BURBOT POPULATION ASSESSMENT SQUANGA LAKE
2013

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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 Squanga Lake using mark-recapture methodology, with an initial marking session in May and June 2013, and a recapture session in October 2013. Our study focused only on burbot that were 350 mm in length or longer.

We captured and marked 293 burbot during May and June 2013. We returned in October 2013 and caught 90 burbot, of which 17 were recaptures from the previous capture session. The abundance estimate for burbot 350 mm total length or longer was 1,485 (95% CI 1,014 – 2,242), or 1.46 burbot / hectare (ha).

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

Key Findings

- Squanga Lake is a medium-sized, productive lake, with a lower-than-expected abundance of burbot (1,481 burbot at least 350 mm in total length), suggesting that the population may depleted.

- Burbot in Squanga Lake are relatively large-bodied, with a mean total length of 623 mm and a mean weight of 1,816 g.

- Individual burbot gained length and lost condition over summer 2013.

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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.

The 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 late May and early June 2013 we used modified cod traps to capture burbot in Squanga Lake. Each burbot was uniquely marked and released. Marked fish were then allowed to mix with unmarked fish over the summer and in mid-October 2013 we used the same traps to search for marked burbot.

Study Area

Squanga Lake is a medium-sized (1,020 ha), easily-accessible lake. It is 100 km from Whitehorse, adjacent to the Alaska Highway between Jake's Corner and Johnsons Crossing (Figure 1). A Yukon government campground and boat launch, as well as several private cabins, are situated at the south end of the lake. Squanga Lake is within the traditional territories of the Carcross/Tagish First Nation and Teslin Tlingit Council.

Squanga Lake receives angling pressure from recreational anglers seeking northern pike, burbot, and lake whitefish. Burbot in Squanga Lake are also targeted by a licensed winter set-line fishery.

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. Squanga Lake is managed as a General (Regulations) Water.
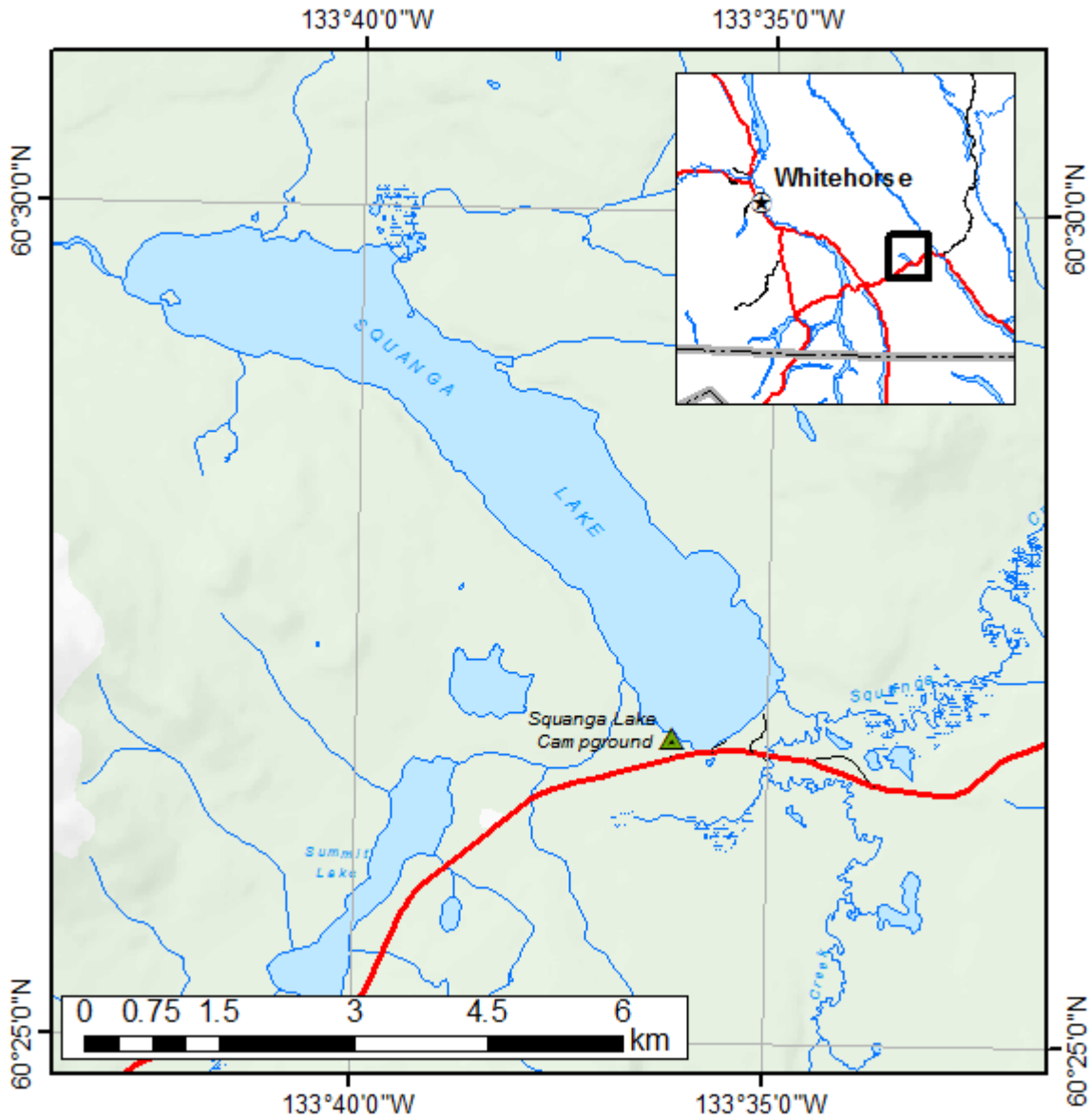
Figure 1. Location of Squanga Lake, Yukon

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. Abundance can then be estimated using a simple formula (e.g., Petersen method; Krebs 1999). Variations to this method involve using more than 2 capture sessions (e.g., an initial marking session, and more than 1 recapture sessions).

