Fishery Data Series No. 06-73

Vulnerability of Arctic Grayling to the Brushkana Creek Sport Fishery

by
Andrew D. Gryska

December 2006

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

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VULNERABILITY OF ARCTIC GRAYLING TO THE BRUSHKANA CREEK SPORT FISHERY

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

During the spring 2002 spawning period, 35 mature Arctic grayling of the Brushkana Creek drainage were implanted with radio tags to determine their vulnerability in the summer Brushkana Creek sport fishery. Their seasonal distributions and movements were described relative to the sport fishery area, which extends 11 km from its mouth at the Nenana River to a location approximately 1.6-km upstream of the Denali Highway. This study suggested that most (i.e., > 50%) of the Arctic grayling that utilized the Brushkana drainage for spawning migrated out of the sport fishery area and that a mark-recapture experiment to assess the rate of exploitation is not warranted. In addition, based on wide-ranging movements of radio-tagged fish, upper Nenana River drainage Arctic grayling should be managed as a single stock.

Key words: Arctic grayling, *Thymallus arcticus*, radiotelemetry, Brushkana Creek, Nenana River, Alaska.

INTRODUCTION

Within the upper Nenana River drainage (upstream of the Yanert River), there are a number of small-order, non-anadromous, clear-water tributaries that support low-level Arctic grayling *Thymallus arcticus* fisheries in the greater Cantwell area (Figure 1). Many of these tributaries are accessible from the Denali Highway, which runs between Cantwell and Paxson, Alaska. These include Fish and Cantwell creeks that are near Cantwell, and Seattle, Stickwan and Brushkana creeks that are 35 to 47 km from Cantwell. Other tributaries, such as Brushkana and Wells creeks, that are not accessible from the Denali Highway, have small seasonal fisheries that are accessed by boat from the Nenana River. Of all these tributaries, Brushkana Creek is believed to receive the greatest level of angler effort, which is almost exclusively directed at Arctic grayling.

The Brushkana sport fishery is considered a semi-remote fishery, and therefore the background fishing regulation for the Tanana River drainage is applied, which allows anglers to harvest five Arctic grayling per day with no size limits, seasonal closures, or gear restrictions. Statewide sport fisheries surveys conducted by the Alaska Department of Fish and Game (ADF&G) have indicated slightly declining effort and harvests since the mid 1990s (Table 1; Mills 1991-1994; Howe et al. 1995, 1996, 2001a–d; Walker et al. 2003; Jennings et al. 2004, 2006a-b). Between 1993 and 2003, estimates of angler-days ranged from 676 to 1,508. In the same period, estimated catches of Arctic grayling ranged from 1,937 to 6,996, and estimated harvests ranged from 220 to 1,488 Arctic grayling.

Local and visiting anglers traveling along the Denali Highway fish for Arctic grayling in Brushkana Creek. Upon reaching Brushkana Creek, travelers may stay at a public campground maintained by the U.S. Bureau of Land Management (BLM) and fish nearby. It is believed that most Denali Highway travelers fish in the immediate vicinity (e.g., within a 1.5 km radius) of the campground (W. Gallentine and M. Caress, residents of Cantwell; personal communication). Local Cantwell area anglers more often fish in an area farther downstream below the confluence of Monahan Creek that is reached by hiking or by all terrain vehicles (ATV). Anglers may fish elsewhere in the Brushkana drainage, but this requires more extensive hiking or 4-wheeler travel.

Anglers that fish Brushkana Creek downstream of Monahan Creek often target Arctic grayling after spring break-up (late May to mid June), which likely includes mature fish traversing from downriver overwintering locations to spawning and summer feeding areas. It had been assumed that these Arctic grayling remained in the Brushkana Creek drainage for the summer, including near the campground, until they migrated out of the drainage to overwintering areas. The timing of the fall or late summer downstream migration toward overwintering areas likely coincides

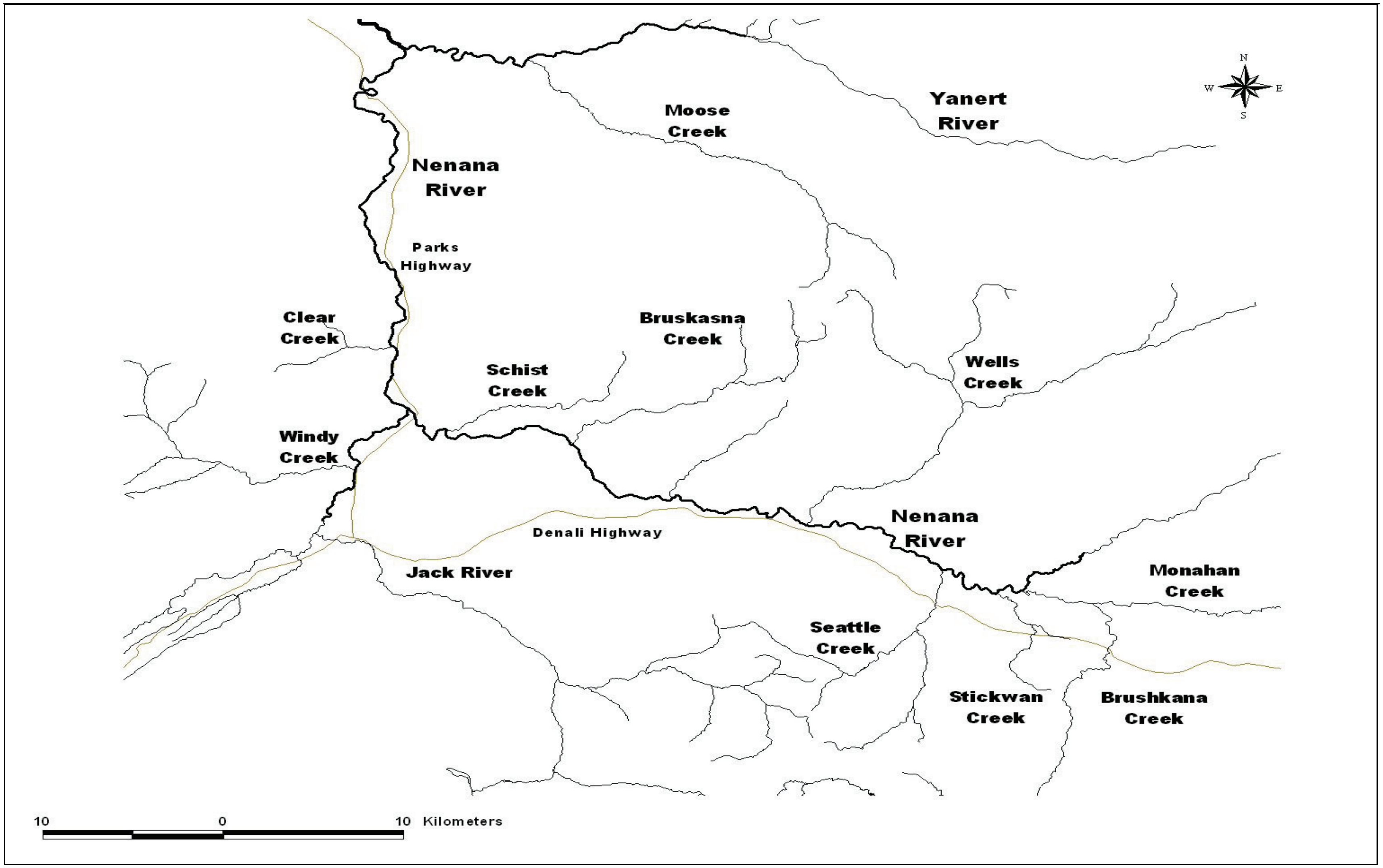

Figure 1.–Upper Nenana River drainage.

Table 1.-Summary of angling effort and Arctic grayling catches and harvests from Brushkana Creek, 1990 - 2003.

Year	Effort[a]	Catch	Harvest
1990	725	2,532	574
1991	666	844	526
1992	1,120	3,111	639
1993	1,149	3,193	557
1994	1,277	3,717	676
1995	1,432	3,975	919
1996	1,202	3,634	447
1997	1,508	4,014	1,488
1998	798	6,996	452
1999	1,330	3,475	377
2000	858	1,456	220
2001	815	2,389	247
2002	818	4,726	676
2003	676	1,937	242
Average 1993 - 1998	1,243	4,467	796
Average 1999 - 2003	899	2,797	352

[a] Estimated number of angler-days fished.

with the time of year when relatively large numbers of caribou and moose hunters frequent the area and campground. The distribution of fishing effort and harvests relative to the migratory timing of Arctic grayling through the sport fishery is not well documented.

This study was prompted by two management concerns. First, several long-time anglers to Brushkana Creek expressed concern over an apparent decline in catches of large Arctic grayling following break-up, and also a decline in catches of small Arctic grayling near, or at the public campground during summer (W. Gallentine and M. Caress, residents of Cantwell; personal communication). Second, it was thought that the anticipated upgrading of the Denali Highway to a paved road would increase recreational fishing effort in Brushkana Creek and other waters bordering the Denali Highway. In other areas of Interior Alaska, concern over increased fishing effort by way of increased road access has led to increasingly restrictive regulations for Arctic grayling fisheries, such as Nome Creek in 1994 and Beaver Creek in 2001 (Fleming and McSweeny 2001).

Because no stock assessment research had been conducted on Arctic grayling in Brushkana Creek, this study was initiated to provide baseline biological information to direct future research needs and management actions. Radiotelemetry was used to characterize the seasonal distributions and movements of mature-sized Arctic grayling that utilize Brushkana Creek for spawning. Of particular interest was the seasonal (May – September) presence of Arctic grayling within the sport fishery area, which extends from the Nenana River to a location approximately 1.6-km upstream of the Denali Highway (Figure 2), where most (i.e., > 95%) of the effort is believed to occur. Because the potential risk to a stock increases when more of the stock is vulnerable to anglers, the following criteria were used in conjunction with the results of this study to direct future research activities.

1. If > 75% of radio-tagged Arctic grayling were vulnerable to harvest in the sport fishery area, a mark-recapture study to assess the rate of exploitation would be proposed;
2. If 50% - 75%, of the radio-tagged Arctic grayling were vulnerable to harvest in the sport fishery area and the recent 3-year average catch rate fell to or below 1.5 Arctic grayling per angler day, a mark-recapture study to assess the rate of exploitation would be proposed; and,
3. If < 50% of the radio-tagged Arctic grayling were vulnerable to harvest in the sport fishery area, a mark-recapture study to assess the rate of exploitation would not be proposed unless there was other information that warranted concern.

OBJECTIVES

The research objectives in 2002 were to:

1. estimate the proportion of large (> 330 mm FL) adult Arctic grayling migrating into the Brushkana Creek sport fishery that were present in the sport fishery (vulnerable) during each tracking event conducted between mid-June and mid-September such that the estimate was within 20 percentage points of the true proportions 90% of the time;
2. estimate the proportion of large (> 330 mm FL) adult Arctic grayling migrating into the Brushkana Creek sport fishery that were present in the sport fishery during at least one tracking event conducted between mid-June and mid-September such that the proportion was within 20 percentage points of the true proportion 90% of the time; and,

