EAST KOOTENAY BURBOT POPULATION ASSESSMENT

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Abstract

Due to concerns over declining burbot populations in the Kootenay Region, a study was initiated by the BC Ministry of Environment to provide better information on which to base regulations. The purpose of the study was to assess the population abundance and biological characteristics of burbot in four East Kootenay Lakes: Moyie, St. Mary, Columbia and Windermere. This work builds upon initiatives by Ministry of Environment staff in September 2005 on St. Mary and Moyie Lake burbot populations.

Following a random sampling design, burbot were captured using hoop and cod traps from May – November 2006. To minimize decompression trauma while maximizing sample area, trap locations were restricted to depths < 32 m and special handling procedures followed. A few deeper sets were deployed to address potential bias in CPUE estimates.

Cod traps out performed hoop traps by nearly 2:1 (Mann-Whitney, $P < 0.05$). While trap efficiency differed, mean size of captured burbot did not (Mann-Whitney, $P > 0.05$). Mean CPUE results were 2.12 (SE 0.13) in Moyie Lake, 0.64 (SE 0.28) in St. Mary Lake, 0.58 (SE 0.13) in Columbia Lake and 0.12 (SE 0.04) in Windermere Lake. Catch rates were highest in the spring. Burbot showed no strong depth preference (Kruskal-Wallis, P>0.05) thus, potential bias in estimates of mean CPUE was considered negligible.

Within Moyie Lake, adult burbot moved rapidly and randomly (sign test, $P > 0.05$) between surveys within the same basin. However, burbot were not recaptured in different basins within the same year despite being closely interconnected. Thus, mark-recapture data was separated by basin and a combination of methods (Petersen and Jolly-Seber) used to extend the range of estimates. Population estimates were severely biased (upwards) due to a lack of recaptures (n = 21). Abundance estimates ranged from 1765 to 5915 (SE 979 to 3351) in the North Basin and from 758 to 1397 (SE 303 to 1181) in the South Basin. Survival from September 2005 to May 2006 was estimated at 53% and assumed equal in both basins. With only 3 sample events, it was not possible to estimate recruitment. Density estimates averaged 3.25 burbot per ha in Moyie Lake and were similar across basins. Spring and summer catchability coefficients were estimated at 0.59 to 0.17 in North Moyie and 0.93 to 0.54 in South Moyie, respectively.

Immediate trap induced mortality occurred at rates of 0% for depths < 14 m (n =113), 2.4% for depths 15-35 m (n = 449) and 31.25 % for depths > 35 m (n = 24). Delayed handling mortality appeared negligible, as recapture rates were similar regardless of depth of initial capture ($r = -0.277$, $P > 0.05$, n = 21). Special handling procedures and sampling when water temperatures are low and isothermal are believed to reduce the rate of gas diffusion that results in decompression trauma.

There was no relationship between fish size and capture depth nor were there any seasonal differences in mean length of captured burbot (Kruskal-Walis, $P > 0.05$). Burbot were in the best condition in November, just prior to spawning and after a summer of feeding (Mann-Whiney, $P < 0.05$). Moyie Lake burbot had the highest mean relative weight in all size categories and Columbia Lake fish the lowest. Columbia, and Windermere Lake burbot were below the published relative weight objective range proposed for the species (i.e., 80 +/- 5). The low relative abundance and poor condition of Columbia, Windermere and St. Mary Lake populations support severely restricted harvest regulations and the need for continued investigation of limiting factors affecting burbot growth and survival in these lakes.

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Thank you to Colin Spence, Matt Neufeld, Herb Tepper, Kevin Heidt, John Bell, and Don Miller of the BC Ministry of Environment for technical assistance throughout the field program. Colin Spence was instrumental in developing experimental design and handling procedures, as well as providing editorial reviews, which greatly improved this document. Vaughn Paragamian of Idaho Fish and Game was very helpful with discussions on burbot behavior and genetics. Similarly, Steve Arndt (Columbia Basin Fish and Wildlife Compensation Program) was gracious in sharing his knowledge of the Columbia Lake burbot fishery in discussions of burbot growth and condition. Carl Schwarz (Simon Fraser University) assisted with data analysis and provided useful instruction for the program MARK. I also wish to thank Scott Cope (Westslope Fisheries Ltd.) for collecting data and Paul Giroux (BC Ministry of Environment, Skeena Region) and Bill Westover for providing editorial reviews. Kenton Andreashuk of Columbia-Kootenay Fisheries Renewal Partnership provided useful data on the Moyie Lake winter fishery.

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1. Introduction

Historically, burbot supported popular and productive fisheries in a number of East Kootenay lakes and streams. In recent years, however, concerns have developed over the status of this species following significant declines in several regional populations (Arndt 2002, Paragamian et al. 2000). Local knowledge investigations indicate that populations in Columbia and Windermere lakes once consisted of much larger fish, in larger numbers and possibly with broader distribution than exist at present (Prince 2001). This evidence, combined with the complete collapse of regional populations due to over harvesting (i.e., West Arm Kootenay Lake, Ahrens and Korman 2002) suggests burbot stocks in this area urgently require additional management attention. In the absence of better information on East Kootenay burbot status, severely restricted harvest regulations have been proposed (or already implemented) by the Ministry of Environment.

The purpose of this study was to assess the abundance and biological characteristics of burbot populations in four East Kootenay Lakes: Moyie, St. Mary, Columbia and Windermere (Figure 1.1.1). Each population chosen for this study has (or had) a popular sport fishery for burbot and is readily accessible to anglers. It was hypothesized that currently, burbot stocks are severely depressed in St. Mary, Columbia and Windermere Lakes but are relatively healthy in Moyie Lake. The objectives for work in 2006 were to estimate:

1. Mean catch per unit of effort (CPUE) of burbot in four lakes as an index of abundance;

2. Abundance of burbot in Moyie Lake;

3. Mean total length, length at age, and parameters in the length-weight relationships of burbot in the four lakes and;

4. Comparison of catch success between two trap styles (hoop vs. cod).

This work builds upon sampling by Ministry of Environment staff in late 2005 on St. Mary and Moyie Lake burbot populations and utilizes techniques developed in the West Kootenay for burbot stock monitoring (Neufeld and Spence 2004).

1.1. Study Area

Columbia and Windermere are shallow, eutrophic lakes located at the headwaters of the Columbia River in southeastern British Columbia. Columbia Lake drains north via the Columbia River into Windermere Lake, which is approximately 20 km downstream. In contrast, St. Mary and Moyie Lakes are deeper, oligotrophic lakes that drain into the Kootenay River (Table 1.1.1). St. Mary Lake divides the St. Mary River 45 km upstream from its confluence with the Kootenay River and 40 km downstream from its headwaters in the Purcell Mountains. Moyie Lake is actually two basins, North and South Moyie separated by 2 km of river. Moyie Lake drains into the Moyie River, which flows south where it empties into the Kootenai River near Bonner's Ferry, Idaho (Figure 1.1.1). Recent genetic studies have shown that Moyie Lake burbot are most closely related to stocks in the Kootenay River in Idaho while St. Mary River fish are more closely related to stocks in the Kootenay River, Montana, and Lake Koocanusa (Vaughn Paragamian, *pers. comm.* 2006).

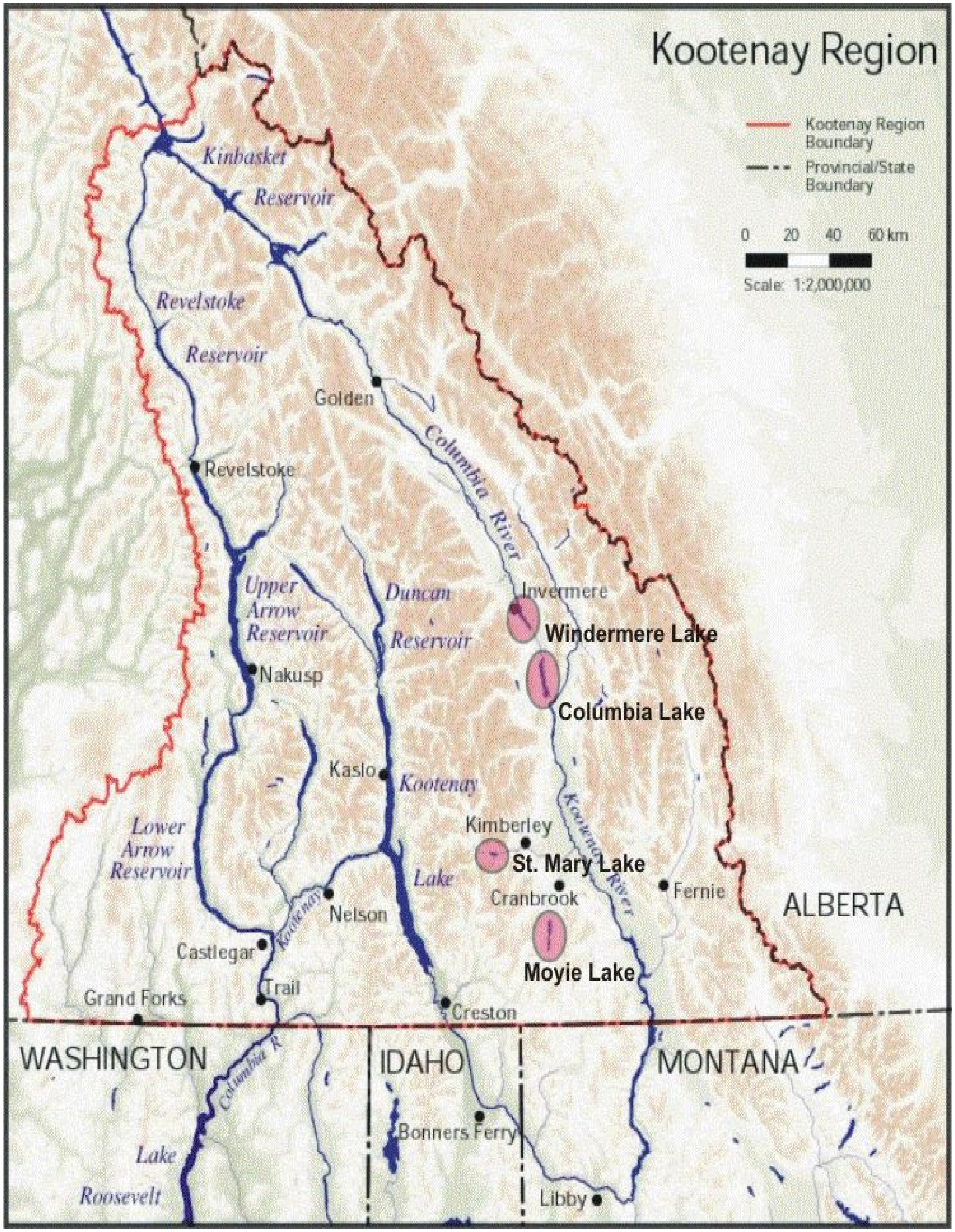

Figure 1.1.1 Location of burbot study lakes in the East Kootenay.

