Fishery Data Series No. 11-42

Salcha River Arctic Grayling Stock Assessment, 2003–2004

by

Andrew D. Gryska

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

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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ABSTRACT

A stock assessment of the Salcha River Arctic grayling fishery was completed during 2003 and 2004 using radio telemetry and mark recapture experiments. Objectives of the study were to determine the proportion of radio tagged Arctic grayling that remained in the study area after spawning, estimate abundance in the study area during spring and summer, and estimate exploitation of the spring and summer populations in the study area. Monthly radio telemetry surveys indicated 51%–74% of Arctic grayling ≥ 330 mm FL remained in the study area during the summer of 2003. Abundance of Arctic grayling ≥ 270 mm FL during spring of 2004 was 13,407 (SE=1,643) and during summer of 2004 was 12,765 (SE=1,727). During 2004, harvest of Arctic grayling was estimated as 1,422 fish and the exploitation rates of the spring population were 5.8%–8.0% and of the summer population was 11.3%.

Key words: Arctic grayling, *Thymallus arcticus,* radiotelemetry, abundance, exploitation, length composition, electrofishing, mark-recapture, Salcha River, Alaska.

INTRODUCTION

The Salcha River flows southwest out of the Tanana Hills into the Tanana River, and it passes under the Richardson Highway at milepost 348, approximately 70 km southeast of Fairbanks (Figure 1). The mainstem Salcha River is 247 km long and has a drainage area of 5,620 km^2 upstream of the Richardson Highway Bridge (Brabets et al. 2000). The river is a rapid run-off stream that ranges from clear to slightly tannin stained, and it becomes turbid during periods of heavy runoff (Tack 1980).

Holmes (1984) characterized the lower 207 km of the mainstem Salcha River and described four discrete sections based on differences in hydrology. From Dan Creek to Paldo Creek (16 km), Holmes observed a small (18 m wide), shallow (average depth 0.45 m), swift (0.93 m/s) river, which dropped 4.1 m/km. Between Paldo Creek and the North Fork Salcha River (69 km), Holmes observed a river increasing in width (18 to 36 m), average depth (1.2 m), and average velocity (0.96 m/s), and decreasing in gradient (3.7 m/km). Between the North Fork Salcha River and Butte Creek (36 km), Holmes observed a wide (> 67.5 m) and deep (> 2.1 m) river, which continued flowing quickly (0.87 m/s) but less gradient (1.8 m/km). Between Butte Creek to the Tanana River (86 km), Holmes observed that the Salcha River remained wide and deep and the average velocity (0.8 m/s) and average gradient (1.1 m/km) had decreased.

The Salcha River is accessible by automobiles at the Richardson Highway Bridge at river kilometer (rkm) 3.3; however, access by car is limited to a 1.6-km section of river adjacent to the Salcha River State Recreation Area. The recreation area provides a public boat ramp, parking lot, and picnic and camping areas. Access to the river above the state recreation area is limited to riverboats or aircraft. Landing strips are located at Caribou Creek at rkm 98 Pasco Creek rkm 104, and Paldo Creek rkm 188. The Salcha River has numerous recreational cabins located along the lower 113 km (Doxey 2001). The Arctic grayling *Thymallus arcticus* fishery (hereafter referred to as “the fishery”) largely occurs within the lower 116.4 km from the downstream end of “the splits” to the mouth on the Tanana River, which closely corresponds to the lower two sections described by Holmes (1984; Figure 1; M. Doxey, Alaska Department of Fish and Game-retired, Fairbanks, personal communication).

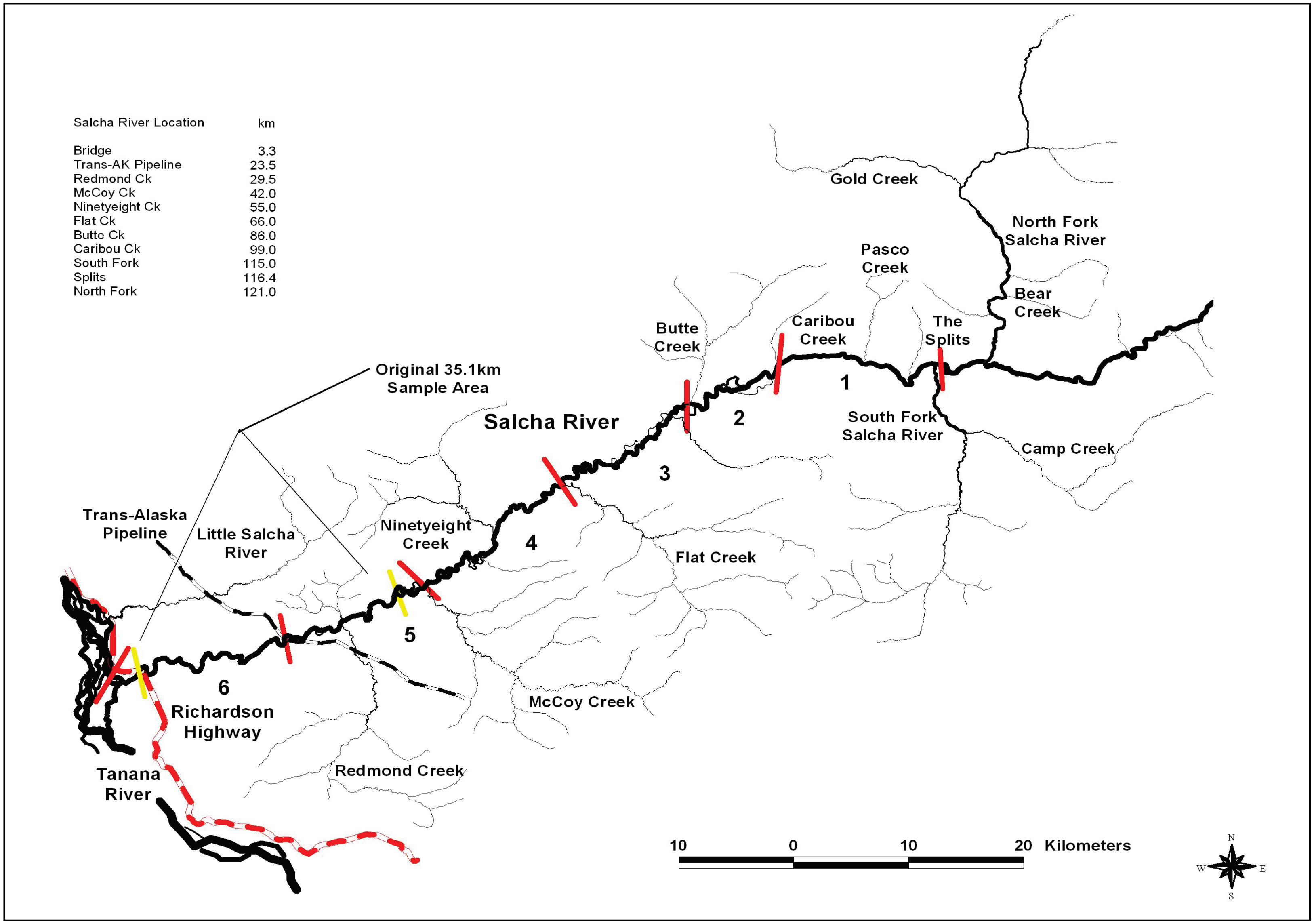

Figure 1.–Salcha River drainage and study area showing the boundaries for the six sections, boundaries of the original (1989–1994) sample area, and distances from the mouth to key landmarks.

Since 1977, the Alaska statewide sport fish harvest survey (SWHS) has provided annual estimates of the effort, catch, and harvest (Table 1; Mills 1979–1994; Howe et al. 1995, 2001 a-d). Prior to the SWHS, creel surveys occurred intermittently between 1953 and 1974 and provided estimates of the catch, harvest, and effort (Warner 1959; Roguski and Winslow 1969; Kramer 1975). Although, the SWHS provides estimates of total angler effort for the entire Salcha River drainage, the apportionment of effort for individual species is unknown. The Salcha River has fisheries for Arctic grayling, Chinook salmon *Oncorhynchus tshawytscha*, northern pike *Esox lucius*, burbot *Lota lota*, and multiple species of whitefish *Coregonidae* (Howe et al. 2001d), but the majority of recreational fishing effort on the Salcha River is directed at Arctic grayling and Chinook salmon (M. Doxey, Alaska Department of Fish and Game-retired, Fairbanks, personal communication). Estimates of harvest and catch provide an indication of the importance of the Arctic grayling fishery. During 2004, Arctic grayling accounted for almost 73% of all fish harvested in the drainage (Jennings et al. 2007).

Prior to 1977, sport fishing regulations in the Tanana River drainage were liberal and daily bag and possession limits were 10 fish daily and 20 fish in possession. Between 1977 and 1986, daily bag and possession limits were 5 fish daily and 10 fish in possession. Drainagewide declines in Arctic grayling for both harvest and abundance indices in the mid-1980s (Roach 1994; Fleming 1995; Ridder 1998a; Doxey 2001) led to more restrictive regulations for many Tanana Drainage fisheries beginning in 1987. For the Salcha River, this included a catch-and-release season from April 1 to the first Saturday in June (subsequently changed to May 31), a 12 in TL (270 mm FL) minimum size limit, a no-bait restriction upstream of the Richardson Highway bridge (except for single hooks with a > ¾ in gap), and daily bag and possession limit of 5 fish.

Although the regulations were applied throughout the Tanana Basin, very little research about the biology and population of Arctic grayling in the Salcha River had occurred prior to 1989 (Tack 1973; Bendock 1974; Kramer 1975; Holmes et al. 1986; Clark and Ridder 1987 and 1988). Between 1989 and 1994, population abundance and length and age composition were estimated for Arctic grayling in a 35.1 km section of the Salcha River between the Richardson Highway Bridge and rkm 38.4 each June (Table 2; Clark and Ridder 1990; Clark et al. 1991; Fleming et al. 1992; Ridder et al. 1993; Roach 1994, 1995).

Periodic assessments of abundance and length and age compositions of a fishery are useful for managing fisheries, and the need to assess this fishery had been identified (Doxey 2001). Prior to 2004, the Salcha River Arctic grayling population had not been assessed since 1994, nor had any significant description of their life history ever occurred. Ideally, an assessment of the population would encompass the entire geographic area of the fishery while it is unaffected by immigration or emigration. The prior assessments encompassed only the lower third of the fishery and movements of fish indicated that immigration and emigration had likely occurred while sampling, resulting in biased estimates (Clark and Ridder 1990; Clark et al. 1991; Fleming et al. 1992; Ridder et al. 1993; Roach 1994, 1995). Therefore the utility of the information attained from these assessments was limited, particularly because the effects of exploitation could not be related to a clearly identified management stock.

Table 1.-Estimates of effort and Arctic grayling harvest and catch on the Salcha River, 1977–2004.

Year	Angler-days	Catch	Harvest
1977	8,167		6,387
1978	9,715		9,067
1979	14,788		5,980
1980	8,858		5,351
1981	8,090		3,983
1982	14,126		6,843
1983	11,802		9,640
1984	8,449		13,305
1985	13,109		5,826
1986	13,792		7,540
1987	10,576		4,762
1988	7,494		2,383
1989	9,704		5,721
1990	9,783	8,609	1,992
1991	11,242	4,697	1,688
1992	4,833	8,265	1,592
1993	7,313	11,254	1,768
1994	7,653	9,995	2,308
1995	14,516	12,173	2,685
1996	9,241	12,502	2,371
1997	8,647	27,307	2,959
1998	5,789	18,829	2,179
1999	7,539	13,932	1,524
2000	4,862	7,200	1,544
2001	5,471	5,831	602
2002	5,954	7,532	1,287
2003	5,032	6,756	1,225
2004	4,859	7,355	1,501
Average			
Overall	8,979	10,816	4,072
1995–2004	7,191	11,942	1,788
2000–2004	5,236	6,935	1,232

Arctic grayling are seasonally migratory and their migrations vary in duration, occur within a river and among rivers, and often involve homing to specific areas (Reed 1964; Tack 1980; Ridder 1991, 1998a, 1998b, 1998c, 2000; Buzby and Deegan 2000; Gryska 2006). Tack (1980) characterized the Salcha River as a large, clear, rapid-runoff river, which probably had a large resident population of Arctic grayling that, for the most part, used the drainage for all seasonal habitats. For approximately 2–4 months in the summer and 6–8 months in the winter, Arctic grayling are relatively stationary as they occupy their seasonal habitats (Fish 1998; Ridder 1998b, 1998c; Gryska 2006). The occupation of spawning areas is short term (about 2 weeks) and a dynamic part of the migration from winter habitats to summer habitats. Movement from wintering habitat to spawning grounds is initiated when waters warm to 1°C and spawning occurs between 4 and 10°C (Bishop 1971; Tack 1980; Mogen 1996). After ice-out, rivers tend to warm sequentially from downstream to upstream and, therefore, spawning typically begins in downstream areas and progresses upstream. Spawning can occur throughout a river drainage, but Arctic grayling tend to use discrete areas based on availability of suitable habitat. After spawning, fish continue to redistribute themselves throughout the drainage or migrate to other river systems (Tack 1980; Ridder 1994, 1998a, 1998b, 1998c, 2000; Gryska 2006). After the post-spawning migrations, a gradient by size is generally established in a clear run-off river with the upper river dominated by larger fish and the lower reaches occupied mostly by smaller fish (Tack 1980; Hughes and Reynolds 1994). The previous Salcha River research indicated that: 1) Arctic grayling were probably migrating between spawning habitats and summer habitats during June (Clark and Ridder 1990; Clark et al. 1991; Fleming et al. 1992; Ridder et al. 1993; Roach 1994, 1995); 2) the proportion of large fish increased going upstream during the summer (Holmes 1984); and, 3) there was at least a small amount of interchange between other rivers and the Salcha River (Ridder 1991; B. Ridder, Alaska Department of Fish and Game – retired, Delta Junction, personal communication).

The goals of this study were to: 1) characterize the spring and summer populations using two-event mark-recapture experiments to establish a baseline for the population residing in the entire 116.4 km study area; 2) estimate the proportion of the spawning population that remains in the study area during summer using radiotelemetry; 3) estimate the proportion of the summer population that is comprised of Salcha River spawners using the abundance estimates and telemetry data; and, 4) estimate stock-specific exploitation rates using the abundance estimates, telemetry data, and estimates of harvest from the SWHS. Determining exploitation rates will be useful for selecting an appropriate regulatory action should future increases in harvest (i.e., 25%, 50%, or 75%) require a management action as identified in the Arctic grayling management plan (Swanton and Wuttig 2004). For example, if exploitation rates on either stock were unexpectedly high (i.e., 10%–20%), then further research may be proposed to determine what management actions, if any, were needed. At the time of this study, there was not a conservation concern for the Salcha River Arctic grayling population and exploitation rates were expected to be relatively low.

The data collected in this study was expected to: 1) develop our understanding of Arctic grayling life history; 2) increase our ability to adequately address public concerns or perceptions about the population status; and, 3) allow for comparisons with other Arctic grayling populations within Alaska. This project was consistent with policies and research needs identified in the Arctic grayling management plan (Swanton and Wuttig 2004).

To achieve the project goals, a multi-year plan was developed to implement the project in two phases: phase (1) - radiotelemetry to estimate the proportion of the spring spawning population of Arctic grayling that remained in the Salcha River fishery during the summer and to describe the timing and extent of their migrations; and, phase (2) - using mark-recapture experiments to estimate the abundance and composition of the Arctic grayling within the fishery during two distinct periods (spring spawning and summer feeding).

Table 2.–Abundance estimates of Arctic grayling for the lower 35.1 km of the Salcha River (bridge to river kilometer 38.4) during mid-to-late June 1988–1994.

Year	N (SE)	Size (mm FL)	Date	N (SE)	Size	n_1	n_2	m_2	m_2/n_2	m_2/n_1
1988[a]	2,181 (542)	≥150	May 24–June 8			208	373	28	0.08	0.13
1989	6,935 (766)	≥150	June 12–20			616	593	55	0.09	0.09
1990	5,792 (659)	≥150	June 19–27			495	500	40	0.08	0.08
1991	5,429 (1,044)	≥150	June 18–July 2	4,182 (907)	>199	821[b]	237	27	0.11	0.03
1992			June 15–25	7,076 (2,555)	>199	782[b]	643	52	0.08	0.07
1993	15,950 (2,442)	≥150	June 7–17			1,294[b]	668	66	0.10	0.05
1994	14,562 (1,762)	≥150	June 13–30	5,774 (1,002)	>235	1,103[b]	913	57	0.06	0.05

[a] Sample section in 1988 was 16 km long.

[b] Two passes were made through the study area with the electrofishing boat.

CHAPTER 1: SEASONAL MOVEMENTS OF RADIOTAGGED ARCTIC GRAYLING IN THE SALCHA RIVER

OBJECTIVES

The research objectives for this phase of the project were to:

1. estimate the proportion of large (≥330 mm FL) Arctic grayling spawning in the lower 116.4 km of the Salcha River sport fishery in spring 2003 that were present in the study area during each of 4 tracking events conducted between mid-June and mid-September of 2003 such that each estimate was within 15 percentage points of the true proportions 90% of the time;
2. estimate the proportion of large (≥ 330 mm FL) Arctic grayling spawning in the lower 116.4 km of the Salcha River sport fishery in spring 2003 that were present in the study area during at least one tracking event conducted between mid-June and mid-September of 2003 such that the estimate was within 15 percentage points of the true proportion 90% of the time; and,
3. test the hypothesis that the proportion of large (≥ 330 mm FL) Arctic grayling spawning in the lower 116.4 km of the Salcha River study area in spring 2003 that were present in the study area during at least one of the tracking events conducted between mid-June and mid-September of 2003 was greater than or equal to 0.50 with $\alpha = 0.05$ such that $\beta = 0.10$ if the true proportion was 0.25.

The probability of a type I error, α, was set such that there was less than a 5% chance of deciding that less than 50% of the Arctic grayling remained in the study area (rejecting the null) when, in fact, more than 50% remained. Given $\alpha = 0.05$ and a sample size of 52, the power to reject the null when the true proportion remaining was ≤ 25% was estimated to be ≥ 93 %.

In addition, project tasks were to:

1. describe the relative abundance (based on CPUE) of Arctic grayling spawning within the study area as attained using an electrofishing boat in 2003;
2. describe length composition of the electrofishing sample within the study area in 2003; and,
3. conduct periodic aerial tracking surveys of radiotagged Arctic grayling and describe their locations during biologically meaningful periods (spring spawning 2003, summer feeding 2003, fall migration 2003, overwintering 2003–2004, spawning year 2004, and summer feeding year 2004).

METHODS

STUDY AREA

The study area encompassed the lower 116.4 km of the Salcha River, from the lower end of "The Splits" down to the mouth at the Tanana River (Figure 1). The study area was three times as large as the previous assessment area (Clark and Ridder 1990; Clark et al. 1991; Fleming et al. 1992; Ridder et al. 1993; Roach 1994, 1995). The study area boundaries were deemed to contain almost all (>95%) of the Salcha River fishing effort (M. Doxey, Alaska Department of Fish and Game-retired, Fairbanks, personal communication). Tributaries to the Salcha River within the study area were not considered part of the fishery.

SAMPLING DESIGN

Radiotelemetry was used to estimate the proportion of large (≥ 330 mm FL) Arctic grayling spawning within the lower 116.4 km of the Salcha River fishery during 2003 that were present in the same area during specific periods between mid-June and mid-September, and the proportion that were present within the study area at least one time during that period. For the estimated proportions to be unbiased, the migration patterns of the radiotagged Arctic grayling had to be representative of the population of large Arctic grayling spawning within the sport fishery. As such, radiotagged fish were mature, tagged near their spawning location, and sampled in proportion to their density distribution within the study area.

Large (≥ 330 mm FL), mature fish were captured and implanted with transmitters during the time when they were most likely to be at their spawning locations. Maturity data collected by Clark (1992a) indicated that all but 3.6% (SE=0.17%) of Arctic grayling ≥ 330 mm FL collected in the spring of 1991 and 1992 were mature. No information on specific spawning locations was available for the Salcha River population; however, these fish were expected to follow the general sequence described by Tack (1974, 1980). Just before, during, and after break-up, Arctic grayling migrate to their spawning grounds. Arctic grayling spawn when temperatures reach 4 to 10°C, soon after break-up (Bishop 1971; Tack 1972; Fleming and Reynolds 1991). By monitoring water temperatures several times during the day, initiation of spawning was identified. Occupation of spawning sites and duration of spawning are likely dependent on water temperatures (Tack 1972; Morrison and Smith 1986; Parks et al. 1986; Fleming and Reynolds 1991) and can range from 2 to 23 days (Bishop 1971; Tack 1972; Kratt and Smith 1980; Beauchamp 1990); however, actual spawning usually occurs after several days of spawning area occupation. Sampling fish and implanting radio tags during this period likely targeted the spawning fish within the study area.

Arctic grayling densities were expected to differ along the length of the study area during spawning. Tack (1980) hypothesized that Arctic grayling seek out those portions of a drainage that warm the fastest in which to spawn, thus affording maximal growth for their progeny. In the clearwater tributaries of the Tanana drainage, this is usually in the river's lower reaches. For instance, Arctic grayling spawn throughout the Goodpaster River (Tack 1980), but in 1995, 86% of adult fish sampled in the lower 112 km of the Goodpaster River spawned in the lower 52 km (Ridder 1998a). Conversely, Ridder (2000) observed that densities were more equally distributed along the lower 144 km in the Chena River. In the absence of population density information, CPUE information collected from electrofishing boats was used as a surrogate measure for the variability in densities of spawning fish. The 52 radio tags were apportioned to each of six sections (Figure 1) proportional to the mean CPUE from each section. Then, within each section the radio tags were distributed as evenly as possible.

Within each section, Arctic grayling were captured by electrofishing and individuals of appropriate size, sex, and condition were surgically implanted with a radio tag. During the following 14 months (May 2003 through July 2004), geographic locations of these fish were observed from aerial tracking surveys. Determining the vulnerability of these fish to angling was of interest, and therefore, the proportion of Arctic grayling remaining in the study area during summer was estimated, and the hypothesis test defined in Objective 3 was performed. The areas of seasonal residence and fidelity to those areas were described.

It was assumed that the geographic distribution of Arctic grayling in the Salcha River would be most widespread during the summer feeding period, which occurs between mid-June and mid-September. The greatest frequency of tracking flights occurred during the summer when the fishery occurred. An aerial tracking survey was conducted in winter (mid-December) to identify overwintering locations when fish were more stationary (Lubinski 1995). During 2004, a flight during the spawning season and one in July were conducted to examine for fidelity to spawning and summer feeding areas.

Fish Capture

Two boats equipped with electrofishing gear were used to capture Arctic grayling. The electrofishing boats were equipped with a pulsed-DC variable-voltage pulsator (Coffelt Model VVP-15) powered by a 3,500-watt single-phase gasoline generator. Anodes consisted of four 15 mm diameter steel cables (1.5 m long) spaced 1 m apart and arranged perpendicular to the long axis of the boat and 2.1 m forward of the bow. The unpainted bottom of the boat served as the cathode. The electrical output (voltage, amperage, and duty cycle) was adjusted based on observed response of shocked fish. To minimize fish mortality and injury, electrical output values were adjusted to minimize exposure to zones of tetany (Snyder 1992). Initially, settings on the pulsator were set at 50% duty cycle and 30 Hz. Because output amperage varied at a given voltage due to conductivity, substrate and water depth, the boat operator attempted to keep amperage constant to minimize injury to fish. Voltage was adjusted to keep output amperage between 2 and 4 amperes.

Each boat consisted of a three-person crew; two to capture fish with dip nets, and one to pilot the boat and operate the electrofishing gear. A complete pass through each section was conducted with one electrofishing boat. The boats were operated for 20-min intervals, defined as a run, and captured Arctic grayling were held in an aerated tub until they were sampled and returned to the river approximately 100 to 200 m upstream from the lower boundary of a run. The run boundaries were defined during the first pass by the end of a 20-min fishing interval or the confluences of major tributaries or the boundaries of the old study area (e.g. Flat Creek and Koepke Slough). The length of a run ranged between 2.0 and 2.5 km depending on water velocities. During the first pass run boundaries were flagged and locations recorded using a GPS. The first pass was used to determine relative density throughout the area by estimating CPUE so that radio tags could be allocated in proportion to the relative abundance in each section. The second pass was used to capture Arctic grayling so that radio tags could be surgically implanted. Within each section, radio tags were equally distributed among runs.

When electrofishing for Arctic grayling, it is preferred to use two electrofishing boats so that both margins of the river can be sampled. However, because of resource and time constraints, only one boat per section was available to sample, and only one bank at any given time was sampled. To compensate for this limitation, the boat pilot chose the portion of the river that was believed to hold the most fish (e.g., choosing stream edges and back eddies, when the water temperature was < 4°C and choosing riffles when the temperature was > 4°C), rather than following the shoreline in a passive fashion. If multiple channels were encountered, the largest among them was sampled.

The study area encompassed the lower 116.4 km of the Salcha River and was divided into 6 sections with lengths ranging from 12.5 to 23.7 km (Figure 1). Arctic grayling were sampled over a six-day period by 2 three-person crews immediately following ice-out as waters warmed rapidly and spawning occurred. Because water in the lower river sections generally warms more quickly, sampling began in the lower study area (Ridder 2000, Table 3). Because the length of time the fish stay on the spawning grounds can be quite short, 2–23 days (Bishop 1971; Tack 1972; Kratt and Smith 1980; Beauchamp 1990), the sampling events were scheduled back-to-back to minimize the chance of emigration of spawning fish.

Table 3.–Sampling schedule for deployment of radio tags in the Salcha River, 2003.

