Copper Lake Burbot Stock Assessment, 2008

Annual Report for Study 07-501

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ABSTRACT

A stock assessment of burbot *Lota lota* was conducted at Copper Lake in 2008 using a two-event mark-recapture experiment. Burbot were captured using baited hoop traps soaked for two nights (approximately 48 h) and systematically set along equally spaced transects. The first event occurred from 7 to 15 June and 382 traps were set. The second event took place from 10 to 17 September and 311 traps were set. Mean catch per unit effort (CPUE), length composition and abundance were estimated. Mean CPUE of fully recruited burbot (i.e., ≥ 450 mm TL) for the first event was 0.041 (SE = 0.016) burbot/trap and was 0.096 (SE = 0.031) burbot/trap for the second event. A length-stratified, Chapman-modified Petersen model was used and the abundance estimate of burbot ≥ 315 mm TL was 943 (90% CI = 550 – 1,337). Smaller sized fish (315–425 mm TL) dominated the catches. Measurements (1.0 m depth increments) of water temperature (°C), conductivity (µS/cm), dissolved oxygen (DO) and pH were recorded at several occasions during the spring, summer, and fall and all measurements were within expected ranges.

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INTRODUCTION

This annual report summarizes work conducted during the 2008 reporting period relative to FIS 07-501. As specified in the investigation plan, the overall goal of this project is to attain abundance-based information from both Tanada and Copper Lakes to ensure that harvests from both subsistence and sport fisheries are sustainable. In 2007, field work was completed at Tanada Lake (Schwanke and McCormick 2008) and in 2008 work was completed at Copper Lake (Figure 1). The remaining portions of this annual report are therefore focused on the work conducted at Copper Lake.

Burbot *Lota lota* in Copper Lake have never been studied and have been managed under the general sport fish regulations for the Upper Copper Upper Susitna Management Area (UCUSMA). The bag and possession limit was reduced from 15 to 5 burbot in 1987, and the use of setlines was banned in 1991. Since then, no regulation changes have been made for Copper Lake burbot. Estimated annual harvest has ranged from 0 to 450 burbot, and the most recent 5-year (2003–2007) annual mean harvest is 40 burbot (Jennings et al. 2006a-b, 2007, *in press, in prep*; Figure 2). Copper Lake lies within the Wrangell-St. Elias National Park/Preserve (WRST), and subsistence fishing opportunities exist for federally qualified users. Currently no Federal subsistence harvest limits have been established for freshwater fish species in the Copper River drainage.

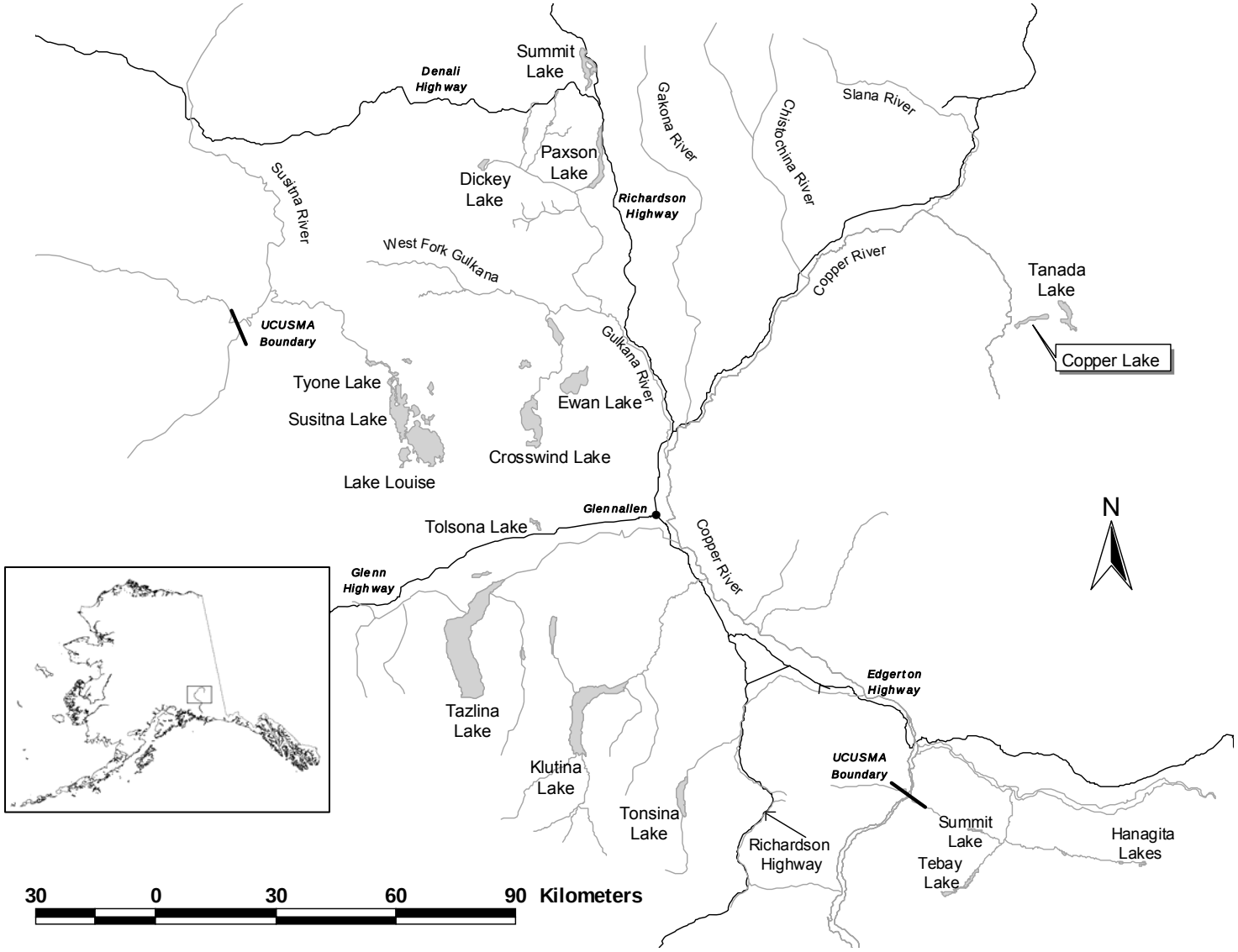

Figure 1.–Location of Copper Lake in the Upper Copper/Upper Susitna Management Area (UCUSMA).

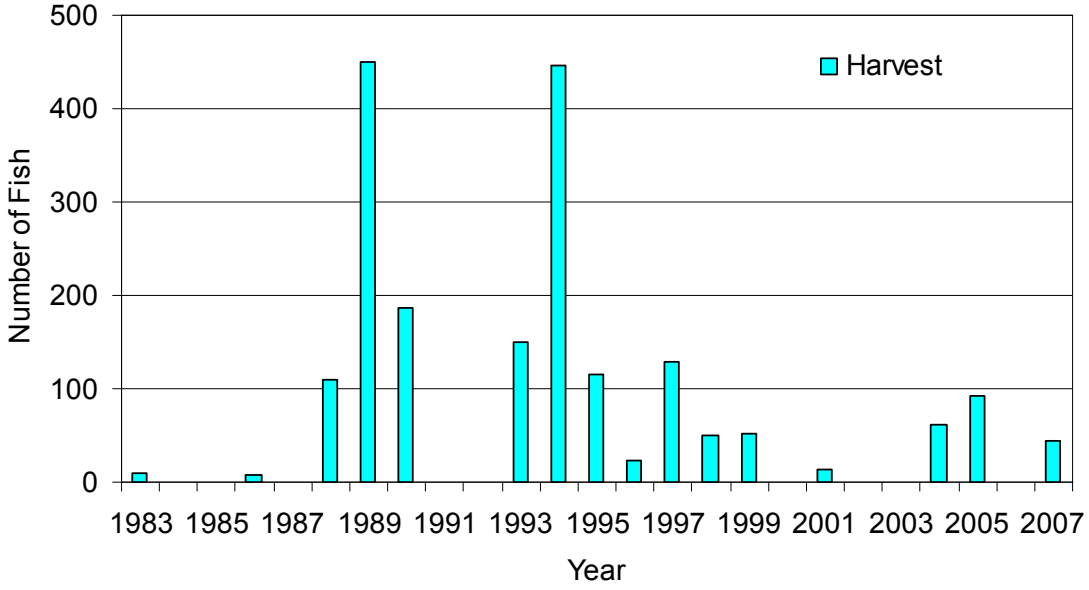

Figure 2.–Estimated harvest of burbot from Copper Lake (Mills 1985-1994; Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2004, 2006a-b, 2007, *in press, in prep*; Walker et al. 2003).

While Federal subsistence fishing permits have recently been issued for Copper Lake, no harvests have been reported. It is possible that federally qualified subsistence users are already meeting their needs for burbot in Copper Lake by fishing under State of Alaska sport fish regulations. However, this situation could change if federally qualified users decide to fish under Federal subsistence fishing regulations that provide greater harvest opportunities. To examine the status of the burbot population in Copper Lake, an assessment project in Copper Lake was undertaken by the Alaska Department of Fish and Game (ADF&G) and WRST during 2008. Information on abundance and size structure of the burbot population will allow managers to estimate sustainable harvest levels for this resource.

Specific objectives for 2008 were to:

1. estimate the length composition of fully recruited burbot (≥ 450 mm TL) at Copper Lake such that the estimated proportions were within ± 10 percentage points of the actual values 95% of the time;
2. estimate mean catch per unit of effort (CPUE) of fully recruited burbot (≥ 450 mm TL) in Copper Lake such that the estimated mean CPUE was within ± 50% of its asymptotic value 90% of the time;

3. estimate the abundance of fully recruited burbot (≥ 450 mm TL) in Copper Lake for spring 2008 such that the estimated abundance was within ± 25% of the true abundance 90% of the time; and,

4. collect limnological information from Copper Lake during April and on a monthly basis during the open water period.

These objectives, as well as the study design, were altered after the original Investigative Plan (IP) had been approved. We decided that a two-event mark-recapture experiment would result in more precise estimates of abundance and the study design was changed from conducting concurrent (i.e., sampling both Tanada and Copper lakes each spring) three-year Jolly-Seber experiments to conduct sequentially conducting a single two-event mark-recapture experiment in each lake. The first event (marking) occurred in the spring, the second event (recapturing) occurred in the fall. Tanada Lake was assessed in 2007 (Schwanke and McCormick 2008), and Copper Lake was assessed in 2008. Also, limnological sampling was added as an objective since it was included in the methods of the IP, but omitted from the list of objectives.

