Fishery Data Series No. 11-01

Stock Assessment of Arctic Grayling in the Delta River, 2008

by

Andrew D. Gryska

January 2011

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

FISHERY DATA SERIES NO. 11-01

STOCK ASSESSMENT OF ARCTIC GRAYLING IN THE DELTA RIVER, 2008

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ABSTRACT

The Alaska Department of Fish and Game and the U.S. Bureau of Land Management cooperated in a stock assessment of the Arctic grayling *Thymallus arcticus* population inhabiting a 17-km portion of the Delta River federally designated as Wild and Scenic and located in the central Alaska Range. The study was conducted during July 2008 using a mark-recapture experiment to estimate abundance and length composition of the population. Abundance was estimated for Arctic grayling ≥240 mm FL ($\hat{N}$ = 44,212; SE = 9,108), ≥270 mm FL ($\hat{N}$ = 23,152; SE = 3,189), and ≥330 mm FL ($\hat{N}$ = 5,864; SE = 818). Of Arctic grayling ≥240 mm FL, 48% were 240 – 269 mm FL and 24% were 270 – 299 mm FL, and among Arctic grayling ≥270 mm FL, 55% were 270 – 299 mm FL. The density of Arctic grayling ≥240 and ≥270 mm FL in the Delta River was the greatest ever observed among published density estimates for Alaskan fluvial Arctic grayling.

Key words: Arctic grayling, *Thymallus arcticus*, abundance, length composition, hook-and-line, mark-recapture, Delta River, Alaska.

INTRODUCTION

The Delta River begins at the outlet of Lower Tangle Lake in the Alaska Range about 100 km south-southwest of Delta Junction, Alaska. A large portion of the river and drainage have been designated a wild and scenic river by the US Bureau of Land Management (BLM); specifically, the Tangle Lakes portion of the drainage is classified as scenic, the Delta River from Lower Tangle Lake to mile 212 Richardson Highway is classified as wild, and the remaining portion through Black Rapids is classified as recreational (Figure 1). Initially, the river is a clear stream rarely prone to high muddy water due to the buffering of the large Tangle Lakes system. The river traverses 3.1 km from Lower Tangle Lake before it passes over a series of waterfalls, which are neither navigable nor allow fish to pass upstream. From the waterfalls, the river travels 17 km before the glacial Eureka Creek tributary intercepts the Delta River and it is the first of several glacial tributaries to render the Delta River glacially turbid for the remainder of its course to the Tanana River.

Each year, numerous recreational floaters and anglers travel through the Tangle Lakes and the Upper Delta River, almost all of whom take-out at Mile 212. For anglers, Arctic grayling *Thymallus arcticus* and lake trout *Salvelinus namaycush* (primarily in the Tangle Lakes) comprise most of the catch, though burbot *Lota lota* and round whitefish *Prosopium cylindraceum* are also caught to a lesser degree. Other species in the drainage include longnose sucker *Catostomus catostomus*, Dolly Varden *Salvelinus malma*, slimy sculpin *Cottus cognatus*, and at the Delta River mouth a spawning population of chum salmon *Oncorhynchus keta* (Peckham 1976). Despite the number of floaters, the level of harvest is moderate (Table 1), and accordingly the regulations for Arctic grayling in the Delta River drainage are as liberal as allowed in the Arctic grayling management plan (Swanton and Wuttig *In prep*). The regulations are:

1. a daily bag and possession limit of five Arctic grayling;
2. any size Arctic grayling may be retained; and,
3. no seasonal spawning period closure.

