Tanada Lake Burbot Stock Assessment, 2007

Annual Report for Study 07-501

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ABSTRACT

A stock assessment of burbot *Lota lota* was conducted at Tanada Lake in 2007. Burbot were captured using baited hoop traps soaked for two nights (approximately 48 h) and systematically set along equally spaced transects. Sampling was conducted twice as part of a two-event mark-recapture experiment. The first event occurred from 25 June to 6 July and 388 traps were set. The second event took place from 12 to 19 September and 333 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 1.17 (SE = 0.19) burbot/trap and was 0.89 (SE = 0.13) burbot/trap for the second event. A pooled Chapman's modified Petersen estimator was used to estimate the abundance of fully recruited burbot at 2,217 (90% CI = 1,821 - 2,613). Burbot from 450 to 549 mm TL composed 77% of the total estimated abundance of fully recruited burbot. 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.

Key words: Burbot, *Lota lota,* abundance, length composition, catch per unit effort, hoop traps, mean length, Tanada Lake.

INTRODUCTION

This annual report summarizes work conducted during the 2007 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. During 2007, field work was completed at Tanada Lake, and work at Copper Lake will be conducted during the open water period of 2008. The remaining portions of this annual report are therefore focused on Tanada Lake.

Burbot *Lota lota* in Tanada Lake (Figure 1) have never been studied and have always been managed under the general sport fishing regulations. The present bag and possession limit under state regulations is five burbot. Estimated annual harvest from the ADF&G Statewide Harvest Survey has ranged from 0 to 637, and averaged < 7 burbot during the last five years (2002-2006; Figure 2). Since Tanada Lake lies within the Wrangell-St. Elias National Park (WRST) boundaries, the potential for a subsistence based fishery exists. Currently there are no federal subsistence harvest limits established for freshwater fish species in the Copper River drainage. In addition, the WRST has no data to support a potential harvest limit. Subsistence permits have recently been issued for Tanada Lake, but no fish harvest has been reported and the harvest of burbot by these permit holders is believed to be occurring under State of Alaska sport fishing regulations. This practice may change as users become more aware of their additional opportunities provided by federal subsistence fishing regulations.

Specific objectives for 2007 were to:

1. estimate the length composition of fully recruited burbot (≥ 450 mm TL) at Tanada Lake such that the estimated proportions are 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 Tanada Lake such that the estimated mean CPUE is within ± 50% of its asymptotic value 90% of the time;
3. estimate the abundance of fully recruited burbot (≥ 450 mm TL) in Tanada Lake for spring 2008 such that the estimated abundance is within ± 25% of the true abundance 90% of the time; and,
4. collect limnological information from Tanada Lake through a hole in the ice during April and on a monthly basis during the open water period.

These objectives (and the study design) were adjusted since the Investigative Plan (IP) was approved. It was decided that a two-event mark-recapture experiment would result in more precise estimates of abundance, and the study design was switched from conducting concurrent (i.e., sampling both Tanada and Copper lakes each spring) three-year Jolly-Seber experiments to conducting a single two-event mark-recapture experiment. One lake would be sampled each year and the first event would occur in the spring, the second event in the fall. Tanada Lake was sampled in 2007 and Copper Lake will be assessed in 2008. Also, the limnological sampling was added as an objective. This sampling was discussed in the methods of the IP, but was omitted from the list of objectives.

METHODS

Study Area

Tanada Lake (62°25’ N, 143°22’ W) is located within the Wrangell-St. Elias National Park/Preserve in the Upper Copper River drainage. Its surface area is 1,100 ha, and it has a maximum depth of 60 m and an elevation of 835 m. At present there are no public recreational facilities on the lake, although a lodge did operate until the early 1990s. Tanada Lake supports lake trout S*alvelinus namaycush*, burbot, Arctic grayling *Thymallus arcticus*, round whitefish *Prosopium cylindraceum*, longnose sucker *Catostomus catostomus* and sockeye salmon *Oncorynchus nerka* (both anadromous and non-anadromous forms). Tanada Lake has four inlet streams (Grayling, Goat, Sawmill and one that is unnamed) and one outlet stream (Tanada Creek) which flows directly into the Copper River.

Study Design and Burbot Capture

In 2007, a two-event mark-recapture experiment was conducted to estimate abundance and length composition of burbot in Tanada 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 are 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 a transect at 125-m intervals; transects were also spaced at 125-m intervals. No traps were set shallower than 1.5 m and no traps were set deeper than 15 m to avoid decompression-induced mortality associated with burbot captured at greater depths (Bernard et al. 1993). Bernard et al. (1993) found that adult burbot did not exhibit a strong depth preference and that mean adult CPUE for sets above 15 m was similar to that for sets at all depths in their study. 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. Six days were required to systematically fish all transects down the length of the lake.

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 burbot > 300 mm TL that were not previously tagged were marked with an individually numbered T-bar 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 *unpublished*) for all lakes. Data forms were optically scanned, and electronic data files (ASCII format) were imported into Microsoft Office 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 25 June and ended on 6 July 2007. 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 Tanada Lake, the lake was sampled twice in spring to ensure that sufficient sample sizes of burbot were attained to meet objective criteria. Two complete passes were made down the entire length of the lake using the transect protocol described in Bernard et al. (1993). During the first pass, 200 hoop traps were set and during the second pass, 188 traps were set (Table 1).

Fall sampling took place from 12-19 September 2007. After an initial first pass in which 218 hoop traps were set the entire length of the lake (Table 1), it was determined that the objective criteria for both the length distribution and abundance estimate would be easily attained and that another complete pass was not necessary. It was decided to make another pass down the length of the lake, but this time half the transects were set (i.e., every other transect; 115 traps). This was done to further increase the precision of the abundance estimate, as well as to increase the number of recaptured burbot for diagnostic testing.

The sampling strategy for this experiment was to: 1) sample the entire study area as well as our sampling gear would allow in order to subject all burbot 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 burbot mixing within the lake between events; and, 3) repeat step "1" for the second event. The study area was arbitrarily divided into seven 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 into 3 equally sized sections.

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.

The experiment was designed to allow the validity of these assumptions to be examined. The specific form of the population estimator was determined from the experimental design and from the results of the diagnostic tests performed to evaluate whether the assumptions were met (Appendices A1 and A2)

Evaluation of Assumptions

Assumption 1: It was unlikely that burbot, at least individuals of the size in the population being estimated, entered or left the lake via Tanada Creek during the mark-recapture event. WRST operates a weir on the creek to count Pacific salmon *Oncorhynchus* and have never passed a burbot through it. It was recognized that growth recruitment would likely occur during the three month interval allowed for mixing. Marking burbot with individually-numbered tags permitted us to determine growth in

length of recaptured individuals. These growth data were used to determine whether adjustments to the abundance estimate or the population of inference were needed to eliminate related bias. We also assumed that some natural mortality would occur, but as with growth, this can also be addressed when considering the population of inference. Angling induced mortality was assumed to be insignificant because Tanada Lake has a very small burbot harvest reported from the lake (none were reported during each of the last three years), the lake is remote and burbot typically are not harvested in the summer months.

