METHOD DEVELOPMENT

ASSESSMENT OF ARCTIC GRAYLING POPULATIONS USING SNORKEL SURVEYS

LUBBOCK RIVER 2010

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Summary

Arctic grayling are the fish most frequently caught by anglers in Yukon (DFO, 2007). Several grayling populations in Yukon have declined, prompting the introduction of restrictive regulations (Environment Yukon, 2010). Despite the importance of grayling fisheries and the potential for over-harvest, the information currently available for making management decisions about grayling is limited and there is no monitoring program in place. We reviewed several possible methods for monitoring grayling populations in a Yukon context and began development of a grayling monitoring program in 2010.

In May and June 2010, Environment Yukon surveyed Arctic grayling in the Lubbock River by counting fish while snorkelling stretches of the river. The purpose was to evaluate the suitability of this technique for counting grayling and to obtain instantaneous population estimates of the annual spawning migration. The proportion of the population seen by snorkellers (sightability) was estimated by marking grayling then comparing the number of marks seen to the number known to be present. Population estimates were made by expanding numbers of grayling seen by the calculated sightability. Peak estimated number of grayling in the approximately 250 m of stream reach that we surveyed was 210 on 20 May, 183 on 26 May, and 91 on 3 June. There was low variation in both sightability and grayling population estimates for surveys done on the same day; the method was a precise estimate of counting grayling in the Lubbock River.

Overall the method is relatively fast, non-intrusive, and may be adaptable to an array of different stream types. We suggest that future work focus on developing a snorkel sightability model which considers measurable variables such as underwater visibility or habitat type. We also recommend testing this method in other Yukon streams.

Key Findings

- Snorkel counts are an effective, low-impact, and inexpensive method for counting Arctic grayling in the Lubbock River. This method could be expanded to other Yukon streams.
- Grayling sightability, or the proportion of fish seen by snorkellers, can be measured and used to estimate population size and density.
- Subjectively, numbers of grayling in Lubbock River in 2010 seemed healthy. Large numbers of young-of-the-year grayling were observed, indicating successful spawning.

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Introduction

The Status of Yukon Fisheries report (Environment Yukon 2010) identified improved monitoring and assessment for Arctic grayling as a management priority. Arctic grayling are the fish most frequently caught by anglers in Yukon (DFO, 2007). As they migrate in late April or May from larger rivers or lakes into smaller tributaries, grayling form spawning aggregations. During this period, grayling are easily caught and populations are susceptible to over-harvest. Several grayling populations in Yukon have shown evidence of marked declines, prompting the introduction of restrictive angling regulations (Environment Yukon, 2010).

Despite the importance of grayling fisheries and the potential for over-harvest and slow recovery, the information available for making management decisions about grayling is limited (Environment Yukon, 2010). Grayling management currently relies mostly on anecdotal information received from anglers about the health of the population. Angler harvest surveys have been done on occasion and are useful for understanding the quantity and quality of angling pressure and harvest. However, these surveys do not provide information on the abundance of grayling. Managers have identified a need for a grayling monitoring technique which provides empirical data that can be used as a basis for decision making.

The ideal monitoring tool would be fast, inexpensive, and yet robust enough to allow tracking of grayling populations through time. Any monitoring tool should also have a low impact on the population. We may be monitoring impacted populations during potentially sensitive life stages such as spawning, where disturbance to fish or their habitat could result in reduced spawning success or destruction of eggs. We describe our work on developing such a tool, conclusions about its applicability, and recommendations for further work.

Review of Potential Monitoring Methods

We first looked at several potential methods available to assess grayling populations including electrofishing, mark-recapture, underwater counts (snorkelling), and complete census using fish traps or weirs. This review determined that underwater methods (snorkel surveys) could best meet our needs as a low-impact cost-effective monitoring technique that can provide accurate estimates of population size and density. We therefore focused our efforts on testing the applicability of snorkel methods for estimating grayling. Here we review the range of methods that we initially considered:

Underwater Counts (Snorkel Surveys)

Snorkel counts have been widely used to evaluate distribution, abundance, and habitat use of stream dwelling salmonids (Slaney and Martin 1987, Hankin and Reeves 1988, Zubik and Fraley 1988, Thurow 1994, Christie et al. 2010, and others). Snorkel surveys are advantageous because they:

- do not require the handling of fish;
- can be done without disturbing stream bottoms and therefore are suitable for evaluating spawning or sensitive populations;
- require minimal equipment and time to perform and so can be cost effective; and
- provide valuable opportunity to observe and quantify habitat and observe fish under natural conditions.