Date	Activity	Crew 1	Crew 2
May 2	CPUE sampling	Section 6	Section 5
May 3	CPUE sampling	Section 4	Section 3
May 4	CPUE sampling	Section 2	Section 1
May 5	radio-tagging	Section 6	Section 5
May 6	radio-tagging	Section 4	Section 3
May 7	radio-tagging	Section 2	Section 1

Radiotagging Procedures

Mature fish ≥ 330 mm FL were surgically implanted with a radio tag if the fish had not been previously handled (as indicated by a floy tag) and appeared to be in good shape. The male to female ratio of this spawning population was expected to be close to one; therefore, each crew attempted to alternately deploy radio tags equally by sex, which minimized the potential for inadvertently selecting for fish of one sex or the other. Tagging in proportion to the expected sex composition was expected to control for bias in the unlikely event that the migratory behavior of males and females differed. This control, however, can be compromised if tagging mortality were also dependent on sex. Tests for independence of tagging mortality by sex (as well as size) were performed and, if necessary, stratified estimators for the proportion estimates would be used to account for differences in tagging mortality. The design required that all fish implanted with transmitters were sufficiently large to accommodate a transmitter (Winter 1983). It was unknown how the rigors of spawning would impact survival of implanted Arctic grayling. Unlike earlier telemetry projects conducted with Arctic grayling (Lubinski 1995; Ridder 1998b, 1998c; Fish 1998), implantation was planned to occur just prior to spawning, as opposed to late summer. A study of Arctic grayling radiotagged during spawning in Brushkana Creek had a mortality rate of about 30% through summer and an overall mortality rate of 71% by study end (Gryska 2006). Other species such as cutthroat trout *Oncorhynchus clarki* have been successfully radiotagged prior to spawning (Brown and Mackay 1995).

Fish selected for radio-tagging were anesthetized with a clove oil solution at a concentration of 25 mg l^{-1} based on the procedures outlined by Anderson et al. (1997). When fish had succumbed to the anesthesia (rolling over and lack of response to handling), the fish were weighed to the nearest gram, measured to the nearest mm FL, and assigned a gender. Each fish was then placed in a padded cradle upside down and their gills were bathed in water with clove oil solution to maintain their anesthetized state. A 15 mm incision was cut anterior to the pelvic girdle, along the left ventral side, about 5–10 mm from the center line. A grooved director was placed into the coelomic cavity and directed towards the posterior 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 was fully inserted into the coelomic cavity. 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™). Immediately after surgery, the fish was released into a current-less location of the river and observed until recovery.

Radiotelemetry

The number of radiotagged grayling required to meet the precision criteria specified in objectives 1 and 2 was estimated to be 52 (Cochran 1977). This calculation assumed a survival rate of 75% and a tag failure rate of 4.5% during the 4-month period between tag implantation and the end of summer feeding (mid-September 2003). In recent studies, Arctic grayling were radiotagged during late summer and the short-term (mid-August to late October) survival rate was 74% (Ridder 1998c) and 70% (Fish 1998). Although this study implanted radio tags in Arctic grayling during spring spawning, the same rate of mortality was assumed because findings from a similar study of Arctic grayling in Brushkana Creek indicated a similar short-term survival rate (71% until mid-August and 63% until mid-October; Gryska 2006). Tag failure rate was assumed to be 4.5% based on recent experience with Lotek tags sharing identical technology (Fleming 2004; Gryska 2006). The number of remaining viable tags was also estimated as sufficient to perform the hypothesis test described in Objective 3 at the significance level and power specified (Fleiss 1981; Zar 1984).

This project required transmitters that were small, lightweight, and had a 14-month operational life. Transmitter frequencies were within the 149 MHz bandwidth, and all tag frequencies were separated by at least 20 kHz. The transmitters selected for this project were Lotek™ model MCFT-3EM. This coded transmitter had a guaranteed operational life of 451 days when operated 10 hr per day, 7 days per week using dual level activation. The transmitters operated at 5 different frequencies with 10 to 11 codes per frequency. The burst rate was 3 s and all frequencies were scanned within 18 s. Transmitters weighed 8.9 g in air and 4.3 g in water. The air weight was expected to be $\leq$ 3% of the live weight of the fish, 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 mature fish as small as 330 mm FL in the Delta Clearwater and Chena rivers and Brushkana Creek (Ridder 1998b, 1998c; Gryska 2006).

Tracking flights were conducted in a Piper PA-18 Super Cub fixed-wing aircraft during a 14-month period. Locations determined by a fixed-wing aircraft were deemed identifiable within 1.3 km (Ridder 1998c); however, the ability to detect fish was dependent on the density of radiotagged fish and variable signal strengths related to river hydrology, water depth, and local topography that affect decoding of radio tags even when multiple passes occur. Flights corresponded to biologically meaningful activities (summer feeding, overwintering, pre-spawning, and spawning). Summer locations, intra-summer movements, and fidelity to summer locations during 2003 and 2004 were described by noting fish locations during periodic flights. Overwintering locations were determined during a flight conducted in mid-December. Spring tracking flights provided information about migration timing and fidelity to spawning locations, and also provided detection of overwintering mortalities (a fish that failed to move from overwintering locations).

DATA COLLECTION

All captured grayling ≥150 mm FL were measured for fork length to the nearest millimeter and marked with individually-numbered internal anchor tags (gray in color; and numbered 3001–3204 and 3501–3823) and given a lower caudal finclip. Grayling implanted with radio transmitters were weighed to the nearest gram using a self-taring digital balance, measured for fork length to the nearest millimeter, and tagged with an individually-numbered Floy anchor tag. Radiotagged fish were not given a lower caudal clip.

Gender was recorded if a determination was possible, and degree of maturity for females was assessed as green, ripe, or spent. These determinations were more evident for individuals that were surgically implanted with radio tags. The purpose of assessing degree of maturity was to evaluate whether sampling and radio tag implantation occurred during the spawning period at or near their spawning sites. Because Arctic grayling were sampled during spawning, sex and maturity were determined primarily by inspecting for the presence of milt or eggs and secondarily by external characteristics. Dimorphism was evident from differences in height and length of the dorsal fin and length of the pelvic fin (Bishop 1967; McPhail and Lindsey 1970); males have larger and longer dorsal and pelvic fins than females. In females, the vents are swollen. Abdomen fullness (gravid) or flaccidity (spawned out) denoted state of maturity (Ridder 1989). Females were ripe if eggs were easily extruded. There is some error associated with using these characteristics to assign gender. Small males may be classified as juveniles because their fins may not be noticeably large and, if recently spawned, may not give milt. Clark (1992a) assessed this error and found it negligible.

The numbers of captured fish were tallied for each electrofishing run. Using a GPS unit, waypoints were recorded for each run's beginning and end as well as fish release sites. During aerial tracking surveys, a GPS unit was used to identify coordinates of located fish and these were stored as waypoints into the GPS unit. Following flights or surveys, dates and location coordinates were entered into a Microsoft Excel spreadsheet and plotted on maps using ARCView.[1]

DATA ANALYSIS

To facilitate data analysis, all radiotagged Arctic grayling were assigned a "fate" during each tracking survey. Fates were assigned based on inferences developed from observations during all aerial tracking surveys and for fish which were recaptured by anglers or by Department staff during subsequent sampling. A mortality fate was assigned to a fish when no movement was observed over two or more tracking surveys between summer and winter or winter and spring

[1] Product names are used in this publication for scientific completeness but do not constitute product endorsement.

(when substantial movement was expected, e.g., a fish moved downstream for overwintering and never moved again). The data were interpreted in two ways, one of which was based on a conservative fate determination which assumed a tagged fish became non-viable as soon as evidence (e.g. no movement or downstream movements) were suggestive of a non-viable tag. An alternative interpretation that was less conservative was also performed, which tended to assign a mortality fate when a fish did not move at expected times (e.g. if a fish moved significantly between tagging and the June survey, then did not move between July 2003 and July 2004, it was generally assigned a mortality in September because it was expected to move downstream after September).

Fates were defined as follows:

1. Tagging Mortality (TM) - a fish that died in response to tag implantation (either within the fishery area or outside the fishery area) between tagging and the first aerial survey. This was inferred from aerial surveys. Fish with this fate were not used for calculating proportions;
2. Post Tagging Mortality In (PTMI) – a fish located <u>within</u> the 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). Fish with this fate were not used for calculating proportions for tracking surveys subsequent to the survey it was known to be dead;
3. Post-Tagging Mortality Out (PTMO) – a fish located <u>outside</u> the 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. Fish 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 Inside (FMI) – a fish that was reported harvested within the fishery area. Fish 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 Outside (FMO) – a fish that was reported harvested outside the fishery area. Fish 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) – a fish 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 fish was harvested was unknown. Fish with this fate were not used to calculate proportions in, and subsequent to, the survey it was known to be dead;
7. In the fishery area (IN) – a fish known to be alive at the time of a survey that was located within the fishery area;
8. Outside the fishery area (OUT) – a fish known to be alive at the time of a survey that was located outside the fishery area.

9. Unknown (U) – a fish that was never located after tagging or any subsequent survey because of tag failure or because it migrated outside the search area of the survey. Fish with this fate were not used to calculate proportions once this fate was assigned; and,

10. At large (AL) – A fish that was not located during an aerial survey, but was located again during one or more subsequent surveys. The AL fate was a temporary assignment until completion of all surveys at which point the fate was assigned IN, OUT, AL, or U. An IN or OUT was assigned if evidence (history of survey fates) strongly suggested its location was in or out of study area. AL was assigned if it was unclear if the fish was IN or OUT but was subsequently found. U was assigned when the fish was never found again.

Estimates of Proportions (Objectives 1 and 2)

The proportion of the large (≥ 330 mm) adult grayling population that spawned in the fishery area and remained in the fishery area at the time of the survey was estimated as the proportion of radiotagged Arctic grayling found within the sport fishery during each tracking event.

The proportion and variance estimators were:

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

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

where:

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

x_i = all fish with fates IN, PTMI, and FMI located during aerial survey *i*;

and

n_i = all fish with fates IN, PTMI, FMI, OUT, PTMO, and FMO located during aerial survey *i*.

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

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

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

where:

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

x_{SA} = all fish assigned an IN, PTMI, or FMI fate at least once between the end of the tagging event and the September survey; and,

n = includes xSA, and all fish assigned an OUT, PTMO, or FMO fate (i.e. never located in the fishery area between the end of the tagging event and the September survey).

Hypothesis Test (Objective 3)

The null hypothesis was tested:

H_o: $p_{SA} \geq 0.50$

vs. the alternative hypothesis:

H_a: $p_{SA} < 0.50$

where p_{SA} was the proportion of large grayling ≥ 330 mm FL in the study area during at least one of the tracking events conducted between mid-June and September. The test was performed with the significance level $\alpha = 0.05$.

In the event that both $\hat{p}_{SA} * n > 10$ and $(1 - \hat{p}_{SA}) * n > 10$ methods based on the normal distribution may be used to approximate the exact binomial procedures for performing this test. In this case, a z-test would be performed using the following test statistic:

$$z = \frac{(p_{SA} - p_{SA,0}) \pm 1/(2n)}{\sqrt{\frac{p_{SA,0}(1 - p_{SA,0})}{n}}} \qquad (5)$$

where $p_{SA,0}$ is the proportion specified by the null hypothesis (i.e. 0.5) and p_{SA} is the true underlying proportion estimated by $\hat{p}_{SA}$. The quantity $1/(2n)$ is a continuity correction, which should be applied only when it is numerically smaller than $|p_{SA} - p_{SA,0}|$ (Fleiss 1981). The minus sign is used when p_{SA} exceeds $p_{SA,0}$ and the plus sign when p_{SA} is less than $p_{SA,0}$. In the event that the criteria for using the normal approximation could not be met, exact binomial procedures were used to perform the test (Mendenhall et al. 1990).

RESULTS

During the first pass through the study area to determine relative density, 523 fish were captured between The Splits and the mouth of the river. CPUE was greater in the upriver sections (Table 4). Size also tended to be larger in upriver sections. The upper two sections received the greatest number of radio tags based on CPUE (Table 4).

Radio tags were surgically implanted in 52 Arctic grayling ≥ 330 mm FL. The fish ranged in size from 330 to 425 mm FL, and they ranged in weight from 340 to 855 g (Appendix B1). The air weight of tags relative to fish weight ranged from 1% to 2.1%. Among the fish implanted with radio tags, 27 were females and 25 were males. None of the females were spent, which indicated that sampling occurred during or just prior to the spawning period.

The results of a conservative assessment of fates are presented in Table 5 and Appendix B2. Regardless of a conservative or less conservative assessment (Appendix B3) of fate, the overall conclusions with respect to the objectives were not altered. However, the less conservative interpretation resulted in slightly longer and greater overall survival (Appendix B3). The two interpretations provide likely confidence bounds for the results.

Initially, one fish did not survive or expelled its radio tag soon after surgery, which left 51 viable, radiotagged fish by the first tracking flight of May 23, 2003 (Table 5). After the June flight, another 14 fish were identified as non-viable due to unknown fate, mortality, or tag expulsion. An additional 5, 6, and 7 fish were identified as non-viable after each tracking event of July, August, and September, respectively. Therefore prior to fall migrations, 31 fish had died or expelled their tags. In addition, two fish were assigned unknown fates during June and August. After the December, March, and May flights, an additional four radiotagged Arctic grayling had become non-viable. At study's end, a total of 37 of 52 fish (71%) had died, expelled a tag, or had a tag failure. Evaluation of mortality by gender or size identified no significant differences (Tables 6, 7, and 8).

Between tagging and the first tracking flight, the proportion of fish within the fishery decreased to 84% (Table 5). The proportion decreased each tracking flight through July, when the proportion reached a study low of 51%. After an increase to 68% in August, the proportion slowly increased to a high of 94% during March and May. By July 2004, 14 of 15 viable radiotagged Arctic grayling were located, of which, 10 (71%) were within the fishery.

In general, most fish that moved had migrated upstream between spawning and August, moved downstream between August and March, and again moved upstream subsequent to spawning (Figures 2-11). When radiotagged fish had maximally dispersed (survey of July 18, 2003; Figure 5), nearly half of viable, radiotagged fish (18 of 37) were outside the fishery (Table 5). Ten of those were in the North Fork Salcha River, four were in the mainstem upstream of the study area, one was in the South Fork Salcha River, two were in Flat Creek, and one was AL but very likely in Redmond Creek as it was located there during the following survey with a PTMO fate (Figure 6). Individual fish demonstrated great variability in movements and fidelity. Seasonal migrations ranged from negligible to extremely far (Appendix B2), and fidelity to seasonal locations also varied from none to extreme.

Relative to objective 1, the monthly proportions (with SD in parentheses) of fish present in the fishery between mid-June and mid-September (4 tracking flights) were 0.69 (0.07), 0.51 (0.08), 0.68 (0.09), and 0.76 (0.09), respectively (Table 5). Relative to Objective 2, 82% (SD=0.05; Table 5) of all viable Arctic grayling were present in the fishery during at least one tracking flight between mid-June and mid-September. Relative to Objective 3, the hypothesis failed to reject that the proportion of large (≥ 330 mm FL) Arctic grayling present in the study area during at least one of the tracking events conducted between mid-June and mid-September of 2003 was greater than or equal to 0.50. Z-test yielded $z = 3.57$ and a P-value of 0.99, which strongly suggested that the proportion was greater than 0.5.

As for the project tasks, the relative abundance of fish was greatest in the upper two sections between The Splits and Butte Creek (Table 4). The relative abundance was moderate between Butte Creek and the trans-Alaska pipeline, and relative abundance was very low between the pipeline and the Salcha River mouth. Captured fish ranged in size from 124 to 443 mm FL, the mean FL was 334 mm, and the median length was 353 mm FL (Table 4). The upper 3 sections (Flat Creek to The Splits) had larger fish than the downstream 3 sections (Table 4).

Table 4.–Summary of statistics relative to sampling of study sections, CPUE, allocation of radio tags, and fish length in the Salcha river study area, May 2–4, 2003.

Section	River km	Runs	Time (min)	Average Run (min)	Min/km	Distance (km)/run	Catch	CPUE	Radiotag Allotment	Mean FL (mm)	Max FL (mm)	Min FL (mm)	SE (FL)
1	17.4	5	94	18.8	5.4	3.5	92	0.98	14	371	435	291	26.4
2	12.5	7	133	19.0	10.6	1.8	125	0.94	13	367	438	282	31.9
3	21.1	8	172	21.5	8.2	2.6	104	0.60	8	354	443	161	52.1
4	23.5	10	191	19.1	8.1	2.4	76	0.40	6	279	413	124	66.5
5	18.2	7	152	21.7	8.4	2.6	96	0.63	9	293	407	185	59.3
6	23.7	11	229	20.8	9.7	2.2	30	0.13	2	277	400	128	60.7
Overall	116.4	48	971	20.2	8.2	2.4	523	0.54	52	334	443	124	62.5

Table 5–Fate of each radio tagged fish during each flight and number of radiotagged Arctic grayling assigned to each fate, proportions of Arctic grayling remaining in the sport fishery for each tracking event, and cumulative mortality.

	Flight Date								
Radio Tag Fate	5/23/2003	6/26&28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
IN	41	22	16	17	15	15	14	14	10
OUT	8	14	16	9	3	2	1	1	4
TM	1								
PTMI		12	3	4	4	1	1	1	
PTMO		1	2	1	3	1			
U		1		1					
AL	2	1			1		1		1
Total	52	51	37	32	26	19	17	16	15
n_i	49	49	37	31	25	19	16	16	14
x_i	41	34	19	21	19	16	15	15	10
$P_{SF,i}$	0.84	0.69	0.51	0.68	0.76	0.84	0.94	0.94	0.71
$SE[P_{SF,i}]$	0.053	0.067	0.083	0.085	0.087	0.086	0.062	0.062	0.125
UCL[b]	0.92	0.80	0.65	0.81	0.88	0.95	1.00	1.00	0.93
LCL[b]	0.76	0.59	0.38	0.55	0.60	0.68	0.81	0.81	0.50
Cumulative non-viable[c]	1	15	20	26	33	35	36	37	37
Non-viable rate	2%	29%	38%	50%	63%	67%	69%	71%	71%

Note: Fates were in 'IN, out 'OUT', tagging mortality 'TM', post-tagging mortality in 'PTMI', post-tagging mortality out 'PTMO', at large 'AL', and at large in 'AL-IN', and at large out 'AL-OUT'. AL-IN and AL-OUT indicates fish which were at large during the flight but were assumed to be in or out of study area based on evidence (history of survey fates) that strongly suggested its location was in or out of study area.

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

[c] Includes TM, PTMI, PTMO, FMI, FMO, U, and UH fates.

Table 6.–Test for equal probability of mortality of radiotagged Arctic grayling with respect to gender in the Salcha River Study Area, 2003–2004.

	Gender	
Category	Male	Female
Survived	7	8
Died	18	19
Mortality rate	0.72	0.70

χ^2 =0.017; df = 1; P = 0.90; fail to reject H_0.

Table 7.–Test for equal probability of mortality of radiotagged Arctic grayling with respect to length in the Salcha River Study Area, 2003–2004.

	Length	
Category	<380 mm FL	≥380 mm FL
Survived	5	10
Died	18	19
Mortality rate	0.78	0.66

χ^2 =1.015; df = 1; P = 0.31; fail to reject H_0.

Table 8.–Test for equal probability of mortality of radiotagged Arctic grayling with respect to weight in the Salcha River Study Area, 2003–2004.

	Weight	
Category	<585 g	≥ 585 g
Survived	5	10
Died	20	17
Mortality rate	0.80	0.63

χ^2 =1.836; df = 1; P = 0.17; fail to reject H_0.

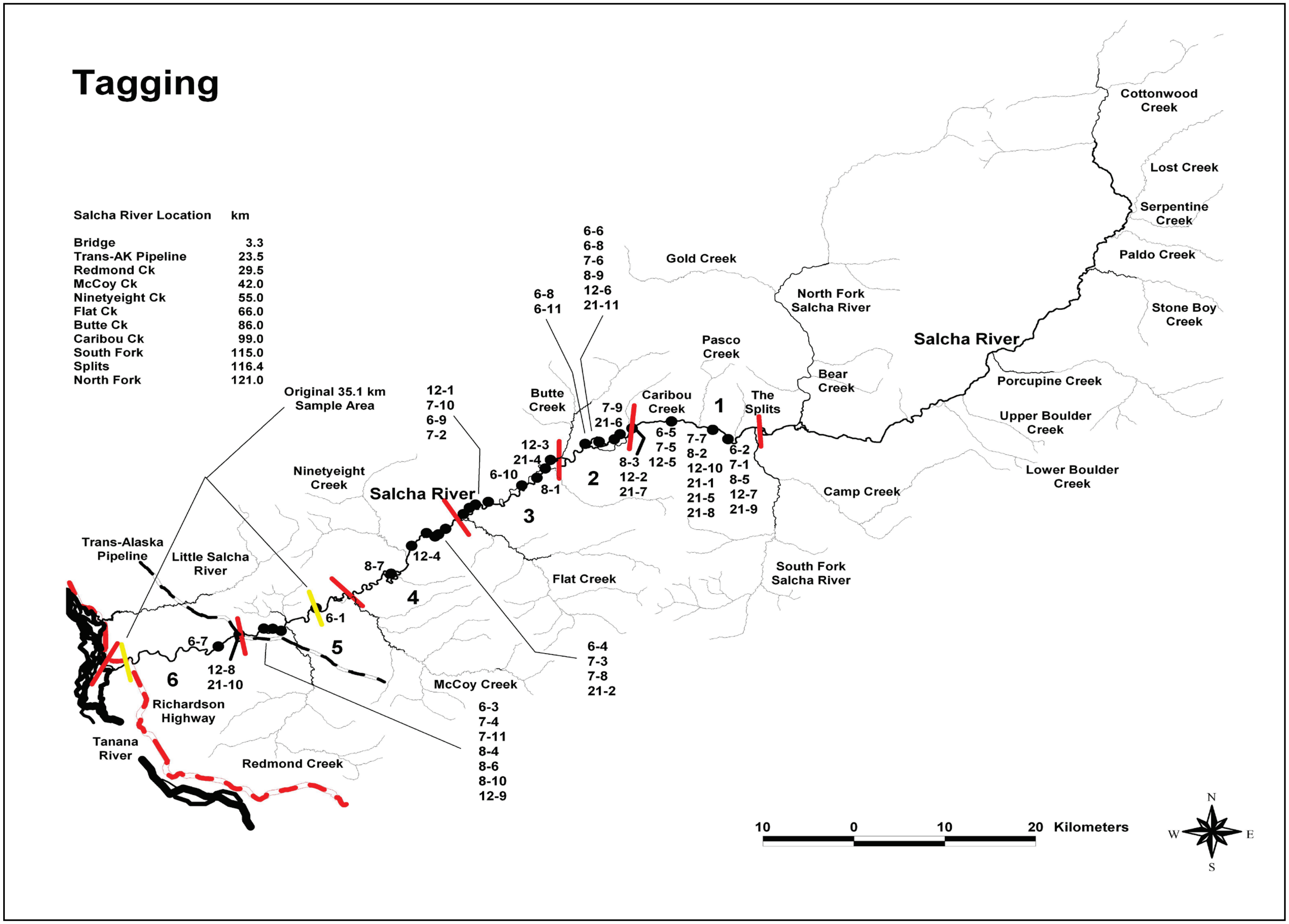

Figure 2.–Tagging locations of individual radiotagged fish (shown as black dots with a channel-code identifier), May 5–7, 2003.

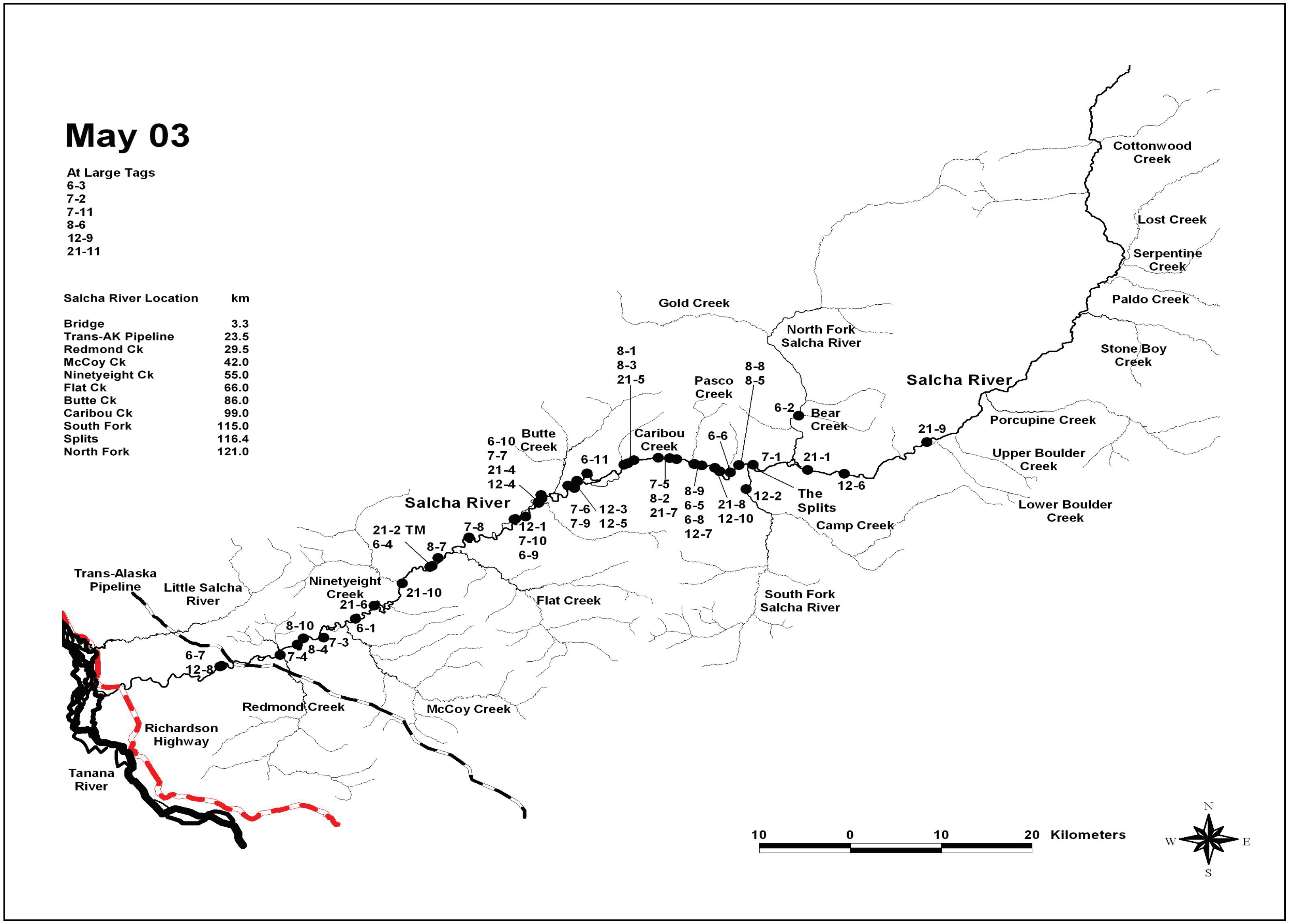

Figure 3.-Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), May 23, 2003. All fish shown were judged to be alive at the time of the survey except one with a 2 letter identifier, which indicates a mortality fate.

