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Abundance and Length Composition of Arctic Grayling in the Niukluk River, 2005

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

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. 07-22

ABUNDANCE AND LENGTH COMPOSITION OF ARCTIC GRAYLING IN THE NIUKLUK RIVER, 2005

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ABSTRACT

A mark-recapture experiment was conducted along a 25.0-km (15.5-mi) section of the Niukluk River during June 2005 to estimate abundance and length and age compositions of Arctic grayling *Thymallus arcticus.* The population in this index section is periodically assessed to ensure that it is sustained at or above a management-prescribed level of 3,500 fish ≥ 350 mm FL. During June 2005, 1,264 fish were captured using hook-and-line gear and beach seines and abundance was estimated to be 7,324 (SE = 1,298) Arctic grayling ≥ 350 mm FL. No fish less than 350 mm FL were recaptured precluding estimates of abundance for Arctic grayling ≥ 270 mm FL or ≥ 230 mm FL as planned. Most (58%) of the population of Arctic grayling ≥ 350 mm FL ranged from 380 to 424 mm FL. Ages were obtained for 99 Arctic grayling < 350 mm FL and ranged from age-2 to -7+.

Key words: Arctic grayling, *Thymallus arcticus*, abundance, length composition, hook-and-line, beach seine, mark-recapture, Niukluk 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, including the Niukluk River, support some angling effort for Arctic grayling *Thymallus arcticus*. The Niukluk River begins in the Bendeleben Mountains, is approximately 96 km in length, and is accessed at the village of Council approximately 20 km upstream of the Fish River (Figure 1). The river contains populations of Arctic grayling, northern pike *Esox lucius*, burbot *Lota lota*, longnose sucker *Catostomus catostomus*, whitefish *Coregonus* spp., Dolly Varden *Salvelinus malma*, and all five North American species of Pacific salmon *Oncorhynchus* spp.

Among road-accessible streams on the Seward Peninsula, the Niukluk River is a relatively popular sport fishing destination because it is one of the few streams where there are sport fishing opportunities for five species of Pacific salmon (coho salmon being the most popular), Dolly Varden, and a relatively dense population of large (≥ 15 in) Arctic grayling. Two guiding operations with small lodges are located on the Niukluk River, Nome-based guides fish the river, and many residents of Nome have summer cabins at Council or fish camps along the river (DeCicco 2006). River-specific estimates of harvest and catch for the Niukluk River were not available prior to 2002, when the Statewide Harvest Survey combined data from the Niukluk and Fish rivers. The pronounced decline in the harvest on the Niukluk and Fish rivers since 1989 (Table 1) was attributed to a change from a liberal fishing regulation (15 fish per day with only 2 over 20 inches) to the current regulation, a bag limit of 5 fish per day of which only one may be ≥ 15 in TL (350 mm FL; DeCicco 2006). The 15-in length restriction was implemented to reduce harvest and to help maintain a population of larger fish, which the Niukluk River and many other Nome-area streams are known for producing. For example, approximately 25% of all registered trophy Arctic grayling (≥ 18 inches or 3.0 lbs) have been taken from the Seward Peninsula.

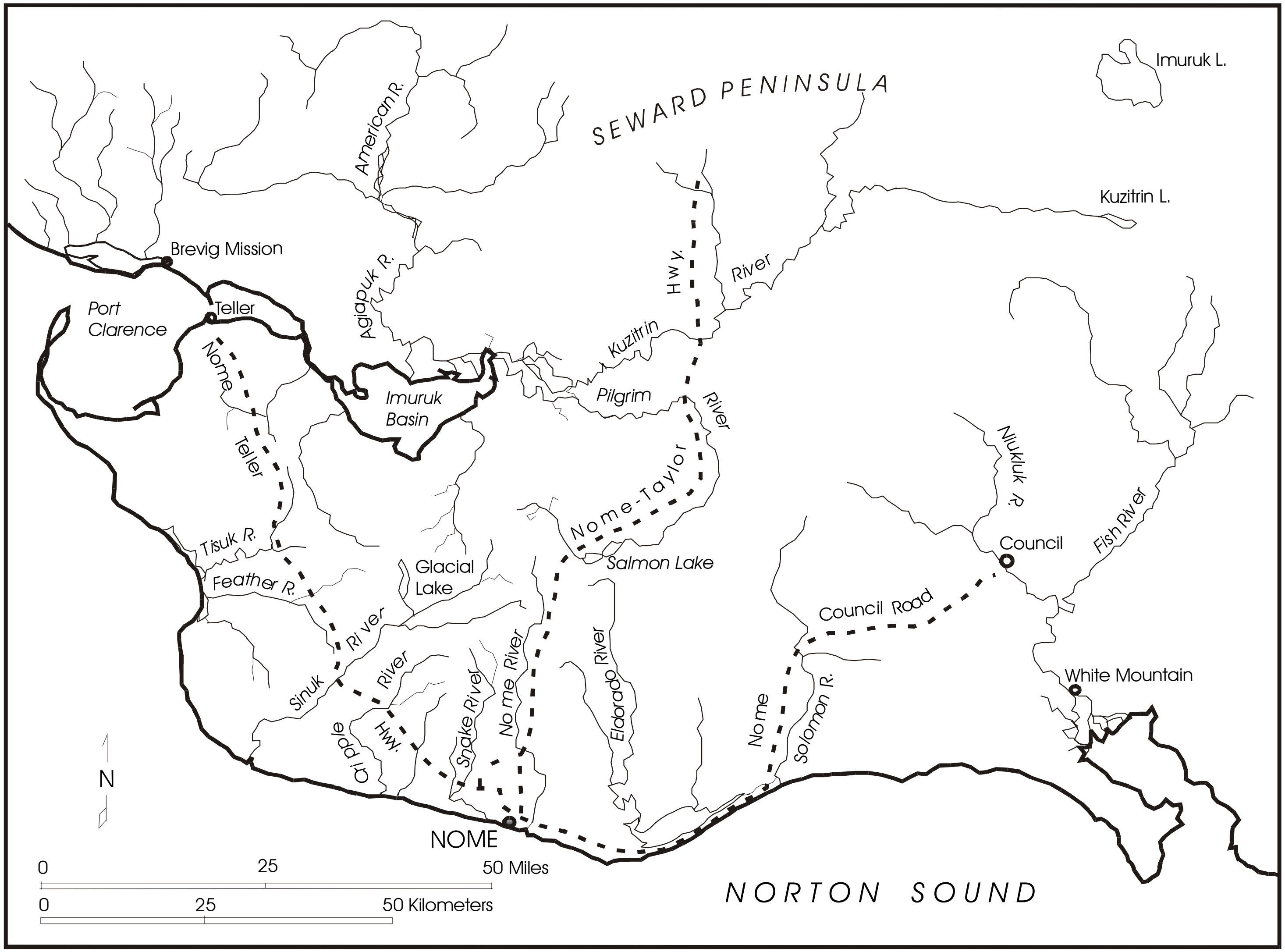

Figure 1.-Southern Seward Peninsula with road accessible waters.

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

Drainage	Period/year	Effort	Harvest	Catch[a]
Niukluk and Fish Rivers Combined				
	1983 - 1989	1,722	1,614	
	1990 - 1998	2,373	491	4,613
	1999 - 2003	2,910	493	4,958
Fish River				
	2002	167	13	285
	2003	298	32	2,211
Niukluk River				
	2002	648	84	1,050
	2003	1,625	256	4,352

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

Data from: Mills 1984-1994; Howe et al. 1995-1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006 a-b.

From 1988 to 2000, research was conducted on several important Arctic grayling populations on the Seward Peninsula (Merritt 1989; DeCicco 1990-1997, 2000, 2002a) that culminated in a fishery management plan for Arctic grayling in rivers along the Nome Road system and the current regulatory structure (DeCicco 2002b). This plan established specific management objectives for the Niukluk, Fish, Pilgrim, Nome, Snake, and Sinuk rivers (Figure 1), which were prescribed minimum abundances of Arctic grayling (≥ 15 in TL) for an index area in each river. The research program, as described in the management plan, recommends periodic population assessments for these and other road-accessible streams to ensure that abundances are being maintained at or above prescribed levels.

The management objective for the Niukluk River is to maintain a minimum abundance of 3,500 Arctic grayling ≥ 15 in TL (350 mm FL) within a 25-km index area between the Casadepaga River and the village of Council (Figure 2). This objective was based on stock assessments in 1989 and 1998, as well as an assessment of the population's ability to support existing catch and harvest (DeCicco 2002b). In 1989, an estimated 3,025 (SE = 640) Arctic grayling ≥ 250 mm FL were in the index area, of which 54% (SE = 0.02) were ≥ 350 mm FL (DeCicco 1990). In 1998, an estimated 4,975 (SE = 611) fish ≥ 250 mm FL were in the upper 17 km of the index area, of which 98% (SE=0.01) were ≥ 350 mm FL (DeCicco 1999). The lower eight kilometers of the assessment area was not included in the 1998 estimate because a large pink salmon run crowded the lower portions of the study area during the second event rendering the sampling gear ineffective. Six years had passed since the last assessment; therefore, the goal of this study was to reassess the Arctic grayling population in the Niukluk River in the 25-km index area to determine whether or not the prescribed abundance of at least 3,500 Arctic grayling ≥ 15 in TL (350 mm FL) had been maintained.

