Fishery Data Series No. 04-15

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

by

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September 2004

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 SERIES NO. 04-15

ABUNDANCE AND LENGTH AND AGE COMPOSITION OF ARCTIC GRAYLING IN THE SNAKE RIVER, 2001

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ABSTRACT

A mark-recapture experiment was conducted along a 14.7-km (9.1-mi) section of the Snake River during August 2001 to estimate abundance and length and age composition of Arctic grayling *Thymallus arcticus.* This population is periodically assessed to ensure that it is sustained at or above a management-prescribed level of 600 fish ≥ 350 mm FL. This population was last assessed during 1994. Using hook-and-line gear and beach seines, 565 fish were captured. Movement of tagged fish between geographic strata was observed and a partially-stratified Darroch estimator was used to estimate abundance. Abundance was estimated at 1,116 (SE = 116) Arctic grayling ≥ 250 mm FL and 952 (SE = 93) Arctic grayling ≥ 350 mm FL. Most (73%) captured fish ranged from 360 to 439 mm FL, and most (85%) fish were ≥ age-7. Typical of many Arctic grayling populations, ages > 8 are difficult to determine accurately.

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

INTRODUCTION

The Seward Peninsula of western Alaska has many rivers and streams that are easily accessible by way of an extensive road system (approximately 420 km in length), which emanates from Nome (Figure 1). Most streams along this road system support some angling effort for Arctic grayling, including the Snake River, by many of the 9,200 residents of the Nome census area (U.S. Census Bureau 2001), as well as numerous tourists.

The Snake River is approximately 57 km in length and drains an area south of the Sinuk River between the Nome River to the east and the Cripple River to the west and enters the Bering Sea at Nome (Figure 1) where it serves as the port for Nome. The Snake River is accessible from the Nome-Teller Highway where it crosses the river and from Glacier Creek road, a gravel road that parallels much of the upper river (Figure 2).

Between 1996 and 2000, the Snake River averaged 698 angler days of fishing effort, 52 Arctic grayling harvested, and 513 Arctic grayling caught (Table 1; Howe et al. 1995-1996, 2001a-d). Since 1993, the Snake River has had a bag limit of 2 fish/day of which only one may be > 15 in TL (350 mm FL). The Snake River and many other Nome area streams are known for producing large Arctic grayling and the 15-in length restriction was implemented to afford some protection of these larger fish. In general, streams with roadside access have more stringent regulations (5 grayling/day and only one may be ≥ 15 in TL) than the background 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).

Concurrent with this study was the development of a management plan for several of the Nome area streams, including the Snake River (DeCicco 2002a). In this plan, a management objective for maintaining a minimum abundance of 600 Arctic grayling ≥ 15 in TL (350 mm FL) was established in an index area 14.7 km in length bounded by Boulder Creek and the Nome-Teller Highway. This objective was established based on assessments conducted between 1991 and 1994 (Table 2). These previous assessment (index) areas ranged between 28 and 48 km in length and were divided into 4 or 5 sections. The index section for this study was reduced to 14.7 km because: 1) it corresponded to the area of the management objective for the river and two sections of the previous assessment area, which facilitated direct comparisons; 2) it contained most of the previously assessed populations; and, 3) it receives most of the fishing pressure. Due to the Snake River's accessibility, sustained effort, and relatively small population, DeCicco (2002a) also recommended assessments of the Snake River population be conducted every

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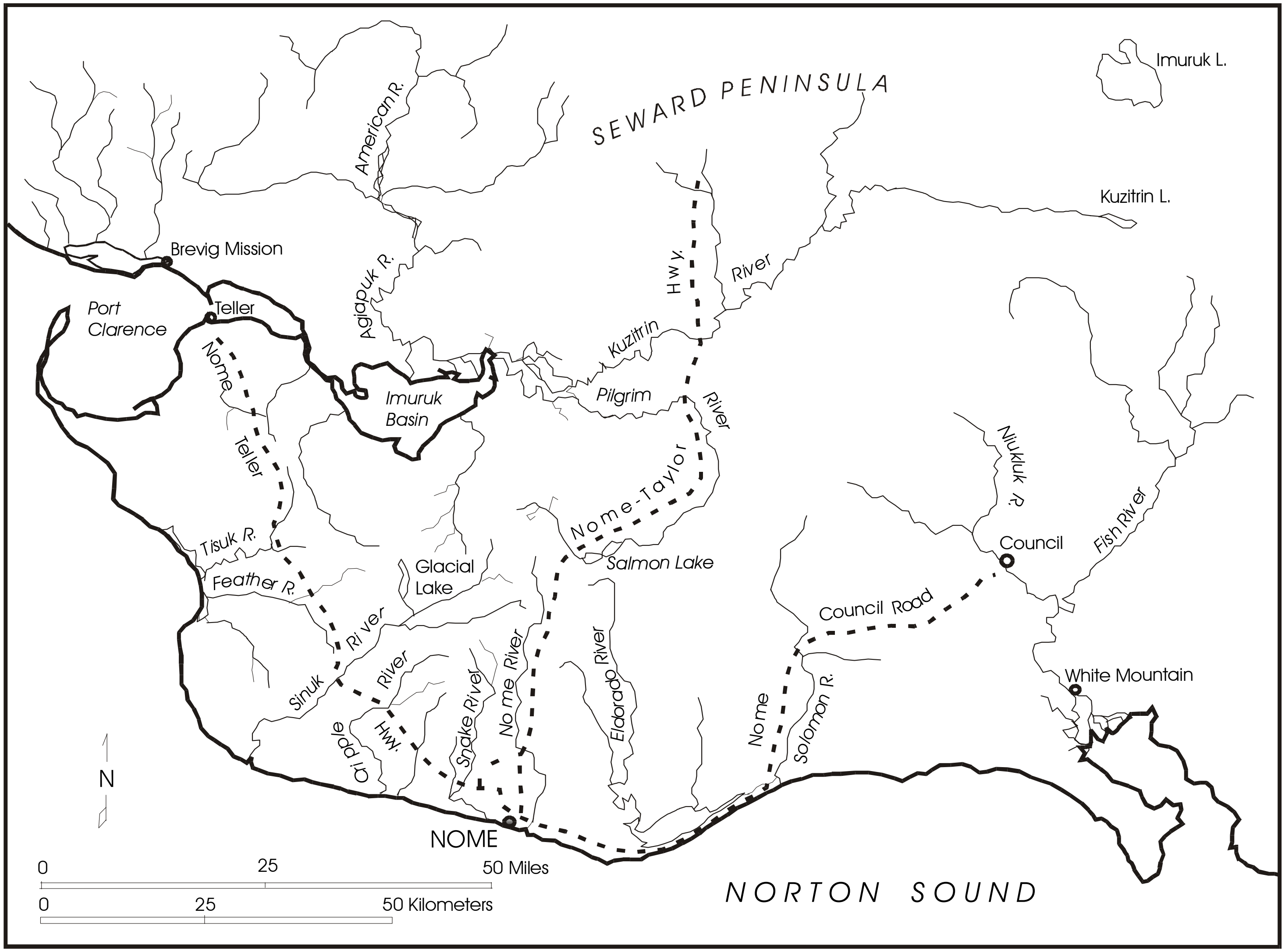

Figure 1.-Southern Seward Peninsula with road accessible waters.

