Fishery Data Series No. 14-05

Abundance and Length Composition of Arctic Grayling in the Fish River, 2007

by

Tim Viavant

January 2014

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

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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, χ^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. 14-05

ABUNDANCE AND LENGTH COMPOSITION OF ARCTIC GRAYLING IN THE FISH RIVER, 2007

by
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ABSTRACT

A two-event, mark-recapture experiment was conducted within a 25-km (15.5-mi) section of the Fish River during June 2007 to estimate abundance and length composition of Arctic grayling *Thymallus arcticus* ≥350 mm FL. The population in this index section is periodically assessed to ensure that it is sustained at or above a management-prescribed level of 4,500 fish ≥350 mm FL. Using hook-and-line gear, 552 fish ≥ 350 mm FL were marked during the first event, and 496 fish ≥350 mm FL were examined during the second event. Using a Bailey-modified Petersen estimator, abundance was estimated at 21,103 (SE = 5,566) Arctic grayling ≥350 mm FL. Due to the small number of fish captured in both events relative to population size, the estimate failed to meet its planned precision goal. Despite the poor precision of the estimate, abundance still was significantly larger than the management-prescribed level of 4,500 fish ≥350 mm FL. This population was previously assessed in 1991 and in 1999, and estimated abundance in the index section in 2007 was over twice the abundance estimate of fish ≥300 mm FL from 1999, and over seven times the abundance estimate of fish ≥300 mm FL from 1991. Although most (73%) captured fish ranged from 350 to 480 mm FL, the length distribution included a much higher percentage of fish <350 mm FL than the length distribution of fish captured in 1999.

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

INTRODUCTION

There are many rivers and streams on the Seward Peninsula that can be accessed from the road system that surrounds the community of Nome. Most of these drainages support at least some angling effort directed toward Arctic grayling *Thymallus arcticus*, either by residents of Nome and the surrounding area, or by tourists visiting the area. The Fish River is one of the larger drainages that support sport fisheries. The Fish River flows from the Bendeleben Mountains some 100 km into Golovin Bay and Norton Sound, and has numerous tributaries, including the Niukluk River (Figure 1).

The Fish River is accessed by the Nome area road system via the Niukluk River at the community of Council, approximately 19 km upstream of the Fish River (Figure 2). Fish River also flows past the community of White Mountain, located approximately 25 km below the mouth of the Niukluk River. The river contains populations of Arctic grayling, northern pike *Esox lucius*, burbot *Lota lota*, longnose sucker *Catostomus catostomus*, whitefish *Coregonus* spp., Dolly Varden *Salvelinus malma*, and all five North American species of Pacific salmon *Oncorhynchus*.

Most of the sport fishing effort in the Fish River drainage is directed at Arctic grayling, Dolly Varden, and coho salmon (*O. kisutch*; A. DeCicco, Sport Fish Biologist, retired, ADF&G, Fairbanks; personal communication). Sport fishing effort is relatively light compared to other Nome area drainages that are more easily accessed directly from the road system. From 1992 through 2001, the Fish and Niukluk rivers averaged 2,746 angler-days of fishing effort, 429 Arctic grayling harvested, and 4,518 Arctic grayling caught (Table 1; Mills 1993, 1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003). From 2002 through 2006, average annual total effort on the Fish River was 721 angler-days, average annual Arctic grayling harvest was 90 fish, and average annual Arctic grayling catch was 735 fish. These numbers, however, result from expansions of Statewide Harvest Survey (SWHS) estimates based on low numbers of respondents, and therefore should be interpreted as minimum levels of effort and harvest.