METHODS

Study Area

Copper Lake (Figure 1) is located within the WRST (62°25' N, 143°30' W) about 18 mi from the Nabesna Road near the Sportsman's Paradise Lodge. Its surface area is 1,170 ha, maximum depth is 70 m, and elevation is 884 m. There are no public recreational facilities on the lake, although a lodge does operate on the lake with cabin and boat rentals available. Copper Lake supports burbot, lake trout *Salvelinus namaycush*, Arctic grayling *Thymallus arcticus*, whitefish *Coregonus sp*., longnose sucker *Catostomus catostomus*, and sockeye salmon *Oncorhynchus nerka* (both anadromous and non anadromous forms). Copper Lake has three small inlet streams and one short outlet stream which flows directly into the Copper River.

Study Design and Fish Capture

In 2008, a two-event mark-recapture experiment was conducted to estimate abundance and length composition of burbot in Copper Lake. Burbot were captured in 3-m long baited hoop traps with 25-mm mesh netting set on the bottom as described in Bernard et al. (1991). Burbot ≥ 450 mm TL were assumed to be fully recruited to this gear. Traps were positioned according to a systematic sampling design as described in Bernard et al. (1993) to minimize competition among the gear while still covering the bottom of the lake. A grid system was used with traps

placed along transects at approximately 125-m intervals; transects were also spaced at approximately 125-m intervals. These spacing intervals serve as a guideline and were estimated by the field crews on a trap by trap, transect by transect basis. Variations in the number of traps per complete pass of the lake vary with the experience of the crew. For example, during the first pass down the lake the field crew underestimated the spacing distance and ended up setting many more traps during the first pass. No traps were set deeper than 15 m to avoid decompression-induced mortality associated with burbot captured at greater depths (Bernard et al. 1993). A set was defined as a single hoop trap baited with Pacific herring *Clupea pallasi* fished for approximately 48 hours. On a daily basis, the crew would bait and place approximately 60 traps. Two days later these traps were lifted, rebaited and reset along new transects. Five to seven days were required to systematically fish all transects down the length of the lake. For each event, all transects down the length of the lake were sampled twice to improve sample sizes.

After lifting a hoop trap, the catch was emptied into a holding tank and all burbot were measured for total length (to the nearest 1 mm) and examined for previous tags and secondary marks. All captured fish > 300 mm TL that were not previously tagged were marked with an individually numbered internal anchor tag (Floy™ FD-94) inserted in the musculature beneath the dorsal fin and given a secondary mark in the form of a fin clip. All tags were checked to ensure that they were locked between the pterygiophores of the dorsal fin. A partial left ventral fin clip was used in the spring and a partial right ventral clip was used in the fall.

Individual trap and associated catch information were recorded on standard hoop-net mark-sense forms (Heineman 1998) for all lakes. Data forms were optically scanned and electronic data files (ASCII format) were produced and imported into Excel spreadsheets for data analysis. Trap information included: hoop trap number, location of set, depth of set, hour set and pulled, and number of fish caught by species. Total length, tag number and color, secondary mark, fate, and recapture status were recorded on the mark-sense form for each burbot caught in each set.

The first event (spring sampling) commenced on 7 June and ended on 15 June 2008 (Table 1). The lake became ice free < 5 days prior to the initiation of sampling. Sampling near the time of ice-out is essential because burbot have the highest catchability at these times and experiments can be repeated more easily to ensure accurate CPUE comparisons with future projects (Bernard et al. 1993). Because no prior sampling had occurred at Copper Lake, the lake was sampled twice in spring to ensure that sufficient sample sizes of burbot were attained to meet objective criteria. Two passes were made down the entire length of the lake using the transect protocol described in Bernard et al. (1993). During the first pass, 250 hoop traps were set and during the second pass, 132 traps were set (Table 1). The discrepancy in the total number of traps per pass down the lake is due to the crew underestimating 125 m distance during the first pass.

Table 1.–Number of sets and dates of sampling events for the stock assessment of burbot in Copper Lake, 2008.

Event–Pass #	Dates of Sampling Events	Number of Sets
Spring–Pass 1	6/7–6/12	250
Spring–Pass 2	6/11–6/15	132
Fall–Pass 1	9/10–9/14	161
Fall–Pass 2	9/13–9/17	150

Fall sampling took place from 10–17 September 2008. As in the spring event, two complete passes were made along all transects to bolster sample sizes (Table 1). During the first pass 161 traps were set, and during the second pass 150 traps were set.

The sampling strategy for this experiment was to: 1) sample the entire study area and place our sampling gear in an attempt to subject all fish to an equal probability of capture during the first event (i.e., to the extent possible, distribute marks in proportion to abundance throughout the study area); 2) facilitate mixing of marked and unmarked fish within the lake with a long hiatus; and, 3) repeat step "1" for the second event. The study area was arbitrarily divided into three nearly equal sections (Figure 3) prior to sampling to serve as initial strata for performing diagnostic tests (i.e., examine movement and capture probabilities). Other geographic stratification schemes were also analyzed such as dividing the lake in half.

Abundance was estimated using a two-event Petersen mark-recapture experiment (Seber 1982) designed to satisfy the following assumptions:

1. the population was closed (burbot did not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment);
2. all burbot had a similar probability of capture in the first event or in the second event, or marked and unmarked burbot mixed completely between events;
3. marking of burbot in the first event did not affect the probability of capture in the second event;
4. marked burbot were identifiable during the second event; and,
5. all marked burbot were reported when examined during the second event.

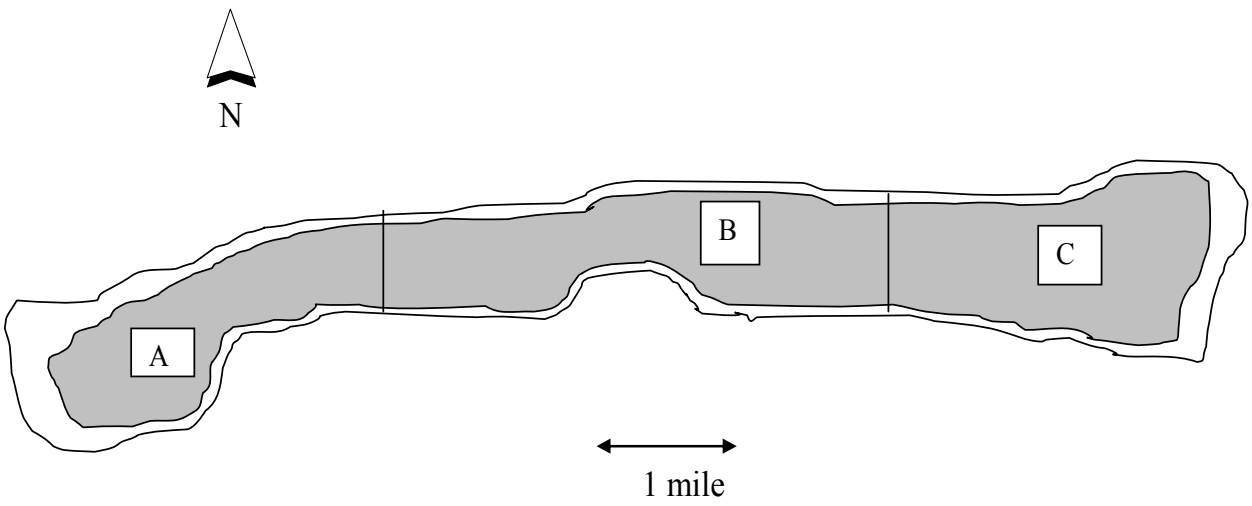

Figure 3.–Map of Copper Lake with section boundaries. Shaded area represents water that is > 15 m deep.

The experiment was designed to allow us to test these assumptions. The specific form of the population estimator used was based on results of the diagnostic tests performed to evaluate whether assumptions concerning size selectivity, mixing, and capture probability were met (Appendices A1 and A2).

Evaluation of Assumptions

Assumption 1: It was unlikely that burbot exited the lake via the outlet creek. The creek is small, shallow and swift thus not suitable for burbot. Additionally, no movement out of nearby Tanada Lake has been documented. It was recognized that growth recruitment would likely occur during the three-month hiatus needed to promote mixing. Marking fish with individually-numbered tags permitted an evaluation of growth using lengths of recaptured fish. These growth data were used to determine whether adjustments to the abundance estimate or the population of inference were needed to eliminate related bias. It was known that some natural mortality would occur, but as with growth, this can be addressed when considering the population of inference. Angling-induced mortality during the hiatus was assumed to be insignificant because Copper Lake has a very small reported harvest (i.e., 40 annually), the lake is remote and burbot typically are not harvested in the summer months.

Assumption 2: Sampling with hoop traps was limited to water depths ≤ 15 m. Efforts were made to subject all fish within sampled portions of the lake to an equal probability of capture during each event to the best of our ability by uniformly setting areas within the transect/grid system for deploying hoop traps (Bernard et al. 1993). This design promoted similar trap densities for each

pass down the lake throughout all waters ≤ 15 m. This experiment relies on ensuring equal probability of capture during at least one event, or complete mixing of marked and unmarked fish so that event specific probabilities of capture are equal. We hoped that the three-month hiatus between events would allow for complete mixing. We used diagnostic tests to identify heterogeneous capture probabilities (Appendix A2) and then selected an appropriate method to correct for any biases that were detected.

Assumption 3: The hiatus of almost three months between the first and second events was assumed to be long enough to allow marked fish to recover from handling and marking-induced behavioral effects from the first event.

Assumptions 4 and 5**:** Burbot captured during the first event were double marked with an individually-numbered Floy™ FD-67 internal anchor tag and the removal of the tip of the left pectoral fin. In the second event, the tip of the right pectoral fin was removed from all fish and served as an identifying mark to prevent resampling. All fish were carefully examined for these marks.

Limnological Sampling

Limnological measurements were made at a sampling station located in the deeper area of the lake (62.4251° N, 143.5472° W**;** Figure 3). Measurements of the following parameters were made at 1.0 m depth increments from the surface (0 m) to the bottom (about 60 or 70 m): water temperature (°C), conductivity (µS/cm), dissolved oxygen (DO) and pH. Measurements were to taken once each month throughout the open water period (June–September), and once when the lake was ice-covered (April). Measurements were taken with a Quantra Series Hydrolab[1].