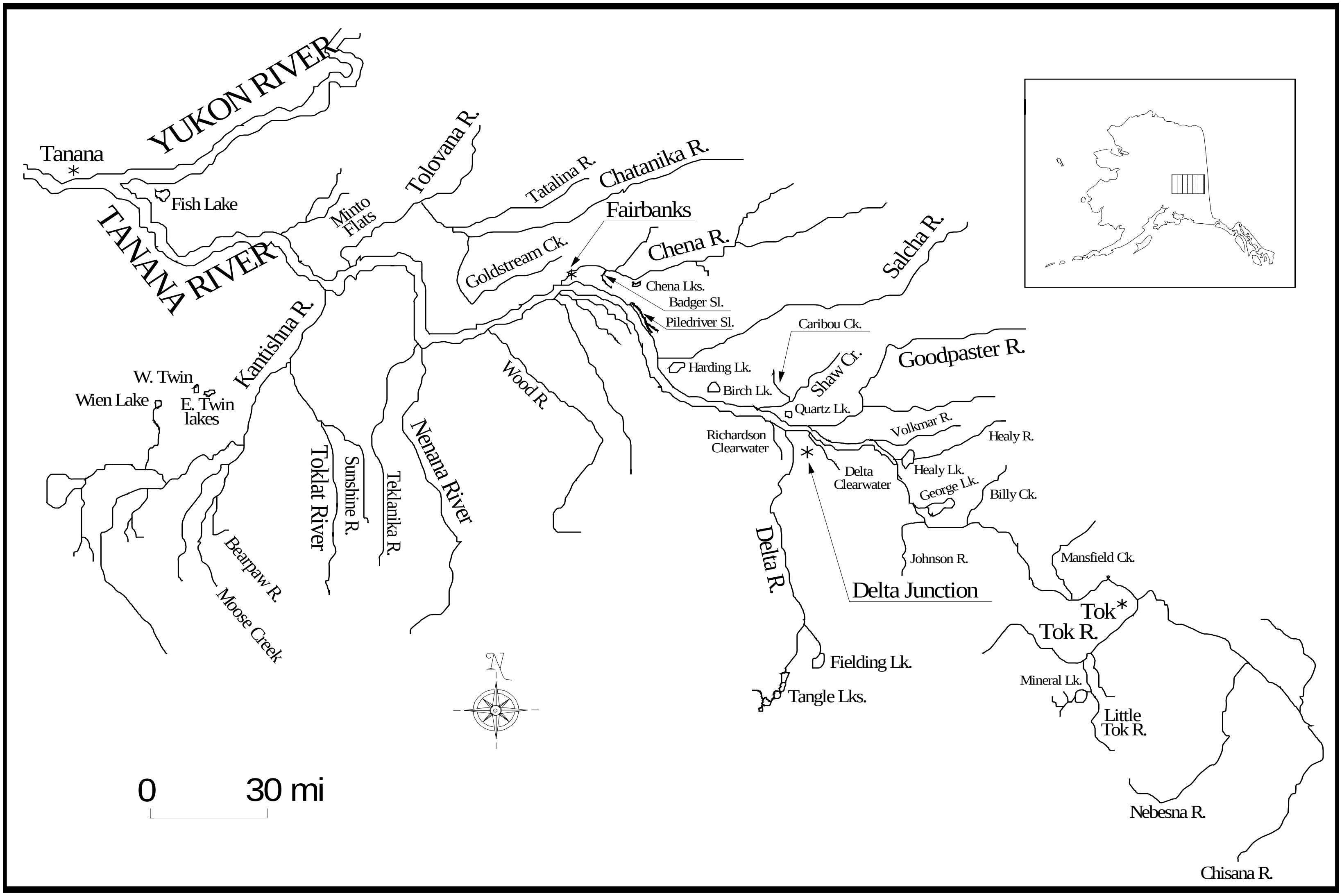

Figure 1.–Location of the Delta River drainage.

Table 1.–Estimated sport fishing effort (angler days) for all species of fish, and estimates of sport fishing catch and harvest of Arctic grayling in the Delta River, Alaska.

	All species	Arctic grayling	
Year[a]	Angler days	Harvest	Catch
1996	654	291	3,215
1997	553	770	4,112
1998	410	160	5,562
1999	1,023	640	5,924
2000	551	243	2,813
2002	663	121	5,600
2005	847	259	2,593
2006	882	304	3,317
		Average	
	698	349	4,142

[a] Data from Howe et al. 2001a-d; Jennings et al., 2006, 2009 a-b; Walker et al. 2003.

In addition to being a recreationally significant area, the Delta and Eureka drainages hold large deposits of economically important minerals and gold has been intermittently mined by small operations. The scope of the mining operations may increase dramatically with the development of the Pure Nickel Inc. MAN Alaska Project that has located significant amounts of platinum group elements, nickel, gold, cobalt and copper in an area ~280-mi^2 (Figure 2). Actual mining is projected to begin within as little as five years and this potential development increased the need for more comprehensive understanding of resident fishes that may be affected by the mining area.

This need prompted a cooperative project between the BLM and ADF&G, Division of Sport Fish, for which two mutual informational needs were identified: improved understanding of the Arctic grayling population within the Delta River between the falls and Eureka Creek and more comprehensive information on fish distributions within the drainage. Information on this Arctic grayling population was very limited and based on a few small-scaled studies during which fish were sampled (Peckham 1974, 1975; Baker 1989; Holmes et al. 1990). Distribution information of fish species was collected by Carlton (1976) and Peckham (1976), but large areas of the drainage to the west of the river were not sampled.

The cooperative project had three goals to be completed over a 2-year period: 1) estimate population size of Arctic grayling between the falls and Eureka Creek; 2) determine seasonal distribution and habitat use of those Arctic grayling using radiotelemetry; and 3) conduct species inventory of streams and lakes within an established Upper Delta River study area via helicopter transport. This report focuses on the first goal related to estimating Arctic grayling population size in the Delta River.

