Fishery Data Series No. 04-03

Abundance and Length and Age Composition of Arctic Grayling in the Richardson Clearwater River, 2001

Andrew D. Gryska

March 2004

Alaska Department of Fish and Game

Division of Sport Fish

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
Metric ton	Mt
Milliliter	Ml
Millimeter	Mm

Weights and measures (English)

Cubic feet per second	ft^3/s
Foot	Ft
Gallon	Gal
Inch	In
Mile	Mi
Ounce	Oz
Pound	Lb
Quart	Qt
Yard	Yd

Spell out acre and ton.

Time and temperature

Day	D
Degrees Celsius	°C
Degrees Fahrenheit	°F
Hour (spell out for 24-hour clock)	H
Minute	Min
Second	S

Spell out year, month, and week.

Physics and chemistry

all atomic symbols	
Alternating current	AC
Ampere	A
Calorie	Cal
Direct current	DC
Hertz	Hz
Horsepower	Hp
Hydrogen ion activity	PH
Parts per million	Ppm
Parts per thousand	ppt, ‰
Volts	V
Watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
And	&
At	@
Compass directions:	
East	E
North	N
South	S
West	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
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
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
Trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	E
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	Cov
degree (angular or temperature)	°
degrees of freedom	Df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
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.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	X
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
standard length	SL
total length	TL
variance	Var

FISHERY DATA SERIES NO. 04-03

ABUNDANCE AND LENGTH AND AGE COMPOSTION OF ARCTIC GRAYLING IN THE RICHARDSON CLEARWATER RIVER, 2001

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ABSTRACT

During July 2001, a mark-recapture experiment was conducted to the estimate abundance and length and age composition of Arctic grayling *Thymallus arcticus* along the lower 14 km (8.4 mi) of the Richardson Clearwater River. This study was the first assessment of the population since 1988. A total of 1,282 unique fish were captured over 8 days of sampling. A stratified estimator was used due to size-selective sampling. The smaller fish stratum (250 – 314 mm FL) had an estimated abundance of 2,863 fish and a bias corrected 95% confidence interval of 1,485-6,307 fish, which was calculated using bootstrap methods because there were only six recaptures of small fish. The larger fish stratum (≥ 315 mm FL) had an abundance of 2,788 fish (SE = 296). The total estimated abundance was 5,651 Arctic grayling ≥ 250 mm FL, and the bias corrected 95% confidence interval was 4,075 - 8,827. Most fish (85%) in the population were between 260 and 389 mm FL, and most (87%) fish were age-4 - 8. Based on comparisons of the 2001 abundance estimate with previous studies (1982-1988) there is no conservation concern for this Arctic grayling population. It is recommended that regulations not be changed, angler use and harvest be monitored, and periodic stock assessments be performed once every 5-10 years or when meaningful increases in harvests have occurred.

Key words: Arctic grayling, *Thymallus arcticus,* abundance, age composition, length composition, hook-and-line sampling, mark-recapture, Richardson Clearwater River, Alaska.

INTRODUCTION

The Richardson Clearwater River (RCR) is a 19.2-km long spring-fed system located 134 km southeast of Fairbanks and 43 km northwest of Delta Junction in the middle Tanana River drainage (Figure 1). It is a semi-remote river that has more than 20 recreational cabins along its banks. It is accessible by boat and floatplane and the nearest boat launch is at Shaw Creek, a Tanana River tributary located 9 km upstream of the mouth of the RCR.

The RCR is one of several spring-fed systems that originate in alluvial deposits on the south side of the Tanana River drainage. It is characterized by clear, cold water (3 - 7°C) and discharges of 8.5 – 11.3 m^3/s (Ridder 1989). These clear water systems provide quality summer feeding habitat for Arctic grayling, but Arctic grayling neither spawn nor overwinter in these systems (Reed 1961; Tack 1980; Ridder 1991). The Arctic grayling population in the RCR is composed of fish that spawn in at least three different systems, and of these three, fish that spawn in the Shaw Creek tributary, Caribou Creek, is thought to be the largest component (Ridder 1991, 1994). Immigration to the RCR begins in April with juvenile fish, followed by post-spawn adults between mid-May and mid-June. Emigration begins in August and is complete by December (Tack 1980; Ridder 1998a).

The RCR has a relatively small but productive and popular Arctic grayling fishery on its lower 14 km (8.4 mi) and it is known for high catch rates of large sized Arctic grayling (i.e., >14 in), pristine water quality, and a wilderness aesthetic. From 1991 through 2000, the average estimated annual effort was 878 angler days, catch was 4,309 Arctic grayling, and harvest was 369 Arctic grayling (Table 1; Mills 1992-1994; Howe et al. 1995, 1996, 2001 a-d; Walker et al. 2003).

Declines in harvest and abundance indices of Arctic grayling stocks in the Tanana River drainage prior to the mid-1980s (Roach 1994; Fleming 1995; Ridder 1998b; Doxey 2001) led to more restrictive regulations for many Tanana drainage fisheries beginning in 1987. Regulations implemented for many Tanana drainage fisheries, including the RCR and Shaw Creek, were a catch and release season from April 1 to the first Saturday in June (subsequently changed to May 31), a 12-in TL (280 mm FL) minimum size limit, a no-bait restriction, and a 5-fish daily

