**Fishery Data Series No. 10-28**

# Goodpaster River Arctic Grayling Stock Assessment, 2006

**by**

**Andrew D. Gryska**

**April 2010**

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

## Symbols and Abbreviations

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**Weights and measures (metric)**

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

**Weights and measures (English)**

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

**Time and temperature**

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

**Physics and chemistry**

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

**General**

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

**Measures (fisheries)**

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

**Mathematics, statistics**

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

# *FISHERY DATA REPORT NO. 10-28*

# GOODPASTER RIVER ARCTIC GRAYLING STOCK ASSESSMENT, 2006

By
Andrew D. Gryska
Division of Sport Fish, Fairbanks

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1599

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*Andrew D. Gryska,*
*Alaska Department of Fish and Game, Division of Sport Fish,*
*1300 College Road, Fairbanks, AK 99701-1599 USA*

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# ABSTRACT

A stock assessment of the Goodpaster River Arctic grayling fishery was completed during 2006 using mark-recapture experiments. Objectives of the study were to estimate abundance and length and age composition in 101.4-km and 58.5-km study areas during spring and summer and to determine if the management objective for the river (≥9,000 fish ≥270 mm FL in the 58.5-km study area during spring) was achieved. In the 101.4-km study area, abundance of Arctic grayling ≥270 mm FL during spring was 37,751 (SE=8,493) and during summer was 4,698 (SE=821). In the 58.5-km study area, abundance of Arctic grayling ≥270 mm FL during spring was 32,907 (SE=10,363) and during summer was 1,847 (SE=190). The spring abundance estimate of Arctic grayling far exceeded the management objective of 9,000 fish and indicated only a 1% probability (one tail z-value = 2.307) that the actual population was < 9,000 fish.



Key words: Arctic grayling, *Thymallus arcticus,* abundance, length composition, electrofishing, mark-recapture, Goodpaster River, Alaska.


# INTRODUCTION

Within the Tanana Basin, Arctic grayling *Thymallus arcticus* inhabit two hydrologically distinct rivers, the Goodpaster and Delta Clearwater rivers (Figure 1). They support important Arctic grayling sport fisheries that are strongly related because of seasonal migrations between the two rivers (Ridder 1998a, b). The mainstem Goodpaster River (GPR) is 211 km long and has a drainage area of 3,890 km$^2$ (Figure 2). The river is a rapid run-off stream that ranges from clear to slightly tannin stained, and it becomes turbid during periods of heavy run-off (Tack 1980). At river kilometer (rkm) 114 with a drainage area of 1,753 km$^2$, annual mean daily discharge was 13.2 m$^3$ (467 ft$^3$) from 1997 through 2008, and average monthly discharge has ranged between 1.3 m$^3$/s during March and 29.4 m$^3$/s during August (USGS 2009).

The GPR is accessible by river boat or airplane during the summer. The river can be reached via the Tanana River from boat launches at Big Delta (13.5 rkm downstream of GPR mouth) and at Clearwater Lake (12 rkm upstream from the GPR mouth). Riverboat navigation is consistently possible in the lower 101.4 km of the river (up to Central Creek) and the lower 16.1 km of the South Fork GPR. Floatplane access is feasible in the lower 37.0 km of the river. Private landing strips are at Central Creek (rkm 101.4), at Pogo Creek (rkm 109), and at Tibbs Creek (rkm 161). There are 66 recreational cabins on the river, and all but eight are between rkm 4.8 and 48.3 (Parker 2003). There are no recreational cabins upstream of Central Creek. The Goodpaster River fishery occurs mostly in the lower 53.1 km of the river (i.e., below the South Fork) but extends up to Central Creek (101.4 km) and very infrequently up to Tibbs Creek (161 km). Nearly all the fishing effort in the GPR is directed at Arctic grayling as the river has a small Chinook salmon population (catch-and-release fishing only) and densities of other sport species are small (Table 1).

Currently the GPR fishery is managed by the guidelines identified within the *Region III Wild Arctic Grayling Management Plan* that stipulates wild Arctic grayling are to be managed for long-term sustained yield employing a conservative harvest regime by utilizing one of three management policies (Swanton and Wuttig *Unpublished*). The GPR is managed under Policy 1 in which the regional background regulations are applied (daily bag and possession limit of 5 Arctic grayling with no gear or seasonal restrictions). Consistent with the policies in the *Region III Wild Arctic Grayling Management Plan*, a specific fishery management objective has been established for the GPR fishery (Parker 2003). The objective is to maintain a minimum of 9,000 Arctic grayling ≥270 mm FL during the spring spawning period within a 58.5-km index area (hereafter referred to as the Management Index Area or MIA) in the mainstem GPR between the South Fork GPR and its mouth. The objective was developed and evaluated using information

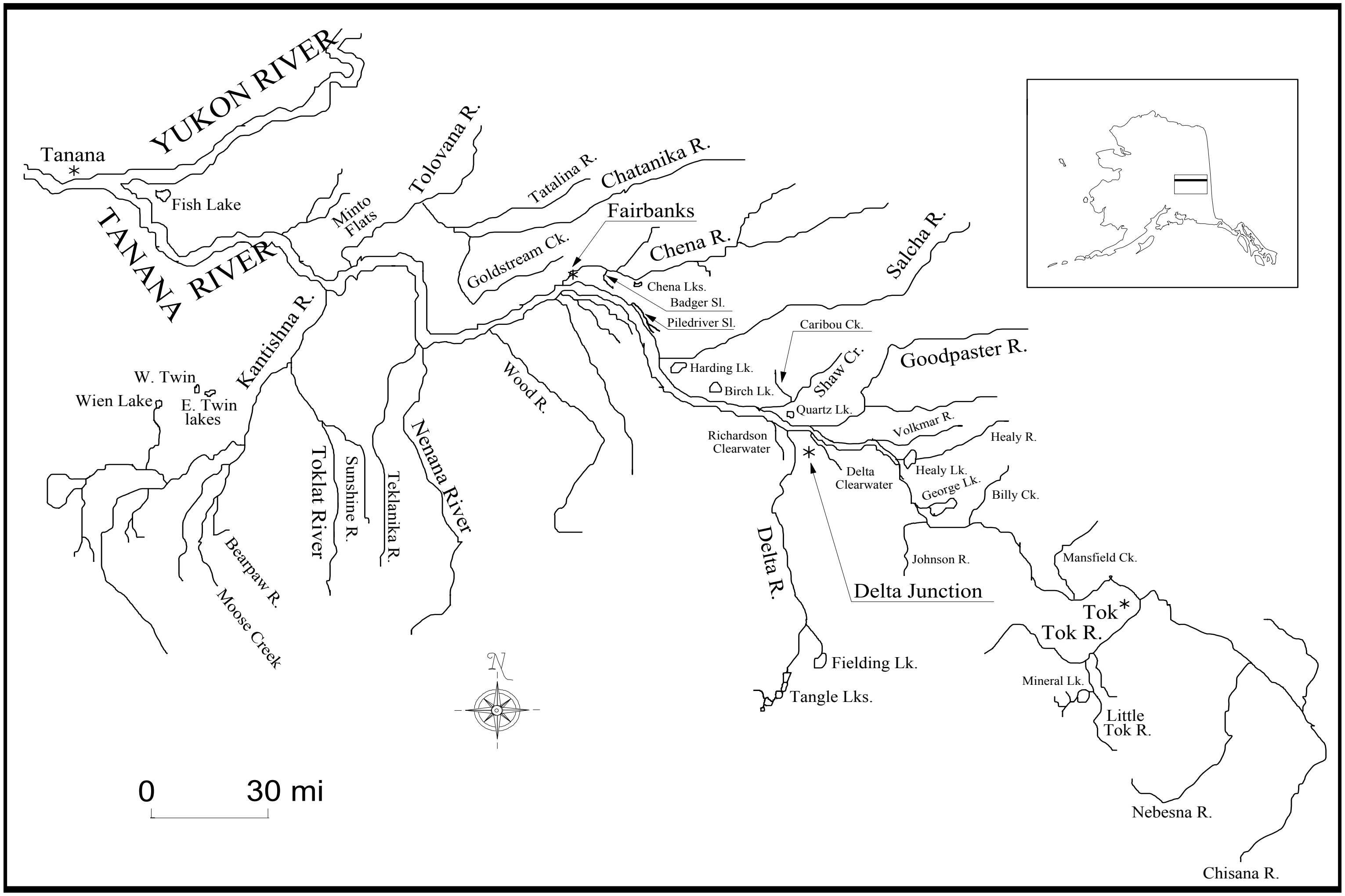


Figure 1.–Location of the Goodpaster River in the Tanana River drainage.

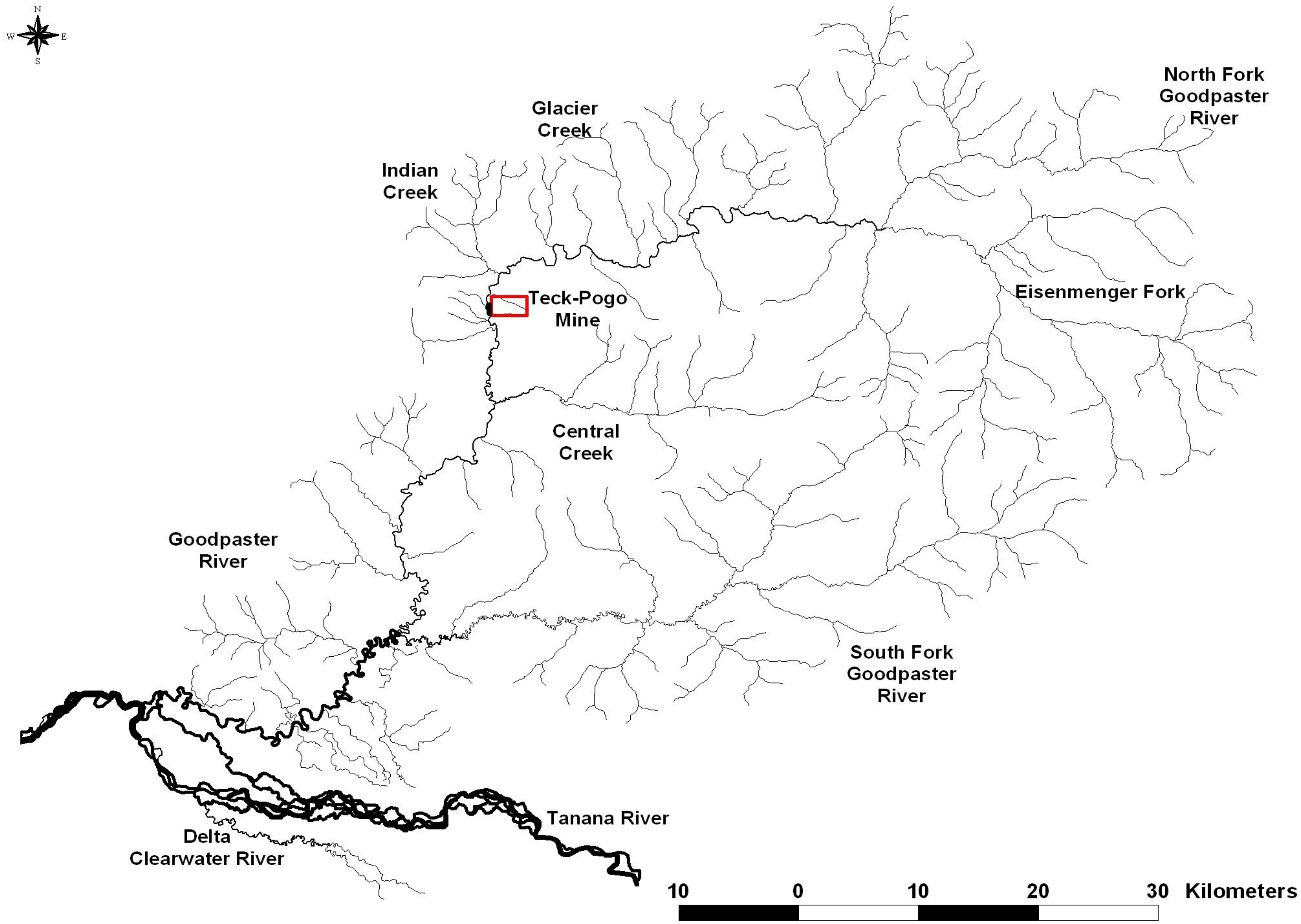


Figure 2.–Goodpaster River drainage.

Table 1.–Estimates of harvest and catch of Arctic grayling and effort for all species on the Goodpaster River, 1983–2007.[a]

| Year | Effort Angler-days | Harvest All | Catch All |
|---|---|---|---|
| 1983 | 1,989 | 3,021 | |
| 1984 | 766 | 1,194 | |
| 1985 | 2,844 | 2,757 | |
| 1986 | 933 | 1,508 | |
| 1987 | 3,061 | 1,702 | |
| 1988 | 1,037 | 1,273 | |
| 1989 | 1,930 | 1,964 | |
| 1990 | 2,083 | 760 | 3,342 |
| 1991 | 786 | 636 | 905 |
| 1992 | 1,430 | 766 | 3,599 |
| 1993 | 1,692 | 588 | 1,923 |
| 1994 | 825 | 700 | 1,809 |
| 1995 | 2,028 | 325 | 3,177 |
| 1996 | 1,244 | 835 | 2,921 |
| 1997 | 2,266 | 644 | 4,448 |
| 1998 | 774 | 668 | 4,705 |
| 1999 | 1,915 | 852 | 3,882 |
| 2000[b] | 472 | 63 | 1,283 |
| 2001 | 787 | 873 | 1,815 |
| 2002 | 912 | 229 | 1,346 |
| 2003 | 925 | 56 | 1,499 |
| 2004 | 612 | 176 | 1,735 |
| 2005 | 1,402 | 617 | 2,464 |
| 2006 | 892 | 212 | 1,467 |
| 2007 | 1,305 | 677 | 2,956 |
| **Averages** | | | |
| 1983–1989 | 1,794 | 1,917 | |
| 1990–1999 | 1,504 | 677 | 3,071 |
| 2000–2007 | 913 | 363 | 1,821 |

[a] Data from Mills 1984-1994; Howe et al. 1995, 1996, 2001a-d; Jennings et al. 2004, 2010a-b.

[b] Data from 2000 and 2003–2006 are not published because of too few responses to the statewide harvest survey (Walker et al. 2003).

from periodic stock assessments primarily designed to estimate abundance and size composition, and from catch and harvest estimates from the Alaska Statewide Harvest Survey.

