Regional Operational Plan SF.3F.2013.06

Stock Assessment of Niukluk River Arctic Grayling, 2013

by

Andrew D. Gryska

May 2013

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

Symbols and Abbreviations

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Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm
Weights and measures (English)	
cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd
Time and temperature	
day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s
Physics and chemistry	
all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

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

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

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STOCK ASSESSMENT OF NIUKLUK RIVER ARCTIC GRAYLING, 2013

by

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Alaska Department of Fish and Game, Sport Fish Division, Fairbanks

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Sport Fish Division

May 2013

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SIGNATURE PAGE

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TABLE OF CONTENTS

Page

LIST OF FIGURES ... ii

LIST OF APPENDICES ... ii

PURPOSE ... 1

OBJECTIVES ... 5

STUDY DESIGN ... 6

SCHEDULE AND DELIVERABLES ... 14

RESPONSIBILITIES ... 15

REFERENCE CITED ... 16

LIST OF TABLES

Table		Page
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	3

LIST OF FIGURES

Figure		Page
1	Southern Seward Peninsula with road accessible waters.	2
2	Sampling area in the Niukluk River, 2013	4

LIST OF APPENDICES.

Figure		Page
A1	Methodologies for detecting and alleviating bias due to size selectivity	20
A2	Tests of consistency for the Petersen estimator	21
A3	Description of an algorithm used to estimate bias associated with violation of closure	22

PURPOSE

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 angling effort for Arctic grayling *Thymallus arcticus* by many of the 9,200 residents of the Nome census area (U.S. Census Bureau 2001), as well as numerous tourists. The Niukluk River begins in the Bendeleben Mountains, is approximately 90 km in length, and is accessed at the village of Council approximately 19 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 guided anglers fish the river, and many residents of Nome have summer cabins on the river at Council or fish camps along the river (Scanlon *In prep*). 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 more 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; Scanlon and DeCicco 2007). 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 15% of all registered trophy Arctic grayling in Alaska (≥18 inches or 3.0 lbs) have been taken from the Seward Peninsula (Scanlon *In prep*).

From 1988 to 2000, concerted research was conducted on several important Arctic grayling populations on the Seward Peninsula (Merritt 1989; DeCicco 1990-2000, 2002a) that culminated in the development of a fishery management plan for rivers with Arctic grayling along the Nome road system and the current regulatory structure (DeCicco 2002b). The management plan endeavors "to maintain population characteristics that users presently consider to be producing a high quality sport fishery and maintain minimum spawning stock abundances" (DeCicco 2002b). The plan establishes specific management objectives for the Niukluk, Fish, Pilgrim, Nome, Snake, and Sinuk rivers (Figure 1), which consist of maintaining a prescribed minimum abundance of Arctic grayling (≥15 in TL) in an index area. The research program, as described in the management plan, recommends periodic population assessments (i.e. every 5 years) for these and other road-accessible streams to ensure that abundances are being maintained at or above prescribed levels.