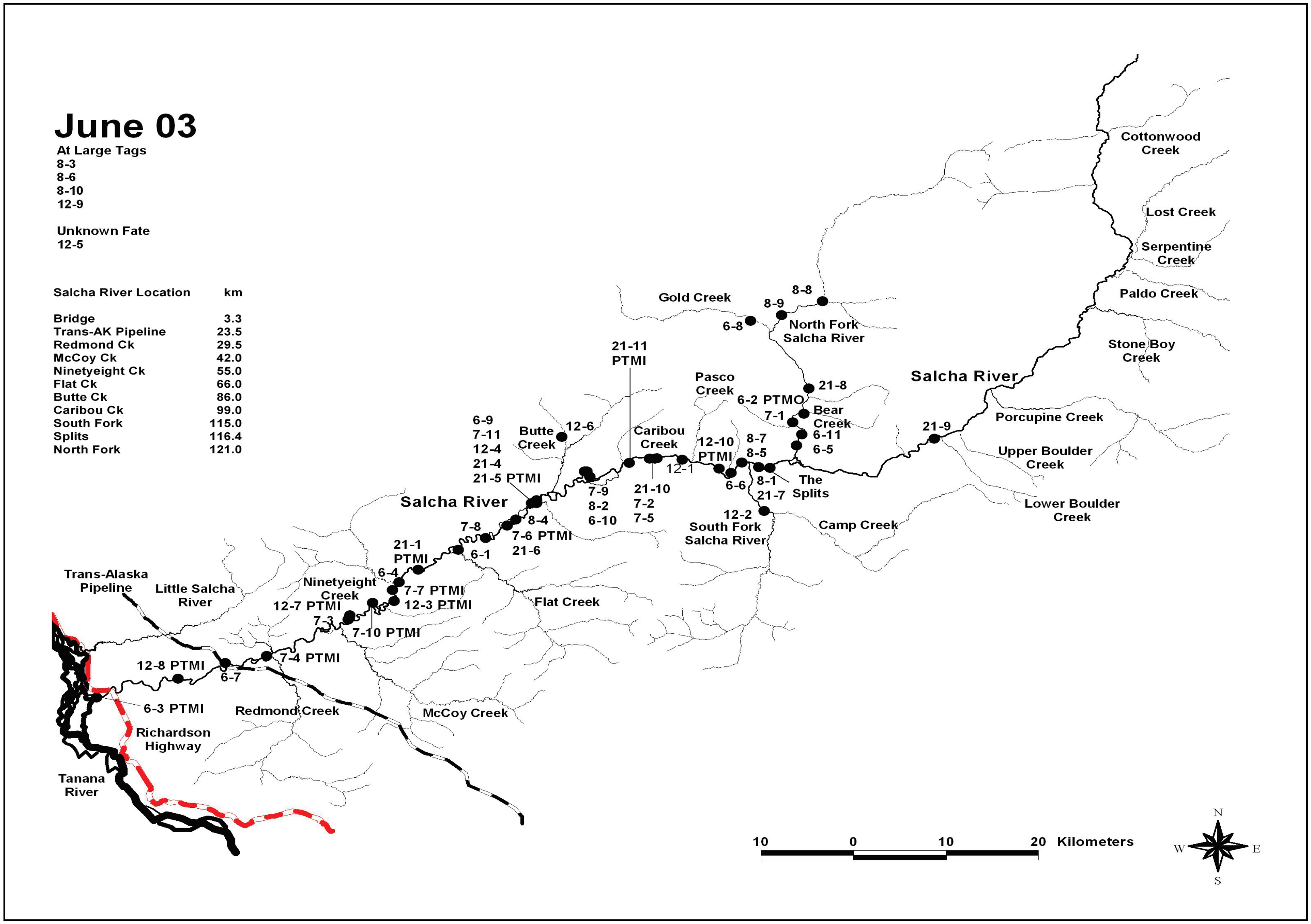

Figure 4.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), June 26 and 28, 2003. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

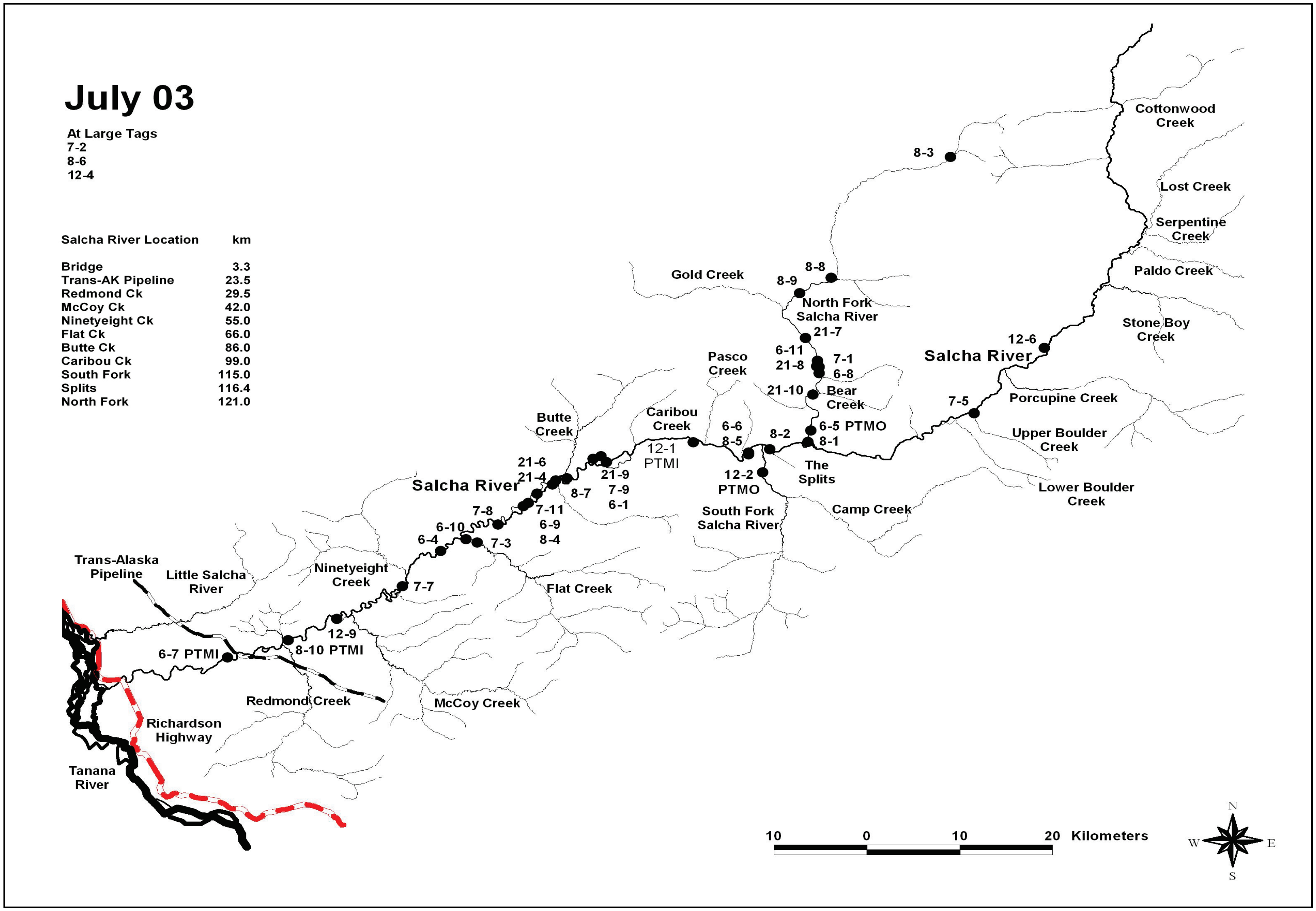

Figure 5.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), July 18, 2003. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

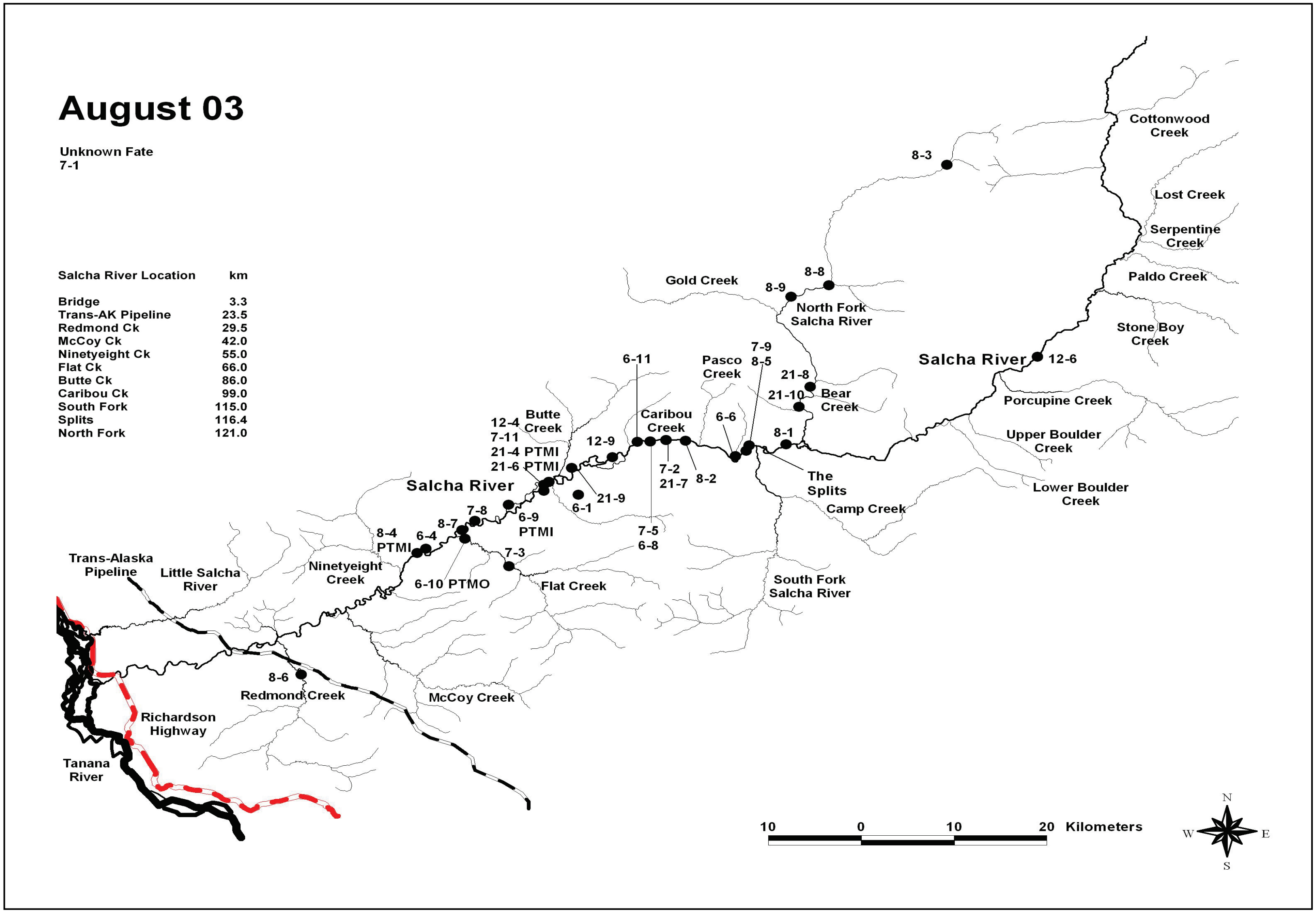

Figure 6.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), August 21, 2003. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

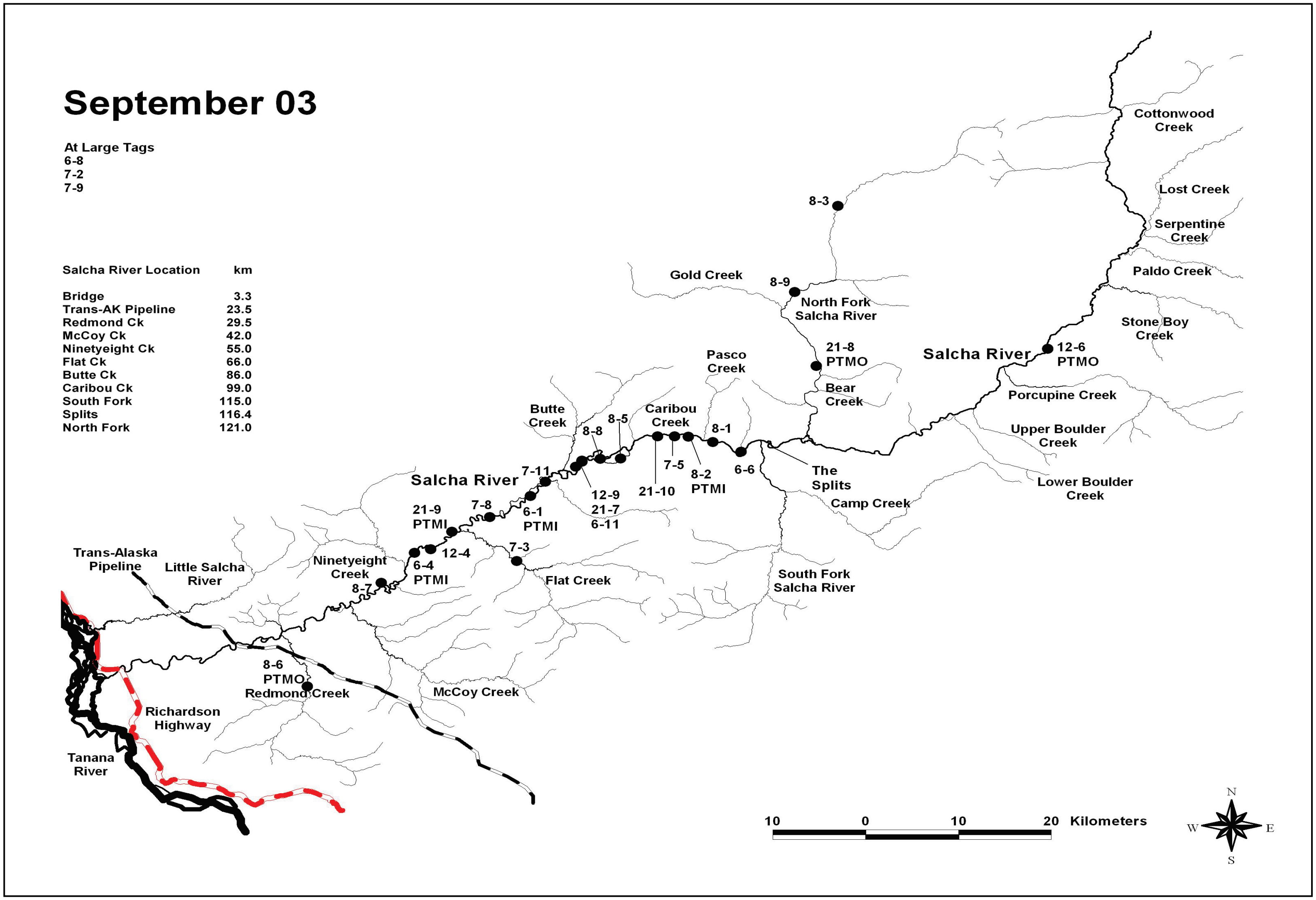

Figure 7.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), September 22, 2003. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

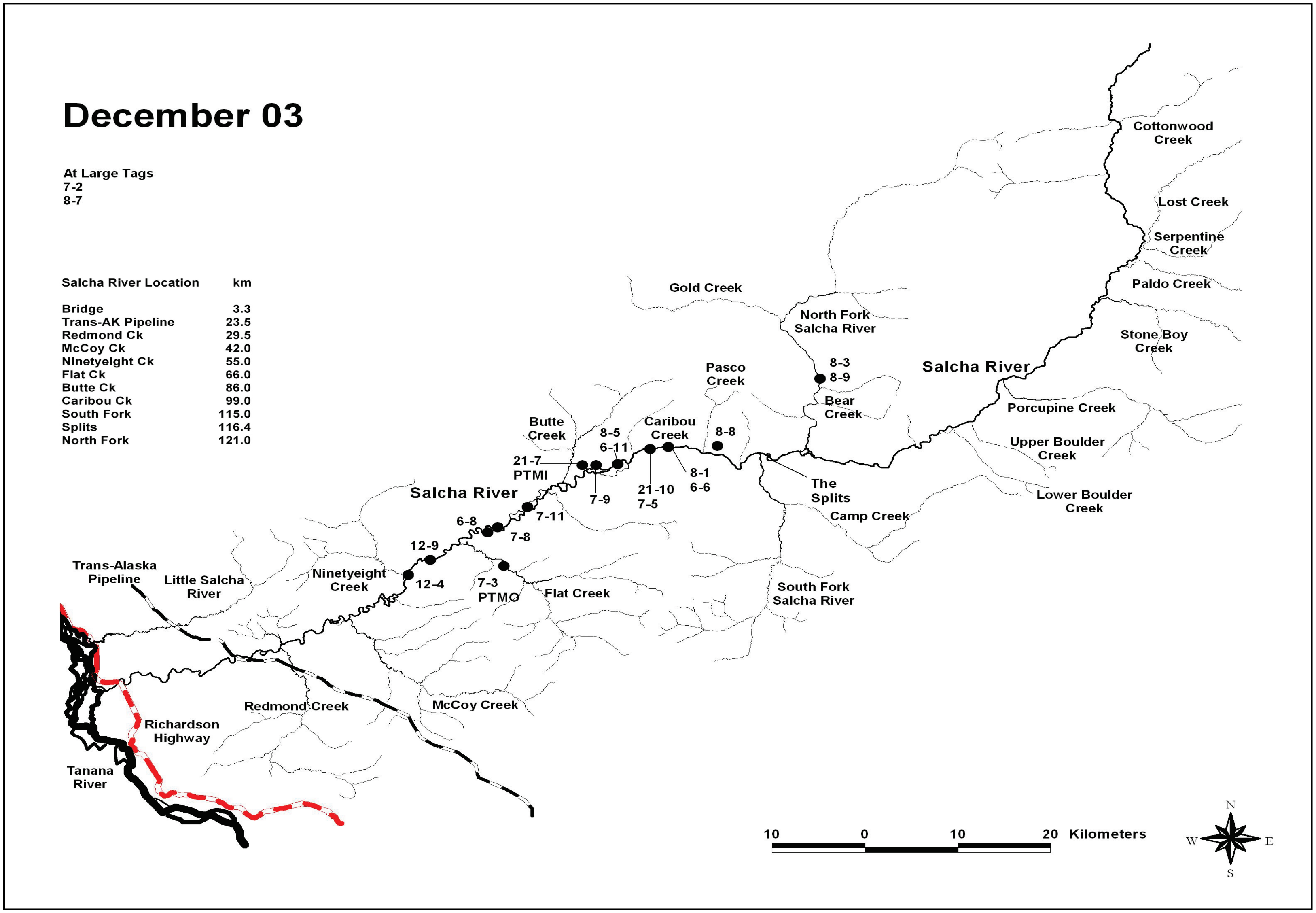

Figure 8.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), December 10, 2003. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

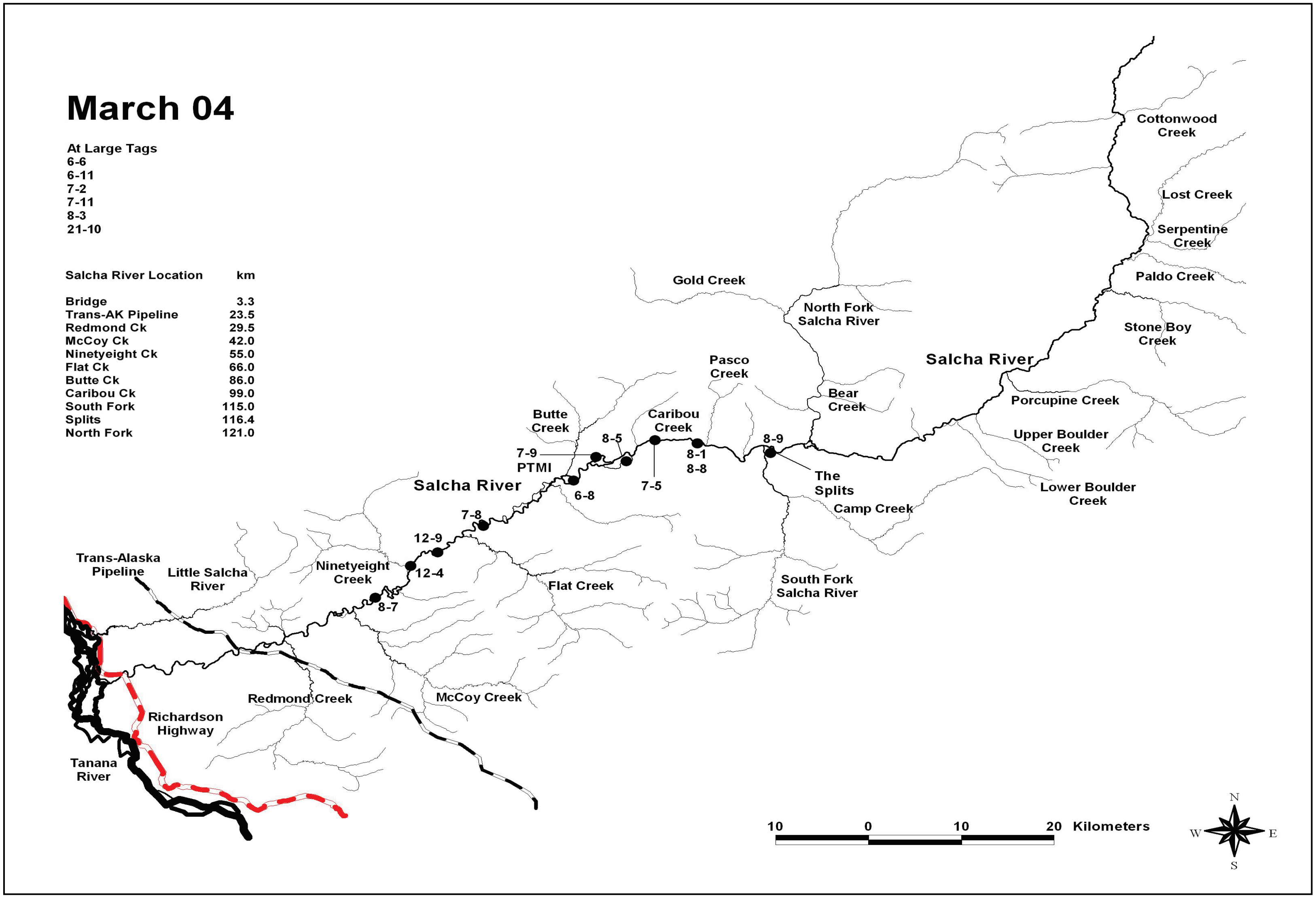

Figure 9.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), March 2, 2004. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

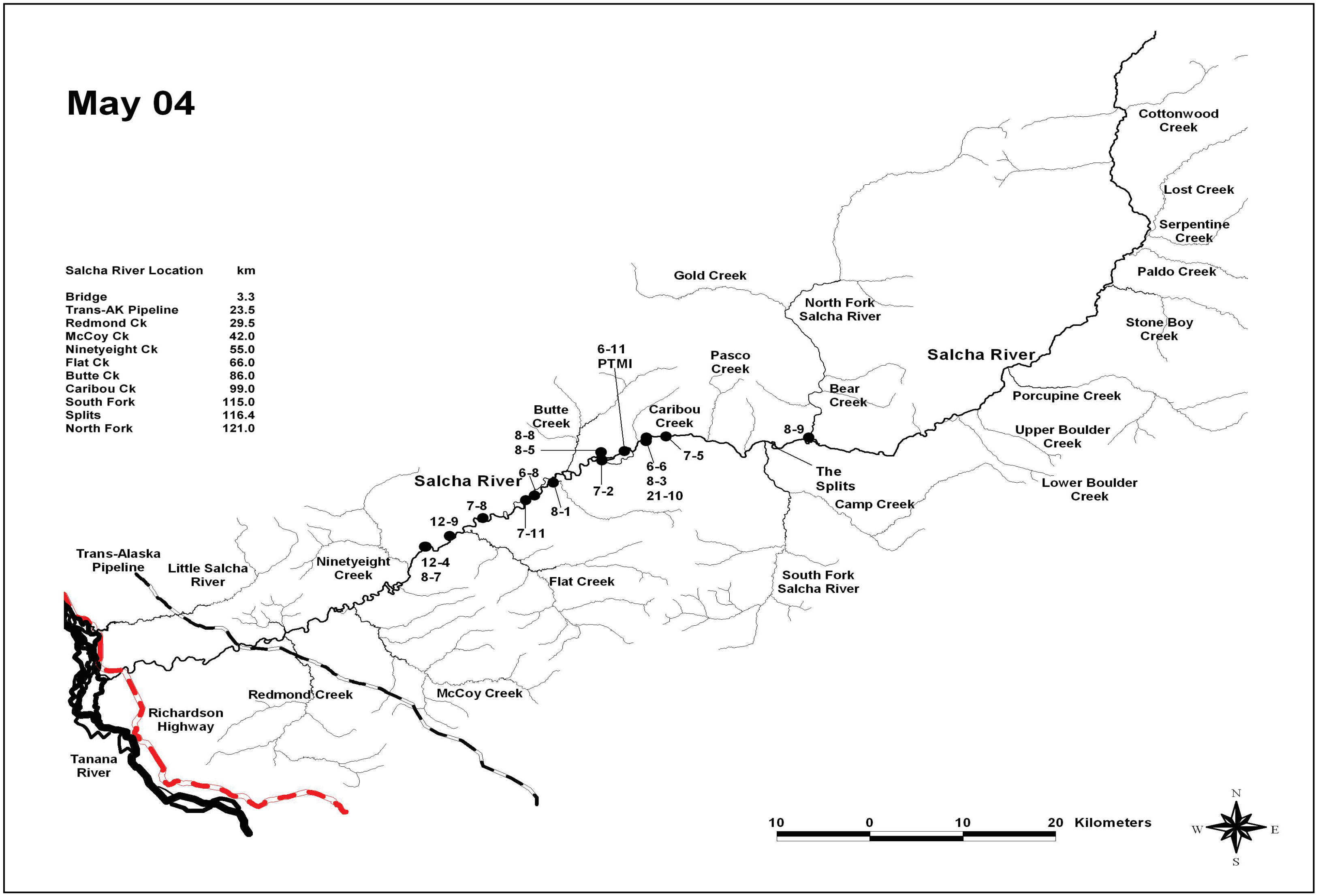

Figure 10.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), May 11, 2004. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