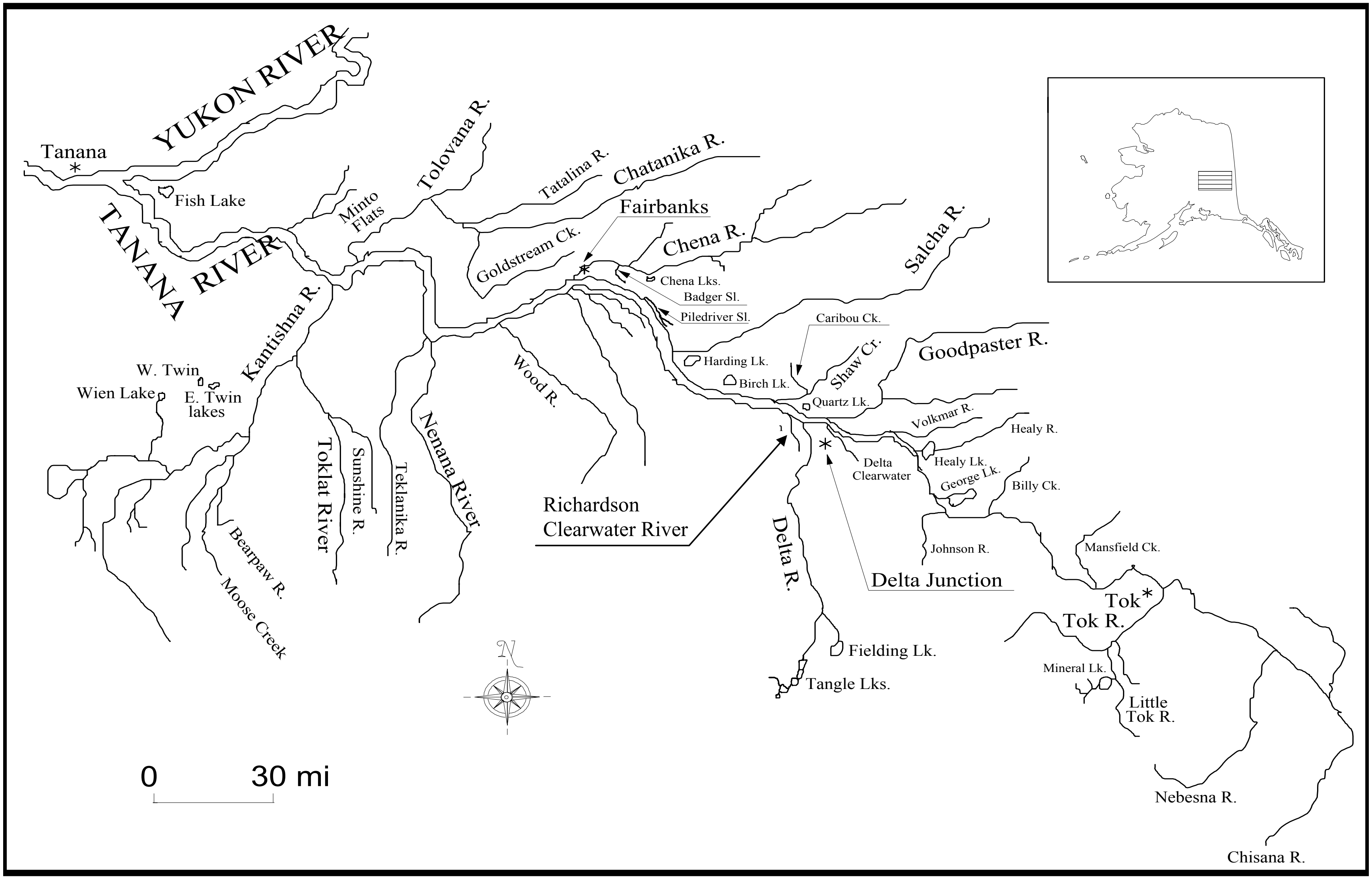

Figure 1.-The Tanana River drainage.

Table 1.-Number of anglers, angler days, catch, and harvest of Arctic grayling from the Richardson Clearwater River, 1981-2000.

			Catch		Harvest	
Year	Anglers[a]	Angler Days	<12 in	>12 in	<12 in	>12 in
1981	na[b]	916	na	na	1,562	na
1982	na	1,365	na	na	1,769	na
1983	na	1,349	na	na	2,822	na
1984	na	1,080	na	na	1,376	na
1985	na	na	na	na	798	na
1986	na	596	na	na	827	na
1987	na	na	na	na	na	na
1988	na	na	na	na	na	na
1989	390	1,364	na	na	972	na
1990	378	518	996	na	523	na
1991	561	1,199	489	2,495	0	1,419
1992	411	1,355	874	1,230	58	378
1993	368	514	262	1,530	222	183
1994	344	566	1,980	3,852	130	461
1995	346	1,168	1,213	558	0	244
1996	216	808	2,074	2,232	0	49
1997	285	462	2,627	2,337	0	105
1998	365	716	2,413	5,995	42	83
1999	168	1,253	194	7,793	0	139
2000	233	736	na	2,934	na	176
			Averages			
1991-2000	330	878	1,213	3,096	45	324
1996-2000	253	795	1,462	4,258	11	110

Data from Mills 1982-1994; Howe et al. 1995, 1996, 2001 a-d; Walker et al. 2003.

[a] Anglers and days fished represents effort on all species, although the Richardson Clearwater River is almost exclusively an Arctic grayling fishery.

[b] na = not available.

bag and possession limit (limits were 10-fish daily and 20 fish in possession prior to 1977 and 5 and 10, respectively, through 1986).

Annual stock assessments of Arctic grayling on the RCR were conducted from 1982 through 1988 (Table 2), and only one stock assessment had been conducted since the implementation of more restrictive regulations in 1987. From 1982 through 1984, a 3.2 km index section of the RCR was examined and was expanded to the lower 14 km in subsequent years. Currently, no management plan or explicit management objectives in terms of population size and length composition exist for Arctic grayling in the RCR. Because the RCR had not been examined since 1988 this study was undertaken to update our understanding of the population status, and to identify potential changes needed in the regulatory structure.

OBJECTIVES

The research objectives for this study during July 2001 were to:

1. estimate the abundance of Arctic grayling (≥ 240 mm FL) in the lower 14 km (8.4 mi.) of the Richardson Clearwater River, such that the estimate was within 25% of the true abundance 95% of the time;
2. estimate the length composition of the Arctic grayling (≥ 240 mm FL) in the lower 14 km (8.4 mi.) of the Richardson Clearwater River, such that all proportions were within 5 percentage points of the true proportions 95% of the time; and,
3. estimate the age composition of the Arctic grayling (≥ 240 mm FL) in the lower 14 km (8.4 mi.) of the Richardson Clearwater River, such that all proportions were within 5 percentage points of the true proportions 95% of the time.

METHODS

SAMPLING DESIGN AND FISH CAPTURE

This study was designed to estimate the abundance and the length and age composition of Arctic grayling within the 14-km study area during July, 2001 by conducting a two-event mark-recapture experiment. The study area encompassed virtually the entire population of Arctic grayling in the RCR because just upstream the discharge diminishes rapidly and only a few fish have been observed above this boundary (Ridder 1989). The first (marking) event occurred from July 10-13 and the second (examination) event from July 23-27. The study area was broken into seven sampling sections ranging from 1.85 to 2.40 km in length (Figure 2). During each event, the sections were sampled sequentially beginning with the upper most section. Each section was fished with approximately eight hours of sampling effort by a two-person crew, usually between 1000 and 2000 hours. During both events fish were captured using hook-and-line gear (terminal gear was flies and jigs) while casting from a 20-ft riverboat anchored in the channel. During the first event, flies (nymphs and dry flies) were most frequently used (> 95%) and during the second event, 1/16- to 1/4- oz rubber-bodied jigs (e.g., Mister Twister) were most frequently used (> 77%). The choice of terminal gear was left to each angler's discretion. In the first event, fish ≥ 200 mm FL were marked with an individually-numbered anchor tag (Floy FD 94) and given a small upper-caudal finclip to identify lost tags. In the second event, fish were not tagged but a partial lower caudal finclip was given to all captures to identify fish sampled multiple times.

Table 2.-Upper and whole river abundance estimates of Arctic grayling, Richardson Clearwater River during July, 1982 – 1988 and 2001.