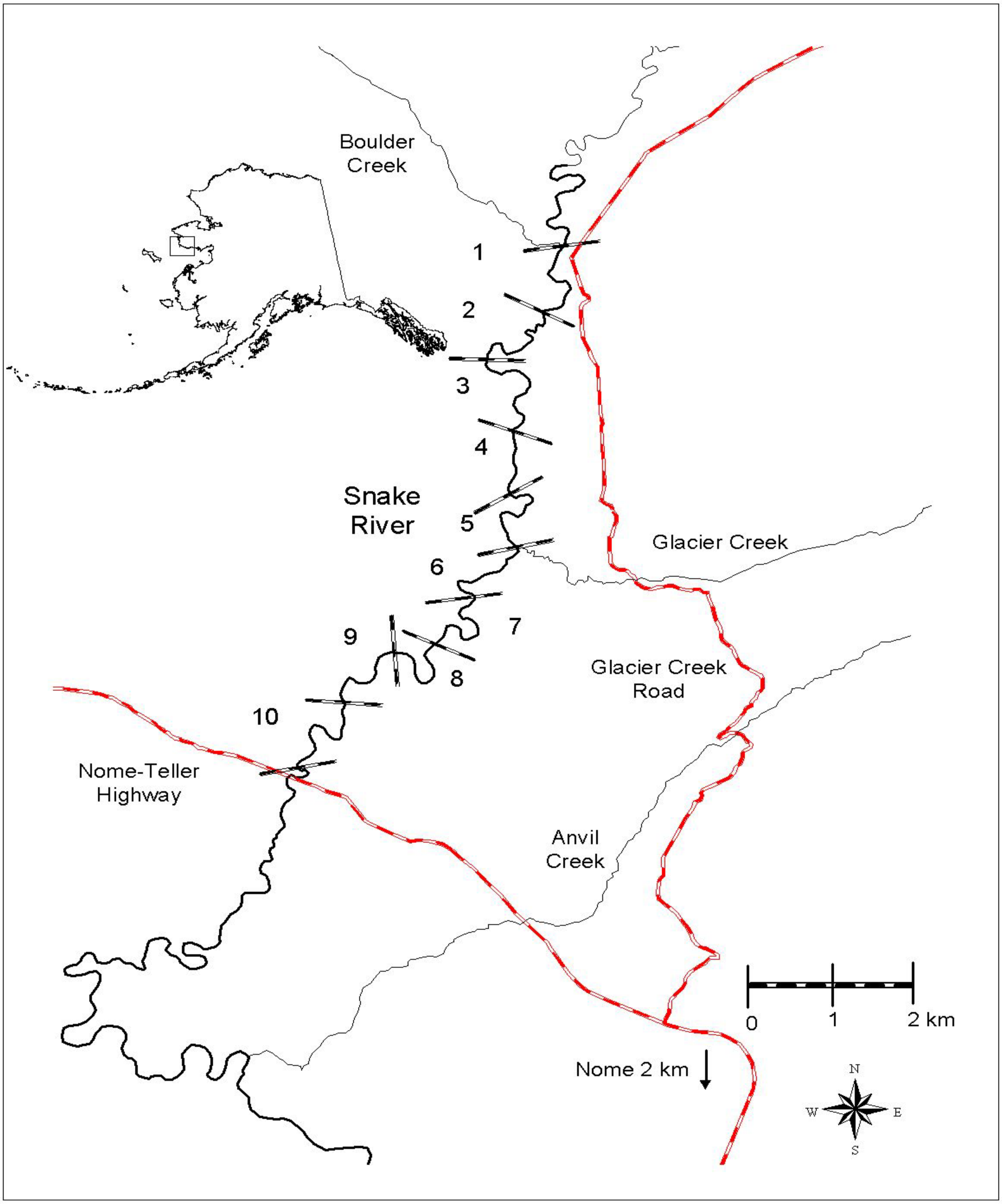

Figure 2.–Snake River and study area with sections 1-10**.**

Table 1.–Number of anglers, days fished, catch, and harvest of Arctic grayling from the Snake River, 1983 – 2000.

Year	Number Anglers	Days Fished	Catch[a]	Harvest
1983	0	119		278
1984	245	418		26
1985	129	361		139
1986	136	850		378
1987	No estimate[b]	No estimate[b]		No estimate[b]
1988	340	2,128		709
1989	148	436		101
1990	298	775	199	116
1991	647	2,384	2,096	402
1992	461	2,379	158	16
1993	622	1,468	1,614	467
1994	341	880	377	32
1995	640	1,968	887	18
1996	433	1,296	1,055	121
1997	235	445	123	0
1998	164	376	218	8
1999	313	977	723	113
2000	197	397	446	16
1983-2000 Average	315	1,039		173
1991-2000 Average	405	1,257	770	119
1996-2000 Average	268	698	513	52

Data from: Mills 1984-1994; Howe et al. 1995-1996, 2001a-d.

[a] No data available for catch prior to 1990.

[b] Estimates not made due to insufficient number of households reporting fishing at this location for 1987.

Table 2.–Estimated abundance, SE, length of study section, and number of fish/km for Arctic grayling in the Snake River during 1991, 1992, 1993, and 1994.

Year	Abundance	SE	River Segment	Fish/km
1991[a]	1,109	160	28 km	40/km
1992[b]	2,418	200	48 km	50/km
1993[b]	1,761	129	48 km	36/km
1994[b]	1,379	166	48 km	28/km

Data from: DeCicco 1992-1995.

[a] Abundance estimate for Arctic grayling ≥ 270 mm FL.

b Abundance estimate for Arctic grayling ≥ 250 mm FL.

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 Snake River in the 14.7-km index area to establish whether or not the population was at or above the prescribed level of ≥ 600 Arctic grayling ≥ 15 in TL (350 mm FL).

OBJECTIVES

The project objectives were to estimate:

1. the abundance of Arctic grayling ≥ 250 mm FL in a 14.7-km (9.1-mi.) section of the Snake River such that the estimate was within 25% of the actual abundance 95% of the time;
2. the length composition of Arctic grayling ≥ 250 mm FL for given FL ranges such that the estimates were within five percentage points of the true value 95% of the time in a 14.7-km (9.1-mi.) section of the Snake River; and,
3. the age composition of Arctic grayling ≥ 250 mm FL for given FL ranges such that the estimates were within five percentage points of the true value 95% of the time in a 14.7 km (9.1-mi.) section of the Snake River.

METHODS

SAMPLING DESIGN AND FISH CAPTURE

In 2001, the Snake River Arctic grayling study was designed to estimate abundance and length and age composition of Arctic grayling within the 14.7-km study area by conducting a two-event mark-recapture experiment. The first (marking) event occurred during August 1-4 and the second (examination) event during August 6-8. The study area was broken into 10 sampling sections ranging from 1.0 to 1.7 km in length (Figure 2) to facilitate the distribution of sampling effort and to provide a minimum scale at which capture probabilities could be examined.

During each event, the sections were sampled sequentially beginning with the upper-most section at Boulder Creek. Each day, a 2- to 5-person crew expended approximately 8-hours of sampling effort to sample two to three sections (Appendix A1). During the first event, a beach seine (50 m x 2 m, 6.5-mm mesh) and hook-and-line gear (fly-fishing and spin fishing) were used to capture fish. During the second event, only hook-and-line gear was used. When angling, a variety of terminal gears (flies or jigs) was utilized. The choice of terminal gear was left to the discretion of each angler.

In the first event only, fish ≥ 250 mm FL were marked (primary) with an individually-numbered anchor tag (Floy FD 94). Additionally, a secondary mark (removal of scales for aging at a standardized location) was used to identify loss of the primary mark during the second event. In the second event, fish were not tagged, but a partial lower caudal 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.

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:

$$\hat{N}_1 = \frac{n_1 n_2}{m_2}, \tag{1}$$

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;

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 1998; 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 the assumption of closure.

To ensure that Assumption 2 was met, an attempt was made 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. Specifically, we sampled for longer periods in areas where densities appeared relatively high (e.g., glides and pools) and for shorter periods where few fish appeared to be available (e.g., slack water areas and riffles). Because Arctic grayling move little during mid-summer, complete mixing of marked and unmarked fish within the study area was not expected; 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 (K-S) 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 B1. 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 B2).

Relative to Assumption 3, a hiatus of three to five 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 scale removal, and all fish caught in the second event were carefully examined for marks.

Documentation of release location for each fish permitted the examination of multiple geographic stratification schemes for purposes of assumption testing. Criteria considered when defining geographic strata included physical characteristics of the river, number of recaptures per stratum, stratum length, and sampling effort. Physical characteristics such as discharge and availability of pool habitat are related to changes in Arctic grayling size composition and density. When estimating abundance it is preferred to have a minimum number of recaptures (approximately 7 fish) to ensure negligible bias in $\hat{N}$ (Seber 1982). Strata length was considered and sections longer than approximately 2 km were preferred to accommodate localized movements of Arctic grayling (e.g., approximately 1-2 km). Finally, differential application of sampling effort, such as a change in gear type or crew size for a portion of the sampled area, was considered as a basis of stratification.