Assumption 2: The sampling with hoop traps was limited to water depths < 15 m. Efforts were made to subject all burbot within sampled portions of the lake to an equal probability of capture during each event by uniformly setting these areas with the transect/grid system for deploying hoop traps (Bernard et al. 1993). This experiment relies on ensuring equal probability of capture during at least one event, or complete mixing in which event specific probabilities of capture become obsolete. The three-month hiatus between events should allow mixing. Only abundance estimates of burbot ≥ 450 mm were calculated because Bernard et al. (1991) found that burbot < 450 mm were not fully recruited to the gear and have much lower capture probabilities than larger burbot.

Assumption 3: The interval of almost three months between the first and second events allowed marked burbot 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 ventral fin. In the second event, the tip of the right ventral fin was removed from all burbot and served as an identifying mark to prevent resampling. All burbot were carefully examined for these marks.

Limnological Sampling

Monthly measurements (@ 1.0 m depth increments) of water temperature (°C), conductivity (µS/cm), dissolved oxygen (DO) and pH were to be taken regularly throughout the field season, with at least one sampling while the ice was still covering the lake. Limnological sampling was taken with a Quantra Series Hydrolab[1].

Data Analysis

CPUE

CPUE was defined as the number of burbot caught per trap fished for a 48-h period. Mean CPUE was estimated for fully and partially recruited burbot 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

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

the CPUE analysis for each pass; however, these burbot were not counted twice for length composition or abundance estimation. Although all transects had an equal probability of being included in a sample event, they were of different lengths depending upon 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 m were used as substitutes because both M and m are directly related to the length of transects. Thus, $\varpi_i = m_i/m$ 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 previous surveys revealed no meaningful trends or autocorrelations among catches along transects (Bernard et al. 1993). Estimates of mean CPUE for two 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 burbot 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 effects of capture and handling (Bernard et al. 1991), CPUE data from only the first pass of each event were used for comparisons.

Abundance Estimate

Relative to Assumption 2, 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 two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two tests relative to evaluating size selectivity (either one of the two samples, both, or neither of the samples were biased) and two possible actions for abundance estimation (length: stratify or not). The tests and possible actions for data analysis are outlined in Appendix A1.

Violations of Assumption 2 were tested using consistency tests described by Seber (1982; Appendix A2). The documentation of release locations for each burbot 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 rejected the null hypothesis, then, depending on the extent of movement, a partially or completely stratified estimator was used. If movement of marked burbot between strata was observed (incomplete mixing), then the methods of Darroch (1961) were used to compute a partially stratified abundance estimate. If no movement of marked burbot between geographic strata was observed, a completely stratified abundance estimate was computed using Chapman's modification of the Petersen estimator (Seber 1982, Appendix A3).

Length Compositions

The occurrence of size selectivity was examined using K-S tests (Appendix A1). If size selectivity was present, abundance estimates were adjusted by summing independent stratum abundance estimates for each length category and then dividing by the summed abundances for all categories (Appendix A4).

RESULTS

Summary of Burbot Captured

A total of 1,110 burbot were captured during this project, of which 377 were partially recruited and 733 were fully recruited to the gear (Table 2). During the first event, 447 fully recruited burbot were captured and released; while during the second event, 286 fully recruited burbot were captured and examined. Of the 286 burbot examined during the second event, 57 had been marked during the first event, and 6 of these had lost their tag (10%). Overall mean length of captured, fully recruited burbot was 538 (SE = 3.1) mm TL for the first event and 523 (SE = 3.3) mm TL for the second event (Table 2).

CPUE

Because it takes 2-3 weeks for burbot to fully recover from effects of capture and handling (Bernard et al. 1993), only the first pass down the lake of each sampling event was used as an index for future comparisons. During the first event, the first pass yielded a mean CPUE of 0.194 (SE = 0.048) for partially and 1.170 (SE = 0.187) for fully recruited burbot (Table 3). During the second event, the first yielded a mean CPUE of 0.837 (SE = 0.143) for partially recruited burbot and 0.884 (SE = 0.126) for fully recruited burbot. In both events, the second pass resulted in slightly higher mean CPUE for fully recruited burbot than the first pass (Table 3). Generally, CPUE was higher in deeper water sets for both events (Appendix B1 and B2).

Length Composition

K-S test results indicated that size selectivity occurred during the first sampling event, but not during the second event. Therefore, only lengths from the second event were used to estimate length composition of the population. The two largest 50-mm length categories, 500-549 and 450-400 mm TL, represented 77% of the population being estimated (Figure 4).

Abundance

K-S tests indicated that size stratification was not necessary for fully recruited burbot (Case II; Appendix A1). While length distribution was different between marked and captured burbot during the first event (P-value = 0.02; D-statistic = 0.12), it was not different between marked and recaptured burbot during the second event (P-value = 0.29; D-statistic = 0.13; Figure 5).

Consistency tests indicated that geographic stratification was not necessary. Using the seven original equal sized strata (Figure 3), the probabilities of capture during both the first (P-value = 0.25; Table 4) and the second event (P-value = 0.65) were equal (Table 5). The complete mixing test (Table 6) did not have sufficient numbers of recaptured burbot in each cell to provide meaningful statistical results, but substantial movement among the seven sections was observed. Only 11% of recaptured burbot stayed in the same section in which they were marked, while 60% of recaptured burbot moved across two or more section boundaries and 30% moved across five or more section boundaries. The complete mixing test was not needed to address Assumption 2 because probabilities of capture were equal during both events. Other stratification schemes, in which strata

were combined, were tested and all schemes (for example, three strata) yielded equal probabilities of capture for both events. Furthermore, burbot movement was also graphically examined in relation to depth (Figure 6). Changes in depth between time of initial capture and recapture of individual burbot suggest that substantial mixing across the water column occurred.

The estimated abundance of burbot ≥ 450 mm TL in Tanada Lake was 2,217 individuals (SE = 241; 90% CI = 1,821-2,613). The relative precision of this estimate was 18%, which exceeded our initial objective of 25%.

Limnological Sampling

Monthly measurements (1.0 m depth increments) of water temperature (°C), conductivity (µS/cm), dissolved oxygen (DO) and pH were made in both Tanada and Copper Lakes. However, we have only included data for Tanada Lake in this report (Appendix C). Based on the 28 June limnological sampling, temperature stratification had not occurred during the spring sampling event; however, based on the results of the 8 September limnological sampling, the lake was stratified four days prior to the commencing of the fall sampling.

DISCUSSION

The study design we chose for estimating the abundance of adult burbot in Tanada Lake appears to have been appropriate to produce an unbiased estimate with a high relative precision. Because of this result, we plan to use a similar study design, with two "passes" during the first event and possibly for the second event, to estimate adult burbot abundance in Copper Lake during 2008.

The abundance of fully-recruited burbot in Tanada lakes appeared to be sound. The density of fully-recruited burbot was approximately 2.0 burbot/ha. This is well above recent estimated densities at Crosswind Lake (1.1 and 0.9 burbot/ha in 2006 and 2007 respectively), slightly above a 2002 density estimate of 1.6 burbot/ha at Susitna Lake and well above the estimated density of 0.7 burbot/ha at Lake Louise in 2005 (Schwanke and Perry-Plake 2007; Schwanke *in Prep*). Density estimates at Tolsona Lake, a shallow highly productive lake, have ranged from 5-11 burbot/ha from 2002 to 2006.

