Fishery Data Series No. 15-05

Stock Assessment of Arctic Grayling in the Snake River, 2011

by

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March 2015

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)

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. 15-05

STOCK ASSESSMENT OF ARCTIC GRAYLING IN THE SNAKE RIVER, 2011

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Development and publication of this manuscript were partially financed by the Federal Aid in Sport fish Restoration Act(16 U.S.C.777-777K) under Project F-10-27, Job No. R-3-2(c).

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

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This document should be cited as:
Gryska, A. D. 2015. Stock assessment of Arctic grayling in the Snake River, 2011. Alaska Department of Fish and Game, Fishery Data Series No. 15-05, Anchorage.

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ABSTRACT

A stock assessment was performed for the Arctic grayling (*Thymallus arcticus*) population inhabiting a 16.2 km portion of the Snake River near Nome, Alaska. The study was conducted during June 2011 and used mark–recapture techniques to estimate abundance and length composition of the population. This population is periodically assessed to ensure that it is sustained at or above a management-prescribed level of 600 fish ≥ 350 mm FL (fork length), and this population was last assessed during 2001. Using hook-and-line gear, a total of 341 fish were captured. Estimated abundance of Arctic grayling ≥ 350 mm FL was 621 (SE = 77), of which 86% of the population was 375–474 mm FL. No management actions were necessary because the abundance estimate exceeded the management objective and was sufficiently precise.

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

INTRODUCTION

The Seward Peninsula of western Alaska has many rivers and streams that are easily accessible by way of a road system (approximately 420 km in length) emanating from Nome (Figure 1). Most streams along the road system, including the Snake River, support some angling effort for Arctic grayling *Thymallus arcticus* for many of the 9,492 residents of the Nome census area (U.S. Census Bureau 2010) as well as numerous tourists. The Snake River is approximately 57 km in length and enters the Bering Sea at the Port of Nome. Upstream reaches of the river are accessible from the Nome–Teller Highway Bridge and from the Snake River Road (Figure 2) that parallels much of the upper river.

The Snake River remains popular with anglers because it is the closest river to Nome open to Arctic grayling fishing. The Snake River has averaged 1,154 days of sport fishing effort (all species) per year over the past ten years (2000–2009) with catches of Arctic grayling averaging 437 per year and harvests averaging 63/year (Table 1). In addition, it is likely that there is some harvest by subsistence anglers, although harvests are not reported and Arctic grayling are not regularly targeted by subsistence fishers. Since 1993, the sport fishing regulation for the Snake River has been a bag limit of 2 Arctic grayling per day of which only one may be > 15 in TL (350 mm fork length [FL]).

The current regulatory structure and fishery management plan for rivers along the Nome Road system supporting Arctic grayling populations (DeCicco 2002a; Scanlon *In prep*) were constructed based on previous stock assessment research (Merritt 1989; DeCicco 1990-2000, 2002b). In the management plan, the Snake River has a specific abundance-based management objective of maintaining a population of 600 or more Arctic grayling greater than 15 in TL (350 mm FL) in a 16.2 km index area, and it has specific hypothesis test criteria for evaluation of abundance estimates. The management plan recommends periodic population assessments for the Snake River and other road-accessible streams to ensure that abundances are being maintained at or above prescribed levels. The Arctic grayling population in the Snake River was last assessed during 2001. Estimates of abundance of Arctic grayling ≥ 350 mm FL from previous assessments have ranged from 489 (SE = 108) in 1991 to 952 (SE = 93) in 2001 (DeCicco 1992-1995; Gryska 2004).

In the 10 years since the last stock assessment, the Snake River has been subject to increased development along the river. The Snake River Road was expanded and improved for the operation (2006–2008) of a large open-pit gold mine near the headwaters of the Snake River in the Rock Creek area. Although this mine is no longer active, it is for sale and a crew continues to monitor the mine, tailings storage pond, and injection wells. In 2005, a sport fish guiding operation specializing in fishing for trophy Arctic grayling in Seward Peninsula opened a small lodge on the Snake River as a base of operations. Due to development and lack of a recent stock assessment, this study was initiated to estimate abundance and size composition and evaluate the estimate of abundance relative to the management goal.