In instances where 2 capture sessions are used (an initial marking session, and a subsequent recapture session), and the recapture is performed with replacement we use the Chapman method – a modification of the Petersen abundance estimate (Seber 1982, Krebs 1999). The Chapman 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:

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

where:

C_t = the total number of burbot caught in the recapture session,

R_t = the number of burbot with previously-existing marks caught in the recapture session,

U_{t-1} = the number of burbot marked and released in the initial marking session

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

The appropriate method for estimation of confidence intervals for Chapman mark-recapture abundance estimates depends on the sample size and the ratio of marked to unmarked fish in the recapture session (Seber 1982). 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.

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 occur 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 first capture session on Squanga Lake was 29 May – 3 June 2013, followed by a second capture session (i.e., the recapture session) on 15 – 24 October 2013.

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).

The modified cod traps were baited with 6 different types of bait, including frozen smelt, fresh whitefish, canned tuna, raw bacon, raw chicken, and dry dog food (60% fish content).

We set each cod trap 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 = Weight (g)/Length (cm)^3 • 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 both the first and second 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 three rays of the left 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.

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 similar locations during both the first and second capture sessions, using a multi-parameter probe (YSI 600QS; YSI Inc., Yellow Springs, OH).

Results and Discussion

Temperature and Dissolved Oxygen

We took 2 temperature and dissolved oxygen profiles during the first capture session. The first, taken 30 May, showed a temperature range between 7°C at the surface to 4°C at the bottom, with a thermocline (zone of steep temperature gradient) at 10 m (Figure 2). Dissolved oxygen was high and steady near 12 mg/l between the surface and 26 m, then declined to just below 6 mg/l near the bottom (Figure 2).
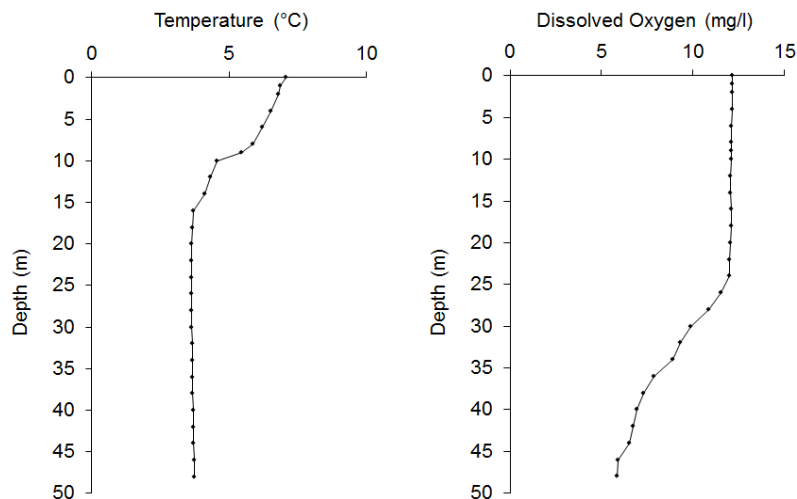
Figure 2. Temperature and dissolved oxygen profile of Squanga Lake, taken 30 May 2013

The second profile, taken in the same location on 2 June, showed rapid changes in dissolved oxygen levels. Over 4 days, surface waters had warmed to 9°C, though the remainder of the water column had similar temperatures to those measured on 30 May (Figures 2 and 3). Dissolved oxygen levels, however, had changed, such that levels of 12 mg/l of dissolved oxygen at the surface rapidly declined to < 4 mg/l at depths below 13 m (Figure 3).
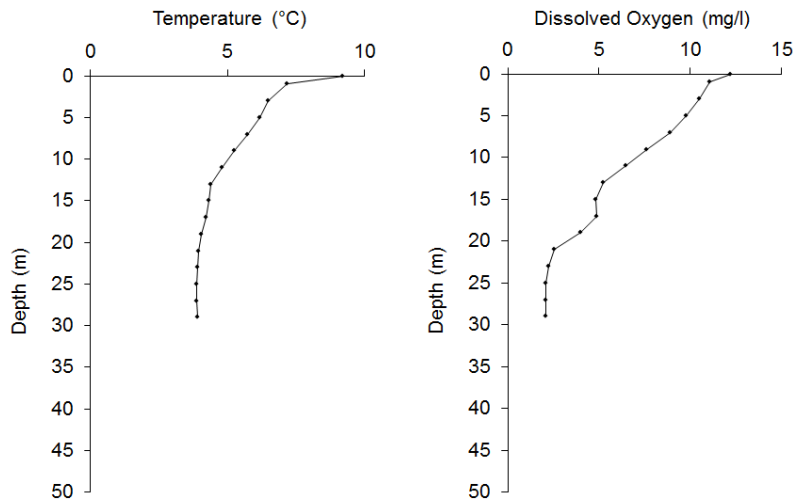
Figure 3. Temperature and dissolved oxygen profile of Squanga Lake, taken 2 June 2013.