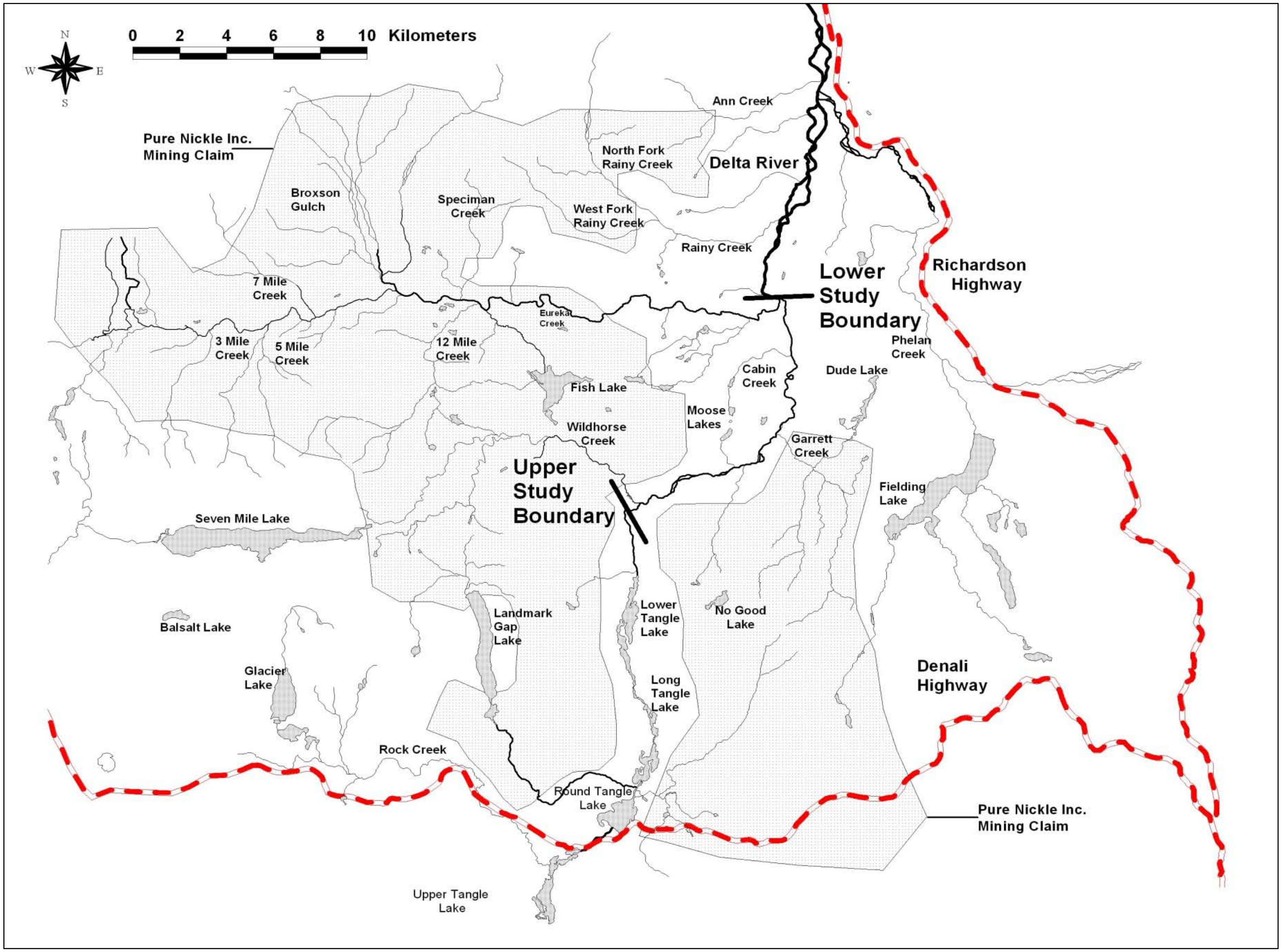

Figure 2.–Delta River study area and adjacent mining claims of Pure Nickel Inc. (demarcated approximately by shaded area).

OBJECTIVES

The research objectives for 2008 were to:

1. estimate the abundance of Arctic grayling ≥ 270 and ≥ 330 mm FL in the Delta River study area (17 km) during July 2008, such that the estimates were within 25% of the actual abundance 95% of the time; and,
2. estimate the length composition (in 10-mm intervals) of the Arctic grayling ≥ 270 mm FL in the Delta River study area (17 km) during July 2008, such that the estimates were within five percentage points of the true value 95% of the time.

The study area encompassed a 17-km reach of the Delta River from the falls to the mouth of glacial Eureka Creek (Figure 2) and it wholly contained the grayling fishery in the Delta River downstream of the falls. The size limits identified in the objectives, 270 and 330 mm FL, are commonly used standards in Arctic grayling stock assessments or management objectives within ADF&G Region III. The 270-mm length limit is related to the minimum harvest length often used in regulations. The 330-mm length limit is the length at which Arctic grayling begin to be considered large by anglers and the abundance of fish of this size is often used to manage or evaluate Interior Alaska fisheries. Because the length at which Arctic grayling recruit to the gear can range between 200 and 270 mm (Gryska 2004a, b; Wuttig 2004), all fish ≥200 mm FL were tagged in the event abundance at a lower length limit could be estimated.

METHODS

EXPERIMENTAL AND SAMPLING DESIGN

During July 2008, the study was designed to estimate abundance and length composition of Arctic grayling within the 17-km study area of the Delta River (Figure 2) using two-event Petersen mark-recapture techniques for a closed population (Seber 1982). The study was 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:

$$\hat{N} = \frac{n_1 n_2}{m_2}, \quad (1)$$

where:

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

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

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

The 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 was 17 km in length and divided into 16 approximately 1.05-km sections (Figure 3). This division served to guide sampling and provided a minimum geographic scale at which to conduct diagnostic tests. The first event occurred during July 8–11, and the second during July 15–18. During each event, three two-person crews sampled in a downstream progression, covering two to five sections a day (variation due to logistical constraints, hydrographic conditions, and densities of Arctic grayling). Daily, each crew was assigned to a section or more to capture fish using hook-and-line gear. The sampling schedule resulted in a 3-day hiatus between events or a 6-day hiatus for each specific reach of river sampled, which was deemed long enough to ensure that capture probability for each fish did not vary between events as a result of being captured and marked (DeCicco 1997). The distribution and allocation of sampling effort were planned to ensure adequate sample sizes were attained, no segments of the population were isolated from the experiment, and the study area was sampled uniformly.

The selection of the sampling area and timing of the experiment ensured that the movement of fish did not violate the assumption of closure due to combined emigration and immigration. No emigration or immigration across the lower boundary of the study area was expected because it was at the mouth of the glacial Eureka Creek, after which the Delta River becomes very turbid and is not preferred habitat for summer feeding. The upper boundary was a waterfall preventing upstream migration and believed to not have much downstream migration based on a previous study (Peckham 1976). During the summer feeding period, Arctic grayling were expected to have only localized movements (e.g., $<$ 1.6 rkm), as has been observed during previous experiments (Ridder and Gryska 2000; Gryska 2001). The duration of the hiatus was designed to: 1) eliminate potential bias due to growth recruitment and mortality; 2) allow for localized mixing of marked and unmarked fish to eliminate isolated pockets of fish; and, 3) allow for marked fish to recover from the effects of handling between events.

During each event, all sampling areas were accessed using canoes or a power boat (one crew during second event). The upper boundaries of individual sampling sections were reached by floating in a canoe, after which each crew waded through its assigned angling section, excepting the lowermost sections (14–16) which were primarily fished from a boat because the channel is deeper and more incised. All waters were angled, and in an effort to subject fish to more similar capture probabilities, the work day was adjusted such that areas of high fish densities were fished for longer periods than low density areas. Areas of higher fish densities were identified by visually observing aggregations of Arctic grayling and by evaluating catch rates and preferred habitat (e.g. heads of pools).