The main disadvantages include:

- failure to detect fish;
- misidentifying fish;
- counting fish more than once;
- difficulty counting large aggregations of fish; and
- differences in sightability depending on stream variables such as clarity, velocity, or amount of cover (Thurow, 1994).

Hankin and Reeves (1988) suggested that mark-resight surveys can be used to measure the proportion of the population seen by snorkellers, thereby addressing one of the main disadvantages which is that not all fish are detected. A small mark-resight exercise within a closed area should provide an accurate method with which to calibrate snorkel estimates while not requiring large expenditures of time or resources. Similar methods have been used for estimating abundance of rainbow trout and steelhead in British Columbia (Korman et al. 2002, Hagen and Baxter 2005). This is a promising method where the benefits of snorkel counts could be realized and reliable estimates obtained.

Mark-recapture

Mark-recapture methods can be time-consuming in streams because they require large numbers of marks (tags) to be applied, and the assumptions about closed populations can be difficult to meet (Zubik and Fraley 1988), especially during spawning. To meet the assumptions of a closed population, some surveys are performed during mid-summer when grayling movements are assumed to be minimal (Gryska 2001). Because we are looking for a rapid yet accurate technique which can also be performed in the spring, we determined that it was unlikely that mark-recapture monitoring methods would be feasible.

Electrofishing

Snyder (2003) reported several potential negative effects of electrofishing on spawning fish and/or fertilized eggs including damage to, or reduced viability, of eggs and sperm. The impact of electrofishing on the behaviour or spawning activity on adult grayling may also be significant. As we will sometimes be counting grayling when they are spawning, any potential risk to spawning grayling from electrofishing is not favourable. Moreover, electrofishing is limited by the size of the stream and pools that are being surveyed. The gear cannot be used in water deeper than waist-high and if moving, considerably less deep. These limitations set boundaries on what types of habitat and streams could be monitored with this method.

Census (weir) counts

Census counts using weirs are suitable for counting migrating fish such as grayling moving to spawning grounds. They require a lot of resources in terms of person-hours and equipment as they are difficult to set up and must be actively operated for the duration of the spawning migration. While this type of survey would be beneficial when a highly accurate census is required, the amount of effort and time required precludes its use as a frequent monitoring tool.

Study Area

To test the applicability of snorkel methods, we studied the grayling population of the Lubbock River. The Lubbock was chosen because its small size lends itself to snorkelling, and because past harvest issues have indicated population decline.

The Lubbock River meanders south from Little Atlin to Atlin Lake. It is accessible by a gravel road which crosses the river about 1 km downstream of Little Atlin Lake (Figure 1). It is a small river, often not deeper than 1 to 2 m and has an average width of approximately 10 m. Its size makes it suitable for snorkel surveys because the bottoms of pools are visible to snorkellers. Riffles, runs, pools, eddies, and debris jams are all present within the study area. River substrate is dominated by gravels but with large amounts of silt, clay, and organic detritus. Riparian areas vary from grassy side channels and oxbows to mossy banks dominated by spruce, willow, and alder; in-stream woody debris is abundant. The river is excellent fish habitat throughout the open-water season and provides spawning habitat for Arctic grayling, northern pike, and longnose sucker in the spring. Snorkellers in this study also observed lake and round whitefish, as well as juvenile lake trout (parr). Beaver are abundant and their dams impact stream morphology, flow, and fish passage.