The temperature profile taken during the second capture session (17 October 2013) showed the lake as nearly isothermal, with temperatures of 6°C at the surface declining to 5°C at the bottom (Figure 4). Dissolved oxygen levels were steady near 9 mg/l between the surface and 30 m, below which they rapidly decreased to near zero (Figure 4).
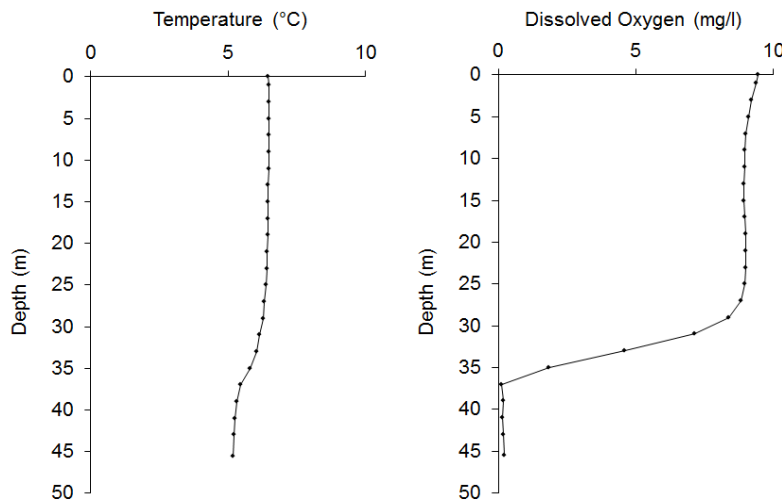
Figure 4. Temperature and dissolved oxygen profile of Squanga Lake, taken 17 October 2013.

Capture details – May/June 2013 capture session

Between 29 May and 3 June 2012 we captured 311 burbot in 174 trap-nights of capture effort (see Appendix 5 for set and capture locations). Discounting 2 traps that were set for 2 nights and contained 8 burbot, we achieved a mean CPUE of 1.78 burbot/set (SE = 0.12).

In the first capture session, we assessed 3 bait types (~250 g dry dog food, 120 g canned tuna, ~400 g fresh whitefish) against the standard bait (~200 g frozen smelt) used in our burbot surveys (Table 1). A comparison of mean CPUE for traps baited with frozen smelt and fresh whitefish revealed no significant difference between the two bait types ($t_{df=27}$ = -0.83, p = 0.417). Canned tuna and dog food had very low CPUE.

Table 1. Comparison of mean CPUE for bait type in Squanga Lake 29 May – 3 June 2013

Bait type	# of trap-nights	Burbot caught	Mean CPUE (burbot/trap-night)
frozen smelt	141	255	1.81
fresh whitefish	21	44	2.10
canned tuna	6	4	0.67
dog food	2	0	0

Of the 311 total burbot captures, 12 were instances of within-session recaptures of marked burbot, giving a total of 299 individual burbot caught. Six burbot were dead when traps were retrieved; these were from traps in 13 – 15 m of water, where oxygen levels became low during the latter part of the survey (Figure 3).

All burbot caught were greater than 350 mm total length and considered large enough to tag. A total of 293 individual burbot were marked and released in the first capture session. No other fish species were captured.
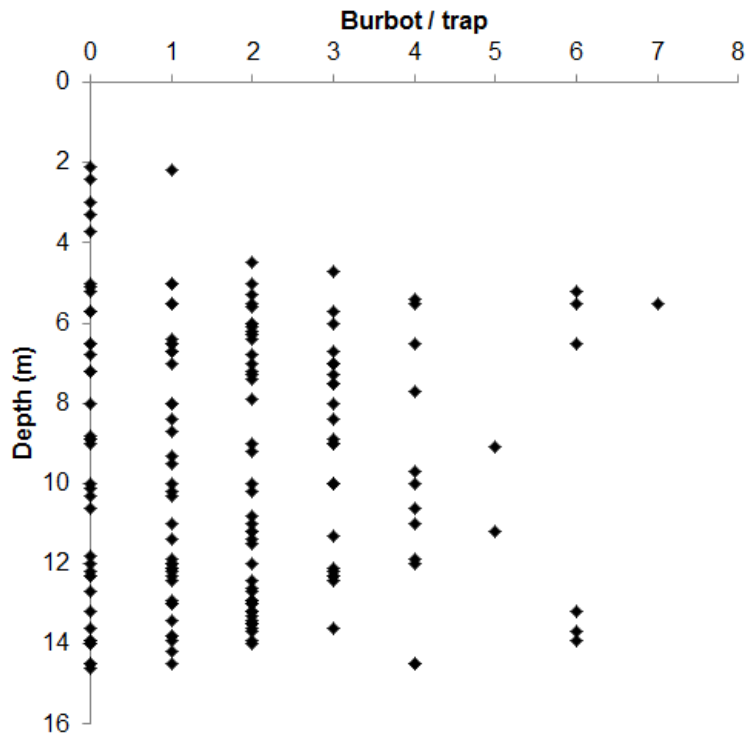
Figure 5. Burbot catch by depth for cod traps set 29 May – 3 June 2013 in Squanga Lake.

The majority of burbot caught were in traps set at depths of 5 m or deeper (Figure 5). Burbot activity in shallow water may have been limited by temperature.

Capture details – October 2013 capture session

Between 15 and 24 October 2012 we captured 97 burbot in 191 trap-nights (see Appendix 6 for set and capture locations). Traps in the second capture session were split between overnight sets (n = 102) and two-night sets (n = 89). Mean CPUE for overnight sets was 0.48 burbot/set (SE = 0.08), and mean CPUE for two-night sets was 0.56 burbot/set (SE = 0.08).

We assessed 2 other bait types, ~250 g raw bacon (n = 6 traps) and ~250 g raw chicken thighs (n = 5 traps), against the standard bait of ~200 g frozen smelt in overnight sets in the second capture session. No burbot were caught in traps baited with bacon or chicken. Mean CPUE for overnight sets with smelt only was 0.54 burbot/set (SE = 0.09).