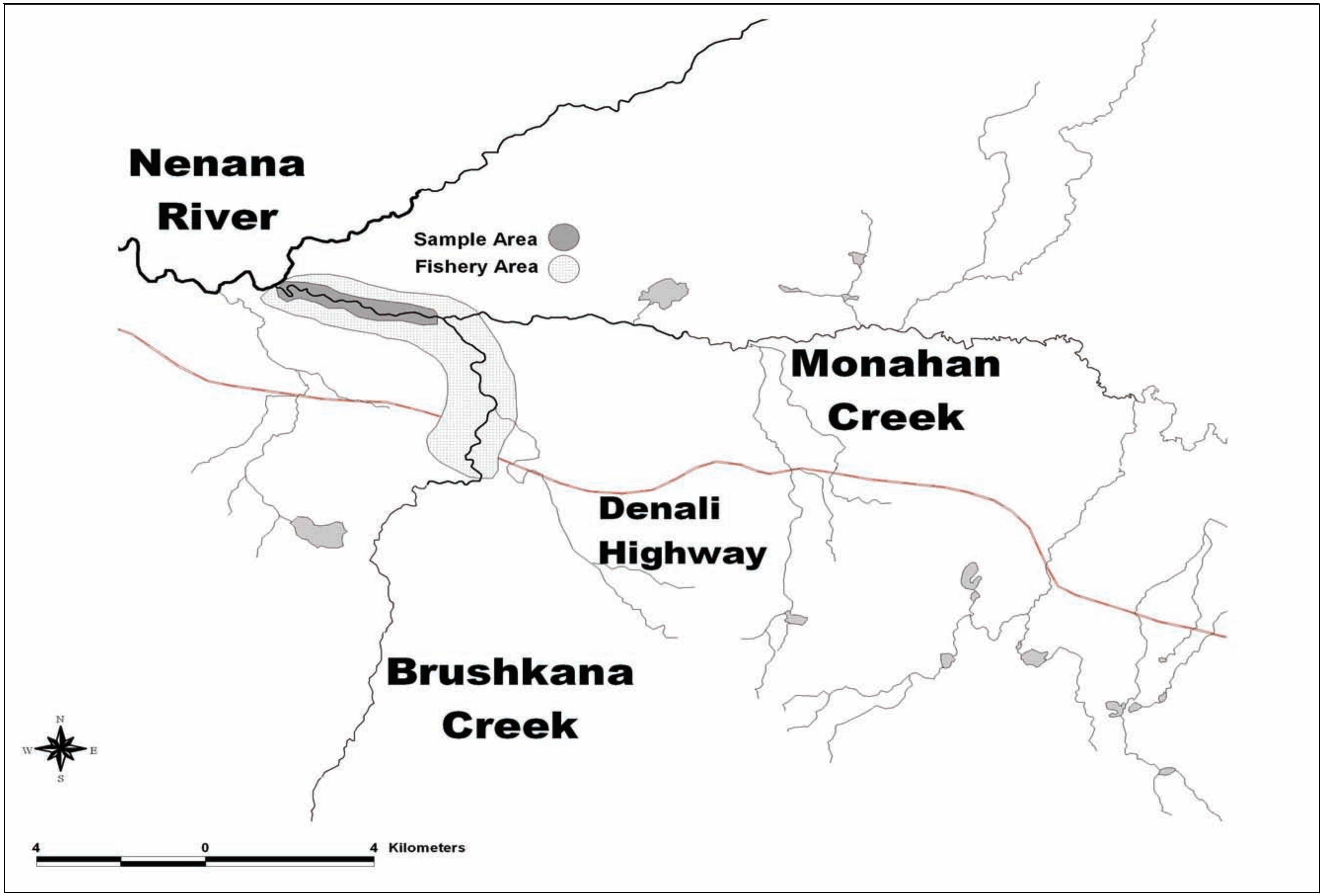

Figure 2.–Study area and fishery area.

3. test the hypothesis that the proportion of large (> 330 mm FL) Arctic grayling migrating into the Brushkana Creek sport fishery that were present in the fishery during at least one of the tracking events conducted between mid-June and mid-September was greater than or equal to 0.50 with $\alpha = 0.05$ such that $\beta = 0.30$ if the true proportion was 0.25.

The probability of a type I error, alpha, was set such that there was less than a 5% chance of deciding that less than 50% of the Arctic grayling remained in the sport fishery (rejecting the null) when, in fact, more than 50% remained. Given $\alpha = 0.05$ and a sample size of 35, the power to reject the null was estimated to be 70%, when the true proportion remaining was < 25%.

In addition, project tasks were to:

1. describe the age composition of Arctic grayling (≥150 mm FL) captured in Brushkana Creek;
2. describe the length composition of Arctic grayling (≥150 mm FL) captured in Brushkana Creek;
3. conduct periodic aerial tracking surveys of radio-tagged Arctic grayling and describe their locations during biologically meaningful periods (spring spawning year #1, summer feeding, fall migration, overwintering, and spawning year #2);
4. evaluate the efficiency of fyke traps to capture Arctic grayling entering Brushkana Creek; and,
5. describe the rate of mortality on Arctic grayling implanted with radio transmitters during the spawning period.

METHODS

BRUSHKANA CREEK STUDY AREA

The Brushkana Creek study area is located 47 km east of Cantwell, Alaska on BLM lands and accessed from the Denali Highway (Figure 2). Lands in the immediate vicinity and in the surrounding area provide recreational opportunities that seasonally include fishing, hunting, camping, and other backcountry recreation.

Brushkana Creek is formed by the joining of smaller unnamed creeks, some originating at elevations over 4,000 ft above sea level, along the northern edge of the Talkeetna Mountains in the central Alaska Range. The drainage includes numerous tributary streams and in-stream ponds or lakes that cumulatively contain roughly 140 km of stream habitat. For the purpose of this project, the area of the sport fishery was defined as the 10.7-km section of Brushkana Creek extending from its confluence with the Nenana River to a location 1.6 km upstream from the Denali Highway (Figure 2). All other areas were deemed outside of the sport fishery area. The upstream boundary of the sport fishery was inferred from the extent of access trails observed during ground surveys. Boulder, large cobble, and bedrock substrate dominate much of the designated sport fishery area upstream of the mouth of Monahan Creek. Monahan Creek enters Brushkana Creek approximately 4.2 km downstream of the Denali Highway crossing, and below this confluence the channel features become more varied. A heavily used angling area (undeveloped campsites, ATV trails, worn streamside trails) are present just downstream of the

Monahan Creek mouth. Adjacent to the campsite is a large "run" with pool-like habitat. This lower-gradient habitat continues and becomes more sinuous (i.e., pool-riffle habitat) until reaching the confluence with the Nenana River.

STUDY DESIGN

Radiotelemetry was used to estimate the proportion of the Brushkana Creek Arctic grayling spawning stock present in the sport fishery area during each tracking event between mid-June and mid-September, and the proportion that were present within the sport fishery area during at least one of these tracking events. This aggregation was expected to be predominantly Brushkana Creek residing spawners, but may have included spawners from other areas of the upper Nenana River drainage. For the estimated proportions to be unbiased, the migration patterns of the radio-tagged Arctic grayling needed to be representative of the population of large Arctic grayling migrating into or through the sport fishery. Run timing was expected to be the most significant source of bias if multiple stocks were present. No information on the entry-timing pattern was available to direct the distribution of the radio transmitters in proportion to abundance and overall run timing. To lessen the probability of introducing bias, such as tagging a segment of the run with potentially different geographical destinations, radio tags were distributed over a 7-day period.

Aerial tracking surveys were conducted between June 2002 and June 2003 at times that corresponded to biologically meaningful activities (summer feeding, overwintering, pre-spawning, and spawning). Four tracking flights were flown between June 11 and August 17, 2002, when the sport fishery occurred and when it was assumed that the geographic distribution of Arctic grayling in Brushkana Creek was most wide-spread throughout summer feeding areas. A foot survey of lower Brushkana Creek was conducted in mid-August to definitively document fates of radio-tagged Arctic grayling within the sport fishery area that were suspected mortalities. Aerial tracking surveys were conducted in October 2002 and March 2003 to identify overwintering locations when Arctic grayling are more stationary (Lubinski 1995). Two tracking flights occurred during the spawning period in mid-May and early June 2003 to account for variation in the timing of spawning.

The number of radio tags available for implantation (n=35) was fixed by budgetary constraints. This sample size was estimated to be sufficient to meet project Objectives 1 and 2 using methods in Cochran (1977) and assuming a 4-month survival rate of 75% (Ridder 1998b) and a tag failure rate of 4.5% (Fleming 2004; Ridder 1998b) from the time of implantation to the end of the sport fishery period in mid September. Thirty-five tags were also estimated to be sufficient to meet precision criteria of Objective 3 using methods in Fleiss (1981) and Zar (1984).

ARCTIC GRAYLING CAPTURE AND RADIO TAG IMPLANTATION

From May 31 to June 6, 2002, a three-person crew used hook-and-line gear and fyke nets, to capture Arctic grayling for radio-tag implantation. In addition, a two-person crew used hook-and-line gear to capture Arctic grayling on June 11, 2002. Angling gear consisted of light spinning tackle and smaller lures including spinners or small lead-headed jigs. The fyke traps had 3 mm mesh, and a 12 m lead extending to near mid channel. All Arctic grayling were sampled in Brushkana Creek between its confluence with the Nenana River and a location approximately 1 km downstream of Monahan Creek.

Arctic grayling selected to receive a radio tag were anesthetized with a clove oil/water solution at a concentration of 25 mg L^{-1} based on the procedures outlined by Anderson et al. (1997). When an Arctic grayling had succumbed to the anesthesia (rolling over and lack of response to handling), it was weighed to the nearest gram, measured to the nearest mm FL, and its gender was determined (after surgery had commenced). Each fish was then placed in a padded cradle upside down and their gills were bathed in the clove oil/water solution to maintain their anesthetized state. A 15-mm incision was made 50 mm anterior to the pelvic girdle, along the left ventral side, about 10 mm from the center line. A grooved director was placed into the coelomic cavity, pointing towards the rear where it directed a needle (16G horse catheter) inserted from posterior of the pelvic girdle towards the incision in the anterior (Brown et al. 2002). The transmitter antenna wire was routed from the incision past the pelvic girdle by threading the wire through the needle. Upon exit, the needle and grooved director were removed and the radio tag fully inserted into the coelomic cavity and treated with topical antibiotic. The incision was sutured with 3 – 4 simple, interrupted stitches of monofilament suture material (Wagner et al. 2000), and treated with an adhesive (Vet Bond™) before placing the fish in a recovery tank. After the fish was upright and reactive, it was released.

Implanted transmitters had a 12-month operational life and all tag frequencies were separated by at least 10 kHz within the 148 MHz bandwidth. Because previous telemetry studies have had problems with frequency drift, which led to aerial tracking difficulties and additional expense (Ridder 1998a, 1998b; Fish 1998; J. Meka, United States Geological Survey, Biological Resources Division, Anchorage; personal communication), a crystal specification of ± 1 kHz was purchased to control frequency drift. The transmitters selected for this project were Lotek™ model MBFT-4 with dual-level programming. These had a guaranteed operational life of 335 days when operated 8 hours per day, 7 days per week while cycling through a 23 week active period and a 17 week inactive period (i.e., late October to early March). The inactive period corresponded to when Arctic grayling were typically stationary in overwinter locations (Lubinski 1995). Each transmitter had a unique frequency and a burst rate of 45 beats per minute, which allowed a complete scan of all 35 radio tags within 105 seconds. Scan time decreased as each tag was located and deleted from the search. Transmitters weighed 7.7 g in air, and 3.7 g in water, and the air-weight was expected to be ≤ 3% of the live weight of an Arctic grayling, which was slightly larger than a recommended 2% maximum (Winter 1983), but well below 6 – 12% found acceptable by Brown et al. (1999). Transmitters of this size (11 mm wide and 43 mm long) and weight had been used to track movements of Arctic grayling as small as 330 mm FL in the Delta Clearwater and Chena rivers (Ridder 1998a, 1998b).

EVALUATION OF FYKE TRAPS

Because fyke traps were one of the gear types used to capture Arctic grayling for radio transmitter implantation, the effectiveness of fyke nets as the primary gear in a possible follow-up mark-recapture experiment was evaluated. It was thought that fyke traps might be used to intercept migrating Arctic grayling near the mouth of Brushkana Creek for marking (1^{st} event) and also at an upstream location below the confluence of Monahan and Brushkana creeks (2^{nd} event). If water conditions permitted, up to four fyke traps would be fished, two on each bank, to capture a representative sample of Arctic grayling from a potentially intense, yet brief, upstream spawning migration. The evaluation of the fyke traps proceeded secondarily to the capture of Arctic grayling for the primary radiotelemetry objectives.

DATA COLLECTION

All captured Arctic grayling ≥150 mm FL were measured for fork length to the nearest millimeter, marked with individually numbered internal-anchor tags (gray in color; and numbered between 1,001 and 1,152) and given a partial lower caudal fin clip. For fyke nets, the sampling crew collected data on daily catches, the frequency of trap failures, and the tending time needed to operate the traps. Arctic grayling implanted with radio transmitters were weighed to the nearest gram using a self-taring digital balance, identified by gender and spawning condition (green, ripe, or spent), and tagged with an individually numbered Floy anchor tag. Radio-tagged Arctic grayling were not given a lower caudal clip.

During tracking surveys, a GPS unit was used to identify coordinates of located Arctic grayling and these were stored as waypoints into the GPS unit. Following surveys, dates and location coordinates were entered into a Microsoft Excel spreadsheet and plotted on maps using GIS software.