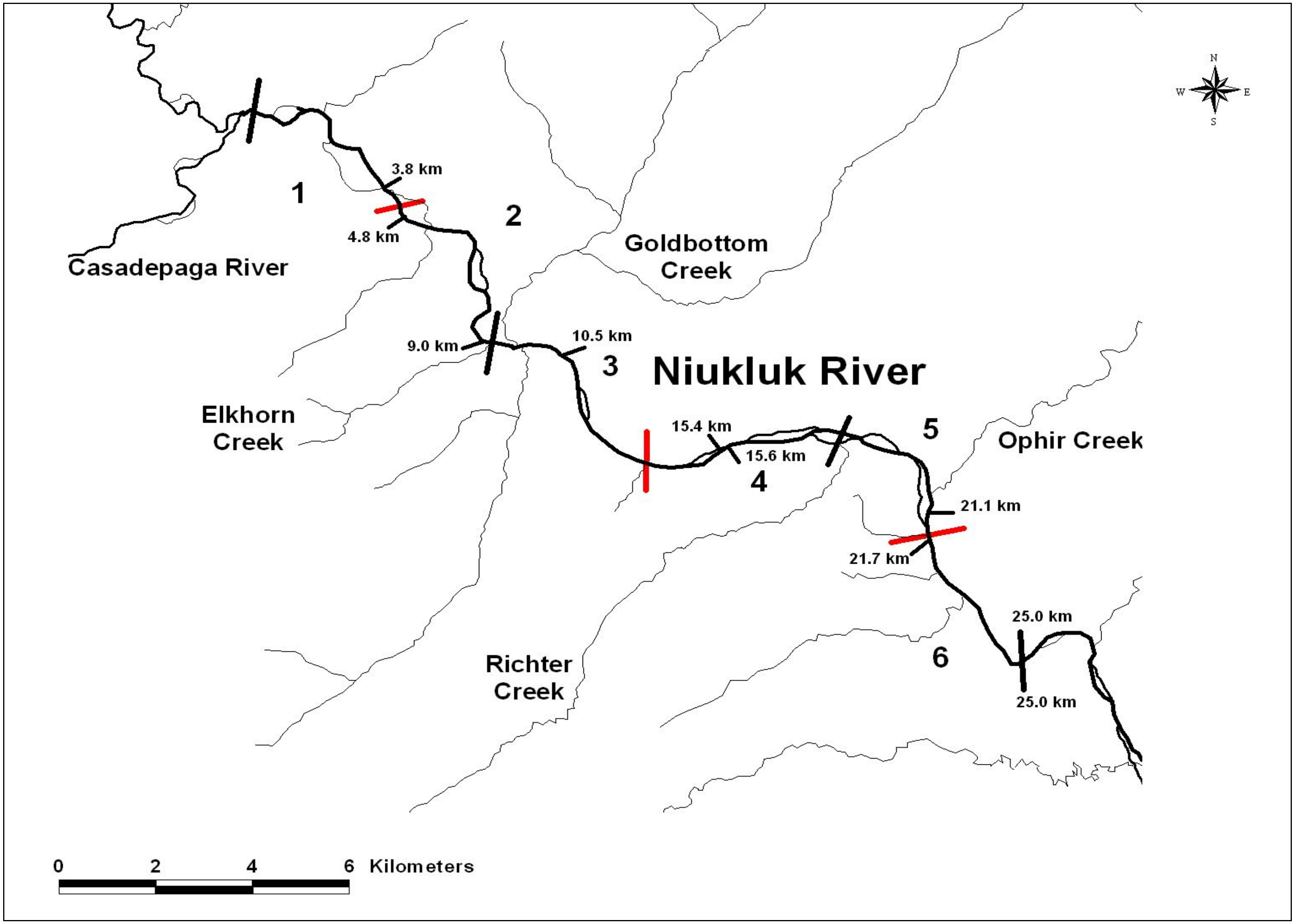


Figure 2.–Niukluk River study area with sections 1-6 and first event (upper values) and second event (lower values) daily sample areas cumulative distances demarcated.

Although not explicitly stated in the management plan, the threshold abundance goal for the Niukluk River is to be evaluated using estimates from mark-recapture experiments that meet minimum precision standards. Also implicit, is that a management action; specifically, a more restrictive regulation would not be considered if the 90% confidence interval of such an estimate included, or was greater than, the threshold abundance level (A. DeCicco, Area Management Biologist, ADF&G, Fairbanks; personal communication). A point estimate of 2,800 with precision equal to 25% of the actual abundance 90% of the time (minimum criteria for Seward Peninsula grayling research projects) would have an upper 90% confidence limit of 3,500 and a lower 90% confidence limit of 2,100. One objective of this study was to estimate the abundance of Arctic grayling ≥ 350 mm FL and its 90% confidence interval (Objective 2). Although this objective was important for research it was not an effective metric for evaluating the management goal. For example, an estimate of 2,800 fish with relative precision of 15% would have a 90% confidence interval that was narrower than that assumed in the management goal, would not contain 3,500 fish, and therefore would not be useful for directly comparing to the threshold abundance goal. This objective was restated (Objective 1) as a test of the null hypothesis that the abundance was ≤ 2,100 (assuming minimum precision criteria, a 5% chance of being below 2,100 corresponds to a 5% chance of being above 3,500), and power calculations were provided to weigh management risks.

OBJECTIVES

The project objectives were to:

1. test the null hypothesis that the abundance of Arctic grayling ≥ 350 mm FL in a 25-km index section of the Niukluk River during August was ≤ 2,100 with 80% power of rejecting the null hypothesis if the true abundance was = 3,160 and 95% power of rejecting the null hypothesis if the true abundance was = 3,500 using alpha = 0.05;
2. estimate the abundance of Arctic grayling ≥ 350 mm FL in a 25-km index section of the Niukluk River during August such that the estimate was within 25% of the actual abundance 90% of the time;
3. estimate the abundance of Arctic grayling ≥ 230 mm FL in a 25-km index section of the Niukluk River during late June such that the estimate was within 25% of the actual abundance 90% of the time;
4. estimate the abundance of Arctic grayling ≥ 270 mm FL in a 25-km index section of the Niukluk River during late June such that the estimate was within 25% of the actual abundance 90% of the time;
5. estimate the length composition (in 25-mm FL length categories) of Arctic grayling ≥ 230 mm FL in a 25-km index section of the Niukluk River such that the estimates were within 10 percentage points of the true value 90% of the time;
6. estimate the age composition using scale ages of Arctic grayling ≥ 230 mm FL in a 25-km index section of the Niukluk River in age groups 1 - 6 and ≥ 7 years such that the estimates were within 10 percentage points of the true value 90% of the time; and,
7. estimate the mean length-at-age for fish of age 4, 5, and 6 such that the estimates were within 10% of the true value 90% of the time.

Objectives 1 and 2 were the primary objectives because they related directly to the evaluation and further development of the management goal and thereby determined the sample size. Power calculations were provided to weigh risks associated with taking management actions at various population abundances. The Area Management Biologist concurred with the high likelihood of rejecting the null for true abundances greater than about 3,200, that there was only 50% power of rejecting the null hypothesis if the true abundance equaled 2,800, and that the chance of rejecting the null decreased greatly as the true abundance approached 2,100. The management objective was considered met if the null hypothesis was rejected. Objective 3 was expected to provide an estimate of the abundance of Arctic grayling that included nearly all age-4 fish (mean length 267 mm FL, SD = 20; DeCicco 1999). Arctic grayling ≥ 230 mm FL are typically recruited to sampling gear (hook-and-line) in Seward Peninsula streams. This estimate would provide a more complete understanding of the population, in particular, of the potential for recruitment to the ≥ 350 mm FL length category. Relative to Objective 4, the lower length limit of 270 mm FL is the most commonly used standard in Arctic grayling stock assessments within Region III, and this estimate would facilitate comparisons with other Arctic grayling populations. For Objective 6, aging error of scales increases markedly after age-6 due to the decrease in annual growth (DeCicco and Brown 2006); therefore, fish of scale > age-6 were grouped in a single age category, 7+. Because of this error, the age information was used primarily to identify cohorts of fish (i.e., ages 4 and 5) that may be recruiting into the ≥ 350 mm FL length category (age-6 Arctic grayling in the Niukluk were found to be on average 357 mm FL, SD=18; DeCicco 1999).

METHODS

SAMPLING DESIGN AND FISH CAPTURE

In 2005, the Niukluk River Arctic grayling study was designed to estimate abundance and length and age compositions of Arctic grayling within a 25-km index area by conducting a two-event mark-recapture experiment. The first (marking) event occurred during June 20-24 and the second (examination) event during June 26-30. The timing of this study was chosen to avoid complications associated with a large run of pink salmon that arrives en masse in early July (DeCicco 1999). During each event, the river was sampled beginning 0.8 km downstream of the Casadepaga River mouth and moved sequentially downstream to a point 1.2 km upstream of Council, AK. The river was accessed using an 18-ft riverboat with an outboard jet-powered motor. Each day, a four-person crew expended 5 to 11-hours of sampling effort, and for any given section of river this resulted in a 4 to 6-day hiatus between events.

Hook-and-line gear (fly-fishing and spin fishing) and a beach seine (50 m x 2 m, 6.5-mm mesh) were used to capture fish. The river boat was used to deploy the beach seine and served as a fishing platform. Most (≥80%) angling was conducted from the riverboat, which was typically anchored in the middle of the channel or near each shore so that both shorelines were within casting-distance. Some angling was conducted while wading downstream. A variety of terminal gears (flies or jigs) were utilized, however, spin gear was the primary tackle. Terminal spin gear consisted of rubber-bodied jigs of varied size (1/16-1/8 oz) to minimize size selectivity of Arctic grayling ≥ 230 mm FL. Fly gear was an alternate gear type and was used if fish were determined to be present in the area, but could not be captured using spin gear. Angler discretion was used to select the type of terminal fly gear, which consisted of assorted dry flies, nymphs, and egg patterns. During both events, a beach seine was used if: 1) the site was suitable (e.g., no large boulders or swift current); 2) it had been determined by angling or visual inspection that a particular "hole" or riffle likely had five or more fish; and, 3) a beach seine would be more efficient than angling. Sites selected for seining during the second event were not determined *a priori* as those locations seined during the first event.