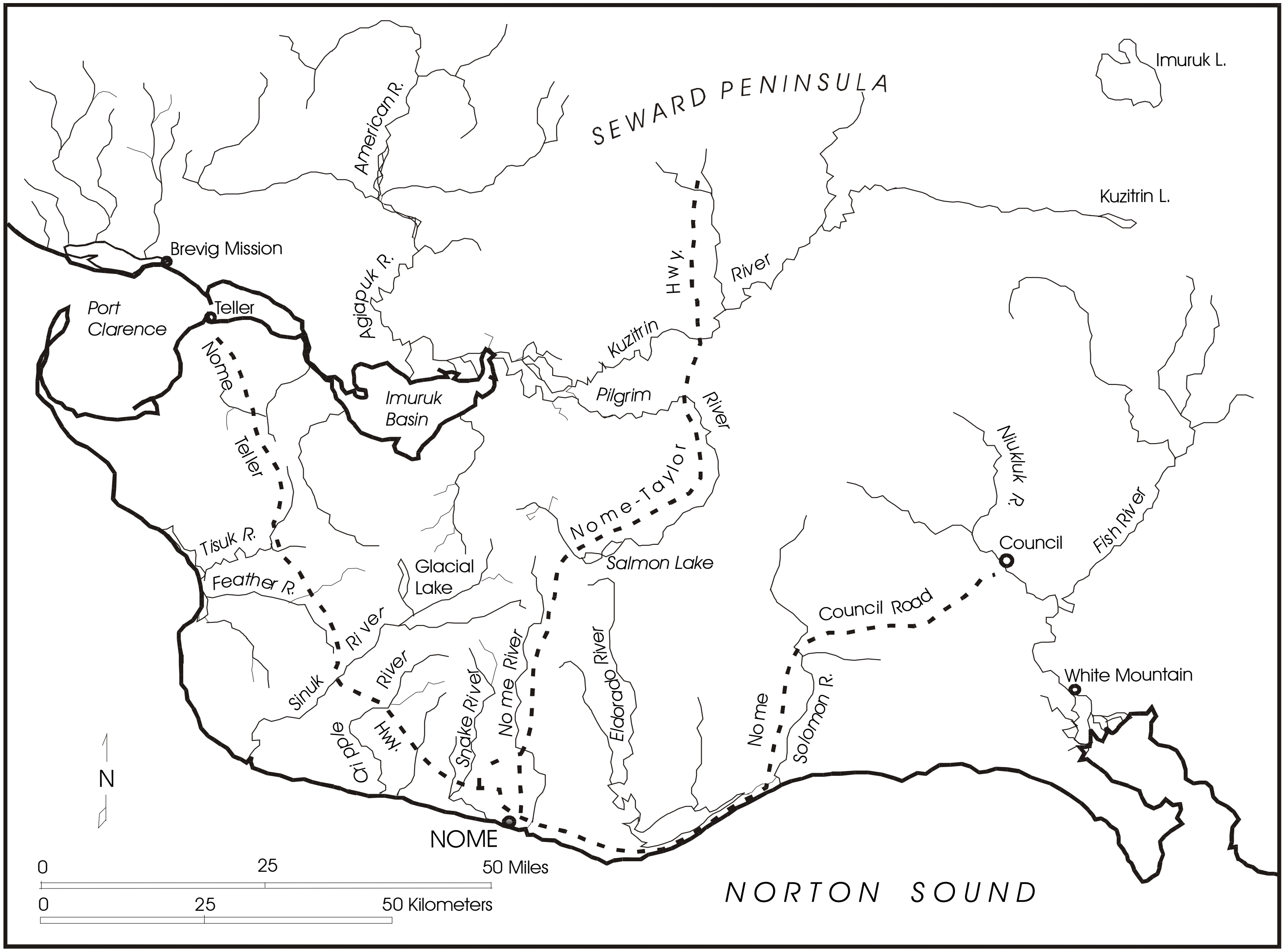

Figure 1.–Southern Seward Peninsula with road accessible waters.

