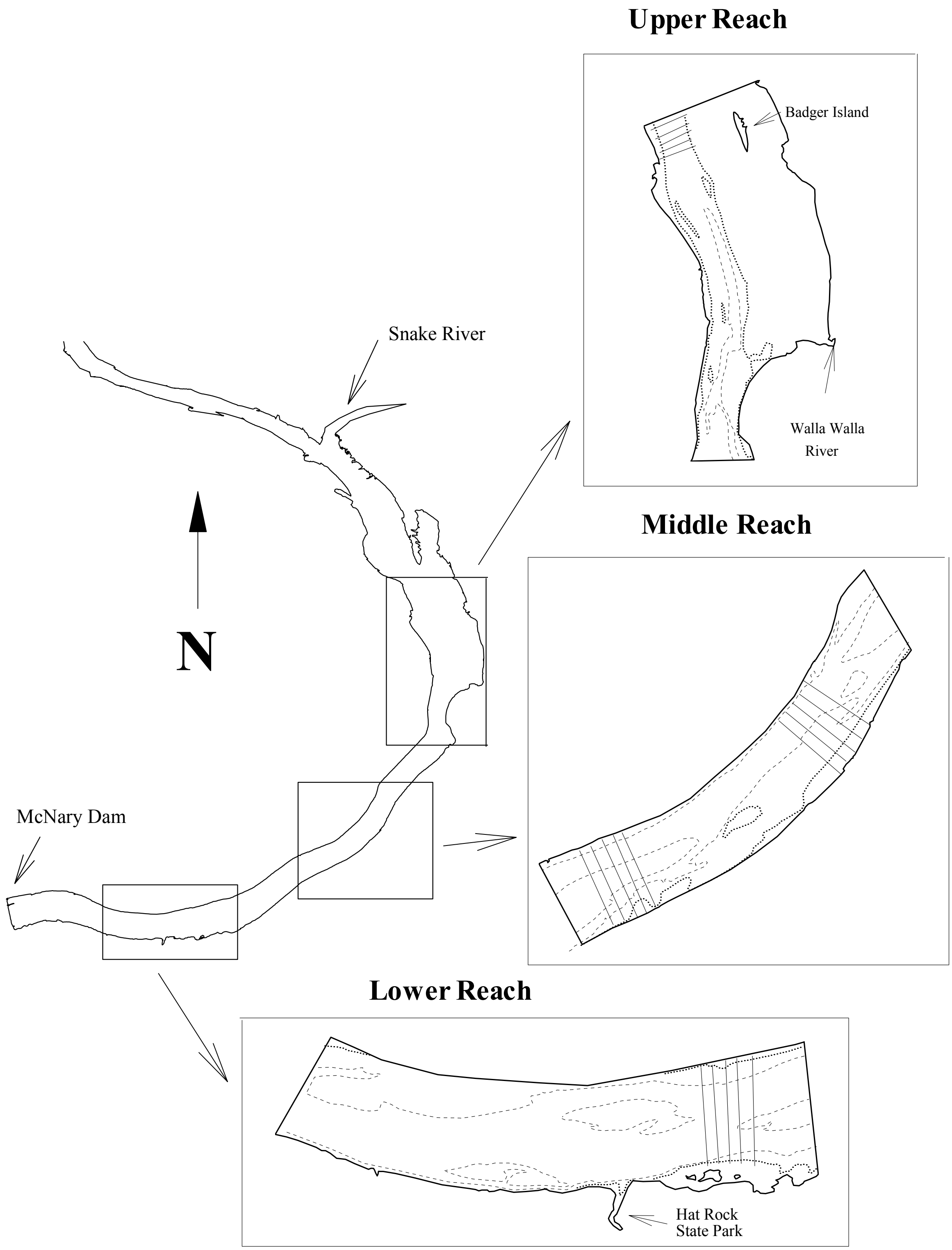


Figure 1.— McNary Reservoir with detail of the sites sampled with hydroacoustics during June and July, 1996. Depth contours are in 30 ft (dotted lines) and 60 ft (dashed lines) increments and transects are indicated by the straight cross-sectional lines.

the randomly selected transect and proceeding upstream until five transects were sampled. This design made it unlikely that fish detected during one transect would be detected in subsequent transects. The transects were repeatedly sampled in this manner over a 48-72 h period. A Trimble Navtrac XL global positioning system (GPS) unit was used for locating and navigating transects sampled with hydroacoustics.

Sampling effort was concentrated in the middle and upper reaches; the lower reach was only sampled when high wind and waves prevented sampling in the other reaches. We completed four surveys during the summer of 1996. The lower reach was sampled from Rkm 482.1-482.8 on June 19-21, 1996. We sampled two sections of the middle reach, from Rkm 491.6-492.3 on July 24-26, and from Rkm 496-496.6 on July 8-12, 1996. Finally, we sampled the upper reach once, from Rkm 511.3-511.9 on July 22-24, 1996.

Hydroacoustic data were collected using a BioSonics Inc. model ES2000 echosounder operating at 420 kHz. The echosounder transmitted a signal at 20 pings/s with a 0.4 ms pulse width. This signal was multiplexed between a dual-beam transducer (6°/15°) oriented vertically and an elliptical single-beam transducer (6° x 12°) oriented either 3° or 10° below horizontal, depending on wave induced surface noise. Both transducers were mounted on a towed platform and deployed one meter below the surface. This down-looking and side-looking configuration allowed simultaneous data collection through the two transducers, allowing better coverage in the upper water column than would be possible with a single down-looking transducer. Additional hydroacoustic equipment consisted of the following: a model 151 chart recorder, a model 111 thermal chart recorder, and a portable computer using ESP_Dbm version 3.2 software.

Water velocity information was collected using a 600 kHz ADCP. The ADCP ensonified small particles in the water column such as silt, plankton, and organic debris and measured the Doppler shift from the returned echoes off the particles within a specified depth stratum. ADCP data were collected in raw form and in a processed form that averaged 10 m segments in 0.5 m depth strata. Navigation data were collected directly from the Trimble GPS unit and recorded along with data from the ADCP, thus assigning each segment a discreet latitude and longitude.

To determine species composition of fish ensonified by the hydroacoustic system, we deployed a trawl net every 4 h in areas where high concentrations of fish were detected. The net was made of monofilament, had a 47 m^2 opening, and was equipped with a sanctuary type of cod-end to reduce injury to fish. Fish captured with the trawl net were identified to species and measured to the nearest millimeter in fork length (FL). Additional species composition data were collected by the CRITFC with a 5 m deep purse seine deployed within our sample areas in the lower and middle reaches.

Total dissolved gas levels were monitored during sampling periods using Common Sensing Inc. model TBO-L TDG monitors equipped with Common Sensing Inc. model DL3 data loggers. The monitors were placed in two small boats that were anchored along opposite shores at the upstream end of the section sampled with hydroacoustics. The boats were anchored in approximately 10 m of water and the gas detector probe was weighted and suspended 4.6 m below the surface. The data loggers were downloaded daily.

BioSonics Inc. ESP_Echo version 3.0 software was used to process the hydroacoustic data. A ping returned from a single object was referred to as an echo. A grouping of echoes that matched user-defined criteria was classified as a fish. The criteria used for dual-beam data were based on average target strengths ranging from -65 dB to -35 dB, a ping concentration between 0.35 and 1.0, a maximum offaxis of $\leq 3.75^{\circ}$ corresponding to -5 dB on the transducer directivity plot, and number of absolute echoes (ABS) at depth: ≥ 2 ABS at 0-10 m; ≥ 3 ABS at 10-20 m; ≥ 4 ABS at >20 m. Fish density was calculated for each ADCP segment using the number of fish detected and the volume of water ensonified by the acoustic beam for each 1 m strata and reported as the fish/10,000 m^3 of water ensonified.

Aerial or plan views of fish distribution within each reach were produced using an interpolation algorithm based on the kriging method (Cressie 1991). All depth strata ≤ 4 m and all depth strata >4 m were pooled for every transect within each reach. Four meters was selected because that depth was considered to be an adequate compensation for all TDG levels likely to occur at the study sites. Fish densities were calculated over the selected depth strata and adjusted for depth to obtain density on a square meter basis for each segment of each transect. Daytime and nighttime transects were separated, resulting in four data sets for each group of transects: fish/m^2 ≤ 4 m during daytime transects, fish/m^2 >4 m during daytime transects, fish/m^2 ≤ 4 m during nighttime transects, and fish/m^2 >4 m during nighttime transects.

In order to examine fish density in the nearshore areas relative to the center of the reservoir, we made plots of the horizontal distribution of fish densities. To produce these plots all transects were divided into segments equal to 10% of the total length of each transect, then pooled based on reach (or section of reach) and day or night time periods. Fish densities were calculated within each segment.

Results

Species Composition

Juvenile chinook salmon made up 99% of the trawl catch in McNary Reservoir surveys (Table 1). The average fork length of juvenile chinook salmon captured in samples was 94 mm (range 42 mm to 177 mm). Catch per trawl remained fairly constant throughout the sampling season. Juvenile chinook salmon comprised 99% of the catch in CRITFC purse seines. Natural production of chinook salmon occurred upstream of our study sites in the Hanford Reach of the Columbia River (Rkm 563-638). Hatchery releases from main stem Columbia River facilities totaling 10.88 million juvenile chinook salmon occurred from June 13-30, 1996 (Figure 2).

Table 1.— Percentage of juvenile chinook salmon caught in trawl and seining operations at hydroacoustic sampling sites on McNary Reservoir, June and July of 1996.

Diel period	Sampling method	Number of samples	River kilometer	Percent chinook
		Week 1 6/19/96 - 6/21/96		
	Shallow trawl	10	482.7	99.1
Day	Deep trawl	1	482.4	100
	Surface seine	9	483	100
	Shallow trawl	2	482.4	100
Night	Deep trawl	1	482.4	100
	Surface seine	6	483	100
		Week 2 7/8/96 - 7/12/96		
	Shallow trawl	4	496.2	100
Day	Deep trawl	0	-	-
	Surface seine	26	495.9	99.5
	Shallow trawl	3	496.2	98
Night	Deep trawl	5	496.2	100
	Surface seine	5	496.2	94.4
		Week 3 7/22/96 - 7/26/96		
	Shallow trawl	2	491.9, 511.5	100
Day	Deep trawl	2	511.5, 511.7	100
	Surface seine	0	-	-
	Shallow trawl	2	490.8, 511.7	96.5
Night	Deep trawl	3	511.2	100
	Surface seine	0	-	-

Total Dissolved Gas Monitoring

Total dissolved gas levels ranged from approximately 113-124% (Figures 3 and 4). We experienced some problems with malfunctioning data loggers, but with few exceptions at least one of the two units was always operating correctly during our sampling periods. When both data loggers were functioning, the maximum difference in TDG readings during any time period was 2%.

Fish Density

Fish density, the number of fish per unit volume of water ensonified, was estimated for the selected reaches of McNary Reservoir during the time periods sampled. Estimated fish density for all transects sampled during the daytime was 4.1 fish/10,000 m^3 of water. This was about 50% of the overall fish density of 8.1 fish/10,000 m^3 estimated for transects sampled at night.

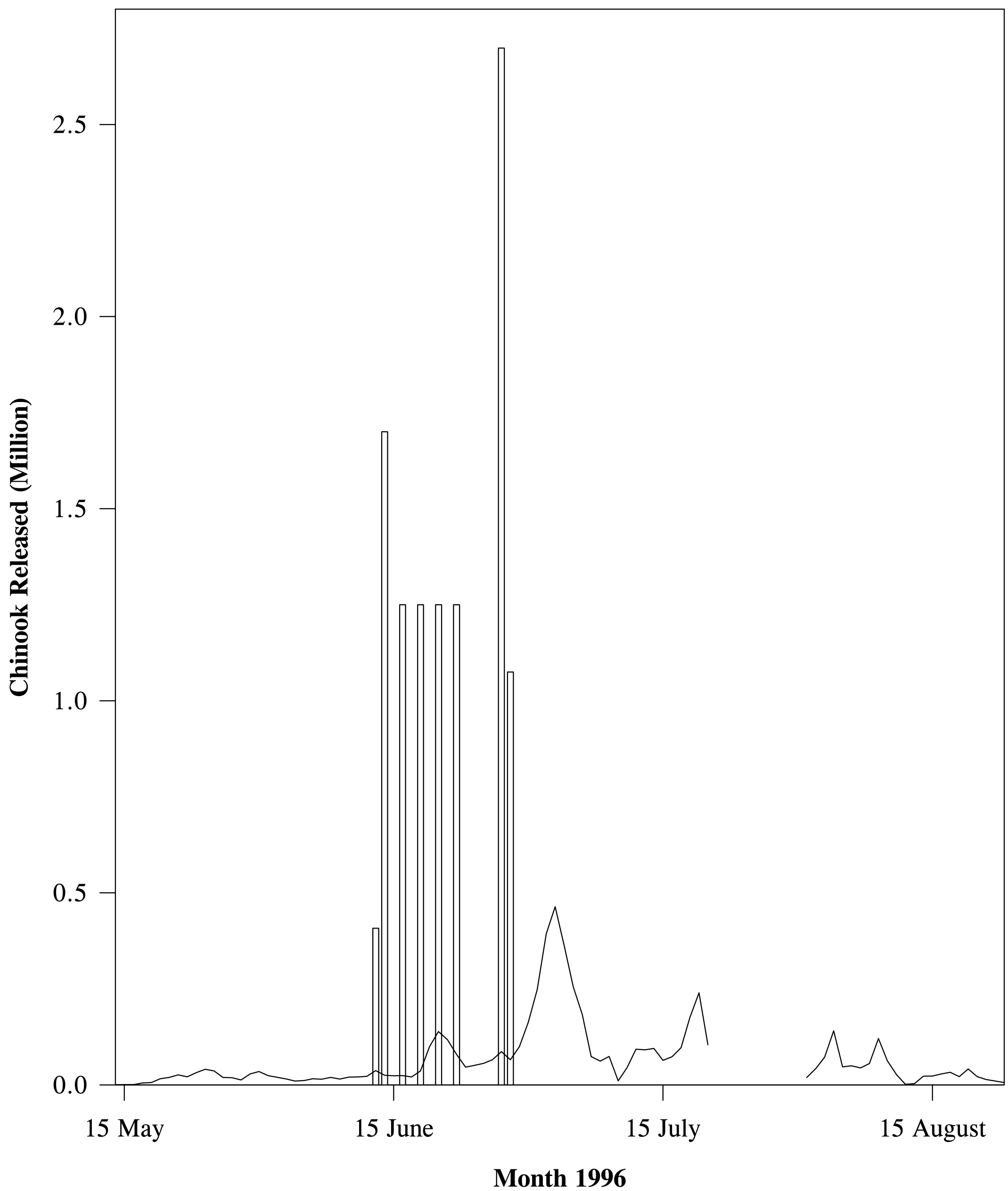


Figure 2.— Bars represent subyearling chinook salmon released from Priest Rapids, Turtle Rock, Wells, and Ringold Washington State hatcheries. Line represents the McNary Dam passage index for subyearling wild and hatchery chinook salmon.

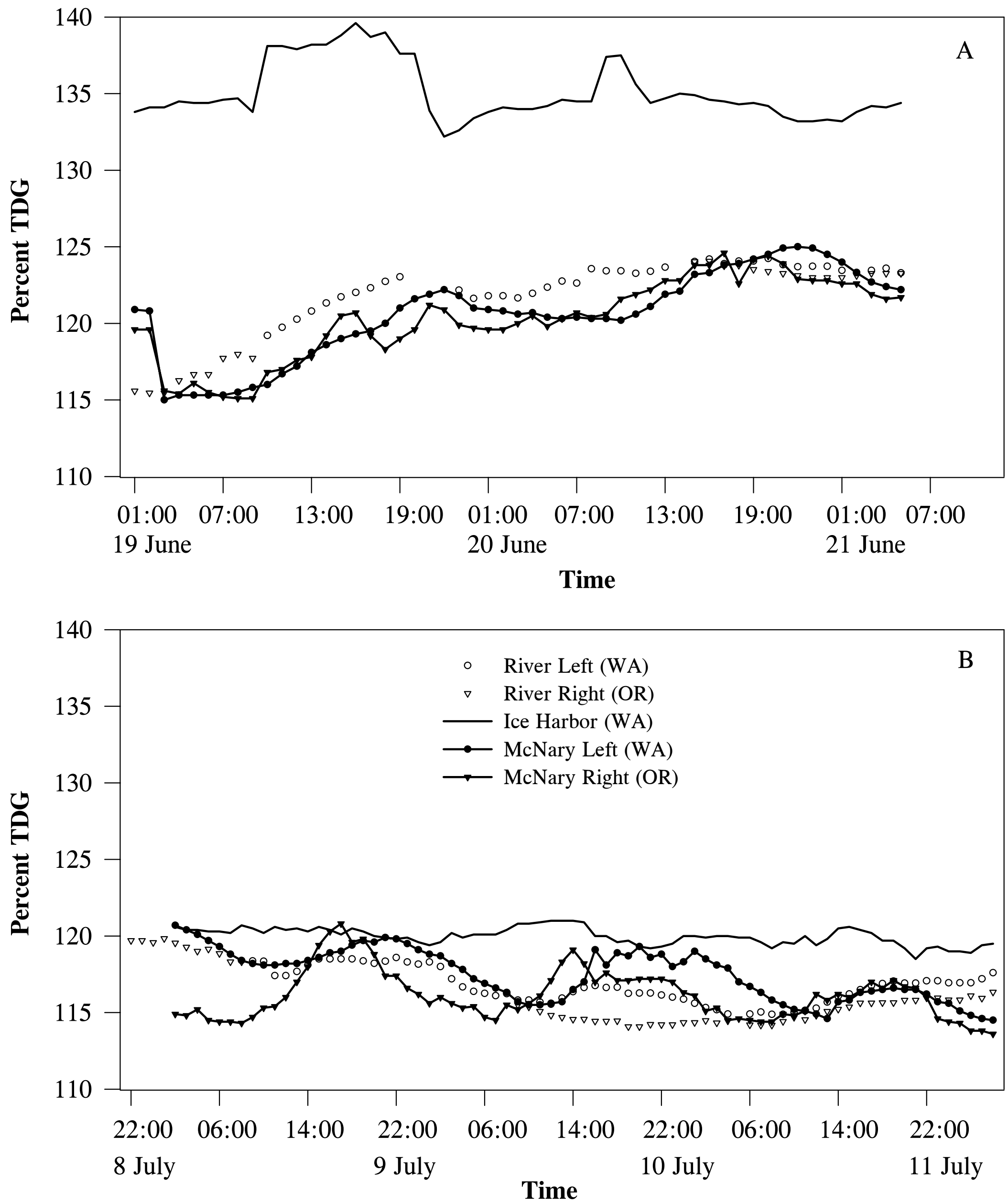
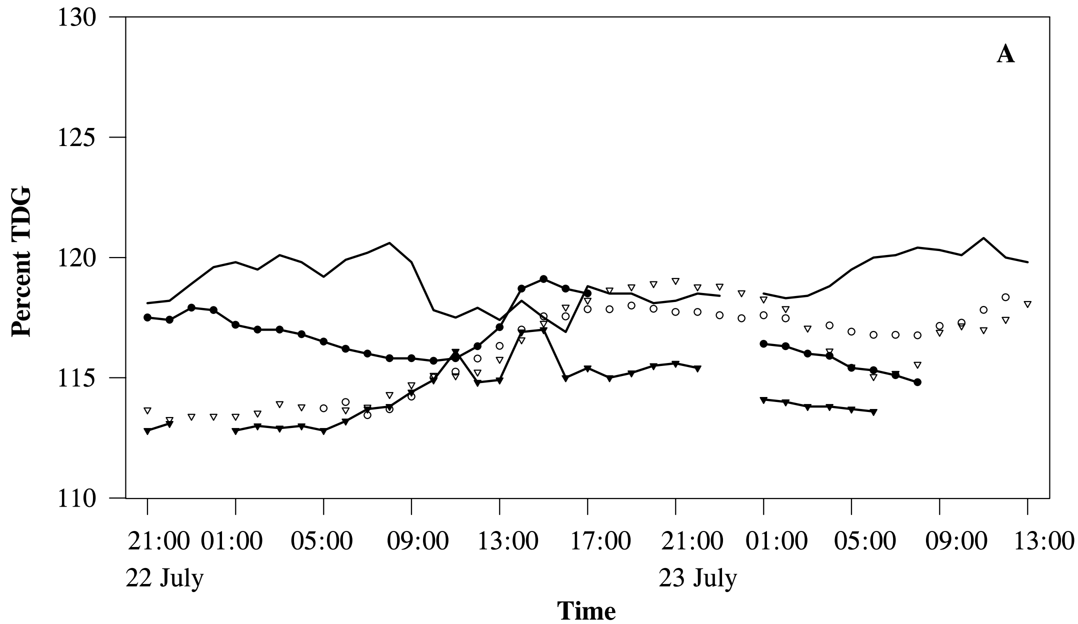


Figure 3.— Percent total dissolved gas levels (TDG) in the tailrace of Ice Harbor Dam, McNary Reservoir at (A) Rkm 482.5 and (B) Rkm 496, and the McNary Dam forebay during June 18-21, 1996 and Jul 8-12, 1996.



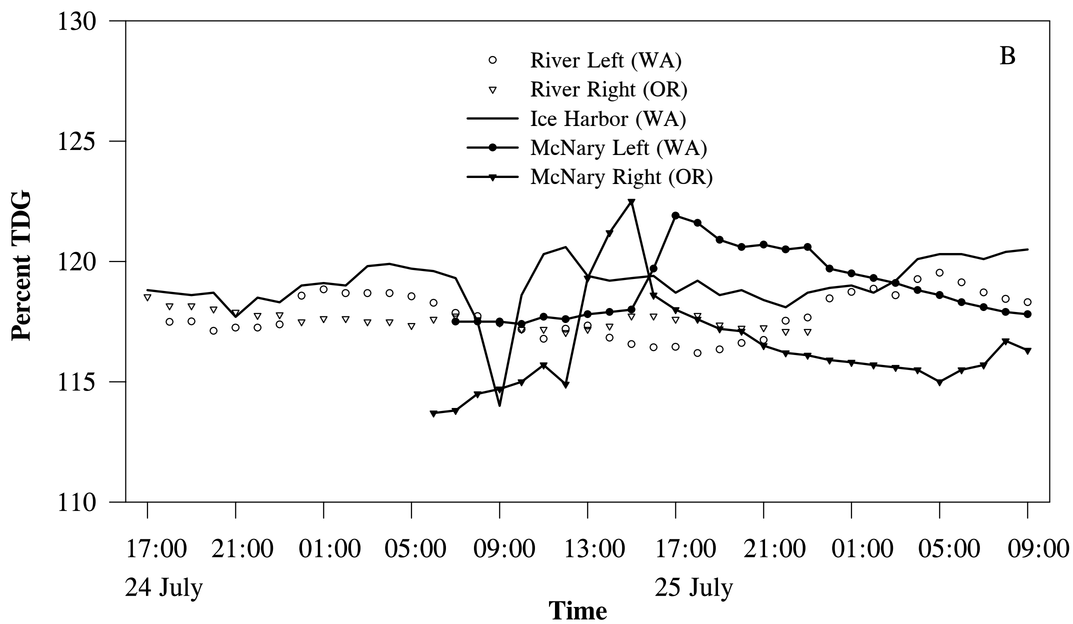


Figure 4.— Percent total dissolved gas levels (TDG) in the tailrace of Ice Harbor Dam, McNary Reservoir at (A) Rkm 511.8.5 and (B) Rkm 496, and the McNary Dam forebay during June 22-26, 1996.

We found fish density was relatively low in the lower and middle reaches compared to the upper reach (Table 2). Fish density was 1.9 fish/10,000 m^3 during daytime sampling and 4.7 fish/10,000 m^3 during nighttime sampling in the lower reach. In the first section of the middle reach, fish density was 2.1 fish/10,000 m^3 during daytime sampling and 5.8 fish/10,000 m^3 at night. In the second section of the middle reach, fish density was 3.2 fish/10,000 m^3 during the day and 7.0 fish/10,000 m^3 at night.

Fish density in the upper reach of the reservoir was much greater than in the other reaches, averaging greater than 14 fish/10,000 m^3. Fish density in the upper reach was 13.0 fish/10,000 m^3 during daytime sampling and 17.1 fish/10,000 m^3 during nighttime sampling. The difference between fish densities in the upper reach during daytime and nighttime sampling was relatively small, whereas the density in other reaches at night was about twice that of daytime fish densities.

Table 2.— Daytime and nighttime fish densities estimated using hydroacoustics in a lower, middle, and upper reach of McNary Reservoir, Columbia River.

Reach	Date	Daytime fish density (fish/10,000 m^3)	Nighttime fish density (fish/10,000 m^3)
Lower	June 19-21	1.9	4.7
Middle 1	July 24-26	2.1	5.8
Middle 2	July 8-12	3.2	7.0
Upper	July 22-24	13.0	17.1

Vertical Distribution

Vertical fish distribution in the lower and middle reaches had a consistent diel periodicity. About 19% of all fish detected during the day in the lower and middle reaches were at depths $\leq$4 m. At night, only about 5% of all fish detected were at depths of $\leq$4 m. Within the lower reach, 25% of all fish detected during the day were located at depths $\leq$4 m, while only 5% of the fish were near the surface at night (Figure 5). Within the two sections of the middle reach, percentage of fish detected $\leq$4 m from the surface were identical, with values of 17% during the day and 5% at night (Figures 6-7).

Patterns of diel vertical fish distribution in the upper reach differed from those of the lower and middle reaches. Fish detected in this reach were consistently deeper in the water column, regardless of time period. Only 3% of all fish detected during the day in the upper reach were located at depths $\leq$4 m, compared with 4% during the night (Figure 8).

The plan views of interpolated fish density were consistent with the vertical distribution histograms. Lower fish densities, represented by lighter blue, occurred during the day than during the night in the lower and middle reaches (Figures 9-11). Fish densities were similar during day and night samples in the upper reach. When examined in an aerial perspective or plan view, the relatively large proportion (97% daytime; 96% nighttime) below 4 m was evident by the numerous orange/red colored areas representing densities ≥ 8 fish/10,000 m^2 in Figure 12C, D.

Cross-sectional Distribution of Fish Density and Water Velocity

Differences in cross-sectional distribution of fish were also apparent when we compared the upper reach to the lower and middle reaches (Figure 13). Calculated densities within 10% of the shoreline at the beginning and end of the transects are represented by the 10% and the 100% intervals along the horizontal axes of Figures 13A-13F. The 50% interval indicates calculated densities in the center of the river. Fish densities estimated for the lower and middle reaches were skewed towards the shorelines, especially during the daytime (Figures 13C, 13D, 13E, 13F). Estimated fish densities in the upper reach were concentrated near the center of the river channel during both daytime and nighttime sampling periods (Figures 13A, 13B).

Differences in spatial and diel patterns of fish density were also observed in plan views of interpolated fish density. Higher fish densities, represented by colored shading, were observed near the shoreline during the day in the lower and middle reaches (Figures 9-11). During the night, areas of high fish density still occurred near the shoreline, with some additional high-density areas extending out into the center of the river. In the upper reach, most of the areas with high fish densities were near the center of the river, regardless of time period (Figure 12).

The distinct differences between fish distribution in the lower and middle reaches compared to the upper reach suggested the most obvious differences between the reaches depth and water velocity may play a determining role. Fish densities and water velocities for representative cross-sections from each reach were examined (Figures 14-19). These plots were in agreement with the previous observations that fish densities were higher during the night than during the day, and that fish were detected higher in the water column during the day than the night. They also show higher fish densities in the relatively shallow upper reach (Figures 18-19) than in the lower and middle reaches (Figures 14-17).