Stock assessment research, conducted periodically since 1961, has focused primarily on two Arctic grayling stocks within the MIA defined as GPR spring (≥ 270 mm FL) and GPR summer (≥ 150 mm FL; Appendix B1). In addition to these core stock assessment studies, there have been a number of other studies conducted that have investigated the status and migratory behavior of GPR Arctic grayling populations and their related populations. Findings from these research projects have demonstrated that Arctic grayling in the Upper Tanana River basin have dynamic life-history movement patterns that can vary between and within river drainages (Clark and Ridder 1987; Gryska 2004, *In prep a, b*; Ridder 1984, 1989, 1991, 1994, 1998a, b, c; Tack 1980). This research has also demonstrated that the spring spawning population in the GPR MIA is the most significant Arctic grayling spawning stock in the Upper Tanana River drainage in terms of supporting the area fisheries. Tagging studies in the GPR and radiotelemetry studies in the Delta Clearwater River (DCR) have estimated that about half of the DCR summer population utilizes the GPR during spawning (Ridder 1983, 1998b). Conversely, based on scale pattern analysis and recaptures of tagged Arctic grayling from two independent stock assessments in the GPR and DCR, ~10 and 35% of Arctic grayling spawning in the GPR MIA were estimated to reside in the DCR for the summer (Peckham and Ridder 1979; Ridder 1998a). A more reliable estimate based on radiotelemetry was obtained during 2006, when 45% (32 of 71) of radio tags deployed in the GPR during the spring spawning period resided in the DCR during the same summer (Gryska *Unpublished*).

While considerable information has been collected on the spring spawning population of Arctic grayling in the GPR, and an abundance-based management objective has been developed for that stock, several questions remained. These questions were related to better understanding the relationship (i.e. in terms of abundance and movements) between the DCR and GPR Arctic grayling stocks, and their relationships to other rivers within the Upper Tanana drainage. Pursuant to these questions, three primary information needs were identified and investigated in 2006 and 2007: estimates of abundance and length compositions of Arctic grayling spawning during spring within the GPR fishery (i.e. upper 101.4 km) and the MIA; estimates of abundance and length compositions of Arctic grayling during summer in the DCR and GPR fisheries and index areas; and, estimates of the seasonal distribution for the spring GPR spawning population within the Upper Tanana River drainage. This report details the work conducted in 2006 relative to estimating abundance and length compositions of Arctic grayling (spring and summer populations) in the lower 101.4 km of the GPR (Central Creek to Tanana River) and in the 58.5-km MIA. A synthesis of the research conducted in 2006 and 2007, which included stock assessments of the DCR and radiotelemetry work, will be presented in the report that finalizes the telemetry findings.

# OBJECTIVES

The research objectives for this project were to:

1. estimate the abundances of Arctic grayling ≥ 270 and ≥ 330 mm FL in the Goodpaster River study area (lower 101.4-km), as well as that within the 58.5-km MIA, during May 2006 such that the estimates were within 25% of the actual abundance 95% of the time;

2. test the null hypothesis that the abundance of Arctic grayling ≥ 270 mm FL in the 58.5-km MIA of the Goodpaster River during early May was ≥ 9,000 using significance level *alpha* = 0.50.

   If Objective 1 was attained and yielded a point estimate ≥ 9,000 the null hypotheses would be accepted and a management action would not be recommended. If Objective 1 was attained and yielded a point estimate <9,000 the null hypotheses would be rejected and a management action would be recommended;

   1) if Objective 1 was attained and if the true abundance was 7,440 there would be a 95% chance that the abundance estimate was <9,000.
   2) if Objective 1 was attained and if the true abundance was 9,000 there would be a 50% chance that the abundance estimate was <9,000.
   3) if Objective 1 was attained and if the true abundance was 10,083 there would be a 20% chance that the abundance estimate was <9,000.
   4) if Objective 1 was attained and if the true abundance was 11,390 there would be a 5% chance that the abundance estimate was <9,000.

3. estimate the length composition (in 10-mm intervals) of the Arctic grayling population ≥ 150 mm FL in the Goodpaster River study area (lower 101.4-km), as well as that within the 58.5-km MIA, during May 2006 such that the estimates were within five percentage points of the true value 95% of the time;
4. estimate the abundances of Arctic grayling ≥150, ≥270, and ≥330 mm FL in the Goodpaster River study area (lower 101.4-km), as well as that within the 58.5-km MIA, during July 2006, such that the estimates were within 25% of the actual abundance 95% of the time;
5. estimate the length composition (in 10-mm intervals) of the Arctic grayling population ≥ 150 mm FL in the Goodpaster River study area (lower 101.4-km), as well as that within the 58.5-km MIA, during July 2006 such that the estimates were within five percentage points of the true value 95% of the time; and,

In addition, project tasks were to:

1. Observe and record recapture locations of May-tagged fish during the July assessment; and,
2. Compare cumulative length frequency distributions of the spring and summer populations using a Kolmogorov-Smirnov test.

Precision criteria for Objectives 1 and 4 were set to ensure precise estimates of abundance were obtained regardless of population size. This information would be useful for evaluating potential exploitation on this stock and for future refinements of the management objective.

Relative to Objective 2, the choice of *alpha* and *beta* (or power = 1-*beta*) were based on discussions among the area manager, research staff, and biometrician, which were directed towards appropriately balancing the risks of Type I error (*alpha*) and Type II error (*beta*) from both research and management perspectives. The choice of a large *alpha* (0.5) led to the increased power of the test or, in other words, increased probability of detection if the population size was below 9000 fish. The definition of a management action is broad and includes a range of possibilities from a recommendation for another abundance estimate to "verify" initial estimates to an emergency order (EO) that reduces harvest. The severity of the action would depend on a combination of several factors such as: the magnitude of the difference between the management objective, evidence of potential large or small recruitment, or the effectiveness of an EO to result in a meaningful reduction in harvest.

The size limits identified in the objectives, 150, 270, and 330 mm FL, are commonly used standards in Arctic grayling stock assessments or management objectives within Region III. The 150-mm length limit is typically the smallest size that fish are recruited to boat electrofishing equipment during summer, which was used in the GPR. A 150-mm objective was not included for the GPR in spring because for unexplained reasons sufficient sample sizes have been unattainable for smaller sized-fish (i.e., 150 to 270) in previous studies. However, if supported by the data, additional abundance and composition estimates having a lower size limit between 150 and 270 mm FL were to be calculated to provide insight on the magnitude of potential recruitment. The 270-mm length limit relates to the 12-in TL regulation used in the Tanana River basin, management objectives, and the size at which fish reliably recruit to hook-and-line gear, which was the capture gear used on the DCR during 2006. The 330-mm (14 in TL) length limit relates directly to the management objective in the DCR, which as described above is related to the GPR.

# METHODS

## STUDY AREA

The study area was the lower 101.4 km of river between Central Creek and its mouth on the Tanana River (Figure 2). The study area boundaries were deemed to contain almost all (i.e., >95%) of the GPR fishing effort (F. Parker, Alaska Department of Fish and Game, Fisheries Area Management Biologist, Delta Junction, personal communication), and the study area duplicated the area sampled in the spring of 1995 (Ridder 1998a). The study area also encompassed several different sampling areas (i.e. index areas) from past assessments (summarized in Roach 1995; Ridder 1998a; Parker 2006; Parker et al. 2007), which in general consisted of the lower 58.5 km of the river (i.e. from the South Fork GPR to the Tanana River). Tributaries to the GPR study area are not typically fished and were therefore not considered part of the study area. In the spring of 2005, the density of spawners in the mainstem of the GPR upstream of Central Creek was surveyed to determine if the proposed study area was appropriate. It was determined that densities between Central and Glacier creeks were relatively low and that extending the upstream boundary of the study area would not result in meaningful gains relative to managing the fishery (Appendix B2).

## EXPERIMENTAL AND SAMPLING DESIGN

During spring and summer 2006, this study was designed to estimate abundance and length composition of Arctic grayling within a 104.1-km study area of the GPR (Figure 1) using two-event Petersen mark-recapture techniques for a closed population (Seber 1982) designed to satisfy the following assumptions:

1. the population was closed (Arctic grayling did not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment);
2. all Arctic grayling had a similar probability of capture in the first event or in the second event, or marked and unmarked Arctic grayling mixed completely between events;

3. marking of Arctic grayling did not affect the probability of capture in the second event;
4. marked Arctic grayling were identifiable during the second event; and,
5. all marked Arctic grayling were reported when recovered in the second event.

The estimator used was a modification of the general form of the Petersen estimator:

$$\hat{N} = \frac{n_1 n_2}{m_2}, \tag{1}$$

where:

$n_1$ = the number of Arctic grayling marked and released during the first event;

$n_2$ = the number of Arctic grayling examined for marks during the second event; and,

$m_2$ = the number of marked Arctic grayling recaptured during the second event.

The sampling design and data collected allowed the validity of the five assumptions to be ensured or tested. The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate if the assumptions were met (Appendices A1, A2, and A3).

The 101.4-km sampling area was divided into six nearly equidistant sections approximately 17.0 km in length (Figure 3). These divisions served to guide sampling and provided a geographic scale at which to conduct diagnostic tests. Abundance and composition were also estimated in the original 58.5-km GPR index area between the mouth and the South Fork GPR so that estimates obtained in 2006 were comparable to previous estimates. However, the primary objectives of the larger study area determined the sampling effort needed to provide sufficiently precise estimates, and data from the larger study area was truncated to produce estimates for the original index area.

Sampling for the spring abundance estimate occurred May 13–14 (1st event) and May 15–16 (2nd event). Sampling for the summer abundance estimate occurred from July 6–9 (1st event) and July 10–13 (2nd event). The timing and short duration of the experiments helped to ensure that the movement of fish did not violate the assumption of closure. The spring sampling began just after break-up in early May when Arctic grayling are relatively stationary during the brief spawning period (Tack 1980; Ridder 1985, 2000; Beauchamp 1990). After spawning, Arctic grayling migrate to summer feeding areas. Upon reaching summer feeding areas by mid-June, Arctic grayling remain relatively stationary (in general, only localized movements of <2.5 river km or rkm) until mid-September (Tack 1973; Ridder 1999; Gryska 2006, *In prep a, b*; Wuttig and Stroka 2007). The summer sampling occurred during the stationary summer feeding period. Each event required 2–3 days, and the hiatus between events was kept as short as possible to ensure that few fish were likely to have immigrated into or emigrated from the study area between events. The short duration of the experiments rendered growth recruitment and mortality insignificant, allowed for localized mixing of marked and unmarked fish, and allowed marked fish to recover from the effects of handling between events.

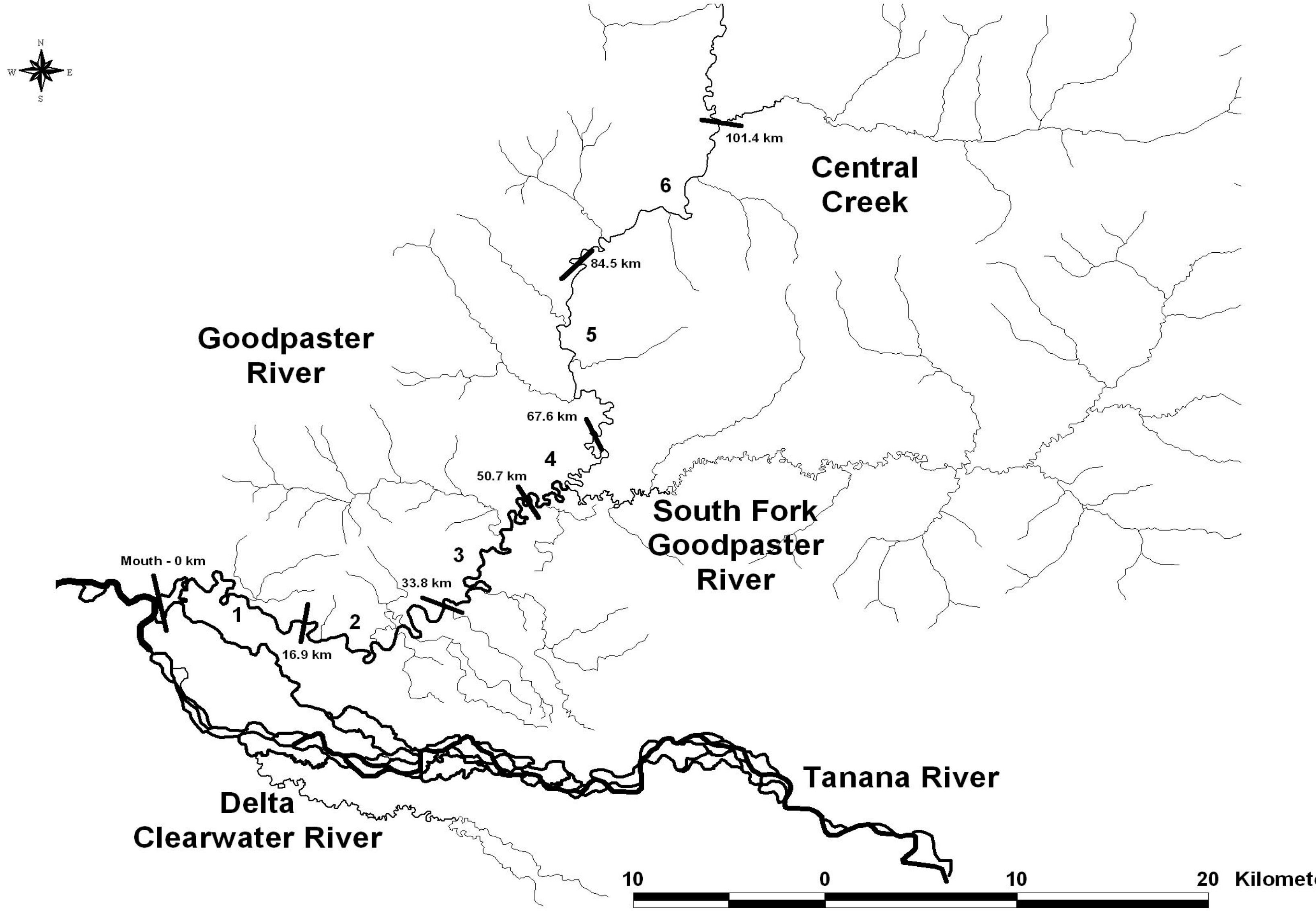


Figure 3.–Goodpaster River study area with demarcation of six equidistant sections, each 16.9 km in length.