The burbot population ≥ 450 mm TL in Tanada Lake appeared healthy, although length frequency distributions showed an unexpected large proportion of burbot less than 550 mm TL (approximately 77% of the estimated population). Statewide harvest reports do not indicate that Tanada Lake was ever overexploited, so it is likely that the lack of larger sized burbot in the population is natural. Tanada Lake is covered with ice up to nine months each year, so burbot may grow slowly and not typically reach large sizes. It is

also possible that the experiment was conducted during a time when the strongest cohorts were smaller sized burbot.

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FIGURES

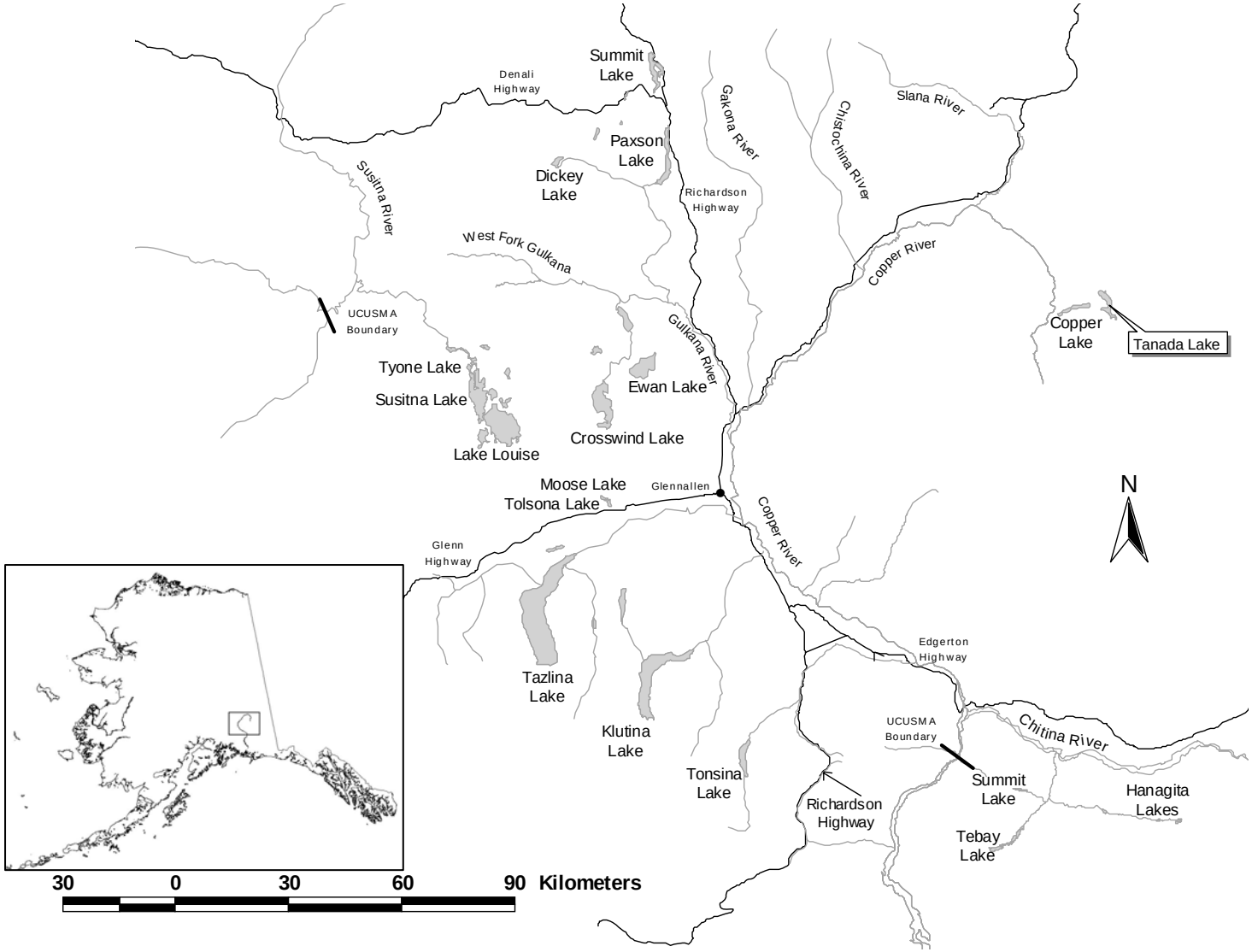


Figure 1.–Location of Tanada Lake in the Upper Copper/Upper Susitna Management Area (UCUSMA).

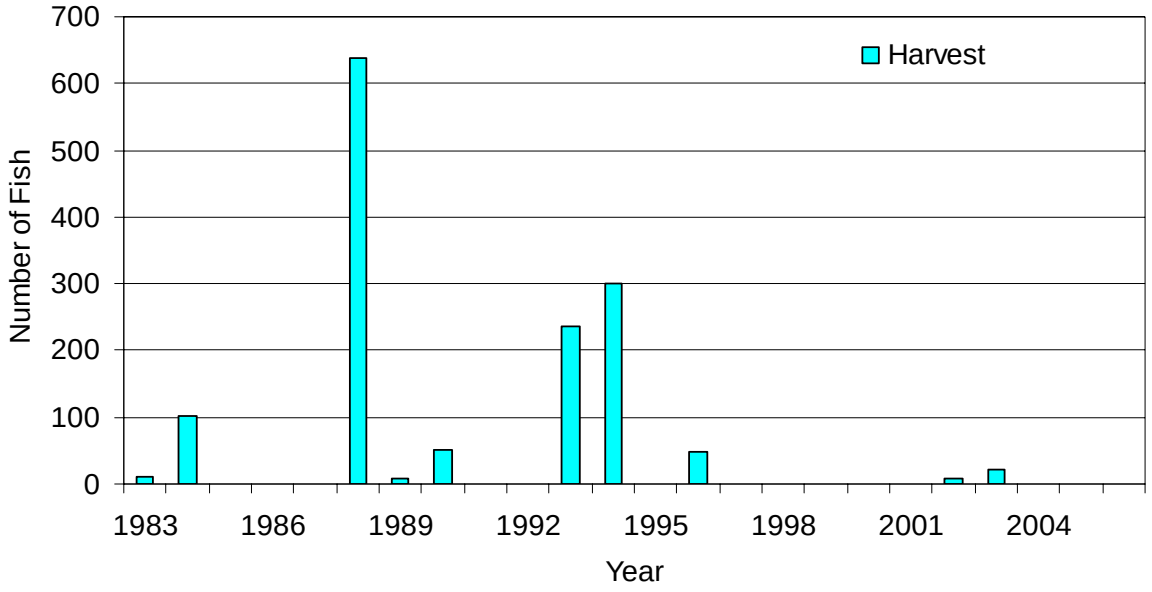


Figure 2.–Estimated harvest of burbot from Tanada Lake (data from Mills 1985-1994; Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2004, 2006a-b, 2007, *In press*; and Walker et al. 2003).