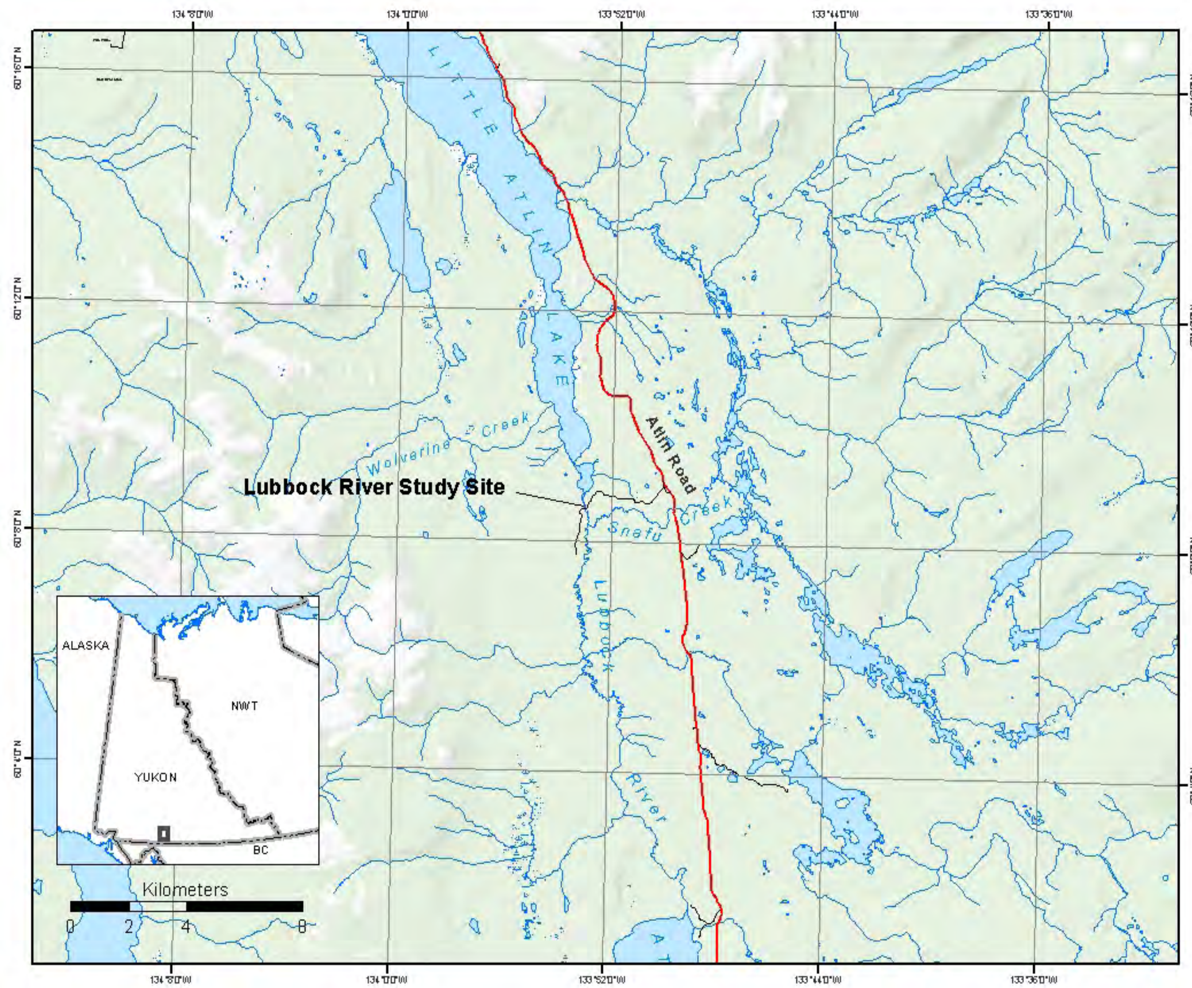

Figure 1. Location of Lubbock River study site.

Methods

We conducted snorkel counts on the Lubbock River on 11, 20, and 26 May and 3 June 2010. Snorkellers swam a defined stretch of river and counted all grayling seen. Recognizing that observers did not see all the fish, the raw count was increased by a sightability correction factor to obtain instantaneous estimates of population size within the study area. In order to determine sightability (correction factor), we performed concurrent mark-resight surveys.

An approximately 250 m section of stream beginning upstream of the bridge and ending just below it was selected as the study site (Figure 2). At the beginning of each survey, we set up block nets composed of 7 mm nylon mesh at the upstream and downstream ends of the study site and anchored the nets to the stream bottom with wooden stakes and heavy rocks. With the block nets in place, we temporarily created a closed population of grayling for study.

Grayling within the study area were captured by angling, tagged, and then released. The stream reach was then snorkelled multiple times and on each swim the numbers of tagged and untagged grayling were counted. We assessed our sightability as the number of re-sights (tagged grayling) seen within the enclosed stream reach compared with the known number of tagged grayling. We then adjusted our grayling count by our sightability to arrive at an estimate of the total number of grayling within the study area.

Safety

Snorkelling can be risky and safety must be a priority. Safety considerations during this survey generally followed the recommendations of O'Neal (2007) and Thurow (1994). Prior to snorkelling all team members walked the stream reaches to assess potential hazards. Hazards and required snorkelling techniques were discussed before entering the water. All surveyors had first aid training and at least one team member on site was also trained in swift-water rescue techniques.

Figure 2. Orthophoto showing Lubbock River study reach.