Data Analysis

CPUE

CPUE was defined as the number of fish caught per trap fished for a 48-h period. Mean CPUE of partially (< 450 mm TL) and fully recruited burbot (≥ 450 mm TL) were estimated for each pass down the lake following a two-stage sampling design with transects as first-stage units and sets along transects as second-stage units (Bernard et al. 1993; Sukhatme et al. 1984). Burbot captured in the second pass that were previously captured in the first pass were used in the CPUE analysis for each pass; however, these fish were not counted twice for the length composition or abundance estimation. Although all transects had an equal probability of being included in a

[1] Product names used in this report are included for scientific completeness, but do not constitute product endorsement.

sample event, they were of different lengths due to the shape of the lake. Under these conditions, an unbiased estimate of mean CPUE was:

$$\overline{CPUE} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{m_i}\sum_{j=1}^{m_i}\omega_i c_{ij} \tag{1}$$

where:

c_{ij} = catch of burbot from the jth set on the ith transect;

n = number of transects;

m_i = number of sets sampled on the ith transect;

$\omega_i = M_i / \overline{M}$;

M_i = maximum possible sets on the ith transect; and,

$\overline{M}$ = mean of possible sets across all transects.

Although the M_i and $\overline{M}$ are unknown, the m_i and $\overline{m}$ were used as substitutes because both M and m are directly related to the length of transects. Thus $\varpi_i = m_i / \overline{m}$ was used to estimate ω_i. Because few burbot enter traps during daylight (Bernard et al. 1991), catches were not adjusted for the few hours deviation in soak times from the standard 48-h for most sets. A two-stage resampling procedure (Efron 1982; Rao and Wu 1988) was used to generate an empirical distribution of mean CPUE for each sample event from which variance of mean CPUE and bias from using ω_i were estimated. In resampling procedures, sets were chosen randomly within each transect although the original selection of sets was systematic. Systematically drawn data can be treated as randomly drawn with little concern for bias in the resultant statistics only so long as these data are not auto-correlated or follow a trend (Wolter 1984). Analysis of data from surveys in other Alaska lakes has revealed no meaningful trends or autocorrelations among catches along transects (Bernard et al. 1993). Estimates of mean CPUE for two size groups of burbot (≥ 450 mm and < 450 mm TL) were calculated for each sample event using procedures described in Bernard et al. (1993). The computer program RAOWU.EXE was used to estimate mean CPUE, approximate its variance, and estimate inherent bias in the estimate according to a two-stage bootstrap procedure based on a model in Rao and Wu (1988). Individual burbot captured more than once in a given year were considered different fish each time captured in calculation of mean CPUE. Conditions for the accurate calculation of mean CPUE as an index of abundance were:

1. gear do not compete for burbot;
2. burbot do not saturate the gear; and,
3. gear is not size-selective.

Bernard et al. (1993) showed that the spacing of sets used in this project (125 m) was sufficient to avoid competition among gear for burbot and that saturation of gear by burbot was negligible.

Because hoop traps fished in this project were size-selective for burbot (Bernard et al. 1991, 1993), only mean CPUE for fully recruited burbot was considered as a valid index of abundance. Also, because captured burbot take as many as 2–3 weeks to fully adjust to the effects of capture and handling (Bernard et al. 1991), CPUE from only the first pass of each event should be used for future CPUE comparisons.

Abundance Estimate

Relative to Assumption 2 (equal probability of capture or complete mixing), variations in capture probability related to size, location, and time were examined. Violations of Assumption 2 relative to size-selective sampling were tested by using results of two Kolmogorov-Smirnov (K-S) two-sample tests (α =0.05) that compared length frequency distributions of 1) marked and recaptured fish; and, 2) marked and all fish captured during event two. There are four possible combinations of outcomes of these two tests, each of which requires using different procedures to calculate a population abundance estimate (Appendix A1).

Violations of Assumption 2 were tested using consistency tests described by Seber (1982; Appendix A2). The documentation of release locations for each fish permitted the examination of multiple geographic stratification schemes and capture probabilities. Criteria considered when defining geographic strata included number of recaptures per stratum and stratum size relative to anticipated movements. If at least one of the three consistency tests resulted in a failure-to-reject the null hypothesis, then we concluded that at least one of the conditions in Assumption 2 was satisfied. If all three of these tests reject the null hypothesis, then depending on the extent of movement, a partially or completely stratified estimator would be used. If movement of marked burbot between strata occurred (incomplete mixing), then a partially stratified abundance estimate was computed using Darroch's (1961) methods. If no movement of marked burbot between geographic strata occurred, then a completely stratified abundance estimate was computed using Chapman’s modification of the Petersen estimator (Seber 1982).

Length Composition

Based on results of the K-S tests outlined in Appendix A1 (i.e., to length-stratify or not), length composition of the population was estimated as the following proportion(s):

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{2}$$

where:

n_j = the number sampled from length stratum j in the mark-recapture experiment;

n_{jk} = the number sampled from length stratum j that were in length category k; and,

$\hat{p}_{jk}$ = the estimated proportion of length category k in length stratum j.

Each length stratum was 10 mm wide, and the bounds were set based on the length of the smallest fish captured.

Variance was estimated as (Cochran 1977):

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1-\hat{p}_{jk}\right)}{n_j - 1}. \tag{3}$$

Results of the same K-S two-sample tests used to determine procedures for calculating population abundance were also used to determine whether the length composition estimate for the population needed to be adjusted for differential capture probabilities (Appendix A1). If length stratification was warranted (Case III or IV), strata were formed based on the x-value (length) of the maximum vertical deviation between the two curves being compared (*D* statistic of K-S test). K-S tests were then performed on each group to determine whether additional stratification was needed.

RESULTS

Summary of Fish Captured

A total of 391 burbot of all sizes were captured during this project. Of these, 188 burbot were 315–424 mm TL and 44 were ≥ 425 mm TL (Table 2). During the first event, 100 burbot ≥ 315 mm TL were captured and only 19 were ≥ 425 mm TL. During the second event, 132 burbot ≥ 315 mm TL were captured and only 25 were ≥ 425 mm TL. A total of 9 burbot 315–424 mm TL and a total of 8 burbot ≥ 425 mm TL were captured during both events. Mean length of all burbot captured was 349 mm (SE = 6.0 mm) for the first event and 348 mm (SE = 3.9 mm) for the second event (Table 2).

Table 2.–Mean length (mm TL) of burbot measured during both sampling events at Copper Lake, 2008.

Date of sampling	Statistic	Partially Recruited[a]	Fully Recruited[b]	All
6/7–6/15	Mean	332	538	349
	SE	3.8	27.2	6.0
	Sample size	154	15	169
9/10–9/17	Mean	331	534	348
	SE	3.2	14.8	4.9
	Sample size	204	18	222

[a] Burbot < 450 mm TL are partially recruited to the sampling gear.

[b] Burbot ≥ 450 mm TL are fully recruited to the sampling gear.

CPUE

During the first sampling event of the experiment, the first pass down the lake yielded a mean CPUE of 0.371 (SE = 0.063) for partially recruited burbot and 0.041 (SE = 0.016) for fully recruited burbot (Table 3). During the second event, the first pass down the lake resulted in a mean CPUE of 0.788 (SE = 0.100) for partially recruited burbot and 0.096 (SE = 0.031) for fully recruited burbot. Generally, CPUE was higher in the deeper water sets for partially recruited burbot, and no partially recruited burbot were captured at depths < 4 m (Appendix B1). There was no apparent trend for fully-recruited burbot (Appendix B2). However, unlike partially recruited burbot, fully recruited burbot were captured at depths > 4 m during both sampling events.

Length Composition and Abundance

The length of the smallest burbot caught, 315 mm TL, was chosen as the lower bound for abundance estimation. Results of the pooled K-S tests (Appendix A1: Case III) indicated that length-stratification was required and two length strata were formed: one for burbot 315–424 mm TL and a second for burbot ≥ 425 mm TL. Additional K-S tests for the smaller length stratum indicated that additional stratification was not needed (Figures 4, Appendix A1: Case I). Therefore, the length composition of fish in the smaller length stratum was estimated by pooling samples from both sampling events and calculating proportions and standard deviations in 10 mm length increments (Figure 5). The three smallest length categories (315–324, 325–334 and 335–344 mm TL) comprised about 42% of the estimated length proportions for the strata. Additional K-S tests were not done for the larger length stratum due to small sample sizes, but visual examination of graphed data suggested that length frequencies of marked, recaptured, and event two captured fish were similar (Figure 6). Since the sample size was small, we simply plotted the length frequency histogram of captured fish ≥ 425 mm TL in 50 mm TL increments from both events rather than calculating proportions (Figure 7).

Table 3.–Hoop trap and catch information for all captured burbot from Copper Lake, 2008. All sets were made at depths of 15 m or less.

Sample Dates	Sets	Transects	Mean CPUE			Bootstrapped	
			Bootstrapped	Arithmetic	%Δ	SE	CV
			First Sampling Event				
Pass 1	250	113					
6/7–6/12	Fully Recruited[a]:		0.041	0.041	0.%	0.016	39.4%
	Partially Recruited[b]:		0.371	0.369	-0.3%	0.063	17.1%
Pass 2	132	59					
6/11–6/15	Fully Recruited[a]:		0.067	0.069	-2.0%	0.028	42.0%
	Partially Recruited[b]:		0.529	0.527	0.5%	0.099	18.8%
			Second Sampling Event				
Pass 1	161	73					
9/10–9/14	Fully Recruited[a]:		0.096	0.093	2.6%	0.031	32.3%
	Partially Recruited[b]:		0.788	0.789	-0.1%	0.100	12.6%
Pass 2	150	75					
9/13–9/17	Fully Recruited[a]:		0.060	0.060	0.0%	0.024	40.0%
	Partially Recruited[b]:		0.604	0.600	0.7%	0.093	15.4%

[a] Burbot ≥ 450 mm TL are fully recruited to the sampling gear .

[b] Burbot < 450 mm TL are partially recruited to the sampling gear .