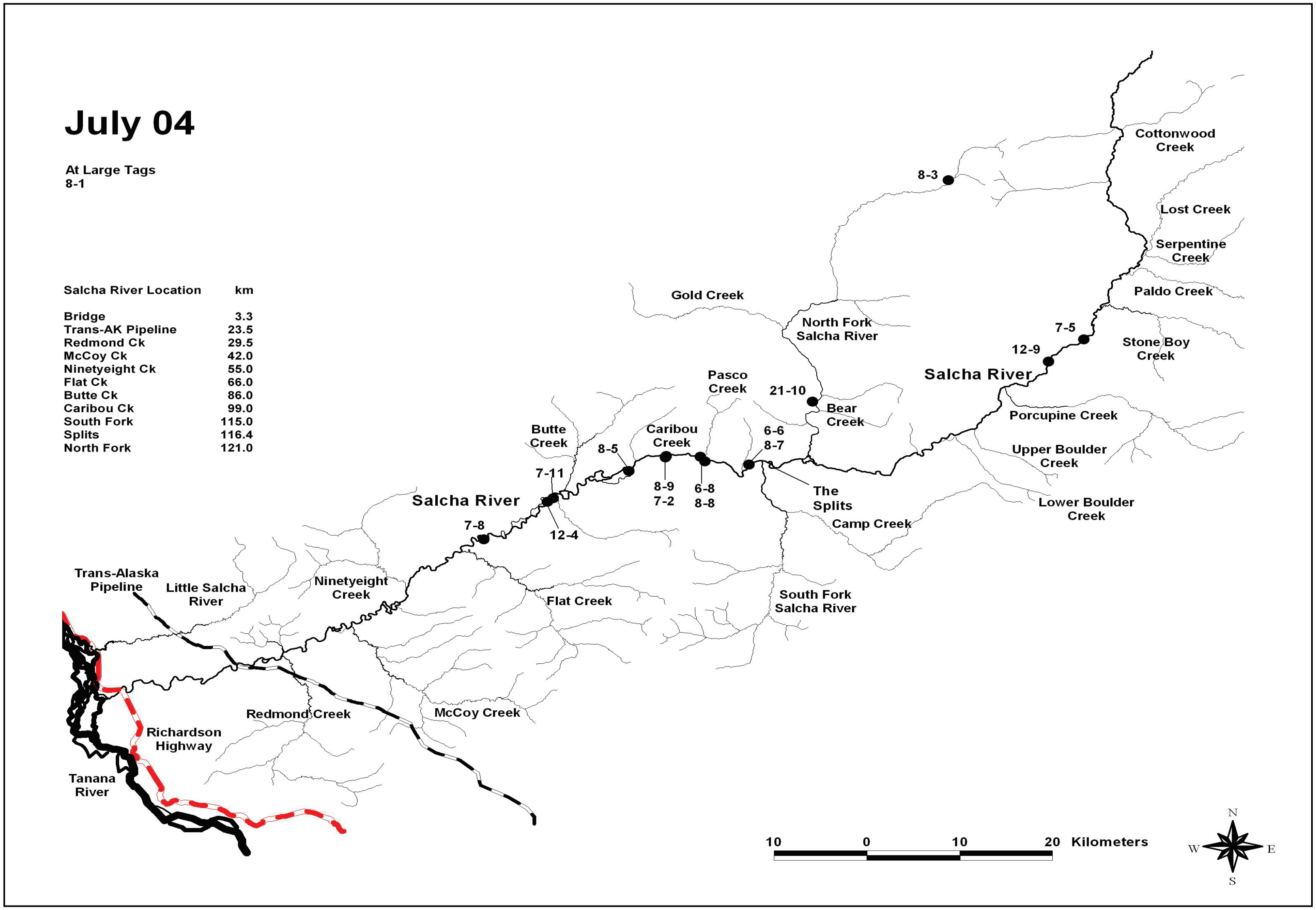

Figure 11.–Locations of individual radiotagged fish (shown as black dots with a channel-code identifier), July 22, 2004. All fish shown were judged to be alive at the time of the survey except those with a 3-4 letter identifier, which indicates a mortality fate.

DISCUSSION

This study suggested that a substantial proportion (24%–49%) of the Arctic grayling population that utilized the Salcha River study area for spawning migrated out of the study area during the summer. However, it is necessary to discuss limitations on these inferences that result from: 1) the representativeness of the sample; 2) the behavior of radiotagged Arctic grayling; and, 3) the accuracy of fate assignments.

To attain a representative sample of the mature population, this study was designed to sample Arctic grayling as they were at or near their spawning locations. This was ensured by monitoring spawning condition and behavior, by monitoring water temperature, and by sampling a large study area. Fish became ripe after several days of sampling and began to move onto riffles as surgeries began. Spent individuals were not encountered, and water temperatures never exceeded 5.0°C. Therefore, the intended spawning population was likely sampled and implanted with radio tags.

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 dying or expelling its tag 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 most radiotagged Arctic grayling surviving until the June flight had moved a significant, if not substantial, distance from original release location (in absolute numerical terms, an average of 29.6 km, range 0.3–84.6 km). Additional evidence supporting Arctic grayling resiliency to effects of radiotagging has been reported (Fish 1998; Ridder 1998b, 1998c; Gryska 2006). 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 study area 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 study area 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, 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, 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, particularly as the resolution of location identification is about 1.3 km when flying with a receiver (Ridder 1998c). For example, one fish (channel 7, code 5, nomenclature hereafter being 'fish 7-5') demonstrated the use of a small home range (≤ 2.65 km), which would have been indicative of a non-viable tag if it were not for irrefutably significant movements observed during July 2003 and July 2004 (Figure 12, fish 7-5). Therefore, each radiotagged Arctic grayling fate was determined on a case-by-case basis under a conservative and less conservative approach so that the effect of differing fate determinations could be evaluated (Table 5 and Appendices B2 and B3). The ultimate fate of each fish was usually the same under each interpretation; however, there was a tendency to survive a bit longer, generally until the September survey, under the less conservative approach. Despite the differences, conclusions with regard to the objectives remained the same.

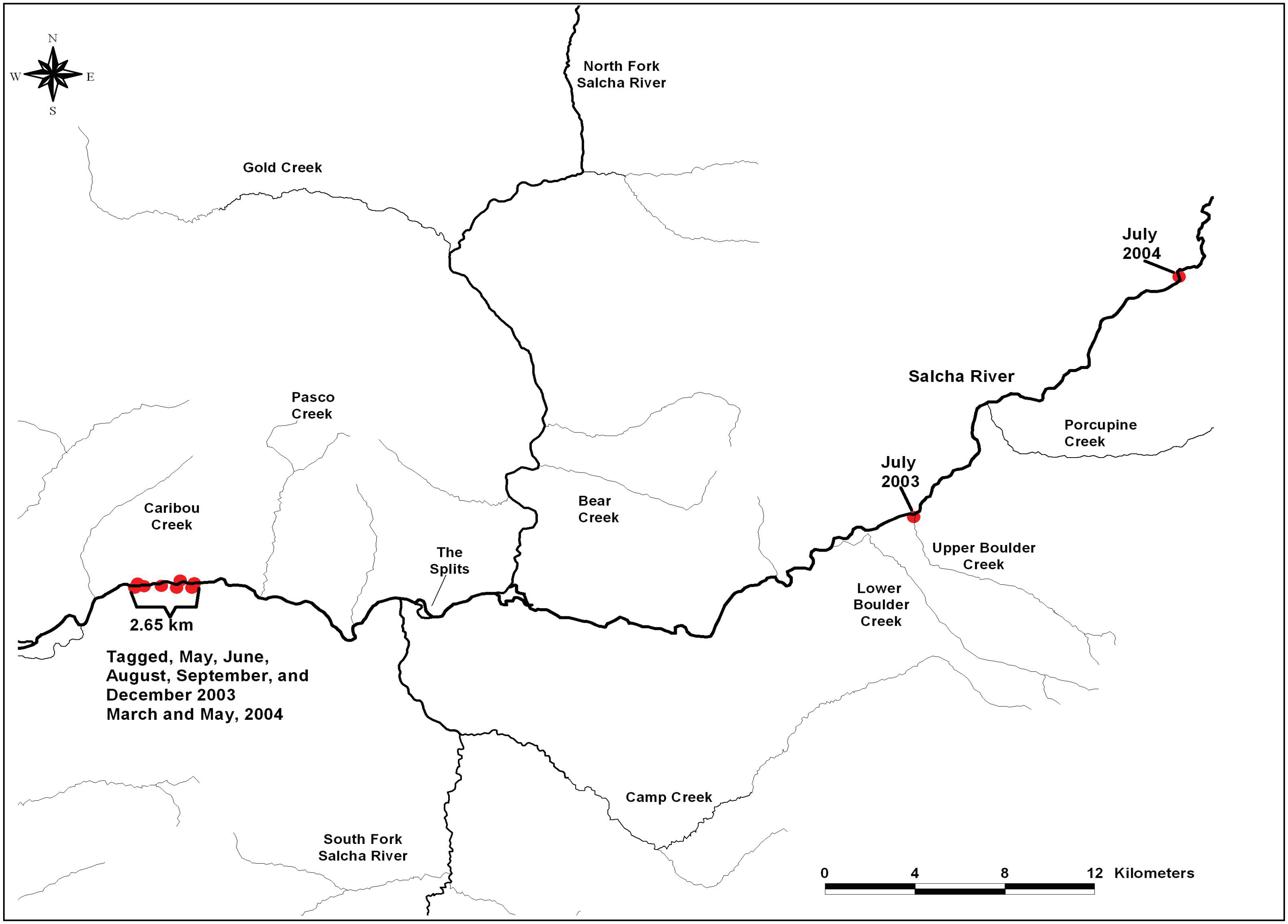

Figure 12.–Movements of fish 7–5 during the study period (May 2003–July 2004).

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). Northcote (1997) stated that trophic, refuge, and reproductive migrations resulted from spatial, seasonal, and ontogenetic separation of optimal habitats for growth, survival, and reproduction, and which also has much regional variation of these complex cycles of Arctic grayling. 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, 1998b, 1998c; Gryska 2006). These migrations vary in duration, occur within a river and among rivers, and often involve homing to specific areas (Reed 1964; Tack 1980; Ridder 1985, 1991, 1998b, 1998c, 2000; Buzby and Deegan 2000; Gryska 2006). This study indicated that the behavior is complex and can not be easily generalized, as behavior varied substantially by individual and by year (Tables 9 and 10, Figures 12-14, Appendix B2).

Although small numbers of Arctic grayling tagged in other rivers have been observed to migrate to the Salcha River for the summer (Ridder 1991), the migrations of the spring spawning population in the Salcha River study area occurred wholly in the Salcha River drainage. Fidelity and infidelity to spring spawning and summer feeding was observed (Table 10, Figures 12–14). Among 15 viably tagged fish during spring 2004, 7 fish were within 2 km of their previous spawning location, and 8 fish were between 7 and 78 km distant from the previous year's spawning location. The degree of fidelity to summer feeding areas was similar with 6 of 13 viably tagged fish returning to within 2 km of the previous years' feeding locations and the 7 others were between 15 and 110 km distant from the previous summer location.

The variability in fidelity (albeit from a small sample size) did not appear to be related to length, weight, or sex, however this study did not attempt to describe potential causes of the behavior. It has been previously observed that homing to summer feeding and spring spawning habitat occurs frequently (Deegan and Buzby 2000; Northcote 1997; Ridder 1985, 1998b, 1998c, 2000). Ridder (2000) observed that fidelity to spawning areas (based on Floy tags) to be a bit higher on the Chena (69%) and Goodpaster (76% to 80 %) rivers. With respect to fidelity to summer feeding areas, Hughes (2000) predicted, based on Chena River data, that the larger fish of the population were less likely to move a significant distance (> 10 km) because a habitat model (Hughes and Reynolds 1994; Hughes 1998) suggested that there is no reason for the largest fish to leave the most profitable (in terms of growth) space. Hughes' (2000) model also suggested that smaller fish will be more likely to move as they grow to occupy the most profitable spaces. In contrast, Buzby and Deegan (2000) found a high degree of fidelity for Arctic grayling in the Kuparuk River, but no evidence of a shift in locations due to size or the previous year's growth. They postulated that inter-annual variability in physical factors (e.g. river discharge and water temperature) was of greater significance than spatial variability in habitat quality; therefore it was unrewarding for Arctic grayling to travel significantly from year-to-year during the brief Arctic summer. Because of the variability of movements observed in this study without any obvious patterns, the results of this study do not fully support the conclusions of Hughes (2000) or Buzby and Deegan (2000) as applicable to the Salcha River.

Table 9.–Maximum, minimum, and average movement (km) observed between surveys.

	Survey Date								
Movement	5/23/2003	6/26&28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
Maximum downstream movement	-46.5	-63.3	-48.7	-45.2	-57.3	-29.3	-16.5	-34.3	-19.1
Minimum movement	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5
Maximum upstream movement	35.5	56.6	82.6	56.4	3.1	15.7	15.8	11.3	96.6
Average absolute distance[a]	11.4	20.3	14.9	10.7	10.7	10.0	2.8	7.4	31.6

[a] Average absolute distance is the average distance in absolute numbers for the migratory period.

Table 10.–Homing of radiotagged Arctic grayling alive during May and July 2004 to the previous years' spring spawning and summer feeding locations.

				Same location		Distance (km) between	
Channel-Code	mm FL	Weight (g)	Gender	May	July	May locations	July locations
7-1[a]	349	427	F	No	?	14	?
6-8	356	476	F	No	No	9	20
6-6	390	592	F	No	Yes	11	<2
8-1[a]	374	599	F	Yes	?	<2	?
8-9	395	626	F	No	No	21	35
12-4[b]	380	651	F	Yes	Yes	<2	<2
8-3	425	664	F	Yes	Yes	<2	<2
7-2[b]	340	466	F	No	Yes	15	<2
12-9	375	542	M	No	No	40	110
21-10	393	598	M	No	Yes	78	<2
8-5	403	665	M	No	No	15	15
8-7	410	689	M	No	No	7	20
8-8	424	693	M	Yes	No	<2	40
7-5	385	544	M	Yes	No	<2	15
7-8	395	630	M	Yes	Yes	<2	<2

[a] A location was not obtained during July 2004.

[b] A location was not obtained during July 2003, but locations during June and August 2003 were the same and substituted in this analysis.

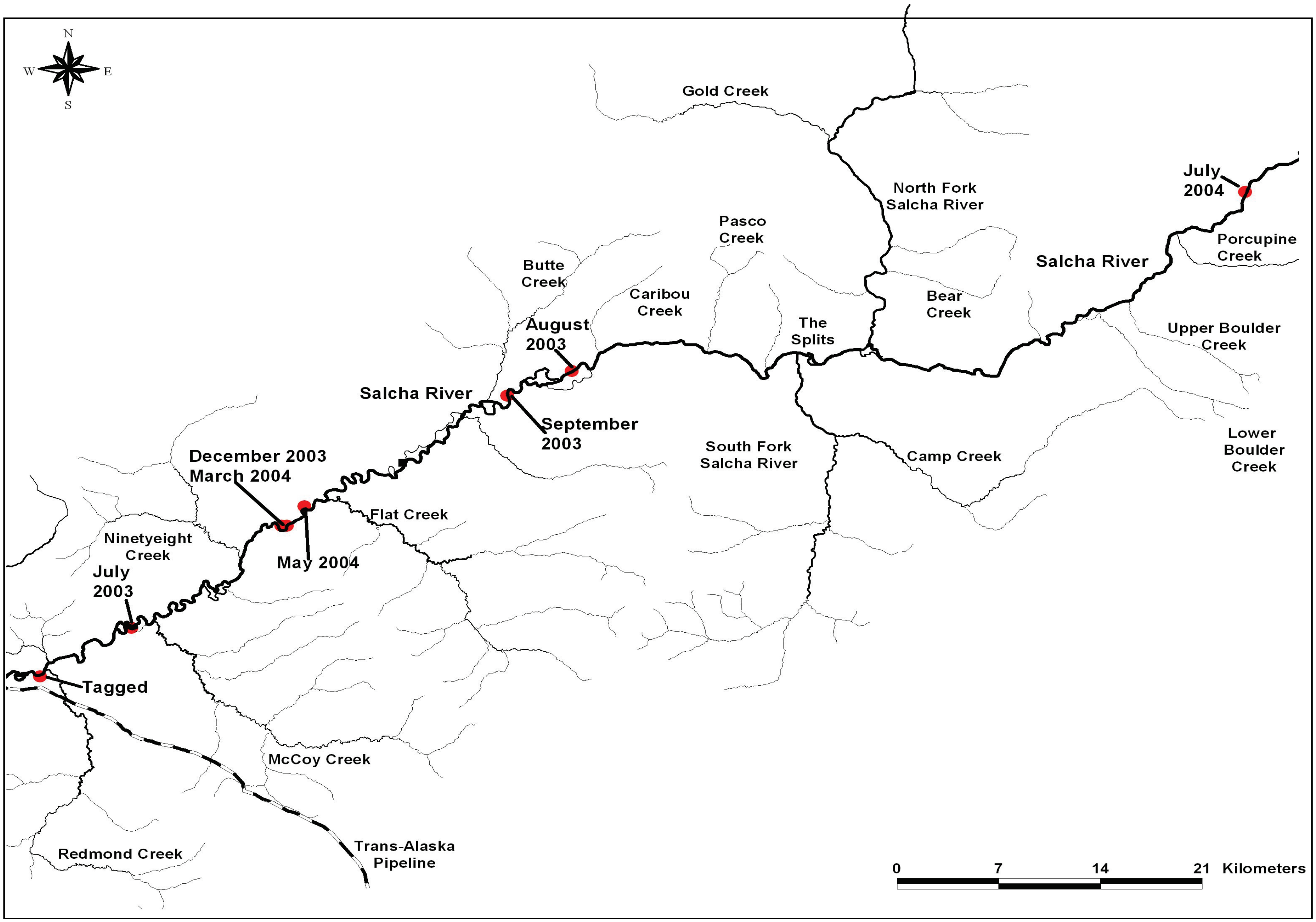

Figure 13.–Movements of fish 12–9 during the study period (May 2003–July 2004).

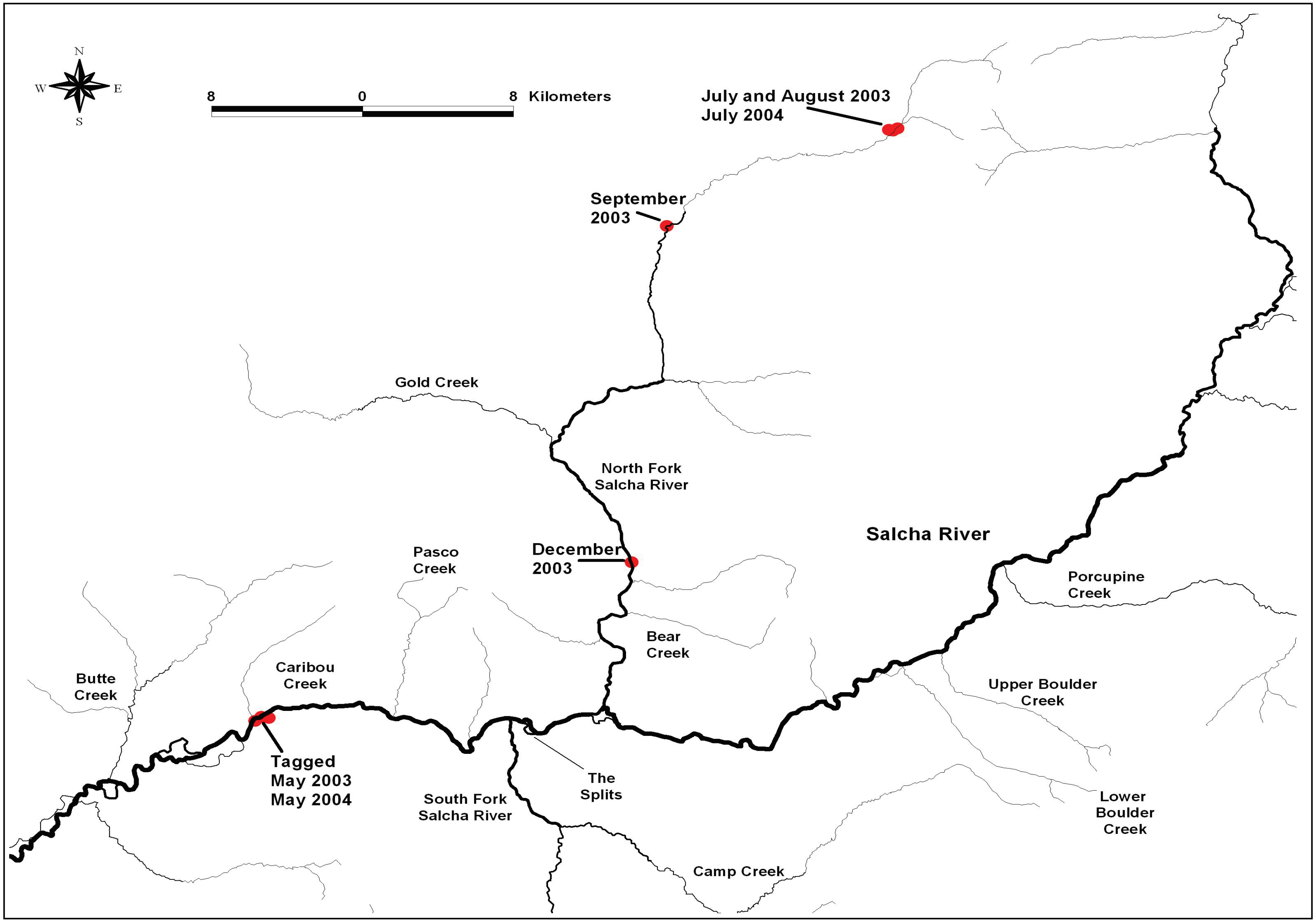

Figure 14.–Movements of fish 8–3 during the study period (May 2003–July 2004).

CONCLUSIONS AND RECOMMENDATIONS

The results of this phase of the study demonstrated that a large proportion (i.e., 30%–50%) of the Arctic grayling that utilized the Salcha River study area for spawning exited that area during the summer. In addition, most other radiotagged fish inside the fishery area (14 of 19 during July 2003) were upstream of Flat Creek (rkm 75.4), which lies outside the area where most of the recreational cabins are located and a considerable distance from the boat launch. Therefore, it is likely that a smaller portion of the total Salcha River fishery effort occurs upstream of Flat Creek, and it is reasonable to assume exploitation of Salcha River spawners is less than when SWHS estimates are applied uniformly across the entire study area.

The movements of the radiotagged fish indicated that the mainstem Salcha River between Flat Creek and the North Fork Salcha River is an important area containing all three habitat types (overwinter, spawning, and feeding) necessary for Arctic grayling survival, growth and reproduction. In addition, the portion of the mainstem Salcha River between the North Fork Salcha River and Porcupine Creek, based on aerial surveys and inspections of topographical maps, has very similar habitats and very well could hold a similar population of Arctic grayling. Very little is known of this portion of the Salcha River. Holmes (1984) had sampled this area and had higher hook-and-line catch rates of large Arctic grayling then downstream of the North Fork Salcha River. It is likely that a large, less exploited stock of spawning Arctic grayling exists upstream of the North Fork Salcha River mouth and that their progeny contribute to recruitment of Arctic grayling in downstream reaches.

There was no evidence indicating additional mortality occurred when implanting radio tags during the spring spawning period as compared to the summer months. Very few studies have been conducted where internal radio tags have been placed in 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, 1998b, 1998c; West et al. 1992; Gryska 2006). Additionally, a portion of the mortality was likely natural, which has been estimated at 26.7% annually for fish ≥ age-3 in the Chena River (Clark 1992b), and 28% at a Kupurak River study site (unpublished data presented in Buzby and Deegan 2000). Applying the Chena River natural mortality rate to these fish would have resulted in about 14 deaths within a year.

Because the determination of fate of radiotagged fish can be problematic, future studies need to focus on improving the ability to accurately assess fate assignments. Ground surveys, where and when possible, should be employed to verify fate. In addition, the use of radio tags with motion or mortality sensors could prove to be more accurate and easier and cheaper logistically. Currently, similar sized, programmable radio tags with motion sensors and potential life spans of 3 years are available for a nominal extra expense.