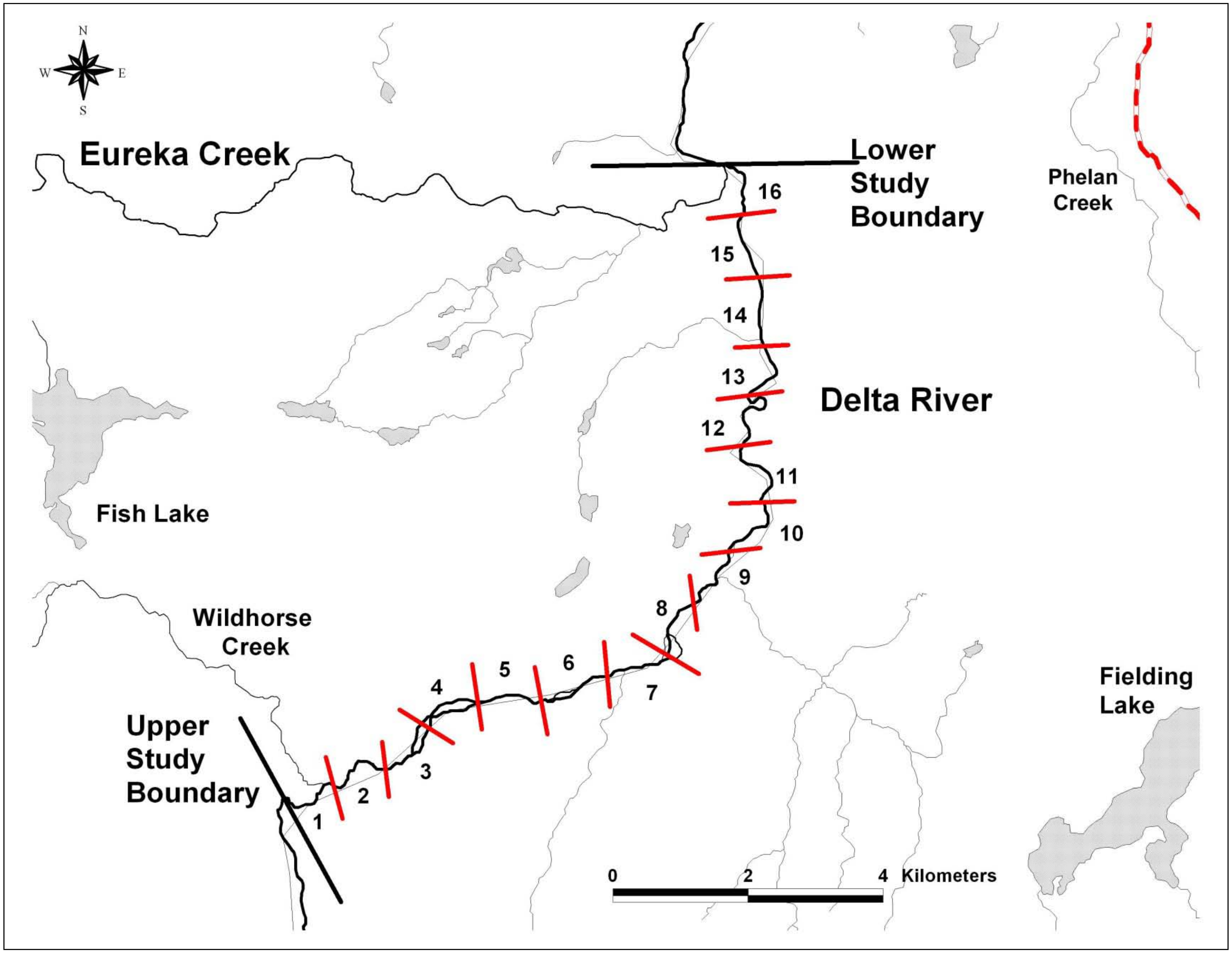

Figure 3.–Delta River study area with demarcation of each 1.05-km angling section. For consistency tests data from angling sections were pooled in the following manner: I (1–4), II (5–9), and III (10–16).

The terminal gear consisted of a combination of flies (dry and wet) and rubber-bodied jigs. The degree to which each gear was used was left to each angler's discretion. Typically, jigs were used most often. At each angling location, captured Arctic grayling were temporarily held 1–10 minutes in a five-gallon bucket until data were collected. Afterwards they were generally released at or within 25 m of their capture locations and in no cases were fish displaced by more than 100 m or from a distinct feature such as a pool.

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

DATA COLLECTION

After angling a portion of a section (25–50 m) all temporarily held fish were measured for length (mm FL), and carefully examined for marks. In the first event, all fish ≥200 mm FL were tagged with an individually numbered Floy™ FD-94 internal anchor tag (brown color, white print, numbered between 7,001 and 8,961) placed at the insertion of the dorsal fin so that the tag locks between the posterior interneural rays and received an upper caudal finclip to identify tag loss. To eliminate duplicate sampling in the second event, all fish received a lower caudal finclip. All fish in both events were carefully inspected for attendant Floy™ tags and fin clips and had their capture/release locations recorded using a GPS (latitude and longitude coordinate as decimal degrees, NAD27 Alaska datum). Fish captured in the first event that exhibited signs of injury, excessive stress, or imminent death were not marked and censored from the experiment.

DATA ANALYSIS

Abundance Estimate

When capturing fish in a river using angling equipment it is inherently difficult to approximate the taking of a simple random sample (i.e., a random sample without replacement). Therefore, samples from the Delta 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.

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 significant immigration and emigration.

Violations of Assumption 2 relative to size were evaluated using Kolmogorov-Smirnov (K-S) two-sample tests with a significance level of $\alpha = 0.05$. 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 had size selectivity) 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.