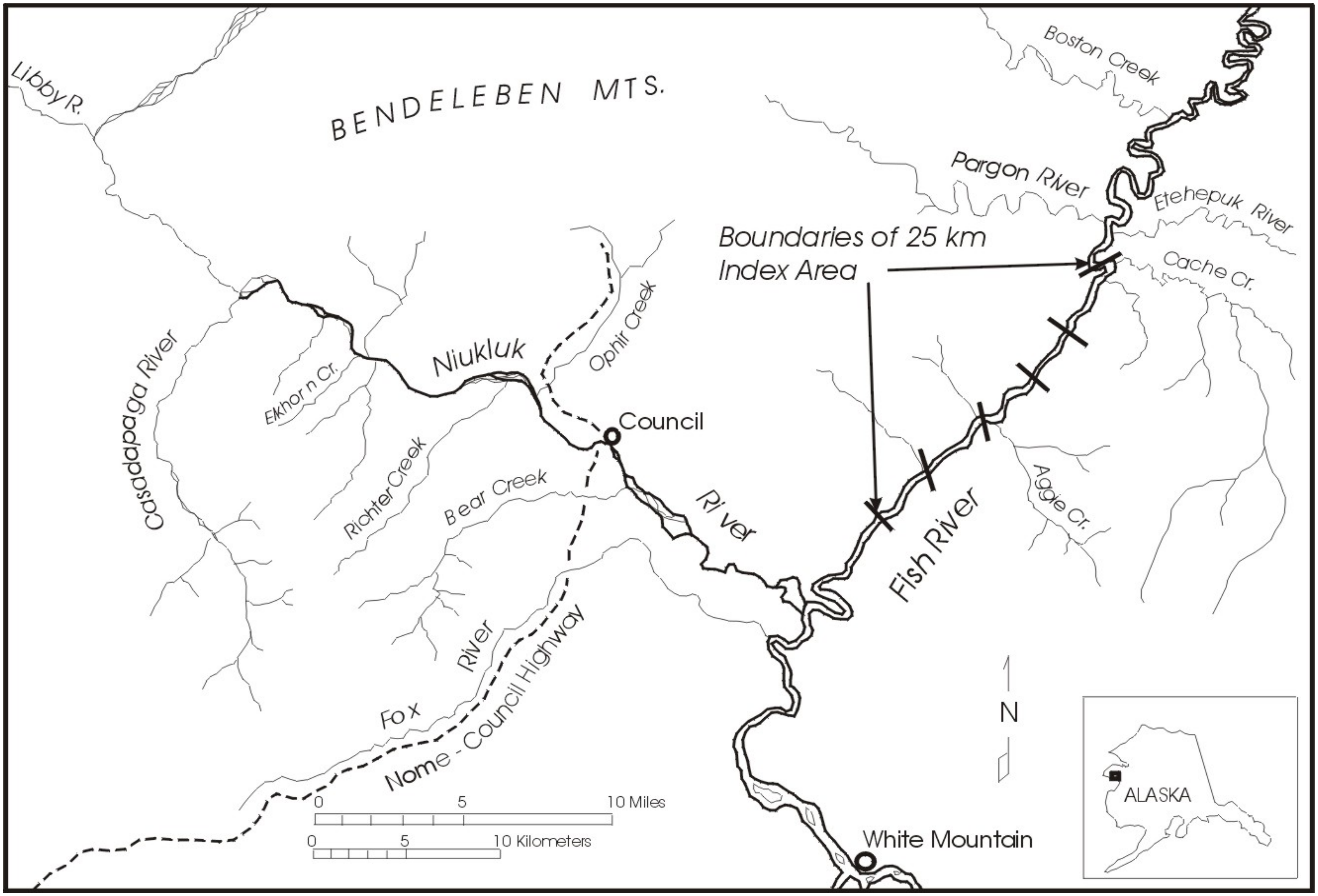

Figure 2.–Sampling area in the Fish River, 2007, showing section boundaries.

Table 1.–Estimated total sport fishing effort (angler-days) for all species of fish, and estimates of sport fishing catch and harvest of Arctic grayling in the Niukluk and Fish rivers of the Seward Peninsula, Alaska.

Drainage	Period/year	Effort	Harvest	Catch
Niukluk and Fish Rivers combined				
	1992–2001	2,746	429	4,518
Fish River				
	2002	167	13	285
	2003	648	84	1,050
	2004	825	0	823
	2005	1,138	354	1,499
	2006	828	0	18
Niukluk River				
	2002	298	32	2,211
	2003	1,625	256	4,352
	2004	1,961	102	771
	2005	816	48	1,817
	2006	221	0	311

Source: Data from: Mills 1993, 1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b.

Nome area streams are known for producing large Arctic grayling. A 15-in length restriction was implemented to afford some protection of these larger fish in some of the more popular and easily accessed streams. In general, streams with roadside access have more stringent regulations (5 grayling/day and only one may be ≥15 in TL) than the regulations that are applied to the remote streams of the Seward Peninsula (5 grayling/day and no size limit; formerly 10 grayling/day and no size limit prior to 2004). The Fish River has had a bag limit of 5 Arctic grayling/day with no size limit since 2004 because access is somewhat limited and fishing pressure is relatively low compared to Arctic grayling abundance.

From 1989 to 2000, concerted research was conducted on several important Arctic grayling populations on the Seward Peninsula (Merritt 1989; DeCicco 1990-1997, 2002a; DeCicco and Wallendorf 2000) that culminated in a fishery management plan for rivers with Arctic grayling along the Nome Road system and the current regulatory structure (DeCicco 2002b). In this plan, specific management objectives were established for the Niukluk, Fish, Pilgrim, Nome, Snake, and Sinuk rivers (Figure 1), which prescribe minimum abundances of Arctic grayling (≥15 in TL) in index areas. The research program, as described in the management plan, recommends periodic population assessments for these and other road-accessible streams to ensure that abundances are being maintained at or above prescribed levels.

The management objective for the Fish River Arctic grayling fishery is to maintain a minimum abundance of 4,500 Arctic grayling ≥15 in TL (350 mm FL) within a 25-km index area having an upper boundary at Cache Creek (Figure 2). This objective was established based on assessments conducted during 1991 and 1999. DeCicco (2002b, 2004) recommended assessments of the Fish River population be conducted every 5 years; however, prior to this study it had not been assessed for 7 years. Therefore, the goal of this study was to reassess the Arctic grayling population in the Fish River in the 25-km index area to determine if the prescribed level of ≥350 Arctic grayling ≥15 in TL (350 mm FL) has been maintained.

