Burbot Population Assessment
Little Fox Lake
2012

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Summary

Environment Yukon has been surveying burbot populations since 2011. Along with harvest data collected from set-line harvest reports and angler harvest surveys, these population estimates can provide a basis for assessing the sustainability of Yukon's burbot fisheries.

We surveyed Little Fox Lake using mark-recapture methodology, with an initial marking session in October 2011, and recapture sessions in June 2012 and October 2012. Our study focused only on burbot that were 350 mm in length of longer.

We captured and marked 71 burbot in October 2011. We returned in June 2012 and captured 101 burbot, of which 10 were recaptures from the October 2011 capture session. We returned again in October 2012 and caught 150 burbot, of which 39 were recaptures from the October 2011 or June 2012 capture sessions. The abundance estimate for burbot 350 mm total length or longer was 620 (95% CI 414 – 1,237), or 4.53 burbot / hectare (ha).

Little Fox Lake has a lower abundance of burbot than is expected for a lake of its size and productivity, suggesting that the Little Fox Lake burbot population is depleted.

Key Findings

- Little Fox Lake is a small, productive lake, with a lower-than-expected abundance of burbot (620 burbot at least 350 mm in total length), suggesting that the population may be depleted.
- Burbot in Little Fox Lake are relatively small-bodied, with a mean total length of 474 mm and weight of 798 g.
- Individual burbot from Little Fox Lake gained length over both winter 2011/12 and summer 2012.

Table of Contents

List of Figures

List of Tables

Introduction

Burbot are a commonly-harvested Yukon fish, with most of the recreational harvest occurring in winter. Burbot are also the specific target of a set-line fishery. Reports of declines in burbot size and abundance in some popular fishing areas, combined with measured declines in burbot abundance in other jurisdictions have prompted concern over the state of Yukon burbot populations. In response, Environment Yukon has been assessing burbot abundance using mark-recapture methodology.

Mark-recapture methodology has 3 phases:

- an initial capture and marking session;
- a sufficient period of time for marked and unmarked fish to thoroughly mix; and
- at least one subsequent recapture session, when the catch is examined for burbot marked in the previous capture session or sessions.

Burbot mark-recapture surveys provide us information on:

- estimated current burbot abundance and density in a lake;
- changes in burbot abundance and density from previous surveys;
- length and weight of individual burbot;
- growth rates of recaptured burbot; and
- sex, age, and diet of any burbot killed

In October 2011, we used modified cod traps to capture burbot in the south basin of Little Fox Lake. Each burbot was uniquely marked and released. Marked fish mixed with unmarked fish over the winter, and in June 2012 we used the same traps to search for marked burbot. We uniquely marked and released burbot caught in June 2012, and allowed them to mix with unmarked burbot over the summer. In October 2012, we returned to Little Fox Lake and used cod traps to search for marked burbot again.

Study Area

Little Fox Lake is a small (222 ha), easily-accessible lake. Lying next to the Klondike Highway, 85 km north of Whitehorse, Little Fox Lake receives angling pressure by recreational anglers seeking lake trout, Arctic grayling, whitefish, and burbot. Little Fox Lake is also a popular lake for set-line burbot harvest.

For the purposes of this assessment, we limited our burbot abundance estimate to the south basin of Little Fox Lake (137 ha). In 2003, a daily catch limit of 10 and a possession limit of 20 were established for burbot in Yukon. Before 2003, burbot were not considered a game fish, and there were no daily catch or possession limits.

In 2003/04, Special Management Waters regulations were introduced that made barbless hook use mandatory for anglers on Little Fox Lake.

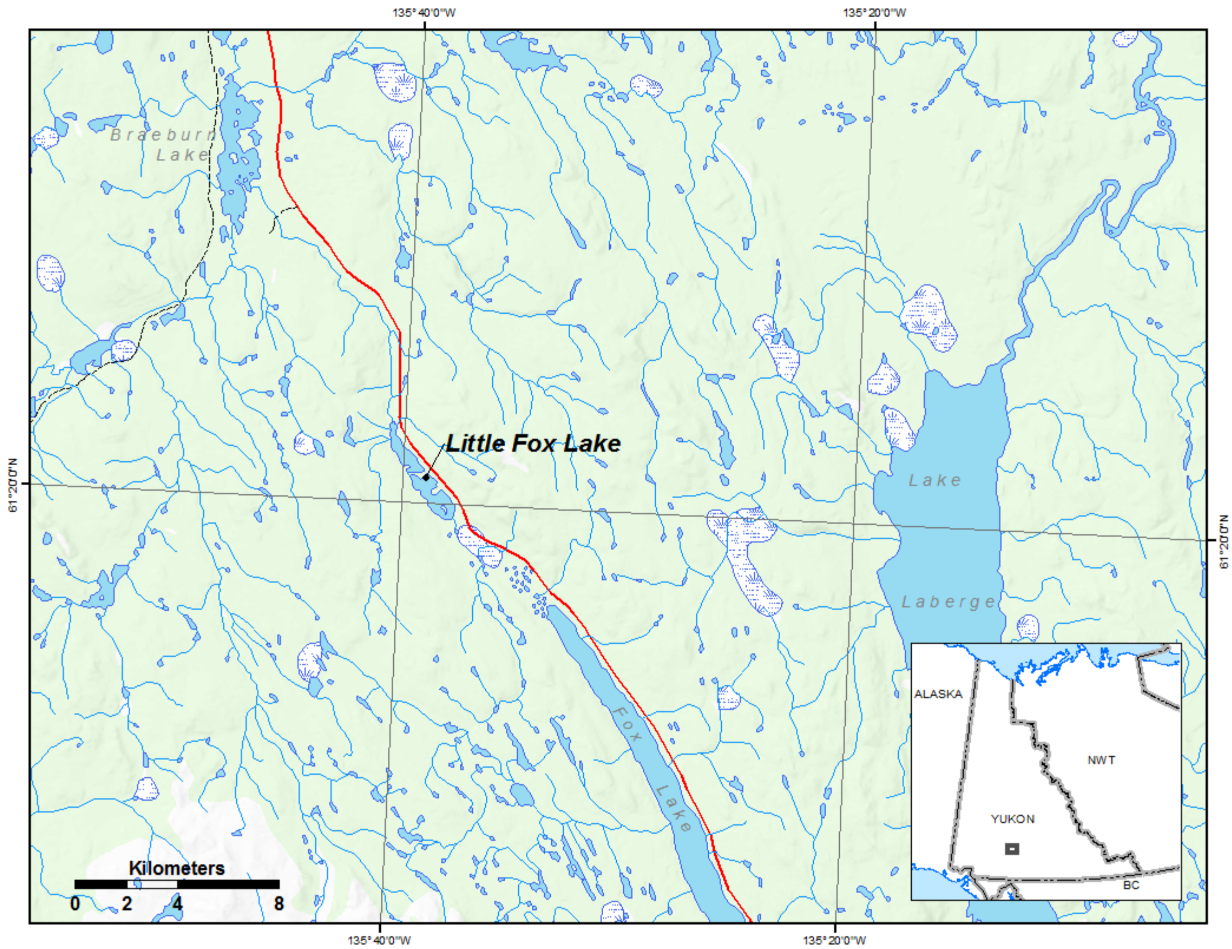

Figure 1. Location of Little Fox Lake, Yukon.

Methods

Estimating abundance

We use mark-recapture methodology to estimate burbot abundance. This involves marking burbot, releasing them, waiting a sufficient amount of time for marked individuals to mix with the unmarked population, and capturing a sample of marked and unmarked burbot.

In instances where 3 capture sessions are used (an initial marking session, and 2 subsequent recapture sessions), the Schumacher-Eschmeyer method of abundance estimation is appropriate (Seber 1982, Krebs 1999). The Schumacher-Eschmeyer method calculates an abundance estimate, N_{est}, such that:

$$N_{est} = \frac{\sum_{i=1}^{s} (C_t M^2_t)}{\sum_{i=1}^{s} (R_t M_t)}$$

where:

s = the total number of capture events,

C_t = the total number of burbot caught in capture event t,

R_t = the number of burbot with previously-existing marks caught in capture event t,

U_t = the number of marked burbot marked and released in capture event t, and,

M_t = the cumulative number of marked burbot in the population just before capture event t, such that:

$$M_t = \sum_{i=1}^{t-1} U_i$$

The Schumacher-Eschmeyer method of mark-recapture abundance estimation requires that several criteria be met (see Appendix 2).

Appropriate methods for estimation of confidence intervals for Schumacher-Eschmeyer mark-recapture abundance estimates vary depending on the total number of recaptures among all capture events (Seber 1982, Krebs 1999). In cases where $R_t / C_t \leq 0.10$, confidence intervals should be determined using Poisson distribution where $R_t < 50$, and using the normal distribution where $R_t > 50$. In cases where $R_t / C_t > 0.10$, the binomial distribution should be used.

Assessing survey design

In addition to completing a Schumacher-Eschmeyer estimate of population abundance using data from 3 capture sessions, we also estimated abundance using the Bailey modification of the Petersen method (Seber 1982, Krebs 1999), using data from paired capture sessions only. We estimated abundance using mark-recapture data from the first and second session, the first and third session, and the second and third session, and compared these abundance estimates and their associated confidence intervals against those of the Schumacher-Eschmeyer 3-session estimate. The Bailey method uses data from an initial marking session ($t - 1$) and a subsequent recapture session (t) to calculate an abundance estimate, N_{est}, such that:

$$N_{est} = \frac{C_t\,(U_{t-1} + 1)}{(R_t + 1)}$$

Burbot capture and handling

Burbot catch rates are highest in spring and autumn, just after and just before ice cover, and lowest in summer (Bernard et al. 1993). An initial capture event should be scheduled for just after ice-out or just before freeze-up. The subsequent capture period(s) would typically be during the next ice-out or freeze-up, but can follow in as little as 3 weeks if initial capture occurs after ice-out (Bernard et al. 1991, 1993). Our initial capture session on Little Fox Lake was 12 – 16 October 2011, followed by 2 subsequent capture sessions, on 5 – 6 June 2012 and 17 – 18 October 2012.

We set traps throughout the lake at depths from 1 to 15 m; a maximum set depth of 15 m was used to prevent barotrauma (physical injury caused by pressure change in fish retrieved from depth) in captured burbot (Bernard et al. 1993). To limit competition among adjacent traps, we set traps a minimum of 125 m apart (Bernard et al. 1993, Schwanke 2009).