DATA ANALYSIS

To facilitate data analysis, all radio-tagged Arctic grayling were assigned a "fate" during each tracking survey. Fates were assigned based on observations from aerial tracking surveys, foot-surveys of radio tags with uncertain fates within the sport fishery area, and harvested Arctic grayling for which tags were returned. Fates were defined as follows:

1. Tagging Mortality (TM) - An Arctic grayling that died in response to tag implantation (either within the sport fishery area or outside the sport fishery area) between tagging and the first aerial survey. This was inferred by lack of movement from original tagging location during subsequent aerial surveys. Arctic grayling with this fate were not used for calculating proportions;
2. Post Tagging Mortality In (PTMI) – An Arctic grayling located within the sport fishery area that was known to be alive during at least one prior survey, but was judged to be dead at the time of the survey being conducted. Such tags could be located in a stream or out of the water away from the stream not near a human abode (e.g., drug out of the water by a bear or eagle). Arctic grayling with this fate were not used for calculating proportions for tracking surveys that followed the assignment of this fate;
3. Post-Tagging Mortality Out (PTMO) – An Arctic grayling located outside the sport fishery area that was known to be alive during at least one prior survey, but was judged to be dead at the time of the survey being conducted. Arctic grayling with this fate were not used for calculating proportions for tracking surveys subsequent to the survey it was known to be dead;
4. Fishery Mortality In (FMI) – An Arctic grayling that was reported harvested within the sport fishery area. Arctic grayling with this fate were not used for calculating proportions for tracking surveys subsequent to the survey it was known to be dead;
5. Fishery Mortality Out (FMO) – An Arctic grayling that was reported harvested outside the sport fishery area. Arctic grayling with this fate were not used for calculating proportions for tracking surveys subsequent to the survey it was known to be dead;

6. Unreported Harvest (UH) – An Arctic grayling that was not reported as harvested but was assumed so because the radio tag was judged to be out of the water, away from any river, and was located in or near a human abode. Radio tags out of the water have a pronounced increase in signal strength. The location where the Arctic grayling was harvested was unknown. Arctic grayling with this fate were not used to calculate proportions in, and subsequent to, the survey it was known to be dead;
7. In the sport fishery area (IN) – An Arctic grayling known to be alive at the time of a survey that was located within the sport fishery area;
8. Outside the sport fishery area (OUT) – An Arctic grayling known to be alive at the time of a survey that was located outside the sport fishery area;
9. Unknown (U) – An Arctic grayling that was never located after tagging because of tag failure or because it migrated outside the search area of the survey. In addition, those Arctic grayling with fates not determinable with a reasonable degree of reliability were designated "unknown" and accompanied by a rationale for the determination in the fate table. Arctic grayling with this fate were not used to calculate proportions; and,
10. At large (AL) – An Arctic grayling that was not located during an aerial survey but was located again during one or more subsequent surveys. Arctic grayling with this fate were assigned a fate OUT for all previous surveys that they were not located. OUT was assigned rather than IN because aerial surveys were flown in such a way to insure that radio-tagged fish in the sport fishery area were detected with >95% confidence; whereas, areas outside the study area were not flown as comprehensively. Therefore, it was very unlikely that a radio-tagged fish that was not located during an aerial survey was in the sport fishery area. Although unlikely, it is possible that an AL could be changed to IN; however, such an assignment would require a high standard of evidence. The AL fate was a temporary assignment until completion of all surveys, at which time, the fate was assigned as OUT or U.

The PTMI and PTMO fates were assigned to an Arctic grayling when no significant movement was observed over two or more tracking surveys when substantial movement was expected. Substantial movements of Arctic grayling (e.g., $\geq$ 5 km) generally occur between periods of spring spawning, summer feeding, and overwintering. For example, the overwintering flights (mid October and mid March) were used for determining if an Arctic grayling died during the summer by failing to move downstream when all other Arctic grayling did move to downriver overwintering areas. Similarly, failing to migrate upstream in the spring to a spawning tributary indicated an Arctic grayling died during the overwintering period. The amount of movement for determining the exact month an Arctic grayling died during the summer feeding period (i.e., during July to September) was assumed to be smaller (i.e., $\geq$ 1.0 km) because Arctic grayling are often more stationary during this period. Previous studies indicate locations of radio tags are generally accurate to within a 1.3 km radius (Ridder 1998b).

ESTIMATES OF PROPORTIONS (OBJECTIVES 1 & 2)

The proportion of radio-tagged Arctic grayling found within the sport fishery during each tracking event was considered an estimate of the proportion of the large (≥ 330 mm) adult Arctic grayling population that utilized the Brushkana Creek drainage for spawning and were in the sport fishery at the time of the survey. To facilitate calculating proportions, a fate history was prepared for each radio-tagged Arctic grayling. Fate assignments were then tallied by survey.

The proportion and variance estimators were:

$$\hat{p}_{SF,i} = \frac{x_i}{n_i} \tag{1}$$

$$\hat{V}\left[\hat{p}_{SF,i}\right] = \left[\frac{\hat{p}_{SF,i}(1-\hat{p}_{SF,i})}{n_i - 1}\right] \tag{2}$$

where:

$\hat{p}_{SF,i}$ = the proportion of Arctic grayling that were located in the sport fishery area during each aerial survey, *i*;

x_i = all Arctic grayling with fates IN, PTMI, and FMI; and,

n_i = Includes x_i, and all Arctic grayling with fates OUT, PTMO, and FMO.

The proportion of Arctic grayling that were located in the sport fishery area between the end of the tagging event and the August survey were estimated by:

$$\hat{p}_{SF} = \frac{x_{SF}}{n} \tag{3}$$

$$\hat{V}\left[\hat{p}_{SF}\right] = \left[\frac{\hat{p}_{SF}(1-\hat{p}_{SF})}{n - 1}\right] \tag{4}$$

where:

$\hat{p}_{SF}$ = the proportion of Arctic grayling that were located in the sport fishery area at least one time between the end of the tagging event and the August survey;

x_{SF} = all Arctic grayling assigned an IN, PTMI, or FMI fate at least once between the end of the tagging event and August; and,

n = includes x_{SF}, and all Arctic grayling assigned an OUT, PTMO, or FMO fate (includes all Arctic grayling except those with TM, UH, and U fates).

Exact confidence intervals (Fleiss 1981) were calculated for proportion estimates.

Objective 3

The null hypothesis tested was: H_o: $p_{SF} \geq 0.50$ vs. the alternative hypothesis: H_a: $p_{SF} < 0.50$ where p_{SF} was the proportion of large Arctic grayling ≥ 330 mm FL in the sport fishery area during at least one of the tracking events conducted between mid-June and August. Exact binomial procedures were used to perform the test (Fleiss 1981).

RESULTS

Few Arctic grayling ≥ 330 mm FL were captured during the first few days of sampling. Therefore, it was decided that the minimum length for radio-tagging be lowered to 315 mm FL. This decision likely did not compromise the study objectives because the body weight to transmitter weight ratio was still within the acceptable range, fish of this size are equally as likely to be sexually mature or harvested as fish 330 mm FL, and lowering the minimum size ensured all available radio tags would be deployed. Thirty-five radio tags were surgically implanted in Arctic grayling between May 31 and June 11, 2002 (Table 2). Radio-tagged Arctic grayling ranged in size from 315 to 378 mm FL, and ranged in weight from 325 to 572 g. The air weight of transmitters relative to fish weight ranged from 1.3 to 2.4%. Among the Arctic grayling implanted with radio tags, 29 were males, 5 were females, and one was of undetermined gender. The females encountered during sampling were either spent or ripe which indicated that sampling occurred near the end of the spawning period. In addition, afternoon water temperatures ranged between 6.0ºC and 12.0ºC, which indicated spawning had initiated prior to sampling, as spawning typically begins when water temperatures warm to 4.0 to 5.0ºC (Fleming and Reynolds 1991; Tack 1972).

Initially, seven Arctic grayling failed to move from their original capture location. These fish either did not survive the surgery or quickly expelled their radio tag after surgery, and in either case, were labeled as tagging mortalities (fate TM). There were then 28 live, radio-tagged Arctic grayling by the first tracking flight of June 11, 2002 (Table 3). Mortality occurred between each tracking event, but it was most pronounced after surgery (7 fish), between August and October (6 fish), and between March and May (5 fish). Contingency table analysis showed that the proportion of tagging mortalities for Arctic grayling < 330 mm FL (25%) was not significantly different than that for Arctic grayling > 330 mm FL (19%; $\chi^2 = 0.16$, df = 1, p-value = 0.69). In addition, Kolmogorov-Smirnoff tests indicated that the length composition of tagging mortalities was not significantly different than that of those radio-tagged (p-value = 0.44).

The greatest number of live radio-tagged Arctic grayling observed in the sport fishery area was 10 fish during the first tracking flight (Table 3). Thereafter, the number of radio-tagged Arctic grayling observed residing in the sport fishery area declined each tracking event to zero during October and March. During the May and June 2003 tracking events, three Arctic grayling returned to or passed through the sport fishery area.

Table 2.–Date of capture, biological statistics, and final fate assignments for each radio-tagged Arctic grayling.

Date of Capture	Fish	Length (mm FL)	Weight (g)	Sex	Tag Weight:Body Weight Ratio	Final Fate	Date of Fate Assignment
5/31/2002	1	349	430	Male	0.018	U	May 2003
5/31/2002	2	349	440	Male	0.018	FMO	June 2002
6/01/2002	3	329	395	Male	0.019	PTMO	May 2003
6/01/2002	4	360	490	Male	0.016	PTMO	August 2002
6/02/2002	5	378	553	Male	0.014	PTMO	August 2002
6/02/2002	6	360	506	Female	0.015	TM	June 2002
6/02/2002	7	329	387	Female	0.020	OUT	June 2003
6/02/2002	8	337	435	Male	0.018	TM	June 2002
6/03/2002	9	376	505	Male	0.015	PTMO	May 2003
6/03/2002	10	325	387	Male	0.020	PTMO	May 2003
6/03/2002	11	350	430	Male	0.018	OUT	June 2003
6/03/2002	12	374	532	Male	0.014	PTMO	July 2002
6/04/2002	13	363	508	Male	0.015	PTMO	May 2003
6/04/2002	14	321	325	Male	0.024	PTMO	October 2002
6/04/2002	15	369	545	Male	0.014	U	July 2002
6/04/2002	16	375	572	Male	0.013	PTMO	March 2003
6/04/2002	17	364	483	Male	0.016	PTMO	October 2002
6/04/2002	18	355	445	Male	0.017	PTMO	October 2002
6/04/2002	19	350	433	Male	0.018	OUT	June 2003
6/04/2002	20	338	419	Male	0.018	PTMO	October 2002
6/05/2002	21	337	415	Male	0.019	PTMO	August 2002
6/05/2002	22	315	330	Unknown	0.023	IN	June 2003
6/05/2002	23	348	420	Female	0.018	PTMO	October 2002
6/05/2002	24	370	540	Male	0.014	TM	June 2002
6/05/2002	25	322	355	Male	0.022	TM	June 2002
6/05/2002	26	339	395	Male	0.019	TM	June 2002
6/05/2002	27	340	401	Female	0.019	PTMO	May 2003
6/05/2002	28	353	439	Male	0.018	OUT	June 2003
6/05/2002	29	333	373	Male	0.021	TM	June 2002
6/05/2002	30	372	567	Female	0.014	OUT	June 2003
6/06/2002	31	348	427	Male	0.018	IN	June 2003
6/06/2002	32	319	350	Male	0.022	TM	June 2002
6/06/2002	33	360	416	Male	0.019	PTMO	October 2002
6/11/2002	34	328	358	Male	0.022	OUT	June 2003
6/11/2002	35	349	413	Male	0.019	PTMO	June 2003

Table 3.–Assigned fates of radio-tagged Arctic grayling during each of eight aerial tracking flights.

Tracking			Fate			
Flight	Date	IN	OUT	U	Dead[a]	Mortality Rate
Tagged	May 31 – June 11, 2002	35				
1	June 11, 2002	10	18		7	20%
2	June 24, 2002	6	21		8	23%
3	July 12, 2002	3	22	1	9	26%
4	August 17, 2002	2	20	1	12	34%
5	October 15, 2002	0	16	1	18	51%
6	March 19, 2003	0	15	1	19	54%
7	May 17, 2003	1	8	2	24	69%
8	June 6, 2003	2	6	2	25	71%

[a] Includes PTMO, FMI, FMO, and UH fates.

After tagging in late May and early June, Arctic grayling tended to disperse away from the area of the fishery. During July, 22 radio-tagged Arctic grayling were located outside the area of the (Tables 3 and 4). Three of those were in the upper Brushkana drainage, and the others ranged within a large area of the Nenana River drainage between Brushkana Creek and Clear Creek. Between June and August, Arctic grayling were observed in Stickwan, Seattle, Wells, Brushkana, Schist, Windy, and Clear creeks and in the Jack River (Figures 3-7). Between August and October, most surviving Arctic grayling migrated to the Nenana River to overwinter, the exceptions being two Arctic grayling in the upper Brushkana Creek, one in Stickwan Creek, and one in the Jack River (Figure 8). Mostly minor movements occurred between October and March (Figures 8-9), but between March and May, most surviving Arctic grayling migrated significant distances again (Figure 10). River break-up occurred between May 17 and June 11, 2003, and it is likely spawning occurred or began during that period. At the time of the June 2003 flight, three Arctic grayling (33% of tags with known fates) had returned to the Brushkana system, three Arctic grayling had returned to their Nenana River tributary summer feeding locations, two Arctic grayling were in the Nenana River, one had remained in the upper Brushkana drainage, and two Arctic grayling were not found (Figure 11). It is unknown if the two Arctic grayling in the Nenana River had been to or were transiting to the Brushkana drainage for a short duration to spawn, but it was noted that they had been the last two fish tagged on June 11, 2002. The three Arctic grayling (# 320, 800, 920) that had returned to their summer feeding locations likely spawned somewhere near those locations, if they spawned at all, but spawning locations were difficult to infer because there were 20 days between the last two tracking flights.

