Fishery Data Series No. 06-63

Abundance and Age and Length Compositions of Arctic Grayling in the Sinuk River, 2003

by

Phil Joy

November 2006

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

FISHERY DATA REPORT NO. 06-63

ABUNDANCE AND AGE AND LENGTH COMPOSITIONS OF ARCTIC GRAYLING IN THE SINUK RIVER, 2003

by

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ABSTRACT

The Sinuk River is one of several streams and rivers that fall under a special management plan for Arctic grayling *Thymallus arcticus* on the Seward Peninsula that calls for periodic assessments of index populations to determine if abundances of Arctic grayling are being maintained at or above prescribed levels. A two-event mark-recapture experiment was performed on a 40-km index section of the Sinuk River in August, 2003 and during each 6-day event Arctic grayling were captured using hook-and-line gear. Diagnostic tests indicated that Arctic grayling ≥325 mm FL had similar capture probabilities by length, significantly different capture probabilities by defined geographic strata, and had moved significantly between strata. These results along with elements of the study design determined that a partially stratified estimator be used to estimate abundance. Estimated abundance of Arctic grayling ≥ 325 mm FL was 2,675 (SE = 414) and for Arctic grayling ≥ 350 mm FL was 2,534 (SE = 363). Ninety-one percent of the population of Arctic grayling ≥ 325 mm FL were age six and older. The abundance in 2003 was within the historically observed range (1989 – 1996), and the management goal of maintaining a population of 1,000 or more Arctic grayling ≥ 350 mm FL was met.

Keywords: Seward Peninsula, Sinuk river, Nome, Arctic grayling, *Thymallus arcticus*, management plan, stock assessment study, age, length, mark-recapture.

INTRODUCTION

The waters of the Seward Peninsula contain populations of anadromous Pacific salmon *Oncorhynchus spp*., Dolly Varden *Salvelinus malma*, and whitefish *Coregonus spp*. as well as resident populations of Arctic grayling *Thymallus arcticus*, Dolly Varden, northern pike *Esox lucius*, burbot *Lota lota* and whitefish (Figure 1). The city of Nome is the largest community in the area which has an extensive road system, approximately 420 km in length that provides access to many streams in the area.

Stock assessments of Arctic grayling populations of the Seward Peninsula were initiated by the Alaska Department of Fish and Game (ADF&G) because the Alaska Statewide Harvest Survey (Mills 1979-1994; Howe et al. 1995) indicated that sport harvests increased during the 1980s, and past studies (Alt 1978-1980; DeCicco 1991-2000) showed that Arctic grayling were being heavily exploited in some streams on the Seward Peninsula. The Seward Peninsula is one of the few areas in Alaska that regularly produces trophy-sized (≥18 in TL) Arctic grayling; about 25% of all trophy-sized Arctic grayling registered with the state of Alaska have come from this area (ADF&G trophy fish database, Juneau). Additionally, increased subsistence harvest of Arctic grayling in some streams raised concern regarding stock status among recreational anglers. Based on the available information, regulations were promulgated in 1988 to restrict harvest of Arctic grayling on the road accessible rivers of the Seward Peninsula to five per day, five in possession, with only one over 15 in TL (~350 mm FL).

Data on population abundance, mean length-at-age, and age and size composition of important Arctic grayling populations on the Seward Peninsula have been collected and published (Merritt 1989; DeCicco 1990-2000). These data culminated in a management plan for Arctic grayling in these streams (DeCicco 2002a). Specific streams for which management objectives have been developed in the management plan include the Niukluk, Fish, Pilgrim, Nome, Snake, and Sinuk rivers (Figure 1). The Seward Peninsula Arctic grayling research program as described in the management plan prescribes periodic population assessments in streams for which comparable population data exist in order to determine if abundances of mature fish (it was assumed all fish ≥ 350 mm FL were mature) are being maintained at or above prescribed levels outlined in the plan. The goal for this ongoing Arctic grayling research program, now that baseline data have been collected from most streams, is to reassess the Arctic grayling populations on a rotational basis every 4 to 6 years to ensure that populations are sustained at or above prescribed levels.