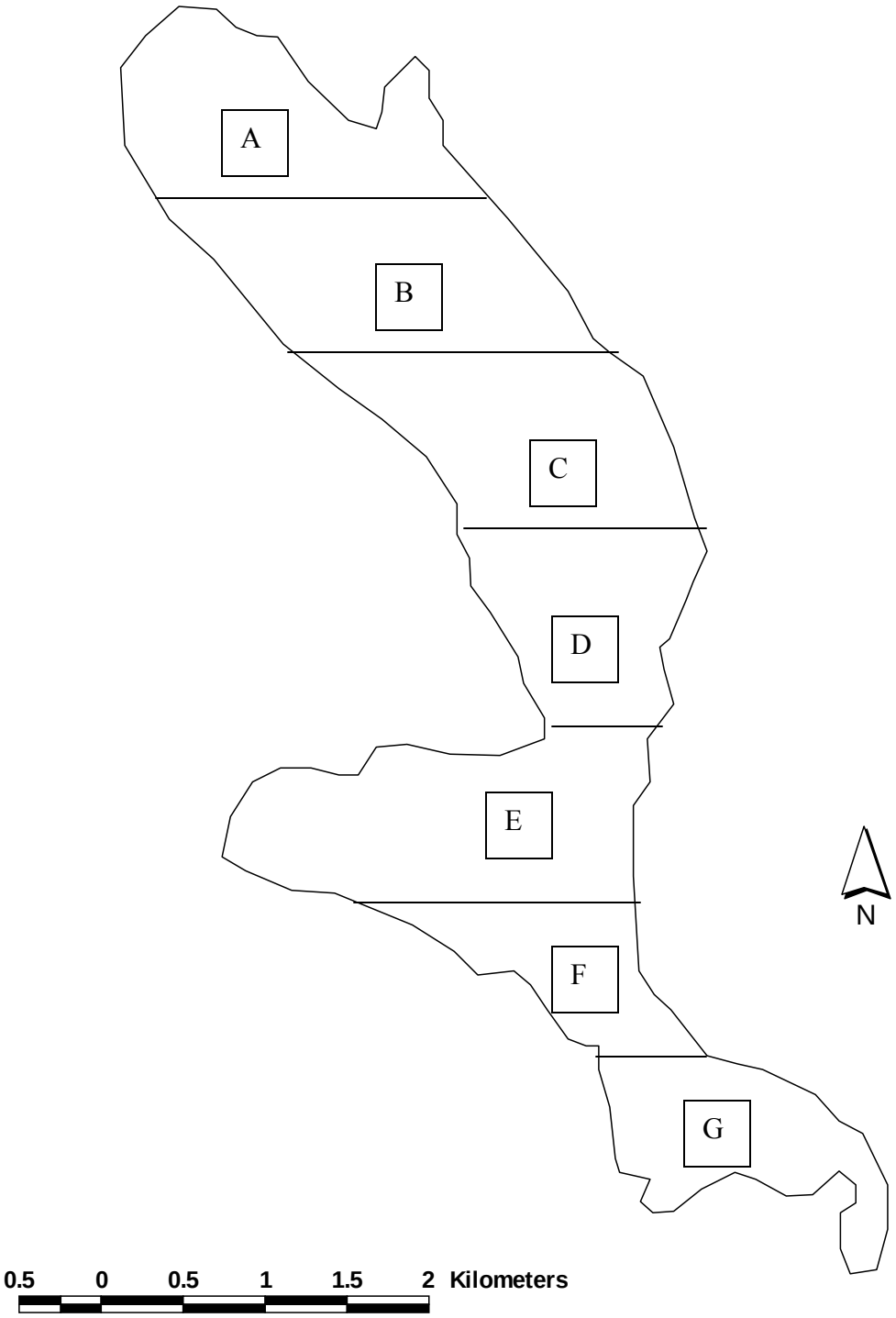


Figure 3.–Map of Tanada Lake with section boundaries.

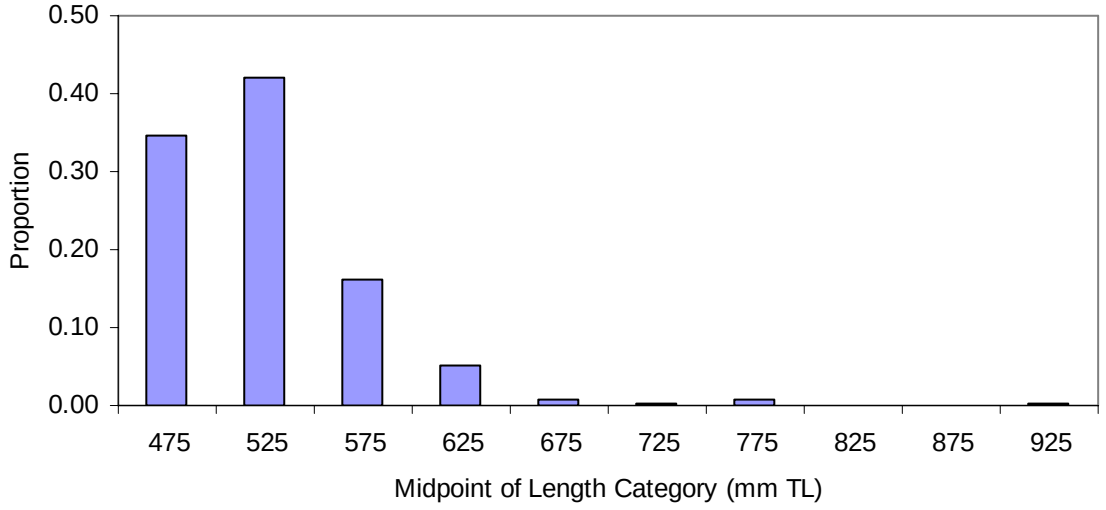


Figure 4.–Estimated length frequency of fully recruited burbot in Tanada Lake, 2007.