Table 1.–Estimated annual sport fishing effort (angler-days) for all species of fish, and estimates of sport fishing catch and harvest of Arctic grayling in the Snake River, Alaska, 1990–2009[1].

Year	Angler-days	Catch	Harvest
1990	775	199	116
1991	2,384	2,096	402
1992	2,379	158	16
1993	1,468	1,614	467
1994	880	377	32
1995	1,968	887	18
1996	1,269	1,055	121
1997	445	123	0
1998	376	218	8
1999	977	723	113
2000	377	449	16
2001	853	1,385	63
2002	514	279	110
2003	701	559	140
2004	468	238	91
2005	836	338	33
2006	855	262	0
2007	1,873	260	141
2008	1,740	234	34
2009	564	364	0
Average 2000–2009	878	437	63
Average 2005–2009	1,174	292	42

[1] Data from Scanlon (2011).

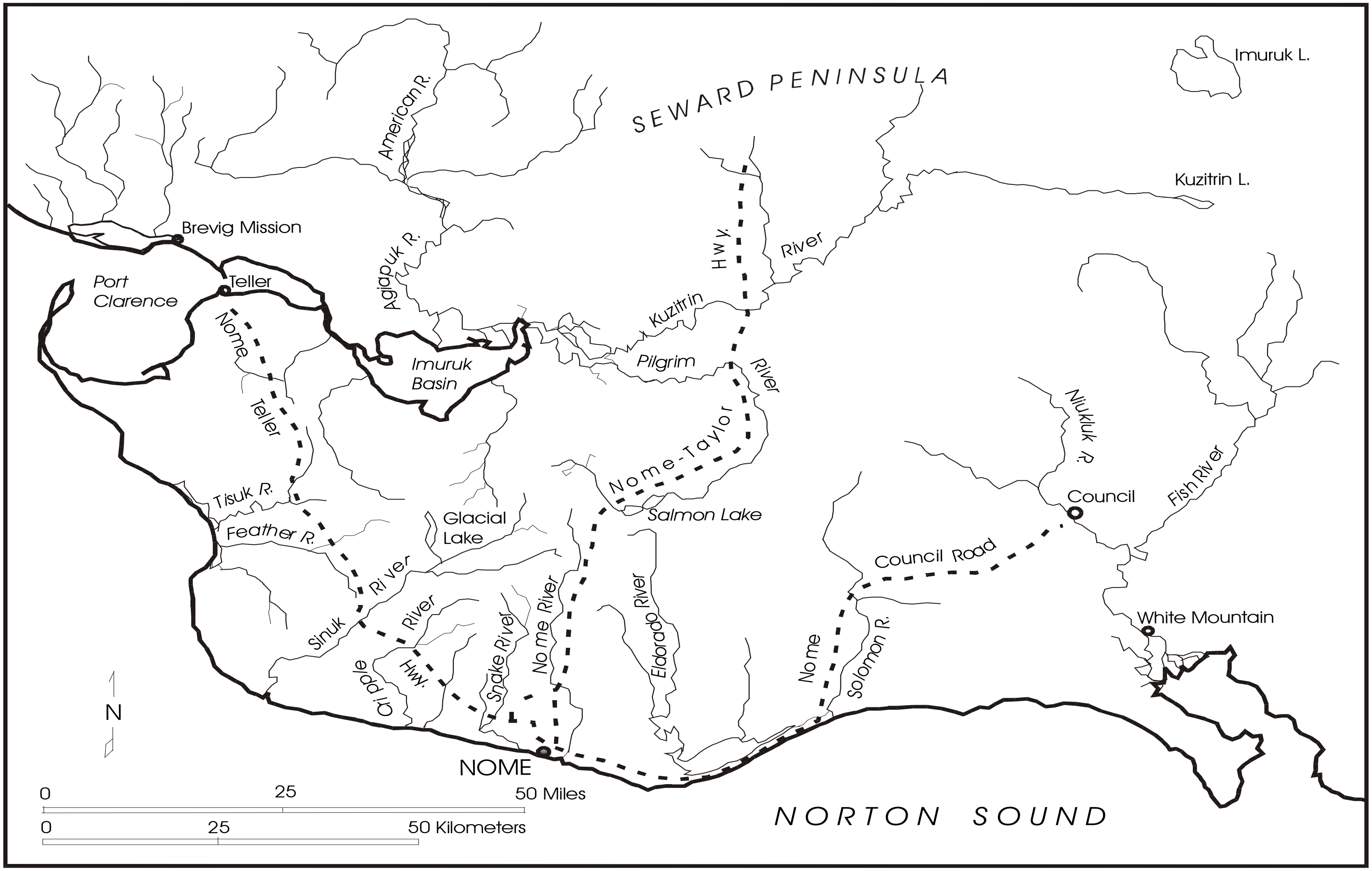

Figure 1.–Southern Seward Peninsula with road-accessible waters.

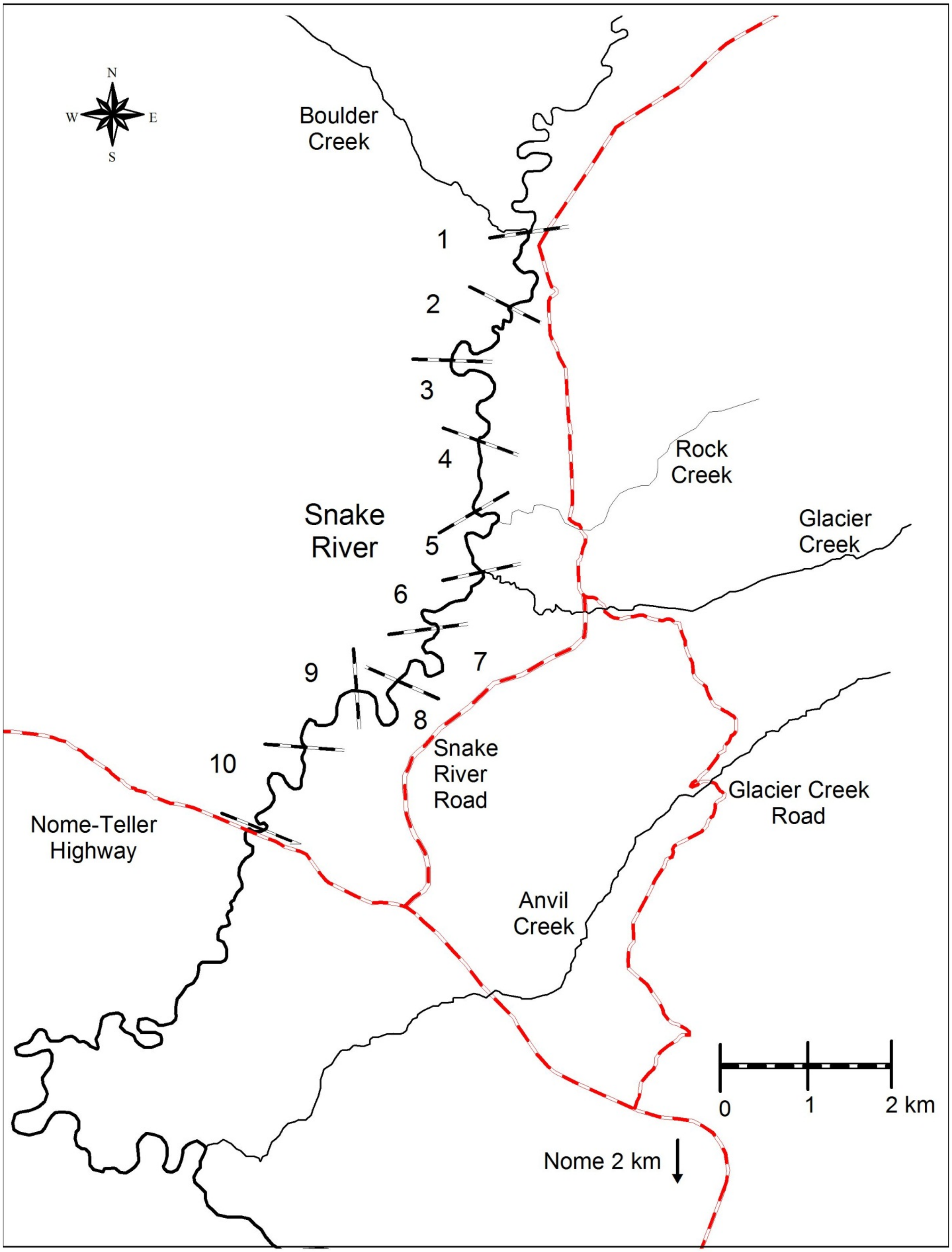

Figure 2.–Snake River study area with sample sections 1–10 denoted.