We used modified cod traps to capture burbot (Redden Custom Nets, Ltd., Port Coquitlam, BC). Cod traps were 0.64 m tall, with a bottom diameter of 1 m and a top diameter of 0.69 m. Trap netting was knotless 1.3 cm bar mesh. Cod traps had a throat with a 25 cm wide opening extending from one side to the middle centre of the trap. A bait bag of plastic mesh was suspended from the centre top of the trap, and extended to the floor of the trap. Trap frames were constructed of 1.3 cm diameter metal bar. A bridle was attached to the top hoop of the cod trap, and a buoy line was tied to the bridle. Cod traps used in this study were of the same design used in burbot stock assessments in British Columbia, Idaho and Montana (Giroux 2005, Prince 2007, Hardy et al. 2008, Horton and Strainer 2008). We baited each cod trap with about 200 g of frozen smelt and set them overnight; the first trap hauled each morning was the first trap set the previous morning, giving each trap an approximate 24 h soak time. Burbot are most active at night, so differences in daylight soak time can be considered inconsequential, as long as all traps are deployed for a full night (Bernard et al. 1993).

We recorded weight and total length for all burbot captured. The relationship between a fish's weight and length can be described by its condition factor (K) and is calculated as: $K = \text{Weight (g)}/\text{Length (cm)}^3 \bullet 100$ (Ricker 1975). The heavier a fish is at a given length, the better its condition. At the individual level, K can be an indication of fish health. We averaged K over the entire catch and used it as an indication of overall condition of burbot within the population. We used a t-test to compare the length, weight, and condition factor of burbot between the first and second capture sessions.

Any fish that died was sampled for age (using otoliths or ear “bones”) and diet (stomach contents).

In the October 2011 and June 2012 capture sessions, we marked burbot 350 mm total length or longer with an individually-numbered T-bar anchor tag, inserted just behind the leading edge of the first dorsal fin. A redundant second mark, a clip removing the first 3 rays of the right pelvic fin, was used to establish tag loss rates. Fin clip material was retained as an archival genetic sample. We considered burbot less than 350 mm total length too small to tag. We did not mark fish caught in the October 2012 capture session. For this capture session, we used the October 2012 within-session recapture rate of previously-marked burbot to estimate an overall within-session recapture rate, for the purposes of mark-recapture abundance estimation.

Burbot are sensitive to rapid changes in water temperature and pressure. To ensure high post-release survival, we immediately placed captured burbot in tubs of water, which we flushed continuously with cold water drawn from lake depths of 5 – 8 m using high-flow pumps. Following handling, burbot showing difficulty in returning to their original depth were returned to the lake bottom using a deepwater fish release tool (West Marine, Watsonville, CA).

Water temperature and dissolved oxygen can influence burbot distribution within a lake. We took temperature and dissolved oxygen profiles in the similar locations during both the first, second, and third capture sessions, using a multi-parameter probe (YSI 600QS; YSI Inc., Yellow Springs, OH).

During the first capture session, in October 2011, we also evaluated the efficiency of hoop traps and longlines for burbot capture (Barker et al. 2014a). Because of the possibility of differential post-release survival rates among burbot caught on longlines and those caught in hoop and cod traps, we excluded burbot caught on longlines in October 2011 from our analyses. Burbot caught in hoop traps were considered to have similar post-release survival rates to those caught in cod traps, and were used in the mark-recapture population estimation.

Results and Discussion

Temperature and Dissolved Oxygen

The temperature profile for mid-October 2011 showed Little Fox Lake was isothermal, with the same temperature from top to bottom (Figure 2). Dissolved oxygen levels were high and uniform throughout the water column (Figure 2).

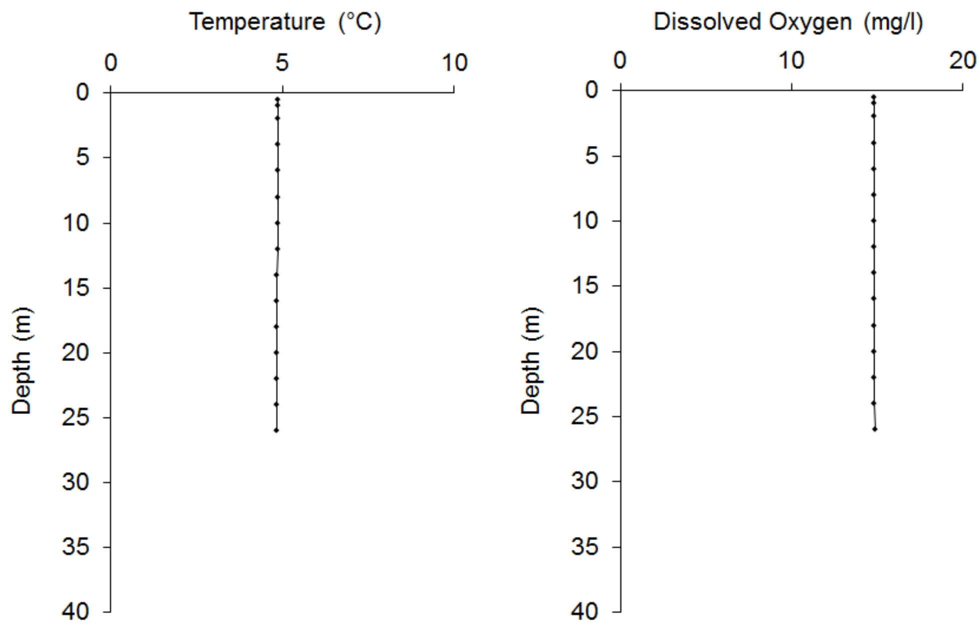

Figure 2. Temperature and dissolved oxygen profile of the south basin of Little Fox Lake, taken 14 October 2011.

In early June 2012, the water temperature was just above 7°C at the surface, and declined to just above 4°C at depth (Figure 3). Dissolved oxygen readings were not available, because of equipment malfunction.

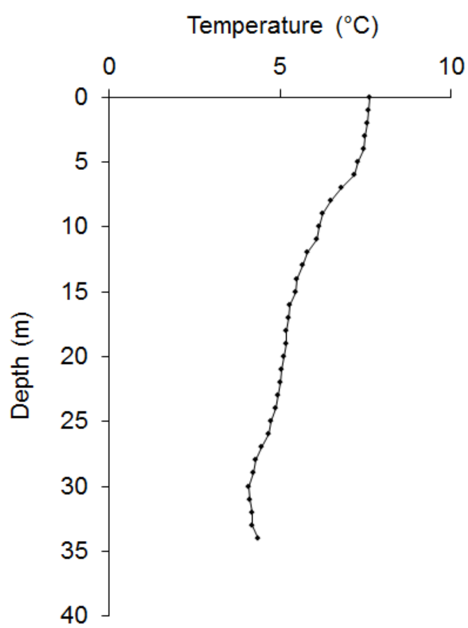

Figure 3. Temperature profile of the south basin of Little Fox Lake, taken 6 June 2012.

The temperature profile for mid-October 2012 showed the lake as isothermal at just below 6°C (Figure 4). Dissolved oxygen levels were high, with a decline present below 30 m (Figure 4).

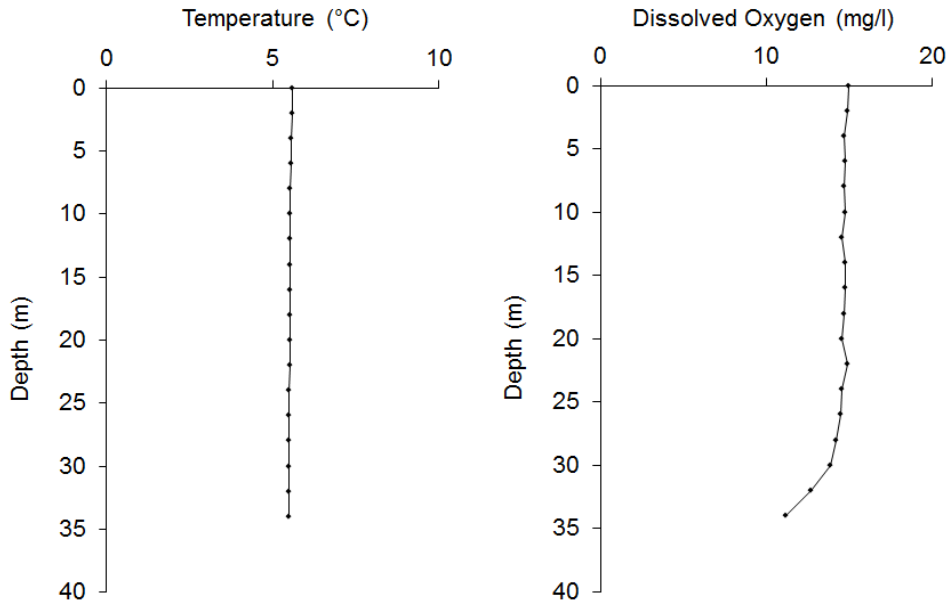

Figure 4. Temperature and dissolved oxygen profile of the south basin of Little Fox Lake, taken 16 October 2012.

Capture details – October 2011 capture session

Between 12 and 16 October 2011, we captured 97 burbot in cod and hoop traps. From the 12 nights of cod trap effort (discounting 3 nights using cod traps set without fresh bait, and the 1 burbot caught in these traps), we calculated a cod-trap CPUE (catch per unit effort) of 4.25 burbot/trap night (SE = 0.39).

Of the 97 burbot captures in cod and hoop traps, 3 were instances of within-session recaptures of marked burbot, giving a total of 94 individual burbot caught. On the first sampling day, the field crew did not have tagging equipment; the 22 burbot caught that day were given a fin-clip only, and were not considered in subsequent mark-recapture calculations. One burbot was less than 350 mm total length, and was released unmarked. In total, we released 71 individual burbot with uniquely-numbered tags in the south basin of Little Fox Lake following the initial capture session. There were no capture mortalities among trap-caught burbot. No other fish species were captured.

Subsequent to the October 2011 capture session, but before the June 2012 capture session, 2 tagged burbot were reported caught by anglers; one burbot had the tag removed, and was returned to the lake, the other burbot was harvested. See Table 1 for a summary of capture and tagging details.

Table 1. Summary of capture and tagging details for burbot capture sessions in the south basin of Little Fox Lake.