The selection of the sampling area diminished the influence of movements on the abundance estimates because the scale of movements was very small compared to the large size of the study area. Moreover the lower boundary of the GPR was located at the mouth on the glacial Tanana River which is not preferred habitat for spawning or summer feeding. Most tributaries were very small and provided little desirable habitat for spawning or summer feeding of larger fish. Therefore, the number of fish immigrating and emigrating due to local movements relative to the tributaries or at the upper and lower boundaries was anticipated to be inconsequential.

To capture Arctic grayling, up to three boats equipped with electrofishing gear were used, each having a pulsed-DC variable-voltage pulsator (Coffelt Model VVP-15) powered by a 3,500-watt single-phase gasoline generator. Anodes consisted of four 15-mm diameter steel cables (1.5-m long) spaced 1 m apart and arranged perpendicular to the long axis of the boat and 2.1 m forward of the bow. The unpainted bottom of the boat served as the cathode. The electrical output (voltage, amperage, and cycle) was adjusted based on observed responses of shocked fish. To minimize fish mortality and injury, using electrical output values that cause fish to roll over and become paralyzed were avoided. Initially, settings on the pulsator were set at 50% duty cycle and 30 Hz. Since output amperage can vary at a given voltage due to conductivity, substrate, and water depth, the boat operator attempted to keep amperage constant to minimize injury to fish. Voltage was adjusted (250–300 V) to keep output amperage between 2 and 4 amperes.

Each boat consisted of a three-person crew; two to capture fish with dip nets, and one to pilot the boat and operate the electrofishing gear. In an attempt to distribute effort uniformly, the entire sampling area was fished in a downstream progression. During the spring, one boat sampled each section, and during summer, one boat fished the upper three sections (4-6), where the channel is smaller, and two boats operated in tandem on opposite sides of the river in the three lower river sections. If multiple channels were encountered, either one or two boats, depending on the size of the channel, sampled all channels that were navigable.

Electrofishing boats were operated for 20-min intervals, defined as a run, and captured Arctic grayling were held in an aerated tub until they were sampled and returned to the river approximately 100 to 200 m upstream from the end of a run. The run boundaries of the experiment (spring or summer) were defined by the end of a 20-min run in the first event, the confluences of major tributaries, or the boundaries of the old study area (e.g. South Fork GPR). During the first event, run boundaries were flagged and locations recorded using a GPS. The same boundaries were used during the second event and provided a minimum scale (i.e. 20-min run) at which to evaluate capture probabilities and movement throughout the study area. The length of a run ranged between 1.5 and 3.5 km depending on water velocities and section boundaries. Runs were not identical between summer and spring due to variability in water velocities and boat drivers; however, all section boundaries, except one, were nearly the same (slight variations of a few hundred meters) for both mark-recapture experiments to facilitate comparisons. The section boundary that changed was the mouth of the GPR, which is located 3 km upstream during summer because a Tanana River slough infiltrates the Lower GPR with highly turbid water.

Sample size objectives for estimating abundance were established using methods described in Robson and Regier (1964) and for length compositions using criteria developed by Thompson (1987) for multinomial proportions.

## DATA COLLECTION

At the completion of each run, all captured fish were measured for length (mm FL) and carefully examined for marks. Data were recorded on mark-sense forms. In the first event for both experiments, fish ≥150 mm FL were tagged with an individually numbered Floy FD-94™ internal anchor tag (gray in color and numbered between 12901 and 16505) and received an experiment-specific fin clip to identify tag loss (the left pelvic fin clipped during spring and the left pectoral fin during summer). To eliminate duplicate sampling in the second event, each fish had a fin clipped (the right pelvic fin clipped during spring and the right pectoral fin during summer). All fish were carefully inspected for attendant Floy™ tags and fin clips. Fish captured in the first event that exhibited signs of injury, excessive stress, or imminent death were not marked and censored from the experiment.

## DATA ANALYSIS

### Abundance Estimate

When capturing fish in a river using electrofishing boats it is inherently difficult to approximate the taking of a simple random sample (i.e., a random sample without replacement). Samples from the GPR were taken while progressively moving downstream and sampling uniformly as described above so that, to the extent possible, fish were captured in proportion to their abundance throughout the study area. Under these circumstances the Bailey-modified Petersen estimator (Appendix A1; Bailey 1951, 1952) is preferred over the Chapman-modified Petersen estimator (Chapman 1951) for estimating abundance.

Violations of Assumption 2 relative to size effects were tested using two two-sample Kolmogorov-Smirnov (K-S) tests with significance level *alpha* = 0.05. There were four possible outcomes of these tests relative to evaluating size selective sampling (either one of the two samples, both, or neither of the samples were biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A2. If stratification by size was required, capture probability by location was examined for each length stratum.

Tests for consistency of the Petersen estimator (Seber 1982; Appendix A3) were used to determine if stratification by location was required due to spatiotemporal effects and to determine the appropriate abundance estimator: the pooled Bailey-modified Petersen estimator, the completely stratified Bailey-modified Petersen estimator, or a partially stratified estimator (Darroch 1961). Assumption testing was performed at the scale of a section (with significance level *alpha* = 0.05). This grouping strategy generally provided a sufficient number of recaptures for diagnostic testing to ensure negligible statistical bias in $\hat{N}$ (Seber 1982) and accommodated localized movements of Arctic grayling.

### Movement

Relative to Assumption 1, closure was not tested directly but inferred from examination of the movement of recaptured Arctic grayling within the study area. Data were examined for evidence of movement away from or towards the boundaries of the study area to provide evidence of immigration and emigration.

## Length Compositions

Length compositions of the population were estimated using the procedures outlined in Appendices A2 and A4. Length composition was estimated in 10-mm length categories.

# RESULTS

## SPRING

### Movement

Because fish were released relatively close to the lower boundary of a run after sampling, downstream movement was defined as a fish that was recaptured beyond the adjacent downstream run, and upstream movement was defined as a fish that had moved into or beyond the adjacent upstream run. Using this definition of movement, 29 of the 45 (64%) recaptured Arctic grayling had not moved (Figure 4), and 10 (22%) recaptured Arctic grayling had moved between 1 and 8 km. Only 6 (13%) fish moved between 10 and 20 km. Among all recaptures, 10 moved downstream and 6 moved upstream. It was inferred that this observed movement (magnitude and direction) relative to the size of the index areas did not result in any significant bias due to the combined effects of immigration and emigration (i.e. the population was closed).

### Abundance Estimate

In the 101.4-km study area, 2,516 Arctic grayling ≥125 mm FL were captured ($n_1$ = 1,302, $n_2$ = 1,214), but the smallest recaptured fish was 214 mm FL and abundance was estimated for fish ≥200 mm FL. In the original 58.5-km study area, 2,020 Arctic grayling ≥125 mm FL were captured ($n_1$ = 1,104, $n_2$ = 916), but the smallest recaptured fish was 214 mm FL and abundance was estimated for fish ≥200 mm FL.

For both the 101.4-km and 58.5-km study areas, K-S tests results indicated Case IV for Arctic grayling ≥200 mm FL (Table 2), and data and estimates were stratified by length; 200–329 mm FL, 240–329 mm FL, 270–329 mm FL, and ≥330 mm FL. Each stratum was Case I, which indicated there was no size selective sampling during both events and the data were pooled for composition estimates within each length stratum.

Among both study areas and all length strata, except for one, one or more consistency tests failed to be rejected (Tables 3–5). Therefore, there was no need to geographically stratify, and the Bailey-modified Petersen estimator was used to calculate abundance (Tables 3–5). For the ≥330-mm FL stratum from the larger study area, the Darroch estimator was used because movement occurred between sections (Appendix B3), and was calculated using the software package Stratified Population Analysis System (SPAS) (Arnason et al. 1996).

Estimated abundances of Arctic grayling were:

1) for the 101.4-km study area:
    a. 200–329 mm FL was 27,061 (SE = 8,083);
    b. 240–329 mm FL was 24,939 (SE = 7,813);
    c. 270–329 mm FL was 19,667 (SE = 6,891);
    d. ≥200 mm FL was 45,145 (SE = 9,486);
    e. ≥240 mm FL was 43,023 (SE = 9,257);

f. ≥270 mm FL was 37,751 (SE = 8,493);

g. ≥330 mm FL was 18,084 (SE = 4,964); and,

2) for the original 58.5-km study area:

   a. 200–329 mm FL was 28,475 (SE = 11,545);

   b. 240–329 mm FL was 27,767 (SE = 12,340);

   c. 270–329 mm FL was 20,309 (SE = 10,090);

   d. ≥200 mm FL was 41,072 (SE = 11,784);

   e. ≥240 mm FL was 40,364 (SE = 12,564);

   f. ≥270 mm FL was 32,907 (SE = 10,363); and,

   g. ≥330 mm FL was 12,598 (SE = 2,362).

With regard to Objective 2 (testing the null hypothesis that the abundance of Arctic grayling was greater than the management objective), the abundance estimate of 32,907 (SE = 10,363) Arctic grayling ≥270 mm FL far exceeded the management objective of 9,000 fish and indicated only a 1% probability (one tail z-value = 2.307) that the actual population was <9,000 fish.

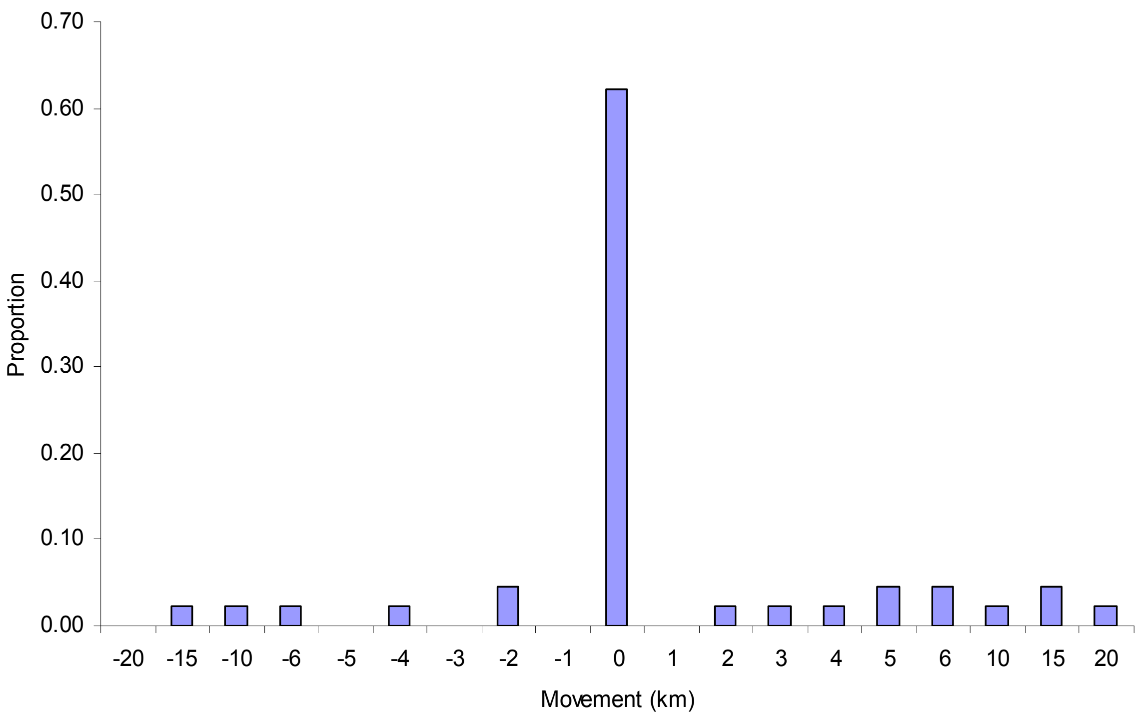


Figure 4.–Proportions of recaptured Arctic grayling (n = 45) that moved (km) upstream (negative values) or downstream (positive values) in the Goodpaster River study area, spring 2006.

Table 2.–Results of K-S tests used to detect and correct for size-selective sampling (Appendix A2) for estimating abundance and length and age compositions of Arctic grayling in the Goodpaster River for the 101.4- and 58.5-km study areas, spring 2006.

| Study area and FL group | Comparison and Test Statistic | | Result |
|---|---|---|---|
| | M vs. R | C vs. R | |
| **101.4 km Section** | | | |
| ≥200 mm FL | D = 0.239<br>P-value = 0.012<br>Reject $H_0$ | D = 0.290<br>P-value = 0.001<br>Reject $H_0$ | Case IV, stratify at 240 mm FL. |
| 200–329 mm FL | D = 0.241<br>P-value = 0.680<br>Fail to reject $H_0$ | D = 0.246<br>P-value = 0.653<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |
| 240–329 mm FL | D = 0.264<br>P-value = 0.640<br>Fail to reject $H_0$ | D = 0.270<br>P-value = 0.607<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |
| 270–329 mm FL | D = 0.343<br>P-value = 0.487<br>Fail to reject $H_0$ | D = 0.339<br>P-value = 0.499<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |
| ≥330 mm FL | D = 0.167<br>P-value = 0.272<br>Fail to reject $H_0$ | D = 0.213<br>P-value = 0.079<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |
| **58.5-km Section** | | | |
| ≥200 mm FL | D = 0.307<br>P-value = 0.009<br>Reject $H_0$ | D = 0.368<br>P-value = 0.001<br>Reject $H_0$ | Case IV, stratify. |
| 200–329 mm FL | D = 0.414<br>P-value = 0.504<br>Fail to reject $H_0$ | D = 0.416<br>P-value = 0.496<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |
| 240–329 mm FL | D = 0.465<br>P-value = 0.539<br>Fail to reject $H_0$ | D = 0.475<br>P-value = 0.512<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |
| 270–329 mm FL | D = 0.629<br>P-value = 0.411<br>Fail to reject $H_0$ | D = 0.641<br>P-value = 0.387<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |
| ≥330 mm FL | D = 0.236<br>P-value = 0.125<br>Fail to reject $H_0$ | D = 0.268<br>P-value = 0.057<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths and ages from both events for composition analysis |

Table 3.–Results of consistency tests for the Petersen estimator (Appendix A3) for estimating abundance of Arctic grayling in the Goodpaster River for the 101.4-km and 58.5-km study areas, spring 2006.