OBJECTIVES

The project had three objectives:

1. Test the null hypothesis that the abundance of Arctic grayling ≥350 mm FL in a 25-km index section of the Fish River during June is ≤3,000 with a 10% or less chance of taking a management action if the true abundance is ≥ 4,500, and a 80% or greater chance of taking a management action if the true abundance is ≤3,250 using alpha = 0.10.
2. Estimate the abundance of Arctic grayling ≥350 mm FL in a 25-km index section of the Fish River during August such that the estimate is within 25% of the actual abundance 90% of the time.
3. Estimate the length composition (in 25-mm FL length categories) of Arctic grayling ≥300 mm FL in a 25-km index section of the Fish River such that the estimates are within 10 percentage points of the true value 90% of the time.

METHODS

SAMPLING DESIGN AND FISH CAPTURE

In 2007, the Fish River Arctic grayling study was designed to estimate abundance of Arctic grayling ≥350 mm FL and length composition of Arctic grayling ≥300 mm FL within the 25-km index area by conducting a two-event mark-recapture experiment. The first (marking) event occurred during June 18–22 and the second (examination) event during June 25–29.

During each event, sampling began at Cache Creek (the upper boundary of the index area) and proceeded sequentially downstream. Each day, two crews of two or three people expended approximately 8 hours of sampling effort using hook-and-line gear (fly-fishing and spin fishing) to capture fish. Terminal gear used primarily consisted of size 12–16 flies and 1/8 and 1/16 ounce jigs with size 1 or 2 hooks, several colors of rubber bodies, and rubber salmon eggs. The choice of terminal gear was made based on the angling conditions and the success of the gear being used.

In the first event, fish ≥200 mm FL were given a primary mark with an individually-numbered anchor tag (Floy FD 94[1]). Additionally, a secondary mark (a partial left pectoral fin clip) was used to identify and mitigate effects of tag loss. In the second event, fish were not tagged, but a partial left ventral fin clip was given to all captured fish to avoid double counting. 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.

The 25-km index area was divided into 5 sections of approximately 5 km each to allow for the evaluation of movement during the experiment. Fish were released near their capture site (within 100 m), and the release location was recorded for all fish captured.

[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

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

1. The population was closed (Arctic grayling did not enter or leave 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 the Bailey modification of the general form of the Petersen estimator (Bailey 1951, 1952):

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

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

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 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.

Sampling was designed so that the validity of these assumptions could 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 1998; Ridder and Gryska 2000; Gryska 2001). Movement was expected, but only on a localized scale (e.g., up to 2 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 to evaluate the appropriateness of the assumption of closure. Sampling was conducted in attempt to subject all fish during each sampling event to the same probability of capture by sampling each pool and run with effort in proportion to the distribution of Arctic grayling. The entire length of each section was sampled, with the amount of angling effort based on Arctic grayling distribution based on initial catch rates and direct observation when possible.

Because Arctic grayling move little during midsummer, complete mixing of marked and unmarked fish within the study area was not expected; rather Arctic grayling were expected to mix within approximately 1-5 km reaches. Diagnostic tests to identify heterogeneous capture probabilities and methods to correct for potential biases are presented in the *Data Analysis* section.

Relative to Assumption 3, a hiatus of 5 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 captured and handled and to resume their normal behavior. In addition, the use of active gear and two different types of terminal gear when angling 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 fin clip, and all fish caught in the second event were carefully examined for marks.

DATA COLLECTION

Captured Arctic grayling were measured and marked immediately or soon after capture, and released at or very near their capture location. Each fish was marked and released. Crews recorded the date, location, fork length, old fin clips, tag number, tag color, recapture status, and mortality (if that occurred) into a field notebook. These data were later entered into an Excel spreadsheet for analysis and archival (Appendix B1). Floy tags were gray and were numbered between 2,001 and 2,900.

DATA ANALYSIS

Abundance Estimate

The specific form of the Petersen estimator used was determined from the results of diagnostic tests and from the constraints of the available data. Violations of Assumption 2 relative to size effects were tested for using two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two tests relative to evaluating size selective sampling (either one of the two samples, both, or neither of the samples were biased, Appendix C1) and two possible actions for abundance estimation (length stratify or not).

To check for spatiotemporal differences in capture probability, tests for consistency of the Petersen estimator (Seber 1982) were performed (Appendix C2). The sample area was divided into five sections of approximately 5 km in length to provide a minimum scale at which capture probabilities could be examined (Figure 2). When estimating abundance a minimum number of recaptures (approximately 7 fish) are preferred to ensure negligible statistical bias in the estimate, $\hat{N}$ (Seber 1982).

Length Composition

Length composition of the population was estimated using the procedure outlined in Appendices C1 and C3.

RESULTS

SUMMARY STATISTICS OF FISH SAMPLED

A total of 1,361 Arctic grayling were captured during the 10 days of sampling. Of these, 650 were captured during the first event, and 552 of these fish were over 350 mm FL and were tagged (n_1). A total of 711 fish were captured during the second event. Of these, 496 were ≥350 mm FL (n_2). A total of 13 fish were recaptured during the second event, and 12 of those fish were ≥350 mm (m_2). The smallest Arctic grayling caught was 199 mm FL and the largest was 518 mm FL.