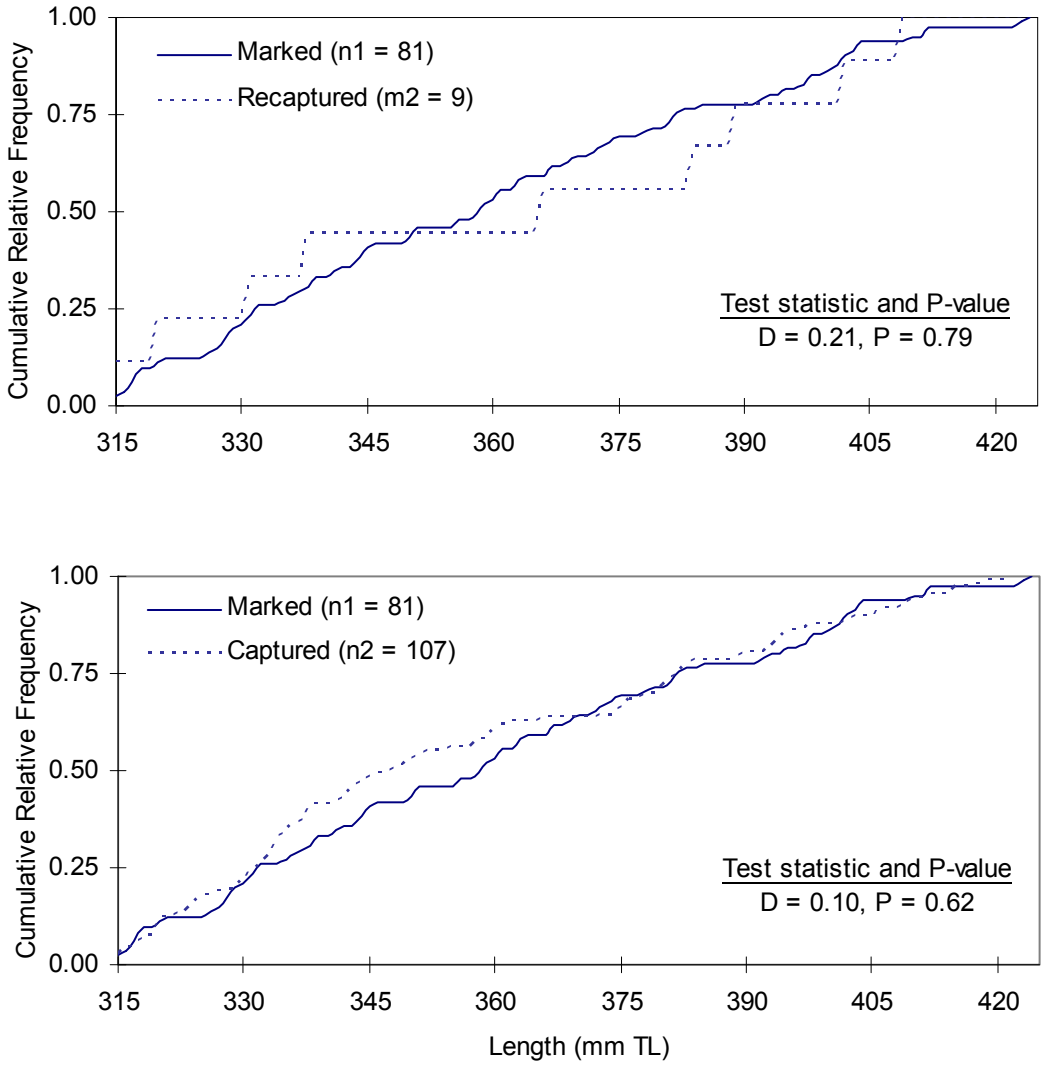

Figure 4.–Cumulative relative frequency distributions of burbot 315–424 mm TL, Copper Lake, 2008.

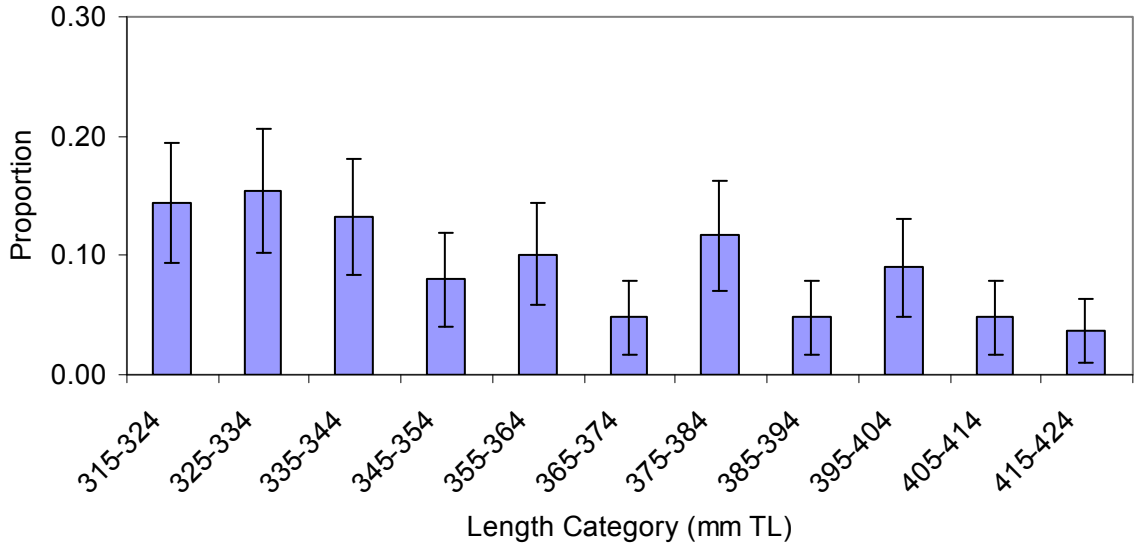

Figure 5.–Estimated length composition of burbot 315–424 mm TL in Copper Lake, 2008. Vertical bars represent 95% confidence intervals.

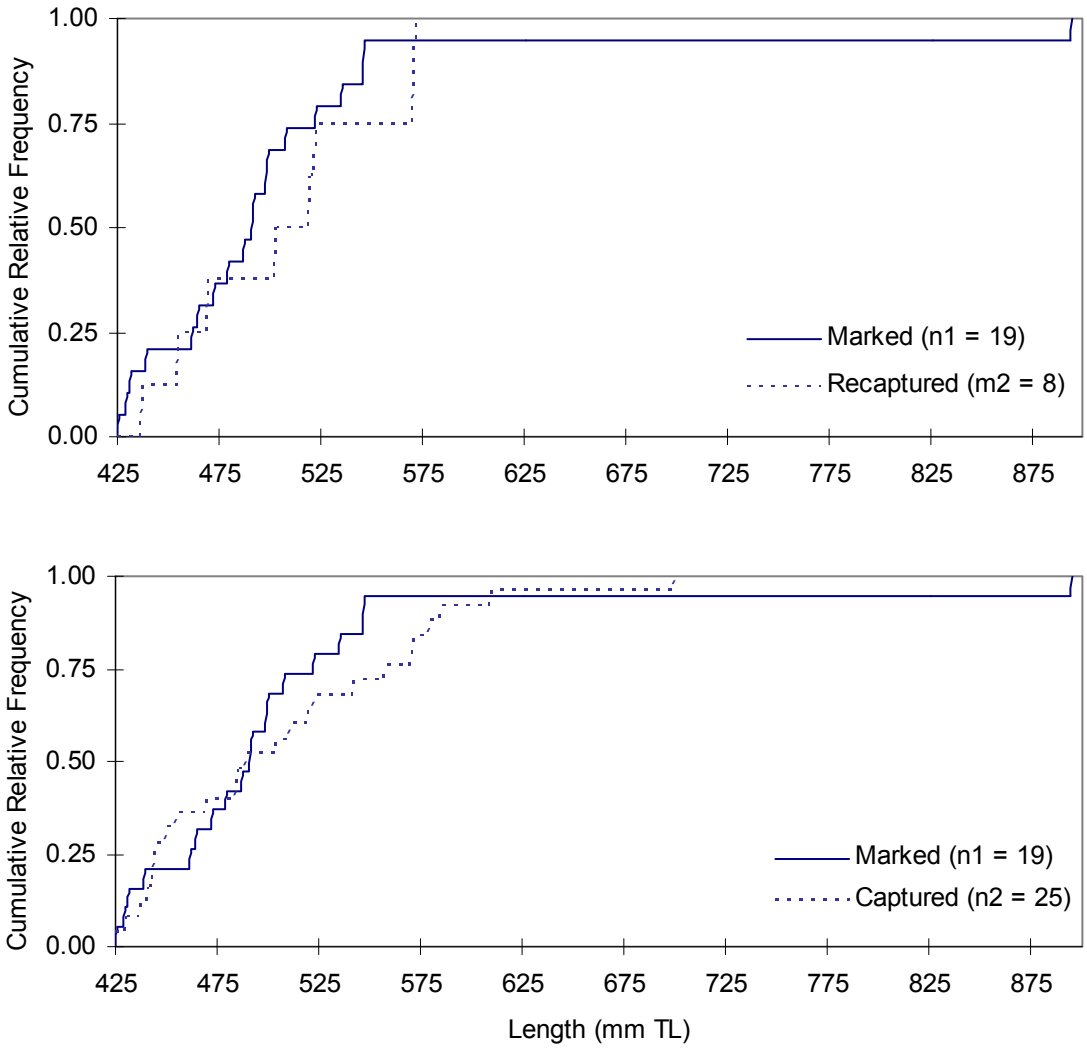

Figure 6.–Cumulative relative length frequency distributions of burbot ≥ 425 mm TL, Copper Lake, 2008.

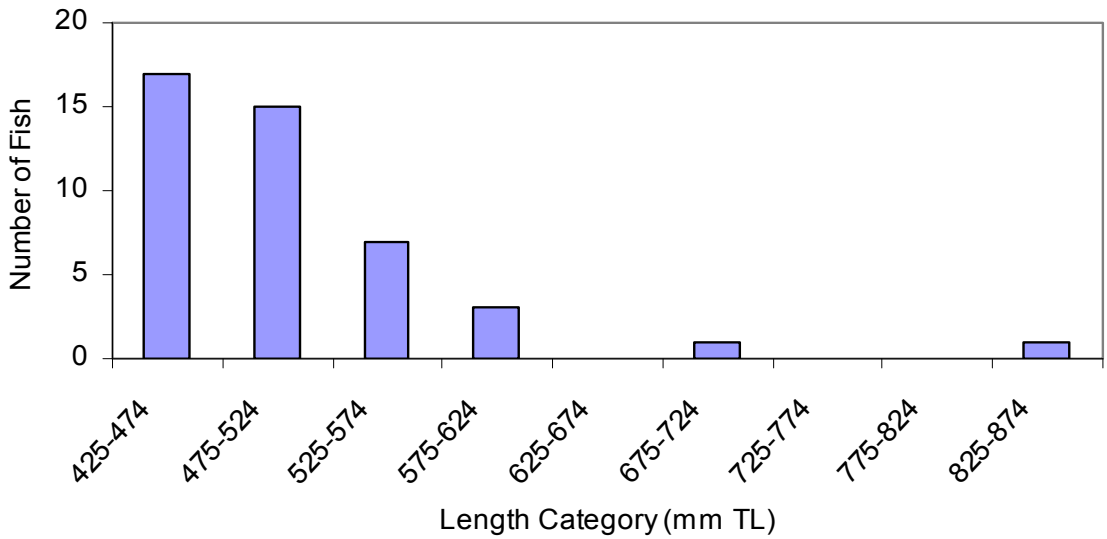

Figure 7.–Length frequency of burbot ≥ 425 mm TL captured during both events in Copper Lake, 2008.