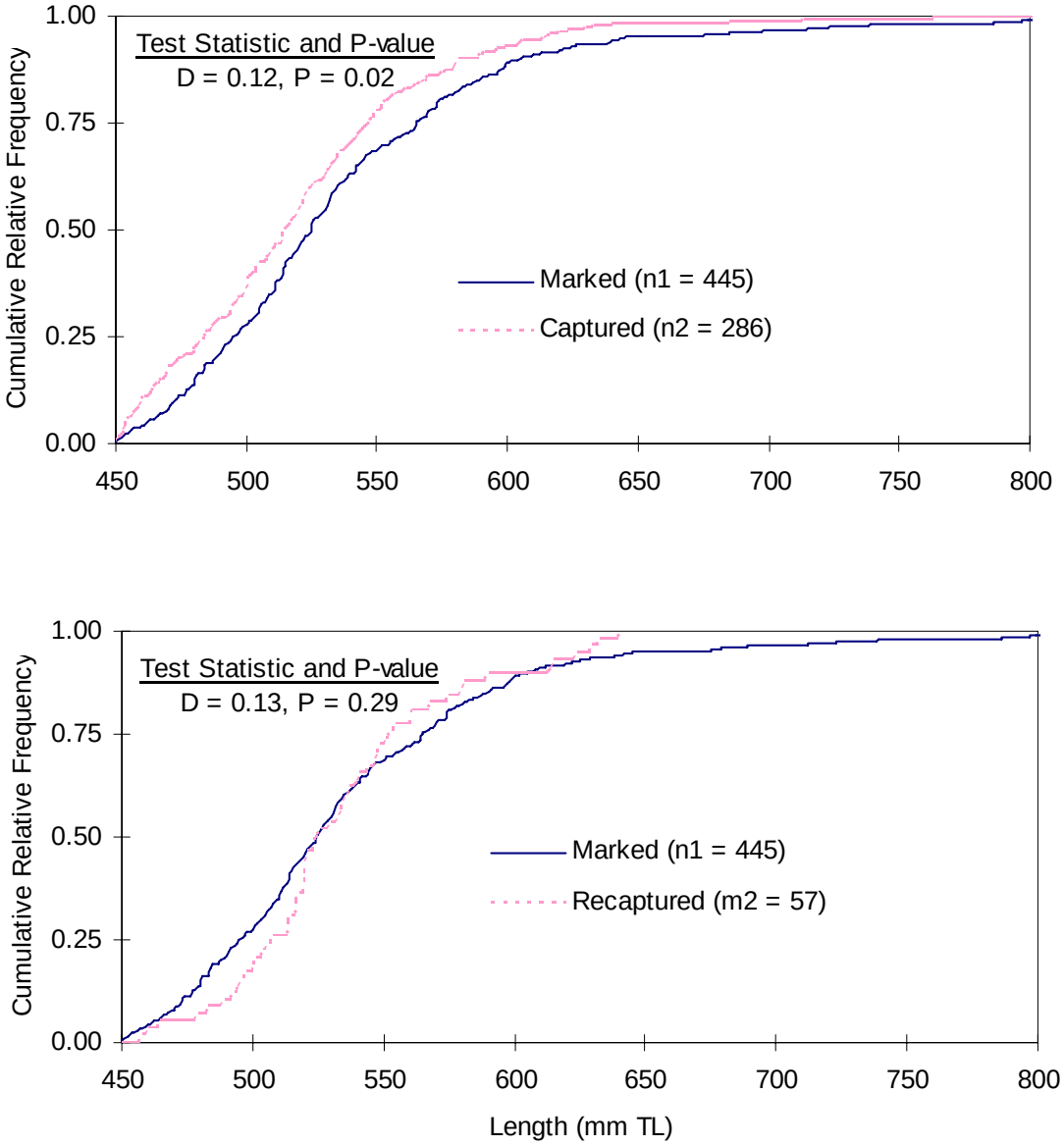


Figure 5.-Cumulative relative frequency distributions of fully recruited burbot, Tanada Lake, 2007.

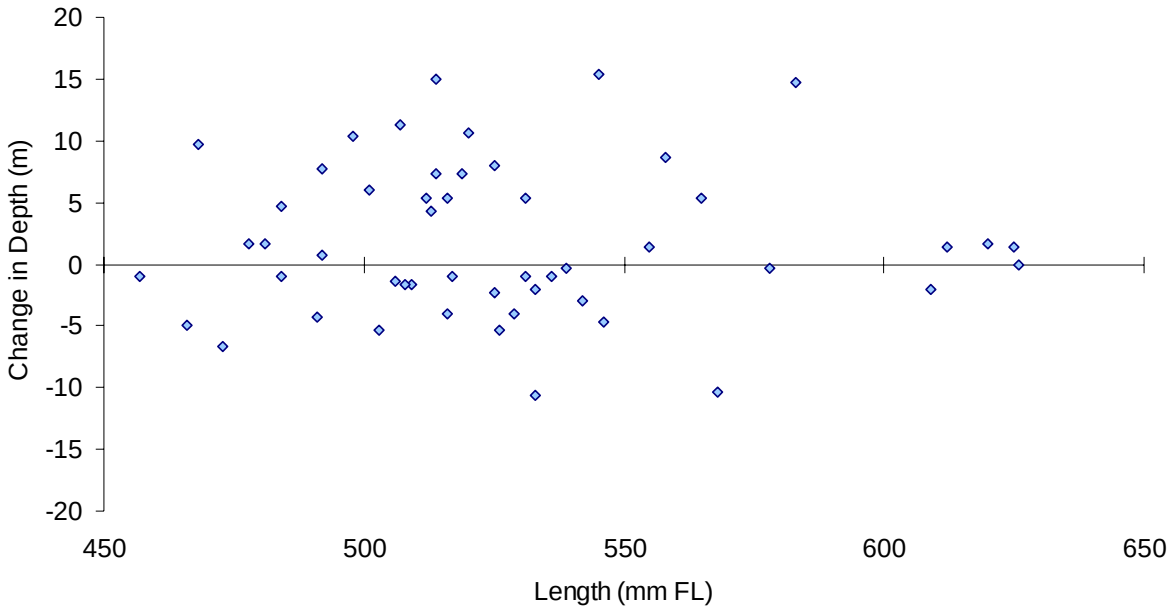


Figure 6.-Change in depth (m) of recaptured burbot from the time of first capture (spring) to the time of second capture (fall), Tanada Lake, 2007.

TABLES

Table 1.–Number of sets and dates of sampling events for the stock assessment of burbot in Tanada Lake, 2007.

Lake	Year – Event – Pass #	Dates of Sampling Events	Number of Sets
Tanada	2007 - Spring - Pass 1	6/25 – 6/30	200
	2007 - Spring - Pass 2	6/28 – 7/06	188
	2007 - Fall – Pass 1	9/12 – 9/17	218
	2007 - Fall – Pass 2	9/16 – 9/19	115

Table 2.–Mean length (mm TL) of burbot measured during both sampling events at Tanada Lake, 2007.

Lake	Dates	Statistic	Partially Recruited[a]	Fully Recruited	All
Tanada	6/25 – 7/06	Mean	391	538	510
		SE	4.5	3.1	3.6
		Sample size	104	447	549
	9/12 – 9/19	Mean	383	523	454
		SE	2.6	3.3	3.6
		Sample size	273	286	561

[a] Burbot partially recruited to the gear are < 450 mm TL and fully recruited burbot are ≥ 450 mm TL.

Table 3.–Hoop trap and catch information for burbot from Tanada Lake, 2007.

Lakes and Dates	Strata	Sets	Tran-sects	Mean CPUE			Bootstrapped	
				Bootstrapped	Arithmetic	%Δ	SE	CV
Tanada (Pass 1) 6/25 – 6/30, 2007	< 15 m	200	55					
	Fully Recruited:			1.170	1.165	0.4%	0.187	16.0%
	Partially Recruited:			0.194	0.195	-0.3%	0.048	24.6%
Tanada (Pass 2) 6/28 – 7/6, 2007	< 15 m	188	54					
	Fully Recruited:			1.238	1.228	0.8%	0.201	17.7%
	Partially Recruited:			0.401	0.399	0.5%	0.086	24.7%
Tanada (Pass 1) 9/12 – 9/17, 2007	< 15 m	218	73					
	Fully Recruited:			0.884	0.875	1.0%	0.126	14.2%
	Partially Recruited:			0.837	0.833	0.5%	0.143	17.0%
Tanada (Pass 2) 9/16 – 9/19, 2007	< 15 m	115	37					
	Fully Recruited:			0.983	0.973	1.0%	0.176	17.9%
	Partially Recruited:			0.908	0.902	0.7%	0.223	24.6%

Table 4.–Test for equal probability of capture during the first event for burbot ≥ 450 mm TL. Number of marked and unmarked burbot examined during the second event by section (A-G) of Tanada Lake, 2007.

Category	Section Where Examined							All Sections
	A	B	C	D	E	F	G	
Marked (m_2)	12	13	4	5	5	10	8	57
Unmarked (n_2-m_2)	25	36	13	33	22	55	45	229
Examined (n_2)	37	49	17	38	27	65	53	286
$P_{capture}$ 1st event (m_2/n_2)	0.32	0.27	0.24	0.13	0.19	0.15	0.15	0.20

$\chi^2 = 7.84$, df = 6, P-value = 0.25, fail to reject H_0.