CHAPTER II: ABUNDANCE AND LENGTH AND AGE COMPOSITION OF ARCTIC GRAYLING IN THE SALCHA RIVER DURING SPRING AND SUMMER, 2004

OBJECTIVES

The research objectives for this phase of the project were to:

1) Estimate the abundances of Arctic grayling ≥ 150, ≥ 270, and ≥ 330 mm FL in the Salcha River between its mouth and rkm 116.4, as well as that within the original 35.1 km index area between rkm 3.3 and 38.4, during May 2004 such that the estimates are within 25% of the actual abundance 95% of the time;
2) Estimate the age composition (age-1 to -6 and ≥ age-7) of the Arctic grayling population ≥ 150 mm FL in the Salcha River between its mouth and rkm 116.4 during May 2004 such that the estimates are within five percentage points of the true value 95% of the time;
3) Estimate the length composition (in 10 mm intervals) of the Arctic grayling population ≥ 150 mm FL in the Salcha River between its mouth and rkm 116.4 during May 2004 such that the estimates are within five percentage points of the true value 95% of the time;
4) Estimate the age and length composition of the summer Arctic grayling population within the original 35.1 km Salcha River index area between rkm 3.3 and 38.4 during May 2004 such that all proportion estimates are within five percentage points of the true value 95% of the time.
5) Estimate the abundances of Arctic grayling ≥ 150, ≥ 270, and ≥ 300 mm FL in the Salcha River between its mouth and rkm 116.4, as well as that within the original 35.1 km Salcha River index area between rkm 3.3 and 38.4, during the last week of June 2004 such that the estimates are within 25% of the actual abundance 95% of the time;
6) Estimate the age composition (age-1 to -6 and ≥ age-7) of the Arctic grayling population ≥ 150 mm FL in the Salcha River between its mouth and rkm 116.4 during the last week of June 2004 such that the estimates are within five percentage points of the true value 95% of the time;
7) Estimate the length composition (in 10 mm intervals) of the Arctic grayling population ≥ 150 mm FL in the Salcha River between its mouth and rkm 116.4 during the last week of June 2004 such that the estimates are within five percentage points of the true value 95% of the time;
8) Estimate the age and length composition of the summer Arctic grayling population within the original 35.1 km Salcha River index area between rkm 3.3 and 38.4 during the last week of June 2004 such that all proportion estimates are within five percentage points of the true value 95% of the time.

METHODS

STUDY DESIGN

During spring and summer 2004, the study was designed to estimate abundance and length and age composition of Arctic grayling within a 116.4 km study area of the Salcha River (Figure 1) using two-event Petersen mark-recapture techniques for a closed population (Seber 1982) designed to satisfy the following assumptions:

1) The population was closed (Arctic grayling did not enter the population, via growth or immigration, or leave the population, via death or emigration, during the experiment);
2) All Arctic grayling had a similar probability of capture in the first event or in the second event, or marked and unmarked Arctic grayling mixed completely between events;
3) Marking of Arctic grayling did not affect the probability of capture in the second event;
4) Marked Arctic grayling were identifiable during the second event; and,
5) All marked Arctic grayling were reported when recovered in the second event.

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

$$\hat{N} = \frac{n_1 n_2}{m_2} \tag{6}$$

where:

$n1$ = the number of Arctic grayling marked and released during the first event;

$n2$ = the number of Arctic grayling examined for marks during the second event; and,

$m2$ = the number of marked Arctic grayling recaptured during the second event.

The sampling design and data collected allowed the validity of the five assumptions to be ensured or tested. The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate if the assumptions were met (Appendices A1, A2, and A3).

The study area encompassed the lower 116.4 km of the Salcha River, from the lower end of "The Splits" (rkm 116.4) down to the mouth at the Tanana River (Figure 1), and it excluded tributaries of the Salcha River within the reach. This study area was three times as large as the previous 35.1 km assessment area (Clark and Ridder 1990; Clark et al. 1991; Fleming et al. 1992; Ridder et al. 1993; Roach 1994, 1995). The study area boundaries were deemed to contain almost all (i.e., >95%) of the Salcha River fishing effort (M. Doxey, Alaska Department of Fish and Game-retired, Fairbanks, personal communication). Abundance and composition was also estimated in the original 35.1 km Salcha River index area between rkm 3.3 and 38.4 so that estimates obtained in 2004 were comparable to estimates from 1989 to 1994. However, sampling effort was designed for the primary objective of the larger study area, and estimates for the original index area were formed from data culled from the primary study.

Sampling for the spring abundance estimate occurred May 4–8 (1st event) and May 12–16 (2nd event). A brief, unplanned, 4-day hiatus occurred between events due to high water. Sampling for the summer abundance estimate occurred from June 25–29 and July 8 and 9 (1st event) and

July 10–16 (2nd event). The break in summer sampling during the 1st event was due to an outdoor work-stop order when dense smoke from forest fires resulted in hazardous health conditions.

The timing and short duration of the experiments helped to ensure that the movement of fish did not violate the assumption of closure. The spring sampling began just after breakup in early May when Arctic grayling are relatively stationary during the brief spawning period (Tack 1980; Ridder 1985, 2000; Beauchamp 1990). After spawning, Arctic grayling migrate to summer feeding areas. Upon reaching summer feeding areas by mid-June, Arctic grayling have been thought to remain relatively stationary (in general, only localized movements of < 2.5 rkm) until mid-September (Tack 1973; Ridder 1999; Gryska 2006, 2007; Wuttig and Stroka 2007), but the radiotelemetry study indicated that month to month movements during this period were more substantial, averaging 10.7 to 14.9 km (Table 9 and Appendix B2). Nonetheless, to ensure that fish were less likely to have moved between events during the summer sampling period, each event was 5–6 days and the hiatus between events was kept as short as possible. The short duration of the experiments rendered growth, recruitment, and mortality insignificant in terms of potential bias, allowed for localized mixing of marked and unmarked fish, and allowed marked fish to recover from the effects of handling between events.

The selection of the large sampling area diminished the influence of movements on the abundance estimates because the scale of movements was relatively small compared to the size of the sampling sections. Moreover, the lower boundary of the study area was located in an area of very low fish densities and was bounded by the glacial Tanana River which is not preferred habitat for summer feeding. Most Salcha River tributaries were frozen in the spring and were undesirable large fish habitat in the summer. Therefore, the number of fish immigrating and emigrating due to local movements was anticipated to be insignificant.

Two boats equipped with electrofishing gear (see description in chapter 1) were used to capture Arctic grayling. Each boat consisted of a three-person crew; two to capture fish with dip nets, and one to pilot the boat and operate the electrofishing gear. In an attempt to distribute effort uniformly, the entire sampling area was fished in a downstream progression with both boats operating simultaneously on opposite sides of the river seeking areas of highest fish densities (except May 6–8, when mechanical problems rendered only one boat available to sample runs 20–48). During spring, areas most likely to hold fish included stream edges and back eddies when the water temperature was less than 4°C, and riffles when the temperature was greater than 4°C. During summer, fish were typically found in glides and pools immediately downstream of riffles. If multiple channels were encountered, either one or two boats, depending on the size of the channel, sampled all that were navigable.

The boats were operated for 20 min intervals, defined as a run, and captured Arctic grayling were held in an aerated tub until they were sampled and returned to the river approximately 100 to 200 m upstream from the lower boundary of a run. The run boundaries of the experiment (spring or summer) were defined in the first event by the end of each run or the confluences of major tributaries or the boundaries of the old study area (e.g., Flat Creek and Koepke Slough). During the first event, run boundaries were flagged and locations recorded using a GPS. The same boundaries were used during the second event to evaluate variability of capture probabilities and movement throughout the study area at a scale of a run. The length of a run ranged between 2.0 and 2.5 km depending on water velocities. Runs in summer were shorter in general due to slower flows, however run boundaries associated with the section boundaries and the past assessment area were the same for both mark-recapture experiments to facilitate comparisons.

Sample size objectives for estimating abundance were established using methods in Robson and Regier (1964) and for length and age compositions using criteria developed by Thompson (1987) for multinomial proportions.

DATA COLLECTION

At the completion of each run, all captured fish were measured for length (mm FL) and carefully examined for marks. In the first event for both experiments, fish ≥ 150 mm FL were tagged with an individually numbered Floy FD-94 internal anchor tag (gray in color and numbered between 6,001 and 10,000) and received an experiment-specific finclip to identify tag loss (the left pelvic clipped during spring and the left pectoral during summer). To eliminate duplicate sampling in the second event, each fish had a fin clipped (the right pelvic clipped during spring and the right pectoral during summer). All fish were carefully inspected for attendant Floy tags and finclips. Fish captured in the first event that exhibited signs of injury, excessive stress, or imminent death were not marked and censored from the experiment.

For all fish ≥150 mm FL sampled in the first and second events, two scales from each fish were removed for aging and placed on gummed scale cards. Scales were taken from six scale rows above the lateral line just posterior to the insertion of the dorsal fin (Brown 1943). After completion of fieldwork, the gummed cards were used to make triacetate impressions of the scales (30 s at 137,895 kPa, at a temperature of 97ºC). Ages were determined by counting annuli from the triacetate impressions magnified to 40X with a microfiche reader as described by Yole (1975).

DATA ANALYSIS

Abundance Estimate

When capturing fish in a river using electrofishing boats it is inherently difficult to approximate the taking of a simple random sample (i.e., a random sample without replacement). Therefore, samples from the Salcha River were taken systematically in the sense of progressively moving downstream and sampling proportionally to the abundance of fish present (discussed above with respect to Assumption 2). Under these circumstances the Bailey-modified Petersen estimator (Appendix A1; Bailey 1951, 1952) is preferred over the Chapman-modified Petersen estimator (Chapman 1951) for estimating abundance.

Violations of Assumption 2 relative to size effects were tested for using two-sample Kolmogorov-Smirnov (K-S) tests with significance level $\alpha = 0.05$. There were four possible outcomes of these tests relative to evaluating size selective sampling (either one of the two samples, both, or neither of the samples were biased) and two possible actions for abundance estimation (length stratify or not). The tests and possible actions for data analysis are outlined in Appendix A2. If stratification by size was required, capture probability by location were examined for each length stratum.

Tests for consistency of the Petersen estimator (Seber 1982; Appendix A3) were used to determine if stratification by location was required due to spatiotemporal effects and to determine the appropriate abundance estimator: the pooled Bailey-modified Petersen estimator, the completely stratified Bailey-modified Petersen estimator, or a partially stratified estimator

(Darroch 1961). Assumption testing was performed at the scale of a section with significance level $\alpha = 0.05$. This grouping strategy generally provided a sufficient number of recaptures for diagnostic testing to ensure negligible statistical bias in $\hat{N}$ (Seber 1982) and accommodated localized movements of Arctic grayling.

Movement

Relative to Assumption 1, closure was not tested directly but inferred from examination of the movement of recaptured Arctic grayling within the study area. The data were examined for evidence of movement away from or towards the boundaries of the study area to provide evidence of immigration and emigration.

Length and Age Compositions

Length and age compositions of the population were estimated using the procedures outlined in Appendices A2 and A4. Length composition was estimated in 10 mm length categories. Age composition was described for individual age classes 1-6, but fish 7 years and older were lumped into a single age category (7+) because of error associated with assigning ages to older Arctic grayling (DeCicco and Brown 2006)

RESULTS

SPRING ABUNDANCE ESTIMATE

Movement was evaluated for 69 of 70 recaptured fish as one recaptured fish was missing a Floy tag which rendered its marking run unknown. Because fish were released relatively close to the lower boundary of a run, downstream movement was defined as a fish that was recaptured beyond the adjacent downstream run and upstream movement was defined as a fish that had moved into or beyond an adjacent upstream run. Using this definition of movement, only 17 of the 69 (25%) recaptured Arctic grayling had not moved (Figure 15), and 44 (64%) recaptured Arctic grayling had moved 1 to 6 runs (the length of a run ranged between 2–2.5 km). Only one fish moved more than 10 runs (28 runs downstream). Among all recaptures, 28 moved downstream and 24 moved upstream. Grouping recaptured fish by the larger sections, 43 out of 69 fish (62%) were recaptured within the same section they were tagged in (Table 13). Very low densities of fish were observed near the lower boundary of the study area as only 20 fish were captured in the lower most run during both events combined.

In the 116.4 km study area, 2,760 Arctic grayling ≥ 150 mm FL were captured (n1 = 1,195, n2 = 1,565, m2 = 70, however the smallest recapture was 210 mm FL. Therefore, abundance was estimated for fish ≥200 mm FL (of which 2,567 Arctic grayling were handled, n1 = 1,174, n2 = 1,393, m2 = 70) because the estimate would likely be biased as capture probabilities decrease with decreasing fish size. In the original 35.1 km study area, 598 Arctic grayling ≥ 150 mm FL were captured (n1 = 188, n2 = 410, m2 = 12), but the smallest recaptured fish was 242 mm FL, therefore abundance was estimated for fish ≥200 mm FL, of which there were 457 Arctic grayling handled (n1 = 174, n2 = 283, m2 = 12). Only one recaptured fish from the larger study area was observed to have lost its primary mark (Floy tag).

For the 116.4 km study area, K-S test (Appendix A2) results indicated that for three size groups (≥ 200, ≥ 240, and ≥ 270) there was size-selective sampling during the first event but not during the second event (Case III; Table 11). Therefore, data and estimates were not stratified by length, but composition estimates were generated from second event samples only. For Arctic grayling ≥ 330 mm FL, the K-S tests indicated samples were not size selective for either event (Case I; Table 11).

For the original 35.1 km study area, K-S tests results indicated for all Arctic grayling ≥ 200 mm FL, there was size-selective sampling during the first event but not during the second event (Case III; Table 11). Therefore, data and abundance estimates were not stratified by length, but composition estimates were generated from second event samples only. For Arctic grayling ≥ 240 and ≥ 270 the K-S tests indicated samples were not size selective for either event (Case I; Table 11). Stratification by length was not necessary and composition estimates were generated from first and second event samples combined. For Arctic grayling ≥ 330 mm FL, there were only three fish recaptured during the second event making the K-S tests unreliable. Case I was assumed for this group based on the K-S test results in the 116.4 km study area.

For both study areas and all size groups, one or more consistency tests failed to be rejected (Tables 12, 13, and 14; Appendix A3). Therefore, there was no need to geographically stratify the data and the Bailey-modified Petersen estimator was used to calculate all abundance estimates for each study area and length stratum.

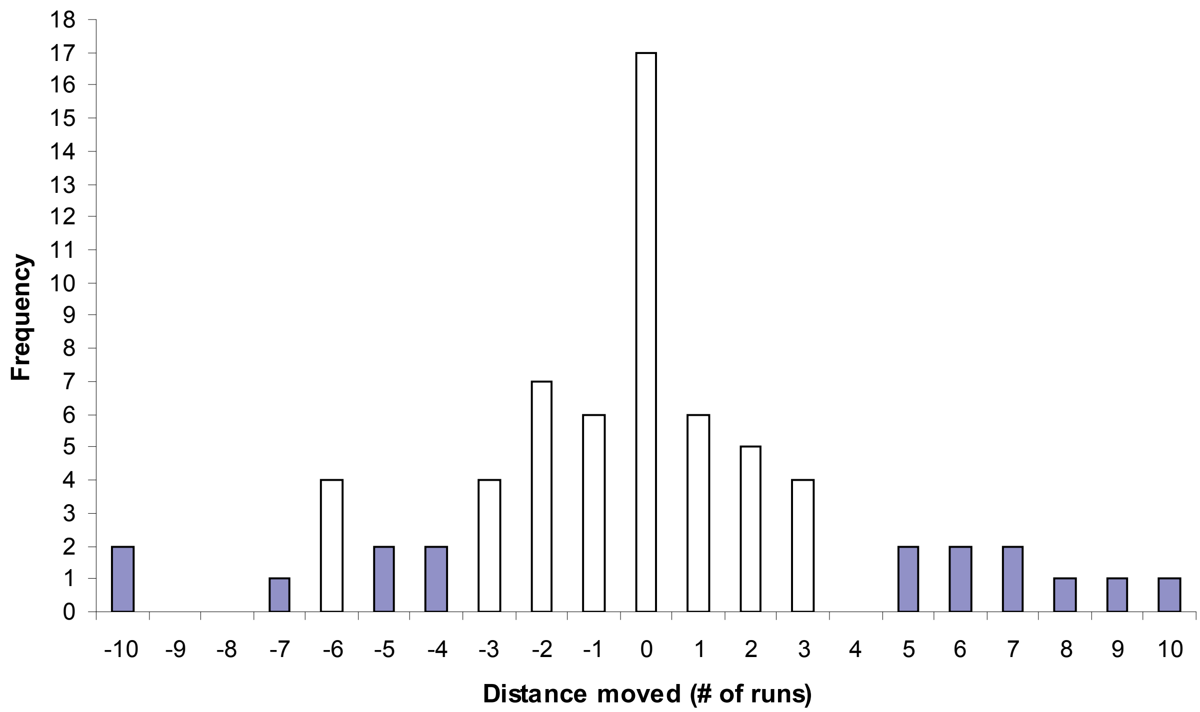

Figure 15.–Frequency of recaptured Arctic grayling (n = 69; one additional recapture had a missing tag and unknown mark run) that remained in the run where tagged (0), or moved upstream (positive values) or downstream (negative values) one or more runs in the Salcha River study area, spring 2004.

Table 11.–Results of diagnostics used to detect and correct for size-selective sampling (Appendix A2) for estimating abundance and length and age compositions of Arctic grayling in the 116.4 and 35.1 km Salcha River study areas, spring 2004.

Study area and FL group	Comparison and Test Statistic: M vs. R	Comparison and Test Statistic: C vs. R	Result
116.4 km Section			
≥ 200 mm FL	D = 0.12 P-value = 0.31 Fail to reject H_0	D = 0.30 P-value = 0.00 Reject H_0	Case III, do not stratify, use lengths and ages from the second event only for composition analysis
≥ 240 mm FL	D = 0.13 P-value = 0.20 Fail to reject H_0	D = 0.29 P-value = 0.00 Reject H_0	Case III, do not stratify, use lengths and ages from the second event only for composition analysis
≥ 270 mm FL	D = 0.08 P-value = 0.87 Fail to reject H_0	D = 0.20 P-value = 0.02 Reject H_0	Case III, do not stratify, use lengths and ages from the second event only for composition analysis
≥ 330 mm FL	D = 0.14 P-value = 0.46 Fail to reject H_0	D = 0.09 P-value = 0.89 Fail to reject H_0	Case I, do not stratify, use lengths and ages from both events for composition analysis
35.1 km Section			
≥ 200 mm FL	D = 0.22 P-value = 0.65 Fail to Reject H_0	D = 0.40 P-value = 0.04 Reject Ho	Case III, do not stratify, use lengths and ages from the second event only for composition analysis
≥ 240 mm FL	D = 0.16 P-value = 0.94 Fail to reject H_0	D = 0.23 P-value = 0.54 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis
≥ 270 mm FL	D = 0.21 P-value = 0.85 Fail to reject H_0	D = 0.18 P-value = 0.94 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis
≥ 330 mm FL[a]			Case I (assumed), do not stratify, use lengths from both events for composition analysis

[a] Due to small sample sizes (n_1=33, n_2=37, m_2=3), K-S tests could not be performed.

Table 12.–Results of consistency tests for the Petersen estimator (Appendix A3) for estimating abundance of Arctic grayling for the 116.4 and 35.1 km Salcha River study areas, spring 2004.

	Consistency Test		
	I	II	III
Study area and FL group	**Complete Mixing**	**Equal probability of Capture, 1st Event**	**Equal Probability of Capture, 2nd Event**
116.4 km Section			
≥ 200 mm FL	$\chi^2 = 162.62$ P-value ≤ 0.01	$\chi^2 = 8.67$ P-value = 0.12	$\chi^2 = 8.42$ P-value = 0.13
≥ 240 mm FL	$\chi^2 = 167.64$ P-value ≤ 0.01	$\chi^2 = 7.01$ P-value = 0.22	$\chi^2 = 9.49$ P-value = 0.09
≥ 270 mm FL	$\chi^2 = 156.42$ P-value ≤ 0.01	$\chi^2 = 6.56$ P-value = 0.25	$\chi^2 = 8.54$ P-value = 0.13
≥ 330 mm FL	$\chi^2 = 132.15$ P-value ≤ 0.01	$\chi^2 = 5.67$ P-value = 0.34	$\chi^2 = 7.92$ P-value = 0.16
35.1 km Section			
≥ 200 mm FL	$\chi^2 = 1.49$ P-value = 0.48	$\chi^2 = 0.15$ P-value = 0.70	$\chi^2 \leq 0.01$ P-value = 0.97
≥ 240 mm FL	$\chi^2 = 1.51$ P-value = 0.47	$\chi^2 = 0.24$ P-value = 0.62	$\chi^2 \leq 0.01$ P-value = 0.97
≥ 270 mm FL	$\chi^2 = 1.00$ P-value = 0.61	$\chi^2 = 0.77$ P-value = 0.38	$\chi^2 = 0.05$ P-value = 0.82
≥ 330 mm FL	$\chi^2 = 1.63$ P-value = 0.44	$\chi^2 = 0.31$ P-value = 0.58	$\chi^2 = 0.51$ P-value = 0.47

Table 13.–Number of Arctic grayling ≥200 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in the 116.4 km Salcha River study area, spring 2004.

		Section where recaptured								
		1	2	3	4	5	6	m_2	n_1	m_2/n_1[b]
Section where marked	1	10	3	0	0	1	0	14	342	0.04
	2	3	9	2	0	0	0	14	181	0.08
	3	1	7	8	4	0	0	20	283	0.07
	4	0	0	1	4	0	0	5	172	0.03
	5	0	0	0	0	8	3	11	135	0.08
	6	0	0	0	0	1	4	5	61	0.08
	m_2	15[c]	19	11	8	10	7			
	n_2	282	226	270	265	178	172			
	(m_2/n_2)[a]	0.05	0.08	0.04	0.03	0.06	0.04			

[a] Probability of capture during first event.

[b] Probability of capture during second event.

[c] One fish was recaptured without Floy tag (section marked unknown) and was not presented in the matrix but added to the section 1 recaptured total.

Table 14.–Number of Arctic grayling ≥200 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in the 35.1 km Salcha River study area, spring 2004.

		Section where recaptured				
		5	6	m_2	n_1	m_2/n_1[b]
	5	5	3	8	115	0.07
Section where marked	6	1	3	4	59	0.07
	m_2	6	6			
	n_2	126	157			
	(m_2/n_2)[a]	0.05	0.04			

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Estimated abundances of Arctic grayling were:

1) 116.4 km study area:
    a. ≥ 200 mm FL was 23,050 (SE = 2,646);
    b. ≥ 240 mm FL was 19,372 (SE = 2,232);
    c. ≥ 270 mm FL was 13,407 (SE = 1,643); and,
    d. ≥ 330 mm FL was 6,258 (SE = 898).
2) Original 35.1 km study area:
    a. ≥ 200 mm FL was 3,801 (SE = 992);
    b. ≥ 240 mm FL was 2,145 (SE = 553);
    c. ≥ 270 mm FL was 1,331 (SE = 384); and,
    d. ≥ 330 mm FL was 314 (SE = 133).
    e.

SPRING LENGTH AND AGE COMPOSITION

A large majority of Arctic grayling ≥ 200 mm FL were in the 240 to 299 mm FL (47%) and 350 to 389 mm FL (20%) length categories, and were predominately ages-4, 5, and 6 (72%; Appendix B5; Appendix B6). Length and age composition of Arctic grayling in the upper (1–3) and lower (4–6) sections of the study area exhibited differences with the upper sections containing slightly older and larger fish. The upper section had 44% of its Arctic grayling ≥ 350 mm FL, 43% ≤ 300 mm FL, and 37% of fish ≥ age-7. The lower sections had 8% of Arctic grayling ≥ 350 mm FL, 80% ≤ 300 mm FL, and only 7% ≥ age-7. The 35.1 km study area was similar in composition to the lower study area as it was nearly 2/3 of the lower study area.

SUMMER ABUNDANCE ESTIMATE

Movement, as previously defined, was less frequent in summer than during spring. Forty of the 59 (68%) recaptured Arctic grayling did not move (Figure 16), and 15 (25%) recaptured fish moved 1 to 3 runs. The one fish that travelled farthest moved 7 runs downstream. Among all recaptures, 7 moved downstream and 12 moved upstream. Grouping recaptured fish by the larger sections, 52 out of 59 fish (88%) were recaptured within the same section they were tagged in (Table 17). Very low densities of fish were observed near the lower boundary of the study area as only 14 fish were captured in the lower most run during both events combined.