Consistency tests using the three original geographic sections (A-C, Figure 3) indicated that geographic stratification was not necessary for either of the length strata. However, these results were based on small sample sizes. For fish within the smaller length stratum, the tests indicated that the probabilities of capture during both events were equal (P-value = 0.16, Table 4; P-value = 0.85, Table 5). While the test for complete mixing did not have a sufficient number of recaptured fish within the geographic sections to provide meaningful statistical results, some movement among the three sections occurred (3 of 8 fish; Table 6). For fish within the larger length strata the probabilities of capture during both events was also equal (P-value = 0.27, Table 7; P-value = 0.75, Table 8). Again, while the test for complete mixing did not have a sufficient number of recaptured fish within the geographic sections to provide meaningful statistical results, some movement among the three sections occurred (2 of 5 fish; Table 9).

Table 4.–Test for equal probability of capture during the first event for burbot 315-424 mm TL. Number of marked and unmarked burbot examined during the second event by section (A-C) of Copper Lake, 2008.

Category	Section Where Examined			
	A	B	C	All
Marked (m_2)	4	0	5	9
Unmarked (n_2-m_2)	25	27	46	98
Examined (n_2)	29	27	51	107
$P_{capture}$ 1st event (m_2/n_2)	0.14	0.00	0.10	0.08

χ^2 = 3.69, df = 2, P-value = 0.16, fail to reject H_0.

Table 5.–Test for equal probability of capture during the second event for burbot 315–424 mm TL. Number of burbot marked by section (A-C) during the first event that were recaptured or not recaptured during the second event, Copper Lake, 2008. One burbot was recaptured that had lost its tag and could not be assigned to the section where it was marked.

Category	Section Where Marked			All Sections
	A	B	C	
Recaptured (m_2)	1	3	4	8
Not Recaptured (n_1-m_2)	14	29	30	73
Marked (n_1)	15	32	34	81
$P_{capture}$ 2nd event (m_2/n_1)	0.07	0.09	0.12	0.10

$\chi^2 = 0.32$, df = 2, P-value = 0.85, fail to reject H_0.

Table 6.–Test for complete mixing. Number of burbot 315–424 mm TL marked in each section (A-C) and either recaptured or not recaptured in each section of Copper Lake, 2008.

Section Where Marked	Section Where Recaptured			Not Recaptured (n_1-m_2)	Total Marked (n_1)
	A	B	C		
A	1	0	0	14	15
B	2	0	1	29	32
C	0	0	4	30	34
Total	3	0	5	73	81

Table 7.–Test for equal probability of capture during the first event for burbot rainbow trout ≥ 425 mm TL. Number of marked and unmarked burbot examined during the second event by section (A-C) of Copper Lake, 2008.

Category	Section Where Examined			All Sections
	A	B	C	
Marked (m_2)	3	3	2	8
Unmarked (n_2-m_2)	2	7	8	17
Examined (n_2)	5	10	10	25
$P_{capture}$ 1st event (m_2/n_2)	0.60	0.30	0.20	0.36

$\chi^2 = 2.48$, df = 2, P-value = 0.29, fail to reject H_0.

Table 8.–Test for equal probability of capture during the second event for burbot ≥ 425 mm TL. Number of burbot marked by section (A-C) during the first event that were either recaptured or not recaptured during the second event, Copper Lake, 2008. Three burbot were recaptured that had lost their tags and could not be assigned the sections where they were marked.

Category	Section Where Marked			All Sections
	A	B	C	
Recaptured (m_2)	1	1	3	5
Not Recaptured (n_1-m_2)	3	4	7	14
Marked (n_1)	4	5	10	19
$P_{capture}$ 2nd event (m_2/n_1)	0.25	0.20	0.30	0.26

χ^2 = 5.89, df = 2, P-value = 0.75, fail to reject H_0.

Table 9.–Test for complete mixing. Number of burbot ≥ 425 mm TL marked in each section (A-C) and either recaptured or not recaptured in each section of Copper Lake, 2008.

Section Where Marked	Section Where Recaptured			Not Recaptured (n_1-m_2)	Total Marked (n_1)
	A	B	C		
A	1	0	0	3	4
B	0	1	0	4	5
C	1	1	1	7	10
Total	2	2	1	14	19

Movement was also examined by measuring 1) the difference between capture and recapture depth; and, 2) the straight line distance between capture and recapture locations. All but two burbot were recaptured in shallower water during the second sampling event than during the first sampling event (Figure 8). The change in capture depth for all but one recaptured burbot was <5 m. Horizontal movements suggest that at least partial mixing occurred since the mean straight line distance between capture and recapture locations was 1,600 m (Figure 9). Nine fish moved <1,000 m, while 4 moved > 2,000 m.

The total abundance estimate for the population sampled in Copper Lake was 944 burbot ≥ 315 mm TL (SE = 238; 90% CI = 550-1,337). This estimate was the sum of estimates for burbot between 315 and 424 mm TL (886, SE = 238; 90% CI = 494-1,278) and burbot ≥ 425 mm TL (58, SE = 11; 90% CI = 40-76). Relative precision (RP) of the total estimate was 0.42, which was less than our objective of 0.25.

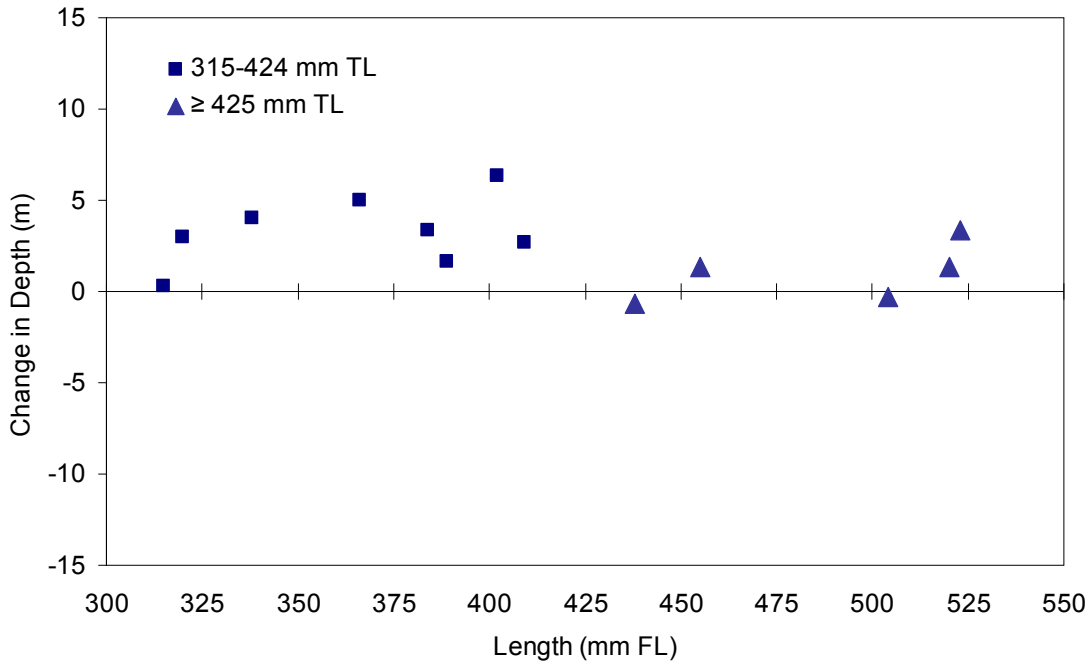

Figure 8.–Change in depth (m) of recaptured burbot between the first (spring) and second (fall) sampling events, Copper Lake 2008.

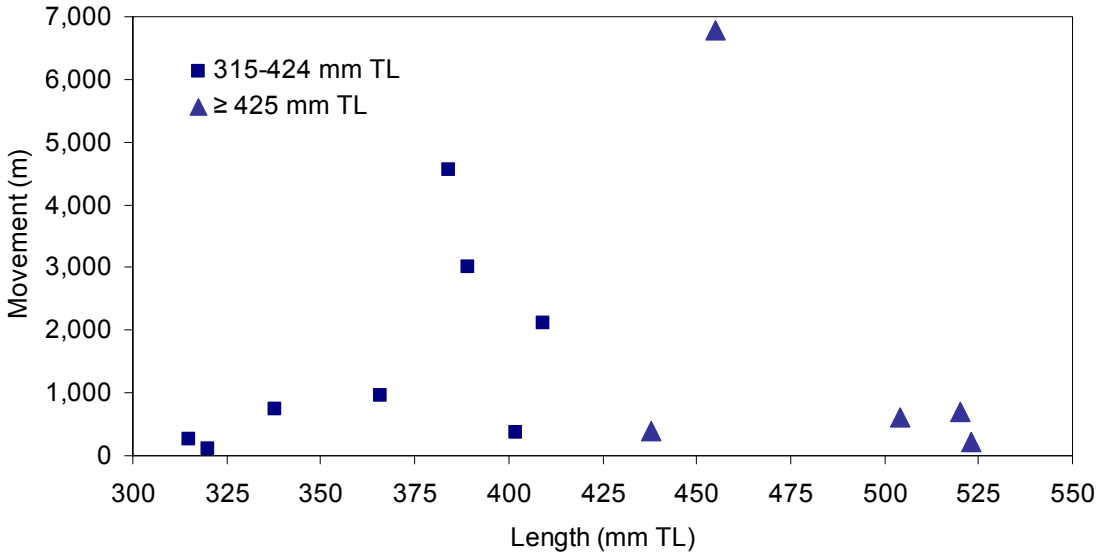

Figure 9.–Change in horizontal distance of recaptured burbot between the first (spring) and second (fall) sampling events, Copper Lake 2008.

Limnological Sampling

Monthly measurements (1.0 m depth increments) of water temperature (°C), conductivity (µS/cm), dissolved oxygen (DO) and pH were taken in Copper Lake during April, June, July, August, and September 2008 (Appendix C). Measurements for April were obtained while the lake was still covered with ice, and temperatures ranging from 0.05°C at the surface to about 4.00°C at the bottom of the water column (70 m). Water temperatures at depths where burbot were captured (<3m to 15m) probably ranged from about 8°C to 4°C during the first sampling event in June, and from about 9°C to 4°C during the second event in September. Dissolved oxygen levels at these depths ranged about 9.0 mg/l to 10.3 mg/L during the first event, and from about 7.1 mg/L to 9.1 mg/L during the second event.

