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Abundance and Length Composition of Arctic Grayling in the Delta Clearwater River, 2006

by

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and

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

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DEPARTMENT OF FISH AND GAME

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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. 10-84

ABUNDANCE AND LENGTH COMPOSITION OF ARCTIC GRAYLING IN THE DELTA CLEARWATER RIVER, 2006

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ABSTRACT

The abundance, size and age composition of Arctic grayling in the lower 23 km of the Delta Clearwater River was estimated using a two-sample mark-recapture experiment. Fish were captured by systematically fishing using hook-and-line gear in a downstream progression with the first event conducted from July 24 to 28, 2006 and with the second from July 31 to August 4, 2006. The estimated abundance of Arctic grayling ≥ 270 mm FL in the DCR study area was 14,799 (SE = 2,204) and for fish ≥ 330 mm FL, the estimated abundance was 11,311 (SE = 1,513). The proportion of the estimated population ≥ 270 mm FL that was ≥ 330 mm FL (i.e. 14 inches) was 0.82 (SE = 0.01) and fish ≥ age -7 was comprised 0.72 (SE = 0.01) of the population ≥ 270 mm FL. Compared with previous estimates attained during 1996–2000, there was a significant increase in the abundance of fish, primarily due to a large increase in the abundance of fish ≥330 mm FL. The management objectives for the DCR to maintain a fishery in which at least 40% of the assessed population exceeds 14 inches in length, to ensure harvest does not exceed 900 fish less than 12 inches in length, and to provide a fishery that provides for a minimum catch rate of one Arctic grayling per angler day have been achieved. Continued periodic monitoring of this system is recommended for further refinement of the management objectives.

Key words: Arctic grayling, Delta Clearwater River, abundance, size composition, mark recapture experiment, hook-and-line.

INTRODUCTION

The Delta Clearwater River (DCR), located near Delta Junction (Figure 1 and 2) supports one of the most important road-accessible Arctic grayling fisheries within the Tanana Drainage (Figure 2 and 3, Appendix A1). The DCR and its Arctic grayling population are unique compared to more typical rapid run-off Interior river systems. The DCR is a relatively short (approximately 34 km) almost exclusively spring-fed system that remains relatively cool year round (typical annual water temperatures ranging from 0 to 7.8ºC), and is very productive with benthic Algal standing crop at least an order of magnitude greater than the Chena River (LaPerriere 1994).

The DCR is utilized by juvenile and adult Arctic grayling for feeding during summer and fall but not for overwintering and spawning (Ridder 1998a). Immigration to the DCR for feeding begins in April with juvenile fish as well as some adults, followed by post-spawning adults from mid-May through June, and emigration to overwintering areas (e.g. Tanana River) from September to December (Clark 1988, Ridder 1998a). The adult feeding population is composed of fish that spawn in at least eight different systems, with a majority (approximately 50%) from the nearby Goodpaster River (Ridder 1998a). With the absence of spawning in the DCR, the recruitment mechanism of juvenile and adult fish into the DCR is not fully understood but is likely a combination of straying at all ages and hydrological dispersal of larval fish (Clark 1988; Clark and Ridder 1988); however, once recruited they exhibit a high degree of fidelity to this system for summer feeding (Ridder 1998a). Due to its productive ecology the DCR supports a high-density population of Arctic grayling that are on average larger (e.g., 14-18 in FL) than other Interior Alaska rapid run-off systems (Gryska 2001; Wuttig and Stroka 2007). That, when combined with its attractive setting and relatively easy access, results in a much sought-after fishery by anglers (Parker 2006).