Year	Whole River		Upper River (Sections 6 and 7)	
	$\hat{N}$	95% C.I.	$\hat{N}$	95% C.I.
1982[a]	na		5,340	3,028 – 10,680
1983[a]	na		1,792	1,016 – 3,460
1984[a]	na		2,076	1,148 – 4,520
1985[a]	3,114	1,939 – 4,289	1,610	974 – 2,876
1986[a]	1,418	786 – 2,837	468	191 – 1,170
1987[b]	2,775	1,653 – 3,896	1,368	476 – 2,260
1988[b]	4,599	3,127 – 6,071	2,193	1,274 – 3,112
2001[b]	5,651	4,075 – 8,827	326	174 – 499

Table reproduced from Ridder (1989) with 2001 data added.

[a] Estimate is composed of fish ≥ 150 mm FL

[b] Estimate is composed of fish ≥ 250 mm FL

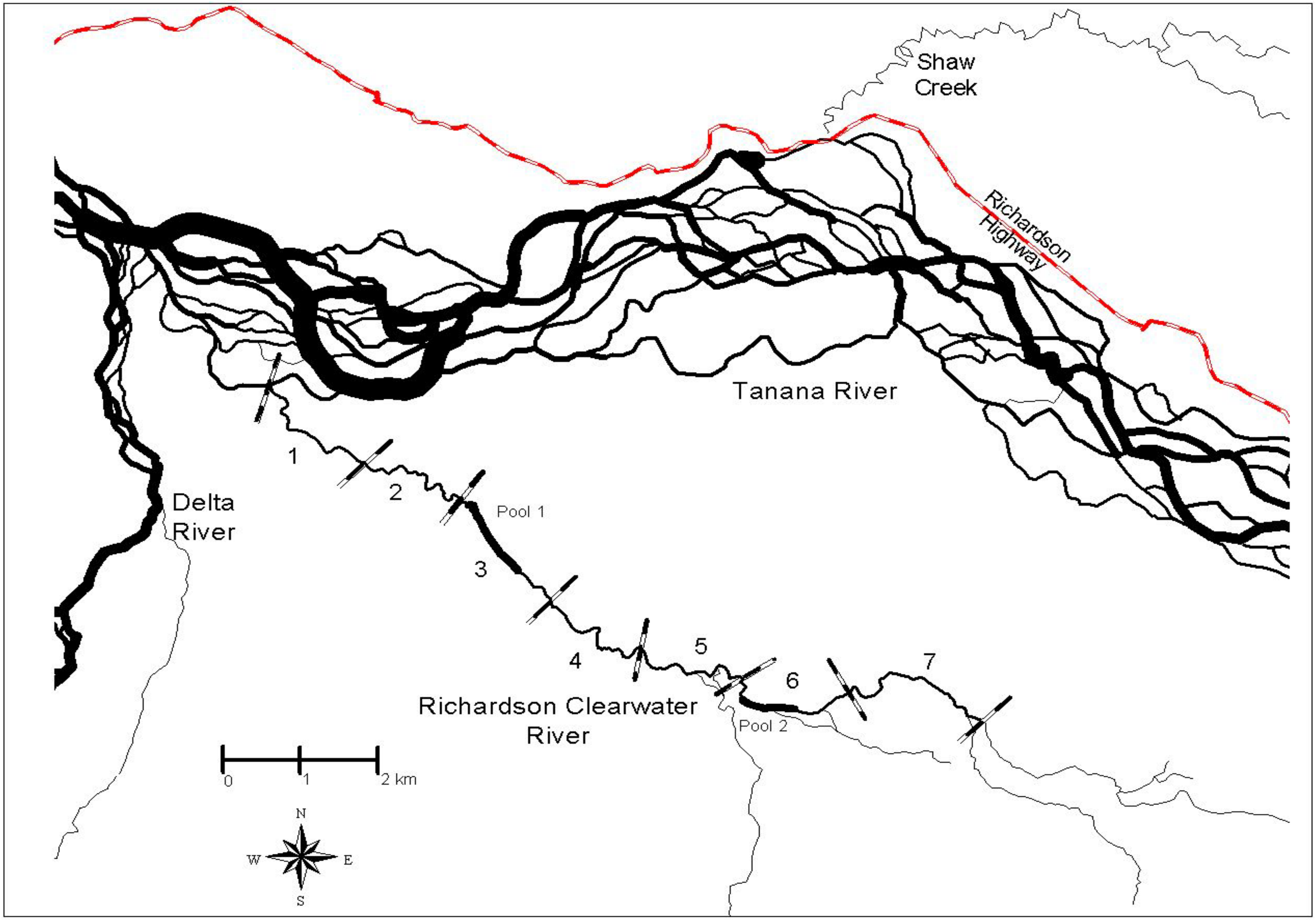

Figure 2.-The Richardson Clearwater River and sample sections 1 - 7.

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

Abundance was estimated using a two-event Petersen mark-recapture experiment (Seber 1982) designed to satisfy the following assumptions:

1. the population was closed (there was no change in the number or composition of Arctic grayling in the population 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 the first and second events;
3. marking of Arctic grayling in the first event 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 examined during the second event.

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

$$\hat{N}_1 = \frac{n_1 n_2}{m_2}, \quad (1)$$

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;

m_2 = the number of marked Arctic grayling recaptured during the second event; and

$\hat{N}_1$ = estimated abundance of Arctic grayling during the first event.

The specific form of the estimator was determined from the experimental design and the results of tests performed to evaluate if the assumptions were met.

The sampling design allowed the validity of these assumptions to be ensured or tested. To help ensure that the movement of fish did not violate the assumption of closure, the experiment was conducted during the summer feeding period when Arctic grayling were not expected to be migrating (Tack 1973; Ridder 1998a; Ridder and Gryska 2000; Gryska 2001). Movement was expected but only on a localized scale (e.g., within 1 river km). The duration of the study was kept short to render growth recruitment and mortality insignificant. Location data for recaptured fish were examined for evidence of movement into and out of the study area to evaluate the appropriateness of our assumption.

To ensure that Assumption 2 was met, we attempted to subject all fish within each sampling event to the same probability of capture, which was facilitated by creating the seven sampling sections. Within each section, we attempted to fish each pool and run with effort in proportion to the distribution of Arctic grayling. Specifically, we fished for longer periods in areas (e.g., glides) where densities appeared relatively high and for shorter periods where few fish appeared to be available (e.g., slack water areas). Because Arctic grayling move little during mid-summer, we did not rely on complete mixing of marked and unmarked fish within the study area; rather Arctic grayling were expected to mix on the scale of a river km. Violations of Assumption 2 relative to size-selective sampling were tested by using two Kolmogorov-Smirnov tests. There were four possible outcomes of these two tests; either one or both of the samples was biased or neither was biased. Tests and possible adjustments to correct for bias due to size-selective sampling are outlined in Appendix A1. To check for differences in capture probability by location, tests for consistency of the Petersen estimator (Seber 1982) were performed and the appropriate estimator selected (Appendix A2).