ABUNDANCE HYPOTHESIS TESTING

The null hypothesis that the abundance of Arctic grayling ≥350 mm FL in the 25-km index section of the Fish River during June was ≤3,000 was strongly rejected ($P = 0.0006$). Given that the lower 95% confidence interval for the abundance estimate is significantly higher than the "caution point" of the hypothesis test, the abundance level is not currently a management concern.

ABUNDANCE ESTIMATE

The estimated abundance of Arctic grayling ≥350 mm FL within the 25-km index area was 21,103 fish (SE = 5,566). The lower and upper 95% confidence intervals of the estimate were 10,194 and 32,012, respectively. The relative precision of the estimate was 0.434. The sampling design and the results of the testing procedures (Figure 3; Tables 2–4, and Appendices C1 and C2) determined that stratification by size or area was not required. Therefore, the Bailey-modified Petersen estimator (Bailey 1951, 1952) was used to estimate abundance of Arctic grayling ≥350 mm FL. The use of the Bailey-modified Peterson estimator was appropriate because fishing occurred in a systematic downstream progression while attempting to subject all fish to the same probability of capture.

The tests of consistency were conducted at the scale of the original sampling scheme (5 sections of 5 km each). Because of the low number of recaptures, testing for mixing of fish between sections was not meaningful. First event capture probabilities were equal between sections (*P*-value = 0.27; Table 2), and the second event capture probabilities were equal between section (*P*-value = 0.51; Table 3). Tests for equal capture probabilities were also collapsed into 2 x 2 contingency tables to provide a more robust test, but these tests did not change the conclusions of the uncollapsed tests. Although the tests failed to reject the hypothesis of equal capture probabilities during each event (suggesting Assumption 2 was satisfied), the actual capture probabilities were variable and the tests had little power to detect differences due to an inadequate number of recaptures.

Therefore, while it was possible to examine other geographic stratification schemes, there was little utility in such an exercise, given that there were insufficient recaptures available to obtain an estimate stratified geographically.

LENGTH COMPOSITION

The K-S tests indicated there was no size-selective sampling during the second sampling event, but that there was size selectivity during the first event (Case II scenario; Appendix C1); therefore, population compositions of lengths of Arctic grayling ≥ 300 mm FL were estimated using measurements from only the second sampling event (n = 619). About half of the estimated population ranged between 350 and 399 mm FL, and 71% was between 350 and 449 mm FL (Figure 4; Table 4).