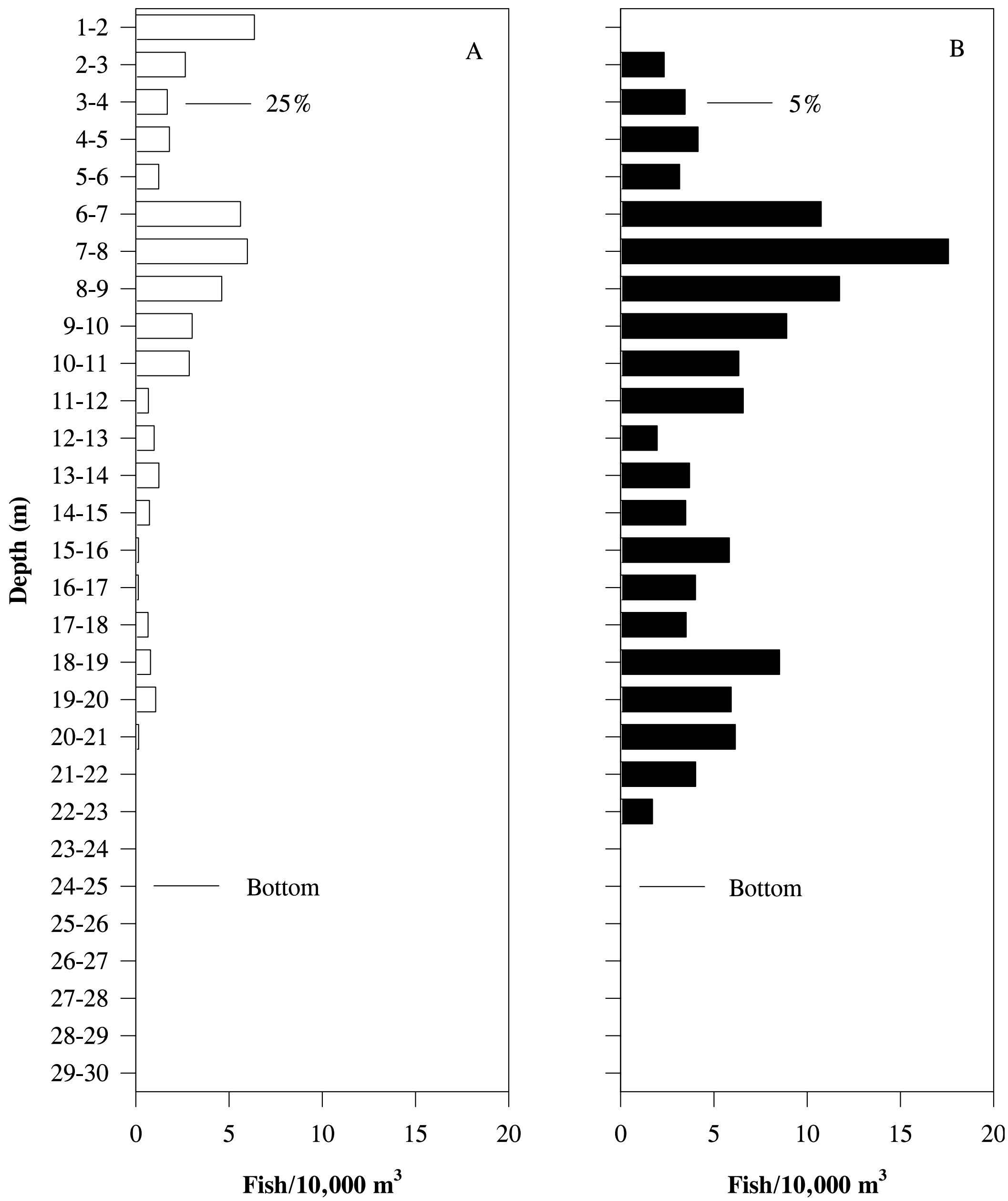


Figure 5.— Vertical fish distributions for Rkm 482.1-482.2 of the lower reach of McNary Reservoir for transects sampled during (A) the daytime and (B) the nighttime on June 19-21, 1996.

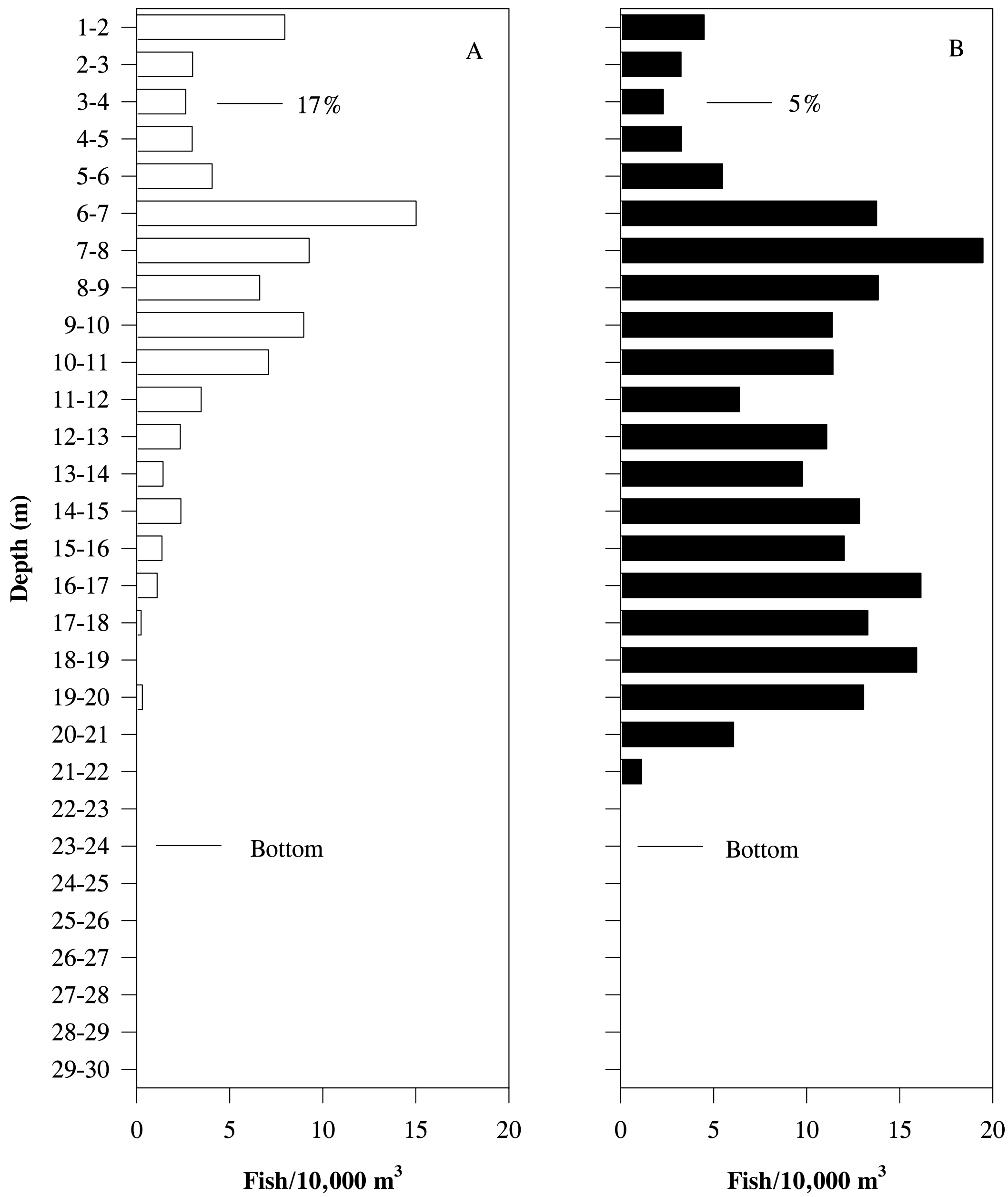


Figure 6.— Vertical fish distributions for Rkm 491.6-492.3 of the middle reach of McNary Reservoir for transects sampled during (A) the daytime and (B) the nighttime on June 24-26, 1996.

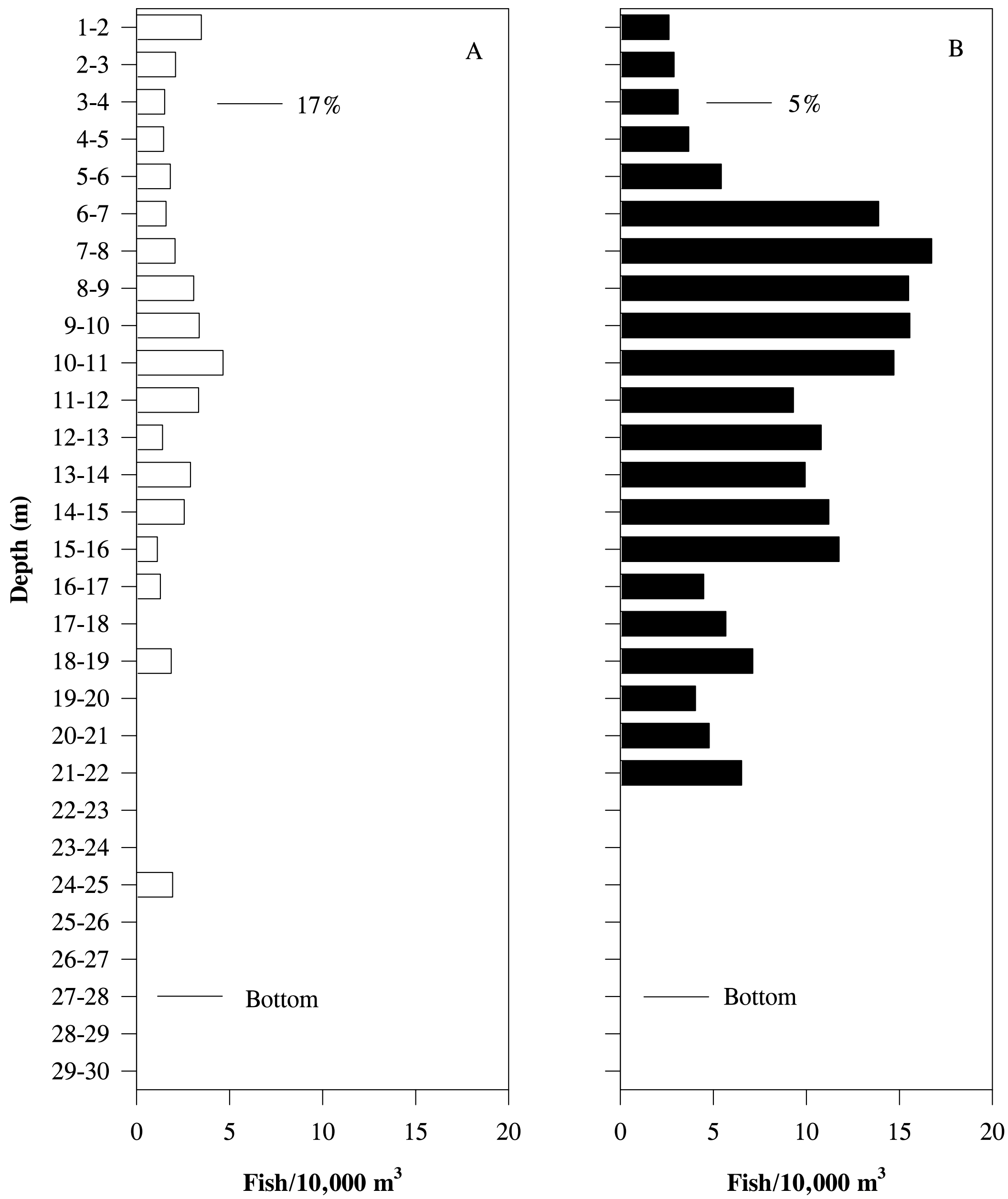


Figure 7.— Vertical fish distributions for Rkm 496-496.6 of the middle reach of McNary Reservoir for transects sampled during (A) the daytime and (B) the nighttime on July 8-12, 1996.

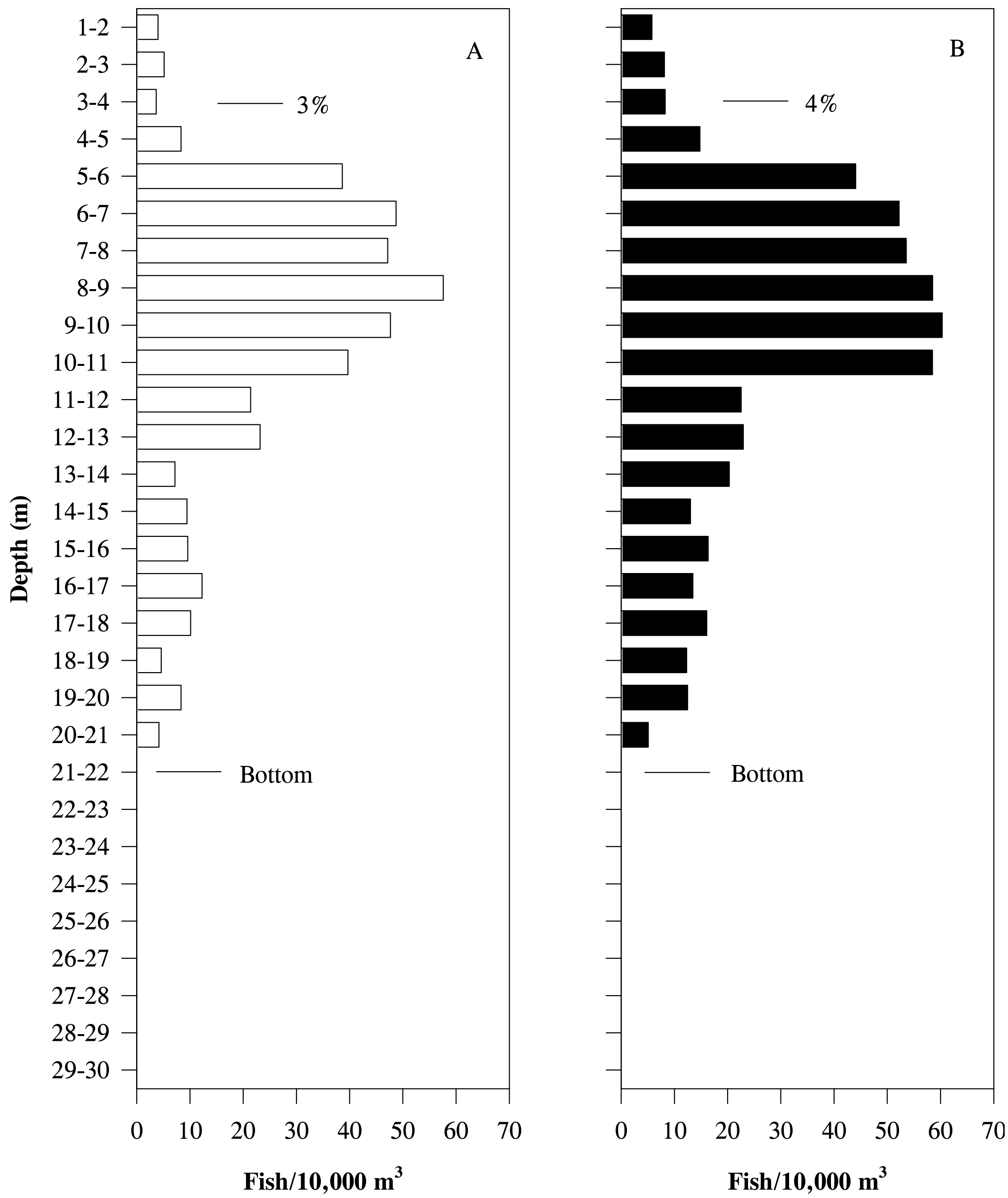


Figure 8.— Vertical fish distributions for Rkm 511.3-511.9 of the upper reach of McNary Reservoir for transects sampled during (A) the daytime and (B) the nighttime on July 22-24, 1996.

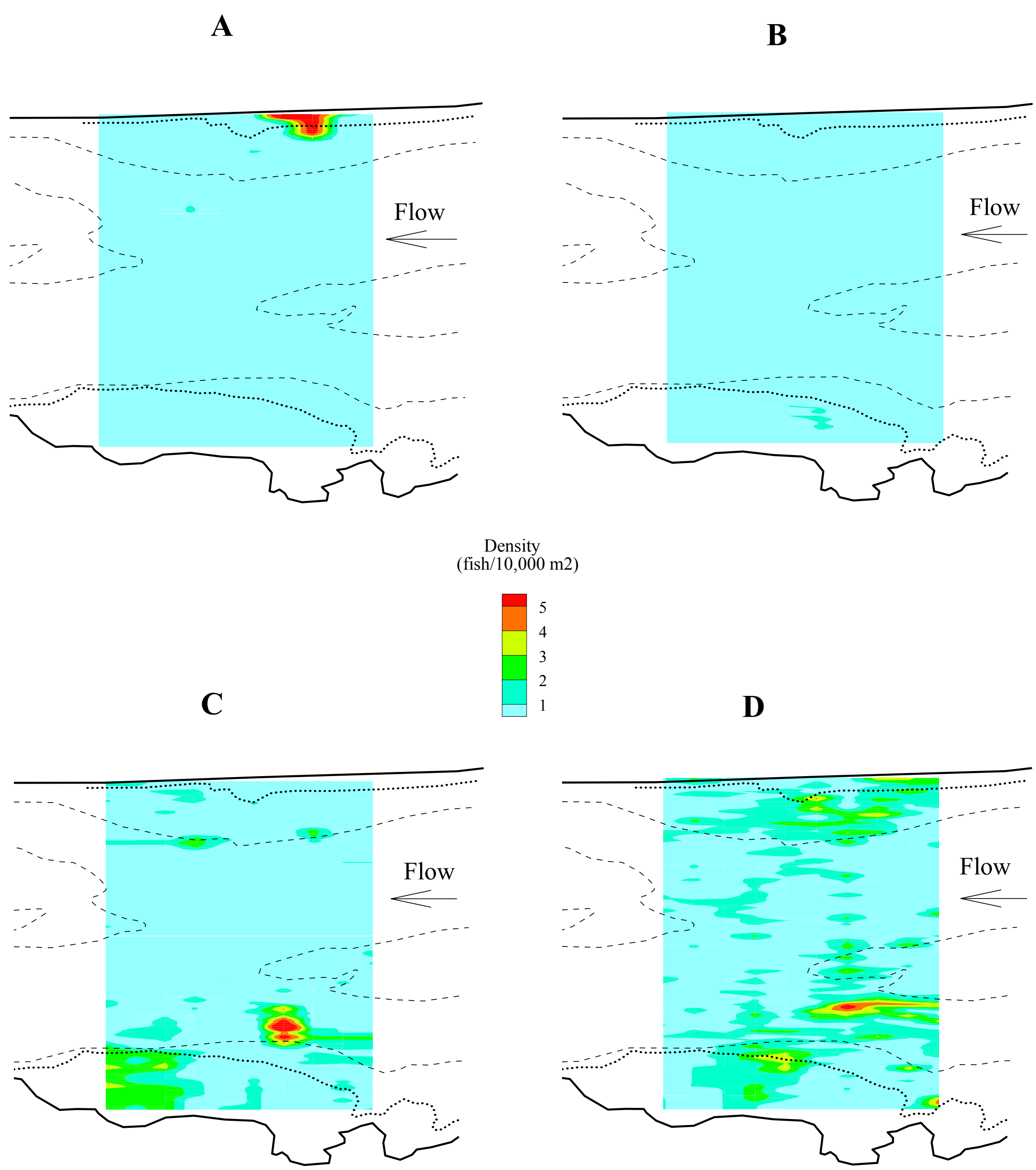


Figure 9.— Plan views of interpolated fish densities for Rkm 482.1-482.8 of the lower reach of McNary Reservoir, fish density <4 m for (A) daytime and (B) nighttime transects, and fish density (C) >4 m for daytime and (D) nighttime transects.

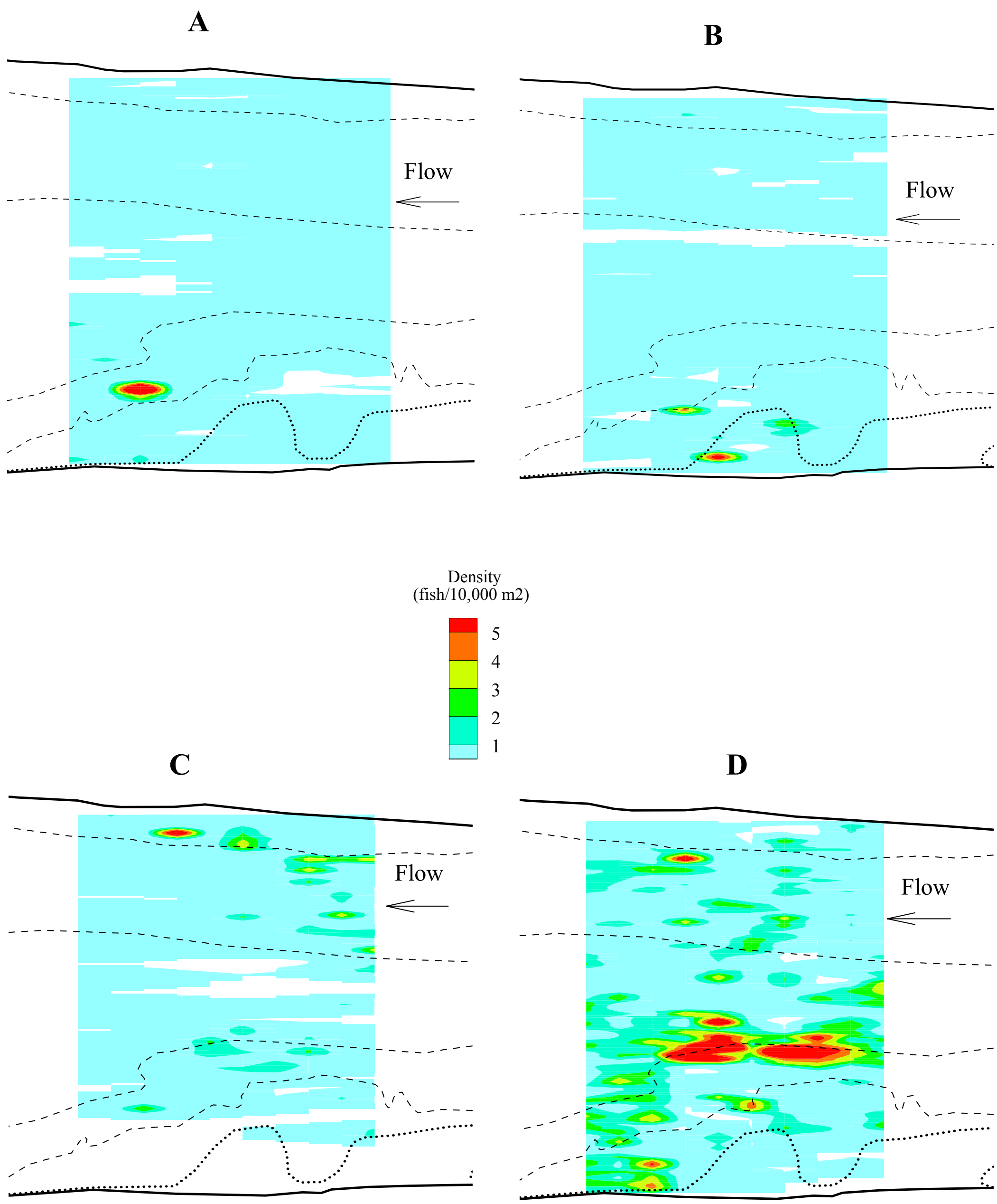


Figure 10.— Plan views of interpolated fish densities for Rkm 491.6-492.3 of the middle reach of McNary Reservoir, fish density <4 m for (A) daytime and (B) nighttime transects, and fish density (C) >4 m for daytime and (D) nighttime transects.

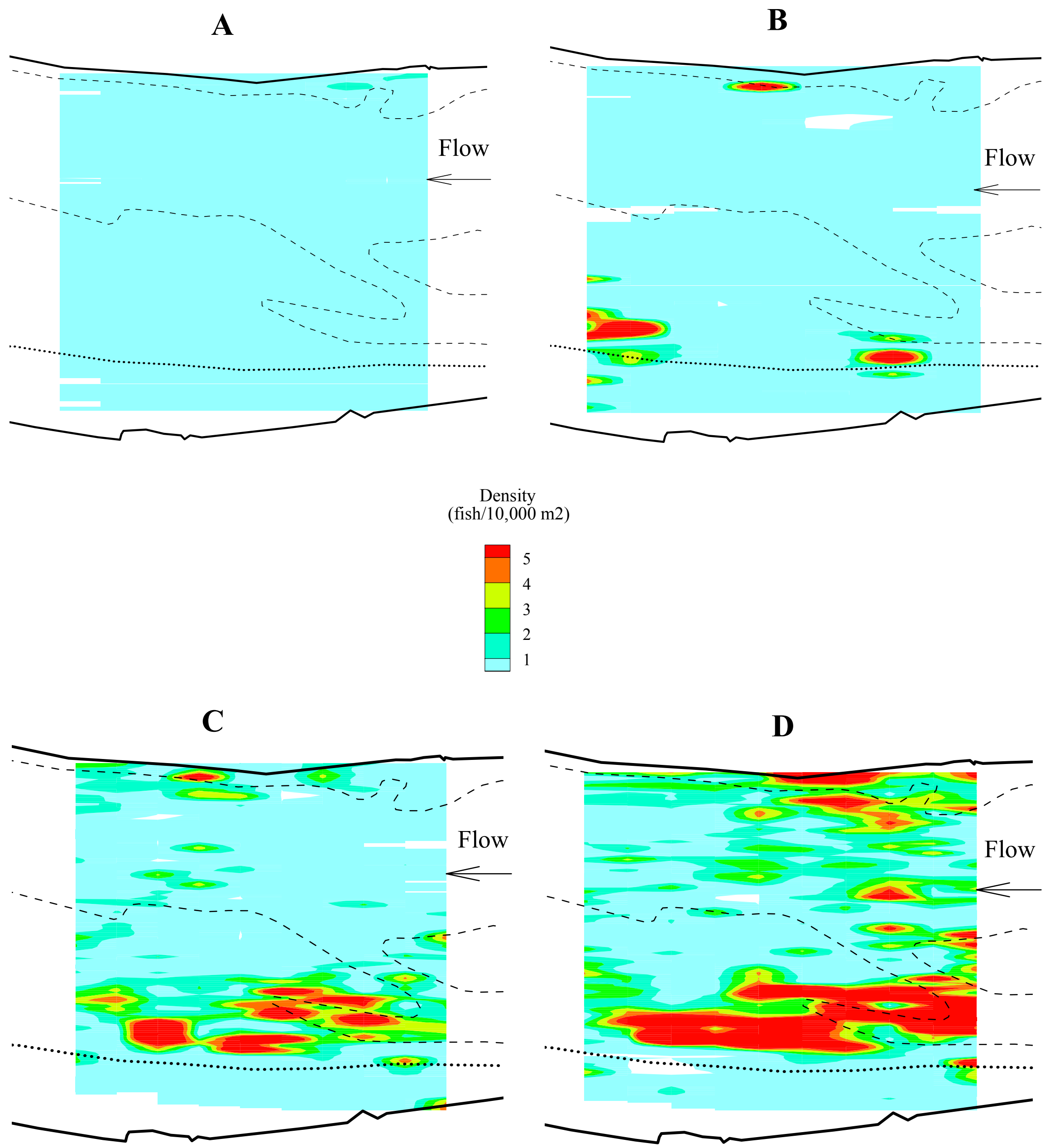


Figure 11.— Plan views of interpolated fish densities for Rkm 496-496.6 of the middle reach of McNary Reservoir, fish density <4 m for (A) daytime and (B) nighttime transects, and fish density (C) >4 m for daytime and (D) nighttime transects.