Relative to Assumption 3, a hiatus of 13 days between the first and second events in a given river section was included to allow marked fish the time to recover from the effects of being hooked and handled and to resume normal feeding behavior. In addition, the use of active gear and using primarily different types of terminal gear between events served to mitigate potential marking-induced effects in behavior (e.g., gear avoidance).

Relative to Assumptions 4 and 5, Arctic grayling captured during the first event were double marked with an internal anchor tag and a single finclip, and all fish caught in the second event were carefully examined for marks.

Length and age composition of the population were estimated using the procedures outlined in Appendix A4.

DATA COLLECTION

All captured Arctic grayling were processed immediately or soon after capture and released at or very near their capture location. As each fish was caught, crews collected and recorded data for date, location, crew, fork length, scale samples, fin clips, tag number, tag color, recapture status, and mortality. Floy tags were gray in color and were numbered between 1 and 603. Two scales were removed for aging from all fish caught during the second event. Data were recorded onto mark-sense forms. These were transformed into an electronic (ASCII) data file for analysis and archival (Appendix B).

For aging, scales were taken from the area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin (William Ridder, Alaska Department of Fish and Game, retired, Delta Junction, personal communication; Brown 1943). Scales were processed by wiping slime and dirt off each scale and mounting them on gummed cards. The cards were used to make triacetate impressions of the scales (30 s at 137,895 kPa, at a temperature of 97ºC). Ages were determined by counting annuli from the triacetate impressions magnified to 40X with a microfiche reader. The presence of an annulus was determined as described by Kruse (1959).

RESULTS

SUMMARY STATISTICS OF FISH SAMPLED

One thousand two hundred ninety-four Arctic grayling (≥ 200 mm FL) were captured during both events. Eleven (1%) of these fish were caught twice within the same event and 3 captured fish died due to handling. The data used for estimating abundance were truncated to correspond to fish ≥ 250 mm FL because few fish < 250 mm FL were captured or recaptured ($n_1 = 25$; $n_2 = 7$; $m_2 = 0$), and the two most recent estimates were also for fish ≥ 250 mm FL (Clark and Ridder

1988; Ridder 1989). Of the 1,250 fish ≥ 250 mm FL included in the experiment, 475 were captured during the first event (marks or n_1), 775 during the second event (captures or n_2), and 82 fish were marked in the first event and recaptured in the second event (recaptures or m_2). One tag loss was detected (length = 374 mm FL). Sixteen fish carried marks from studies on the Goodpaster River.

ABUNDANCE ESTIMATE

The sampling design and the results of the testing procedures (Appendices A1 and A2) dictated: 1) that the estimator be stratified by size using two strata, fish 250 - 314 mm FL (small fish stratum) and fish ≥ 315 mm FL (large fish stratum); and 2) that the Bailey-modified Petersen estimator (Bailey 1951 and 1952) be used for both strata (Appendix A3). The use of the Bailey-modified Petersen estimator was appropriate because fishing occurred in a systematic downstream progression while attempting to subject all fish to the same probability of capture. For the purpose of testing assumptions, the one fish that lost its tag was assumed to have been marked within the same section (4) it was recaptured. The decision to do so was based on the limited movement of recaptured fish; 65 of 82 fish were recaptured within the same section marked and an additional 10 were recaptured in the section adjacent to their marking location. Also, the sensitivity of the analysis to exclusion of the fish with tag loss was explored and found to be insignificant.

Size stratification was necessary because K-S tests indicated that the length composition of fish ≥ 250 mm FL released in the first event differed significantly from those recovered during the second event (D = 0.25; P-value < 0.01; Figure 3 – upper panel) and from fish captured in the second event (D = 0.12; P-value < 0.01; Figure 3 – lower panel). The strata break point was identified using statistical tests. A chi-square test for homogeneity of first event capture probabilities was performed for all possible 2-strata break points. Over a range of break points (311 to 344 mm FL), the chi-square test statistics were relatively large (> 20) and arguably similar. Within this range, a strata break point of 315 mm FL was chosen because above this point fish tended to be more similar in terms of their capture probabilities and their distributions.

For the small fish stratum, 131 fish were released with marks, and 152 fish were examined for marks, of which 6 had marks. No fish < 315 mm FL were captured in upper river (i.e., sections 5, 6, and 7). Tests of consistency indicated that mixing of fish between sections was not complete (P-value = 0.01; Table 3). However, the probabilities of being captured by area were not significantly different during the first event (P-value = 0.24) and during the second event (P-value = 0.60; Tables 4 and 5), which satisfied Assumption 2. Using the pooled Bailey estimator, the resultant population estimate for fish 250 - 314 mm FL in sections 1 - 4 was 2,863 (SE = 989). However, due to the limited number of recaptured fish, bootstrap methods of Efron and Tibshirani (1993) and Buckland and Garthwaite (1991) were used to identify possible bias and provide bias corrected confidence intervals using the BCa (bias-corrected and accelerated) method. The bootstrap sampling distribution for $\hat{N}_{250-314}$ was positively skewed and the preferred, bias-corrected 95% confidence interval was (1,485 - 6,307). The bootstrap estimate of bias was 437 fish. While there may be a tendency to “bias-correct” the abundance estimate by subtracting from it the estimate of bias, doing so was not recommended primarily because of the large uncertainty associated with the estimate of bias (Efron and Tibshirani 1993). Therefore, the Bailey estimate of 2,863 fish is preferred.