To refine the analysis of movement patterns, efforts were made to minimize the displacement of fish from their capture locations after sampling, and in no cases were they displaced by more than 200 m. Seine-caught fish were placed in a water-filled tub near the end of the haul-out site, sampled, and released. When angling, if capture rates were high, fish were typically released within the immediate vicinity (e.g., < 50 m), and if catch rates were low and intermittent, fish were sampled once sufficient numbers (e.g., 3-5 fish) were collected in a holding tub or 5-gallon bucket to promote efficiency. In both cases, high and low capture rates, efforts were made to release fish into the same hydrologic feature, such as a pool, from which they were captured. All release locations (latitude and longitude) were recorded using a GPS. To quantify movement (i.e., river kilometers) of recaptured Arctic grayling between events, the distance between capture and release locations was measured.

In the first event, fish ≥ 230 mm FL were given a primary mark with an individually-numbered anchor tag (Floy FD 94). Additionally, a secondary mark (a partial upper caudal fin clip) was used to identify and mitigate effects of tag loss. 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 (Arctic grayling did not enter or leave the population during the experiment);
2. all Arctic grayling had a similar probability of capture in the first event or in the second event, or marked and unmarked Arctic grayling mixed completely between the first and second events;
3. marking of Arctic grayling in the first event did not affect the probability of capture in the second event;
4. marked Arctic grayling were identifiable during the second event; and,
5. all marked Arctic grayling were reported when examined during the second event.

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

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

where:

n_1 = the number of Arctic grayling marked and released during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event; and,

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

The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate whether the assumptions were satisfied (see Data Analysis Section). The experiment was designed to allow the validity of these assumptions to be insured or tested because failure to satisfy these assumptions could result in substantially biased estimates.

Assumption 1: The relatively short duration (i.e., 11 days) and timing (summer) of the experiment were selected to minimize or eliminate potential bias associated with large-scale emigration and immigration. Studies have demonstrated that movements of Arctic grayling tend to be at a much smaller scale (e.g., 0-3 km) during the mid-summer feeding period (generally defined as mid June to mid August), as compared to larger-scaled migrations (e.g., 5 – 100 km) associated with spring spawning and overwintering (Tack 1973; Ridder 1998a-b; Gryska 2006). Even if larger-scale movements of Arctic grayling were successfully avoided by design, combined immigration and emigration at the study area boundaries could have resulted in significant a positive bias in the abundance estimate. The movement data collected from recaptured fish were analyzed to evaluate the appropriateness of the assumption of closure. The short duration of the hiatus rendered immigration due to growth recruitment and emigration due to mortality insignificant.

Assumption 2: Because most marked and unmarked fish were expected to move as little as 0 to 3 river km during the experiment, it was unlikely that the condition of complete mixing would be satisfied. Therefore, the study was designed to satisfy the conditions of equal probability of capture during each event. This was done by attempting to distribute fishing effort throughout the entire index area and in proportion to the apparent distribution of Arctic grayling. Each gear type was fished wherever it was possible and most effective as determined by the crew (e.g., the beach seine was not used where there were large rocks or swift current). Arctic grayling distributions were assessed "real-time" using initial catch rates and visual observations if conditions permitted. For example effort was increased in areas where densities appeared relatively high (e.g., pools and glides immediately following riffles when initial catch rates were high or many fish were observed) and decreased but not eliminated where there appeared to be few Arctic grayling available (e.g., fast, shallow, riffles where, in general, catch rates were low and few fish were observed). Effort was allocated in this manner, rather than trying to maintain constant effort across the entire study area, because experience has shown that it typically requires additional effort to catch the same proportion of fish at locations with greater abundances.

This sampling protocol, while not as quantifiable as distributing effort equally regardless of the distribution of fish, has been shown to result in reasonably consistent probabilities of capture throughout study areas during an event (Gryska 2004; Wuttig 2004). Hook and line gear was supplemented with a seine to be more efficient when fishing reaches with many fish in an effort to counter the potential for lower capture probabilities when angling a productive reach given time constraints. Clearly, there is uncertainty in estimating the relative abundance of fish "real time" and the effectiveness of seines vary by location and by seine haul, so it can not be known *a priori* how to distribute effort to ensure equal capture probabilities throughout the study area. However, diagnostics are performed to test for equal probability of capture by location and to assess the potential for the combination of gears to induce heterogeneities in capture probabilities by size and by location.

It was also unknown if Arctic grayling would have equal probability of capture by length. The combination of hook-and-line gear and beach seine has been shown to capture representative samples of Arctic grayling in Seward Peninsula streams for the size range of Arctic grayling addressed in this experiment (DeCicco 1999, 2000). However, size selective sampling has also occurred when using this gear combination (DeCicco 1993, 1999). Diagnostic tests to identify and correct for potential biases due to size selectivity and spatio-temporal variability in capture probabilities have been presented in the Data Analysis section.

Assumption 3: The 4 to 6-day hiatus between the first and second events for a given river section was included to allow marked Arctic grayling to recover from the effects of handling and marking induced behavioral effects during the first event. In addition, multiple gear types were used to mitigate marking induced behavioral effects.

Assumption 4: This assumption was addressed by double-marking each Arctic grayling captured during the first event so that a marked fish would be identifiable in the event of tag loss. In addition, tag placement was standardized, which enabled the fish handler to reliably verify tag loss by locating recent tag wounds. Tag loss was noted when an Arctic grayling was recovered during the second event with a first-event finclip (left pectoral fin) but without a Floy™ tag.

Assumption 5: All Arctic grayling were thoroughly examined for tags or recent finclips. All markings (tag number, tag color, fin clip, and tag wound) for each Arctic grayling were recorded.

DATA COLLECTION

All captured Arctic grayling were processed immediately or soon after capture and released at or very near their capture location. For each Arctic grayling ≥ 150 mm FL captured, crews recorded the date, release location (latitude and longitude), fork length measured to the nearest mm, the type of finclip present or given, number of tag present or given (for fish ≥ 230 mm FL), color of tag present or given, recapture status, and mortality status. Floy™ tags were gray and were numbered between 10001 and 10584. From all Arctic grayling < 350 mm FL, two scales were removed from an area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin (W. Ridder, Sport Fish Biologist-retired, ADF&G, Delta Junction; personal communication; Brown 1943) and stored in coin envelopes. After completion of fieldwork, scales were cleaned in hot water and detergent, and then mounted on 30-sample 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). The triacetate impressions were magnified to 40X with a microfiche reader, and ages were determined by counting annuli, as described by Yole (1975). Data were either recorded on coin envelopes and later transferred into field notebooks or recorded directly into field notebooks. These data were later entered into an Excel spreadsheet for analysis and archival (Appendix C1).

DATA ANALYSIS

Relative to Assumption 1, closure was not tested directly but inferred from examination of the movement of recaptured Arctic grayling within the study area. The data were examined for evidence of movement away from or towards, either or both boundaries of the study area to provide evidence of immigration and emigration. Monte Carlo simulations (Appendix B1) were performed to estimate the potential bias due to these larger-scale movements and/or combined immigration and emigration at the boundaries. These simulations assumed that the observed movements of recaptured fish were representative of Arctic grayling in and near the study area. Because of uncertainties inherent in the simulations stemming from the assumptions made, these estimates of bias were not used to adjust abundance estimates. Rather the bias estimates were taken to reflect the potential for bias to be considered when interpreting results, designing experiments, and evaluating whether or not the management objective of maintaining a minimum abundance of 3,500 Arctic grayling ≥ 15 in TL (350 mm FL) within the index area was achieved. If movements were strongly directional, it would be determined if a Petersen model was appropriate (e.g., in the case of immigration only), or if the modified Petersen estimator of Evenson (1988) should be used.

Relative to Assumption 2, variations in capture probability related to Arctic grayling size, location, time, and gear types were examined. Size-selective sampling was tested using two Kolmogorov-Smirnov 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 were biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix B5. If stratification by size was required, capture probability by location would be examined for each stratum, and total abundance and its variance estimate would be calculated by summing strata estimates.

Temporal and spatial violations of Assumption 2 were tested using consistency tests described by Seber (1982; Appendix B6). The sample area was divided into six sections between 3.5 and 4.5 km in length to provide a minimum scale at which capture probabilities could be examined (Figure 2). Criteria considered when defining geographic strata included number of recaptures per stratum, hydrology, and stratum length relative to anticipated movements. If at least one of the three consistency tests resulted in a failure-to-reject the null hypothesis, then it was concluded that at least one of the conditions in Assumption 2 was satisfied. If all three of these tests rejected the null hypothesis, then depending on the extent of movement, a partially or completely stratified estimator must be used. If movement of marked Arctic grayling between strata was observed (incomplete mixing), the methods of Darroch (1961) would be used to compute a partially stratified abundance estimate. If no movement of marked Arctic grayling between geographic strata was observed, a completely stratified abundance estimate would be computed using the methods of Bailey (1951, 1952) or Darroch (1961).

Because the combination of gears and their distribution may affect the probabilities of capture by size or by location/time in a potentially complicated manner, diagnostic tests were performed to aid in understanding possible gear effects. These tests were not intended to result in stratification by gear, but instead to aid in understanding the diagnostics test results and adjustments made relative to size and spatiotemporal factors. K-S tests were performed to compare the length distributions of fish caught using each gear to aid in interpreting size related variability in probability of capture. Contingency tables analysis was performed to: 1) assess whether the probability of recapture during the second event was independent of gear of marking event; 2) determine whether recapture gear was independent of marking gear (essentially examines mixing between gears); and, 3) assess whether the recapture rate was independent of recapture gear.

Relative to Objective 1, a z-test statistic and corresponding P-value were calculated to assess the likelihood of obtaining the observed abundance estimate assuming the null hypothesis was true. A P-value < 0.05 would reject the null hypotheses. The 90% confidence interval for the abundance estimate was also estimated and the lower confidence limit was compared to 2,100 fish.

Length and age compositions of the population and mean length at age were estimated (Objectives 5-7) using the procedures outlined in Appendices B2, B4, and B5.