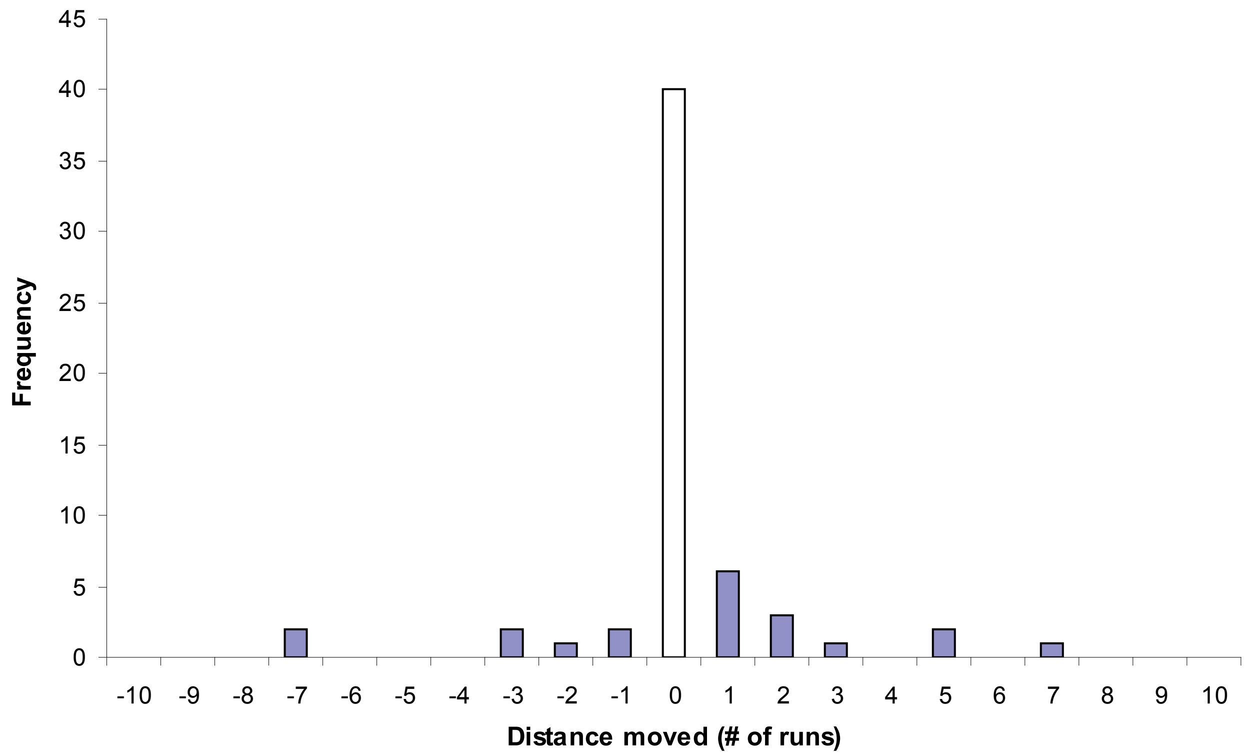

Figure 16.–Frequency of recaptured Arctic grayling (n = 59) that remained in the run where tagged (0), or moved upstream (positive values) or downstream (negative values) one or more runs in the Salcha River study area, summer 2004.

In the 116.4 km study area, 2,436 Arctic grayling ≥ 150 mm FL were captured (n_1 = 1,229, n_2 = 1,207, m_2 = 60) and the smallest recaptured fish was 196 mm FL. To be comparable to the spring estimate, the abundance was estimated for fish ≥ 200 mm FL, of which there were 2,253 Arctic grayling handled (n_1 = 1,144, n_2 = 1,109, m_2 = 59). In the original 35.1 km study area, 671 Arctic grayling ≥ 150 mm FL were captured (n_1 = 333, n_2 = 338, m_2 = 21), but the smallest recaptured fish was 265 mm FL. To be comparable to the spring estimate, abundance was estimated for fish ≥ 270 mm FL of which there were 393 Arctic grayling handled (n_1 = 200, n_2 = 193, m_2 = 18).

For the 116.4 km study area, K-S tests (Appendix A2) results indicated that for Arctic grayling ≥ 200 mm FL there was size-selective sampling during the first event but not during the second event (Case III; Table 15). Therefore, data and estimates were not stratified by length, but compositions were estimated from second event samples only. For Arctic grayling ≥ 240, ≥ 270, and ≥ 330 mm FL, the K-S tests indicated samples were not size-selective for either event (Case I; Table 15), and stratification by length was not necessary. Compositions were estimated from first and second event samples combined. For the original 35.1 km study area, K-S tests results indicated that for Arctic grayling ≥ 270 mm FL and ≥ 330 mm FL samples were not size-selective for either event (Case I; Table 15). Stratification by length was not necessary and composition estimates were generated from first and second event samples combined.

For both study areas and all size groups, one or more consistency tests (Appendix A3) failed to be rejected (Tables 16, 17, and 18). Therefore, there was no need to stratify by section and the Bailey-modified Petersen estimator was used to calculate all abundance estimates for each sample area and size group of fish.

Table 15.–Results of diagnostics used to detect and correct for size-selective sampling (Appendix A2) for estimating abundance and length and age compositions of Arctic grayling in the 116.4 and 35.1 km Salcha River study areas, summer 2004.

	Comparison and Test Statistic		
Study area and FL group	**M vs. R**	**C vs. R**	**Result**
116.4 km Section			
≥ 200 mm FL	D = 0.14 P-value = 0.21 Fail to reject H_0	D = 0.19 P-value = 0.03 Reject H_0	Case III, do not stratify, use lengths and ages from the second event only for composition analysis
≥ 240 mm FL	D = 0.14 P-value = 0.27 Fail to reject H_0	D = 0.16 P-value = 0.12 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis
≥ 270 mm FL	D = 0.13 P-value = 0.36 Fail to reject H_0	D = 0.16 P-value = 0.15 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis
≥ 330 mm FL	D = 0.23 P-value = 0.10 Fail to reject H_0	D = 0.24 P-value = 0.07 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis
35.1 km Section			
≥ 270 mm FL	D = 0.12 P-value = 0.96 Fail to reject H_0	D = 0.15 P-value = 0.84 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis
≥ 330 mm FL	D = 0.20 P-value = 0.97 Fail to reject H_0	D = 0.19 P-value = 0.99 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis

Table 16.–Results of consistency tests for the Petersen estimator (Appendix A3) for estimating abundance of Arctic grayling in the 116.4 and 35.1 km Salcha River study areas, summer 2004.

Study area and FL group	Consistency Test I: Complete Mixing	Consistency Test II: Equal Probability of Capture, 1st Event	Consistency Test III: Equal Probability of Capture, 2nd Event
116.4 km Section			
≥ 200 mm FL	χ^2 = 209.53 P-value ≤ 0.01	χ^2 = 10.75 P-value = 0.06	χ^2 = 4.36 P-value = 0.50
≥ 240 mm FL	χ^2 = 201.89 P-value ≤ 0.01	χ^2 = 12.48 P-value = 0.03	χ^2 = 8.70 P-value = 0.12
≥ 270 mm FL	χ^2 = 186.39 P-value ≤ 0.01	χ^2 = 10.46 P-value = 0.06	χ^2 = 7.17 P-value = 0.21
≥ 330 mm FL	χ^2 = 104.83 P-value ≤ 0.01	χ^2 = 5.40 P-value = 0.37	χ^2 = 3.36 P-value = 0.64
35.1 km Section			
≥ 270 mm FL	χ^2 = 13.97 P-value ≤ 0.01	χ^2 = 1.52 P-value = 0.22	χ^2 = 0.02 P-value = 0.88
≥ 330 mm FL	χ^2 = 14.52 P-value = 0.10	χ^2 = 1.59 P-value = 0.21	χ^2 = 0.48 P-value = 0.49

Table 17.–Number of Arctic grayling ≥ 200 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in the 116.4 km Salcha River study area, summer 2004.

Section where marked		Section where recaptured: 1	2	3	4	5	6	m_2	n_1	m_2/n_1[b]
	1	2	1	0	0	0	0	3	130	0.02
	2	0	5	0	0	0	0	5	123	0.04
	3	0	2	12	1	0	0	15	283	0.05
	4	0	0		11	1	0	12	244	0.05
	5	0	0	0	1	15	0	16	225	0.07
	6	0	0	0	0	1	7	8	139	0.06
	m_2	2	8	12	13	17	7			
	n_2	158	138	216	246	188	163			
	(m_2/n_2)[a]	0.01	0.06	0.06	0.05	0.09	0.04			

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Table 18.–Number of Arctic grayling ≥ 270 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section in the 35.1 km Salcha River study area, summer 2004.

		Section where recaptured				
		5	6	m_2	n_1	m_2/n_1 [b]
Section where marked	5	11	0	11	119	0.09
	6	1	6	7	81	0.09
	m_2	12	6			
	n_2	102	91			
	(m_2/n_2) [a]	0.12	0.07			

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Estimated abundances of Arctic grayling were:

1) 116.4 km study area:
    a. ≥ 200 mm FL was 21,164 (SE = 2,636);
    b. ≥ 240 mm FL was 15,744 (SE = 2,037);
    c. ≥ 270 mm FL was 12,765 (SE = 1,727); and,
    d. ≥ 330 mm FL was 6,928 (SE = 1,198).
2) Original 35.1 km study area:
    a. ≥ 270 mm FL was 2,042 (SE = 434); and,
    b. ≥ 330 mm FL was 1,118 (SE = 380).

SUMMER LENGTH AND AGE COMPOSITION

Overall, Arctic grayling were fairly evenly distributed in size between 200 to 399 mm FL (Appendix B7). Only 19% of fish were ≥ age-7 (Appendix B8). Length and age composition of Arctic grayling in the upper (1–3) and lower (4–6) sections of the study area were similar. The upper section had 33% of its Arctic grayling ≥ 350 mm FL, 44% ≤ 300 mm FL, and 23% of fish ≥ age-7. The lower sections had 23% of Arctic grayling ≥ 350 mm FL, 49% ≤ 300 mm FL, and 15% ≥ age-7. The 35.1 km study area was similar in composition to the lower study area as it was nearly 2/3 of the lower study area.

DISCUSSION

Prior to 2004, the Salcha River Arctic grayling population had not been assessed since 1994. The prior assessments encompassed only the lower third of the fishery and the utility of the information attained from these assessments was limited particularly because the effects of exploitation could not be related to a clearly identified management stock. The goal of this study was to characterize the spring and summer populations in the entire 116.4 km study area using two-event mark-recapture experiments which would establish a baseline and provide for a comparison to previous stock assessments.

Estimates of abundance and length and age composition were attempted for all fish ≥ 150 mm FL but were unsuccessful due to inadequate recaptures of fish < 200 mm FL which inhibited the determination of capture probabilities of these small fish. Valid estimates were generated for fish ≥ 200, ≥ 240, ≥ 270, and ≥ 330 mm FL for all seasons and study areas, except for summer when the 35.1 km area had estimates for fish ≥ 270 and ≥ 330 mm FL only. The estimates of Arctic grayling ≥ 240 mm FL were provided so that future comparisons and insights could be undertaken (some older stock assessments in the Tanana Drainage used this as a size category).

This project was designed to estimate abundance in the larger study area, and secondarily, to estimate the abundance in the smaller area using data extracted from the larger study area data set. The relative precision of estimates of abundance in the larger study area exceeded the objective criteria (≤ ±25%) in all cases, except during summer for fish ≥ 270 (±26.5%) and ≥ 330 (±33.9%). The relative precision of estimates in the smaller study area was quite large, ranging from ±51.2% to ±82.9%, and was well short of objective criteria. Because data from this area were parsed from data collected for the larger area, adequate effort was likely not applied to achieve sample sizes to meet the objective criteria. Estimating abundance of small populations (<5,000), such as in the original index area, requires high capture probabilities (10%–21%) to yield estimates with precision within 25%, 95% of the time. The estimates in the smaller study area were provided for comparison to historical data but were not necessarily expected to provide an authoritative comparison. Rather, in the context of the larger study area estimate, the estimate would be used as evidence of a problem (if one existed), and additional research in the study area was a contingency if deemed necessary. Under these circumstances, the precision was reasonable for the estimate.

There were some differences between the spring and summer estimates of abundance and composition, but they were not very dramatic. Movement was greater during the spring as may be expected of a migratory population in transition between overwinter and spawning. The composition of length and ages was fairly similar overall and for upper and lower sections during summer; however during spring, there was a much larger proportion of smaller, younger Arctic grayling in the lower river and a much larger proportion of larger, older Arctic grayling in the upper river. The study area abundance estimates were not significantly different between spring and summer for any size group of Arctic grayling. In general, densities were much less in the lower river and greater in the upper river during both periods as evidenced by catch rates by section and estimates of abundance (e.g. the 35.1 km study area contained 28% of linear distance of the 116.4 km study area but contained only 10% and 16% of the Arctic grayling abundance ≥ 270 during spring and summer, respectively).

This was the first time abundance was estimated in the 116.4 km study area, and therefore, there were no previous estimates with which to compare. However, the estimate was somewhat comparable to the Chena River estimate of 2005 as the study areas were similarly sized. The abundance of Arctic grayling ≥ 270 mm FL in the 116.4 km study area of the Salcha River during summer 2004 ($\hat{N}$=12,765; *SE*=1,727) was significantly greater than the abundance estimate from the 136 km Chena River study area ($\hat{N}$=7,393, *SE*=606; Wuttig and Stroka 2007), although the abundance of Arctic grayling ≥ 200 mm FL was more similar (Salcha River $\hat{N}$=21,164; *SE*=2,636; and Chena River $\hat{N}$=21,429; *SE*=1,116). A direct comparison of estimates from the original 35.1 km Salcha River index area was possible. Using relative stock densities presented in the reports, abundance of Arctic grayling ≥ 270 mm FL was reconstructed for each year, though variance was not. Nonetheless the 2004 abundance estimate was near the middle of the range of previous estimates, and its 95% confidence interval was inclusive of all other estimates (Table 19). These comparisons indicate the population is presently not a management concern as the Salcha River summer 2004 population estimate is no less than previous estimates and has a larger number of large fish (≥ 270 mm FL) than the Chena River.

Table 19.–Abundance estimates of Arctic grayling ≥ 270 mm FL in the original Salcha River study area (35.1 km) during summer 1989–1994 and 2004.

				95% Confidence Limits	
Year	$\hat{N}$	Period	SE[a]	Lower	Upper
1989	2,081	6/12–6/20			
1990	1,564	6/19–6/27			
1991	1,046	6/18–6/28			
1992	2,235	6/15–6/25			
1993	3,031	6/7–6/17			
1994	2,184	6/13–6/30			
2004	2,042	6/25–7/16	434	1,192	2,893

[a] SE could not be obtained from the table of relative stock indices from which $\hat{N}$ was constructed for 1989–1994 estimates (Roach 1995).

CHAPTER III: EXPLOITATION OF THE 2004 SPRING AND SUMMER POPULATION OF ARCTIC GRAYLING IN THE SALCHA RIVER FISHERY.

OBJECTIVES

1. Estimate the proportion of the summer 2004 population of Arctic grayling ≥ 330 mm FL that is comprised of Salcha River spawners such that the estimate is within 50% of the true value 95% of the time;
2. Estimate exploitation rates on the spring 2004 spawning stock ≥ 270 mm FL and the summer 2004 stock ≥ 270 mm FL present during the last week of June such that the estimates are within 80% of the true value 95% of the time.

In addition, project tasks were to:

1. Observe and record recapture locations of May-tagged fish during the July assessment;
2. Compare length frequency distributions of the spring and summer populations using a Kolmogorov-Smirnov test; and,
3. Observe and record status of sexual maturity of each fish and determine gender for each mature fish.

METHODS

PROPORTION OF THE SUMMER POPULATION COMPRISED OF SALCHA RIVER SPAWNERS (OBJECTIVE 1)

To estimate the proportion of the summer population of Arctic grayling ≥ 330 mm FL that was comprised of Salcha River spawners, results from radio tracking surveys during 2003 and 2004 were used. Two estimates, one from 2003 and one from 2004 were available for the proportion of Salcha River spawners that remained in the fishery during the summer. The 2004 estimate was expected to be less precise due to mortality reducing the sample size. Accounting for the uncertainties in the abundance and proportion estimates, relative precisions of 0.41 (using 2003 proportion) and 0.47 (using 2004 proportion) were expected for the estimate of the proportion of the summer population ≥ 330 mm FL comprised of Salcha River spawners. The precision criterion of the objective was selected to accommodate both the 2003 and 2004 telemetry results and provided a small buffer in the event that actual precision was less than anticipated.

The proportion of the summer feeding stock ≥330 mm FL comprised of Salcha River spawners was estimated as:

$$\hat{p}_{\substack{spawners\\in\ summer}} = \frac{\hat{N}_{\substack{spawners\\in\ summer}}}{\hat{N}_{summer}} = \frac{\hat{p}_{spawners,IN}\hat{N}_{spring}}{\hat{N}_{summer}} \tag{7}$$

where:

$\hat{N}_{\substack{spawners \\ in\ summer}}$ = the estimated number of Arctic grayling ≥ 330 mm FL that spawned in the Salcha River study area during spring and remained as part of the summer feeding stock;

$\hat{p}_{spawners,\,IN}$ = the estimated proportion of Arctic grayling ≥ 330 mm FL that spawned in the Salcha River during spring and remained as part of the summer feeding stock (obtained from the radiotelemetry study initiated in 2003);

$\hat{N}_{spring}$ = the estimated abundance of Arctic grayling ≥ 330 mm FL in the study area during the May 2004; and,

$\hat{N}_{summer}$ = the estimated abundance of Arctic grayling ≥ 330 mm FL in the study area at the end of June 2004.

Each estimate was obtained in a separate experiment; therefore the estimates were independent. As a result, the variance of the proportion of the summer stock comprised of Salcha River spawners was estimated using Goodman's (1960) formula for an exact variance of a product. First, the variance associated with the number of Arctic grayling ≥ 330 mm FL that spawned in the Salcha River study area and remained as part of the summer feeding stock was calculated as:

$$\hat{V}\left[\hat{N}_{\substack{spawners \\ in\ summer}}\right] = \hat{p}^2_{spawners,IN} * \hat{V}\left[\hat{N}_{spring}\right] + N^2_{spring} * \hat{V}\left[\hat{p}_{spawners,IN}\right] - \hat{V}\left[\hat{p}_{spawners,IN}\right] * \hat{V}\left[\hat{N}_{spring}\right] \qquad (8)$$

where:

$\hat{V}\left[\hat{N}_{spring}\right]$ was obtained from equation 2; and,

$\hat{V}\left[\hat{p}_{spawners,IN}\right]$ was obtained from results of 2003 study (see Chapter I).

The variance associated with the estimate of the proportion of the summer feeding stock ≥ 330 mm FL comprised of Salcha River spawners was calculated as:

$$\hat{V}\left[\hat{p}_{\substack{spawners \\ in\ summer}}\right] = \left(\frac{1}{\hat{N}_{summer}}\right)^2 * \hat{V}\left[\hat{N}_{\substack{spawners \\ in\ summer}}\right] + \left(\hat{N}_{\substack{spawners \\ in\ summer}}\right)^2 * \hat{V}\left[\frac{1}{\hat{N}_{summer}}\right] - \hat{V}\left[\frac{1}{\hat{N}_{summer}}\right] * \hat{V}\left[\hat{N}_{\substack{spawners \\ in\ summer}}\right] \qquad (9)$$

where:

$$\hat{V}\left(\frac{1}{\hat{N}_{summer}}\right) \approx \frac{1}{\hat{N}^4_{summer}} \hat{V}\left(\hat{N}_{summer}\right) \qquad (10)$$

by the delta method (Seber 1982).

EXPLOITATION RATES (OBJECTIVE 2)

The precision criteria for this objective were developed using an approach similar to that described for Objective 1. For the exploitation rate on the Salcha River spawning stock to apply to harvestable fish (i.e., Arctic grayling ≥ 270 mm FL), it was assumed that the proportion of fish that migrate out of the study area was the same for fish between 270 and 329 mm FL as it was for fish ≥ 330 mm FL (the minimum size of fish in the radiotelemetry study). In general, 270 mm FL corresponds to the mean length of maturity for Arctic grayling in Tanana Basin fisheries (Clark 1992a); therefore, fish exceeding this size were expected to behave as other adult fish ≥ 330 mm FL. On the other hand, the proportion of large fish has been observed to increase going upstream during the summer in the Salcha River (Holmes 1984) consistent with size segregation behavior characteristics of grayling populations in interior river systems (Tack 1974; Hughes 1999). Because the majority of fish ≥ 330 mm FL that left the system did so by migrating further into the Salcha Drainage, it was possible that a larger percentage of fish between 270 and 329 mm FL remained in the fishery. Such an occurrence would result in an exploitation rate of the spring stock that was biased low. In addition, the estimated exploitation rate of the spring stock may be biased low if Salcha River spawners destined to leave the study area were harvested during their migration (i.e., by regulation harvest may begin on June 1, and some fish that migrated out of the fishery by the June 26 survey may have been transiting within the fishery between June 1 and June 26 and therefore susceptible to harvest). The selected precision criterion accommodated both the 2003 and 2004 telemetry results but did not address this potential bias. Estimation of the exploitation rate of the summer stock residing in the study area was more straight forward, although the parameter estimates (abundance and harvest) used for computation are not constants. In reality, abundance varies throughout the summer due to such events as immigration, emigration, growth recruitment, death, and cumulative harvest. While there is the potential for some bias, it was expected to be negligible.

Efforts were made to identify potential bias using information such as: 1) observed differences in the proportion of Arctic grayling migrating out of the study area as a function of size for fish ≥ 330 in the 2003 radiotelemetry experiment; and, 2) the relative abundance of the spring spawners between 270 and 329 mm FL (e.g., a small relative abundance would correspond to a small potential bias). Although the relative precision of estimated exploitation rate was expected to be relatively poor, the estimates were expected to provide managers a range of reasonable exploitation rates that could be used to evaluate current regulations. For example, if the point estimate was low (e.g., 0.05 – 0.10) and the specified precision was reached, the upper bound would be small enough that no management action to reduce harvest would be needed. However, if the exploitation rate estimate was moderately high (e.g., > 0.15), then confidence that the harvests were sustainable would be low. The later scenario could prompt further research, such as a radiotelemetry study of the summer stock to more accurately estimate the proportion of the spawners in the summer population and subsequently exploitation rate.

Exploitation rates for both the spring spawning stock and the summer feeding stock were estimated. The exploitation rate for the summer stock was the estimated harvest divided by the estimated summer abundance:

$$\hat{\mu}_{summer} = \frac{\hat{H}}{\hat{N}_{summer}} \tag{11}$$

where:

$\hat{H}$ = the estimated harvest of Arctic grayling ≥ 270 mm FL during 2004 obtained from the SWHS.

$\hat{N}_{summer}$ = the estimated abundance of Arctic grayling ≥ 270 mm FL in the study area at the end of June 2004.

The estimates were obtained in separate experiments and were therefore independent. As a result, the variance of the summer stock exploitation rate was estimated using Goodman's (1960) formula for an exact variance of a product:

$$\hat{V}[\hat{\mu}_{summer}] = \left(\frac{1}{\hat{N}_{summer}}\right)^2 * \hat{V}[\hat{H}] + \hat{H}^2 * \hat{V}\left[\frac{1}{\hat{N}_{summer}}\right] - \hat{V}\left[\frac{1}{\hat{N}_{summer}}\right] * \hat{V}[\hat{H}] \tag{12}$$

where:

$\hat{V}[\hat{H}]$ = estimated variance of the estimated harvest of Arctic grayling ≥ 270 mm FL obtained from the SWHS.

The exploitation rate for the spring spawning stock was estimated by the product of the estimates of 2004 harvest and the fraction of the spring spawners in the summer stock divided by the estimate of the abundance of 2004 Salcha River spawners. Alternatively, the spring stock exploitation rate was equal to the product of the estimated exploitation rate for the summer stock and the estimated proportion of the spring spawning stock that remained in the study area obtained from the radio telemetry study initiated in 2003.

$$\hat{\mu}_{spawners} = \hat{H}\left(\frac{\hat{N}_{\substack{spawners\\ in\ summer}}}{\hat{N}_{summer}}\right)\frac{1}{\hat{N}_{spring}} = \hat{H}\left(\frac{\hat{N}_{spring}\hat{p}_{spawners,IN}}{\hat{N}_{summer}}\right)\frac{1}{\hat{N}_{spring}} = \hat{p}_{spawners,IN}\,\hat{\mu}_{summer}\,. \tag{13}$$

where:

$\hat{p}_{spawners,IN}$ = the estimated proportion of Arctic grayling ≥ 270 mm FL that spawned in the Salcha River during spring and remained as part of the summer feeding stock (assumed equal to that of fish ≥ 330 mm FL, obtained from the radiotelemetry study initiated in 2003);

$\hat{N}_{spring}$ = the estimated abundance of Arctic grayling ≥ 270 mm FL in the study area during the May 2004;

$\hat{N}_{summer}$ = the estimated abundance of Arctic grayling ≥ 270 mm FL in the study area at the end of June 2004; and,

$\hat{N}_{\substack{spawners\\ in\ summer}}$ = the estimated number of Arctic grayling ≥ 270 mm FL that spawned in the Salcha River study area during spring and remained as part of the summer feeding stock.

The variance of the spring stock exploitation rate was estimated using Goodman's (1960) formula for an exact variance of a product:

$$\hat{V}[\hat{\mu}_{spawners}] = (\hat{p}_{spawners,IN})^2\hat{V}[\hat{\mu}_{summer}] + (\hat{\mu}_{summer})^2\hat{V}[\hat{p}_{spawners,IN}] - \hat{V}[\hat{p}_{spawners,IN}] * \hat{V}[\hat{\mu}_{summer}]. \tag{14}$$

Observe and record recapture locations of Arctic grayling marked during the spring and recaptured during the summer (Task 1)

All Arctic grayling marked during spring 2004 and recaptured during summer 2004 were identified and the distance between sample locations was determined. Because fish were captured by electrofishing during a 20-minute run, the actual capture location was unknown but the release locations were known. Runs were 0.79 to 4.9 km in length (though typically 2.0 to 3.5 km) and it was, therefore, possible for a recaptured fish to have been moved downstream during a run by up to 4.9 km.

Compare length frequency distribution of spring and summer populations of Arctic grayling in the study area (Task 2)

Length frequency distributions of the 2004 spring and summer samples (from both events excluding recaptures) were plotted and compared using two-sample Kolmogorov-Smirnov test with the significance level $\alpha = 0.05$.

Identify gender and maturity status of the spring population (Task 3)

During spring sampling, each fish was examined to determine its maturity status (mature or immature) and gender, if mature. Because Arctic grayling were sampled during spawning, sex and maturity were determined primarily by inspecting for the presence of sex products (milt or eggs) and secondarily by three specific external characteristics:

1) Size of dorsal and pelvic fins: males have markedly larger and longer dorsal and pelvic fins relative to body size than females (Bishop 1967). Dorsal fins when laid onto the back reach or extend beyond the adipose fin and pelvic fins nearly reach the vent (McPhail and Lindsey 1970; Mecklenberg et al. 2002).
2) Swollen vents: females have anal vents that are red and swollen during spawning, where as males do not.
3) Gravid abdomens: the abdomens of pre-spawning females are swollen and the ovaries can be felt through the abdominal wall. Immature fish, males, and spawned out females do not have a swollen abdomen.