	Oct 2011	**June 2012**	**Oct 2012**
Total burbot captures	97	109	173
Burbot released with fin-clip only	*22*	*0*	*0*
Burbot too small to mark	*1*	*3*	*5*
Capture mortalities	*0*	*1*	*0*
Subsequent removal of tagged burbot reported by anglers	*2*	*0*	*0*
Effective number of burbot caught (for MR purposes)	69	100	150*
Captures of fish marked October 2011	3	10	12
Captures of fish marked June 2012	-	4	25
Captures of fish marked October 2011 and previously recaptured June 2012	-	1	2
Captures of fish marked October 2011 and previously recaptured October 2012	-	-	1
Captures of fish marked June 2012 and previously recaptured October 2012	-	-	5
Captures of fish marked October 2011, and previously recaptured June 2012 and October 2012	-	-	0
Total recaptures (excludes within-session recaptures)	0	10	39
Total new tagged burbot available for next capture session	69	90	0
Cumulative total of tagged burbot available for next capture session	69	159	159

**Total number of individual burbot captured in October 2012 was estimated from total unmarked burbot captures using the 13% within-session recapture rate demonstrated by previously-marked burbot in October 2012*

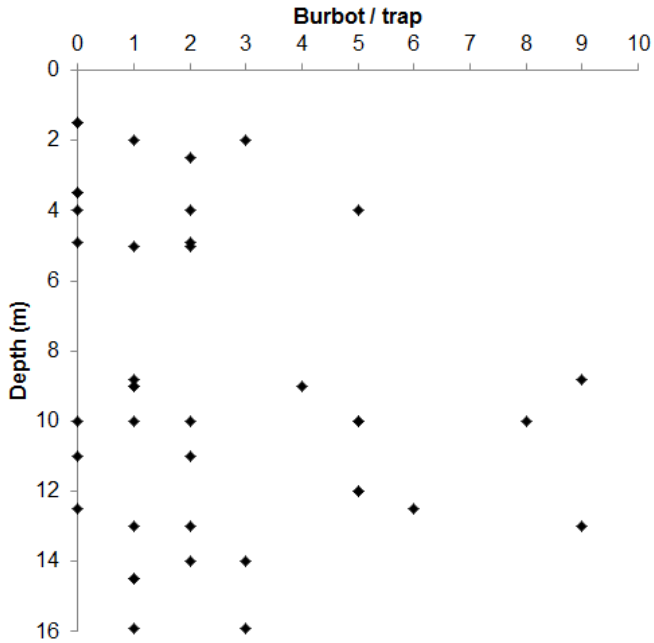

Figure 5. Burbot catch by depth for cod- and hoop traps set 12 – 16 October 2011 in the south basin of Little Fox Lake.

Burbot were caught at all depths at which we set traps, although the highest catch rates were in traps set at depths of 8 – 14 m, where we achieved catches of up to 9 burbot per trap (Figure 5).

Capture details – June 2012 recapture session

On 5 and 6 June 2012, we caught 109 burbot in 48 trap nights in the south basin of Little Fox Lake, achieving a mean CPUE of 2.27 burbot/trap night (SE = 0.26). Of the 109 total burbot captures, 3 burbot were considered too small to tag (less than 350 mm total length), and 10 were of burbot marked in the first capture session. Five of the 109 total captures were within-session recaptures (i.e. burbot that were caught on both trap nights of the June 2012 capture session). There were 2 burbot capture mortalities during the June 2012 capture session. No other fish species were captured. See Table 1 for a summary of capture and tagging details.

Burbot catch rates were relatively uniform among depths in the June 2012 capture session (Figure 6). Water temperatures ranged between 5 and 7°C within the capture depths of 1 – 15 m (Figure 3), and burbot distribution was likely not limited by temperature. We achieved catch rates of up to 7 burbot per trap-night in the June 2012 capture session.

To detect movement of tagged burbot from one basin to another we also set traps in the north basin of Little Fox Lake. In 8 trap nights we caught 8 burbot. None of the 8 burbot captured in the north basin of Little Fox Lake had tags or fin clips. Seven were tagged and released, and 1 burbot was too small to tag and was released unmarked. There were no capture mortalities in the north basin.

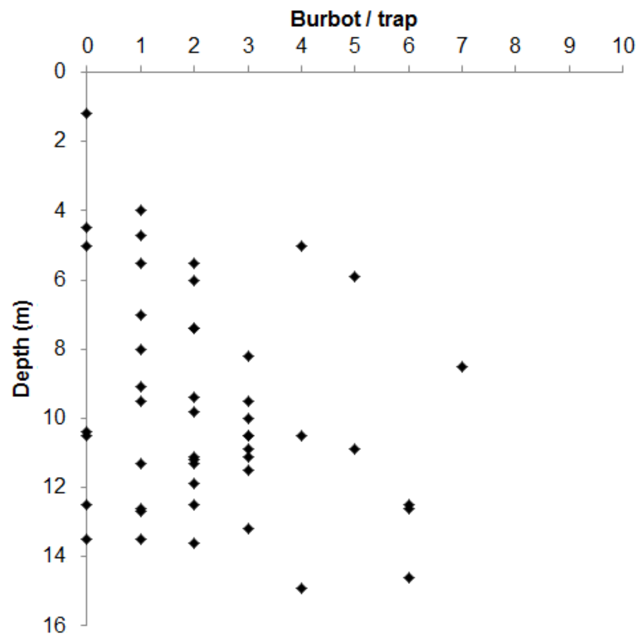

Figure 6. Burbot catch by depth for cod traps set 5 – 6 June 2012 in the south basin of Little Fox Lake.

Capture details – October 2012 recapture session

Between 17 – 18 October 2012, we had 173 burbot captures in 45 trap nights in the south basin of Little Fox Lake, achieving a mean CPUE of 3.84 burbot/trap-night (SE = 0.42). Of the 173 total burbot captures, 5 burbot were considered too small to tag (less than 350 mm total length). Of the remaining 168 burbot captures, 12 were of burbot marked in the first capture session, and 25 were burbot marked in the second capture session. Of the 12 burbot recaptured with marks applied in the first capture session, 2 had been recaptured in the second recapture session, as well as the third. Six of the 39 recaptured burbot with tags applied in previous capture sessions were caught more than once in the October 2012 capture session, providing a 13% within-session recapture rate for previously-tagged burbot. None of the burbot marked in the north basin of Little Fox Lake in June 2012 were recaptured in the south basin. See Table 1 for a summary of capture and tagging details.

We again set traps in the north basin of Little Fox Lake, to detect movement of tagged burbot from one basin to another. In 10 trap nights, we caught 19 burbot. None of the 19 burbot captured in the north basin of Little Fox Lake had tags or fin clips. All were released without tags or fin clips.

There were no capture mortalities during the October 2012 capture session. Two burbot were lethally sampled for fish health monitoring. No other fish species were captured.

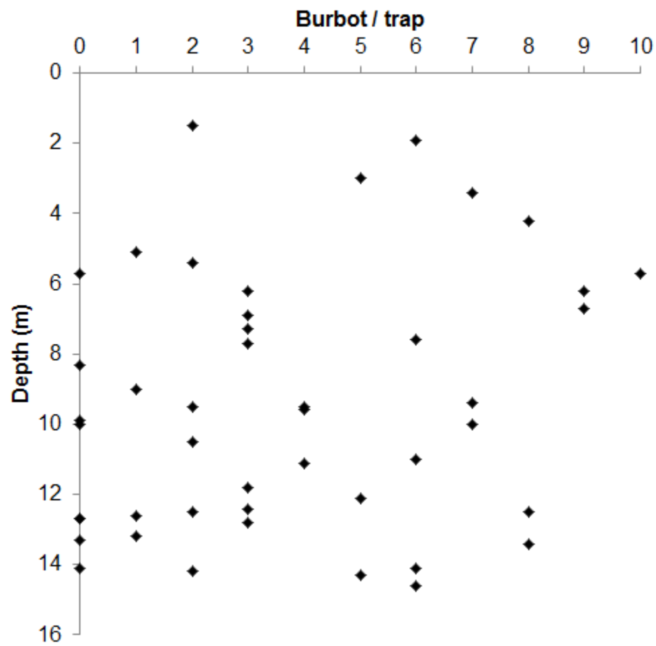

Figure 7. Burbot catch by depth for cod traps set 17-18 October 2012 in the south basin of Little Fox Lake.

Burbot catch rates were uniform among depths in the June 2012 capture session (Figure 7). Water temperature and dissolved oxygen levels were stable within the capture depth range of 1 – 15 m (Figure 4); burbot distribution was likely not limited by temperature or oxygen levels.

Length, weight, condition, and growth

We were interested to see whether burbot that we captured in the 3 capture sessions differed in length, weight, or condition. Burbot total length ($F_{df=2}$= 3.182, P = 0.023) and weight ($F_{df=2}$ = 7.142, P = 0.001) differed significantly among burbot caught in the 3 capture sessions.

Burbot condition, however, showed no significant difference among capture sessions ($F_{df=2}$ = 1.466, P = 0.232), indicating that while burbot of different sizes may have been caught among capture sessions, overall burbot condition did not increase or decline significantly. Average burbot length and weight was highest in the June 2012 capture session (Table 2). More large burbot were caught in June 2012 than in either October 2011 or October 2012 (Figures 8, 9, and 10).

Burbot in the south basin of Little Fox Lake were smaller than burbot from Pine Lake and Squanga Lake (see Appendix 1).

Table 2. Average length, weight, and condition factor of burbot.

