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Stock Assessment and Biological Characteristics of Burbot in Crosswind and Tolsona Lakes, 2006 and 2007

by

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December 2009

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat. or long.
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Measures (fisheries)

fork length	FL
mideye-to-fork	MEF
mideye-to-tail-fork	METF
standard length	SL
total length	TL

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

FISHERY DATA REPORT NO. 09-64

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ABSTRACT

Stock assessments of burbot *Lota lota* were conducted at Tolsona and Crosswind lakes in 2006 and 2007 to estimate CPUE, abundance and length composition. In both lakes baited hoop traps were systematically set along transects to sample fish. Abundance was only estimated for burbot ≥450 mm TL, the size at which they were considered fully recruited to the gear. In Tolsona Lake, sampling was conducted annually each spring shortly after ice out and abundance for 2005 and 2006 was estimated using the Jolly-Seber estimator, while abundance for 2007 was estimated using CPUE expansion. Mean CPUE of fully recruited burbot (≥450 mm TL) per 48-h set at Tolsona Lake was 4.25 (SE = 0.72) in 2007 and 4.28 (SE = 0.67) in 2008. Abundance of fully recruited burbot at Tolsona Lake was estimated at 1,145 (90% CI = 757–1,533) in 2005, 1,322 (90% CI = 862–1,784) in 2006, and 1,077 (90% CI = 437–1,717) in 2007. The length frequency distribution of all captured burbot in 2007 at Tolsona Lake was bimodal with modes occurring at the 400–449 mm length class and the 550–599 mm length class. In Crosswind Lake, a pair of two-event Petersen mark-recapture experiments was conducted, one in 2006 and one in 2007. For both experiments, the first event took place in early June and the second event took place in mid-September. Mean CPUE of fully recruited burbot at Crosswind Lake was 0.50 (SE = 0.11) in spring 2006, 0.45 (SE = 0.08) in fall 2006, 0.52 (SE = 0.12) in spring 2007 and 0.36 (SE = 0.05) in fall 2007. Abundance of fully recruited burbot at Crosswind Lake was estimated at 3,860 (90% CI = 2,262–5,549) in 2006 and at 3,130 (90% CI = 2,170–4,091) in 2007. The predominant length class (50 mm) of burbot in Crosswind Lake was 550–599 mm TL both years.

Key words: Burbot, *Lota lota,* Jolly-Seber, abundance, length composition, catch per unit effort, CPUE, hoop traps, mean length, Tolsona Lake, Crosswind Lake.

INTRODUCTION

OVERVIEW

The lakes of the Upper Copper/Upper Susitna Management Area (UCUSMA; Figure 1) have supported the largest burbot *Lota lota* fishery in the state. Harvest was greatest during a 10-year period from 1977 to 1986, averaging over 9,000 burbot a year (Somerville and Taube 2007). The fishery peaked in 1985 with a harvest of over 19,000 burbot, which accounted for 71% of the statewide harvest (Mills 1986). Concerns for overexploitation resulted in the Alaska Department of Fish and Game (ADF&G) initiating research studies in 1986 to assess stock status and to estimate sustainable yields of burbot from Interior Alaska lakes (Lafferty et al. 1990-1992; Lafferty and Bernard 1993; Parker et al. 1987-1989; Schwanke and Bernard 2005; Schwanke and Perry-Plake 2007; Taube et al. 1994, 2000; Taube and Bernard 1995, 1999, 2001, 2004). In 1988 the Alaska Board of Fisheries adopted a management plan (5 AAC 52.045, 1989) that directs the lake burbot fisheries in the UCUSMA be managed for maximum sustained yield. The department has since managed these fisheries with daily bag limits, closures and gear restrictions. Presently, the bag and possession limit for burbot from most lakes is five (including Crosswind Lake). One lake is closed to the retention of burbot (Tolsona Lake), one lake presently has a bag and possession limit of one burbot (Lake Louise), and several road accessible lakes have bag and possession limits of two burbot (Summit, Hudson, Moose, Susitna and Tyone lakes; 5 AAC 52.022, 2002). Use of setlines as a fishing gear was prohibited by emergency order in the Tyone River drainage and at Tolsona and Moose lakes in 1989, then in all of the UCUSMA by regulation in 1991. Since 1991 annual harvests have remained relatively stable ranging between 1,000–3,000 burbot (Somerville and Taube 2007).

TOLSONA LAKE

Tolsona Lake is within the Tazlina River drainage and is a relatively small and shallow lake with a surface area of 130 ha and a maximum depth of 5 m (Figure 1). Stock assessments of burbot at

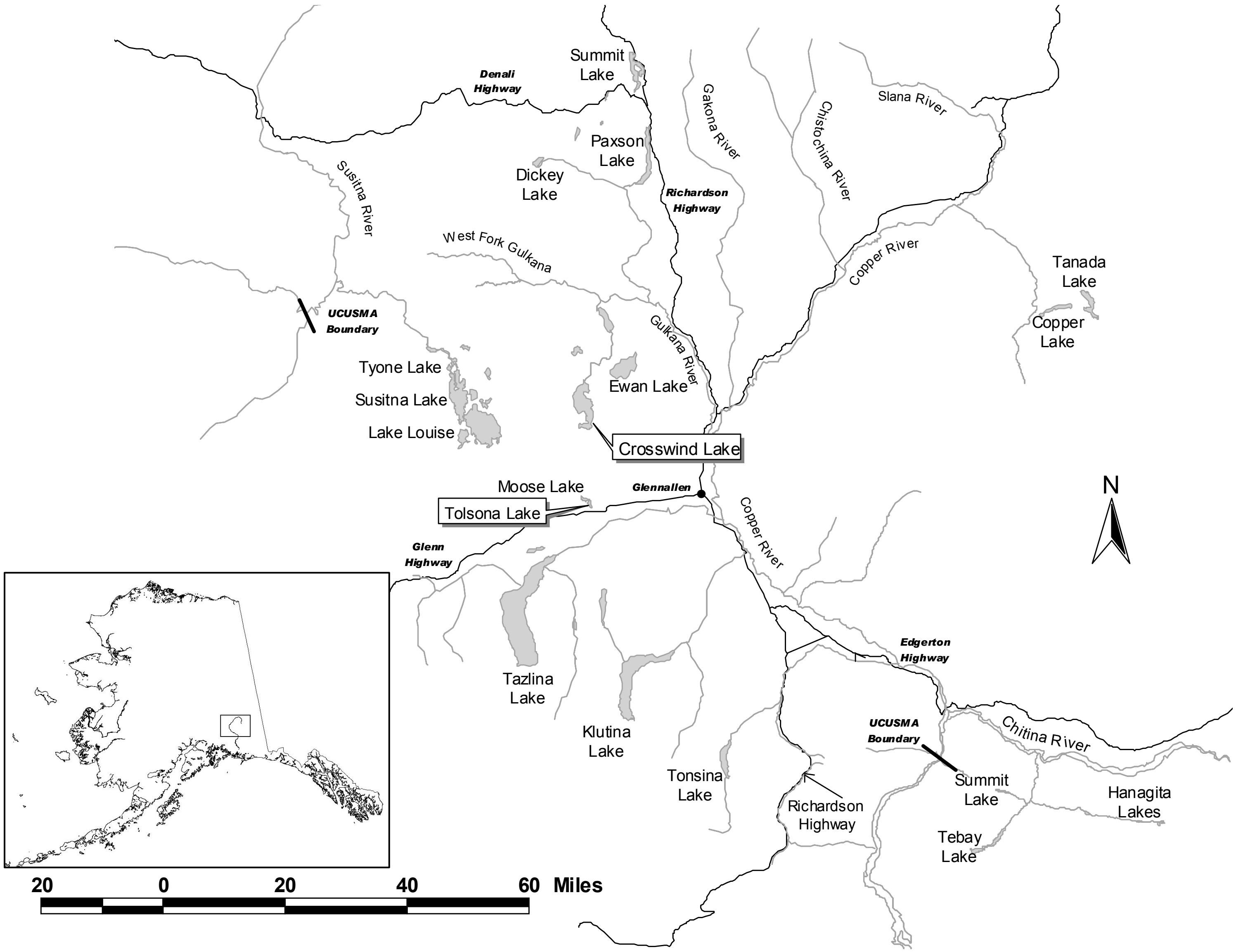

Figure 1.–Locations of Tolsona and Crosswind lakes in the Upper Copper/Upper Susitna Management Area.

Tolsona Lake have been conducted annually since 1986 (Lafferty et al. 1990-1992; Lafferty and Bernard 1993; Parker et al. 1987-1989; Schwanke and Bernard 2005; Schwanke and Perry-Plake 2007; Taube et al. 1994, 2000; Taube and Bernard 1995, 1999, 2001, 2004). These annual assessments were conducted to determine the population's status relative to prescribed management objectives. The continuous and long-term nature of this project has provided an improved understanding of the population dynamics of a burbot stock that resides in a shallow, productive lake, which is atypical for burbot within the UCUSMA. The cost of this information is low compared to other burbot lakes in the UCUSMA because Tolsona Lake is small (130 ha) and easily accessible.

Since 1986, several changes have been made to fishery regulations in Tolsona Lake, not all being exclusive to Tolsona Lake. Bag limits and the number of allowable lines were reduced from 15 to 5 in 1987. The use of setlines was prohibited by emergency order in 1989 and by regulation in 1991. In 1998 Tolsona Lake was closed to burbot fishing by emergency order because of a significant decline in burbot abundance from 1994 to 1997. Annual sampling has indicated that the population has increased from the lows experienced in 1997 (Schwanke and Perry-Plake 2007).

Since Tolsona Lake is relatively small (130 ha) and shallow (< 5 m), it frequently exceeds the preferred temperature for burbot (Scott and Crossman 1973) in summer. The lake may also be prone to reaching the lethal range for dissolved oxygen (DO) in late winter and early spring (Simpson 1997). High water temperature and low DO are suspected to be the primary factors relative to the observed variation in estimated abundance in Tolsona Lake.

CROSSWIND LAKE

Crosswind Lake is within the West Fork Gulkana River drainage and is one of the larger lakes within the UCUSMA (Figure 1). Its surface area is 3,232 ha and the lake's maximum depth is in excess of 37 m. Crosswind Lake burbot have always been managed under the general fishing regulations for the UCUSMA. The bag and possession limit was reduced from 15 to 5 burbot in 1987, and the use of setlines was banned in 1991. No regulation changes have been made for Crosswind Lake burbot since then. According the Statewide Harvest Survey, annual estimated harvests have had an increasing trend since the last regulation change took effect in 1991 (Figure 2). The highest estimated harvested of 859 burbot occurred in 2005. The ice fishery at Crosswind Lake is the most popular winter fishery in the UCUSMA (M. Somerville, Sport Fish Biologist, ADF&G, Glennallen; personal communication) and most of these burbot are probably taken through the ice.

Crosswind Lake was sampled three different times prior to 2006: 23 July–6 August 1987, 8–27 August 1987, and 23–26 July 1988 (Parker et al. 1988 and 1989). Average CPUE for fully recruited burbot (≥450 mm TL) was 0.59 (SE = 0.04), 0.30 (SE = 0.04) and 0.58 (SE = 0.09), respectively.

The increase in the popularity of the fishery as well as the increase in burbot harvest, along with the lack of information on the stock, stressed the need to assess the abundance of burbot in Crosswind Lake.

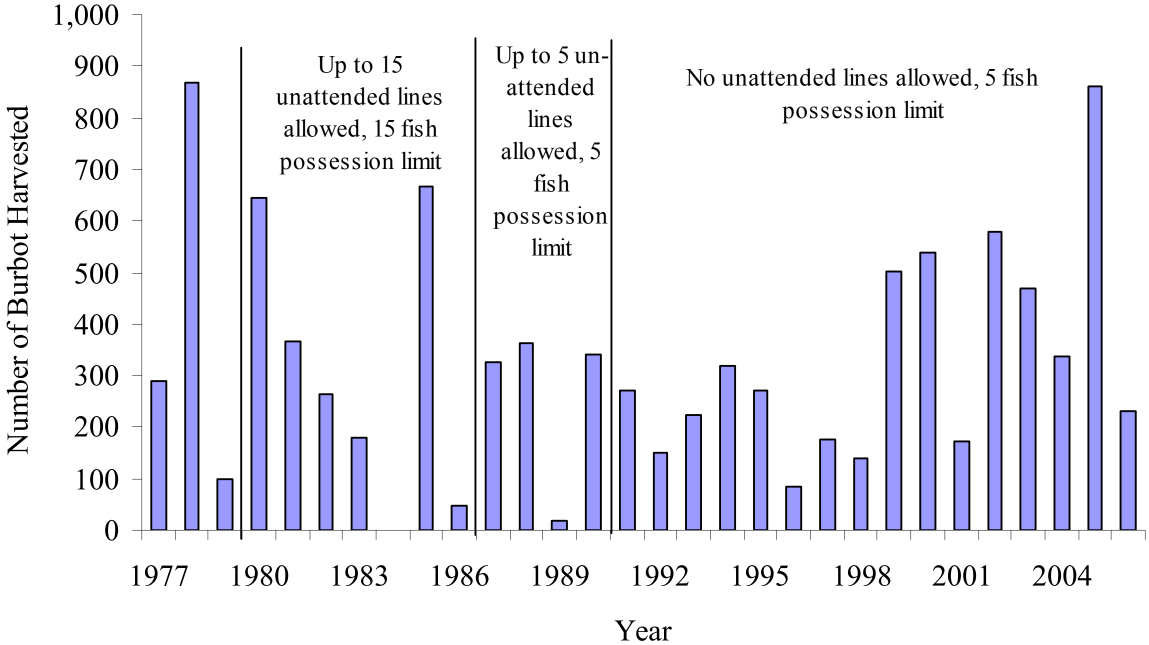

Figure 2.–Estimated harvest of burbot from Crosswind Lake (Mills 1985-1994; Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2004, 2006a-b, 2007, *in press*, *in prep*; Walker et al. 2003).