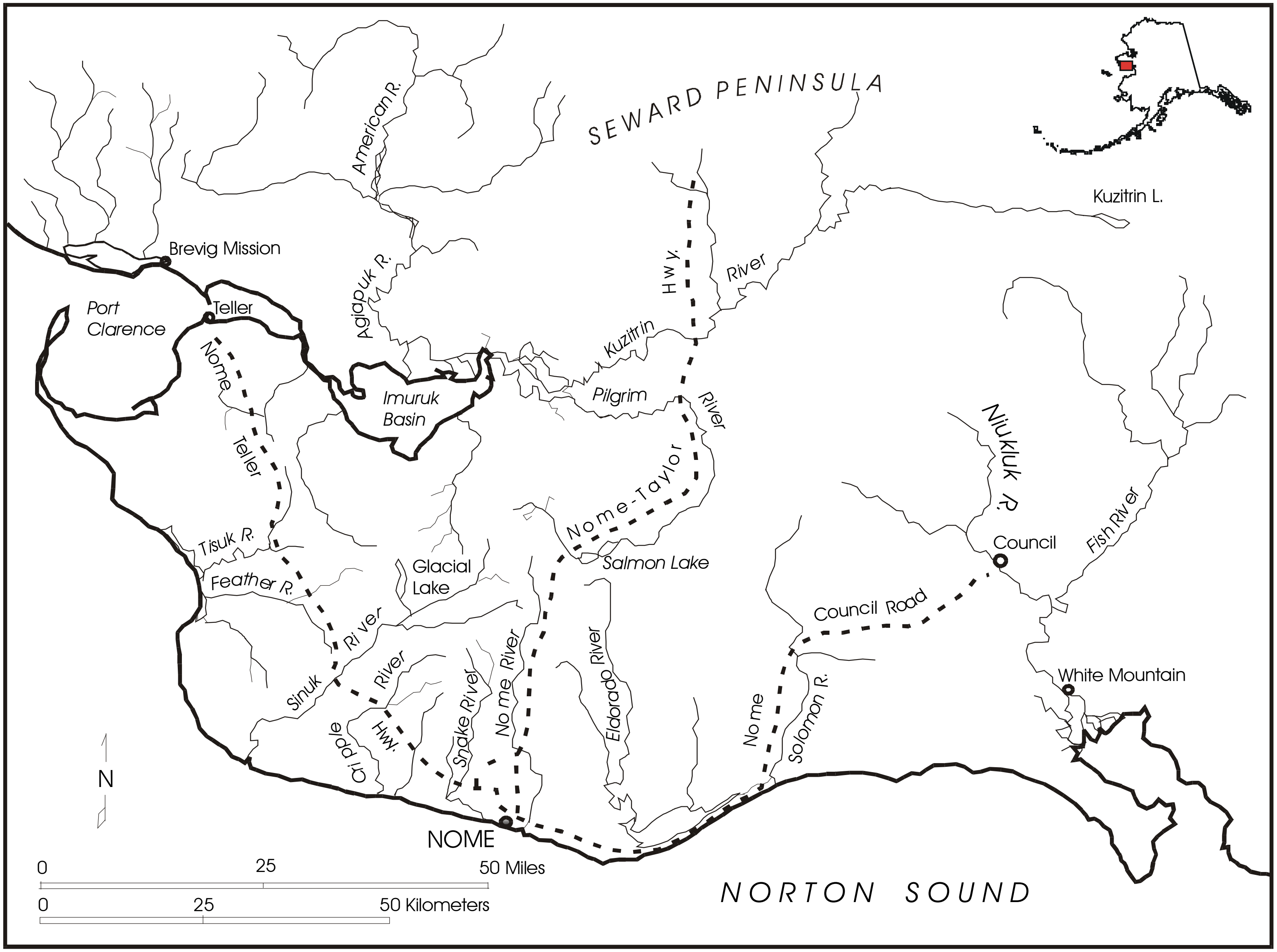

Figure 1.-Southern Seward Peninsula with road accessible waters.

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[a].

Period/year	Effort	Harvest	Catch
1992–2011	2,747	403	4,271
2002–2011	2,543	348	3,737
2007–2011	3,144	426	4,013

[a]Reproduced from Scanlon 2012.

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, which included two-event mark-recapture experiments. 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 overran the lower portions of the study area during the second event rendering the sampling gear ineffective. The last stock assessment occurred during 2005, and the abundance estimate was 7,324 (SE=1,298) Arctic grayling ≥350 mm FL (Gryska and Taras 2007). This project will estimate abundance and size composition of the Arctic grayling population present in the Niukluk River in 2013. Based on the results of this assessment, management of the fishery will be reevaluated as prescribed in the Nome Roadside Arctic Grayling Management Plan (Scanlon *In prep*).