RESULTS

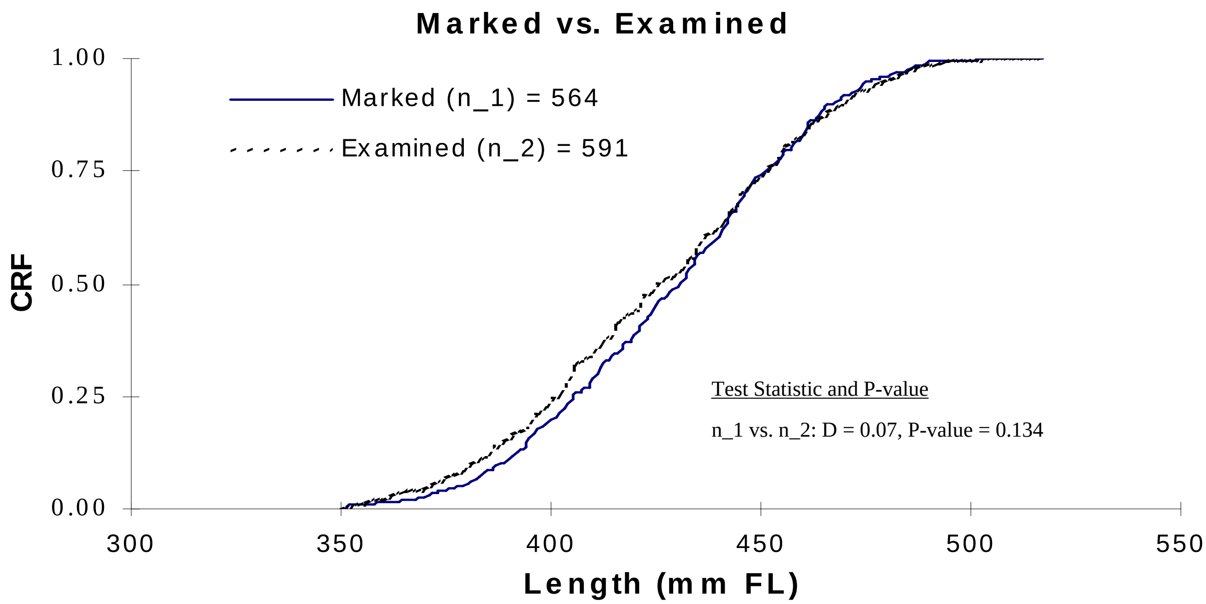
SUMMARY STATISTICS OF ARCTIC GRAYLING SAMPLED

During June 20 – 30, 1,264 Arctic grayling were captured during the experiment (Appendix A1), and lengths ranged from 147 to 517 mm FL (Appendix A2). Hook-and-line gear captured 1,133 Arctic grayling, and seine gear caught 131 Arctic grayling. The smallest Arctic grayling captured during the first event was 157 mm FL, smallest examined during the second event was 142 mm FL, and smallest recaptured was 374 mm FL. Of the 1,155 Arctic grayling ≥ 350 mm FL, 564 were captured during the first event (marked or n_1), 591 during the second event (examined or n_2), and 54 Arctic grayling were marked in the first event and recaptured in the second event (recaptured or m_2).

ABUNDANCE ESTIMATION AND HYPOTHESIS TESTING

The estimated abundance of Arctic grayling ≥ 350 mm FL was 7,324 (SE = 1,298) with a relative precision of 29.2% (α = 10%). Because the smallest Arctic grayling recaptured was 374 mm FL, estimates for the abundance of Arctic grayling < 350 mm FL were not possible, and consequently Objectives 3 and 4 were not achieved. An abundance estimate having 350 mm FL as a lower size limit was considered appropriate because: 1) there was one recapture of a marked Arctic grayling within the smallest 25-mm FL length category (i.e., 350 – 374 mm FL) and 2) K-S diagnostic tests (see below) did not reject the hypothesis of equal probability of capture for Arctic grayling 350 - 424 mm FL. The results of the testing procedures (Appendices B2 and B3) determined that for Arctic grayling ≥ 350 mm FL stratification by size was required but not by location. Therefore, the abundance of Arctic grayling ≥ 350 mm FL (Objective 2) was estimated using the size-stratified Bailey modified Petersen estimator (Bailey 1951, 1952; Appendix B9).

Size stratification was necessary because K-S tests indicated a Case III (Appendix B1) scenario, in which the length composition of Arctic grayling ≥ 350 mm FL released in the first event (n_1) differed significantly from those recaptured (m_2) during the second event (D = 0.21; P-value = 0.02; Figure 3), although not from Arctic grayling examined (n_2) in the second event (D = 0.07; P-value = 0.13; Figure 3). The strata break point was identified by testing for homogeneity of second event capture probabilities for all possible 2-strata break points using contingency table methods. Over a range of break points (414 to 448 mm FL), the chi-square test statistics were



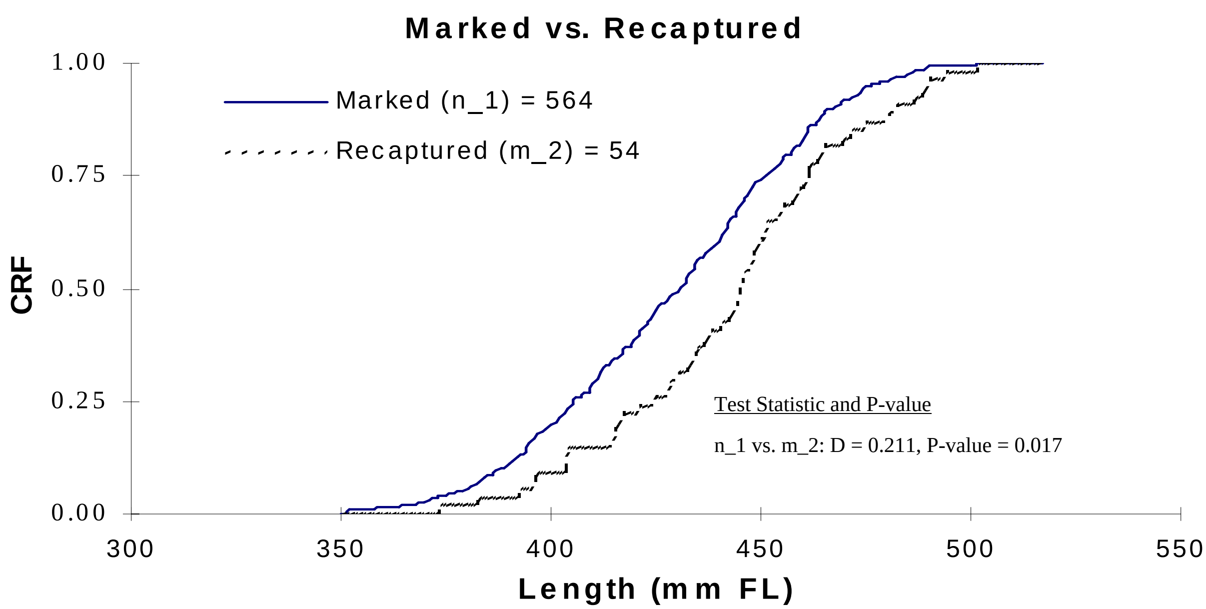


Figure 3.–Cumulative relative frequency (CRF) of Arctic grayling ≥ 350 mm FL marked and examined (upper panel) and marked and recaptured (lower panel), Niukluk River, June 2005.

relatively large (> 8) and arguably similar. Within this range, a strata break point of 425 mm FL was chosen because this point corresponded to 18 in TL (the designated length of a trophy sport-caught Arctic grayling). K-S tests of lengths within each stratum resulted in Case I scenarios. K-S tests comparing the lengths of Arctic grayling ≥ 350 mm FL captured by seine (n=97) and by hook and line (n=1,058) rejected the null hypothesis that both gears were sampling the same population. The seine tended to catch smaller fish; however, the minimum and maximum lengths sampled by the gears were quite similar. K-S tests performed on only hook and line caught fish resulted in very similar P-values indicating that, despite some differences in the length distributions of seine and hook and line caught fish, the seine caught fish did not induce the observed size selectivity.

Tests of consistency were performed for each fork length stratum. The results presented below correspond to the study area being divided into six sections each 3.5 to 4.5 km in length. Consistency tests were also performed with the study area divided into three subsections by combining adjacent sections in the six-section scheme and with section boundaries selected to closely correspond to the daily sampling schedule. Results were similar for each geographic scale (Appendices A3-A8). There were no obvious hydrologic features that may have influenced capture probabilities and to delineate sections.

For the smaller fish stratum (350 – 424 mm FL), tests of consistency indicated that, as anticipated, mixing of Arctic grayling between sections was not complete (P-value = 0.02; Table 2). Probabilities of capture by area were not significantly different during the first event (P-value = 0.69; Table 3) and during the second event (P-value = 0.63; Table 4); therefore, the equal probability of capture assumption was satisfied during both events and a Bailey-modified Petersen estimator was used to estimate an abundance for Arctic grayling 350 - 424 mm FL of 4,985 (SE = 1,255). For the larger fish stratum (≥ 425 mm FL), Arctic grayling failed to mix completely (P-value < 0.01; Table 5). Probabilities of capture by area were not significantly different during the first event (P-value = 0.62; Table 6), however during the second event capture probabilities by area were significantly different (P-value = 0.04; Table 7); therefore, the equal probability of capture assumption was satisfied during the first event and a Bailey-modified Petersen estimator was used to estimate the abundance for Arctic grayling ≥ 425 mm FL of 2,339 (SE = 331). Diagnostic test results suggest that supplementing hook and line sampling with the seine did not induce significant spatiotemporal heterogeneities in probability of capture. Contingency table analysis indicated that mixing of Arctic grayling between gear types was complete (P-value = 0.98), that probabilities of capture in the second event were independent of gear used during the first event (P-value = 0.90), and that recapture rates did not differ by the gear used during the second event (P-value = 0.14; Appendices A9–A11).