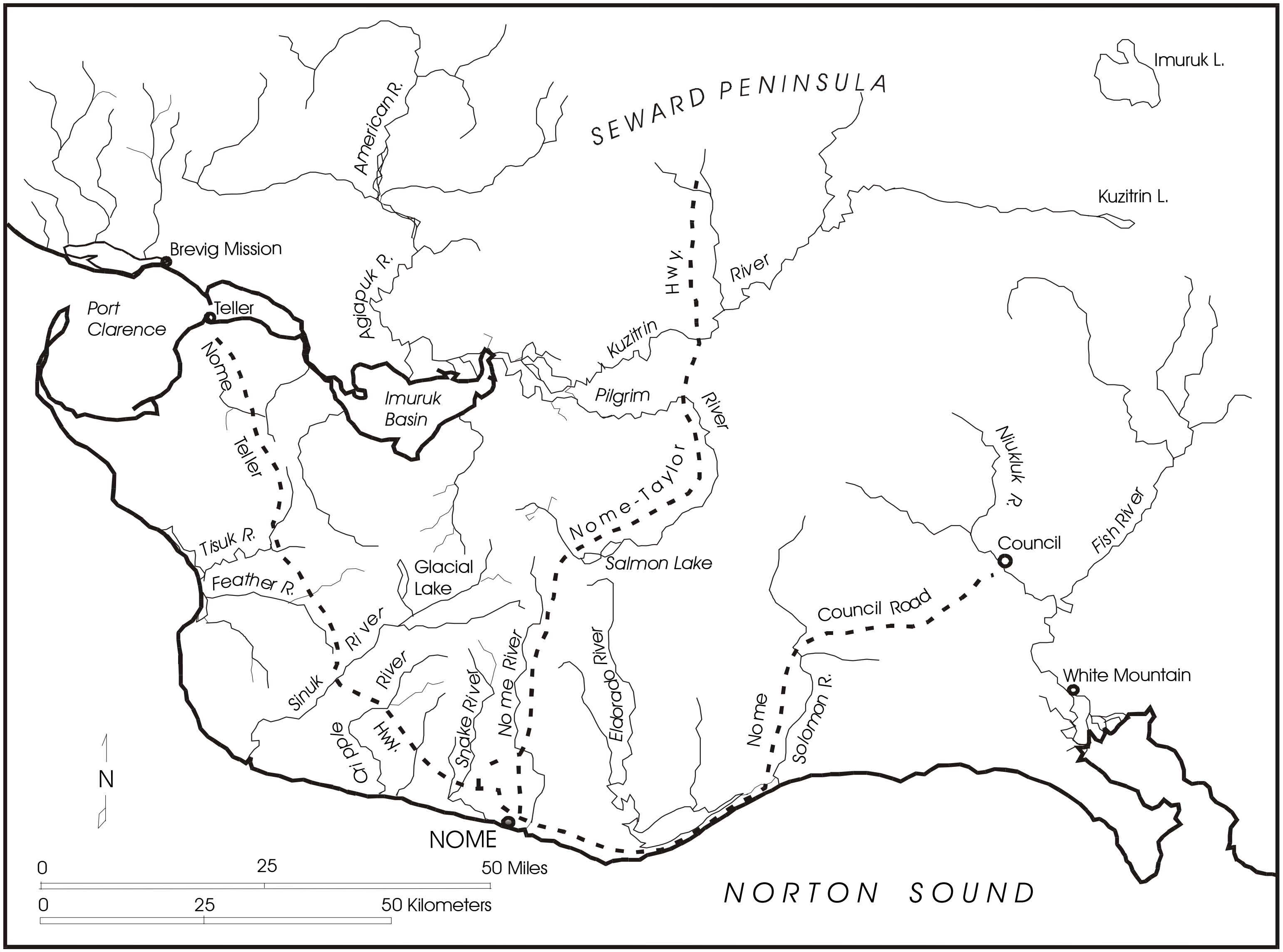


Figure 1.-Southern Seward Peninsula with road accessible waters.

The upper Sinuk River experiences very low sport fishing pressure (DeCicco 1994). Annual catches of Arctic grayling between 1992 and 2001 ranged from 25 to 1,464 fish (average of 419) and annual harvests ranged from zero to 103 fish (average of 22 fish; DeCicco 2003). The Sinuk River was last sampled during 1993 as part of a 4-year multiple event mark-recapture experiment. Abundance estimates were calculated from the Jolly-Seber model (Seber 1982) for 1990-1992. Additionally, a 2-event mark-recapture estimate was calculated for 1989 from samples collected in 1989 and 1990 (Table 1; DeCicco 1991). The average abundance within an approximately 40 km index area from Windy Creek to the Nome-Teller Bridge (Figure 2) between 1989 and 1993 was 1,350 fish of which 96% were greater than 350 mm FL (Table 1).

Table 1.–Estimates of abundance and variance between 1989 and 1992 for a 40 km section of the Sinuk River.

Year	Abundance	SE	Estimator	Size Range
1989	1,120	264	2-year Petersen	≥ 250 mm FL
1990	1,290	186	Jolly Seber	≥ 325 mm FL
1991	1,114	198	Jolly Seber	≥ 325 mm FL
1992	1,782	255	Jolly Seber	≥ 325 mm FL

Arctic grayling from this river attain a large maximum size with fish >520 mm FL having been captured during each year of prior studies (DeCicco 2002a). Also in previous studies, the Arctic grayling population in the Sinuk has consistently had a relatively high proportion (e.g., > 50%) of large (≥ 400 mm FL), old fish (≥ age-8). Seward Peninsula rivers such as the Snake and Pilgrim that experience higher sport fishing pressure tend to have fewer old, large fish (DeCicco 1994).

The management objective for the Sinuk River is to maintain a minimum abundance of 1,000 Arctic grayling ≥ 350 mm FL in the 40-km index section upstream from the Nome-Teller Highway Bridge. If the management objective is not met, then a reduction in bag limits would likely occur until the population had recovered to the prescribed levels (DeCicco 2002a). This stock assessment study was conducted in 2003 on the 40-km index section of the Sinuk River (Figure 2) to evaluate whether the management objective was being met.

OBJECTIVES

The project objectives for 2003 were to:

1. Estimate the abundance of Arctic grayling ≥ 325 mm FL in a 40-km index section of the Sinuk River during August such that the estimate was within 25% of the actual abundance 95% of the time;

2. Estimate the length composition in 25-mm FL length categories of Arctic grayling ≥ 325 mm FL on the Sinuk River such that the estimates were within 10 percentage points of the true value 95% of the time;

3. Estimate the age composition using scale ages of Arctic grayling ≥ 325 mm FL on the Sinuk River in age groups 4, 5, 6 and, > 6 years such that the estimates were within 10 percentage points of the true value 95% of the time; and,

4. Estimate the abundance of Arctic grayling ≥ 350 mm FL in a 40-km index section of the Sinuk River during August such that the estimate was within 25% of the actual abundance 95% of the time.

Objective four was included to determine if the management objective was being met. Objective one was included in order to directly compare abundance to previous estimates. For Objective three, the age groups were selected because Arctic grayling ≥325 mm FL would be at least 4 years old (DeCicco 1994) and ages for Arctic grayling older than 6 years on the Seward Peninsula cannot be determined accurately (DeCicco 2002b).

