Regional Operational Plan No. ROP.SF.3F.2023.07

Stock Assessment of Arctic Grayling in Beaver and Nome Creeks, 2023

by

Lisa Stuby

August 2023

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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SIGNATURE PAGE

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Plan Type:	Category II

Approval

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ABSTRACT

This project plan outlines a two-event mark recapture experiment on Arctic grayling *Thymallus arcticus* in Beaver and Nome Creeks. Sampling will be conducted in 36 river kilometers (rkm) of the mostly road-accessible portion of Nome Creek and in the 44 rkm floatable portion of Nome Creek to the confluence of Beaver and Wickersham Creeks during July 2023. This follows a 2-year radiotelemetry study on Arctic grayling in the Beaver Creek drainage, where information acquired on life history such as migration timing, seasonal habitat preferences, and distribution has informed the timing, index area, and future data analyses for this mark-recapture experiment. The marking event will occur in early July, where three 2-person crews will sample a total of 6 rkm each day (i.e., 2 rkm per crew) and deploy approximately 1,000 Floy tags in Arctic grayling ≥250 mm FL. The recapture event will occur in late July, where Arctic grayling will be captured throughout the index area using the same methodologies employed during the first event and fish will be examined for tags. The population estimates acquired in 2023 will be compared to the last assessment conducted in 2000.

Key words: Arctic grayling, *Thymallus arcticus*, mark-recapture, abundance, length composition, radiotelemetry, Beaver Creek, Nome Creek, seasonal movements, spawning areas, stationary tracking station.

PURPOSE

Because Nome Creek is road accessible and attracts a large number of visitors from the Fairbanks North Star Borough, sport fishing for Arctic grayling *Thymallus arcticus* is catch-and-release only (Stuby 2021). Concerns were recently brought to the Federal Subsistence Board by the Eastern Interior Regional Advisory Council about the possibility that catch-and-release mortality may be adversely affecting the Arctic grayling population in Beaver and Nome Creeks. As a result, managers from the Alaska Department of Fish and Game and Bureau of Land Management collaborated on recent projects to acquire information on seasonal movements, habitat, and abundance of Arctic grayling in an index area of the Beaver Creek drainage to better understand critical habitat areas and the availability of Arctic grayling to sport anglers. These data are needed to evaluate current use trends and respond to the concerns posed by the Eastern Interior Regional Advisory Council.

BACKGROUND

Arctic grayling (*Thymallus arcticus*) are salmonids distinguished by their brilliant iridescent coloration and large sail-like dorsal fins. They have a Holarctic distribution and are fairly ubiquitous throughout most Alaskan drainages, with the exception of Kodiak Island, portions of the Kenai Peninsula, the islands in Southeast Alaska, and along the Alaska Peninsula west of Ugashik Lake (Swanton and Wuttig 2014). Arctic grayling are distributed throughout the entire 3,190-km Yukon River drainage, from the headwaters in Canada to streams that originate in the Yukon Delta (Stuby 2022). Beaver Creek is a major tributary of the Yukon River and is 452 km in length. The first 204 river kilometers (rkm) of Beaver Creek has been designated a Wild and Scenic River, with most of the river flowing through the White Mountains National Recreation Area, which is managed by the Bureau of Land Management.

Arctic grayling are a popular sport and subsistence species throughout the Yukon River drainage. They readily strike a lure and are therefore one of the most sought-after species by sport anglers in Alaska. Within the Alaska Department of Fish and Game, Division of Sport Fish, Yukon Management Area (Yukon River drainage, excluding the Tanana River), Arctic grayling accounted for 45% of the total harvest and 47% of the total catch (harvest + catch-and-release) during 2009–2018 (Stuby 2021). Beaver Creek is located within the Yukon Management Area and the Fairbanks nonsubsistence area (Figure 1) and supports a popular Arctic grayling sport fishery. Nome Creek, a road-accessible tributary of Beaver Creek, is approximately 90 km (56 miles) northeast of

Fairbanks and is easily accessed from the Steese Highway. Improvements to the Steese Highway in the early 1990s, and the creation of 2 campgrounds along a road that parallels Nome Creek, resulted in increased visitation to the area. The Board of Fish anticipated an increase in fishing pressure resulting from this use and adopted a catch-and-release regulation in 1994 for Arctic grayling in Nome Creek. For the remainder of the Beaver Creek drainage, the sport fish regulation for Arctic grayling is 5 fish per day, 5 in possession. People frequently float and fish from the lowermost accessible point of Nome Creek to about 15 km above Victoria Creek (Figure 2). Nome Creek is currently closed to federal subsistence harvests of Arctic grayling; however, a subsistence harvest of 5 Arctic grayling per day is allowed along Beaver Creek from the mouth of Nome Creek to O'Brien Creek, and harvests of 10 fish per day are allowed below O'Brien Creek (Figure 2, Stuby 2021).

Until recently, little work has been conducted on Arctic grayling in the Beaver Creek drainage. The Bureau of Land Management has periodically conducted fisheries surveys on Beaver Creek within the White Mountains National Recreation Area since 1988, with an emphasis on Arctic grayling because of their recreational value as a sport fish species (Carufel 1990). Radiotelemetry techniques were used in 1992 to locate Arctic grayling during the winter within the White Mountains National Recreation Area and examine winter habitat needs (Lubinski 1995). Between 1991 and 1995, baseline length and weight samples from Beaver Creek indicated Arctic grayling were of similar sizes and weights to those from other Interior Alaska rapid-runoff rivers (Fleming and McSweeny 2001). In 2000, a mark-recapture experiment was conducted in a 30-mile section of Beaver Creek and a separate mark-recapture study was conducted in Nome Creek (Fleming and McSweeny 2001). During this experiment, Fleming and McSweeny (2001) estimated 1,325 Arctic grayling per river mile in Beaver Creek. However, for the separate effort in Nome Creek, they reported an inability to maintain geographic closure within the lower 5 miles, which resulted in inconclusive results and large errors. This lack of geographic closure was attributed to conducting the experiment too soon after Arctic grayling had spawned, while the fish were still migrating to their summer feeding areas, and the long hiatus of 19 days between sampling events, which allowed time for additional movement of Arctic grayling from Beaver to Nome Creek.

This study is the final project in a two-phase cooperative study funded by the Bureau of Land Management to acquire updated population information for Beaver Creek Arctic grayling using radiotelemetry and mark-recapture techniques. A radiotelemetry study was initiated in 2021 and has identified critical habitat areas used for overwintering, spring spawning, and summer feeding, yearly fidelity to these areas, and migration timing between Beaver and Nome Creeks. Resulting movement and timing data has been used to identify an appropriate index area to conduct this mark-recapture experiment in both Beaver and Nome Creeks. The 2023 abundance estimate will be compared to previous assessments and current use trends. Results from both studies will be used to evaluate the relative health of the Arctic grayling population in Beaver and Nome Creeks. This type of study approach is recommended by the Arctic Grayling Management Plan, where life history information is necessary for designing effective stock assessment programs and resulting stock status information is needed to ensure populations are managed in accordance with goals, objectives, or thresholds that are defined by area managers, research staff, and the public process, such as the Board of Fish and Federal Subsistence Board (Swanton and Wuttig 2014).

OBJECTIVES

The objectives of the 2023 abundance study are to:

1) estimate the abundance of Arctic grayling ≥ 250 mm fork length (FL) in the identified index area such that the estimate is within 25% of the true abundance 95% of the time; and,
2) estimate the length composition (in 10-mm intervals) of Arctic grayling ≥ 250 mm FL in the identified index area such that the estimated proportions are within 5 percentage points of the true proportions 95% of the time.

METHODS

STUDY AREA

The study area for the 2023 mark-recapture experiment will include Nome Creek from near the Mt. Prindle Campground down to Beaver Creek and from this confluence to Wickersham Creek, a distance of 80 rkm (Figure 2). This area represents where the majority of sport fishing effort occurs in Beaver and Nome Creeks, but differs from the 2000 mark-recapture study area. The 2000 study area included Nome Creek from Moose Creek down to the confluence with Beaver Creek, and Beaver Creek from the Champion and Bear Creek confluence down to a point just above Wickersham Creek (Fleming and McSweeney 2001). The approximately 14-km section of Nome Creek from the Mount Prindle Campground to Moose Creek was added to the 2023 study area because sport fishing effort in this area is frequently observed by the Alaska Department of Fish and Game (ADF&G) staff. The approximate 10-km section of Beaver Creek upriver from Nome Creek (Figure 2) was excluded from the 2023 study area because it was accessed via helicopter in 2000 and receives very little to no fishing pressure.