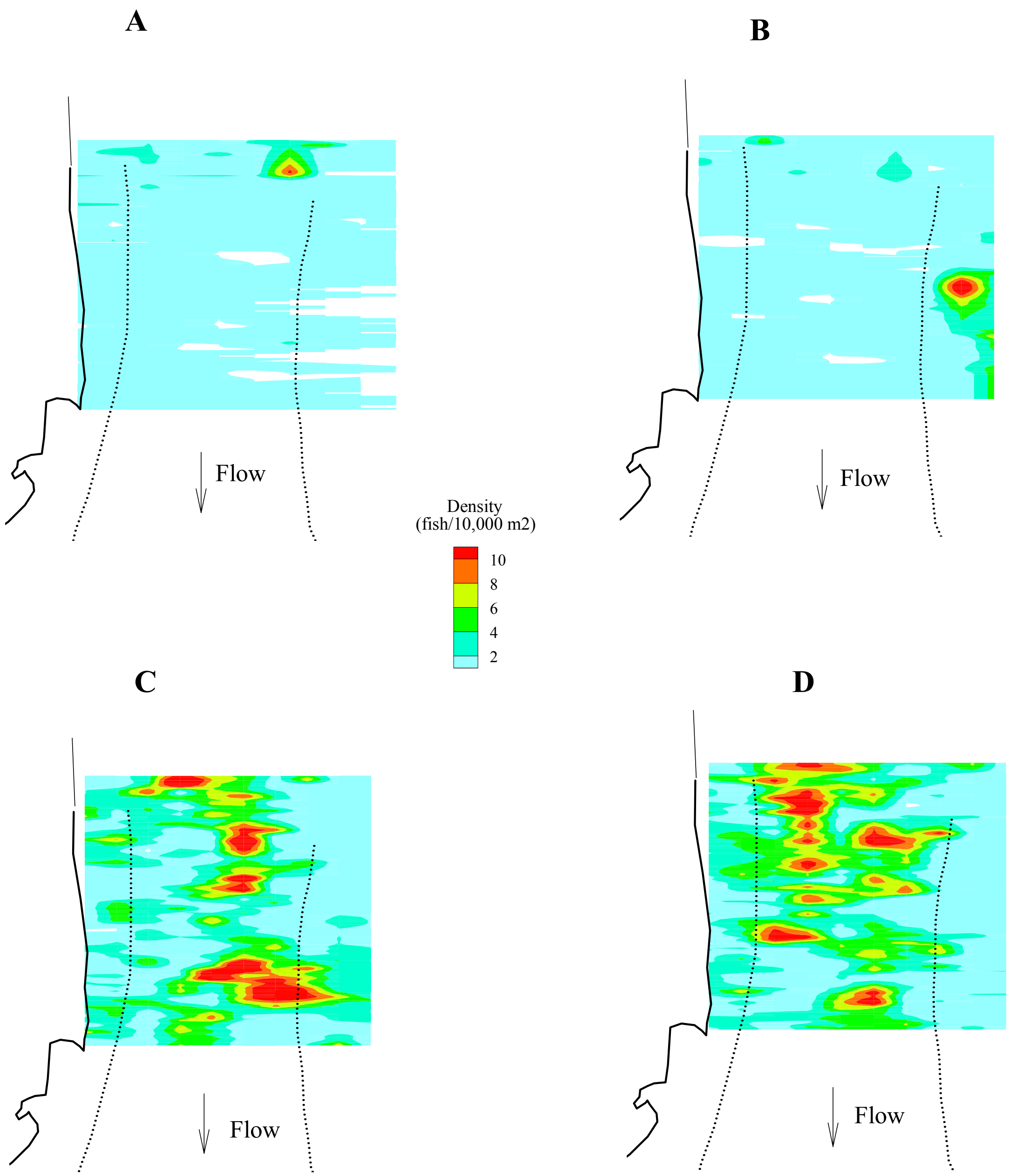


Figure 12.— Plan views of interpolated fish densities for Rkm 511.3-511.9 of the upper reach of McNary Reservoir, fish density <4 m for (A) daytime and (B) nighttime transects, and fish density (C) >4 m for daytime and (D) nighttime transects.

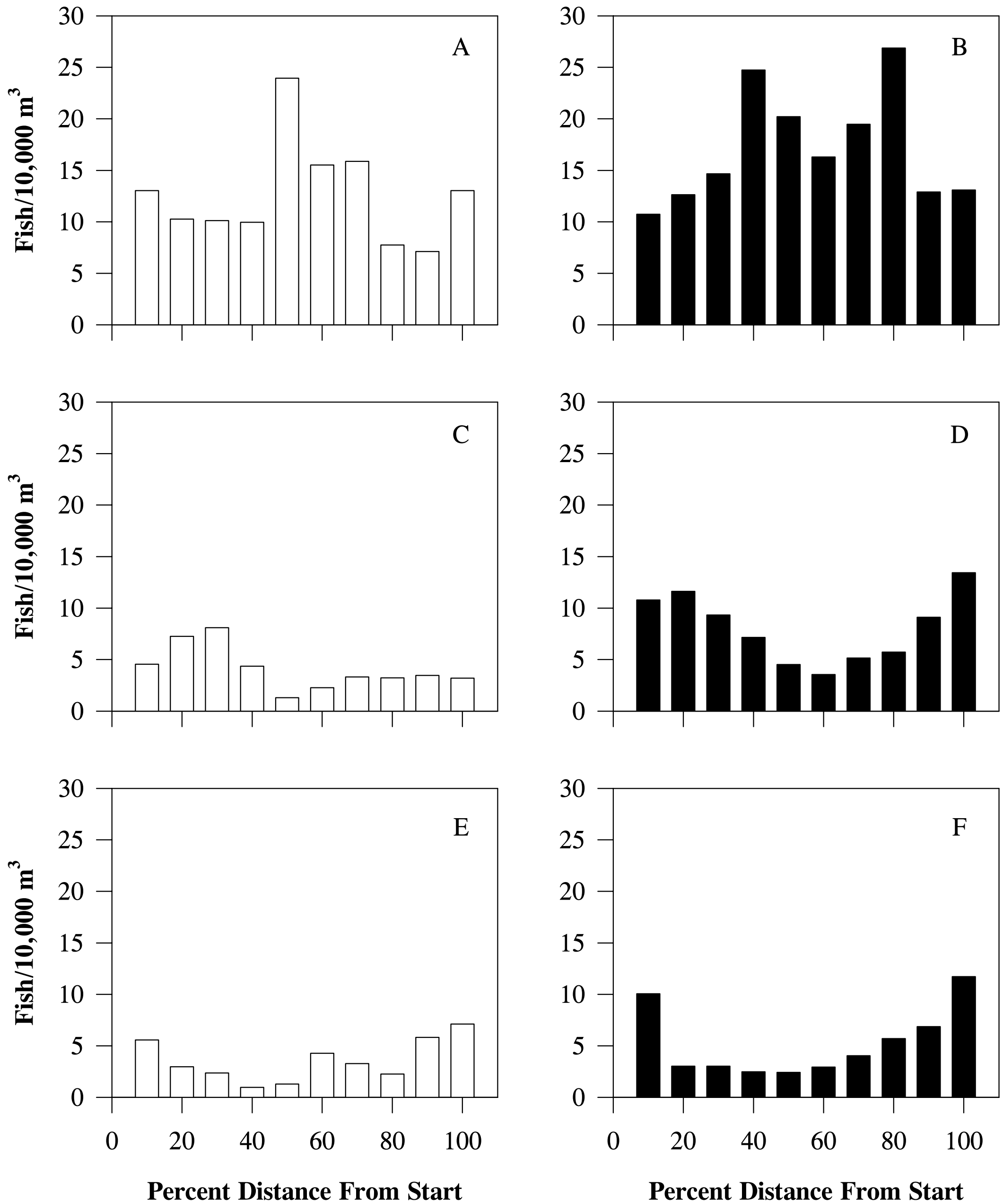


Figure 13.— Fish densities in 10% increments from the beginning of pooled transects for (A) the upper reach during the daytime, (B) the upper reach during the nighttime, (C) the middle reach during the daytime, (D) the middle reach during the nighttime, (E) the lower reach during the daytime, and (F) the lower reach during the nighttime.

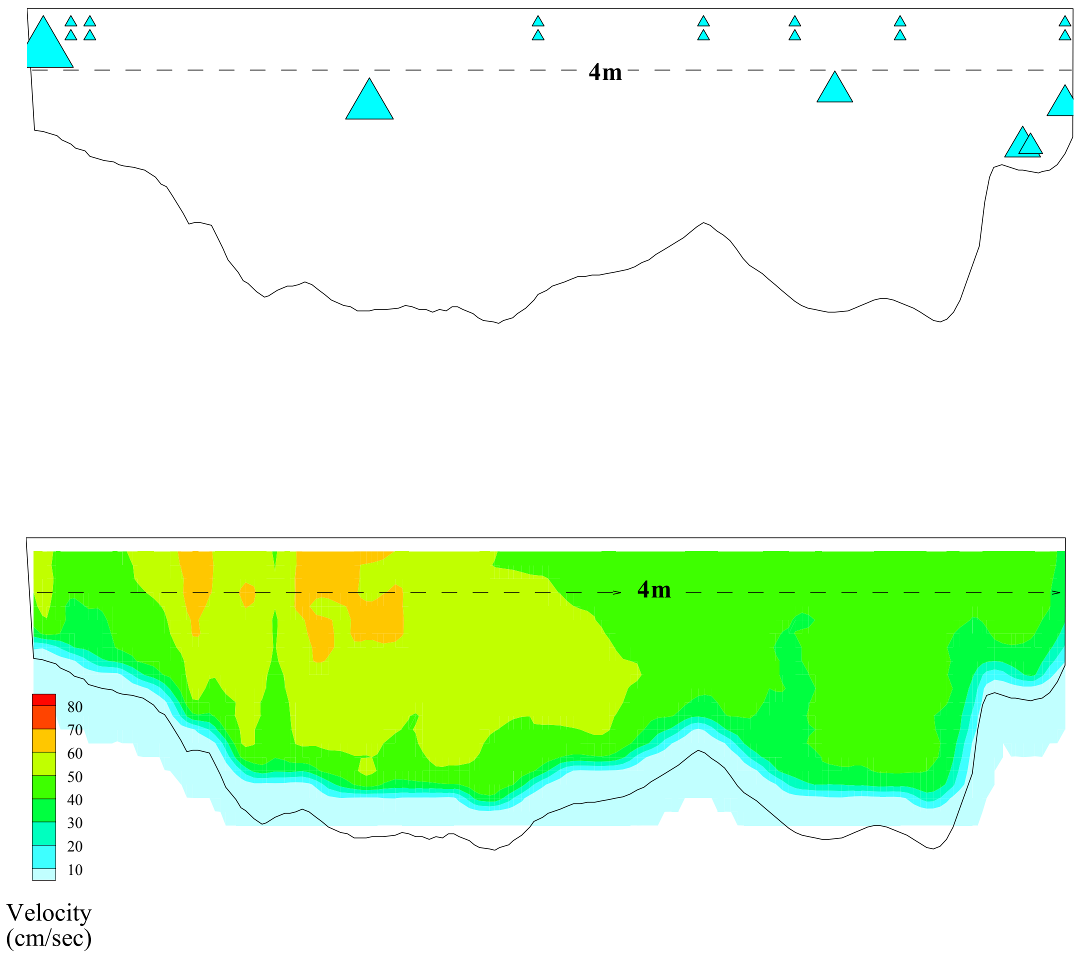


Figure 14.— Representative daytime transect from Rkm 482.7 of McNary Reservoir on June 19, 1996 with triangle size proportional to fish density and with velocity (cm/s).

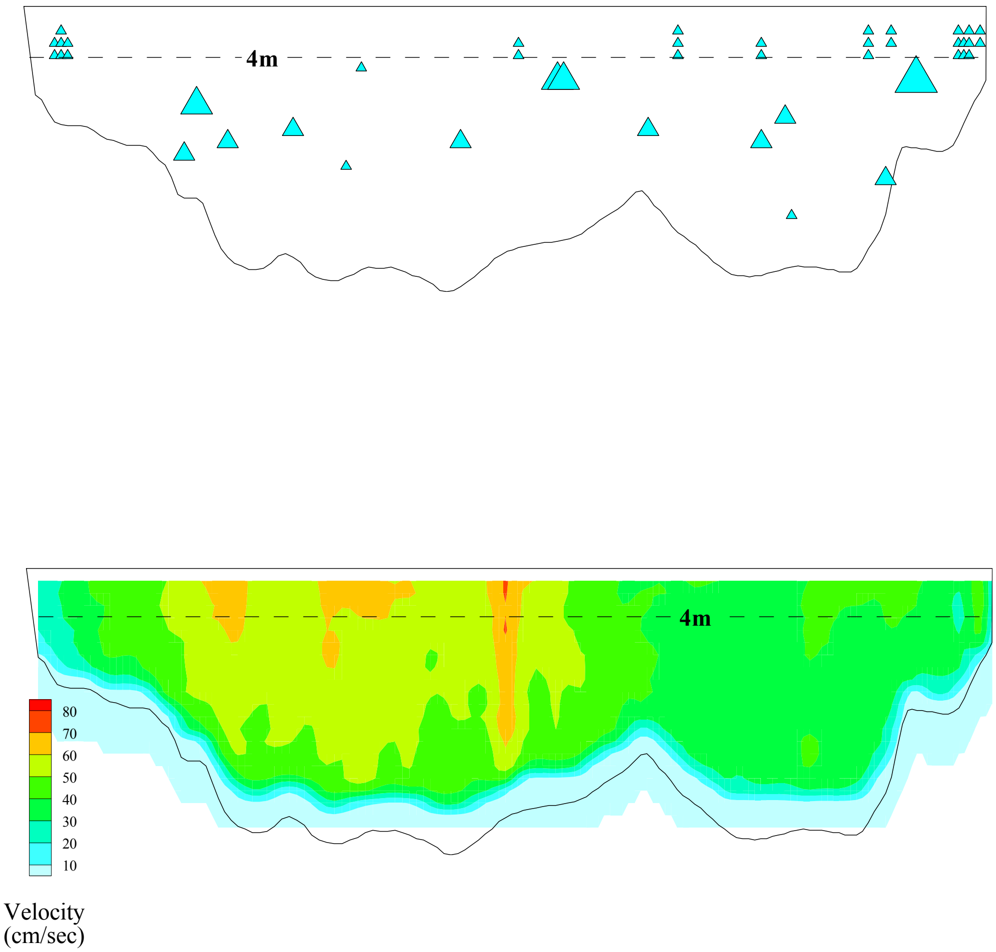


Figure 15.— Representative nighttime transect from Rkm 482.7 of McNary Reservoir on June 20, 1996 with triangle size proportional to fish density and with velocity (cm/s).

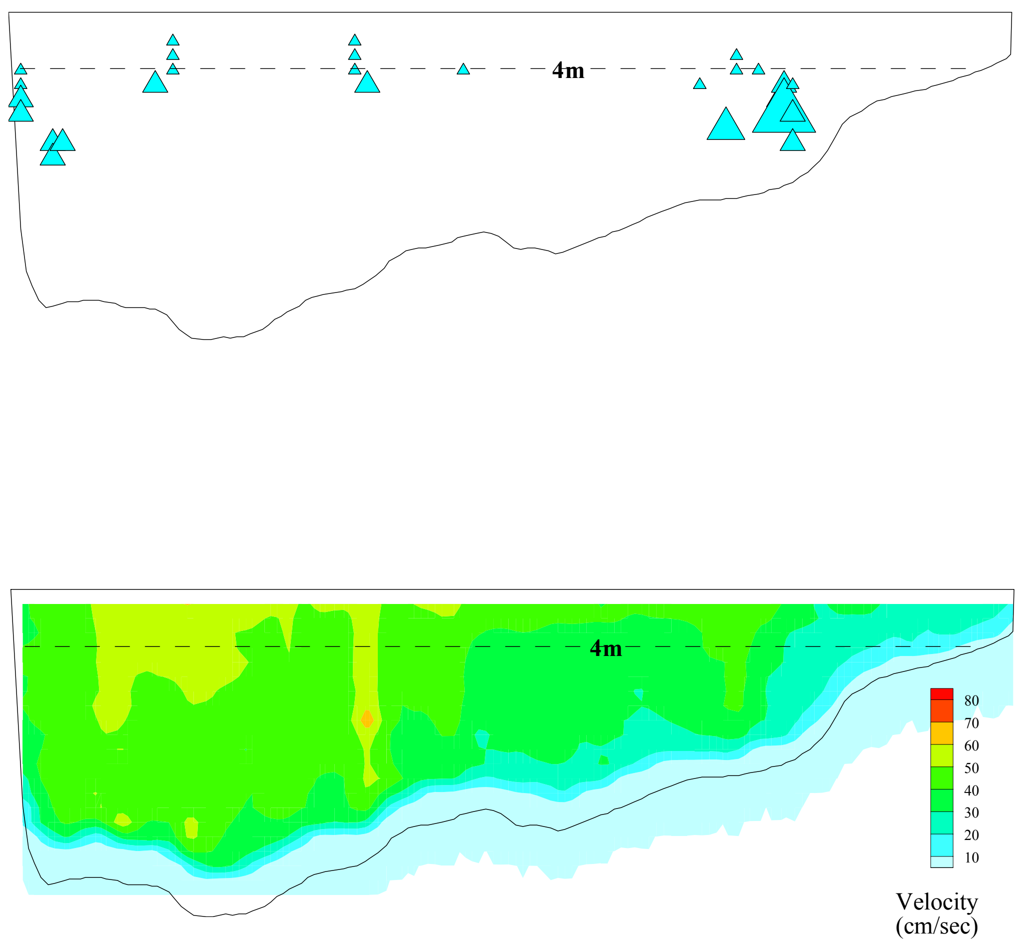


Figure 16.— Representative daytime transect from Rkm 496.1 of McNary Reservoir on July 11, 1996 with triangle size proportional to fish density and with velocity (cm/s).

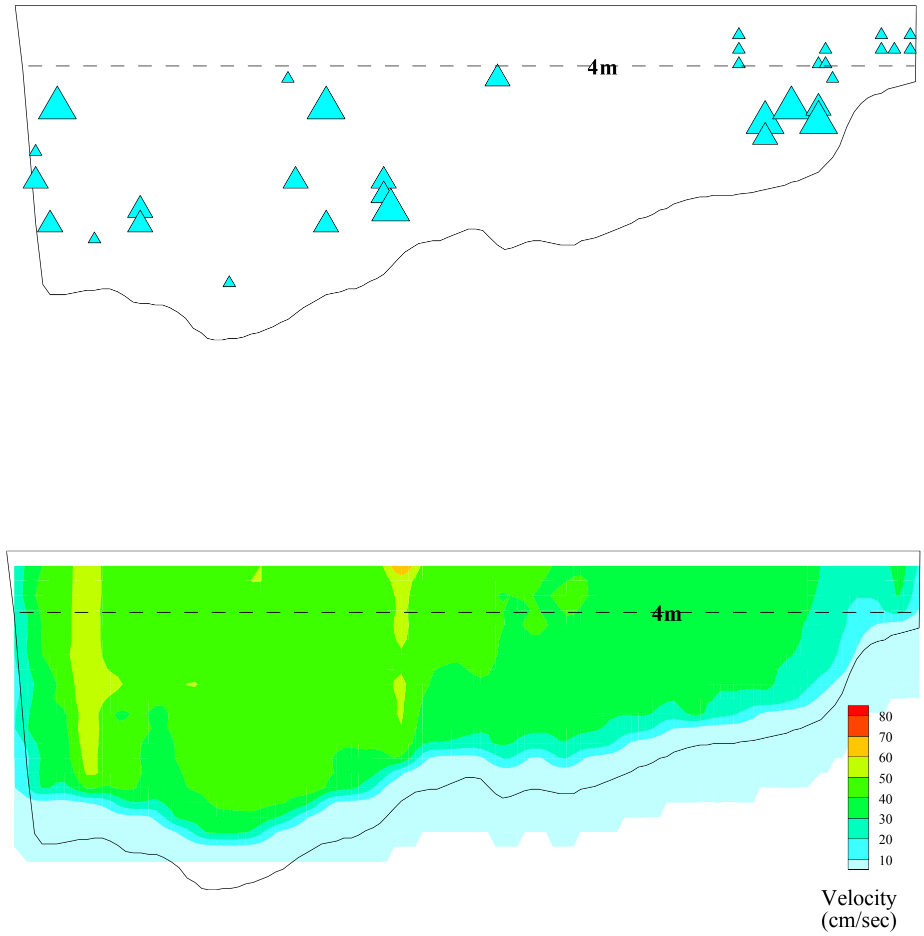


Figure 17.— Representative nighttime transect from Rkm 496.1 of McNary Reservoir on July 7, 1996 with triangle size proportional to fish density and with velocity (cm/s).

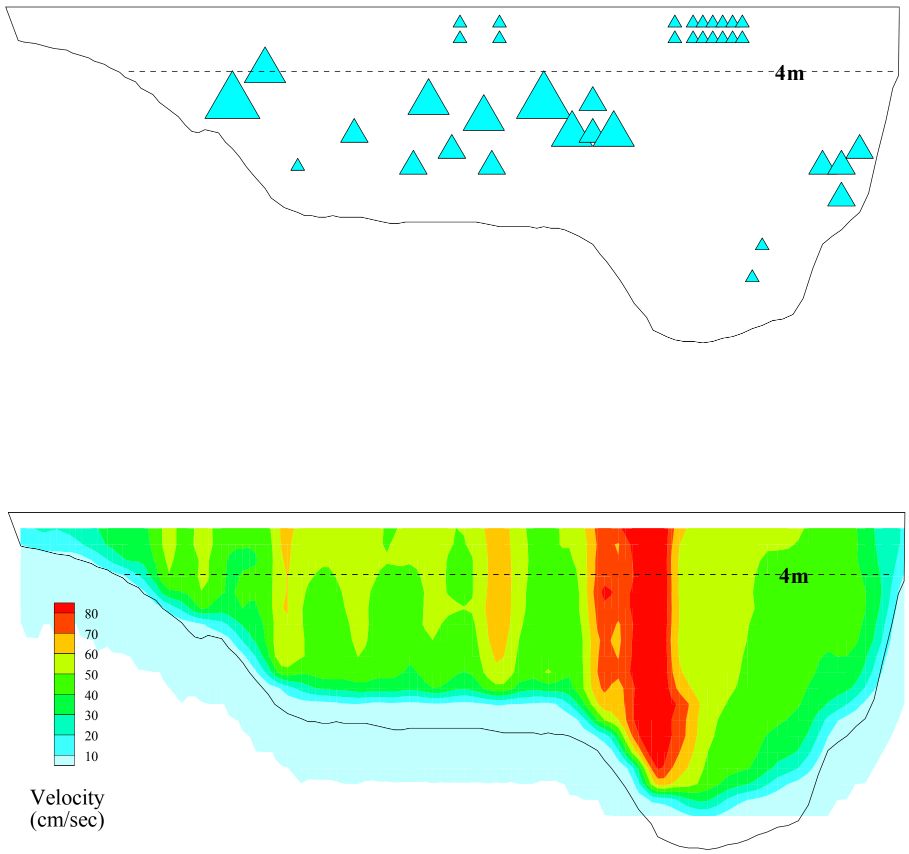


Figure 18.— Representative daytime transect from Rkm 511.3 of McNary Reservoir on July 23, 1996 with triangle size proportional to fish density and with velocity (cm/s).

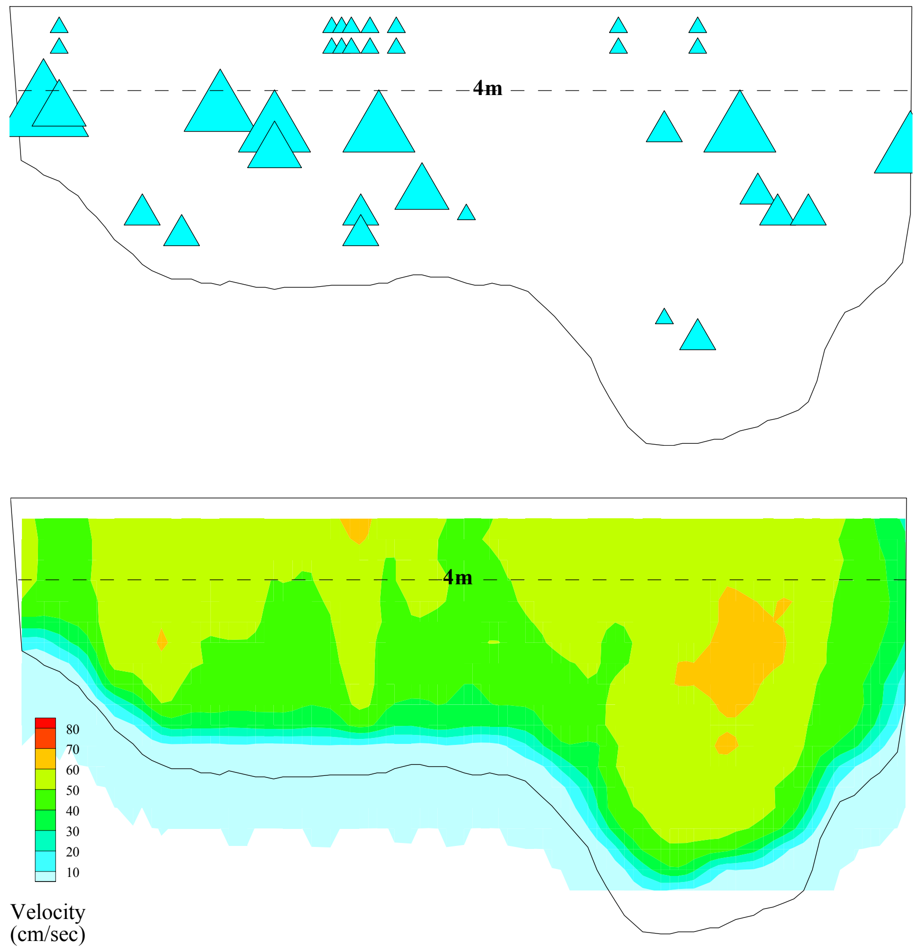


Figure 18.— Representative daytime transect from Rkm 511.3 of McNary Reservoir on July 23, 1996 with triangle size proportional to fish density and with velocity (cm/s).

Discussion

Based on the high percentage of juvenile chinook salmon in our trawl catches, we assumed that most of the targets detected with the hydroacoustic sampling system in McNary Reservoir during June and July, 1996 were subyearling chinook salmon. Species composition of the CRITFC's purse seine catches also support this assumption (Table 1).

Total dissolved gas levels collected during our sampling showed good correlation with readings taken at other sites by other agencies. Our readings from the lower reach were very similar to the readings taken by the Water Experiment Station (WES)/COE in the forebay of McNary Reservoir (Figure 3A). Both sets of data from the middle reach had the same general trends and ranges that data from the McNary forebay and the tailrace of Ice Harbor Dam had (Figures 3B, 4A). Total dissolved gas levels in the upper reach rose following a rise in TDG levels in the tailrace of Ice Harbor Dam; the lag time was about 9 h for the 26 km distance (Figure 4B).

The down-looking and side-looking transducer orientation that we employed in this survey had some limitations. Even when optimal sampling conditions enabled the side-looking transducer to be aimed 3° below horizontal, the top meter of the water column was not sampled. When the side-looking transducer was angled 10° below horizontal because of increased surface noise, the sampling area of the 1 m to 2 m depth range was greatly reduced. Of data presented here, 75% of the transects from the lower and middle reaches and 5% of the transects from the upper reach were sampled with the 10 ° side-looking transducer orientation.

It was difficult to reliably estimate the percentage of the juvenile chinook salmon population that was exposed to supersaturated water and consequently at risk to gas bubble disease. The TDG levels were approximately 120% during our surveys. This corresponded to a compensation depth of 2 m, the precise level that was undersampled with our hydroacoustic system using a down and side-looking transducer deployment method. Total dissolved gas readings in excess of 140% occurred for a total of 25 h at the gas meters at the permanent monitoring site below Ice Harbor Dam during the entire spring and summer outmigration of 1996. We selected 4 m as the depth of compensation to divide our data set because it allowed for a conservative estimate of exposure to the maximum expected TDG levels.

Fish densities in the lower and middle reaches showed marked differences between daytime and nighttime sampling. Within the lower and middle reaches, fish density from all transects sampled during the day was 36% of the total fish density of nighttime transects. Thorne (1992) reported similar findings in Lower Granite Reservoir, and attributed the lower daytime densities to stronger bottom and nearshore orientation of fish. Fish located within an area termed the "dead zone" near boundaries (surface and bottom) are impossible to acoustically differentiate from the boundary (Mitson 1983). The size of this near-boundary zone is determined by the pulse width transmitted by the echosounder; the greater the pulse width, the larger the zone (approximately 30 cm for the system used in these surveys). Therefore, it is possible fish escape detection during hydroacoustic sampling if their behavior patterns placed them within this zone or near shorelines at anytime throughout the diel period. The differences observed in the lower and middle reaches between daytime and nighttime densities could be explained by this limitation of hydroacoustics in describing fish distribution near boundaries or the shoreline.

In contrast to the relatively low daytime fish density in the lower and middle reaches, fish density from all daytime transects in the upper reach was more than 76% of fish density at night. Total fish density in the upper reach was nearly twice that of the lower and middle reaches. Also, vertical distribution of detected fish was nearly identical during day and night sampling periods in the upper reach. Unlike the lower and middle reaches, where a relatively large percentage of fish detected in the daytime were located in water ≤ 4 m in depth, only 3% of fish detected during the day in the upper reach were in the top 4 m of the water column. There was also little difference between the daytime and nighttime cross-sectional distributions of fish densities in the upper reach.