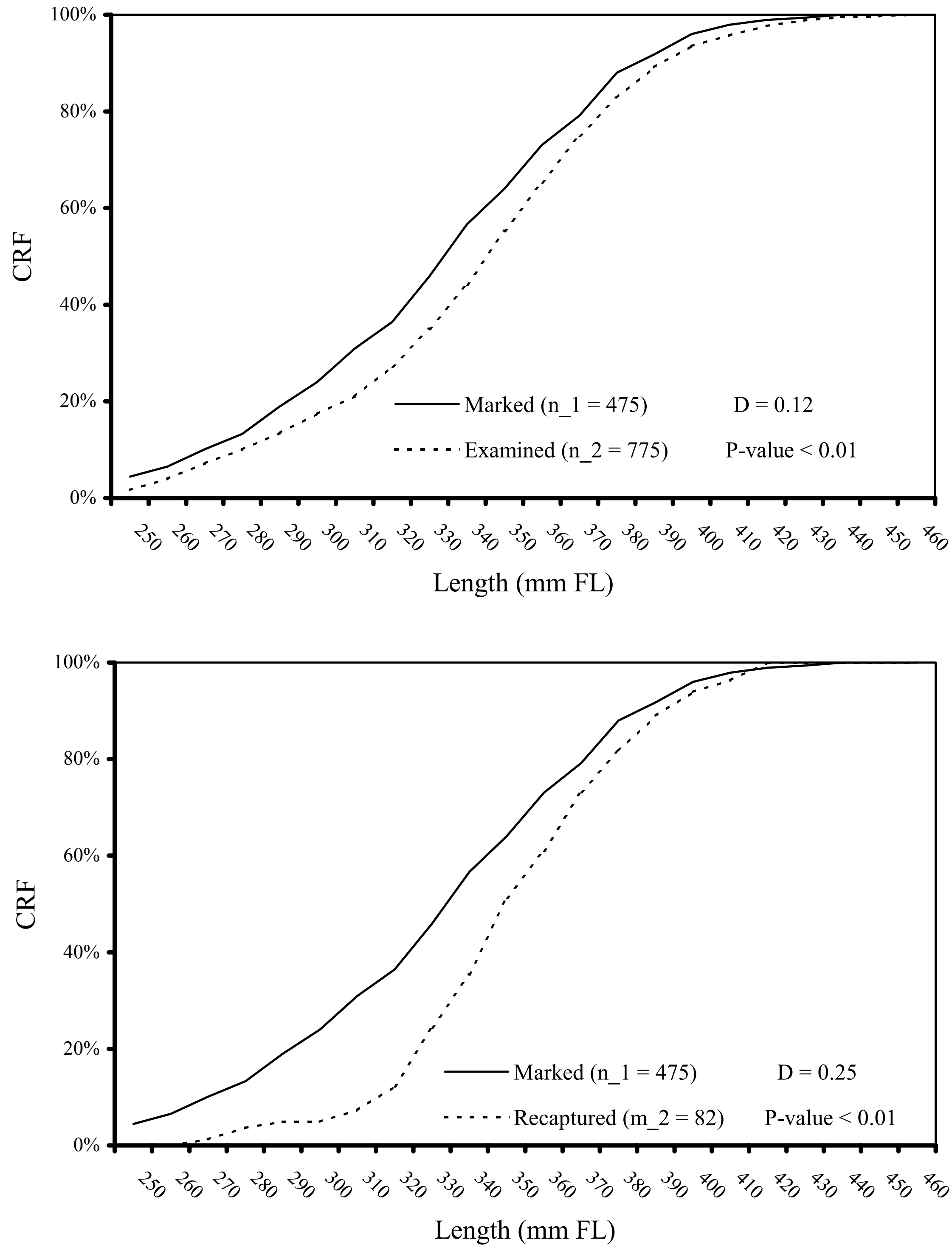

Figure 3.-Cumulative relative frequency (CRF) of Arctic grayling ≥ 250 mm FL marked and examined (upper panel) and marked and recaptured (lower panel), Richardson Clearwater River, July 2001.

Table 3.-Test for complete mixing. Number of Arctic grayling 250 - 314 mm FL marked in each section (1 - 4) and recaptured or not recaptured in each section of the Richardson Clearwater River, July 2001.

	Section Where Recaptured					
Section Where Marked	1	2	3	4	Not Recaptured (n_1-m_2)	Total Marked (n_1)
1	4				71	75
2					23	23
3			1		22	23
4				1	9	10
Total	4		1	1	125	131

χ^2 = 18.18, df = 6, P-value = 0.01, reject H_0.

Table 4.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling 250 – 314 mm FL examined during the second event by section (1 - 4) of the Richardson Clearwater River, July 2001.

	Section Where Examined				
Category	1	2	3	4	All Sections
Marked (m_2)	4	0	1	1	6
Unmarked (n_2-m_2)	118	14	9	5	146
Examined (n_2)	122	14	10	6	152
$P_{capture}$ 1st event (m_2/n_2)	0.03	0.00	0.10	0.17	0.04

χ^2 = 4.25, df = 3, P-value = 0.24, fail to reject H_0.

Table 5.-Test for equal probability of capture during the second event. Number of Arctic grayling 250 – 314 mm FL marked by section (1 - 4) during the first event that were recaptured and not recaptured during the second event, Richardson Clearwater River, July 2001.

	Section Where Marked				
Category	1	2	3	4	All Sections
Recaptured (m_2)	4	0	1	1	6
Not Recaptured (n_1-m_2)	71	23	22	9	125
Marked (n_1)	75	23	23	10	131
$P_{capture}$ 2^{nd} Event (m_2/n_1)	0.05	0.00	0.04	0.10	0.05

χ^2 = 1.88, df = 3, P-value = 0.60, fail to reject H_0.

For the large fish stratum, 344 fish were released with marks, and 623 fish were examined for marks, of which 76 had marks. Fish ≥ 315 mm FL were captured throughout the study area but they failed to mix completely (P-value < 0.01; Table 6). However, Assumption 2 was met because there was not a significant difference in probability of capture by area during either the first event (P-value = 0.79; Table 7) or the second event (P-value = 0.85; Table 8). Therefore, the pooled Bailey estimator was used. The population estimate for fish ≥ 315 mm FL was 2,788 (SE = 296). The Bailey estimates for the large and small size strata were combined for an overall estimate of 5,651 (SE = 1,032) fish ≥ 250 mm FL. The preferred, bias-corrected 95% confidence interval, calculated using the BCa method, was 4,075-8,827 and the bootstrap estimate of bias was 467 fish.

LENGTH AND AGE COMPOSITION

The length of fish caught during the two events ranged from 202 to 461 mm FL but composition estimates pertain to the population of fish ≥ 250 mm FL. K-S test results indicated that inferences about the composition of the population were to be based upon the lengths of fish captured during the second event (Case IV; Appendix A1). The composition estimates were adjusted (Appendix A4) to account for different capture probabilities in the two size-strata (Table 9). The age composition estimates were similarly adjusted. Ages were obtained from 436 fish ≥ 250 mm FL, and they ranged from age-3 to age-12 (Table 10).

MOVEMENT

Among 81 fish with known release and recapture locations (one recaptured fish had lost its tag), 65 (80%) were recaptured within the same section in which marked. Of the 16 fish that moved outside their original marking section, 12 moved downstream and 4 upstream (Tables 3 and 6), and only 3 fish moved more than 3 sections.

DISCUSSION

EVALUATION OF STUDY DESIGN

The precision of the overall abundance estimate did not meet our expectations, however, the estimate for fish ≥ 315 mm FL did meet precision expectations with a 95% C.I. of ±21%. For fish 250-314 mm FL the 95% C.I. was ±68% and the uncertainty in this stratum lowered the confidence interval to ±36% of the overall estimate of abundance of Arctic grayling ≥ 250 mm FL.