	Sample Size	Total Length (mm)	Weight (g)	Condition Factor
October 2011	92	464	710	0.69
June 2012	104	491	974	0.70
October 2012	166	469	736	0.68
June 2012 (recaptures only)	10	492	790	0.66
October 2012 (recaptures only)	37	482	778	0.69
Three-session average		474	798	0.69

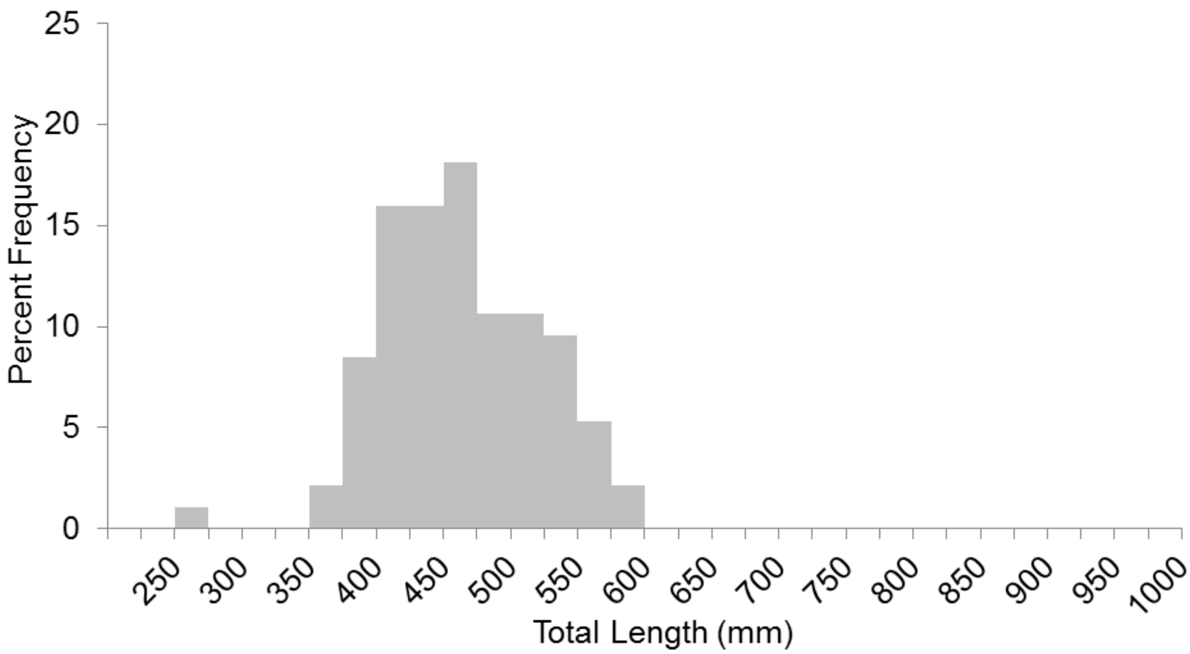

Figure 8. Histogram of burbot total length from the October 2011 capture session.

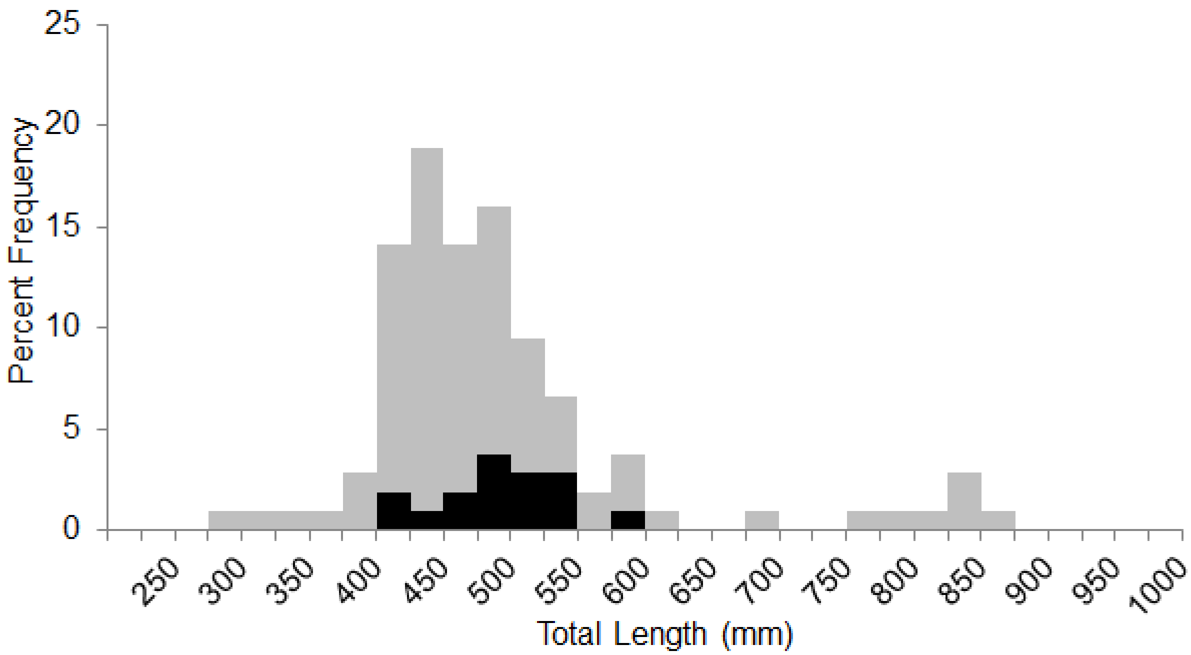

Figure 9. Histogram of burbot total length from the June 2012 capture session (grey), and of marked burbot recaptured in the June 2012 capture session (black).

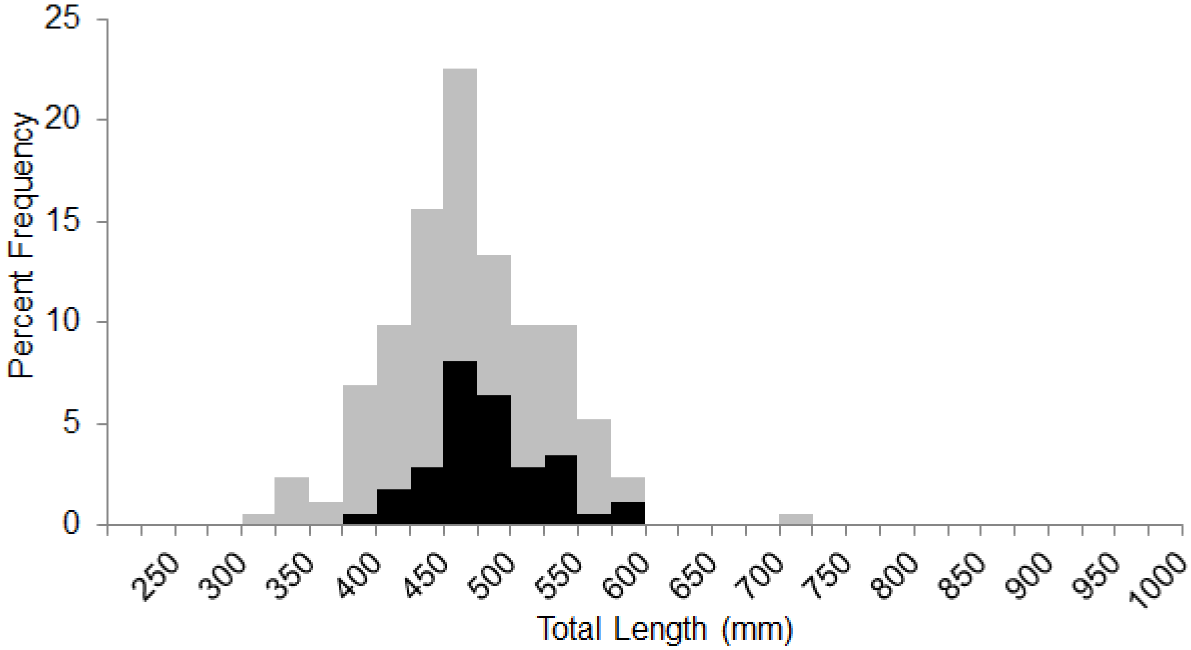

Figure 10. Histogram of burbot total length from the October 2012 capture session (grey), and of marked burbot recaptured in the October 2012 capture session (black).

Individual burbot growth

We also tracked changes in length and weight of individual burbot that were caught in one session *and* were recaptured in a subsequent session. Over the winter of 2011/12, burbot caught in the first session and recaptured in the second session (n = 10) grew an average of 12 mm (SE = 2.13) in total length ($t_{df=9}$ = 4.993, P = 0.001), but did not gain weight ($t_{df=9}$ = -0.426, P = 0.680; Figure 11).

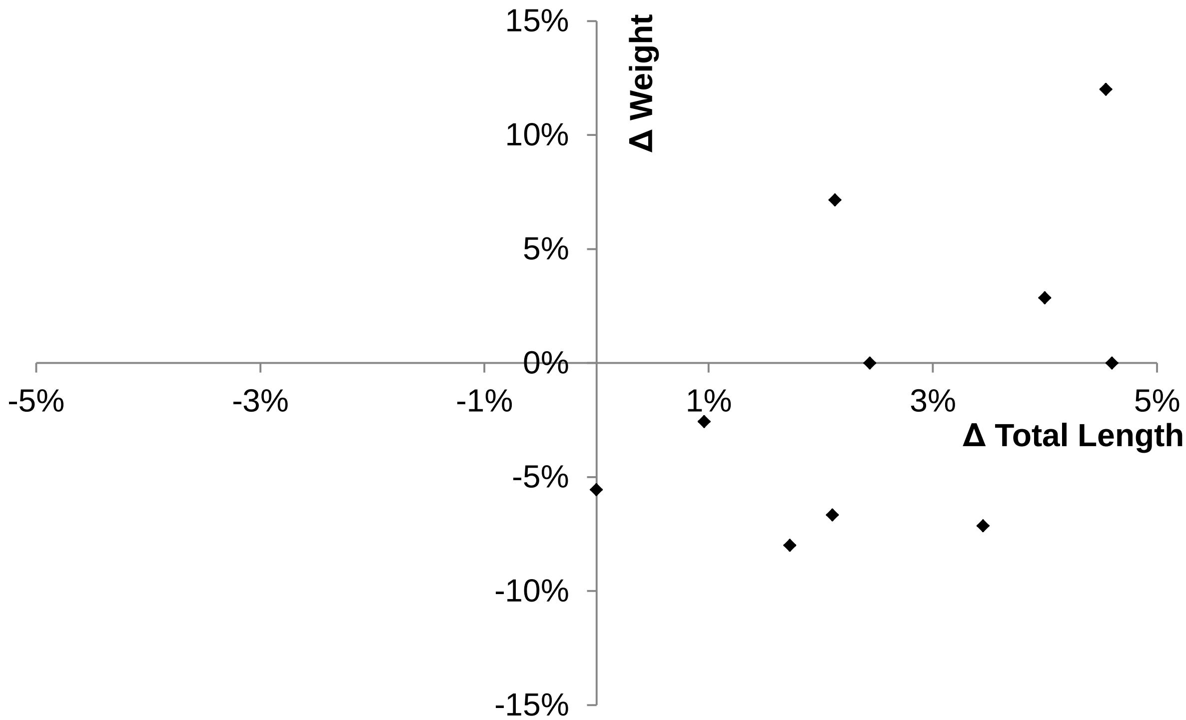

Figure 11. Percent change in total length and weight of individual burbot between October 2011 and June 2012 in the south basin of Little Fox Lake.