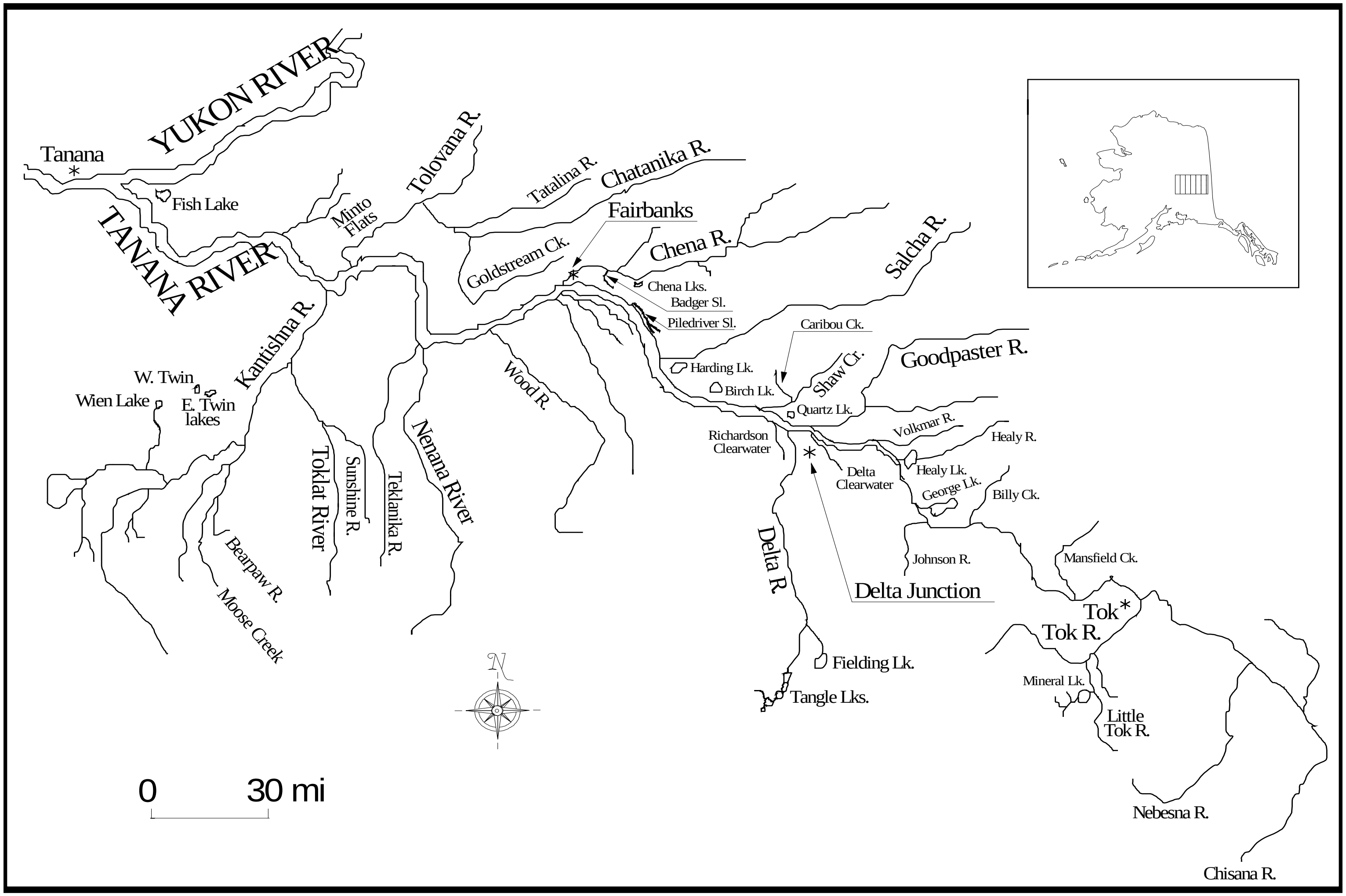

Figure 1.-Location of the Goodpaster and Delta Clearwater rivers in the Tanana River drainage.