Length and age composition of the population were estimated using the procedures outlined in Appendix B3.

DATA COLLECTION

All captured Arctic grayling were processed immediately or soon after capture and released at or very near their capture location. After each fish was caught, crews collected and recorded data for date, location, crew, fork length, scale samples, old fin clips, tag number, tag color, recapture status, and mortality. Floy tags were gray and were numbered between 551 and 600 and between 604 and 895. Two scales were removed for aging from all fish caught during the first and second events and stored in coin envelopes. Data were recorded onto coin envelopes and then into field notebooks. These data were later entered into an MS Excel spreadsheet for analyzing and archiving (Appendix C1).

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 (W. 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 gummed 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

Five hundred sixty-five Arctic grayling (≥ 250 mm FL) were captured. One fish was caught twice within the same event and 1 captured fish died from handling during the second event. Of the 564 unique fish ≥ 250 mm FL, 360 were captured during the first event (marked or n_1), 204 during the second event (examined or n_2), and 69 fish were marked in the first event and recaptured in the second event (recaptured or m_2). The smallest fish marked during the first event was 258 mm FL, examined during the second event was 278 mm FL, and recaptured was 330 mm FL. During the second event, one recaptured fish in section 1 was released before its tag number and marking location were identified. Thirty-four fish (6%) carried marks from previous studies on the Snake River.

ABUNDANCE ESTIMATE

The sampling design and the results of the testing procedures (Appendices B1 and B2) determined that: 1) stratification by size was not required; 2) geographic stratification using two strata was required; and, 3) there was movement between the two geographic strata. Therefore, the partially-stratified Darroch estimator (Darroch 1961) was used to estimate abundance of fish ≥ 250 mm FL.

Although the smallest recaptured fish was 330 mm FL, the 250-mm lower boundary defined in the objectives was retained because: 1) fish as small as 258 mm FL were sampled demonstrating that above this boundary Arctic grayling were recruited to the gear; 2) the same gear was used to catch fish as small as 225 mm FL in experiments on the Snake River in the early 1990s (DeCicco 1993) and, 3) the absence of smaller-sized recaptures (i.e., <330) during the second event was a function of their relatively low density in the population (only 5 fish <320 mm FL were marked resulting in a high probability (>30%) that no marked fish <320 mm FL would have been recaptured during the second event).

Size stratification was not necessary because K-S tests indicated that the length composition of fish ≥ 250 mm FL marked in the first event did not differ significantly from fish examined during the second event (D = 0.08; P-value = 0.36; Figure 3) or from fish recaptured during the second event (D = 0.09; P-value = 0.61; Figure 3). The latter test result showed that the probability of capture during the second event did not vary by size, which supported setting the minimum size limit at 250 mm FL.

Of the 68 fish with known release and recapture locations, 57 (84%) were recaptured within the same section in which marked. Of the 11 fish that moved outside their original marking section, four moved upstream and seven moved downstream (Table 3).

Initially, the tests of consistency were conducted at the smallest geographic scale (10 sections). At this scale, mixing of fish between sections was not complete (P-value < 0.01; Table 3), first event capture probabilities were not equal between sections (P-value < 0.01; Table 4), and the statistical significance of the second event capture probabilities by sections was dependent on the assignment of the recaptured fish with an unknown tag number to a marking section. Assigning this fish to various marking locations throughout the study area resulted in P-values that ranged from 0.09 to 0.23, and 0.14 when not included (Table 5). Due to the uncertainty of assigning this

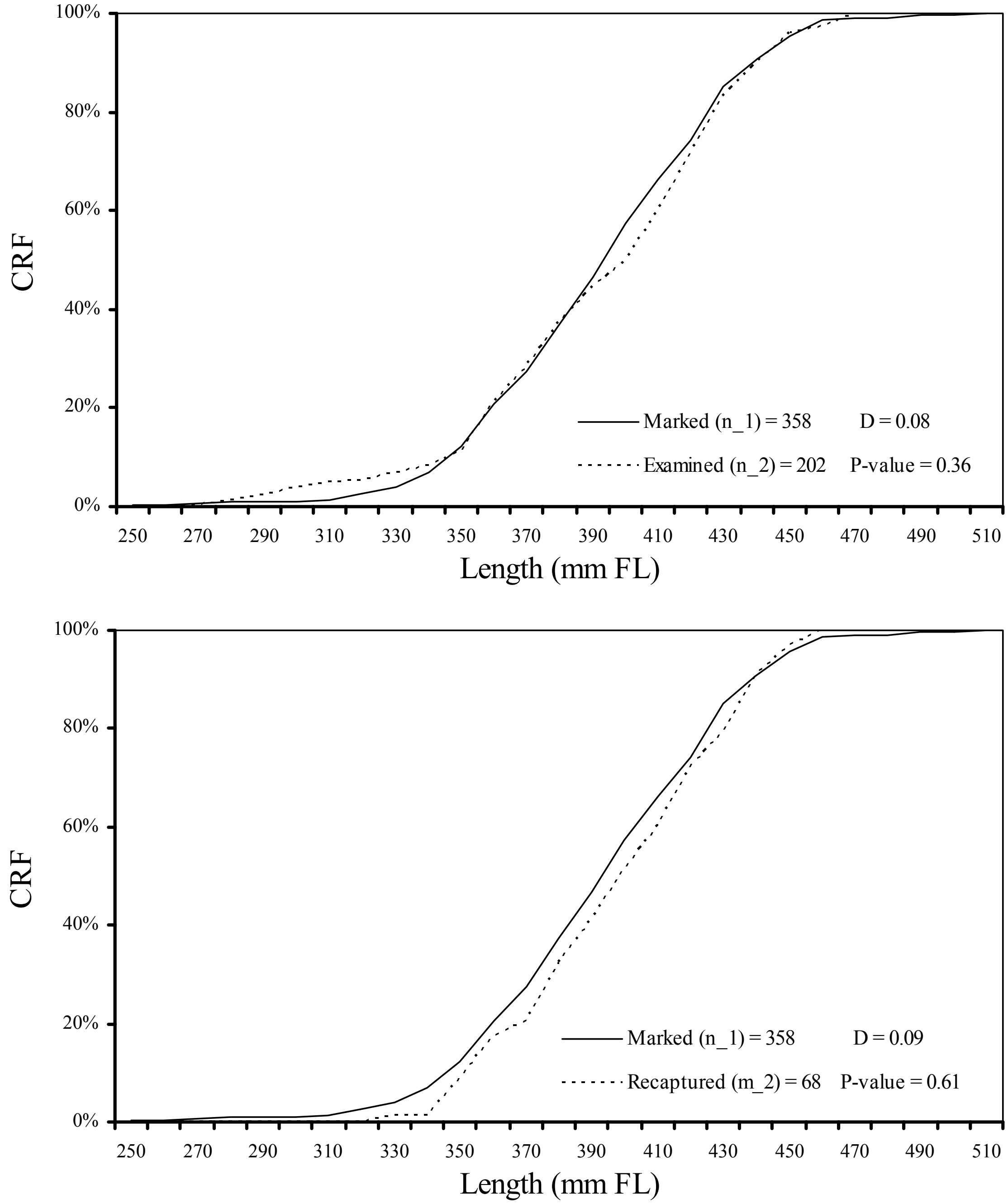

Figure 3.–Cumulative relative frequency (CRF) of Arctic grayling ≥ 250 mm FL marked and examined (upper panel) and marked and recaptured (lower panel), Snake River, August 2001.

Table 3.–Test for complete mixing. Number of Arctic grayling ≥ 250 mm FL marked in each section (1 - 10) and recaptured or not recaptured in each section of the Snake River, August 2001.

	Section Where Recaptured											
Section Where Marked	1	2	3	4	5	6	7	8	9	10	Not Recaptured (n_1-m_2)	Marked (n_1)
1	1[a]										7	8
2		1									16	17
3			5								23	28
4				4		1					34	39
5				1	4						30	35
6					1	7		1			48	57
7						2	11	1			34	48
8								16			37	53
9								3	3	1	36	43
10										6	26	32
Total	1	1	5	5	5	10	11	21	3	7	291	360

χ^2 = 418.06; df = 90; P-value < 0.01; reject H_0.