OBJECTIVES

The project objectives were to

1. estimate the abundance of Arctic grayling ≥ 350 mm FL in a 16.2 km index area of the Snake River such that the estimate was within 25% of the actual abundance 90% of the time;
2. test the null hypothesis that the abundance of Arctic grayling ≥ 350 mm FL in a 16.2 km index section of the Snake River during June was ≤ 360 with a 10% or less chance of taking a management action if the true abundance was ≥ 600 and an 85% or greater chance of taking a management action if the true abundance was ≤ 395 fish using alpha = 0.10; and
3. estimate the length composition in 25 mm length increments of Arctic grayling ≥ 350 mm FL in the Snake River index area in 2011 such that the estimates were within 10 percentage points of the true value 95% of the time.

Secondary objectives, or project tasks, were to

1. estimate the abundance of Arctic grayling ≥ 270 mm FL in the Snake River index area such that the estimate was within 25% of the actual abundance 90% of the time; and
2. estimate the abundance of Arctic grayling ≥ 330 mm FL in the Snake River index area such that the estimate was within 25% of the actual abundance 90% of the time.

The precision criterion for Objective 1 was established as a minimum standard regardless of population size and was thought to provide sufficient power for the hypothesis test in Objective 2.

The management action associated with Objective 2 is to close the fishery or restrict the fishery to catch-and-release fishing if abundance is less than 600 Arctic grayling ≥350 mm FL in the Snake River index area. The hypothesis test was designed with a very low probability (0.10) of experiencing a type II error (failure to reject the null hypothesis when it is false) when the abundance was near 600. In other words, a type II error is the null hypothesis (H_0: N $\leq$ 360) being accepted as true when the actual abundance was greater, resulting in an unnecessary management action being invoked to conserve the population by closing the fishery. On the other hand, there would be a high probability (85%) of a management action if the true abundance was ≤ 395 Arctic grayling.

Objective 3 provides an estimate of length composition of the population in the study area that is comparable to previous assessments. The length threshold identified in the objectives, 350 mm FL (15 in TL), is related to the regulations applied to the rivers along the Nome Road system (daily bag limit of 2 fish, of which only 1 can be > 15 in TL) and is used to determine, by way of Objective 2, whether the management objective has been reached.

For project tasks, abundance was also estimated for two additional length thresholds. The 270 mm length limit is a commonly used standard to compare populations and is often the size at which Arctic grayling are reliably recruited to sampling gear. The 330 mm length limit is the length at which Arctic grayling begin to be considered large by anglers and is also a standard used for comparing Interior Alaska fisheries. Because the length at which Arctic grayling recruit to the gear can range between 200 and 270 mm, all fish ≥ 200 mm FL were tagged in the event that abundance at a smaller size could be accurately estimated pending adequate samples.

METHODS

EXPERIMENTAL AND SAMPLING DESIGN

The study was designed to estimate abundance and length composition of Arctic grayling within the 16.2 km study area of the Snake River (Figure 2) using two-event Petersen mark–recapture techniques for a closed population (Seber 1982). The study was 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 whether the assumptions were met (Appendices A1, A2, and A3).

The study area was 16.2 km in length and divided into 10 sections of approximately 1.6 km each (Figure 2). The divisions served to guide sampling and provided a minimum geographic scale at which to conduct diagnostic tests. The first event occurred during June 23–25 and the second during June 28–30. During each event, 2 two-person crews sampled in a downstream progression, covering 2 to 4 sections a day (variation occurred due to logistical constraints, hydrologic conditions, and densities of Arctic grayling). Each day, crews were assigned one or more sections to capture fish using hook-and-line gear. The sampling schedule resulted in a 3-day hiatus between events or a 5-day hiatus for each specific reach of river sampled, which was deemed long enough to ensure that capture probabilities of marked fish were not affected in the second event due to handling and tagging (DeCicco 1997). The distribution and allocation of sampling effort were planned to ensure adequate sample sizes were attained, no segments of the population were isolated from the experiment, and the study area was sampled uniformly.