| | Consistency Test | | |
|---|---|---|---|
| | I | II | III |
| Study area and FL group | Complete Mixing | Equal probability of Capture, 1st Event | Equal Probability of Capture, 2nd Event |
| **101.4-km Section** | | | |
| 200–329 mm FL | $\chi^2$ = 46.97 | $\chi^2$ = 6.21 | $X^2$ = 8.00 |
| | P-value <0.01 | P-value = 0.29 | P-value = 0.16 |
| 240–329 mm FL | $\chi^2$ = 44.04 | $\chi^2$ = 6.05 | $X^2$ = 7.77 |
| | P-value = 0.01 | P-value = 0.30 | P-value = 0.17 |
| 270–329 mm FL | $\chi^2$ = 32.13 | $\chi^2$ = 3.70 | $X^2$ = 6.15 |
| | P-value = 0.15 | P-value = 0.59 | P-value = 0.29 |
| ≥330 mm FL | $\chi^2$ = 223.96 | $\chi^2$ = 19.94 | $X^2$ = 27.60 |
| | P-value <0.01 | P-value <0.01 | P-value <0.01 |
| **58.5-km Section** | | | |
| 200–329 mm FL | $\chi^2$ = 4.74 | $\chi^2$ = 2.34 | $X^2$ = 4.74 |
| | P-value = 0.31 | P-value = 0.31 | P-value = 0.09 |
| 240–329 mm FL | $\chi^2$ = 4.84 | $\chi^2$ = 1.47 | $X^2$ = 3.64 |
| | P-value = 0.30 | P-value = 0.48 | P-value = 0.16 |
| 270–329 mm FL | $\chi^2$ = 2.55 | $\chi^2$ = 1.09 | $X^2$ = 2.55 |
| | P-value = 0.64 | P-value = 0.58 | P-value = 0.28 |
| ≥330 mm FL | $\chi^2$ = 45.96 | $\chi^2$ = 2.92 | $X^2$ = 8.10 |
| | P-value <0.01 | P-value = 0.23 | P-value = 0.02 |

Table 4.–Number of Arctic grayling ≥200 mm FL marked (n1), examined (n2), and recaptured (m2) by section in the 101.4-km Goodpaster River study area, spring 2006.

| | | Section where recaptured | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | $m_2$ | $n_1$ | $m_2/n_1$[a] |
| Section where marked | 1 | 7 | 2 | 0 | 0 | 0 | 0 | 9 | 79 | 0.11 |
| | 2 | 0 | 4 | 0 | 0 | 0 | 0 | 4 | 61 | 0.07 |
| | 3 | 0 | 1 | 2 | 1 | 0 | 0 | 4 | 70 | 0.06 |
| | 4 | 0 | 0 | 0 | 4 | 1 | 0 | 5 | 154 | 0.03 |
| | 5 | 0 | 0 | 0 | 2 | 13 | 2 | 17 | 422 | 0.04 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 435 | 0.01 |
| | $m_2$ | 7 | 7 | 2 | 7 | 14 | 8 | | | |
| | $n_2$ | 63 | 111 | 151 | 163 | 322 | 366 | | | |
| | $(m_2/n_2)$[b] | 0.11 | 0.07 | 0.01 | 0.04 | 0.04 | 0.02 | | | |

[a] Probability of capture during second event.
[b] Probability of capture during first event.

Table 5.–Number of Arctic grayling ≥200 mm FL marked (n1), examined (n2), and recaptured (m2) by section in the original 58.5-km Goodpaster River study area, spring 2006.

| | | Section where recaptured | | | | | |
|---|---|---|---|---|---|---|---|
| | | 4 | 5 | 6 | $m_2$ | $n_1$ | $M_2/n_1$[a] |
| Section where marked | 4[b] | 5 | 1 | 0 | 6 | 168 | 0.04 |
| | 5 | 2 | 13 | 2 | 17 | 422 | 0.04 |
| | 6 | 0 | 0 | 6 | 6 | 435 | 0.01 |
| | $m_2$ | 7 | 14 | 8 | | | |
| | $n_2$ | 191 | 322 | 366 | | | |
| | $(m_2/n_2)$[c] | 0.04 | 0.04 | 0.02 | | | |

[a] Probability of capture during second event.
[b] For this study area, section 4 includes the last run of section 3 of the larger 101.4 km study area.
[c] Probability of capture during first event.

## Length Composition

In the 101.4-km study area, a majority of Arctic grayling ≥200 mm FL were 250 to 389 mm FL (80%; Appendix B4). In the 58.5-km study area, a majority of Arctic grayling ≥200 mm FL were 240 to 329 mm FL (61%; Appendix B5).

## SUMMER

## Movement

Using the definition of movement provided above, 140 of the 166 (84%) recaptured Arctic grayling had not moved (Figure 5), and 22 (13%) recaptured Arctic grayling had moved between 1 and 8 km. Only 4 fish (<3%) moved between 10 and 14 km. Among all recaptures, 9 moved downstream and 17 moved upstream. It was inferred that this observed movement (magnitude and direction) relative to the size of the index areas did not result in any significant bias due to the combined effects of immigration and emigration (i.e. the population was closed).

## Abundance Estimate

In the 101.4-km study area, 3,323 Arctic grayling ≥100 mm FL were captured ($n_1$ = 1,839, $n_2$ = 1,484, $m_2$ = 166) and the smallest recaptured fish was 156 mm FL. In the original 58.5-km study area, 2,707 Arctic grayling ≥100 mm FL were captured ($n_1$ = 1,543, $n_2$ = 1,164, $m_2$ = 150).

For both the 101.4-km and 58.5-km study areas, K-S tests (Appendix A2) results indicated a case IV for Arctic grayling ≥150 mm FL (Table 6), and the data were stratified. For Arctic grayling 150–239 mm FL, 200–239 mm FL; ≥240, ≥270, and ≥330 mm FL, the K-S tests indicated samples were not size selective for either event (Case I). Length compositions were estimated from first and second event samples combined.

For the 101.4-km study area, all consistency tests (Appendix A3) were rejected (with *alpha*=0.05) for each stratum (Tables 7 and 8) except in one instance when equal probability of capture was indicated for the second event only for the 200–239 mm stratum (p-value=0.15) and weakly indicated for the 150–239 mm stratum (p-value= 0.07). A Bailey-modified Petersen estimator was used to calculate abundance estimates for the 150–239 and 200–239 mm strata. The ≥240, ≥270, and ≥330 mm strata required geographic stratification. Sections 1–3 and 4–6 were each pooled, and because there was no movement between these two groupings (Table 8), the Bailey-modified Petersen estimator was used.

For the 58.5-km study area, consistency tests were rejected for the 150–239 mm FL stratum; however, for all other strata, at least one consistency test failed to be rejected (Tables 7 and 9). A Darroch estimator was used to calculate abundance of the 150–239 mm stratum because there was movement between sections (Appendix B6). A Bailey-modified Petersen estimator was used to calculate abundance estimates for the 200–239, ≥240, ≥270, and ≥330 mm strata.

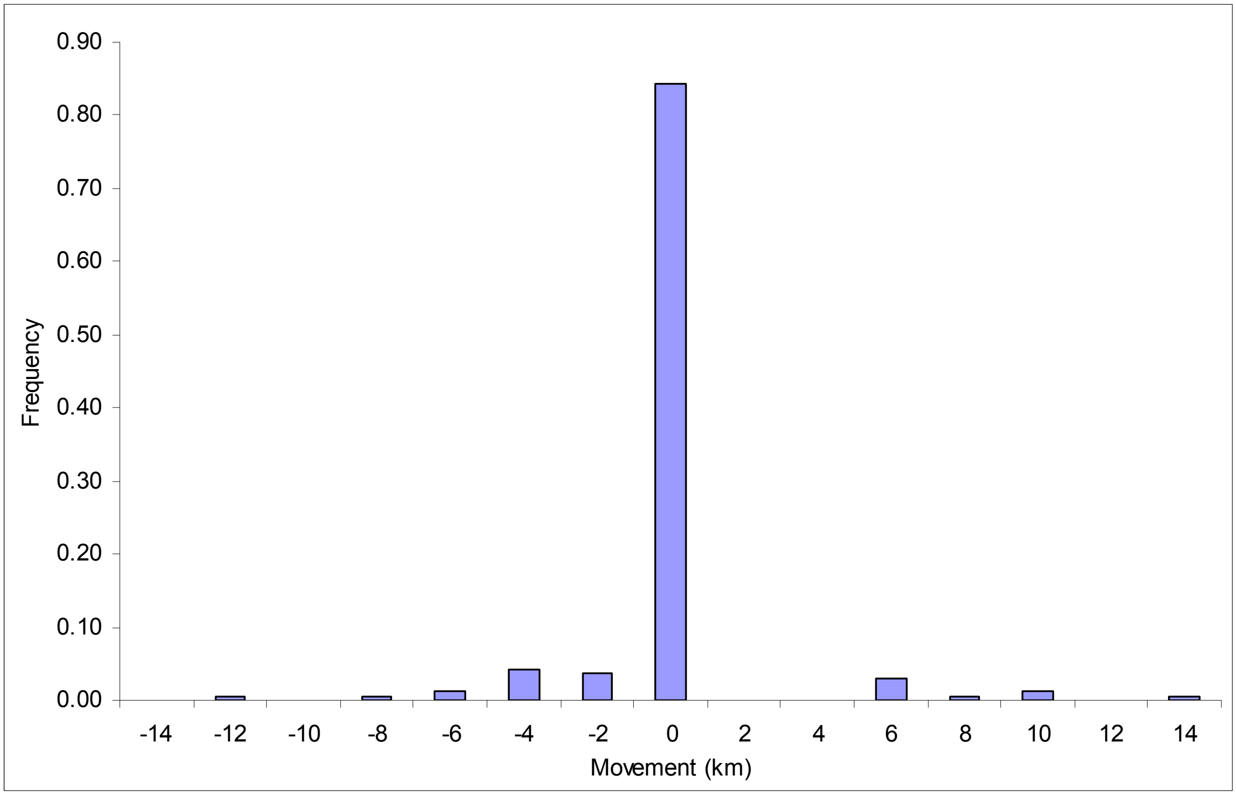


Figure 5.–Proportions of recaptured Arctic grayling (n = 166) that moved (km) upstream (negative values) or downstream (positive values) in the Goodpaster River study area, summer 2006.

Table 6.–Results of K-S tests used to detect and correct for size-selective sampling (Appendix A2) for estimating abundance and length and age compositions of Arctic grayling in the Goodpaster River for the 101.4- and 58.5-km study areas, summer 2006.

| | Comparison and Test Statistic | | |
|---|---|---|---|
| **Study area and FL group** | **M vs. R** | **C vs. R** | **Result** |
| **101.4-km Section** | | | |
| ≥150 mm FL | D = 0.26<br>P-value <0.01<br>Reject $H_0$ | D = 0.23<br>P-value <0.01<br>Reject $H_0$ | Case IV, stratify |
| 150–239 mm FL | D = 0.11<br>P-value = 0.49<br>Fail to reject $H_0$ | D = 0.07<br>P-value = 0.51<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| 200–239 mm FL | D = 0.14<br>P-value = 0.52<br>Fail to reject $H_0$ | D = 0.20<br>P-value = 0.14<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| ≥240 mm FL | D = 0.11<br>P-value = 0.14<br>Fail to reject $H_0$ | D = 0.07<br>P-value = 0.67<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| ≥270 mm FL | D = 0.14<br>P-value = 0.12<br>Fail to reject $H_0$ | D = 0.11<br>P-value = 0.37<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| ≥330 mm FL | D = 0.34<br>P-value = 0.16<br>Fail to reject $H_0$ | D = 0.28<br>P-value = 0.36<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| **58.5-km Section** | | | |
| ≥150 mm FL | D = 0.30<br>P-value <0.01<br>Fail to reject $H_0$ | D = 0.25<br>P-value <0.01<br>Fail to reject $H_0$ | Case IV, stratify |
| 150–239 mm FL | D = 0.13<br>P-value = 0.34<br>Fail to reject $H_0$ | D = 0.11<br>P-value = 0.57<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| 200–239 mm FL | D = 0.10<br>P-value = 0.90<br>Fail to reject $H_0$ | D = 0.15<br>P-value = 0.48<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| ≥240 mm FL | D = 0.06<br>P-value = 0.95<br>Fail to reject $H_0$ | D = 0.10<br>P-value = 0.35<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| ≥270 mm FL | D = 0.05<br>P-value = 0.99<br>Fail to reject $H_0$ | D = 0.05<br>P-value > 0.99<br>Fail to reject $H_0$ | Case I, do not stratify, use lengths from both events for composition analysis |
| ≥330 mm FL | D = 0.33<br>P-value = 0.97 | D = 0.32<br>P-value = 0.99 | Case I, do not stratify, use lengths from both events for composition analysis |

Table 7.–Results of consistency tests for the Petersen estimator (Appendix A3) for estimating abundance of Arctic grayling in the Goodpaster River for the 101.4- and 58.5-km study areas, summer 2006.

| | Consistency Test | | |
|---|---|---|---|
| | I | II | III |
| Study area and FL group | Complete Mixing | Equal probability of Capture, 1st Event | Equal Probability of Capture, 2nd Event |
| **101.4-km Section** | | | |
| 150–239 mm FL | $\chi^2$ = 146.11<br>P-value <0.01 | $\chi^2$ = 19.38<br>P-value <0.01 | $\chi^2$ = 10.07<br>P-value = 0.07 |
| 200–239 mm FL | $\chi^2$ = 52.50<br>P-value <0.01 | $\chi^2$ = 21.17<br>P-value <0.01 | $\chi^2$ = 8.15<br>P-value = 0.15 |
| ≥240 mm FL | $\chi^2$ = 383.11<br>P-value <0.01 | $\chi^2$ = 21.89<br>P-value <0.01 | $\chi^2$ = 27.11<br>P-value <0.01 |
| ≥270 mm FL | $\chi^2$ = 296.75<br>P-value <0.01 | $\chi^2$ = 20.26<br>P-value <0.01 | $\chi^2$ = 25.32<br>P-value <0.01 |
| ≥330 mm FL | $\chi^2$ = 75.18<br>P-value <0.01 | $\chi^2$ = 20.40<br>P-value <0.01 | $\chi^2$ = 13.43<br>P-value = 0.02 |
| **58.5-km Section** | | | |
| 150–239 mm FL | χ2 = 58.55<br>P-value <0.01 | χ2 = 11.89<br>P-value <0.01 | χ2 = 7.58<br>P-value = 0.02 |
| 200–239 mm FL | χ2 = 32.25<br>P-value <0.01 | χ2 = 9.67<br>P-value <0.01 | χ2 = 5.19<br>P-value = 0.07 |
| ≥240 mm FL | χ2 = 161.54<br>P-value <0.01 | χ2 = 2.64<br>P-value = 0.27 | χ2 = 4.19<br>P-value = 0.12 |
| ≥270 mm FL | χ2 = 121.53<br>P-value ≤ 0.01 | χ2 = 1.57<br>P-value = 0.46 | χ2 = 2.73<br>P-value = 0.25 |
| ≥330 mm FL | χ2 = 7.71<br>P-value = 0.10 | χ2 = 1.77<br>P-value = 0.41 | χ2 = 0.96<br>P-value = 0.62 |

Table 8.–Number of Arctic grayling ≥150 mm FL marked (n1), examined (n2), and recaptured (m2) by section in the 101.4-km Goodpaster River study area, summer 2006.

| | | Section where recaptured | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | $m_2$ | $n_1$ | $m_2/n_1$ [a] |
| Section where marked | 1 | 5 | 0 | 0 | 0 | 0 | 0 | 5 | 125 | 0.04 |
| | 2 | 0 | 4 | 1 | 0 | 0 | 0 | 5 | 111 | 0.05 |
| | 3 | 0 | 1 | 5 | 0 | 0 | 0 | 6 | 83 | 0.07 |
| | 4 | 0 | 0 | | 33 | 1 | 0 | 34 | 264 | 0.13 |
| | 5 | 0 | 0 | 0 | 0 | 94 | 2 | 96 | 861 | 0.11 |
| | 6 | 0 | 0 | 0 | 0 | 1 | 19 | 20 | 381 | 0.05 |
| | $m_2$ | 5 | 5 | 6 | 33 | 96 | 21 | | | |
| | $n_2$ | 73 | 146 | 152 | 261 | 631 | 210 | | | |
| | $(m_2/n_2)$ [b] | 0.07 | 0.03 | 0.04 | 0.13 | 0.15 | 0.10 | | | |

[a] Probability of capture during second event.
[b] Probability of capture during first event.