Table 1.1.1. Descriptive statistics for East Kootenay study lakes with populations of burbot (Source: BC Fisheries Data Warehouse).

Lake	Area (ha)	Depth (m) Maximum	Depth (m) Mean	Elevation (m)	TDS (mg/L)	Trophic Status
North Moyie	583	73	32	929	n/a	Oligotrophic
South Moyie	316	57	17	929	42	Oligotrophic
St. Mary	295	21	8	960	46	Oligotrophic
Columbia	2574	5	3	808	230	Eutrophic
Windermere	1817	6	3	800	270	Eutrophic

A winter fishery occurs from January through early March on the study lakes in which the majority of burbot harvesting occurs. Recent creel surveys on Columbia Lake (1995-2001, Arndt 2001) indicate effort of 300-500 angler days per winter and highly variable annual harvest (50-500 burbot; 0.08-0.54 fish/hr). Yields averaging 0.15 kg/ha in Columbia Lake are similar to less productive oligotrophic lakes in Maine and Alaska (Quinn 2000). Effort on Windermere Lake was reported higher than on Columbia but with a much lower CPUE. Of a total 91 fish captured in 1996/97, only 26 were harvested (0.02 fish/hr, yield averaging 0.01 kg/ha; Arndt 2001). Burbot catch rates on Moyie Lake were similar to those reported for Columbia Lake and ranged from 0 to 1.0 fish/hr in 2002 with a mean rate of 0.06 fish/hr (Table 1.1.2.). Empirical information on the St. Mary Lake burbot fishery was unavailable.

Table 1.1.2. Summary of Moyie Lake winter creel data for the period of 26 Jan to 23 Feb 2002 (unpublished data from Kenton Andreashuk, Columbia-Kootenay Fisheries Renewal Partnership). Note: CPUE was calculated for each angler/angling party on each day.

Anglers	Effort (hrs)	Catch Burbot	Catch Largescale Sucker	Catch Rainbow Trout	Burbot CPUE Mean	Burbot CPUE SE	Burbot CPUE n
223	711	31	6	10	0.06	0.02	79

2. Methods

2.1. Study Design

Trap locations were randomly selected from a grid placed over a map of the lake. Traps were placed at the nodes of the grid where each block represented an area of 200 X 200 m. Since significant differences in mortality can occur when burbot are captured deeper than 15 m (Bernard et al. 1993), the sampling grid was restricted by depth in Moyie Lake (Appendix A1). To minimize severe decompression trauma (i.e., stomach evulsion or ruptured blood vessels) while maximizing sample area, the majority of traps were restricted to depths < 32 m (mean depth of North Moyie, Table 1.1.1) and special handling procedures followed (see below). To address the potential bias in mean CPUE estimates, a few deeper sets were also deployed.

Three sampling sessions were scheduled for 2006 (Table 2.1.1). Sessions were scheduled to coincide with maximum catch rates, which occur within 30 days of spring thaw and just before ice-up, to maximize precision of abundance estimates (Bernard et al. 1993). Two sessions were scheduled in the spring on Moyie Lake to meet closed population model assumptions of no recruitment or mortality. All other lakes were sampled once to generate relative indices of abundance (CPUE).

Table 2.1.1. Sampling schedule for East Kootenay Burbot stock assessment program.

Lake	Sample Event	Sample Dates
North Moyie	1	09-12 Sep 2005*
(upper basin)	2	12-19 May 2006
	2'	07-09 June 2006
	3	30 Oct-05 Nov 2006
South Moyie	1	13-15 Sep 2005*
(lower basin)	2	08-15 May 2006
	2'	05-07 June 2006
	3	03-09 Nov 2006
St. Mary Lake	1	16-19 Sep 2005*
Columbia Lake	1	23-27 Oct 2006
Windermere Lake	1	16-22 Oct 2006

*Trap placement did not follow randomized design.

2.1.1. Gear Description

Two types of traps were used to capture burbot in this study: hoop and cod traps. Hoop traps have been employed for burbot work throughout the United States (Bernard et al. 1991; Paragamian 2000) while cod traps have been preferred in British Columbia (Spence 2000; Bisset et al. 2002; Giroux 2005; Arndt and Baxter 2006). Detailed descriptions of each trap type are provided in Spence 2000. Hoop traps were used for one sample session in Moyie Lake to test hypothesis regarding trap type and catch success (Mann-Whitney, P = 0.05). In all other lakes and sample sessions, cod traps were used.

Each trap was baited with two kokanee that were scored and placed into a mesh bag attached opposite the trap throat. The baited trap was lowered under tension (important for cod traps to ensure they do not tip over and block the throat) to the bottom and an individually numbered floating buoy attached for retrieval and identification. Depth (to the nearest foot), time, location (UTM with recreational grade GPS), and grid cell were recorded. Traps were soaked for approximately 48 hours as Bernard et al. (1991) showed that trap effectiveness was reduced after 48 hours. Each trap's catch was processed and released at the capture site and the empty trap stored on board. Old bait was discarded on shore. Traps were not reset until all previous deployments had been recovered; then, traps were rebaited and redeployed in another randomly selected grid cell. The total number of traps set and pulled in a day ranged from 15 in 2005 to 22 in 2006.

2.1.2. Handling Procedures

In all lakes except Moyie, traps were set and retrieved by a two person crew. One person piloted the boat and recorded data while the other handled traps, tagged and sampled captured burbot. Previous research has found that handling mortality may be minimized by deflating burbot (Bruesewitz et al. 1993) and limiting the time they are exposed to the surface (Neufeld and Spence 2004). Thus, in Moyie Lake where catches were large (up to 15 fish/trap) and traps deep, a third crewmember was added to facilitate fish processing. To further minimize surface exposure time, an electric winch was used to rapidly retrieve traps and random sub-sampling employed for measurements of weight (g) and length (mm).

All captured burbot were examined for tag presence and, if absent, a numbered Floy tag was inserted at the base of the anterior dorsal fin. If a fish showed signs of mild decompression trauma (i.e., gas accumulation in the abdominal cavity and/or behind pectoral fins) the fish was deflated with a hollow needle using techniques similar to those of Bruesewitz et al. (1993). The fish was then placed in a weighted, open bottom cage that was immersed and suspended off the side of the boat. Once the entire catch was processed, the cage was inverted and lowered to the bottom. There, fish were released with a quick pull of the tether rope (attached to the top) and the cage retrieved. Crews remained at the capture location for another 3-5 minutes to observe any resurfacing burbot resulting from decompression trauma (Neufeld and Spence 2004). Mortalities were sampled for sex, stomach contents, and age determinations (otolith).

2.2. Data Analysis

2.2.1. Mean CPUE

Mean catch per unit effort (CPUE) and variances were calculated for all four lakes as follows (Parker et al. 1987):

Equation 1) $$\text{Mean CPUE} = \sum_{j=1}^{m} x_j \quad \text{where } x_j = \frac{C_j}{E_j}$$

Equation 2) $$\text{Variance of mean CPUE} = \sum_{j=1}^{m} \frac{(x_j - x)^2}{m\,(m-1)}$$

Where:

C = catch;

E = effort in units of 48 hours; and

m = number of sets

Because few burbot enter traps during daylight and traps stop fishing after 48h (Bernard et al. 1991) catches were not adjusted for the few hours deviation in soak times from the standard 48 hours. Adjusting catches for longer or shorter soak times introduces significant bias as a division of catch does not adjust “zero” catches but does adjust large ones (Parker et al. 1987). Therefore, CPUE for the two occasions (15 traps set 09-12 Sept 2005 and 22 traps 12-15 May 2006) when crews retrieved traps after 72 hrs were not adjusted from the standard set duration.

Due to the non-normal, heteroscedastic nature of the data (i.e., data is highly skewed due to frequency of zero catches), non-parametric analyses were used throughout the study with a significance level of 0.05 (Zar 1984). Estimates of mean CPUE were post-stratified by depth in Moyie Lake to examine depth preference (Kruskal-Walis).

2.2.2. Abundance, Survival Rates and Recruitment

In those lakes with multiple sampling events (i.e., North and South Moyie), abundance of burbot was estimated by mark-recapture. Due to uncertainty as to the length at full recruitment to cod traps (burbot are fully recruited to hoop traps at 450 mm length, Bernard et al. 1991), a single estimate of abundance was computed for each population. A combination of methods, Jolly-Seber and Petersen, were used to extend the range of estimates according to the approach suggested in Pollock (1982). Surveys designed for 1-year, two-sample experiments using Chapman's (1951) modification of the Petersen model were completed only a few weeks apart to allow for mixing of marks with untagged fish and to minimize growth recruitment and mortality between sample events (assumptions of closed population model). Chapman's modification of the Petersen estimate (omitting the -1 which is of no practical significance) is as follows:

Equation 3)

$$N^* = \frac{(M + 1)(C + 1)}{R + 1}$$

Where:

M = number of burbot marked and released alive in sample event 2 (May)
C = number of burbot captured in sample event 2' (June)
R = number of sample event 2 marks recaptured in event 2'

A second abundance estimate for mark-recapture experiments with two events separated by more than 4 weeks was generated with the techniques of Jolly (1965) and Seber (1965). Since Jolly-Seber methods are unbiased only for situations with large sample sizes and with large numbers of recaptured fish (Gilbert 1973), sampling events separated by 4 weeks or less were pooled into one event. With the North and South Moyie Lakes population having been sampled for at least three consecutive events, estimates of abundance, survival rate, recruitment and their variances were calculated using the program MARK (White and Burnham 1999). Dr. Carl Schwarz, Department of Statistics and Actuarial Sciences, Simon Fraser University, Burnaby B.C., conducted all analysis with MARK. Recaptures during a single event were considered captured only once to estimate abundance with the mark-recapture experiments, but were considered captured every time to estimate mean CPUE.