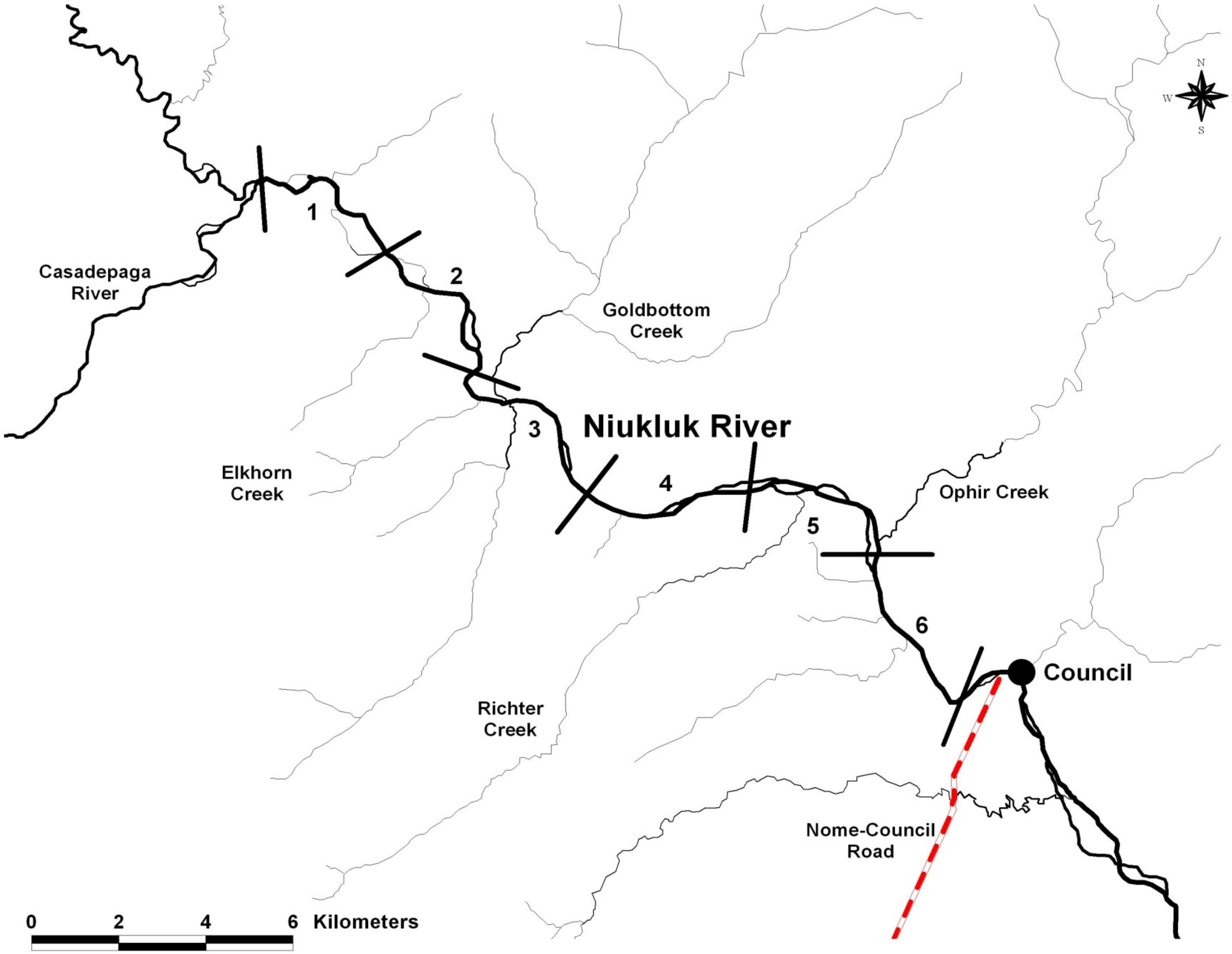

Figure 2.–Sampling area in the Niukluk River, 2013.

OBJECTIVES

The project objectives for 2013 will be to:

1. estimate the abundance of Arctic grayling ≥350 mm FL in a 25-km index section of the Niukluk River during late June such that the estimate is within 25% of the actual abundance 90% of the time;
2. test the null hypothesis that the abundance of Arctic grayling ≥350 mm FL in a 25-km index section of the Niukluk River during late June is ≤2,100 with a 10% or less chance of taking a management action if the true abundance is ≥3,500 and a 80% or greater chance of taking a management action if the true abundance is ≤2,300 fish using alpha = 0.10;
3. estimate the length composition (in 25-mm FL length categories) of Arctic grayling ≥350 mm FL in a 25-km index section of the Niukluk River such that the estimates are within 10 percentage points of the true value 90% of the time;

The project tasks for 2013 will be to:

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

The precision criterion for Objective 1 was established as minimum standard regardless of population size, and was thought to provide sufficient power for the hypothesis test in Objective 2. The management action associated with Objective 2 will be to close the fishery or restrict the fishery to catch and release fishing provided abundance is less than 3,500 Arctic grayling ≥350 mm in FL in the Niukluk River index area. The hypothesis test was designed with a very low probability of experiencing a type I error (rejecting the null hypothesis when it is true); in other words, opening the fishery (or keeping the fishery open) when true abundance is less than 2,100 fish. Objective 3 provides an estimate of length compositions of the population in the study area. The size limit identified in the objectives, 350 mm FL, is related to several Seward Peninsula regulations (350 mm FL is equal to 15 in TL) and is used to determine, by way of Objective 2, whether the management objective has been reached. Objective 3 will provide an estimate of the size composition of the population that can be compared to past data for the Niukluk River. For tasks, abundance is also being estimated for two additional length thresholds. The 270-mm length limit is related to a commonly used stock assessment descriptor and is often the size at which Arctic grayling are reliably recruited to sampling gear. The 330-mm length limit is the length at which Arctic grayling begin to be considered large by anglers and the abundance of this size is often used for comparison among Interior Alaska fisheries. Because the length at which Arctic grayling recruit to the gear can range between 200 and 270 mm, all fish ≥200 mm FL will be tagged in the event abundance for a lower length limit can be estimated.

STUDY DESIGN

STUDY AREA

A 25-km (15.4-mi.) section of the Niukluk River from the mouth of Casadepaga River downstream to the village of Council will be sampled during late-June 2013 (Figure 2). This reach of the river is representative of the Arctic grayling stock in the Niukluk River and is comparable to previous assessments that occurred several times during the previous 20 years. In 2005, the sample area was divided into 6 sections in order to assess mixing and determine if there is movement between sections between events.

EXPERIMENTAL AND SAMPLING DESIGN

This study is designed to estimate abundances and length compositions of Arctic grayling within the 25-km study area of the Niukluk River (Figure 2) using two-event Petersen mark-recapture techniques for a closed population (Seber 1982) designed to satisfy the following assumptions:

1. the population is 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 will have a similar probability of capture in the first event or in the second event, or marked and unmarked Arctic grayling will mix completely between events;
3. marking of Arctic grayling will not affect the probability of capture in the second event;
4. marked Arctic grayling will be identifiable during the second event; and,
5. all marked Arctic grayling will be reported when recovered in the second event.