The relatively short duration (9 days) and timing (summer) of the experiment minimized or eliminated bias associated with movements into or out of the study area. The short duration of the hiatus minimized potential bias due to growth recruitment and mortality, allowed for localized mixing of marked and unmarked fish to eliminate pockets of fish isolated from the sampling gear, and let marked fish adequately recover from the effects of handling between events. Studies have demonstrated that movements of Arctic grayling tend to be at a much smaller scale during the midsummer feeding period (generally defined as mid-June to August), as compared to post-summer and post-winter migrations associated with spring-spawning and overwintering (Tack 1973; Ridder 1998a-b; Gryska 2006). In addition, the movements of recaptured individuals were analyzed to evaluate the appropriateness of the assumption of closure.

During each event, the upper boundaries of individual sampling sections were reached by floating in an inflatable canoe. Upon reaching the starting point of a section, crews waded through their assigned section to angle and sample fish. All waters were angled in an effort to subject all fish to capture, and the daily effort was adjusted such that areas of high fish densities were fished for longer periods than low-density areas to subject fish to more similar capture probabilities. Areas of higher fish densities were identified by visually observing aggregations of Arctic grayling and by evaluating catch rates and preferred habitat (e.g., heads of pools). Terminal fishing gear consisted of a combination of flies (dry and wet) and rubber-bodied jigs. The degree to which each gear was used was left to each angler’s discretion. Typically, jigs were used most often. At each angling location, captured Arctic grayling were temporarily held 1–10 minutes in a five-gallon bucket until data were collected. Sampled fish were generally released at or within 25 m of their capture locations, and in no cases were fish displaced by more than 100 m from their capture location.

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

DATA COLLECTION

All fish were measured for length (mm FL) and carefully examined for marks. In the first event, all fish ≥ 200 mm FL were tagged with an individually numbered Floy[1] FD-94 internal anchor tag (brown color, white print, numbered between 1,179–1,200; 1,276–1,300; 5,902–5,925; 6,617–6,650; 6,901–6,918; and 6,926–6,975) placed at the insertion of the dorsal fin so that the tag locked between the posterior interneural rays, and received an upper caudal finclip to identify tag loss. To eliminate duplicate sampling in the second event, all fish received a lower caudal finclip. All fish in both events were carefully inspected for attendant Floy tags and finclips and their capture/release locations were recorded using a GPS (latitude and longitude coordinate as decimal degrees, NAD27 Alaska datum). Fish captured in the first event that exhibited signs of injury, excessive stress, or imminent death were not marked and were censored from the experiment.

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[1] Product names are included for completeness but do not constitute endorsement.

Data Analysis

Abundance Estimate

When capturing fish in a river using angling equipment, it is inherently difficult to approximate the taking of a simple random sample (i.e., a random sample without replacement). Therefore, samples from the Snake River were taken systematically in the sense of progressively moving downstream and sampling proportionally to the abundance of fish present (discussed above with respect to Assumption 2). 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.

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

Violations of Assumption 2 relative to size were evaluated using Kolmogorov–Smirnov (K–S) two-sample tests with a significance level of $\alpha = 0.05$. 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 had size selectivity) 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 were examined for each length stratum.

The tests for consistency of the Petersen estimator (Seber 1982; Appendix A3) were used to determine if, for each identified length stratum, 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). Documentation of release location by section for each fish permitted the examination of multiple geographic stratification schemes for purposes of assumption testing, and testing was performed at the scale of a cluster defined by grouping of adjacent angling sections (sections 1–5 and 6–10), which corresponded to upstream and downstream of the Glacier Creek tributary as well to the previous study's groupings (Gryska 2004). This grouping strategy also provided a sufficient number of recaptures for diagnostic testing to ensure negligible statistical bias in $\hat{N}$ (Seber 1982) and accommodated localized movements (i.e. within a 1 km radius) of Arctic grayling.