[a] Marking location of this fish was uncertain, but was placed in section 1 of this table.

Table 4.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥ 250 mm FL examined during the second event by section (1 – 10) of the Snake River, August 2001.

	Section Where Examined										
Category	1	2	3	4	5	6	7	8	9	10	All Sections
Marked (m_2)	1	1	5	5	5	10	11	21	3	7	69
Unmarked (n_2-m_2)	7	15	10	7	10	24	16	9	9	28	135
Examined (n_2)	8	16	15	12	15	34	27	30	12	35	204
$P_{capture}$ 1st Event (m_2/n_2)	0.13	0.06	0.33	0.42	0.33	0.29	0.41	0.70	0.25	0.20	0.34

χ^2 = 29.21; df = 9; P-value < 0.01; reject H_0.

Table 5.-Test for equal probability of capture during the second event. Number of Arctic grayling ≥ 250 mm FL marked by section (1 - 10) during the first event that were recaptured and not recaptured during the second event, Snake River, August 2001.

	Section Where Marked										
Category	1	2	3	4	5	6	7	8	9	10	All Sections
Recaptured (m_2)	1[a]	1	5	5	5	9	14	16	7	6	69
Not Recaptured (n_1-m_2)	7	16	23	34	30	48	34	37	36	26	291
Marked (n_1)	8	17	28	39	35	57	48	53	43	32	360
$P_{capture}$ 2nd Event (m_2/n_1)	0.13	0.06	0.18	0.13	0.14	0.16	0.29	0.30	0.16	0.19	0.19

χ^2 = 11.66; df = 9; P = 0.23; fail to reject H_0.

[a] Marking location of this fish was uncertain, but was placed in section 1 of this table.

recaptured fish to a marking section, the marginal P-values, and an inadequate number of recaptures in sections one and two, other geographic stratification schemes were examined.

The formation of two geographic strata by pooling sections 1 - 5 (upper stratum) and sections 6 - 10 (lower stratum) was deemed most appropriate because: 1) it included ≥ 7 recaptures in each stratum; 2) the marking location of the recaptured fish with the unknown tag number was highly likely to have been within the upper stratum; 3) the two stratum areas had the same boundaries as two sections from previous studies (1991 - 1994); and, 4) Glacier Creek, a significant tributary, which conceivably could have been related to the differences in capture probabilities, enters between the two strata. Mixing of fish between upper and lower strata was not complete (P-value < 0.01; Table 6), and capture probabilities were not equal between sections during the first event at greater than 90% confidence (P-value = 0.09; Table 7) and the second event (P-value = 0.04; Table 8). A single "marginal" P-value (i.e., that for the first event capture probability) was considered insufficient evidence for meeting the second assumption; therefore, a stratified estimator was used. Two fish moved between the two strata, therefore, the partially stratified Darroch estimator (Darroch 1961) was used to calculate an abundance of 1,116 (SE = 116) Arctic grayling ≥ 250 mm FL (Table 9). The abundance of Arctic grayling ≥ 350 mm FL was 952 (SE = 93). This estimate was also calculated using the partially stratified Darroch estimator.

LENGTH AND AGE COMPOSITION

The length of fish caught during the two events ranged from 258 to 513 mm FL, and the smallest recaptured fish was 330 mm FL. K-S tests indicated a Case I scenario; therefore, population compositions of lengths and ages were estimated using measurements from both sampling events. However, compositions were estimated for each geographic stratum then combined by weighting each stratum according to its relative abundance, to obtain the compositions of the index area population (Appendix B1 and B3). Most (73%) of the estimated population ranged between 360 and 439 mm FL (Table 10). Ages were obtained from 359 of 531 (68%) fish sampled for age, and they ranged from age-4 to -12 (Table 11). Most (80%) of the estimated population were ages-7 to -10.

Table 6.–Test for complete mixing. Number of Arctic grayling ≥ 250 mm FL marked in each pooled section (1 - 5 and 6 - 10) and recaptured or not recaptured in each section of the Snake River, August 2001.

	Section Where Recaptured			
Section Where Marked	1 - 5	6 – 10	Not Recaptured (n_1-m_2)	Marked (n_1)
1 - 5	16[a]	1	110	127
6 - 10	1	51	181	233
Total	17	52	291	360

$\chi^2 = 50.25$; df = 2; P-value < 0.01; reject H_0.

[a]Marking location of one fish was uncertain, but was placed in section 1 - 5 of this table.

Table 7.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥ 250 mm FL examined during the second event by pooled section (1 - 5 and 6 - 10) of the Snake River, August 2001.

	Section Where Examined		
Category	1 – 5	6 - 10	All Sections
Marked (m_2)	17	52	69
Unmarked (n_2-m_2)	49	86	135
Examined (n_2)	66	138	204
$P_{capture}$ 1st Event (m_2/n_2)	0.26	0.38	0.34

$\chi^2 = 2.83$; df = 1; P-value = 0.09; reject H_0 at the 90% confidence level.

Table 8.-Test for equal probability of capture during the second event. Number of Arctic grayling ≥ 250 mm FL marked by pooled section (1 – 5 and 6 - 10) during the first event that were recaptured and not recaptured during the second event, Snake River, August 2001.

Category	Section Where Marked 1 - 5	Section Where Marked 6 – 10	All Sections
Recaptured (m_2)	17	52	69
Not Recaptured (n_1-m_2)	110	181	291
Marked (n_1)	127	233	360
$P_{capture}$ 2nd Event (m_2/n_1)	0.13	0.22	0.19

$\chi^2 = 4.23$; df = 1; P = 0.04; reject H_0.

Table 9.–Stratum estimates of abundance and probability of capture using the Darroch estimator and pooling sections 1 – 5 and 6 – 10, Snake River, August 2001.

Sections	Stratum Abundance	SE	$P_{capture}$ (m_2/n_2)	SE ($P_{capture}$)
1 - 5	503	111	0.25	0.055
6 - 10	613	70	0.38	0.043
Total	1,116			

Table 10.-Estimates of length composition and abundance by 10 mm FL groups for Arctic grayling ≥ 250 mm FL, Snake River, August 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	3	3	1.00	<0.01	<0.01
260 – 269	0	0		0.00	
270 – 279	3	2	0.71	<0.01	<0.01
280 – 289	7	4	0.60	0.01	<0.01
290 – 290	4	3	0.73	<0.01	<0.01
300 – 309	0	0		0.00	
310 – 319	15	6	0.40	0.01	0.01
320 – 329	9	4	0.46	0.01	<0.01
330 – 339	15	6	0.37	0.01	0.01
340 – 349	32	10	0.31	0.03	0.01
350 – 359	52	12	0.24	0.05	0.01
360 – 369	96	17	0.17	0.09	0.01
370 – 379	74	14	0.19	0.07	0.01
380 – 389	108	19	0.17	0.10	0.01
390 – 399	94	17	0.18	0.08	0.01
400 – 409	93	16	0.17	0.08	0.01
410 – 419	108	20	0.19	0.10	0.01
420 – 429	103	18	0.17	0.09	0.01
430 – 439	123	21	0.17	0.11	0.01
440 – 449	65	13	0.20	0.06	0.01
450 – 459	62	14	0.23	0.06	0.01
460 – 469	30	9	0.30	0.03	0.01
470 – 479	11	5	0.42	0.01	<0.01
480 – 489	3	3	1.00	<0.01	<0.01
490 – 499	5	4	0.72	<0.01	<0.01
500 – 509	0	0		0.00	
510 – 519	2	2	1.00	<0.01	<0.01
≥ 350				0.92	0.07

Table 11.-Estimates of age composition and abundance by age class for Arctic grayling ≥ 250 mm FL, Snake River, August 2001.

	Range mm FL						
Age Class[a]	Minimum	Mean	Maximum	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
4	258	317	374	36	14	0.03	0.01
5	278	335	386	39	14	0.03	0.01
6	324	372	432	98	25	0.09	0.02
7	332	384	446	200	33	0.18	0.02
8	342	396	452	278	41	0.25	0.03
9	308	414	464	251	39	0.22	0.03
10	370	431	484	156	33	0.14	0.02
11	387	433	472	54	14	0.05	0.01
12	474	474	474	4	5	<0.01	<0.01
8+				743	92	0.67	0.17

[a] Of the 531 Arctic grayling sampled for age, 359 (68%) were assigned an age.