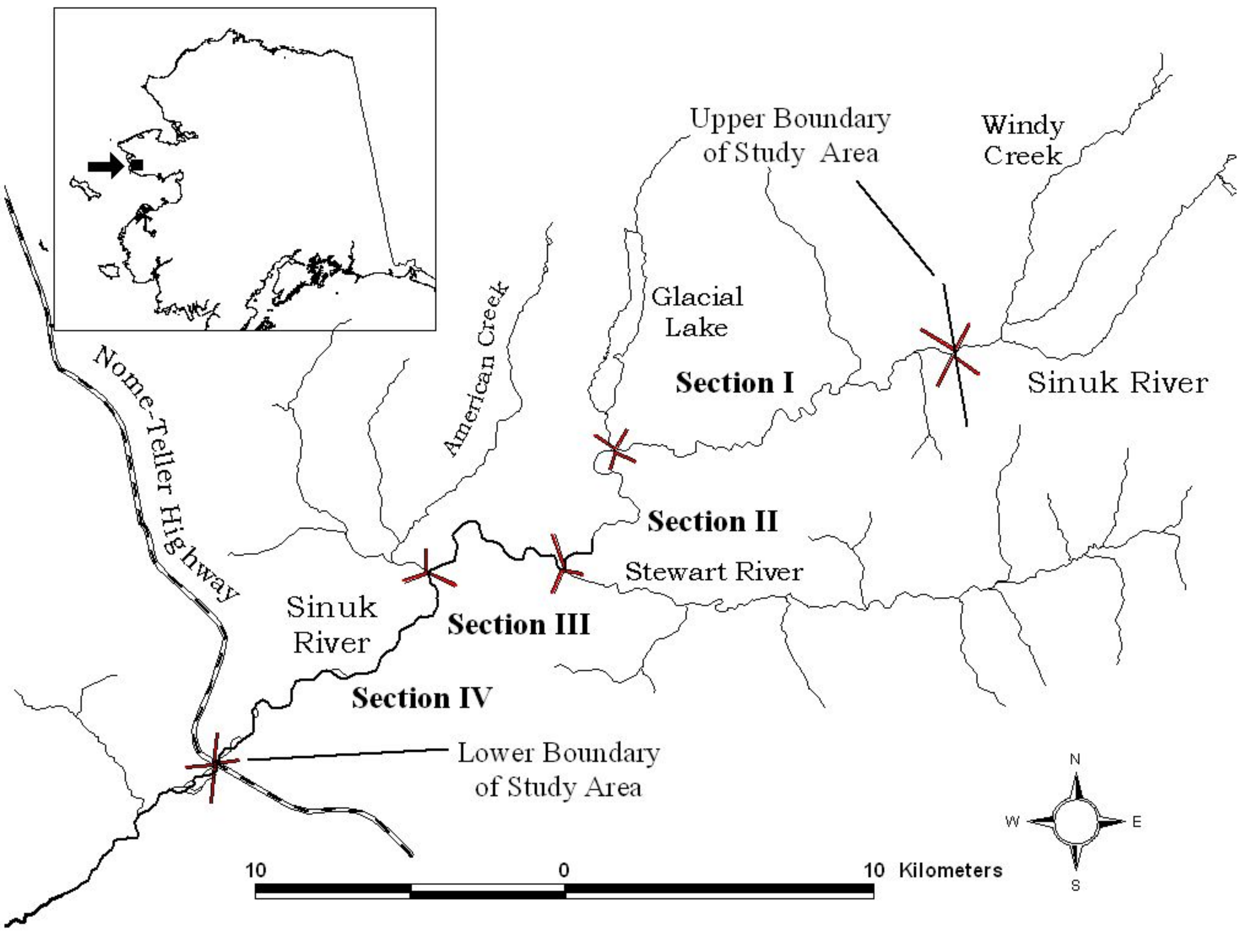


Figure 2.–The Sinuk River index study area and demarcation of the four sampling sections (I – IV).

METHODS

STUDY AREA

The Sinuk River is 87 km in length and drains a 794-km^2 area of the western Seward Peninsula (Figures 1 and 2). The river flows in a southwesterly direction and enters the Bering Sea approximately 40 km northwest of Nome, Alaska. Major tributaries of the Sinuk River include the catchments of Glacial Lake and the Stewart River. The index section of the Sinuk River starts 1.7 km downstream from its confluence with Windy Creek and ends at the Nome Teller Highway Bridge (approximately 40 km; Figure 2). This same section of the Sinuk River was sampled during 1989-1993, and abundance of Arctic grayling was estimated within this area from 1989 –1992 (Table 1).

SAMPLING DESIGN AND FISH CAPTURE

The Sinuk River Arctic grayling study was designed to estimate abundance and length and age compositions of Arctic grayling within the 40-km index area using a two-event mark-recapture experiment. Sampling was conducted over two six-day periods beginning at the uppermost boundary. The first event (marking) began on August 12 and concluded on August 17. The second event (examination) began on August 26 and concluded on August 31. Each day, a two-person crew expended approximately 10-11 hours of effort to sample between 5 and 10 km of river. During both events fish were captured using hook-and-line gear and terminal gear used was 1/16- to 1/4-oz rubber-bodied jigs.

In the first event, Arctic grayling ≥ 300 mm FL were marked with an individually-numbered anchor tag (Floy FD 94[1]). The second left pelvic fin ray was removed as a secondary mark to identify lost tags. In the second event, fish were not tagged but the second right pelvic fin ray was removed to identify fish sampled multiple times. Sample size objectives for the abundance estimate were established using methods in Robson and Regier (1964) and for composition estimates 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 (Arctic grayling do 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 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.

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

The abundance estimator used was derived from the general form of the Petersen estimator:

$$\hat{N} = \frac{n_1 n_2}{m_2}; \qquad (1)$$

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,

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

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 1-2 river km). 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. The duration of the study was kept short to render growth recruitment and mortality insignificant.

To ensure that Assumption 2 was met, attempts were made to subject all fish, within each sampling event, to the same probability of capture. Attempts were made to fish the entire study area with effort in proportion to the distribution of Arctic grayling. Specifically, fishing was conducted for longer periods in areas where densities appeared relatively high (e.g., glides) and for shorter periods where few fish appeared to be available (e.g., slack water areas). 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 1-2 km. Diagnostic tests to identify heterogeneous capture probabilities and methods to correct for potential biases are presented under in the Data Analysis section.

Relative to Assumption 3, a hiatus of 14 days between the first and second events in a given river section was included to allow marked fish the time to recover from the effects of being hooked and handled and to resume normal feeding behavior.

Relative to Assumption 4 and 5, Arctic grayling captured during the first event were double marked with an individually-numbered Floy FD-67 internal anchor tag and the removal of the second ray of the left pelvic fin. In the second event, the second ray of the right pelvic fin was removed from all fish and served as an identifying mark to prevent resampling, and all fish were carefully examined for marks.

DATA COLLECTION

All captured Arctic grayling were processed immediately or soon after capture and released at or near their capture locations. As each fish was caught, crews collected scale samples and a fin ray and recorded: the date, location (latitude and longitude from a GPS unit), fork length (mm), tag number, tag color, recapture status, and mortality. Floy tags were gray in color and numbered between 3,251 and 3,500 and between 3,851 and 3,961. Two scales were removed for aging from all fish caught during both events. Data were recorded onto coin envelopes, which held scales and fin rays for each captured fish. Daily summaries were recorded into field notebooks. These were transformed into an electronic (ASCII) data file for analysis and archival.

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 (Brown 1943). Scales were processed by wiping slime and dirt off each scale and mounting them on gummed cards. The cards were used to make triacetate impressions of the scales (30 s at 137,895 kPa, at a temperature of 97°C). 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).

DATA ANALYSIS

Abundance Estimate

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 relative to evaluating size selectivity (either one of the two samples, both, or neither of the samples could be biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A1. If stratification by size was required, capture probability by location were examined for each stratum, and total abundance and its variance estimate were calculated by summing strata estimates.