RESULTS

PROPORTION OF THE SUMMER 2004 POPULATION COMPRISED OF SALCHA RIVER SPAWNERS

The proportion of spawners in the summer fishery as indicated by radiotelemetry (Table 5) varied slightly each month (68%–71% during June 2003, August 2003, and July 2004) except July 2003 when only 51% of spawners were present in the study area. This in turn resulted in an estimated 46%–64% of the summer 2004 population being comprised of Arctic grayling ≥ 330 mm FL that had been in the study area during preceding spring (Table 20). Assuming similar behavior of Arctic grayling 270–329 mm FL to that ≥ 330 mm FL resulted in an estimated 54%–75% of the summer population comprised of the spring Arctic grayling population ≥ 270 mm FL (Table 20).

EXPLOITATION RATES

The SWHS indicated 1,442 (SE=638) Arctic grayling ≥ 270 mm FL were harvested from the Salcha River during 2004 (Jennings et al. 2007). This resulted in an exploitation rate of 11.3% (SE=5.2%) on the summer population and 5.8%–8.0% (SE from 2.8% to 3.9%) on the spring spawner population (Table 21).

RECAPTURED FISH

There were 43 Arctic grayling recaptured during July 2004 that were tagged during May 2004 mark-recapture experiment. Among 43 Arctic grayling recaptured, 12 had moved an undistinguishable distance (within the distance of a run which was 0.79 to 4.9 km in length, though typically 2.0 to 3.5 km). Overall, 17 had moved downstream, and 26 had moved upstream (Appendix B3). Average absolute distance moved was 18.4 km, and maximal distance traveled was 37.6 km downstream and 75.2 km upstream.

CUMULATIVE LENGTH FREQUENCY DISTRIBUTION OF SPRING AND SUMMER SAMPLES

There were 2,498 Arctic grayling ≥ 200 mm FL captured during spring 2004 mark-recapture experiment and 2,185 during summer 2004. The two-sample Kolmogorov-Smirnov test indicated the samples were significantly different ($D = 0.083$; $p < 0.01$). The spring sample was more variable than the summer sample (Figure 17).

MATURITY

Only 3 fish less than 270 mm FL were identified as mature among 617 fish (<0.01%) between 227 and 270 mm FL. Among 767 fish 270-329 mm FL, only 72 (0.09%) were identified as mature, but 988 of 1,053 fish ≥ 330 mm FL (94%) were identified as mature (Table 22). Of fish identified as mature during each event, a nearly 1:1 ratio of males and females was observed. Females were identified primarily by extrusion of eggs (63%), and the vent alone was used to identify 37% of females. A fairly large proportion (36%) of females had "large" dorsal fins that reached or passed the adipose fin when laid flat along the back. Males were identified primarily by extrusion of milt (90%) and secondarily by the presence of a large dorsal.

Males predominately (90%) had large dorsal fins. The 10% of identified males without a large dorsal fin had a size range of 285 to 413 mm FL. The second event had larger proportions of males (96% vs. 86%) and females (74% vs. 55%) which extruded milt or eggs. Size differences were evident between sexes. Most identified females were 330 - 374 mm FL (60%) and 375 - 399 mm FL (28%). Most identified males were 375 - 399 mm FL (40%), >400 mm FL (29%), and 330 - 374 mm FL (25%).

Table 20.–Proportions of radiotagged Arctic grayling remaining in the study area during summer 2003 and 2004, and resulting estimates of abundance of the spring 2004 population of Arctic grayling ≥ 330 mm FL and ≥ 270 mm FL remaining in the study area during summer ($\hat{N}_{\substack{spawners \\ in\ summer}}$) and its proportion of the summer population in 2004 ($\hat{p}_{\substack{spawners \\ in\ summer}}$).

Strata	Period of aerial survey	$\hat{p}_{SA,i}$ [a]	$\hat{N}_{\substack{spawners \\ in\ summer}}$	SE [$\hat{N}_{\substack{spawners \\ in\ summer}}$]	$\hat{p}_{\substack{spawners \\ in\ summer}}$	SE [$\hat{p}_{\substack{spawners \\ in\ summer}}$]
≥ 330 mm FL						
	June 2003	0.69	4,318	620	0.62	0.15
	July 2003	0.51	3,192	459	0.46	0.13
	August 2003	0.68	4,255	612	0.61	0.16
	July 2004	0.71	4,443	642	0.64	0.18
≥ 270 mm FL						
	June 2003	0.69	9,251	1,135	0.72	0.15
	July 2003	0.51	6,838	840	0.54	0.13
	August 2003	0.68	9,117	1,119	0.71	0.16
	July 2004	0.71	9,519	1,177	0.75	0.19

[a] $\hat{p}_{SA,i}$ = the proportion of radio tagged grayling that were located in the fishery area during each aerial survey, *i*.

Table 21.–Point estimates and standard errors of Arctic grayling harvest, exploitation rate of the summer population, and exploitation rate of the spring population based on radiotelemetry estimates, Salcha River, 2004.

Harvest		Summer population		Spring population		
$\hat{N}$	SE [$\hat{N}$]	$\hat{\mu}$	SE [$\hat{\mu}$]	Survey period	$\hat{\mu}$	SE [$\hat{\mu}$]
1,442	638	0.113	0.0518	June 2003	0.078	0.0363
				July 2003	0.058	0.0277
				August 2003	0.077	0.0362
				July 2004	0.080	0.0389

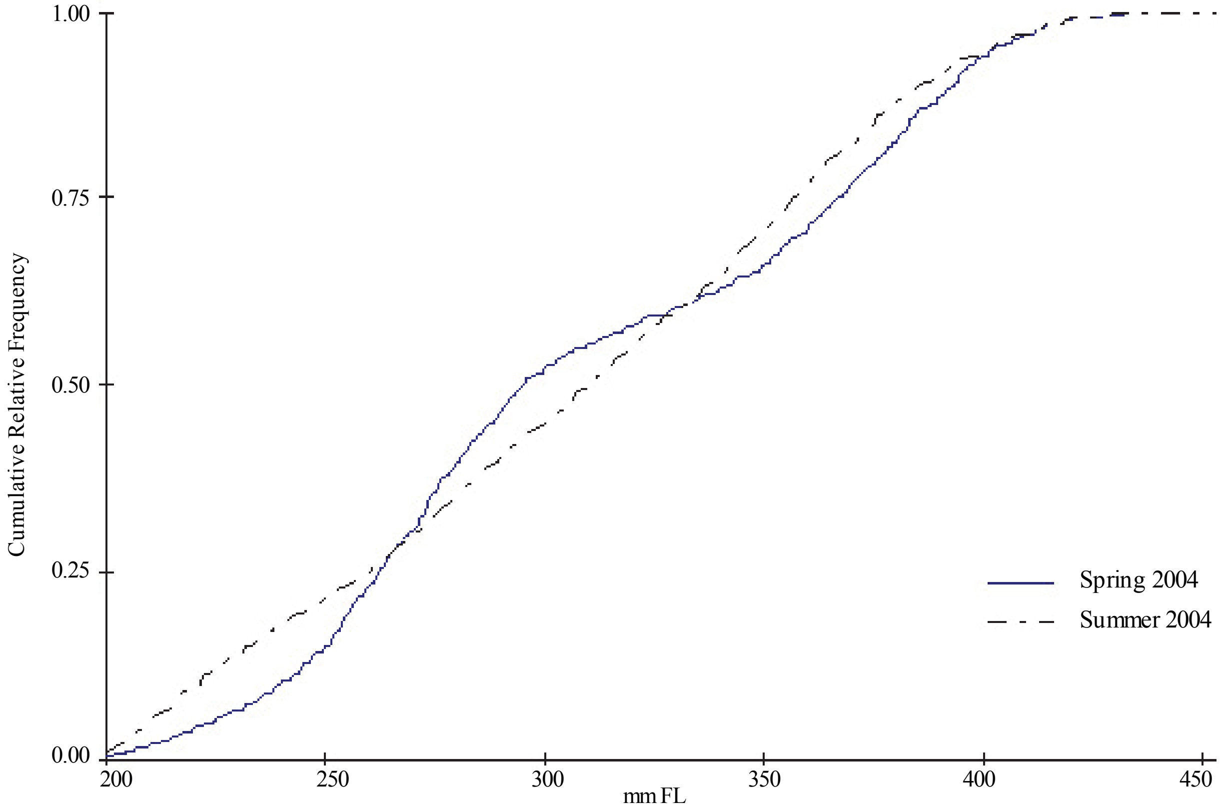

Figure 17.–Cumulative relative frequency of Arctic grayling ≥ 200 mm FL captured during spring (n= 2,498) and summer (n= 2,185), Salcha River 2004.

Table 22.–Proportion of mature fish observed by size group, Salcha River study area May 2004.

	228 – 269 mm FL			270 – 330 mm FL			≥ 330 mm FL		
	N	*i*	p	n	*i*	p	n	*i*	p
First Event	222	2	0.01	340	44	0.13	589	552	0.94
Second Event	395	1	<0.01	427	21	0.05	464	436	0.94
Total/Overall	617	3	<0.01	767	65	0.09	1,053	988	0.94

Table 23.–Presence of diagnostic features of mature male and female Arctic grayling in the Salcha River study area, May 2004.

	Male						
	i mature	ID by milt	p	ID by fin	p	Possessed a large fin	p
First Event	306	269	0.87	41	0.13	279	0.91
Second Event	225	215	0.96	10	0.04	199	0.88
Total/Overall	531	484	0.90	51	0.10	478	0.90

	Female						
	i mature	ID by egg		ID by vent	p	Possessed a large fin	p
First Event	292	161	0.55	131	0.45	108	0.37
Second Event	233	172	0.74	61	0.26	80	0.34
Total/Overall	525	333	0.63	192	0.37	188	0.36

DISCUSSION

The radiotagging study indicated that typically about 70% of the spring population ≥ 330 mm FL remained in the study area during summer (June and August 2003 and July 2004), although only 51% (SE=8%) remained during July 2003. It is difficult to know if the July 2003 estimate was an anomaly or the usual condition which was not observed in July 2004 ($\hat{p}$=71%, SE=13%) because the sample size was small. To better understand the uncertainty of these proportions and concomitant estimates of exploitation, monthly proportions of radiotagged fish remaining in the study area during summer were examined.

Estimates of exploitation of the spring population ranged from 5.8% to 8.0% and for the summer population it was 11.3%. The estimated exploitation rate of the spring population required an assumption that the behavior of Arctic grayling 270–329 mm FL be similar to that of Arctic grayling ≥ 330 mm FL. However, the available evidence did not substantiate the assumption. Using spring and summer location information available from radiotagged fish and recaptures of Floy-tagged fish marked during spring, it was determined that Arctic grayling ≥ 330 mm FL were more mobile and more likely moving upstream (Figure 18). In addition, larger fish had lower recapture rates than the small fish, even though larger fish typically have higher capture probabilities. Based on these observations, it is believed smaller fish behaved differently and a smaller proportion migrated out of the study area. Although the evidence of differential movements by size group is not definitive, it is more conservative to evaluate exploitation under this circumstance. Since not accounting for this difference in movement leads to underestimation of the exploitation rate, it is believed that the exploitation rate of the spring stock was somewhat higher than the estimated 5.8% to 8.0% but likely not exceeding the summer rate of 11.3%.

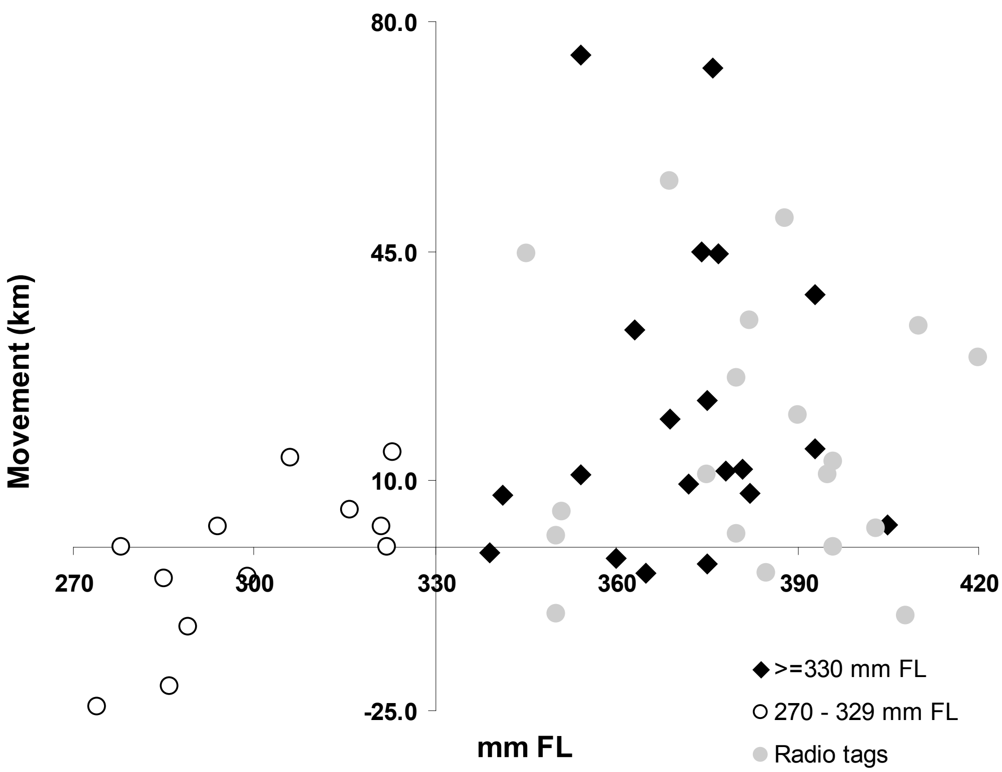

Figure 18.–Plot of Arctic grayling movement between spring location and summer location of recaptured Floy-tagged fish and radiotagged fish, Salcha River 2004.

The estimation of the exploitation rate for the summer population was straightforward as the abundance estimate coincided with the harvest estimate. A portion of the harvest occurred prior to the abundance estimate because the first event, to which estimate was germane, occurred June 25–29 and July 8–9. Therefore the overall abundance and its estimate were likely reduced by the harvest, and the estimate of exploitation rate had a slight positive bias. While there was undoubtedly some harvest prior to the abundance estimate that may have caused positive bias, it may easily have been counteracted by growth recruitment.

Despite any bias that may have existed, the levels of exploitation were low (spring population) to moderate (summer population) and in either case likely sustainable. In addition, exploitation of the Arctic grayling population in the study area is buffered by the large source of additional recruitment from the extensive Salcha River drainage.

The assessments of maturity indicated Arctic grayling were nearly all mature when they were larger than 330 mm FL as they had been during 1990 and 1991 (Clark 1992a). However, maturity was less prevalent among fish < 330 mm FL, occurring in 9% of fish 270 – 329 mm FL as opposed to 35% during 1991–1992. The maturity schedule may have changed over time; however, the differences were more likely the result of different observers using subjective techniques. Although personnel were trained, the potential for incorrect identification of maturity and of gender existed because morphological characteristics used in lieu of primary identifiers, extruded eggs or milt, were neither exclusive nor pervasive to a gender. For example, in the absence of extruded sexual products the swollen vent was used to identify females and a large dorsal fin was used to identify males. Yet there were observations of females lacking swollen vents and males with swollen vents, and males without large dorsal fins and females with large dorsal fins. Although Clark (1992a) assessed and found no errors of identification on a small sample size during 1991, the methods and results were summarized to such an extent as to make them incomparable to these results. Because descriptive language (e.g. swollen vent does not articulate the difference between male and female vents) has not been properly developed, future studies should refrain from using secondary characteristics to identify maturity and gender.

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APPENDIX A
EQUATIONS AND STATISTICAL METHODOLOGY

Appendix A1.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

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

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

The abundance of Arctic grayling was estimated as:

$$\hat{N} = \frac{n_1(n_2+1)}{m_2+1}, \qquad \text{(A1-1)}$$

where:

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

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

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

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \qquad \text{(A1-2)}$$

Appendix A2.–Procedures for detecting and adjusting for size or sex selective sampling during a 2-sample 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 Kolmogorov-Smirnov two sample (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.

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 test 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 R. Chi-square tests are used to compare the counts of observed males to females between M&R and 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 C), rather than observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are compared between samples 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 but do not include recaptured fish twice.

-continued-

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 sampling. 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. 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 sampling. 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 of 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.

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Protocols when Power Suspect (re-classifying the experiment)

When sample sizes are small (guidelines provided in 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 the 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 M or C are < 100 and the sample size for R is < 30, 2) p-values are not large (~0.20 or less), and the D statistics are 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 the 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: no difference between the M & C. 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 are called into question when 1) sample sizes M or C are > 500, 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 A3.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

The following two assumptions must be fulfilled:

1. catching and handling the fish does not affect the probability of recapture; and,
2. marked fish do not lose their mark.

Of the following assumptions, only one must be fulfilled:

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

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

TEST I [a]

First Event Sampling Area Released	Second Event				
	Sampling Area Recaptured				Not Recaptured
	A	**B**	**…**	**S**	(total)
A					
B					
…					
S					

TEST II [b]

	Second Event: Sampling Area			
	A	**B**	**…**	**S**
Recaptured				
Not Recaptured				

TEST III [c]

	Captured During Second Event			
	A	**B**	**…**	**S**
Marked				
Unmarked				

[a] This tests the hypothesis that movement probabilities are the same among sections: H_1: $\theta_{ij} = \theta_j$. Theta applies to both marked and unmarked fish.

[b] This tests the hypothesis of homogeneity on the columns of this 2-by-s contingency table with respect to recapture probabilities between the three river areas: H_2: $\Sigma_j \theta_{ij} p_j = d$. Theta applies to both marked and unmarked fish.

[c] This tests the homogeneity on the columns of the 2-by-t contingency table with respect to the probability of movement of marked fish in stratum i to the unmarked fraction in j: H_4: $\Sigma_i a_i \theta_{ij} = kU_j$. Theta only applies to marked fish.

Appendix A4.–Equations for estimating length and age composition and their variances for the population.

For Case I-IV scenarios (Appendix A2), the proportions of Arctic grayling within each age or length class *k* were estimated:

$$\hat{p}_k = \frac{n_k}{n} \quad \textbf{(A4-1)}$$

where:

n_k = the number of Arctic grayling sampled within age or length class *k* and,

n = the total number of Arctic grayling sampled.

When calculating *n* and n_k the diagnostic test results were used to determine the fish were included (Appendix A2). For Case I, used fish from both events.

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

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1}. \quad \textbf{(A4-2)}$$

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

$$\hat{N}_k = \sum_{k=1}^{s} \hat{p}_k \hat{N}, \quad \textbf{(A4-3)}$$

where:

$\hat{N}$ = the estimated overall abundance (Appendix A1); and,

s = the number of age or length classes.

The variance for $\hat{N}_k$ was then estimated using the formulation for the exact variance of the product of two independent random variables (Goodman 1960):

$$\hat{V}[\hat{N}_k] \approx \sum_{k=1}^{s} \left(\hat{V}[\hat{p}_k]\hat{N}^2 + \hat{V}[\hat{N}]\hat{p}_k^2 - \hat{V}[\hat{p}_k]\hat{V}[\hat{N}]\right). \quad \textbf{(A4-4)}$$

For the Case IV scenario (Appendix A2), that requiring stratification by size or sex, the proportions of Arctic grayling within each age or length class *k* were estimated by first calculating:

-continued-

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{A4-5}$$

where:

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

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

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

When calculating n_j and n_{jk} the within stratum diagnostic test results were used to determine which fish were included in the analysis following the rules for n and n_k provided above.

The variance calculation for $\hat{p}_{jk}$ is equation 2 substituting $\hat{p}_{jk}$ for $\hat{p}_k$ and n_j for n.

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

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk} \hat{N}_j \tag{A4-6}$$

where:

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

s = the number of size strata.

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

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s} \left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right] \right). \tag{A4-7}$$

-continued-

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

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \tag{A4-8}$$

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

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

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s} \left\{ \left(\frac{\hat{N}_j}{\hat{N}} \right)^2 \hat{V}\left[\hat{p}_{jk}\right] \right\} + \frac{\sum_{j=1}^{s} \left\{ \hat{V}\left[\hat{N}_j\right] \left(\hat{p}_{jk} - \hat{p}_k\right)^2 \right\}}{\hat{N}^2} . \tag{A4-9}$$

APPENDIX B
ADDITIONAL TABLES

Appendix B1.–Date of capture, biological statistics, final fate assignments, and release location for each radiotagged Arctic grayling.

Date	Floy Tag Number	FL (mm)	Weight (g)	Gender	Radio Tag frequency 149.xxx MHz	Channel	Code	Ratio Tag Weight: Body Weight	Final Fate	Survey of Fate Assignment	Latitude Decimal Degrees	Longitude Decimal Degrees
5/5/2003	3214	369	512	Male	380	6	1	0.017	PTMI	Sep-03	64.50690	-146.48160
5/7/2003	3834	380	585	Female	380	6	2	0.015	PTMO	June-03	64.64237	-145.49047
5/5/2003	3218	351	438	Male	380	6	3	0.020	PTMI	June-03	64.48600	-146.56725
5/6/2003	3225	415	855	Female	380	6	4	0.010	PTMI	Sep-03	64.57642	-146.20812
5/7/2003	3845	422	780	Male	380	6	5	0.011	PTMO	Jul-03	64.66882	-145.61407
5/7/2003	3234	390	592	Female	380	6	6	0.015	IN	Jul-04	64.65543	-145.78578
5/5/2003	3223	380	607	Female	380	6	7	0.015	PTMI	Jul-03	64.47565	-146.71498
5/7/2003	3239	356	476	Female	380	6	8	0.019	IN	Jul-04	64.65543	-145.78578
5/6/2003	3831	396	702	Male	380	6	9	0.013	PTMI	Aug-03	64.59267	-146.11817
5/6/2003	3827	354	467	Male	380	6	10	0.019	PTMO	Aug-03	64.61712	-145.97583
5/7/2003	3241	380	340	Female	380	6	11	0.026	PTMI	May-04	64.65478	-145.81875
5/7/2003	3833	349	427	Female	420	7	1	0.021	U	Aug-03	64.64237	-145.49047
5/6/2003	3828	340	466	Female	420	7	2	0.019	IN	Jul-04	64.60312	-146.05765
5/8/2003	3242	343	516	Female	420	7	3	0.017	PTMO	Dec-03	64.57358	-146.18110
5/5/2003	3219	352	525	Female	420	7	4	0.017	PTMI	Jun-03	64.49040	-146.60605
5/7/2003	3844	385	544	Male	420	7	5	0.016	OUT	Jul-04	64.66882	-145.61407
5/7/2003	3238	404	651	Male	420	7	6	0.014	PTMI	Jun-03	64.65543	-145.78578
5/7/2003	3838	347	419	Female	420	7	7	0.021	PTMI	Jun-03	64.65452	-145.52268
5/6/2003	3224	395	630	Male	420	7	8	0.014	IN	Jul-04	64.57883	-146.16330
5/7/2003	3232	385	526	Male	420	7	9	0.017	PTMI	Mar-04	64.66108	-145.73570
5/6/2003	3830	370	542	Female	420	7	10	0.016	PTMI	Jun-03	64.59883	-146.10242
5/5/2003	3217	388	612	Female	420	7	11	0.015	IN	Jul-04	64.48600	-146.56725

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Appendix B1–Page 2 of 3.

Date	Floy Tag Number	FL (mm)	Weight (g)	Gender	Radio Tag frequency 149.xxx MHz	Channel	Code	Ratio Tag Weight: Body Weight	Final Fate	Survey of Fate Assignment	Latitude Decimal Degrees	Longitude Decimal Degrees
5/6/2003	3826	374	599	Female	440	8	1	0.015	AL	Jul-04	64.62355	-145.93920
5/7/2003	3839	365	510	Male	440	8	2	0.017	PTMI	Sep-03	64.65452	-145.52268
5/7/2003	3231	425	664	Female	440	8	3	0.013	OUT	Jul-04	64.66611	-145.70618
5/8/2003	3243	345	415	Female	440	8	4	0.021	PTMI	Aug-03	64.48919	-146.58605
5/7/2003	3836	403	665	Male	440	8	5	0.013	IN	Jul-04	64.64237	-145.49047
5/5/2003	3220	393	665	Male	440	8	6	0.013	PTMO	Sep-03	64.49040	-146.60605
5/6/2003	3227	410	689	Male	440	8	7	0.013	IN	Jul-04	64.53612	-146.30039
5/7/2003	3240	424	693	Male	440	8	8	0.013	IN	Jul-04	64.65478	-145.81875
5/7/2003	3237	395	626	Female	440	8	9	0.014	IN	Jul-04	64.65543	-145.78578
5/5/2003	3215	350	448	Female	440	8	10	0.020	PTMI	Jul-03	64.48600	-146.56725
5/6/2003	3829	382	685	Female	540	12	1	0.013	PTMI	Jul-03	64.60162	-146.08738
5/7/2003	3228	400	581	Male	540	12	2	0.015	PTMO	Jul-03	64.66611	-145.70618
5/6/2003	3824	348	477	Male	540	12	3	0.019	PTMI	Jun-03	64.64158	-145.90270
5/6/2003	3226	380	651	Female	540	12	4	0.014	IN	Jul-04	64.56418	-146.24554
5/7/2003	3843	389	604	Male	540	12	5	0.015	U	Jun-03	64.66882	-145.61407
5/7/2003	3235	400	634	Female	540	12	6	0.014	PTMO	Sep-03	64.65543	-145.78578
5/7/2003	3832	367	585	Female	540	12	7	0.015	PTMI	Jun-03	64.64237	-145.49047
5/5/2003	3222	330	476	Female	540	12	8	0.019	PTMI	Jun-03	64.48660	-146.66360
5/5/2003	3216	375	542	Male	540	12	9	0.016	OUT	Jul-04	64.48600	-146.56725
5/7/2003	3840	395	640	Male	540	12	10	0.014	PTMI	Jun-03	64.65452	-145.52268
5/7/2003	3837	419	706	Male	360	21	1	0.013	PTMI	Jun-03	64.65452	-145.52268
5/8/2003	3845	375	635	Female	360	21	2	0.014	TM	May-03	64.57148	-146.18937

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Appendix B1–Page 3 of 3.