Thirty-four Arctic grayling were sampled in August 2001 that had been previously sampled and tagged from studies conducted during the early 1990s (Appendix A2). Of these, fish grew the most, up to 217 mm FL in eight years, during the interim when they had been < 300 mm FL at original capture date. Fish grew the least, as little as 22 mm FL in eight years, when they had been ≥ 350 mm FL at original capture.

Of the 34 fish previously tagged, 20 had assigned ages from both earlier studies and from this study. This age information provided an opportunity to examine error of ages. Age assignment error was defined as the difference between the age of the fish as determined from scale analysis in 2001 and an assumed minimum age. The minimum age was determined by adding the period between time of initial capture and 2001 (interim period) to the originally assigned age (e.g., age of the fish in 1991). To ensure accuracy of the minimum age, only those fish that were likely assigned an accurate age (fish ≤ age-7) at initial capture were used for examining age assignment error (17 fish were ≤ age-7, and 3 were > age-7). The difference in determined age for each fish was plotted against an assumed minimum age and a nearly 1:1 linear relationship was observed. Thus demonstrating that older fish (i.e., > age-10) cannot be reliably assigned an age and that the magnitude of the error increases in approximately 1:1 proportion to the true age of a fish (Figure 4).

DISCUSSION

The 2001 estimate of abundance of Arctic grayling ≥ 350 mm FL (952 fish) significantly exceeded management objectives for the index area of the Snake River (600 Arctic grayling ≥ 350 mm FL). The overall estimate of abundance of Arctic grayling ≥ 250 mm FL was 1,116 (SE = 116). For each estimate, precision expectations were met (i.e., 95% C.I. were ± 19.1 % and ± 20.4 % of the estimate, respectively).

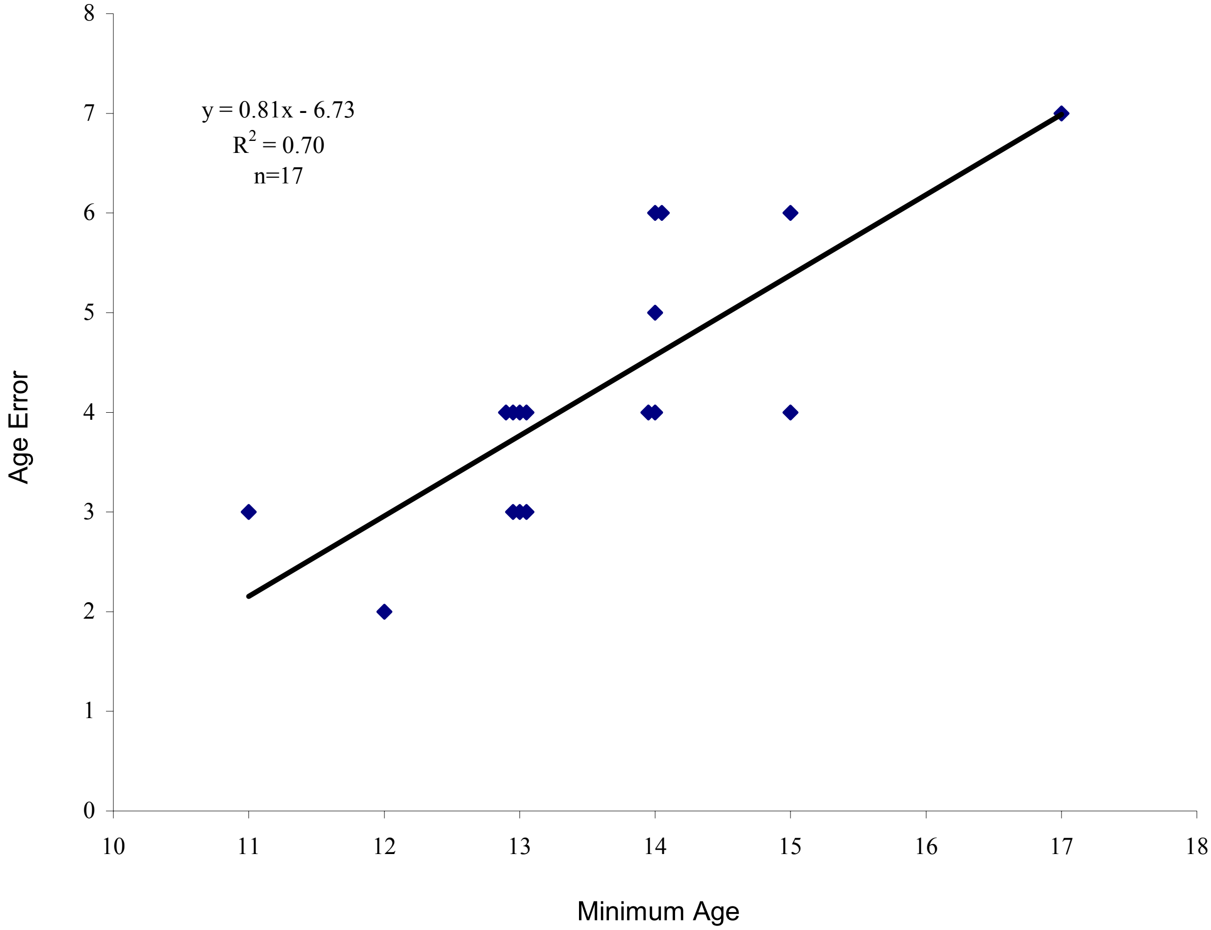

Figure 4.–Plot of minimum age (sum of age at initial capture and interim time) and the error in 2001 age (2001 age subtracted from minimum age) and regression equation. For data having superimposed symbols, the assigned ages (x-axis) were jittered.

Comparison of this abundance estimate with estimates for the same index area obtained during 1991 – 1994 indicated the total abundance of Arctic grayling ≥ 250 mm FL did not markedly change because it was within previously observed ranges (Figure 5), despite more restrictive regulations and reduced harvest (Table 1). However, notable differences were observed in population length and age compositions between the early 1990s and 2001 (Figures 5, 6 and 7; Appendices A3 – A7). Specifically, the length and age distributions shifted from a population equally distributed among nearly all ages and sizes (1991), to one dominated by young, small fish (1992 - 1994), and finally, to one that is dominated by large, old fish (2001). The present distribution is similar to that observed in other Seward Peninsula streams (DeCicco 1999, 2000, 2002b). Possible explanations for the observed shift are: 1) episodic recruitment occurring in the early 1990s; or, 2) a reduction in harvest from the more restrictive bag and length limits instituted during 1993 (Table 1). Recruitment of Arctic grayling is highly dependent on favorable water conditions for a period (e.g., 2-3 weeks) after hatching and emergence as well as for rearing (Armstrong 1986; Clark 1992a). In Seward Peninsula streams, it has been hypothesized that the occurrence of favorable water conditions is relatively infrequent or episodic (e.g., once every 5 – 10 years), which results in a particularly strong cohort that can effectively sustain the population of long-lived fish (A. DeCicco, Alaska Department of Fish and Game, Fairbanks, personal communication). However, the evidence supporting the episodic recruitment hypothesis is confounded by the lower exploitation levels observed after 1993 (Table 1), which may have contributed to an increase of large fish in the population. The relative importance of these factors remains unknown, as this study was not designed to assess their influence.

EVALUATION OF STUDY DESIGN

During 2001, the study design produced an abundance estimate meeting precision expectations, but improvement in future estimates may be obtained if two sampling issues are addressed: 1) the distribution of effort across the study area, and 2) the use of a beach seine as a capture gear to increase sample size and thereby the precision of the estimate. In lieu of complete mixing between events, the general Petersen estimator requires that all fish be subjected to a similar probability of capture during an event. While variability in capture probabilities that results from factors such as a physical characteristic of the fish (e.g., sex or size) or fish behavior can often be accommodated by modifying the estimator, variability induced by inconsistent distribution of effort may result in significant bias and decrease the precision of the estimate. The distribution of effort and selection of sample gear are important factors in attaining homogenous capture probabilities that an investigator can attempt to control (Williams et al. 2002).