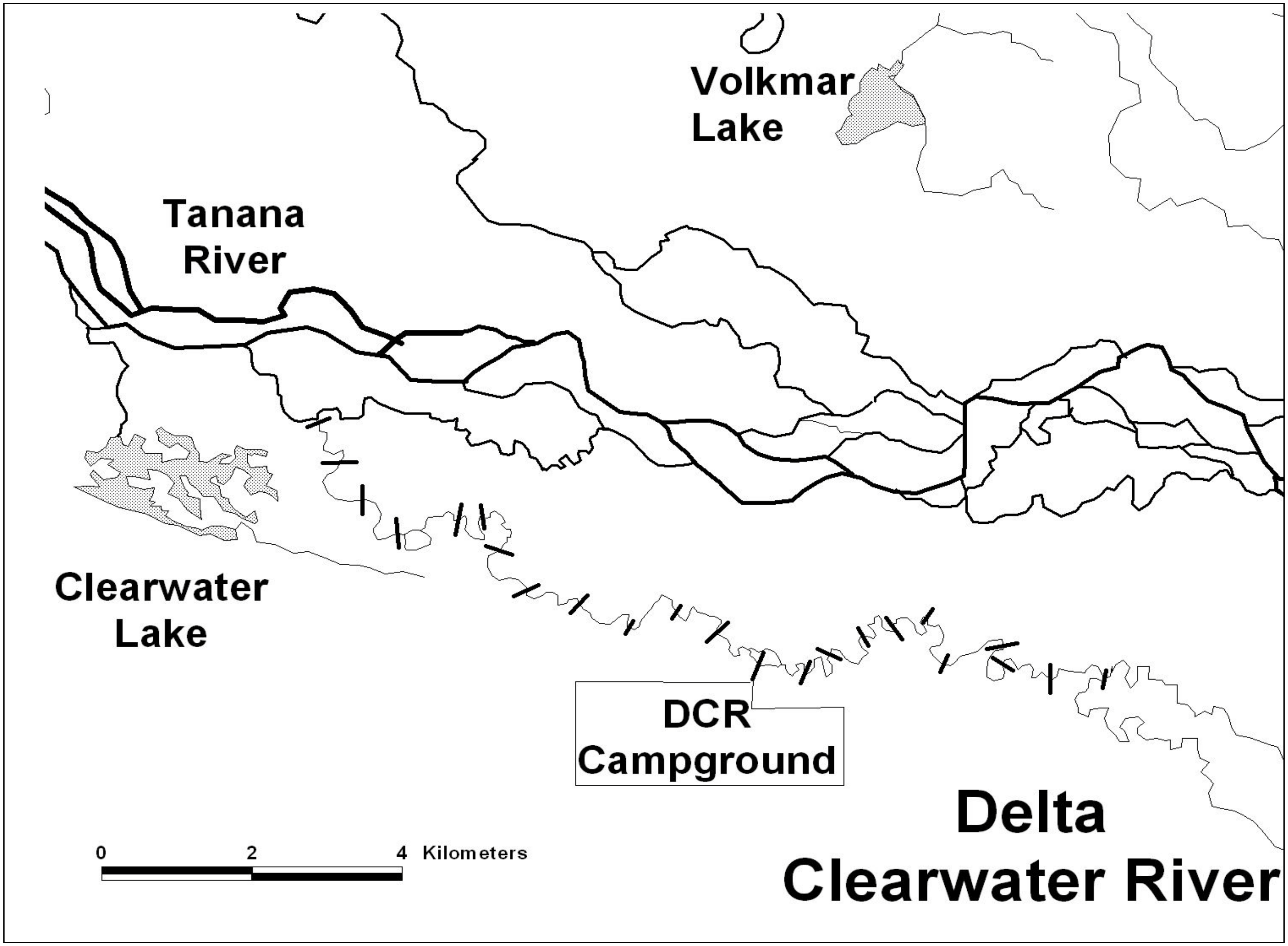

Figure 2.–Delta Clearwater River study area (22.66 km) with the 22 sampling sections demarcated.

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Currently the DCR fishery is managed by the guidelines identified within the *Region III Wild Arctic Grayling Management Plan* that stipulates wild Arctic grayling are to be managed for long-term sustained yield employing a conservative harvest regime by utilizing one of three management policies (Swanton and Wuttig *In prep*). The DCR is managed under Policy 3, the purpose of which is to provide for unique angling opportunities through the application of more restrictive regulations. The DCR Arctic grayling fishery has a history of consumptive use (Figure 3, Appendix A1 and A2), but because the population is unique in that it provides for highcatch rates of relatively large (≥ 14 in) fish, current regulations restrict the fishery to catch-and-release for fish >12 inches. Specific fishery management objectives have been established for the DCR (Parker 2003a, b), which are to:

1) maintain a fishery in which at least 40% of the assessed population of Arctic grayling exceeds 14 inches in total length (330 mm FL) ;
2) allow a harvest that does not exceed 900 fish less than 12 inches in total length (270 mm FL); and,
3) prosecute the fishery in such a way as to provide for a minimum catch rate of one Arctic grayling per angler day.

These objectives were developed and are evaluated using information from periodic stock assessments in a 23-km index section primarily designed to estimate abundance and size composition, and from catch and harvest estimates from the Alaska Statewide Harvest Survey (SWHS).

Stock assessments on the DCR have been conducted since 1961 and have varied in intensity and complexity including:

1) programs centered on creel surveys, age and length sampling, and relative abundance indices such as the catch rate from one downstream pass of an electrofishing boat (Peckham and Ridder 1979, Ridder 1985);
2) conducting retrospective catch-at-age analyses on creel data collected from 1977 to 1990 (Clark and Ridder 1994);
3) radiotelemetry studies (Ridder 1998a);
4) assessments of contributing spawning populations such as Caribou Creek and the Goodpaster River (Ridder 1991, 1998a, 1998b); and,
5) a series of mark-recapture experiments designed to estimate the abundance of Arctic grayling in a 23-km long index section of the DCR (Ridder 1998c, 1999; Ridder and Gryska 2000; Gryska 2001; Appendix A3).

The goal of this project was to provide current information on the status of the Arctic grayling population relative to the aforementioned management objectives. The Arctic grayling population in the DCR had not been assessed since 2000. In 2006, a two sample mark-recapture experiment designed to estimate the abundance and length composition was conducted in the lower 23 km of the DCR.