2.2.3. Catchability coefficients

Catchability coefficients from the mark-recapture experiments were calculated as the ratio of mean CPUE to density of burbot (Bernard et al. 1993):

Equation 4)

$$q_{ij} = \frac{A_i * \text{meanCPUE}_{ij}}{N_{ij}}$$

Where:

N_{ij} = the estimated abundance during the jth survey of the ith population
q_{ij} = Catchability coefficient for the jth survey of the ith population
A_i = surface area (ha) of the lake containing the ith population and
$meanCPUE_{ij}$ = mean CPUE for the jth survey of the ith population

3. Results and Discussion

3.1. Catch

Burbot traps captured a variety of species ranging in size from 1010 mm (North Moyie burbot) to 60 mm (largemouth bass; Table 3.1.1). Both the longnose sucker and sculpin captured in Moyie Lakes were found in the mouths of captured burbot. Thus, incidental species capture in these lakes may have been greater than observed.

Table 3.1.1 Species composition of fish captured with hoop and cod traps during the burbot sampling program 2005/06 (hoop traps used only in Moyie Lakes).

		Effort	Catch						
Lake	Area (ha)	No. of Traps	BB	NSC	PMB	LMB	LSU	CC	BT
North Moyie	583	146	298	0	0	0	1	0	0
South Moyie	316	131	288	0	0	0	0	1	1
St. Mary	295	11	7	0	0	0	0	0	0
Columbia	2574	40	23	23	0	0	0	0	0
Windermere	1817	60	7	8	40	3	0	1	0

BB = burbot
NSC = northern pikeminnow
PMB = pumpkinseed
LMB = largemouth bass
LSU = longnose sucker
CC = sculpin spp.
BT = bull trout

3.2. Mean CPUE

Mean CPUE was highest in Moyie Lake and lowest in Windermere Lake (Table 3.2.1). Mean CPUE was similar between North and South Basins of Moyie Lake (Mann-Whitney, $P > 0.05$) (Sept 2005 session omitted from analysis as it did not follow the same experimental design). As expected, catch rates were highest in the spring/fall and declined by June (Bernard et al. 1993).

Table 3.2.1. Mean CPUE of East Kootenay burbot populations. Two trap types (cod and hoop) were used in the fall sample sessions of Moyie Lake, otherwise, cod traps were used.

Lake	Area (ha)	Sample Dates	Effort (# of traps)	Catch Total	Catch Min	Catch Max	CPUE	SE
North Moyie	583	09-12 Sep 2005*	15	66	1	10	4.40	0.56
		12-19 May 2006	59	114	0	8	1.93	0.25
		07-09 June 2006	22	32	0	8	1.45	0.44
		30 Oct-05 Nov 2006[cod]	25	61	0	6	2.44	0.41
		30 Oct-05 Nov 2006[hoop]	25	25	0	4	1.00	0.25
South Moyie	316	13-15 Sep 2005*	15	59	0	15	3.93	0.92
		08-15 May 2006	51	142	0	8	2.78	0.31
		05-07 June 2006	22	21	0	4	0.95	0.25
		03-09 Nov 2006[cod]	23	39	0	5	1.70	0.25
		03-09 Nov 2006[hoop]	20	27	0	7	1.35	0.44
St. Mary	295	16-19 Sep 2005	11	7	0	3	0.64	0.28
Columbia	2574	23-27 Oct 2006	40	23	0	3	0.58	0.13
Windermere	1817	16-22 Oct 2006	60	7	0	1	0.12	0.04

* Trap placement did not follow randomized grid design

3.2.1. Depth Preference

Burbot captured in Moyie Lake showed no strong depth preference (Kruskal-Wallis, $P > 0.05$) in either basin; thus, surveys restricted by depth (i.e., < 35 m) to avoid decompression related mortality should not bias abundance estimates (Figure 3.2.1). The lack of any relationship between depth and burbot catch rates has also been reported for 5 populations sampled in Alaska (Bernard et al. 1993) and 4 populations in the Skeena Region of British Columbia (Giroux in prep; Giroux 2005).

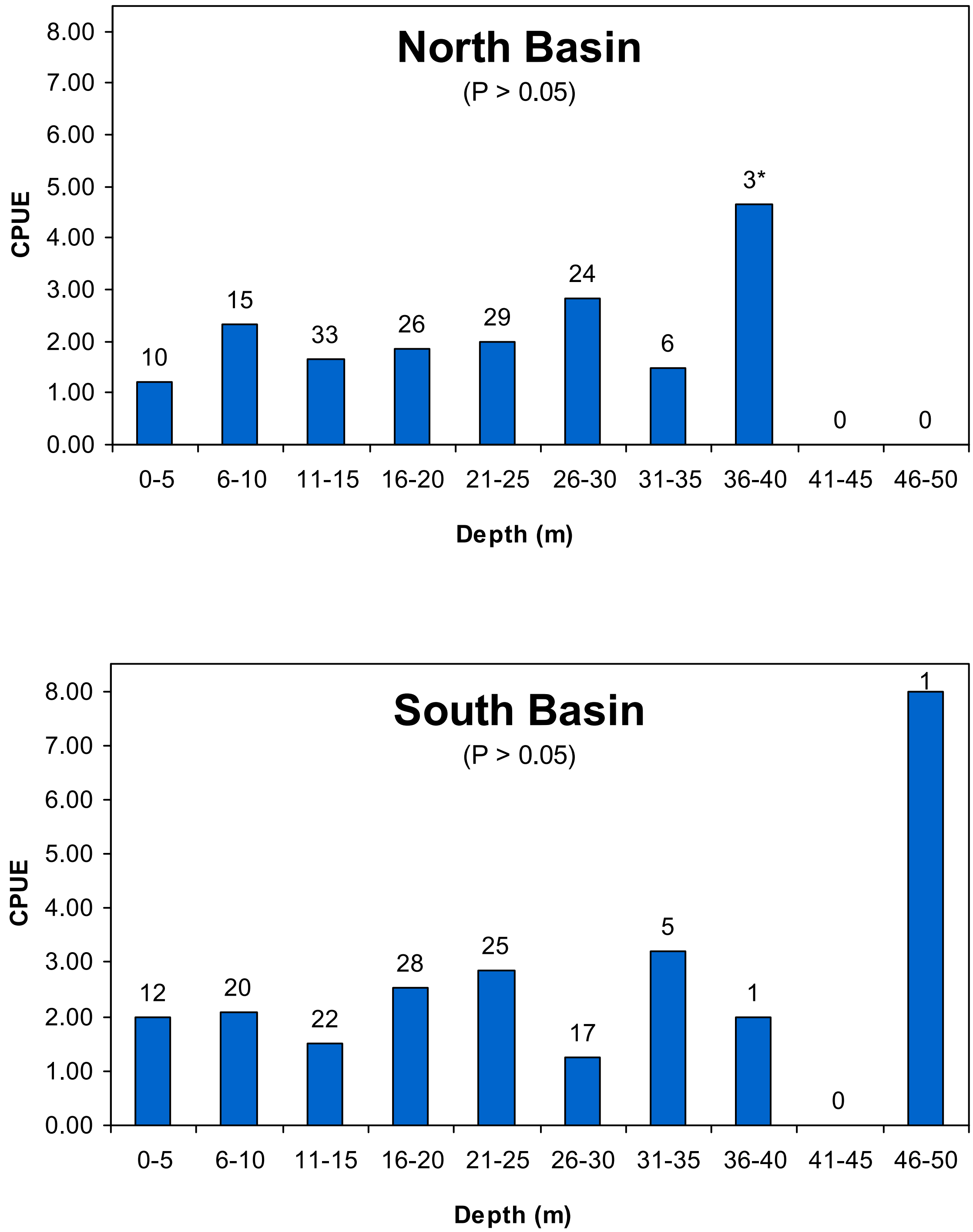

Figure 3.2.1. Burbot catch rates by depth (m) in Moyie Lake (Kruskal-Walis, $P > 0.05$). Numbers above bars indicate the number of sets in each depth category. Depth categories from Bernard et al. (1993). *Note that one trap with 8 fish skews distribution.

3.2.2. Trap Efficiencies

During the November 2006 sample session in Moyie Lake, 48 cod traps and 45 hoop traps were randomly deployed in both basins to examine differences in catch rates. Cod traps outperformed hoop traps by nearly 2:1 (Table 3.2.2, Mann-Whitney, $P < 0.05$). While trap efficiency differed, mean length did not (Mann-Whitney, $P > 0.05$). These findings support those reported for burbot populations in Duncan and Kootenay Lakes (Spence 2000); but contradict efficiencies reported for other locations. For example, in a northern B.C. lake, hoop traps out fished cod traps by 1.3: 1, however, cod traps did out fish hoop traps on occasion (Paul Giroux, B.C. Ministry of Environment, *pers. comm.*). It is hypothesized that variations in mesh size and throat design account for discrepancies in catch rates.

Table 3.2.2. Comparison of burbot catch rates and size for cod and hoop traps in Moyie Lake, 2006.

Trap	CPUE (burbot/set)			Burbot Length (mm)		
	Mean	SE	n	Mean	SE	n
Cod	2.08	0.25	48	613.28	6.23	95
Hoop	1.16	0.24	45	611.55	7.8	42

3.3. Abundance, Survival and Recruitment

The accuracy of abundance estimates from the mark-recapture experiments are predicated on certain conditions, including equal probability of capture for all individuals during at least one sample event or complete dispersal of tagged individuals throughout the population (Ricker 1975). Since the basins of Moyie Lake are closely interconnected and burbot are known to move rapidly and randomly across depths between surveys within the same season (Bernard et al. 1993), this study was designed to treat burbot in the North and South basins of Moyie Lake as one population. However, throughout the course of the study, only one out of 21 recaptures was found in a different basin and it was recovered in a different year. In addition, we discovered that five years of mark-recapture experiments on burbot populations in six closely interconnected Alaskan lakes (separated by 800-1700m of river) had also shown negligible stray rates with none of the strays ever recovered in different lakes in the same year (Lafferty et al. 1992). Since the model assumption of equal probability of capture was likely not met in Moyie Lake, the data was separated by basin (north and south) and estimates of abundance, survival and recruitment were calculated separately for each population. Unfortunately, a consequence of this post-hoc stratification was reduced precision in abundance estimates (i.e., not enough recaptures per basin).