Factors that could explain the variability in the observed capture probabilities were examined; these included changes in crew size, selective use of the beach seine, and stream morphology. During the first event, the crew size increased near the midpoint of the study area and the beach seine was used more often in downriver areas (Appendix A1). While these first two factors arguably could have influenced capture probabilities in the first event, they could not explain the observed differences during the second event. Even though a clear correlation between the variability in capture probabilities and the level of effort and gear selection was not evident, the design for future experiments should specify consistent use of gear and allocation of effort.

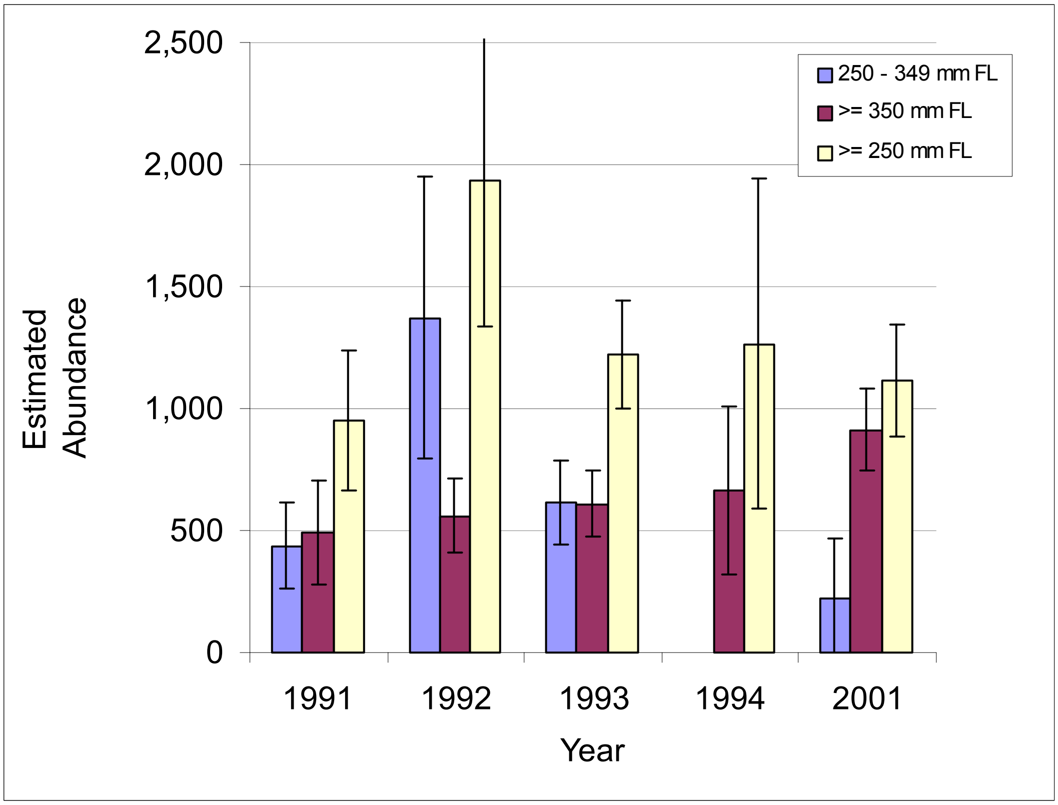

Figure 5.–Abundance of Arctic grayling ≥ 250 mm FL, 250 – 349 mm FL, and ≥ 350 mm FL during 1991 – 1994 and 2001, in the Snake River between Boulder Creek and Nome Teller Highway Bridge.

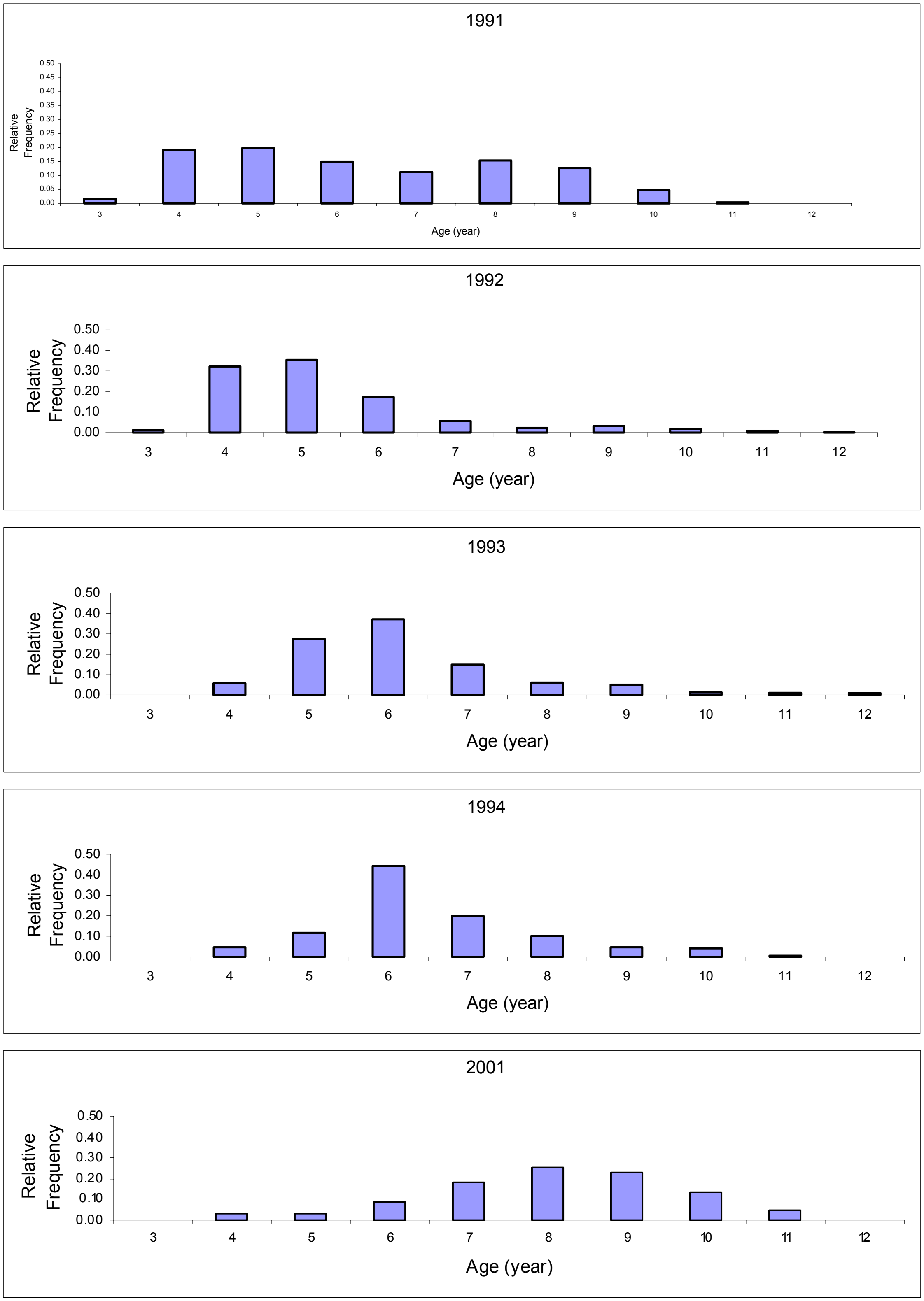

Figure 6.–Relative frequency distribution of the age composition of Arctic grayling during 1991–1994 and 2001, in the Snake River between Boulder Creek and Nome Teller Highway Bridge.