Temporal and spatial violations of Assumption 2 were tested for using consistency tests described by Seber (1982; Appendix A2). If all three of these tests rejected the null hypothesis, then a partially or completely stratified estimator must be used. If movements of marked fish between strata were observed (incomplete mixing), the methods of Darroch (1961) would be used to compute a partially stratified abundance estimate. If no movements of marked fish between geographic strata were observed, a completely stratified abundance estimate would be computed using the methods of Bailey (1951, 1952) or Darroch (1961). Otherwise, at least one of the three consistency tests will fail-to-reject the null hypothesis and it will be concluded that at least one of the conditions in Assumption 2 was satisfied.

For evaluating Assumption 2, the documentation of release location for each fish permitted the examination of multiple geographic stratification schemes. Criteria considered when defining geographic strata included: 1) hydrologic characteristics and conditions; 2) the distribution of captured and recaptured fish among strata; and, 3) the distribution of sampling effort among strata. Hydrologic characteristics such as discharge and channel topography (pools, riffle, and sinuosity) are related to Arctic grayling length and density distribution, as are hydrologic conditions such as high water events. If geographic stratification was required, a sufficient number of recaptures per strata (e.g., $m_2 \geq 7$) would be preferred to minimize bias and permit reliable diagnostic testing. Finally, changes in sampling effort such as changes in crew size, coverage, or gear types may also have resulted in heterogeneous capture probabilities.

Length and Age Compositions

Length and age compositions of the population were estimated using the procedures outlined in Appendices A1 and A3.

RESULTS

SUMMARY OF FISH SAMPLED

A total of 765 Arctic grayling (≥ 280 mm FL) were sampled over the course of the study. In the first event, 366 fish were captured and marked (marks, or n_1), 399 fish were captured and examined in the second event (captures, or n_2). Of the 399 fish sampled in the second event, 59 were recaptures (m_2) and the smallest recaptured fish was 337 mm FL. The lengths of all Arctic grayling sampled during the two events ranged from 281 to 514 mm FL and 84% of the Arctic grayling captured exceeded 374 mm FL (Appendix B).

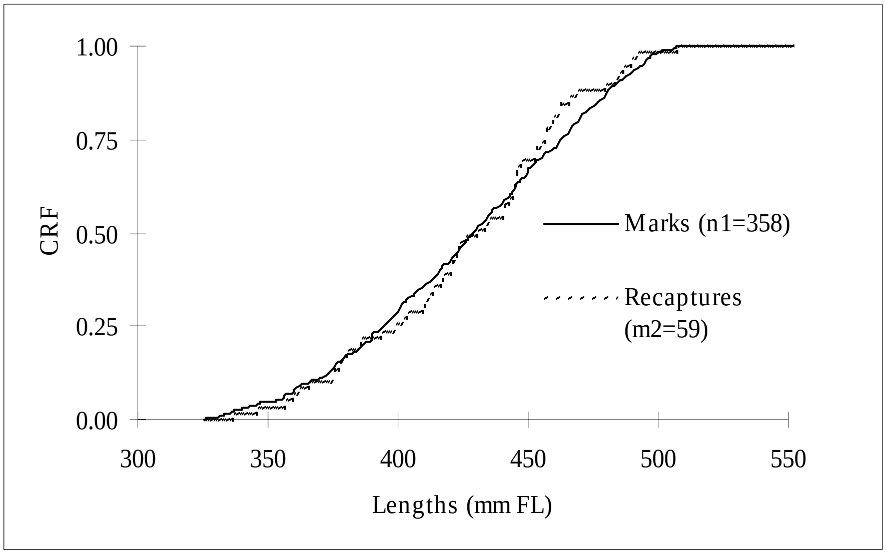
ABUNDANCE ESTIMATION

The sampling design and the results of the diagnostic testing procedures (Appendices A1 and A2) indicated that: 1) there was no need to stratify by size as fish of different sizes had similar capture probabilities; and, 2) geographic stratification was required and the two strata model was preferred. Because there was movement between the two geographic strata, a partially-stratified estimator (Darroch 1961) was used to estimate the abundance of fish ≥ 325 mm FL.

For fish ≥ 325 mm FL, stratification by size was not necessary because K-S tests indicated that the length composition did not vary between fish captured in the first event (n_1) and fish examined in the second event (n_2; D = 0.04; P-value = 0.85; Figure 3), nor did it vary between those captured in the first event (n_1) and those recaptured in the second event (m_2; D = 0.10; P-value = 0.63; Figure 3).

Initially, four geographic strata (sections I – IV shown on Figure 2) were selected for performing the consistency tests. The primary criteria used in demarcation of the boundaries were: 1) changes in channel morphology; and, 2) the distribution of sampling effort. The boundaries were placed at the confluences of the three primary tributaries, which corresponded to changes in the channel morphology and discharge. Marked changes in sampling effort also occurred at the boundary between sections I and II. During both sampling events, three days of sampling effort were expended in section I (15 km of river) and three days were spent in sections II, III, IV (25 km of river). Therefore, an alternative 2-strata approach, which combined sections II-IV, was also explored.

For fish ≥ 325 mm FL the test of consistency performed using both four and two geographic locations indicated that geographic stratification was necessary. The test for complete mixing indicated that mixing of fish among the four sampling sections was incomplete (P-value < 0.01; Table 2). For the four strata approach, test results also indicated that probability of capture was unequal (P-value = 0.03; Table 3) during the first event and in the second event (P-value = 0.02; Table 4). The results for the two section stratification were similar and indicated that mixing was incomplete (P-value < 0.01; Table 5), first-event capture probabilities were unequal (P-value < 0.01; Table 6), and second-event capture probabilities were unequal (P-value < 0.01; Table 7).