The Petersen estimate is a closed population model in which immigration, death, etc., are considered negligible. The Petersen model uses the ratio of marked to unmarked individuals to estimate population size. Since the Petersen model tends to overestimate the true population, a modified formula was used to achieve an unbiased estimate (Chapman 1951). The one stray was treated as staying in the North basin for mark-recapture analysis. With only one 48-hr set array (set array = 22 traps) per basin during the second sampling event in June (Appendix A2), there were too few recaptures (n=1) to generate an unbiased

Petersen estimate for North Moyie (Table 3.3.1). However, with (n=3) June recaptures in the South Basin, the probability of statistical bias in a Petersen estimate can be ignored and a reliable estimate obtained (Ricker 1975). The South Basin of Moyie Lake contained an estimated 758 (SE 303) burbot in May 2006 (Table 3.3.1).

The Jolly-Seber estimate is an extension of the Petersen two sample closed population model where fish can enter (through immigration, or recruitment to catchable size) or leave (through emigration or death). The Jolly-Seber is therefore referred to as an open population model. As sample events 2 and 2' were very close (i.e., < 4 weeks apart), they were pooled into a single period to increase sample size. Pooling increased the number of recaptures (sample size) to 5 in the north basin and 16 in the south (Appendix A2). The resulting abundance estimates were 1851 (SE 1576) and 1397 (SE 1181) for the north and south basins, respectively (Table 3.3.1).

The Jolly-Seber models estimate abundance for the second population size (N2), which was May/June, 2006. The estimates were poor despite the increase in sample size because the model has too many parameters to estimate given the sparse data (Schwarz 2007). In the Jolly-Seber models, not all parameters were identifiable. With only three sample times, only the first survival rate from Sept 2005 to May 2006, the second capture rate, and the second population size (N2) were estimable without further constraints. In addition, it was not possible to estimate any of the recruitment numbers. Survival rates were assumed to be equal across basins and estimated at 53% from Sept 2005 to May 2006 (Table 3.3.1).

Given the very close time between events 2, 2' and 3 (May to Nov), and the fact that angling and spawning for this species occurs during the winter, the population may be considered essentially closed. Consequently, a closed population model was fit to these three time events. Since the number of traps varied over the three events, the capture rates were modeled as a function of the number of traps. That is, for each basin, the capture rate was proportional to the number of traps set for each event. The abundance estimates using this "pooled" closed population model were 5915 (SE 3351) and 1153 (SE 329) for the north and south basins respectively (Table 3.3.1).

Table 3.3.1. Abundance and Survival Estimates for Moyie Lake Burbot 2006 (Schwarz 2007).

Population	Dates (2006)	Abundance Estimate	SE	Survival Rate (%) Estimate	SE
North Moyie	12 May - 9 June	1765[a]	979	53%	30.45
	12 May - 9 June	1851[b]	1576		
	12 May – 5 Nov	5915[c]	3351		
South Moyie	8 May - 7 June	758[a]	303	53%	30.45
	8 May - 7 June	1397[b]	1181		
	8 May - 7 Nov	1153[c]	329		

[a] Chapman's closed population estimate for events 2 and 2'

[b] Jolly-Seber open population estimate (pooled events 2 and 2')

[c] Closed population estimate for events 2, 2' and 3 with capture rates as a function of the # of traps

While all abundance estimates for North Moyie are severely biased upwards, the Chapman modification has less bias. The closed population models based on the last three events may be a close approximation, with the estimated population size in the North basin about 6 times larger than in the South basin. These results are somewhat consistent with the raw data as similar numbers of traps were deployed in both basins with similar catches, but over 4X the number of recaptures were obtained in the south basin compared to the north (Schwarz 2007*)*.

3.4. Model Assumptions

3.4.1. Handling Mortality

Immediate trap induced mortality occurs within 10 minutes of capture and is predicated by the appearance of pale gill filaments, indicative of a ruptured aorta (Neufeld and Spence 2004). As with Alaskan populations (Bernard et al. 1993), burbot captured at depths less than 14 m had 0% mortality while fish captured deeper than 35 m experienced significant 25-31% mortality (Table 3.4.1).

Table 3.4.1. Immediate trap induced mortality rate for Moyie Lake burbot captured May – November, 2006.

Depth Category (m)	Catch	Mortalities	Mortality Rate (%)
0-5	36	0	0.00
6-10	77	0	0.00
11-15	87	1	1.15
16-20	119	3	2.52
21-25	129	4	3.10
26-30	89	3	3.37
31-35	25	0	0.00
36-40	16	5	31.25
41-45	0	0	0.00
46-50	8	2	25.00

Delayed handling mortality of marked burbot was investigated by comparing recapture rates of burbot against depth of initial capture (Spearman Rank Correlation, Figure 3.4.1). Again, as in Alaskan burbot populations, recapture rates were similar regardless of depth of initial capture ($P > 0.10$, Bernard et al. 1993), thus, potential bias in abundance estimates was considered negligible. The use of special handling procedures (i.e., immediately deflating fish and rapidly retrieving and returning them to depth) is believed critical in reducing decompression trauma (Neufeld and Spence 2004). Trauma results from gases coming out of solution with the rapid decline in ambient pressure from decreasing water depth. Since the rate of diffusion is affected by water temperature, sampling when temperatures are cool and isothermal (i.e., just after ice off) may further reduce the incidence of trap induced mortality.

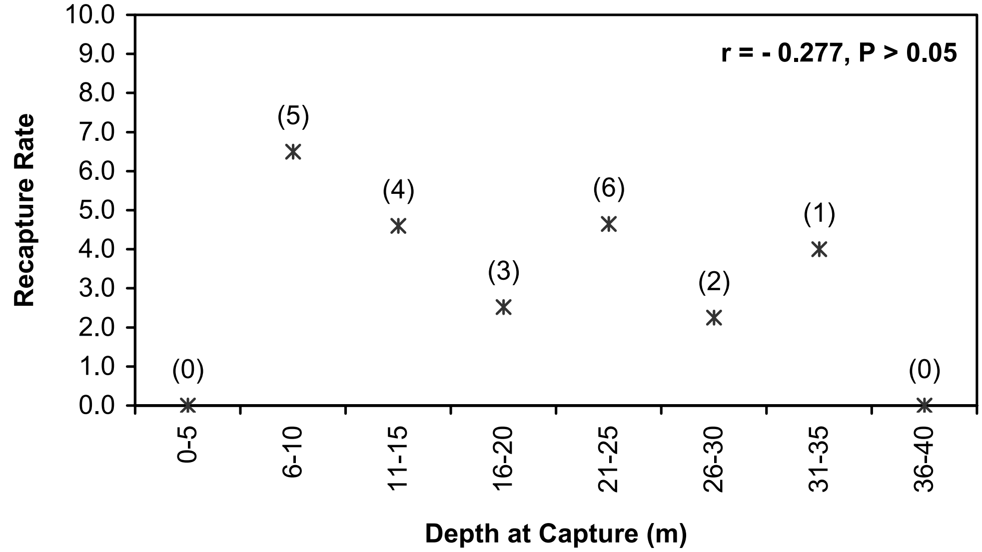

Figure 3.4.1. Recapture rates of burbot captured at various depths. Data labels above points indicate numbers of fish recaptured in that depth category. Table 3.3.1 lists numbers of fish captured in each depth category.

3.4.2. Mixing of Marks

To test random mixing assumptions, recapture depth was plotted against depth of initial capture (Spearman Rank Correlation, Figure 3.4.2). In addition, the spatial distribution of captures and recaptures was examined (Table 3.4.2). Of the burbot that changed their depth (only one did not), 12 went shallower and 8 went deeper which is typical of random movement (sign test P = 0.26). While adult burbot moved rapidly and randomly between surveys within the same basin, burbot were not recaptured in different basins within the same year. The depth distribution for adult burbot recaptured in six mark-recapture experiments was also random in deep Alaskan lakes (Bernard et al. 1993).

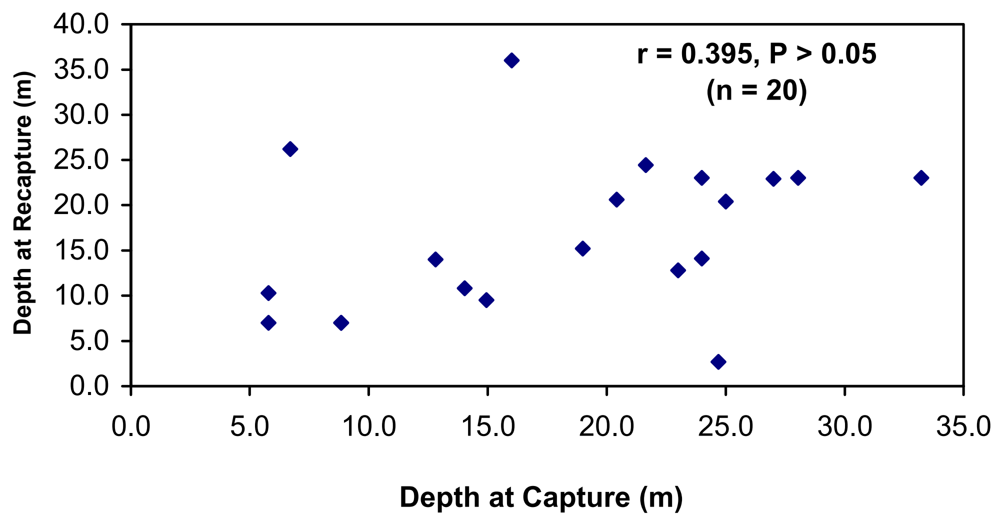

Figure 3.4.2. Depths of capture and recaptured burbot in mark-recapture experiments in Moyie Lake, 2006 (Note: one fish did not change depth).

Table 3.4.2. Spatial distribution of captured and recaptured burbot in Moyie Lake. Note that eight recaptures were originally tagged in 2005 before the grid overlay sampling design was implemented; therefore comparisons were not possible. Refer to Appendix A1 for cell locations.