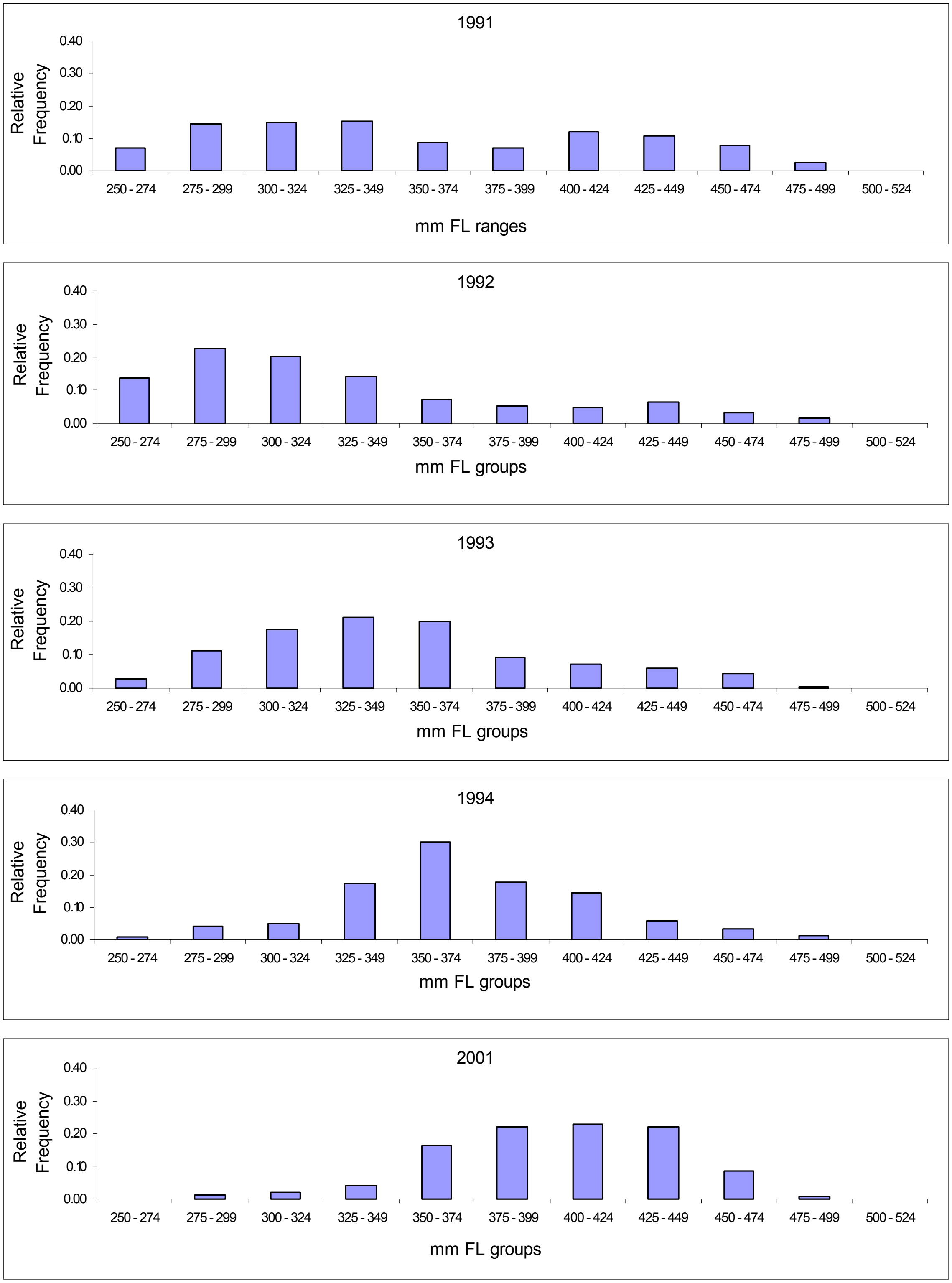

Figure 7.–Relative frequency distribution of the length composition of Arctic grayling during 1991–1994 and 2001, in the Snake River between Boulder Creek and Nome Teller Highway Bridge.

A factor that likely influenced capture probabilities during both events was related to morphological differences between upper and lower stream areas. The lower half of the study area had more pool habitat that concentrated fish and made them visually apparent, which intuitively led an angler to expend more effort angling where the fish density was greatest. The upper river had more riffle habitat where fish were more evenly distributed and difficult to locate, and this led to less effective angling. While this effect was largely addressed by stratifying, variability remained, albeit to a significantly less degree within each stratum. In future experiments, it would be prudent to allocate more effort in the upper reach where angling was more difficult.

In this study, a combination of sample gear was used to ensure desired sample sizes were attained. However, the hook-and-line gear alone provided an adequate sample size and an abundance estimate meeting precision expectations ($\hat{N}$ = 1,089; SE = 136). The seine gear provided an additional 105 fish captures and thereby improved the estimated coefficient of variation ($= SE(\hat{N})/\hat{N}$) by 2.1 percentage points. In general, seine gear has the advantage of not being size-selective and can be an efficient tool in some instances where hydrologic features are conducive (e.g., slow current, few or no snags, and a suitable bank to pull out the seine). However, it is difficult to apply effort with a seine proportional to fish density because its application is limited by the frequency of suitable locations. Moreover, even if conditions are suitable, a failed seining attempt can disrupt the "hole" rendering all gear types ineffective for a period of time that alters a sampling crews movement through the study area. Hook-and-line gear should be solely used in future sampling of the Snake River because the seine gear: 1) may have been a factor in promoting variable capture probabilities among sample sections during the first event, 2) provided little additional precision, (some of that precision, i.e. samples, would have been provided by additional use of hook-and-line gear); and, 3) was logistically more work than its value as a sample tool.

EVALUATING THE USE OF SCALES TO AGE FISH

The age analysis of recaptured fish previously tagged 8 to 10 years before yielded a data set containing a fairly large sample of fish that had been at large for a considerable length of time. These samples provided another example of the unreliability of using scales to age northern populations of Arctic grayling beyond the age of maturity when somatic growth diminishes (Armstrong 1986; DeCicco 2002a; Merritt and Fleming 1991; Sikstrom 1983). In this case, all recaptured fish were assigned an incorrect age based upon criteria for age determination, and the data suggested fish > age-10 were difficult to age correctly. This is an age when all Arctic grayling are very likely to be mature (Clark 1992b; Gryska 2003; DeCicco *In prep*). In turn, age composition estimates can be misleading due to age assignment errors. For instance, the strong age-6 cohort in 1994 would be expected to be age-13 in 2001, yet the strength of that year class is not evident in the 2001 composition (Figure 6). However, ages-8, -9, and -10 have large proportions. These ages coincide with the incorrectly assigned ages of the older fish. It is quite likely that age-6 fish of 1994 were assigned age-8, -9, or -10 (Appendix A2). Because some of the Arctic grayling age-8 and older were assigned incorrect ages in the Snake River, fish assigned an age of 8 or older should be assigned an age of 8+.

RECOMMENDATIONS

Current regulations are effectively maintaining abundance and composition of the population of Arctic grayling in the Snake River at satisfactory levels based upon the management objectives. Future stock assessments should attempt to better control probability of capture by applying more effort between Boulder Creek and Glacier Creek, using a consistent crew size (a crew size of two would be sufficient), using hook-and-line gear only, and using individuals with similar angling skills. When developing age compositions for future estimates, adequate sample sizes should be obtained; due to illegible and regenerated scales, only 68% of fish sampled for age yielded an age. Additionally, fish should be assigned to an age of 8+ if they are assigned age-8 or greater.

In 2002, the Seward Peninsula experienced favorable environmental conditions and a very strong cohort of young of year fish was observed on the nearby Nome River for the first time in about ten years (A. DeCicco, Alaska Department of Fish and Game, Fairbanks, personal communication). Any future assessment in the Snake River should be designed to determine if a strong recruitment also occurred; these fish may be vulnerable to hook and line gear between 2006 and 2009.

Finally, the results of this study indicate that, when attempting to assess the impact of regulations on a population, consideration needs to be given to the potential role of episodic recruitment of a large cohort in determining the population's size and age composition. Variable recruitment can obscure or exacerbate differences in population parameters that may have resulted from changes in regulations or indicate differences when regulation changes had little or no effect (Allen and Pine III 2000). It should be expected that without a comprehensive study prior to and during the implementation of a regulation change, it would be difficult to determine conclusively if the regulation resulted in any population changes (Allen and Pine III 2000).