OBJECTIVES AND TASKS

Specific objectives for 2006 and 2007 were to:

1. estimate the length composition of fully recruited burbot (≥450 mm TL) at Tolsona and Crosswind lakes in 2006 and 2007 such that the estimated proportions were within 10 percentage points of the actual values 95% of the time;
2. estimate mean CPUE of burbot (≥450 mm TL) in Tolsona and Crosswind lakes for each sampling event 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 in Tolsona Lake for May 2005 and 2006 such that the estimated abundance was within 40% of the true abundance 90% of the time;
4. estimate abundance of fully recruited burbot in Tolsona Lake for May 2007 such that the estimated abundance was within 50% of the true abundance 90% of the time;
5. estimate abundance of fully recruited burbot at Crosswind Lake for the open water period 2006 and 2007 such that the estimated abundance was within 30% of the true abundance 90% of the time; and,

Project tasks for 2006 and 2007 were to:

1. measure water temperature in Tolsona Lake throughout the open water period in both years.

METHODS

Fish Capture

In both lakes, 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. Extremely large burbot (>900 mm TL) are not fully recruited to the gears (Bernard et al. 1991), but the proportion of fish >900 mm TL in both Tolsona and Crosswind lakes is negligible.

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 each lake. The number of transects selected to be set depended upon the number of traps to be set. Transects were randomly removed until the desired number of possible sets was equal to the number of sets planned to be made for that event. All transects were approximately 125 m apart, and traps along transects were set approximately 125 m apart. No traps were set deeper than 15 m in Crosswind Lake to avoid decompression-induced mortality associated with burbot captured at greater depths (Bernard et al. 1993). The maximum depth of Tolsona Lake is 5 m so no areas were precluded from sampling. Spring sampling at both lakes commenced within a few days after each lake became ice-free to maximize the catch per set and to ensure accurate CPUE comparisons with past experiments (Bernard et al. 1993). Fall sampling at Crosswind Lake took place in mid–September to take advantage of the increase in catchabilty of burbot as the water temperature cools. A set was defined as a single hoop trap baited with Pacific herring *Clupea pallasi* fished for approximately 48 h.

After lifting a hoop trap, the catch was emptied into a holding tank and all burbot were measured for total length (to the nearest 5 mm in Tolsona Lake and to the nearest 1 mm in Crosswind Lake) and examined for previous tags and secondary marks. All captured fish 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 fish that were previously tagged were still given a secondary mark for that sampling event. All tags were checked to ensure that they were locked between the pterygiophores of the dorsal fin. Fin clips varied by lake and event (Table 1). Specific secondary marks have been used with Tolsona Lake burbot in a three–year rotation to allow tag loss to be accounted for: partial excision of the right ventral fin (2005), a hole cut with a paper punch in the left operculum (2006), and a partial excision of the left ventral fin (2007). A recaptured burbot exhibiting a secondary mark(s), but missing a tag, was considered to have been last captured during the most recent year the secondary mark was used.

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 produced for archival (Appendix A) and were 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, unless the burbot was too small to tag (<300 mm TL).

Table 1.–Number of sets and dates of sampling events for stock assessments of burbot populations in Crosswind and Tolsona lakes, 2006 and 2007.

Lake	Year	Area (ha)	Dates of Sampling Events	Number of Sets	Secondary Mark
Tolsona	2006	130	5/31–6/02	60	Opercular Punch
Tolsona	2007	130	5/25–5/27	60	Left Ventral
			5/27–5/29	59	Left Ventral
Crosswind	2006	3,232	6/08–6/16	488	Left Ventral
			9/19–9/27	494	Right Ventral
Crosswind	2007	3,232	6/05–6/13	492	Left Pectoral
	2007		6/12–6/15	120[a]	Left Pectoral
	2007		9/14–9/23	522	Right Pectoral
	2007		9/21–9/24	96[a]	Right Pectoral

[a] Additional effort (used for abundance and length estimation, but not CPUE)

STUDY DESIGN

Tolsona Lake

For the last 15 years, Tolsona Lake has been sampled once a year following a protocol: set 60 traps as close to ice-out as possible and retrieve them approximately 48 hours later (Schwanke and Perry-Plake 2007). The annual data collected have been used to estimate abundance (i.e., using Jolly-Seber Model) and CPUE. This same protocol was used in 2006, but in 2007 effort was increased (Table 1). Sixty sets were still set after ice-out and were retrieved two days later. Once the last trap was pulled and the last captured fish released back into the lake, the sixty traps were reset on different transects for another two days. This doubling of effort was used to improve the precision of the Jolly-Seber estimate. The first 60 sets mimicked sampling protocol from prior years and were used to make the inter-annual comparisons of CPUE.

Abundance of fully recruited burbot in May 2005 and 2006 was estimated through sampling in May 2006 and 2007 as part of a continuing Jolly-Seber mark-recapture experiment (there is a one-year lag in abundance estimates with this model). The Jolly-Seber model was also used to estimate survival and recruitment rates for the population from May 2004 to 2005 and from May 2005 to 2006. Conditions for producing unbiased abundance, survival and recruitment estimates with the Jolly-Seber model were:

1. all burbot have the same probability of capture during each sampling event (probability of capture can vary among events) or marked burbot will completely mix with unmarked burbot between sampling events;
2. no marks were lost between sampling events;
3. marked burbot behave (enter traps) the same as unmarked burbot;
4. marked burbot have the same mortality and growth rates as unmarked burbot; and,
5. immigration and emigration is permanent.

Evaluation of Assumptions

Assumption 1: The year-long hiatus between events benefited the experiment by increasing mixing of marked and unmarked fish. Bernard et al. (1993) showed that adult burbot showed no depth preference during the open water period, that distribution across lakes was generally random (not aggregated), and that adult burbot moved rapidly and randomly across depths between surveys within the same season. They found that marked and unmarked burbot can completely mix in as little as 2–3 weeks with crude sampling densities of 0.9–3.6 ha/set. Traps at Tolsona Lake were placed approximately 125 meters apart, and a sampling density of roughly one trap per 2 ha.

The relatively uniform distribution of traps set also helped to ensure that capture probabilities did not vary geographically within an event and no fish were isolated from the experiment.

Assumption 2: This assumption was addressed by double marking each burbot with Floy tags and partial fin clips.

Assumption 3: Based on a meta-analysis from the sampling of several lakes over several years within the UCUSMA, Bernard et al. (1991 and 1993), did not find any evidence of trap-induced behavior after 2–3 weeks.

Assumption 4: Bernard et al. (1993) found that burbot captured in traps set in water depths <15 m (Tolsona Lake is <5 m deep) showed no ill effects from being sampled and no evidence was found indicating higher post sampling mortality with marked vs. unmarked burbot. There is no evidence to suggest that handling and tagging burbot affects their growth for any substantial period of time.

Assumption 5: Over 20 years there has only been one report of a tagged burbot mixing between Moose and Tolsona lakes, suggesting that immigration or emigration is a rare occurrence and is negligible even in years of high water levers. Moreover, for the last 5–7 years, the lake has virtually been landlocked, and when water does flow from the lake into Tolsona Creek, it is not passable by adult burbot.

Abundance of fully recruited burbot in May 2007 was estimated through CPUE expansion using an estimated catchability coefficient for 2007 based on a mean catchability calculated from prior years.

Water temperature was recorded hourly throughout the open water period with Hobo® Water Temp Pro[1] temperature loggers. The loggers were suspended in the water column using a rope and buoy tethered to an anchor at the deepest part of the lake (~5 m), one just off the lake bottom and the other at a depth of ~2.5 m.

Crosswind Lake

Two distinct two-event Petersen mark-recapture experiments were conducted at Crosswind Lake: one in 2006 and one in 2007. In both years, the first event took place soon after ice-out (early June) and the second event took place in mid-to-late September. In 2006, 488 and 492 traps were set in the spring and fall, respectively (Table 1). During the fall, 31 traps ended up being set three nights and 67 traps were set for one night. These traps were not used in the CPUE analysis, but the captured fish were used in the abundance and length composition estimates.

In 2007, two days of more effort during each event was used to increase sample sizes, diagnostics, and improve precision of the abundance estimate. To keep our effort comparable to

2006 and to have unbiased estimated of CPUE, we used the same approach for the first nine days of sampling (roughly 490 sets) where transects were chosen randomly throughout the lake. For the last two days, we set traps with a nonrandom approach where we set transects adjacent to ones that had good catch rates during the first nine days. A total of 612 and 618 traps were set in the spring and fall events, respectively (Table 1). Of these, 492 and 522 were set during the first pass for spring and fall respectively.

The sampling strategy for this experiment was to: 1) sample the entire study area as best as our sampling gear would allow 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) rely on mixing between events; and, 3) repeat step “1” for the second event.

Abundance was estimated in 2006 and 2007 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.

If no assumptions were violated, the number of burbot ≥450 mm TL in Crosswind Lake would be estimated using Chapman’s modification of the Petersen estimator (Seber 1982). The modified Petersen estimator is:

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

where:

n_1 = the number of fully recruited burbot marked and released 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 marked fully recruited burbot recaptured during the second event.

The sampling design and data collected allowed the validity of the five assumptions to be ensured or tested. The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate if the assumptions were met (Appendices B1-B3).

Evaluation of Assumptions

Assumption 1: The relatively long hiatus (three months) between events increased the potential for closure violations due to growth recruitment and mortality. Mortality and potential emigration would not bias the estimate as long as these happen at the same rate for marked and unmarked fish. Mortality and emigration would, however, dictate which time frame (i.e., spring or fall) the abundance estimate is germane to. Although the possibility exists, it was not expected that burbot immigrate to, or emigrate from, Crosswind Lake between events. The inlet and outlet streams are quite small, and burbot habitat is negligible within these creeks. The outlet creek does flow through a series of shallow lakes, but these are not the preferred habitat for burbot (Scott and Crossman 1973). Growth recruitment was expected to be negligible because recruited burbot (i.e. ≥450 mm TL) are slow growing.

Assumption 2: The four-month hiatus between events promoted mixing of marked and unmarked fish. Bernard et al. (1993) showed that adult burbot showed no depth preference during the open water period, that distribution across lakes was generally random (not aggregated) and that adult burbot moved rapidly and randomly across depths between surveys within the same season. Therefore, near equal opportunities of capture likely existed for each burbot, regardless of where and when they were captured.

Bernard et al. (1993) found that marked and unmarked burbot can completely mix in as little as 2–3 weeks with crude sampling densities of 0.9–3.6 hectares/set. Our traps were placed approximately 125 meters apart resulting in a sampling density of roughly 8 hectares/set at Crosswind Lake after the first pass. It was anticipated that this, in conjunction with a three-month sampling hiatus (vs. 2–3 weeks), would ensure proper mixing.

The study area was divided into multiple geographic sections and analyzed for equal probabilities of capture by section as well as for complete mixing. Only the final selection of geographic strata was presented along with the corresponding consistency tests. The recording of GPS coordinates allowed us measure distances moved between events and to assign a geographic stratum indicating where fish were initially caught and subsequently recaptured.

The relatively uniform distribution of sampling effort also helped to ensure that fish were subjected to equal capture probabilities during the first or second event in case mixing was not complete.

Assumption 3: Bernard et al. (1991 and 1993) showed that burbot caught in hoop traps exhibited no evidence of trap induced behavior (trap shyness/happiness) and burbot captured at depths <15 m showed no ill effects of being captured. The three-month hiatus between events allowed marked fish to recover from any possible effects of handling and marking had on them.

Assumption 4: This assumption was addressed by double marking each burbot during the first event. Tag loss was noted when a fish was recovered during the second event with a first-event fin clip and without a Floy® tag. In addition, tag placement was standardized which enabled the fish handler to verify tag loss by locating recent tag wounds.

Assumption 5: All fish were thoroughly examined for tags or recent fin clips. All markings (tag number, tag color, fin clip and tag wound) for each fish was recorded.

DATA ANALYSIS

CPUE

CPUE was defined as the number of fish caught per trap fished for a 48-h period. Mean CPUE was estimated for fully and partially recruited burbot for each pass down both Tolsona and Crosswind lakes following a two-stage sampling design with transects as first-stage units and sets along transects as second-stage units (Bernard et al. 1993 and Sukhatme et al. 1984). Burbot that were 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 sample event, they were of different lengths depending upon the shape of each lake. Under these conditions, an unbiased estimate of mean CPUE was:

$$\overline{CPUE} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{m_i}\sum_{j=1}^{m_i}\omega_i c_{ij} \qquad (2)$$

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 has 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 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, since 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.