Lake	Tag Number	Capture Date	Capture Cell	Recapture Cell
North Moyie	010986	17-May	29	53
	010975*	17-May	outside grid/deep set	51
South Moyie	010338*	8-May	30	42
	010677*	8-May	30	42
	010333*	8-May	42	42
	010633	8-May	33	48
	010332	8-May	42	33
	010681	8-May	43	51
	010636	8-May	45	52
	010643	10-May	14	48
	010276	10-May	24	14
	010605	10-May	3	3
	7967	5-Jun	28	11

* Recaptures within 4 weeks of original capture, all others were recaptured after 6 months.

3.5. Catchability Coefficients

The relationship between stock density, abundance and catch per unit effort (CPUE) is an important method of monitoring major fish stocks. In general, CPUE is related to stock density and is proportional to abundance under conditions of standard fishing time, gear density and area inhabited by the fish stock (Pearse and Conrad 1986).

The catchability coefficient represents the fraction of a hectare fished with one unit of effort (a set). Once defined, the coefficient allows for estimates of abundance with CPUE data. Calculations of point estimates of abundance are obtained by multiplying mean CPUE by the surface area of the lake by one over the catchability coefficient (Lafferty et al. 1992).

In Moyie Lake, catchability coefficients in the south basin were much higher than those in the north basin (Table 3.5.1). In both basins, coefficients were highest just after the spring thaw (Table 3.5.1). These observations are similar to those reported for 12 Alaskan Lake populations where summer coefficients were estimated at 0.42 and spring coefficients at 0.87 (Bernard et al. 1993).

The components of catchability coefficients (i.e., density, abundance and mean CPUE) are subject to variability. Given the low precision of abundance estimates in this preliminary study, the catchability coefficients calculated with those estimates are also highly variable. The ultimate goal of this research is to describe the sources of variability and to standardize fishing methods, time and gear density such that CPUE accurately reflects burbot abundance in East Kootenay waters. This would allow for long-term stock monitoring in a cost effective manner using CPUE and the mean catchability coefficient.

Table 3.5.1. Seasonal catchability coefficients for Moyie Lake burbot populations (2006).

Population	Date (2006)	Season	Surface Area (ha)	Mean CPUE	Abundance	Density (fish/ha)	Catchability Coefficient
North Moyie	12 May - 9 June	Spring	582.75	1.80	1765[a]	3.03	0.59
	12 May - 9 June	Spring		1.80	1851[b]	3.18	0.57
	12 May - 5 Nov	Summer		1.77	5915[c]	10.15	0.17
South Moyie	8 May - 7 June	Spring	316.06	2.23	758[a]	2.4	0.93
	8 May - 7 June	Spring		2.23	1397[b]	4.42	0.51
	8 May - 7 Nov	Summer		1.97	1153[c]	3.65	0.54

[a] Closed population estimate for events 2 and 2'

[b] Jolly-Seber open population estimate pooling events 2 and 2'

[c] Closed population estimate for events 2, 2' and 3

3.6. Biological Characteristics

Data on the sex and age structure of burbot were not available at the time of publication of this report.

3.6.1. Length, Weight, and Condition

On average, Columbia and Windermere Lakes had the smallest burbot while St. Mary and Moyie Lakes had the largest (Table 3.6.1). The size of Columbia and Windermere burbot captured in this study was similar to that reported previously for these populations (Table 3.6.1; Arndt 2001; Arndt and Hutchinson 2000). Age-length analysis and known growth rates of recaptured burbot indicate that Columbia Lake burbot have a maximum size ($L\infty$) of approximately 600 mm (Arndt 2006). Historically, the upper size limit for these burbot populations was much greater as the largest known burbot capture in British Columbia was in Windermere Lake circa 1923 and weighed 15.44 kg (McPhail and Paragamian 2000).

The largest burbot in this study was captured in North Moyie and measured 1.10 m and 6.80 kg. This burbot was larger than any previously reported for Kootenay populations (Baxter and Arndt 2006). Within Moyie, the South Basin yielded significantly larger fish than the North Basin (Mann-Whitney, $P < 0.05$; Table 3.6.1). Mean length of South Basin fish was 622.14 mm (SE 5.93) and in the North Basin mean length was 612.17 mm (SE 4.45). Though a larger area of South Moyie was sampled due to depth restrictions (Appendix A1), there was no relationship between fish size and depth (Figure 3.6.1). Investigators in the Skeena Region of British Columbia also found no relationship between burbot length and capture depth in four lakes sampled (Giroux 2005).

Table 3.6.1. Comparison of burbot lengths (mm) in East Kootenay lakes, 2005/06.

Lake	Length (mm) Mean	SE	Range	n
North Moyie	612.17	4.45	470-930	226
South Moyie	622.14	5.93	410-1010	167
St. Mary	683.57	24.39	570-735	7
Columbia[1]	508.65	18.07	395-693	23
Columbia[2]	454-500	1.7-2.0	n/a	1365-745
Windermere[1]	520.71	33.03	391-636	7
Windermere[3]	< 450	n/a	390-450	6

[1] Data from present study (2006).
[2] Data from Arndt and Hutchinson (2000).
[3] Data from Arndt (2001).

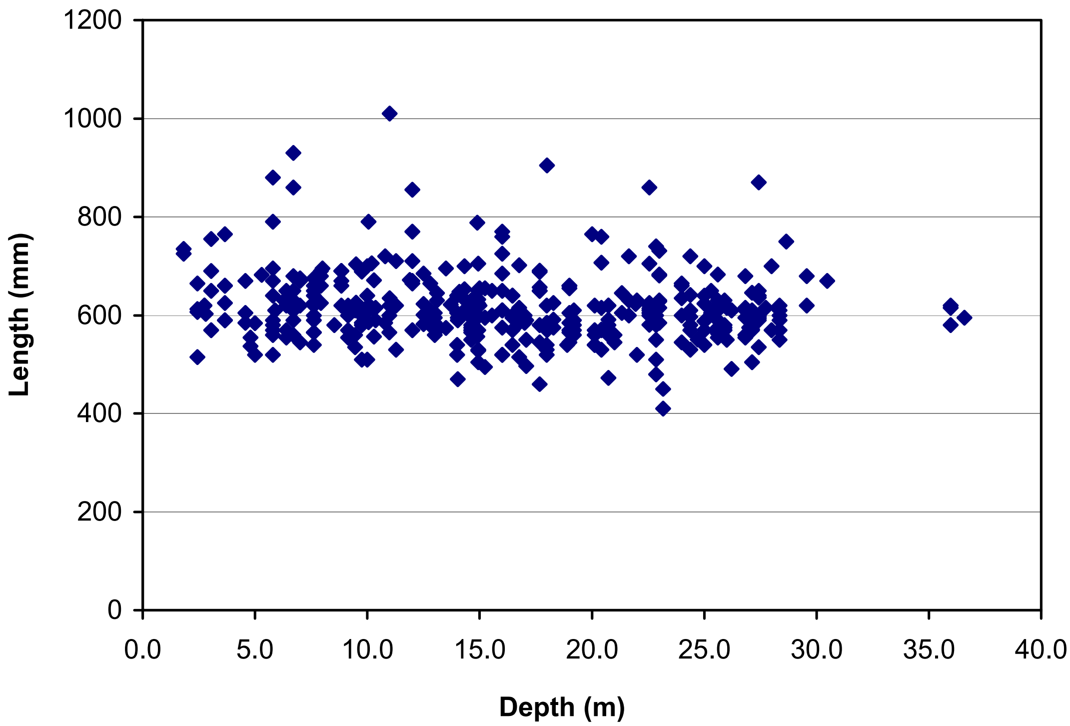

Figure 3.6.1. Plot of burbot length mm (n = 393) against trap depth for Moyie Lake, 2005/06.

While both basins of Moyie Lake had the majority of their catch in the 550-650 mm size range, South Moyie had a greater proportion of larger fish and North Moyie showed a much more restricted length frequency distribution (Figure 3.6.2).

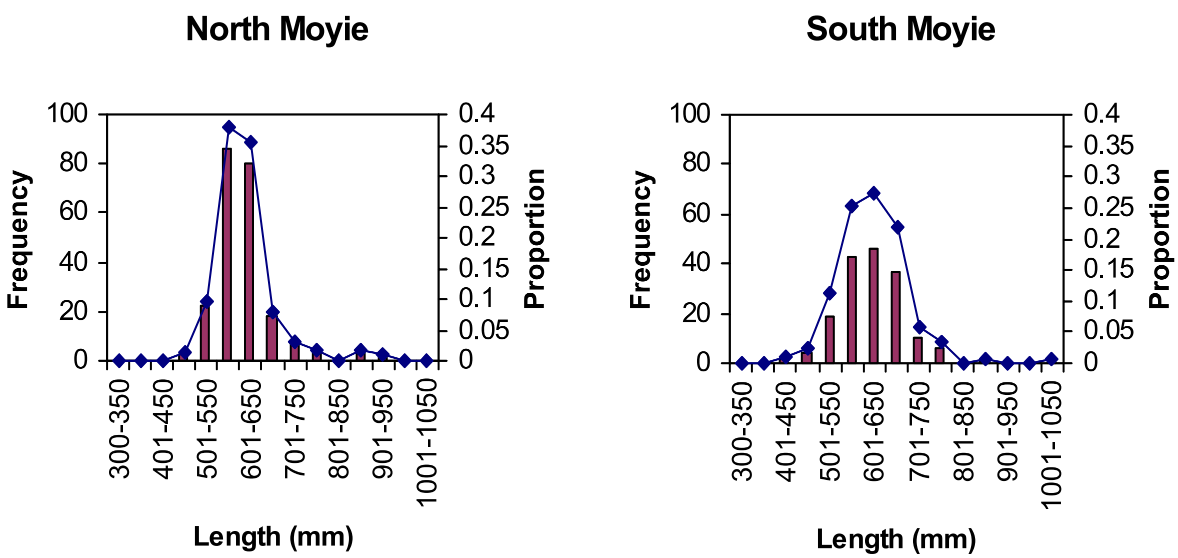

Figure 3.6.2. Length-frequency distributions for Moyie Lake burbot, 2005/06. Note: bars represent frequencies and lines, proportions.

Within a basin, there were no seasonal differences in mean length of captured burbot (Kruskal-Walis, $P > 0.05$; Table 3.6.2); however, there were differences in their length-frequency distributions that were assumed to represent growth (Appendix B1). Most of the distributions had ascending left limbs with the mode increasing by a length category over the course of the year and steeply descending right limbs as few burbot over 750 mm were captured (Appendix 1B).