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APPENDIX A

DATA SUMMARY

Appendix A1.–Personnel and effort used each day by section**.**

Date	Section									
	1	2	3	4	5	6	7	8	9	10
8/1/2001	A (0%)[a]	A (0%)	A (0%)							
8/2/2001			A (0%)	B (26%)	B (46%)					
8/3/2001						B (51%)	B (21%)	B (45%)		
8/4/2001								B (45%)	B (0%)	B (50%)
8/5/2001					no sampling					
8/6/2001	C	C	D	D						
8/7/2001					C	C	D	D		
8/8/2001									C	D2/3,E1/3

Crew A was composed of personnel 1 & 2.
Crew B was composed of personnel 1, 2, & 3.
Crew C was composed of personnel 1 & 4.
Crew D was composed of personnel 2 & 5.
Crew E was composed of personnel 1, 2, 3, 4, & 5.

[a] Values in parentheses indicate percent of Arctic grayling caught using seine.

Appendix A2.–Changes in lengths and ages of fish sampled in 2001 that were originally tagged during previous studies (1991 – 1994).

Growth between captures (mm)	2001 Length (mm FL)	Original Capture Length (mm FL)	Difference in Length (mm FL)	2001 Age (years)	Original Capture Age	Years Between Capture Dates (*t*)	Sum of Original Age and *t*
< 50	442	420	22	9	10	8	18
	474	443	31	10	9	8	17
	441	395	46	10	10	9	19
50 – 99	423	372	51	ND	6	8	14
	430	375	55	8	6	8	14
	474	417	57	8	ND	9	-
	431	364	67	10	7	10	17
	425	352	73	8	ND	8	-
	429	350	79	8	6	8	14
	419	339	80	ND	5	9	14
	426	340	86	9	6	8	14
100-149	455	343	112	9	5	8	13
	440	325	115	ND	7	8	15
	432	306	126	ND	5	8	13
	490	356	134	ND	ND	9	-
	449	310	139	9	5	8	13
	410	270	140	10	4	9	13
	484	341	143	10	ND	10	-
	447	304	143	9	5	10	15
	468	323	145	ND	6	8	14
	458	310	148	ND	5	8	13
>150	454	302	152	11	7	8	15
	434	268	166	ND	4	10	14
	430	263	167	ND	5	10	15
	460	288	172	10	4	8	12
	458	282	176	10	4	10	14
	431	252	179	9	4	9	13
	436	257	179	10	6	8	14
	432	252	180	10	ND	9	-
	415	229	186	10	4	9	13
	428	238	190	8	3	8	11
	449	234	215	9	3	10	13
	455	238	217	ND	4	8	12
ND	ND	340		10	5	8	13

ND = no data

Appendix A3.-Estimates of length composition and abundance by 25 mm FL groups for Arctic grayling ≥ 250 mm FL, in the Snake River between the Nome–Teller Highway Bridge and Boulder Creek (14.7 km), 1991.

Length Class (mm FL)	n	$\hat{p}_k$	SE [$\hat{p}_k$]	$\hat{N}_k$	SE [$\hat{N}_k$]
250 – 274	25	0.07	0.01	65	16
275 – 299	52	0.14	0.02	136	27
300 – 324	54	0.15	0.02	141	28
325 – 349	55	0.15	0.02	144	28
350 – 374	31	0.09	0.01	81	19
375 – 399	26	0.07	0.01	68	16
400 – 424	43	0.12	0.02	112	24
425 – 449	39	0.11	0.02	102	22
450 – 474	29	0.08	0.01	76	18
475 – 499	9	0.02	0.01	24	8
Total	363			948	

Appendix A4.-Estimates of length composition and abundance by 25 mm FL groups for Arctic grayling ≥ 250 mm FL, in the Snake River between the Nome–Teller Highway Bridge and Boulder Creek (14.7 km), 1992.

Length Class (mm FL)	n	$\hat{p}_k$	SE [$\hat{p}_k$]	$\hat{N}_k$	SE [$\hat{N}_k$]
250 – 274	46	0.14	0.01	158	27
275 – 299	76	0.23	0.01	290	43
300 – 324	68	0.20	0.01	245	38
325 – 349	48	0.14	0.01	222	35
350 – 374	75	0.07	0.01	198	32
375 – 399	56	0.05	0.01	148	26
400 – 424	51	0.05	0.01	135	24
425 – 449	65	0.06	0.01	171	29
450 – 474	35	0.03	0.01	92	19
475 – 499	16	0.02	0.01	42	12
Total	645			1,931	

Appendix A5.-Estimates of length composition and abundance by 25 mm FL groups for Arctic grayling ≥ 250 mm FL, in the Snake River between the Nome–Teller Highway Bridge and Boulder Creek (14.7 km), 1993.

Length Class (mm FL)	n	$\hat{p}_k$	SE [$\hat{p}_k$]	$\hat{N}_k$	SE [$\hat{N}_k$]
250 - 274	16	0.03	0.02	36	11
275 - 299	60	0.11	0.03	136	28
300 - 324	95	0.18	0.03	216	41
325 - 349	143	0.21	0.03	257	30
350 - 374	153	0.20	0.02	244	29
375 - 399	72	0.09	0.02	115	17
400 - 424	56	0.07	0.02	89	14
425 - 449	47	0.06	0.01	75	13
450 - 474	33	0.04	0.01	53	10
475 - 499	2	< 0.01	< 0.00	3	2
Total	677			1,224	

Appendix A6.-Estimates of length composition and abundance by 25 mm FL groups for Arctic grayling ≥ 250 mm FL, in the Snake River between the Nome–Teller Highway Bridge and Boulder Creek (14.7 km), 1994.

Length Class (mm FL)	n	$\hat{p}_k$	SE [$\hat{p}_k$]	$\hat{N}_k$	SE [$\hat{N}_k$]
250 - 274	2	0.01	0.01	11	15
275 - 299	10	0.04	0.03	55	35
300 - 324	11	0.05	0.03	60	37
325 - 349	40	0.17	0.05	219	84
350 - 374	70	0.30	0.06	383	127
375 - 399	41	0.18	0.05	224	85
400 - 424	33	0.14	0.04	181	73
425 - 449	13	0.06	0.03	71	41
450 - 474	8	0.03	0.02	44	31
475 - 499	3	0.01	0.01	16	18
Total	231			1,265	

Appendix A7.-Estimates of length composition and abundance by 25 mm FL groups for Arctic grayling ≥ 250 mm FL, in the Snake River between the Nome–Teller Highway Bridge and Boulder Creek (14.7 km), 2001.

Length Class (mm FL)	n	$\hat{p}_k$	SE [$\hat{p}_k$]	$\hat{N}_k$	SE [$\hat{N}_k$]
250 - 274	1	<0.01	<0.01	3	3
275 - 299	7	0.01	0.03	15	6
300 - 324	12	0.01	0.04	24	7
325 - 349	22	0.02	0.05	47	12
350 - 374	91	0.02	0.10	179	27
375 - 399	124	0.02	0.12	245	34
400 - 424	127	0.02	0.12	253	36
425 - 449	123	0.02	0.12	238	33
450 - 474	48	0.01	0.07	101	20
475 - 499	4	<0.01	0.02	10	5
500 - 524	1	<0.01	0.01	2	2
Total	560			1,116	

APPENDIX B

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

Appendix B1.-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_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 B2.-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 Where Marked	Section Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	$(n_1\text{-}m_2)$
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 $(n_2\text{-}m_2)$				

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

	Section Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured $(n_1\text{-}m_2)$				

[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 B3.-Equations for estimating length and age compositions and their variances for the population.

From Appendix B1, Case I was found through inference testing, indicating there was no size selective sampling during either event. However, the data were stratified geographically, and the estimates were adjusted to minimize bias due to differences in each area. 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 geographic strata. First, the conditional proportions from the sample were calculated:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j}, \tag{1}$$

where:

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

n_{jk} = the number sampled from geographic stratum *j* that were age *k*; and,

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

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

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

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

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

where:

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

s = the number of geographic 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):

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

-continued-

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

$$\hat{p}_k = \hat{N}_k \big/ \hat{N}\,, \tag{5}$$

where:

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

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

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

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

APPENDIX C

DATA FILE LISTING

Appendix C1.-Data files[a] for all Arctic grayling captured in the Snake River, August 2001.

Data file	Description
Snake River 2001 Data.csv	Sample data from 1-4 and 6-8 August 2001.
Snake 2001 analysis 01-22-04.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.