Table 2.–Test for complete mixing. Number of Arctic grayling 350 - 424 mm FL marked in each section (1 - 6) and recaptured or not recaptured in each section of the Niukluk River, June 2005.

	Section Where Recaptured							
Section Where Marked	1	2	3	4	5	6	Not Recaptured (n_1-m_2)	Marked (n_1)
1	2						15	17
2		1					33	34
3			2				30	32
4		1	1	0			68	70
5			1	1	2	1	61	66
6						1	24	25
Total	2	2	4	1	2	2	231	244

χ^2 = 48.46; df = 30; P-value = 0.02; reject H_0.

Table 3.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling 350 - 424 mm FL examined during the second event by section (1 – 6) of the Niukluk River, June 2005.

	Section Where Examined						
Category	1	2	3	4	5	6	All Sections
Marked (m_2)	2	2	4	1	2	2	13
Unmarked (n_2-m_2)	41	30	46	60	36	59	272
Examined (n_2)	43	32	50	61	38	61	285
$P_{capture}$ 1st Event (m_2/n_2)	0.05	0.06	0.08	0.02	0.05	0.03	0.05

χ^2 = 3.04; df = 5; P-value = 0.69; fail to reject H_0.

Table 4.-Test for equal probability of capture during the second event. Number of Arctic grayling 350 - 424 mm FL marked by section (1 - 6) during the first event that were recaptured and not recaptured during the second event, Niukluk River, June 2005.

	Section Where Marked						
Category	1	2	3	4	5	6	All Sections
Recaptured (m_2)	2	1	2	2	5	1	13
Not Recaptured (n_1-m_2)	15	33	30	68	61	24	231
Marked (n_1)	17	34	32	70	66	25	244
$P_{capture}$ 2nd Event (m_2/n_1)	0.12	0.03	0.06	0.03	0.08	0.04	0.05

$\chi^2 = 3.43$; df = 5; P = 0.63; fail to reject H_0.

Table 5.–Test for complete mixing. Number of Arctic grayling ≥425 mm FL marked in each section (1 - 6) and recaptured or not recaptured in each section of the Niukluk River, June 2005.

	Section Where Recaptured							
Section Where Marked	1	2	3	4	5	6	Not Recaptured (n_1-m_2)	Marked (n_1)
1	5						40	45
2	2	11					36	49
3			8				73	81
4	1		2	3			49	55
5	1				1	1	47	50
6			1			5	34	40
Total	9	11	11	3	1	6	279	320

$\chi^2 = 140.40$; df = 30; P-value < 0.01; reject H_0.

Table 6.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥ 425 mm FL examined during the second event by section (1 – 6) of the Niukluk River, June 2005.

	Section Where Examined						
Category	1	2	3	4	5	6	All Sections
Marked (m_2)	9	11	11	3	1	6	41
Unmarked (n_2-m_2)	45	57	71	46	11	35	265
Examined (n_2)	54	68	82	49	12	41	306
$P_{capture}$ 1st Event (m_2/n_2)	0.17	0.16	0.13	0.06	0.08	0.15	0.13

$\chi^2 = 3.50$; df = 5; P-value = 0.62; fail to reject H_0.

Table 7.-Test for equal probability of capture during the second event. Number of Arctic grayling ≥ 425 mm FL marked by section (1 - 6) during the first event that were recaptured and not recaptured during the second event, Niukluk River, June 2005.

	Section Where Marked						
Category	1	2	3	4	5	6	All Sections
Recaptured (m_2)	5	13	8	6	3	6	41
Not Recaptured (n_1-m_2)	40	36	73	49	47	34	279
Marked (n_1)	45	49	81	55	50	40	320
$P_{capture}$ 2nd Event (m_2/n_1)	0.11	0.27	0.10	0.11	0.06	0.15	0.13

$\chi^2 = 11.42$; df = 5; P = 0.04; reject H_0.

Of the 54 Arctic grayling ≥ 350 mm FL with known release and recapture locations, 42 (81%) were recaptured within 1.0 km of where they had been marked (Figure 4). Seven of 54 (13%) Arctic grayling were recaptured more than 4 km upstream from where they had been marked. Several fish marked in the downstream portion of the study area were recaptured near the upstream boundary (Figure 4), which suggests that a proportion of the population was migrating into and through the index area. Monte Carlo simulations estimated the potential for positive bias due to fish movements (including the larger scale movements) of between 6 to 11%. The modified Petersen estimator of Evenson (1988) could not be applied for comparison purposes because model assumptions could not be met. Growth of the recaptured fish was indistinguishable from measurement error.

Relative to Objective 1, the z-test statistic was 4.0, which corresponded to a P-value <0.001, strongly rejecting the null hypothesis. In addition, the lower limit of the 90% confidence interval for the abundance estimate (90% CI = 5,188-9,459) far exceeded both 2,100 and 3,500 fish, even when accounting for the estimated potential for bias.

LENGTH AND AGE COMPOSITIONS

Because the smallest Arctic grayling recaptured was 374 mm FL, estimates of length composition were restricted to the population of Arctic grayling ≥ 350 mm FL. Age composition was only estimated for the sampled catch of Arctic grayling < 350 mm FL because it was assumed that all fish ≥ 350 mm FL were age 7+. K-S tests indicated a Case III scenario (Appendix B5); therefore, lengths were pooled from both sampling events within each length stratum and composition estimates were adjusted for differential capture probabilities of each stratum (Appendix B7). Most (58%) of the estimated population was between 380 and 424 mm FL (Table 8; Appendix A12). Ages were obtained from 99 Arctic grayling < 350 mm FL and mean length at age for ages 2 through 6 were calculated (Table 9).

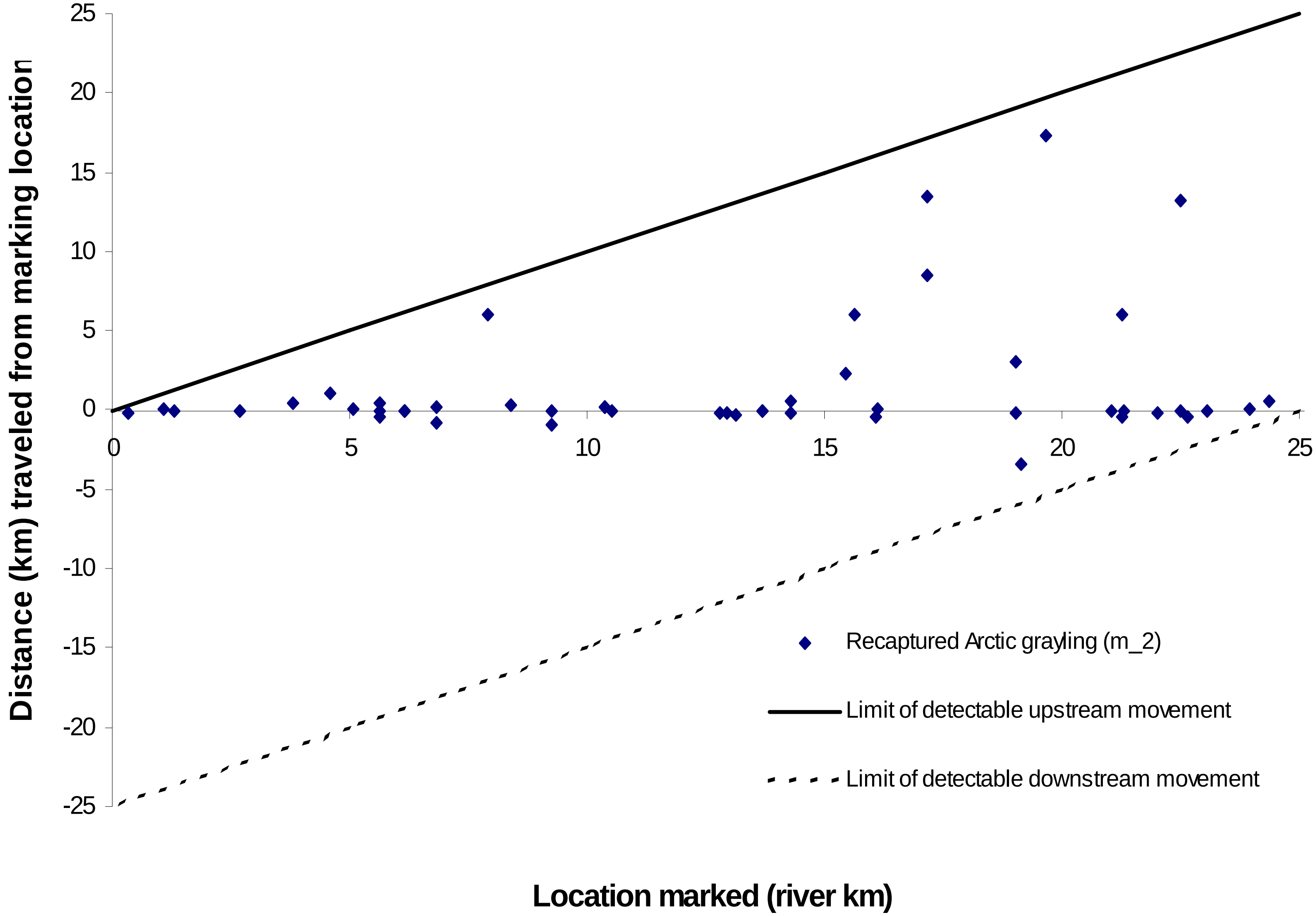


Figure 4.-Distance traveled from marking location by each recaptured Arctic grayling (m_2=54), Niukluk River June 2005.

Table 8.-Estimates of length composition and abundance by 10-mm FL groups for Arctic grayling ≥ 350 mm FL, Niukluk River, June 2005.