Table 4.–Number of radio-tagged Arctic grayling assigned to each fate and proportions of Arctic grayling remaining in the sport fishery for each tracking event.

Radio Tag	Flight Date							
Frequency	6/11/2002	6/24/2002	7/12/2002	8/17/2002	10/15/2002	3/19/2003	5/17/2003	6/6/2003
IN	10	6	3	2			1	2
OUT	18	21	22	20	16	15	8	6
TM	7							
PTMO			1	3	6	1	5	1
FMO		1						
U			1				1	
Total	35	28	27	25	22	16	15	9
n_i	28	28	26	25	22	16	14	9
x_i	10	6	3	2	0	0	1	2
$P_{SF,i}$	0.36	0.21	0.12	0.08	0.00	0.00	0.07	0.22
$V[P_{SF,i}]$	0.009	0.006	0.004	0.003	0.000	0.000	0.005	0.022
UCL[a]	0.53	0.38	0.27	0.23	0.10	0.13	0.30	0.55
LCL[a]	0.21	0.10	0.03	0.01	NA	NA	0.00	0.04

[a] Upper and lower 90% confidence limits determined using exact methods.

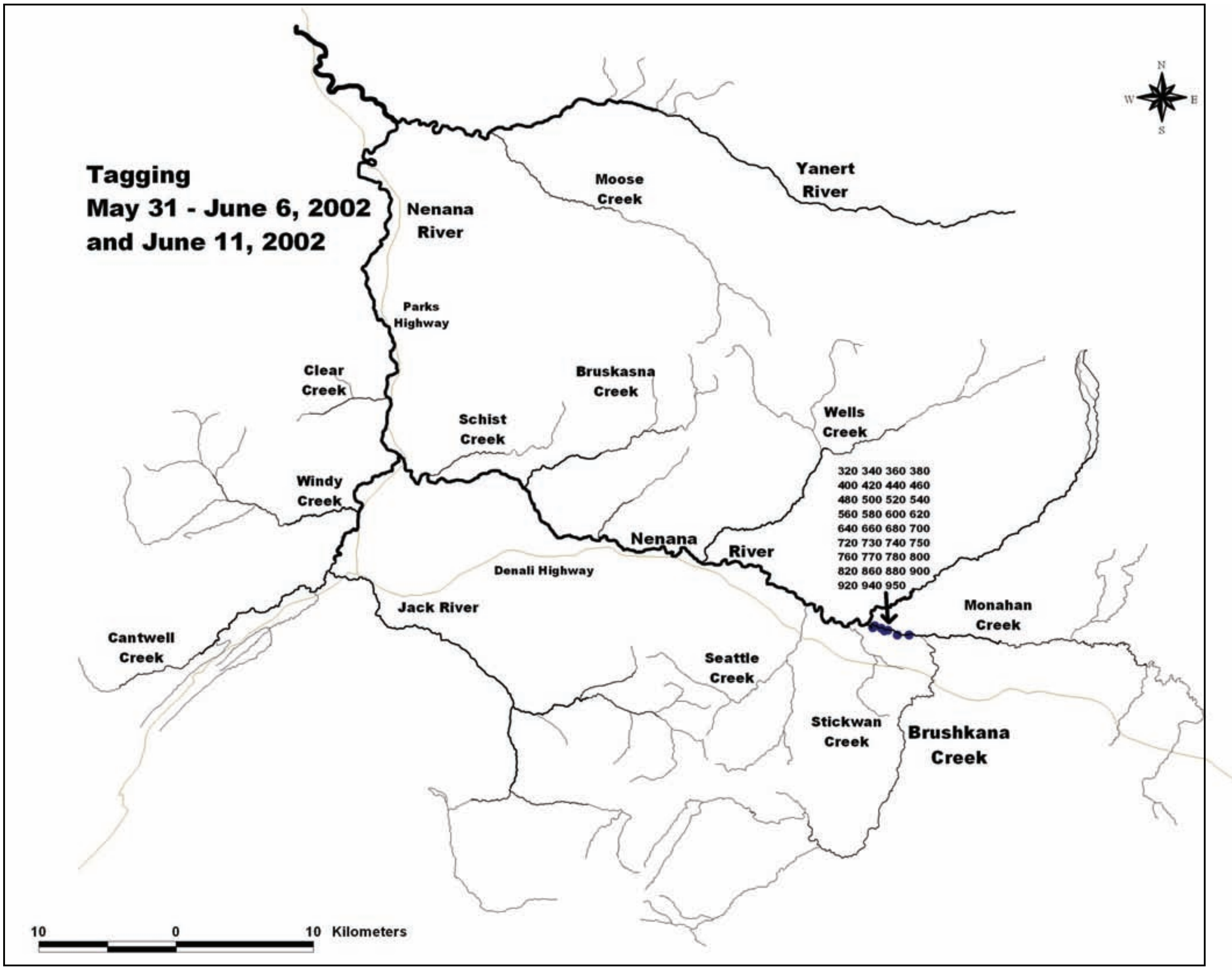

Figure 3.–Tagging locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), May 31 – June 6 and June 11, 2002.

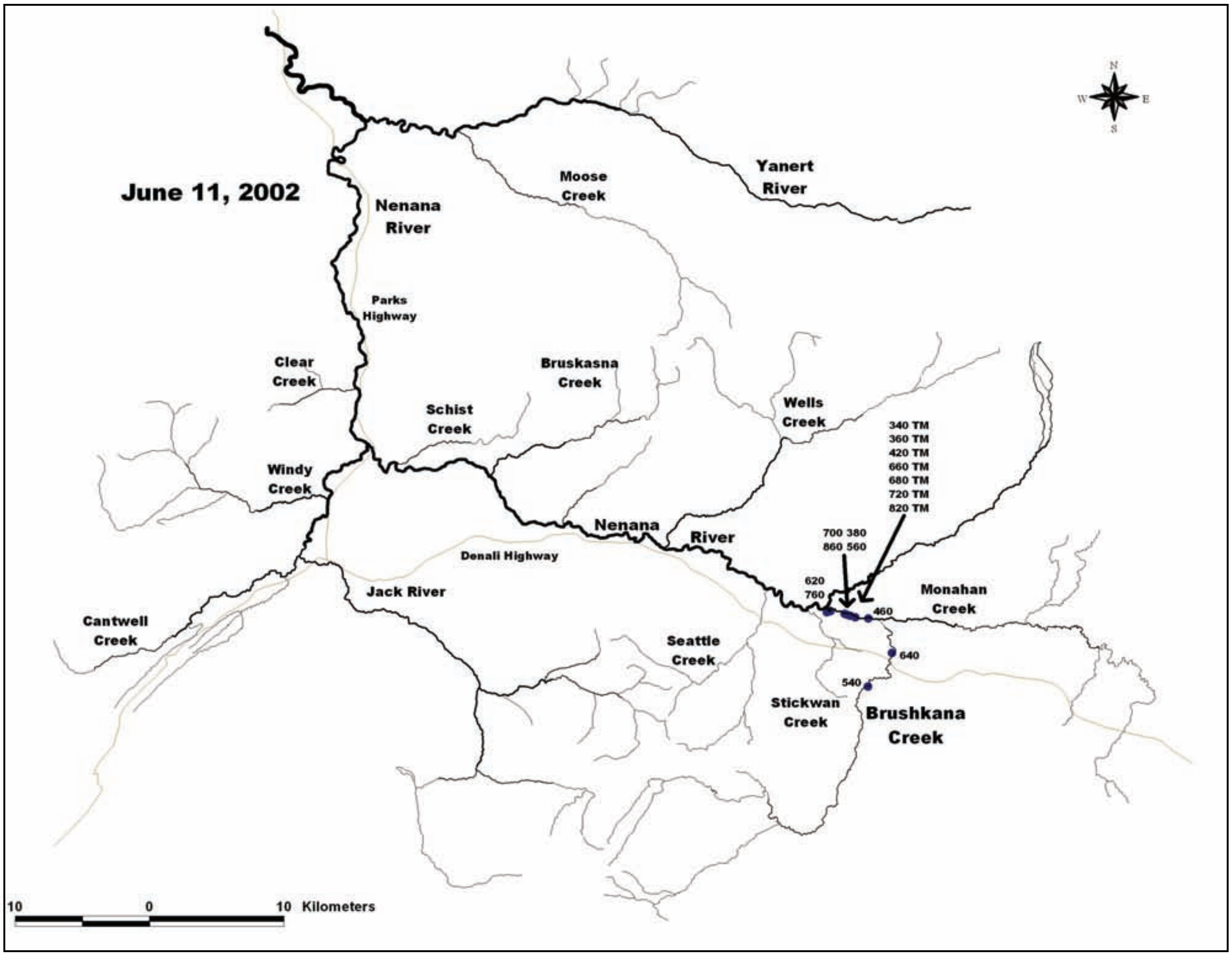

Figure 4.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), June 11, 2002. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

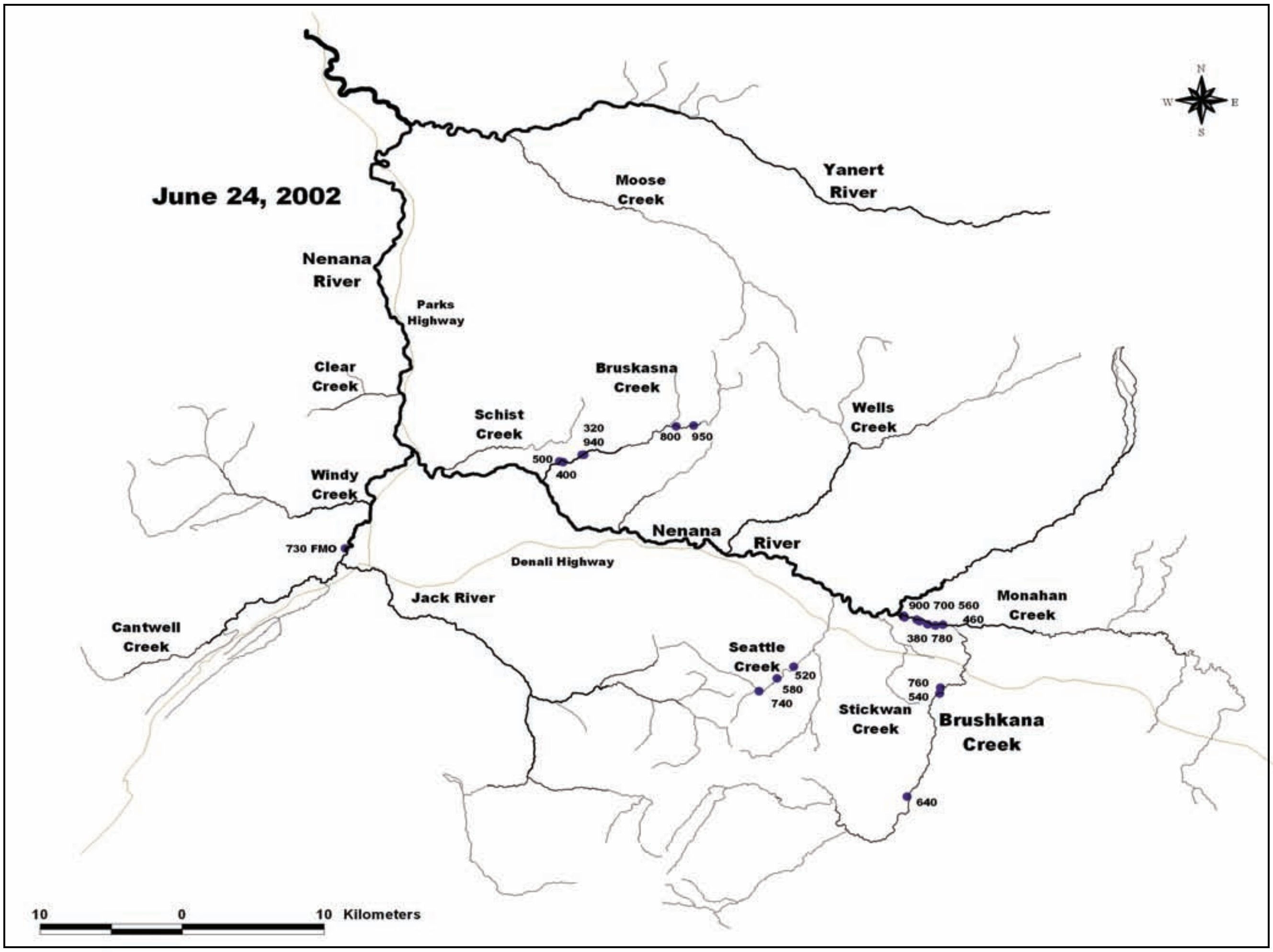

Figure 5.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), June 24, 2002. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