Tolsona Lake Abundance Estimation

Abundance, survival rate and recruitment statistics were generated for the burbot population in Tolsona Lake with the Jolly-Seber model (Seber 1982) using the computer program JOLLY (Model A) developed by Brownie et al. (1986)[1]. Model A is the most general form of the Jolly-Seber model and assumes capture probabilities and survival rates vary over time. Individual burbot captured more than once in an event were considered caught only once in this analysis to estimate abundance. Estimates of abundance are lagged one year and estimates of survival and recruitment are lagged two years from the most recent sampling event due to the nature of the model. Sampling in 2006 and 2007 produced abundance estimates for 2005 and 2006.

For Tolsona Lake in 2007, mean CPUE was used to estimate abundance of fully recruited burbot using

$$\hat{N} = A(\overline{CPUE})\bar{q}^{-1}, \tag{3}$$

where

A = surface area of the lake (ha); and,

$\bar{q}$ = expected catchability coefficient (the fraction of the population removed instantaneously with one unit of sampling effort) as estimated from previous surveys.

Estimated variance of $\hat{N}$ was approximated with the delta method (Seber 1982) as:

$$v(\hat{N}) \cong \hat{N}^2 \left[\frac{v(\overline{CPUE})}{\overline{CPUE}^2} + \frac{v(\hat{q})}{\bar{q}^2} \right], \tag{4}$$

where

$v(\overline{\text{CPUE}})$ = obtained from Raowu.exe.

Estimates of the catchability coefficient (q_i) from previous surveys was calculated by:

$$\hat{q}_i = \frac{A(\overline{CPUE_i})}{\hat{N}_i} \tag{5}$$

where:

$\hat{q}_i$ = estimated catchability coefficient for the *i*th survey prior to the sampling event in 2006 or 2007;

$\hat{N}_i$ = estimated abundance during the ith survey prior to sampling in 2006 or 2007; and,

---

[1] see Pollock et al. (1990) for a description of JOLLY.

$\overline{CPUE}_i$ = estimated mean CPUE during the ith survey prior to sampling in 2006 or 2007.

Catchability coefficients (q_i) were calculated only for those past surveys that were conducted during the same time period relative to ice-out. Statistics for use in equation (2) were:

$$\bar{q} = \frac{\sum_{i=1}^{k} \hat{q}_i}{k} \tag{6}$$

Estimated variance of $(\hat{q}_i)$ is from Bernard et al. (1993):

$$v(\hat{q}_i) \approx \hat{q}_i^2 \left[\frac{v(\hat{N})_i}{\hat{N}_i^2} + \frac{v(\overline{CPUE}_i)}{\overline{CPUE}_i^2} \right]. \tag{7}$$

For Tolsona Lake, *i* encompassed years 1987 through 2006.

The CPUE expansion technique generally does not have the precision, nor does it garner the information that the Jolly-Seber model does, but it allows the estimation of abundance the same year the lakes were sampled. Jolly-Seber estimates are presented in this report when available. When they were not available, CPUE expansion abundance estimates are reported. The methods used to estimate abundances were noted in the titles of figures or as footnotes in tables. The management objective of two consecutive years with an estimated population abundance of at least 1,500 fully recruited burbot in Tolsona Lake is evaluated based exclusively on estimates from the Jolly-Seber method (Taube and Bernard 2001).

Crosswind Lake Abundance Estimation

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 B1.

Temporal and spatial violations of Assumption 2 were tested using consistency tests described by Seber (1982; Appendix B2). 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 length relative to anticipated movements. If at least one of the three consistency tests resulted in a failure-to-reject the null hypothesis, then it would be concluded that at least one of the conditions in Assumption 2 was satisfied and a pooled estimator could be used (Appendix B3). 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 was observed (incomplete mixing), the methods of Darroch (1961) would be used to compute a partially stratified abundance estimate. If no movement of marked burbot between geographic strata was observed, a completely stratified abundance estimate would be computed by summing individual strata estimates, each calculated using the Chapman-modified Petersen model (Chapman 1951).

Length Composition

Length composition of the Crosswind Lake burbot population was estimated using the procedures outlined in Appendices B1 and B4.

RESULTS

TOLSONA LAKE

CPUE and Length Composition, 2006 and 2007

Two hundred ninety-seven (297) burbot were captured from Tolsona Lake in 2006, 256 of which were fully recruited to the gear. Of these 256, 51 had been previously captured at a fully recruited length (≥450 mm TL; Table 2). Three of these recaptured burbot exhibited tag loss, but the presence of secondary marks allowed us to determine the year of last capture. The mean length of fully recruited burbot captured increased from 600 mm TL (SD = 62.3) in 2005 to 617 mm TL (SD = 70.4) in 2006 (Schwanke and Perry-Plake 2007). The length frequency distribution was bimodal with a peak occurring at the 600–649 mm TL category and a smaller peak of partially recruited burbot in the 350–400 mm range (Figure 3). There was a significant difference between the cumulative length frequency distribution of fully recruited burbot sampled between 2005 and 2006 ($DN = 0.20$, $P < 0.01$; Figure 4).

Mean CPUE of fully recruited burbot in Tolsona Lake in 2006 was 4.25 (SE = 0.72), while the mean CPUE of partially recruited burbot was 0.68 (SE = 0.25; Table 3).

Seven hundred and sixteen burbot were captured from Tolsona Lake in 2007 and about half of these (362) were fully recruited to the gear. Seventy-one of these fish had been previously captured at a fully recruited length (≥450 mm TL; Table 2). Three of these recaptured burbot exhibited tag loss, but secondary marks allowed them to be assigned a year of last capture. Mean length of fully recruited burbot was 570 mm TL (SD = 85.6), a decrease from 617 mm TL (SD = 70.4) the prior year. Length distribution was bimodal with a peak occurring at 550–600 mm TL category and a larger peak of partially recruited burbot in the 400–450 mm TL class (Figure 3). There was a significant difference in the cumulative length frequency distribution of fully recruited burbot sampled burbot between 2006 and 2007 ($DN = 0.23$, $P < 0.01$; Figure 4).

Mean CPUE of fully recruited burbot at Tolsona Lake during the first pass in 2007 was 4.28 (SE = 0.67), while mean CPUE of partially recruited burbot was 3.30 (SE = 0.52; Table 3). Mean CPUE for both fully and partially recruited burbot during the second pass dropped by 55% and 19%, respectively.

Table 2.–Mean length (mm TL) of burbot measured during sampling events at Tolsona and Crosswind lakes, 2006 and 2007.

Lake	Date	Statistic	Partially Recruited[a]	Fully Recruited[a]	All
Tolsona	5/31–6/2, 2006	Mean	372	617	583
		SD	30.7	70.4	106.8
		Sample size	41	256	297
Tolsona	5/25–5/29, 2007	Mean	414	570	493
		SD	20.7	85.6	99.0
		Sample size	354	362	716
Crosswind	6/8–6/17, 2006	Mean	343	635	616
		SD	49.7	81.4	107.5
		Sample size	17	245	262
Crosswind	9/19–9/27, 2006	Mean	379	613	580
		SD	50.6	95.1	120.8
		Sample size	31	203	234
Crosswind	6/5–6/15, 2007	Mean	387	629	619
		SD	51.5	80.6	92.3
		Sample size	12	299	311
Crosswind	9/14–9/24, 2007	Mean	393	602	579
		SD	36.5	81.6	101.9
		Sample size	30	239	269

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

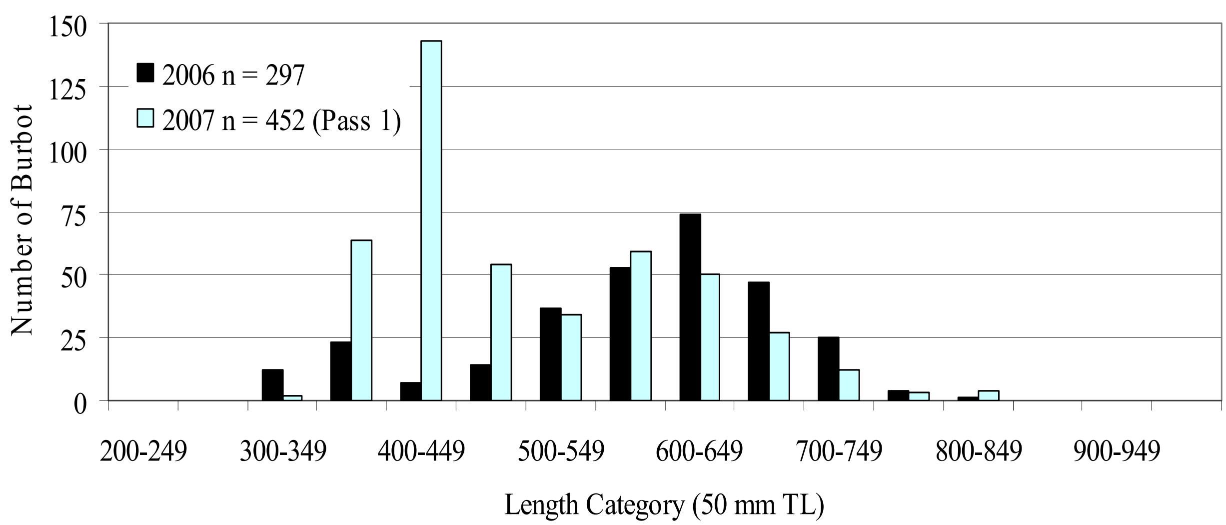

Figure 3.–Length histogram of burbot sampled from Tolsona Lake, 2006 and 2007.

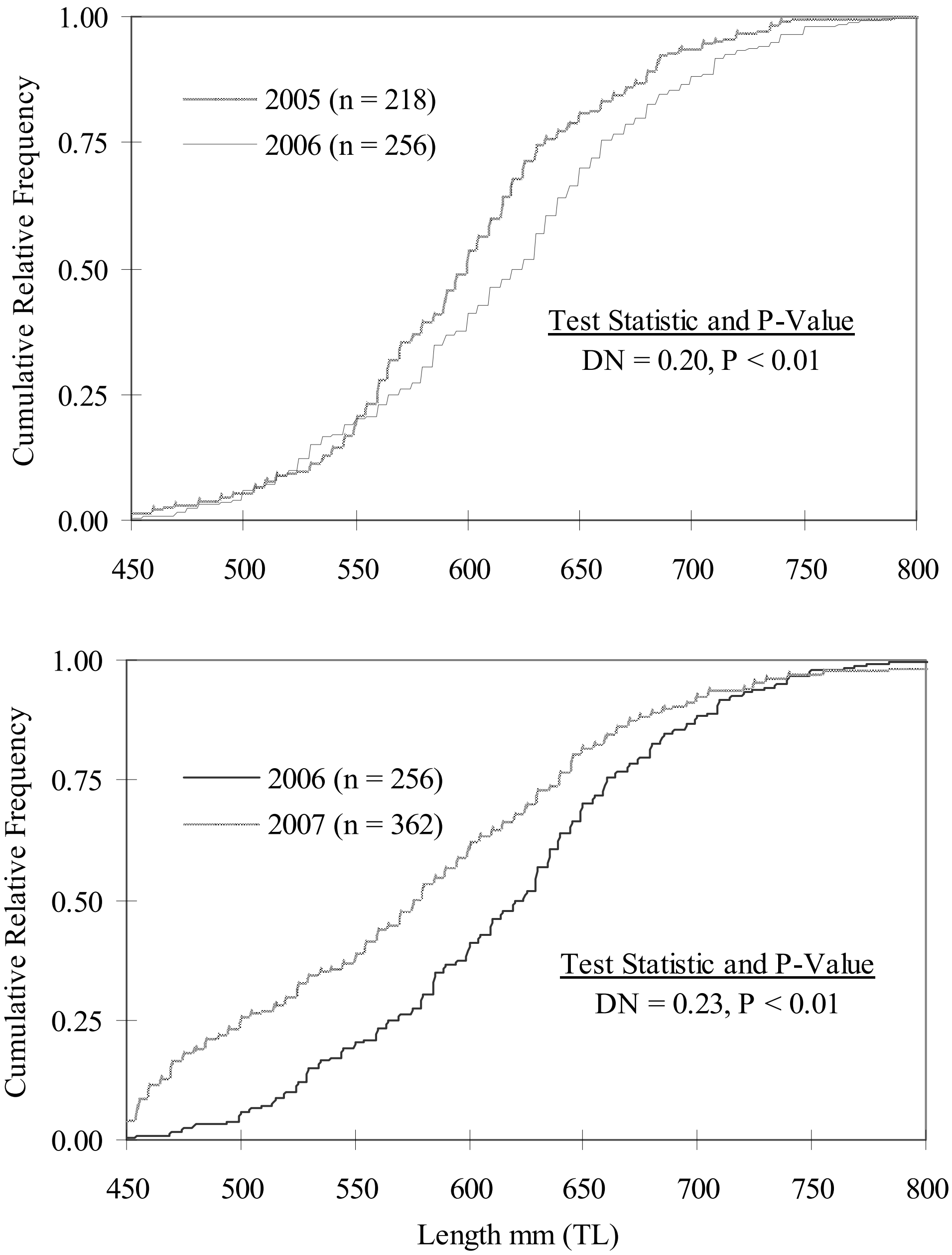

Figure 4.–Cumulative relative frequencies distributions of fully recruited burbot, Tolsona Lake. Top figure compares 2005 and 2006 and bottom figure compares 2006 and 2007.