Table 3.6.2. Length of burbot captured in Moyie Lake by season.

		Length (mm)		
Lake	Date	Mean	SE	n
North Moyie	Sep-05	628.83	16.95	30
	May-06	610.77	8.69	78
	Jun-06	609.06	9.03	32
	Nov-06	608.79	5.40	86
South Moyie	Sep-05	629.29	15.29	35
	May-06	623.52	9.48	66
	Jun-06	608.67	18.54	15
	Nov-06	619.43	9.59	51

The use of a standard weight equation is a valuable stock evaluation tool that allows comparisons across populations. We used the equation and length categories proposed by Fisher et al. (1996) in assessing the relative condition of East Kootenay burbot. The length categories correspond to angler preferences: 380-529 (quality), 530-669 (preferred), 670-819 (memorable), and 820+ (trophy). The equation shows declining condition with total length, a morphological trait that has not been exhibited by most other species with the exception of landlocked chinook salmon (Shannon Fisher, *pers. comm*. University of South Dakota). In the Moyie Lake burbot population, the relationship between length and weight was best described by a polynomial equation where the slope declined for lengths greater than 850 mm (Appendix B2).

Caution must be used when comparing the relative weights of fish populations, as condition can vary across seasons and with sexual maturity (Arndt and Hutchinson 2000). For example, in South Moyie Lake fish were in significantly lower condition when captured in May than in November (length category 530-669 mm; Mann-Whitney $P < 0.05$; Table 3.6.3). Other categories were not compared due to small sample size. Thus, the mean relative weights presented here for Moyie Lake burbot (fish captured throughout the year) are negatively biased when compared to other East Kootenay populations as burbot from St. Mary, Columbia and Windermere Lakes were sampled only when fish were in their best condition (i.e., Oct/Nov), just prior to spawning and after a summer and fall of feeding.

Table 3.6.3. Mean relative weights of Moyie Lake burbot (length category 530 – 669 mm) by season.

		Length 530-669(mm)		
Lake	Date	Mean	SE	n
North Moyie	Sep-05	97.01	1.92	22
	May-06	93.39	1.75	67
	Jun-06	92.18	2.18	26
	Nov-06	93.79	1.77	51
South Moyie	Sep-05	104.29	2.36	24
	May-06	93.85	5.12	19
	Jun-06	82.96	4.09	11
	Nov-06	108.00	3.79	35

Even with the negative bias, Moyie Lake burbot were in the best condition in all size categories (Figure 3.6.3). The mean relative weights for Moyie Lake fish were higher than those reported for West Kootenay and Thomson-Nicola populations (sampled November 2003 & 2004; Baxter and Arndt 2006). It has been proposed that a relative weight objective range for burbot should be 80 +/- 5, for which Columbia and Windermere Lake burbot are below (Fisher et al. 1996). It is hypothesized that high water temperatures (> 25^{o}C) and habitat loss are the main factors limiting burbot growth and survival in these lakes (Colin Spence, *pers. comm*. B.C. Ministry of Environment). The loss of anadromous salmon stocks due to the construction of Grand Coulee Dam in 1936 may also be a contributing factor limiting growth.

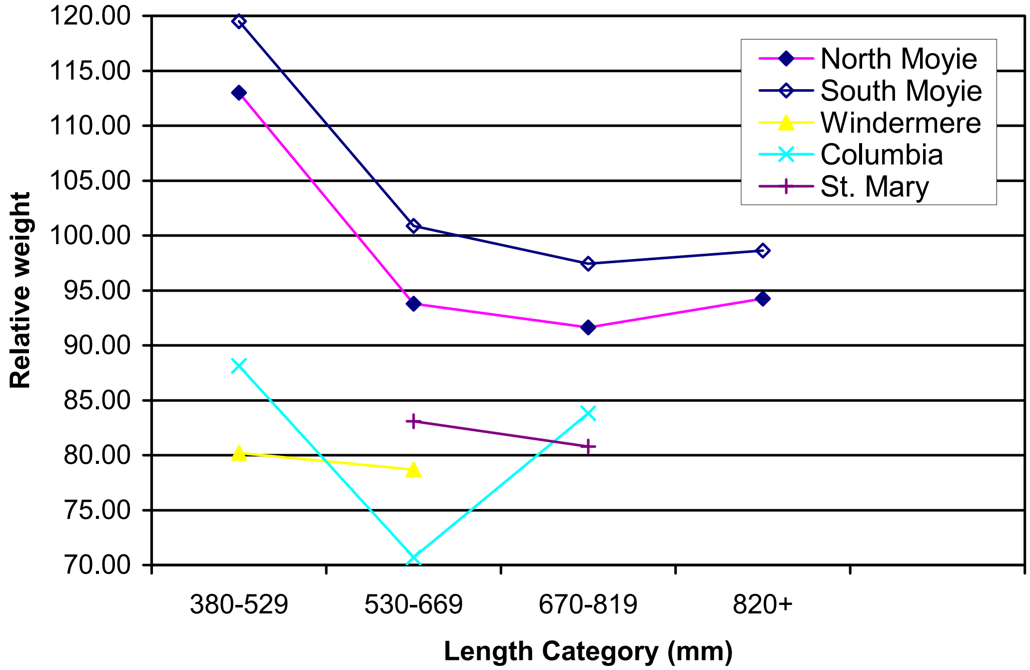

Figure 3.6.3. Mean relative weights for East Kootenay burbot populations, 2005/06. Standardized weight equation and length categories are from Fisher et al. (1996).

Within Moyie Lake, burbot in the South Basin were in significantly better condition than those in the North (category 530-669 mm; Mann-Whitney, $P < 0.05$; Table 3.6.4). Not unexpectedly, the smallest and largest size categories had the greatest variability in relative weight. As outlined in length-frequency histograms, South Moyie had a higher proportion (24%) of larger fish (> 670 mm) than North Moyie Lake (12.6%; Table 3.6.4).

Table 3.6.4 Mean relative weights for East Kootenay burbot populations, 2005/06.

	Quality (380-529mm)			Preferred (530-669mm)			Memorable (670-819mm)			Trophy (820+mm)			
Lake	Mean	SE	n	Mean	SE	n	Mean	SE	n	Mean	SE	n	N
North Moyie	112.99	5.49	8	93.8	0.99	166	91.62	3.66	20	94.24	7.16	5	199
South Moyie	119.5	6.16	8	100.88	2.19	89	97.45	3.34	30	98.63	0	1	128
St. Mary				83.09	0.64	2	80.78	5.43	5				7
Columbia	88.12	3.65	14	70.71	4.03	8	83.82	0	1				23
Windermere	80.21	10.66	3	78.68	14.69	4							7

4. Conclusions and Recommendations

The low relative abundance and poor condition of Columbia, Windermere, and St. Mary Lake burbot populations support severely restricted harvest regulations. In contrast, these same indicators show the Moyie Lake burbot population to be adequate to support a harvest. Uncertainty regarding population estimates for Moyie Lake (particularly in the North Basin) precludes calculations of sustainable yield. Thus, future studies should focus on increasing sampling effort in Moyie Lake to achieve precision in abundance, survival, and recruitment estimates. With very sparse data, the calculated population sizes are likely to be biased high (Schwarz 2007). Without additional effort in the North Basin, it may be several years before enough tags are applied to obtain sufficiently precise estimates. The South Basin study is in better shape and with the amount of marks released in 2006, future years should give more precise estimates.

The desired number of sets for each survey in mark-recapture experiments may be estimated by dividing an estimate of mean CPUE into the numbers of burbot needed for the experiment. For closed population models, the total number of samples (n) required to achieve a given level of precision was determined from the charts given in Robson and Reiger (1964). With an estimated population size (*N*) of approximately 1000 in the South basin (average of 3 estimates, Table 3.3.1), the sample size needed to achieve the 95% confidence intervals for P = 0.25 (level recommended for management studies) is 210 (where M = C; Robson and Reiger 1964).

By extension, the total number of samples required to meet precision objectives in the open population model may be approximated using the Petersen model estimate of sample size. Since 248 marks were released in to the South Basin in 2006 (Appendix A2), the total number of samples is reduced by that amount less mortality. The fall-spring mortality rate from this study was estimated at 53% (Table 3.3.1), thus, the total number of samples (n) required in each sample session is actually 79 (i.e., 210-(248*0.53)) for P = 0.25. For P = 0.10 (recommended for research studies), the total number of samples (n) required in each sample session would be 385 (from Robson and Reiger) less (248*0.53) or 254. With a mean CPUE of 2.78 in May (Table 3.3.1), the number of sets required per session to achieve the desired precision for population estimates in the South basin is between 28 (P = 0.25) and 91 (P = 0.10).

In the North basin, the average estimated population size was 3177 (Table 3.3.1). The sample size needed to achieve 95% confidence intervals for P = 0.25 (level recommended for management studies) where N = 3200 is 400 (where M = C, Robson and Reiger 1964). Since 285 marks were released in to the North Basin in 2006 (Appendix A2) the sample size needed is (400-(285*0.53)) or 249. Similarly, for P = 0.10 (recommended for research studies), the total number of samples (n) required in each sample session for N = 3200 would be 750 (from Robson and Reiger) less (285*0.53) or 599. With a May CPUE of 1.93 (Table 3.3.1), the number of sets required per session to achieve the desired precision for population estimates in the North basin is between 129 (P = 0.25) and 310 (P = 0.10).

With only 56 cells available for sampling with the current 200 X 200 m grid and depth restrictions, each location in the north basin would need to be sampled 2.3 times (for P = 0.25), which could bias results with repeated measures. Therefore, increasing the number of potential sampling locations is preferred. The minimum cell size should be selected such that gear competition is prevented. The effective fishing area of a baited trap may be estimated by dividing the average CPUE of burbot caught per 48 hr set in Moyie Lake (during May) by the density of burbot per hectare from the mark-recapture experiment (Pearse and Conrad 1986). In the North basin that area is estimated at 0.64 ha and in the South basin the estimate is 1.16 ha. The effective fishing area may be arbitrarily increased to 0.75 ha and 1.25 ha respectively to ensure elimination of gear competition, which corresponds to traps set at a distance of 87 m and 125 m. This grid system would result in 129 potential cells in the north basin and 90 cells in the south basin, which would eliminate bias from repeated sampling in the same location.