Table 5.–Test for equal probability of capture during the second event for burbot ≥ 450 mm TL. Number of burbot marked by section (A-G) during the first event that were recaptured and not recaptured during the second event, Tanada Lake, 2007.

Category	Section Where Marked							All Sections
	A	B	C	D	E	F	G	
Recaptured (m_2)	7	13	0	7	2	15	7	51
Not Recaptured (n_1-m_2)	70	87	10	42	37	103	47	396
Marked (n_1)	77	100	10	49	39	118	54	447
$P_{capture}$ 2nd event (m_2/n_1)	0.09	0.13	0.00	0.14	0.05	0.13	0.13	0.11

$\chi^2 = 4.19$, df = 4, P-value = 0.65, fail to reject H_0.

[a] Fifty-seven burbot ≥ 450 mm TL were recaptured, but six had experienced tag loss and could not be assigned a section where marked.

Table 6.–Test for complete mixing. Number of burbot ≥ 450 mm TL marked in each section (A-G) and recaptured or not recaptured in each section of Tanada Lake, 2007.

Section Where Marked	Section Where Recaptured							Not Recaptured	Total Marked
	A	B	C	D	E	F	G	(n_1-m_2)	(n_1)
A	**0**	0	0	2	0	5	0	70	77
B	3	**5**	1	0	1	1	2	87	100
C	0	0	**0**	0	0	0	0	10	10
D	1	2	1	**0**	1	2	0	42	49
E	0	0	0	0	**0**	1	1	37	39
F	4	2	1	1	3	**0**	4	103	118
G	1	3	1	1	0	0	**1**	47	54
Total	9	12	4	4	5	9	8	396	447

APPENDIX A

METHODS FOR TESTING ASSUMPTIONS OF THE PETERSEN ESTIMATOR AND ESTIMATING ABUNDANCE AND LENGTH COMPOSITION

Appendix A1.-Methodologies for alleviating bias due to size selectivity.

	Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]		
	Fail to reject H_o	Fail to reject H_o
	Inferred cause: There is no size-selectivity during either sampling event.	
Case II[d]		
	Fail to reject H_o	Reject H_o
	Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event.	
Case III[e]		
	Reject H_o	Fail to reject H_o
	Inferred cause: There is size-selectivity during both sampling events.	
Case IV[f]		
	Reject H_o	Reject H_o
	Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

[a] The first Kolmogorov-Smirnov (K-S) test is on the lengths of burbot marked during the first event versus the lengths of burbot recaptured during the second event. H_o for this test is: The distribution of lengths of burbot sampled during the first event is the same as the distribution of lengths of burbot recaptured during the second event.

[b] The second K-S test is on the lengths of burbot marked during the first event versus the lengths of burbot captured during the second event. H_o for this test is: The distribution of lengths of burbot sampled during the first event is the same as the distribution of lengths of burbot sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Estimate length and age distributions from second event and adjust these estimates 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 burbot mix completely with unmarked burbot between events;
2. Every burbot has an equal probability of being captured and marked during event 1; or,
3. Every burbot 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[a]

Section Where Marked	Section Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	(n_1-m_2)
1					
2					
…					
s					

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

	Section Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked (n_2-m_2)				

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

	Section Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from section i (i = 1, 2, ...s) to section j (j = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

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

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among the river sections: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a burbot in section j during the second event, and d is a constant.

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):

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

From Appendix B1, Case II was found through inference testing and occurs when there is size selectivity during the first event, but not for the second event. To adjust estimates, the proportion of burbot in a length category (50 mm TL) were calculated by summing independent stratum abundance estimates for the length category and then dividing by the summed abundances for all categories (i.e., total abundance). First the conditional proportions from the sample were calculated:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{A4-1}$$

where:

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

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

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

The variance of this proportion was estimated as (from Cochran 1977):

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1-\hat{p}_{jk}\right)}{n_j - 1}. \tag{A4-2}$$

The estimated abundance of burbot in length category k in the population was then:

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk}\hat{N}_j \tag{A4-3}$$

where:

$\hat{N}_j$ = the estimated abundance in size stratum j; and,

s = the number of size strata.

The variance for $\hat{N}_k$ in this case was estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s}\left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right]\right). \tag{A4-4}$$

The estimated proportion of the population in length category k $\left(\hat{p}_k\right)$ was then:

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \tag{A4-5}$$

where: $\hat{N} = \sum_{j=1}^{s} \hat{N}_j$.

Variance of the estimated proportion was approximated with the delta method (Seber 1982):

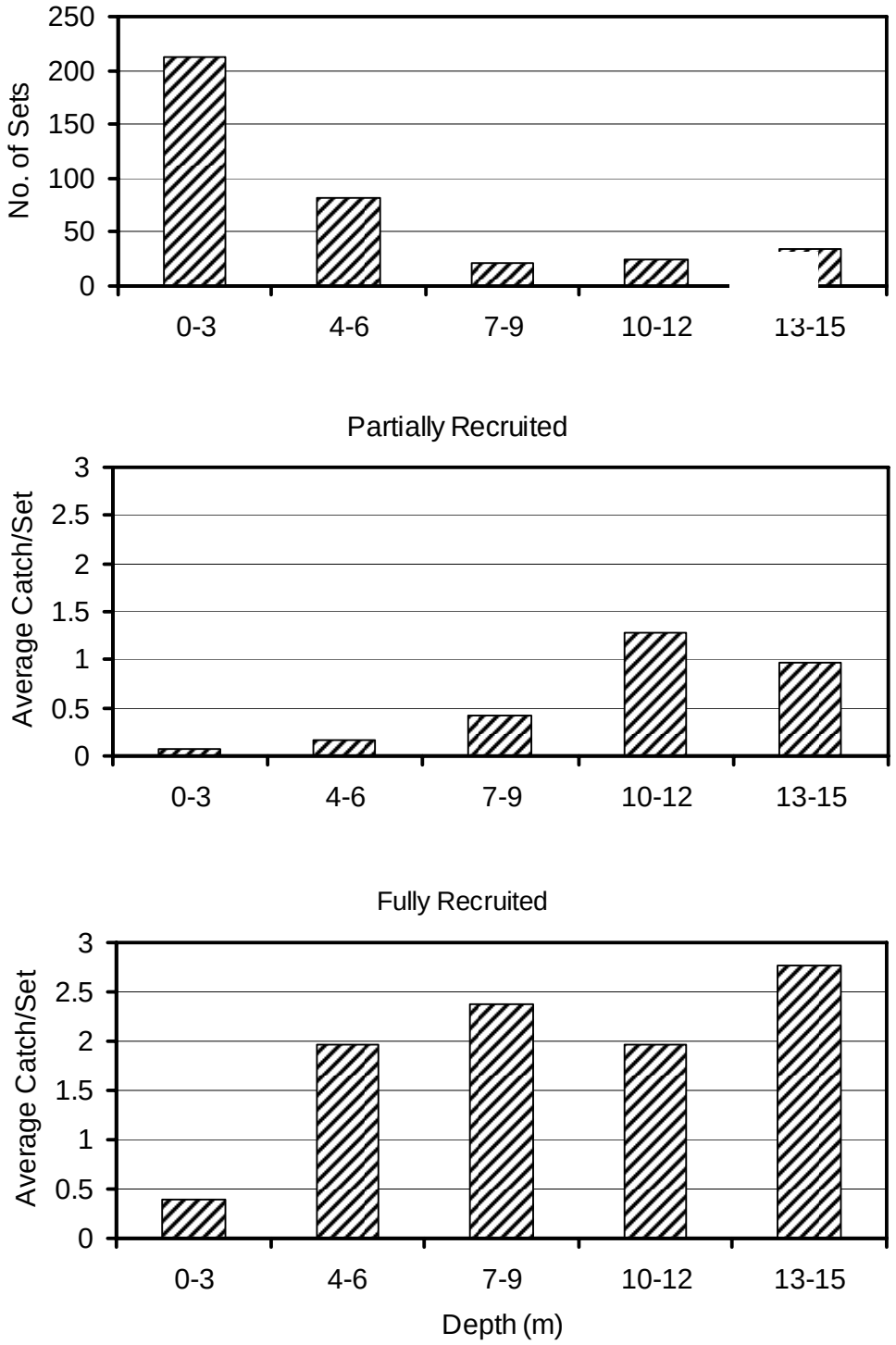
$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s}\left\{\left(\frac{\hat{N}_j}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{jk}\right]\right\} + \frac{\sum_{j=1}^{s}\left\{\hat{V}\left[\hat{N}_j\right]\left(\hat{p}_{jk} - \hat{p}_k\right)^2\right\}}{\hat{N}^2}. \tag{A4-6}$$