The tests for consistency of the Petersen estimator (Seber 1982; Appendix A3) were used to determine if, for each identified length stratum, 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). Documentation of release location by section for each fish permitted the examination of multiple geographic stratification schemes for purposes of assumption testing, and testing was performed at the scale of a cluster defined by grouping of adjacent angling sections (sections 1–4, 5–9, and 10–16), which also corresponded to different hydrological characteristics in the river. Sections 1–4 have a relatively narrow and swift channels (e.g. <15 m); sections 5–9 are relatively moderate in width (e.g. 15–25 m) with well defined pool-riffle sequences that meander in a wider valley; and the lower most sections are generally wide (e.g. 25 to 50 m) with few discernible riffles and elongated, deep pools. This grouping strategy also provided a sufficient number of recaptures for diagnostic testing to ensure negligible statistical bias in $\hat{N}$ (Seber 1982) and accommodated localized movements (i.e. within a 1-km radius) of Arctic grayling.

Length Composition

Length composition of the population was estimated in 10-mm length categories using the procedures outlined in Appendix A4.

RESULTS

MOVEMENT

Because fish were released relatively close to their capture location (within about 25 m), movement was defined as a fish that was recaptured ≥0.5 km from its release location. Using this definition of movement, 69 of the 87 (79%) recaptured Arctic grayling had not moved (Figure 4), and 7 (8%) other recaptured Arctic grayling had moved between 0.5 and 1.5 km. Only 2 (2%) fish moved > 5 km, having moved 6 and 8 km downstream. The virtual lack of any large or directional movements indicated that no meaningful immigration or emigration occurred during the experiment.

ABUNDANCE ESTIMATE

In the 17-km study area, 3,597 Arctic grayling ≥136 mm FL were captured (n_1 = 1,767, n_2 = 1,830, m_2 = 87), but the smallest recapture was 242 mm FL and abundance was estimated for fish ≥240 mm FL. Two hooking mortalities occurred during the second event. K-S tests (Appendix A2) results indicated Case IV for Arctic grayling ≥240 and ≥270 mm FL (Table 2). Although a single stratum of 240–299 mm FL was found to be Case I due to a marginally acceptable p-value (0.061) for one test and a borderline p-value (0.047) for the other, the stratum was assigned a Case IV (Appendix A2 has a more extensive discussion for this reasoning) because the D-value (0.35) was large, there were few recaptures (m_2 =15), and the capture probability for Arctic grayling 240–269 mm FL was half of that for those 270–299 mm FL (Tables 4 and 5). Abundance estimates were stratified by length in the following categories: 240–269 mm FL, 270–299 mm FL, ≥300 mm FL, and ≥330 mm FL. These strata were Case I, which indicated that there was no size selective sampling during both capture events and the data from both events were pooled for composition estimates of each stratum (Table 2).

Among all size groups, at least one consistency test (Appendix A3) failed to be rejected (Tables 3–7). Therefore, there was no need to geographically stratify and the Bailey-modified Petersen estimator was used to calculate abundance estimates for each stratum, which were pooled for total abundance.

Estimated abundances of Arctic grayling were:

a. 240–269 mm FL was 21,060 (SE = 8,531);

b. 270–299 mm FL was 10,465 (SE = 2,856);

c. ≥240 mm FL was 44,212 (SE = 9,108);

d. ≥270 mm FL was 23,152 (SE = 3,189);

e. ≥300 mm FL was 12,686 (SE = 1,419); and,

f. ≥330 mm FL was 5,864 (SE = 818).

LENGTH COMPOSITION

A substantial proportion of the estimated population of Arctic grayling ≥240 mm FL was 240 to 269 mm FL (48%; Table 8), although that estimate of abundance was most imprecise. The more precise estimates of abundance of Arctic grayling ≥270 mm FL indicated that abundance of fish 270–299 mm FL comprised 45% of the estimated population, ≥300 mm FL comprised 55% of the estimated population, and ≥330 mm FL comprised 30% of the estimated population (Table 9).