Failure to satisfy these assumptions may result in biased estimates; therefore the experiment is designed to allow the validity of these assumptions to be ensured or tested. Sufficient data will be collected to perform diagnostic tests to identify heterogeneous capture probabilities (violations of Assumption 2) and prescribed model selection procedures will be followed in the event of such violations. Diagnostic tests are not available to evaluate Assumptions 1, 3, 4 and 5 (although Assumption 1 will be tested to a limited extent). Instead the experiment is designed to ensure that these assumptions will be met thereby avoiding potential biases. The design will ensure that sample sizes will be adequate to meet objective precision criteria and to perform reliable diagnostic tests. For diagnostic tests, the sample area will be divided into six sample sections, 4.0-4.5 km in length (Figure 2).

For each event, sampling will be conducted by two crews of two people over a 4-day period. The first sampling event will begin on June 21 and conclude on June 24. The second sampling event will begin on June 26 and conclude on June 30. Approximately eight hours per day will be expended by each crew each day. Each crew will usually fish from a power boat though wading will also occur occasionally.

The timing of this study was chosen to coincide with the summer feeding period when Arctic grayling move little (Ridder 1998a, 1999; Ridder and Gryska 2000; Gryska 2001) and prior to salmon entering the river. Spawning usually occurs in late-May, and by the time the assessment begins, the Arctic grayling should be distributed in their upriver foraging habitat (A. Gryska, Sport Fish Biologist ADF&G, Fairbanks, personal communication). Movement of Arctic grayling during the study will be described by movements of recaptured fish. The sampling schedule will result in a 5-day hiatus for each sampling subsection. This hiatus is important to enhance localized mixing of marked and unmarked fish and to allow marked fish to recover from the effects of handling between events. However, the hiatus is kept relatively short to minimize growth and mortality between events.

The logistics of capturing fish in a river, unlike in a lake, make it difficult to approximate the taking of a simple random sample (i.e., a random sample taken without replacement). In addition, given the territorial behavior of Arctic grayling, complete mixing across the study area during the experiment is highly improbable. The Niukluk River will be sampled systematically in the sense of progressively moving downstream while sampling; therefore, the Bailey-modified Petersen estimator (Bailey 1951 and 1952), which is based on the binomial model (sampling with replacement), will be the appropriate abundance estimator. The sampling strategy for this project will be to: 1) sample the entire study area attempting to subject all fish to an equal probability of capture during the first event (i.e. to the extent possible, distribute marks in proportion to abundance throughout the study area); 2) rely on local mixing (i.e. scale of 1–3 km) to produce a uniform marked proportion at that scale and to mitigate potential bias due to pockets of fish isolated from sampling); and, 3) repeat strategy one for the second event. It is anticipated that the effort made to evenly distribute marks across the study area combined with local mixing will approximate a uniform marked proportion across large (i.e. larger than the scale of mixing) portions of the study area or perhaps across the entire study area. Sampling in any portion of the river during the second event takes place over a short period of time as the crew progresses downriver. Also, Arctic grayling are expected to move only a short distance compared to the distance sampled during a given day. Under these conditions fish recaptured more than once are considered anomalies resulting from releasing fish close to the boundaries between sampling sections. Therefore, fish captured during the second event are given a secondary mark (fin clip) to avoid recounting. If the marked proportion and the second event capture probabilities are not uniform across the entire study area, a completely stratified Bailey-modified Petersen estimator or, if mixing occurs across stratum boundaries, a partially stratified estimator (Darroch 1961) would be used (Data Analysis Section).

Sampling Methods

Both spin and fly gear will be used and will select for fish ≥ 200 mm FL. Terminal spin gear will consist of rubber-bodied jigs of varied size (1/16–1/4 oz and size 2–6 hooks) and fly gear will consist of an assortment of flies (e.g., Adams fly, Blue Dunn fly, or bead-head nymphs). Both jigs and flies will fish in all waters; however, the ratio of time spent angling a particular reach or hole using flies and jigs will be left to the discretion of the angler as to which appears to be more effective. Fishing the secondary gear at a minimal level (e.g. five casts per hole) will help to catch additional fish that would not have been selected with the primary gear and identify changes in fish preferences for either gear type.

The entire length of each channel in a section will be sampled and attempts will be made to subject all Arctic grayling to the same probability of capture during each event by fishing each pool or run with effort in proportion to the distribution of Arctic grayling. Distribution will be assessed based on initial catch rates and by observation of fish if water conditions permit. After sampling, all fish will be released at or near their capture location. In no cases will fish be displaced by more than 100 m from the capture location.

During the first event, each captured Arctic grayling ≥ 200 mm FL will be marked with an individually numbered Floy™ FD-94 internal anchor tag placed at the insertion of the dorsal fin so that the tag locks between the posterior interneural rays. A partial upper caudal fin clip will be given to evaluate tag loss. To prevent double sampling of fish during the second event, all captured fish will receive a lower caudal fin clip. The movement of fish during the experiment will be evaluated by recording capture/release locations of all fish as a GPS waypoint (latitude and longitude coordinate as decimal degrees, NAD27 Alaska datum) during each event.