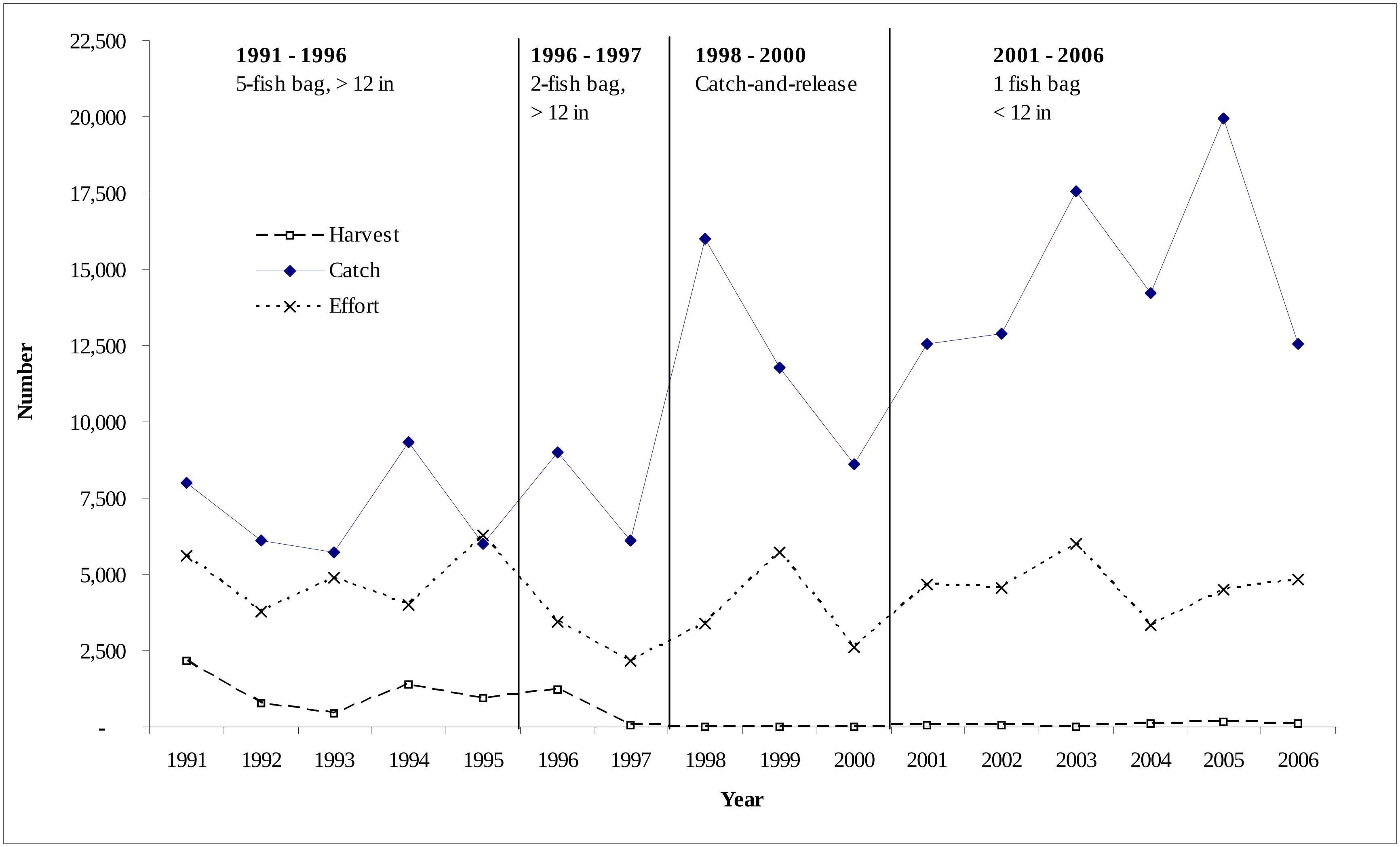

Figure 3.–Estimated number of Arctic grayling harvested and caught, and angling effort (number of days fished for all species) in the Delta Clearwater River drainage from 1991 to 2006. Values reported by Parker (2008). Vertical lines delineate major changes in regulation (i.e. bag and length limits). Length limits are expressed as total length where 12 inches corresponds to approximately 270 mm FL.