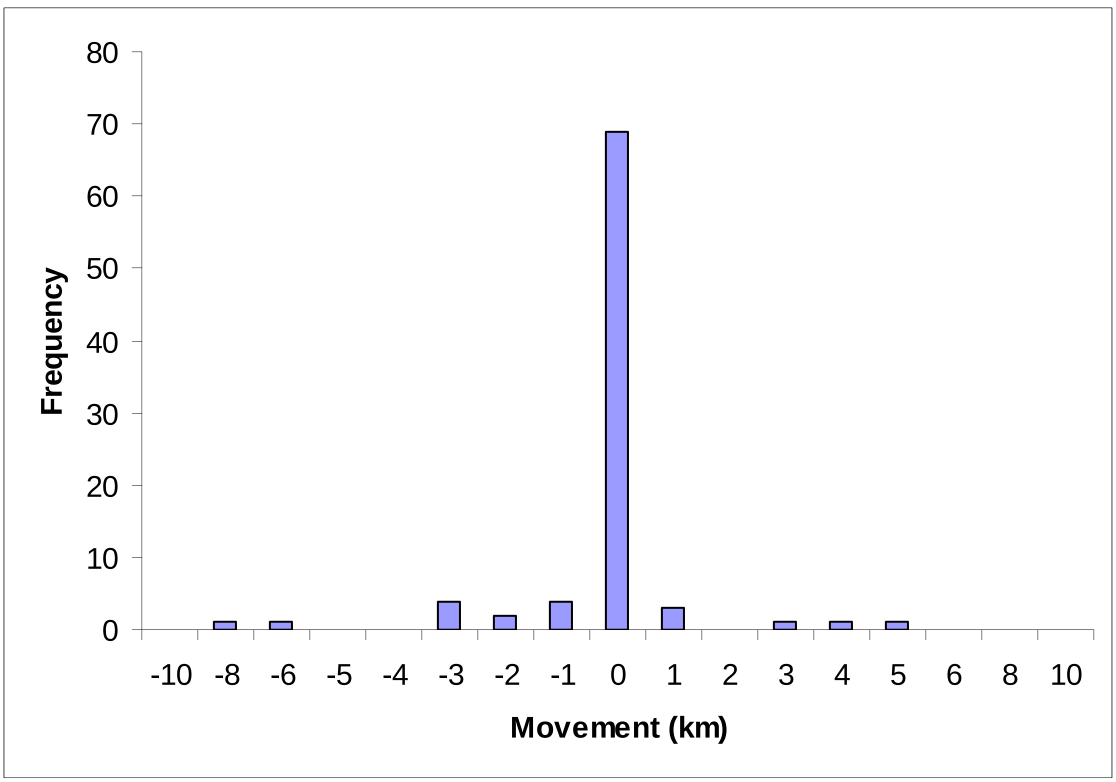

Figure 4.–Proportions of recaptured Arctic grayling (n = 87) that moved (km) upstream (positive values) or downstream (negative values) in the Delta River study area, July 2008.

Table 2.–Results of diagnostics used to detect and correct for size-selective sampling (Appendix A2) for estimating abundance and length compositions of Arctic grayling in the Delta River, July 2008.

Stratum	Comparison and Test Statistic			Result
	M vs. R	**C vs. R**	**M vs. C**	
≥240 mm FL	D = 0.263 P-value < 0.001 Reject H_0	D = 0.269 P-value < 0.001 Reject H_0	D = 0.031 P-value = 0.382 Fail to Reject H_0	Case IV, stratify
240–299 mm FL	D = 0.342 P-value = 0.061 Reject H_0	D = 0.354 P-value = 0.047 Reject H_0	D = 0.047 P-value = 0.426 Fail to reject H_0	Case IV, stratify
240–269 mm FL	D = 0.194 P-value = 0.998 Fail to reject H_0	D = 0.202 P-value = 0.997 Fail to reject H_0	D = 0.052 P-value = 0.737 Fail to reject H_0	Case I, do not stratify, use lengths and ages from both events for composition analysis
270–299 mm FL	D = 0.270 P-value = 0.405 Fail to reject H_0	D = 0.328 P-value = 0.192 Fail to reject H_0	D = 0.071 P-value = 0.303 Fail to reject H_0	Case I, do not stratify, use lengths and ages from both events for composition analysis
≥300 mm FL	D = 0.139 P-value = 0.124 Fail to reject H_0	D = 0.093 P-value = 0.566 Fail to reject H_0	D = 0.060 P-value = 0.061 Fail to reject H_0	Case I, do not stratify, use lengths and ages from both events for composition analysis
≥330 mm FL	D = 0.125 P-value = 0.491 Fail to reject H_0	D = 0.073 P-value = 0.972 Fail to reject H_0	D = 0.063 P-value = 0.242 Fail to reject H_0	Case I, do not stratify, use lengths and ages from both events for composition analysis

Table 3.–Results of consistency tests for the Petersen estimator (Appendix A3) for estimating abundance of Arctic grayling in the Delta River, July 2008.

	Consistency Test		
	I	**II**	**III**
Stratum	**Complete Mixing**	**Equal probability of Capture, 1st Event**	**Equal Probability of Capture, 2nd Event**
240–269 mm FL	$\chi^2 = 5.61$ P-value = 0.23	$\chi^2 = 1.69$ P-value = 0.43	$\chi^2 = 0.81$ P-value = 0.67
270–299 mm FL	$\chi^2 = 15.52$ P-value = 0.02	$\chi^2 = 1.46$ P-value = 0.48	$\chi^2 = 1.25$ P-value = 0.53
≥300 mm FL	$\chi^2 = 92.52$ P-value <0.01	$\chi^2 = 3.56$ P-value = 0.17	$\chi^2 = 5.04$ P-value = 0.08
≥330 mm FL	$\chi^2 = 66.77$ P-value <0.01	$\chi^2 = 2.79$ P-value = 0.25	$\chi^2 = 2.22$ P-value = 0.33

Table 4.–Number of Arctic grayling 240–269 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by cluster in the Delta River study area, July 2008.

		Cluster where recaptured					
		I	II	III	m_2	n_1	m_2/n_1[c]
Cluster[a] where marked	I	2	0	0	2	102	0.02
	II	0	1	0	1	146	0.01
	II	0	1	0	1	77	0.01
	m_2	2	2	0			
	n_2	87	165	71			
	(m_2/n_2)[b]	0.02	0.01	0.00			

[a] Cluster refers to a grouping of adjacent sections: Cluster I = Sections 1-4; Cluster II = Sections 5-9, and Cluster III = Sections 10-16.

[b] Probability of capture during first event.

[c] Probability of capture during second event.

Table 5.–Number of Arctic grayling 270-299 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by cluster in the Delta River study area, July 2008.

		Cluster where recaptured					
		I	II	III	m_2	n_1	m_2/n_1[c]
Cluster[a] where marked	I	4	1	0	5	110	0.05
	II	0	5	0	5	156	0.03
	II	0	0	1	1	68	0.01
	m_2	4	6	1			
	n_2	93	200	82			
	(m_2/n_2)[b]	0.04	0.03	0.01			

[a] Cluster refers to a grouping of adjacent sections: Cluster I = Sections 1-4; Cluster II = Sections 5-9, and Cluster III = Sections 10-16.

[b] Probability of capture during first event.

[c] Probability of capture during second event.

Table 6.–Number of Arctic grayling ≥300 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by cluster in the Delta River study area, July 2008.

		Cluster where recaptured					
		I	II	III	m_2	n_1	m_2/n_1[c]
Cluster[a] where marked	I	27	1	1	29	317	0.09
	II	0	36	3	39	496	0.08
	II	0	0	4	4	132	0.03
	m_2	27	37	8			
	n_2	321	467	191			
	(m_2/n_2)[b]	0.08	0.08	0.04			

[a] Cluster refers to a grouping of adjacent sections: Cluster I = Sections 1-4; Cluster II = Sections 5-9, and Cluster III = Sections 10-16.