The increased effort requirements may be achieved without increasing study costs by redistributing sample effort and marginally increasing the number of traps deployed in a day. Sampling in April-May when CPUE is greatest, and allocating the November sample effort to the spring, would allow for both closed and open population estimates with minimal increases in budget expenditures. By increasing the number of traps set and retrieved in a day from 22 to 25, a total of 5.16 set days in the North Basin and 2.08 in the South Basin would be required per session to meet capture objectives. In the 2006 program, there were a total of 17 sampling days on Moyie Lake. The above scenario would require a total of 18 sampling days since one pull day is required to finish each session. Increasing the number of traps deployed in a day beyond 25 is not recommended as the random placement of sets has proved time consuming because of the difficulty in navigation to a set location (Parker et al. 1987).

While it may take several years to achieve precision in abundance, survival, and recruitment estimates in Moyie Lake, once obtained, long term trend monitoring (i.e., CPUE) could accurately and cost effectively determine stock abundance and annual sustainable yield.

To summarize, the following recommendations are made for the 2007 burbot program on Moyie Lake:

1. Cod traps should be used exclusively to maximize catch rates. Each trap should be carefully inspected and modified as required to ensure the most effective, escape-proof throat configuration.

2. A combination of methods, Jolly-Seber and Petersen, should be used to extend the range of estimates.

3. Sampling should be conducted in April and May (just after ice off) when catch rates are greatest and temperatures low to reduce the rate of gas diffusion that causes decompression trauma.

4. At least 129 and 52 sets should be made in North and South Moyie Lakes, respectively, to insure that a minimum relative precision of +/- 25% is attained with 95% CI. The first capture session in 2007 should be used to modify the sampling level, if necessary (e.g., if CPUE is less than 1.93 to 2.78).

5. The minimum cell size should be decreased to 87 X 87 m in North Moyie and 125 X 125 m in South Moyie to increase the number of available sample locations while preventing gear competition.

6. Depth restrictions of 35 m should remain for trap locations in Moyie Lake to minimize trap-induced mortality while maximizing sample area.

7. The number of traps set/day should be increased to 25 to meet capture objectives.

8. Spatial distribution of fish within systems should be noted, both within and between years, and correlated with habitat and depth.

9. The size for which burbot are fully recruited to cod traps should be determined.

10. Data on the sex and age structure of burbot populations should be completed.

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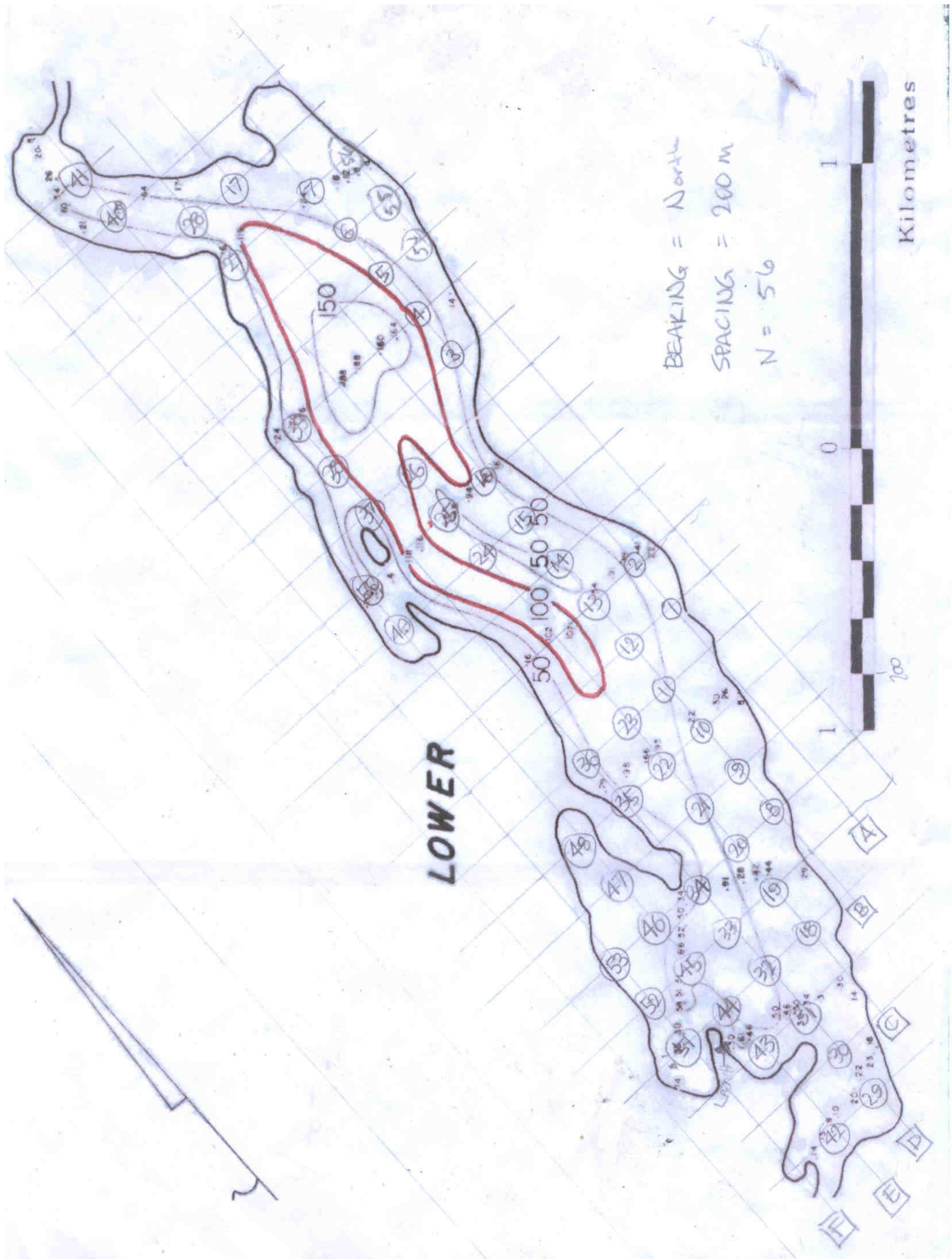
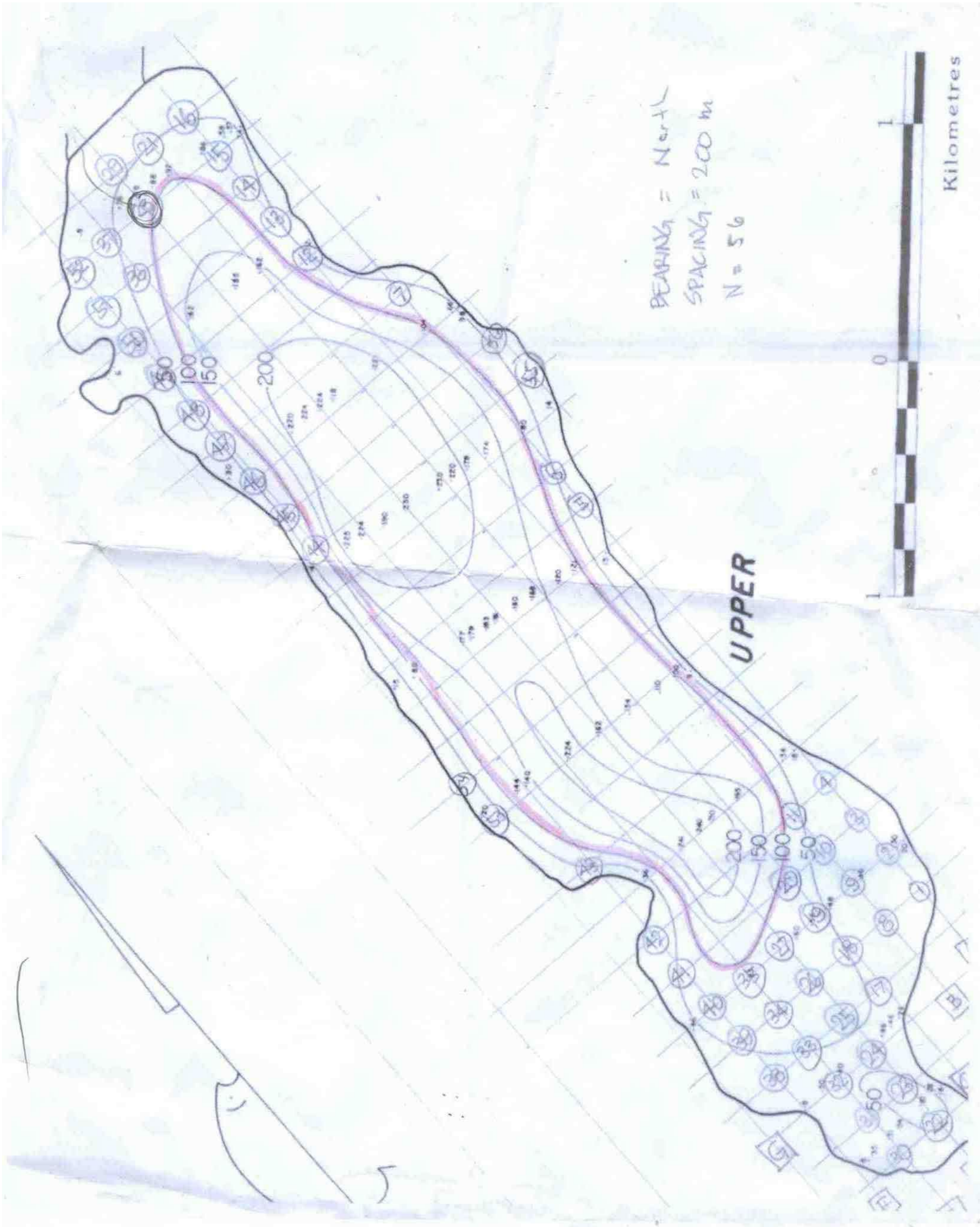


Appendix A1. South Moyie Lake showing sampling grid for randomized study design.



Appendix A1. North Moyie Lake showing sampling grid for randomized study design.

Appendix A2-Mark-recapture data for Moyie Lake Burbot 2005-2006.