Table 9.–Number of Arctic grayling ≥150 mm FL marked (n1), examined (n2), and recaptured (m2) by section in the original 58.5-km Goodpaster River study area, summer 2006.

| | | Section where recaptured | | | | | |
|---|---|---|---|---|---|---|---|
| | | 4 | 5 | 6 | $m_2$ | $n_1$ | $m_2/n_1$ [a] |
| Section where marked | 4 [b] | 33 | 1 | 0 | 34 | 287 | 0.12 |
| | 5 | 0 | 94 | 2 | 96 | 861 | 0.11 |
| | 6 | 0 | 1 | 19 | 20 | 381 | 0.05 |
| | $m_2$ | 33 | 96 | 21 | | | |
| | $n_2$ | 312 | 631 | 210 | | | |
| | $(m_2/n_2)$ [c] | 0.11 | 0.15 | 0.10 | | | |

[a] Probability of capture during second event.
[b] Section 4 in this matrix includes the last run of section 3, which began at the mouth of the South Fork Goodpaster River.
[c] Probability of capture during first event.

Estimated abundances of Arctic grayling were:

1) for the 101.4 km study area:
    a. 150–239 mm FL was 15,291 (SE = 1,972);
    b. 200–239 mm FL was 8,142 (SE = 1,289);
    c. ≥150 mm FL was 21,240 (SE = 2,158);
    d. ≥200 mm FL was 14,091 (SE = 1,558);
    e. ≥240 mm FL was
        i. 3,393 (SE = 845) in Sections 1–3;
        ii. 2,556 (SE = 226) in Sections 4–6;
        iii. 5,949 (SE = 875) in Sections 1–6;
    f. ≥270 mm FL was;
        i. 3,003 (SE = 803) in Sections 1–3;
        ii. 1,695 (SE = 173) in Sections 4–6;
        iii. 4,698 (SE = 821) in Sections 1–6;
    g. ≥330 mm FL was;
        i. 1,161 (SE = 419) in Sections 1–3;
        ii. 38 (SE = 8) in Sections 4–6; and
        iii. 1,199 (SE = 419) in Sections 1–6.

2) for the original 58.5-km study area:
    a. 150–239 mm FL was 18,664 (SE = 6,923);
    b. 200–239 mm FL was 5,769 (SE = 916);
    c. ≥150 mm FL was 21,400 (SE = 6,928);
    d. ≥200 mm FL was 8,505 (SE = 947);
    e. ≥240 mm FL was 2,736 (SE = 243);
    f. ≥270 mm FL was 1,847 (SE = 190); and,
    g. ≥330 mm FL was 62 (SE = 16).

## Length and Age Composition

In the 101.4-km study area, a majority of Arctic grayling ≥150 mm FL were 160 to 229 mm FL (67%; Appendix B7). In the 58.5-km study area, a majority of Arctic grayling ≥150 mm FL were 160 to 229 mm FL (82%; Appendix B8).

# DISCUSSION

The study goal was to characterize the population in the 101.4-km study area during spring and summer. Prior assessments had only encompassed a smaller portion of the fishery and only during either the spring or summer in a given year, which limited their interpretation with respect to exploitation. Estimates of abundance were calculated for all objectives ≥150 (summer only), ≥270, and ≥330 mm FL. Additional strata between 200–270 mm FL were estimated because several fish in this size range were recaptured, which permitted additional comparisons between spring and summer estimates.

This study, in contrast to most prior studies, was designed to estimate abundance in a larger study area, and estimates were expected to be within 25% of the actual abundance 95% of the time. However, most estimates tended to not meet the precision expectations, likely due to insufficient sampling effort. When this study was originally designed, there were constraints of time and personnel imposed on the design, generally allowing for only one boat per section. Previous experience had indicated this method was feasible (Ridder 1998a, Roach 1995). In retrospect, it is evident that when two boats per section were used, as for the lower three sections during summer, suitably precise estimates were usually obtained. For this reason, it is suggested future studies on the Goodpaster River utilize two boats per section.

The spring and summer populations were different in several respects. The abundance of the spring population was significantly greater than the summer population. The greatest difference between spring and summer was the large number of larger Arctic grayling (≥270 mm FL) present during spring but largely vacant during summer (Figure 6). This result was consistent with well-known and documented Arctic grayling behavior in this river, which is that a large number of Arctic grayling spawn in the lower river during spring and disperse to the DCR, Richardson Clearwater River (RCR), and Upper GPR during summer (Ridder 1998b, Gryska *In prep b*, Tack 1980). For smaller fish there was also a notable difference, but the confidence in the interpretation is very limited because the spring estimate was based on very few recaptures (only 3 recaptured fish between 200 and 279 mm FL in the larger study area). Although there was a similar estimate of Arctic grayling (about 10,000) between 200 and 279 mm FL during spring and summer, the composition was quite different (Figure 7). During spring there were about 8,000 Arctic grayling between 240 and 279 mm Fl, whereas during summer there were about 8,000 Arctic grayling between 200 and 239 mm FL. The absence of fish 240–279 mm FL during summer was likely due to either the general movement patterns after the spawning period, when many larger fish move upstream or over to the DCR and RCR, or that so few smaller fish were recaptured that the true capture probability and ultimately abundance were not accurately estimated.

The appearance of the smallest fish (150–239 mm FL) during summer was due to one or more reasons. One reason could have been that these fish were actually present in the same habitats in both spring and summer, but were not adequately sampled in spring (i.e. insufficient capture probabilities) to attain an accurate estimate. In summer, estimates of capture probability likely improved because there was more sampling effort (2 boats were used during the summer in the lower 3 sections) and in the absence of larger fish, which are more easily stunned, personnel were more adept at catching small fish. Because there was a better estimate of capture probability for the smallest fish during summer, estimates were stratified by length and this indicated that there was large population of these fish (i.e. 150–239 mm FL). Another related

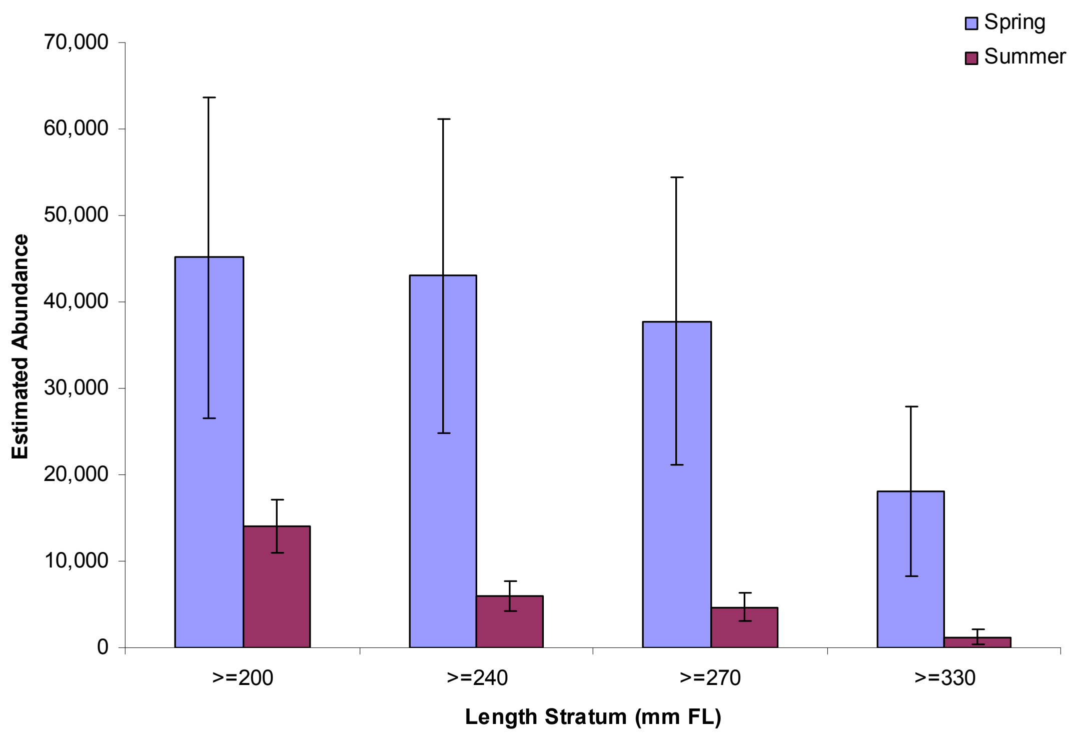


Figure 6.–Estimated abundance and 95% CI of Arctic grayling ≥200, ≥240, ≥270 and ≥330 mm FL in the 101.4 km Goodpaster River study area during spring and summer 2006.

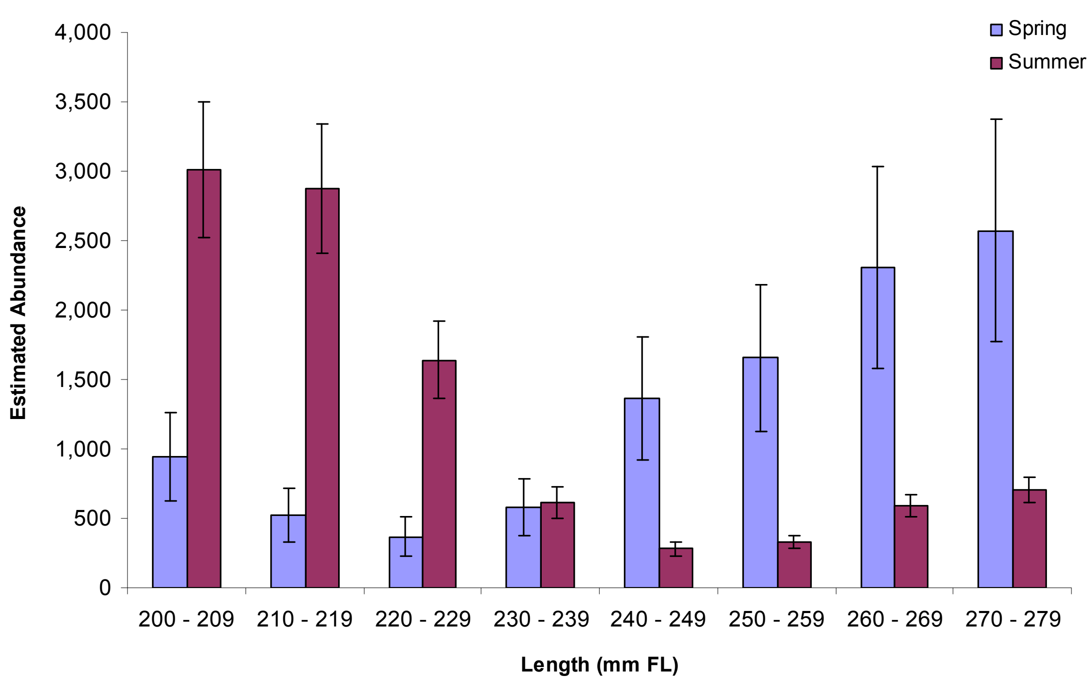


Figure 7.–Estimated abundance and SE by FL group of Arctic grayling 200–279 mm FL in the 104.8-km Goodpaster River study area during spring and summer 2006.

reason may have been a seasonal difference in habitat use for these fish. Riffles and their downstream eddies and pools tend to hold many fish during spawning and during the summer feeding period. It is possible the smallest fish were not located in these areas during spring but were located there during summer. Little is known about the preferred habitats for these smallest fish during spring, and it has always been difficult to estimate the abundance of Arctic grayling <270 mm FL in the GPR during spring (Parker 2006 *Unpublished*; Ridder 1998a).

The 2006 estimates were comparable to a number of previous estimates in the old 58.5-km study area and for the only study conducted in the larger study area during 1995. For both spring and summer, the 2006 population estimates were not significantly different (95% CI) from previous estimates (Figures 8 and 9 and Appendices B9, B10, and B11). However, they were at least as large as the previous estimates and quite likely larger. For example, a 90% CI yielded some 2006 estimates significantly different from previous years. Additionally, the DCR estimate of abundance ($\hat{N}$ = 14,799; SE = 2,204) for Arctic grayling ≥270 mm FL during summer 2006 (Wuttig and Gryska *in prep*) was nearly twice as large as the 2000 estimate (Gryska 2001); this being relevant to the discussion and supporting the conclusion because, nearly half of the DCR population is composed of GPR Arctic grayling that migrate after spawning (Ridder 1998a and b Gryska *in prep b*). Therefore, an increase in the DCR population is likely to have a corresponding increase in the GPR spring population. Ultimately, for management purposes, there is no concern for the Arctic grayling population in the GPR because it likely was at least as large as previous estimates, it exceeded the management objective, and angler effort and harvest have declined as compared to the 1980s (Table 1).