Of the 97 total burbot captures, 17 were burbot marked in the first capture session, and 7 were within-session recaptures (Table 2). All burbot captured were longer than 350 mm total length. No other fish species were captured.

There were no capture mortalities in the second capture session.
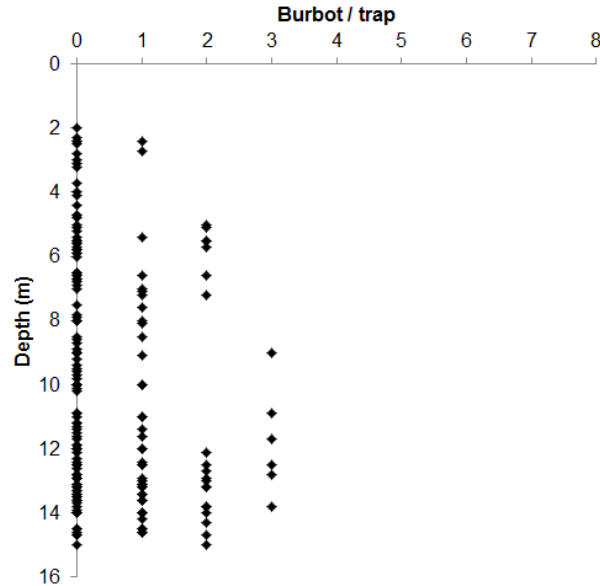
Figure 6. Burbot catch by depth for cod traps set 15 - 22 October 2013 in Squanga Lake

Catch rates were low at all depths during the second capture sessions, but increased slightly with depth (Figure 6). Temperature and dissolved oxygen levels were stable within the capture depth range of 2 – 15 m (Figure 4); burbot distribution was not likely limited by temperature or oxygen levels.

Table 2. Summary of capture and marking details for burbot capture sessions on Squanga Lake.

	May/June 2013	October 2013
Total burbot captures	311	97
Burbot too small to mark	*0*	*0*
Capture mortalities	*6*	*0*
Subsequent removal of tagged burbot reported by anglers	*0*	*-*
Effective number of burbot (for MR purposes)	293	97
Captures of fish marked May-June 2013	12	17
Captures of fish marked October 2013	-	7
Captures of fish marked May-June 2013, and previously recaptured October 2013	-	0
Total recaptures (excludes within-session recaptures)	-	17
Total new marked burbot available for next capture session	293	73
Cumulative total of marked burbot available for the next capture session	293	366

CPUE was much lower in the second capture session than in the first. Dissolved oxygen levels in water deeper than 13 m in the first capture session (Figure 3) may have concentrated the entire burbot population of Squanga Lake into depths where they were accessible to traps (0 – 15 m). Lake conditions during the second capture session were suitable over a greater depth range (Figure 4), including those below the maximum depth for effective live-trapping, thereby creating a lower density of burbot within effective trapping depths during the second capture session.

Length, weight, condition, and growth

We were interested to see if the burbot that we captured in the spring differed from those we caught in the autumn. Burbot caught in the spring (first capture session) were significantly longer ($t_{df=136}$ = 2.23, P = 0.027), heavier ($t_{df=150}$ = 3.47, P = 0.001) and in better condition ($t_{df=159}$ = 8.511, P <0.001) than those captured in the autumn recapture session (Table 3, Figures 7 and 8).

Burbot in Squanga Lake were considerable larger than burbot in Pine Lake and Little Fox Lake (see Appendix 1).

Table 3. Average length, weight and condition factor of burbot caught in Squanga Lake.