Table 3.–Estimated mean CPUE of fully recruited (≥450 mm TL) and partially recruited (<450 mm TL) burbot in Tolsona and Crosswind lakes, 2006 and 2007.

Lakes and Dates	Strata	Sets	Transects	Mean CPUE Bootstrapped	Mean CPUE Arithmetic	Bootstrapped SE	Bootstrapped CV
Tolsona 5/31–6/2, 2006	1–5 m	60	10				
	Fully recruited:			4.29	4.25	0.72	16.7%
	Partially recruited:			0.67	0.68	0.25	36.8%
Crosswind 6/8–6/16, 2006	< 15 m	488	43				
	Fully Recruited:			0.49	0.50	0.11	22.1%
	Partially Recruited:			0.04	0.04	0.01	40.0%
Crosswind 9/19–9/27, 2006	< 15 m	394[a]	38				
	Fully Recruited:			0.45	0.45	0.08	17.6%
	Partially Recruited:			0.08	0.08	0.03	36.7%
Tolsona (Pass 1) 5/25–5/27, 2007	1–5 m	60	9				
	Fully recruited:			4.29	4.28	0.67	15.5%
	Partially recruited:			3.26	3.30	0.52	15.8%
Tolsona (Pass 2) 5/27–5/29, 2007	1–5 m	59	10				
	Fully recruited:			1.93	1.93	0.35	17.8%
	Partially recruited:			2.63	2.66	0.66	25.1%
Crosswind (Pass 1)[b] 6/5–6/13, 2007	< 15 m	492	41				
	Fully Recruited:			0.51	0.52	0.12	22.7%
	Partially Recruited:			0.02	0.02	0.01	57.1%
Crosswind (Pass 1)[b] 9/14–9/23, 2007	< 15 m	522	42				
	Fully Recruited:			0.36	0.36	0.05	14.3%
	Partially Recruited:			0.04	0.04	0.02	33.3%

[a] In fall 2006, 494 sets were made, but only 394 were set for the two day period and used for calculating CPUE.

[b] Extra effort is not included in the CPUE analyses because transects were not randomly chosen.

Abundance, 2005, 2006 and 2007

Estimated abundance for May 2005 based on the Jolly-Seber method was 1,145 (90% CI = 757 – 1,533; Table 4). Recruitment between spring sampling events from 2004 and 2005 was estimated at 568 (SE = 207; Appendix C1). Survival rate over the time period was estimated to be 0.76 (SE = 12.8).

Using the Jolly-Seber method, abundance of fully recruited burbot for May 2006 was estimated as 1,322 (90% CI = 862 – 1,784; Table 4). Recruitment between the spring sampling events of 2005 and 2006 was estimated at 538 (SE = 211). Survival rate over the time period was estimated to be 0.69 (SE = 13.9; Appendix C1).

Expansion of CPUE resulted in a population estimate of 1,077 (90% CI = 437 – 1,716) fully recruited burbot for spring 2007 (Table 4).

Table 4.–Estimated abundance and density of fully recruited (≥ 450 mm TL) burbot in Tolsona and Crosswind lakes, 2006 and 2007.

Lake	Date	Abundance[a]	SE	Lake Area (ha)	Density (burbot/ha)	SE
Tolsona	5/16/05–5/18/05	1,145	236	130	8.81	1.82
	5/31/06–6/02/06	1,323	280	130	10.18	2.15
	5/25/07–5/27/07	1,077	389	130	8.28	2.99
Crosswind	6/08/06–6/17/06	3,860	972	3,232	1.19	0.28
Crosswind	6/05/07–6/15/07	3,130	584	3,500	0.97	0.17

[a] Abundance estimates at Tolsona Lake from 2005 and 2006 are from the Jolly-Seber model and incorporate information collected up to and including 2007, while the 2007 Tolsona Lake abundance estimate is from CPUE expansion. Abundance estimates from Crosswind Lake for both 2006 and 2007 are from within-year two-event Petersen estimates.

Water Temperature, 2006 and 2007

Hourly water temperatures were collected from 2 June to 2 October 2006 from two positions in the water column: the bottom and the middle. A third temperature data logger was placed near the surface but it was missing when the loggers were pulled. Results were that the bottom half of the water column never exceeded the preferred level for burbot (i.e., 18 °C). The maximum temperature on the bottom (4.5 m) was recorded on 13 July as 19.87 °C, while the maximum reading for the middle of the water column (2.5 m) was recorded two days later at 18.18 °C (Figure 5).

In 2007, water temperature recorders were deployed from 29 May to 25 September. During this time period, bottom depth (4.5 m) attained a maximum temperature of 19.5 °C on July 30 (Figure 6). The middle of the water column (2.5 m) experienced a maximum temperature of 20.3 °C on 28 June.

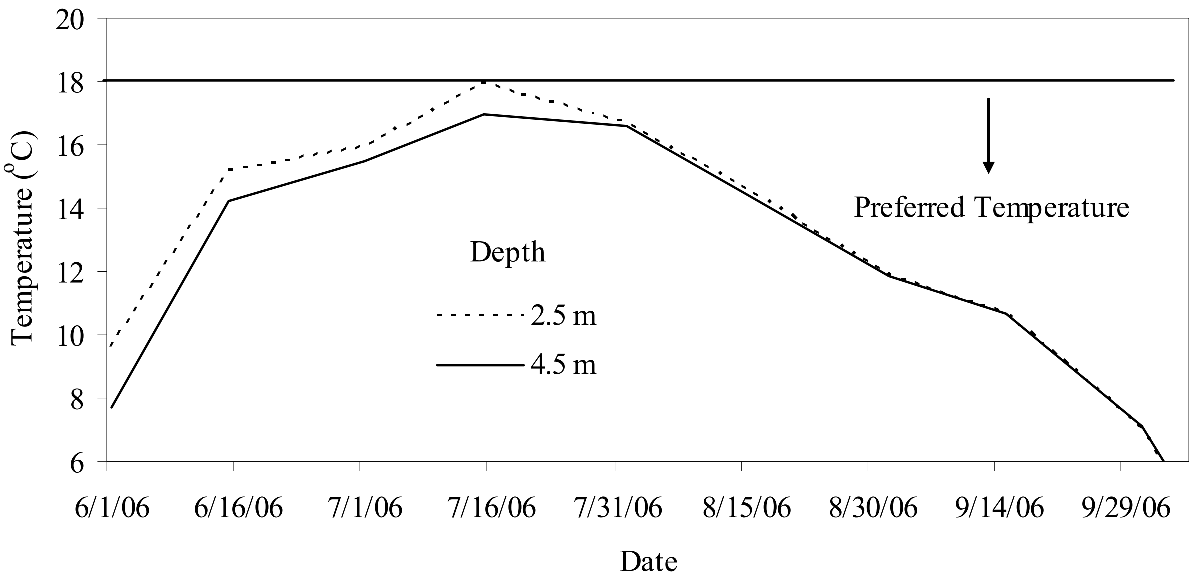

Figure 5.–Water temperature measurements from Tolsona Lake, 2006.

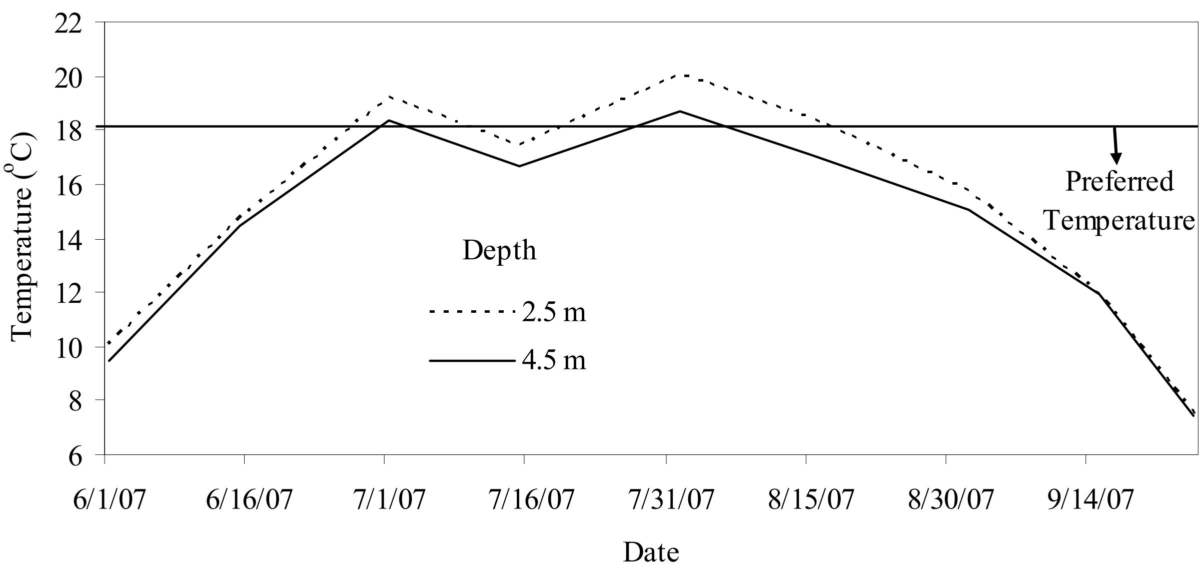

Figure 6.–Water temperature measurements from Tolsona Lake, 2007.

Crosswind Lake

CPUE and Length Composition, 2006

A total of 448 burbot ≥450 mm TL were captured in 2006 and used in the mark-recapture analysis (Table 2). During the first event, 245 fully recruited burbot were captured and marked. During the second event 203 fully recruited burbot were captured and examined, 12 of which were marked during the first event. Four of the recaptured fish experienced tag loss but were detected because of the secondary mark. The smallest recaptured fish was 534 mm TL. An additional 17 partially recruited burbot were captured in the first event and 31 in the second event (Table 2). Mean length of fully recruited burbot from the first event was 635 mm TL (SD = 81.4), while mean length of fully recruited burbot sampled in the second event was 613 mm TL (SD = 95.1; Table 2).

CPUE of fully recruited burbot during the first event was 0.50 (SE = 0.11), while CPUE of fully recruited burbot during the second event was 0.45 (SE = 0.08; Table 3).

K-S test results indicated that there was no size selectivity during the second event, but that there was during the first event (Appendix B1; Case II). The M vs. C test rejected the null hypothesis (DN = 0.16, P-value = 0.001), but the M vs. R test failed to reject the null hypothesis (DN = 0.17, P-value = 0.88; Figure 7). Therefore, lengths from the second sampling event were used to estimate length composition. The length frequency distribution was unimodal with the peak occurring at the 550–599 mm TL category (Figure 8).

CPUE and Length Composition, 2007

A total of 538 burbot ≥450 mm TL were captured in 2007 (Table 2). During the first event 299 fully recruited burbot were captured and marked. During the second event 239 fully recruited burbot were captured and examined, 22 (one fish experienced tag loss) of which were marked during the first event. The smallest recaptured fish was 505 mm TL. Forty-two additional burbot were captured at <450 mm TL (Table 2). Mean total length of fully recruited burbot from spring and fall were 629 mm TL (SD = 80.6) and 602 mm TL (SD = 81.6), respectively (Table 2).

CPUE of fully recruited burbot was 0.52 (SE = 0.12) during the initial pass down the lake in spring (Table 3). In fall, the initial pass down the lake resulted in a mean CPUE of 0.36 (SE = 0.05) for fully recruited burbot.

K-S test results indicated no presence of size selectivity during the second event, but showed probable size selectivity occurring during the first event. The M vs. C test rejected the null hypothesis (DN = 0.18, P-value = 0.02), but the M vs. R test failed to reject the null hypothesis (DN = 0.11, P-value = 0.97; Figure 9). Therefore, lengths from the second sampling event were used to estimate length composition (Appendix B1; Case II). The length frequency distribution was unimodal with the peak occurring at the 550–599 mm TL category (Figure 8).