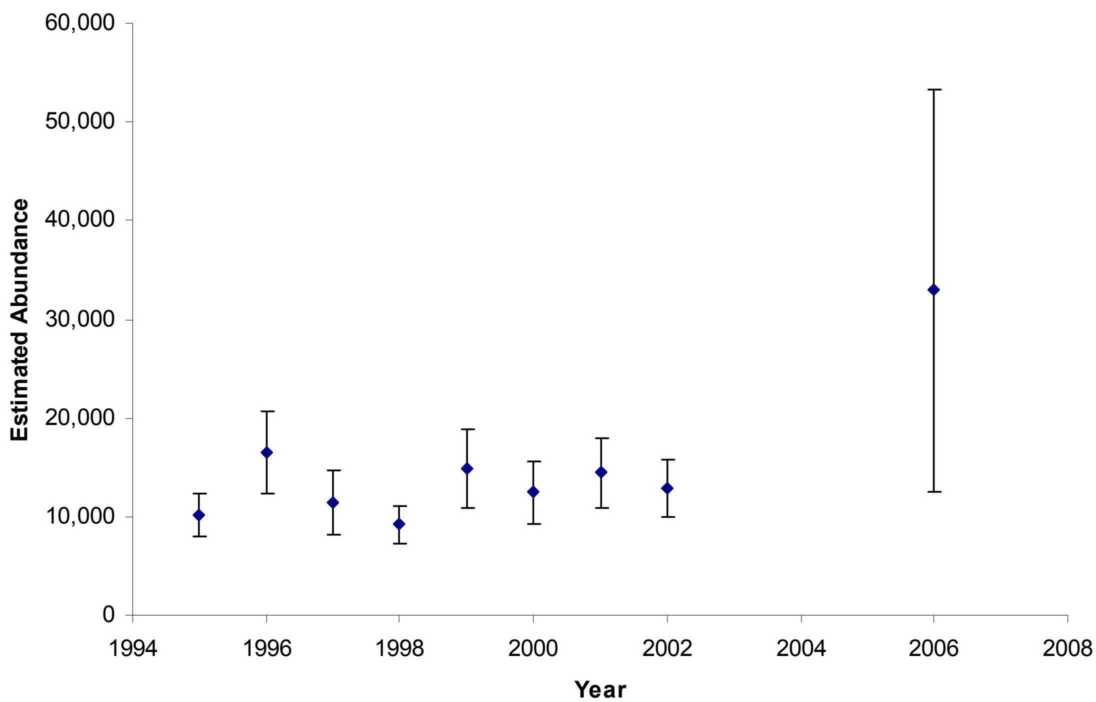


Figure 8.–Estimated abundance and 95% CI of Arctic grayling ≥270 mm FL in the 58.5-km Goodpaster River study area during spring, 1995–2002, and 2006.

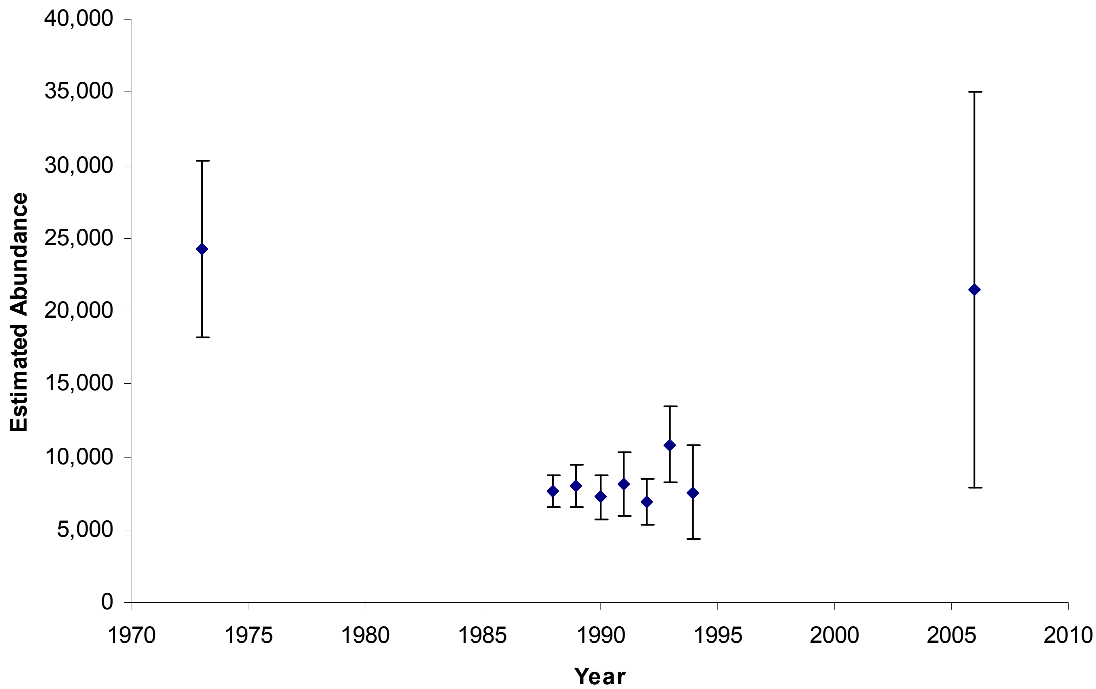


Figure 9.–Estimated abundance and 95% CI of Arctic grayling ≥150 mm FL in the 58.5-km Goodpaster River study area during summer, 1973, 1988–1994, and 2006.

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# APPENDIX A
# EQUATIONS AND STATISTICAL METHODOLOGY

Appendix A1.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

The Bailey-modified Petersen estimator (Bailey 1951 and 1952) was used because the sampling design called for a systematic downstream progression, fishing each pool and run and attempting to subject all fish to the same probability of capture while sampling with replacement. The Bailey modification to the Petersen estimator may be used even when the assumption of a random sample for the second sample is false when a systematic sample is taken provided:

1) there is uniform mixing of marked and unmarked fish; and,
2) all fish, whether marked or unmarked, have the same probability of capture (Seber 1982).

The abundance of Arctic grayling was estimated as:

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

where:

$n_1$ = the number of Arctic grayling marked and released alive during the first event;

$n_2$ = the number of Arctic grayling examined for marks during the second event; and,

$m_2$ = the number of Arctic grayling marked in the first event that were recaptured during the second event; and

The variance was estimated as (Seber 1982):

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

Appendix A2.–Procedures for detecting and adjusting for size or sex selective sampling during a 2-sample mark-recapture experiment.

Overview

Size and sex selective sampling may result in the need to stratify by size and/or sex in order to obtain unbiased estimates of abundance and composition. In addition, the nature of the selectivity determines whether the first, second or both event samples are used for estimating composition. The Kolmogorov-Smirnov two sample (K-S) test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first or second sampling events and contingency table analysis (Chi-square test) is generally used to detect significant evidence that sex selective sampling occurred during the first or second sampling events.

K-S tests are used to evaluate the second sampling event by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R), using the null test hypothesis ($H_o$) of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. Chi-square tests are used to compare the counts of observed males to females between M&R and C&R according to the null hypothesis that the probability that a sampled fish is male or female is independent of the sample. When the proportions by gender are estimated for a subsample (usually from C), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are compared between samples using a two sample test (e.g. Student's t-test).

Mark-recapture experiments are designed to obtain sample sizes sufficient to 1) achieve precision objectives for abundance and composition estimates and 2) ensure that the diagnostic tests (i.e., tests for selectivity) have power adequate for identifying selectivity that could result in significantly biased estimates. Despite careful design, experiments may result in inadequate sample sizes leading to unreliable diagnostic test results due to low power. As a result, detection and adjusting for size and sex selectivity involves evaluating the power of the diagnostic tests.

The protocols that follow are used to classify the experiment into one of four cases. For each case the following are specified: 1) whether stratification is necessary, 2) which sample event's data should be used when estimating composition, and 3) the estimators to be used for composition estimates when stratifying. The first protocols assume adequate power. These are followed by supplemental protocols to be used when power is suspect and guidelines for evaluating power.

Protocols given Adequate Power

*Case I:*

| **M vs. R** | **C vs. R** |
|---|---|
| Fail to reject $H_o$ | Fail to reject $H_o$ |

There is no size/sex selectivity detected during either sampling event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events but do not include recaptured fish twice.

-continued-

*Case II:*

| **M vs. R** | **C vs. R** |
|---|---|
| Reject $H_o$ | Fail to reject $H_o$ |

There is no size/sex selectivity detected during the first event but there is during the second event sampling. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula.

Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

*Case III:*

| **M vs. R** | **C vs. R** |
|---|---|
| Fail to reject $H_o$ | Reject $H_o$ |

There is no size/sex selectivity detected during the second event but there is during the first event sampling. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

*Case IV:*

| **M vs. R** | **C vs. R** |
|---|---|
| Reject $H_o$ | Reject $H_o$ |

There is size/sex selectivity detected during both the first and second sampling events. The <u>ratio</u> of the probability of captures for size of sex categories can either be the same or different between events. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

-continued-

Protocols when Power Suspect (re-classifying the experiment)

When sample sizes are small (guidelines provided in next section) power needs to be evaluated when diagnostic tests fail to reject the null hypothesis. If this failure to identify selectivity is due to low power (that is, if selectivity is actually present) data will be pooled when stratifying is necessary for unbiased estimates. For example, if the both the M vs. R and C vs. R tests failed to identify selectivity due to low power, Case I may be selected when Case IV is true. In this scenario, the need to stratify could have been overlooked leading to biased estimates. The following protocols should be followed when sample sizes are small.

*Case I:*

| **M vs. R** | **C vs. R** | **Implication** |
|---|---|---|
| Fail to reject Ho | Fail to reject Ho | re-evaluate both tests |
| Power OK/retain test result | Power OK/retain test result | Case I |
| Power suspect/change to Reject Ho | Power OK/retain test result | Case II |
| Power OK/retain test result | Power suspect/change to Reject Ho | Case III |
| Power suspect/change to Reject Ho | Power suspect/change to Reject Ho | Case IV |

*Case II:*

| **M vs. R** | **C vs. R** | **Implication** |
|---|---|---|
| Reject Ho | Fail to reject Ho | re-evaluate C vs. R |
| | Power OK/retain test result | Case II |
| | Power suspect/change to Reject Ho | Case IV |

*Case III:*

| **M vs. R** | **C vs. R** | **Implication** |
|---|---|---|
| Fail to reject Ho | Reject Ho | re-evaluate M vs. R |
| Power OK/retain test result | | Case III |
| Power suspect/change to Reject Ho | | Case IV |

-continued-

<u>Guidelines for evaluating power:</u>

The following guidelines to assess power are based upon the experiences of Sport Fish biometricians; they have not been comprehensively evaluated by simulation. Because some “art” in interpretation remains these guidelines are not intended to be used in lieu of discussions with biometricians when possible. When the evaluation does not lead to a clear choice, a stratified estimator should be selected (i.e., the experiment should be classified as Case IV) in order to minimize potential bias.

The reliability of M vs. R and C vs. R tests that fail to reject $H_o$ are called into question when 1) sample sizes M or C are <100 and the sample size for R is <30, 2) p-values are not large (~0.20 or less), and the D statistics are large (≥0.2). If sample sizes are small, the p-value is not large, and the D statistic is large then the power of the test is suspect and, when re-classifying the experiment, the test should be considered as having rejected the null hypothesis. If for example, sample sizes are marginal (close to the recommended values), the p-value is large, and the D-statistic is not large then the test result may be considered reliable. It is when results are close to the recommended “cutoffs” that interpretation becomes somewhat more complicated.

Apparent inconsistencies between the combination of the M vs. R and C vs. R test results and the M vs. C test results may also arise from low power. For example, if one of the tests involving R rejects the null hypothesis and the other fails to reject one could infer a difference between M & C; however, the M vs. C test may still fail to reject the null indicating no difference between the M & C. In this case, the apparent inconsistency may be due to low power in the test involving R that failed to reject the null. Finally, an additional Case I scenario is flagged by an apparent inconsistency between test results, this time resulting from power being too high. Under this scenario both the M vs. R and C vs. R tests fail to reject the null hypothesis and their power is thought to be sufficient; however, the M vs. C test rejects $H_o$: no difference between the M & C. The apparent inconsistency may result from the M vs. C test being so powerful as to detect selectivity that would result in insignificant bias when estimating abundance and composition. The reliability of M vs. C tests that reject are called into question when 1) sample sizes M or C are > 500, 2) p-values are not extremely small (~0.010-0.049), and the D statistics are small (< 0.08). In general all three K-S tests should be performed to permit these evaluations.

Appendix A3.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

The following two assumptions must be fulfilled:

1. catching and handling the fish does not affect the probability of recapture; and,
2. marked fish do not lose their mark.

Of the following assumptions, only one must be fulfilled:

1. marked fish mix completely with unmarked fish between events;
2. every fish has an equal probability of being marked and released during event 1; or,
3. every fish has an equal probability of being captured during event 2.

To evaluate these three assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982). At least one null hypothesis needs to be accepted for assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all three tests are rejected, a geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

**TEST I** [a]

| First Event Sampling Area Released | Second Event | | | | |
|---|---|---|---|---|---|
| | Sampling Area Recaptured | | | | Not Recaptured |
| | **A** | **B** | **…** | **S Recaptured** | (total) |
| **A** | | | | | |
| **B** | | | | | |
| **…** | | | | | |
| **S** | | | | | |

**TEST II** [b]

| | Second Event: Sampling Area | | | |
|---|---|---|---|---|
| | **A** | **B** | **…** | **S** |
| Recaptured | | | | |
| Not Recaptured | | | | |

**TEST III** [c]

| | Captured During Second Event River Section | | | |
|---|---|---|---|---|
| | **A** | **B** | **…** | **S** |
| Marked | | | | |
| Unmarked | | | | |

[a] This tests the hypothesis that movement probabilities are the same among sections: $H_1$: $\theta_{ij} = \theta_j$. Theta applies to both marked and unmarked fish.

[b] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities between the three river areas: $H_2$: $\Sigma_j \theta_{ij} p_j = d$. Theta applies to both marked and unmarked fish.

[c] This tests the homogeneity on the columns of the 2-by-t contingency table with respect to the probability of movement of marked fish in stratum $i$ to the unmarked fraction in $j$: $H_4$: $\Sigma_i a_i \theta_{ij} = k U_j$. Theta only applies to marked fish.