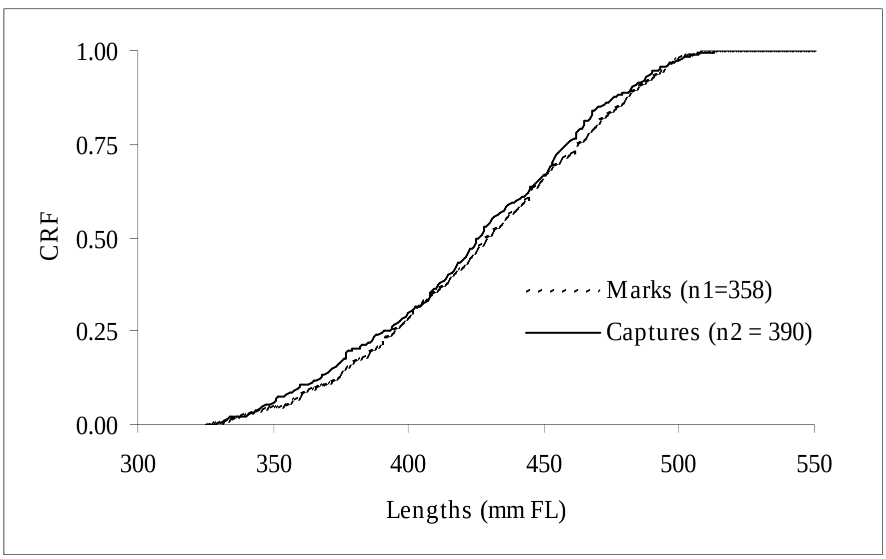


Figure 3.–Cumulative relative frequency (CRF) of Arctic grayling ≥ 325 mm FL marked and recaptured (top figure) and marked and examined (bottom figure), Sinuk River, August 2003.

Table 2.–Test for complete mixing. Number of Arctic grayling ≥ 325 mm FL marked and recaptured or not recaptured in each section (I-IV) of the Sinuk River, August 2003.

Section Where Marked	Section Where Recaptured				Note Recaptured (n_1-m_2)	Total Marked (n_1)
	I	II	III	IV		
I	30	0	1	0	94	125
II	1	9	1	0	78	89
III	0	0	10	3	87	100
IV	0	0	1	3	40	44
Total	31	9	13	6	299	358

χ^2 = 108.40, df = 12, p-value < 0.0001, reject H_0.

Table 3.–Test for equal probability of capture during the first event for Arctic grayling ≥ 325 mm FL. Number of marked and unmarked Arctic grayling examined during the second event by section (I-IV) of the Sinuk River, August 2003.

Category	Section Where Examined				All Sections
	I	II	III	IV	
Marked (m_2)	31	11	13	6	59
Unmarked (n_2-m_2)	107	77	91	56	331
Examined (n_2)	138	86	104	62	390
$P_{capture}$ 1st event (m_2/n_2)	0.22	0.10	0.13	0.10	0.15

χ^2 = 9.23, df = 3, P-value = 0.03, reject H_0.

Table 4.–Test for equal probability of capture during the second event for Arctic grayling ≥ 325 mm FL. Number of Arctic grayling marked by section (I-IV) during the first event that were recaptured and not recaptured during the second event, Sinuk River, August 2003.

Category	Section Where Marked				All Sections
	I	II	III	IV	
Recaptured (m_2)	31	11	13	6	59
Not Recaptured (n_1-m_2)	94	78	87	40	299
Marked (n_1)	125	89	100	44	358
$P_{capture}$ 2nd event (m_2/n_1)	0.25	0.12	0.13	0.09	0.16

χ^2 = 10.01, df = 3, P-value = 0.02, reject H_0.

Table 5.–Test for complete mixing. Number of Arctic grayling ≥ 325 mm FL marked in each of two sections (upper and lower) and recaptured or not recaptured in each section of the Sinuk River, August 2003.

Section Where Marked	Section Where Recaptured		Note Recaptured	Total Marked
	Upper	Lower	$(n_1\text{-}m_2)$	(n_1)
Upper	30	1	94	125
Lower	1	27	205	233
Total	31	28	299	358

$\chi^2 = 65.90$, df = 2, p-value < 0.0001, reject H_0.

Table 6.–Test for equal probability of capture during the first event for Arctic grayling ≥ 325 mm FL. Number of marked and unmarked Arctic grayling examined during the second event by section (upper and lower) of the Sinuk River, August 2003.

Category	Section Where Examined		
	Upper	Lower	All Sections
Marked (m_2)	31	28	59
Unmarked $(n_2\text{-}m_2)$	107	224	331
Examined (n_2)	138	252	390
$P_{capture}$ 1st event (m_2/n_2)	0.22	0.11	0.15

$\chi^2 = 8.95$, df = 1, P-value < 0.01, reject H_0.

Table 7.–Test for equal probability of capture during the second event for Arctic grayling ≥ 325 mm FL in the upper and lower sections of the river. Number of Arctic grayling marked by section (upper and lower) during the first event that were recaptured and not recaptured during the second event, Sinuk River, August 2003.

Category	Section Where Examined		
	Upper	Lower	All Sections
Recaptured (m_2)	31	28	59
Not Recaptured $(n_1\text{-}m_2)$	94	205	299
Marked (n_1)	125	233	358
$P_{capture}$ 2nd event (m_2/n_1)	0.25	0.12	0.16

$\chi^2 = 9.66$, df = 1, P-value < 0.01, reject H_0.

The two section stratification scheme was deemed appropriate because it pooled sections with similar capture probabilities in a manner consistent with: 1) changes in sampling effort; 2) changes in channel morphology; and, 3) a need for an adequate number of recaptures in each stratum.

Because there was partial movement between the two strata, the partially-stratified Darroch estimator was used to estimate the abundance of Arctic grayling ≥ 325 mm FL in the Sinuk River study area. Estimated total abundance was 2,675 fish (SE = 414), estimated abundance for the upper section was 537 fish (SE = 94), and estimated abundance for the lower section was 2,138 fish (SE = 391).

For Arctic grayling ≥ 350 mm FL, the same testing procedures, criteria, stratification schemes, and estimator were used. Therefore, using the partially-stratified Darroch estimator, the estimated abundance of Arctic grayling ≥ 350 mm FL in the Sinuk River study area was 2,534 fish (SE = 363), estimated abundance in the upper section was 503 fish (SE = 88), and estimated abundance in the lower section was 2,031 fish (SE = 386).

LENGTH AND AGE COMPOSITION

For Arctic grayling ≥ 325 mm FL, the K-S test results indicated that inferences about the composition of the population be based upon the lengths of fish captured during both events (Case I; Appendix A1). Length composition of Arctic grayling ≥ 325 mm FL was relatively evenly distributed between 350 and 500 mm, with only 0.05 less than 350 mm and only 0.02 ≥ 500 mm (Table 8). Most of the Arctic grayling population ≥ 325 mm FL (91%) were age-6 or older fish (Table 9).