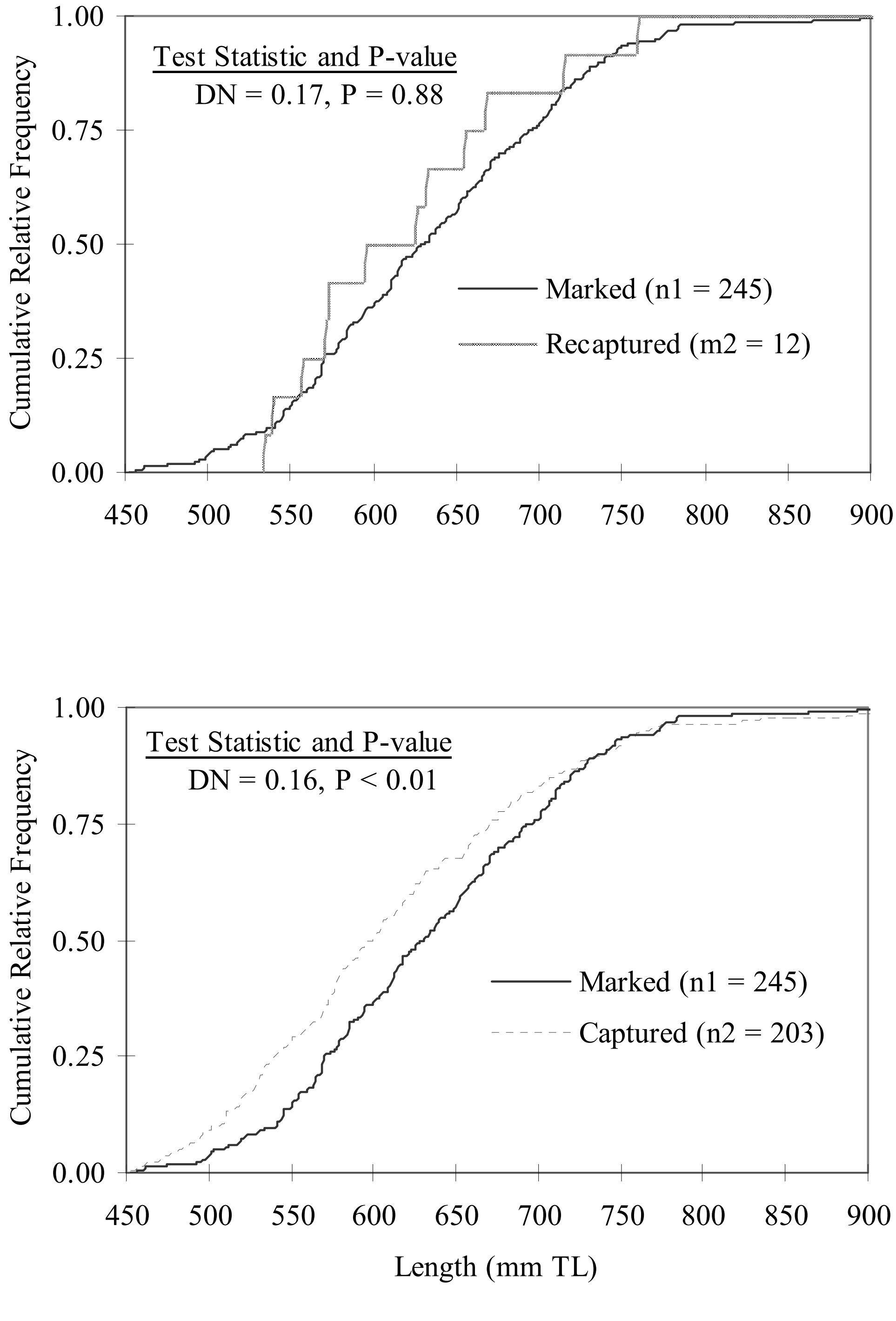

Figure 7.–Cumulative relative frequency distributions of fully recruited burbot, Crosswind Lake, 2006.

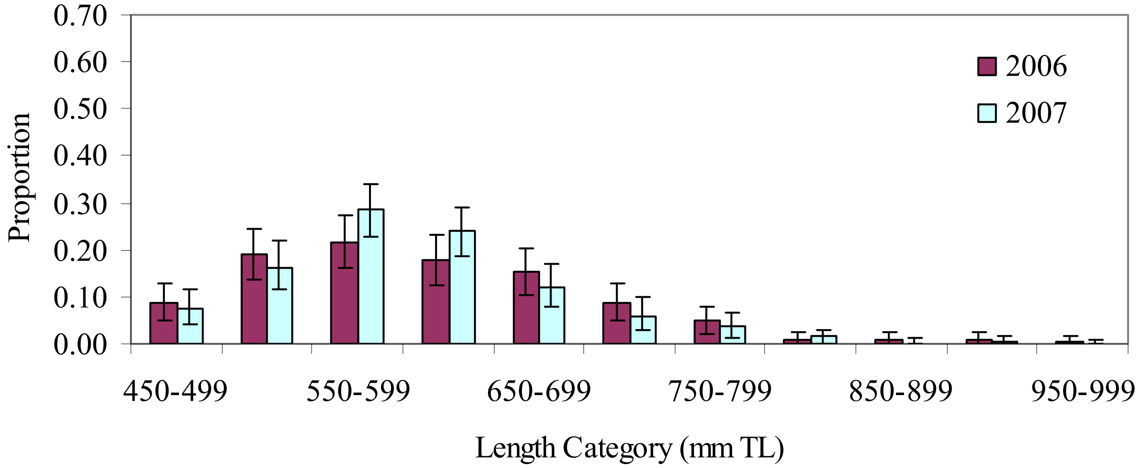

Figure 8.–Estimated proportions (with 95% confidence intervals) of fully recruited burbot at Crosswind Lake, 2006 and 2007.

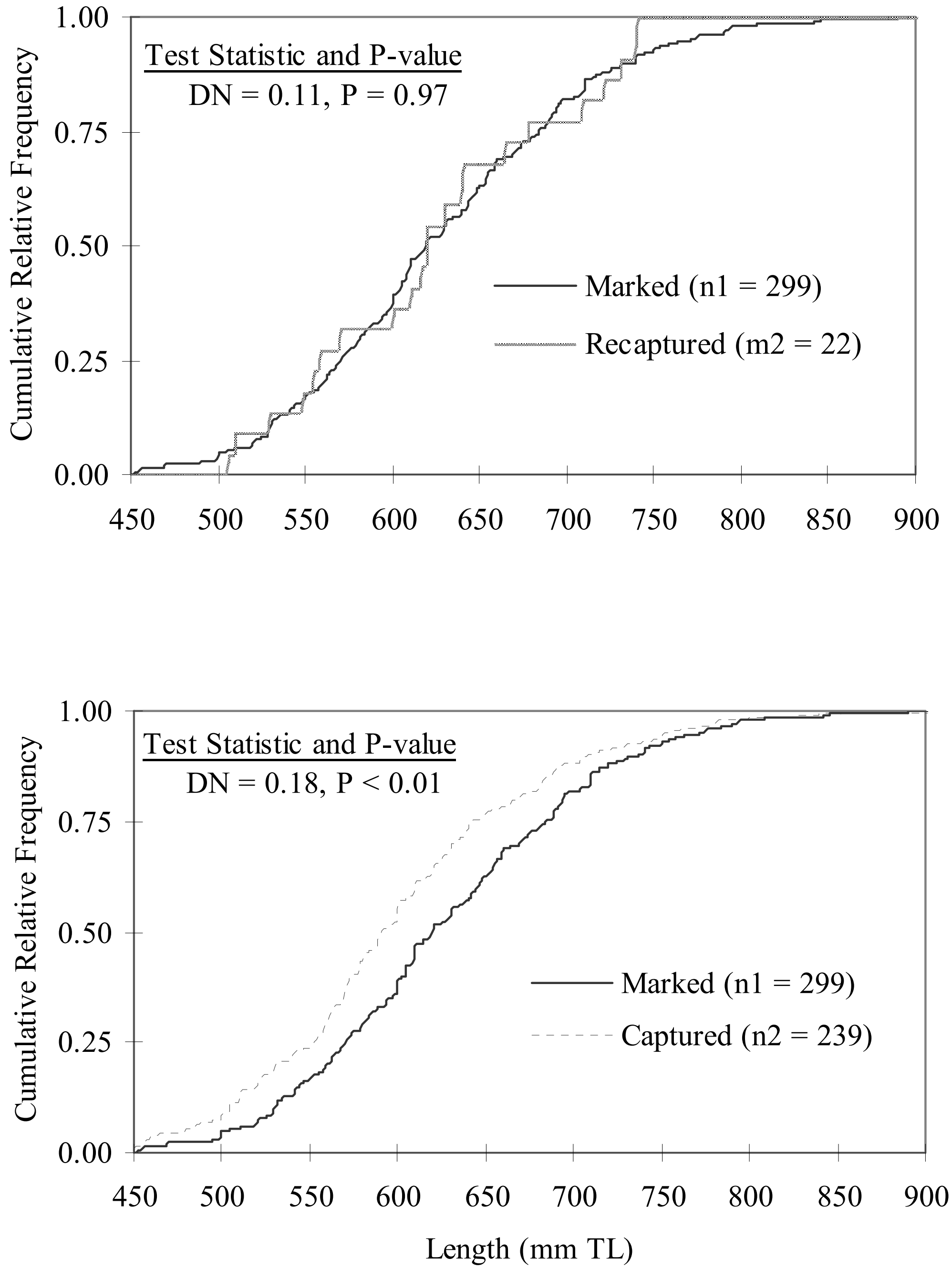

Figure 9.–Cumulative relative frequency distributions of fully recruited burbot, Crosswind Lake, 2007.

Abundance

2006

K-S tests indicated that there was no size selectivity during the second sampling event, but that there was during the first event (Figure 7; Appendix B1; Case II); therefore, stratification by size was not necessary. Multiple geographic stratification schemes were analyzed to address the possible need to calculate a stratified abundance estimate. We chose to use a 3-strata scheme because of the limited number of recaptured fish in the middle and northern sections of the lake (Figure 10). Using three strata, analysis concluded equal probability of capture of burbot existed during both the first and second events (Tables 5 and 6). The complete mixing test (Table 7) was not able to provide meaningful statistical results because of the small number of recaptured fish in the middle of the lake. Considering that no fish were recaptured in Section A (with few fish examined), we chose to examine a 2 X 2 collapsed contingency table comprising the two southern sections of the lake (Sections B and C). The test results again indicated equal probability of capture during the both events and complete mixing could not be rejected. Furthermore, distances traveled (i.e., straight line measurement between capture locations) by recaptured burbot indicated they moved between 100 and 3,000 m and averaged 1,400 m which suggested partial mixing.

Average growth of the eight recaptured burbot with known lengths from both events was 15.8 mm (SE = 4.4). This was considered inconsequential to the abundance calculations considering the precision of the estimate and the small percentage of fish that possibly recruited to the gear between events (i.e., grew from a <450 mm TL to ≥450 mm TL).

The abundance estimate of fully recruited burbot at Crosswind Lake in 2006 was 3,860 (90% CI = 2,262–5,459; Table 4).

2007

K-S tests indicated that there was no size selectivity during the second sampling event, but that there was during the first event (Figure 9, Appendix B1; Case II); therefore, stratification by size was not necessary.

Contingency table analysis indicated that geographic stratification was not necessary. Using the same three geographic strata as in 2006 (Figure 10), tests indicated that the probabilities of capture were equal during both the first and second events (Table 8; Table 9). The complete mixing test (Table 10) was not able to provide meaningful statistical results because of the small number of recaptured fish in the middle of the lake. To further explore these tests, multiple geographic schemes were analyzed. One approach was a collapsed contingency table analysis using sections B and C only. Eighteen burbot were either marked or recaptured in these sections and results were equal probabilities of capture with both events, and mixing could not be rejected. Furthermore, known travel distances of recaptured burbot suggested partial mixing occurred. Distances traveled (i.e., straight line measurement between capture locations) ranged from 380 to 12,640 m and averaged 2,670 m.

Average growth of recaptured burbot was 7.8 mm (SE = 1.8). This was considered inconsequential to the abundance calculations considering the precision of the estimate and the small percentage of fish that possibly recruited to the gear between events (i.e., grew from a <450 mm length TL to ≥450 mm TL). The abundance estimate of fully recruited burbot in Crosswind Lake in 2007 was 3,130 (90% CI = 2,170–4,091; Table 4).