Length Composition

Length composition of the population was estimated in 25 mm length categories using the procedures outlined in Appendix A4.

RESULTS

Movement

Because fish were released relatively close to their capture location (within about 25 m), movement was defined as a fish that was recaptured $\geq$ 0.5 river km from its release location. Using this definition of movement, 42 of the 46 (91%) recaptured Arctic grayling did not move from their release location (Appendix B1). The average distance moved by recaptured Arctic grayling was 83 m, with a range of 370 m downstream and 1,600 m upstream. The lack of any large or directional movements indicated that no meaningful immigration or emigration occurred during the experiment.

Abundance Estimate

In the 16.2 km study area, 341 Arctic grayling were captured (n_1 = 164, n_2 = 177, m_2 = 46), and one hooking mortality occurred during the second event. Abundance was only estimated for fish ≥ 350 mm FL because no fish < 350 mm FL were caught and the smallest recaptured fish was 356 mm FL. Results of K–S tests (Appendix A2) were Case I for Arctic grayling ≥350 mm FL (Table 2), which indicated that there was no size-selective sampling during both events. The entire data set was used without length stratification to estimate abundance, and data from both events were pooled for composition estimates. Consistency tests (Appendix A3) of capture probability during each event failed to be rejected (Tables 2–4), although the test of mixing did fail. Therefore, there was no need to geographically stratify the data, and the Bailey-modified Petersen estimator was used to calculate an abundance estimate. Estimated abundance within the 16.2 km study area was 621 (SE = 77) Arctic grayling ≥ 350 mm FL. Relative to objective 2, the null hypothesis was strongly rejected (z = 3.39; P-value < 0.001). In addition, the lower limit of the 90% confidence interval for the abundance estimate (90% CI = 495–748) far exceeded 360 fish. A substantial proportion (86%) of the estimated population of Arctic grayling was 375 to 474 mm FL (Table 5).

Table 2.–Results of diagnostics used to detect and correct for size-selective sampling (Appendix A2) for estimating abundance and length compositions of Arctic grayling in the Snake River, June 2011.

	Comparison and Test Statistic			
Stratum	M vs. R	C vs. R	M vs. C	Result
≥350 mm FL	D = 0.081 P-value = 0.943 Fail to reject H_0	D = 0.122 P-value = 0.528 Fail to reject H_0	D = 0.068 P-value = 0.766 Fail to reject H_0	Case I, do not stratify, use lengths 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 Snake River, June 2011.

	Consistency Test		
	I	II	III
Stratum	Complete Mixing	Equal probability of Capture, 1st Event	Equal Probability of Capture, 2nd Event
≥350 mm FL	$\chi^2 = 42.18$ P-value < 0.01	$\chi^2 = 0.12$ P-value = 0.73	$\chi^2 = 2.09$ P-value = 0.15

Table 4.–Number of Arctic grayling ≥ 350 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by cluster in the Snake River study area, June 2011.

		Cluster where recaptured				
		I	II	m_2	n_1	m_2/n_1 [c]
Cluster [a] where marked	I	18	0	18	79	0.23
	II	1	27	28	85	0.33
m_2		19	27			
n_2		77	100			
(m_2/n_2) [b]		0.25	0.27			

[a] Cluster refers to a grouping of adjacent sections: Cluster I = Sections 1-5; Cluster II = Sections 6-10.
[b] Estimated probability of capture during first event.
[c] Estimated probability of capture during second event.

Table 5.–Number of representative fish sampled (n), sample proportion (p), and estimated abundance ($\hat{N}_k$) by length category for the population of Arctic grayling (≥ 350 mm FL) in the Snake River, June 2011.

Length (mm FL)	n	p	SE[p]	$\hat{N}_k$	$\hat{SE}\left[\hat{N}_k\right]$
350–374	18	0.053	0.0121	33	9
375–399	53	0.155	0.0196	97	17
400–424	68	0.199	0.0217	124	20
425–449	97	0.284	0.0245	177	27
450–474	74	0.217	0.0224	135	22
475–499	28	0.082	0.0149	51	11
500–525	3	0.009	0.0051	5	3

DISCUSSION

The 2011 estimate of abundance for Arctic grayling ≥ 350 mm FL (621 Arctic grayling; 90% CI = 495–748) exceeded the management objective for the index area of the Snake River (600 Arctic grayling ≥ 350 mm FL). Although the estimate was only slightly larger than the management objective, it was sufficiently precise (within 20% of the true value 90% of the time). In fact, 48% (295 Arctic grayling) of the estimated population was captured during both events combined. Therefore, the population estimate had a very high probability (> 99.9%) of exceeding 360 Arctic grayling (H_0) and there was essentially no risk of erroneously closing the fishery when population level was in fact satisfactory.