Evaluation of Assumptions

Assumption 1: Assumption 1 will likely not be violated because Arctic grayling typically move little during the summer feeding season (Tack 1973; Ridder 1998b, c; Ridder and Gryska 2000; Gryska 2001). Conducting this experiment during late June, when Arctic grayling are occupying their summer feeding locations will minimize the probability of fish entering or leaving the study area between or during sampling events. Nonetheless, some fish may still be completing migrations to summer feeding areas, as occurred during 2005 when the potential for positive bias was estimated to be 6%–11% (Gryska and Taras 2007). Overall, it is expected that most Arctic grayling will execute inconsequential small-scale movements (e.g., <2 km). Locations of recaptured fish will be examined for movement away from or towards boundaries of study area to provide evidence of immigration and emigration. This study will be of short duration, and therefore, growth recruitment and mortality will be insignificant.

Assumption 2: Marked and unmarked fish are expected to mix on the scale of 1–2 river km, and not throughout the study area. Therefore, Assumption 2 will be met by attempting to subject all fish to the same probability of capture during the first or second event and by relying on mixing at a local scale. While angling, fishing effort will be distributed in proportion to the distribution of Arctic grayling. Based on catch rates and visual observations, effort will be increased in areas where densities appear relatively high (e.g., pools immediately following riffles) and decreased where there appear to be few fish available (e.g., fast, shallow, riffles). If multiple channels are encountered, all navigable channels will be fished. To avoid the possibility of incurring a negative bias resulting from fish that are not subject to capture during the experiment (i.e., during either event) the entire study area (longitudinally) will be sampled (see Sampling Methods). In addition, movement of recaptured fish will be examined at a fine scale (i.e., 200 m) to determine whether mixing was likely sufficient to minimize or eliminate the potential for fish having been isolated from the experiment.

It is also unknown whether fish will have equal probability of capture by length, and although capture probabilities usually are similar for fish ≥350 mm FL, results from the 2005 stock assessment indicated that capture probabilities differed (Gryska and Taras 2007). Hook-and-line gear has been shown to capture representative samples of Arctic grayling for the size range of fish addressed in this experiment (Fish 1996, Wuttig 2004). However, size selective sampling has also occurred when using these gear types (Ridder et al. 1993; Gryska 2004). Data sufficient for investigating this potential bias and adjusting for it will be collected and analyzed as described in subsequent sections.

Assumption 3: The 5-day hiatus between mark and recapture samples of each section should allow marked fish to recover from the effects of handling and marking induced behavioral effects during the first event; therefore, Assumption 3 should be valid. In addition, the use of spin and fly gear will also help mitigate marking induced behavioral effects.

Assumption 4: This assumption will be addressed by double-marking each Arctic grayling captured during the first event. Tag loss will be noted when a fish is recovered during the second event with a first-event fin clip but without a Floy^{TM} tag. In addition, tag placement will be standardized, which will enable the fish handler to verify tag loss by locating recent tag wounds.

Assumption 5: All fish will be thoroughly examined for tags or recent fin clips. All markings (tag number, tag color, fin clip, and tag wound) for each fish will be recorded.

To evaluate the movement of fish during the experiment capture locations of all fish marked during the first event and recapture locations of fish bearing marks during the second will be recorded using a GPS. During the first event, each captured Arctic grayling ≥ 200 mm FL will be marked with an individually numbered Floy^{TM} FD-94 internal anchor tag and a partial left-pectoral fin clip will be given to evaluate tag loss. Although a task is to estimate abundance of Arctic grayling ≥ 270 mm FL, tagging all fish ≥ 200 mm FL will allow a better assessment of gear selectivity for fish near 270 mm FL. To prevent double sampling of fish during the second event, all captured fish will receive a right-pectoral fin clip.

SAMPLE SIZES

It has been demonstrated that angling on other similar rivers with the effort proposed (Gryska 2001; Parker 2006) has typically yielded sufficient sample sizes to achieve same precision criteria. While sample size calculations are presented, the demonstrated performance of the selected sampling methods at the prescribed levels of effort will be the strongest evidence in support of our ability to obtain sample sizes necessary to meet the precision criteria.

Because the most recent stock assessment of the Arctic grayling population in the Niukluk River yielded the largest abundance estimate among previous assessments, the 2006 abundance estimate 7,324 was used to calculate anticipated sample size. A sample size of 537 Arctic grayling ≥350 mm FL will be needed during each event to meet the criteria specified in Objective 1 (Robson and Regier 1964). Similar sampling requirements can be calculated for Tasks 1 and 2, but Objective 1 is most meaningful to the management objective and will be the main driver of sample sizes. Nonetheless, field efforts will not be focused on sampling fish in specific size ranges; rather, efforts will be directed at attempting to ensure similar probabilities of capture of all fish during both sampling events.