Diel shifts in vertical fish distribution were also apparent in the lower and middle reaches. During the day, 19% of all fish detected within the lower and middle reaches were in the top 4 m of the water column. At night, only 5% of fish detected in these reaches were located at ≤ 4 m of the water column. These differences in vertical distribution were consistent with Johnson et al.'s (1992) findings on the salmonids migrating downstream in the forebay of Wells Dam, where he found that 50% of fish detected during the day were within 7 m of the surface. During the night, however, fish tended to be located deeper in the water column, with 50% of the fish located within 22 m of the surface.

Various factors have been attributed to inducing diel vertical migrations of salmonids. Daily vertical migrations of age 1 pink salmon *Oncorhynchus gorbuscha* in the ocean have been attributed to food availability (Groot and Margolis 1991). Narver (1970) concluded that diel changes in the amount of underwater illumination strongly influenced the timing and amplitude of diel movements of juvenile sockeye salmon *Oncorhynchus nerka*. Clark and Levy (1988) expanded this idea by suggesting that daytime vertical migrations of juvenile sockeye salmon were a response to changes in feeding opportunities and predation risks, both of which were light dependent; nighttime movements, they stated, may be related to bioenergetic factors.

Cross-sectional distribution of fish densities within the lower and middle reaches also showed some differences between daytime and nighttime samples. During the day, fish densities were much higher near the shorelines of the lower and middle reaches than in the center of the reservoir. At night, although fish densities were still highest near the shores, some areas with high fish densities were also observed near the center of the reservoir. These differences were slight, however, indicating that fish detected within the lower and middle reaches were strongly oriented towards nearshore areas.

The smaller cross-sectional area of the upper reach may alter fish distributions through higher water velocity and possibly greater water turbulence. In the free-flowing Hanford

Reach of the Columbia River, Dauble et al. (1989) found higher numbers of 0-age fall chinook salmon in deep, mid-river fyke-net sets than in shallow shoreline sets during June and July. Similar behavior of fish within the more riverine-like upper reach could have resulted in greater hydroacoustic detection rates and the associated higher fish densities. Analysis of our data revealed that horizontal water velocity averaged approximately 50 cm/s in the upper reach and 30 cm/s in the lower and middle reaches.

In summary, we found large differences in vertical and cross-sectional fish distribution between the upper and the lower and middle reaches of McNary Reservoir. Patterns of fish distribution within the upper reach were similar to those observed by Dauble et al. (1989) during the mid to late summer outmigration in the Hanford Reach, an area that is representative of the conditions to which fall chinook salmon have adapted. Fish distributions in the lower and middle reaches were characterized by nearshore orientation and by vertical migration towards the surface during the day. This behavior may increase exposure to supersaturated water during high flow events.

References

Backman, T.W.H., D.W. Rondorf, and A.G. Maule. 1996. Symptoms of gas bubble trauma induced in salmon (*Oncorhynchus spp.*) by total dissolved gas saturation in the Snake and Columbia Rivers, USA: Collection of preliminary data and development of protocols. Proposal to the Bonneville Power Administration, Portland, Oregon.

Beiningen, K.T. and W.J. Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Transactions of the American Fisheries Society 99:664-671.

Blahm, T.H., R.J. McConnell, and G.R. Synder. 1976. Gas saturation research, National Marine Fisheries Service, Prescott Facility - 1971-1974. Proceedings of Gas Bubble Disease Workshop. U.S. Department of Commerce, Technical Information Service CONF-741033, 11-19.

Clark, C.W., and D.A. Levy 1988. Diel vertical migrations by juvenile sockeye salmon and the antipredation window. American Naturalist 131:271-290.

Cressie, N.A.C. 1991. Statistics for spatial data. John Wiley and Sons, New York.

Dauble, D.D., T.L. Page, and R.W. Hanf, Jr. 1989. Spatial distribution of juvenile salmon in the Hanford Reach, Columbia River. Fishery Bulletin 87:775-790.

Dawley, E.M. 1986. Effects of 1985-86 levels of dissolved gas on salmonids in the Columbia River. Report to U.S. Army Corps of Engineers, Contract DACW-57-85F-0623, 31p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, Washington 98112-2097.)

Dawson, J.J., W.A. Karp, and G.A. Raemhild. 1985. Fixed location hydroacoustics for quantitative fisheries studies (Revised 04/06/88). (Available from BioSonics, Inc. 4027 Leary Way NW, Seattle, Washington 98105.)

Dell, M.B., M.W. Erho, and B.D. Leman. 1974. Occurrence of gas bubble disease symptoms on fish in mid-Columbia River reservoirs, 49 p. (Available from Public Utility District of Grant County, P.O. Box 878, Ephrata, Washington 98823.)

Ebel, W.J. 1969. Saturation of nitrogen concentrations in the Columbia and its effects on salmon and steelhead trout. U.S. Fish and Wildlife Service, Fishery Bulletin 68:1-11.

Ebel, W.J. 1971. Dissolved nitrogen concentrations in the Columbia and Snake Rivers in 1970 and their effect on chinook salmon and steelhead trout. National Oceanographic and Atmospheric Administration Technical Report, National Marine Fisheries Service, SSRF-646, 7p.

Giorgi, A.E., G.A. Swan, W.S. Zaugg, T. Coley, and T.Y. Barila. 1988. Susceptibility of chinook salmon smolts to bypass systems at hydroelectric dams. North American Journal of Fisheries management 8:25-29.

Groot, C., and L. Margolis, editors. 1991. Pacific Salmon Life Histories. University of British Columbia Press, Vancouver, British Columbia.

Johnson, G.E., C.M. Sullivan, and M.W. Erho. 1992. Hydroacoustic studies for developing a smolt bypass system at Wells Dam. Fisheries Research, 14: 221-237.

Meekin, T. K., and R. L. Allen 1974. Nitrogen saturation levels in the mid-Columbia River, 1965-1971. Washington Department of Fisheries, Technical Report 12, p. 32-77.

Mitson R.B. 1983. Fisheries Sonar. Fishing News Books Ltd. Farnham, Surrey, England.

Narver, D.W. 1970. Diel vertical movements and feeding of underyearling sockeye salmon and the limnetic zooplankton in Babine Lake, British Columbia. Journal of the Fisheries Research Board of Canada 9:450-491

Panel. 1994. Panel on gas bubble disease, report and recommendations (June 21-22, 1994). (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, Washington 98112-2097.).

Smith, J.R. 1974. Distribution of seaward-migrating chinook salmon and steelhead trout in the Snake river above Lower Monumental Dam. Marine Fisheries Review 36(8)42-45.

Thorne, R.E., C.J. McClain, J. Hedgepeth, E. S. Kuehl, and J. Thorne. 1992. Hydroacoustic surveys of the distribution and abundance of fish in Lower Granite Reservoir, 1989-1990, Final report to Walla Walla District Corps of Engineers, Contract No. DACW68-C-0022. (Available from BioSonics, Inc.3670 Stone Way North, Seattle, Washington 98103).

Weitkamp, D. E. 1974. Snake River 1973, dissolved gas studies. Report to Idaho Power Company, Boise, Idaho, 81 p. (Available from Idaho Power Co., P.O. Box 70, Boise, Idaho 83707).

Weitkamp, D.E. 1976. Dissolved gas saturation: live cage bioassays at Rock Island Dam, Washington. Proceedings of Gas Bubble Disease Workshop. U.S.Department of Commerce, Technical Information Service CONF-741033, p. 24-36.

Weitkamp, D.E., and M. Katz. 1975. Resource and literature review, dissolved gas saturation and gas bubble disease, 1975. Environmental Services Section, 4122 Stone Way N. Seattle, Washington, Report to Northwest Utility Cooperative. (Available from Idaho Power Co., P.O. Box 70, Boise, Idaho 83707).

CHAPTER THREE

Horizontal and Vertical Distribution of Juvenile Salmonids During Spring in the Columbia River Relative to Total Dissolved Gas

by

Dan H. Feil, Derrek M. Faber, Timothy J. Darland, and Dennis W. Rondorf

U.S. Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
5501A Cook-Underwood Road
Cook, Washington 98605

Introduction

Accurately estimating the spatial distribution of juvenile salmon in reservoirs of the Columbia River is a critical element in assessing the impacts of total dissolved gas (TDG) supersaturation on smolt populations. Fish distributed in the upper portion of the water column (0-3 m) can be exposed to the effects of gas bubble disease, depending on TDG levels present in the reservoir. Generally, each meter of water depth provides hydrostatic compensation for each 10% of TDG supersaturation. Consequently, for each 10% of TDG supersaturation, a fish must be positioned 1 m below the surface to avoid the effects of gas bubble disease.

With the recent development of a miniature radio transmitter equipped with a pressure transducer small enough to implant in juvenile salmonids, radio-telemetry techniques can be used to obtain individual depth histories of migrating smolts. In 1997, Beeman et al. (1998) used this method to obtain depth data on migrating juvenile steelhead and chinook salmon. Although limitations such as small sample sizes and tag effects on the behavior of smolts is of concern, this method uses the latest available technology to measure the depth distribution of migrating fish.

Hydroacoustics, a fisheries stock assessment tool, is commonly used to estimate the spatial distribution of fish populations in reservoirs. Hydroacoustic techniques compliment the individual depth histories of radio-tagged smolts by providing a synoptic description of the distribution of the entire smolt population in the study area. Traditional methods of hydroacoustic transducer deployment have been inadequate in providing an accurate estimate of the near-surface distribution and relative abundance of fish, especially juvenile salmonids. The U.S. Geological Survey's Biological Resources Division (USGS-BRD) tested alternative methods of hydroacoustic transducer deployment in an effort to maximize the near-surface detectability of targets, thus providing a more accurate estimate of the near-surface distribution and relative abundance of smolts. Since the acoustic beam transmitted by a transducer is conical in shape, equal coverage of all water strata is not possible with a single transducer (i.e., area closest to transducer is not adequately sampled). Therefore, multiple transducers must be used to more evenly sample all reservoir strata. Ideally, to make valid comparisons among data collected with multiple transducers, the ensonification aspect at which targets are detected should be consistent throughout the water column. From previous tests (Chapter 1 of this report), we concluded that deploying a down-looking transducer mounted on a towed platform, and an up-looking transducer mounted on a remotely operated vehicle (ROV) deployed from a research boat would be the most desirable method of collecting comparable data from the entire water column. Although these two different transducer deployment methods ensonify targets from different aspects (dorsal and ventral), examination of a directivity plot suggested these two aspects were nearly equal in their sound reflective properties (Tom Carlson Waterways Experiment Station, unpublished data) and were therefore deemed comparable.

We used the up-looking and down-looking hydroacoustic transducer deployment methods described in Chapter 1 of this report to evaluate the distribution of juvenile salmonids in McNary Reservoir on the Columbia River. This study was conducted concurrently with in-river sampling for gas bubble disease in juvenile salmon (Backman et al. 1998) and a radio-telemetry study using pressure sensitive radio tags to determine the depth histories of individual juvenile steelhead and chinook salmon (Beeman et al. 1998). The specific objectives of this study were (1) identify the vertical distribution patterns of juvenile salmonids, (2) determine the proportion of smolts above the depth of compensation for prevailing TDG levels in McNary Reservoir, and (3) determine the horizontal distribution of juvenile salmonids.

Methods

Total Dissolved Gas Monitoring

Total dissolved gas supersaturation levels were monitored in McNary Reservoir from May 7-20 and from May 27 to June 11, 1997. Yellow Springs Instruments (YSI) Inc. SI 6000UPG multi-parameter water quality monitors were placed near shorelines and in the center of the reservoir at Rkms 475.5, 486.6, and 504.2. One monitor was suspended from a marker buoy in the forebay boat restricted zone of McNary Dam at Rkm 471.5. Shoreline monitors were positioned 50 m from shore if water depth at the site was ≥6 m. If water depth at the site was <6 m they were positioned at the closest point to shore where water depth was at least 6 m. Shoreline monitors were suspended in the water column approximately 5 m from the surface. Monitors in the center of the reservoir were suspended between 6 and 9 m from the surface to avoid barge traffic.

All YSI monitors were deployed in PVC pipe cases for protection. Holes were drilled in the cases and then covered with wire mesh screen. This allowed adequate water flow over the sensors, yet protected them from debris. Shoreline monitors were suspended with cable between an anchor and a flotation buoy. Monitors in the center of the reservoir were attached with cable to a Benthos model 875 shallow water acoustic release, a flotation buoy, and an anchor. A Benthos model DS-7000 deck box was used to activate the acoustic release mechanism for retrieval of the monitor. Each monitor was equipped with a radio transmitter to aid recovery in the event that a monitor was lost.

Monitors were deployed for 2 to 3 week intervals and programmed to record data every 15 min. Temperature, conductivity, dissolved oxygen, and depth were recorded in addition to TDG. Data were downloaded and monitors were maintained and calibrated between the sampling intervals. Conductivity was calibrated before the first deployment using a 1 mS/cm standard. Depth, TDG, and percent dissolved oxygen were calibrated before each monitor was deployed. Percent dissolved oxygen and TDG were calibrated to barometric pressure obtained from a certified wall barometer at the Columbia River Research Laboratory, USGS. Each gas collector was replaced and then cleaned and dried for the next deployment. Teflon membranes on the oxygen sensors were inspected for tears or air bubbles and replaced if needed. Every 30 d the batteries in each monitor were replaced. Percent TDG supersaturation was calculated with barometric pressure measurements obtained from the USACE barometer located on the south side of McNary Dam.

Turbidity measurements and illuminance extinction profiles were also taken throughout the sampling season. Transects for these parameters were located at Rkm 477.0 and 479.9, the upper and lower boundaries of the hydroacoustic sampling area (Figure 1). Five sample sites were located along each transect: one at each shore, one at ¼ reservoir width from each shore, and one at the center of the reservoir. Turbidity measurements were taken with a HACH 2100P turbidimeter at each of the five points along the transects. Illuminance profiles were taken each day at 1300 hours at the center points with an International Light IL1400A Radiometer/Photometer. Illuminance measurements were taken above the water surface, at 1 m, and in 1 m intervals until illuminance was 0.0 lm/m.

Hydroacoustic Surveys

Hydroacoustic surveys were conducted on McNary Reservoir from May 7-30, 1997 to determine vertical and horizontal fish distributions. The study area for hydroacoustic sampling was located between river kilometers (Rkm) 474.7 and 482.8 (Figure 1). This area is immediately downstream of Hat Rock State Park, Oregon and is characterized by a gradually sloping river bottom on the south and a moderately sloping bottom on the north side of the reservoir, with a maximum depth of approximately 30 m.

The locations of transects sampled were determined by randomly selecting the beginning transect. Cross-sectional transects spaced 161 m apart were sampled, starting at the most downstream transect and working upstream until four transects were sampled. This design made it unlikely that fish detected during one transect would be detected in subsequent transects assuming the fish detected were migrating downstream. The transects were repeatedly sampled in this manner over 24 h periods in 3-17 d blocks. Due to equipment failure, stationary point sampling methods were used from May 14-21, 1997 to collect hydroacoustic data at three points across the reservoir (Figure 1). A Trimble NT200D differentially corrected global positioning system (DGPS, ±15 m) was used for locating transects sampled with the hydroacoustic system.

Water surface temperature and wind speed readings were taken at the beginning of every transect. At the end of every transect, three illuminance measurements were recorded using an International Light IL1400A Radiometer/Photometer. The first measurement was taken just above the surface (ambient), the second at 0.3 m below the surface, and the third at 1.0 m below the surface.

Hydroacoustic data were collected using a BioSonics Inc. DT5000 echosounder operating at 430 kHz. The echosounder transmitted a 0.4 ms pulse at a rate of 5 pings/s. The signal was fast-multiplexed between a 6/15° dual-beam transducer, aimed 90° down, and a 6/15° dual-beam transducer (actually operating as a 6° single-beam transducer due to manufacturer's error) aimed 90° up. The down-looking transducer was mounted on an

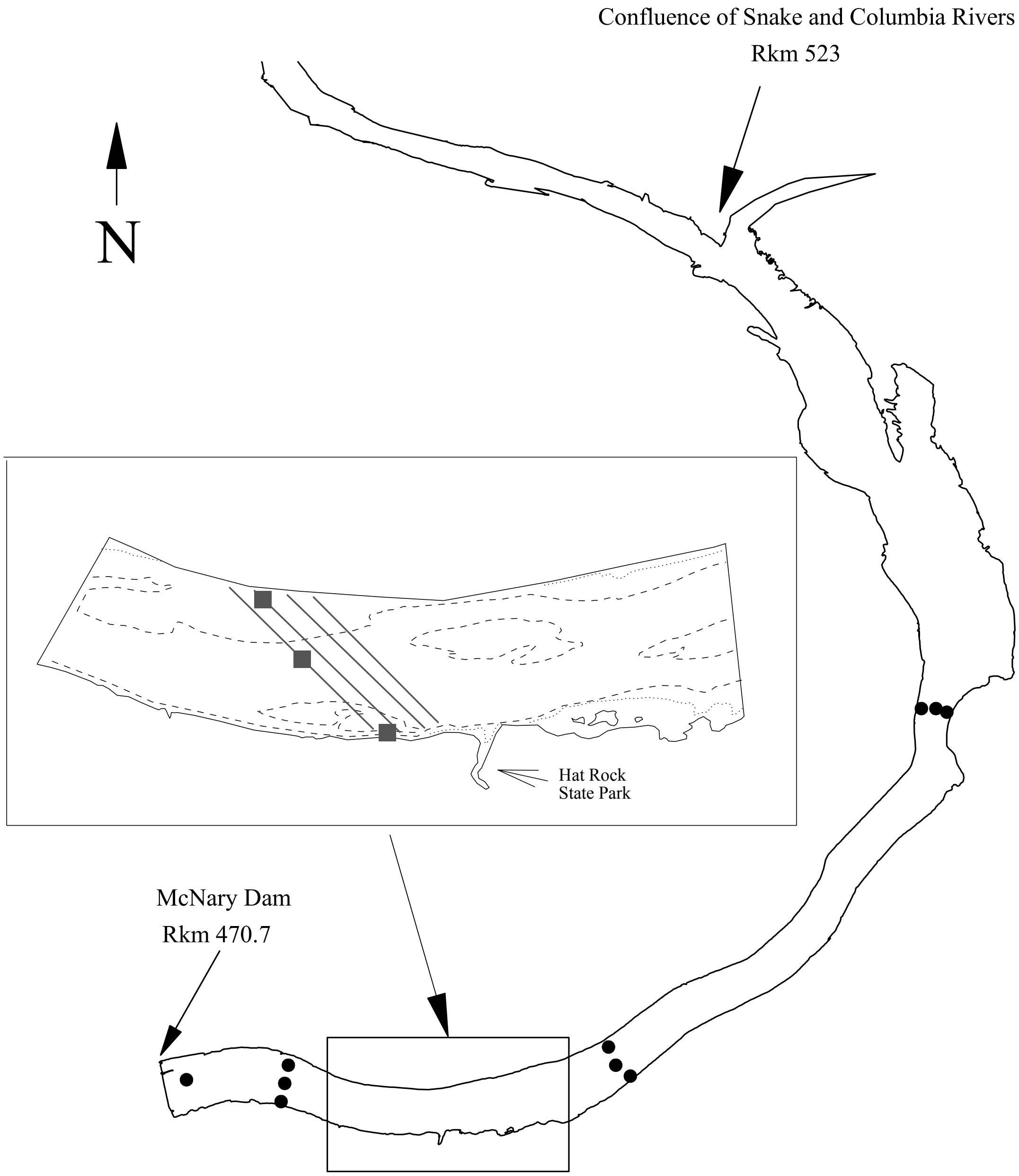


Figure 1.— Map of McNary Reservoir showing sites sampled with hydroacoustics in May 1997. Transects are indicated by the straight cross-sectional lines, hydroacoustic stationary points by squares, and dissolved gas meter locations are indicated by solid circles.

aluminum platform towed along side the boat at a depth of 1 m. The up-looking transducer was mounted on a Deep Ocean Engineering Phantom HD2+2 remotely operated vehicle (ROV). The ROV was maneuvered approximately 15 m in front of the boat and at a depth of 10 m where reservoir bathymetry permitted.

The ROV was equipped with an array of sensors to provide feedback to the operator on the attitude, depth, and position of the ROV. The attitude (pitch and roll) of the ROV was monitored by a Jasco Research Ltd. underwater triaxial attitude measurement unit that was attached to the top of the ROV. A Datasonics model PSA-916 altimeter was attached to the underside of the ROV and provided the operator with ROV distance to bottom. An ORE model 4410C Trackpoint II ROV acoustic tracking system consisting of a command/display module, electronic flux-gate compass, hydrophone, and multibeacon were used to monitor the position of the ROV relative to the boat. The hydrophone was deployed 0.3 m below the boats keel to reduce interference caused by reflecting signals. The multibeacon was attached to the topside of the ROV's crash frame.

All hydroacoustic data were processed using BioSonics Inc. Visual Analyzer software. This program separated potential fish targets from the data file and provided information such as depth, time, and strength of each valid returned echo. Fish target depth and relative abundance were calculated for each transect. Fish target information was then pooled into 0.5 m depth strata for stationary transects and pooled into 0.5 m (vertical) by 10 m (horizontal) strata for mobile transects. All data, including hydroacoustic, attitude and position of ROV, and GPS data were recorded on laptop computers.

Hydroacoustic data were analyzed to examine any differences that may have existed in vertical fish distribution. To determine the relation of fish distribution and TDG data from an upstream TDG monitor, fish densities were grouped by reservoir cross-section location divided into three equal sections: OR shore to Northing 218674; center, between Northing 218674 and 220462; and Northing 220462 to the WA shore. Each segment of the cross-section is distinct in its physical attributes. Both WA and OR shore sections were shallow (<20 m), with the WA shore most influenced by the Columbia River, and the OR side influenced by the Snake River. The center third contains the main channel (30 m maximum depth) and the convergence of Snake and Columbia rivers.

Since TDG compensation depth increases as TDG supersaturation levels increase, we were concerned about detecting more fish above the compensation depth as TDG levels increased even though actual vertical fish distribution remained unchanged. If fish were exhibiting avoidance behavior to elevated levels of TDG supersaturation, then one would expect to observe a corresponding decrease in the abundance of fish at some static depth as TDG supersaturation levels increased. Therefore, in addition to the percent of total fish density at or above the TDG compensation depth, we elected to examine the percent of total fish density above static depths (2.0, 4.0, and 8.0 m) over the range of TDG supersaturation levels measured in McNary Reservoir to determine if any differences in vertical fish distribution could be related to changing TDG supersaturation levels. The 80th percentile of fish depth (80th), defined as the depth at which 80 percent of the total fish density occurred was also used as a metric in the analyses of fish distribution.

Total dissolved gas levels used in the analyses were those that corresponded to a TDG monitor directly upstream of the hydroacoustic sampling area (WA, CTR, or OR). Mean TDG compensation depths were calculated using the mean percent TDG for each sampling period at each location, approximately 1.0 m for each 10% over 100% saturation (Weitkamp and Katz 1980).

Three-way analysis of variance (ANOVA) was used to determine if differences in diel period, sampling location, and sampling period were present among metrics of vertical fish distribution. Metrics to describe vertical fish distribution included the percent of total fish density at or above the TDG compensation depth, the percent of total fish density at or above 2 m, the percent of total fish density at or above 4 m, the percent of total fish density at or above 8 m, and the depth at which 80 percent of the total fish density occurred.

Simple linear regression analyses were used to relate fish distribution patterns to percent TDG supersaturation and day of the month (seasonal component) during hydroacoustic surveys of McNary Reservoir in May 1997. We determined that it may be appropriate to separate the early and mid-May sampling periods from the late-May sampling period for analyses due to the significant change in species composition in the reservoir as indicated by daily juvenile fish passage indices at McNary Dam. Passage indices at McNary indicated that mostly yearling chinook salmon and steelhead were present in the reservoir during the early and mid-May sampling periods, while mostly subyearling chinook salmon were present during the late-May sampling period. In some cases, the late-May sampling period was omitted from the analyses due to the inadequate sample sizes that resulted from stratifying the data by location.

Stepwise multiple-regression analysis was used to develop a predictive model to describe the spatial distribution patterns of juvenile salmon in McNary Reservoir during the early and mid-May sampling periods. The cumulative percent of vertical fish density was selected as the dependent variable due to its relatively high correlation with vertical depth (r = 0.87). Independent variables used in the multiple-regression model included: $\log_e$(depth(m)+1), diel period (daytime or nighttime), sampling period (early-May, 5/7-12/97; mid-May, 5/14-21/97), and location (shore (WA\OR) or CTR). The independent variable depth was transformed using a natural logarithmic transformation of the form: $\log_e$(depth+1), to obtain a linear relationship with the dependent variable. Diel period, sampling period, and location were all coded as dummy or categorical variables as described in Schroeder et al. (1986). Residual plots were examined to confirm homoskedasticity and tolerance values were reviewed to confirm independence among predictor variables used in the model.

Species composition and the occurrence of gas bubble disease in smolts were assessed by the Columbia River Inter-Tribal Fish Commission (CRITFC). The CRITFC deployed a 5 m deep purse seine where concentrations of targets (fish) were detected with USGS-BRD hydroacoustic equipment. Fish captured with the purse seine were identified, measured to the nearest millimeter in fork length (FL) and examined by CRITFC personnel for symptoms of gas bubble disease.

Results

Environmental Variables

Total dissolved gas supersaturation levels recorded in McNary Reservoir from May 7-20 and from May 27-June 11, 1997 ranged from 112% to 129% supersaturation. Generally, TDG supersaturation levels at OR shore and center monitoring stations increased as total flow and spill increased at Ice Harbor Dam (Figure 2). Consequently, TDG supersaturation levels were highest at OR shore and center monitoring stations (mostly Snake River water) while TDG levels at WA shore monitoring stations (mostly mid-Columbia River water) remained relatively low throughout the season (Table 1; Figures 3, 4, and 5). Differences in TDG supersaturation of up to 10% were recorded between OR and WA shore gas meters at the Rkm 504.2 monitoring station (Figure 3A). Differences between OR and WA shore TDG levels became less distinct at downstream stations.

Table 1.— Summary table of percent TDG supersaturation, Minimum (Min), Maximum (Max) and Mean, at monitoring stations during hydroacoustic surveys of McNary Reservoir in 1997.

Statistic	Location (Rkm)									
	504.2			486.6			475.5			471.5
	WA	CTR	OR	WA	CTR	OR	WA	CTR	OR	CTR
					5/7-20/1997					
Mn	114.6	-	113.8	115.8	118.9	115.7	115.4	117.7	115.7	119.2
Mx	119.8	-	128.1	120.8	128.3	128.4	121.3	124.4	126.1	125.9
Mean	117.7	-	121.8	118.7	122.9	122.5	119.0	120.8	121.7	121.7
					5/27-6/11/1997					
Mn	115.8	119.7	112.5	116.6	118.1	116.2	116.6	-	117.2	117.9
Mx	121.2	125.0	129.1	122.6	127.0	125.8	122.2	-	124.5	125.2
Mean	119.0	122.7	120.5	119.8	123.2	121.5	119.7	-	121.5	122.2

Diel TDG supersaturation cycling was observed at TDG monitoring stations in McNary Reservoir in 1997. Diel TDG cycling was most evident at Rkm 504.2 with the greatest fluctuations occurring along the OR shore. Daily TDG fluctuations were less evident at center and WA shore monitoring stations (Figures 2A, 3A). Differences of up to 12% supersaturation during a 24 h period were recorded at the OR shore, Rkm 504.2 gas meter. Daily TDG fluctuations recorded by the OR shore gas meters from May 7-20 at Rkms 504.2, 486.6 and 475.5 were highly correlated with spill patterns at Ice Harbor Dam when offset by time to allow for travel time of TDG plumes to the monitoring stations downstream (Table 2).