Date	Floy Tag Number	FL (mm)	Weight (g)	Gender	Radio Tag frequency 149.xxx MHz	Channel	Code	Ratio Tag Weight: Body Weight	Final Fate	Survey of Fate Assignment	Latitude Decimal Degrees	Longitude Decimal Degrees
5/6/2003	3825	396	690	Male	360	21	4	0.013	PTMI	Aug-03	64.63280	-145.91707
5/7/2003	3841	353	560	Female	360	21	5	0.016	PTMI	Jun-03	64.65452	-145.52268
5/7/2003	3233	350	471	Male	360	21	6	0.019	PTMI	Aug-03	64.65626	-145.75010
5/7/2003	3230	390	577	Male	360	21	7	0.015	PTMI	Dec-03	64.66611	-145.70618
5/7/2003	3842	365	530	Female	360	21	8	0.017	PTMO	Sep-03	64.65452	-145.52268
5/7/2003	3835	408	662	Male	360	21	9	0.013	PTMI	Sep-03	64.64237	-145.49047
5/5/2003	3221	393	598	Male	360	21	10	0.015	OUT	Jul-04	64.48660	-146.66360
5/7/2003	3236	355	468	Female	360	21	11	0.019	PTMI	Jun-03	64.65543	-145.78578

Appendix B2.–Distance from previous location (Δkm) and fate[a] for each radio tagged fish at each survey date.

Radio Tag		Survey Date								
Channel - Code		5/23/2003	6/26-28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
6-1	Δkm	9.3	23.7	25.7	4.5	-7.9				
	Fate	IN	IN	IN	IN	**PTMI**				
6-2	Δkm	18.4	0.0							
	Fate	OUT	**PTMO**							
6-3	Δkm		-29.5							
	Fate	AL	**PTMI**							
6-4	Δkm	2.1	-5.5	5.6	-2.0	-2.4				
	Fate	IN	IN	IN	IN	**PTMI**				
6-5	Δkm	3.9	16.1	-0.6						
	Fate	IN	OUT	**PTMO**						
6-6	Δkm	20.0	0.0	0.0	0.0	0.0.	-10.0		-3.1	14.1
	Fate	IN	IN	IN	IN	IN	IN	AL-IN	IN	IN
6-7	Δkm	1.7	2.7	-2.5						
	Fate	IN	IN	**PTMI**						
6-8	Δkm	14.3	38.2	-12.6	-31.8		-29.3	15.8	-7.6	21.4
	Fate	IN	OUT	OUT	IN	AL-IN	IN	IN	IN	IN
6-9	Δkm	12.4	3.8	-2.9	-1.0					
	Fate	IN	IN	IN	**PTMI**					

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Radio Tag		Flight Date								
Channel-Code		5/23/2003	6/26-28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
6-10	Δkm	5.4	10.0	-14.1	-0.5					
	Fate	IN	IN	OUT	**PTMO**					
6-11	Δkm	1.7	33.2	9.6	-35.2	-8.9	5.0		0.2	
	Fate	IN	OUT	OUT	IN	IN	IN	AL-IN	**PTMI**	
7-1	Δkm	5.3	11.6	6.2						
	Fate	OUT	OUT	OUT	**U**					
7-2	Δkm		30.5		0.4				-9.9	9.4
	Fate	AL-IN	IN	AL-IN	IN	AL-IN	AL-IN	AL-IN	IN	IN
7-3	Δkm	-25.3	7.6	24.8	7.2	0.5	-2.2			
	Fate	IN	IN	OUT	OUT	OUT	**PTMO**			
7-4	Δkm	3.0	0.0							
	Fate	IN	**PTMI**							
7-5	Δkm	-0.6	-0.2	43.3	-45.2	2.4	-2.7	0.0	1.1	63.8
	Fate	IN	IN	OUT	IN	IN	IN	IN	IN	OUT
7-6	Δkm	-2.9	-13.2							
	Fate	IN	**PTMI**							
7-7	Δkm	-24.0	-29.9							
	Fate	IN	**PTMI**							

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Radio Tag		Flight Date								
Channel-Code		5/23/2003	6/26-28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
7-8	Δkm	7.5	3.5	0.0	-3.3	1.5	2.0	-2.6	-0.6	0.5
	Fate	IN	IN	IN	IN	IN	IN	IN	IN	IN
7-9	Δkm	-6.0	3.0	0.0	22.8		-22.9	-0.3		
	Fate	IN	IN	IN	IN	AL	IN	**PTMI**		
7-10	Δkm	11.2	-30.2							
	Fate	IN	**PTMI**							
7-11	Δkm		54.3	-1.6	2.6	-1.3	-3.5		-1.0	5.3
	Fate	AL-IN	IN	IN	IN	IN	IN	AL-IN	IN	IN
8-1	Δkm	18.8	18.8	3.0	-1.6	-11.8	-5.6	3.2	-20.5	
	Fate	IN	OUT	OUT	OUT	IN	IN	IN	IN	AL
8-2	Δkm	-4.5	-12.2	24.8	-13.5	0.0				
	Fate	IN	IN	OUT	IN	**PTMI**				
8-3	Δkm	0.4		81.1	0.0	-16.1	-27.4		-34.3	81.1
	Fate	IN		AL-OUT	OUT	OUT	OUT	AL	IN	OUT
8-4	Δkm	4.6	47.0	-1.0	-20.1					
	Fate	IN	IN	IN	**PTMI**					
8-5	Δkm	3.6	0.2	-1.3	0.5	-19.4	0.0	0.0	-3.9	5.0
	Fate	IN	IN	IN	IN	IN	IN	IN	IN	IN

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Radio Tag		Flight Date								
Channel-Code		5/23/2003	6/26-28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
8-6	Δkm				10.0	3.1				
	Fate	AL-OUT	AL-OUT	AL-OUT	OUT	**PTMO**				
8-7	Δkm	12.0	56.6	-27.8	-19.0	-18.5		-2.2	11.3	54.5
	Fate	IN	IN	IN	IN	IN	AL-IN	IN	IN	IN
8-8	Δkm	23.3	36.1	0.0	0.0	-57.3	15.7	-2.9	-13.8	14.3
	Fate	OUT	OUT	OUT	OUT	IN	IN	IN	IN	IN
8-9	Δkm	15.3	37.4	0.0	0.0	0.0	-11.6	-16.5	4.6	-19.1
	Fate	IN	OUT	OUT	OUT	OUT	OUT	OUT	OUT	IN
8-10	Δkm	5.9		-4.2						
	Fate	IN	AL-IN	**PTMI**						
12-1	Δkm	10.5	25.4	0.0						
	Fate	IN	IN	**PTMI**						
12-2	Δkm	19.6	3.8	-3.8						
	Fate	OUT	OUT	**PTMO**						
12-3	Δkm	4.7	-35.1							
	Fate	IN	**PTMI**							
12-4	Δkm	27.0	0.0		0.0	-23.7	4.2	0.0	2.6	25.0
	Fate	IN	IN	AL-IN	IN	IN	IN	IN	IN	IN

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Radio Tag		Flight Date								
Channel-Code		5/23/2003	6/26-28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
12-5	Δkm	-12.2								
	Fate	IN	**U**							
12-6	Δkm	35.5	-51.3	82.6	0.0	0.0				
	Fate	OUT	OUT	OUT	OUT	**PTMO**				
12-7	Δkm	-3.7	-63.3							
	Fate	IN	**PTMI**							
12-8	Δkm	-2.7	-5.6							
	Fate	IN	**PTMI**							
12-9	Δkm			10.8	56.4	-6.5	-27.1	0.0	2.3	96.6
	Fate	AL	AL	IN	IN	IN	IN	IN	IN	OUT
12-10	Δkm	1.8	0.0							
	Fate	IN	**PTMI**							
21-1	Δkm	15.6	-63.2							
	Fate	OUT	**PTMI**							
21-2	Δkm	0								
	Fate	**TM**								
21-4	Δkm	0.1	0.2	0.4	0.4					
	Fate	IN	IN	IN	**PTMI**					

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Radio Tag		Flight Date								
Channel-Code		5/23/2003	6/26-28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
21-5	Δkm	-9.9	-14.8							
	Fate	IN	**PTMI**							
21-6	Δkm	-46.7	28.5	5.5	0.0					
	Fate	IN	IN	IN	**PTMI**					
21-7	Δkm	6.3	11.7	20.9	-34.7	-11.9	0.0			
	Fate	IN	OUT	OUT	IN	IN	**PTMI**			
21-8	Δkm	1.3	23.6	0.0	-2.2	2.2				
	Fate	IN	OUT	OUT	OUT	**PTMO**				
21-9	Δkm	31.1	0.5	-48.7	-4.4	-24.2				
	Fate	OUT	OUT	IN	IN	**PTMI**				
21-10	Δkm	32.1	47.8	27.6	-1.9	-26.0	-0.7		-1.4	32.0
	Fate	IN	IN	OUT	OUT	IN	IN	AL-IN	IN	OUT
21-11	Δkm		6.6							
	Fate	AL-IN	**PTMI**							

[a] Fates were in ‘IN, out ‘OUT’, tagging mortality ‘TM’, post-tagging mortality in ‘PTMI’, post-tagging mortality out ‘PTMO’, at large ‘AL’, and at large in ‘AL-IN’, and at large out ‘AL-OUT’. AL-IN and AL-OUT indicates fish which were at large during the flight but were assumed to be in or out of study area based on evidence (history of survey fates) that strongly suggested its location was in or out of study area.

Appendix B3.–Under a less conservative fate assignment approach, fate[a] of each radio tagged fish during each flight and number of radiotagged Arctic grayling assigned to each fate, proportions of Arctic grayling remaining in the sport fishery for each tracking event, and cumulative mortality.

Radio Tag		Flight Date								
Channel	Code	5/23/2003	6/26&28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
6	1	IN	IN	IN	IN	**PTMI**				
6	2	OUT	OUT	OUT	OUT	**PTMO**				
6	3	AL	PTMI							
6	4	IN	IN	IN	IN	**PTMI**				
6	5	IN	OUT	OUT	OUT	**PTMO**				
6	6	IN	IN	IN	IN	IN	IN	AL-IN	IN	IN
6	7	IN	IN	PTMI						
6	8	IN	OUT	OUT	IN	AL-IN	IN	IN	IN	IN
6	9	IN	IN	IN	IN	**PTMI**				
6	10	IN	IN	OUT	OUT	**PTMO**				
6	11	IN	OUT	OUT	IN	IN	IN	AL-IN	IN	IN
7	1	OUT	OUT	OUT	U				**U**-OUT	
7	2	AL-IN	IN	AL-IN	IN	AL-IN	AL-IN	AL-IN	IN	IN
7	3	IN	IN	OUT	OUT	OUT	**PTMO**			
7	4	IN	PTMI							
7	5	IN	IN	OUT	IN	IN	IN	IN	IN	OUT
7	6	IN	IN	IN	IN	**PTMI**				

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Radio Tag		Flight Date								
Channel	Code	5/23/2003	6/26&28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
7	7	IN	IN	IN	IN	**PTMI**				
7	8	IN	IN	IN	IN	IN	IN	IN	IN	IN
7	9	IN	IN	IN	IN	AL	IN	IN	IN	IN
7	10	IN	**PTMI**							
7	11	AL-IN	IN	IN	IN	IN	IN	AL-IN	IN	IN
8	1	IN	OUT	OUT	OUT	IN	IN	IN	IN	AL
8	2	IN	IN	OUT	IN	**PTMI**				
8	3	IN	AL-OUT	OUT	OUT	OUT	OUT	AL	IN	OUT
8	4	IN	IN	IN	IN	**PTMI**				
8	5	IN	IN	IN	IN	IN	IN	IN	IN	IN
8	6	AL-OUT	AL-OUT	AL-OUT	OUT	**PTMO**				
8	7	IN	IN	IN	IN	IN	AL-IN	IN	IN	IN
8	8	OUT	OUT	OUT	OUT	IN	IN	IN	IN	IN
8	9	IN	OUT	OUT	OUT	OUT	OUT	OUT	OUT	IN
8	10	IN	AL-IN	**PTMI**						
12	1	IN	IN	IN	IN	**PTMI**				
12	2	OUT	OUT	OUT	OUT	**PTMO**				

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Radio Tag		Flight Date								
Channel	Code	5/23/2003	6/26&28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
12	3	IN	**PTMI**							
12	4	IN	IN	AL-IN	IN	IN	IN	IN	IN	IN
12	5	IN	**U**							
12	6	OUT	OUT	OUT	OUT	**PTMO**				
12	7	IN	**PTMI**							
12	8	IN	**PTMI**							
12	9	AL	AL	IN	IN	IN	IN	IN	IN	OUT
12	10	IN	**PTMI**							
21	1	OUT	**PTMI**							
21	2	**TM**								
21	4	IN	IN	IN	IN	AL-IN	**PTMI**			
21	5	IN	IN	IN	IN	IN	IN	IN	IN	IN
21	6	IN	IN	IN	**PTMI**					
21	7	IN	OUT	OUT	IN	IN	**PTMI**			
21	8	IN	OUT	OUT	OUT	**PTMO**				
21	9	OUT	OUT	IN	IN	**PTMI**				
21	10	IN	IN	OUT	OUT	IN	IN	AL-IN	IN	OUT
21	11	AL-IN	IN	IN	IN	**PTMI**				

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	Flight Date								
Radio Tag Fate	5/23/2003	6/26&28/2003	7/18/2003	8/21/2003	9/22/2003	12/10/2003	3/2/2004	5/11/2004	7/22/2004
IN	42	26	21	25	17	16	16	17	13
OUT	7	15	19	13	3	2	1	1	4
TM	1								
PTMI		8	2	1	10	2			
PTMO					7	1			
U		1		1					
AL	2	1			1		1		1
Total	52	51	42	40	38	21	18	18	18
n_i	49	49	42	39	37	21	17	18	17
x_i	42	34	23	26	27	18	16	17	13
$P_{SF,i}$	0.86	0.69	0.55	0.67	0.73	0.86	0.94	0.94	0.76
$SE[P_{SF,i}]$	0.051	0.067	0.078	0.076	0.074	0.078	0.059	0.056	0.106
UCL[b]	0.94	0.80	0.67	0.79	0.84	0.95	1.00	1.00	0.94
LCL[b]	0.78	0.59	0.43	0.54	0.59	0.71	0.82	0.83	0.59
Cumulative non-viable[c]	1	10	12	14	31	34	34	34	34
Non-viable rate	2%	19%	23%	27%	60%	65%	65%	65%	65%

[a] Fates were in ‘IN, out ‘OUT’, tagging mortality ‘TM’, post-tagging mortality in ‘PTMI’, post-tagging mortality out ‘PTMO’, at large ‘AL’, and at large in ‘AL-IN’, and at large out ‘AL-OUT’. AL-IN and AL-OUT indicates fish which were at large during the flight but were assumed to be in or out of study area based on evidence (history of survey fates) that strongly suggested its location was in or out of study area.

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

[c] Includes TM, PTMI, PTMO, FMI, FMO, U, and UH fates.

Appendix B4.–Location, fish length, and movement between capture and recapture locations for fish marked during May 2004 and recaptured July 2004, Salcha River study area.

Tag #	Date	Section	Run	FL (mm)	Date	Section	Run	FL (mm)	Movement (km)
6979	5/5/2004	3	17	264	6/29/2004	5	35	263	-37.6
6298	5/4/2004	1	5	257	7/10/2004	3	17	272	-28.8
6395	5/5/2004	2	9	251	7/10/2004	3	18	-	-24.6
6735	5/4/2004	1	5	274	7/12/2004	3	15	-	-24.3
6843	5/5/2004	2	12	288	7/10/2004	3	21	286	-21.4
7154	5/6/2004	4	23	292	6/28/2004	4	29	289	-12.2
7038	5/6/2004	3	20	264	6/28/2004	4	26	260	-11.7
7414	5/7/2004	6	43	208	7/8/2004	6	48	292	-5.1
6812	5/5/2004	2	10	296	7/12/2004	2	12	285	-5.0
7391	5/7/2004	6	41	296	7/9/2004	6	45	299	-4.7
6854	5/5/2004	2	12	378	6/26/2004	3	13	365	-4.1
7109	5/14/2004	3	20	366	7/10/2004	3	22	375	-2.5
7176	5/7/2004	4	24	353	6/28/2004	4	25	360	-1.7
7016	5/6/2004	3	20	325	7/10/2004	3	21	339	-1.0
7319	5/7/2004	5	37	319	7/14/2004	5	39	322	-0.2
7322	5/7/2004	5	37	225	7/9/2004	5	39	225	-0.2
7325	5/7/2004	5	37	278	7/9/2004	5	39	278	-0.2
7315	5/7/2004	5	37	253	6/29/2004	5	38	263	2.4
7405	5/7/2004	6	42	306	7/9/2004	6	44	294	2.9
6504	5/7/2004	5	35	301	7/13/2004	5	35	321	3.0
6907	5/5/2004	3	15	405	6/26/2004	3	13	405	3.3
6166	5/4/2004	1	3	321	6/25/2004	1	1	316	5.5

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Tag #	Date	Section	Run	FL (mm)	Date	Section	Run	FL (mm)	Movement (km)
6465	5/5/2004	3	14	381	7/12/2004	2	9	341	7.8
6879	5/5/2004	3	14	383	6/26/2004	2	9	382	8.0
6781	5/4/2004	2	8	373	7/11/2004	1	4	372	9.6
7214	5/7/2004	4	26	360	7/10/2004	3	21	354	11.0
6863	5/5/2004	2	12	381	7/11/2004	1	7	378	11.4
6418	5/5/2004	2	11	380	6/25/2004	1	6	381	11.7
6450	5/5/2004	2	12	321	7/11/2004	1	6	306	13.4
6579	5/5/2004	3	17	322	7/12/2004	2	9	323	14.2
6591	5/5/2004	3	18	393	6/26/2004	2	11	393	14.9
6599	5/7/2004	5	35	227	7/13/2004	4	29	247	15.4
6844	5/13/2004	2	10	370	7/11/2004	1	2	369	19.4
6898	5/5/2004	3	14	375	7/11/2004	1	4	375	22.2
7048	5/6/2004	3	21	245	6/26/2004	2	9	249	26.5
6515	5/7/2004	5	35	251	7/10/2004	3	22	257	31.6
7362	5/7/2004	5	40	363	6/29/2004	4	31	363	32.9
6956	5/5/2004	3	17	395	7/11/2004	1	1	393	38.3
7511	5/8/2004	5	33	381	7/12/2004	3	13	377	44.7
7347	5/7/2004	5	38	378	7/10/2004	3	20	374	44.8
7295	5/7/2004	4	30	258	7/11/2004	1	4	280	61.7
7304	5/7/2004	5	37	373	6/25/2004	1	3	376	73.0
7502	5/8/2004	5	33	355	7/11/2004	1	1	354	75.2

Appendix B5.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by length category for the population of Arctic grayling (≥200 mm FL) in the upper section (sections 1-3), lower section (section 4–6), and both sections combined in the Salcha River study area, spring 2004.

	Upper Section			**Lower Section**			**Combined**				
Length (mm FL)	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
200–209	2	<0.01	0.002	28	0.05	0.008	30	0.02	0.004	511	109
210–219	8	0.01	0.004	35	0.06	0.009	43	0.03	0.005	732	139
220–229	10	0.01	0.004	40	0.07	0.010	50	0.04	0.005	851	154
230–239	21	0.03	0.006	36	0.06	0.009	57	0.04	0.005	971	169
240–249	30	0.04	0.007	51	0.08	0.011	81	0.06	0.006	1379	218
250–259	55	0.07	0.009	71	0.12	0.013	126	0.09	0.008	2145	309
260–269	59	0.08	0.009	60	0.10	0.012	119	0.09	0.007	2026	295
270–279	62	0.08	0.010	74	0.12	0.013	136	0.10	0.008	2316	329
280–289	52	0.07	0.009	48	0.08	0.011	100	0.07	0.007	1703	257
290–299	38	0.05	0.008	48	0.08	0.011	86	0.06	0.006	1464	228
300–309	12	0.02	0.004	19	0.03	0.007	31	0.02	0.004	528	112
310–319	26	0.03	0.006	24	0.04	0.008	50	0.04	0.005	851	154
320–329	13	0.02	0.005	12	0.02	0.006	25	0.02	0.004	426	97
330–339	21	0.03	0.006	11	0.02	0.005	32	0.02	0.004	545	114
340–349	25	0.03	0.006	10	0.02	0.005	35	0.03	0.004	596	121
350–359	52	0.07	0.009	14	0.02	0.006	66	0.05	0.006	1124	187
360–369	62	0.08	0.010	7	0.01	0.004	69	0.05	0.006	1175	194
370–379	59	0.08	0.009	6	0.01	0.004	65	0.05	0.006	1107	185
380–389	61	0.08	0.010	6	0.01	0.004	67	0.05	0.006	1141	190
390–399	50	0.06	0.009	6	0.01	0.004	56	0.04	0.005	953	167
400–409	31	0.04	0.007	3	<0.01	0.003	34	0.02	0.004	579	119
410–419	13	0.02	0.005	3	<0.01	0.003	16	0.01	0.003	272	74
420–429	9	0.01	0.004	0	0.00	0.000	9	0.01	0.002	153	54
430–439	6	0.01	0.003	2	<0.01	0.002	8	0.01	0.002	136	50
440–449	1	<0.01	0.001	1	<0.01	0.002	2	<0.01	0.001	34	24

Appendix B6.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by age category for the population of Arctic grayling (≥200 mm FL) in the upper section (sections 1–3), lower section (sections 4–6), and both sections combined in the Salcha River study area, spring 2004.

	Upper Section			Lower Section			Combined				
Age	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
3	2	<0.01	0.003	46	0.12	0.017	48	0.06	0.008	1,420	258
4	44	0.10	0.015	117	0.30	0.023	161	0.20	0.014	4,761	647
5	166	0.39	0.024	164	0.43	0.025	330	0.41	0.017	9,759	1,209
6	59	0.14	0.017	32	0.08	0.014	91	0.11	0.011	2,691	410
≥7	158	0.37	0.017	26	0.07	0.013	184	0.23	0.015	5,442	724

Appendix B7.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by length category for the population of Arctic grayling (≥200 mm FL) in the upper section (sections 1-3), lower section (section 4–6), and both sections combined in the Salcha River study area, summer 2004.

Length (mm FL)	Upper Section			Lower Section			Combined				
	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
200–209	26	0.05	0.010	29	0.05	0.009	55	0.05	0.007	1,053	190
210–219	32	0.06	0.011	35	0.06	0.010	67	0.06	0.007	1,283	220
220–229	17	0.03	0.008	39	0.07	0.010	56	0.05	0.007	1,073	192
230–239	14	0.03	0.007	38	0.06	0.010	52	0.05	0.006	996	182
240–249	18	0.04	0.008	22	0.04	0.008	40	0.04	0.006	766	152
250–259	17	0.03	0.008	13	0.02	0.006	30	0.03	0.005	575	125
260–269	18	0.04	0.008	34	0.06	0.010	52	0.05	0.006	996	182
270–279	28	0.06	0.010	31	0.05	0.009	59	0.05	0.007	1,130	200
280–289	27	0.05	0.010	27	0.05	0.009	54	0.05	0.006	1,034	187
290–299	25	0.05	0.010	27	0.05	0.006	52	0.05	0.006	996	182
300–309	13	0.03	0.007	15	0.03	0.012	61	0.06	0.007	1,168	205
310–319	35	0.07	0.011	52	0.09	0.009	54	0.05	0.006	1,034	187
320–329	29	0.06	0.010	31	0.05	0.009	60	0.05	0.007	1,149	202
330–339	16	0.03	0.008	28	0.05	0.010	44	0.04	0.006	843	162
340–349	26	0.05	0.010	36	0.06	0.009	62	0.06	0.007	1,187	207
350–359	33	0.06	0.011	29	0.05	0.008	62	0.06	0.007	1,187	207
360–369	30	0.06	0.010	26	0.04	0.009	56	0.05	0.007	1,073	192
370–379	29	0.06	0.010	29	0.05	0.008	58	0.05	0.007	1,111	197
380–389	14	0.03	0.007	24	0.04	0.007	38	0.03	0.005	728	147
390–399	21	0.04	0.009	18	0.03	0.004	39	0.04	0.006	747	149
400–409	17	0.03	0.008	6	0.01	0.004	23	0.02	0.004	441	106
410–419	16	0.03	0.008	6	0.01	0.002	22	0.02	0.004	421	103
420–429	6	0.01	0.005	1	<0.01	0.000	7	0.01	0.002	134	53
430–439	2	<0.01	0.003	0	0.00	0.002	2	<0.01	0.001	38	27

Appendix B8.–Number of fish sampled (n), estimated proportion ($\hat{p}_k$), and estimated abundance ($\hat{N}_k$) by age category for the population of Arctic grayling (≥200 mm FL) in the upper section (sections 1–3), lower section (sections 4 – 6), and both sections combined in the Salcha River study area, summer 2004.

	Upper Section			Lower Section			Combined				
Age	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	n	$\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$
2	2	0.01	0.004	0	0.00	0.000	2	<0.01	0.002	56	40
3	49	0.14	0.018	86	0.22	0.021	135	0.18	0.014	3,810	559
4	56	0.16	0.019	71	0.18	0.019	127	0.17	0.014	3,584	531
5	100	0.28	0.024	96	0.24	0.022	196	0.26	0.016	5,531	767
6	66	0.19	0.021	83	0.21	0.020	149	0.20	0.015	4,205	607
≥7	80	0.23	0.022	61	0.15	0.018	141	0.19	0.014	3,979	579

APPENDIX C
DATA FILE LISTING

Appendix C 1.–Data files for all Arctic grayling captured in the Salcha River, 2003–2004 relative to this study.

File Name
Salcha River Arctic grayling data files for archive-2004.xls

Note: Data files are archived at and are available from the Alaska Department of Fish and Game, Sport Fish Division, 1300 College Road, Fairbanks, Alaska 99701-1599.