DISCUSSION

The term "fully recruited burbot" generally refers to fish ≥ 450 mm. Bernard et al. (1991) found that this is the general size that fish enter traps at the same rate. This was attributed to the belief that burbot typically become piscivorous at this length, and therefore are fully susceptible to being captured in the baited hoop traps. Additionally, this trait essentially recruits them to the fishery (attracted to bait). Recapture rates of smaller partially recruited burbot are often too low to estimate abundance of smaller fish. Consequentially, burbot estimation projects typically only estimate abundances of burbot ≥ 450 mm. After sampling Copper Lake, small sample sizes of fish ≥ 450 mm precluded the estimation of fish that size. While examining pooled data of all captured fish, diagnostic tests for this project revealed that stratification by size was appropriate, and that the appropriate strata were 315–424 mm TL and ≥ 425 mm TL. It is not known why so many small sized burbot were captured in this lake. Copper Lake has very few shallow benthic zones and perhaps invertebrate abundances are low. These types of habitat conditions may mean fish have no dietary choice other than piscivory regardless of their size.

Our efforts to estimate the abundance of burbot in Copper Lake was met with limited success. The relative precision of our estimate (0.42) was less than what we planned for in our study design (0.25). Part of this is because we estimated the population of fish ≥ 315 mm TL. At nearby Tanada Lake, we were able to obtain an estimate with a much greater relative precision (0.18) using a similar study design (Schwanke and McCormick 2008), but this estimate was only for larger fish (i.e., ≥ 450 mm TL), which have higher probability of captures. Furthermore, several diagnostic tests for Copper Lake data either could not be done or provided questionable results due to small sample sizes, leaving us concerned about meeting all the assumptions of the two-event Petersen mark-recapture experiment.

Since > 80% of Copper Lake was too deep (> 15 m) to sample during either event, we relied upon mixing to obtain an unbiased abundance estimate. Although we achieved excellent results with a similar sampling design at adjacent Tanada Lake (Schwanke and McCormick 2008), our results were not as good for Copper Lake. Despite similar sampling effort, we captured fewer and smaller burbot in Copper Lake, and the reduced number of marked and recaptured burbot did not allow us to obtain good information on mixing. The horizontal distance moved between capture and recapture locations did not fully support the assumption of complete mixing since travel distances were generally not great enough for these fish to cross the deeper areas of the lake. Therefore, the total abundance estimate is likely biased low. Movements of recaptured fish among the three lake study sections also yielded little information. There is some indication that smaller burbot, which comprise most of the sampled population, may have mixed better than larger ones, which leads us to believe that the overall abundance estimate may be biased low by < 30%. We do not know whether burbot utilize areas of Copper Lake deeper than 15 m. While no large burbot (≥ 425 mm TL) were captured in the deepest water we sampled (13–15 m) during the second event, the greatest average CPUE for small burbot (≤ 424 mm TL) occurred in water depths of 13-15 m. A University of Alaska graduate student will be placing archival tags in burbot to determine movements in relation to depth and temperature in both Copper and Tanada lakes during 2009–2011. This study should provide us with a better understanding of potential biases with mark-recapture experiments in these lakes.

The lack of large burbot in our Copper Lake mark-recapture experiment is troubling, particularly since local knowledge suggests that substantial numbers of large burbot were present in the lake during the 1980s (Doug Fredricks, Sportsman's Paradise Lodge, Personal Communication). Estimated annual harvest during the late 1980s and early 1990s also support the presence of a population that was substantially more abundant than our recent estimate (Figure 2). We collected otoliths from some smaller specimens we captured, but have not analyzed them yet to estimate age or examine growth rates. The previously mentioned graduate student study will also provide some information on burbot growth rates in Copper and Tanada lakes through measurement of previously tagged burbot recaptured during tagging operations. This information could help us determine whether Copper Lake has poor growing conditions for burbot.

ACKNOWLEDGEMENTS

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APPENDIX A
METHODS FOR TESTING ASSUMPTIONS OF THE PETERSON ESTIMATOR AND ESTIMATING ABUNDANCE

Appendix A1.-Procedures for determining presence of bias due to size selectivity in a two-event mark-recapture experiment, and calculating abundance estimates based on test results. Size selectivity was examined using Kolmogorov-Smirnov (K-S) tests of two hypotheses: 1) the length distribution of marked and recaptured fish was the same; and, 2) the length distribution of marked fish and all fish caught during the second event was the same.

Case I

First K-S test: Accept H_o Second K-S test: Accept H_o

Inferred cause: No length selectivity occurred for fish within the size range of the marked population and marked fish were a size representative subset of the population. Therefore, size selective sampling did not occur during either sampling event.

Action: Calculate a single unstratified abundance estimate. Pool lengths from both sampling events to estimate length composition of the population.

Case II

First K-S test: Accept H_o Second K-S test: Reject H_o

Inferred cause: No length selectivity occurred for fish within the size range of the marked population, but marked fish were a size-biased subset of the population. Therefore, size selective sampling only occurred during the first sampling event.

Action: Calculate a single unstratified abundance estimate. Use lengths from the second sampling event to estimate length composition of the population.

Case III

First K-S test: Reject H_o Second K-S test: Accept H_o

Inferred cause: Length selectivity occurred for fish within the size range of the marked population, but marked fish were a size-representative subset of the population, therefore, size selective sampling occurred during both sampling events.

Action: Stratify both sampling events based on length selectivity, estimate abundance separately for each length stratum, and add abundance estimates across strata. Pool lengths from both sampling events to estimate length composition of population, and adjust estimate for differential capture probabilities.

Case IV

First K-S test: Reject H_o Second K-S test: Reject H_o

Inferred cause: Length selectivity occurred for fish within the size range of the marked population and marked fish were a size-biased subset of the population. Therefore, size selective sampling occurred during the second sampling event, but the occurrence cannot be determined for the first sampling event.

Action: Stratify both sampling events based on length selectivity, estimate abundance separately for each length stratum, and add abundance estimates across strata. Use lengths from the second sampling event to estimate length composition of the population, and adjust estimate for differential capture probabilities.

Appendix A2.–Tests of consistency for the Petersen estimator (from Seber (1982), page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

1. Marked fish mix completely with unmarked fish between events;
2. Every fish has an equal probability of being captured and marked during event 1; or,
3. Every fish has an equal probability of being captured and examined during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test For Complete Mixing

Ho: movement probabilities (θ) from section i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$

Section Where Marked	Section Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	$(n_1\text{-}m_2)$
1					
2					
…					
s					

II.-Test For Equal Probability of capture during the first event[a]

H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum j at the time of sampling, and a_i = number of marked fish released in stratum i.

	Section Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked ($n_2\text{-}m_2$)				

III.-Test for equal probability of capture during the second event[b]

H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section j during the second event, and d is a constant.

	Section Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured ($n_1\text{-}m_2$)				

[a] Tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among river sections

[b] Tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among the river sections .

Appendix A3.–Equations for calculating estimates of abundance and its variance using the Chapman-modified Petersen estimator.

The abundance of fully recruited burbot was estimated as:

$$\hat{N} = \frac{(n_2 + 1)(n_1 + 1)}{(m_2 + 1)} - 1, \tag{A3-1}$$

where:

n_1 = the number of fully recruited burbot marked and released alive during the first event;

n_2 = the number of fully recruited burbot examined for marks during the second event; and,

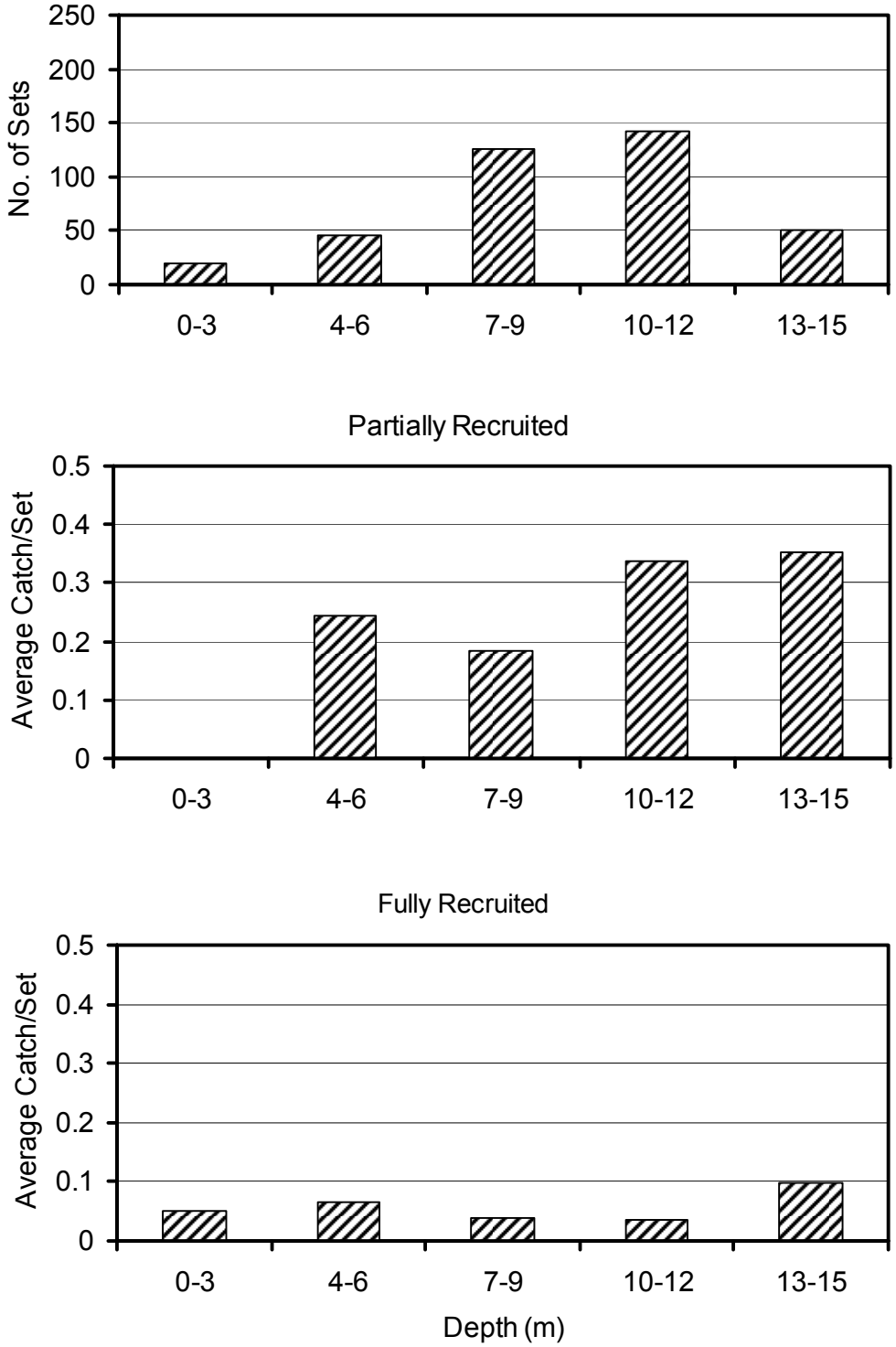
m_2 = the number of fully recruited burbot marked in the first event that were recaptured during the second event; and,