STUDY DESIGN

Overview

This study is designed to estimate the length composition and abundance of Arctic grayling within an 80-rkm area of Beaver and Nome Creeks (Figure 2) using two-event Petersen mark-recapture techniques for a closed population (Seber 1982). To obtain an unbiased abundance estimate using this study design, the following assumptions must be satisfied:

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 a biased estimate; 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; instead, the experiment is designed to ensure that these assumptions will be met thereby avoiding potential biases. In addition, the design will ensure that sample sizes will be adequate to meet objective precision criteria and to perform reliable diagnostic tests.

Given the length of the study area and staffing and time constraints, the study area is divided into 2 geographic strata: Mt. Prindle to ~1.5 rkm below the Nome Creek put-in, which will be accessed on foot, and the Nome Creek put-in to Wickersham Creek on Beaver Creek, which will be floated (Figures 3 and 4, Table 1). Up to four 2-person crews for each of the 2 strata will be employed for a total of 2–4 crews per day, with some overlap during both events where both strata are sampled on the same day (Appendix A). Effort will be allocated evenly throughout the study area with each crew covering a 2-rkm section each day (i.e., 3 crews would cover 6 rkm per day, 4 crews would cover 8 rkm per day, etc.). Given this strategy, the 36-km section of Nome Creek will take approximately 6 days to complete and the 44-km section of Nome and Beaver Creeks to Wickersham Creek will take approximately 8 days to complete. The crews will travel downstream in a single pass through the study area for each sampling event. During each day of sampling the field crews will reference and manage downstream progress to reach the designated geographic landmarks or global positioning system waypoints (Figures 3 and 4; Table 1). This approach will help ensure that all areas are sampled uniformly and thoroughly, and that tagged fish will be released throughout the study area. With time, staff availability, and ease of fishing, the crews may fish > 2 km each day to achieve sample size goals. Also, the length and number of strata may be adjusted as the data analysis is completed.

Given the constraints imposed by sampling fish in a river and the sampling protocol selected to accommodate them, the Bailey-modified Petersen estimator (Bailey 1951, 1952), which is based on the binomial model and assumes 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 limited mixing (during the 14 days between the first and second sampling events) to produce a uniform marked proportion of the population over small subsections of the study area; and, 3) repeat 1 for the second event.

The first event will begin on 4 July for the float starting at ~1.5 rkm below the Nome Creek put-in and ending at Wickersham Creek on 12 July, including an extra day for travel. Arctic grayling will be sampled from the Mt. Prindle Campground to ~1.5 rkm below the put-in on Nome Creek from 15–20 July (Appendix A). The second event for the float from below the Nome Creek put-in to Wickersham Creek will take place during 17–25 July, with a 13-day hiatus between events. The second event from the Mt. Prindle Campground to ~1.5 rkm below the Nome Creek put-in will take place during 26–31 July, with an 11-day hiatus between events. The intent of the 13 and 11-day hiatuses for the 2 strata is to alleviate potential positive biases associated with immigration and emigration into the study area. In addition, the small study area should expose almost all Arctic grayling to our capture gear and rely on limited mixing over the course of the hiatuses. The potential for violating the closure assumption, even with the hiatuses is addressed in the "Evaluation of Assumptions" subsection.

Comparison to 2000 Study

Results from this study will be compared to results from the 2000 study; however, in addition to the geographic distinctions in study area listed above, there are some notable differences between the 2 study designs due to logistical constraints, information acquired from the recent radiotelemetry study, and a current understanding of the sport fishery.

This project will occur in a shorter timeframe than the 2000 study. Sampling in 2023 will occur from 3 July through 31 July, which is during the summer feeding period when Arctic grayling are less prone to migrate. During the telemetry study preceding this project, a stationary tracking station at the confluence with Beaver and Nome Creeks recorded Arctic grayling travelling to Nome Creek to spawn and/or oversummer during 1 May to 17 June 2022 (Stuby and Clark, *In prep*). Also, a trip to the Upper Quartz Creek from 12 through 13 July 2022 found oversummering fish well-established in this first-order tributary that is approximately 40–50 km from the mouth of Nome Creek. Given these observations, it is expected that the timeframe selected for this project will coincide with when Arctic grayling are established in their oversummering areas.

The 2000 mark-recapture study targeted Arctic grayling down to 150 mm FL, but this study will examine fish ≥ 250 mm FL. It has been shown that Arctic grayling ≥ 270 mm FL are usually mature and reliably recruited to sampling gear, although smaller lengths have been noted to recruit to hook and line gear (Gryska and Tyers 2017). For mark-recapture studies on the Gulkana River, fish down to 240 mm FL were tagged (Gryska 2019). Arctic grayling ≥ 250 mm FL will be targeted in this study because Fleming and McSweeny (2001) used this size to define "large" Arctic grayling in this system. Additionally, a fishery management objective for Beaver Creek has been to maintain total harvest of Arctic grayling below 10% of the estimated abundance of fish ≥ 250 mm FL (Burr 2004, Stuby 2021).

Similar to the 2000 Beaver and Nome Creeks mark-recapture project, an attempt will be made to generate separate estimates for Nome and Beaver Creeks, as well as a total estimate. However, from the tracking station located at the confluence of Beaver and Nome Creeks, radiotagged Arctic grayling that oversummer near the confluence do travel back and forth, thus violating the assumption of closed systems (outlined below). The lower bound for the Nome Creek study area and upper and lower bounds for Beaver Creek will be defined using movement data acquired from recaptured fish and the recent radiotelemetry project.

Evaluation of Assumptions

Assumption 1: This study is designed to guard against violations of closure due to migration. Sampling will take place during most of July 2023, when Arctic grayling will be relatively stationary at their summer feeding areas. Therefore, the fish will not be prone to migrate between or during sampling events (Fish 1998; Gryska 2006), and a relatively closed system is ensured. Although Arctic grayling are unlikely to move in or out of the study area during this short time, the potential for immigration and emigration exists because there are no barriers surrounding the study area (Schwanke 2019). Radiotagged Arctic grayling migrated between the overwintering and spawning locations of Beaver and Nome Creeks from 1 May to 17 June 2022, with no movement noted during July and August (Stuby and Clark, *In prep*). However, there was some ongoing movement for fish that were radiotagged at or near the confluence. This movement, along with movements of fish recaptured during the second event, will be considered when estimating a Nome Creek specific abundance estimate, which may end up excluding the lowermost portions of Nome Creek. Similar small-scale movements are expected on Beaver Creek downriver of

Wickersham Creek and upriver of Nome Creek. To account for these movements, recaptured fish will be examined at a fine scale (i.e., approximately 200 m) to determine whether mixing was likely sufficient to minimize or eliminate the potential for fish having been isolated from the experiment (Gryska and Tyers 2017). Given the relatively short hiatuses of 13 (~1.5 rkm below the Nome Creek put-in to Wickersham Creek) and 11 (Mt. Prindle to ~1.5 rkm below the Nome Creek put-in) days between sampling events, violations of closure due to natural mortality or growth are unlikely. Angling mortality should also be minimal because the more heavily fished Nome Creek is catch-and-release only and the remainder of Nome and Beaver Creeks are remote and only accessible through floating. In order to minimize bias due to angling mortality, the project biologist will post informational fliers describing the mark-recapture project as well as provide contact information, give a reminder that the fishery is catch-and-release only for Nome Creek, and encourage proper catch-and-release techniques. The individual marking and recapturing of fish will permit an evaluation of growth to determine if adjustments to the estimate or the population of inference are needed.

Assumption 2: This study is designed to subject all fish to an equal probability of capture during each event and to allow enough time for sufficient mixing to occur (i.e., 13 and 11 days). Because marked and unmarked Arctic grayling at their summer feeding areas are expected to be relatively stationary, complete mixing between the entire study area is not expected to occur. However, small-scale mixing may occur and has been seen with radiotagged fish between the confluence of Beaver and Nome Creeks. Fishing effort will be similar for both events and crews will try to capture, tag, and examine as many Arctic grayling as possible.