Appendix A4.–Equations for estimating length and age composition and their variances for the population.

For Case I-IV scenarios (Appendix A2), the proportions of Arctic grayling within each age or length class *k* were estimated:

$$\hat{p}_k = \frac{n_k}{n} \tag{1}$$

where:

$n_k$ = the number of Arctic grayling sampled within age or length class *k* and,

$n$ = the total number of Arctic grayling sampled.

When calculating $n$ and $n_k$ the diagnostic test results were used to determine which fish were included (Appendix A2). For Case I, fish from both events were used.

The variance of each proportion was estimated as (from Cochran 1977):

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1}. \tag{2}$$

The abundance of Arctic grayling in each length or age category, *k,* in the population was then estimated:

$$\hat{N}_k = \hat{p}_k \hat{N}, \tag{3}$$

where:

$\hat{N}$ = the estimated overall abundance (Appendix A1).

The variance for $\hat{N}_k$ was then estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_k\right] \approx \hat{V}[\hat{p}_k]\hat{N}^2 + \hat{V}\left[\hat{N}\right]\hat{p}_k^2 - \hat{V}[\hat{p}_k]\hat{V}\left[\hat{N}\right]. \tag{4}$$

For the Case IV scenario (Appendix A2), that requiring stratification by size or sex, the proportions of Arctic grayling within each age or length class *k* were estimated by first calculating:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{5}$$

where:

$n_j$ = the number sampled from size stratum *j* in the mark-recapture experiment;

$n_{jk}$ =the number sampled from size stratum *j* that are in length or age category *k*; and,

$\hat{p}_{jk}$ = the estimated proportion of length or age category *k* fish in size stratum *j*.

-continued-

When calculating $n_j$ and $n_{jk}$ the within stratum diagnostic test results were used to determine which fish were included in the analysis following the rules for $n$ and $n_k$ provided above.

The variance calculation for $\hat{p}_{jk}$ is equation 2 substituting $\hat{p}_{jk}$ for $\hat{p}_k$ and $n_j$ for $n$.

The estimated abundance of fish in length or age category $k$ in the population is then:

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk} \hat{N}_j \tag{6}$$

where:

$\hat{N}_j$ = the estimated abundance in size stratum $j$; and,

$s$ = the number of size strata.

The variance for $\hat{N}_k$ will be estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s} \left( \hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right] \right). \tag{7}$$

The estimated proportion of the population in length or age category $k$ $\left(\hat{p}_k\right)$ is then:

$$\hat{p}_k = \hat{N}_k / \hat{N} \tag{8}$$

where: $\hat{N} = \sum_{j=1}^{s} \hat{N}_j$ .

Variance of the estimated proportion can be approximated with the delta method (Seber 1982):

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s} \left\{ \left( \frac{\hat{N}_j}{\hat{N}} \right)^2 \hat{V}\left[\hat{p}_{jk}\right] \right\} + \frac{\sum_{j=1}^{s} \left\{ \hat{V}\left[\hat{N}_j\right] \left(\hat{p}_{jk} - \hat{p}_k\right)^2 \right\}}{\hat{N}^2}. \tag{9}$$

# APPENDIX B
# ADDITIONAL TABLES

Appendix B1.–Summary of Arctic grayling stock assessments (≥150 mm FL) in the Goodpaster River, 1960–2005.

| Year[a] | Day/Month | River km | $n_1$ | $n_2$ | $m_2$ | Fish/km[b] $\hat{N}$ | 95% CI[c] or (SE) |
|---|---|---|---|---|---|---|---|
| 1972 | 12–14 Jul | 4.8–9.6 | 210 | --- | 30 | 189 | --- |
| 1973 | 1 Jun–30 Aug | 0–53 | 2,328 | 1,734 | 122 | 480 | 411–590 |
| | | 53–98 | 561 | 680 | 16 | 322 | 223–732 |
| | | 98–184 | 415 | 410 | 19 | 81 | 57–164 |
| | | 0–184 | --- | --- | --- | 241 | 209–287 |
| 1974[d] | 15–29 Jul | 0–53 | 1,217 | 489 | 55 | 201 | 155–260 |
| | | 53–98 | 479 | 279 | 9 | 298 | 165–596 |
| | | 98–184 | 343 | 275 | 27 | 63 | 44–93 |
| | | 0–184 | --- | --- | --- | 152 | 124–186 |
| 1975 | 23–27 Jun | 4.8–9.6 | 330 | 145 | 31 | 314 | 223–456 |
| | | 24–28.8 | 317 | 319 | 34 | 604 | 436–863 |
| | | combined | 647 | 464 | 65 | 475 | 374–603 |
| 1976 | 21–24 Jun | 4.8–9.6 | 155 | 99 | 9 | 323 | 178–646 |
| | | 24–28.8 | 202 | 165 | 18 | 368 | 238–597 |
| | | combined | 357 | 264 | 27 | 351 | 245-524 |
| 1977 | 21–24 Jun | 4.8–9.6 | 234 | 150 | 11 | 613 | 356–1,150 |
| | | 24–28.8 | 396 | 263 | 60 | 357 | 278–457 |
| | | combined | 630 | 413 | 71 | 377 | 300–474 |
| 1978 | 20–23 Jun | 4.8–9.6 | 248 | 167 | 19 | 434 | 284–694 |
| | | 24–28.8 | 373 | 212 | 32 | 502 | 359–726 |
| | | combined | 621 | 379 | 51 | 473 | 361–618 |
| 1980 | 24–27 Jun | 4.8–9.6 | 231 | 153 | 13 | 529 | 318–938 |
| | | 24–28.8 | 337 | 213 | 31 | 470 | 334–683 |
| | | combined | 568 | 366 | 44 | 483 | 362–658 |
| 1982 | 29 Jun–2 Jul | 4.8–9.6 | 79 | 107 | 9 | 178 | 98–356 |
| | | 24–28.8 | 214 | 155 | 39 | 174 | 128–242 |
| | | combined | 293 | 260 | 48 | 163 | 123–219 |
| 1984 | 27–29 Jun | 4.8–9.6 | 265 | 91 | 12 | 391 | 153–629 |
| | | 24–28.8 | 216 | 169 | 28 | 264 | 161–367 |
| | | combined | 481 | 260 | 40 | 352 | 249–455 |

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Appendix B1.–Page 2 of 3.

| Year[a] | Day/Month | River km | $n_1$ | $n_2$ | $m_2$ | $\hat{N}$ | Fish/km[b] 95% CI[c] or (SE) |
|---|---|---|---|---|---|---|---|
| 1985 | 25–27 Jun | 4.8–9.6 | 189 | 213 | 7 | 459 | 238–966 |
| 1985 | 6–13 Aug | 4.8–9.6 | 307 | 455 | 42 | 400 | 296–554 |
| | | 24–28.8 | 303 | 424 | 45 | 328 | 245–450 |
| | | combined | 610 | 879 | 87 | 364 | 271–502 |
| 1986 | 11–15 Aug | 4.8–9.6 | 230 | 312 | 15 | 403 | 250–686 |
| | | 24–28.8 | 293 | 389 | 42 | 256 | 193–352 |
| | | combined | 523 | 701 | 57 | 305 | 234–397 |
| 1987 | 4–10 Aug | 4.8–9.6 | 138 | 191 | 14 | 188 | 115–324 |
| | | 24–28.8 | 158 | 213 | 24 | 133 | 91–203 |
| | | combined | 274 | 363 | 35 | 134 | 97–191 |
| 1988 | 8–18 Aug | 4.8–53 | 1,130 | 1,002 | 139 | 158 | (12) |
| 1989 | 8–17 Aug | 3–53 | 955 | 984 | 124 | 161 | (15) |
| 1990 | 8–16 Aug | 3–53 | 1,051 | 554 | 82 | 145 | (15) |
| 1991 | 7–14 Aug | 3–53 | 780 | 429 | 42 | 157 | (17) |
| 1992 | 4-14 Aug | 3–53 | 922 | 562 | 80 | 138 | (16) |
| 1993 | 3–13 Aug | 3–53 | 730 | 890 | 59 | 219 | (27) |
| 1994 | 2–11 Aug | 3–53 | 668 | 294 | 29 | 151 | (32) |
| 1995[e] | 5–10 May | 0–104 | 1,815 | 1,621 | 159 | 205 | (22) |
| 1996 | 10–16 May | 0–53 | 1,533 | 1,357 | 101 | 434 | (53) |
| 1997[e] | 6–11 May | 0–53 | 881 | 814 | 63 | 221 | (32) |
| 1998[f] | 1–3 May | 0–53 | 1,260 | | | 156 | (17) |
| 1999[f] | 12–14 May | 0–53 | 933 | | | 254 | (35) |
| 2000[f] | 10–12 May | 0–53 | 986 | | | 213 | (27) |
| 2001[f] | 14–17 May | 0–53 | 1,675 | | | 247 | (30) |

-continued-

Appendix B1.–Page 3 of 3.

| Year[a] | Day/Month | River km | $n_1$ | $n_2$ | $m_2$ | $\hat{N}$ | Fish/km[b] 95% CI[c] or (SE) |
|---|---|---|---|---|---|---|---|
| 2003[g] | 7–25 Jul | 131–90 | 699 | 449 | 85 | 89 | (9) |
| 2004[g] | 3–13 Jul | 131–90 | 1,164 | 629 | 153 | 130 | (8) |
| 2005[h] | 3–5 May | 0–150 | 1,350 | | | | |

[a] Data sources: 1972–1974 (Tack 1973, 1974, 1975); 1975–1978 and 1980 (Peckham 1976, 1977, 1978, 1979, 1981); 1982 and 1984 (Ridder 1983, 1985); 1985 (Holmes et al. 1986); 1986–1987 (Clark and Ridder 1987, 1988; Ridder 1989); 1989 (Clark and Ridder 1990); 1990 (Clark et al. 1991); 1991 (Fleming et al. 1992); 1992 (Ridder et al. 1993); 1993, 1994 (Roach 1994, 1995), 1995–1997 (Ridder 1998a), 1998–2004 (Parker *Unpublished,* 2006; Parker et al. 2007), 2005 (Gryska *Unpublished*).

[b] Schnabel estimator was used in 1972, 1973, 1985–1987; modified Petersen (Bailey 1951, 1952) estimator in 1974–1984, 1992–1994, and 2002–2004; modified Petersen (Evenson 1988) in 1988; and bootstrapped modified Petersen (Bailey 1951, 1952) in 1989–1991, and Jolly-Seber in 1998–2001.

[c] The confidence interval is based on a Poisson distribution of recaptures (Ricker 1975). Estimates of standard error for 1988 through 1991 were from bootstrap methods (Efron 1982).

[d] Estimate was based on total marks in 1973, which were adjusted with a mortality rate of 0.46 (Tack 1975). Number of marks presented shown for 1973 do not include those applied during the final 1973 sampling event.

[e] Estimates for Arctic grayling ≥230 mm FL

[f] Unpublished, Arctic grayling ≥270 mm FL

[g] Unpublished, Arctic grayling ≥240 mm FL

[h] Catch information only.

Appendix B2.–Summary of catch data from a preliminary assessment of the spring Arctic grayling population in the Goodpaster River during May 3–10, 2005.

| Section | 1 | 2 | 3 | 4 | Total |
|---|---|---|---|---|---|
| River km | 0–34 | 34.1–68 | 68.1–101.4 | 101.4–50.4 | |
| Length (km) | 34 | 34 | 34 | 49 | 151 |
| Runs | 14 | 15 | 15.5 | 15 | 59.5 |
| Time (min) | 280 | 310 | 308 | 321 | 1219 |
| Mean distance/run | 2.4 | 2.3 | 2.2 | 3.3 | 2.5 |
| Minutes/km | 8.2 | 9.1 | 9.1 | 6.6 | 8.1 |
| Catch | 540 | 440 | 164 | 231 | 1375 |
| CPUE | 1.93 | 1.42 | 0.53 | 0.72 | 1.13 |
| Relative catch ($n_i/n_{all}$) | 0.39 | 0.32 | 0.12 | 0.17 | |

Appendix B3.–Number of Arctic grayling ≥330 mm FL marked ($n_1$), examined ($n_2$), and recaptured ($m_2$) by section in the 101.4-km Goodpaster River study area, spring 2006.

| | | Section where recaptured | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | $m_2$ | $n_1$ | $m_2/n_1$[b] |
| Section where marked | 1 | 6 | 1 | 0 | 0 | 0 | 0 | 7 | 33 | 0.21 |
| | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 2 | 18 | 0.11 |
| | 3 | 0 | 1 | 1 | 1 | 0 | 0 | 3 | 39 | 0.08 |
| | 4 | 0 | 0 | 0 | 4 | 1 | 0 | 5 | 67 | 0.07 |
| | 5 | 0 | 0 | 0 | 1 | 10 | 2 | 13 | 243 | 0.05 |
| | 6 | 0 | 0 | 0 | 0 | 0 | 6 | 6 | 318 | 0.02 |
| | $m_2$ | 6 | 4 | 1 | 6 | 11 | 8 | | | |
| | $n_2$ | 27 | 48 | 62 | 83 | 169 | 250 | | | |
| | $(m_2/n_2)$[a] | 0.22 | 0.08 | 0.02 | 0.07 | 0.07 | 0.03 | | | |

[a] Probability of capture during first event.
[b] Probability of capture during second event.