Length Class (mm FL)	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$	$CV[\hat{N}_k]$	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$
350 – 359	188	62	0.33	0.03	0.01
360 – 369	170	57	0.34	0.02	0.01
370 – 379	386	112	0.29	0.05	0.01
380 – 389	631	174	0.28	0.09	0.01
390 – 399	876	235	0.27	0.12	0.02
400 – 409	1,055	279	0.26	0.14	0.02
410 – 419	1,084	286	0.26	0.15	0.02
420 – 424	594	164	0.28	0.08	0.01
425 - 429	194	38	0.19	0.03	<0.01
430 – 439	448	73	0.16	0.06	0.01
440 – 449	542	86	0.16	0.07	0.01
450 – 459	381	64	0.17	0.05	0.01
460 – 469	347	59	0.17	0.05	0.01
470 – 479	224	42	0.19	0.03	0.01
480 – 489	138	29	0.21	0.02	<0.01
490 – 499	45	14	0.32	0.01	<0.01
500 – 509	11	7	0.59	<0.01	<0.01
510 - 510	7	5	0.71	<0.01	<0.01
≥ 350	7,324	1,298			

Table 9.–Mean length at age of Arctic grayling that were captured in the Niukluk River, June 2005.

				Sample statistics		
Age	n	Mean length	SE	Standard Deviation	Maximum Length	Minimum length
2	19	176	3.6	15.6	210	142
3	48	265	4.3	30.0	356	208
4	17	289	8.4	34.6	340	232
5	7	296	11.1	29.4	327	245
6	7	317	10.3	27.2	346	273
≥ 7	1	N/A	N/A	N/A	322	

DISCUSSION

The 2005 estimate of abundance of Arctic grayling ≥ 350 mm FL (7,324 Arctic grayling; 90% CI = 5,188-9,459) significantly exceeded management objectives for the index area of the Niukluk River (3,500 Arctic grayling ≥ 350 mm FL) despite a potential for significant positive bias of between 6 to 11%, which was attributed to combined immigration and emigration. The magnitude of this bias was small relative to the difference between the management goal and the lower boundary of the 90% confidence interval. Current regulations appear sufficient for maintaining abundance and composition of the population of Arctic grayling in the Niukluk River at satisfactory levels, and therefore, no management actions need be taken to reduce harvest.

As described for the Pilgrim River (Gryska *In prep*), management objectives within the *Fishery Management Plan for Arctic Grayling Sport Fisheries Along the Nome Road System* (DeCicco 2002b) should be revised to clearly articulate the statistical tests that must be performed or parameter estimates that are required to evaluate the management objectives. Such research criteria were not available when preparing the operational plan for this study and had to be developed through personal communications with the area management biologist and author of the management plan. A peer-reviewed management plan with that includes these research criteria would provide a long-term document to unambiguously guide future research.

Although the management objective was significantly exceeded in this study, the precision expectation for the abundance estimate was not achieved (for Arctic grayling ≥ 350 mm FL the overall abundance estimate's relative precision at the 90% confidence level was ± 29.2%). To attain estimates within research precision would have required at least a 25 to 30% increase in sample size. Assuming similar catch rates, about 10.5 hours of additional sampling effort per event would have been needed, which can realistically be accommodated in future research design. Although there appeared to be many smaller (< 350 mm FL) Arctic grayling, estimating their abundance within objective precision would likely have required substantially more effort, and it is unlikely that the information need or resources (time and personnel) will exist to warrant the extra effort needed to estimate the abundance of these fish.

Bias present in this study due to combined immigration and emigration was significant, but given current abundance, it was not large enough to merit near term design changes. However, because the timing and extent of these movements may vary annually and the abundance will also vary and may near the management threshold, it remains important to accurately record capture/release locations and estimate the potential for bias. If necessary, bias may be reduced in two ways: 1) increase study area length, and 2) change dates of sampling to a period when Arctic grayling may move less. Increasing study area size is not desirable because, although it would yield a reduction in bias, it would require a substantial increase in resources. Although the study was designed to coincide with the period of minimal fish movement, movement data suggested some tendency for upstream movement, which may have been related to post spawning migrations. A later sampling date (July or August) may coincide with a more stationary Arctic grayling population, but the capture efficiency of those fish would likely diminish greatly (DeCicco 1999) after the arrival of numerous spawning pink salmon. However, beginning the experiment a week or two later may be a viable option.

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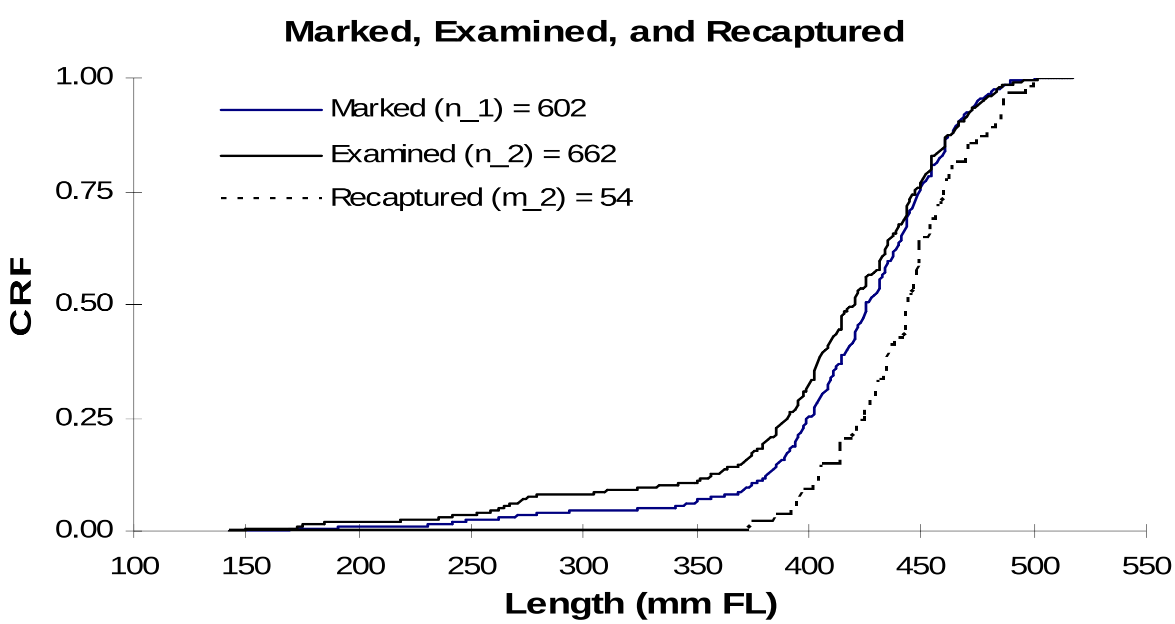
APPENDIX A
DATA SUMMARY

Appendix.A1.–Sampling schedule for the Niukluk River, 2005.

Date	# Fish Caught	River km Sampled	Duration (hours)
6/20/2005	57	3.82	5.0
6/21/2005	124	6.71	10.0
6/22/2005	153	4.91	10.0
6/23/2005	177	5.61	9.5
6/24/2005	91	3.95	6.0
6/25/2005		No sampling	
6/26/2005	111	4.78	6.0
6/27/2005	79	4.18	10.0
6/28/2005	190	6.60	11.0
6/29/2005	180	6.15	10.5
6/30/2005	102	3.29	5.0



Appendix A2.–Cumulative relative frequency (CRF) of Arctic grayling ≥ 147 mm FL marked and examined (upper panel) and marked and recaptured (lower panel), Niukluk River, June 2005.

Appendix A3.–Test for complete mixing. Number of Arctic grayling 350 - 424 mm FL marked in each section (1 - 3) and recaptured or not recaptured in each section of the Niukluk River, June 2005.

	Section Where Recaptured				
Section Where Marked	1	2	3	Not Recaptured (n_1-m_2)	Marked (n_1)
1	3			48	51
2	1	3		98	102
3		2	4	85	91
Total	4	5	4	231	244

χ^2 = 15.31; df = 6; P-value = 0.02; reject H_0.

Appendix A4.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling 350 - 424 mm FL examined during the second event by section (1 – 3) of the Niukluk River, June 2005.

	Section Where Examined			
Category	1	2	3	All Sections
Marked (m_2)	4	5	4	13
Unmarked (n_2-m_2)	70	107	95	272
Examined (n_2)	74	112	99	285
$P_{capture}$ 1st Event (m_2/n_2)	0.05	0.04	0.04	0.05

χ^2 = 0.17; df = 2; P-value = 0.92; fail to reject H_0.

Appendix A5.-Test for equal probability of capture during the second event. Number of Arctic grayling 350 - 424 mm FL marked by section (1 - 3) during the first event that were recaptured and not recaptured during the second event, Niukluk River, June 2005.

	Section Where Marked			
Category	1	2	3	All Sections
Recaptured (m_2)	3	4	6	13
Not Recaptured (n_1-m_2)	48	98	85	231
Marked (n_1)	51	102	91	244
$P_{capture}$ 2nd Event (m_2/n_1)	0.06	0.04	0.07	0.05

χ^2 = 0.72; df = 2; P > 0.70; fail to reject H_0.

Appendix A6.–Test for complete mixing. Number of Arctic grayling ≥ 425 mm FL marked in each section (1 - 3) and recaptured or not recaptured in each section of the Niukluk River, June 2005.

	Section Where Recaptured				
Section Where Marked	1	2	3	Not Recaptured (n_1-m_2)	Marked (n_1)
1	18			76	94
2	1	13		122	136
3	1	1	7	81	90
Total	20	14	8	279	320

χ^2 = 70.15; df = 6; P-value < 0.01; reject H_0.

Appendix A7.-Test for equal probability of capture during the first event. Number of marked and unmarked Arctic grayling ≥ 425 mm FL examined during the second event by section (1 – 3) of the Niukluk River, June 2005.

	Section Where Examined			
Category	1	2	3	All Sections
Marked (m_2)	20	14	7	41
Unmarked (n_2-m_2)	103	116	46	265
Examined (n_2)	123	130	53	306
$P_{capture}$ 1st Event (m_2/n_2)	0.16	0.11	0.13	0.13

χ^2 = 1.77; df = 2; P-value = 0.41; fail to reject H_0.