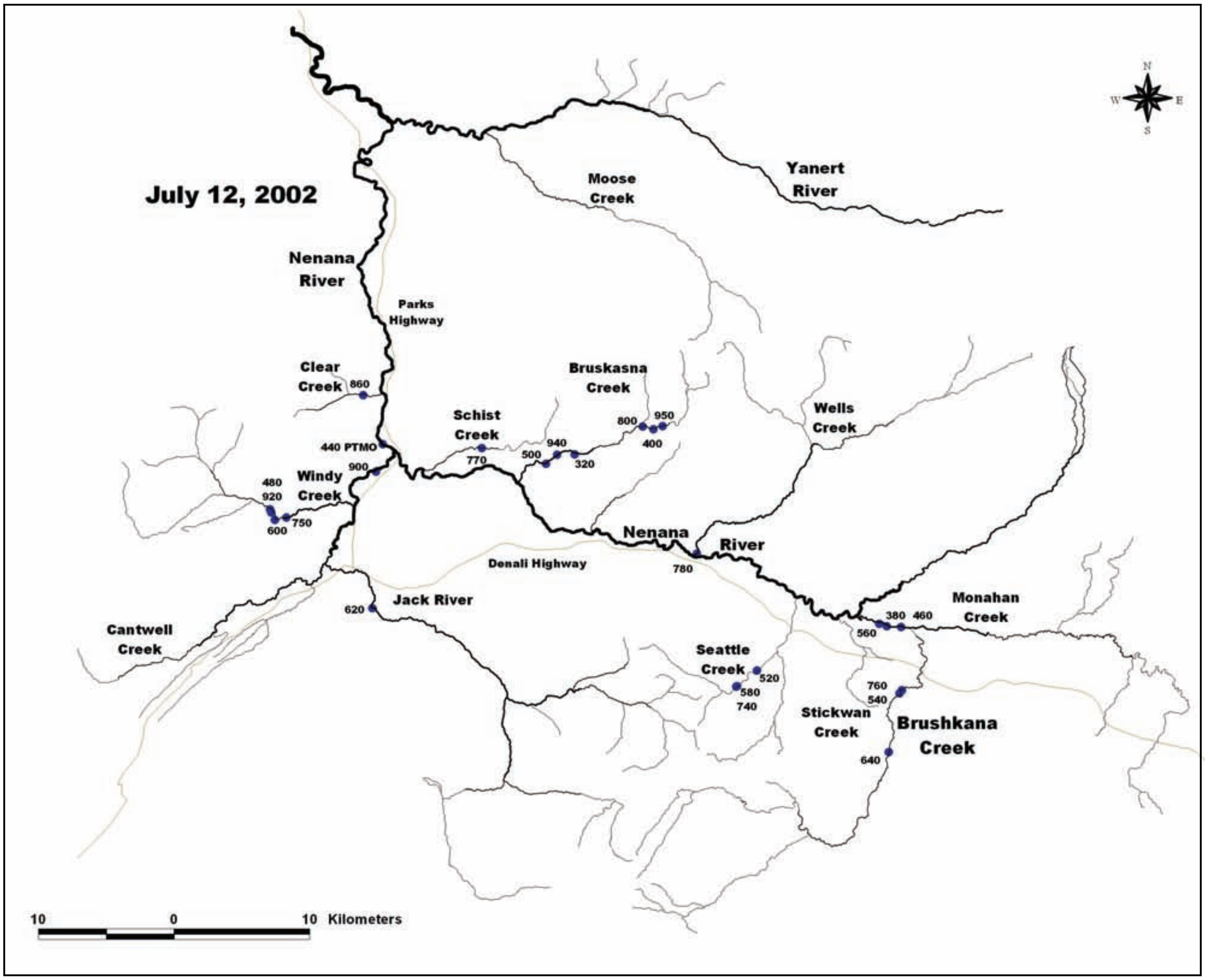

Figure 6.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), July 12, 2002. All fish shown were judged to be alive at the time of the survey.

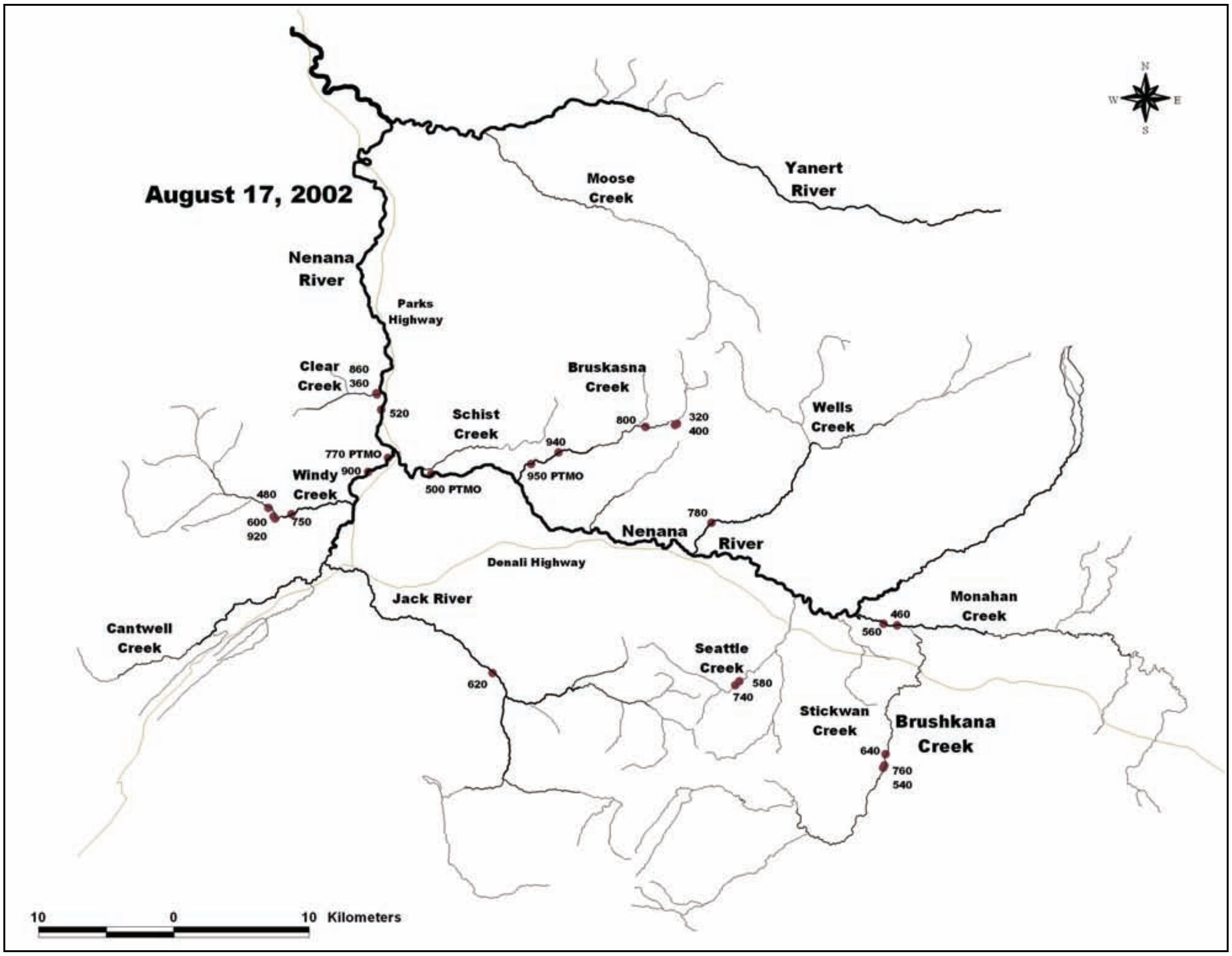

Figure 7.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), August 17, 2002. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

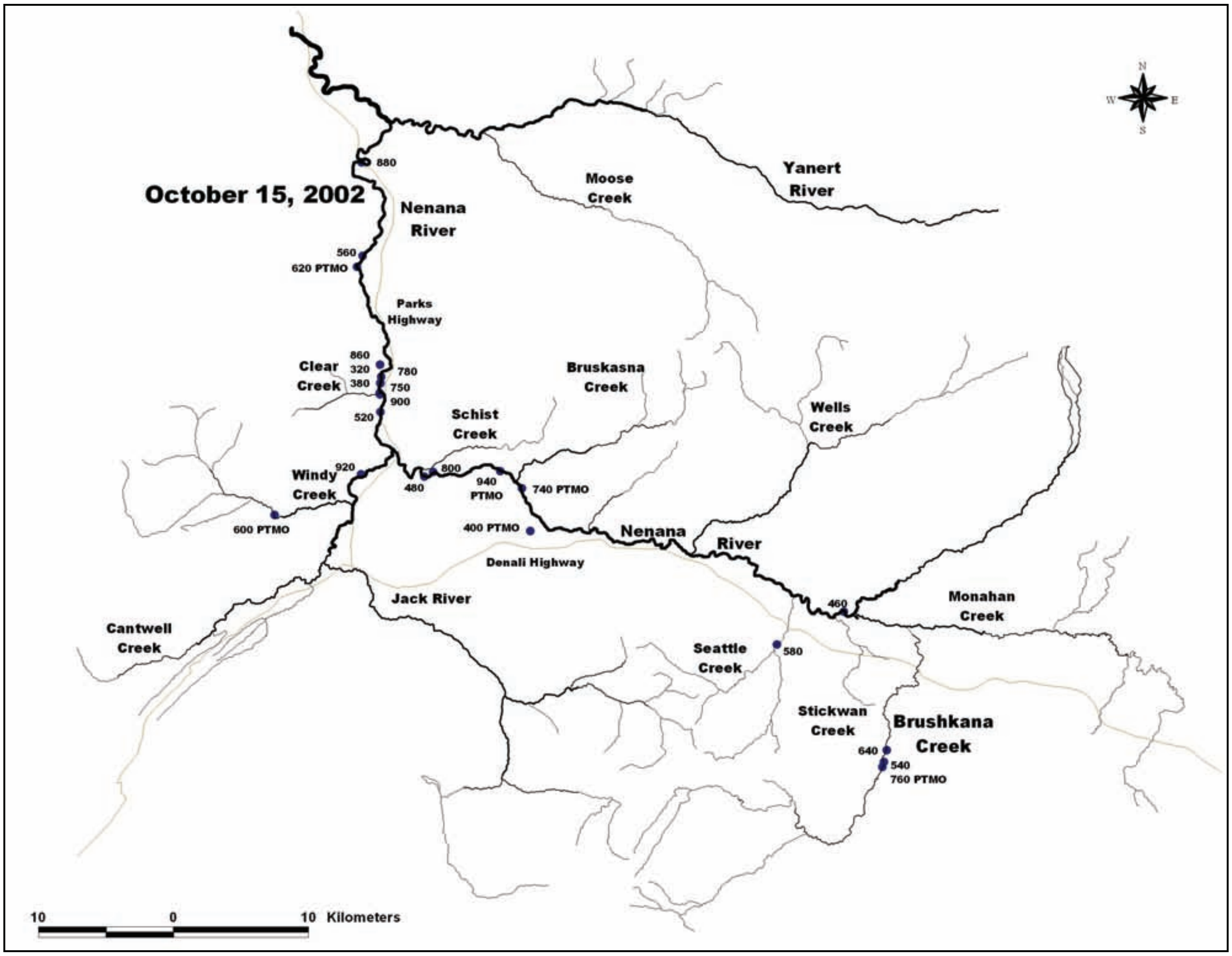

Figure 8.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), October 15, 2002. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