Marking Grayling

We captured grayling in the study reach (i.e., between the block nets) by angling using single barbless hooks (mostly flies). Each captured grayling was measured for fork length and a brightly coloured “t-bar anchor” tag was placed on the left side near the back of the dorsal fin (Figure 3). We released grayling at the same location as they were captured. Grayling less than 300 mm fork length were not tagged because of concern over the impact of the tag and tagging procedure on such small fish. We were able to tag between 10 and 20 grayling on each sampling occasion, depending on the length of time required for each capture.

Figure 3. Grayling with t-bar anchor tag placed on the left side near the back of the dorsal fin.

Counting Grayling by Snorkelling

Once the last fish was marked and released we waited between 3 and 15 hours before we began our survey. This gave grayling time to recover from tagging and behave normally when snorkel surveys were underway. The surveys began at the upstream block net and proceeded in a downstream direction; river current and depth would not allow upstream movement without a great deal of effort and disturbance. Snorkellers had a tally-counter in each hand: one for tagged grayling and one for untagged grayling. The survey focused on counting adult grayling (>300 mm), so snorkellers avoided counting juvenile grayling which were obviously too small to be engaged in spawning activity. Juveniles were easily identifiable and were occasionally seen in large schools.

With the exception of the 11 May survey, surveys were conducted by 2 snorkellers simultaneously so that the entire width of the stream was viewed during each survey. The river was divided into 2 ‘lanes’ from mid-river to the river bank on each side and each snorkeller was assigned a lane. Both snorkellers proceeded downstream following the mid-line of their lane while trying to stay in line with each other as much as possible. Snorkellers counted adult grayling only within their own lane; to help ensure grayling were counted accurately, snorkellers maintained close proximity so they could communicate and they did not count the grayling until the fish had passed upstream of them. Only fish that could be identified as adult grayling were counted. Counts from each snorkeller were summed to obtain the total count for the entire stream reach.

During the first survey we found that by entering the water snorkellers could easily stir sediment and detritus into the current and that it could take a long time to settle, which decreased visibility. Snorkellers were therefore careful to avoid the soft part of the stream bottom when entering the stream and, when possible, they avoided contact with the stream bottom. All surveys were done during daylight hours when the sun was overhead.

Swims were repeated up to 6 times per survey, with all available snorkellers making multiple swims. Variation in sightability and in the total number of fish counted between swims was taken as a measure of precision of the snorkel surveys. For each survey, grayling abundance within the survey area was estimated by taking the average number of grayling seen over all swims and expanding that number by the average sightability over all swims.

Calculating Sightability

On any given swim it was highly probable that not all grayling in the study were seen by the snorkellers and so our unadjusted counts were underestimates of the true number. However, by adjusting our counts by the sightability of grayling (the proportion of the tagged fish seen) we can closely approximate the true number. We calculated sightability as the proportion of tags seen compared to the number of tags known to be present in the study site (Rosenberger and Dunham 2005).

We repeatedly measured sightability within the study reach to understand the variability in our measure of sightability. Our estimates will be more precise the more consistent we are in our sightability. For example, we would prefer a situation of low variability where we always counted 75% of the fish that were there, rather than one where we counted 75% one swim, 50% one swim, and 100% on another. In both cases the average estimate of sightability is 75%, but the precision of the estimate is higher in the first case.

A highly precise estimate of sightability within the study reach indicates that this method would be appropriate over large areas with few repeat swims. This is important because we want to adopt a method that does not require a lot of effort.

Sightability on any given day is likely to be affected by several factors: underwater visibility (and environmental conditions that affect underwater visibility), habitat factors (the presence of riffles and pools, large woody debris, or stream width and depth), density of grayling, and experience of the snorkellers. In order to predict sightability in future surveys, we will have to understand the effect of these factors.

1. Visibility

To estimate underwater visibility one snorkeller stood in the river while the other moved backwards until he could no longer see the standing snorkeller's wading boots (approximately the size of a grayling). This distance was considered to be maximum visibility and was recorded on each survey day. We consider underwater visibility to be the prime determinant of sightability.

2. Habitat type

Sightability is also affected by habitat type; for example fish may be more or less visible in fast-flowing riffles compared with slow, deep pools. Measuring the effect of habitat type would require a time-consuming process of quantifying habitats and measuring sightability by habitat type. In the interest of efficiency, we accounted for the effect of habitat on sightability by selecting a study area that had as many habitat types as possible: runs, riffles, pools, eddies, undercut banks, and large woody debris jams. By encompassing many habitat types, we hoped to obtain an estimate of sightability which would be suitable, on average, for the entire river. If the proportion of each habitat type within the study area is similar to the proportions in the river as a whole, this will likely be true. To test this, sightability will need to be measured in other reaches and compared. When surveys are done in very different habitats, sightability should be re-calibrated or the results should be interpreted with caution. Future work could focus on a more quantitative assessment of the impact of habitat type on sightability.