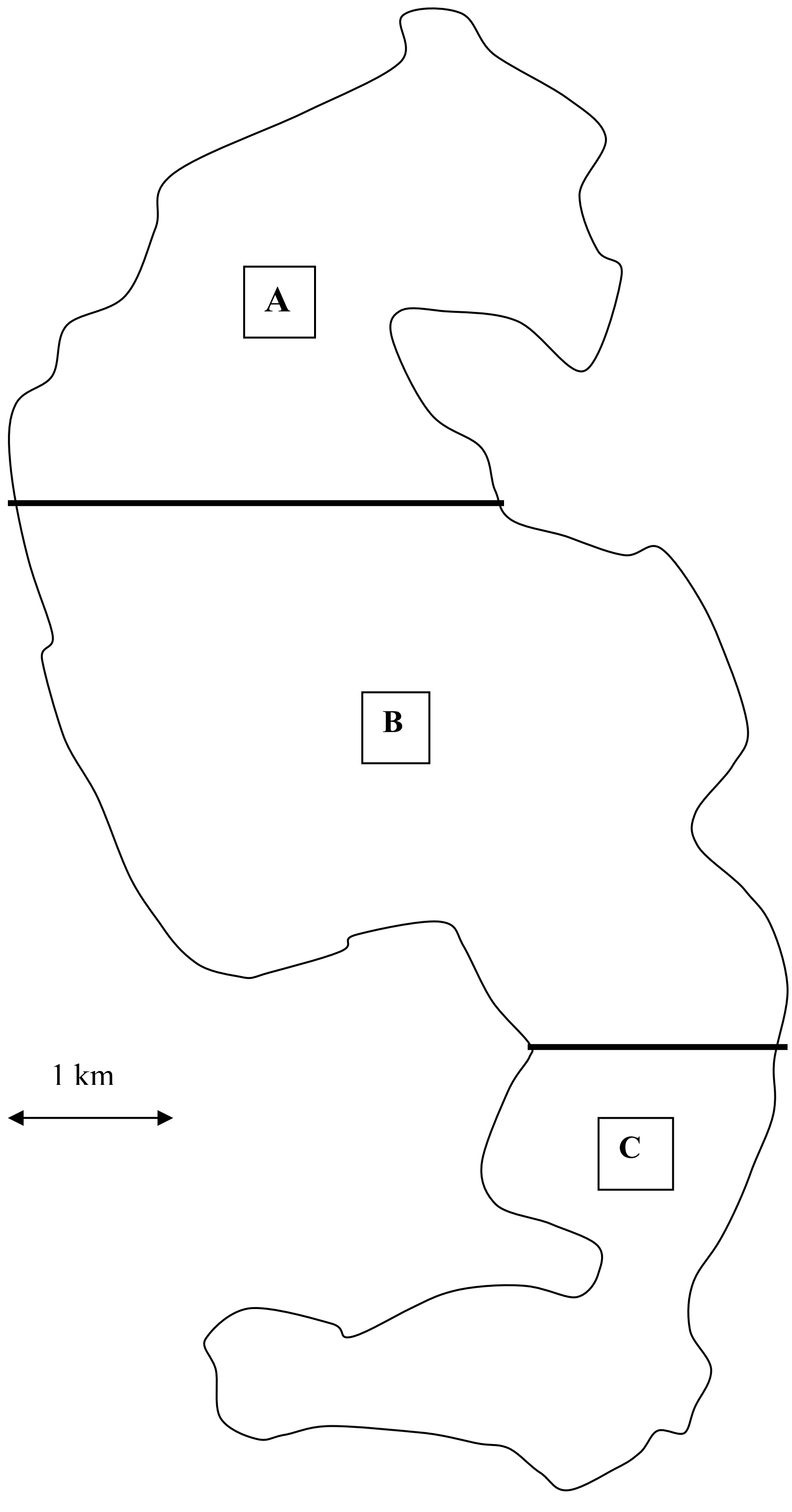

Figure 10.–Map of Crosswind Lake with section boundaries.

Table 5.–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–C) of Crosswind Lake, 2006.

Category	Section Where Examined			
	A	B	C	All Sections
Marked (m_2)	0	3	9	12
Unmarked (n_2-m_2)	26	39	126	191
Examined (n_2)	26	42	135	203
$P_{capture}$ 1st event (m_2/n_2)	0.00	0.07	0.07	0.06

χ^2 = 1.88, df = 4, P-value = 0.39, fail to reject H_0.

Table 6.–Test for equal probability of capture during the second event for burbot ≥450 mm TL. Number of burbot marked by section (A–C) during the first event that were recaptured and not recaptured during the second event, Crosswind Lake, 2006.

Category	Section Where Marked			
	A	B	C	All Sections
Recaptured (m_2)	0	2	6	8
Not Recaptured (n_1-m_2)	29	41	167	237
Marked (n_1)	29	43	173	245
$P_{capture}$ 2nd event (m_2/n_1)	0.00	0.05	0.03	0.03

χ^2 = 1.26, df = 4, P-value = 0.53, fail to reject H_0.

Table 7.–Test for complete mixing. Number of burbot ≥450 mm TL marked in each geographic section (A–C) and recaptured or not recaptured in each section of the Crosswind Lake, 2006.

Section Where Marked	Section Where Recaptured			Not Recaptured (n_1-m_2)	Total Marked (n_1)
	A	B	C		
A	**0**	0	0	29	29
B	0	**2**	0	39	41
C	0	1	**5**	161	167
Total	0	3	5	229	237

Table 8.–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–C) of Crosswind Lake, 2007.

Category	Section Where Examined			
	A	B	C	All Sections
Marked (m_2)	2	6	14	22
Unmarked (n_2-m_2)	39	74	104	217
Examined (n_2)	41	80	118	239
$P_{capture}$ 1st event (m_2/n_2)	0.05	0.08	0.12	0.09

χ^2 = 2.19, df = 4, P-value = 0.33, fail to reject H_0.

Table 9.–Test for equal probability of capture during the second event for burbot ≥450 mm TL. Number of burbot marked by section (A–C) during the first event that were recaptured and not recaptured during the second event, Crosswind Lake, 2007.

Category	Section Where Marked			
	A	B	C	All Sections
Recaptured (m_2)	1	6	14	21
Not Recaptured (n_1-m_2)	25	83	170	278
Marked (n_1)	26	89	184	299
$P_{capture}$ 2nd event (m_2/n_1)	0.04	0.07	0.08	0.07

χ^2 = 0.51, df = 4, P-value = 0.78, fail to reject H_0

Table 10.–Test for complete mixing. Number of burbot ≥450 mm TL marked in each geographic section (A–C) and recaptured or not recaptured in each section of the Crosswind Lake, 2007.

Section Where Marked	Section Where Recaptured			Not Recaptured	Total Marked
	A	B	C	(n_1-m_2)	(n_1)
A	**0**	1	0	25	26
B	1	**2**	3	83	89
C	1	3	**10**	170	184
Total	2	6	13	278	299

DISCUSSION

TOLSONA LAKE

Tolsona Lake burbot appear to be still recovering from low abundances estimated from 1995 through 1997 (Figure 11). The most current Jolly-Seber estimate is about 200 fish below the 1,500 needed to open the lake to the taking of burbot (Taube and Bernard 2001). The length frequency histograms of captured fish show an apparently large cohort of burbot ready to recruit to the population of inference (i.e., ≥450 mm TL; Figure 3). Presently, these fish are not represented in the abundance estimates. If these fish survive, they could possibly drive the abundance estimate to over 1,500 fish in 2008. This possibility will remain unknown until after the 2009 sampling period because of the one year lag when using the Jolly-Seber model.

Using the CPUE expansion method, the abundance estimate was 1,077 (Table 4) fully recruited burbot for 2007 and is probably biased low. Five of the last six years' estimates have been tracking lower than the Jolly-Seber estimates for a given year and these differences have approached 20% (Figure 12). Although CPUE expanded estimates and Jolly-Seber estimates are not always the same, they do typically show the same trends.

Continuous assessment is recommended at Tolsona Lake until the burbot population recovers to a prescribed level capable of sustaining harvest. The present management strategy was outlined in Taube and Bernard (2001) and states that the fishery will reopen when the estimated abundance of burbot is at least 1,500 burbot ≥450 mm TL for two consecutive years. It was believed that this abundance level could support a daily bag limit of 2 burbot.

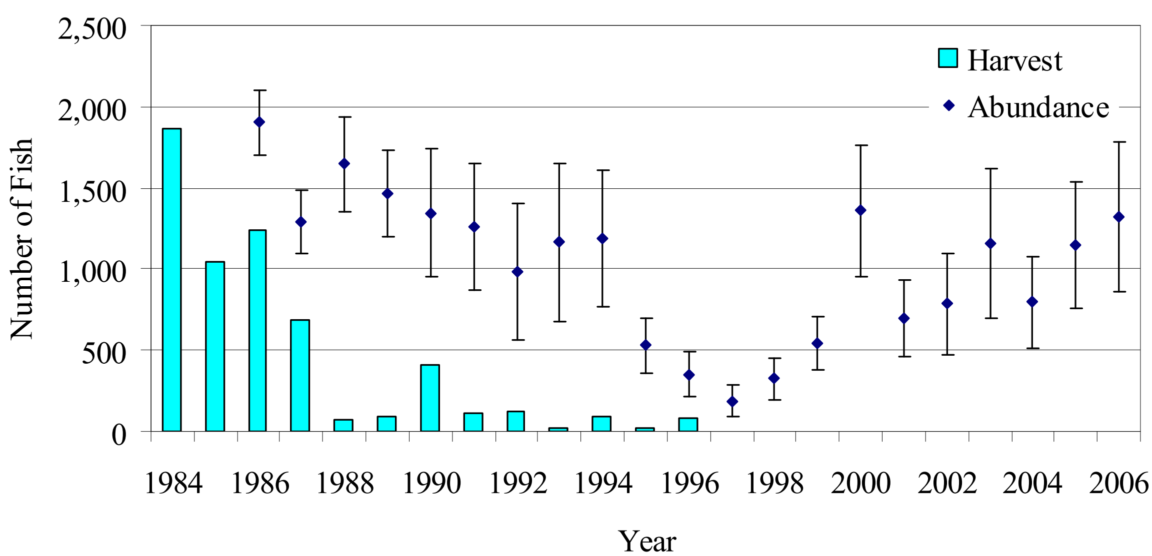

Figure 11.–Estimated harvest (Mills 1985-1994; Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2004, 2006a-b, 2007, *in press*, *in prep*; Walker et al. 2003) and abundance with 90% confidence intervals of fully recruited (≥450 mm TL) burbot in Tolsona Lake, 1984–2006. Abundance estimate for 1986 is from a within-season Petersen mark-recapture experiment. Estimates from 1987 to 2006 are from the Jolly-Seber method.

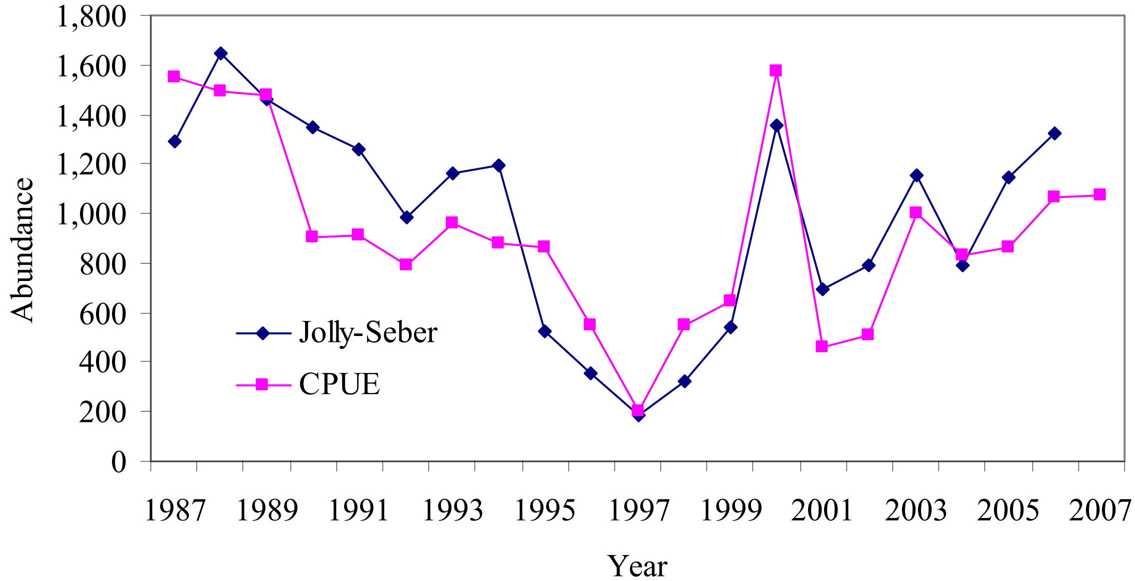

Figure 12.–Comparisons of Jolly-Seber abundance estimates and CPUE expansion abundance estimates, Tolsona Lake, 1987–2007.

CROSSWIND LAKE

The 2006 abundance estimate for Crosswind Lake was relatively imprecise with a relative precision of 0.41. This was attributed to insufficient sample sizes. To further complicate matters, 4 of the 12 recaptured fish experienced tag loss and reduced the power of our diagnostic tests. For example, no recaptured fish in 2006 were either marked or recovered from Section A. Another mark-recapture experiment was conducted in 2007 wherein the effort was increased by approximately 25%. The results were more fish were captured, a more precise abundance estimate was attained (RP = 0.31) and stronger diagnostic test results were achieved.

It is our belief that the abundance estimates achieved in this study are biased low, with the level of bias being undeterminable. We believe they are biased low because some fish presumably resided in unsampled waters during both events and were consequentially isolated from the study. Approximately 40% of the lake was too deep (>15 m) to sample burbot, and this zone was a single expansive area (vs. many small ones) spanning a width of ~4,000 m and a length of ~10,000 m (Figure 13). Relative to the deep waters, straight line horizontal movements of recaptured fish appeared insufficient to assume that all fish were subjected to our capture gear in at least one event. For example, 9 of 29 recaptured fish were captured <1,000 m away from their marking location, and the overall mean distance among capture locations of all recaptured fish during both years was 2,300 m. Despite these uncertainties, we believe the bias was not substantial (e.g. >10%) because it appeared that burbot densities were low in the deeper waters and evidence suggests partial mixing did occur. Shallow sets had the highest CPUE during all sampling events (Appendix D). Furthermore, CPUE was the lowest for fully recruited burbot in the deepest depth bin that we were able to sample (13-15 m) during all four sampling events, indicating a preference for shallower water during our sampling periods.

Of interest, the cumulative length frequency distributions of marked (M) and captured (C) burbot were significantly different between events both years with more small fish (between 450 and ~550 mm FL) being captured during the second event. This trend is consistent with the finding of Bernard et al. (1993) where smaller burbot were typically found deeper (i.e., >15 m) in the spring than in summer and fall, and may have occurred these experiments. Conversely, the abundance of fish between 450 and ~550 mm TL may have simply been greater than the larger fish (>550 TL) and the diagnostic test (e.g., M vs. R) was not powerful enough to detect a true difference in capture probabilities between the two groups.