MOVEMENT

Among the 59 fish with known release and recapture locations, the maximum distances moved were 5.4 km upriver and 13.8 km downriver (Figure 4). Three Arctic grayling (5%) moved more than 2 km upriver and 12 (20%) moved more than 2 km downriver, and five (8%) moved more than 10 km downriver. Twelve Arctic grayling were recaptured in the same location as their initial capture and the average distance moved by recaptured Arctic grayling was 1.6 km downriver (SD = 3.97). The tendency to move downstream was shown to be significant using a Wilcoxon Signed Ranks Test ($T = -3.12$; $P < 0.001$). The significant downward movement of recaptured fish provided evidence that the assumption of closure was violated due to immigration at the upriver boundary and emigration at the lower boundary. In general, combined immigration and emigration results in positively biased abundance estimates with the bias of unknown magnitude. However, using the Petersen mark recapture abundance estimate for open rivers (Evenson 1988) it was shown that the bias induced by the downstream movement was small considering the uncertainty associated with the abundance estimate (Appendix C).

Table 8.–Estimates of length composition and abundance by length group for Arctic grayling ≥ 325 mm FL, Sinuk River, August 2003.

Length Class (mm FL)	Sample Size n	Proportion $\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
325-349	36	0.05	0.008
350-374	67	0.10	0.011
375-399	96	0.14	0.013
400-424	124	0.18	0.015
425-449	127	0.18	0.015
450-474	132	0.19	0.015
475-499	90	0.13	0.013
≥ 500	17	0.02	0.006

Table 9.–Estimates of age composition for Arctic grayling ≥ 325 mm FL, Sinuk River, August 2003.

Age Class (Years)	Sample Size n	Proportion $\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
4	1	0.002	0.002
5	39	0.091	0.014
6	102	0.239	0.021
7+	285	0.667	0.023

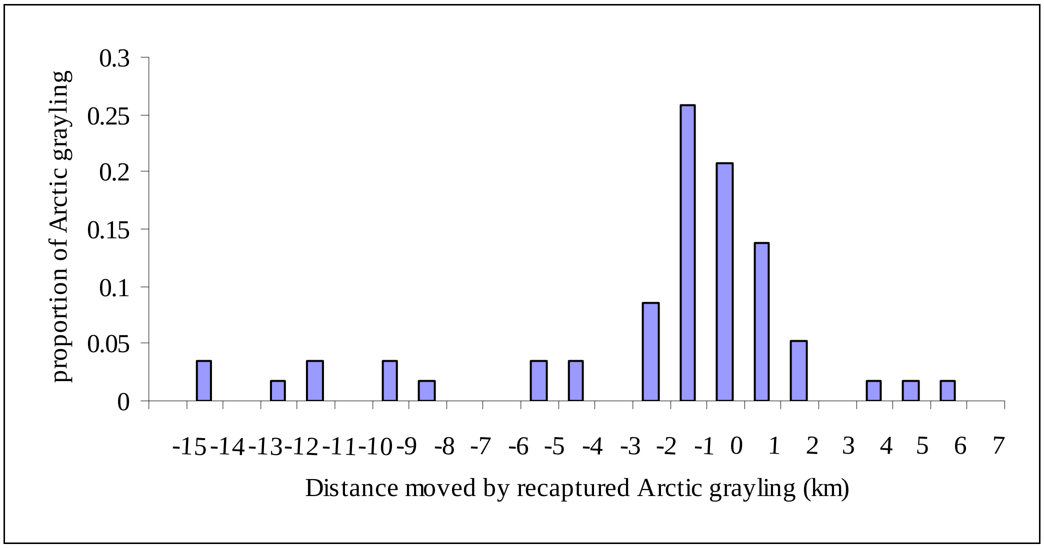


Figure 4.–Relative movement in kilometers of 58 Arctic grayling captured in the first event and recaptured in the second event, Sinuk River, August 2003. Negative numbers connote downriver movement and positive numbers connote upriver movement.

DISCUSSION

In 2003, the estimated abundance of Arctic grayling ≥ 350 mm FL in the 40-km index area of the Sinuk River far exceeded the management objective of maintaining a minimum abundance of 1,000 Arctic grayling ≥ 350 mm FL. Evidence for downstream movement of Arctic grayling during the experiment was shown to lead to insignificant bias. In addition to the directional nature of the movement, these data also indicated the potential positive bias due to combined immigration and emigration at each boundary. However, because the index area is large relative to the movements of most fish, the bias is expected to be relatively small, certainly far less than that necessary to alter the interpretation that the management goal has been met. Given that the abundance of fish ≥ 325 mm FL has increased since 1988 and that harvest levels continue to be low (Figure 5), more restrictive regulations are not needed to maintain this stock at or above the prescribed level.

Although the management objective was achieved, the precision for the abundance estimate attained in this study (95% C.I. of ±28%) was marginally below the desired precision of the research objective (i.e., ±25%) despite exceeding sample size objectives (criteria = 296 fish/event vs. 746 fish sampled in total). If all five assumptions of the mark-recapture experiment had been satisfied, the sample sizes attained would have been sufficient for meeting the research objective despite the higher than anticipated abundance - the assumed abundance was 1,800 fish. However, the sample size was insufficient to accommodate the geographic stratification requirements and movement between geographic strata, which called for using a partially stratified estimator (Darroch 1961).

Geographic stratification was required because of differences in capture probabilities between the upper and lower sampling strata. Although several factors can influence capture probabilities, the observed differences in capture probabilities in part was attributed to the unequal distribution in the sampling effort relative to actual population densities. In this study, approximately half of the sampling effort was spent (2.5 days) in Section I (15 km) where 20% of the population was located, while only 3 days were spent in the lower 25 km of river. In future studies it is recommended that the river be divided into daily sampling sections based on the observed distribution of fish densities in this and previous studies. Moreover, determination of sample size requirements should be made on an assumed abundance of 3,000 Arctic grayling ≥ 325 mm FL, to ensure sufficient sampling effort is expended in each sampling section. Finally, the documentation of release locations of each fish sampled using a GPS should be continued because it permitted a better evaluation of meaningful geographic stratification schemes.