The imprecision associated with the abundance estimate for the smaller fish stratum was due to an insufficient number of fish sampled, which was attributed to a failure to distribute fishing effort in proportion to their abundance and the size selectivity of the capture gear. The study design called for distributing effort equally among sections, however, densities of both small and large fish varied substantially among the sampling sections. There were relatively few fish in the uppermost sections (5-7), all of which were large fish, and most small fish were in the lowermost sections (1-3). The inefficiency of the sampling gear also contributed to the low sample size for smaller fish. Failure to recruit smaller fish to the fishing gear is a common occurrence among sampling gears (Murphy and Willis 1996), including hook-and-line. Failure to recruit the smaller Arctic grayling has been observed in previous studies (Gryska 2001; Fleming and McSweeny 2001). The inability to capture small Arctic grayling using hook-and-line gear may have been

Table 6.-Test for complete mixing. Number of Arctic grayling ≥ 315 mm FL marked in each section (1 - 7) and recaptured or not recaptured in each section of the Richardson Clearwater River, July 2001.

	Section Where Recaptured								
Section Where Marked	1	2	3	4	5	6	7	Not Recaptured (n_1-m_2)	Marked (n_1)
1	9	1						32	42
2	2	10		1				53	66
3		1	12	1				64	78
4	1	1		13		1		57	73
5				1	8			28	37
6						6		13	19
7	2					4	2	21	29
Total	14	13	12	16	8	11	2	268	344

χ^2 = 297.54, df = 42, P-value < 0.01, reject H_0.

Table 7.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥ 315 mm FL examined during the second event by section (1 – 7) of the Richardson Clearwater River, July 2001.

	Section Where Examined							
Category	1	2	3	4	5	6	7	All Sections
Marked (m_2)	14	13	12	16	8	11	2	76
Unmarked (n_2-m_2)	109	64	90	118	85	71	10	547
Examined (n_2)	123	77	102	134	93	82	12	623
$P_{capture}$ 1st Event (m_2/n_2)	0.11	0.17	0.12	0.12	0.09	0.13	0.17	0.12

χ^2 = 3.14, df = 6, P-value = 0.79, fail to reject H_0.

Table 8.-Test for equal probability of capture during the second event. Number of Arctic grayling ≥ 315 mm FL marked by section (1 - 7) during the first event that were recaptured and not recaptured during the second event, Richardson Clearwater River, July 2001.

	Section Where Marked							
Category	1	2	3	4	5	6	7	All Sections
Recaptured (m_2)	10	13	14	16	9	6	8	76
Not Recaptured (n_1-m_2)	32	53	64	57	28	13	21	268
Marked (n_1)	42	66	78	73	37	19	29	344
$P_{capture}$ 2nd Event (m_2/n_1)	0.24	0.20	0.18	0.22	0.24	0.32	0.28	0.22

χ^2 = 2.68, df = 6, P-value = 0.85, fail to reject H_0.

Table 9.-Estimates of length composition and abundance by length group for Arctic grayling ≥ 250 mm FL, Richardson Clearwater River, July 2001.

Length Class (mm FL)	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$	$CV[\hat{N}_k]$	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
250 – 259	245	104.4	0.42	0.04	0.003
260 – 269	339	136.8	0.40	0.06	0.003
270 – 279	490	188.1	0.38	0.09	0.004
280 – 289	396	156.1	0.40	0.07	0.003
290 – 290	490	188.1	0.38	0.09	0.004
300 – 309	603	226.5	0.38	0.11	0.004
310 – 319	359	123.9	0.35	0.06	0.003
320 – 329	206	36.3	0.18	0.04	0.002
330 – 339	273	43.9	0.16	0.05	0.003
340 – 349	331	50.3	0.15	0.06	0.003
350 – 359	376	55.0	0.15	0.07	0.003
360 – 369	358	53.1	0.15	0.06	0.003
370 – 379	322	49.3	0.15	0.06	0.003
380 – 389	286	45.4	0.16	0.05	0.003
390 – 399	201	35.8	0.18	0.04	0.002
400 – 409	152	30.0	0.20	0.03	0.002
410 – 419	81	20.5	0.25	0.01	0.002
420 – 429	63	17.8	0.28	0.01	0.001
430 – 439	40	13.9	0.35	0.01	0.001
440 – 449	22	10.2	0.46	<0.01	0.001
450 – 459	9	6.4	0.71	<0.01	0.001
460 – 469	9	6.4	0.71	<0.01	0.001
≥ 250	5,651	1,032.1	0.18	1.00	
≥ 270	5,067	845.8	0.167	0.90	0.075

Table 10.-Estimates of age composition and abundance by age class for Arctic grayling ≥ 250 mm FL, Richardson Clearwater River, July 2001.

Age Class	$\hat{N}_k$	$\hat{S}E[\hat{N}_k]$	$CV[\hat{N}_k]$	$\hat{p}_k$	$\hat{S}E[\hat{p}_k]$
3	87	55	0.64	0.02	0.010
4	1,636	575	0.35	0.29	0.076
5	839	260	0.31	0.15	0.031
6	905	164	0.18	0.16	0.023
7	852	131	0.15	0.15	0.029
8	695	99	0.14	0.12	0.034
9	347	62	0.18	0.06	0.018
10	215	46	0.22	0.04	0.012
11	66	24	0.36	0.01	0.005
12	8	8	1.00	<0.01	0.002
3+	5,651	1,032.1	0.18	1.00	
5+	3,928	513.6	0.13	0.70	0.047

exacerbated by the use of terminal gear (jigs) that may have selected for larger fish. During the first event, small-sized flies (e.g., #12 thru #16 and mostly dry flies) were the primary gear type used (≅95%), and, during the second event, comparatively larger, sinking jigs were the primary gear (≅77%). Large fish capture probabilities increased in the second event (overall 10% greater, Tables 7 and 8); however, small fish capture probabilities did not change (differed by < 1%, Tables 4 and 5). The impact of the change in terminal gear on capture probabilities could not be rigorously assessed in this study nor does this study design permit an evaluation of other possible reasons for observed differences in capture probability including: differences in ability and techniques among anglers, weather, fish behavior, hydrographic features, and other unknown factors.

HISTORICAL COMPARISONS

The experimental design in 2001 differed from studies conducted during the 1980s in the type of capture gear used. During the 1980s, electrofishing boats were used, and as a result, two relatively long reaches of the river that are too wide and deep to be effectively shocked were not sampled (Pools #1 and #2; Figure 2). Because these reaches could not be sampled, it was possible that some portion of the population was subjected to a zero probability of capture (i.e., assuming insufficient mixing) resulting in a minimum abundance estimate. In 2001, these two reaches were effectively sampled using hook-and-line gear eliminating this concern.