Individuals caught in the second session, and subsequently recaptured in the third session (n = 27) grew an average of 8 mm (SE = 1.62) in total length ($t_{df=26}$ = 4.779, P <0.001), but did not gain weight ($t_{df=26}$ = 0.042, P = 0.966; Figure 12).

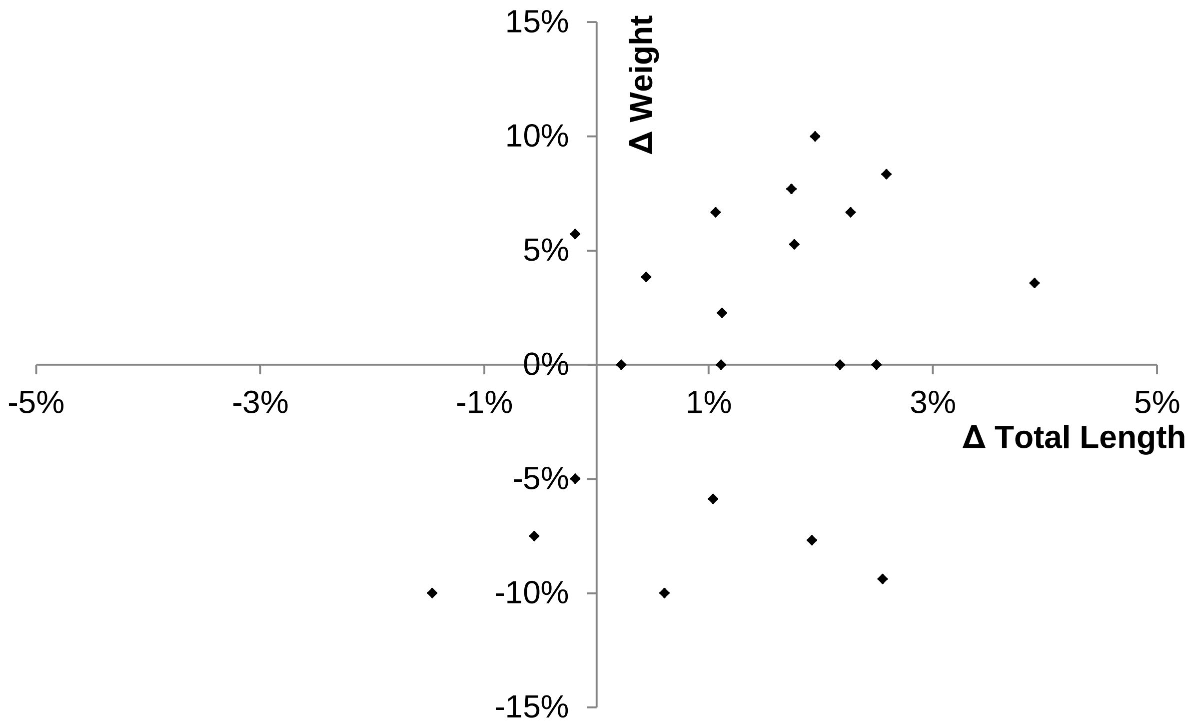

Figure 12. Percent change in total length and weight of individual burbot between June 2012 and October 2012 in the south basin of Little Fox Lake.

Age and diet

Only 3 burbot were sampled for biological data. This sample size is not sufficient to draw meaningful conclusions, and these data are not reported here. All data are housed in the Environment Yukon database.

Abundance and density of burbot

We estimated there were 620 (95% CI 414 – 1,237) burbot 350 mm total length or longer in the south basin of Little Fox Lake. All the assumptions of the statistical tests were met (Appendix 2), and we used the normal distribution to calculate confidence intervals.

The south basin of Little Fox Lake had a density estimate of 4.53 burbot / ha (95% CI 3.02 – 9.03 burbot / ha). We calculated the total biomass of burbot in the south basin of Little Fox Lake using the mean weight of all burbot captured with total length at least 350 mm (859 g; see Appendices 2 and 3 for rationale). The estimated total mass of burbot in the south basin of Squanga Lake at least 350 mm total length was 533 kg.

Evaluation of multiple-recapture methods

We examined the value of having multiple recapture sessions by comparing 2-session Bailey abundance estimates and their confidence intervals against those from the 3-session Schumacher-Eschmeyer method (Tables 3 and 4, Figure 13).

Table 3. Total number of individual burbot captured (C), individual burbot recaptured with tags from previous capture sessions (R), and individual burbot released with marks (U) from the south basin of Little Fox Lake, used for developing Schumacher-Eschmeyer population size estimates.

Capture session	C	R	U
October 2011	71	0	69
June 2012	101	10	100
October 2012	150*	39	39

**Total number of individual burbot captured in October 2012 was estimated from total unmarked burbot captures using the 13% within-session recapture rate demonstrated by previously-marked burbot in October 2012*

Table 4. Total number of individual burbot captured in the second capture session (C_t), number of individual burbot captured in the second capture session with tags from the first capture session (R_t), and number of individual burbot released with marks in the first capture session (U_{t-1}), used for developing Bailey population size estimates.

Capture session pairs	C_t	R_t	U_{t-1}
October 2011 - June 2012	105	10	69
October 2011 - October 2012	162	14	69
June 2012 - October 2012	162	27	101

The Schumacher-Eschmeyer population estimate did not differ significantly from any of the 2-session Bailey population estimates, nor was the confidence interval smaller than those for the 2-session estimates (Figure 13). Consistency among the 4 population estimates indicates that our data provided robust results. Failure of the 3-session data to reduce the confidence interval relative to those for 2-session estimates, however, suggests that 2-session mark-recapture studies may be a reliable and efficient way of developing burbot population estimates.

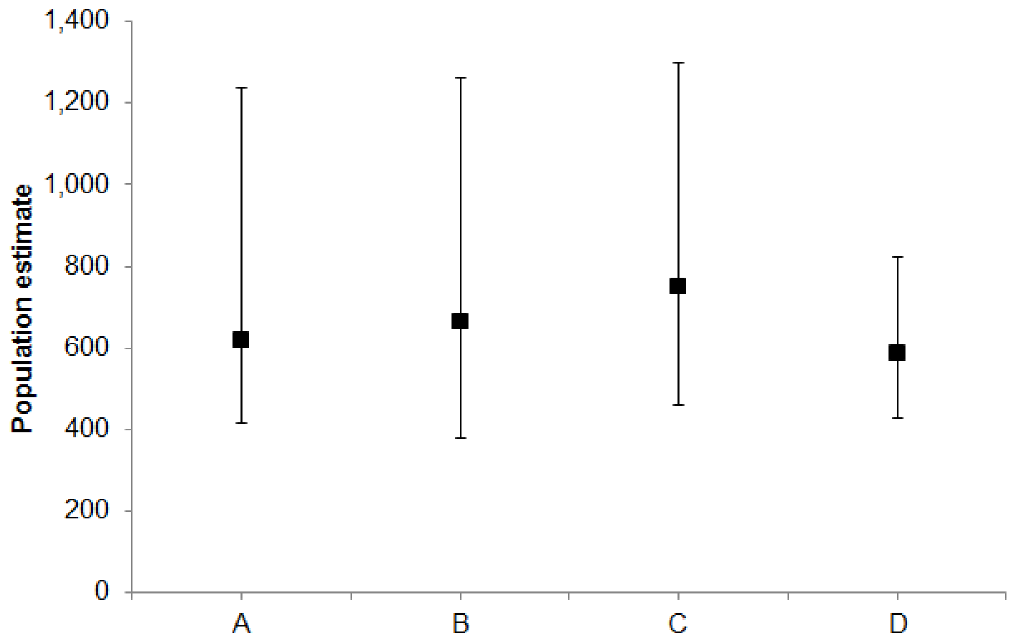

Figure 13. Population estimates and 95% confidence intervals for burbot in the south basin of Little Fox Lake, developed with the Schumacher-Eschmeyer method using data from all 3 capture sessions (A), and with the Bailey method using the October 2011 and June 2012 capture sessions (B), the October 2011 and October 2012 capture sessions (C), and the June 2012 and October 2012 capture sessions (D).

Population status and conclusions

When compared to a model of burbot abundance from Alaska, the burbot population from the south basin of Little Fox Lake appears depleted. Based on a model developed in Alaska, the south basin of Little Fox Lake has a predicted carrying capacity of 5,917 kg of burbot 450 mm total length or longer (see Appendix 4 for methods, data and caveats; Simpson 1998). Lakes used to develop this model ranged from those without competitor species to those containing northern pike, lake trout, and/or rainbow trout. Our biomass estimate for burbot in the south basin of Little Fox Lake incorporates a larger proportion of the population (all burbot 350 mm total length or longer) than the carrying capacity model (all burbot 450 mm total length or longer), and should therefore be larger than 5,917 kg if the population is at carrying capacity. This low estimate compared to modeled carrying capacity suggests a depleted population. As we survey burbot populations in more Yukon lakes, we anticipate being able to revise and recalibrate this model, and we anticipate our confidence in survey conclusions to grow.

When compared to other lakes in Yukon, Little Fox Lake is highly productive, and has relatively few competing piscivorous fish species (lake trout are present, but northern pike are absent). In general, lakes with high productivity can be expected to support higher densities of burbot than lakes with low productivity. Similarly, lakes with fewer competing fish species can be expected to have higher burbot densities than those with one or more competitors. We can compare Little Fox Lake to Pine and Squanga lakes, the only other Yukon lakes where burbot abundance has been assessed (Barker 2013, Barker et al. 2014b; Appendix 1). Pine and Squanga lakes have a similar productivity to Little Fox Lake, but different fish communities; Squanga Lake has northern pike, but no lake trout, and Pine Lake has both northern pike and lake trout (though lake trout densities are notably low; Jessup and Millar 2011). Based on this, we would expect Little Fox Lake to have a similar burbot density to Squanga Lake, and a lower density than Pine Lake. We found a higher burbot density (kg/ha) in Little Fox than we found in either Pine or Squanga lakes (Appendix 1). These comparisons, however, are subject to the limitation that both Squanga and Pine lakes also show evidence for depleted burbot populations (Barker 2013, Barker et al. 2014b).