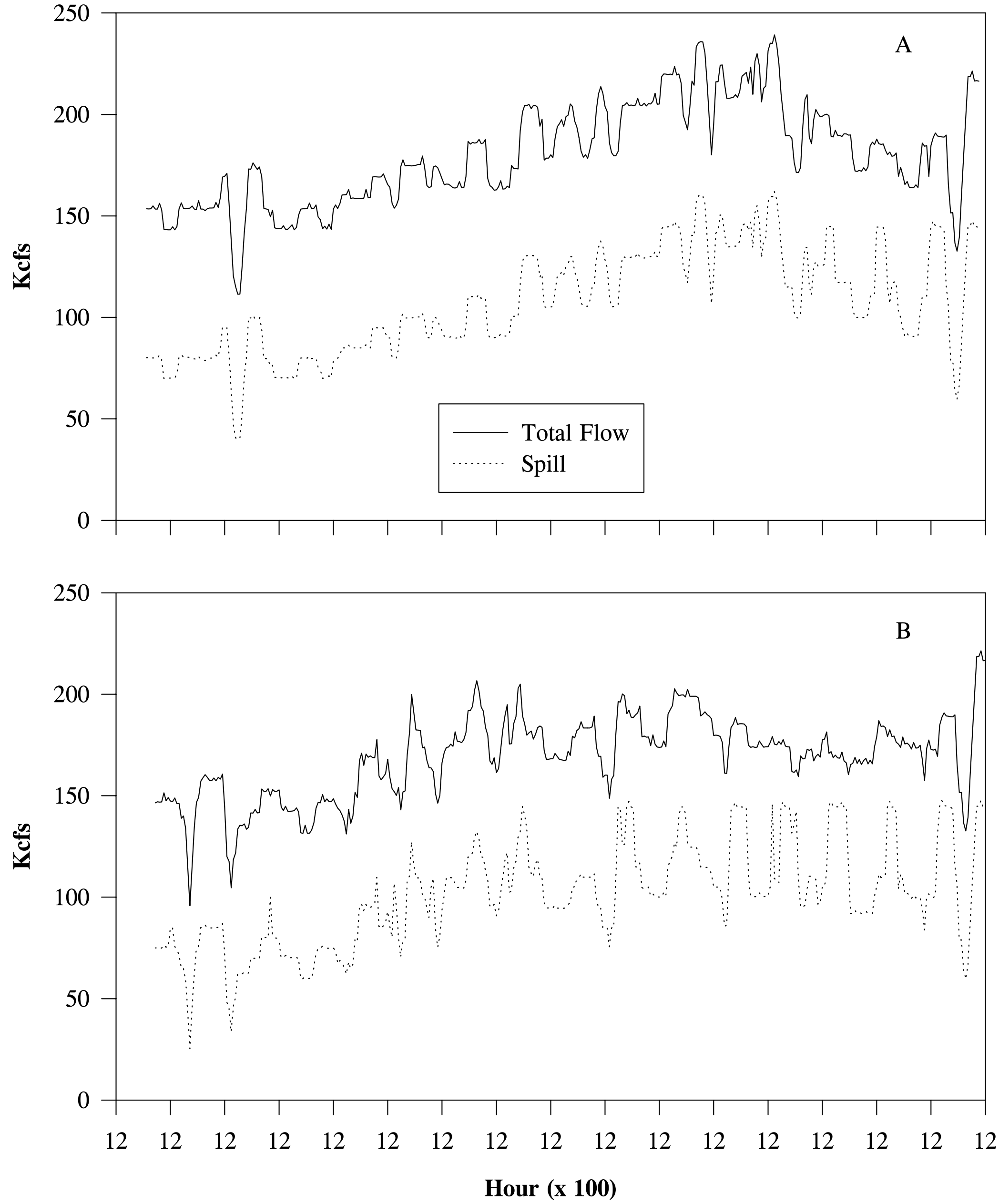


Figure 2.— Total flow and spill at Ice Harbor Dam from May7-21, 1997 (A) and May 27 to June 11, 1997 (B).

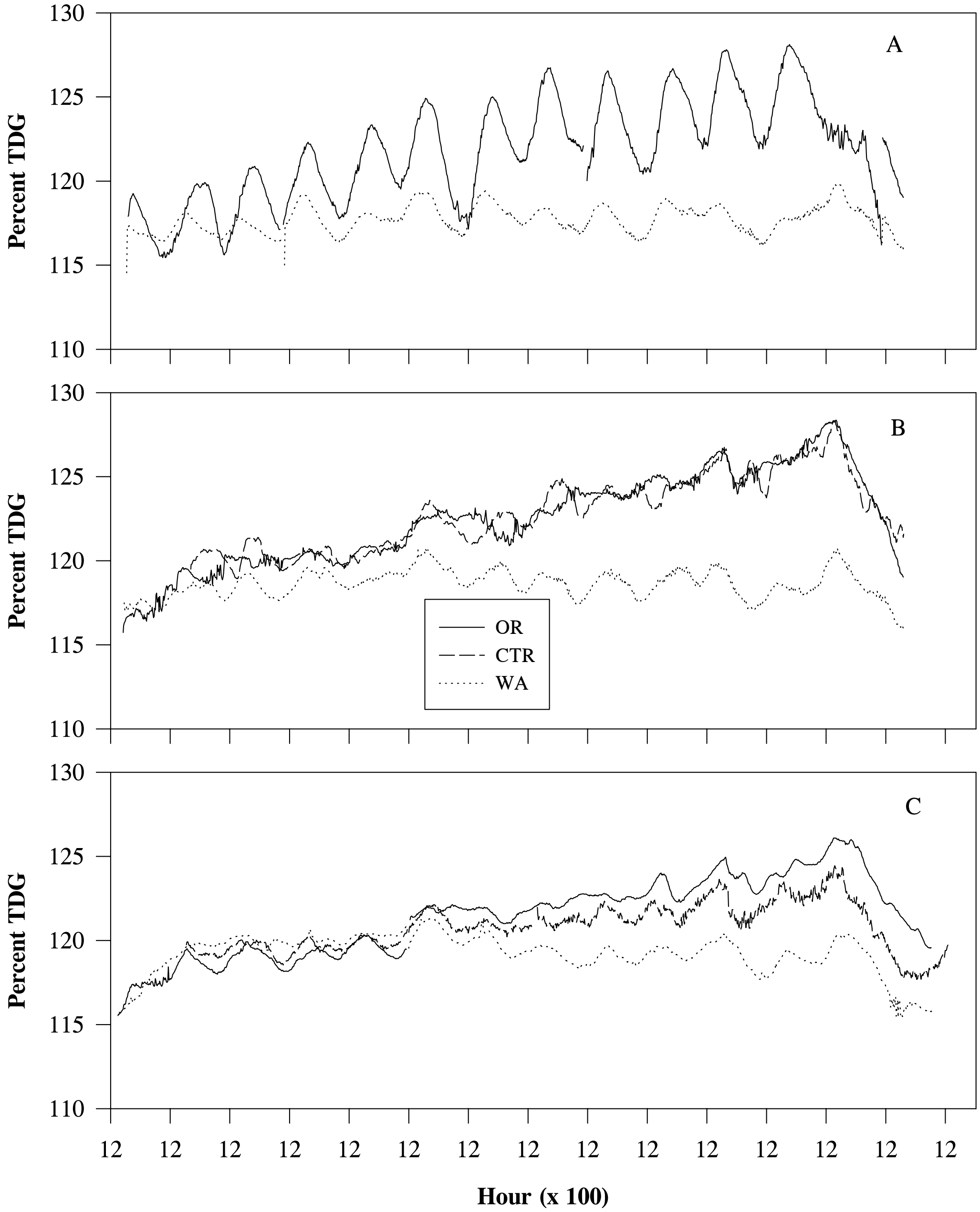


Figure 3.— Percent total dissolved gas levels at (A) Rkm 504.2, (B) 486.6, and (C) 475.5 in McNary Reservoir from May 7-21, 1997.

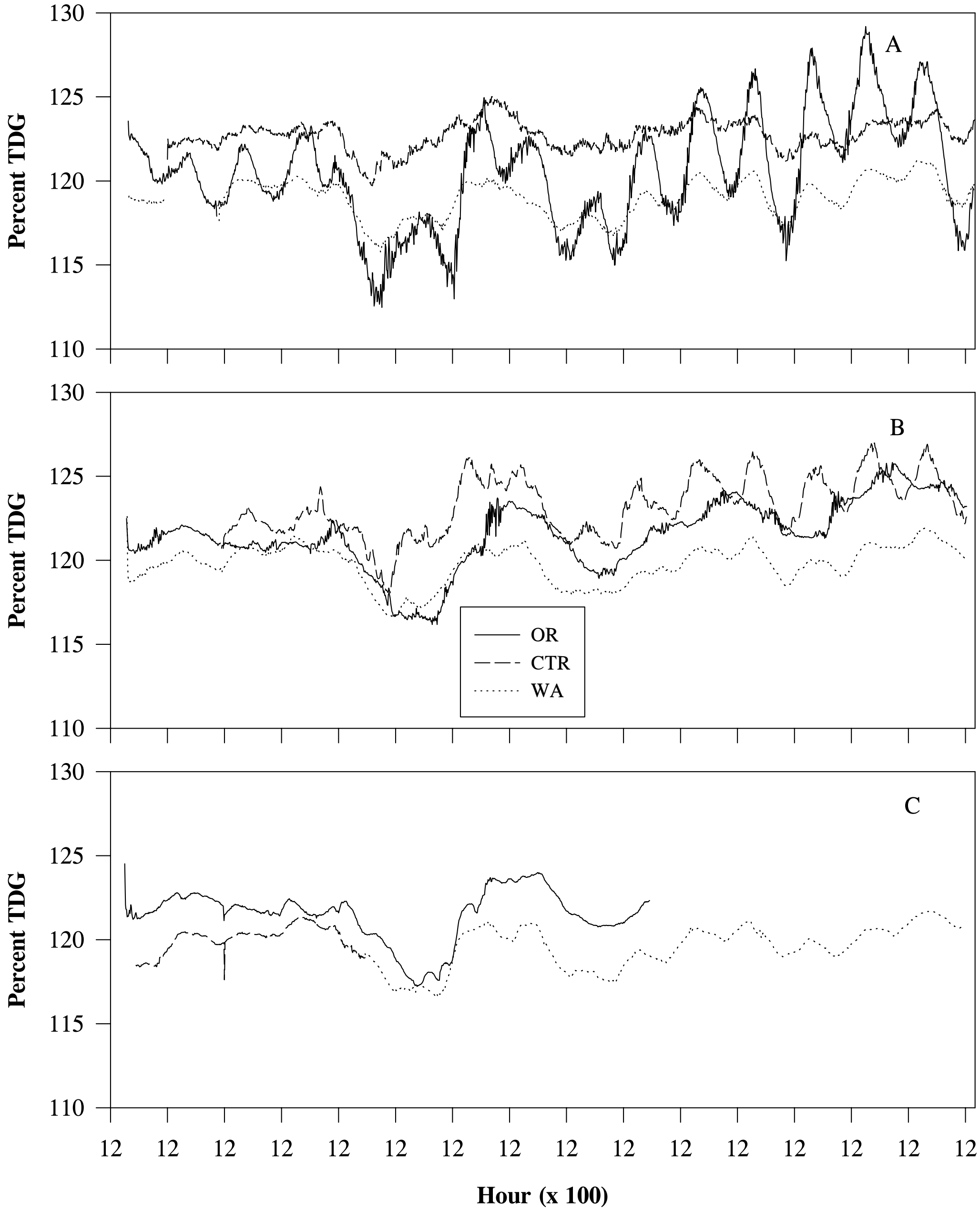


Figure 4.— Percent total dissolved gas levels at (A) Rkm 504.2, (B) 486.6, and (C) 475.5 in McNary Reservoir from May 27 to June 11, 1997.

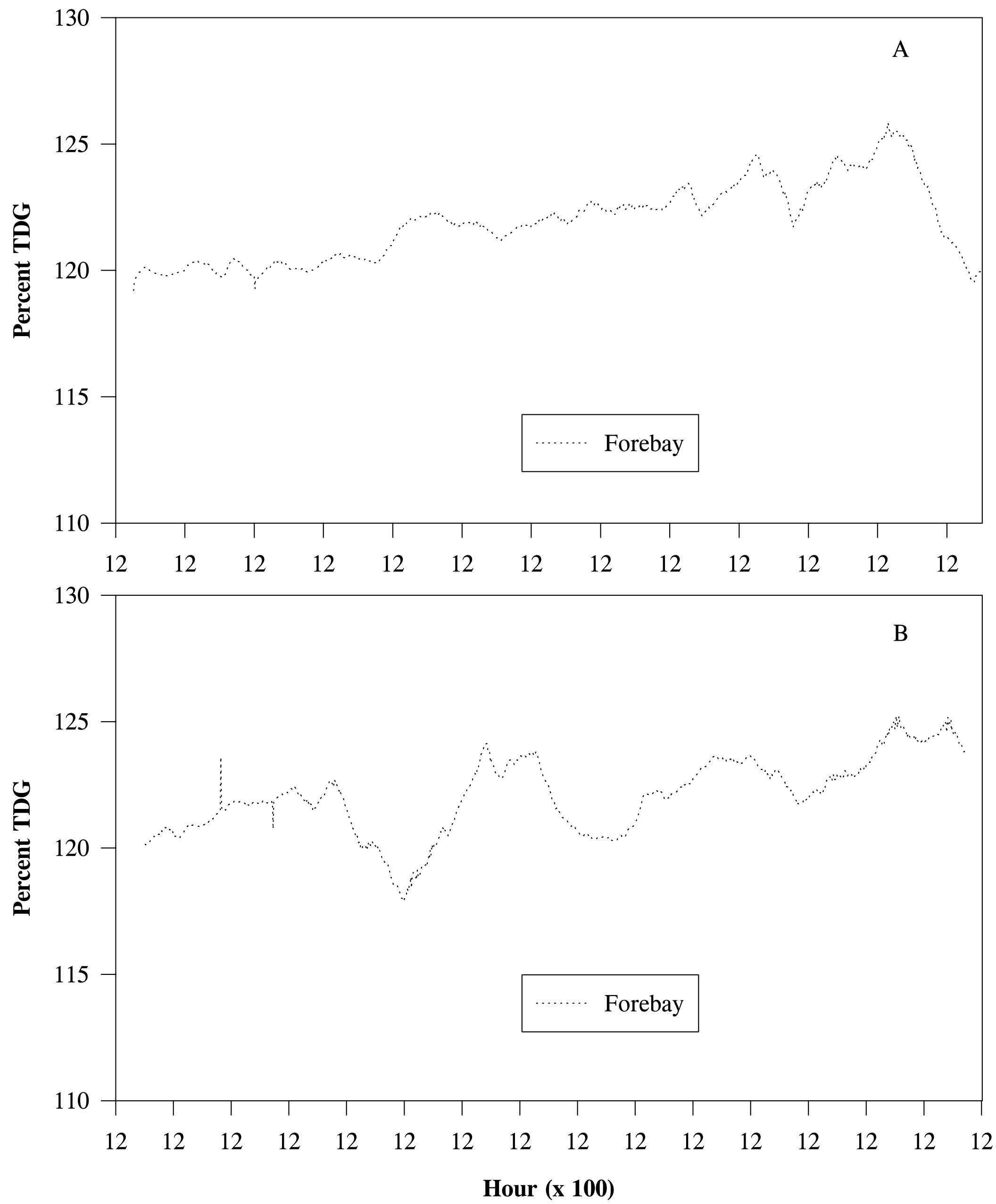


Figure 5.— Percent total dissolved gas levels in McNary forebay at Rkm 471.5 from (A) May 7-21, 1997 and (B) May 27 to June11, 1997.

Table 2.— Correlation (r) between spill at Ice Harbor Dam and TDG levels recorded at OR shore monitoring stations from May 7-20, 1997.

Offset	OR shore Rkm		
(h)	504.2	486.6	475.5
12	0.670		
13	0.676		
14	0.676		
15	0.664		
16	0.663		
17			
18			
19		0.814	
20		0.816	
21		0.818	
22		0.819	0.846
23		0.820	0.860
24		0.818	0.865
25		0.811	0.864
26			0.859
27			0.854

Water temperatures measured at TDG monitoring stations from May 7-20 and May 27-June 6, 1997 ranged from 10 to 15.3°C. Temperatures generally increased throughout the sampling period with the highest temperatures recorded at OR shore monitoring stations. Temperatures recorded at the monitoring stations fluctuated throughout the diel period. As with diel TDG cycling, diel temperature cycling was most distinct at OR shore stations and was less evident at center and WA shore stations progressing downstream (Figures 6, 7, and 8).

Turbidity at hydroacoustic sampling sites increased relative to total flows at Ice Harbor Dam during May 1997. Turbidity was highest along the OR shore (range 12.7-32.1 NTU) and steadily decreased across the reservoir to the WA shore (range 7.7-17.2 NTU). As total flow subsided at the end of May, turbidity tended to decrease as well (Figure 9).

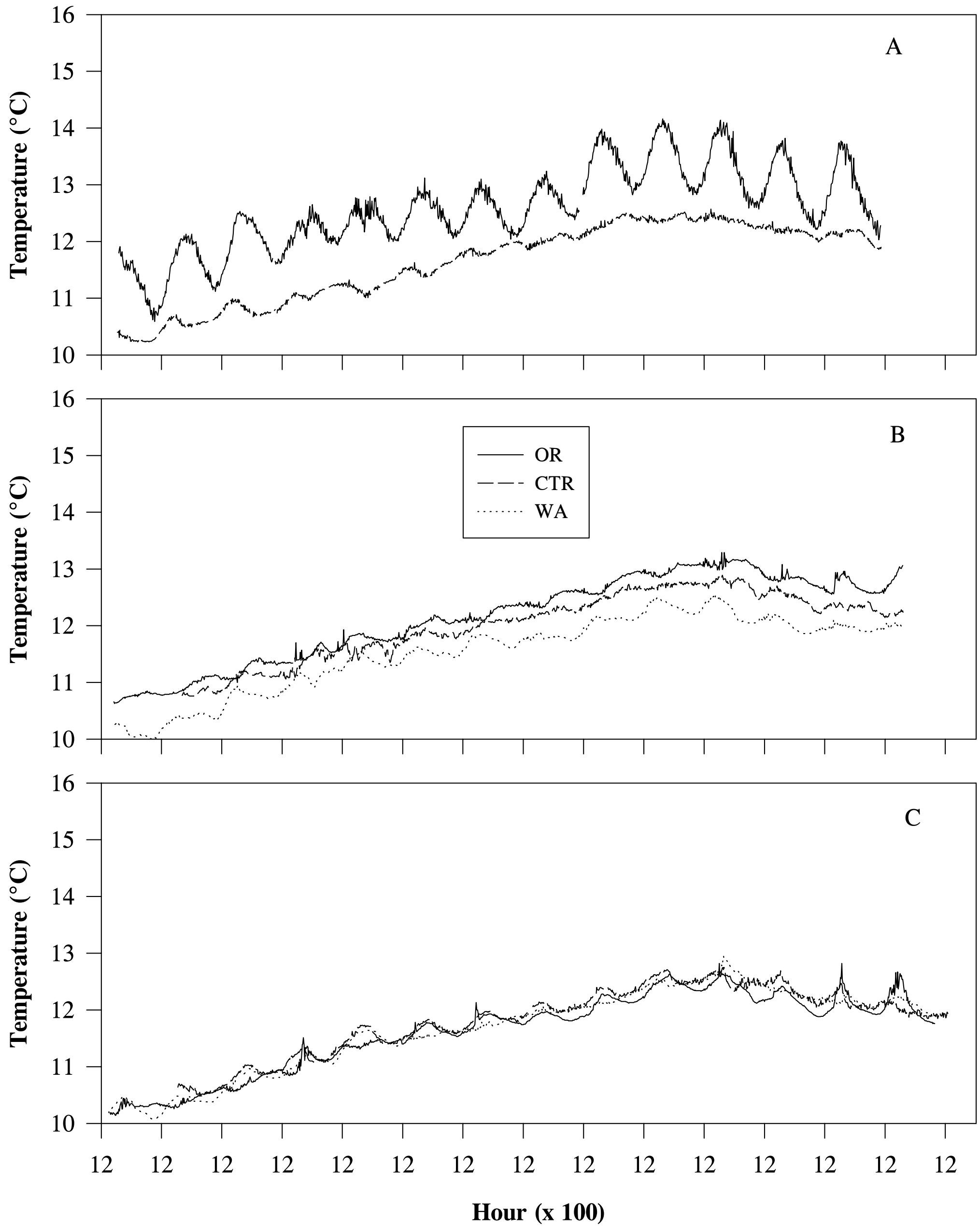


Figure 6.— Temperature measured at monitoring stations at (A) Rkm 504.2, (B) 486.6, and (C) 475.5 in McNary Reservoir from May 7-21, 1997.

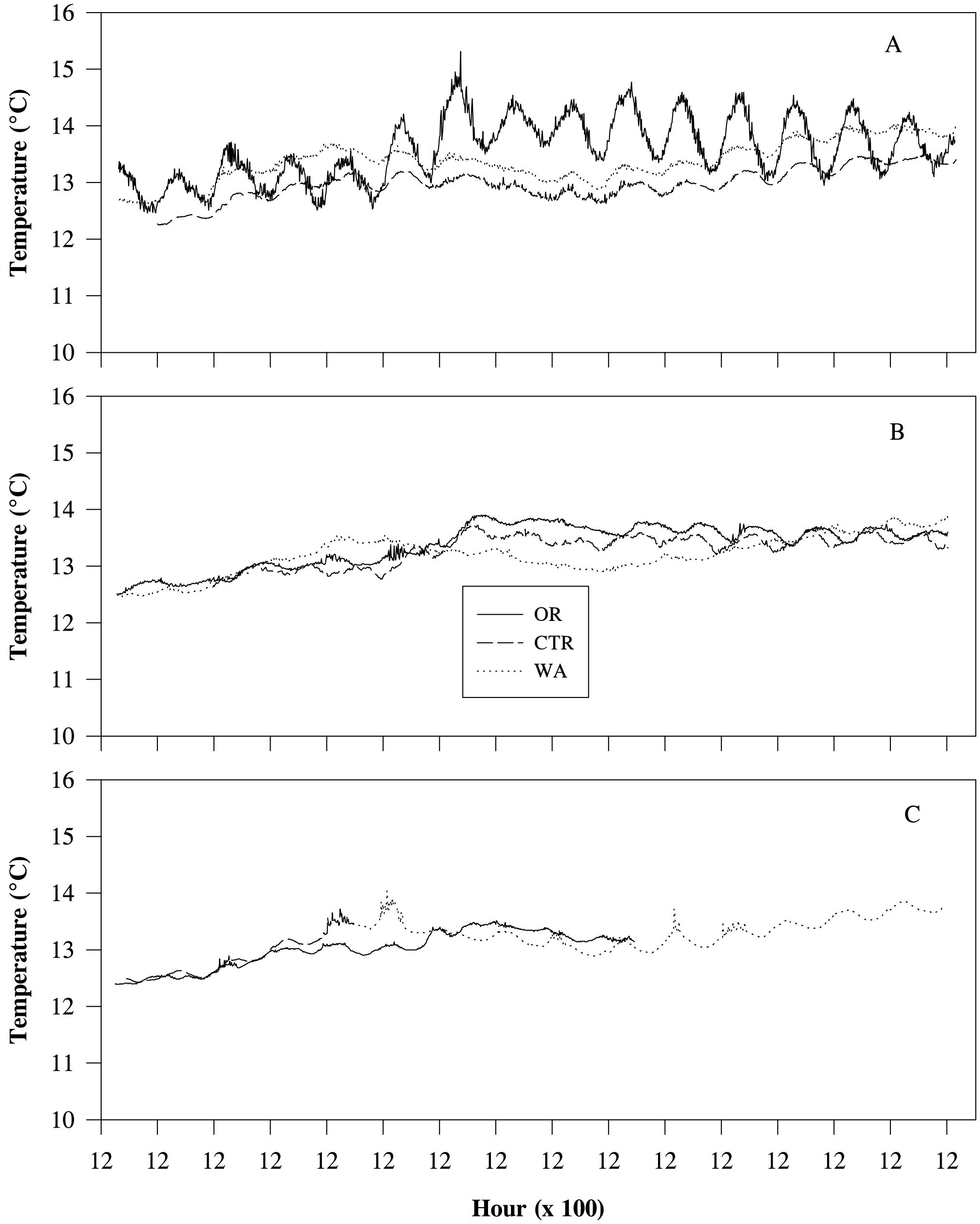


Figure 7.— Temperature measured at monitoring stations at (A) Rkm 504.2, (B) 486.6, and (C) 475.5 in McNary Reservoir from May 27 to June 11, 1997.

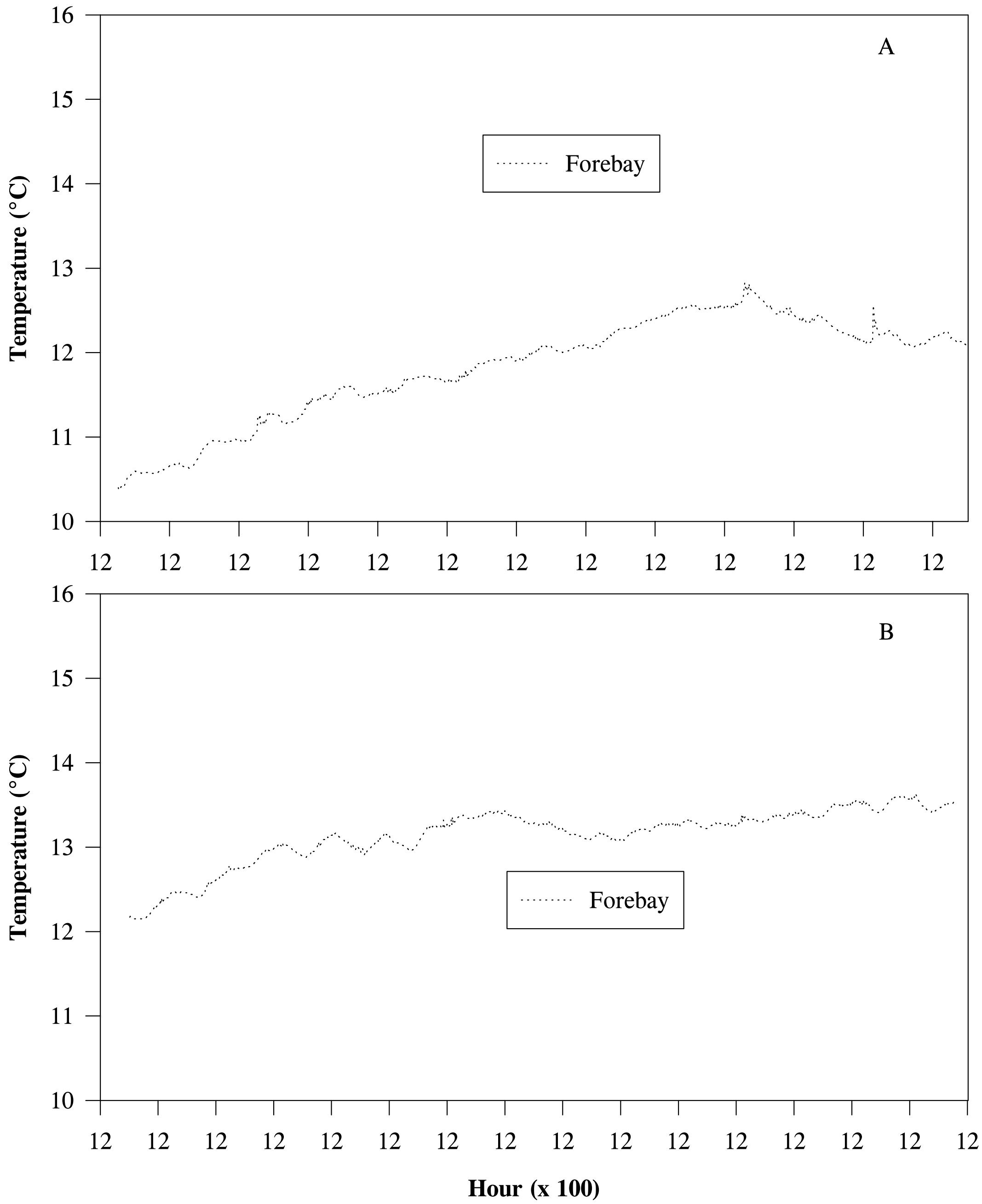


Figure 8.— Temperature measured in McNary forebay at Rkm 471.5 from (A) May 7-21, 1997 and (B) May 27 to June 11, 1997.