	Sample Size	Total Length (mm)	Weight (g)	Condition Factor (k)
May/June 2013	299	655	2,298	0.75
October 2013	90	623	1,816	0.66
October 2013 (recaptures only)	17	690	2,469	0.68
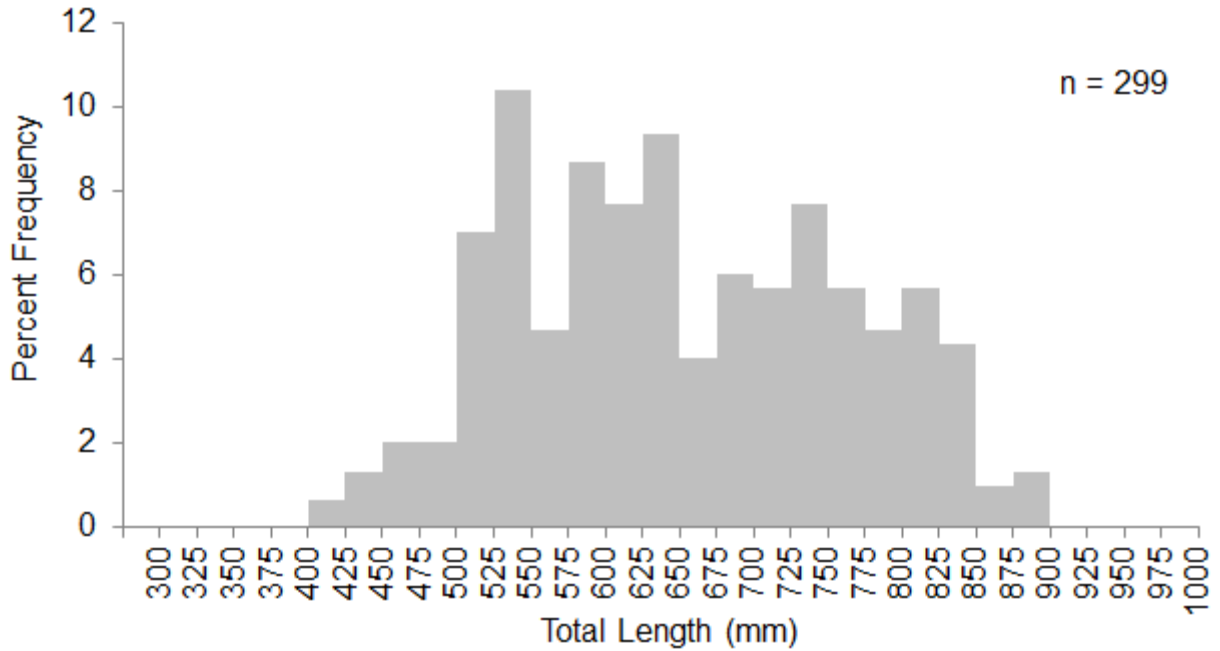
Figure 7. Histogram of burbot total length from the May/June 2013 capture session.
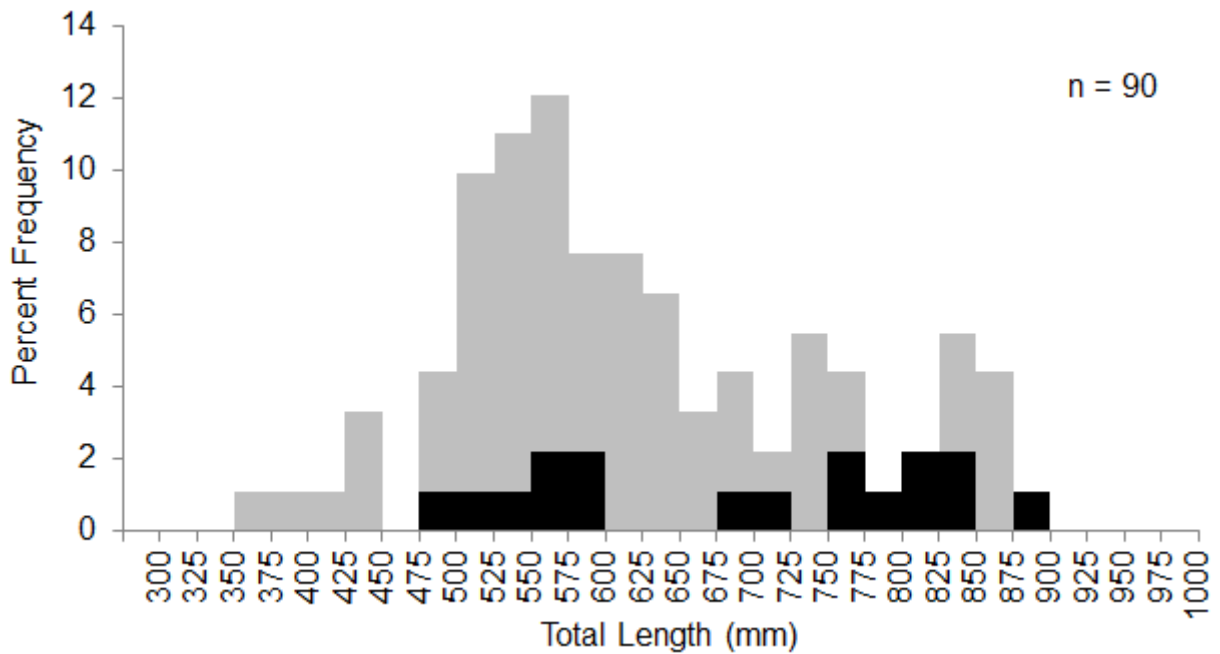
Figure 8. Histogram of burbot total length from the October 2013 capture session (grey), and of previously-marked burbot recaptured in the October 2013 capture session (black).

Individual burbot growth

We also tracked changes in length, weight, and condition of individual burbot that were caught in the first session *and* were recaptured in the second session. Over the summer of 2013, these burbot (n = 17) grew an average of 13 mm (SE = 4.59) in total length ($t_{df=16}$ = 2.755, P = 0.014, Figure 9), and did not change weight ($t_{df=16}$ = -1.575, P = 0.135); this resulted in a decline in condition ($t_{df=16}$ = 0.096, P = 0.003).
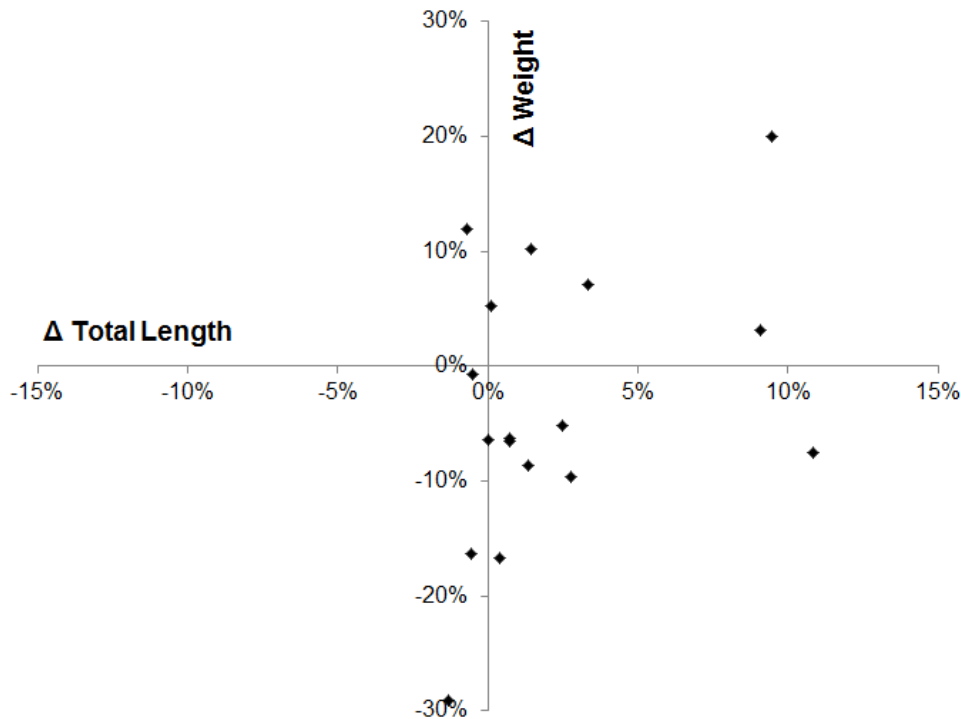
Figure 9. Percent change in total length and weight of individual burbot between May/June 2013 and October 2013 from Squanga Lake.