Lake	Area (ha)	Sample Event	Dates	Effort No. of Traps	Total Catch	CPUE	SE
North Moyie	582.75	1	09-12 Sep 2005*	15	66	4.40	0.56
		2	12-19 May 2006	59	114	1.93	0.25
		2'	07-09 June 2006	22	32	1.45	0.44
		3	30 Oct-05 Nov 2006**	50	86	1.72	0.26
South Moyie	316.06	1	13-15 Sep 2005*	15	59	3.93	0.92
		2	08-15 May 2006	51	142	2.78	0.31
		2'	05-07 June 2006	22	21	0.95	0.25
		3	03-09 Nov 2006**	43	66	1.53	0.24

*Trap placement did not use randomized grid design,

**Hoop traps used which are less effective than cod traps by approx. 2:1 ($P > 0.05$) thereby biasing CPUE.

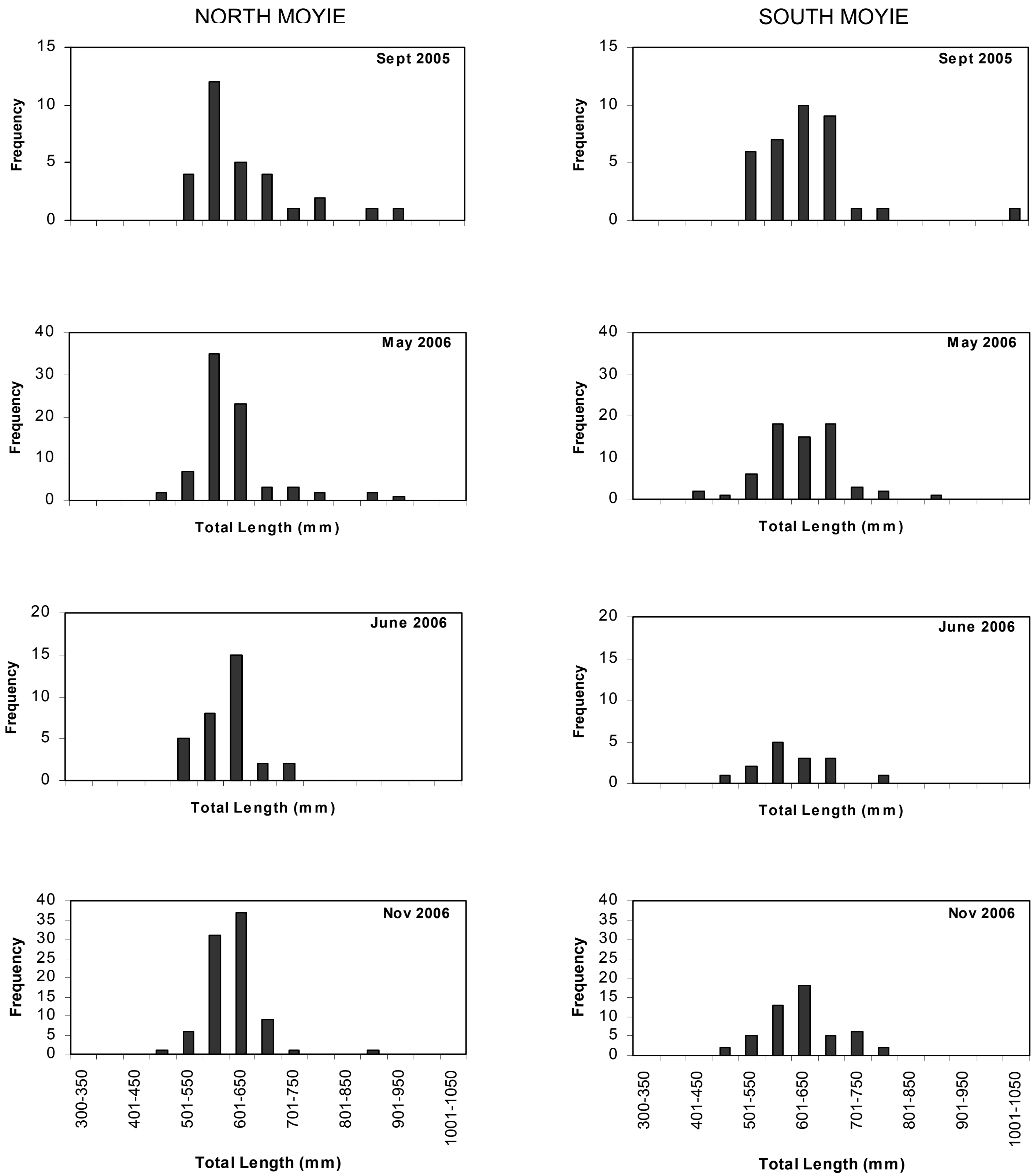
North Moyie Lake

Event		**1**	**2**	**2'**	**3**	
Date:	Year	2005	2006	2006	2006	
	Beginning	09-Sep	12-May	07-Jun	30-Oct	
	Ending	12-Sep	19-May	09-Jun	05-Nov	
Number of Burbot all sizes						**Totals**
Recaptured from Event 1		0	3[a]	0	1	4
Recaptured from Event 2			0	1	0	1
Recaptured from Event 2'				0	0	0
Recaptured from Event 3					0	0
Captured with Tags		0	3	1	1	5
Captured without Tags		66	111	31	85	293
Captured		66	114	32	86	298
Released with Tags		64	107	30	84	285
Handling Related Mortalities		0	7	2	2	11
Removed to Hatchery		0	0	0	0	0
Removed by Anglers		2	0	0	0	2

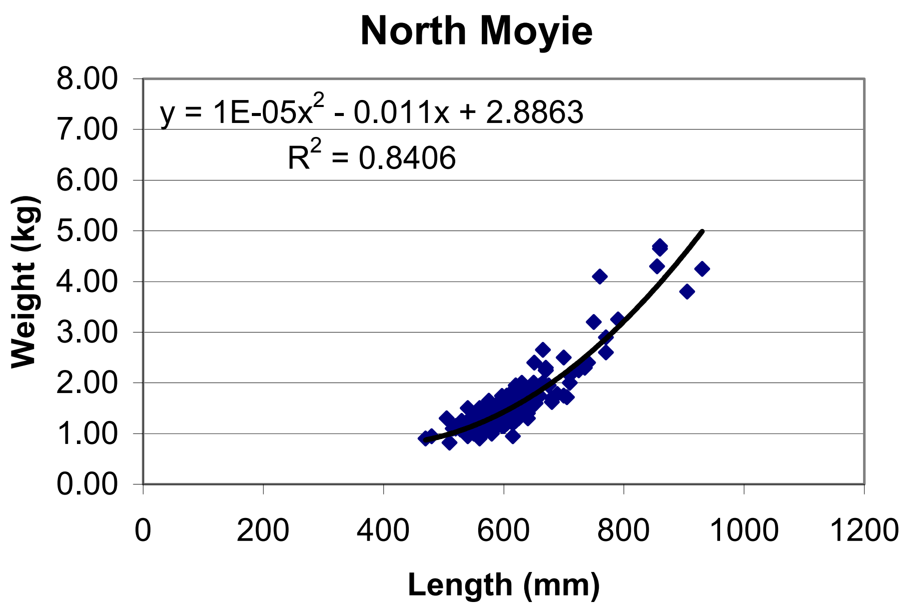
[a] includes stray recap (original capture N. Basin Sep 2005, recap S. Basin May 2006)

South Moyie Lake

Event		**1**	**2**	**2'**	**3**	
Date:	Year	2005	2006	2006	2006	
	Beginning	13-Sep	08-May	05-Jun	03-Nov	
	Ending	15-Sep	15-May	07-Jun	09-Nov	
Number of Burbot all sizes						**Totals**
Recaptured from Event 1		0	3		2	5
Recaptured from Event 2			0	3	7	10
Recaptured from Event 2'				0	1	1
Recaptured from Event 3					0	0
Captured with Tags		0	3	3	10	16
Captured without Tags		59	139	18	56	272
Captured		59	142	21	66	288
Released with Tags		57	136	21	34	248
Handling Related Mortalities		0	5	0	2	7
Removed to Hatchery		0	0	0	30	30
Removed by Anglers		2	1	0	0	3



Appendix B1. Length-frequency distribution of Moyie Lake burbot by season, 2006.



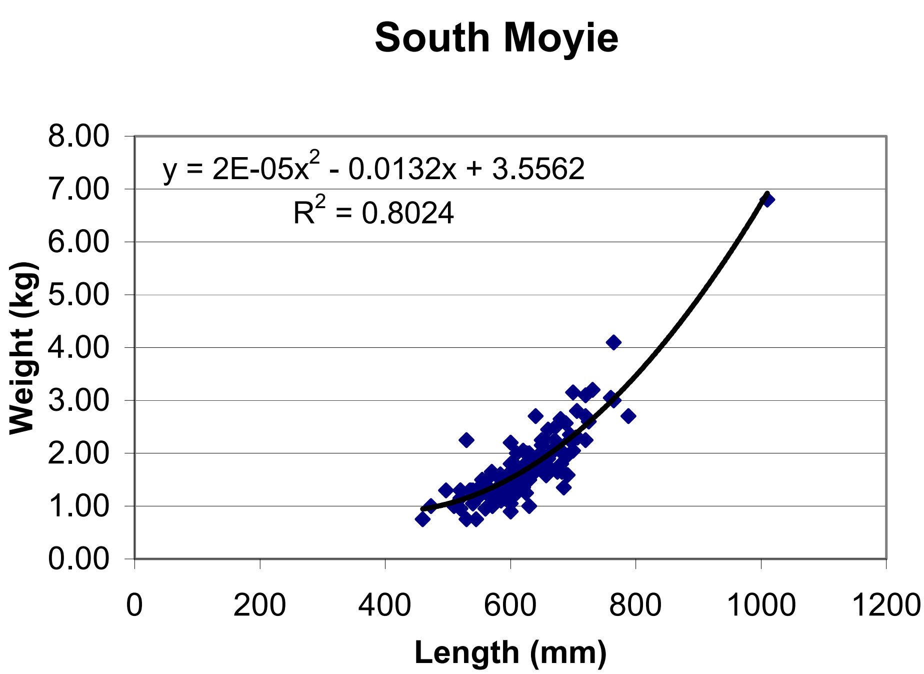


Figure B2. Length-weight regressions for Moyie Lake burbot 2006.

Appendix C Data Archives

File Format: Microsoft Excel

File Name: Master Database (contains raw catch and effort data)

Worksheets:

Moyie Recaps
Moyie Data for MARK
Moyie
St. Mary's
Columbia
Windermere