[b] Probability of capture during first event.

[c] Probability of capture during second event.

Table 7.–Number of Arctic grayling ≥330 mm FL marked (n1), examined (n2), and recaptured (m2) by cluster in the Delta River study area, July 2008.

		Cluster where recaptured					
		I	II	III	m_2	n_1	m_2/n_1[c]
Cluster[a] where marked	I	19	0	0	19	167	0.11
	II	0	21	2	23	269	0.09
	II	0	0	3	3	58	0.05
	m_2	19	21	5			
	n_2	181	261	103			
	(m_2/n_2)[b]	0.10	0.08	0.05			

[a] Cluster refers to a grouping of adjacent sections: Cluster I = Sections 1-4; Cluster II = Sections 5-9, and Cluster III = Sections 10-16.

[b] Probability of capture during first event.

[c] Probability of capture during second event.

Table 8.–Number of representative fish sampled (n), estimated, estimated abundance ($\hat{N}_k$), and estimated proportion of abundance ($\hat{p}[\hat{N}_k]$), by length category for the population of Arctic grayling (≥240 mm FL) in the Delta River, July 2008.

Length (mm FL)	n	$\hat{N}_k$	$\hat{SE}[\hat{N}_k]$	$\hat{p}[\hat{N}_k]$	SE $\hat{p}[\hat{N}_k]$
240–249	179	5,818	2,381	0.13	0.003
250–259	244	7,930	3,233	0.18	0.005
260–269	225	7,313	2,984	0.17	0.005
270–279	210	3,100	863	0.07	<0.001
280–289	228	3,365	935	0.08	<0.001
290–299	271	4,000	1,107	0.09	0.001
300–309	303	1,999	247	0.05	<0.001
310–319	293	1,933	240	0.04	<0.001
320–329	289	1,907	237	0.04	<0.001
330–339	289	1,907	237	0.04	<0.001
340–349	253	1,669	210	0.04	<0.001
350–359	205	1,352	175	0.03	<0.001
360–369	141	930	128	0.02	<0.001
370–379	91	600	91	0.01	<0.001
380–389	34	224	45	0.01	<0.001
390–399	21	139	34	<0.01	<0.001
400–409	4	26	13	<0.01	<0.001

Table 9.–Number of representative fish sampled (n), estimated abundance ($\hat{N}_k$), and estimated proportion of abundance ($\hat{p}\left[\hat{N}_k\right]$), by length category for the population of Arctic grayling (≥270 mm FL) in the Delta River, July 2008.

Length (mm FL)	n	$\hat{N}_k$	$\hat{SE}\left[\hat{N}_k\right]$	$\hat{p}\left[\hat{N}_k\right]$	SE $\hat{p}\left[\hat{N}_k\right]$
270–279	210	3,100	863	0.13	<0.001
280–289	228	3,365	935	0.15	0.001
290–299	271	4,000	1,107	0.17	0.001
300–309	303	1,999	247	0.09	<0.001
310–319	293	1,933	240	0.08	<0.001
320–329	289	1,907	237	0.08	<0.001
330–339	289	1,907	237	0.08	<0.001
340–349	253	1,669	210	0.07	<0.001
350–359	205	1,352	175	0.06	<0.001
360–369	141	930	128	0.04	<0.001
370–379	91	600	91	0.03	<0.001
380–389	34	224	45	0.01	<0.001
390–399	21	139	34	0.01	<0.001
400–409	4	26	13	<0.01	<0.001

DISCUSSION

The study goal was to estimate the abundance and length composition of the population in the study area, and both objectives were met. Estimates of abundance were calculated for Arctic grayling ≥270 and ≥330 mm FL, as well as for ≥240 mm FL. Estimates of abundance were expected to be within 25% of the actual abundance 95% of the time, but both objective estimates were slightly less precise having a precision of 27%. The abundance estimate for ≥300 mm FL stratum did have a precision of 22%. The estimate for 240–269 mm FL stratum was very imprecise (79%) lowering the precision of the abundance estimate for ≥240 mm stratum to 40%. Overall, the estimates were satisfactorily precise. However, given the density of Arctic grayling present in the study area, substantially more effort would be needed to have produced more precise estimates, particularly for fish of smaller sizes (i.e. ≤270 mm FL).

Because this was the first abundance estimate of Arctic grayling in the Delta River, there are no previous estimates with which to compare. However, comparing to the numerous other Arctic grayling abundance estimates throughout the state during the previous 50 years of statehood, it is clear that this population is uniquely abundant as only two other estimates had similarly high densities. Roguski and Tack (1970) estimated 36,985 Arctic grayling ≥145 mm FL in the riverine section between Long Tangle and Lower Tangle lakes, but the veracity of the estimate is questionable because the presentation in the report lacks essential information to validate the estimate. Additionally, it is unclear if a viable estimate is possible because Ridder (1992), after four years of study, concluded that estimating abundance in the large Tangle Lakes system was extremely difficult due to movements of Arctic grayling as well as the logistical difficulties of executing appropriate sampling effort.

The only defensible estimate with similar densities was for the Delta Clearwater River (DCR) during 2006 (Wuttig and Gryska 2010). For that estimate, a 22-km study area contained 14,799 (SE = 2,204) Arctic grayling ≥270 mm FL and 11,311 (SE = 1,513) Arctic grayling ≥330 mm FL. Both the Delta River and DCR are short (terminating at a glacial river or creek), clear, cool, exhibit stable flows and are uniquely productive. The spring-fed DCR is nutrient rich supporting the highest production levels of benthic algae and invertebrate drift documented in Interior Alaska (LaPerriere 1994). The ecology of the Delta River has not been studied, but it is suspected that the long series of lakes upstream buffers turbid flows and supplements production downstream, for example, via transport of nutrients, organic matter, and invertebrates. The hydrological and ecological conditions of both rivers appear to be conducive to supporting high densities of Arctic grayling, which makes sense given that Arctic grayling are physiologically adapted to cold water and are visual predators, primarily consuming invertebrates (Northcote 1995).