Appendix B4.–Number of unique fish (n) as measured during both events (Case I), estimated abundance ($\hat{N}_k$), and estimated proportion of abundance ($\hat{p}_k$), by length category for the population of Arctic grayling (≥200 mm FL) in the 101.4 km study area of the Goodpaster River, spring 2006.

| Length (mm FL) | n | $\hat{N}_k$ | $\hat{SE}[\hat{N}_k]$ | $\hat{p}_k$ | $\hat{SE}[\hat{p}_k]$ |
|---|---|---|---|---|---|
| 200–209 | 36 | 945 | 319 | 0.02 | 0.004 |
| 210–219 | 20 | 525 | 192 | 0.01 | 0.003 |
| 220–229 | 14 | 367 | 144 | 0.01 | 0.002 |
| 230–239 | 22 | 577 | 208 | 0.01 | 0.003 |
| 240–249 | 52 | 1,365 | 444 | 0.03 | 0.005 |
| 250–259 | 63 | 1,654 | 530 | 0.04 | 0.006 |
| 260–269 | 88 | 2,310 | 726 | 0.05 | 0.008 |
| 270–279 | 98 | 2,572 | 804 | 0.06 | 0.009 |
| 280–289 | 112 | 2,940 | 913 | 0.07 | 0.010 |
| 290–299 | 108 | 2,835 | 882 | 0.06 | 0.009 |
| 300–309 | 149 | 3,911 | 1,202 | 0.09 | 0.012 |
| 310–319 | 133 | 3,491 | 1,077 | 0.08 | 0.011 |
| 320–329 | 136 | 3,570 | 1,100 | 0.08 | 0.011 |
| 330–339 | 144 | 1,971 | 561 | 0.04 | 0.013 |
| 340–349 | 157 | 2,149 | 610 | 0.05 | 0.014 |
| 350–359 | 137 | 1,875 | 535 | 0.04 | 0.012 |
| 360–369 | 169 | 2,314 | 655 | 0.05 | 0.015 |
| 370–379 | 167 | 2,286 | 647 | 0.05 | 0.015 |
| 380–389 | 158 | 2,163 | 614 | 0.05 | 0.014 |
| 390–399 | 95 | 1,301 | 378 | 0.03 | 0.009 |
| 400–409 | 93 | 1,273 | 370 | 0.03 | 0.009 |
| 410–419 | 69 | 945 | 280 | 0.02 | 0.007 |
| 420–429 | 60 | 821 | 247 | 0.02 | 0.006 |
| 430–439 | 42 | 575 | 179 | 0.01 | 0.004 |
| 440–449 | 21 | 287 | 99 | 0.01 | 0.003 |
| 450–459 | 6 | 82 | 39 | < 0.01 | 0.001 |
| 460–469 | 2 | 27 | 20 | < 0.01 | 0.001 |
| 470–479 | 1 | 14 | 14 | < 0.01 | 0.000 |

Appendix B5.–Number of unique fish (n) as measured during both events (Case I), estimated abundance ($\hat{N}_k$), and estimated proportion of abundance ($\hat{p}_k$), by length category for the population of Arctic grayling (≥200 mm FL) in the 58.5 km study area of the Goodpaster River, spring 2006.

| Length (mm FL) | n | $\hat{N}_k$ | $\hat{SE}[\hat{N}_k]$ | $\hat{p}_k$ | $\hat{SE}[\hat{p}_k]$ |
|---|---|---|---|---|---|
| 200–209 | 35 | 1,329 | 575 | 0.03 | 0.007 |
| 210–219 | 20 | 759 | 344 | 0.02 | 0.005 |
| 220–229 | 13 | 494 | 235 | 0.01 | 0.004 |
| 230–239 | 19 | 721 | 328 | 0.02 | 0.005 |
| 240–249 | 50 | 1,898 | 805 | 0.05 | 0.009 |
| 250–259 | 50 | 1,898 | 805 | 0.05 | 0.009 |
| 260–269 | 72 | 2,734 | 1,143 | 0.07 | 0.011 |
| 270–279 | 63 | 2,392 | 1,005 | 0.06 | 0.010 |
| 280–289 | 69 | 2,620 | 1,097 | 0.06 | 0.011 |
| 290–299 | 75 | 2,848 | 1,189 | 0.07 | 0.011 |
| 300–309 | 98 | 3,721 | 1,542 | 0.09 | 0.014 |
| 310–319 | 95 | 3,607 | 1,496 | 0.09 | 0.014 |
| 320–329 | 91 | 3,455 | 1,435 | 0.08 | 0.013 |
| 330–339 | 105 | 1,176 | 257 | 0.03 | 0.020 |
| 340–349 | 129 | 1,445 | 307 | 0.04 | 0.024 |
| 350–359 | 120 | 1,344 | 288 | 0.03 | 0.022 |
| 360–369 | 149 | 1,669 | 348 | 0.04 | 0.027 |
| 370–379 | 148 | 1,657 | 346 | 0.04 | 0.027 |
| 380–389 | 132 | 1,478 | 313 | 0.04 | 0.024 |
| 390–399 | 74 | 829 | 192 | 0.02 | 0.014 |
| 400–409 | 83 | 929 | 211 | 0.02 | 0.016 |
| 410–419 | 63 | 705 | 168 | 0.02 | 0.012 |
| 420–429 | 52 | 582 | 145 | 0.01 | 0.010 |
| 430–439 | 40 | 448 | 119 | 0.01 | 0.008 |
| 440–449 | 21 | 235 | 75 | 0.01 | 0.005 |
| 450–459 | 6 | 67 | 35 | < 0.01 | 0.002 |
| 460–469 | 2 | 22 | 20 | < 0.01 | 0.001 |
| 470–479 | 1 | 11 | 14 | < 0.01 | 0.001 |

Appendix B6.–Number of Arctic grayling 150–239 mm FL marked ($n_1$), examined ($n_2$), and recaptured ($m_2$) by section in the original 58.5-km Goodpaster River study area, summer 2006.

| | | Section where recaptured | | | | | |
|---|---|---|---|---|---|---|---|
| | | 4 | 5 | 6 | $m_2$ | $n_1$ | $m_2/n_1$ [b] |
| Section where marked | 4 | 2 | 0 | 0 | 2 | 126 | 0.02 |
| | 5 | 0 | 37 | 1 | 38 | 555 | 0.07 |
| | 6 | 0 | 1 | 10 | 11 | 293 | 0.04 |
| | $m_2$ | 2 | 38 | 11 | | | |
| | $n_2$ | 155 | 382 | 113 | | | |
| | $(m_2/n_2)$ [a] | 0.01 | 0.10 | 0.09 | | | |

[a] Probability of capture during first event.
[b] Probability of capture during second event.
[c] Section 4 in this matrix includes the last run of section 3, which began at the mouth of the South Fork Goodpaster River.

Appendix B7.–Number of unique fish (n) as measured during both events (Case I), estimated abundance ($\hat{N}_k$), and estimated proportion of abundance ($\hat{p}_k$), by length category for the population of Arctic grayling (≥150 mm FL) in the 101.4 km study area of the Goodpaster River, summer 2006. Comprised of stratified estimates for Arctic grayling 150–239 mm FL in sections 1–6, ≥240 mm FL in sections 1–3, and ≥240 mm FL in sections 4–6.

| Length (mm FL) | n | $\hat{N}_k$ | $\hat{SE}[\hat{N}_k]$ | $\hat{p}_k$ | $\hat{SE}[\hat{p}_k]$ |
|---|---|---|---|---|---|
| 150–159 | 43 | 366 | 72 | 0.02 | 0.003 |
| 160–169 | 125 | 1,065 | 165 | 0.05 | 0.005 |
| 170–179 | 177 | 1,508 | 222 | 0.07 | 0.006 |
| 180–189 | 160 | 1,363 | 203 | 0.06 | 0.005 |
| 190–199 | 238 | 2,027 | 288 | 0.10 | 0.007 |
| 200–209 | 385 | 3,280 | 448 | 0.15 | 0.009 |
| 210–219 | 370 | 3,152 | 432 | 0.15 | 0.009 |
| 220–229 | 216 | 1,840 | 264 | 0.09 | 0.006 |
| 230–239 | 81 | 690 | 116 | 0.03 | 0.004 |
| 240–249 | 75 | 283 | 48 | 0.01 | 0.010 |
| 250–259 | 97 | 339 | 50 | 0.02 | 0.009 |
| 260–269 | 161 | 586 | 79 | 0.03 | 0.015 |
| 270–279 | 187 | 695 | 93 | 0.03 | 0.018 |
| 280–289 | 164 | 642 | 93 | 0.03 | 0.019 |
| 290–299 | 159 | 575 | 77 | 0.03 | 0.014 |
| 300–309 | 116 | 497 | 85 | 0.02 | 0.019 |
| 310–319 | 110 | 490 | 88 | 0.02 | 0.020 |
| 320–329 | 75 | 440 | 102 | 0.02 | 0.026 |
| 330–339 | 46 | 312 | 83 | 0.01 | 0.022 |
| 340–349 | 50 | 370 | 101 | 0.02 | 0.026 |
| 350–359 | 29 | 206 | 61 | 0.01 | 0.016 |
| 360–369 | 22 | 176 | 57 | 0.01 | 0.015 |
| 370–379 | 15 | 105 | 36 | < 0.01 | 0.010 |
| 380–389 | 15 | 105 | 36 | < 0.01 | 0.010 |
| 390–399 | 10 | 80 | 31 | < 0.01 | 0.009 |
| 400–409 | 2 | 16 | 12 | < 0.01 | 0.003 |
| 410–419 | 4 | 32 | 17 | < 0.01 | 0.005 |

Appendix B8.–Number of unique fish (n) as measured during both events (Case I), estimated abundance ( $\hat{N}_k$ ), and estimated proportion of abundance ( $\hat{p}_k$ ), by length category for the population of Arctic grayling (≥150 mm FL) in the 58.5 km study area of the Goodpaster River, summer 2006.

| Length (mm FL) | n | $\hat{N}_k$ | $\hat{SE}[\hat{N}_k]$ | $\hat{p}_k$ | $\hat{SE}[\hat{p}_k]$ |
|---|---|---|---|---|---|
| 150–159 | 40 | 471 | 195 | 0.02 | 0.004 |
| 160–169 | 122 | 1,438 | 546 | 0.07 | 0.007 |
| 170–179 | 171 | 2,015 | 740 | 0.09 | 0.008 |
| 180–189 | 157 | 1,850 | 685 | 0.08 | 0.008 |
| 190–199 | 216 | 2,545 | 956 | 0.12 | 0.009 |
| 200–209 | 350 | 4,124 | 1,560 | 0.20 | 0.013 |
| 210–219 | 323 | 3,806 | 1,437 | 0.18 | 0.012 |
| 220–229 | 158 | 1,862 | 694 | 0.09 | 0.008 |
| 230–239 | 47 | 554 | 216 | 0.03 | 0.004 |
| 240–249 | 62 | 179 | 25 | 0.01 | 0.020 |
| 250–259 | 86 | 248 | 32 | 0.01 | 0.027 |
| 260–269 | 136 | 393 | 46 | 0.02 | 0.042 |
| 270–279 | 156 | 450 | 51 | 0.02 | 0.048 |
| 280–289 | 131 | 378 | 44 | 0.02 | 0.040 |
| 290–299 | 137 | 395 | 47 | 0.02 | 0.042 |
| 300–309 | 88 | 254 | 33 | 0.01 | 0.027 |
| 310–319 | 82 | 237 | 31 | 0.01 | 0.026 |
| 320–329 | 34 | 98 | 18 | < 0.01 | 0.011 |
| 330–339 | 14 | 40 | 12 | < 0.01 | 0.005 |
| 340–349 | 9 | 26 | 9 | < 0.01 | 0.004 |
| 350–359 | 5 | 14 | 7 | < 0.01 | 0.003 |
| 360–369 | 0 | 0 | 0 | 0.00 | 0.000 |
| 370–379 | 4 | 12 | 5 | < 0.01 | 0.002 |
| 380–389 | 4 | 12 | 5 | < 0.01 | 0.002 |
| 390–399 | 0 | 0 | 0 | 0.00 | 0.000 |
| 400–409 | 0 | 0 | 0 | 0.00 | 0.000 |
| 410–419 | 0 | 0 | 0 | 0.00 | 0.000 |

Appendix B9.–Abundance estimates in the original Goodpaster River study area (58.5-km) during spring 1995–2002 and 2006.

| | ≥230 mm FL | | ≥270 mm FL | | ≥340 mm FL | |
|---|---|---|---|---|---|---|
| Year | $\hat{N}$ | SE | $\hat{N}$ | SE | $\hat{N}$ | SE |
| 1995 | 13,445 | 1,445 | 10,095 | 1,097 | 4,478 | 515 |
| 1996 | 19,305 | 2,484 | 16,436 | 2,124 | 5,389 | 737 |
| 1997 | 12,893 | 1,900 | 11,364 | 1,682 | 5,822 | 899 |
| 1998 | | | 9,198 | 970 | | |
| 1999 | | | 14,808 | 2,038 | | |
| 2000 | | | 12,442 | 1,601 | | |
| 2001 | | | 14,437 | 1,775 | | |
| 2002 | | | 12,816 | 1,489 | | |
| 2006[a] | 40,364 | 12,564 | 32,907 | 10,363 | 12,598 | 2,362 |

[a.] During 2006, abundance was estimated for Arctic grayling ≥240 mm FL and ≥330 mm FL.

Appendix B10.–Abundance estimates in the 101.4-km Goodpaster River study area during spring 1995 and 2006.

| | ≥230 mm FL | | ≥270 mm FL | | ≥340 mm FL | |
|---|---|---|---|---|---|---|
| Year | $\hat{N}$ | SE | $\hat{N}$ | SE[a] | $\hat{N}$ | SE |
| 1995[a] | 23,196 | 2,241 | 16,632 | 1,654 | 5,878 | 1,183 |
| 2006[b] | 43,023 | 9,257 | 37,751 | 8,493 | 18,084 | 4,964 |

[a.] Estimates include an additional 16 km of the Lower South Fork GPR.
[b.] During 2006, abundance was estimated for Arctic grayling ≥240 mm FL and ≥330 mm FL.

Appendix B11.–Abundance estimates in the original 58.5-km Goodpaster River study area during summer 1973, 1988–1994 and 2006.

| | ≥150 mm FL | | ≥270 mm FL | |
|---|---|---|---|---|
| Year | $\hat{N}$ | SE | $\hat{N}$ | SE |
| 1973 | 24,270 | 3,088 | 10,095 | n/a[a] |
| 1988 | 7,638 | 582 | 3,037 | n/a |
| 1989 | 8,033 | 739 | 1,767 | n/a |
| 1990 | 7,258 | 770 | 1,161 | n/a |
| 1991 | 8,123 | 1,120 | 1,056 | n/a |
| 1992 | 6,886 | 809 | 1,337 | n/a |
| 1993 | 10,841 | 1,340 | 976 | n/a |
| 1994 | 7,574 | 1,617 | 1,514 | n/a |
| 2006 | 21,400 | 6,928 | 1,847 | 190 |

[a.] n/a is statistic not available

## APPENDIX C
## DATA FILE LISTING

Appendix C1.–Data files for all Arctic grayling captured in the Goodpaster River, 2005–2006

| File Name[a] |
| --- |
| Goodpaster River Arctic grayling data files for archive-2005-2006.xls |

[a] Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, 1300 College Road, Fairbanks, Alaska 99701-1599.