The variance was estimated as (Seber 1982):

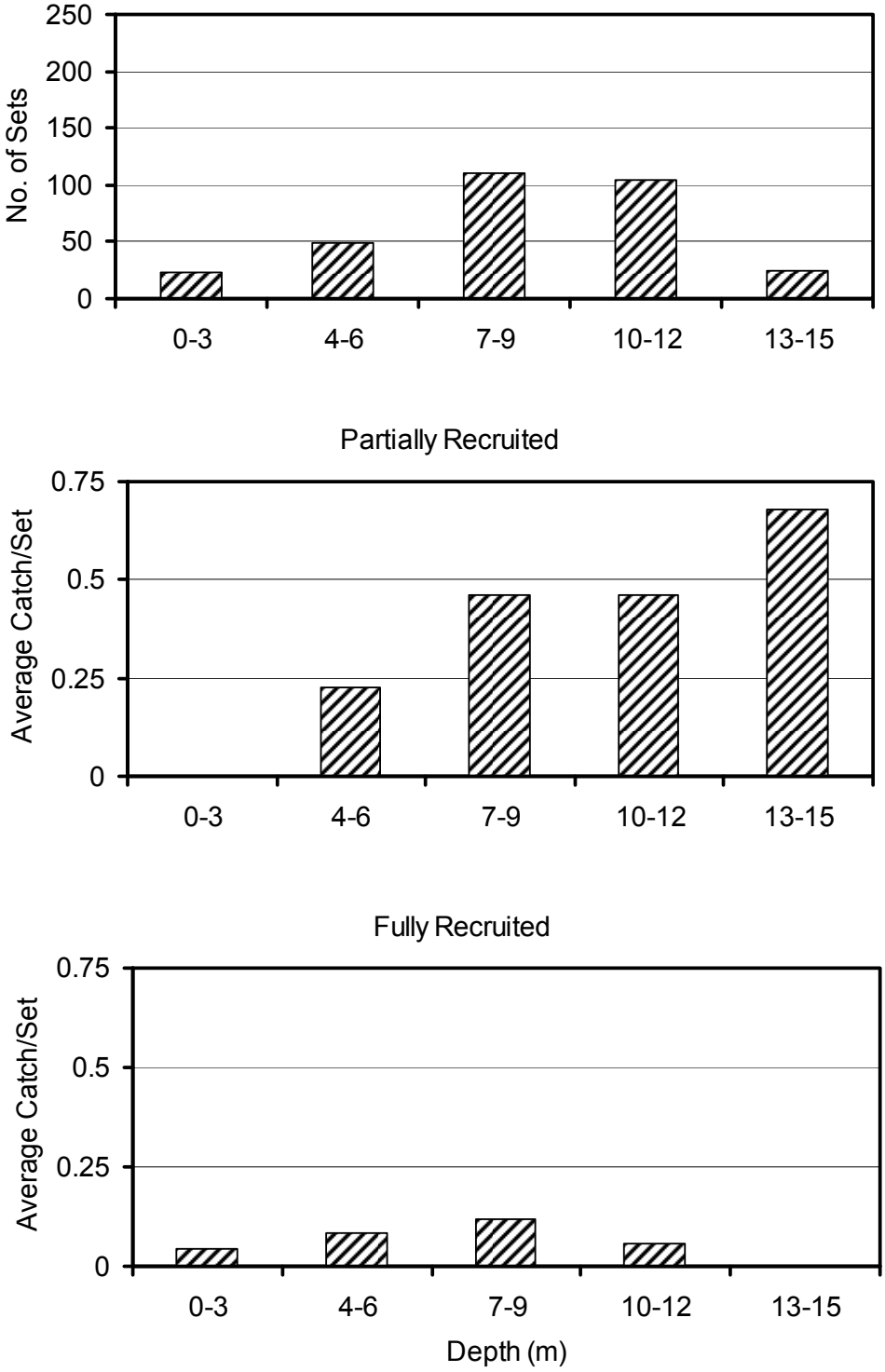
$$\hat{V}[\hat{N}] = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)}. \tag{A3-2}$$

APPENDIX B
HOOP TRAP CATCH INFORMATION

Appendix B1.–Catch information for hoop trap sets in spring, Copper Lake, 2008.



Appendix B2.–Catch information for hoop trap sets in fall, Copper Lake, 2008.



APPENDIX C
LIMNOLOGICAL INFORMATION

Appendix C1.–Limnological data collected on 23 April 2008, Copper Lake (62.4251° N, 143.5472° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	0.05	0.086	10.26	7.41
1	0.06	0.085	9.85	7.49
2	1.16	0.082	9.31	7.50
3	1.68	0.081	8.92	7.51
4	2.07	0.081	8.67	7.45
5	2.25	0.080	8.52	7.45
6	2.40	0.079	8.35	7.45
7	2.50	0.079	8.28	7.46
8	2.66	0.079	8.22	7.47
9	2.76	0.079	8.16	7.48
10	2.87	0.077	8.04	7.49
11	2.98	0.078	7.90	7.49
12	3.06	0.077	7.83	7.49
13	3.20	0.077	7.70	7.49
14	3.29	0.077	7.64	7.49
15	3.37	0.077	7.67	7.49
16	3.46	0.077	7.55	7.49
17	3.53	0.077	7.41	7.49
18	3.60	0.077	7.07	7.47
19	3.63	0.077	6.89	7.46
20	3.68	0.078	6.66	7.45
21	3.77	0.078	6.18	7.43
22	3.79	0.078	6.12	7.42
23	3.84	0.079	5.56	7.40
24	3.87	0.080	5.44	7.38
25	3.91	0.081	5.38	7.36
26	3.93	0.082	5.13	7.35
27	3.96	0.083	4.90	7.34
28	3.97	0.084	4.63	7.33
29	3.99	0.084	4.44	7.32
30	3.99	0.084	4.08	7.30
31	4.00	0.085	3.93	7.30
32	4.01	0.085	3.71	7.29
33	4.01	0.086	3.57	7.28
34	4.01	0.087	3.45	7.27
35	4.01	0.087	3.22	7.27
36	4.02	0.087	3.11	7.26
37	4.02	0.087	2.83	7.26
38	4.02	0.088	2.64	7.26
39	4.02	0.088	2.55	7.26
40	4.02	0.089	2.49	7.26
41	4.02	0.089	2.43	7.26
42	4.02	0.090	2.31	7.25
43	4.02	0.090	2.21	7.26
44	4.02	0.090	2.11	7.25
45	4.02	0.091	1.99	7.37
46	4.02	0.091	1.93	7.35
47	4.01	0.091	1.82	7.33
48	4.01	0.092	1.68	7.31
49	4.01	0.091	1.44	7.27

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Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
50	4.01	0.092	1.54	7.29
51				
52				
53				
54				
	4.00	0.092	1.38	7.28
52	3.99	0.093	1.34	7.27
53	3.99	0.094	1.12	7.27
54	3.98	0.094	1.10	7.26
55	3.98	0.094	1.03	7.26
56	3.98	0.094	0.81	7.26
57	3.98	0.095	0.68	7.25
58	3.99	0.095	0.42	7.24
59	4.00	0.095	0.22	7.24
60	4.00	0.096	0.07	7.24
61	4.01	0.097	0.06	7.24
62	4.01	0.098	0.05	7.24
63	4.01	0.099	0.04	7.25
64	4.02	0.100	0.04	7.26
65	4.02	0.101	0.04	7.26
66	4.02	0.103	0.04	7.27
67	4.01	0.106	0.04	7.27
68	4.01	0.114	0.03	7.28
69	4.01	0.147	0.03	7.35
70	4.00	0.308	0.03	7.51

Appendix C2.–Limnological data collected on 19 June 2008, Copper Lake (62.4251° N, 143.5472° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	7.85	0.069	9.79	8.53
1	7.49	0.710	9.98	8.54
2	6.45	0.710	10.29	8.58
3	6.24	0.710	10.25	8.61
4	6.06	0.710	10.31	8.63
5	5.90	0.710	10.32	8.64
6	5.63	0.072	10.35	8.58
7	5.16	0.073	10.25	8.55
8	4.55	0.076	9.88	8.43
9	4.50	0.074	9.83	8.40
10	4.35	0.074	9.87	8.37
11	4.31	0.075	9.52	8.30
12	4.30	0.076	9.48	8.27
13	4.28	0.077	9.21	8.22
14	4.23	0.077	9.13	8.20
15	4.04	0.078	9.04	8.17
16	3.43	0.078	8.57	8.14
17	3.88	0.079	8.59	8.09
18	3.86	0.078	8.51	8.09
19	3.84	0.078	8.52	8.07
20	3.84	0.079	8.46	8.06
21	3.81	0.079	8.40	8.05
22	3.80	0.079	8.34	8.03
23	3.87	0.080	7.72	8.00
24	3.88	0.080	6.66	7.96
25	3.87	0.082	6.12	7.84
26	3.88	0.083	5.48	7.80
27	3.80	0.082	5.20	7.75
28	3.88	0.084	4.68	7.73
29	3.92	0.085	4.44	7.71
30	3.92	0.085	4.43	7.70
31	3.95	0.086	4.11	7.69
32	3.96	0.085	4.09	7.68
33	3.96	0.086	4.04	7.68
34	3.98	0.087	3.80	7.67
35	3.98	0.087	3.76	7.66
36	4.00	0.088	3.45	7.65
37	3.99	0.088	3.35	7.65
38	3.99	0.089	3.30	7.64
39	3.99	0.089	3.13	7.64
40	3.98	0.089	3.11	7.63
41	3.96	0.089	3.09	7.64
42	3.95	0.090	3.08	7.64
43	3.94	0.090	3.04	7.63
44	3.90	0.091	3.12	7.64
45	3.87	0.091	3.35	7.80
46	3.85	0.092	3.37	7.85
47	3.86	0.091	3.36	7.74
48	3.86	0.092	3.34	7.73
49	3.86	0.092	3.16	7.72