A similar study design used in this experiment is recommended in future years for attaining relatively unbiased abundance estimates of burbot for these large, relatively deep lakes. The three-month hiatus between events allowing marked and unmarked fish to at least partially mix at a relatively broad scale coupled with the transect design resulted in equal probabilities of capture for both events. To alleviate concerns of burbot residing in the deeper waters throughout the experiment, sets could possibly be made deeper if they are raised in increments to allow for decompression (Neufeld and Spence 2004). Although this is time consuming, it is probably the best way to garner an unbiased abundance estimate. If greater precision (i.e., ±25%) is desired, increasing effort is recommended. Specifically, two crews setting close to 1,000 hoop traps per event should yield sample sizes that will improve precision of the estimates and the power of our diagnostic tests.

No changes to the sport fishing regulations were made after these studies and Crosswind Lake remained under the area wide regulation of five burbot per day and in possession. The SWHS estimates that 200–850 burbot have been harvested annually the last five years (2002–2006), which averages to be >10% of our abundance point estimate (Figure 14). With an estimated harvest rate >10%, a future abundance estimate should take place within the next five years to evaluate sustainability.

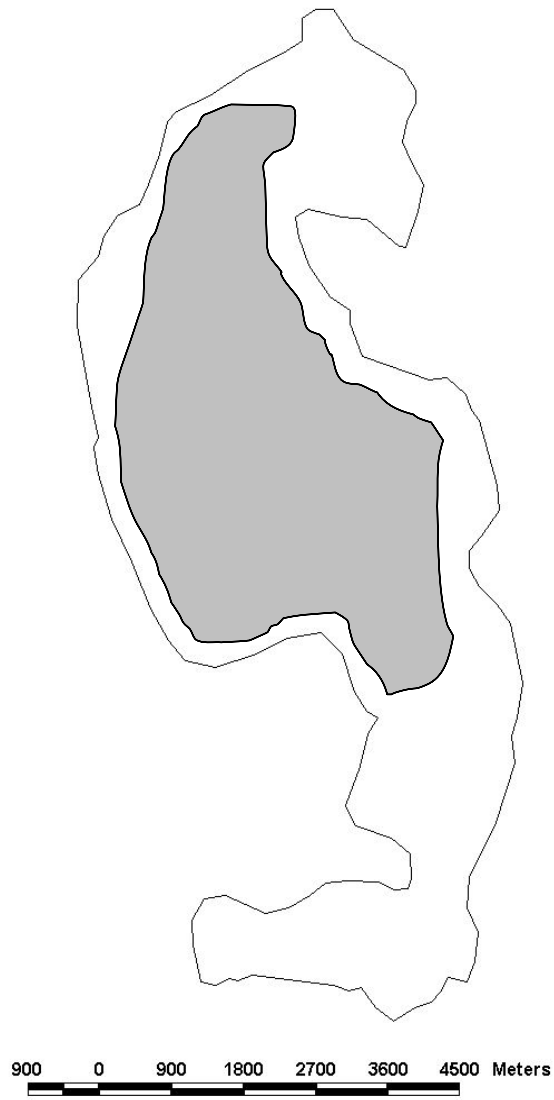

Figure 13.–Map of Crosswind Lake with shaded areas representing unsampled waters (i.e., >15 m).

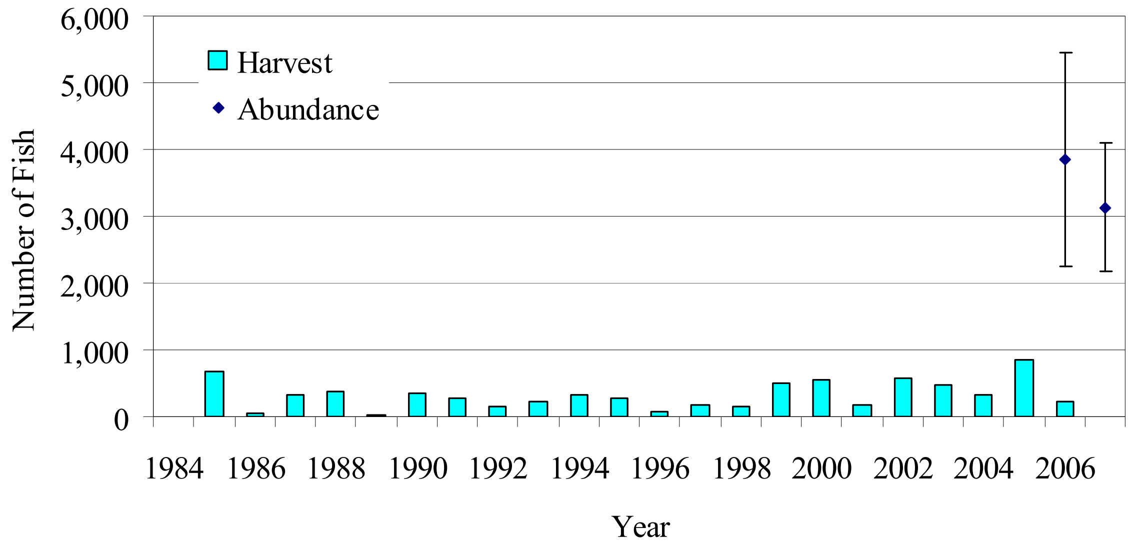

Figure 14.–Estimated harvest (Mills 1985-1994; Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2004, 2006a-b, 2007, in press, in prep; Walker et al. 2003) and abundance with 90% confidence intervals of fully recruited (≥450 mm TL) burbot in Crosswind Lake, 1984–2007.

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APPENDIX A
SUMMARY OF DATA FILE ARCHIVES

Appendix A1.–Summary of data archives.

Location	Project leader	Storage Software
Fairbanks	Corey Schwanke 822-3309	Delimited ASCII files, Microsoft EXCEL workbook

Lake	File Name	Data Format	Software
Tolsona	i-039800h012006.dta	Hoop net	RTS-ASCII
	i-039800h012007.dta	Hoop net	RTS-ASCII
	2007 Tolsona BB tag history.xls	Tag history	Microsoft EXCEL
Crosswind Lake	i-000800h012006.dta	Hoop net	RTS-ASCII
	i-000800h022006.dta	Hoop net	RTS-ASCII
	i-000800h012007.dta	Hoop net	RTS-ASCII
	i-000800h022007.dta	Hoop net	RTS-ASCII

Definition of data formats:

Hoop net: a mark-sense form developed by Alaska Department of Fish and Game, Division of Sport Fish Research and Technical Services (RTS) for the recording of trap, catch, and tagging information. Specific codes and organization of columns for data format is available on request.

Tag history: an EXCEL file that contains lake specific historical tagging information by individual tags and recaptures by sampling events.

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

Appendix B1.–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 fish marked during the first event versus the lengths of fish recaptured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish 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 B2.–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 (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 fish in stratum j at the time of sampling, and a_i = number of marked fish 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 fish in section j during the second event, and d is a constant.

Appendix B3.–Equations for calculating estimates of abundance and its variance using the Chapman-modified Petersen estimator.

The abundance of fully recruited burbot was estimated as:

$$\hat{N} = \frac{(n_2 + 1)(n_1 + 1)}{(m_2 + 1)} - 1, \tag{B3-1}$$

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):

$$\hat{V}[\hat{N}] = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2 (m_2 + 2)}. \tag{B3-2}$$

From Appendix B1, Case II was found at Crosswind Lake through inference testing and occurs when there is size selectivity during the first event, but not for the second event. Proportions from the second event in 50-mm FL categories were calculated by:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{B4-1}$$

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):

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1-\hat{p}_{jk}\right)}{n_j - 1}. \tag{B4-2}$$

APPENDIX C
HISTORICAL TOLSONA LAKE SAMPLING INFORMATION

Appendix C1.–Estimates of population parameters of fully recruited (≥450 mm TL) burbot in Tolsona Lake, 1986–2007.

	Days		Abundance[a]			Survival Rate %		Recruitment	
Date	between events	CPUE	Estimate	SE	CV %	Estimate	SE	Estimate	SE
9/26/86		3.98	1,901	120	6.3				
	235					60.0	4.6	138	209
6/25/87		2.79	1,291	120	9.3				
	335					77.9	7.1	645	144
5/26/88		5.93	1,647	178	10.8				
	95					66.6	7.4	45	111
9/01/88		3.58	1,142	132	11.5				
	263					77.8	9.1	576	124
5/24/89		5.86	1,464	162	11.1				
	110					95.1	17.6	277	174
9/13/89		4.08	1,846	311	16.8				
	251					47.9	9.8	460	153
5/24/90		3.59	1,344	240	17.9				
	104					35.0	6.3	86	67
9/07/90		2.95	556	85	15.3				
	255					67.0	12.2	890	191
5/22/91		3.62	1,262	235	18.6				
	109					35.9	6.5	96	87
9/12/91		1.14	549	105	19.1				
	273					87.5	22.6	505	171
6/11/92		3.14	985	256	26.0				
	341					25.2	6.0	915	275
5/20/93		3.83	1,164	298	25.6				
	375					95.1	18.2	86	349
6/01/94		3.50	1,188	255	21.5				
	354					31.8	7.0	150	74
5/23/95		3.44	528	104	19.7				
	377					38.3	9.3	149	56
6/05/96		2.19	352	84	23.9				
	354					37.6	11.6	54	37
5/27/97		0.80	187	58	31.0				
	355					35.3	10.0	257	74
5/19/98		2.19	323	79	24.5				
	375					74.5	10.1	301	119
6/01/99		2.57	541	98	18.1				
	367					103.0	17.0	805	197
6/08/00		6.25	1,360	247	18.2				
	356					37.9	6.8	180	117
5/31/01		1.83	695	144	20.7				
	371					98.7	23.8	101	130
6/06/02		2.03	787	189	24.0				
	348					52.2	14.1	746	219
5/21/03		4.02	1,157	280	24.2				
	364					30.4	6.2	444	149
5/20/04		3.36	795	169	21.3				
	363					75.6	12.8	568	207
5/18/05		3.45	1,145	236	20.6				
	377					68.6	13.9	538	211
5/31/06		4.25	1,322	279	21.1				
	360								
5/27/07		4.29							

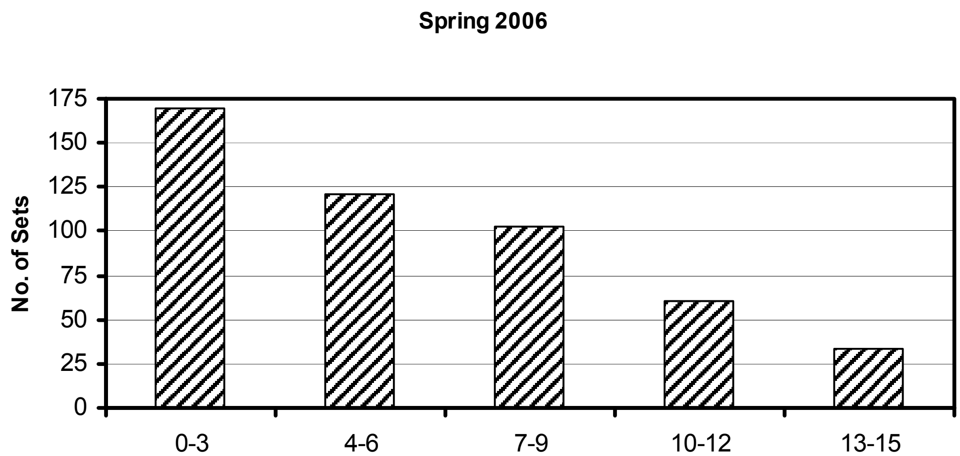
[a] abundance estimate from 1986 is from a two-event mark-recapture experiment, all other years are from the Jolly-Seber method.

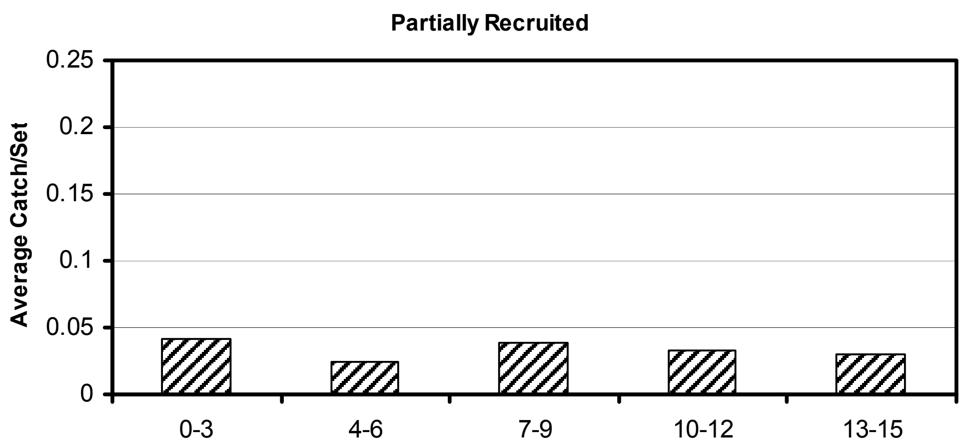
Appendix C2.–Mark-recapture histories of fully recruited (≥450 mm TL) burbot, Tolsona Lake, 1990–2007.