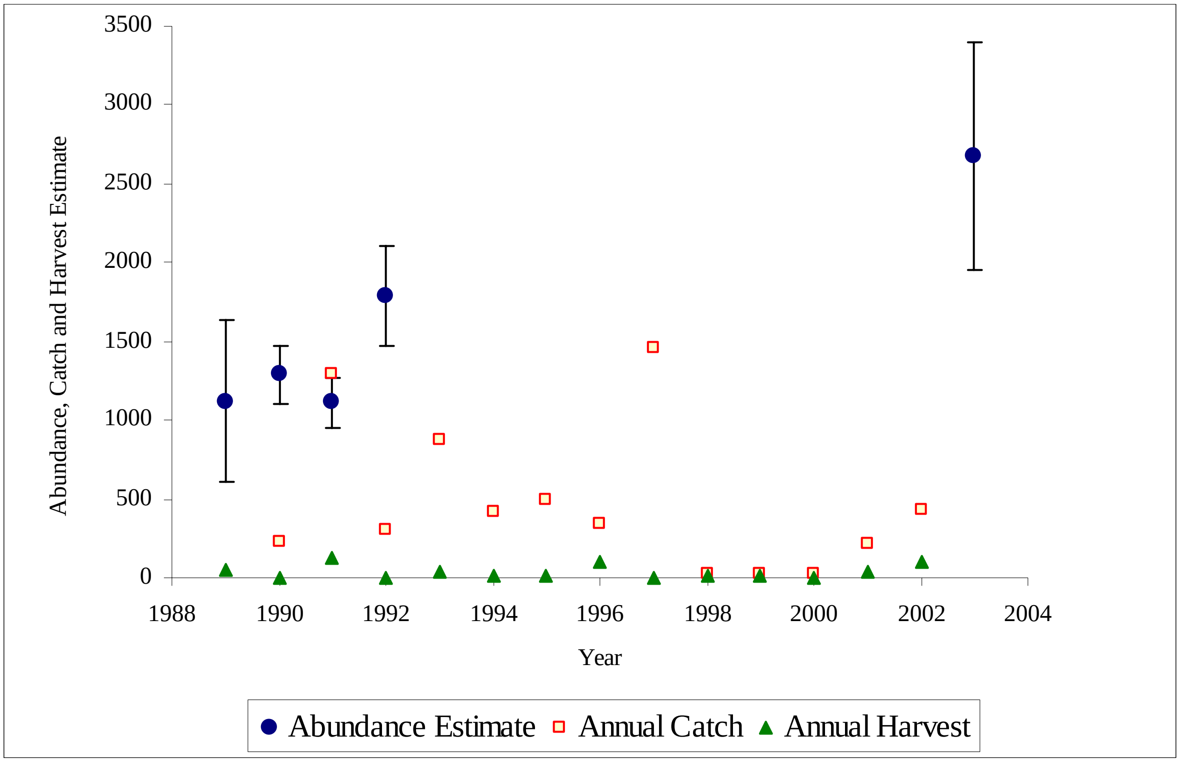


Figure 5.–Abundance estimates (circles) of Arctic grayling >324 mm FL in the 40 km index portion of the Sinuk River, and annual catch (open squares) and harvest estimates (triangles) of Arctic grayling in the entire Sinuk River since 1989. Error bars represent 95% confidence intervals.

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

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

	Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]	Fail to reject H_0	Fail to reject H_0
	Inferred cause: There is no size-selectivity during either sampling event	
Case II[d]	Fail to reject H_0	Reject H_0
	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_0	Fail to reject H_0
	Inferred cause: There is size-selectivity during both sampling events	
Case IV[f]	Reject H_0	Reject H_0
	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_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of length 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_0 for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

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

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

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

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

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

Tests of consistency for Petersen estimator

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

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

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

I.-Test for complete mixing[a]

Section 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 A3.–Equations for estimating length and age compositions and their variances for the population.

From Appendix A1, Case I was found through inference testing. Case I occurs when there is no size selectivity during either event. Therefore, age and length data from both events were used to estimate compositions. Length and age proportions were estimated for the population using:

$$\hat{p}_j = \frac{n_j}{n},$$

where:

n = the total number of Arctic grayling sampled of length or age under consideration;

n_j = the number of Arctic grayling sampled that were within length or age class j; and,

$\hat{p}_j$ = the estimated proportion of the Arctic grayling population in the length or age class j.

The variance of this proportion is estimated as (from Cochran 1977):

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

APPENDIX B. LENGTH CATEGORIES OF ALL FISH SAMPLED IN THE SINUK RIVER, AUGUST 2003

Appendix B1.–Number of Arctic grayling sampled by 25 mm length categories in the 40- km index section of the Sinuk River, August 2003.

Length Class (mm FL)	Sample Size n	Proportion $\hat{p}_k$
275-299	2	0.003
300-324	15	0.02
325-349	36	0.05
350-374	67	0.09
375-399	96	0.14
400-424	124	0.18
425-449	127	0.18
450-474	132	0.19
475-499	90	0.13
≥ 500	17	0.02

APPENDIX C. PETERSEN MARK RECAPTURE ABUNDANCE ESTIMATE FOR OPEN RIVERS

Appendix C1.–Description of a Petersen mark recapture abundance estimator for open rivers taken from Evenson (1988).

The text below is a description of a Petersen mark-recapture abundance estimator for open rivers. The development of this estimator is based on a study area that is divided (or can be divided) into three subsections after the completion of both sampling events. The subsections must be defined such that fish in the midstream section during the first sampling event can not or will not leave the study area between sampling events. Also, each marked fish must be individually identifiable. Each sampling event encompasses the entire study area. The following notation is used in this Appendix:

M_x = the number of fish marked in the first sampling event in Subsection *x* (*x* = 1, 2, and 3 for the downstream, midstream, and upstream subsections, respectively);

m_x = the number of fish that were marked in Subsection *x* during the first sampling event and still remain in one of the three subsections at the start of the second sampling event;

R_{xy} = the number of fish that were marked in Subsection *x* during the first sampling event and were recaptured in Subsection *y* during the second sampling event;

$R_{..}$ = the number of recaptures made during the second sampling event;

$R_{2.}$ = the number of recaptures made during the second sampling event of fish tagged in Subsection 2, the midstream section;

θ_z = the probability that a fish will move out of a subsection in the "*z*" direction (upstream or downstream);

p = the probability that a fish in the study area will be caught in the second sampling event;

Φ_z = the probability that a fish will move out of a subsection in the "*z*" direction (upstream or downstream) and be caught in the second sampling event (note that $\Phi_z = p\theta_z$);

c = the catch made during the second sampling event; and,

N = the abundance of fish in all the subsections at the start of the second sampling event.