OBJECTIVES

The project objectives for 2006 were to:

1. estimate the abundances of Arctic grayling ≥ 240, ≥ 270, and ≥ 330 mm FL in a 22.7-km index section of the DCR River during August such that each estimate was within 25% of the actual abundance 95% of the time;
2. test the hypothesis that the proportion of Arctic grayling ≥ 330 mm FL in the population of Arctic grayling ≥ 240 mm FL in the 22.7 -km index section of the DCR River during August was greater than or equal to 0.40 with $\alpha = 0.05$ such that $\beta = 0.07$ if the true proportion was 0.36;
3. estimate the length composition (in 10-mm FL length categories) of Arctic grayling ≥ 240 mm FL in a 22.7-km index section of the DCR River such that the estimates were within 5 percentage points of the true value 95% of the time;
4. estimate the age composition using scale ages of Arctic grayling < 350 mm FL in a 22.7-km index section of the DCR River in age groups 1–6 and ≥ 7 years such that the estimates were within 5 percentage points of the true value 95% of the time; and,
5. estimate the mean length-at-age for fish of age 3, 4, 5, and 6 such that the estimates were within 5% of the true value 95% of the time.

In addition, a project task was to determine the locations of radio-tagged Arctic grayling using tracking stations at the study area boundaries and by conducting daily boat surveys throughout the study area.

Relative to Objective 1, the size limits identified (240, 270, and 330 mm FL) are commonly used standards in Arctic grayling stock assessments or management objectives within Region III. The 240-mm length limit relates to the management objective for the DCR, and it is the smallest size that Arctic grayling have been sufficiently recruited to hook-and-line gear to produce estimates of abundance during previous studies in the DCR (Ridder 1998c, 1999; Ridder and Gryska 2000; Gryska 2001). The 270-mm length limit related to the 12-in TL regulation on the DCR and to other regulations and stock assessments in the Tanana River basin (Appendix A2). The 330-mm (14 in TL) length limit relates directly to the management objective for the DCR.

Relative to Objective 2, the probability of a Type I error (alpha) was set such that there was less than a 5% chance of deciding that the proportion of Arctic grayling ≥ 330 mm FL was less than 40% (rejecting the null) when, in fact, at least 40% were ≥ 330 mm FL. The choice of alpha and beta were based on discussions among the area manager, research staff, and biometrician, which were directed towards appropriately balancing the risks of these errors for both research and management perspectives. The null hypothesis was chosen to be H_0: $p \geq 0.4$ rather than H_0: $p \leq 0.4$ because the area manager wanted to be convinced that the proportion was low before further restricting regulations.

As put forth in the management plan, the hypothesis test result and the abundance estimate for Arctic grayling ≥ 330 mm FL are used to determine if a management action is necessary and, if needed, what type of action would be appropriate. The definition of a management action was broad and included a range of possibilities from a recommendation for another abundance estimate to “verify” initial estimates to an emergency order (EO) that could reduce harvest. The severity of the action would depend on a combination of several factors such as the magnitude of the difference between the proportion estimate and the management objective, evidence of large or small recruitment potential, and the effectiveness of an EO to result in a meaningful reduction in harvest.

For the age-related objectives, aging error of scales increases markedly after age-6 due to the decrease in annual growth (DeCicco 1999); therefore, fish of scale age > 6 were grouped in a single age category. Because of this error, the age composition estimates were used primarily to identify cohorts of fish (i.e., ages 3, 4, or 5) that may have been recruited into relevant management objectives (i.e., fish greater than 270 or 330 FL).

Regarding the task, radio-tagged Arctic grayling from the Goodpaster River spawning area were present in the DCR study area during this experiment. Determining the daily locations of these radio-tagged Arctic grayling served to evaluate the closure assumption and assumptions regarding movements within the study area during the experiment.

METHODS

STUDY DESIGN

The research objectives and experimental design for this study were similar to successful experiments conducted from 1996 to 2000 in terms of the precision criteria, length strata of interest (≥ 240, ≥ 270 and ≥ 330 mm FL), timing of the experiment (late July), geographic area (22.7 km or 14 river miles), and capture gear (hook-and-line), all which helped to ensure project success and also accommodated historical comparisons. In 2005, this study was designed to estimate abundances and length and age compositions of Arctic grayling within the 22.7-km index area of the DCR (Figure 2) 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:

$$\hat{N} = \frac{n_1 n_2}{m_2}, \tag{1}$$

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 B1–B3).