The 2001 abundance estimate for Arctic grayling ≥ 250 mm FL was at the upper end of the range of abundance estimates obtained in the 1980s (Table 2). One of the objectives of the regulations implemented in 1987 was to increase the numbers of large, mature fish. For Arctic grayling ≥ 350 mm FL, the 2001 abundance estimate ($\hat{N}$ = 1,788; SE = 211) was significantly greater than abundance estimates for 1987 ($\hat{N}$ = 582; SE = 155) and 1988 ($\hat{N}$ = 949; SE = 161). Complete data files were not available for estimating the abundance of large fish for 1982-1986. However, sufficient information was contained in reports (Clark and Ridder 1987, 1988; Holmes et al. 1986; Ridder 1983, 1984, 1985, 1989) and in unpublished data files to determine that: 1) the abundance of large fish in 1982 was likely greater than in 2001; and, 2) that the abundance of large fish in 1984 was probably well within the confidence interval for 2001. For example, assuming that the ratio between the proportion of large fish in the sample and the proportion of large fish in the population was equal to the smallest value observed in 1987, 1988, and 2001 (i.e., 58%), we calculated an abundance of 2,117 large fish in 1982.

Although an increasing trend in the abundance of large Arctic grayling was not detected, the 2001 estimate was at the upper end of the observed range from 1982 to 1988 and posed no conservation concerns, especially given recent levels of harvest. The closure of the Shaw Creek Spring fishery was expected to increase the abundance of large, mature Arctic grayling in the RCR because the Spring fishery had been focused on spawning fish which are an important contributor (≅ 67%) to the summer abundance of Arctic grayling in the RCR (Ridder 1994). However, our study was not designed to assess the impact of the regulatory changes on the population and therefore, we were unable to isolate this mechanism from other influences such as recruitment and sampling variability (Allen and Pine III 2000). For example, there was large inter-annual variability among the estimates of fish abundance from 1982 through 1988 when the old regulations were in effect (Table 2).

In 2001, marked differences were observed in the distribution of Arctic grayling among sampling sections when compared to all studies conducted between 1984 and 1988. In 2001, approximately 6% of the population was in the upper sections 6 and 7 (defined as section 3 in previous studies). In 1987, this proportion was 47% and in 1988 it was 48% (Table 11). Using standardized CPUE data collected by electrofishing boats from 1982 to 1986, similar proportions were observed, which ranged between 46% and 76%. Reasons for this shift are unclear and may be temporary as it could be due to seasonal fluctuations in water temperature, prey availability, or discharge that is heavily influenced by water levels in the Tanana River. This change in distribution should be considered in designing future mark-recapture experiments (e.g., when allocating sampling effort).

Evaluation of an Arctic Grayling Management Strategy

This study provided an opportunity to assess the utility of a proposed management strategy for a large fish fishery among several Arctic grayling populations of the Tanana River basin. The proposed strategy seeks to provide anglers a high probability of catching large Arctic grayling. To achieve this, a proposed objective, stipulated that a population of Arctic grayling be managed such that the proportion of "large-fish" (i.e., ≥ 330 mm FL or 14 in TL) in the population (e.g., Arctic grayling ≥ 250 mm FL in this study) be maintained at ≥ 50 % (Charlie Swanton, Alaska Department of Fish and Game, Fairbanks, personal communication.). Among the Tanana River drainages, the RCR is arguably the most highly ranked candidate for being managed under the proposed management strategy because it has maintained a reputation among anglers and managers for its production and high catch rates of what are loosely defined as "large" or trophy-sized fish. For example, during this study a relatively high proportion (68%) of all fish we sampled while angling were large fish (Appendix C). However, during 2001 only 45% of the estimated population were large fish. Since the RCR is not a "large–fish" fishery by objective criteria even though considered as such by its reputation, argues for a re-evaluation of the management objective. A change in the proposed management objective to a lower proportion (e.g., population proportion of large fish ≥ 40%) could accommodate the 2001 estimate, however difficulties in estimating smaller fish abundance or variable annual recruitment (Clark 1992) could fluctuate the proportion beyond objective criteria again. Although an all encompassing objective based on proportions for large-fish fisheries is appealing, it may be more appropriate to manage in terms of absolute abundance of larger fish (e.g., 2,000 fish ≥ 330 mm FL within the study area); a measure which likely will not vary as greatly as proportions.

CONCLUSIONS AND RECOMMENDATIONS

As of 2001, the population of Arctic grayling in the RCR was at the upper end of the observed range from 1982 to 1988 and therefore, it was concluded that there was no conservation concern. Large increases in harvest are unlikely because traveling to the RCR is not exceptionally easy, as it requires a boat or plane. Harvest of RCR Arctic grayling during spawning season remains in control by closure of the spring fishery at Shaw Creek, where much of the RCR spawning stock is easily accessible and large numbers of large grayling would be susceptible to harvest. Continued closure of this fishery may be important in preserving current abundance of mature-sized Arctic grayling in the RCR. It is recommended that current regulations not be changed, angler use and harvest be monitored, and periodic stock assessments be performed once every 5-10 years or when meaningful increases in harvests have occurred.

Table 11.-Catch statistics, abundance estimates, and 95% confidence intervals by stratum for Arctic grayling captured during July of 1987, 1988, and 2001 in the Richardson Clearwater River.

		Lower Section[a]						Upper Section[b]					
Length Group	Year	n_1	n_2	m_2	$\hat{N}$	95 % C.I.	$P_{capture}$ 1st Event m_2/n_2	n_1	n_2	m_2	$\hat{N}$	95 % C.I.	$P_{capture}$ 1st Event m_2/n_2
250 – 349 mm FL	1987	110	180	9	*1,191	538 – 1,844	0.05	105	121	4	*1,002	144 – 1,860	0.03
	1988	99	199	6	1,697	592 – 2,802	0.03	147	185	13	*1,953	1,046 – 2,860	0.07
	2001	261	341	32	3,803	2,315 – 6,789[d]	0.09	5	5	1	15	4 – 42[d,e]	0.20
≥ 350 mm FL	1987	22	50	4	*216	34 – 398	0.08	111	137	12	366	121 – 611	0.09
	1988	93	121	15	*709	421 – 997	0.12	40	47	7	240	111 – 369	0.15
	2001	166	340	37	1,490	1,049 – 1,930	0.11	43	89	12	298	153 – 443	0.13
≥ 250 mm FL	1987	132	230	13	*1,407	729 – 2,085	0.06	216	258	16	1,368	476 – 2,260	0.06
	1988	192	220	21	*2,406	1,263 – 3,549	0.10	187	232	20	*2,193	1,276 – 3,110	0.09
	2001	427	681	69	5,314	3,735 – 8,640[d]	0.10	48	94	13	326	194 – 582[d]	0.14

* Indicates a population estimate significantly different than the 2001 estimate at the 95% confidence level.

[a] Lower section refers to sections 1 – 5 (named sections 1 and 2 during 1987 and 1988).

[b] Upper section refers to sections 6 and 7 (named section 3 during 1987 and 1988).

[c] The 2001 estimate of abundance is the sum of an estimate of fish < 315 mm FL and of fish between 315 and 349 mm FL using the Bailey modified Petersen estimate procedure.