Appendix A8.-Test for equal probability of capture during the second event. Number of Arctic grayling ≥ 425 mm FL marked by section (1 - 3) during the first event that were recaptured and not recaptured during the second event, Niukluk River, June 2005.

	Section Where Marked			
Category	1	2	3	All Sections
Recaptured (m_2)	18	14	9	41
Not Recaptured (n_1-m_2)	76	122	81	279
Marked (n_1)	94	136	90	320
$P_{capture}$ 2nd Event (m_2/n_1)	0.19	0.10	0.10	0.13

χ^2 = 4.79; df = 2; P = 0.09; fail to reject H_0.

Appendix A9.-Test for complete mixing between gears. Number of Arctic grayling ≥ 350 mm FL marked by each gear type and recaptured or not recaptured by each gear type, Niukluk River, June 2005.

	Recaptured - Gear type			
Marked - Gear type	Hook and line	Beach seine	Not Recaptured	Marked
Hook and line	41	7	484	532
Beach seine	5	1	64	70
Total	46	8	548	602

$\chi^2 = 0.03$; df = 2; P-value = 0.98; fail to reject H_0.

Appendix A10.-Test for equal probability of capture during the second event (by examining recapture rates). Number of Arctic grayling ≥ 350 mm FL marked by gear type during the first event that were recaptured and not recaptured during the second event, Niukluk River, June 2005.

	Marked - gear type		
Category	Hook and line	Beach seine	All Gear
Recaptured (m_2)	48	6	54
Not Recaptured (n_1-m_2)	484	64	548
Marked (n_1)	532	70	602
$P_{capture}$ (m_2/n_1)	0.09	0.09	0.09

$\chi^2 = 0.02$; df = 1; P = 0.90; fail to reject H_0.

Appendix A11.-Test for equal probability of capture during the first event (by examining recapture rates). Number of marked and unmarked Arctic grayling 350 - 424 mm FL examined by gear type during the second event by section (1 – 3) of the Niukluk River, June 2005.

	Examined - gear type		
Category	Hook and line	Beach seine	All Gear
Marked (m_2)	46	8	54
Unmarked (n_2-m_2)	555	53	608
Examined (n_2)	601	61	662
$P_{capture}$ (m_2/n_2)	0.08	0.13	0.08

$\chi^2 = 2.20$; df = 1; P-value = 0.14; fail to reject H_0.

Appendix A12.-Estimates of length composition and abundance by 25-mm FL groups for Arctic grayling ≥ 350 mm FL, in a 25.0-km index section of the Niukluk River, June 2005.

Length Class (mm FL)	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
350 – 374	556	155
375 – 399	1,696	439
400 – 424	2,733	696
425 – 449	1,184	174
450 – 474	856	129
475 – 499	280	50
500 – 525	19	9
Total	7,324	1,298

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

Appendix B1.–Description of the algorithm used to estimate bias associated with lack of closure.

OBJECTIVE

The objective was to estimate the bias associated with violations of the closure assumption resulting from combined immigration and emigration. When combined during a closed system mark-recapture experiment, immigration and emigration cause the abundance estimator to be positively biased with respect to either event. While an individual experiment may result in a point estimate that is greater than, less than, or equal to the true (but unknown) abundance, these differences averaged over many repetitions of the experiment would be positive. The algorithm described below was used to estimate the bias associated with the 2005 Niukluk River mark recapture experiment; however, these estimates were not used to adjust abundance estimates. Rather the bias estimates were taken to reflect the potential-for-bias to be considered when interpreting results, evaluating whether or not management objectives were attained, and providing design recommendations. Estimates of bias were used in this way because, as averages, they cannot be applied to a specific experiment and because of uncertainties associated with assumptions made to constrain the simulations. In spite of these limitations the results provide useful insights.

GENERAL DESCRIPTION

The sizes of the study area and areas adjacent to the study area (i.e., upstream and downstream "boundary" areas) were defined, fish were distributed across the study and boundary areas with constant density (the initial density may be variable), and the study area was sampled with probability of capture equal to that estimated for the first event of the mark recapture experiment. All fish were then moved with movements based on those observed for fish recaptured during the experiment. After fish were moved, the study area was resampled with probability of capture equal to that estimated for the second event of the experiment. The first and second event sample sizes and the number of recaptured fish were tallied and used to estimate abundance and its associated variance with the Bailey-modified Petersen estimator, completing the first of many, typically 2000, replications (or realizations). During each subsequent replication fish were moved (from their location during the first event), sampled (second event), and estimates were calculated. The initial abundance and first event sample were constant through all iterations because the focus of the effort was the effects of movement and because the bias estimates were shown to be insensitive to these variables. The bias was calculated by comparing the abundance estimates for each realization to the true number of fish in the study area, which is known for the simulation. The software R was used.

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Modeling Movements

An important assumption was that the observed movements of recaptured fish were representative of those in the population of interest. To ascertain whether this was indeed the case, a plot of the distance moved as a function of location marked was examined (Appendix B3, upper panel). Restricting sampling to the study area places limits on observing movements (e.g., a 5km downstream movement cannot be observed from a fish marked within 5 km of the lower boundary of the study area). The proximity of the observed movements to these limits of detection is an important consideration when assessing how representative the observed movements are of the population (Appendix B3, lower panel). If movements appear relatively homogeneous throughout the study area (given sample size considerations) and are small relative to the size of the study area, it can be assumed that the observed movements are representative of those of fish in the population of interest. If observed movements are not homogeneous throughout the study area and encroach upon the limits of detection, as was the case for the Niukluk River, then the observed movements must be supplemented by those likely to have occurred but not observable. For the Niukluk River, the recapture data were supplemented with six additional "observations" (Appendix B3; lower panel). The approach taken for supplementing the movement data assumed that true movements were relatively homogeneous as a function of marked location. Movements of distance equal to or larger than the study area are neither observable nor estimable. If they occur, such movements would render the simulation result a lower bound on the potential for bias. It is not possible to quantify this component of potential bias; however, drawing on the general observation that Arctic graying appear relatively stable during the summer feeding season and assuming some degree of smoothness regarding the movement distributions, it is perhaps reasonable to speculate based on the presence of only a few movements that were about one half of the length of the study area that movements greater than the study area in length were not likely. Indeed, the distributions of the mixture model fit to the data suggested that the likelihood of movement exceeding the length of the study area was low (see below).

A mixture model (Venables and Ripley 1999) was used to fit two normal distributions to the observed histogram of movements and these distributions were used to simulate movements. Most Arctic grayling during the summer feeding period are relatively stationary; however, often a small proportion move more extensively (e.g., the Niukluk River). Therefore, modeling the movements required fitting two distributions (Appendix B4). The mixture model's estimates for the mean and variance of each distribution and the estimate of the proportion of fish in each group, were assigned to parameters in the simulation used to move the fish. Fish were moved similarly regardless of their location; however, the algorithm also allows the degree of movement to be varied across the study and boundary areas (for example, a boundary that is closed or nearly closed to movement due to a change in river morphology or quality of habitat may be accommodated). Uncertainties associated with the mixture model fits were not accounted for by the simulations.

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MATCHING SIMULATION TO EXPERIMENTAL RESULTS

Initially, movement distribution parameters and the proportion of fish following each distribution were fixed according to the mixture model output, the probabilities of capture were set equal to estimates from the mark-recapture experiment (**$Pc_{1st\ event}$ & $Pc_{2nd\ event}$**), and the number of fish distributed among the study and boundary areas was set at approximately twice the experimental abundance estimate (boundary areas were ½ the length of the study area and some positive bias was anticipated). After the simulation was performed, the average of the simulated abundance estimates, $\bar{\hat{N}}_{s,final}$, was compared to the experimental abundance estimate, $\hat{N}$, and the simulated first event sample size, $n_{1,s}$, was compared to the actual n_1. The number of fish distributed across the study and boundary areas and to a lesser degree the probabilities of capture were then adjusted to get a close match. Movements of simulated fish were also compared to those observed and slight adjustments were made to the movement parameters, specifically the portions following each distribution, to improve fit. Finally, the true abundance in the study area during the initial event, $N_{s,initial}$, was compared with the mean of the true abundances during the final event, $\bar{N}_{s,final}$, to assess the adequacy of the size of the boundary area.

SIMULATION OUTPUT

Output from simulation included the following: 1) the true abundance in the study area during the initial event, $N_{s,initial}$, 2) the mean of the true abundances during the final event, $\bar{N}_{s,final}$, 3) the mean of the simulated abundance estimates, $\bar{\hat{N}}_{s,final}$ and, 4) an estimate of the mean percent bias, $\%\hat{\bar{b}}ias = \frac{1}{\#reps}\sum_{i=1}^{\#reps}\left(\hat{N}_{s,final} - N_{s,initial}\right)/ N_{s,initial} \times 100\%$ (Appendix B2). Also tracked were the number of emigrating marked fish and movement statistics. Output can be tailored to site-specific needs.