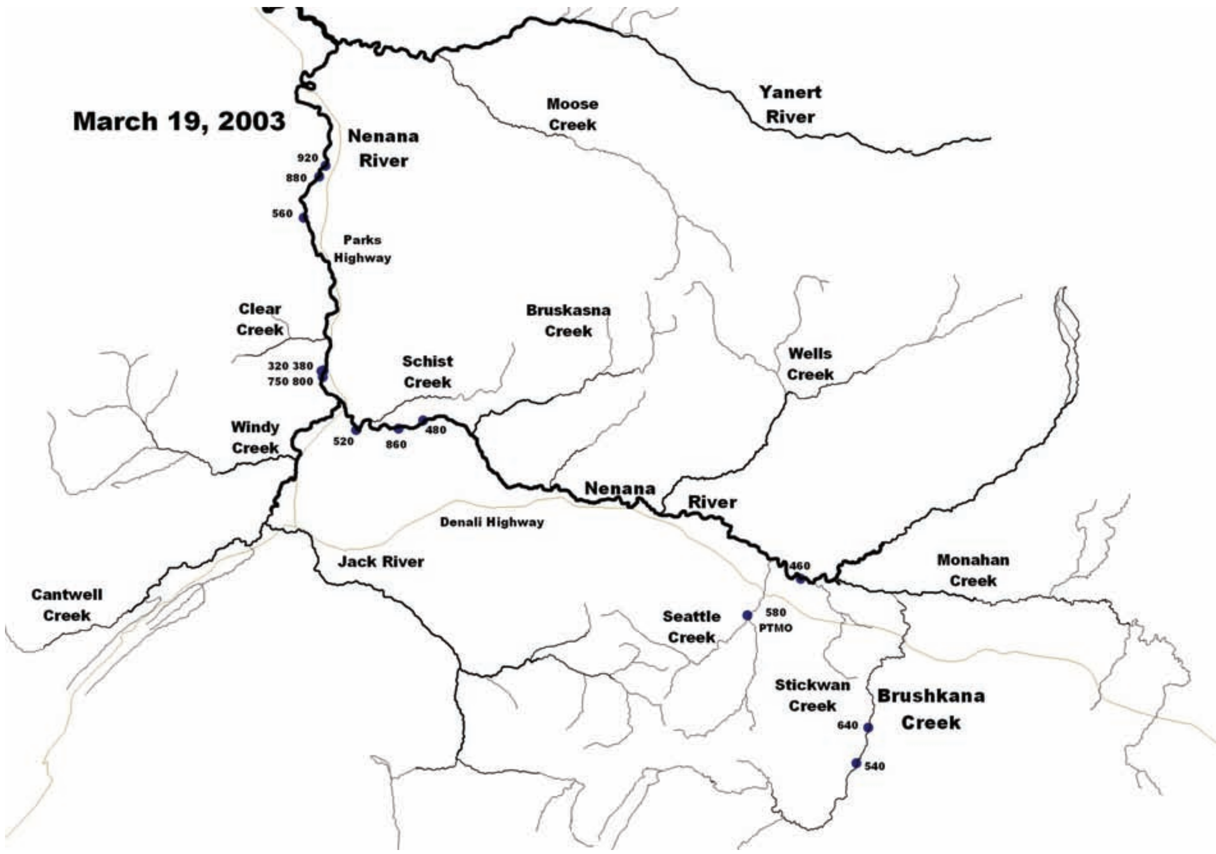

Figure 9.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), March 19, 2003. All fish shown were judged to be alive at the time of the survey.

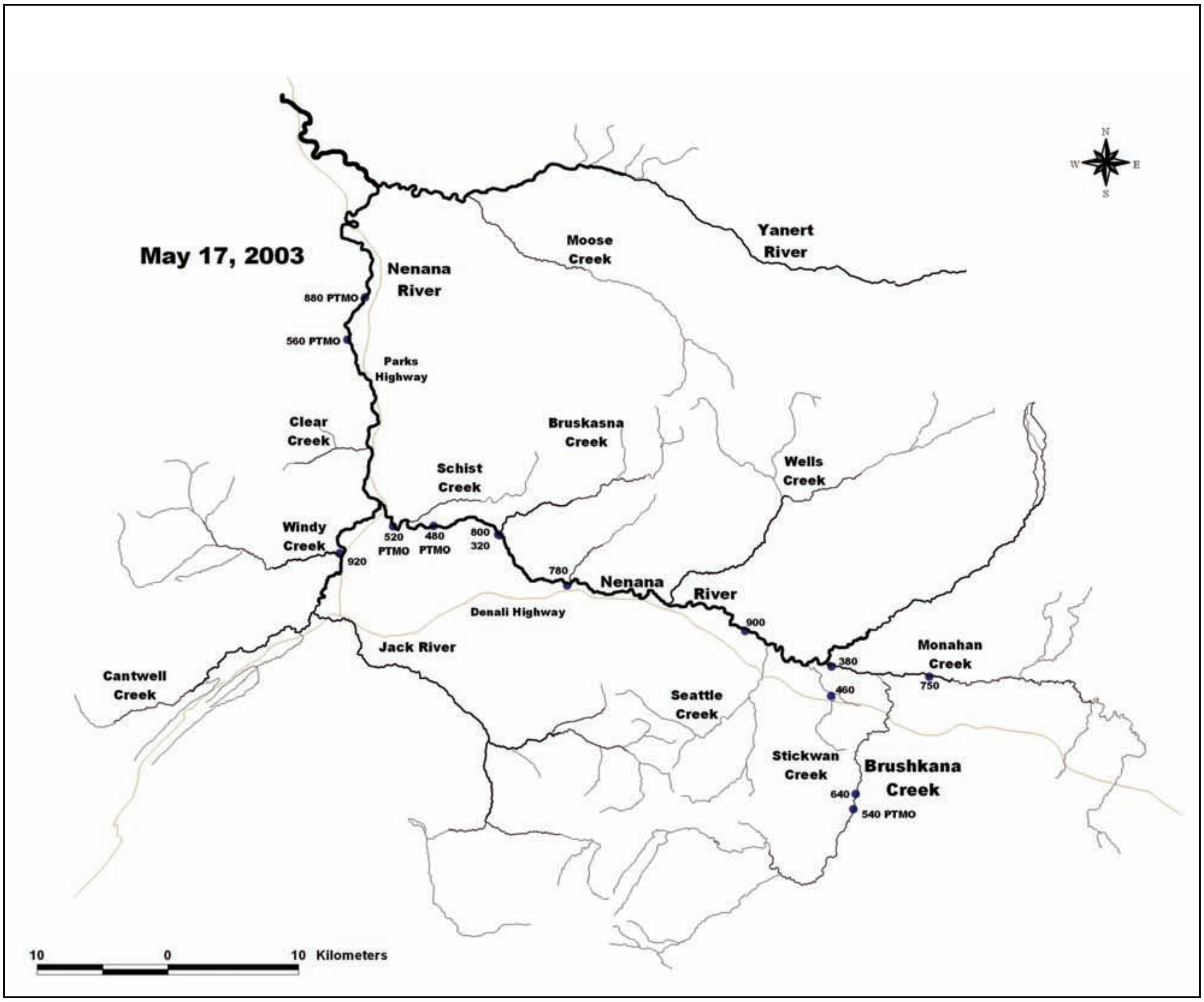

Figure 10.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), May 17, 2003. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

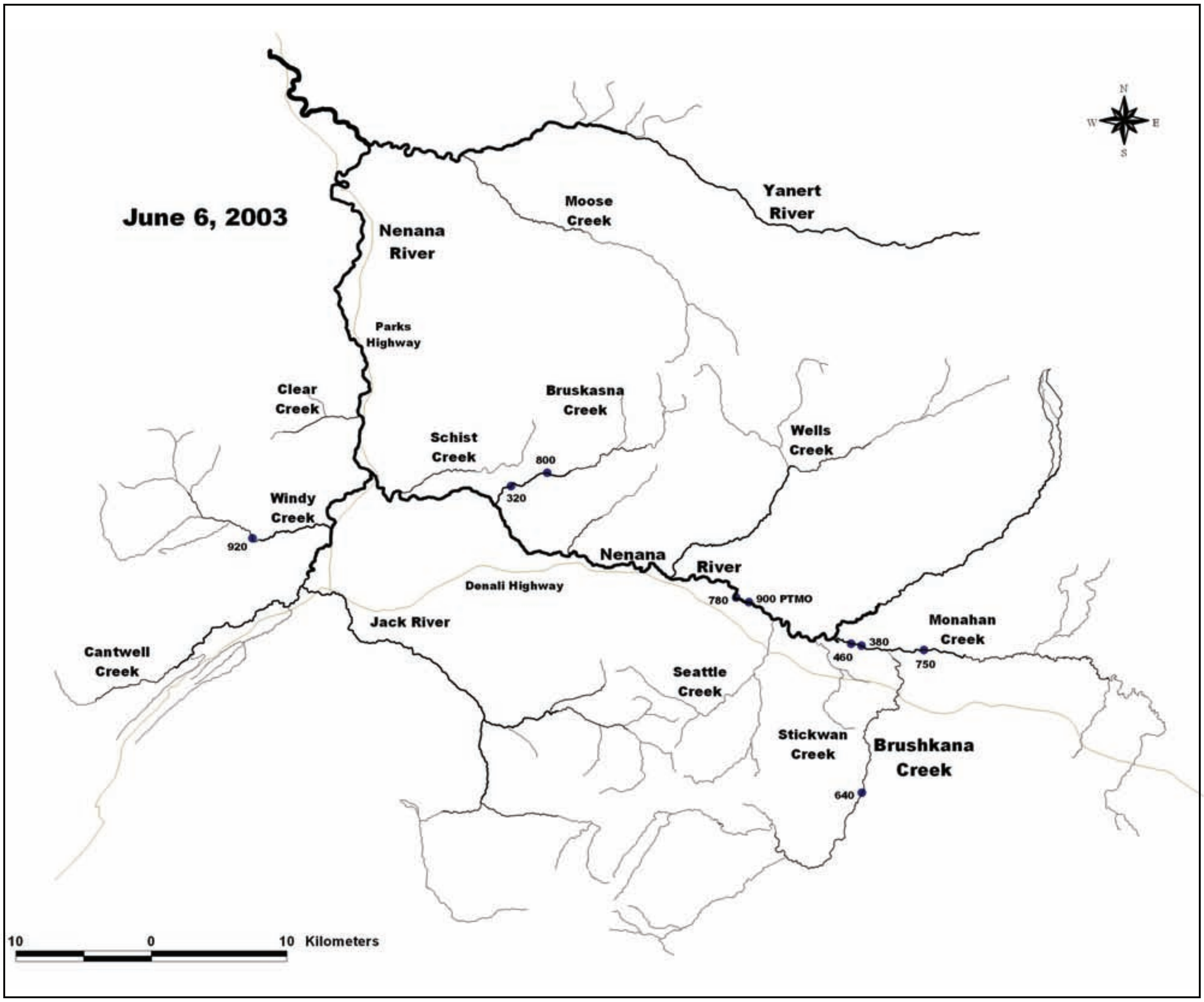

Figure 11.–Locations of individual radio-tagged fish (shown as black dots with a three-digit frequency identifier), June 6, 2003. All fish shown were judged to be alive at the time of the survey.

Relative to Objective 1, the proportion of radio-tagged Arctic grayling present in the sport fishery during each of three tracking flights (June 24, July 12, and August 17) between 0.21 (SE = 0.079) and 0.08 (SE = 0.055; Table 4). Relative to Objective 2, none of the radio-tagged Arctic grayling, which had left the sport fishery returned to the sport fishery during any of the three summer flights. Therefore, the estimated proportion from the late June flight (0.21; SE = 0.079; Table 4) pertained to this objective. Relative to objective 3, the null hypothesis that the proportion of large Arctic grayling remaining in the sport fishery area during at least one tracking event conducted between mid-June and mid-September was equal to or greater than 0.50 was rejected. Again, because all radio-tagged Arctic grayling that left the sport fishery area remained out until the following spring, the proportion in the sport fishery on June 24, 2002 pertained to this objective. The upper confidence limit of the exact confidence interval did not contain 0.50 (Table 4), and as a result, no mark-recapture stock assessment was indicated.

Relative to the project tasks, most (64%) Arctic grayling captured with hook-and-line gear were < 315 mm FL (Table 5), and most (79%) were < age-7 (Table 6). A fyke net was deployed along the south bank of Brushkana Creek 1.7 km upstream from its mouth in 0.5 m of water, and it was fished for three 24-hr periods from May 31 to June 3. The fyke trap was difficult to set-up and maintain in the flowing river, even though water conditions were relatively low and clear. Additionally, beavers damaged the net on two different nights rendering it ineffective. Forty juvenile Arctic grayling were caught over the course of three days, and all were less than 150 mm FL. The fyke trap evaluation was discontinued after several days of effort largely due to a lack of time available (relative to the study objectives) to effectively fish one or more traps.

Immediate mortality was noted for seven of the 35 radio-tagged Arctic grayling (20%). After tagging, most Arctic grayling dispersed widely and moved up many tributaries, which indicated they had recovered from surgery. Mortality was 34% between tagging and August 17, 2002, the period pertaining to the objectives. Mortality continued throughout the remainder of the study: six fish died prior to fall migration between August 17 and October 15, 2002, and an additional six fish died during winter prior to the initiation of the spawning migration (between March 19 and May 17, 2003). By the end of the study in June 2003, 25 Arctic grayling (71%) had been assigned a mortality fate (Tables 3-4).

Table 5.–Length composition of Arctic grayling captured in Brushkana Creek during 2002.