It is recommended that the abundance of Arctic grayling in the Snake River be monitored more frequently than once every ten years (last estimate in 2001) because the 2011 estimate was near the prescribed management guidelines, the population is relatively small and can be easily overexploited, and effort may increase. The abundance estimate for 2011 was within the range of previous estimates but was significantly less than the most recent estimate of 2001 (Table 6). Because the 2011 abundance was near 600 fish, natural variation and fishing pressure could easily and quickly reduce abundance to a level of concern. As was postulated by Gryska (2004), fluctuations in Arctic grayling abundance in Nome areas rivers can be strongly influenced by episodic recruitment, which is the infrequent appearance (i.e., once every 5 or 10 years) of a strong cohort that sustains the population for several years. The prolonged absence of a strong recruitment event when combined with increasing harvests causes the risk of overexploitation to be magnified. In some years, harvests of Arctic grayling in the Snake River are quite large relative to the estimated abundance in 2011. Although there has been no clear increasing trend in effort or harvest, there has been a notable increase in activity along the Snake River relative to mining activity and new guide operators. Moreover, with its improved access, proximity to Nome, and increasingly higher fuel prices, the Snake River will continue to be an attractive angling destination.

Table 6.–Estimates of abundance ($\hat{N}$) of Arctic grayling ≥ 350 mm FL in the 16.2 km study area of the Snake River, 1991–1994, 2001, and 2011.

Year	$\hat{N}$	$\hat{SE}[\hat{N}]$	90% CI
1991	489	109	310 – 668
1992	560	78	432 – 688
1993	609	70	494 – 724
1994	664	177	373 – 955
2001	952	93	799 – 1,105
2011	621	77	495 – 748

ACKNOWLEDGEMENTS

The author thanks Dan Reed, Jiaqi Huang, Brendan Scanlon, and Josh Muhlstein for their assistance in sampling and logistical support. Thanks are due to Don Roach, Matt Evenson, and Klaus Wuttig for their supervisory support; Rachael Kvapil for the editing and formatting of this report for publication; and Jiaqi Huang for his biometric review. This project and report were made possible by partial funding provided by the U.S. Fish and Wildlife Service through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under project F-10-27, Job No. R-3-2(e).

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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 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:

$$\hat{N} = \frac{n_1(n_2+1)}{m_2+1}, \tag{A1-1}$$

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.

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \tag{A1-2}$$

Appendix A2.–Detection of size- and/or sex-selective sampling during a two-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size-selective sampling: The Kolmogorov–Smirnov two-sample test (Conover 1980) is used to detect significant evidence that size-selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated 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) by using the null test hypothesis 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. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex-selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex-selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g. Student's *t*-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o
There is no size/sex-selectivity detected during either sampling event.		
Case II:		
Reject H_o	Fail to reject H_o	Reject H_o
There is no size/sex-selectivity detected during the first event but there is during the second event sampling.		
Case III:		
Fail to reject H_o	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.		
Case IV:		
Reject H_o	Reject H_o	Either result possible
There is size/sex-selectivity detected during both the first and second sampling events.		
Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is probably detecting small differences that have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R *p*-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R *p*-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was probably the result of size/sex-selectivity during the second event that the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

-continued-

C. If a) sample sizes for C vs. R are small, b) the C vs. R *p*-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was probably the result of size/sex-selectivity during the first event that the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R *p*-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex-selectivity during both events that the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. 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.

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

Case IV. 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.