Differences in capture probability related to fish size, location, and time will be examined. Size- or sex-selective sampling will be tested using two-sample Kolmogorov-Smirnov tests. The tests and possible actions for data analysis are outlined in Appendix B1. If stratification by size or sex is required, capture probabilities will be examined for each stratum, and total abundance and its variance estimate will be calculated by summing strata estimates. Capture probabilities and mixing over location or time will be tested with contingency tables (Appendix B2). For these tests, the study area strata and sections within each stratum will be combined at the project conclusion and a matrix will be made to evaluate movement of recaptured fish between events. Additional temporal or geographic strata schemes may be investigated post-sampling.

Assumption 3: The 13 and 11-day hiatuses between mark and recapture events for the geographic strata will allow adequate time for tagged fish to recover from the effects of handling or marking-induced behavioral effects. Arctic grayling respond to catch and release very well and a shorter hiatus of 4–12 days has been successfully employed during past mark-recapture studies (DeCicco 1997; Gryska 2015; Schwanke 2019). Additionally, project staff noted Arctic grayling readily striking a lure 1 to 2 days after being implanted with a radio transmitter during the recent telemetry project. If a fish is injured after being captured during the first event and/or appears sick or physically compromised, and their survival until the second event is questionable, it will not be tagged.

Assumption 4: Each Arctic grayling ≥ 250 mm FL will be double marked during the first event to ensure that recaptured fish are identifiable during the second event. Fish will receive a partial left-pectoral fin clip in addition to a Floy™ tag during the first event, and a partial right-pectoral fin clip during the second event. Tag placement will be standardized (left side below the dorsal fin) to verify tag loss by locating recent tag wounds. Tag loss will be noted if a fish is recovered during the second event with a first-event fin clip and tag wound, but no tag.

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

SAMPLING METHODS

For each event, geographic strata, and 2-rkm section, a crew of 2 people will sample Arctic grayling, beginning on the upstream end of a section and progressing downstream, capturing and sampling fish until they reach the end of their assigned section, which should be accomplished in a day. Fish will be captured with hook and line gear. Single barbless hooks will be used, along with soft landing nets, to minimize stress and ensure tagging success. Both spin and fly-fishing gear will be used, and various lure types will be fished, including shiny spoons and spinners, lead jigs with colorful tails, and assorted floating and sinking flies.

During the first event, each Arctic grayling ≥ 250 mm FL will be given an individually numbered gray Floy™ FD-94 T-bar anchor tag that will be inserted below the dorsal fin on the left side of the fish. Each fish will be measured to the nearest fork length and a partial left-pectoral fin clip will be given as a secondary mark in case the tag is lost. A partial right-pectoral fin clip will be given during the second event to ensure the fish is not double counted if it is captured again downriver. All captured fish will be sampled and released within 50 m of their capture location. If a fish appears unhealthy due to a previous injury or from capture and handling, and it appears it may not live until the second capture event, it will not be tagged. For any mortalities, lengths will be taken, and otoliths will be collected for later size at age analyses. For all collected otoliths, ages will be determined using a compound microscope with polarizing lenses as described by Stuby (2008).

The 36 rkm section from the Mt. Prindle Campground to ~1.5 rkm below the Nome Creek put-in is accessible from the Nome Creek Road. Therefore, each 2-person crew will hike and fish their daily 2-km section. The 44-km section from ~1.5 rkm below the Nome Creek put-in to Wickersham Creek will be floated with 3 rafts equipped with sampling equipment. Each 2-person crew will float to the start of their assigned section at the start of a day, leap-frogging other crews and sections if needed. A total of 6 km per day will be sampled by the three 2-person crews. At the conclusion of sampling, the float crew will be retrieved with a Helio Courier on the large gravel bar near Wickersham Creek if conditions allow, or on a private airstrip that is located about 23 rkm further downriver. An additional day of river travel has been built into the schedule in case of delays (Appendix A).

SAMPLE SIZE

Abundance (Objective 1)

Appropriate mark-recapture first and second event sample sizes are based on expected abundances as well as the anticipated relative precision and desired confidence. For the 2000 mark-recapture experiment, the abundance of Arctic grayling ≥ 250 mm in Beaver Creek was 9,867 fish (Fleming and McSweeny 2001). For the separate Nome Creek mark-recapture, assumptions 1 and 2 were violated. The fish were still migrating from their overwintering and spring spawning locations in Beaver Creek to their oversummering locations in Nome Creek during the first event, followed by a 19-day hiatus until the second event. Thus, it was difficult to assure a closed population and similar probabilities of capture for the Nome Creek mark-recapture experiment. The abundance estimate for the upper portion of Nome Creek, from Moose Creek to the Bureau of Land Management airstrip, was 419 Arctic grayling ≥ 250 mm FL (SE = 81). A point estimate could not be acquired for the lower portion, from the airstrip to Beaver Creek, but assuming closure and similar probabilities of capture, the 95% confidence interval was 878 to 4,522 Arctic grayling ≥ 180 mm (Fleming and McSweeny 2001). Also, given that approximately one-third of the road accessible portion of Nome Creek was not sampled in the 2000 study, it is difficult to estimate how many Arctic grayling ≥ 250 mm had resided in the accessible portion of Nome Creek. Furthermore, the 2000 abundance estimate for Beaver Creek included the section of Beaver Creek from the confluence of Bear and Champion Creeks to Nome Creek, which will not be sampled in 2023. Because of these differences, we chose to use a range of possible abundance estimates to determine expected sample sizes.

Based on the 2000 abundance estimates for Beaver and Nome Creeks Arctic grayling, a total abundance of 10,000–15,000 fish is anticipated. According to Robson and Regier (1964), assuming an abundance of 10,000 Arctic grayling ≥ 250 mm FL with a relative precision level of 0.25 and a confidence level of 95%, the minimum desired sample size is 771 fish per event with 59 expected recaptures, and 1,483 unique individuals observed. Assuming an abundance of 15,000 Arctic grayling ≥ 250 mm FL with the same precision and confidence levels, the minimum desired sample size is 958 fish per event with 61 expected recaptures and 1,855 unique individuals observed. From correspondence with the 2000 Beaver and Nome Creeks Arctic grayling mark-recapture project leader (Doug Fleming, retired Division of Sport Fish biologist, Alaska Department of Fish and Game, Fairbanks, December 13, 2020, email communication), 773 Arctic grayling ≥ 250 mm FL were tagged between Nome and Wickersham Creeks on Beaver Creek during the first event and 1,138 during the second event. Also, for the Nome Creek effort, 148 Arctic grayling ≥ 250 mm were tagged during the first event and 113 fish during the second event. Therefore, a target sample size of at least 1,000 Arctic grayling ≥ 250 mm FL for both strata combined seems plausible. However, 2,000 Floy™ tags will be available, and the field crews will attempt to tag and examine as many Arctic grayling ≥ 250 mm FL as possible.

Length Composition (Objective 2)

Using criteria developed from Thompson (1987) for multinomial proportions without a finite population factor, a sample of at least 509 Arctic grayling ≥ 250 mm FL will estimate size composition with the desired precision criteria (within 5 percentage points of the true value 95% of the time). The sample sizes required for the associated abundance estimate (Objective 1) is larger than 509 fish for both the first and second events, and will be sufficient to satisfy all length composition sample size requirements even if data from only one sampling event can be used in the analysis.

DATA COLLECTION AND REDUCTION

For each Arctic grayling ≥ 250 mm FL captured, the FL measurement of the fish, date of capture, capture location (site number and GPS coordinates), number printed on the Floy™ tag, and any additional comments related to fish condition, weather that could compromise capture ability, crew member names, and significant injuries, will be recorded in Rite in the Rain® books. All tagging data will be incorporated into a master Excel spreadsheet. The spreadsheet and other files pertinent to this project will be archived in a Region 3 Division of Sport Fish network drive and on the project leader’s computer at ADF&G Division of Sport Fish in Fairbanks, Alaska. All data will be available to the public on request.

DATA ANALYSIS

Abundance Estimate (Objective 1)

An attempt will be made to acquire abundance estimates for Arctic grayling ≥ 250 mm FL. However, in the event inadequate numbers of fish between 250 and 270 mm FL are sampled, the abundance of Arctic grayling ≥ 270 mm FL will be estimated.

Prior to diagnostic testing (Appendix B), the marking and recapture lengths of all recaptured Arctic grayling will be examined for growth-recruitment using paired t-tests at an alpha level of 0.05. If significant growth is detected, lengths of sampled fish in the second event will be corrected. If growth is constant between all sizes of fish, growth correction will be done by subtracting the mean growth of recaptured fish from the lengths of all fish captured in the second event. If growth varies by fish size, a regression that allows growth to vary by fish size will be used for second event length corrections.