The study area was 22.7 km in length and divided into 22 approximately 1-km sections (Figure 2). The first event occurred during July 24–28, and the second during July 31–August 4. During each event, sampling progressed in a downstream covering 3 to 5 sections a day (e.g. sections 1–4 on July 28, section 5–8 on July 29). On a given sampling day, 4 to 5 crews were available, and one or two 2-person crews were assigned to a section to capture fish using hook-and-line gear depending on the width of the river (Appendix A4). In sections 1-18, a single crew was assigned to a section because the river is narrow enough that both banks (i.e. all areas) could be effectively fished (i.e. cast to) by anchoring a river boat in the center of the channel. The lowermost sections (19–22) are approximately twice as wide, therefore each crew was assigned to a single bank or side (half) of the river channel. The sampling schedule resulted in a 3-day hiatus between events or a 6-day hiatus for each specific reach of river sampled. 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, the glacial Tanana River, was expected because it is used as a migration corridor and as overwintering habitat. Based on previous sampling and radiotelemetry studies, migration into the DCR via the Tanana River is generally complete by early June, and emigration does not occur until mid-September. The upper boundary was the confluence of two major tributaries, above which boat navigation becomes more hazardous. Arctic grayling were known to use the DCR upstream of this confluence; however, late July corresponded to the summer feeding period for Arctic grayling in the DCR when, in general, only localized movements (e.g., < 1.6 rkm) were expected for a large majority (e.g., >90% of the population), as has been observed during previous experiments (Ridder and Gryska 2000; Gryska 2001).

The short duration of the experiment eliminated potential bias due to growth recruitment and mortality. The duration of the hiatus was kept short to render bias insignificant due to combined immigration and emigration associated with localized mixing at the upper boundary. The hiatus between events was of sufficient duration to allow for localized mixing of marked and unmarked fish and for marked fish to recover from the effects of handling between events.

In a separate, but related study, 70 radio tags were deployed into the spawning population of Arctic grayling (≥350 mm FL) in the Lower Goodpaster River to understand their movement and distribution patterns over an 18-month period. Twenty-six of these radio-tagged Arctic grayling were present in the DCR during the mark-recapture experiment, which permitted an independent assessment of the assumption of closure. During both sampling events, a daily boat survey of the lower 26 rkm of the DCR was conducted in the evening during July 24–28 and July 31–August 3 to record their locations within a range of approximately 100 m. In addition, automated tracking stations positioned at the upper and lower boundaries recorded the passage of any radio-tagged Arctic grayling into and out of the study area.

During each event, all sampling areas were accessed using river boats. The individual sampling sections were sampled by anchoring the boat such that the entire width of the river could be fished (i.e. cast to). The entire length of a section was fished by pulling up the anchor and drifting or idling downstream approximately 50 m to the next portion of unfished water. In an effort to subject fish to an equal probability of capture the downstream pacing of a sampling crew over the 8-hr 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 habitat (e.g. heads of pools are typically preferred habitat).

The terminal gear consisted of a combination of flies (dry and wet) and rubber-bodied jigs and both were fished at each specific location (pool-riffle). The degree to which each gear was used was left to anglers' discretion because the known effectiveness of each gear type was very dependent on the time of day, with jigs being more effective in the morning and flies in the afternoon and evening hours when invertebrates were predictably emerging. Typically, jigs were almost exclusively fished early morning, and flies almost exclusively during peak emergence periods (e.g., 12:00–15:00 h). All captured fish were released within 100 m of their capture locations, typically within 50 m.

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

DATA COLLECTION

After angling a portion of a section (50–100 meters), all captured fish were temporarily held in live wells (i.e. totes), 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 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. 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 <350 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 downstream sequence it is inherently difficult to approximate the taking of a simple random sample (i.e., a random sample without replacement). Therefore, samples from the DCR were taken systematically in the sense of progressively moving downstream and sampling proportionally to the abundance of fish present. Under these circumstances the Bailey-modified Petersen estimator (Appendix B1; 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 using two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two 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 B2. If stratification by size was required, capture probabilities by location were examined for each length stratum.

The tests for consistency of the Petersen estimator (Seber 1982; Appendix B3) 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 runs (sections 1-4, 5-8, 9-12, 13-16, and 17-22), which also corresponded to hydrological differences in the river. Sections 1-8 have a relatively narrow channel (e.g. <15 m); sections 9-16 are relatively moderate in width (e.g. 15 – 25 m) with well defined pool-riffle sequences; and the lowermost 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.

Relative to Assumption 1, closure was not tested directly but inferred from examination of the movement of recaptured Arctic grayling within the study area and the movements of the radio-tagged fish (constrained to fish ≥ 350 mm FL) within and outside of the study area. The data were examined for evidence of movement away from, towards, or across 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 B2 and B4. 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 1999, DeCicco and Brown 2006).

RESULTS

MOVEMENT

The movement data from the radio-tagged and recaptured fish provided strong evidence that the population was closed and any bias due to combined emigration and immigration was undetectable or negligible relative to interpretation of objectives. The inferences to the radio-tagged fish were constrained to fish ≥350 mm FL.

The radio-tagged fish provided evidence that the lower boundary was closed to immigration and emigration during the mark-recapture experiment. Arctic grayling were radio-tagged in the Lower Goodpaster River on May 17-18, and 26 of these fish resided in the DCR during the summer of 2006. By May 28, 25 fish had immigrated, and the last fish to enter the DCR inhabited nearby Clearwater Lake until July 12 (Figure 4).