[d] Bias corrected 95% confidence intervals calculated using bootstrap methods of Efron and Tibshirani (1993) and Buckland and Garthwaite (1991).

[e] The catch indicated a minimum abundance of 9 fish.

Future stock assessments should not rely on using upper sections 6 and 7 (formerly section 3) as an index of abundance due to the marked differences observed in the distribution of fish in 2001 when compared to the 1980s. During all studies in the 1980s, a much greater proportion of the population was in sections 6 and 7 than in 2001.

Future stock assessments should also consider several design changes. First, the distribution of sampling effort should reflect densities of fish throughout the study area rather than within each section. Effort was applied in proportion to abundance within a section, but it would have been better to allocate effort according to densities throughout the study area. It is recommended that a relative measure of fish densities among sampling sections be attained prior to the initiation of the marking event in order to allocate effort in proportion to abundance. A single pass through the study area using an electrofishing boat would be an efficient and effective means for attaining this measure. Secondly, project managers should carefully consider their choice of terminal gear with respect to capture probability of small fish. Third, accurate recording of gear-specific effort is recommended. And finally, an adjustment to the sample size requirement for age determination should be reevaluated due to the abnormally low readability of the scales observed in 2001.

It is recommended that the proposed proportion based management objective strategy to define an Arctic grayling stock as a large-fish fishery be reevaluated. Specifically, it may be more appropriate to manage in terms of absolute abundance of large fish (e.g., 2,000 fish ≥ 330 mm FL within the index area) rather than a proportion of large-fish. The proportion of large fish is dependent on factors such as recruitment, which may vary greatly from year to year. Also, the precision of any proportion estimate depends on an investigators ability to obtain an accurate estimate of the abundance of small-fish, which can be limited by diminishing capture probabilities as fish size decreases (as in the case of this study).

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APPENDIX A

METHODS FOR TESTING ASSUMPTIONS OF THE PETERSEN ESTIMATOR AND ESTIMATING ABUNDANCE AND AGE AND SIZE COMPOSITION

Appendix A1.-Methodologies for alleviating bias due to gear selectivity

	Result of first K-S test[a]	Result of second K-S test[b]
<u>Case I</u>[c]		
	Fail to reject H_o	Fail to reject H_o
	Inferred cause: There is no size-selectivity during either sampling event.	
<u>Case II</u>[d]		
	Fail to reject H_o	Reject H_o
	Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event.	
<u>Case III</u>[e]		
	Reject H_o	Fail to reject H_o
	Inferred cause: There is size-selectivity during both sampling events.	
<u>Case IV</u>[f]		
	Reject H_o	Reject H_o
	Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

[a] The first Kolmogorov-Smirnov (K-S) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Estimate length and age distributions from second event and adjust these estimates for differential capture probabilities.

Appendix A2.-Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Of the following conditions, at least one must be fulfilled to meet assumptions of a Petersen estimator:

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

I.-Test For Complete Mixing[a]

Section	Section Where Recaptured				Not Recaptured
Where Marked	**1**	**2**	**…**	**t**	(n_1-m_2)
1					
2					
…					
s					

II.-Test For Equal Probability of capture during the first event[b]

	Section Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked (n_2-m_2)				

III.-Test for equal probability of capture during the second event[c]

	Section Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from section *i* (*i* = 1, 2, ...s) to section *j* (*j* = 1, 2, ...t) are the same among sections: H_0: $\theta_{ij} = \theta_j$.

[b] This tests the hypothesis of homogeneity on the columns of the 2-by-t contingency table with respect to the marked to unmarked ratio among river sections: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, where k = total marks released/total unmarked in the population, U_j = total unmarked fish in stratum *j* at the time of sampling, and a_i = number of marked fish released in stratum *i*.

[c] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities among the river sections: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in section *j* during the second event, and d is a constant.

Appendix A3.-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 estimator is:

$$\hat{N}_1 = \frac{n_1(n_2+1)}{m_2+1}, \qquad (1)$$

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;

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

$\hat{N}_1$ = estimated abundance of Arctic grayling during the first event.

Variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}_1] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \qquad (2)$$

Appendix A4.-Equations for estimating length and age compositions and their variances for the population.

From Appendix A1, case IV was found through inference testing. When case IV occurs, the second event sample is biased and the status of the first event sample is unknown. Therefore, age and size data from the second event sample were used to estimate compositions. These estimates were adjusted to minimize bias due to size-selectivity. The proportion of fish at age or size was calculated by summing independent abundances for each age or size class and then dividing by the summed abundances for all size strata. First, the conditional proportions from the sample were calculated:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j}, \quad (1)$$

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 were age k; and,

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

The variance calculation for $\hat{p}_{jk}$ was

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1-\hat{p}_{jk}\right)}{n_j - 1}. \quad (2)$$

The estimated abundance of age k fish in the population was then:

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk}\hat{N}_j, \quad (3)$$

where:

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

s = the number of size strata.

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

$$\hat{V}\left[\hat{N}_k\right] \approx \sum_{j=1}^{s}\left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + V\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]V\left[\hat{N}_j\right]\right). \quad (4)$$

-continued-

The estimated proportion of the population that were age k $\left(\hat{p}_k\right)$ was then:

$$\hat{p}_k = \hat{N}_k \big/ \hat{N}\,, \qquad (5)$$

where:

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

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

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s}\left\{\left(\frac{\hat{N}_j}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{jk}\right]\right\} + \frac{\sum_{j=1}^{s}\left\{V\left[\hat{N}_j\right]\left(\hat{p}_{jk} - \hat{p}_k\right)^2\right\}}{\hat{N}^2}. \qquad (6)$$

Equations 4 through 8 were also used to adjust biased size composition estimates, replacing the number sampled at age k that were also in size strata j (n_{jk}) with the number sampled per 10 mm FL incremental size category k that were also in size strata j.

APPENDIX B

DATA FILE LISTING

Appendix B.-Data files[a] for all Arctic grayling captured in the Richardson Clearwater River, July 2001.

Data file	Description
u-000700l012001.dta	Sample data from 10-13 July 2001. Tagging Length Form Version 1.0
u-000700l022001.dta	Sample data from 23-27 July 2001. Tagging Length Form Version 1.0
RCR 315 11-12-03.xls	Data and analysis in excel spreadsheet

[a] Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.

APPENDIX C

DATA SUMMARY

Appendix C.-Catch statistics of Arctic grayling sampled during both events, by section, Richardson Clearwater River, July 2001.

Section	n	n ≥ 330 (mm FL)	p ≥ 330 (mm FL)	Fork Length		
				Mean	Maximum	Minimum
1	394	129	0.33	308	460	202
2	179	123	0.69	349	461	234
3	214	156	0.73	346	440	235
4	223	192	0.86	359	431	264
5	130	124	0.95	374	443	318
6	101	101	1.00	386	434	333
7	41	41	1.00	389	445	331
All Sections	1,282	866	0.68	344	461	202