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Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
50	3.91	0.093	2.48	7.68
51				
52				
53				
54				
	3.09	0.094	2.54	7.66
52	3.87	0.094	2.64	7.66
53	3.86	0.096	2.66	7.66
54	3.85	0.095	2.64	7.66
55	3.84	0.095	2.57	7.65
56	3.84	0.096	2.56	7.65
57	3.84	0.097	2.36	7.64
58	3.84	0.096	2.23	7.64
59	3.85	0.097	1.92	7.63
60	3.90	0.097	1.08	7.60
61	3.91	0.098	0.70	7.58
62	3.91	0.099	0.36	7.56
63	3.94	0.101	0.15	7.54
64	3.94	0.106	0.12	7.52
65	3.96	0.110	0.09	7.54
66	3.96	0.115	0.08	7.56
67	3.96	0.118	0.08	7.59
68	3.91	0.121	0.08	7.62
69	3.91	0.124	0.07	7.67

Appendix C3. Limnological data collected on 29 July 2008, Copper Lake (62.4251° N, 143.5472° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	14.24	0.064	8.70	8.71
1	11.59	0.064	8.75	8.79
2	11.30	0.064	8.82	8.83
3	11.16	0.064	8.78	8.86
4	11.10	0.064	8.79	8.86
5	11.04	0.064	8.73	8.86
6	10.73	0.064	8.72	8.79
7	9.15	0.066	8.85	8.78
8	8.16	0.068	8.88	8.64
9	6.67	0.071	9.00	8.63
10	5.82	0.073	9.00	8.62
11	5.00	0.075	8.52	8.59
12	4.60	0.076	8.35	8.55
13	4.31	0.077	8.13	8.52
14	4.18	0.078	8.00	8.49
15	4.04	0.079	7.85	8.47
16	3.97	0.079	7.58	8.44
17	3.94	0.080	7.53	8.41
18	3.91	0.080	7.16	8.39
19	3.92	0.081	6.68	8.35
20	3.92	0.081	6.20	8.29
21	3.92	0.081	5.89	8.25
22	3.94	0.082	5.63	8.21
23	3.95	0.083	5.30	8.18
24	3.96	0.083	7.93	8.15
25	3.97	0.084	4.57	8.10
26	3.98	0.085	4.21	8.08
27	3.99	0.086	3.95	8.05
28	3.99	0.086	3.82	8.03
29	3.99	0.086	3.75	8.00
30	3.99	0.086	3.74	8.00
31	4.00	0.086	3.57	7.99
32	4.01	0.087	3.27	7.98
33	4.01	0.088	2.96	7.95
34	4.01	0.089	2.69	7.93
35	4.01	0.089	2.54	7.92
36	4.01	0.089	2.47	7.90
37	4.01	0.089	2.43	7.91
38	4.01	0.089	2.38	7.90
39	4.01	0.090	2.22	7.89
40	4.01	0.090	2.16	7.88
41	4.02	0.090	2.08	7.87
42	4.02	0.091	1.91	7.87
43	4.04	0.091	1.91	7.87
44	4.03	0.091	1.87	7.86
45	4.04	0.091	1.83	7.85
46	4.05	0.091	1.78	7.85
47	4.06	0.092	1.75	7.85
48	4.07	0.091	1.71	7.85
49	4.08	0.092	1.67	7.84

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Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
50	4.09	0.093	1.69	7.95
51				
52				
53				
54				
	4.09	0.092	1.65	7.92
52	4.10	0.092	1.62	7.91
53	4.10	0.092	1.60	7.90
54	4.10	0.092	1.59	7.89
55	4.10	0.092	1.48	7.88
56	4.10	0.092	1.44	7.86
57	4.09	0.093	1.16	7.86
58	4.10	0.093	1.09	7.84
59	4.09	0.094	1.08	7.84
60	4.10	0.093	1.02	7.83
61	4.09	0.093	0.97	7.83
62	4.09	0.093	0.93	7.82
63	4.10	0.093	0.88	7.82
64	4.10	0.094	0.80	7.82
65	4.10	0.094	0.71	7.82
66	4.10	0.094	0.68	7.80
67	4.10	0.095	0.44	7.80
68	4.09	0.096	0.16	7.80
69	4.09	0.099	0.10	7.79
70	4.08	0.106	0.08	7.79

Appendix C4.–Limnological data collected on 29 August 2008, Copper Lake (62.4251° N, 143.5472° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	11.22	0.065	8.67	8.30
1	10.92	0.065	8.76	8.45
2	10.82	0.065	8.86	8.56
3	10.76	0.065	8.87	8.65
4	10.65	0.065	8.60	8.69
5	10.57	0.065	8.74	8.73
6	10.39	0.065	8.67	8.73
7	9.91	0.065	8.51	8.74
8	9.05	0.066	8.40	8.72
9	8.58	0.067	8.43	8.68
10	7.71	0.070	8.14	8.66
11	6.84	0.071	7.96	8.63
12	6.12	0.073	7.96	8.59
13	5.50	0.075	8.01	8.58
14	5.13	0.076	7.55	8.57
15	4.85	0.077	7.36	8.53
16	4.35	0.077	7.48	8.52
17	4.09	0.079	7.01	8.50
18	4.04	0.080	6.61	8.47
19	4.00	0.080	6.61	8.43
20	3.97	0.081	5.92	8.42
21	3.97	0.082	5.60	8.38
22	3.97	0.083	5.39	8.35
23	3.96	0.082	5.08	8.33
24	3.97	0.083	4.99	8.31
25	3.95	0.084	4.78	8.29
26	3.97	0.084	4.54	8.29
27	3.98	0.086	4.16	8.26
28	3.99	0.085	3.99	8.24
29	4.00	0.086	3.98	8.22
30	4.01	0.087	3.50	8.21
31	4.01	0.087	3.50	8.19
32	4.02	0.087	3.24	8.19
33	4.02	0.088	3.12	8.26
34	4.02	0.088	3.14	8.24
35	4.03	0.088	2.71	8.22
36	4.03	0.089	2.71	8.18
37	4.04	0.089	2.65	8.17
38	4.04	0.090	2.40	8.17
39	4.05	0.090	2.11	8.15
40	4.05	0.091	2.15	8.13
41	4.05	0.090	2.16	8.12
42	4.06	0.091	2.09	8.13
43	4.06	0.091	2.02	8.12
44	4.06	0.091	1.91	8.12
45	4.06	0.091	1.90	8.11
46	4.06	0.092	1.87	8.11
47	4.07	0.091	1.87	8.10
48	4.08	0.092	1.83	8.10
49	4.08	0.092	1.69	8.10

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Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
50	4.07	0.092	1.55	8.10
51				
52				
53				
54				
	4.09	0.092	1.53	8.08
52	4.08	0.092	1.50	8.08
53	4.09	0.092	1.44	8.08
54	4.09	0.093	1.48	8.08
55	4.08	0.093	1.29	8.07
56	4.09	0.093	1.34	8.07
57	4.09	0.094	1.23	8.07
58	4.09	0.093	1.18	8.06
59	4.09	0.093	1.13	8.06
60	4.09	0.093	1.09	8.06
61	4.09	0.093	0.97	8.06
62	4.09	0.094	0.68	8.05
63	4.09	0.094	0.59	8.05
64	4.09	0.095	0.30	8.03
65	4.09	0.097	0.19	8.03
66	4.09	0.098	0.15	8.03
67	4.09	0.102	0.14	8.03
68	4.09	0.104	0.12	8.04
69	4.08	0.110	0.12	8.16

Appendix C5.–Limnological data collected on 23 September 2008, Copper Lake (62.4251° N, 143.5472° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	9.30	0.067	9.06	8.76
1				
2	8.95	0.066	9.10	8.83
3	8.65	0.067	9.09	8.89
4	8.59	0.067	8.98	8.90
5	8.58	0.066	8.72	8.92
6	8.57	0.066	8.85	8.91
7	8.56	0.066	8.86	8.93
8	8.54	0.066	8.90	8.93
9	8.50	0.067	8.81	8.93
10	8.20	0.068	8.22	8.81
11	7.04	0.072	7.68	8.68
12	6.54	0.073	7.58	8.61
13	5.21	0.077	7.58	8.56
14	4.44	0.078	7.46	8.55
15	4.10	0.080	7.10	8.52
16	4.03	0.081	6.45	8.48
17	4.02	0.081	6.23	8.45
18	4.03	0.082	5.73	8.41
19	4.03	0.084	5.28	8.36
20	4.02	0.084	4.87	8.33
21	4.03	0.085	4.47	8.32
22	4.02	0.086	4.09	8.29
23	4.03	0.087	3.87	8.26
24	4.03	0.086	3.75	8.26
25	4.03	0.087	3.52	8.23
26	4.04	0.087	3.34	8.25
27	4.05	0.088	3.18	8.22
28	4.06	0.089	2.96	8.20
29	4.06	0.089	2.68	8.18
30	4.08	0.091	2.25	8.19
31	4.10	0.092	2.75	8.20
32	4.09	0.092	2.68	8.21
33	4.09	0.092	2.71	8.19
34	4.09	0.092	2.65	8.18
35	4.09	0.092	2.62	8.18
36	4.07	0.092	1.82	8.16
37	4.08	0.092	1.99	8.24
38	4.08	0.092	1.49	8.22
39	4.08	0.092	1.45	8.17
40	4.08	0.093	1.29	8.17
41	4.08	0.093	1.26	8.16
42	4.08	0.093	1.30	8.14
43	4.08	0.094	1.20	8.14
44	4.09	0.094	1.24	8.13
45	4.08	0.094	0.99	8.12
46	4.08	0.094	1.00	8.11
47	4.10	0.094	1.07	8.12
48	4.08	0.094	1.04	8.11
49	4.08	0.094	1.00	8.11

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Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
50	4.08	0.095	0.91	8.11
51				
52				
53				
54				
	4.08	0.095	0.68	8.10
52	4.08	0.095	0.68	8.09
53	4.08	0.096	0.21	8.09
54	4.08	0.096	0.18	8.29
55	4.09	0.096	0.14	8.20
56	4.08	0.098	0.14	8.19
57	4.08	0.099	0.13	8.18
58	4.08	0.103	0.13	8.18
59	4.08	0.106	0.13	8.19
60	4.07	0.112	0.13	8.18
61	4.07	0.260	0.11	8.42

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