After this date, all 26 fish remained in the DCR until their emigration period that occurred from September 1 to December 12. At the upper boundary, minimal movement was detected. Two fish were positioned approximately 0.4 and 0.7 km upstream of the boundary for the entire duration of the experiment, except for one brief period. On July 28, each moved approximately 0.5 km downstream for a few hours, which resulted in one of the two fish briefly (< 4 h) entering the study area (Appendix C1). Both fish returned to their original feeding positions.

During the eight boat surveys, 208 movements (defined by distance traveled during a 24-h period) were recorded by the 24 radio-tagged fish that remained within the study area during the experiment (Appendix C1). Of these 208 movements, 202 were less than 1.0 km in length, and of the remaining six, four were from a single fish traveling over a 4-day period as part of a large-downstream movement (7.3 km), and the remaining two movements were by a pair of fish scaled that each made a single moderately-sized movement over a 24-h period, one fish swimming 3.8 km downstream and one 2.8 km upstream.

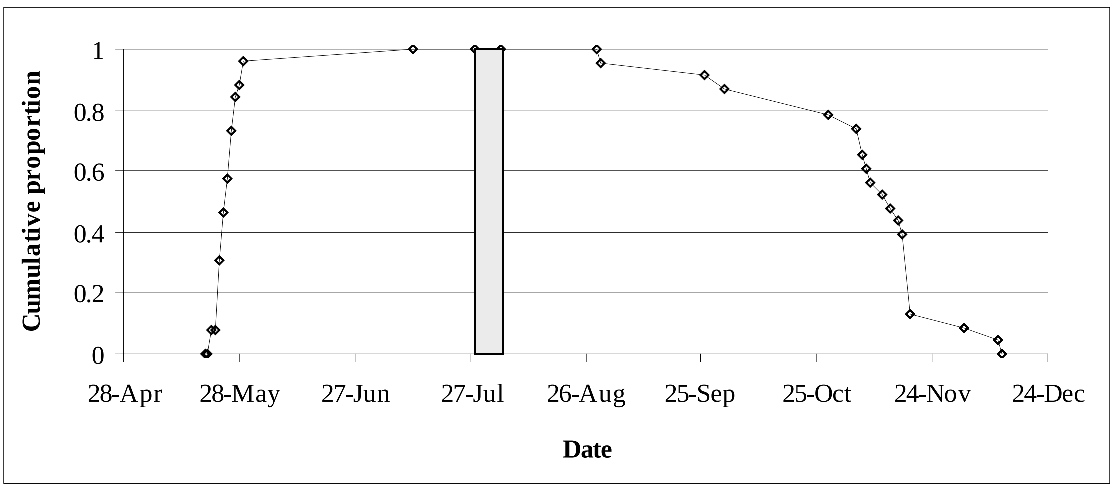

Figure 4.–Cumulative proportion of radio-tagged Arctic grayling (n=26) that entered and exited the Delta Clearwater River between May 1 and December 31, 2006. Shaded area represents the timing of the mark-recapture experiment**.**

Recaptured fish provided 65 recorded movements between time of marking and time of recapture. Of these 65, 51 (79%) moved a distance of less than 1.0 km. Radio-tagged Arctic grayling were treated similarly in that it was "marked" on the day a crew sampled the section it was simultaneously present and it was "recaptured' the day a crew sampled the section it was simultaneously present. Twenty-one radio-tagged fish were treated as recaptures of which, 19 (90%) moved less than 1 km. A plot of the movements of both groups of recaptured fish (n=86) showed that most fish (52%) did not move and 25% moved between 0.1 and 1.0 km (Figure 5). Of those that exceed 1.0 km, three (19%) moved upstream and 13 (81%) moved downstream. The downstream trend exhibited by a small minority of the fish suggests that there may have been a small emigration of fish into the uppermost sections (i.e. sections one and two) resulting in an abundance estimate germane to the second event.