Poorer condition of burbot caught in the second capture session compared to those caught in the first capture session (both for the population as a whole and those individuals caught in both sessions) suggests poor summer foraging conditions. High water temperatures and low concentrations of dissolved oxygen may limit burbot distribution within the water column during summer in Squanga Lake. Similar temperature- and oxygen-driven limitations in summer have been observed for lake trout in other Yukon lakes (Jessup and Millar 2012).

Age and diet

Six burbot (capture mortalities from the first capture session) 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 estimate there were 1,485 (95% CI 1,014 – 2,242) burbot 350 mm total length or longer in Squanga Lake. All of the assumptions of the statistical tests were met (Appendix 2) and we used the binomial distribution to calculate confidence intervals.

Squanga Lake has a density estimate of 1.46 burbot / ha (95% CI 0.99 – 2.20 burbot / ha). We calculated the total biomass of the Squanga Lake burbot population at least 350 mm total length using the mean weight of burbot caught in the second sampling session only (1,816 g; see Appendix 2 for rationale). The estimated total mass of the Squanga Lake burbot population at least 350 mm total length was 2,697 kg.

Population status and conclusions

When compared to a model of burbot abundance from Alaska, the Squanga lake burbot population appears depleted. Based on a model developed in Alaska, Squanga Lake has a carrying capacity of 8,505 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 Squanga 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 8,505 kg if the population is at carrying capacity. At 2,697 kg, however, the estimated mass of the burbot population in Squanga Lake is only 32% of the predicted 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, Squanga Lake is highly productive, and has few competing piscivorous fish species. In general, lakes with high productivity can be expected to support higher densities of burbot than lakes with low productivity. Similarly, lakes without competing fish species can be expected to have higher burbot densities than those with one or more competitors.

We can compare Squanga Lake to Pine and Little Fox lakes, the only other Yukon lakes where burbot abundance has been assessed (Barker 2013, Barker et al. 2014, Appendix 1). Pine and Little Fox lakes have a similar productivity but have an additional predator species, lake trout, though lake trout densities are notably low in Pine Lake (Jessup and Millar 2011). Based on this, we would expect Squanga Lake to have a higher burbot density than both the other lakes; we found a density (kg/ha) higher than Pine Lake but lower than Little Fox Lake (Appendix 1). These comparisons are subject to the limitation that both Little Fox and Pine lakes also show evidence for depleted burbot populations (Barker 2013, Barker et al. 2014).

Given the small population size and current fishing regulations, there is a potential for overharvest. Catch and possession regulations for Squanga Lake (General Waters) allow each licensed angler to harvest 10 burbot per day, with 20 burbot in possession. One full daily catch and possession limit comprises 0.7% and 1.3%, respectively, of the total estimated population of burbot 350 mm total length or longer in Squanga Lake. Under these limits, successful fishing sessions by even a few anglers could seriously reduce burbot population size. The sustainable harvest of burbot from Squanga Lake is likely very low.

Information needs for assessing the sustainability of burbot fisheries

We found a small and potentially depleted population of burbot in Squanga 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 provided by repeat surveys on the same lake. Finally, it will be important to carry out burbot surveys lakes that are not fished, such 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 (ha)	Productivity (kg fish/ha)	Other Top Predators	Year	Mean Total Length (mm)	Mean Weight (g)	Density (#/ha)	(kg/ha)	Abundance Estimate (#)	(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

Appendix 2 - Adherence to mark-recapture assumptions

Schumacher-Eschmeyer mark-recapture assumptions

The Chapman modification of the Petersen method of mark-recapture abundance estimation requires that several criteria be met (Seber 1982, Krebs 1999):

1. Immigration and/or recruitment to gear are negligible, or if immigration and/or 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 both 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 Squanga Lake burbot population can be considered reasonably isolated; the nearest lake (Little Squanga) is 3.2 km upstream, and passage between lakes requires traversing several beaver dams. We assumed no movement between lakes 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 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 survey, the increase in burbot length between capture sessions likely contributed little to growth recruitment; only one burbot caught in the October 2013 capture session was ≤ 13 mm above the 350 mm population estimation length threshold, indicating it may have grown sufficiently in length to enter the population of interest between the 2 capture sessions. We did not adjust mark-recapture abundance estimates for growth recruitment.

2. Emigration:

In conjunction with immigration, emigration of burbot from Squanga Lake is presumed to be minimal. We assumed that angler harvest and natural mortality were equally distributed among marked and unmarked burbot. By limiting the total sampling interval to one summer, we anticipated that angler harvest and natural mortality would not combine to reduce the number of marked burbot in Squanga Lake below that useful for mark-recapture abundance estimation.

3. Equal catchability and 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. See Appendix 3 for methodologies for comparing size selectivity between subsequent capture sessions.