3. Grayling density

If densities of grayling are very high, it may be difficult for snorkellers to accurately count fish, which could lead to error in our estimates of grayling numbers. Upon encountering a large school of grayling containing a small number of tagged grayling, snorkellers may be likely to get an accurate count of tagged grayling but an underestimate of untagged grayling; snorkellers counting fish from a large group while floating downstream would be likely to miss some fish. Accurately counting tagged grayling while under counting untagged grayling would lead to an underestimate of total grayling abundance. At moderate densities such as we typically experienced, snorkellers were able to keep track of all grayling within their vision so we assumed the effect of density on sightability and abundance estimation was negligible.

4. Snorkeller experience

New snorkellers must be given sufficient training and practice before the data they collect is usable. Snorkellers should be comfortable in the water and be familiar with the stream reach so they can best focus on locating and counting fish, rather than navigating the stream. Snorkellers should also be able to differentiate between fish species, adults and juveniles, accurately identify tagged versus untagged grayling, and be able to work well with their partner to avoid double counting.

Estimating Abundance

Once we determine sightability, we can use it to estimate the total number of grayling (abundance) in the study site (Hankin and Reeves 1988). For each swim, we estimated the population size within the block nets by expanding the total number of grayling seen by sightability according to the following formula:

$$N = n / \text{sightability}$$

Where:

N = total population size

n = number of fish seen

sightability = ratio of tagged fish seen to tagged fish present

Grayling abundance within the study area could also have been calculated using mark-resight methods. However, the two methods (sightability expansion and mark-resight) are not independent because they both use the ratio of tagged fish seen to the number of tags present to expand the total number of fish seen. They will therefore always be in close agreement (see Appendix 1 for population estimates using Chapman-Peterson mark-recapture). Here we are interested in developing the sightability expansion method because it does not require large-scale tagging of grayling.

Assumptions

The assumptions for calculating the sightability estimate (and estimating abundance from sightability) are much the same as those for a mark-recapture: the population is closed; marked and unmarked individuals are randomly distributed; all individuals have equal capture probability; and there is no tag loss.

1. Closed population

If any tagged grayling escape the study area, this will affect the estimated sightability. During each survey, the study area was enclosed with block nets secured to the stream bottom with wooden stakes and heavy rocks. These nets remained in place for the duration of each survey and effectively prevented immigration or emigration of adult grayling from the study area. At the end of each survey the block nets were removed to allow fish to freely move in and out of the study area.

2. Random distribution of marked and unmarked individuals

Because we are measuring sightability using only tagged grayling, a difference in behaviour or distribution between tagged and untagged grayling would affect the expansion estimate. After tagging, we allowed a rest period of at least 3 hours to ensure mixing of the marked grayling with unmarked individuals. This seemed sufficient: a rest period of 15 hours did not result in an increased number of tags seen per swim. Snorkellers did not observe a difference in behaviour between tagged and untagged grayling.

3. Equal capture probability

Because grayling were tagged with brightly coloured tags, tagged grayling are potentially more visible than untagged grayling, which would result in the sightability measured for marked individuals being higher than for unmarked individuals. This could result in a negative bias, or systematically lower (more conservative) abundance estimates. Generally, erring towards more conservative estimates is preferable to erring towards more liberal estimates. Snorkellers did not notice any obvious differences in visibility or behaviour between tagged and untagged grayling, so this bias was assumed to be minimal.

4. No tag loss

Because the surveys were all performed in less than 24 hours and tags were applied by experienced personnel, tag loss was reasonably assumed to be zero for each survey.

Results and Discussion

Performance of Snorkel Counts

Sightability varied from 0.04 to 0.65 over the 4 surveys (Table 1). Sightability of 0.04 (11 May) was very low compared to the other surveys. We suspect that having only a single snorkeller, combined with our inexperience during this first survey resulted in poor estimates. We therefore did not use the May 11 data. Snorkellers observed that while swimming alone, the areas on either bank were usually obscured and that only fish in mid-channel were easily visible. In addition, the bottoms of the pools were obscured by sediment disturbed by inexperienced snorkellers entering the water. Therefore, the best hiding locations (where one might expect to find a grayling potentially stressed from tagging) were outside of the visible range of the snorkellers.