Length Class (mm FL)	n	p_k
200 – 224	3	0.02
225 – 249	10	0.06
250 – 274	32	0.20
275 – 299	28	0.17
300 – 324	38	0.23
325 – 349	27	0.17
350 – 374	21	0.13
375 – 399	3	0.02
Total	162	

Table 6.–Age composition of Arctic grayling captured in Brushkana Creek during 2002.

Age Class	n	p_k
3	2	0.02
4	13	0.11
5	41	0.36
6	34	0.30
7	16	0.14
8	5	0.04
9	2	0.02
10	1	0.01
Total	114	

DISCUSSION

This study suggested that most of the Arctic grayling that utilized the Brushkana drainage for spawning migrated out of the sport fishery area. Based on the criteria established for the study, a mark-recapture experiment to assess the rate of exploitation was not warranted. In addition, this study suggested that the upper Nenana drainage Arctic grayling be managed as a single stock. However, it is necessary to discuss limitations on these inferences that result from: 1) the behavior of radio-tagged Arctic grayling; 2) the accuracy of fate assignments; and, 3) the representativeness of the sample.

Implicit in the study design was that tagged Arctic grayling would behave as though they had not been tagged. Behavioral effects (i.e., change in migration timing, duration and destination of migrations) due to the stress of surgery or bearing a transmitter were difficult to identify. Acute effects, such as seven Arctic grayling dying or expelling their tags soon after surgery, were more easily identifiable. However, any chronic effects from surgery and implantation were thought to be minimal relative to the projects short-term objectives. Evidence supporting this conclusion was that 18 Arctic grayling had migrated out of the sport fishery area within 5 to 11 days, and nearly all surviving Arctic grayling completed long migrations and ascended steep, montane tributaries to access summer feeding areas within one month of surgery. During sampling for this project, two radio-tagged Arctic grayling were recaptured with hook-and-line gear, which indicated active foraging soon after surgery. Another radio-tagged Arctic grayling was recaptured by an angler in the Jack River on June 24, 2002 with an open incision (D. Snarski, Cantwell; personal communication). This fish had traveled a long distance in three weeks and was foraging despite a serious wound associated with the surgery. Additional evidence supporting Arctic grayling resiliency has been reported (Fish 1998; Ridder 1998a, 1998b; Gryska *In prep*). It is believed that if any short-term effects occurred, other than death, it would be a delay in the initiation of a migration due to recovery from surgery. Relative to the project objectives, Arctic grayling remaining in Brushkana Creek longer than usual, owing to delayed onset of emigration, would temporarily act to positively bias the proportion of tags remaining in the sport fishery. Long term, chronic post-surgery effects (e.g., higher summer and winter mortality or inability to spawn the following year) may have occurred, but such occurrences are merely speculative.

Correct fate assignments were important in calculating the proportion of Arctic grayling within the sport fishery and relating it to the objectives. However, for several Arctic grayling that failed to move substantial distances between surveys, judging whether the fish was alive or had died or expelled its tag, and if so, when, was not always obvious. Typically, if an Arctic grayling failed to move over several flights, particularly during migration periods, then it was assumed the fish had died or expelled its tag. Although this approach was simple, it was difficult to implement for Arctic grayling that never moved substantial distances. For example, after surgery 10 radio-tagged Arctic grayling moved very little (i.e., <1.0 km), if at all, during the summer. However, three proved to be alive based on fall, winter, and spring migrations. The other seven Arctic grayling never made these migrations, but it is possible they were alive through the summer and remained near their surgery location. The immediate area was sampled in August and captures of similar sized fish demonstrated that suitable summer feeding habitat existed there. Although plausible, this possibility was discounted because most other viable Arctic grayling, including those in other drainages, demonstrated some small-scale localized movements (i.e., $\geq$ 1.0 km) during the summer feeding period. If however, these fish were alive then the proportion in the sport fishery area during the summer would be greater. A more conservative assessment of Objectives would assume that these seven tagging mortalities survived through August, which would result in an increase in the estimated proportion of Arctic grayling remaining in the sport fishery during summer from the maximum value of 0.21 (Table 4) to a maximum of 0.37. The 90% C.I. for this scenario would be 0.24 – 0.52%, which could invoke further stock assessment and possibly a more restrictive management action. However, tagging mortalities have been documented in other studies (West et al. 1992; Fish 1998; Ridder 1998b; Blackman 2002), and it is highly likely that some of the seven Arctic grayling in this study were tagging mortalities. Even if only two were mortalities, then the upper 90% C.I. would be less than 50% and there would be no call for further action. Given the lack of movement of these seven fish following surgery, a tagging mortality fate is believed to be the fate most congruous with their movements.

To attain a representative sample of the mature population, this study was designed to sample Arctic grayling as they migrated upstream into or through the sport fishery area from the Nenana River. Given the condition of the Arctic grayling encountered and the warm water temperatures (6 – 12ºC), it was likely that a combination of late-spawning and post-spawn Arctic grayling were sampled that were either spawning in the lower Brushkana Creek (downstream of Monahan Creek) or migrating out from upstream spawning areas. Therefore, it is unlikely that the entire spawning population was vulnerable to sampling as Arctic grayling were probably distributed throughout upstream areas while sampling. Uncertainty about the representativeness of the sample lies in: 1) the proportion of the spawning population vulnerable (or not vulnerable) to sampling was unknown; and, 2) of the spawning population not vulnerable to sampling, it was unknown what proportion of them remained upstream of the sport fishery area, returned to the sport fishery area, or had already migrated back to the Nenana River. Uncertainty in these parameters was modeled (Table 7 and Appendices A2-A5) and when constrained by biologically reasonable assumptions, the model results were consistent with the conclusions and management determinations.

Based on this study, no additional stock assessment or management action is currently necessary because it is very unlikely that more than 50% of the spawning population in the Brushkana drainage remained in the sport fishery during the summer. It was unlikely that a large proportion of the spawning population that was not vulnerable to sampling later returned to reside in the sport fishery area during the summer. Because the sport fishery area is only 11 km of the more than 140 km (< 8%) of the Brushkana drainage (in addition, habitat is available in other Nenana tributaries), it is more reasonable to think Arctic grayling would disperse to occupy other suitable, summer-feeding habitat outside the fishery area. Therefore, the proportion of the spawning population that was not vulnerable to sampling which returned to the sport fishery area for summer-feeding was constrained to values no greater than 0.30 (i.e. a larger value was implausible). This constraint alone bounds the proportion of the spawning population that resides in the sport fishery area during any time of the summer period to 2 - 29% (Table 7).

Table 7.–Modeled proportions of the population of Arctic grayling "IN" the sport fishery area given that 21% of the radio-tagged fish were in the sport fishery area during the June 24, 2002 survey. The proportion of the population "IN" the sport fishery area was modeled as a function of: 1) the proportion of the spawning population that was vulnerable to sampling, and 2), the proportion of the spawning population not vulnerable to sampling that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled). The shaded proportions are those corresponding to reasonable, biological constraints.

	Of the spawning population not vulnerable to sampling, the proportion that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled)										
Proportion of the spawning population vulnerable to sampling	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
0.1	0.92	0.83	0.74	0.65	0.56	0.47	0.38	0.29	0.20	0.11	0.02
0.2	0.84	0.76	0.68	0.60	0.52	0.44	0.36	0.28	0.20	0.12	0.04
0.3	0.76	0.69	0.62	0.55	0.48	0.41	0.34	0.27	0.20	0.13	0.06
0.4	0.68	0.62	0.56	0.50	0.44	0.38	0.32	0.26	0.20	0.14	0.08
0.5	0.61	0.56	0.51	0.46	0.41	0.36	0.31	0.26	0.21	0.16	0.11
0.6	0.53	0.49	0.45	0.41	0.37	0.33	0.29	0.25	0.21	0.17	0.13
0.7	0.45	0.42	0.39	0.36	0.33	0.30	0.27	0.24	0.21	0.18	0.15
0.8	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.23	0.21	0.19	0.17
0.9	0.29	0.28	0.27	0.26	0.25	0.24	0.23	0.22	0.21	0.20	0.19
1	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21	0.21

Given this constraint, the model results are robust to variation in the proportion of the spawning population that was vulnerable to sampling. In fact, as the proportion vulnerable to sampling increases from 10 to 100% the modeled proportion "IN" approaches the radio tagging study estimate (0.21). The actual proportion vulnerable to sample is difficult to predict; however, a lower limit may be estimated by comparing the area sampled with the likely extent of spawning habitat. It is likely that at least 10% of the population was vulnerable to sampling because the Brushkana drainage has 140+ km of stream of which, we assumed at most, 50 km can be reasonably expected to have habitat suitable for spawning. The sampled area was 4.5 km in length accounting for about 10% of the drainage having potential spawning habitat and by inference about 10% of the spawning population. It was unlikely that more than 50% of the spawners were vulnerable to sampling because it is unlikely that only 10 km of the drainage bore some spawning habitat and because sampling started after upstream migrations had begun. It is expected that some of the Arctic grayling that migrated above the sport fishery area to spawn before sampling began, returned to, or migrated through, the sport fishery area during sampling.

The second implication of this study is that the upper Nenana River drainage may be managed as a single stock, because a large proportion of Brushkana drainage spawners redistributed throughout the upper Nenana drainage. It is unclear what is the actual proportion of spawning fish redistributing to the upper Nenana drainage, but given certain constraints, it is likely significant. A range of possible proportions can be deduced using a modeling approach similar to that presented above with an additional assumption regarding the proportion of the spawning population not vulnerable to sampling that returned to the Nenana River (Appendices A2–A5). If as little as 20% of the spawning population not vulnerable to sampling had returned to the Nenana drainage, then the true proportion of the Brushkana drainage spawning population that returned to the Nenana drainage ranged from 19 – 44% (Appendix A3). This range of proportions is considered significant. It is reasonable to assume that ≥ 19% of the Brushkana spawning population redistribute to the Nenana drainage for the summer because the Brushkana drainage appears (based on aerial surveys and topographic maps) to have the most extensive spawning and rearing habitat upstream of the Yanert River and likely draws mature Arctic grayling from all areas of the upper Nenana drainage for spawning.

Most streams in the upper Nenana drainage are cold, steep montane streams suitable for summer feeding areas, but these streams lack suitable spawning and rearing habitat. Within the Brushkana drainage, the Monahan Creek Flats has the largest (240 km^2) flats area of the Upper Nenana drainage. Within these flats, Monahan Creek has a large meandering complex of tributaries and ponds that likely have slower moving, warmer water than other Nenana tributaries. Areas with quickly warming waters may draw Arctic grayling for spawning and incubation of eggs (Tack 1980). Stream discharge has been negatively correlated with age-0 Arctic grayling growth (Deegan et al. 1999) and recruitment (Clark 1992), and temperature has been positively correlated with age-0 Arctic grayling growth (Deegan et al. 1999; Dion and Hughes 2004). Although conditions are likely favorable for young, small Arctic grayling, they may not be for larger Arctic grayling (Deegan et al. 1999). The Brushkana drainage may not have enough adult habitat relative to the spawner population or better summer feeding habitat is found elsewhere in the Nenana drainage which may stimulate their migrations.

The seasonal migration of Arctic grayling between habitat types, within and between streams, as observed in this study, is consistent with the generalized theory of Arctic grayling potamodromy in Alaska (Tack 1980; Northcote 1995, 1997). Arctic grayling life history has been described as a series of trophic migrations between habitats used for winter-refuge, spring-spawning, and summer-feeding with ontogenetic variations (Northcote 1997). Arctic grayling in the Tanana River basin have demonstrated dynamic life-history movement patterns, which can vary between and within river drainages (Tack 1980; Ridder 1991, 1994, 1998a–c; Gryska *In prep*). These migrations vary in duration, occur within a river and among rivers, and often involve homing to specific areas (Reed 1964; Tack 1980; Ridder 1991, 1998 b, c, 2000; Buzby and Deegan 2000; Gryska *In prep*). The Brushkana drainage has spring-spawning, summer-feeding, winter-refuge and nursery habitats utilized by all ontogenetic phases of Arctic grayling throughout the year, however relative to the upper Nenana drainage; it probably has the most extensive spawning and rearing habitat. As a result, the Brushkana drainage could be quite important to the upper Nenana drainage population of Arctic grayling, and exploitation of both the spawning and rearing Arctic grayling, or other perturbations, could have an impact upon the Nenana drainage Arctic grayling population.