Given the small population size and current fishing regulations, there is a potential for overharvest. Catch and possession regulations for Little Fox Lake (Special Management Waters) allow each licensed angler to harvest 10 burbot per day, with 20 burbot in possession. One full daily catch and possession limit comprises 1.6% and 3.2%, respectively, of the total estimated population of burbot 350 mm total length or longer in the south basin of Little Fox Lake. Under these limits, successful fishing sessions by even a few anglers could seriously reduce burbot population size. The sustainable harvest of burbot from the south basin of Little Fox Lake is likely very low.

Future surveys on Little Fox Lake

Depending on the time interval between this survey and subsequent mark-recapture surveys, marks applied during the October 2011 and June 2012 capture sessions could be used to gain information on growth, survival and changes in abundance between this and future surveys, using multiple-capture methodologies for open populations (e.g. Jolly-Seber method; Seber 1982). Usability of current marks in future surveys, and appropriate methods with which to evaluate them, depends on rates of loss of tagged fish from the population through emigration, mortality, or tag loss. Future surveys should also consider individually marking burbot in all capture sessions, including the final capture session, allowing for improved abundance estimates through the use of robust design mark-recapture analysis (Pollock 1982).

Information needs for assessing the sustainability of burbot fisheries

We found a small and potentially depleted population of burbot in the south basin of Little Fox Lake. Conclusions of this nature (population is or is not depleted) are helpful, but an ability to speak to sustainable harvest and trends in the population is preferable. Assessing the sustainability of burbot fisheries in Yukon is currently challenging as there are several information gaps. First, we do not have a specific target for a sustainable harvest rate. For lake trout, we use an Optimal Sustainable Yield to assess the sustainability of the harvest of the recreational fishery. This level is based on more than 20 years of experience in managing lake trout fisheries in Yukon. Establishing a sustainable harvest rate for burbot in Yukon is an important management need, but one that will take time because it requires knowledge of a number of populations and time to obtain feedback on whether certain harvest rates are sustainable or not. Second, the overall burbot harvest for most lakes is not known. Fishers that use setlines through the ice are required to report their effort and harvest, but anglers that use a single (or 2) attended line(s) to fish through the ice, and summer anglers, are not required to report their catches. Responsive management of sustainable burbot fisheries in Yukon requires improved knowledge of harvest. A third source of information that will be useful is the trend in a burbot population – in abundance, size, and age of burbot – which can be obtained from repeat surveys on the same lake. Finally, it will be important to carry out burbot surveys on lakes that are not fished, so that the productivity model developed in Alaska can be assessed in the Yukon context.

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Appendix 1 – Estimated density, abundance, and total mass of burbot 350 mm total length or longer from Yukon lakes surveyed to date.

Lakes are arranged in descending order of estimated burbot density (#/ha). Information on lake size, productivity, and the presence of other top predators is included. Lake productivity refers to the annual maximum sustainable yield of all fish in kilograms per hectare, and is estimated following the method proposed by Schlesinger and Regier (1982) of relating mean annual air temperature to the morphoedaphic index (Ryder 1965). This information is presented so that comparisons can be made between lakes with similar characteristics.

Lake	Surface Area	Productivity	Other Top Predators	Year	Mean Total Length	Mean Weight	Density		Abundance Estimate	
	(ha)	(kg fish/ha)			(mm)	(g)	(#/ha)	(kg/ha)	(#)	(kg)
Little Fox (south basin)	157	2.67	Lake trout Northern pike	2012	474	859	4.53	3.89	620	533
Pine	603	2.87	Lake trout Northern pike	2012	505	1,017	2.05	2.08	1,236	1,257
Squanga	1,020	2.83	Northern pike	2013	623	1,816	1.46	2.64	1,485	2,697

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Appendix 2 – Adherence to mark-recapture assumptions

Schumacher-Eschmeyer mark-recapture assumptions

The Schumacher-Eschmeyer method of mark-recapture abundance estimation requires that several criteria be met (Seber 1982, Krebs 1999):

1. Immigration and/or growth recruitment to capture gear are negligible, or if immigration and/or growth recruitment are present, the population estimate applies to the time of the second capture session only.
2. Emigration and/or mortality are negligible, or if emigration and/or mortality occur, it is at equal rates for marked and unmarked burbot.
3. All burbot have equal catchability in all capture events, or marked burbot mix completely with unmarked burbot between capture events.
4. Tag loss is negligible, and all marked burbot are identified as such in subsequent capture events.

Adherence to assumptions

1. Immigration and growth recruitment

   a) *Immigration*

   In regard to immigration, the Little Fox Lake burbot population can be considered reasonably isolated, as it is distant from the nearest connected lake (Braeburn Lake – 13 km). Movement of burbot through the small channel between the north and south basins of Little Fox Lake may occur; movement of burbot between basins can be examined by capturing and marking burbot in both basins, and looking for burbot marked in one basin that are recaptured in the other. We looked for movement of burbot 350 mm total length or greater between the north and south basins of Little Fox Lake by directing catch and marking effort to both basins – no movement of marked fish was observed between basins. We assumed no movement between basins of burbot 350 mm total length or longer.

   b) *Growth recruitment*

   Growth recruitment must also be considered; for the purposes of mark-recapture population estimation, this refers to growth of burbot between capture sessions such that burbot too small to be vulnerable to capture in one capture event grow sufficiently to become vulnerable to capture in subsequent events. Burbot growth rates between capture sessions can be observed by examining differences in length in individually-marked burbot captured in both sessions. Where inter-session growth is non-negligible, the population estimate will be considered to apply only to the population at the time of the second capture session.

In this study, the increase in burbot length between capture sessions likely contributed little to growth recruitment; no burbot caught in the June 2012 capture session were ≤12 mm above the 350 mm population estimation length threshold, and only 3 of 166 burbot caught in the October 2012 capture session were ≤8 mm above the 350 mm population estimation length threshold. We did not adjust mark-recapture abundance estimates for growth recruitment.

2. Emigration:

   In conjunction with immigration, emigration of burbot from Little Fox Lake is presumed to be minimal, as Little Fox Lake is relatively distant from other waterbodies and no inter-basin movement was observed in trapping effort in both basins. We assumed that angler harvest and natural mortality were equally distributed among marked and unmarked burbot. By limiting the total sampling interval to one year, we anticipated that angler harvest and natural mortality would not combine to reduce the number of marked burbot in Little Fox Lake below that useful for mark-recapture abundance estimation.

3. Equal catchability or complete mixing of marked and unmarked burbot:

   a. *Size selectivity bias in capture sessions*

   The presence of size selectivity in catches can be examined using Kolmogorov-Smirnov comparisons of burbot size distributions (Seber 1982, Schwanke 2009). Evidence of size-selectivity in the first capture session is provided by a significant difference between burbot size distribution in the first and subsequent capture sessions. Evidence of size-selectivity in the second capture session is provided by a significant difference between burbot size distributions from the first capture event and marked burbot recaptured in the second sampling event. Evidence of size-selectivity in the third capture event is provided by a significant difference between burbot size distributions from the first 2 sampling events, and marked burbot recaptured in the third sampling event. Appendix 3 provides methodologies for comparing size selectivity between subsequent capture sessions.

   In this study, burbot length distributions did not differ significantly among the 3 capture sessions, nor were there significant differences between burbot caught in October 2011 and those marked burbot recaptured in June 2012, nor between burbot caught in June 2012 and those marked burbot recaptured in October 2012 (Table 2.1).

Table 2.1. 2-Sample Kolmogorov-Smirnov tests for equality of distribution of lengths of burbot captures from October 2011, June 2012, October 2012, and those marked burbot recaptured in June 2012 and October 2012 in the south basin of Little Fox Lake.

	June 2012	October 2012	June 2012 recaptures	October 2012 recaptures
October 2011	$D_{92,104} = 0.016$ P = 0.656	$D_{92,166} = 0.139$ P = 0.201	$D_{92,10} = 0.313$ P = 0.278	
June 2012		$D_{104,166} = 0.100$ P = 0.558		$D_{104,37} = 0.236$ P = 0.110

In cases such as this, where no size selectivity is indicated for any capture session, mark-recapture abundance estimations can proceed without stratifying the population by size, and lengths from all capture sessions can be used to estimate proportion in length distribution composition (Bernard and Hansen 1992, Schwanke 2009).

b. *Mixing of marked burbot within the population*

In Alaskan studies, marked and unmarked burbot have been found to mix thoroughly within 2 – 3 weeks (Bernard et al. 1993). The relatively small size of Little Fox Lake, coupled with the 7.5 and 4.5 month sampling intervals, should provide for complete mixing of marked and unmarked burbot. Examination of individual burbot movements between first and subsequent captures can be examined to assess potential for complete mixing.

In this study, the small size of the south basin of Little Fox Lake, combined with the long intervals between October 2011 and June 2012 capture sessions (7.5 months) and June 2012 and October 2012 capture sessions (4.5 months) allowed for thorough mixing of burbot throughout the lake (Appendices 8 and 9). In several cases, individual burbot caught in one end of the lake were recaptured at the other end, having moved more than 2 km since last capture.

4. Tag loss:

Tag loss can be assessed by double-marking burbot. We marked burbot with an individually-numbered T-bar anchor tag, inserted just behind the leading edge of the first dorsal fin, and with a redundant pelvic fin clip. By assessing captured burbot for both T-bar anchor tags and pelvic fin clips, we were able to estimate tag loss rate, which we incorporated into our mark-recapture abundance estimations.

In this study, only one of the 50 individual burbot recaptured with marks from previous captures sessions lost its numbered T-bar anchor tag. Because the tag loss rate was very low (2%), we analysed our capture data without adjustment for tag loss.

Proportional test for violation of assumptions

Because the Schumacher-Eschmeyer method involves multiple recapture sessions, adherence to the assumptions of this method can be tested by plotting the number of marked individuals in the population against the proportion of marked individuals within each capture (Krebs 1999). A linear relationship between marked individuals in the population and proportion of marked individuals in catches indicates Schumacher-Eschmeyer assumptions are being met; a non-linear relationship indicates a failure to meet one or more assumptions (Krebs 1999).

A plot of cumulative number of marked burbot in the south basin of Little Fox Lake against the proportion of marked burbot in each capture session shows a linear relationship, indicating that assumptions of the Schumacher-Eschmeyer mark-recapture method were met (Figure 2.1).