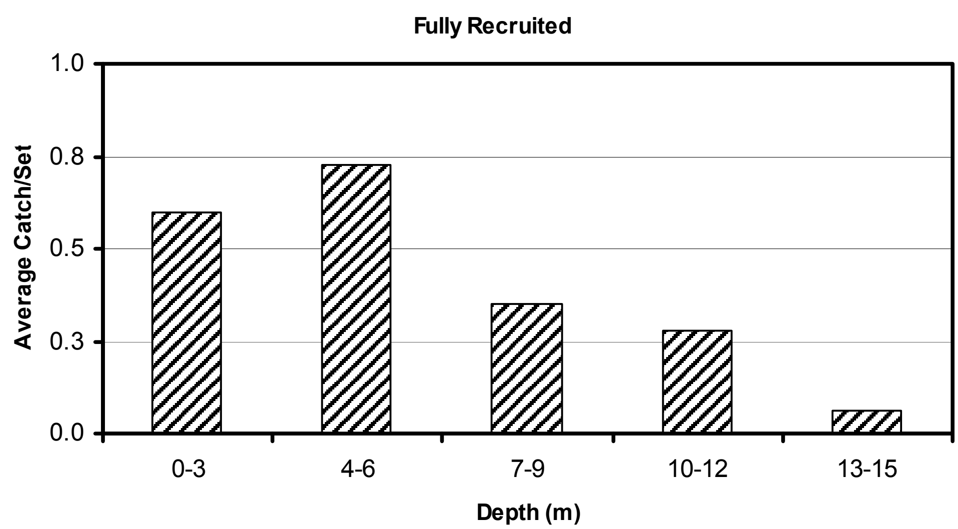
Date : Year	1990	1990	1991	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Beginning	5/22	9/05	5/20	9/09	6/11	5/20	6/01	5/23	6/05	5/27	5/19	6/01	6/06	5/29	6/04	5/19	5/18	5/16	5/31	5/25
Ending	5/24	9/07	5/23	9/12	6/13	5/22	6/03	5/25	6/07	5/29	5/21	6/03	6/08	6/31	6/06	5/21	5/20	5/18	6/02	5/29
Recaptured from Event 1	0	21	15	2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 2		0	33	7	8	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 3			0	35	14	8	1	0	1	0	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 4				0	27	3	3	1	0	0	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 5					0	6	7	6	0	1	1	0	0	0	0	0	0	0	0	0
Recaptured from Event 6						0	39	17	7	2	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 7							0	27	3	2	0	0	0	0	0	0	0	0	0	0
Recaptured from Event 8								0	29	3	2	0	1	0	0	0	0	0	0	0
Recaptured from Event 9									0	11	6	3	1	0	0	0	0	0	0	0
Recaptured from Event 10										0	6	5	0	0	0	0	0	0	0	0
Recaptured from Event 11											0	24	23	4	5	0	0	0	0	0
Recaptured from Event 12												0	41	8	7	4	0	0	0	0
Recaptured from Event 13													0	21	16	10	6	2	2	1
Recaptured from Event 14														0	16	13	3	1	0	0
Recaptured from Event 15															0	13	3	3	1	0
Recaptured from Event 16																0	19	9	4	1
Recaptured from Event 17																	0	24	21	9
Recaptured from Event 18																		0	23	22
Recaptured from Event 19																			0	38
Recaptured from Event 20																				0
Captured with tags	51	51	66	48	51	19	51	53	40	19	15	32	66	33	44	40	31	39	51	71
Captured without tags	164	129	297	89	145	210	159	142	89	29	118	120	308	79	78	201	177	171	205	291
Captured	215	180	363	137	196	229	210	195	129	48	133	152	374	112	122	241	208	210	256	362
Released with tags	215	180	362	136	196	225	209	195	129	48	133	151	372	112	121	240	207	209	255	361

APPENDIX D
HOOP TRAP SUMMARY

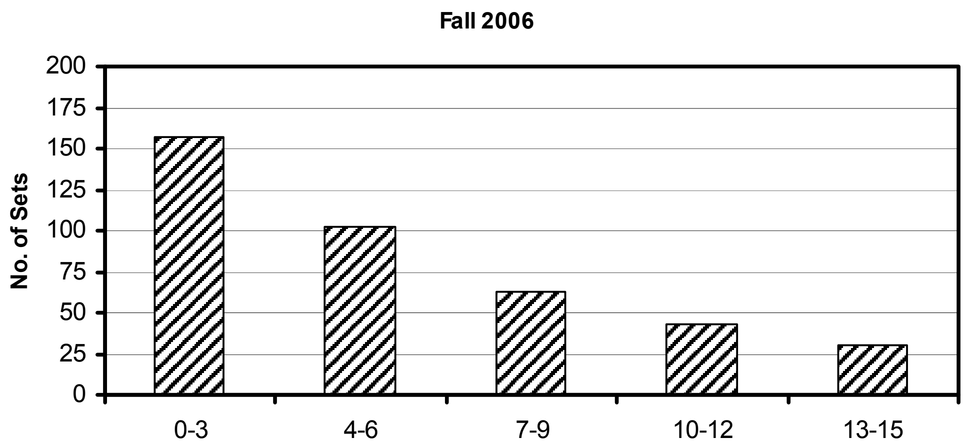
Appendix D1.–Frequency of sets by depth and average catch of burbot by depth in Crosswind Lake during spring, 2006.

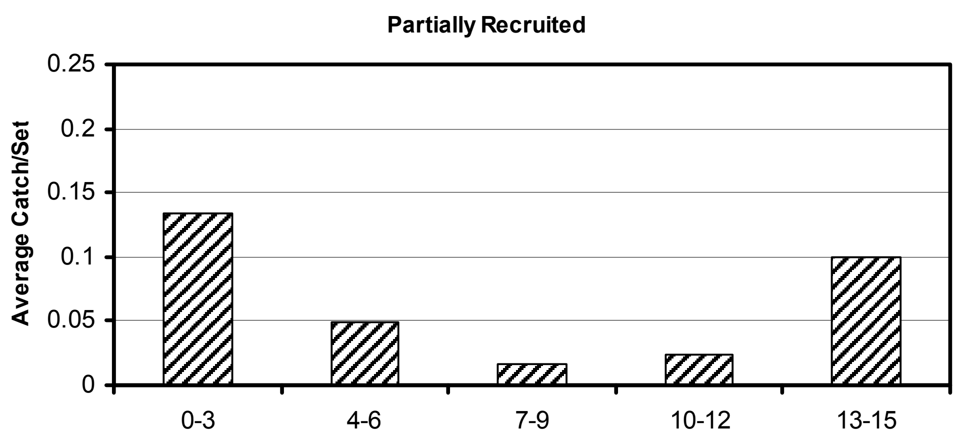


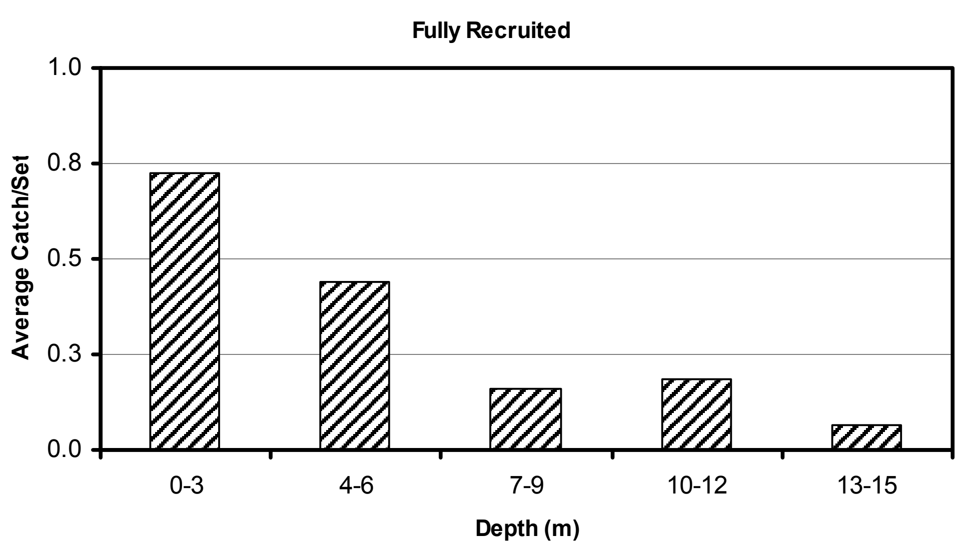




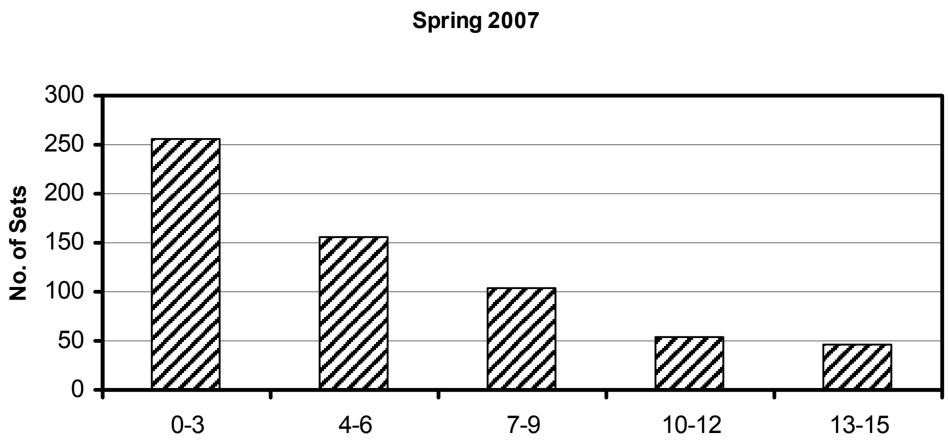
Appendix D2.–Frequency of sets by depth and average catch of burbot by depth in Crosswind Lake during fall, 2006.

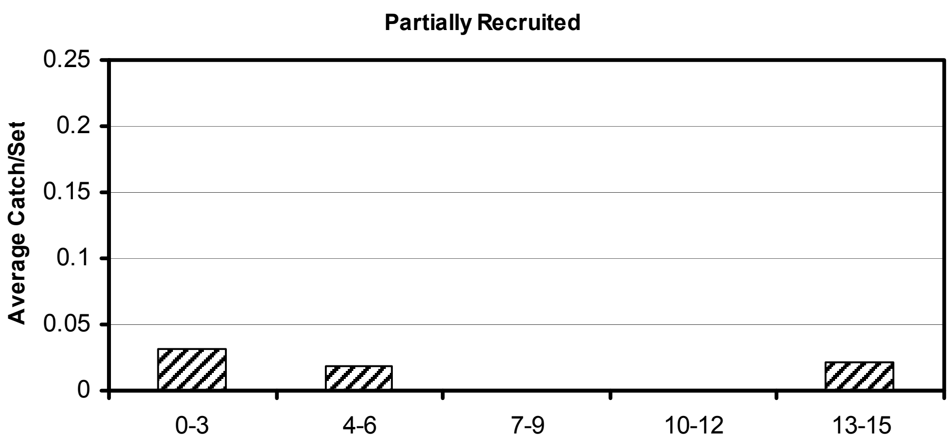


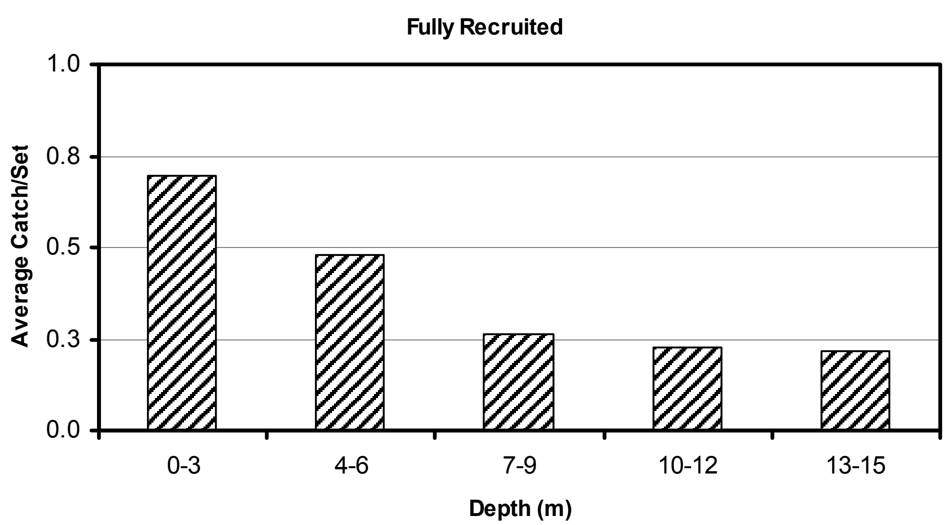




Appendix D3.–Frequency of sets by depth and average catch of burbot by depth in Crosswind Lake during spring, 2007.







Appendix D4.–Frequency of sets by depth and average catch of burbot by depth in Crosswind Lake during fall, 2007.