Despite their limitations, the results of this study strongly suggest that no management action is currently needed because a significant proportion of the Brushkana drainage spawning population migrates to other upper Nenana drainage tributaries that are lightly exploited, if at all. The study also demonstrated the importance of the mainstem Nenana River as overwintering habitat and as a migration corridor for Arctic grayling in the upper Nenana drainage. Because of the interdependency of tributaries for Arctic grayling within the upper Nenana River drainage, these Arctic grayling should be considered a single stock for management purposes. Therefore, current regulations, which apply to the whole drainage, should remain unchanged. Statewide harvest survey estimates for the whole drainage would likely be more meaningful than those solely for the Brushkana. Although localized depletions could occur in some areas, such as near the Denali Highway it is unlikely that the stock as a whole would be negatively impacted as most of the drainage is fairly remote, but future increases in exploitation or development could potentially be detrimental to the upper Nenana River Arctic grayling population. The greatest concern would be if the Brushkana Creek drainage represented most (e.g., >50%) of the upper Nenana River Arctic grayling spawning and rearing habitat, then an impact to the Brushkana drainage could negatively effect the whole Nenana River drainage.

Additional recommendations include, altering the sampling design because the approach used in this study cannot conclusively provide a representative sample of this dynamic population. Future study of the spawning population should determine abundance of spawning Arctic grayling and duration and area of spawning within the Brushkana drainage by distributing more effort in time and space. A mark-recapture study could be attempted by using two or three crews successively angling large sections of the drainage multiple times during a three-week period. Recaptures of Arctic grayling tagged during such a study would provide data on spawning duration, distribution, and in-stream migrations, which would enable a better understanding of this radiotelemetry project. If either the spring or summer sport fishery on Brushkana Creek becomes substantially larger, it may be prudent to determine the relative importance of the Brushkana drainage to the upper Nenana drainage for spawning and rearing of Arctic grayling. With regard to future radiotelemetry studies, it is recommended that additional ground-truth effort and radio tags with mortality or motion sensors be utilized to reduce uncertainty in fate determinations.

Finally, there was no evidence indicating additional mortality occurred when radio tagging during the spring as compared to radio tagging during the summer months. This was the first known surgical implantation of radio tags into Arctic grayling during the spawning period, and additional mortality associated with the stress of spawning event was initially a concern. The overall mortality rate observed in this study was comparable to other Arctic grayling radiotelemetry studies where mortality by project completion (sometimes less than a year) was also fairly high, ranging from 36 to 70% (Blackman 2002; Fish 1998; Lubinski 1995; Morris 2003; Ridder 1995, 1998a, b; West 1992).

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APPENDIX A

Appendix A1.–Fates assigned to each Arctic grayling radio-tagged in Brushkana Creek during spring 2002.

Radio Tag	Flight Date							
Frequency	6/11/02	6/24/02	7/12/02	8/17/02	10/15/02	3/19/03	5/17/03	6/6/03
320	AL-OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
340	**TM**							
360	**TM**							
380	IN	IN	IN	OUT	OUT	OUT	IN	IN
400	AL-OUT	OUT	OUT	OUT	**PTMO**			
420	**TM**							
440	AL-OUT	AL-OUT	**PTMO**					
460	IN	IN	IN	IN	OUT	OUT	OUT	IN
480	AL-OUT	AL-OUT	OUT	OUT	OUT	OUT	**PTMO**	
500	AL-OUT	OUT	OUT	**PTMO**				
520	AL-OUT	OUT	OUT	OUT	OUT	OUT	**PTMO**	
540	OUT	OUT	OUT	OUT	OUT	OUT	**PTMO**	
560	IN	IN	IN	IN	OUT	OUT	**PTMO**	
580	AL-OUT	OUT	OUT	OUT	OUT	**PTMO**		
600	AL-OUT	AL-OUT	OUT	OUT	**PTMO**			
620	IN	AL-OUT	OUT	OUT	**PTMO**			
640	IN	OUT	OUT	OUT	OUT	OUT	OUT	OUT
660	**TM**							
680	**TM**							
700	IN	IN	**U** [a]	**U**	**U**	**U**	**U**	**U**
720	**TM**							
730	AL-OUT	**FMO**						
740	AL-OUT	OUT	OUT	OUT	**PTMO**			
750	AL-OUT	AL-OUT	OUT	OUT	OUT	OUT	OUT	OUT
760	IN	OUT	OUT	OUT	**PTMO**			
770	AL-OUT	AL-OUT	OUT	**PTMO**				

-continued-

Appendix A1.–Page 2 of 2.

Radio Tag	Flight Dates							
Frequency	6/11/02	6/24/02	7/12/02	8/17/02	10/15/02	3/19/03	5/17/03	6/6/03
780	IN	IN	OUT	OUT	OUT	AL-OUT	OUT	OUT
800	AL-OUT	OUT	OUT	OUT	OUT	OUT	OUT	OUT
820	**TM**							
860	IN	AL-OUT	OUT	OUT	OUT	OUT	**U** [b]	U
880	AL-OUT	AL-OUT	AL-OUT	AL-OUT	OUT	OUT	**PTMO**	
900	IN	IN	OUT	OUT	OUT	AL-OUT	OUT	**PTMO**
920	AL-OUT	AL-OUT	OUT	OUT	OUT	OUT	OUT	OUT
940	AL-OUT	OUT	OUT	OUT	**PTMO**			
950	AL-OUT	OUT	OUT	**PTMO**				

[a] Fate uncertain. Likely OUT after 6/24 and PTMO prior to May 17. However, Tag Failure either in or out of the sport fishery or FMO or FMI were possible.

[b] Fate uncertain. It had moved upstream in the Nenana River between October and March, but it was not detected subsequently. It may have relocated to another location outside search area and had a fate of OUT, FMO, or PTMO or the tag failed outside of sport fishery area.

Appendix A2.–Modeled proportions of the Arctic grayling population migrating to the Nenana River given that 68%[a] of the radio-tagged fish returned to the Nenana River during the June 24, 2002 survey. The proportion of the population migrating to the Nenana was modeled as a function of: 1) the proportion of the spawning population that was vulnerable to sampling, 2), the proportion of the spawning population not vulnerable to sampling that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled), and 3) the proportion of the spawning population not vulnerable to sampling that returned to the Nenana River. For this table, it was assumed that 0% of the spawning population not vulnerable to sampling returned to the Nenana River. The shaded proportions are those corresponding to reasonable, biological constraints.

Proportion of the spawning population vulnerable to sampling	Of the spawning population not vulnerable to sampling, the proportion that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled)										
	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
0.1	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
0.2	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
0.3	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
0.4	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
0.5	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34
0.6	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41	0.41
0.7	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48
0.8	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54	0.54
0.9	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61
1	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

[a] 68% is used rather than 79% (Table 7) because some fish assigned fate "OUT" were in the Brushkana Creek upstream of the study area.

Appendix A3.–Modeled proportions of the Arctic grayling population migrating to the Nenana River given that 68%[a] of the radio-tagged fish returned to the Nenana River during the June 24, 2002 survey. The proportion of the population migrating to the Nenana was modeled as a function of: 1) the proportion of the spawning population that was vulnerable to sampling, 2), the proportion of the spawning population not vulnerable to sampling that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled), and 3) the proportion of the spawning population not vulnerable to sampling that returned to the Nenana River. For this table, it was assumed that 20% of the spawning population not vulnerable to sampling returned to the Nenana River. The shaded proportions are those corresponding to reasonable, biological constraints.

Proportion of the spawning population vulnerable to sampling	Of the spawning population not vulnerable to sampling, the proportion that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled)										
	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
0.1	0.07	0.09	0.10	0.12	0.14	0.16	0.18	0.19	0.21	0.23	0.25
0.2	0.14	0.15	0.17	0.18	0.20	0.22	0.23	0.25	0.26	0.28	0.30
0.3	0.20	0.22	0.23	0.25	0.26	0.27	0.29	0.30	0.32	0.33	0.34
0.4	0.27	0.28	0.30	0.31	0.32	0.33	0.34	0.36	0.37	0.38	0.39
0.5	0.34	0.35	0.36	0.37	0.38	0.39	0.40	0.41	0.42	0.43	0.44
0.6	0.41	0.42	0.42	0.43	0.44	0.45	0.46	0.46	0.47	0.48	0.49
0.7	0.48	0.48	0.49	0.49	0.50	0.51	0.51	0.52	0.52	0.53	0.54
0.8	0.54	0.55	0.55	0.56	0.56	0.56	0.57	0.57	0.58	0.58	0.58
0.9	0.61	0.61	0.62	0.62	0.62	0.62	0.62	0.63	0.63	0.63	0.63
1	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

[a] 68% is used rather than 79% (Table 7) because some fish assigned fate "OUT" were in the Brushkana Creek upstream of the study area.

Appendix A4.–Modeled proportions of the Arctic grayling population migrating to the Nenana River given that 68%[a] of the radio-tagged fish returned to the Nenana River during the June 24, 2002 survey. The proportion of the population migrating to the Nenana was modeled as a function of: 1) the proportion of the spawning population that was vulnerable to sampling, 2), the proportion of the spawning population not vulnerable to sampling that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled), and 3) the proportion of the spawning population not vulnerable to sampling that returned to the Nenana River. For this table, it was assumed that 40% of the spawning population not vulnerable to sampling returned to the Nenana River. The shaded proportions are those corresponding to reasonable, biological constraints.

	Of the spawning population not vulnerable to sampling, the proportion that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled)										
Proportion of the spawning population vulnerable to sampling	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
0.1	0.07	0.10	0.14	0.18	0.21	0.25	0.28	0.32	0.36	0.39	0.43
0.2	0.14	0.17	0.20	0.23	0.26	0.30	0.33	0.36	0.39	0.42	0.46
0.3	0.20	0.23	0.26	0.29	0.32	0.34	0.37	0.40	0.43	0.46	0.48
0.4	0.27	0.30	0.32	0.34	0.37	0.39	0.42	0.44	0.46	0.49	0.51
0.5	0.34	0.36	0.38	0.40	0.42	0.44	0.46	0.48	0.50	0.52	0.54
0.6	0.41	0.42	0.44	0.46	0.47	0.49	0.50	0.52	0.54	0.55	0.57
0.7	0.48	0.49	0.50	0.51	0.52	0.54	0.55	0.56	0.57	0.58	0.60
0.8	0.54	0.55	0.56	0.57	0.58	0.58	0.59	0.60	0.61	0.62	0.62
0.9	0.61	0.62	0.62	0.62	0.63	0.63	0.64	0.64	0.64	0.65	0.65
1	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

[a] 68% is used rather than 79% (Table 7) because some fish assigned fate "OUT" were in the Brushkana Creek upstream of the study area.

Appendix A5.–Modeled proportions of the Arctic grayling population migrating to the Nenana River given that 68%[a.] of the radio-tagged fish returned to the Nenana River during the June 24, 2002 survey. The proportion of the population migrating to the Nenana was modeled as a function of: 1) the proportion of the spawning population that was vulnerable to sampling, 2), the proportion of the spawning population not vulnerable to sampling that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled), and 3) the proportion of the spawning population not vulnerable to sampling that returned to the Nenana River. For this table, it was assumed that 60% of the spawning population not vulnerable to sampling returned to the Nenana River. The shaded proportions are those corresponding to reasonable, biological constraints.

	Of the spawning population not vulnerable to sampling, the proportion that returned to the sport fishery area after sampling was complete (or to other areas in the sport fishery not sampled)										
Proportion of the spawning population vulnerable to sampling	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
0.1	0.07	0.12	0.18	0.23	0.28	0.34	0.39	0.45	0.50	0.55	0.61
0.2	0.14	0.18	0.23	0.28	0.33	0.38	0.42	0.47	0.52	0.57	0.62
0.3	0.20	0.25	0.29	0.33	0.37	0.41	0.46	0.50	0.54	0.58	0.62
0.4	0.27	0.31	0.34	0.38	0.42	0.45	0.49	0.52	0.56	0.60	0.63
0.5	0.34	0.37	0.40	0.43	0.46	0.49	0.52	0.55	0.58	0.61	0.64
0.6	0.41	0.43	0.46	0.48	0.50	0.53	0.55	0.58	0.60	0.62	0.65
0.7	0.48	0.49	0.51	0.53	0.55	0.57	0.58	0.60	0.62	0.64	0.66
0.8	0.54	0.56	0.57	0.58	0.59	0.60	0.62	0.63	0.64	0.65	0.66
0.9	0.61	0.62	0.62	0.63	0.64	0.64	0.65	0.65	0.66	0.67	0.67
1	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68

[a.] 68% is used rather than 79% (Table 7) because some fish assigned fate “OUT” were in the Brushkana Creek upstream of the study area.

APPENDIX B

DATA FILE LISTING

Appendix B1.-Data files[a] for all Arctic grayling captured in Brushkana Creek, 2002.

Data file	Description
Brushkana 2002 Data.csv	Sample data from May 31 – June 6, 11 and 18 August 2002
Brushkana 2002 Radio Telemetry Data.xls	Radio Telemetry locations
Brushkana analysis.xls	Data and analysis in excel spreadsheet

[a] Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.