If stratification by sex or length is necessary prior to estimating composition parameters, then overall composition parameters (p_k) is estimated by combining within stratum composition estimates using

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ ; and} \tag{A2-1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \sum_{i=1}^{j} \left(\hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k\right)^2 \hat{V}[\hat{N}_i] \right). \tag{A2-2}$$

where j = the number of sex/size strata;

$\hat{p}_{ik}$ = the estimated proportion of fish that were age or size *k* among fish in stratum *i*;

$\hat{N}_i$ = the estimated abundance in stratum *i*; and,

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

Appendix A3.–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	**A**	**B**	**…**	**F**	(n_1-m_2)
A					
B					
...					
F					

II.–Test for equal probability of capture during the first event [b]

	Section Where Examined			
	A	**B**	**…**	**F**
Marked (m_2)				
Unmarked (n_2-m_2)				

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

	Section Where Marked			
	A	**B**	**…**	**F**
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 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 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 A4.–Equations for estimating length composition and their variances for the population.

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

$$\hat{p}_k = \frac{n_k}{n} \tag{A4-1}$$

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 capture events are used.

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

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1}. \tag{A4-2}$$

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

$$\hat{N}_k = \hat{p}_k \hat{N}, \tag{A4-3}$$

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):

$$\hat{V}\left[\hat{N}_k\right] = \hat{V}[\hat{p}_k]\hat{N}^2 + \hat{V}\left[\hat{N}\right]\hat{p}_k^2 - \hat{V}[\hat{p}_k]\hat{V}\left[\hat{N}\right]. \tag{A4-4}$$

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

$$\hat{\mathrm{p}}_{\mathrm{jk}} = \frac{\mathrm{n}_{\mathrm{jk}}}{\mathrm{n}_{\mathrm{j}}} \tag{A4-5}$$

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*.

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:

-continued-

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk} \hat{N}_j \tag{A4-6}$$

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):

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s} \left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right]\right). \tag{A4-7}$$

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

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \tag{A4-8}$$

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

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

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s} \left\{ \left(\frac{\hat{N}_j}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{jk}\right] \right\} + \frac{\sum_{j=1}^{s} \left\{ \hat{V}\left[\hat{N}_j\right] \left(\hat{p}_{jk} - \hat{p}_k\right)^2 \right\}}{\hat{N}^2}. \tag{A4-9}$$

APPENDIX B: MOVEMENTS OF ALL RECAPTURED FISH

Appendix B1.–Length (mm FL), section marked, section recaptured, and distance moved between sampling events for each recaptured Arctic grayling, Snake River, 2011.

Floy tag number	Length (mm FL)	Section marked	Section recaptured	Distance moved (m)
6628	492	1	1	-50
6642	440	2	2	-40
6641	492	2	2	-40
6639	396	2	2	-350
6635	472	2	2	0
6634	464	2	2	0
1185	448	2	2	240
1183	478	2	2	240
6934	450	2	2	-30
3933	372	2	2	-30
6932	480	2	2	-30
1198	356	3	2	880
1192	453	3	3	0
6974	415	5	5	0
6972	370	5	5	-60
6968	485	5	5	210
6967	435	5	5	0
6965	430	5	5	0
6962	415	5	5	330
6961	375	5	5	-40
6958	445	5	5	-370
1292	447	6	5	1,600
1297	452	6	6	-30
1293	408	6	6	-230
1288	418	6	6	0
5923	437	6	7	-240
5921	403	6	7	1,490
6975	436	7	7	0
6945	480	7	7	0
6940	380	7	7	-310
6937	478	7	7	120
6935	405	7	7	-40

-continued-

Floy tag number	Length (mm FL)	Section marked	Section recaptured	Distance moved (m)
6928	437	7	7	0
5919	453	8	7	150
5918	428	8	8	0
5912	421	8	8	480
5914	446	8	9	510
5911	434	9	9	-270
5910	491	9	9	0
5909	392	9	9	0
6913	440	10	10	0
6912	380	10	10	-100
6909	417	10	10	-150
6625	452	10	10	0
6619	457	10	10	50
5905	418	10	10	-60
			Average	83.3
			SD	383.7

APPENDIX C: DATA FILE LISTING

Appendix C1.–Data files[a] for population estimate of Arctic grayling captured in the Snake River, 2011.

File Name [a]
Snake River Arctic grayling population estimate data files for archive-2011.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.