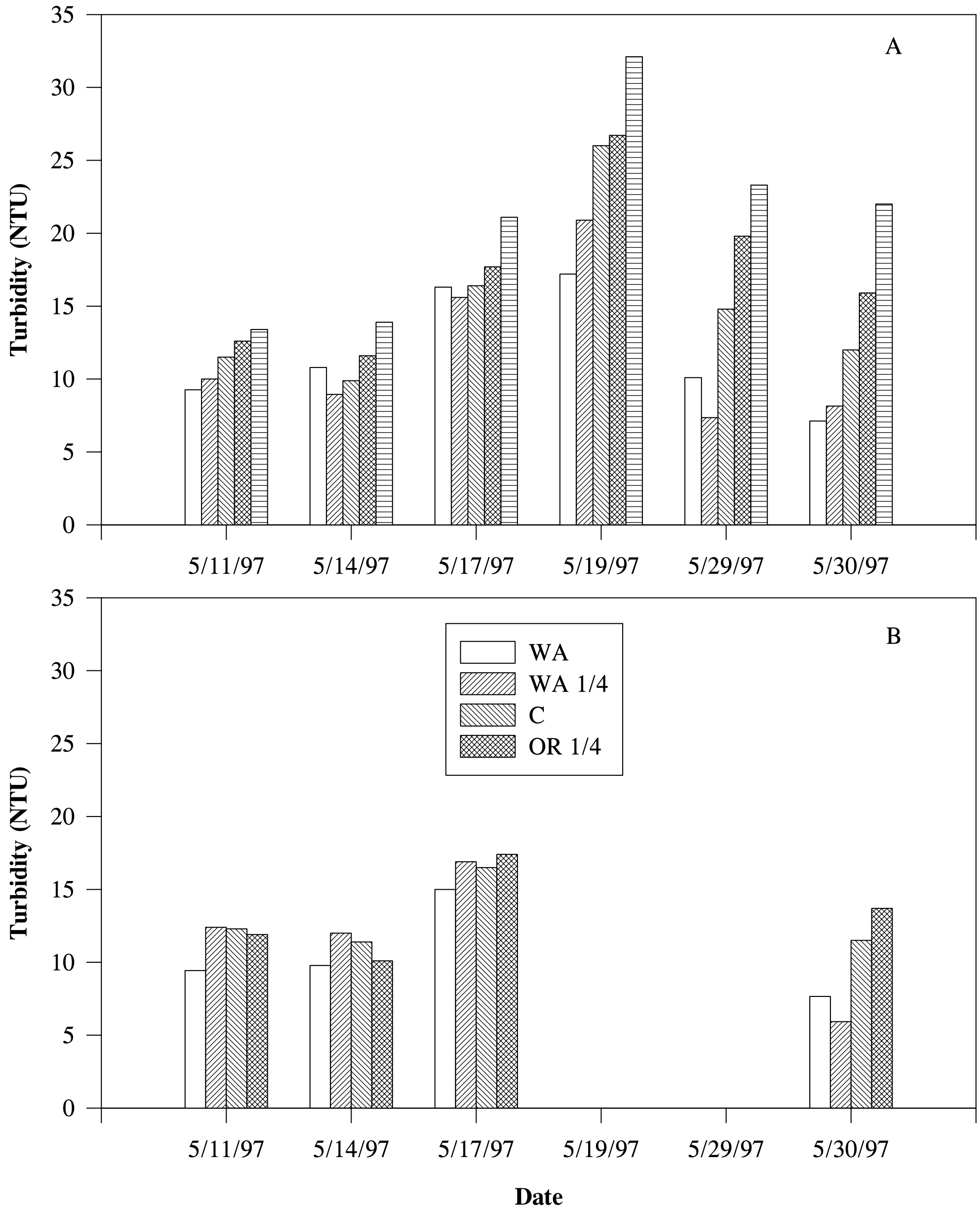


Figure 9.— Turbidity readings taken upstream at (A) Rkm 479.8 and downstream at (B) Rkm 476.9 of hydroacoustic transects during surveys of McNary Reservoir during May, 1997.

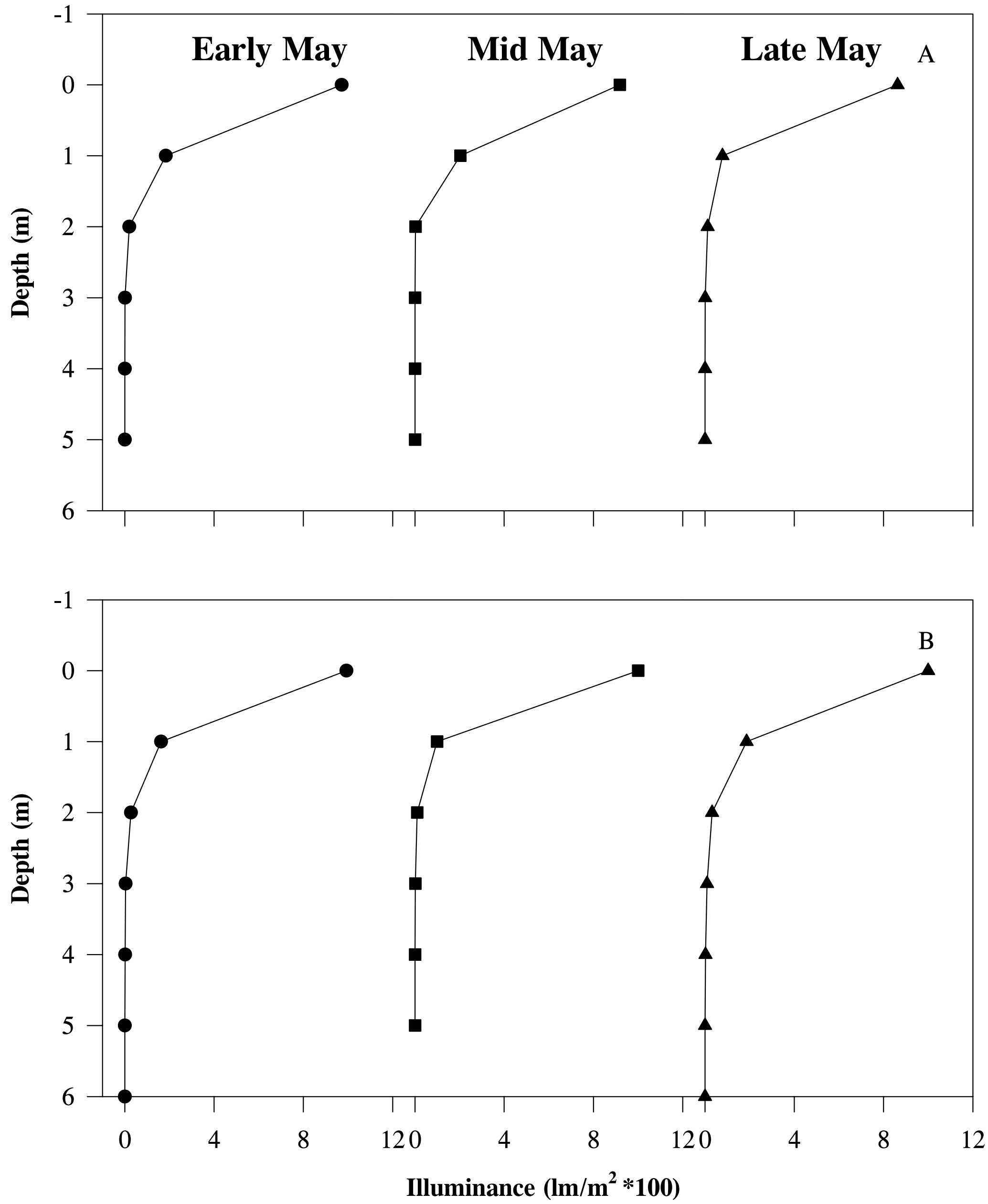


Figure 10.— Representative light extinction curves taken upstream at (A) Rkm 479.8 and downstream at (B) Rkm 476.9 of hydroacoustic transects during surveys of McNary Reservoir during May 1997.

Illuminance profiles collected during the daytime at the hydroacoustic sampling sites during May 1997 exhibited trends similar to turbidity data. Light extinction depths or the depth at which illuminance measurements became zero, were between 6-7 m during early May. Extinction depths were between 4-5 m during mid-May, and between 5-6 m during late May (Figure 10).

Species Composition

Hydroacoustic sampling during May coincided with high numbers of outmigrant juvenile salmon passing through the study area. During early and mid-May surveys, juvenile yearling chinook salmon and steelhead were the most abundant species passing McNary Dam, about 7 Rkm downstream of the study site. Towards the end of May, during the late-May sampling period, subyearling chinook salmon were the predominate species passing McNary Dam (Figure 11A).

Species composition of fish captured by the CRITFC using a purse seine in McNary Reservoir during May consisted of mostly juvenile salmonids (Figure 11B). Juvenile chinook salmon *Oncorhynchus tshawytscha* made up 63.5% (N=395) of the total catch during May. Juvenile steelhead *Oncorhynchus mykiss* made up 35.4% (N=220) of the total catch during May. Juvenile sockeye *Oncorhynchus nerka* made up 0.5% (N=3) of the total catch during May. The remaining 0.6% (N=4) of the total catch consisted of resident species (1 Chiselmouth, *Acrocheilus alutaceus*; 1 Crappie, *Pomoxis spp.*; 2 Peamouth, *Mylocheilus caurinus*).

Horizontal Fish Distribution

Horizontal fish distributions, described by the number of fish/m^2 during the early and late-May sampling periods, were interpolated and plotted in a plan view. Horizontal fish distribution during the mid-May sampling period, when point-sampling methods were used, was displayed as a relative percent of total fish density between the three sample points across the reservoir. The highest densities of fish are represented as yellow, orange, and red in Figures 12A, 12B, 14A, and 14B, and bar length in Figure 13. Relatively high densities of fish were observed near the shorelines during both daytime and nighttime, with relatively low densities near mid-channel. This observation persisted throughout the month of May, even as species composition in the reservoir changed.

Vertical Fish Distribution

Vertical fish distribution was determined in McNary Reservoir during three sampling periods (early, mid, and late) throughout the month of May. Vertical fish distribution for each sampling location, sampling period, and diel period was summarized as a percent of total density in 0.5 m depth intervals. Mean percentages of total fish density at or above the TDG compensation depth ranged from 3-40% during hydroacoustic sampling (Table 3). Mean TDG compensation depths for smolts ranged from 2.0-2.5 m at hydroacoustic sampling sites in McNary Reservoir during May 1997. At the WA shore, TDG supersaturation levels varied

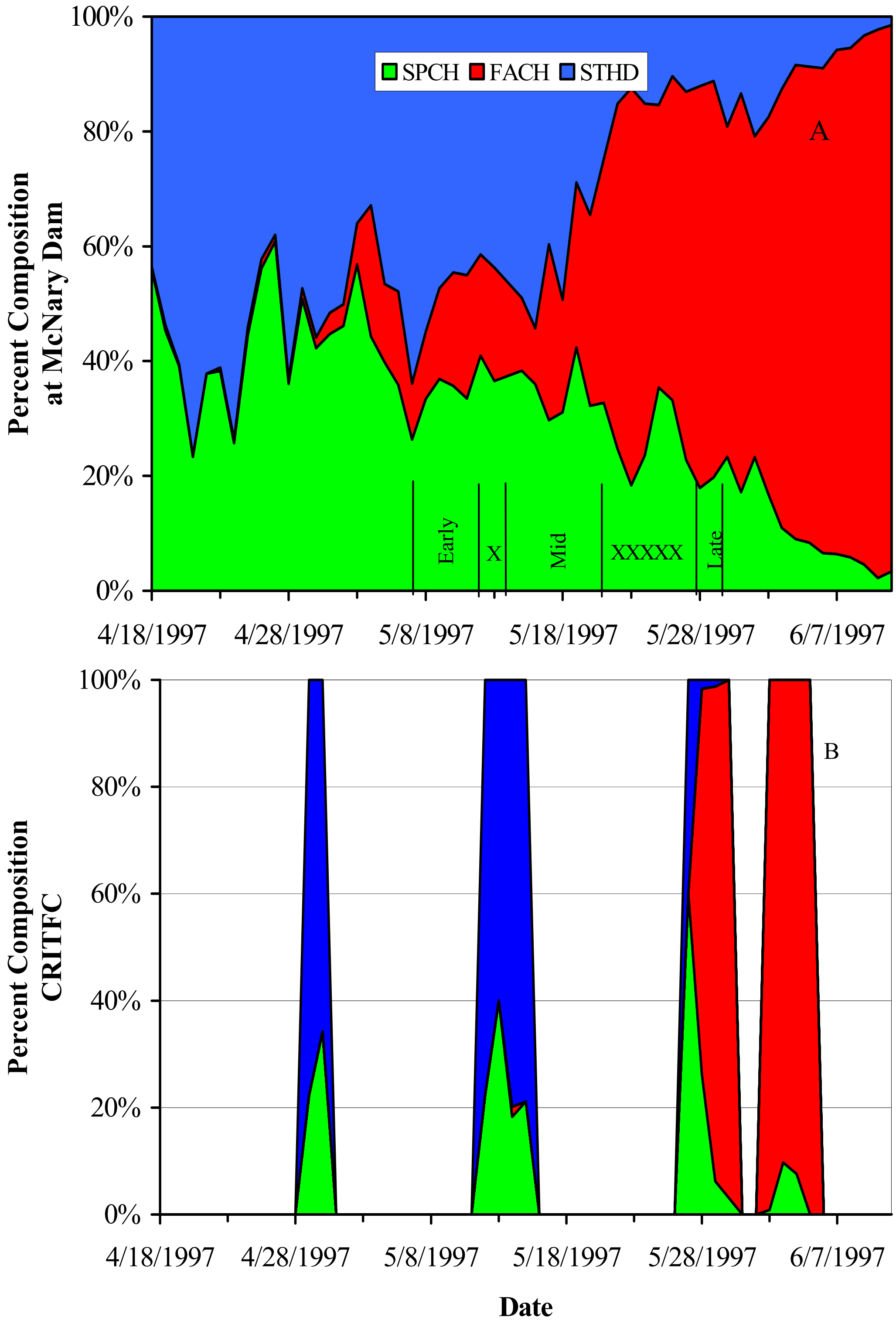


Figure 11.— (A) Percent species composition of fish passing McNary Dam in 1997 and (B) percent species composition of fish captured with purse seine by the CRITFC in McNary Reservoir during 1997.

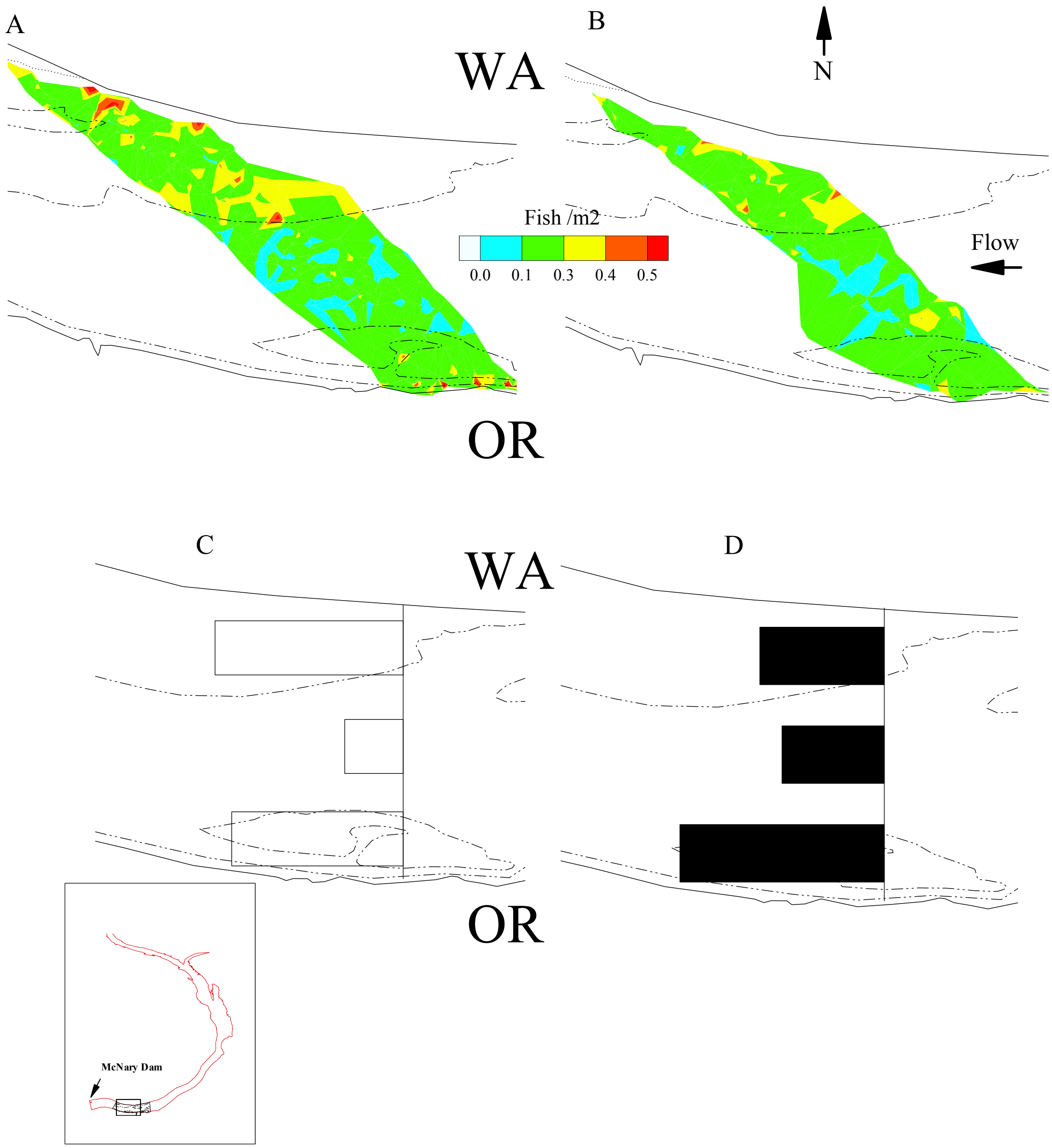


Figure 12.— Horizontal fish distribution from daytime (A, C) and nighttime (B, D) hydroacoustic transects in McNary Reservoir on May 7-12, 1997. Graphs C and D show relative percent of total fish density at WA, CTR, and OR.

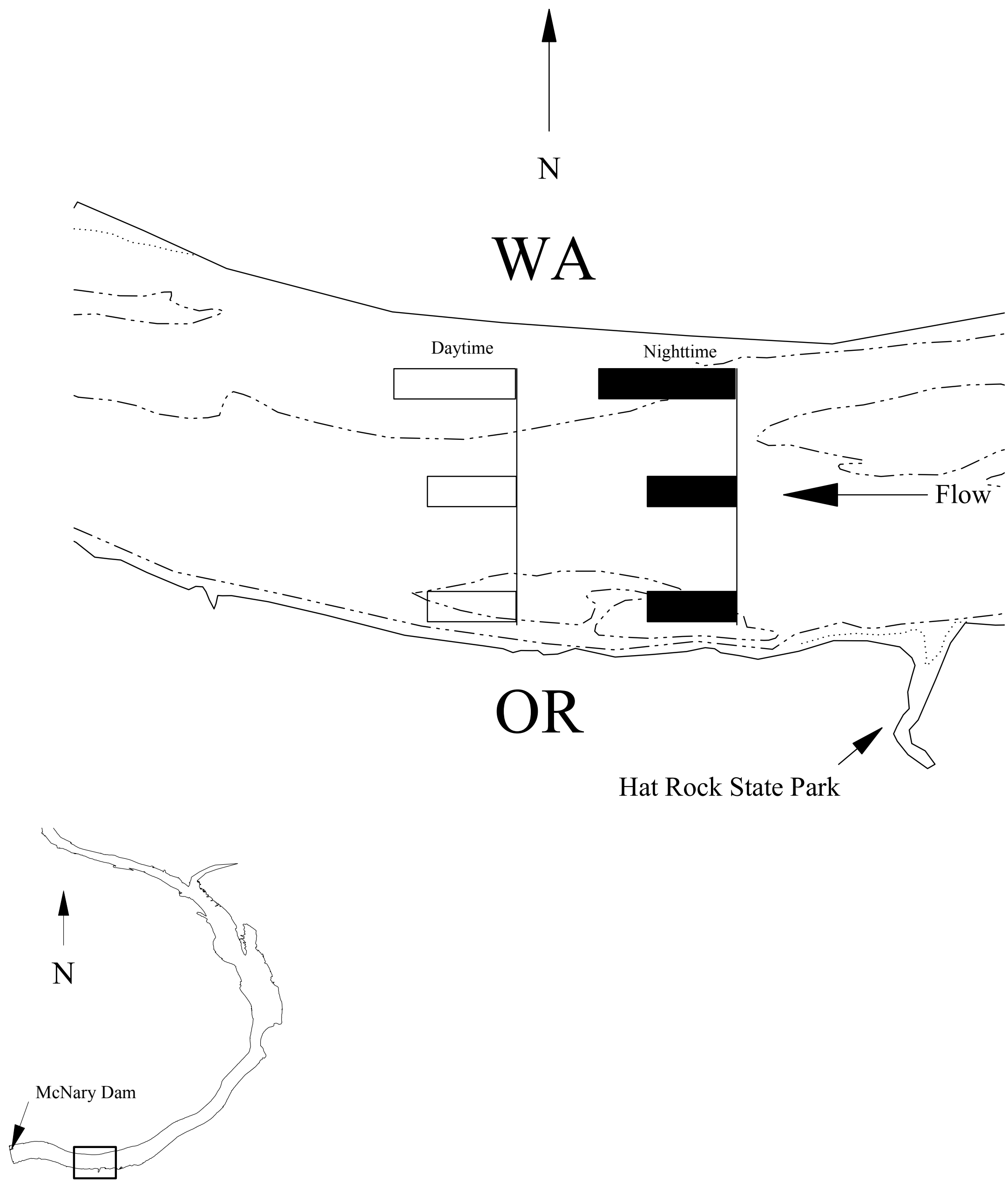


Figure 13.— Horizontal fish distribution from stationary point sample sites in McNary Reservoir on May 14-21, 1997. Relative percent of fish density is represented by bar length.

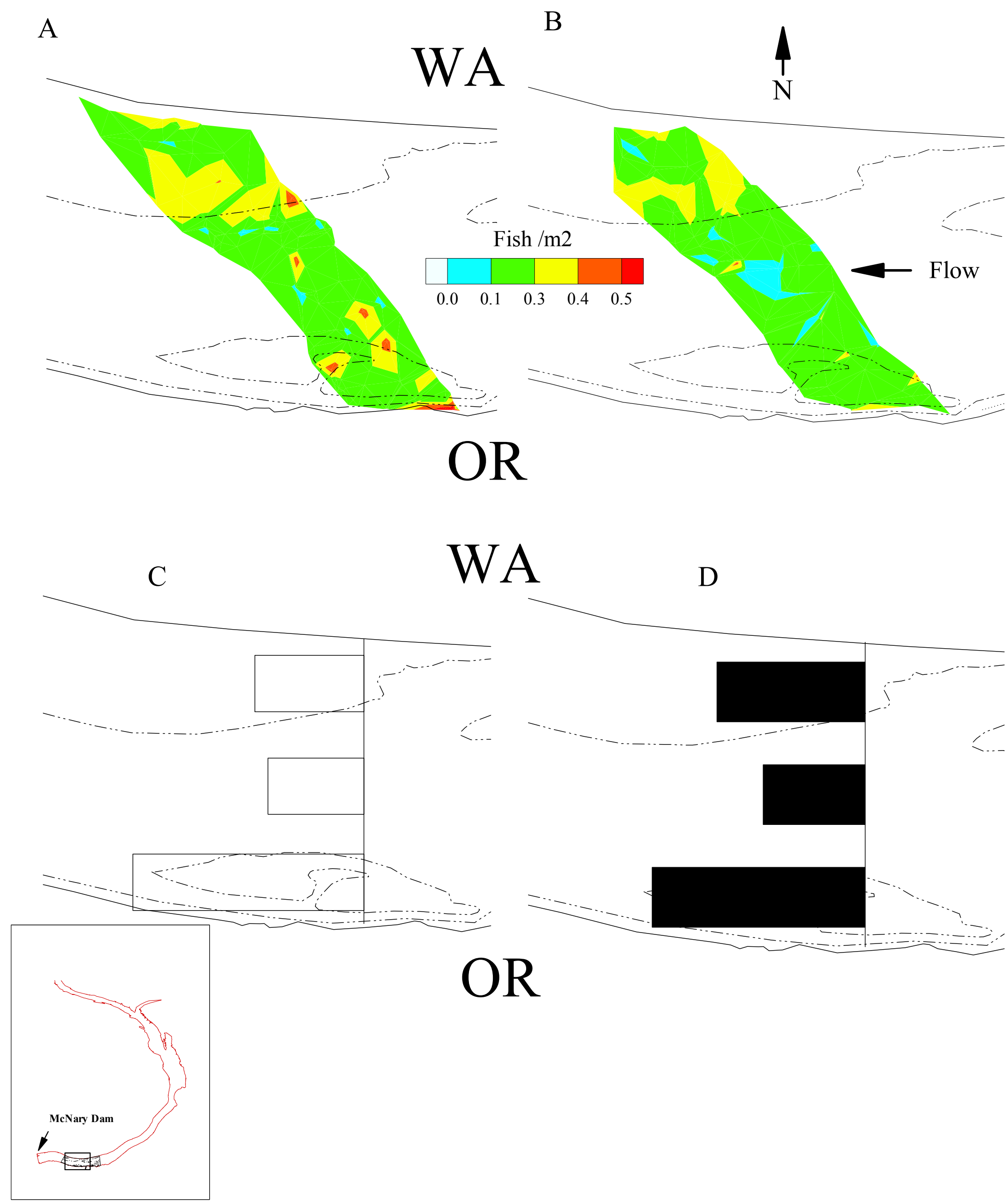


Figure 14.— Horizontal fish distribution from daytime (A, C) and nighttime (B, D) hydroacoustic transects in McNary Reservoir on May 28-30, 1997. Graphs C and D show relative percent of total fish density at WA, CTR, and OR.

relatively little, which resulted in a mean TDG compensation depth of 2.0 m throughout the entire season. At the CTR site and OR shore TDG supersaturation levels fluctuated more resulting in TDG compensation depths ranging from 2.0-2.5 m throughout the season.

Table 3.— Summary table of mean percent TDG, mean percent of total fish density above the TDG compensation depth and standard deviation (SD) at each location during each sampling period.

Date	Sampling Method/Location	Mean Percent TDG	Mean Percent of Total Fish Density Above TDG Compensation Depth	
			Day	Night
May 7-12	Early-mobile			
	WA	119	23 (11.0)	14 (18.2)
	CTR	120	33 (13.1)	20 (9.7)
	OR	120	18 (8.6)	9 (4.2)
May 14-21	Mid-point			
	WA	119	18 (10.9)	18 (4.6)
	CTR	123	39 (13.0)	23 (12.4)
	OR	125	30 (7.7)	25 (16.7)
May 28-30	Late-mobile			
	WA	120	3 (5.4)	19 (8.1)
	CTR	122	40 (9.1)	23 (2.9)
	OR	121	24 (4.1)	28 (3.3)

Three-way analysis of variance (ANOVA) was used to determine if significant differences in vertical fish distribution existed between diel periods, sampling locations, and sampling periods. Significant differences between diel periods were observed in the percent of total fish density at or above the TDG compensation depth, the percent of total fish density at or above 4 m, and the percent of total fish density at or above 8 m (Table 4). Significant differences between sampling locations were observed in the percent of total fish density at or above the TDG compensation depth, the percent of total fish density above at or 2 m, the percent of total fish density at or above 4 m, and the depth at which 80 percent of the total fish density occurred (Table 4). A significant difference between sampling periods was observed in the percent of total fish density at or above 8 m (Table 4).

Of 45 linear regressions used to regress metrics of vertical fish distribution on percent TDG supersaturation (Appendix Tables 1-3), only one significant relation was observed. During the early and mid-May sampling periods, a highly significant relation ($P \leq 0.01$) was observed between the 80th percentile of fish depth (dependent) and the percent TDG (independent) at the OR shore, resulting in an r^2 of 0.28 (Appendix Table 3). No other relations between metrics describing vertical fish distribution and the percent TDG supersaturation were observed during hydroacoustic sampling in McNary Reservoir.