-continued-

The binomial joint probability density function (PDF) for the number of marked fish recaptured during the second sampling event and the number of marked fish available for recapture at the start of the second sampling event is:

$$P\left[R_{..}, m_1, m_3\right] = \tag{1}$$

$$Comb\left[C, R_{..}\right] \left[\frac{m_1 + M_2 + m_3}{N}\right]^{R_{..}} \left[1 - \frac{m_1 + M_2 + m_3}{N}\right]^{C - R_{..}} \times$$

$$Comb\left[M_1, m_1\right] \theta_d^{\,M_1 - m_1} \left(1 - \theta_d\right)^{m_1} \; Comb\left[M_3, m_3\right] \; \theta_u^{\,M_3 - m_3} \left(1 - \theta_u\right)^{m_3}$$

Where $m_1 + M_2 + m_3$ = the number of marked fish that are still in the study area at the start of the second sampling event and where the subscripts "*d*" and "*u*" on θ denote downstream and upstream movements, respectively. Note that M_2 is used in the PDF (Equation 1) instead of m_2 because all fish tagged in the midstream subsection are presumed unable (unwilling) to move far enough to leave the study area between sampling events. The Maximum Likelihood Estimate (MLE) of *N* is therefore:

$$\hat{N} = \frac{\left(m_1 + M_2 + m_3\right) c}{R_{..}} \tag{2}$$

Because the m_x are unknown in Equation 2, the MLE (m_x) must be used in their place. The PDF for m_1 is:

$$P\left[m_1\right] = Comb\left[M_1, m_1\right] \left(1 - \theta_d\right)^{m_1} \theta_d^{\,M_1 - m_1} \tag{3}$$

Note that in Equation 3, the probability $\left(1 - \theta_d\right)$ of a fish marked in Subsection 1 <u>staying</u> in the study area between sampling events is the complement of the probability $\left(\theta_d\right)$ of it leaving Subsection 1 by moving downstream. Therefore the MLE $\left(m_1\right)$ is:

$$\hat{m}_1 = M_1 \left(1 - \theta_d\right) \tag{4}$$

The MLE $\left(m_3\right)$ can be found in the same manner, only the upstream probability of movement is used in the calculations.

Finally, the probabilities of movement, θ_d and θ_u, can be estimated with information on recaptured fish among the subsections. The probabilities of recapturing R_{32} <u>and</u> R_{21} marked

-continued-

fish downstream from where they were released and R_{12} <u>and</u> R_{23} marked upstream are two binomial joint PDFs:

$$P[R_{32}]\ P[R_{21}] = \tag{5}$$

$$Comb[M_3, R_{32}]\ \ \Phi_d^{R_{32}}(1-\Phi_d)^{M_3 - R_{32}}\ \ Comb[M_2, R_{21}]\ \ \Phi_d^{R_{21}}(1-\Phi_d)^{M_2 - R_{21}}$$

$$P[R_{12}]\, P[R_{23}] = \tag{6}$$

$$Comb[M_1, R_{12}]\ \ \Phi_u^{R_{12}}(1-\Phi_u)^{M_1 - R_{12}}\ \ Comb[M_2, R_{23}]\ \ \Phi_u^{R_{23}}(1-\Phi_u)^{M_2 - R_{23}}$$

Note that Φ_d and Φ_u are each presumed to be the same for two out of the three subsections, which can only be so when the two subsections are the same size <u>and</u> when the probability of capture is the same for all fish throughout the study area. From Equation 5 and 6, the MLEs of Φ_d and Φ_u are:

$$\hat{\Phi}_d = \left[\frac{R_{32} + R_{21}}{M_3 + M_2}\right] \qquad\qquad \hat{\Phi}_u = \left[\frac{R_{12} + R_{23}}{M_1 + M_2}\right] \tag{7}$$

To obtain estimates of Φ_d and Φ_u for substitution into Equation 2, the following PDF is used:

$$P[R_{2.}] \quad = \quad Comb[M_2, R_{2.}]\ \ p^{R_{2.}}(1-p)^{M_2 - R_{2.}} \tag{8}$$

The MLE (p) is $R_{2.}/M_2$. Remember that $\Phi_z = p\Phi_z$. Substitution of this relationship and MLE (p) into Equation 7 gives:

$$\hat{\Phi}_d = \left[\frac{M_2(R_{32} + R_{21})}{R_{2.}(M_3 + M_2)}\right] \qquad\qquad \hat{\Phi}_u = \frac{M_2(R_{12} + R_{23})}{R_{2.}(M_1 + M_2)} \tag{9}$$

Substitution of Equations 4 and 9 into Equation 2 gives the estimator of abundance for fish:

$$\hat{N} \quad = \quad \frac{\left\{\ M_1(1-\hat{\theta}_d) + M_2 + M_3(1-\hat{\theta}_u)\ \right\}\ \left\{C \ + \ 1\right\}}{R_{..} \ + \ 1} \tag{10}$$

The quantities (C +1) and (R + 1) are substituted for C and R , respectively, in Equation 2 to correct the bias in the binomial approximation of the hypergeometric probability distribution that is the actual PDF for recaptures (Bailey 1951, 1952) in Equation 2. The exact bias of Equation 10 is unknown, but will be measured with resampling techniques as described in Efron (1982). If this analysis shows that Equation 10 is a biased estimator, then expectations of the joint PDFs will be used to investigate means to change Equation 10 to correct this bias.

Appendix C2.–Petersen mark recapture abundance estimator for open rivers applied to the Sinuk River.

Biases associated with downstream movement of Arctic grayling through the index area were estimated for a variety of reasonable boundaries separating the downstream, midstream, and upstream subsections. Biases were calculated by subtracting the "open river" abundance estimate from that calculated using the pooled Bailey-modified Petersen estimate (Bailey 1951, 1952). The Bailey-modified Petersen estimator was used to estimate bias rather than the partially stratified estimator (Darroch 1961) because the former is more comparable with the "open system" estimator in that neither accounts for temporal-spatial heterogeneities in capture probabilities. As a result, the affects of downstream movement were isolated. The maximum bias was +102 fish.

Lower Boundary (km)	Upper Boundary (km)	
	25	27
15	90	-
13	-	102

Statistics and parameter estimates are provided for the case with the lower boundary at km 13 and an upper boundary at km 27, dividing the into 3 sections of equal length.

Statistic/Parameter	Value/Estimate
M_1	66
M_2	215
M_3	77
C	390
R..	59
R32	2
R21	1
R12	7
R23	2
θ_u	0.051
θ_d	0.160
$\hat{N}$	2,231

The "open river" abundance estimate is 2,231 Arctic grayling compared to the closed system of 2,333 fish (SE = 275). The positive bias of 102 associated with the Bailey modified Petersen estimator was considered relatively small given the estimated standard error of 275 fish.