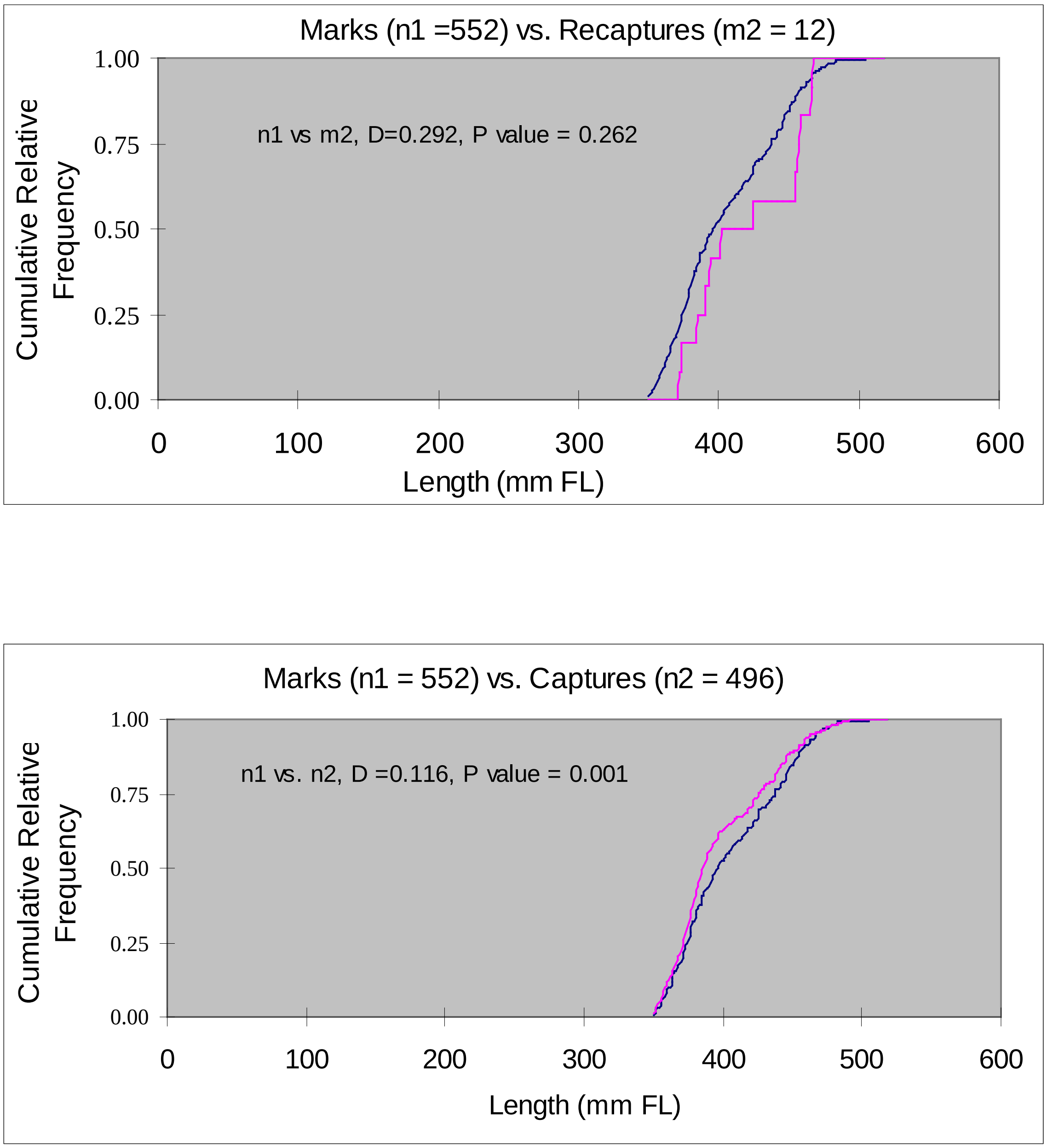

Figure 3.–Cumulative relative frequency of Arctic grayling ≥350 mm FL marked and examined (lower panel) and marked and recaptured (upper panel), Fish River, June 2007.

Table 2.–Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥350 mm FL examined during the second event by 5-km section of the Fish River, June 2007.

	Section Where Marked					
Category	1	2	3	4	5	All Sections
Marked (m_2)	2	1	5	0	4	12
Unmarked (n2-m2)	38	95	137	89	125	484
Examined (n2)	40	96	142	89	129	496
P capture 1st Event (m2/n2)	0.05	0.01	0.04	0.00	0.03	0.02

$\chi^2 = 5.09$; df = 4; *P*-value = 0.27; fail to reject H_0.

Table 3.–Test for equal probability of capture during the second event. Number of Arctic grayling ≥350 mm FL marked by 5-km section during the first event that were recaptured and not recaptured during the second event, Fish River, June 2007.

	Section Where Marked					
Category	1	2	3	4	5	All Sections
Recaptured (m2)	2	2	4	0	4	12
Not Recaptured (n1-m2)	82	115	122	94	127	484
Marked (n1)	84	117	126	94	131	496
P capture 2nd Event (m2/n1)	0.02	0.02	0.03	0.00	0.03	0.02

$\chi^2 = 3.29$; df = 4; *P*-value = 0.51; fail to reject H_0.

Table 4.–Estimates of length composition (Proportions) by 25-mm FL groups for Arctic grayling ≥300 mm FL, Fish River, June 2007.

(mm FL)	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
300–324	0.06	0.01
325–349	0.14	0.01
350–374	0.24	0.02
375–399	0.26	0.02
400–425	0.09	0.01
425–449	0.12	0.01
450–474	0.07	0.01
475–500	0.02	0.01
Total	1.00	

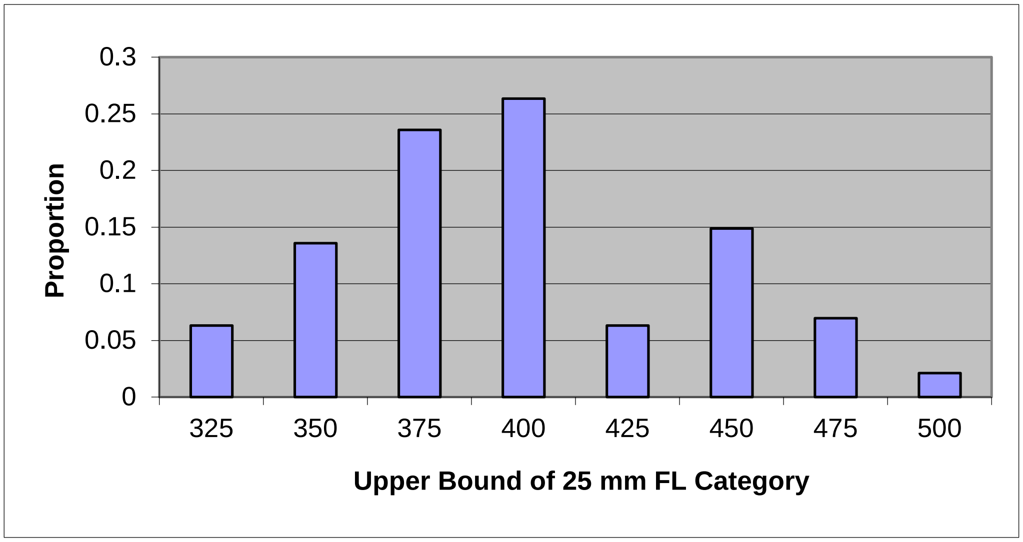

Figure 4.–Proportions of Arctic grayling ≥ 300 mm FL in 25-mm length categories from the Fish River, 2007.