In this study, burbot length distributions differed significantly between the first and second capture sessions (Table 2.1). The length distributions of burbot captured in the first capture session, and the subset of those burbot recaptured in the second capture session, however, were not significantly different.

Table 2.1 – 2-Sample Kolmogorov-Smirnov tests for equality of distribution of lengths of burbot captures from May/June 2013, October 2013, and marked burbot recaptured in October 2013 in Squanga Lake.

	October 2013	October 2013 recaptures
May/June 2013	$D_{299,90} = 0.195$ $P = 0.010$	$D_{299,17} = 0.243$ $P = 0.256$

In cases such as this, where size selectivity is indicated for the first capture session, but not for the second, abundance estimations can proceed without stratifying the population by size, though the population estimate is applicable to the population at the time of the second capture session only (see Appendix 3). Length and weight distributions from the second capture session only should be considered for population composition estimates (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 4.5 month sampling interval in this survey 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 4.5 month interval between capture sessions allowed for thorough mixing of burbot throughout the lake (Appendix 7). In several cases, individual burbot caught in one end of the lake were recaptured at the other end, having moved up to 7 km since last capture.

4. Tag loss:

Tag loss can be assessed by double-marking burbot. We marked burbot with a uniquely-numbered T-bar anchor tag, 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, none of the 17 individual burbot recaptured with marks from the previous captures session had lost its numbered T-bar anchor tag. We analyzed our capture data without adjustment for tag loss.

Literature Cited

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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 length and weight distributions 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 and weight 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 and weight distributions from second capture session only, weighted by stratum capture probabilities, for population composition estimates.

(after Schwanke 2009)

Literature Cited

SCHWANKE, C. J. 2009. Stock assessment and biological characteristics of burbot in Crosswind and Tolsona lakes, 2006 and 2007. Alaska Department of Fish and Game, Anchorage, AK. http://www.sf.adfg.state.ak.us/FedAidPDFs/fds07-24.pdf. Accessed 2013 May 2.

Appendix 4 – Burbot productivity model

We used a productivity model to predict the carrying capacity of burbot ≥450 mm total length in Squanga 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 Squanga Lake

The model for Squanga Lake is based on conductivity (µS/cm), which is then incorporated into the carrying capacity model:

Specific conductivity of Squanga Lake (X) = 236 µS/cm

Burbot carrying capacity (kg/ha) = $10^{-0.266 + 0.00503 (236)}$

$$= 8.34$$

Lake area (ha) = 1,020

Lake-wide burbot carrying capacity (kg) = 8,505

Based on this model, with a specific conductivity of 236 µS/cm and an area of 1,020 ha, Squanga Lake is estimated to have a carrying capacity of 8,505 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

SIMPSON, T. D. 1998. Lake productivity indices as estimators of carrying capacity for burbot and northern pike in interior Alaska. MSc. thesis, University of Alaska Fairbanks, Fairbanks, AK.

Appendix 5 – Set and profile locations, Squanga Lake, May/June 2013.

Squanga Lake Burbot Assessment
May/June 2013

Profile
Location

• Set Locations

N

0   0.5   1   2   3   4
km
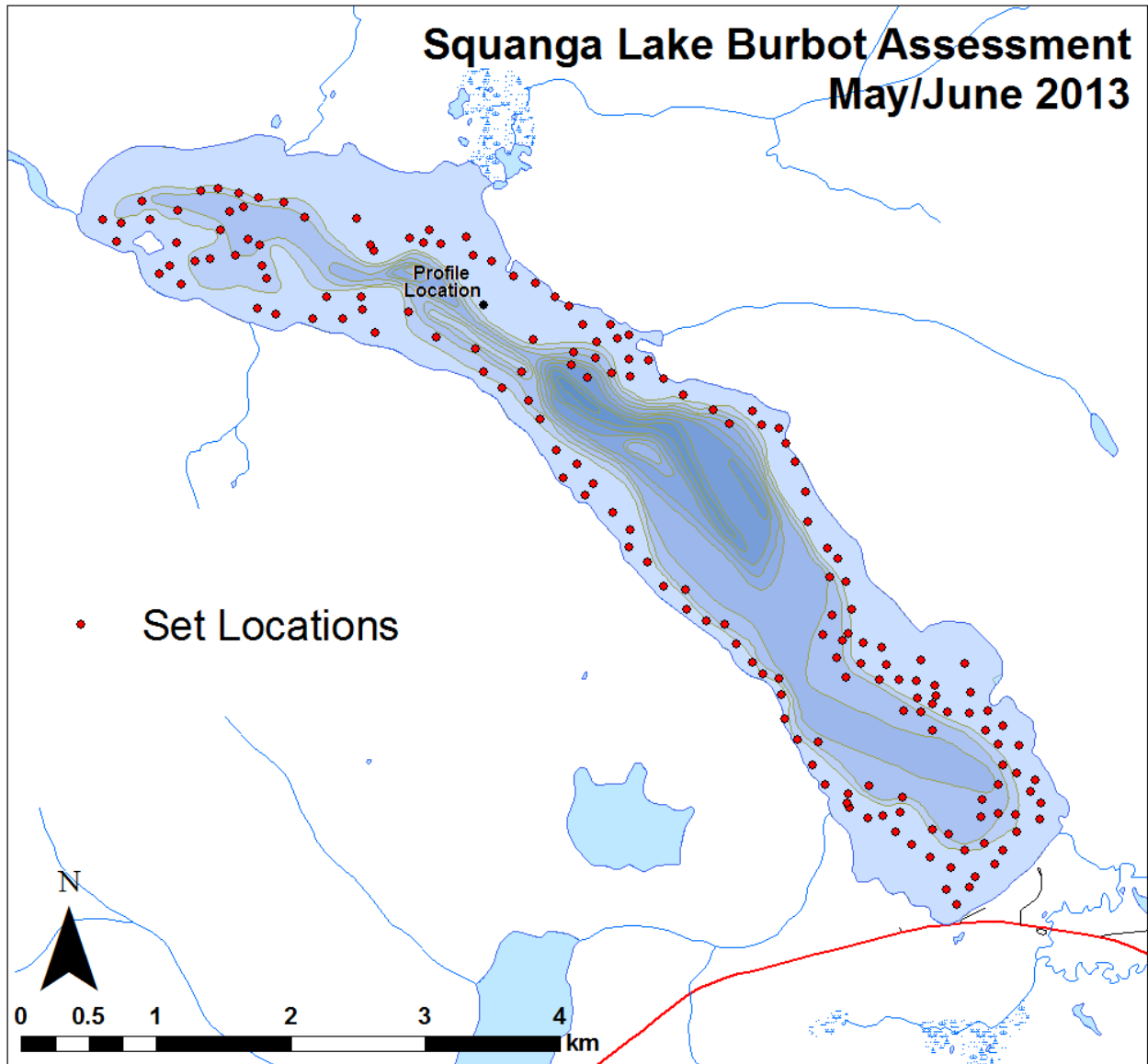
Appendix 6 – Set and profile locations, Squanga Lake, October 2013.