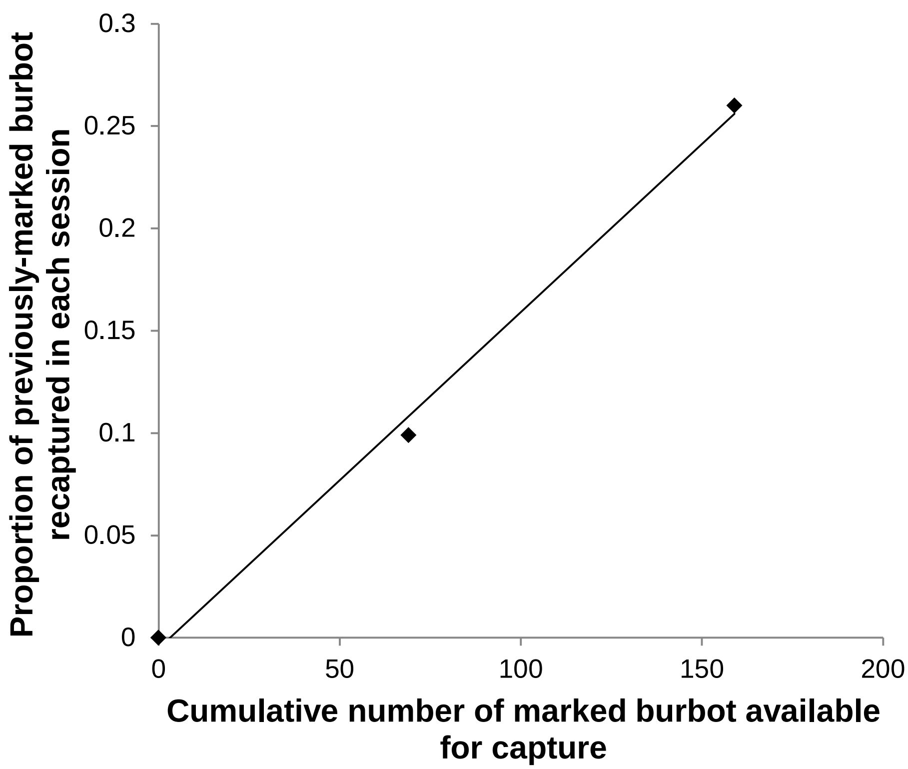

Figure 2.1. Number of marked burbot released into the south basin of Little Fox Lake against the proportion of marked burbot encountered in each capture session.

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Appendix 3 – Burbot population abundance estimation methodologies under differing scenarios of size selectivity bias

	Significant difference between burbot size distribution in first session and recaptures in second session	Significant difference between burbot size distributions in first and second sessions
Case I	No	No
Case II	No	Yes
Case III	Yes	No
Case IV	Yes	Yes

Case I: No evidence for size selectivity in either capture session. Use unstratified abundance estimate. Pool burbot lengths from first and second capture sessions for population composition estimates.

Case II: Evidence for size selectivity in the first capture session, but not the second. Use unstratified abundance estimate, applicable to population estimate at time of second capture session only. Consider only lengths from the second capture session for population composition estimates.

Case III: Evidence for size selectivity in both first and second capture sessions. Stratify abundance estimates within length strata, and sum estimates for total population estimate. Use length distributions from both first and second capture sessions, weighted by stratum capture probabilities, for population composition estimates.

Case IV: Evidence for size selectivity in the second capture session, and unknown status of size selectivity in the first capture session. Stratify abundance estimates within length strata, and sum estimates for total population estimate. Use length distributions from second capture session only, weighted by stratum capture probabilities, for population composition estimates.

(after Schwanke 2009)

Literature cited

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Appendix 4 – Burbot productivity model

We used a productivity model to predict the carrying capacity of burbot ≥450 mm total length in the south basin of Little Fox Lake. The model was developed in Alaska, using lakes in the Upper Copper/Upper Susitna Management Area (Simpson 1998). The model is based on lake conductivity and area.

The model

Carrying capacity of burbot (kg/ha) = $10^{-0.266 + 0.00503 X}$

Where X = lake specific conductivity in µS/cm

Applying the model to the south basin of Little Fox Lake

The model for Little Fox Lake is based on a conversion from total dissolved solids (TDS) to conductivity (µS/cm), which is then incorporated into the carrying capacity model:

Specific conductivity of Little Fox Lake (X) = 378 µS/cm

Burbot carrying capacity (kg/ha) = $10^{-0.266 + 0.00503 (378)}$

= 43.19

Lake area (ha) = 137

Lake-wide burbot carrying capacity (kg) = 5,917

Based on this model, with a conductivity of 378 µS/cm and an area of 137 ha, the south basin of Little Fox Lake is estimated to have a carrying capacity of 5,917 kg of burbot ≥450 mm total length.

Caveats

The sample size of lakes used to produce the model was small at only 11 lakes. Model fit, however, was good; the model explained 93.6% of the variation in carrying capacity among the lakes, and was statistically significant ($P < 0.001$). Burbot carrying capacity in interior Alaska lakes may differ from those in Yukon.