NIUKLUK SPECIFICATIONS

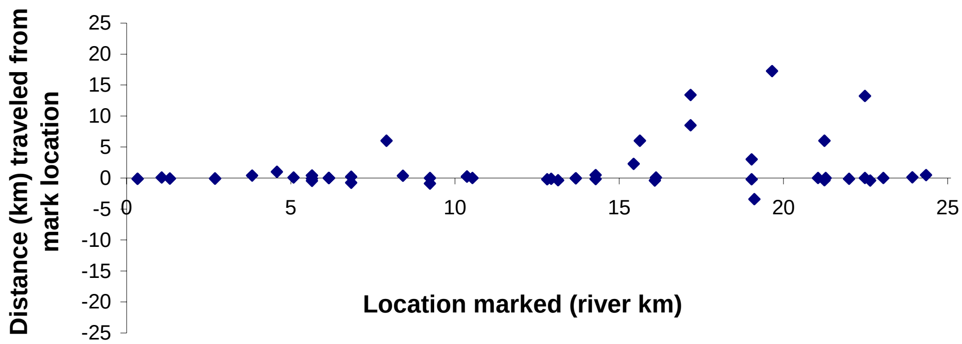
The study area was 25 km (= 50 bins) and each boundary area was 12.5-km (= 25 bins each). The abundance estimator for Arctic grayling ≥350 mm FL was size stratified; therefore, the simulation was conducted for each size stratum. However, it was not anticipated, nor did the data suggest, that fish in these size categories (both comprised of mature fish) moved differently, thus the same movement distributions were used to model movement of fish in each size stratum. The estimated abundances, probability of capture, and sample size for the first event are summarized in Appendix B2). Two sets of movement distributions were used. One set for simulations in which movements were estimated directly from recaptured fish (Simulation A; Appendix B2) and another for simulations in which movements were estimated from recaptured fish supplemented by an estimates of movements not observable due to sampling constraints (Simulation B; Appendix B2).

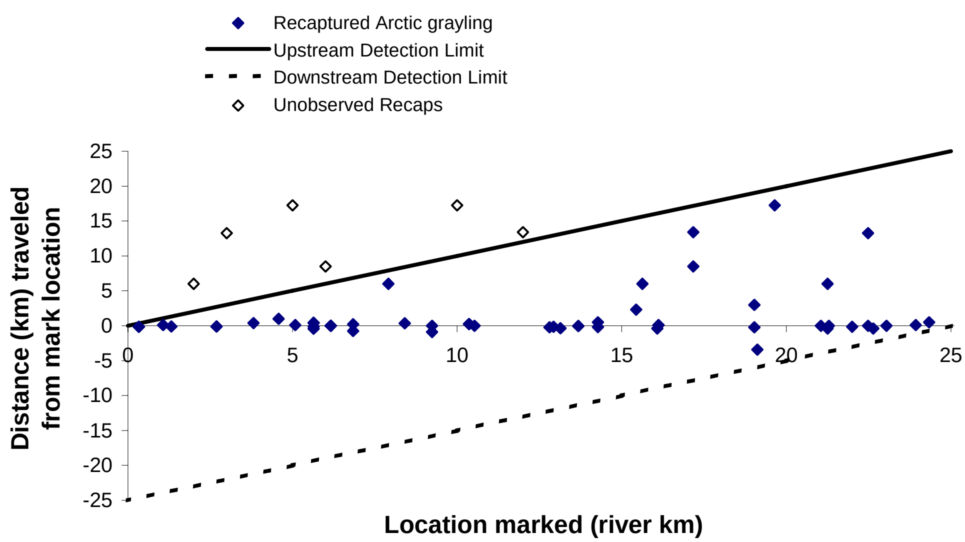
Appendix B2.–Simulation and experimental results for the Niukluk River Arctic grayling mark-recapture study, 2005.

	2005 Experiment Results		Simulation A[a]		Simulation B[b]	
Stratum	Small Fish	Large Fish	Small Fish	Large Fish	Small Fish	Large Fish
$\mathbf{Pc_{1st\ event}}$/ $\mathbf{Pc_{2nd\ event}}$	0.05/0.05	0.13/0.13	0.05/0.05	0.145/0.13	0.05/0.05	0.145/0.13
$\mathbf{n_1}$	244	320				
$\hat{N}$	4,985	2,339				
Movement Distribution 1			*N*(-0.2, 0.3)	*N*(-0.2, 0.3)	*N*(-0.2, 0.3)	*N*(-0.2, 0.3)
Movement Distribution 2			*N*(6.0, 5.9)	*N*(6.0, 5.9)	*N*(8.2, 6.2)	*N*(8.2, 6.2)
Proportion Distribution 2			0.22	0.22	0.30	0.30
$N_{s,initial}$			4,756	2,186	4,562	2,213
$\overline{\hat{N}}_{s,final}$			5,012	2,317	5,041	2,446
Est. Mean % bias			5.4%	6.0%	10.5%	10.5%

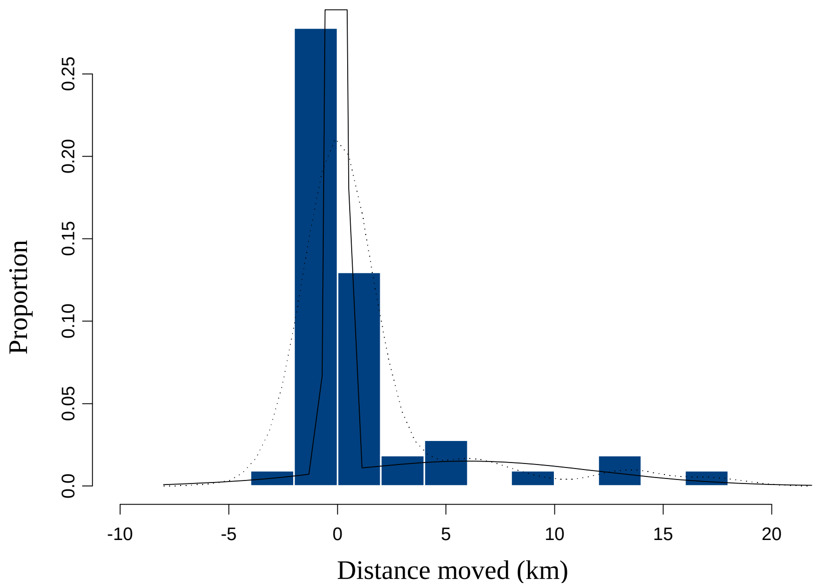
a. Simulation in which movements were estimated directly from recaptured fish.

b. Simulation in which movements were estimated from recaptured fish supplemented with estimates of movements that were not observable due to sampling constraints.





Appendix B3.–Movement of recaptured Arctic grayling by river km where marked depicted in the upper panel. The lower panel also depicts "detection limits" and includes additional "unobserved" recaptured fish.



Appendix B4.–An example of mixture model fitting two normal distributions (solid curve) to the histogram of observed movements. Note: the truncation of the peak of the solid curve is an artifact of the scale selected for presentation. The dotted curve is a smoothed depiction of the histogram.

Appendix B5.-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 B6.-Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

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

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

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

I.-Test for complete mixing[a]

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

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

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

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

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

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

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

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

Appendix B7.–Equations for estimating length and age compositions and their variances for the population.

From Appendix A1, Case III was found through inference testing and occurs when there is size selectivity during each event. Therefore length or age data from both samples were pooled and adjustments were made to minimize the bias.

To adjust estimates, the proportion of Arctic grayling in a length or age category were calculated by summing independent stratum abundance estimates for the length or age category and then dividing by the summed abundances for all categories (i.e., total abundance). First the conditional proportions from the sample were calculated:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \qquad \text{(B7-1)}$$

where:

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

n_{jk} = the number sampled from size stratum *j* that were in length or age category *k*; and,

$\hat{p}_{jk}$ = the estimated proportion of length or age category *k* Arctic grayling in size stratum *j*.

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

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1-\hat{p}_{jk}\right)}{n_j - 1}. \qquad \text{(B7-2)}$$

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

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk}\hat{N}_j \qquad \text{(B7-3)}$$

where:

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

s = the number of size strata.

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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):

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s}\left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right]\right). \qquad \text{(B7-4)}$$

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

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \qquad \text{(B7-5)}$$

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

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

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s}\left\{\left(\frac{\hat{N}_j}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{jk}\right]\right\} + \frac{\sum_{j=1}^{s}\left\{\hat{V}\left[\hat{N}_j\right]\left(\hat{p}_{jk} - \hat{p}_k\right)^2\right\}}{\hat{N}^2}. \qquad \text{(B7-6)}$$

Length composition of Arctic grayling ≥ 350 mm FL was broken down into both 10 and 25-mm FL categories for comparison with previous studies.

Appendix B8.–Equations for estimating mean length-at-age and their variances for the Arctic grayling population.

For each identified age class (age-2 to -6), the mean lengths (mm FL) of Arctic grayling were estimated as the arithmetic mean length of all Arctic grayling assigned to the same age:

$$\hat{\bar{L}}_k = \frac{\sum_{j=1}^{n_k} L_{jk}}{n_k} \qquad \text{(B8-1)}$$

where:

L_{jk} = FL (mm) of the j^{th} Arctic grayling sampled that were age k; and,

n_k = the number sampled for length that were age k.

The variance of the mean was estimated as:

$$\hat{V}\left[\hat{\bar{L}}_k\right] = \frac{\sum_{j=1}^{n_k} \left(L_{jk} - \hat{\bar{L}}_k\right)^2}{n_k\left(n_k - 1\right)}. \qquad \text{(B8-2)}$$

Appendix B9.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

For each length stratum, the Bailey-modified Petersen estimator (Bailey 1951 and 1952) was used for each because the sampling design called for a systematic downstream progression, fishing each pool and run and attempting to subject all fish to the same probability of capture while sampling with replacement. The Bailey modification to the Petersen estimator may be used even when the assumption of a random sample for the second sample is false when a systematic sample is taken provided:

1) there is uniform mixing of marked and unmarked fish; and,
2) all fish, whether marked or unmarked, have the same probability of capture (Seber 1982).

The abundance of Arctic grayling was estimated as:

$$\hat{N} = \frac{n_1(n_2+1)}{m_2+1}, \qquad \text{(B9-1)}$$

where:

n_1 = the number of Arctic grayling marked and released alive during the first event;

n_2 = the number of Arctic grayling examined for marks during the second event; and,

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

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \qquad \text{(B9-2)}$$

APPENDIX C
DATA FILE LISTING

Appendix C1.-Data files[a] for all Arctic grayling captured in the Niukluk River, August 2005.

Data file	Description
Niukluk River 2005 Data.csv	Sample data from June 2005 in ASCII format.
Niukluk 2005 analysis.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.