The surveys on 20 and 26 May and 3 June used 2 snorkellers and resulted in higher total counts of grayling (including tagged fish), than 11 May. Snorkellers did not notice a difference in behaviour between tagged and untagged grayling during these later surveys; a rest period of 3 hours was deemed sufficient to allow tagged grayling to resume normal behaviour.

Snorkellers found it easy to differentiate fish species and grayling were especially easy to identify because of their prominent dorsal fin. Total numbers of fish seen were not enough to overwhelm snorkellers; they were able to count all fish within visible range as they floated downstream. The total number of fish seen during swims on any one survey day was very consistent indicating high repeatability as well as little aversive behaviour by grayling in response to the snorkellers (or in other words little impact from the swims). Variation of the sightability estimates was also low. The two person snorkel method described here seems to be a suitable method of counting grayling on the Lubbock River.

Abundance

We found that the assumptions for estimating grayling abundance by sightability expansion were reasonably met (see *Meeting Assumptions*). Therefore, we assumed that our estimated abundance of grayling approximated the true abundance of grayling within the study area.

Table 1. Summary of snorkel survey data and grayling counts from Lubbock River, 2010.

	11 May	20 May	26 May	3 June
Water Temp (^{o}C)	6	11.5	15	15
Visibility (m)	< 2.5	< 3	< 1.8	< 3
Rest time (hours after tagging)	3	15	3	4
Number of swims	5	5	6	6
Snorkellers per swim	1	2	2	2
Number of fish tagged	20	20	15	10
Number of tagged fish resighted (average)	0.8	12.2	7.33	6.5
Sightability (S)	0.04	0.61	0.49	0.65
95% C.I. (+/-)	0.02	0.14	0.10	0.07
Average number of fish counted (n)	23.8	122.80	85.67	57.83
95% C.I. (+/-)	6.54	17.25	9.31	3.59
Abundance (N)	505.00	209.83	183.44	90.67
95% C.I. (+/-)	152.14	50.21	33.87	13.46

**Note that the 11 May survey did not result in usable estimates of sightability or abundance.

Run Timing – Lubbock River

Coincidental to our grayling survey, an angler harvest survey was being carried out on the Lubbock River. Angler survey staff first observed Arctic grayling young-of-the-year on 30 May and noted that they were present at least until 6 June when their survey ended. They saw grayling young in large numbers in near-shore habitats where currents were calmer, and near aquatic vegetation, woody debris, or rocky cover.

Arctic grayling generally spend 3 to 8 days absorbing the yolk sac before emerging for active feeding (Scott and Crossman 1998) putting their likely hatch date sometime between 22 and 27 May (3 to 8 days prior to 30 May). They require 13 to 18 days at 7 to 10^{o}C to hatch (Scott and Crossman 1998), or 130 ATUs (accumulated thermal units). Using averaged temperature data from our surveys, we back-calculated ATUs to estimate the peak spawning period, which likely occurred between 8 and 17 May (Appendix 2).

Our highest count of adult grayling occurred on 20 May; both following surveys showed declining numbers. Abundance appeared to be fairly high on 11 May, but we did not obtain an accurate estimate. Combined with the emergence data, we can conclude that peak spawning probably occurred before 20 May and likely between 8 and 17 May. Future surveys on Lubbock River should be timed to include peak spawning activity, and could be roughly based on the 2010 timing (i.e. before 20 May).

Conclusion and Recommendations

Snorkel counts worked well on the Lubbock River. We obtained precise counts of grayling abundance within the study area using methods that were low impact, fast, and inexpensive. These methods will likely be effective on other streams of suitable size and visibility and merit further development.

Larger areas of the Lubbock could be surveyed without increasing the marking effort if the habitat within the study area is representative of the river. This question should be looked at in future surveys. This would allow us to use the measured sightability from within the study area to count grayling outside the study area.

A predictive model of sightability using easily measured variables which are likely to affect it could be developed. Snorkel surveys could then be used to estimate abundance over large stretches of stream without needing to measure sightability with mark-resight surveys each time. This would reduce the already low effort and impact of these surveys.

Underwater visibility is likely the best candidate for a predictor variable (sightability was higher on 20 May and 3 June, when visibility was less than 3 m compared to 26 May, when visibility was less than 1.8 m). However, because of other variables (such as habitat), any relationship between visibility and sightability on Lubbock River will likely differ from other streams. A model which incorporates other variables such as habitat or stream size that can be applied to any stream might be possible as more data is available from more streams.