Relative to Assumption 1, data will be examined for evidence of fish movement into or away from study area boundaries to provide evidence of immigration and emigration and to adjust boundaries (Appendix B2). If both immigration and emigration (and/or mortality) are deemed significant, then the abundance estimate will be biased with the degree of bias unknown.

Relative to Assumption 2, differences in capture probability related to fish size and location will be examined. Size-selective sampling will be tested using Kolmogorov-Smirnov tests. There are 4 possible outcomes relative to evaluating size selectivity (either 1 of the 2 samples, both, or neither of the samples are biased) and 2 possible actions for abundance estimation (stratify by length or not). The tests and possible actions for data analysis are outlined in Appendix B1.

Temporal and spatial violations of Assumption 2 will be tested using consistency tests described by Seber (1982; Appendix B2). If all 3 of these tests reject the null hypothesis, then a partially or completely stratified estimator must be used. If movement of marked fish between strata is observed (incomplete mixing), the methods of Darroch (1961) will be used to compute a partially stratified abundance estimate. If no movement of marked fish between geographic strata is observed, a completely stratified abundance estimate will be computed using the methods of Bailey (1951, 1952) or Darroch (1961). Otherwise, at least one of the 3 consistency tests will fail to reject the null hypothesis and it will be concluded that at least one of the conditions in Assumption 2 is satisfied.

If no assumptions are violated, the number of Arctic grayling ≥ 250 mm FL in the described strata and/or sampling area of Beaver and Nome Creeks will be estimated using Bailey's modification of the Petersen estimator (Bailey 1951, 1952). The Bailey estimator 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 of 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.

Protocol for estimating a stratified abundance is outlined in Appendix B1.

Length Composition (Objective 2)

Kolmogorov-Smirnov tests performed to test for size-selective sampling will also be used to determine if stratification is necessary and if data from the first, second, or both events are to be used for the length composition (Appendix B1). For cases I-III, stratification is not necessary and length proportions and variances of proportions for Arctic grayling ≥ 250 mm FL will be estimated using samples from the event(s) without size-selectivity, calculated from the following formulas:

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

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 B1.

SCHEDULE AND DELIVERABLES

The final Fisheries Data Series report will be completed in 2024, and project updates and results will be shared with the Eastern Interior Regional Advisory Council (EIRAC) during their bi-yearly meetings.

Activity	Start Date	Completion Date
Capture and tag Arctic grayling for the first event	7/4/2023	7/20/2023
Capture and examine Arctic grayling for the second event	7/15/2023	7/31/2023
Retrieve stationary tracking station on Nome Creek	9/1/2023	9/30/2023
Conduct data analysis	10/1/2023	12/31/2023
Complete semi-annual progress report		10/30/2023
Draft FDS report submitted to supervisors		6/30/2024
Final FDS report submitted		9/31/2024

RESPONSIBILITIES

PROJECT STAFF AND PRIMARY ASSIGNMENTS

Lisa Stuby, *Fisheries Biologist 3*. YMA Management Biologist and Project Leader. Responsible for supervision of all aspects of the Beaver and Nome Creeks Arctic grayling mark-recapture project, managing the project budget, and writing the annual and final reports.

April Behr, *Fisheries Biologist 3*. Resident Species Supervisor. Assist with capture and tagging of Arctic grayling and review and edit all reports.

James Savereide, *Fisheries Biologist 4*. Regional Research Supervisor. Final report editing and project support.

Mackenzie Ocaña, *Biometrician 2*. Region III Division of Sport Fish Biometrician. Assist in statistical design of field investigation for the operational plan and review data analysis and final report.

Matt Albert, *Fishery Biologist 2*. Crew leader. Assist with second event on Beaver Creek float and help oversee day-to-day project tasks.

Brian Collyard, *Fish & Wildlife Technician 4*. Crew leader. Project mobilization, oversees day-to-day project tasks, all aspects of field work, and demobilization for the first and second events.

Matt Stoller, *Fish & Wildlife Technician 3*. Assistant crew leader. Assists project biologist and crew leader with project mobilization and day-to-day project tasks for the second event.

Mike McNulty, *Fish & Wildlife Technician 3*. Assistant crew leader. Assists project biologist and crew leader with project mobilization and day-to-day project tasks for the first event.

Tim Rashley, *Fish & Wildlife Technician 2*. Assist with capture and tagging for the first and second events.

Hunter Parini, *Fish & Wildlife Technician 2*. Assist with capture and tagging for the second event.

Arnie Erickson, *Fish & Wildlife Technician 2*. Assist with capture and tagging for the first event.

Hannah Wuttig, *Fish & Wildlife Technician 2*. Assist with capture and tagging for the first and second events.

Jack Wade, *Volunteer*, Assist with capture and tagging for the first event.

Chris Clark, *Bureau of Land Management Fisheries Biologist*. Crew Member. Assist with capture and tagging.

TBD, *Fishery Biologist 1-4*. Crew Member. Assist with capture and tagging.

REFERENCES CITED

Bailey, N. J. T. 1951. On estimating the size of mobile populations from capture-recapture data. Biometrika 38:293-306.

Bailey, N. J. T. 1952. Improvements in the interpretation of recapture data. Journal of Animal Ecology 21:120-127. Bendock, T. N. 1979. Inventory and cataloging of Arctic area waters Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1978-1979, Project F-9-11, 20 (G-I-I), Juneau.

Burr, J. 2004. Fishery Management Report for Sport Fisheries in the Arctic-Yukon-Kuskokwim Management Area, 2002-2003. Alaska Department of Fish and Game, Fishery Management Report No.04-02, Anchorage.

Carufel, L. 1990. Fisheries investigations I the Beaver Creek drainage, White Mountains National Recreation Area, Alaska, 1989. BLM-Alaska Open File Report 31.

Cochran, W. G. 1977. Sampling techniques, third edition. John Wiley and Sons, New York.

Conover, W. J. 1980. Practical nonparametric statistics 2nd Ed. John Wiley & Sons, New York.

Darroch, J. N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241-260.

DeCicco, A. L. 1997. Assessment of Arctic grayling in selected streams of the Seward Peninsula, 1996. Alaska Department of Fish and Game, Fishery Data Series 97-15, Anchorage.

Fish, J. T. 1998. Radio-telemetry studies of Arctic grayling in the Jim River (Dalton Highway) during 1997 - 1998. Alaska Department of Fish and Game, Fishery Manuscript Report, No. 98-4, Anchorage.

Fleming, D. F., and I. McSweeney. 2001. Stock assessment of Arctic grayling in Beaver and Nome Creeks. Alaska Department of Fish and Game, Fishery Data Series No. 01.28, Anchorage.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708- 713.

Gryska, A. D. 2006. Vulnerability of Arctic grayling to the Brushkana Creek sport fishery. Alaska Department of Fish and Game, Fishery Data Series No. 06-73, Anchorage.

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

Gryska, A. D. 2019. Stock assessment and evaluation of the Arctic grayling fishery in the mainstem Gulkana River, 2017. Alaska Department of Fish and Game, Fishery Data Series No. 19-29, Anchorage.

Gryska, A. D., and M. Tyers. 2017. Stock assessment of Gulkana River Arctic grayling, 2017. Alaska Department of Fish and Game, Regional Operational Plan ROP.SF.3F.2017.07, Anchorage.

Lubinski, B. R. 1995. Winter habitat of Arctic grayling in an interior Alaska stream. M. Sc. Thesis, University of Alaska.

Robson, D. S., and H. A. Regier. 1964. Sample size in Petersen mark-recapture experiments. Transactions of the American Fisheries Society 93:215-226.

Schwanke, C. J. 2019. Middle Fork Gulkana River Arctic grayling stock assessment. Alaska Department of Fish and Game, Regional Operational Plan ROP.SF.3F.2019.08, Anchorage.

Schwarz, C. J., and C. G. Taylor. 1998. The use of the stratified-Petersen estimator in fisheries management with an illustration of estimating the number of pink salmon (*Oncorhynchus gorbuscha*) that return to spawn in the Fraser River. Canadian Journal of Fisheries and Aquatic Sciences, 55, 281–296.

Seber, G. A. F. 1982. On the estimation of animal abundance and related parameters. Second edition. Griffin and Company, Ltd. London.

Stuby, L. 2008. An evaluation of precision in age assessment of thin-sectioned and whole otoliths and the efficacy of using oxytetracycline as an aid in validating otolith annuli in burbot. Pages 235-247 *in* V. L. Paragamian and D. H. Bennett, editors. Burbot: ecology, management, and culture. American Fisheries Society, Symposium 59, Bethesda, Maryland.