Length composition of burbot ≥ 450 mm TL was broken down into 50-mm FL categories.

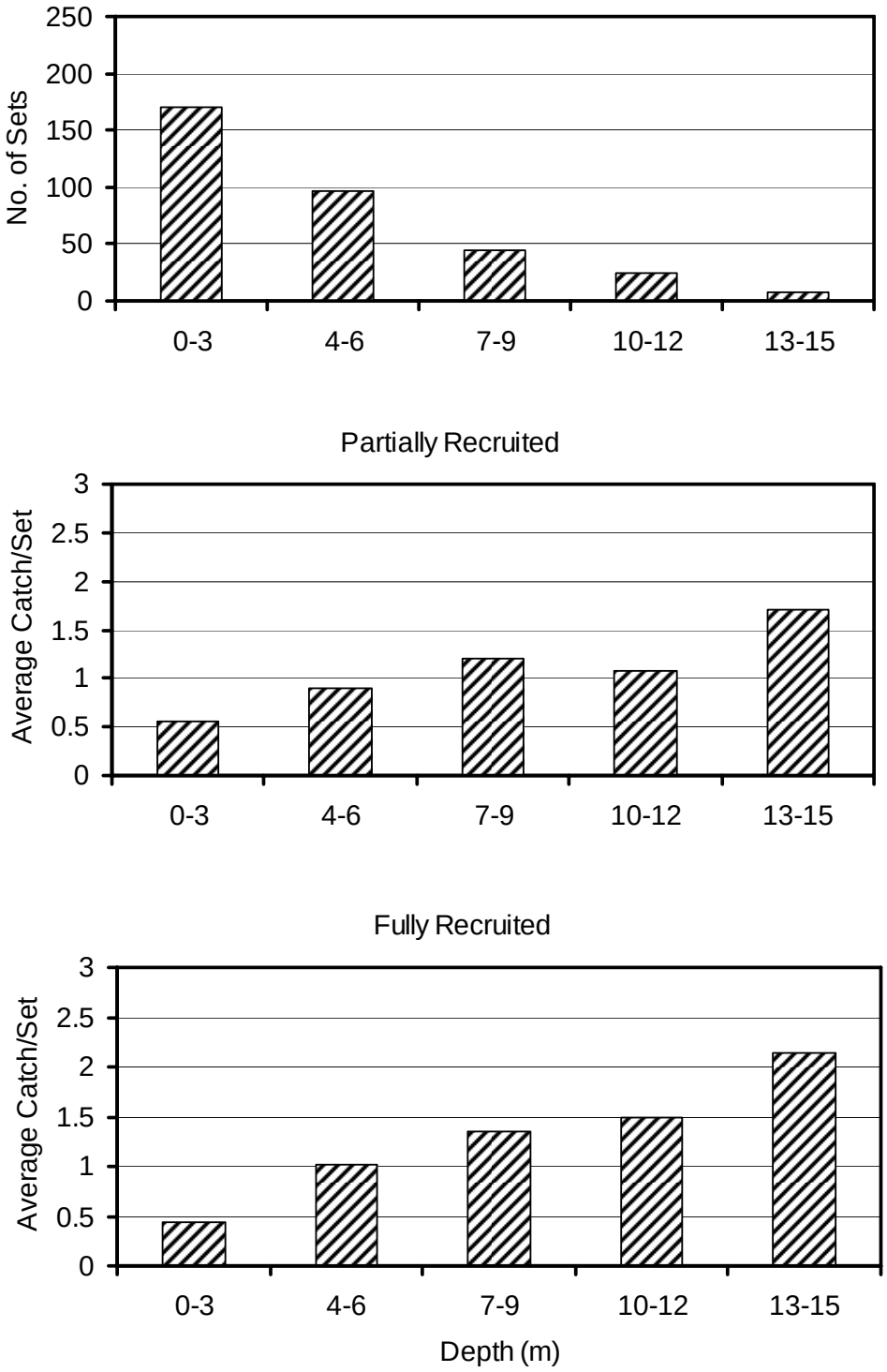
APPENDIX B

HOOP TRAP CATCH INFORMATION

Appendix B1.-Burbot catch information for hoop trap sets in spring, Tanada Lake, 2007.



Appendix B2.-Burbot catch information for hoop trap sets in fall, Tanada Lake, 2007.



APPENDIX C

LIMNOLOGICAL INFORMATION

Appendix C1.-Limonlogical data collected on 5 May 2007, Tanada Lake (62.4219° N, 143.3740° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	0.10	0.134	12.03	7.53
1	0.20	0.140	11.92	7.59
2	1.05	0.149	11.57	7.64
3	1.10	0.148	11.21	7.68
4	1.09	0.149	11.57	7.71
5	1.08	0.149	11.57	7.75
6	1.08	0.149	11.64	7.75
7	1.08	0.149	11.58	7.76
8	1.08	0.148	11.47	7.75
9	1.08	0.148	11.49	7.75
10	1.12	0.148	11.01	7.73
11	1.08	0.148	11.34	7.73
12	1.08	0.149	11.20	7.71
13	1.08	0.149	10.82	7.72
14	1.07	0.148	10.81	7.72
15	1.07	0.148	11.02	7.73
16	1.07	0.148	10.99	7.74
17	1.07	0.148	11.04	7.75
18	1.07	0.148	11.11	7.74
19	1.07	0.148	11.07	7.75
20	1.07	0.148	11.13	7.74
21	1.07	0.148	11.23	7.74
22	1.07	0.148	10.96	7.77
23	1.07	0.148	11.11	7.76
24	1.07	0.148	11.22	7.76
25	1.07	0.148	11.07	7.76
26	1.07	0.148	10.93	7.76
27	1.07	0.148	11.06	7.76
28	1.07	0.148	11.15	7.76
29	1.07	0.148	11.04	7.75
30	1.07	0.148	11.10	7.74
31	1.08	0.148	11.17	7.74
32	1.09	0.148	11.21	7.76
33	1.11	0.147	11.04	7.76
34	1.12	0.147	11.32	7.77
35	1.12	0.147	11.48	7.77
36	1.13	0.147	11.46	7.77
37	1.13	0.147	11.40	7.78
38	1.13	0.147	11.35	7.79
39	1.14	0.147	11.47	7.79
40	1.14	0.147	11.50	7.79
41	1.14	0.147	11.25	7.79
42	1.14	0.147	11.59	7.79
43	1.14	0.147	11.49	7.79
44	1.14	0.147	11.50	7.79
45	1.14	0.146	11.43	7.79
46	1.15	0.146	11.48	7.80
47	1.14	0.148	11.40	7.82
48	1.15	0.149	11.31	7.84
49	1.16	0.149	7.97	7.68