Table 4.— Summary of three-way analyses of variance (ANOVA) between metrics to describe vertical fish distribution and diel period, sampling location, and sampling period.

Response Variable [a]	Source of Variation		
	DAYNITE [b]	LOCATION [c]	PERIOD [d]
CD	0.01** í	<0.01*** í	0.33
2m	0.06	<0.01***	0.89
4m	<0.01***	<0.01*** í	0.45 í
8m	<0.01***	0.35 í	<0.01*** í
80th	0.08	<0.01*** í	0.07 í

[a] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.
[b] DAYNITE = Diel period (daytime/nighttime).
[c] LOCATION = Location in reservoir (WA, CTR, OR).
[d] PERIOD = Sampling period (early, mid, late-May).
** significant when $P \leq 0.01$, *** significant when $P \leq 0.001$.
í significant interaction between main effects.

Of 45 regressions used to regress metrics of vertical fish distribution on day of the month during May (Appendix Tables 4-6), three significant relations were observed. During the early and mid-May hydroacoustic sampling periods, the 80th percentile of fish depth at both the WA and OR shores shifted to shallower depths during the early and mid-May sampling periods. This trend in the 80th percentile of fish depth was not observed at the CTR site. Based on the regression of depth (dependent variable) on day of the month (independent variable), the predicted 80th percentile of fish depth shifted 7 m shallower at the WA shore site and 8 m shallower at the OR shore site ($r^2 = 0.49$, $P < 0.01$ for WA shore; $r^2 = 0.33$, $P < 0.01$ for OR shore; Appendix Table 6). A significant relation between the percent of total fish density at or above 8 m (dependent) and day of the month (independent) was also observed at the WA shore during the early and mid-May sampling periods ($r^2 = 0.46$, $P < 0.01$; Appendix Table 6). No other significant relations were observed between metrics to describe vertical fish distribution and day of the month during May.

Predicting Fish Distribution

Stepwise multiple-regression analyses were used to relate the cumulative percent of vertical fish density to the $\log_e(\text{depth}+1)$, diel period, sampling period, and location in the reservoir using the early and mid-May sampling periods in McNary Reservoir. The resulting predictive model was able to explain 84% of the variation in the cumulative percent of vertical fish density ($R^2 = 0.84$, Table 5). Tolerance values for individual predictor variables were high, indicating a high degree of independence among the predictor variables. The depth variable explained a large portion of the variation observed in the cumulative percent of the total fish density at 81.7%. The remaining variables: diel period, sampling period, and location in the reservoir explained an additional 1.9% of the variation observed in the cumulative percent of the total fish density (Table 6). Observed and predicted vertical distributions for shoreline (WA and OR shores pooled) and CTR, daytime and nighttime, and early and mid-May sampling periods are represented in Figures 15-18.

Table 5.— Multiple-regression model for predicting vertical fish distribution in McNary Reservoir.

N	Variables [a]	Coefficient	SE	*P* [b]	MSE	R^2
1449	Constant	-18.058	1.156	<0.001	166.71	0.84
	LDEPTH	35.989	0.425	<0.001		
	DAYNITE	6.409	0.680	<0.001		
	LOCATION	5.630	0.750	<0.001		
	PERIOD	3.601	0.698	<0.001		

[a] LDEPTH = $\log_e$(Depth+1); DAYNITE = Daytime (1) or nighttime (0) sample, coded as a dummy variable; LOCATION = shorelines (0) or center of reservoir (1), coded as a dummy variable; PERIOD = early-May (5/7-12/97 = 0), or mid-May (5/14-21/97 = 1), coded as a dummy variable.
[b] significant when $P \leq 0.05$.

Table 6.— Measures of importance of individual regressors in the multiple-regression model to predict vertical fish distribution in McNary Reservoir.

Variable [a]	Partial R^2	Tolerance [b]	Standardized Estimate [c]
LDEPTH	0.817	1.000	0.904
DAYNITE	0.010	0.996	0.101
LOCATION	0.003	0.993	0.080
PERIOD	0.006	0.991	0.055

[a] LDEPTH =$\log_e$(depth+1); DAYNITE = Daytime (1) or nighttime (0) sample, coded as a dummy variable; LOCATION = shorelines (0) or center of reservoir (1), coded as a dummy variable; PERIOD = early-May (5/7-12/97 = 0), or mid-May (5/14-21/97 = 1), coded as a dummy variable.
[b] One minus the multiple correlation between a predictor variable and all other predictor variables in the model.
[c] Indicates the relative contribution of each predictor variable in explaining the variation in the dependent variable.

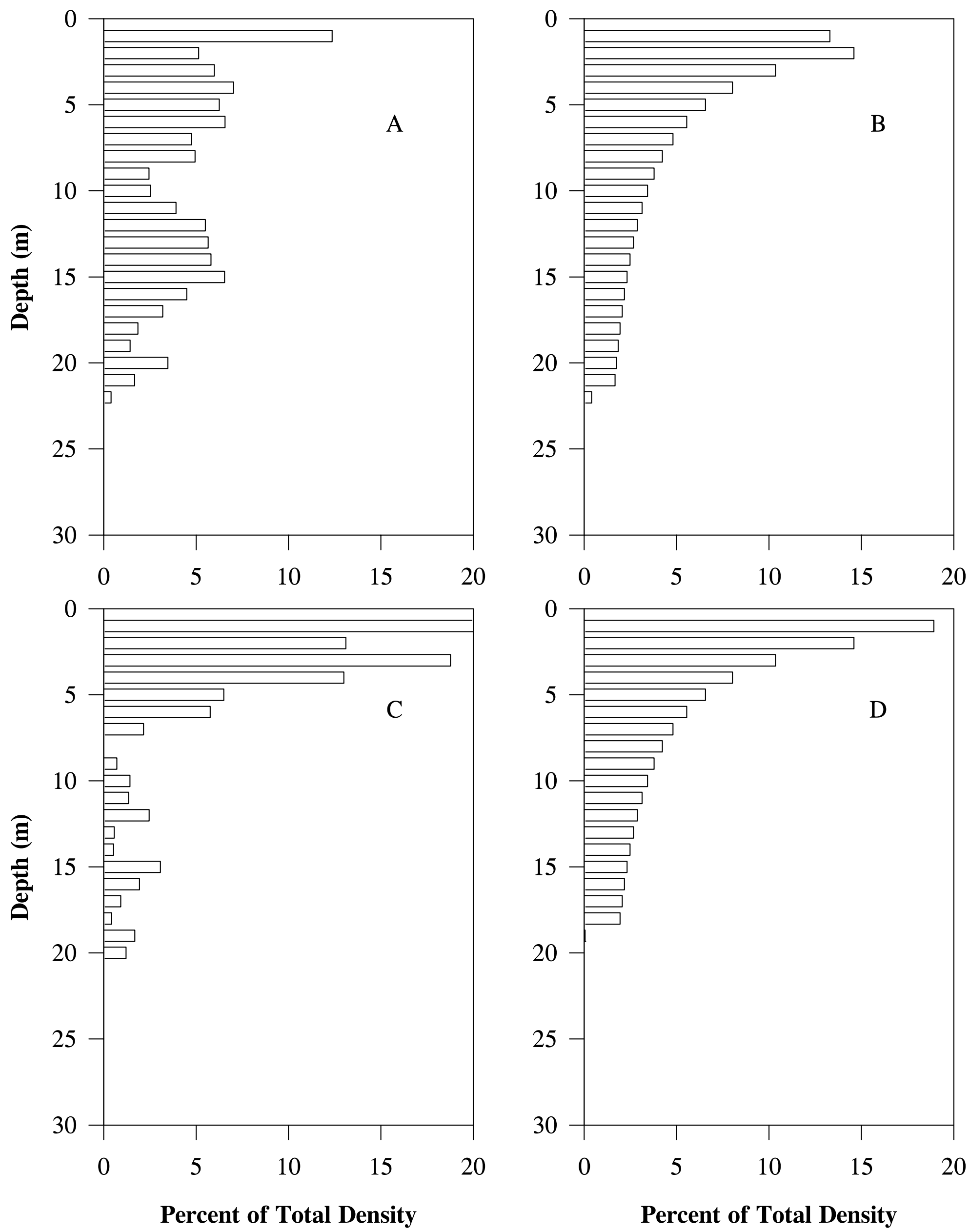


Figure 15.— (A) Observed and (B) predicted fish distribution at the WA and OR shores and (C) observed and (D) predicted fish distribution at the center of the reservoir during daytime sampling in McNary Reservoir for May 7-12, 1997.

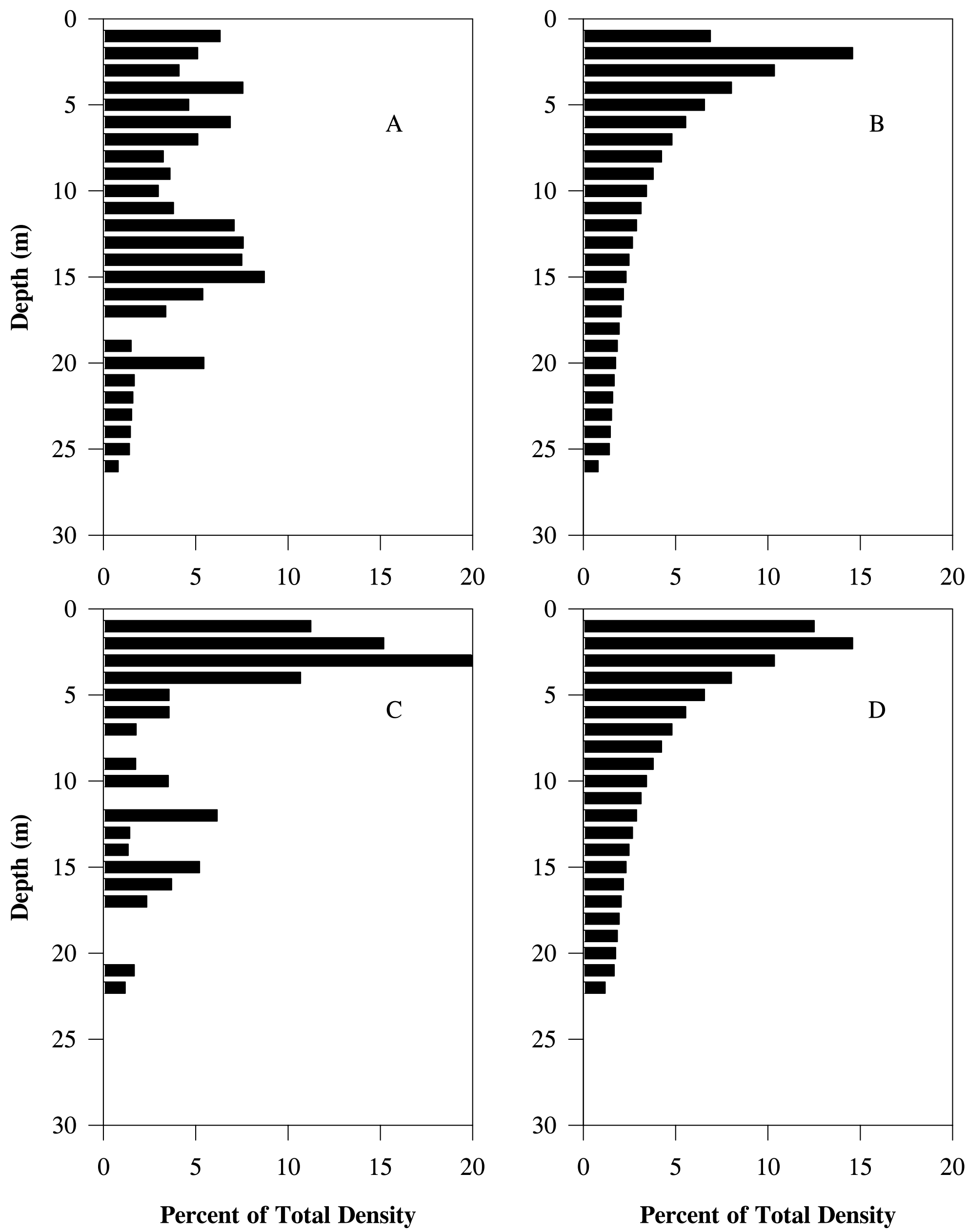


Figure 16.— (A) Observed and (B) predicted fish distribution at the WA and OR shores and (C) observed and (D) predicted fish distribution at the center of the reservoir during nighttime sampling in McNary Reservoir for May 7-12, 1997.

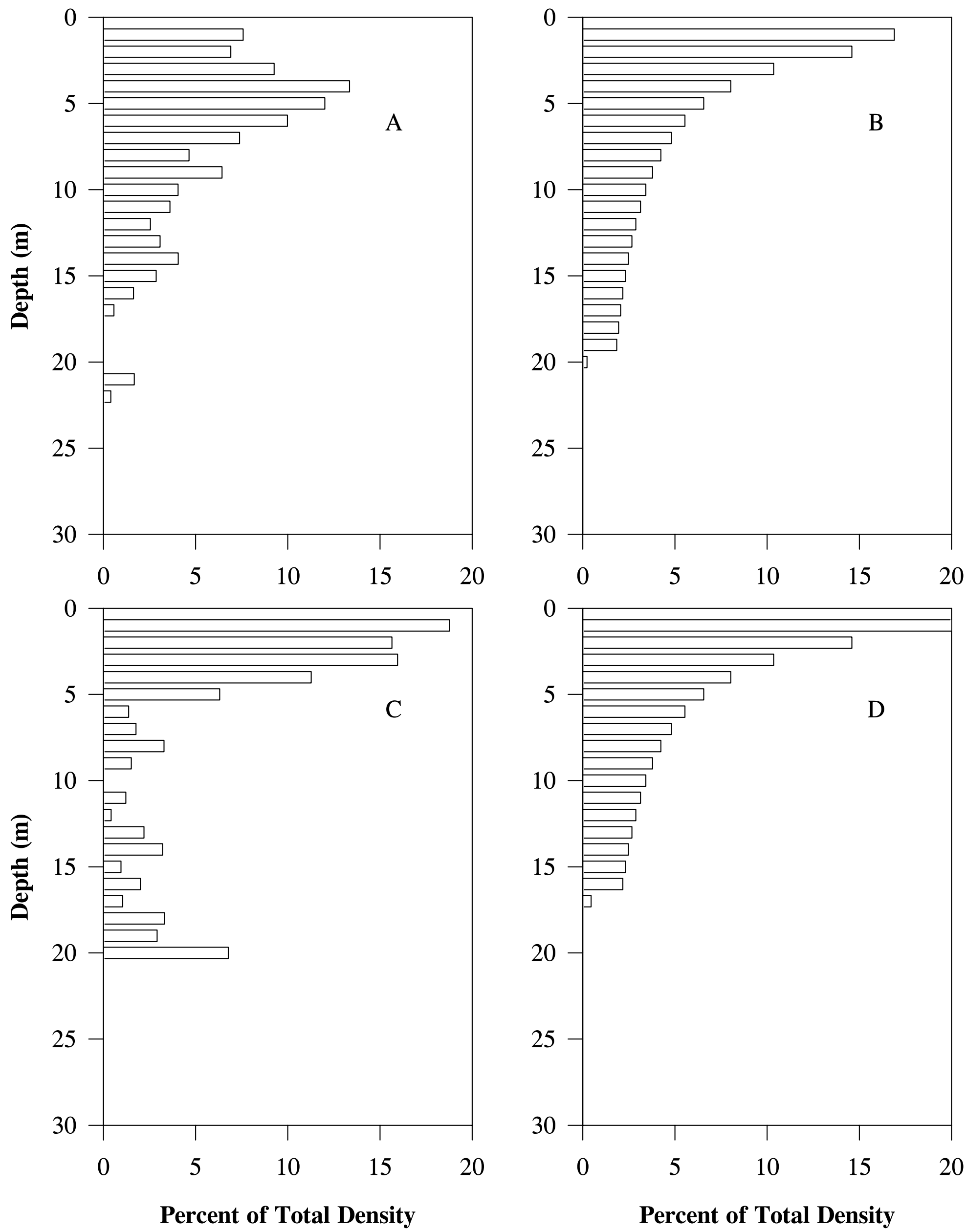


Figure 17.— (A) Observed and (B) predicted fish distribution at the WA and OR shores and (C) observed and (D) predicted fish distribution at the center of the reservoir during daytime sampling in McNary Reservoir for May 14-21, 1997.

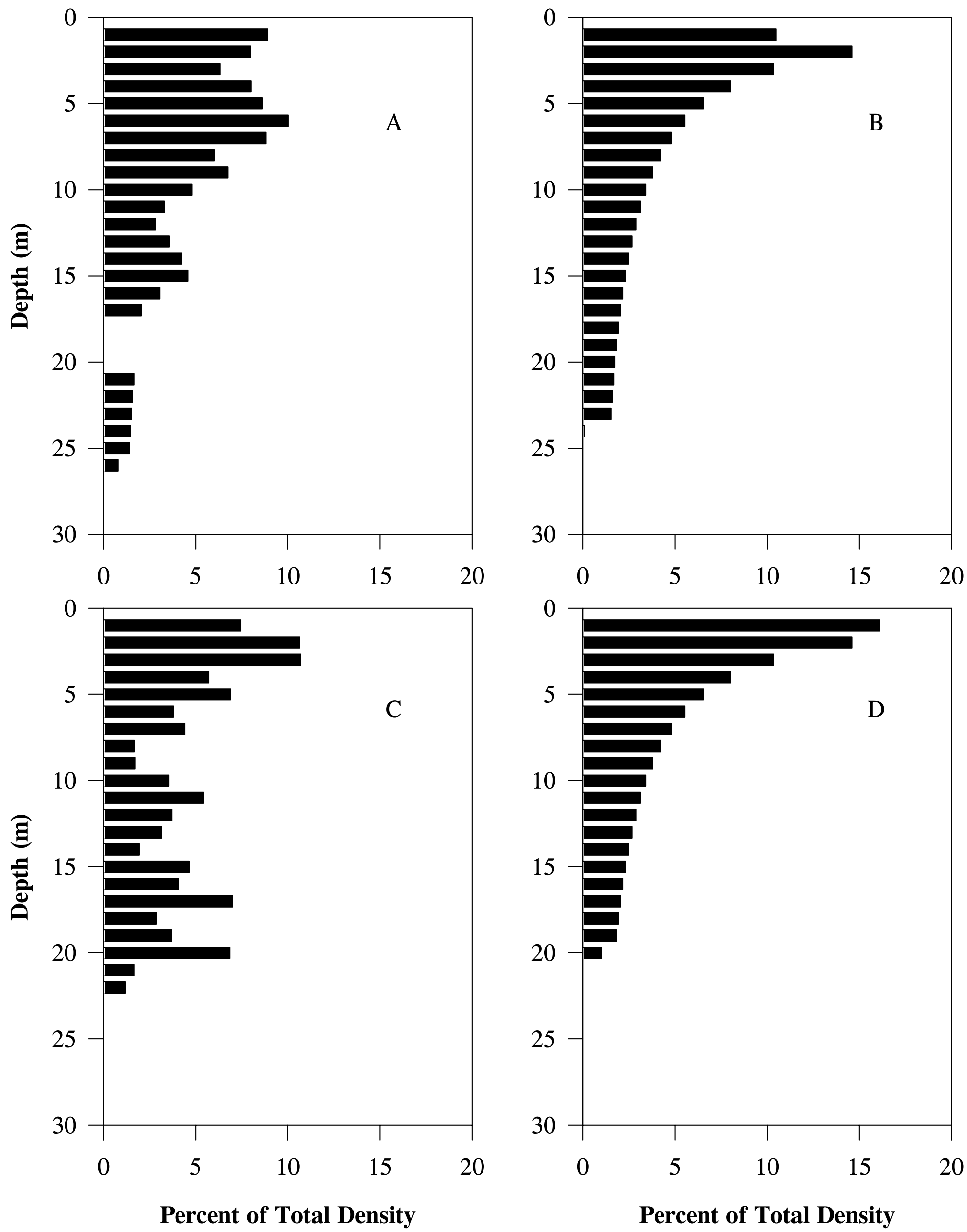


Figure 18.— (A) Observed and (B) predicted fish distribution at the WA and OR shores and (C) observed and (D) predicted fish distribution at the center of the reservoir during nighttime sampling in McNary Reservoir for May 14-21, 1997.

Discussion

Spring flows in the Snake and Columbia rivers during the spring of 1997 were at extreme high levels. However, corresponding TDG supersaturation levels measured in McNary Reservoir were lower than expected for the spill volumes observed in 1997. This reduction in TDG supersaturation likely resulted from the installation of spill deflectors in four of the ten spill bays at Ice Harbor Dam. In 1996, prior to spill deflector installation at Ice Harbor, TDG supersaturation reached levels as high 140% and generally exceeded 1997 TDG levels even though spill levels were higher in 1997.

Considerable diel fluctuations in TDG supersaturation were observed at monitoring stations in McNary Reservoir. These daily fluctuations were most evident at the Rkm 504.2 OR shore TDG monitor and varied by as much as 12% from daytime to nighttime at this site (Figures 3A, 4A). We found these fluctuations to be closely correlated with spill operations at Ice Harbor Dam. We also found that temperature fluctuated on a diel cycle similar to TDG supersaturation measurements recorded at the TDG monitoring sites. Total dissolved gas supersaturation is influenced by water temperature (Colt 1984). Therefore, the TDG supersaturation fluctuations measured in McNary Reservoir although highly correlated with spill at Ice Harbor Dam, may also be somewhat related to daily temperature fluctuations in the reservoir. At Rkm 504.2, where the largest fluctuations in TDG supersaturation and temperature were measured, the TDG monitor was positioned just downstream of a large, shallow, low water velocity area where afternoon warming occurred. Temperature measurements at this location generally peak in the late afternoon and early evening hours, suggesting that daily warming in this area caused TDG supersaturation levels to rise, then fall with cooling nighttime temperatures. This hypothesis is supported by correlations between spill and TDG at the OR shore monitoring stations. The highest correlation coefficients between spill and TDG were obtained at the downstream most gas meter and progressively decreased moving upstream to the Rkm 504.2 meter (Table 2). Any reservoir warming that may occur in the large, shallow area would have less effect on TDG at the farthest meter downstream (Rkm 475.5 monitor) from the warming area due to mixing. Thus, TDG measured at the Rkm 475.5 meter had a higher correlation with spill at Ice Harbor Dam than TDG measured at Rkm 504.2, where water temperature seemed to influence TDG levels.

Turbidity measurements taken near the hydroacoustic sampling site followed an expected pattern of increasing from the WA to OR side of the reservoir. The turbidity plume from the Snake and Walla Walla rivers was observed along the OR shore at Rkm 502-506. Turbidity levels also increased seasonally as the total flow at Ice Harbor Dam increased. As the total flow began to decline near the end of May, turbidity levels concurrently declined, suggesting that turbidity levels in the Columbia River from McNary Dam to the confluence of the Snake and Columbia rivers are strongly influenced by the Snake River.

Despite differences in species composition throughout the season, the highest densities of smolts were usually detected toward the shorelines, regardless of diel or sampling period (Figures 12, 13, and 14). Dauble et al. (1989) reported finding higher numbers of yearling chinook salmon and steelhead near mid-channel in the Hanford Reach of the Columbia River however, he reported that higher densities of subyearling chinook salmon were found closer to the shorelines in May and moved offshore towards mid-channel in June. Presumably, the shorelines at this location in the reservoir have some desirable characteristics that attract fish. The bathymetry of the reservoir at this location is characterized by shallow (<15 m) shelves extending from each shore. These shallower regions and the resulting flow characteristics may be determining factors in juvenile salmon spatial distribution at this location in the reservoir. In 1997, Beeman et al. (1998) found that a large portion of juvenile chinook salmon and steelhead tagged with radio transmitters passed through this same area of the reservoir along the WA shoreline.

Vertical fish distributions were significantly different between daytime and nighttime sampling throughout May 1997 (Table 4). In almost all cases, fish were more abundant above the TDG compensation depth during the daytime than at nighttime. Inasmuch as a higher percentage of the population was above the TDG compensation depth during the daytime, we conclude those fish were at greater risk to the effects of gas bubble disease. Many other investigators have observed differences in diel distributional behavior patterns of juvenile salmonids. For example, Johnson et al. (1992) found significant differences in the diel vertical distribution of smolts approaching Wells Dam on the Columbia River, with higher abundances detected near the surface during the daytime. Ransom et al. (1994) reported finding significant differences in the diel vertical distribution of downstream migrant smolts entrained at Wanapum Dam on the Columbia River. Kofoot et al. (1994, 1996), Hanks et al. (1995, 1997) and Thorne et al. (1992) also observed significant differences in the diel vertical distribution of juvenile salmonids in Lower Granite Reservoir on the Snake River.

Causal mechanisms that induce shifts in juvenile salmonid diel vertical distribution have been attributed to food resource availability and feeding behavior, predation risk, and underwater illumination (Narver 1970; Clark and Levy 1988; Groot and Margolis 1991). However, these studies were conducted on non-migrant juvenile sockeye salmon inhabiting dissimilar environments to the Columbia River. Juvenile subyearling chinook salmon migrating through the lower reach of McNary Reservoir during May feed primarily on cladocerans *(Daphnia spp.)* and terrestrial insects (Rondorf et al. 1990). Muir et al. (1988) determined that juvenile yearling chinook salmon and steelhead passing Bonneville Dam on the Columbia River consumed mostly gammarid amphipods (*Corophium salmonis and C. spinicorne*) during the spring. Although diel vertical migrations of food items can occur (especially cladocerans), they tend to be distributed near the surface during the nighttime, then move deeper during the daytime, opposite of the patterns in smolt vertical distribution that we observed in McNary Reservoir during May. Therefore, relating diel vertical fish distribution to feeding behavior or food resource availability does not provide a plausible explanation for the trends in diel vertical fish distribution that we observed.

We conclude that fish detected above the compensation depth (or any depth) likely do not spend the entire migration period at that depth, instead vertical cycling of smolts most likely occurred. Beeman et al. (1998 draft) has substantiated this claim using depth sensitive radio tags implanted in yearling chinook salmon and steelhead to record the depth histories of tagged individuals. Using this technology, he has found that tagged individuals utilize depths down to 12.6 m (approximate detection range limit 10-12 m). Considering that migrating fish did not spend their entire migration period in the "risk zone", this could account for the relatively low levels of gas bubble disease occurrence observed at smolt bypass facilities (Fish Passage Center 1997) and in-river (Backman 1998) gas bubble disease monitoring sites.

Seasonal trends in vertical fish distribution were observed at both shores during the early and mid-May hydroacoustic sampling periods in McNary Reservoir. During these two sampling periods, we found that the 80th percentile of fish depth shifted closer to the surface at the WA and OR shores as the season progressed. This shift in vertical fish distribution may be a response to physiological and body composition changes caused by the onset and progression of the smoltification process. Pinder et al. (1969) found that the buoyancy of Atlantic salmon (*Salmo salar*) increased during the parr to smolt transformation. Zaugg (1989) found that subyearling chinook salmon captured by purse seine from mid-channel in the Columbia River exhibited higher levels of Na^+ K^+ ATPase than fish captured closer to the shorelines. Our data are consistent with the findings of Zaugg (1989), inasmuch as we found no seasonal trends in vertical distribution at the CTR location. Our results, along with Zaugg's (1989), support the hypotheses that fish detected near the center of the reservoir may be more "smolted", more buoyant, and therefore migrating shallower in the water column relative to fish found closer to the shorelines. Furthermore, yearling chinook salmon and steelhead sampled at McNary Dam exhibited a marked increase in smoltification as indicated by Na^+ K^+ ATPase activity during the month of May in previous years (Beeman et al. 1989, 1990) however, the Smolt Monitoring Program terminated its collection of Na^+ K^+ ATPase data at McNary Dam in 1995, hence no Na^+ K^+ ATPase information existed for smolts passing McNary Dam in 1997. Our observations indicated the progression of smoltification and associated changes in vertical fish distribution may result in more fish being at risk to the effects of gas bubble disease late in the spring outmigration.