REFERENCES CITED (Continued)

Stuby, L. 2021. Fishery management report for sport fisheries in the Yukon Management area, 2019. Alaska Department of Fish and Game, Fishery Management Report No. 21-27, Anchorage.

Stuby, L. 2022. Fishery management report for sport fisheries in the Yukon Management area, 2021. Alaska Department of Fish and Game, Fishery Management Report No. 22-21, Anchorage.

Stuby, L. and C. Clark. *In prep*. Seasonal distribution and abundance of Arctic grayling in Beaver and Nome Creeks. Alaska Department of Fish and Game, Fishery Data Series.

Thompson, S. K. 1987. Sample sizes for estimating multinomial proportions. The American Statistician 41: 42-46.

Swanton, C. O., and K. G. Wuttig. 2014. A management plan and policies for Arctic grayling fisheries within the Arctic-Yukon-Kuskokwim Region. Alaska Department of Fish and Game, Fishery Management Report No. 14-06, Anchorage.

TABLES AND FIGURES

Table 1.–Upstream and downstream boundaries for the 40 sites to be sampled for the 2023 Beaver and Nome Creeks mark-recapture of Arctic grayling.

Sampling Section	Upstream Boundary		Downstream Boundary		Hike or Float
	Latitude	Longitude	Latitude	Longitude	
Site 1	65.3723	-146.5814	65.3592	-146.6097	Hike
Site 2	65.3592	-146.6097	65.3508	-146.6443	Hike
Site 3	65.3508	-146.6443	65.3472	-146.6856	Hike
Site 4	65.3472	-146.6856	65.3388	-146.7229	Hike
Site 5	65.3388	-146.7229	65.3313	-146.7572	Hike
Site 6	65.3313	-146.7572	65.3300	-146.7865	Hike
Site 7	65.3300	-146.7865	65.3359	-146.8243	Hike
Site 8	65.3359	-146.8243	65.3356	-146.8602	Hike
Site 9	65.3356	-146.8602	65.3367	-146.8896	Hike
Site 10	65.3367	-146.8896	65.3384	-146.9168	Hike
Site 11	65.3384	-146.9168	65.3397	-146.9505	Hike
Site 12	65.3397	-146.9505	65.3400	-146.9802	Hike
Site 13	65.3400	-146.9802	65.3482	-146.9979	Hike
Site 14	65.3482	-146.9979	65.3562	-147.0120	Hike
Site 15	65.3562	-147.0120	65.3607	-147.0307	Hike
Site 16	65.3607	-147.0307	65.3661	-147.0549	Hike
Site 17	65.3661	-147.0549	65.3660	-147.0773	Hike
Site 18	65.3660	-147.0773	65.3773	-147.0926	Hike
Site 19	65.3773	-147.0926	65.3837	-147.1207	Float
Site 20	65.3837	-147.1207	65.3921	-147.1485	Float
Site 21	65.3921	-147.1485	65.3922	-147.1681	Float
Site 22	65.3922	-147.1681	65.3952	-147.2028	Float
Site 23	65.3952	-147.2028	65.3923	-147.2418	Float
Site 24	65.3923	-147.2418	65.3885	-147.2726	Float
Site 25	65.3885	-147.2726	65.3930	-147.3058	Float
Site 26	65.3930	-147.3058	65.3846	-147.3367	Float
Site 27	65.3846	-147.3367	65.3840	-147.3608	Float
Site 28	65.3840	-147.3608	65.3864	-147.3761	Float
Site 29	65.3864	-147.3761	65.3879	-147.3942	Float
Site 30	65.3879	-147.3942	65.3819	-147.4208	Float
Site 31	65.3819	-147.4208	65.3769	-147.4519	Float
Site 32	65.3769	-147.4519	65.3791	-147.4805	Float
Site 33	65.3791	-147.4805	65.3784	-147.5128	Float
Site 34	65.3784	-147.5128	65.3861	-147.5409	Float
Site 35	65.3861	-147.5409	65.3844	-147.5721	Float
Site 36	65.3844	-147.5721	65.3850	-147.5972	Float
Site 37	65.3850	-147.5972	65.3769	-147.6317	Float
Site 38	65.3769	-147.6317	65.3782	-147.6562	Float
Site 39	65.3782	-147.6562	65.3818	-147.6983	Float
Site 40	65.3818	-147.6983	65.3790	-147.7385	Float

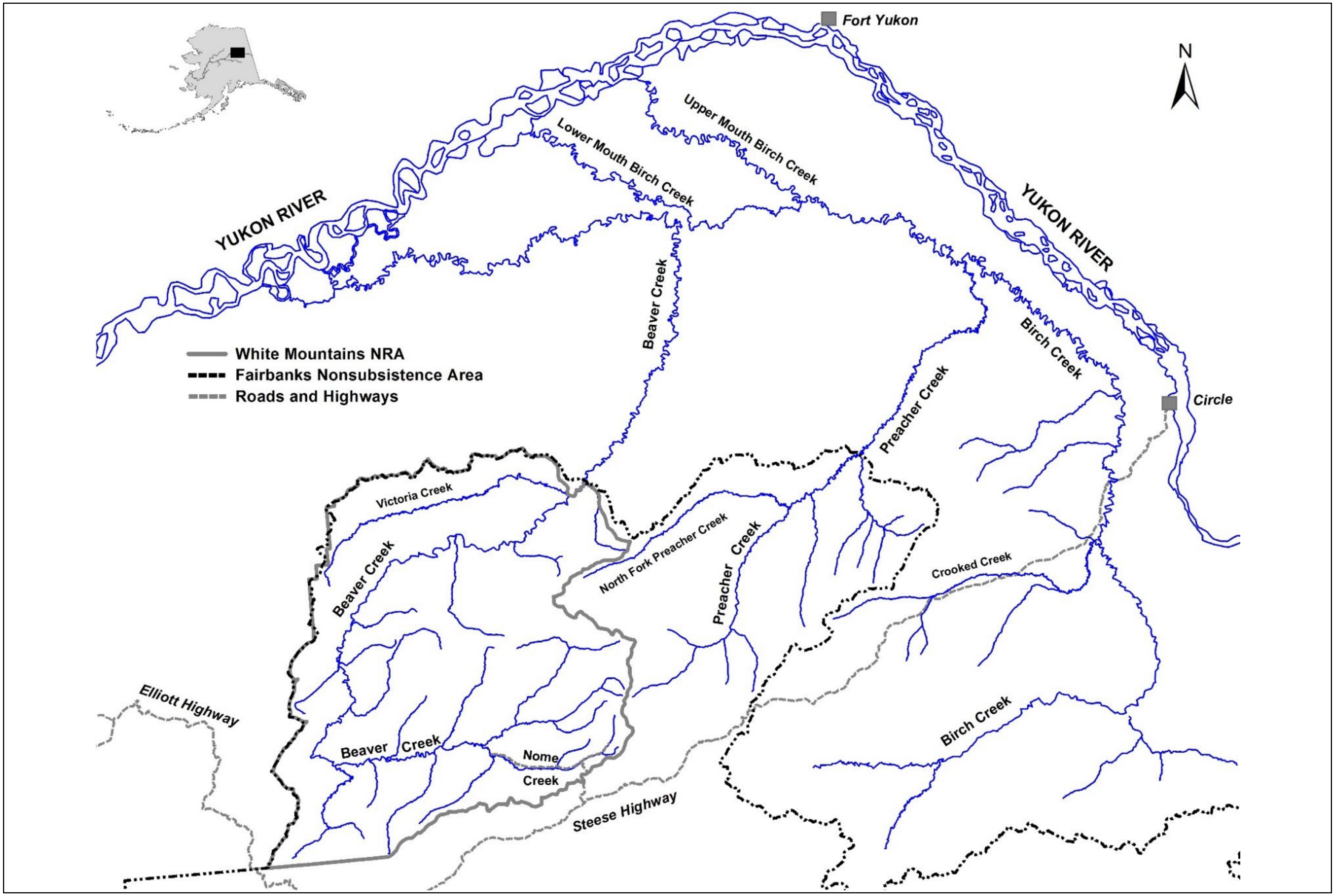

Figure 1.–Outline of the Fairbanks nonsubsistence area within the Yukon Management Area and White Mountains National Recreation Area.