Refinements needed to establish this method as a grayling management tool:

Determine how sightability changes along a stream in different habitats

The measured sightability currently is only valid within the study reach, which must be fairly small so that it can be sampled quickly. To expand estimates outside of the study reach we must assume that the sightability measured within the study area is appropriate for the stream as a whole. To test this assumption, sightability should be compared between multiple reaches. If sightability is similar, it may be possible to use one measure of sightability for the entire river.

Measure underwater visibility consistently

If we are to understand how visibility affects sightability we must standardize our measurements of visibility to ensure accuracy. Measurement of visibility in 2010 was somewhat haphazard, and was assessed by measuring visible distance between snorkellers. Underwater visibility in future surveys should be measured using a cut-out silhouette of a grayling as per Thurow (1994).

Measure water temperature

Temperature is important because it may affect grayling activity or behaviour, is probably linked to run timing, and could help us to establish the best time to do the survey.

Do a basic habitat assessment for each stream sampled

Stream size (width, depth), amount and type of habitats present (e.g. % composition of riffle, run, pool, etc.), and presence of large woody debris or log jams should be recorded. This information is needed to determine how habitat may affect sightability and will help us to begin to develop a predictive model.

Estimate stream size

Stream measurements should be taken in order to quantify the amount of river sampled by area and allow us to convert abundance to density (e.g. grayling per 100 m^2), a measure more easily compared between streams.

Spread sampling out over the spawning period

Grayling densities can be expected to fluctuate over the spawning period. If sampling must be done during the spawning period then it should be spread out over several days to capture some of this variability. Timing may vary, but the peak counts and estimated peak spawning activity on Lubbock in 2010 could be used for planning purposes.

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APPENDIX 1. Raw snorkel data and mark-resight estimates, Lubbock River 2010.

Date:	***May 11, 2010***
Time:	16:30 – 18:00
Water Level:	37cm
Water Temp:	6°C
Underwater Visibility:	< 2.5m
Weather:	Overcast, windy
# Tags:	20 (Pink)
Rest Period:	3 hours

Mark-Resight Estimate:

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

n_1 =	20
n_2 =	23.8
m_2 =	0.8
N =	288.33
varN =	25351.11
SD =	159.22
95% C.I. ± =	312.07

Table 1.1. Raw Snorkel Data and Mark-Resight Estimates, May 11, 2010.

Swim	Tagged	Untagged	Total Sighted	Sightability	Expansion Estimate
1	0	18	18	0	
2	1	18	19	0.05	380
3	1	18	19	0.05	380
4	1	27	28	0.05	560
5	1	34	35	0.05	700
Average	0.8	23	23.8	0.04	505.00
Var	0.2	53	55.7	0.00	24100.00
CoefVar	0.56	0.32	0.31	0.56	0.31
SD	0.45	7.28	7.46	0.02	155.24
SE	0.20	3.26	3.34	0.01	77.62
95%C.I. ±			6.54	0.02	152.14

Date:	***May 20, 2010***
Time:	10:30 – 12:30
Water Level:	38cm
Water Temp:	11.5°C
Underwater Visibility:	< 3m
Weather:	Sunny
# Tags:	20 (White)
Rest Period:	15 hours

Mark-Resight Estimate:

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

n_1 =	20
n_2 =	122.8
m_2 =	12.2
N =	195.95
varN =	906.47
SD =	30.11
95% C.I. ± =	59.01

Table 1.2. Raw Snorkel Data and Mark-Resight Estimates, May 20, 2010.

Swim	Observer 1		Observer 2		Both Observers		Total Sighted	Sightability	Expansion Estimate
	Tagged	Untagged	Tagged	Untagged	Tagged	Untagged			
1	7	52	2	30	9	82	91	0.45	202
2	6	52	7	52	13	104	117	0.65	180
3	9	63	7	52	16	115	131	0.8	164
4	6	61	8	61	14	122	136	0.7	194
5	4	68	5	62	9	130	139	0.45	309
Average	6.40	59.20	5.80	51.40	12.20	110.60	122.80	0.61	209.83
Var	3.30	49.70	5.70	165.80	9.70	346.80	387.20	0.02	3281.34
CoefVar	0.28	0.12	0.41	0.25	0.26	0.17	0.16	0.26	0.27
SD	1.82	7.05	2.39	12.88	3.11	18.62	19.68	0.16	57.28
SE	0.81	3.15	1.07	5.76	1.39	8.33	8.80	0.07	25.62
95%C.I. ±						16.32	17.25	0.14	50.21

Date:	***May 26, 2010***
Time:	16:45 – 18:30
Water Level:	36cm
Water Temp:	15°C
Underwater Visibility:	< 1.8m
Weather:	Sun / Clouds
# Tags:	15 (Green)
Rest Period:	3 hours

Mark-Resight Estimate:

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

n_1 =	15
n_2 =	85.67
m_2 =	7.33
N =	165.40
varN =	1284.85
SD =	35.84
95% C.I. ± =	70.26

Table 1.3. Raw Snorkel Data and Mark-Resight Estimates, May 26, 2010.