The sampling crew will capture and mark as many Arctic grayling as they can during the time allotted. If actual abundance is less than the number assumed above, the recommended sample sizes may not be achieved. However, it is still expected that an adequate number of fish will be sampled in each event to meet the precision criteria based on experience from similarly designed mark-recapture experiments for Arctic grayling on the Seward Peninsula (DeCicco 1990–2000, 2002a; Gryska 2004b, 2006). In these studies, precision criteria were achieved using similar amounts of fishing effort per river kilometer using hook-and-line gear.

Using methods developed by Thompson (1987) for estimating multinomial proportions, a minimum of 101 fish must be sampled in order to estimate length compositions within the precision criteria. The sample size estimates for achieving the precision criteria for the abundance estimates are sufficient for meeting those of length composition estimates even if data from only one of the two sampling events can be used in the analysis (Case III or IV; Appendix A1).

All data and daily summaries will be recorded in "Rite-in-the-Rain®" notebooks. For each fish, length, capture/release location as a GPS waypoint (decimal degree NAD27 Alaska datum), tag number and color, fin clip, will be recorded in the notebook. All captured Arctic grayling will be measured to the nearest mm FL. If any Arctic grayling die during handling, the otoliths will be collected from the fish and its length measured and recorded.

Each crew will also keep a detailed, daily field journal in a "Rite-in-the-Rain®" notebook. An important goal in recording the information below is to identify conditions that may have a substantial effect on the probability of capture during a sampling event. Information collected should include:

1) Gear type that was most effective and at which times it was most effective. For example, a statement such as 'between 2 p.m. and 4 p.m. a hatch of may flies occurred and fly fishing was most effective and used extensively;'
2) Weather and water conditions (e.g., cloud cover, precipitation, temperature, water level, and clarity);
3) Hours worked each day by each crew member;
4) River km and areas sampled each day;
5) Way point locations (as decimal degree latitude and longitude coordinates, NAD27 Alaska datum) of release sites, hydrologic features, camps, beginning and ending points of each day;
6) Number of fish captured; and,
7) Any other relevant details or observations, such as the presence of spawning salmon, logistical information or an itemized listing of first-aid/field/sampling supplies and equipment needs for future field work.

DATA REDUCTION

Data will be transferred from field notebooks to Microsoft Excel worksheets for analysis. Column headings of the worksheet will include: sample number, date of capture, event, section length, tag number, tag color, release location (longitude and latitude in decimal degree NAD27 Alaska datum), gear type, fin clip, and field comments. In addition, a column will be created to document whether a fish captured during the second event was a recapture. Additional columns may be added for clarity and a glossary of all column headings will be provided in a text box along with a brief project description. Location data (NAD27 Alaska Datum) will be plotted on a map using Arc View GIS software. Final copies of the Excel file will be provided with the completed report when it is submitted for review to be archived in the Sport Fish Division Docushare repository. At that time, a file name and directory will be assigned, which will be included as an appendix in the final report.

DATA ANALYSIS

The data analysis will include testing the validity of the mark-recapture experiment Assumption 2 and, to a limited extent, Assumption 1 (it is assumed based on the experimental design that Assumptions 3, 4, and 5 will not be violated), calculating abundance estimates and correcting for bias if violations of Assumption 2 are identified, and calculating length composition estimates.

ABUNDANCE ESTIMATES (OBJECTIVE 1 AND TASKS 1 AND 2)

Relative to Assumption 1, closure will not be tested directly but inferred from examination of the movement of recaptured fish within the study area. The data will be examined for movement away from or towards, either or both boundaries of the study area to provide evidence of immigration and emigration. It is unlikely that migrations will pose a threat to the assumption for several reasons. First, Arctic grayling have been documented to generally be non-migratory during the summer feeding period. Second, previous studies have documented little movement and that the bulk of population exists in this index area (DeCicco 1992, 1993, 1998, 2002a, 2007). Nonetheless during previous stock assessment of this population, there was evidence that spring migrations were not fully completed and the potential for positive bias was estimated at between 6% and 11%. In the event immigration and emigration appear evident, Monte Carlo simulations (Appendix A3) will be performed to estimate the bias due to combined immigration and emigration at the boundaries. The simulations proposed address directional movement and estimate bias under these conditions. If movement is strongly directional, it will be determined if a Petersen model is appropriate (e.g. in the case of immigration only), or if the modified Petersen estimator of Evenson (1988) can be used.

Relative to Assumption 2, differences in capture probability related to fish size, location, and time will be examined. Size-selective sampling will be tested using two Kolmogorov-Smirnov tests (Conover 1980). The tests and possible actions for data analysis are outlined in Appendix A1. If stratification by size is required, capture probability by location will be examined for each stratum, and total abundance and its variance estimate will be calculated by summing strata estimates.