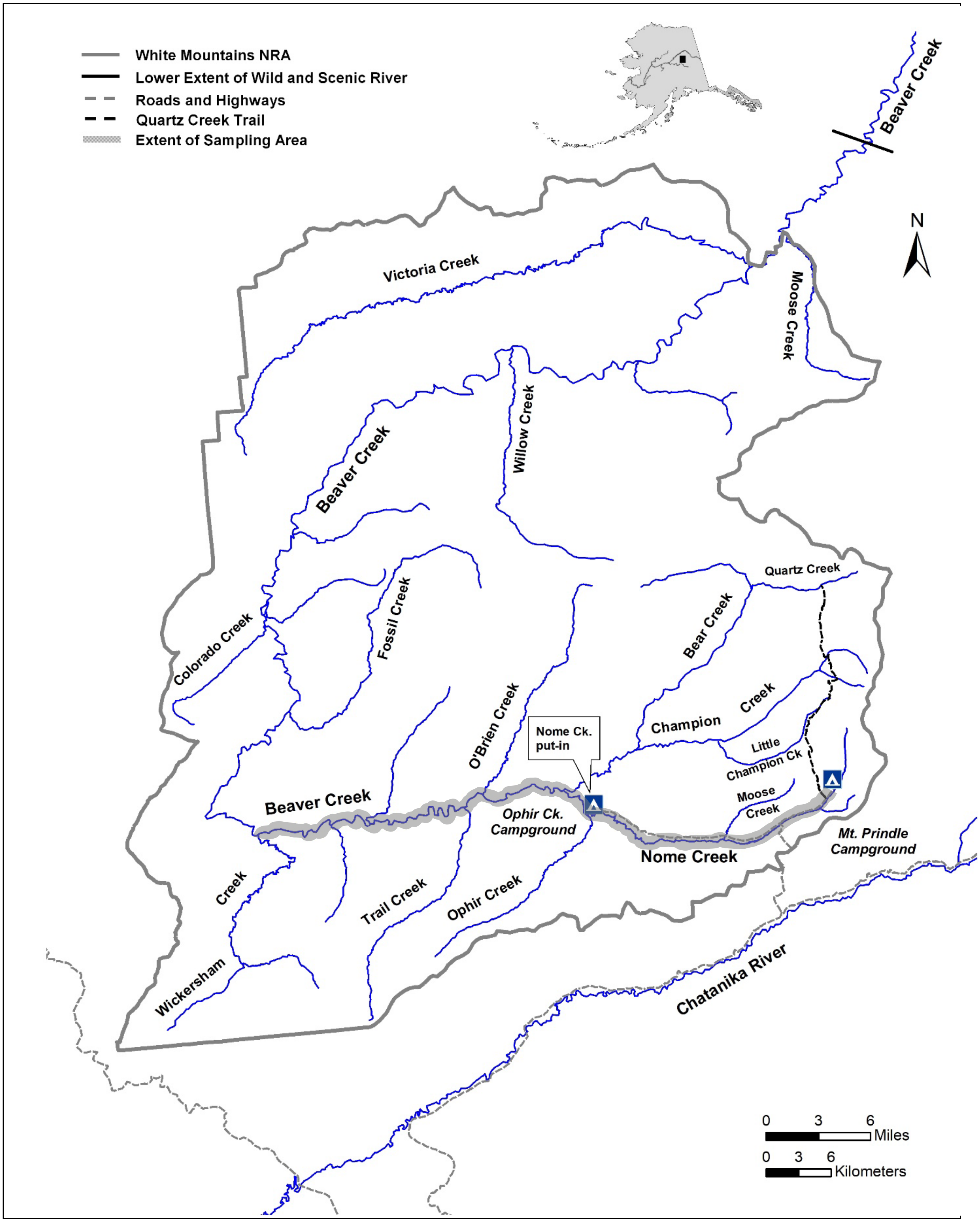

Figure 2.–Map of the Beaver Creek drainage within the White Mountains National Recreation Area with extent of the sampling area for the 2023 mark-recapture.

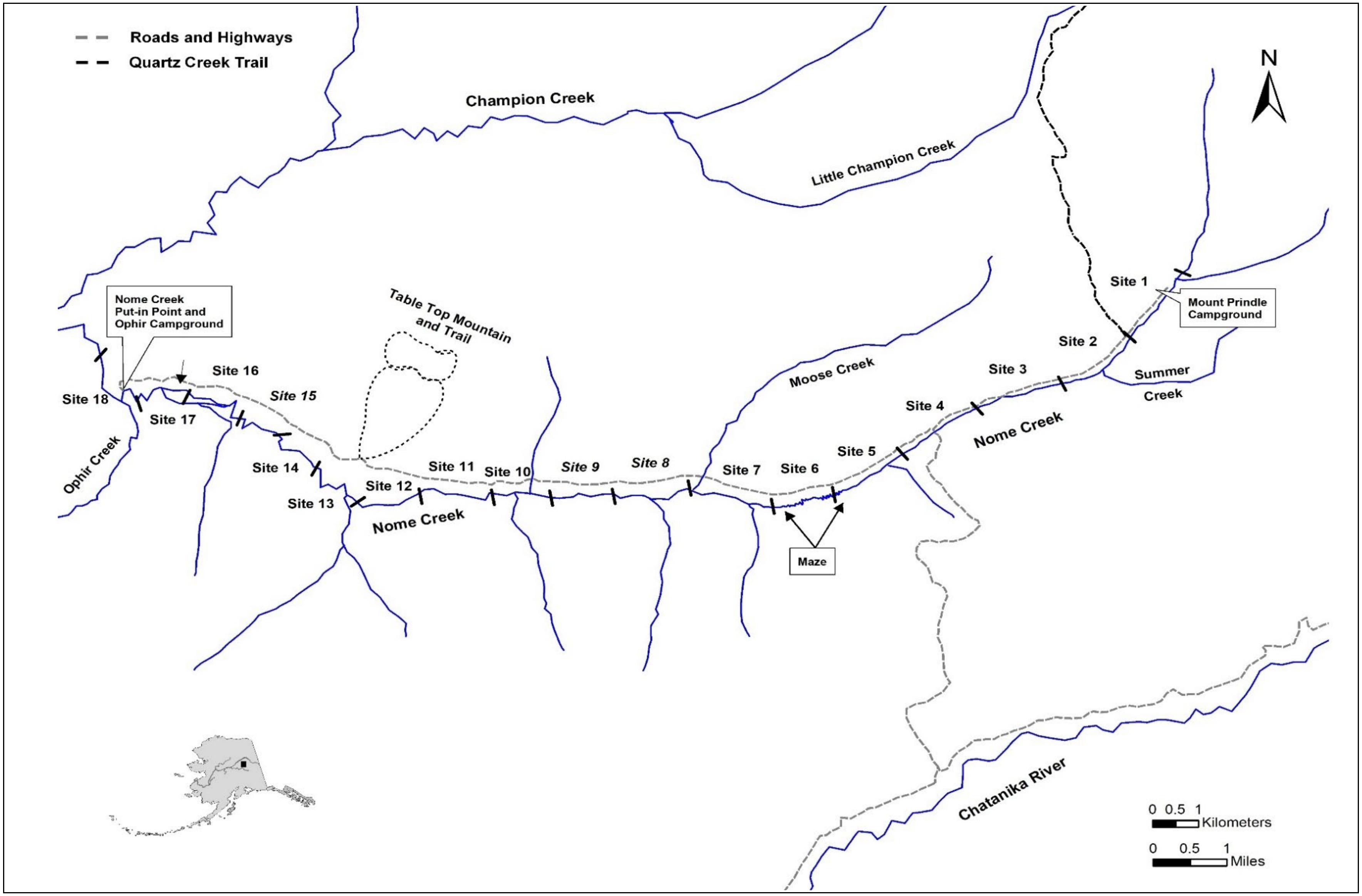

Figure 3.–Map of the road-accessible Nome Creek sampling area for the 2023 mark-recapture experiment showing sampling sites 1–18. Waypoints designating the upper and lower boundaries of the sites are given in Table 1.