Literature cited

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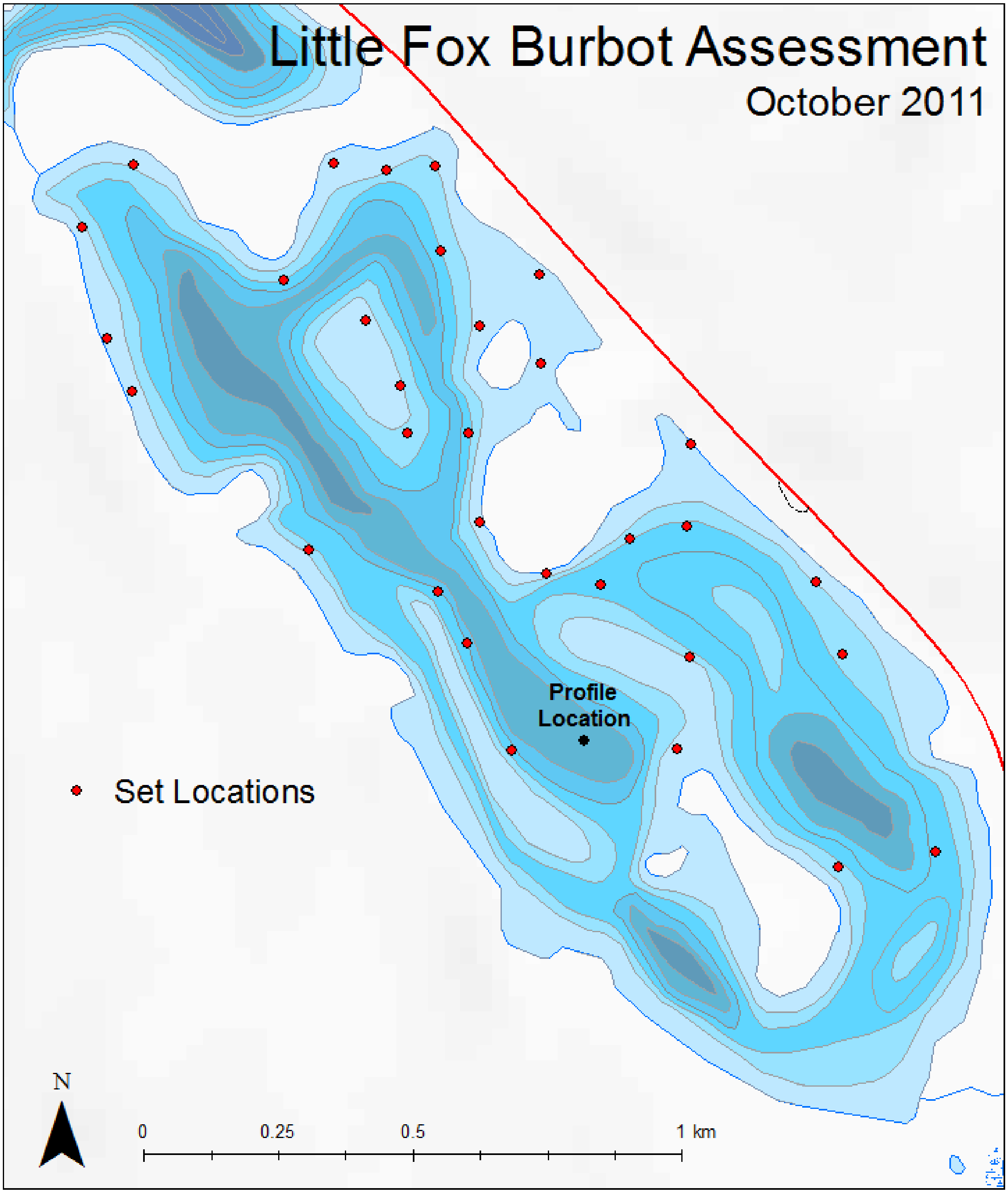
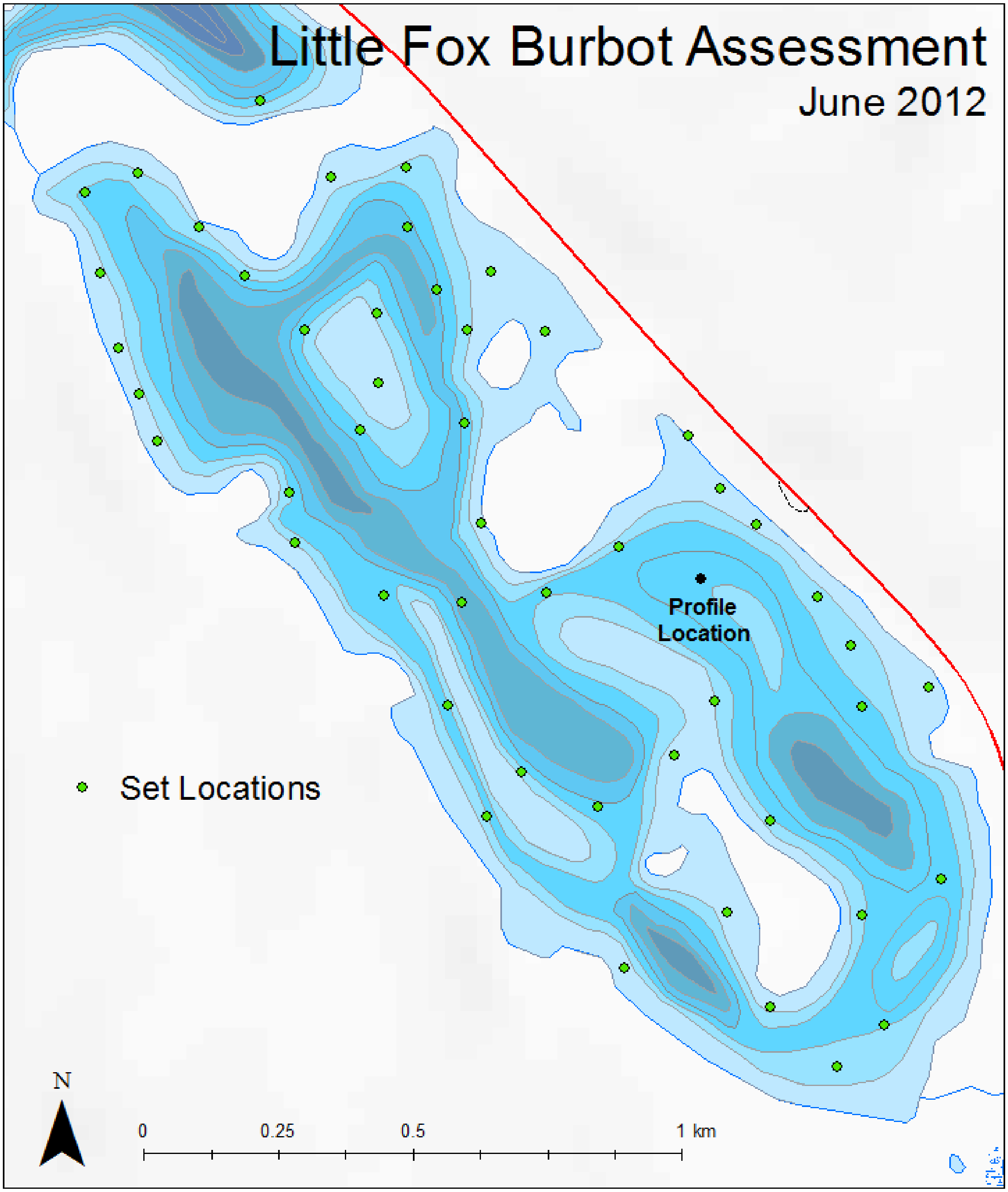
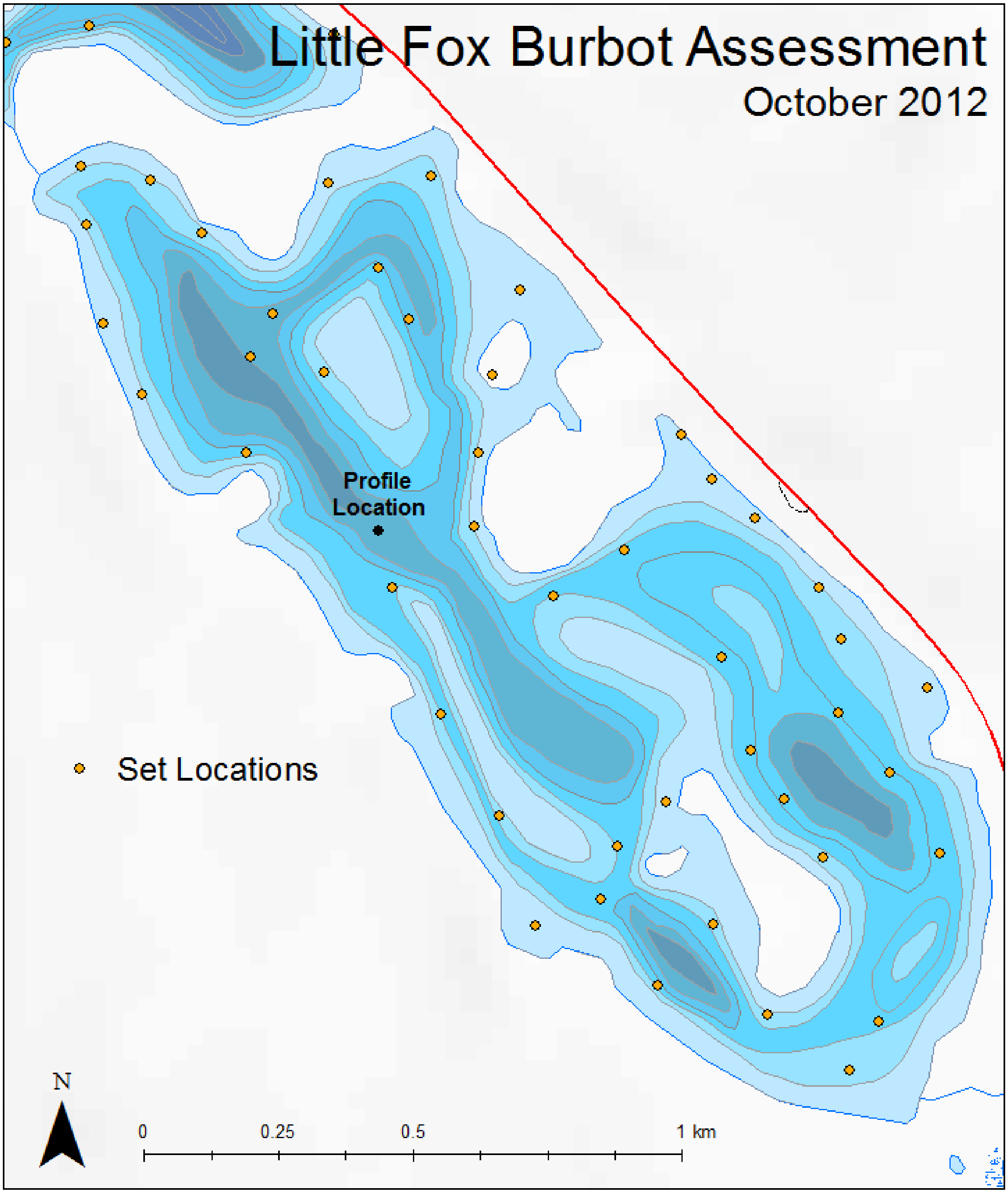
Appendix 5 – Set and profile locations, south basin of Little Fox Lake, October 2011.



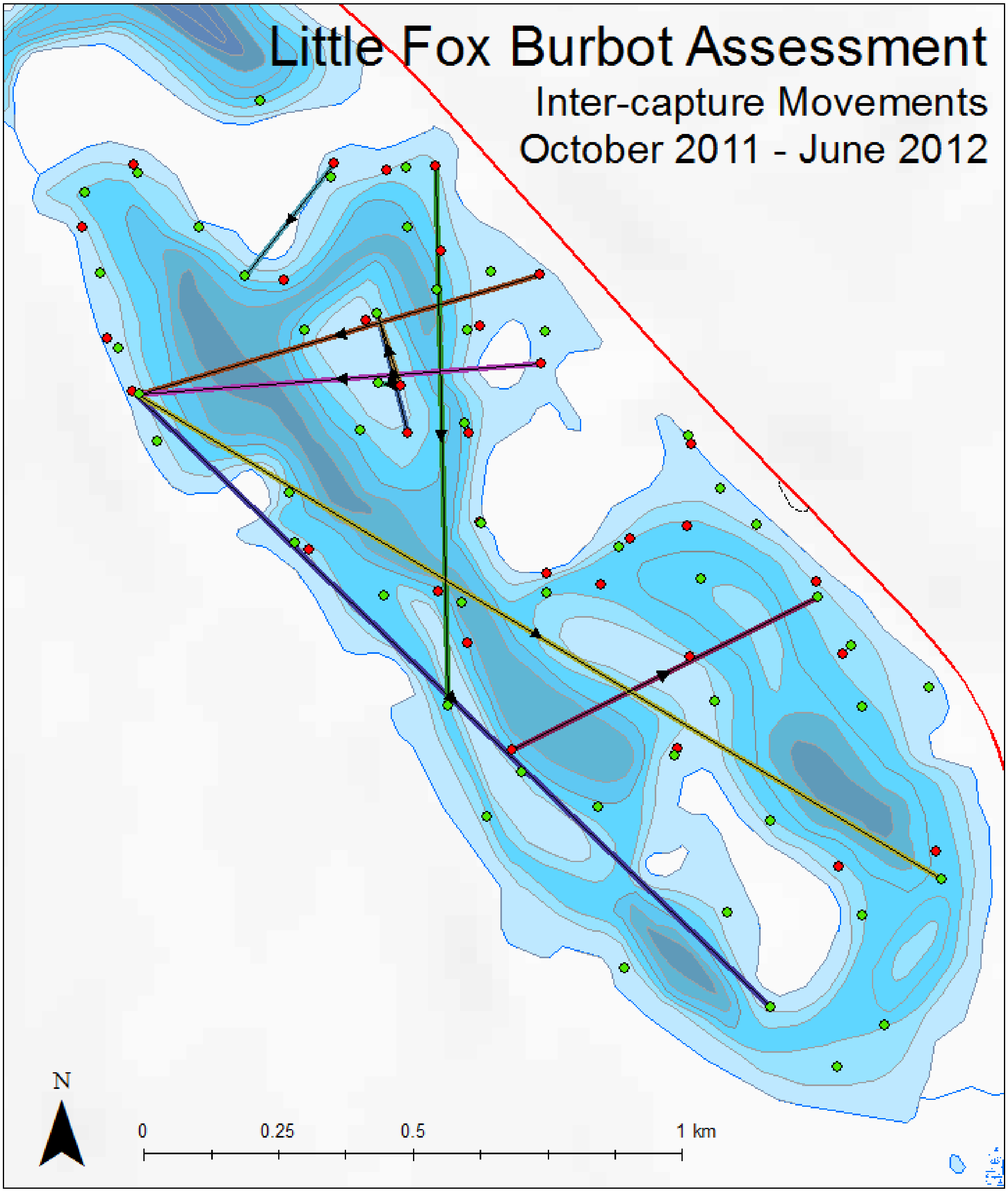
Appendix 6 - Set and profile locations, south basin of Little Fox Lake, June 2012.



Appendix 7 - Set and profile locations, south basin of Little Fox Lake, October 2012.



Appendix 8 – Little Fox Lake intersession movements by individual burbot, between October 2011 initial capture location (red circles) and June 2012 recapture locations (green circles). Individual burbot are denoted by differently-coloured lines, with arrows denoting travel direction.



Appendix 9 – Little Fox Lake intersession movements by individual burbot, between June 2012 capture location (green circles) and October 2012 recapture locations (orange circles). Individual burbot are denoted by differently-coloured lines, with arrows denoting travel direction.