Temporal and spatial violations of Assumption 2 will be tested using consistency tests described by Seber (1982; Appendix A2). If at least one of the three consistency tests results in a failure-to-reject the null hypothesis, then it will be concluded that at least one of the conditions in Assumption 2 was satisfied. If all three of these tests reject the null hypothesis, then depending on the degree of movement, a partially or completely stratified estimator must be used. If there is some movement of marked Arctic grayling between strata but mixing is incomplete, the methods of Darroch (1961) will be used to compute a partially stratified abundance estimate. If no movement of marked Arctic grayling between geographic strata is observed, a completely stratified abundance estimate will be computed using the methods of Bailey (1951, 1952).

To perform the consistency tests the study area will be divided into 6 geographic strata 4.0-4.5 km in length. Additional stratification schemes may be examined. Criteria to be considered when defining these geographic strata include the number of recaptures per stratum, hydrology, and stratum length relative to anticipated movements. When estimating abundance a minimum number of recaptures (approximately 7 fish) will be preferred to permit reliable diagnostic testing and to ensure negligible statistical bias in $\hat{N}$ (Seber 1982). Sections longer than approximately 2 km will be preferred to accommodate localized movements of Arctic grayling (e.g. approximately 1–2 km).

Diagnostic tests will be performed separately on fish ≥ 270, ≥ 330, and ≥ 350 mm FL. If no assumptions are violated, the numbers of Arctic grayling ≥ 270, ≥ 330 and ≥ 350 mm FL in the described section of the Niukluk River will be estimated using Bailey's modification of the Petersen estimator (Bailey 1951, 1952). The modified Petersen estimator of Bailey (1951, 1952) and its variance are:

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

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

where:

n_1 = the number fish marked during the first sampling event;

n_2 = the number of fish examined during the second sampling event; and,

m_2 = the number of fish captured during the second sampling event with marks from the first sampling event.

The abundance estimate may be biased low (with the bias indeterminable), regardless of the estimator used, if fish in the population had zero probability of capture during the experiment (i.e., if fish were physically isolated from all fishing effort during both events). Movement of recaptured fish will be examined at a fine scale (e.g., 200 m) to determine whether mixing was sufficient to minimize or eliminate this potential bias. If, for example, >80% of the recaptured fish exhibit no movement, the potential for failing to subject some fish to a non-zero probability of capture during the experiment may be considered significant enough to interpret the estimate as biased low (again with degree of bias indeterminable). When evaluating the potential for this bias, another consideration includes the likelihood of not fishing areas that hold fish because mixing may be occurring on a scale finer than 200 m.

HYPOTHESIS TEST (OBJECTIVE 2)

A Z-test will be performed to test the null hypothesis in Objective 2. A p-value will be calculated to assess the likelihood of obtaining the observed test statistic assuming the null hypothesis was true. A p-value < 0.10 will reject the null hypotheses.

LENGTH COMPOSITION (OBJECTIVE 3)

Kolmogorov-Smirnov tests performed to test for size-selective sampling and test outcomes will be used to determine if stratification by fish size is necessary and if data from the first, second, or both events are to be used. For cases I-III (Appendix A1) stratification is not necessary and length proportions and variances of proportions for Arctic grayling ≥350 mm FL will be estimated using samples from the event(s) without size-selectivity using:

$$\hat{p}_k = \frac{n_k}{n} \tag{3}$$

where:

$\hat{p}_k$ = the proportion of Arctic grayling that are within length category k;

n_k = the number of Arctic grayling sampled that are within length category k; and,

n = the total number of Arctic grayling sampled.

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

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1} \tag{4}$$

If diagnostic tests indicate case IV, there is size-selectivity during both events and data must be stratified to eliminate variability in capture probabilities within strata for at least one or both sampling events. Formulae to adjust length composition estimates are presented in Appendix A1. To adjust estimates, the proportion of fish in a length category will be calculated by summing independent stratum abundance estimates for the length category and then dividing by the summed abundances for all categories (i.e. total abundance). First the conditional proportions from the sample are calculated:

$$\hat{p}_{ik} = \frac{n_{ik}}{n_i} \tag{5}$$

where:

n_i = the number sampled from size stratum *i* in the mark-recapture experiment;

n_{ik} = the number sampled from size stratum *i* that are in length category *k*; and,

$\hat{p}_{ik}$ = the estimated proportion of length category *k* fish in size stratum *i*.

The variance calculation for $\hat{p}_{ik}$ is identical to equation 4 (with appropriate substitutions).

The estimated abundance of fish in length category *k* in the population is then:

$$\hat{N}_k = \sum_{i=1}^{s} \hat{p}_{ik}\hat{N}_i \tag{6}$$

where:

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

s = the number of size strata.

The variance for $\hat{N}_k$ in this case will be estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}[\hat{N}_k] = \sum_{i=1}^{s} \left(\hat{V}[\hat{p}_{ik}]\hat{N}_i^2 + \hat{V}[\hat{N}_i]\hat{p}_{ik}^2 - \hat{V}[\hat{p}_{ik}]\hat{V}[\hat{N}_i]\right). \tag{7}$$

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

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

where: $\hat{N} = \sum_{i=1}^{s} \hat{N}_i$.

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

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

Length composition of Arctic grayling will be estimated for 25-mm FL categories for comparison with other Arctic grayling studies.