Squanga Lake Burbot Assessment
October 2013

Profile
Location

Set Locations

N

0   0.5   1   2   3   4
                                km
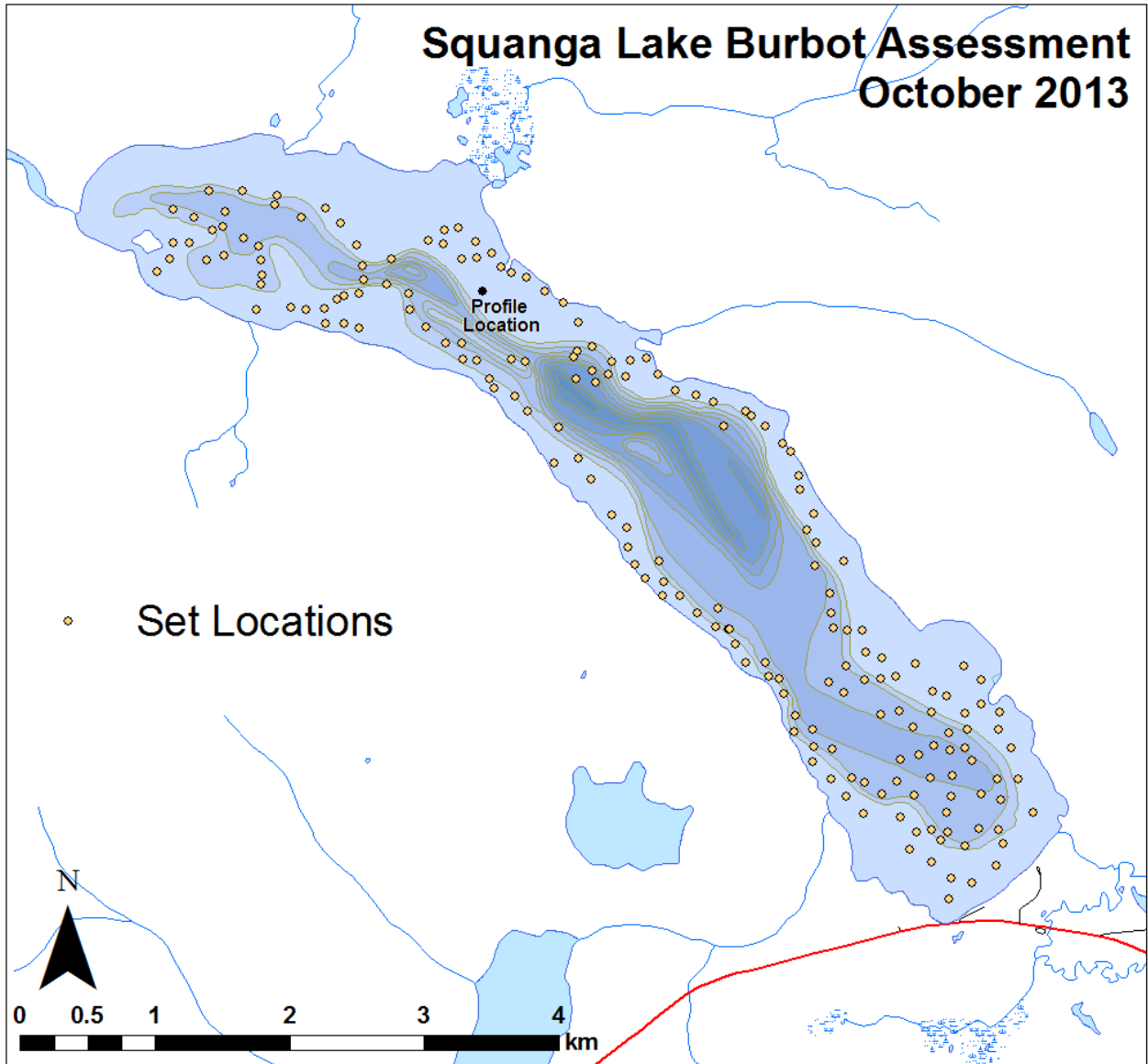
Appendix 7 – Intersession movements by individual burbot, between the May/June capture session (red circles) and October capture session (orange circles). Individual burbot are denoted by differently-coloured lines, with arrows denoting direction of travel.

Squanga Lake Burbot Assessment
Inter-capture Movements
May/June - October 2013