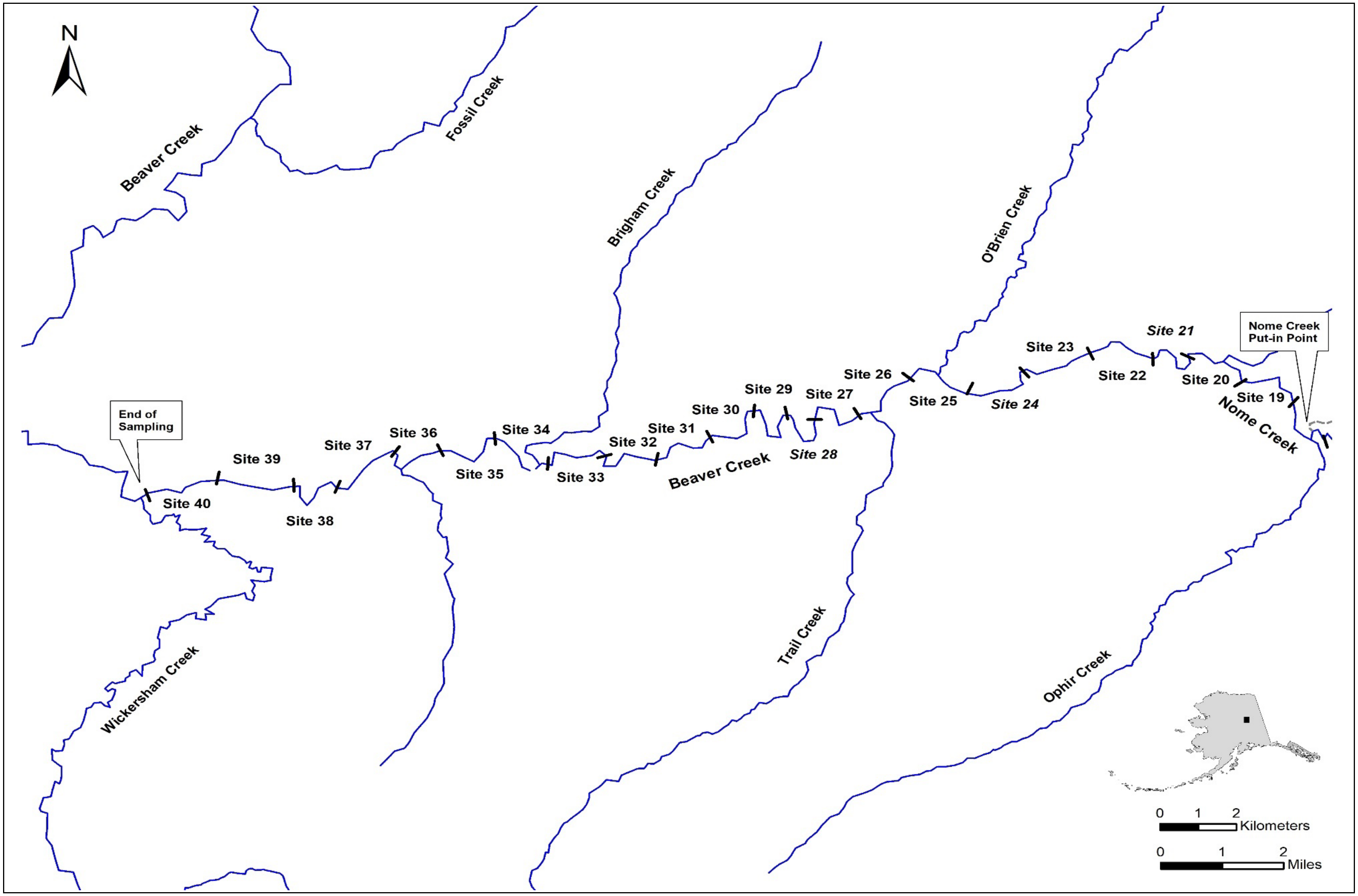

Figure 4.–Map of the floatable Nome and Beaver Creeks sampling area for the 2023 mark-recapture experiment showing sampling sites 19–40. Waypoints designating the upper and lower site boundaries are given in Table 1.

APPENDIX A: CREW SCHEDULE FOR THE 2023 BEAVER AND NOME CREEKS MARK-RECAPTURE OF ARCTIC GRAYLING

Appendix A1.–Approximate sampling dates with field crew for the 2023 Beaver and Nome Creeks mark-recapture. Legend is below the table.

	July 2023																														
Crew Members	Sa	Su	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su	M	T	W	Th	F	Sa	Su	Mo
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Matt Albert																															
April Behr																															
Brian Collyard																															
Arnie Erickson																															
Mike McNulty																															
Hunter Parini																															
Matt Stoller																															
Lisa Stuby																															
Tim Rashley																															
Hanna Wuttig																															
Jake Wade																															
Permanent Staff																															
Permanent Staff																															
Permanent Staff																															

Legend:

= Days off

= Mt. Prindle Campground to Nome Creek put-in (Mark) and = Recapture

= Nome Creek put-in to Wickersham Creek on Beaver Creek (Mark) and = Recapture

= Preparation and additional field dates as needed

APPENDIX B: STATISTICAL TESTS FOR ANALYZING DATA FOR SEX AND SIZE BIAS

Appendix B1.–Detection and mitigation of selective sampling during a two-event mark recapture experiment.

Overview

Size and sex selective sampling may result in the need to stratify by size and/or sex in order to obtain unbiased estimates of abundance and composition. In addition, the nature of the selectivity determines whether the first, second, or both event samples are used for estimating composition. The two-sample Kolmogorov-Smirnov (K-S) test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first or second sampling events and contingency table analysis (Chi-square test) is generally used to detect significant evidence that sex selective sampling occurred during the first or second sampling events (Seber 1982).

K-S tests are used to evaluate the second sampling event by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R), using the null hypothesis (H_o) of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of fish recaptured during the second event (R). Chi-square tests are used to compare the counts of observed males to females between the first event and recaptures (M&R) and the second event and recaptures (C&R) according to the null hypothesis that the probability that a sampled fish is male or female is independent of the sample. When the proportions by gender are estimated for a subsample (usually from the second event), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are compared using a two-sample test (e.g. Student's t-test).

Mark-recapture experiments are designed to obtain sample sizes sufficient to 1) achieve precision objectives for abundance and composition estimates and 2) ensure that the diagnostic tests (i.e., tests for selectivity) have power adequate for identifying selectivity that could result in significantly biased estimates. Despite careful design, experiments may result in inadequate sample sizes leading to unreliable diagnostic test results due to low power. As a result, detection and adjusting for size and sex selectivity involves evaluating the power of the diagnostic tests.

The protocols that follow are used to classify the experiment into one of four cases. For each case, the following are specified: 1) whether stratification is necessary; 2) which sample event's data should be used when estimating composition; and, 3) the estimators to be used for composition estimates when stratifying. The first protocols assume adequate power. These are followed by supplemental protocols to be used when power is suspect and guidelines for evaluating power.

Protocols given Adequate Power

Case I:

M vs. R	**C vs. R**
Fail to reject H_o	Fail to reject H_o

There is no size/sex selectivity detected during either sampling event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II:

M vs. R	**C vs. R**
Reject H_o	Fail to reject H_o

There is no size/sex selectivity detected during the first event but there is during the second event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the first sampling event without stratification. If composition is estimated from second event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the M vs. R test) within strata.

-continued-

Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III:

M vs. R	**C vs. R**
Fail to reject H_o	Reject H_o

There is no size/sex selectivity detected during the second event but there is during the first event. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated using length, sex, and age data from the second sampling event without stratification. If composition is estimated from first event data or after pooling both sampling events, data must first be stratified to eliminate variability in capture probability (detected by the C vs. R test) within strata. Composition parameters are estimated within strata, and abundance for each stratum needs to be estimated using a Petersen-type type formula. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case IV:

M vs. R	**C vs. R**
Reject H_o	Reject H_o

There is size/sex selectivity detected during both the first and second sampling events. The ratio of the probability of captures for size or sex categories can either be the same or different between events. Data must be stratified to eliminate variability in capture probability within strata for at least one or both sampling events. Abundance is calculated using a Petersen-type model for each stratum, and estimates are summed across strata to estimate overall abundance. Composition parameters may be estimated within the strata as determined above, but only using data from sampling events where stratification has eliminated variability in capture probabilities within strata. If data from both sampling events are to be used, further stratification may be necessary to meet the condition of capture homogeneity within strata for both events. Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance.