DISCUSSION

The abundance estimate failed to meet the precision criteria in Objective 2 due to the low proportion of fish sampled during the experiment relative to the population size. The estimate did result in rejecting the null hypothesis stated in Objective 1 with strong statistical significance. This conclusion is supported further in that the lower 95% confidence interval of the estimate is greater than twice the management objective of 4,500 fish >350 mm FL for the Fish River. Although the precision of the estimate is fairly poor, the magnitude indicates that the Arctic grayling population in the index area of the Fish River has increased over the past 16 years. For this same index area the abundance estimates for fish ≥300 mm FL were 2,900 fish in 1991 (SE = 424); and 7,902 fish in 1999 (SE = 1,131).

This experiment failed to capture enough fish between 300 mm FL and 349 mm FL to provide an estimate for all fish >300 mm FL (for purposes of comparison with prior estimates). The estimate for fish ≥350 mm FL, combined with indications of fishing pressure from the SWHS (Table 1), would suggest that there are currently no management concerns with this stock. There are any number of possible explanations for the variability in abundance of this stock, both environmental (i.e., the relationship between spring runoff and recruitment identified by Clark [1992]), and ecological (productivity associated with large pink salmon *O. gorbuscha* returns or predation related to Dolly Varden population fluctuations). Given the low level of participation in this fishery, mortality associated with sport fishing probably plays a relatively small role in variability in population abundance.

The length composition from 2007 includes a much higher proportion of fish between 300 mm FL and 350 mm FL than length compositions from 1999 and 1991 (Figure 5). The distribution from 2007 was slightly bi-modal and, when compared with 1999, suggests good recruitment over the last eight years. This is in contrast to the comparison of the length compositions from 1991 and 1999, where it appears there was relatively poor recruitment.