For management purposes, there is no concern for the Arctic grayling population because the estimated abundance was exceptionally large relative to angler effort and harvest.

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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 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.–Detection of size and/or sex selective sampling during a two-sample mark recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov two sample test (Conover 1980) is used to detect significant evidence that size selective sampling occurred during the first and/or second sampling events. The second sampling event is evaluated 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) by using the null test hypothesis 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. A third test that compares M and C is then conducted and used to evaluate the results of the first two tests when sample sizes are small. Guidelines for small sample sizes are <30 for R and <100 for M or C.

Sex selective sampling: Contingency table analysis (Chi^2-test) is generally used to detect significant evidence that sex selective sampling occurred during the first and/or second sampling events. The counts of observed males to females are compared between M&R, C&R, and M&C using the null hypothesis that the probability that a sampled fish is male or female is independent of sample. If the proportions by gender are estimated for a sample (usually C), rather an observed for all fish in the sample, contingency table analysis is not appropriate and the proportions of females (or males) are then compared between samples using a two sample test (e.g. Student's t-test).

M vs. R	**C vs. R**	**M vs. C**
Case I:		
Fail to reject H_o	Fail to reject H_o	Fail to reject H_o

There is no size/sex selectivity detected during either sampling event.

Case II:		
Reject H_o	Fail to reject H_o	Reject H_o

There is no size/sex selectivity detected during the first event but there is during the second event sampling.

Case III:		
Fail to reject H_o	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.

Case IV:		
Reject H_o	Reject H_o	Either result possible

There is size/sex selectivity detected during both the first and second sampling events.

Evaluation Required:		
Fail to reject H_o	Fail to reject H_o	Reject H_o

Sample sizes and powers of tests must be considered:

A. If sample sizes for M vs. R and C vs. R tests are not small and sample sizes for M vs. C test are very large, the M vs. C test is likely detecting small differences which have little potential to result in bias during estimation. *Case I* is appropriate.

B. If a) sample sizes for M vs. R are small, b) the M vs. R p-value is not large (~0.20 or less), and c) the C vs. R sample sizes are not small and/or the C vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the second event which the M vs. R test was not powerful enough to detect. *Case I* may be considered but *Case II* is the recommended, conservative interpretation.

-continued-

C. If a) sample sizes for C vs. R are small, b) the C vs. R p-value is not large (~0.20 or less), and c) the M vs. R sample sizes are not small and/or the M vs. R p-value is fairly large (~0.30 or more), the rejection of the null in the M vs. C test was likely the result of size/sex selectivity during the first event which the C vs. R test was not powerful enough to detect. *Case I* may be considered but *Case III* is the recommended, conservative interpretation.

D. If a) sample sizes for C vs. R and M vs. R are both small, and b) both the C vs. R and M vs. R p-values are not large (~0.20 or less), the rejection of the null in the M vs. C test may be the result of size/sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect. *Cases I, II, or III* may be considered but *Case IV* is the recommended, conservative interpretation.

Case I. Abundance is calculated using a Petersen-type model from the entire data set without stratification. Composition parameters may be estimated after pooling length, sex, and age data from both sampling events.

Case II. 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. 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. 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.

If stratification by sex or length is necessary prior to estimating composition parameters, then an overall composition parameters (p_k) is estimated by combining within stratum composition estimates using:

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{ ; and,} \qquad \text{(A2-1)}$$

$$\hat{V}\left[\hat{p}_k\right] \approx \frac{1}{\hat{N}_\Sigma^2} \sum_{i=1}^{j} \left(\hat{N}_i^2 \hat{V}\left[\hat{p}_{ik}\right] + \left(\hat{p}_{ik} - \hat{p}_k\right)^2 \hat{V}\left[\hat{N}_i\right] \right). \qquad \text{(A2-2)}$$

where:

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

Appendix A3.–Tests of consistency for the Petersen estimator (from Seber 1982, page 438).

Tests of consistency for Petersen Estimator

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

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

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

I.-Test for complete mixing[a]

Section Where Marked	Section Where Recaptured				Not Recaptured
	A	**B**	**…**	**F**	(n_1-m_2)
A					
B					
...					
F					

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

	Section Where Examined			
	A	**B**	**…**	**F**
Marked (m_2)				
Unmarked (n_2-m_2)				

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

	Section Where Marked			
	A	**B**	**…**	**F**
Recaptured (m_2)				
Not Recaptured (n_1-m_2)				

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

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

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

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

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

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

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 which fish were included (Appendix A2). For Case I, fish from both capture events are used.

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

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

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

$$\hat{N}_k = \hat{p}_k \hat{N}, \qquad \textbf{(A4-3)}$$

where:

$\hat{N}$ = the estimated overall abundance (Appendix A1).

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):

$$\hat{V}\left[\hat{N}_k\right] = \hat{V}[\hat{p}_k]\hat{N}^2 + \hat{V}\left[\hat{N}\right]\hat{p}_k^2 - \hat{V}[\hat{p}_k]\hat{V}\left[\hat{N}\right]. \qquad \textbf{(A4-4)}$$

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:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \qquad \text{(A4-5)}$$

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:

-continued-

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

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):

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

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

$$\hat{p}_k = \hat{N}_k \big/ \hat{N} \qquad \text{(A4-8)}$$

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

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

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

APPENDIX B
DATA FILE LISTING

Appendix B1.–Data files for population estimate of Arctic grayling captured in the Delta River, 2008.

File Name[a]
Delta River Arctic grayling population estimate data files for archive-2008.xls

[a] 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.