When stratification by sex or length is necessary prior to estimating composition parameters, overall composition parameters (p_k) are estimated by combining within stratum composition estimates using (Goodman 1960; Cochran 1977; Seber 1982):

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{, and} \qquad \text{(A1-1)}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + (\hat{p}_{ik} - \hat{p}_k)^2 \hat{V}[\hat{N}_i] \right), \qquad \text{(A1-2)}$$

where:

j	=	the number of sex/size strata;
$\hat{p}_{ik}$	=	the estimated proportion of fish that were sex or size k among fish in stratum i;
$\hat{N}_i$	=	the estimated abundance in stratum i;
$\hat{N}_\Sigma$	=	sum of the $\hat{N}_i$ across strata.

-continued-

Protocols when Power Suspect (re-classifying the experiment)

When sample sizes are small (guidelines provided in the next section), power needs to be evaluated when diagnostic tests fail to reject the null hypothesis. If this failure to identify selectivity is due to low power (that is, if selectivity is actually present) data will be pooled when stratifying is necessary for unbiased estimates. For example, if both the
M vs. R and C vs. R tests failed to identify selectivity due to low power, Case I may be selected when Case IV is true. In this scenario, the need to stratify could have been overlooked leading to biased estimates. The following protocols should be followed when sample sizes are small.

Case I:

M vs. R	**C vs. R**	**Implication**
Fail to reject Ho	Fail to reject Ho	re-evaluate both tests
Power OK/retain test result	Power OK/retain test result	Case I
Power suspect/change to Reject Ho	Power OK/retain test result	Case II
Power OK/retain test result	Power suspect/change to Reject Ho	Case III
Power suspect/change to Reject Ho	Power suspect/change to Reject Ho	Case IV

Case II:

M vs. R	**C vs. R**	**Implication**
Reject Ho	Fail to reject Ho	re-evaluate C vs. R
	Power OK/retain test result	Case II
	Power suspect/change to Reject Ho	Case IV

Case III:

M vs. R	**C vs. R**	**Implication**
Fail to reject Ho	Reject Ho	re-evaluate M vs. R
Power OK/retain test result		Case III
Power suspect/change to Reject Ho		Case IV

-continued-

Guidelines for evaluating power:

The following guidelines to assess power are based upon the experiences of Sport Fish biometricians; they have not been comprehensively evaluated by simulation. Because some "art" in interpretation remains, these guidelines are not intended to be used in lieu of discussions with biometricians when possible. When the evaluation does not lead to a clear choice, a stratified estimator should be selected (i.e., the experiment should be classified as Case IV) in order to minimize potential bias.

The reliability of M vs. R and C vs. R tests that fail to reject H_o are called into question when 1) sample sizes for M or C are small (< 100) and the sample size for R is also small (< 30), 2) the p-value is not large (~0.20 or less), and the D-statistic is large (≥ 0.2). If sample sizes are small, the p-value is not large, and the D-statistic is large then the power of the test is suspect and, when re-classifying the experiment, the test should be considered as having rejected the null hypothesis. If for example, sample sizes are marginal (close to the recommended values), the p-value is large, and the D-statistic is not large then the test result may be considered reliable. It is when results are close to the recommended "cutoffs" that interpretation becomes somewhat more complicated.

Apparent inconsistencies between the combination of the M vs. R and C vs. R test results and the M vs. C test results may also arise from low power. For example, if one of the tests involving R rejects the null hypothesis and the other fails to reject, one could infer a difference between M & C; however, the M vs. C test may still fail to reject the null indicating no difference between M & C. In this case, the apparent inconsistency may be due to low power in the test involving R that failed to reject the null. Finally, an additional Case I scenario is flagged by an apparent inconsistency between test results, this time resulting from power being too high. Under this scenario both the M vs. R and C vs. R tests fail to reject the null hypothesis and their power is thought to be sufficient; however, the M vs. C test rejects H_o. The apparent inconsistency may result from the M vs. C test being so powerful as to detect selectivity that would result in insignificant bias when estimating abundance and composition. The reliability of M vs. C tests that reject is called into question when 1) sample sizes for M or C are large (> 500); and, 2) p-values are not extremely small (~0.010-0.049), and the D-statistics are small (< 0.08). In general, all three K-S tests should be performed to permit these evaluations.

Appendix B2.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Three contingency table analyses are used to determine if the Petersen estimate can be used (Seber 1982). If any of the null hypotheses are not rejected, then a Petersen estimator may be used. If all three of the null hypotheses are rejected, a temporally or spatially-stratified estimator (Darroch 1961) should be used to estimate abundance.

Seber (1982) describes 4 conditions that lead to an unbiased Petersen estimate, some of which can be tested directly:

1. Marked fish mix completely with unmarked fish between events.
2. Equal probability of capture in event 1 and equal movement patterns of marked and unmarked fish.
3. Equal probability of capture in event 2.
4. The expected number of marked fish in recapture strata is proportional to the number of unmarked fish.

In the following tables, the terminology of Seber (1982) is followed, where *a* represents fish marked in the first event, *n* fish captured in second event, and *m* marked fish recaptured; $m_{\bullet j}$ and $m_{i\bullet}$ represent summation over the i^{th} and j^{th} indices, respectively.

I. Mixing Test

Tests the hypothesis (condition 1) that movement probabilities (θ_{ij}), describing the probability that a fish moves from marking stratum *i* to recapture stratum *j*, are independent of marking stratum: H_0: $\theta_{ij} = \theta_j$ for all *i* and *j*.

Area/Time Marking Strata *(i)*	Area/Time Recapture Strata *(j)*				Not Recaptured
	1	2	…	t	$a_i - m_{i\bullet}$
1	m_{11}	m_{12}	...	m_{1t}	$a_1 - m_{1\bullet}$
2	m_{21}	m_{22}	...	m_{2t}	$a_2 - m_{2\bullet}$
...	...	...	...	...	…
s	m_{s1}	m_{s2}	...	m_{st}	$a_s - m_{s\bullet}$

II. Equal Proportions Test[a] (SPAS[b] terminology)

Tests the hypothesis (condition 4) that the marked to unmarked ratio among recapture strata is constant: H_0: $\Sigma_i a_i\theta_{ij} / U_j = k$ for all stratum *j*, where k = a constant, U_j = the number of unmarked fish in stratum *j* at the time of 2[nd] event sampling, θ_{ij} = the probability that a fish moves from marking stratum *i* to recapture stratum *j*, and a_i = number of marked fish released in stratum *i*. Failure to reject H_0 means the Petersen estimator should be used only if the degree of closure among tagging strata is constant, i.e., $\Sigma_j\theta_{ij} = \lambda$ (Schwarz and Taylor 1998; p 289). A special case of closure is when all recapture strata are sampled, such as in a fish wheel to fish wheel experiment, where $\Sigma_j\theta_{ij} = 1.0$; otherwise, biological and experimental design information should be used to assess the degree of closure.

	Area/Time Recapture Strata *(j)*			
	1	2	…	t
Recaptured ($m_{.j}$)	$m_{\bullet 1}$	$m_{\bullet 2}$	…	$m_{\bullet t}$
Unmarked (n_j - $m_{.j}$)	n_1 - $m_{\bullet 1}$	n_2 - $m_{\bullet 2}$	…	n_t - $m_{\bullet t}$

-continued-

III. Complete Mixing Test[a] (SPAS[b] terminology)

Tests the hypothesis that the probability of re-sighting a released animal is independent of its stratum of origin: H_0: $\Sigma_j \theta_{ij} p_j = d$, where θ_{ij} is the probability that a fish moves from marking stratum *i* to recapture stratum *j*, p_j is the probability of capturing a fish in recapture stratum *j* during the second event, and *d* is a constant.

	Area/Time Marking Strata *(i)*			
	1	2	…	s
Recaptured (m_i)	$m_{1\bullet}$	$m_{2\bullet}$	…	$m_{s\bullet}$
Not Recaptured (a_i - $m_{i\bullet}$)	$a_1 - m_{1\bullet}$	$a_2 - m_{2\bullet}$	…	$a_s - m_{s\bullet}$

[a] There is no 1:1 correspondence between Tests II and III and conditions 2-3 above. It is pointed out that equal probability of capture in event 1 will lead to (expected) non-significant Test II results, as will mixing, and that equal probability of capture in event 2 along with equal closure
($\Sigma j \theta ij = \lambda$) will also lead to (expected) non-significant Test III results.

[b] Stratified Population Analysis System (Arnason, A.N., C.W. Kirby, C.J. Schwarz, and J.R. Irvine. 1996. Computer Analysis of Data from Stratified Mark-Recovery Experiments for Estimation of Salmon Escapements and Other Populations, Canadian Technical Report of Fisheries and Aquatic Sciences 2106.