We found no conclusive evidence during the simple regression analyses to indicate that fish avoided relatively higher levels of TDG. Current literature on the detection and avoidance of supersaturated waters by juvenile salmonids is contradictory. For example, Ebel (1971) found that juvenile chinook salmon held in 0-4.5 m deep cages suffered higher mortalities than fish held in 3-4 m deep cages when placed in supersaturated water, suggesting that fish in the 0-4.5 m cages were unable to detect supersaturation and sound to compensate for or avoid the effects of supersaturated water. However, Meekin and Turner (1974), Blahm et al. (1976), Dawley et al. (1976), and Stevens et al. (1980) all reported that juvenile chinook salmon demonstrated apparent detection and avoidance behavior. Blahm et al. (1976) and Stevens et al. (1980) noted that steelhead did not avoid supersaturated water, while Dawley et al. (1976) found that juvenile steelhead displayed avoidance behavior similar to chinook salmon. The aforementioned studies were conducted under controlled laboratory conditions in tanks or cages with limited depth. Although these studies provide valuable insight on the ability of juvenile salmonids to detect and avoid TDG supersaturation, entirely different behavior may be observed among fish migrating in the Columbia and Snake rivers; much more complex, dynamic environments than tanks or cages in a laboratory. Furthermore, had higher levels of TDG (130-140%) been present in the reservoir to provide a greater range of TDG levels during this study, a more measurable response of avoidance behavior of juvenile salmon to TDG may have been detected.

Multiple-regression analyses were used to create a predictive model to describe the distribution patterns of juvenile salmonid observed in McNary Reservoir during this study. The resulting model predicts a cumulative percent of fish density over a vertical depth scale using the $\log_e$(depth+1), diel period (daytime/nighttime), sampling period (early/mid-May), and location in the reservoir cross-section (shoreline/center). The model was successful in explaining 84% ($R^2 = 0.84$) of the variation in the cumulative percent of fish density observed during the early and mid-May sampling periods. Although sampling period and location contributed little to the overall regression model, we elected to include these variables due to the differences observed in seasonal vertical fish distribution (80th percentile) near shorelines and the significant differences in metrics of vertical fish distribution for sampling locations detected by the ANOVA (Table 4).

In summary, we successfully deployed an up-looking hydroacoustic transducer with a ROV to assess the near-surface vertical and horizontal distribution of smolts in 1997. We found that generally, more fish were near the surface during the daytime than at nighttime and therefore, more “at risk” to the effects of gas bubble disease. We found no patterns in fish distribution that suggested fish distribution was influenced by TDG supersaturation. We did find that fish detected along the WA and OR shores during the early and mid-May sampling periods moved shallower in the water column as the season progressed, resulting in more fish being at risk to gas bubble disease later in the season. Our data, as do data from Beeman et al. (1998) indicate that vertical cycling of smolts occurred. This vertical cycling, depending on levels of TDG supersaturation present in the reservoir, results in only a portion of the population being exposed to the risk of developing gas bubble disease at any one time. Finally, some caution should be used because our data was collected in a relatively short reach of the reservoir, under high flow conditions, and over a narrow range of TDG supersaturation levels.

References

Backman, T.W.H., A.F. Evans, and M.A. Hawbecker. 1998. Symptoms of gas bubble trauma induced in salmon (*Oncorhynchus spp.*) by total dissolved gas supersaturation of the Snake and Columbia rivers, USA. 1997 Draft Annual Report Contract No. 95BI39861 to Bonneville Power Administration, Portland, Oregon.

Beeman, J.W., D.W. Rondorf, J.C. Faler, M.E. Free, and P.V. Haner. 1990. Assessment of smolt condition for travel time analysis. 1989 Annual Report Contract No. DE-A179-87BP35245 to Bonneville Power Administration, Portland, Oregon.

Beeman, J.W., D.W. Rondorf, J.C. Faler, P.V. Haner, S.T. Sauter, and D.A. Venditti. 1991. Assessment of smolt condition for travel time analysis. 1990 Annual Report Contract No. DE-A179-87BP35245. to Bonneville Power Administration, Portland, Oregon.

Beeman, J. W., P.V. Haner, T.C. Robinson, and A.G. Maule. 1998. Vertical and horizontal distribution of individual juvenile salmonids based on radiotelemetry. 1997 Draft Report to Bonneville Power Administration, Portland, Oregon.

Beiningen, K.T., and W.J. Ebel. 1970. Effect of John Day Dam on dissolved nitrogen concentrations and salmon in the Columbia River, 1968. Transactions of the American Fisheries Society 99:664-671.

Blahm, T.H., R.J. McConnell, and G.R. Synder. 1976. Gas saturation research, National Marine Fisheries Service, Prescott Facility - 1971-1974. Proceedings of Gas Bubble Disease Workshop. U.S. Department of Commerce, Technical Information Service CONF-741033, 11-19.

Colt, J. 1984. Computation of dissolved gas concentrations in water as a function of temperature, salinity, and pressure. American Fisheries Society Special Publication 14.

Clark, C.W., and D.A. Levy 1988. Diel vertical migrations by juvenile sockeye salmon and the antipredation window. American Naturalist 131:271-290.

Dauble, D.D., T.L. Page, and R.W. Hanf, Jr. 1989. Spatial distribution of juvenile salmon in the Hanford Reach, Columbia River. Fishery Bulletin 87:775-790.

Dawley, E.M. 1986. Effects of 1985-86 levels of dissolved gas on salmonids in the Columbia River. Report to U.S. Army Corps of Engineers, Contract DACW-57-85F-0623, 31p. (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, Washington 98112-2097.)

Dawley, E.M., M. Schiewe, and B. Monk. 1976. Effects of long-term exposure to supersaturation of dissolved atmospheric gases on juvenile chinook salmon and steelhead trout in deep and shallow tank tests. Pages 1-10 *in* Fickeisen and Schneider (1976). Gas bubble disease. CONF-741033, Technical Information Center, Energy Research and Development Administration, Oak Ridge, Tennessee.

Dawson, J.J., W.A. Karp, and G.A. Raemhild. 1985. Fixed location hydroacoustics for quantitative fisheries studies (Revised 04/06/88). (Available from BioSonics, Inc. 4027 Leary Way NW, Seattle, Washington 98105.)

Dell, M.B., M.W. Erho, and B.D. Leman. 1974. Occurrence of gas bubble disease symptoms on fish in mid-Columbia River reservoirs, 49 p. (Available from Public Utility District of Grant County, P.O. Box 878, Ephrata, Washington 98823.)

Ebel, W.J. 1969. Saturation of nitrogen concentrations in the Columbia and its effects on salmon and steelhead trout. U.S. Fish and Wildlife Service, Fishery Bulletin 68:1-11.

Ebel, W.J. 1971. Dissolved nitrogen concentrations in the Columbia and Snake Rivers in 1970 and their effect on chinook salmon and steelhead trout. National Oceanographic and Atmospheric Administration Technical Report, National Marine Fisheries Service, Special Scientific Report Fisheries 646. Seattle, Washington.

Hanks, M.E., and E.E. Kofoot. 1995. Distribution of juvenile salmonids and water velocities during mobile hydroacoustic surveys in the forebay of Lower Granite Dam. Pages 61-78 *in* Adams et al. 1995. Migrational characteristics of juvenile spring chinook salmon and steelhead in the forebay of Lower Granite Reservoir and tributaries, Snake River. Report to the U.S. Army Corps of Engineers, Contract E 86930151, Walla Walla, Washington.

Hanks, M. E., and K. M. Cash. 1997. Distribution and movement of juvenile salmonids detected during hydroacoustic surveys in the forebay of Lower Granite Dam. Pages 78-112 *in* Adams et al. 1997. Migrational characteristics of juvenile spring and fall chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1997 surface bypass collector tests. Report to the U.S. Army Corps of Engineers, Contract E86930151, Walla Walla, Washington.

Groot, C., and L. Margolis, editors. 1991. Pacific Salmon Life Histories. University of British Columbia Press, Vancouver, British Columbia.

Johnson, G.E., C.M. Sullivan, and M.W. Erho. 1992. Hydroacoustic studies for developing a smolt bypass system at Wells Dam. Fisheries Research 14: 221-237.

Kofoot, E.E., D.H. Feil, R.D. Garland, M.E. Hanks, and D.W. Rondorf. 1994. Use of hydroacoustics in assessing the migrational behavior of juvenile spring chinook salmon and steelhead in Lower Granite Reservoir. Pages 76-107 *in* D.W. Rondorf and M.J. Banach, editors, 1995. Migrational characteristics of juvenile spring chinook and steelhead in Lower Granite Reservoir and tributaries, Snake River. Report to the U.S. Army Corps of Engineers, Contract E 86930151, Walla Walla, Washington.

Kofoot, E.E., M.E. Hanks, and J.B. Oleyar. 1996. Distribution of juvenile salmonids in the forebay of Lower Granite Dam detected during mobile hydroacoustic surveys. Pages 6-1 to 6-62 *in* Adams et al. 1996. Migrational characteristics of juvenile spring chinook salmon and steelhead in the forebay of Lower Granite Dam relative to the 1996 surface bypass collector tests. Report to the U.S Army Corps of Engineers, Contract E 86930151, Walla Walla, Washington.

Meekin, T. K., and R. L. Allen. 1974. Nitrogen saturation levels in the mid-Columbia River, 1965-1971. Washington Department of Fisheries, Technical Report 12, p. 32-77.

Meekin, T. K., and B. K. Turner. 1974. Tolerance of salmonid eggs, juveniles and squawfish to supersaturated nitrogen. Washington Department of Fisheries Technical Report 12:78-126.

Muir, W.D., and R.L. Emmett. 1988. Food habits of migrating salmon smolts passing Bonneville Dam in the Columbia River, 1984. Regulated Rivers: Research and Management 2:1-10.

Narver, D.W. 1970. Diel vertical movements and feeding of underyearling sockeye salmon and the limnetic zooplankton in Babine Lake, British Columbia. Journal of the Fisheries Research Board of Canada 9:450-491.

NMFS (National Marine Fisheries Service). 1995. Biological Opinion. NMFS, Seattle Washington.

NMFS (National Marine Fisheries Service). 1996. NMFS gas bubble disease research plan. NMFS, Portland, Oregon.

Panel. 1994. Panel on Gas Bubble Disease, Report and Recommendations (June 21-22, 1994). (Available from Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, Washington 98112-2097.)

Pinder, L.J., and J.G. Eales. 1969. Seasonal buoyancy changes in Atlantic salmon (*Salmo salar*) parr and smolt. Journal of Fisheries Research Board of Canada 8:2093-2100.

Ransom, B. H., and T.W. Stieg. 1994. Using hydroacoustics to monitor fish at hydropower dams. Lake and Reservoir Management 9 (1): 163-169.

Rondorf, D. W., G.A. Gray, and R.B. Fairley. 1990. Feeding ecology of subyearling chinook salmon in riverine and reservoir habitats of the Columbia River. Transactions of the American Fisheries Society 119:16-24.

Schroeder, L.D., D.L. Sjoquist, and P.E. Stephan. 1986. Understanding regression analysis, an introductory guide. Sage Publications, Series 7-57, Newbury Park, California.

Smith, J.R. 1974. Distribution of seaward-migrating chinook salmon and steelhead trout in the Snake river above Lower Monumental Dam. Marine Fisheries Review 36(8)42-45.

Stevens, D.G., A.V. Nebeker, and R.J. Baker. 1980. Avoidance responses of salmon and trout to air-supersaturated water. Transactions of the American Fisheries Society 109:751-754.

Thorne, R.E., C.J. McClain, J. Hedgepeth, E. S. Kuehl, and J. Thorne. 1992. Hydroacoustic surveys of the distribution and abundance of fish in Lower Granite Reservoir, 1989-1990. Final report to Walla Walla District Corps of Engineers, Contract No. DACW68-C-0022. (Available from BioSonics, Inc. 3670 Stone Way North, Seattle, Washington 98103)

Weitkamp, D. E. 1974. Snake River 1973, dissolved gas studies. Report to Idaho Power Company, Boise, Idaho, 81 p. (Available from Idaho Power Co., P.O. Box 70, Boise, Idaho 83707.)

Weitkamp, D.E. 1976. Dissolved gas saturation: live cage bioassays at Rock Island Dam, Washington. Proceedings of Gas Bubble Disease Workshop. U.S. Department of Commerce, Technical Information Service CONF-741033, p. 24-36.

Weitkamp, D.E., and M. Katz. 1975. Resource and literature review, dissolved gas saturation and gas bubble disease. Environmental Services Section, 4122 Stone Way N. Seattle, Washington, Report to Northwest Utility Cooperative. (Available from Idaho Power Co., P.O. Box 70, Boise, Idaho 83707).

Weitkamp, D.E., and M. Katz. 1980. A review of dissolved gas supersaturation literature. Transactions of the American Fisheries Society 109:659-702.

Zaugg, W.S. 1989. Migratory behavior of underyearling *Oncorhynchus tshawytscha* and survival to adulthood as related to prerelease gill (Na^+-K^+) -ATPase development. Aquaculture 82:339-353.

LIST OF APPENDICES

Appendix Table 1.— Results of three-factor analyses of variance (ANOVA) for changes in metrics of vertical fish distribution.

Response Variable [a]	Source of Variation [b]	df	*F*	*P*
CD	DAYNITE	1	6.97	0.01**
	LOCATION	2	12.69	0.0001****
	PERIOD	2	1.14	0.33
	DAYNITE x LOCATION	2	3.23	0.05*
	LOCATION x PERIOD	4	1.96	0.11
	DAYNITE x PERIOD	2	1.67	0.20
	DAYNITE x LOCATION x PERIOD	4	0.49	0.74
2m	DAYNITE	1	3.65	0.06
	LOCATION	2	5.64	<0.01***
	PERIOD	2	0.11	0.89
	DAYNITE x LOCATION	2	1.55	0.22
	LOCATION x PERIOD	4	1.70	0.16
	DAYNITE x PERIOD	2	2.51	0.09
	DAYNITE x LOCATION x PERIOD	4	0.14	0.97
4m	DAYNITE	1	11.05	<0.01***
	LOCATION	2	10.38	0.0001****
	PERIOD	2	0.81	0.45
	DAYNITE x LOCATION	2	0.60	0.55
	LOCATION x PERIOD	4	3.23	0.02
	DAYNITE x PERIOD	2	1.98	0.15
	DAYNITE x LOCATION x PERIOD	4	0.26	0.90
8m	DAYNITE	1	9.61	<0.01***
	LOCATION	2	1.07	0.35
	PERIOD	2	5.15	<0.01***
	DAYNITE x LOCATION	2	0.58	0.56
	LOCATION x PERIOD	4	4.62	<0.01***
	DAYNITE x PERIOD	2	0.55	0.58
	DAYNITE x LOCATION x PERIOD	4	0.44	0.78
80TH	DAYNITE	1	3.20	0.08
	LOCATION	2	8.78	<0.01***
	PERIOD	2	2.72	0.07
	DAYNITE x LOCATION	2	0.11	0.90
	LOCATION x PERIOD	4	4.64	<0.01***
	DAYNITE x PERIOD	2	0.62	0.54
	DAYNITE x LOCATION x PERIOD	4	0.25	0.91

[a] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.

[b] DAYNITE = Diel period (daytime/nighttime), LOCATION = Location in reservoir (WA, CTR, OR), PERIOD = Sampling period (early, mid, late-May).

Appendix Table 2.— Results of simple regression analyses for metrics describing vertical fish distribution and percent TDG during hydroacoustic sampling in McNary Reservoir.

Group [a]	Sub Group [b]	*N*	Variable	Coefficient	SE	*P* [c]	MSE	r^2
				All Sampling Periods				
All Locations	CD	76	Constant	-176.09	62.83	<0.01	154.37	0.12
			TDG	1.64	0.52	<0.01		
	2m	76	Constant	-56.71	62.14	0.36	150.97	0.02
			TDG	0.64	0.51	0.22		
	4m	76	Constant	-90.71	78.90	0.25	243.42	0.04
			TDG	1.07	0.65	0.11		
	8m	76	Constant	105.01	88.59	0.24	306.84	<0.01
			TDG	-0.36	0.73	0.62		
	80th	76	Constant	-11.47	22.24	0.61	19.34	0.02
			TDG	0.20	0.18	0.27		
				Early and Mid-May Sampling Periods				
All Locations	CD	63	Constant	-172.91	62.81	0.01	151.03	0.14
			TDG	1.62	0.52	<0.01		
	2m	63	Constant	-60.62	62.96	0.34	151.73	0.03
			TDG	0.67	0.52	0.20		
	4m	63	Constant	-91.66	80.65	0.26	249.01	0.04
			TDG	1.08	0.67	0.11		
	8m	63	Constant	109.76	95.27	0.25	347.43	<0.01
			TDG	-0.40	0.79	0.61		
	80th	63	Constant	-11.44	23.08	0.62	20.39	0.02
			TDG	0.20	0.19	0.29		
				Late-May Sampling Period				
All Locations	CD	13	Constant	-327.04	489.51	0.52	196.32	0.04
			TDG	2.87	4.04	0.49		
	2m	13	Constant	123.16	451.25	0.79	166.83	<0.01
			TDG	-0.86	3.72	0.82		
	4m	13	Constant	-47.80	558.02	0.93	255.12	<0.01
			TDG	0.70	4.60	0.88		
	8m	13	Constant	-113.06	392.16	0.78	126.00	0.02
			TDG	1.46	3.24	0.66		
	80th	13	Constant	-13.06	143.73	0.93	16.92	<0.01
			TDG	0.22	1.19	0.86		

[a] Locations = WA, CTR, OR.
[b] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.
[c] significant when $P \leq 0.05$.

Appendix Table 3.— Results of simple regression analyses for metrics describing vertical fish distribution and percent TDG during hydroacoustic sampling in McNary Reservoir.

Location	Group [a]	*N*	Variable	Coefficient	SE	*P* [b]	MSE	r^2
				All Sampling Periods				
WA	CD	28	Constant	153.28	202.06	0.45	126.84	0.02
			TDG	-1.15	1.70	0.50		
	2m	28	Constant	180.60	195.47	0.36	118.70	0.03
			TDG	-1.38	1.64	0.41		
	4m	28	Constant	264.55	230.17	0.26	164.59	0.04
			TDG	-1.95	1.94	0.32		
	8m	28	Constant	215.83	268.86	0.43	224.57	0.01
			TDG	-1.28	2.26	0.58		
	80th	28	Constant	-64.91	59.50	0.29	11.00	0.06
			TDG	0.64	0.50	0.21		
CTR	CD	21	Constant	-6.98	178.73	0.97	180.12	<0.01
			TDG	0.32	1.45	0.83		
	2m	21	Constant	130.88	185.52	0.49	194.05	0.02
			TDG	-0.84	1.51	0.58		
	4m	21	Constant	363.13	193.82	0.08	211.79	0.12
			TDG	-2.55	1.57	0.12		
	8m	21	Constant	375.92	210.86	0.09	250.70	0.10
			TDG	-2.55	1.71	0.15		
	80th	21	Constant	-45.24	70.49	0.53	28.02	0.04
			TDG	0.50	0.57	0.39		
OR	CD	27	Constant	-93.74	89.16	0.30	113.58	0.06
			TDG	0.94	0.73	0.21		
	2m	27	Constant	25.92	90.55	0.78	117.16	<0.01
			TDG	-0.05	0.74	0.94		
	4m	27	Constant	-49.15	127.98	0.70	234.03	0.02
			TDG	0.70	1.05	0.51		
	8m	27	Constant	-90.47	173.21	0.61	428.68	0.03
			TDG	1.22	1.42	0.40		
	80th	27	Constant	81.67	28.68	<0.01	11.75	0.19
			TDG	-0.57	0.24	0.02		

[a] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.
[b] significant when $P \leq 0.05$.

Appendix Table 4.- Results of simple regression analyses for metrics describing vertical fish distribution and percent TDG during hydroacoustic sampling in McNary Reservoir.

Location	Group [a]	*N*	Variable	Coefficient	SE	*P* [b]	MSE	r^2
				Early and Mid-May Sampling Periods				
WA								
	CD	23	Constant	-813.47	371.44	0.04	103.00	0.19
			TDG	7.02	3.13	0.04		
	2m	23	Constant	-732.25	362.20	0.06	98.15	0.17
			TDG	6.26	3.06	0.05		
	4m	23	Constant	-646.75	422.35	0.14	133.46	0.11
			TDG	5.75	3.57	0.12		
	8m	23	Constant	-709.98	549.45	0.21	225.88	0.09
			TDG	6.55	4.64	0.17		
	80th	23	Constant	154.01	110.18	0.18	9.08	0.07
			TDG	-1.20	0.93	0.21		
CTR								
	CD	18	Constant	-5.97	184.94	0.97	190.78	0.01
			TDG	0.31	1.50	0.84		
	2m	18	Constant	149.69	184.55	0.43	189.98	0.03
			TDG	-0.99	1.50	0.52		
	4m	18	Constant	364.60	210.86	0.10	248.00	0.12
			TDG	-2.56	1.71	0.15		
	8m	18	Constant	366.84	214.33	0.11	256.23	0.11
			TDG	-2.49	1.74	0.17		
	80th	18	Constant	-42.12	68.18	0.55	25.92	0.04
			TDG	0.48	0.55	0.40		
OR								
	CD	22	Constant	-134.22	98.23	0.19	126.49	0.11
			TDG	1.26	0.80	0.13		
	2m	22	Constant	-17.42	99.45	0.86	129.63	0.01
			TDG	0.29	0.81	0.73		
	4m	22	Constant	-100.88	140.33	0.48	258.12	0.04
			TDG	1.11	1.15	0.35		
	8m	22	Constant	-172.41	191.14	0.38	478.88	0.07
			TDG	1.86	1.56	0.25		
	80th	22	Constant	96.57	29.93	<0.01	11.74	0.28
			TDG	-0.69	0.24	0.01		

[a] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.
[b] significant when $P \leq 0.05$.

Appendix Table 5.— Results of simple regression analyses for metrics describing vertical fish distribution and day of the month (May) during hydroacoustic sampling in McNary Reservoir.

Group [a]	Sub Group [b]	*N*	Variable	Coefficient	SE	*P* [c]	MSE	r^2
				All Sampling Periods				
All Locations	CD	76	Constant	21.38	3.95	<0.01	174.98	0.01
			MDAY	0.07	0.22	0.75		
	2m	76	Constant	22.21	3.70	<0.01	153.69	0.01
			MDAY	-0.10	0.21	0.65		
	4m	76	Constant	36.34	4.73	<0.01	251.44	0.01
			MDAY	0.13	0.27	0.63		
	8m	76	Constant	52.68	5.12	<0.01	294.65	0.04
			MDAY	0.53	0.29	0.07		
	80th	76	Constant	14.98	1.31	<0.01	19.16	0.03
			MDAY	-0.10	0.07	0.17		
				Early and Mid-May Sampling Periods				
All Locations	CD	63	Constant	15.85	5.94	0.01	170.89	0.02
			MDAY	0.51	0.41	0.23		
	2m	63	Constant	20.69	5.68	<0.01	155.90	0.01
			MDAY	0.02	0.40	0.95		
	4m	63	Constant	30.53	7.24	<0.01	254.00	0.02
			MDAY	0.59	0.51	0.25		
	8m	63	Constant	41.26	8.08	<0.01	316.06	0.09
			MDAY	1.42	0.56	0.01		
	80th	63	Constant	17.79	1.99	<0.01	19.08	0.08
			MDAY	-0.32	0.14	0.02		
				Late-May Sampling Period				
All Locations	CD	13	Constant	-64.31	167.32	0.71	200.58	0.02
			MDAY	2.94	5.75	0.62		
	2m	13	Constant	29.83	152.93	0.85	167.57	0.01
			MDAY	-0.38	5.25	0.94		
	4m	13	Constant	-223.60	171.70	0.23	211.23	0.17
			MDAY	8.96	5.90	0.16		
	8m	13	Constant	134.63	132.11	0.33	125.04	0.03
			MDAY	-2.44	4.54	0.60		
	80th	13	Constant	-32.20	46.72	0.51	15.64	0.08
			MDAY	1.55	1.60	0.35		

[a] Locations = WA, CTR, OR.
[b] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.
[c] significant when $P \leq 0.05$.

Appendix Table 6.- Results of simple regression analyses for metrics describing vertical fish distribution and day of the month (May) during hydroacoustic sampling in McNary Reservoir.

Location	Group [a]	*N*	Variable	Coefficient	SE	*P* [b]	MSE	r^2
				All Sampling Periods				
WA								
	CD	76	Constant	24.26	5.29	<0.01	117.16	0.09
			MDAY	-0.48	0.30	0.12		
	2m	76	Constant	25.14	5.09	<0.01	108.23	0.11
			MDAY	-0.52	0.28	0.08		
	4m	76	Constant	35.71	6.36	<0.01	169.11	0.01
			MDAY	-0.19	0.36	0.59		
	8m	76	Constant	60.77	7.34	<0.01	225.51	0.01
			MDAY	0.19	0.41	0.65		
	80th	76	Constant	11.58	1.67	<0.01	11.65	0.01
			MDAY	0.03	0.09	0.72		
CTR								
	CD	63	Constant	27.73	7.87	<0.01	176.81	0.02
			MDAY	0.29	0.45	0.53		
	2m	63	Constant	30.64	8.25	<0.01	194.56	0.01
			MDAY	-0.24	0.47	0.62		
	4m	63	Constant	51.96	9.16	<0.01	239.91	0.01
			MDAY	-0.15	0.53	0.77		
	8m	63	Constant	58.73	9.86	<0.01	277.77	0.01
			MDAY	0.22	0.57	0.71		
	80th	63	Constant	18.04	3.16	<0.01	28.51	0.02
			MDAY	-0.12	0.18	0.53		
OR								
	CD	13	Constant	12.65	5.04	0.02	106.00	0.13
			MDAY	0.53	0.28	0.07		
	2m	13	Constant	11.87	5.04	0.03	106.34	0.09
			MDAY	0.45	0.28	0.12		
	4m	13	Constant	24.81	7.14	<0.01	213.24	0.10
			MDAY	0.69	0.40	0.10		
	8m	13	Constant	40.43	9.55	<0.01	381.06	0.14
			MDAY	1.06	0.54	0.06		
	80th	13	Constant	15.90	1.69	<0.01	11.93	0.18
			MDAY	-0.22	0.09	0.03		

[a] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.
[b] significant when $P \leq 0.05$.

Appendix Table 7.— Results of simple regression analyses for metrics describing vertical fish distribution and day of the month (May) during hydroacoustic sampling in McNary Reservoir.

Location	Group [a]	N	Variable	Coefficient	SE	P [b]	MSE	r^2
				Early and Mid-May Sampling Periods				
WA								
	CD	23	Constant	18.98	8.24	0.03	127.58	0.01
			MDAY	-0.06	0.57	0.92		
	2m	23	Constant	20.60	7.90	0.02	117.31	0.01
			MDAY	-0.15	0.55	0.78		
	4m	23	Constant	21.95	8.47	0.02	134.90	0.10
			MDAY	0.90	0.59	0.14		
	8m	23	Constant	31.59	8.40	$<$0.01	132.60	0.46
			MDAY	2.49	0.58	$<$0.01		
	80th	23	Constant	18.46	1.64	$<$0.01	5.03	0.49
			MDAY	-0.51	0.11	$<$0.01		
CTR								
	CD	18	Constant	25.95	12.56	0.06	188.51	0.01
			MDAY	0.42	0.87	0.63		
	2m	18	Constant	31.78	12.74	0.02	194.10	0.01
			MDAY	-0.26	0.88	0.77		
	4m	18	Constant	61.71	15.03	$<$0.01	270.02	0.04
			MDAY	-0.90	1.04	0.40		
	8m	18	Constant	72.98	15.22	$<$0.01	276.93	0.04
			MDAY	-0.87	1.05	0.42		
	80th	18	Constant	13.68	4.70	0.01	26.39	0.03
			MDAY	0.22	0.32	0.51		
OR								
	CD	22	Constant	5.88	8.33	0.49	121.98	0.14
			MDAY	1.07	0.59	0.08		
	2m	22	Constant	13.83	8.56	0.12	128.94	0.01
			MDAY	0.29	0.61	0.63		
	4m	22	Constant	19.15	11.86	0.12	247.53	0.08
			MDAY	1.14	0.84	0.19		
	8m	22	Constant	31.23	16.11	0.07	456.44	0.11
			MDAY	1.79	1.14	0.13		
	80th	22	Constant	20.06	2.50	$<$0.01	11.02	0.33
			MDAY	-0.55	0.18	$<$0.01		

[a] CD = percent of total fish density at or above the TDG compensation depth, 2m = percent of total fish density at or above 2m, 4m = percent of total fish density at or above 4m, 8m = percent of total fish density at or above 8m, and 80th = depth at which 80 percent of the total fish density occurs.
[b] significant when $P \leq 0.05$.