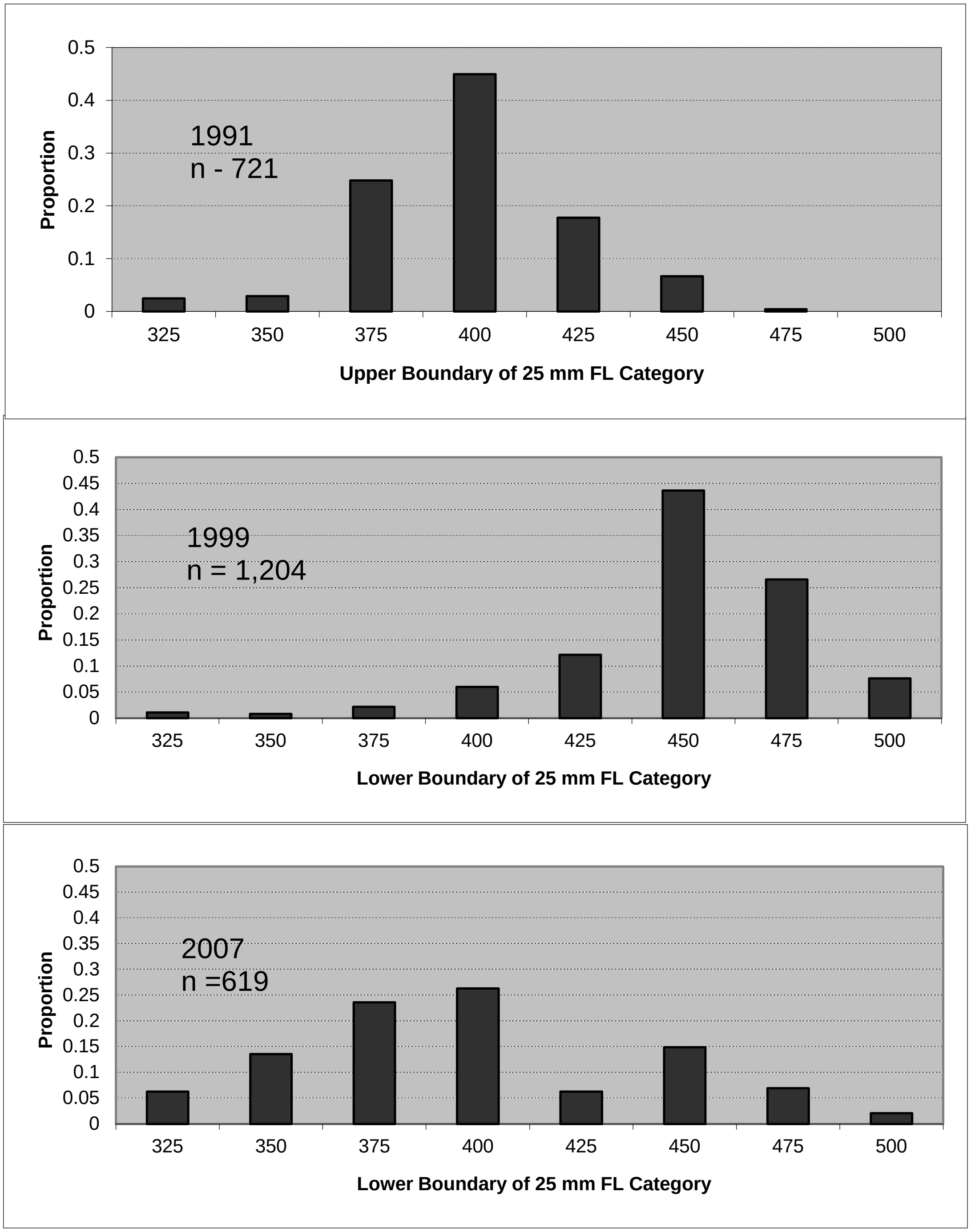

Figure 5.–Proportions of Arctic grayling ≥ 300 mm FL in 25-mm length categories from the Fish River, 1991, 1999, and 2007.

The poor precision of the abundance estimate suggests insufficient sampling effort was expended during both events of the study. The study was designed with the assumption that abundance would be much less; similar to what was estimated in 1991 and 1999. It is recommended that future experiments either implement a third sampling crew or increase the number of sampling days during each event.

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APPENDIX A
SAMPLING SCHEDULE AND CATCH STATISTICS FOR THE FISH RIVER, 2007

Appendix A1.–Sampling dates and catches of Arctic grayling per sampling section for the Fish River, 2007.

	Section				
Date	**1**	**2**	**3**	**4**	**5**
6/18/2007	66				
6/19/2007	26	136			
6/20/2007			146		
6/21/2007				118	
6/22/2007				77	81
6/23/2007			No sampling		
6/24/2007			No sampling		
6/25/2007	36				
6/26/2007	19	152			
6/27/2007			205		
6/28/2007				127	
6/29/2007				85	87

APPENDIX B.
DATA FILES FOR ARCTIC GRAYLING CAPTURED IN THE FISH RIVER, JUNE, 2007

Appendix B1.–Data files for Arctic grayling captured in the Fish River, June 2007.

Data file	Description
07 Fish River AG Data.xls	Sample data from June 18–29, 2007.
07 Fish AG Analysis.xls	Data and analysis in excel spreadsheet

Note: 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 99518-1565.

APPENDIX C.
METHODS

Appendix C1.–Methodologies for alleviating bias due to size selectivity.

	Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]		
	Fail to reject H_o	Fail to reject H_o
	Inferred cause: There is no size-selectivity during either sampling event.	
Case II[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.	
Case III[e]		
	Reject H_o	Fail to reject H_o
	Inferred cause: There is size-selectivity during both sampling events.	
Case IV[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° 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° 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 events 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 C2.–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 C3.–Equations for estimating length composition and variances for the population.

The diagnostic tests indicated that there was no size selective sampling during the second event, but that there was size selectivity during the first event (Case II, Appendix C1). Therefore, length composition was estimated using data from only the second sampling event. The proportions of Arctic grayling within each age or length class *k* were estimated:

$$\hat{p}_k = \frac{n_k}{n} \qquad \text{(C-1)}$$

where:

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

n = the total number of Arctic grayling sampled.

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

$$\hat{V}\left[\hat{p}_k\right] = \frac{\hat{p}_k\left(1-\hat{p}_k\right)}{n-1}. \qquad \text{(C-2)}$$

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

$$\hat{N}_k = \sum_{k=1}^{s} \hat{p}_k \hat{N}, \qquad \text{(C-3)}$$

where:

$\hat{N}$ = the estimated overall abundance; and,

s = the number of age or length classes.

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):

$$\hat{V}\left[\hat{N}_k\right] \approx \sum_{k=1}^{s} \left(\hat{V}\left[\hat{p}_k\right]\hat{N}^2 + \hat{V}\left[\hat{N}\right]\hat{p}_k^2 - \hat{V}\left[\hat{p}_k\right]\hat{V}\left[\hat{N}\right]\right). \qquad \text{(C-4)}$$

Appendix C4.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

The Bailey-modified Petersen estimator (Bailey 1951, 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:

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:

$$\hat{N} = \frac{n_1(n_2+1)}{m_2+1}, \qquad \text{(C-5)}$$

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):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \qquad \text{(C-6)}$$