Swim	Observer 1		Observer 2		Both Observers		All Observers		Total Sighted	Sightability	Expansion Estimate
	Tagged	Untagged	Tagged	Untagged	Tagged	Untagged	Tagged	Untagged			
1	3	44	3	26	-	-	6	70	76	0.40	190
2	5	50	4	28	-	-	9	78	87	0.60	145
3	-	-	4	34	0	30	4	64	68	0.27	255
4	-	-	4	32	4	58	8	90	98	0.53	184
5	5	29	-	-	4	58	9	87	96	0.60	160
6	4	31	-	-	4	50	8	81	89	0.53	167
Average	4.25	38.50	3.75	30.00	3.00	49.00	7.33	78.33	85.67	0.49	183.44
Var	0.92	103.00	0.25	13.33	4.00	174.67	3.87	98.67	135.47	0.02	1493.09
CoefVar	0.23	0.26	0.13	0.12	0.67	0.27	0.27	0.13	0.14	0.27	0.21
SD	0.96	10.15	0.50	3.65	2.00	13.22	1.97	9.93	11.64	0.13	38.64
SE	0.48	5.07	0.25	1.83	1.00	6.61	0.80	4.06	4.75	0.05	17.28
95%C.I. ±									9.31	0.10	33.87

Date:	***June 3, 2010***
Time:	17:00 +
Water Level:	28cm
Water Temp:	15°C
Underwater Visibility:	< 3m
Weather:	Sun / Clouds
# Tags:	10 (Yellow)
Rest Period:	3-4 hours

Mark-Resight Estimate:

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

n_1 =	10
n_2 =	557.83
m_2 =	6.5
N =	85.29
varN =	243.19
SD =	15.59
95% C.I. ± =	30.57

Table 1.4. Raw Snorkel Data and Mark-Resight Estimates, June 3, 2010.

Swim	Observer 1		Observer 2		Both Observers		All Observers		Total Sighted	Sightability	Expansion Estimate
	Tagged	Untagged	Tagged	Untagged	Tagged	Untagged	Tagged	Untagged			
1	4	25	3	25			7	50	57	0.7	81
2	2	32	4	28			6	60	66	0.6	110
3			2	16	5	32	7	48	55	0.7	79
4			3	31	4	21	7	52	59	0.7	84
5	2	37			3	15	5	52	57	0.5	114
6	5	36			2	10	7	46	53	0.7	76
Average	3.25	32.50	3.00	25.00	3.50	19.50	6.50	51.33	57.83	0.65	90.67
Var	2.25	29.67	0.67	42.00	1.67	89.67	0.70	23.47	20.17	0.01	282.83
CoefVar	0.46	0.17	0.27	0.26	0.37	0.49	0.13	0.09	0.08	0.13	0.19
SD	1.50	5.45	0.82	6.48	1.29	9.47	0.84	4.84	4.49	0.08	16.82
SE	0.75	2.72	0.41	3.24	0.65	4.73	0.34	1.98	1.83	0.03	6.87
95%C.I. ±									3.59	0.07	13.46

APPENDIX 2. Calculation of peak spawning period based on ATU.

	Date (May)	Temp	ATU* Back from 27 May	ATU* Back from 22 May
Hatch	27	15	15	
	26	15	30	
	25	13.25	43	
	24	13.25	57	
	23	13.25	70	
	22	13.25	83	13
	21	13.25	96	27
	20	11.5	108	38
	19	8.75	117	47
	18	8.75	125	56
Spawning	17	8.75	134	64
	16	8.75		73
	15	8.75		82
	14	8.75		91
	13	8.75		99
	12	8.75		108
	11	6		114
	10	6		120
	9	6		126
	8	6		132

(Grey) Potential hatch dates (3–8 days prior to date of observed emergence, 30 May)

(Blue) Potential spawning dates based on back calculation of ATU from potential hatch dates

(Green) Dates with known temperatures; other temperatures are averaged between the known dates

*ATU Accumulated Thermal Units: the sum of the temperatures, working backwards from the possible hatch dates. Incubation time is approximately 135 ATU.