Appendix C2.-Limonlogical data collected on 28 June 2007, Tanada Lake (62.4219° N, 143.3740° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	9.59	0.135	12.86	8.24
1	3.72	0.138	14.11	8.03
2	3.71	0.139	13.66	8.09
3	3.74	0.138	13.58	8.11
4	3.67	0.138	13.50	8.14
5	3.64	0.139	13.37	8.14
6	3.64	0.139	13.24	8.14
7	3.63	0.139	13.14	8.15
8	3.62	0.139	13.10	8.15
9	3.63	0.138	13.09	8.15
10	3.65	0.139	13.09	8.15
11	3.62	0.138	13.05	8.15
12	3.63	0.138	13.03	8.15
13	3.66	0.138	13.02	8.15
14	3.67	0.138	13.06	8.16
15	3.68	0.138	13.09	8.15
16	3.64	0.138	13.07	8.15
17	3.66	0.138	13.05	8.15
18	3.67	0.138	13.06	8.14
19	3.66	0.138	13.04	8.14
20	3.68	0.138	13.05	8.13
21	3.67	0.138	13.03	8.13
22	3.63	0.137	12.98	8.12
23	3.63	0.138	12.95	8.11
24	3.62	0.138	12.95	8.10
25	3.63	0.138	12.88	8.10
26	3.63	0.138	12.90	8.10
27	3.66	0.138	12.95	8.09
28	3.66	0.138	12.93	8.09
29	3.66	0.137	12.92	8.09
30	3.67	0.138	12.93	8.08
31	3.66	0.138	12.92	8.08
32	3.67	0.137	12.90	8.07
33	3.67	0.138	12.89	8.05
34	3.66	0.137	12.90	8.07
35	3.66	0.137	12.92	8.06
36	3.67	0.137	12.88	8.06
37	3.66	0.137	12.88	8.06
38	3.66	0.137	12.88	8.06
39	3.66	0.137	12.89	8.05
40	3.67	0.137	12.90	8.05
41	3.67	0.137	12.89	8.06
42	3.67	0.137	12.89	8.05
43	3.67	0.137	12.93	8.05
44	3.66	0.137	12.90	8.04
45	3.66	0.137	12.88	8.04

Appendix C3.-Limonlogical data collected on 30 July 2007, Tanada Lake (62.4219° N, 143.3740° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	16.03	0.128	9.63	8.00
1	14.14	0.128	9.99	8.02
2	14.15	0.128	10.00	7.98
3	13.08	0.129	10.30	8.04
4	12.61	0.129	10.46	8.02
5	10.69	0.129	10.87	8.00
6	8.15	0.132	7.89	7.87
7	7.68	0.132	11.13	7.78
8	5.83	0.133	11.12	7.69
9	8.22	0.134	11.01	7.56
10	4.42	0.135	10.94	7.51
11	4.34	0.137	11.02	7.48
12	4.11	0.137	11.00	7.44
13	4.02	0.137	10.99	7.45
14	3.43	0.137	10.99	7.43
15	3.41	0.137	10.97	7.42
16	3.42	0.137	10.96	7.41
17	3.41	0.137	10.95	7.41
18	3.40	0.138	10.98	7.40
19	3.43	0.137	10.92	7.40
20	3.44	0.137	10.93	7.39
21	3.45	0.137	10.91	7.38
22	4.03	0.137	10.86	7.38
23	4.07	0.137	10.78	7.36
24	4.10	0.137	10.60	7.36
25	4.10	0.137	10.64	7.33
26	4.10	0.137	10.57	7.34
27	4.12	0.137	10.56	7.33
28	4.12	0.137	10.52	7.31
29	4.10	0.138	10.47	7.31
30	4.10	0.137	10.40	7.29
31	4.04	0.138	10.37	7.28
32	4.10	0.137	10.43	7.27
33	4.10	0.137	10.47	7.28
34	4.10	0.137	10.41	7.26
35	4.10	0.137	10.41	7.26
36	4.08	0.137	10.32	7.26
37	4.10	0.137	10.29	7.25
38	4.06	0.136	9.78	7.23
39	4.05	0.137	9.35	7.04

Appendix C4.-Limonlogical data collected on 7 September 2007, Tanada Lake (62.4219° N, 143.3740° W).

Depth (m)	Temperature (°C)	Specific Conductance (µS/cm)	Dissolved Oxygen (mg/L)	pH
0	12.27	0.130	11.02	8.91
1	12.00	0.130	10.80	8.88
2	11.85	0.131	10.80	8.80
3	11.78	0.130	10.80	8.84
4	11.67	0.130	10.76	8.81
5	11.59	0.131	10.45	8.78
6	11.51	0.130	10.59	8.77
7	11.41	0.131	10.56	8.70
8	11.23	0.133	10.53	7.62
9	9.69	0.135	10.24	7.05
10	8.21	0.135	10.00	7.72
11	6.81	0.135	10.07	7.67
12	5.22	0.136	10.16	7.64
13	4.60	0.136	10.18	7.60
14	4.40	0.137	10.10	7.56
15	4.31	0.137	10.08	7.55
16	4.24	0.137	10.03	7.53
17	4.20	0.137	10.04	7.51
18	4.13	0.137	10.08	7.51
19	4.07	0.137	10.17	7.51
20	4.06	0.137	10.19	7.50
21	4.06	0.137	10.18	7.49
22	4.06	0.137	10.20	7.50
23	4.06	0.137	10.16	7.46
24	4.06	0.137	10.13	7.48
25	4.04	0.137	10.07	7.46
26	4.10	0.137	10.02	7.45
27	4.08	0.137	9.88	7.44
28	4.09	0.137	9.82	7.43
29	4.04	0.137	9.78	7.42
30	4.09	0.137	9.66	7.40
31	4.09	0.137	9.63	7.39
32	4.10	0.137	9.53	7.38
33	4.09	0.137	9.50	7.37
34	4.10	0.137	9.46	7.37
35	4.09	0.137	9.45	7.35
36	4.09	0.137	9.44	7.35
37	4.07	0.137	9.24	7.34
38	4.07	0.137	9.08	7.32
39	4.07	0.137	8.99	7.31
40	4.08	0.137	8.94	7.30
41	4.06	0.137	8.75	7.29
42	4.05	0.137	8.54	7.27
43	4.04	0.137	8.35	7.26
44	4.02	0.138		7.26

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