SCHEDULES AND DELIVERABLES

Dates of sampling events in 2013 and other field and office activities are summarized below. All research results will be compiled in a State of Alaska Fisheries Data Series Report.

Date(s)	Activity
June 21–24, 2013	First sampling event on the Niukluk River
June 26–June 30, 2013	Second sampling event on the Niukluk River
Sept. 1–Sept. 30, 2013	Data Entry and Analysis
Oct 1–Oct 31, 2013	FDS report preparation
November 1 , 2013	Draft Report due to project biometrician
December 1, 2013	Draft Report due to immediate supervisor
January 1, 2014	Draft Report to research supervisor

RESPONSIBILITIES

List of Personnel and Duties:

Andy Gryska:	Fishery Biologist II; Project Leader
Duties:	Overall supervision of the project. Coordinate sampling schedules with project personnel. Analyze data and prepare reports with technical assistance.
Brendan Scanlon:	Fishery Biologist III; Area Management Biologist
Duties:	Assist in planning of project as needed. Assist in sampling and field collection of data and by providing equipment for field aspects of the project.
Jiaqi Huang:	Biometrician II
Duties:	Assist in preparation of statistical design of field investigation for operational plan, and review data analysis and final report. Assist with capture, sampling, and data collection
Tim Viavant:	Fishery Biologist II
Duties:	Assist with capture, sampling, and data collection.
Tom Taube:	Fishery Biologist IV
Duties:	Assist with capture, sampling, and data collection.
April Behr:	Fishery Biologist II
Duties:	Assist with capture, sampling, and data collection.
Dave Stoller:	Fish and Wildlife Technician V
Duties:	Assist with capture, sampling, and data collection.
Matt Robinson:	Fish and Wildlife Technician III
Duties:	Assist with capture, sampling, and data collection.

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Appendix A
ANALYTICAL METHODS

Appendix A1.–Methodologies for detecting and alleviating bias due to size selectivity.

Case	Result of 1st K-S Test[a]	Result of 2nd K-S Test[b]	Inference	Action
I	Fail to Reject H_o	Fail to Reject H_o	There is no size-selectivity during either sampling event.	Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling event for size and age composition estimates.
II	Fail to Reject H_o	Reject H_o	There is no size-selectivity during the second sampling event, but there is during the first sampling event.	Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.
III	Reject H_o	Fail to Reject H_o	There is size-selectivity during both sampling events.	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.
IV	Reject H_o	Reject H_o	There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown	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

[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.

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 or temporally stratified estimator (Darroch 1961) should be used to estimate abundance.

I.-Test For Complete Mixing[a]

Area/Time Where Marked	Area/Time Where Recaptured				Not Recaptured
	1	**2**	**…**	**t**	(n_1-m_2)
1					
2					
…					
s					

II.-Test For Equal Probability of capture during the first event[b]

	Area/Time 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]

	Area/Time Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

[a] This tests the hypothesis that movement probabilities (θ) from area or time *i* (*i* = 1, 2, ...s) to area or time *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 areas or times: 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 area or time designations: H_0: $\Sigma_j\theta_{ij}p_j$ = d, where p_j is the probability of capturing a fish in area or time *j* during the second event, and d is a constant.

Appendix A3.–Description of an algorithm used to estimate bias associated with violation of closure.

Objective: Estimate bias associated with violations of the closure assumption resulting from combined immigration and emigration at boundaries of study area

Description of Algorithm: Movement data from fish recaptured within the study area are used to simulate the movement of all fish during the experiment. The size of the study area and areas adjacent to the study area (i.e., upstream and downstream "boundary" areas) are defined, a parameter is assigned a value corresponding to the total number of fish, fish are distributed across the study and boundary areas with constant or varied density, and the study area is then sampled according to a specified probability of capture.

Fish within and outside the study area are then moved. Parameters are adjusted until distances moved reflect the observed movements of recaptured fish. It has been observed that successfully modeling the distribution of movements requires at least two sub-populations of fish: 1) a relatively stationary portion of the population and 2) a transient sub-population. The algorithm accommodates a mixture of these two sub-populations and includes a parameter defining their relative proportion. 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 may be accommodated). In addition, directional movement may be accommodated. After fish are moved, the study area is resampled according to a second probability of capture parameter and the second event sample size and the number of recaptured fish are tallied and used to estimate abundance and its associated variance using the Bailey-modified Petersen estimator. Fish are moved and resampled, and estimates are calculated multiple times (defined by a parameter), with each constituting a repetition (or realization).

Model output: 1) the mean value of the abundance estimates and the mean value of the associated variance estimates over all realizations and the variance estimates for both determined from the variability among the realizations, 2) the true abundance in the study area during the initial event and the mean of the true abundances during the final event, 3) the estimated percent bias $\%\hat{bias} = \left(\overline{\hat{N}} - N_{initial}\right) \times 100\%$, 4) the number of emigrating marked fish, 5) movement statistics, and 6) histograms of the movements, abundance estimates, and associated variances.