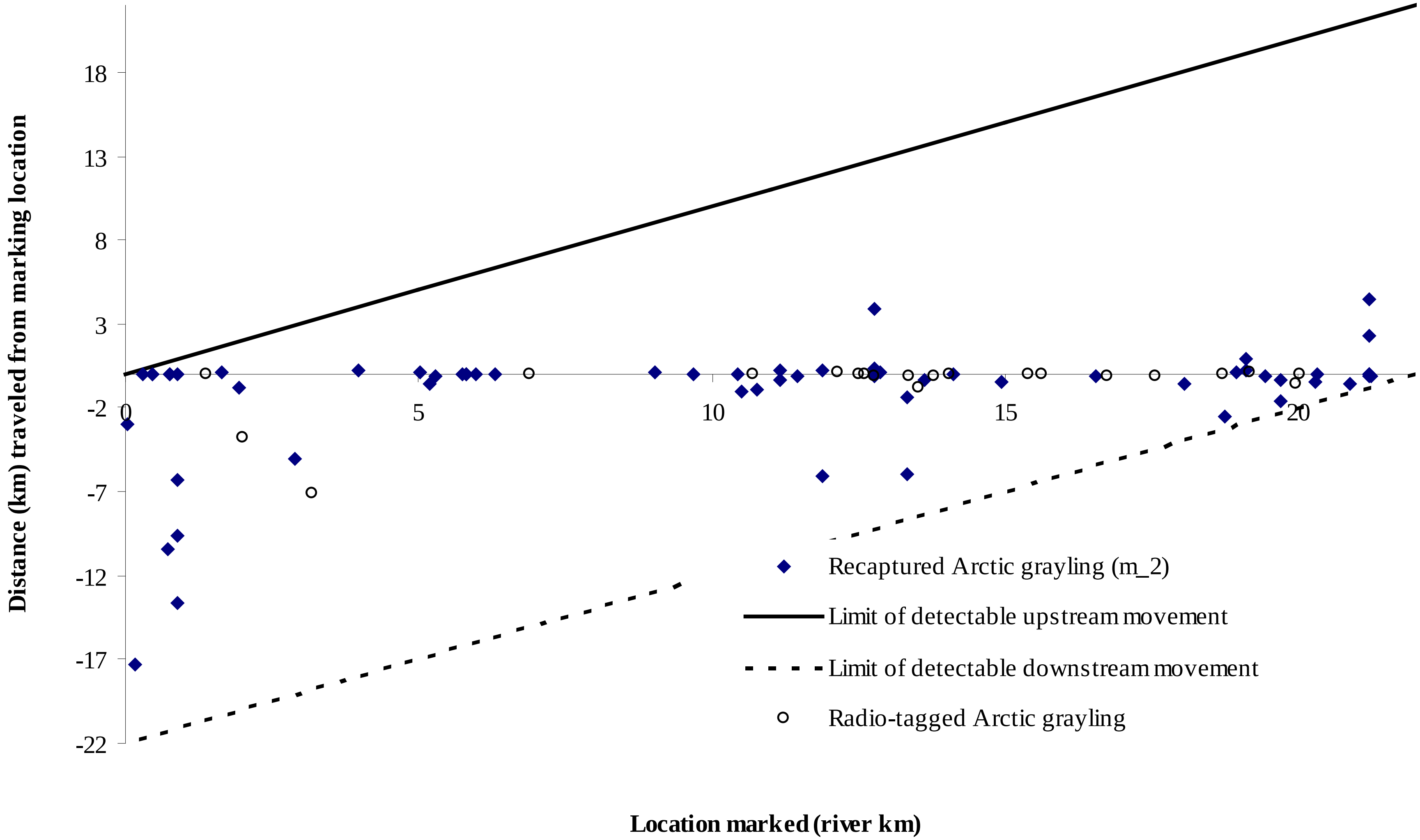

Figure 5.-Distance traveled from marking location by each recaptured Arctic grayling (m2=65), and radio-tagged fish (n = 21) in the Delta Clearwater River study area, 2006.

ABUNDANCE ESTIMATE

A total of 1,945 Arctic grayling ≥ 195 mm FL were captured (n_1 = 1,044, n_2 = 901, m_2 = 63) ranging from 195 to 465 mm FL, and the length of the smallest recaptured fish was 265 mm FL. Therefore, the abundance for fish ≥ 240 mm FL was not calculated. No recaptured fish were noted to have lost their primary mark (Floy tag).

Based on the diagnostic procedures outlined in Appendix B2, K-S test results indicated that for both abundance estimates (≥ 270 and ≥ 330 mm FL), sampling was not size selective (i.e. Case I) and stratification by length was not required (Table 1; Figure 6). For each abundance estimate, samples from both events were used to estimate length and age compositions (Table 1).

For fish ≥ 270 mm FL, examination of the capture probabilities (first and second event) among geographic strata identified a comparatively large capture probability for section 22 (Tables 2-4). When testing the six strata with section 22 as it own strata, a significant difference among first event capture probabilities was identified (P-value = 0.001), and while not significant, the test result when comparing second event capture probabilities was marginal (P-value = 0.054). Therefore, a partially-stratified estimator (Darroch 1961) was used to estimate abundance for fish ≥ 270 (Objective 1). To enable the SPAS software to perform the "Darroch" calculations, four geographic pairings were formed (sections 1-5, 6-11, 12-21, and 22). To gauge influence of section 22 on the estimated abundance, two independent estimates were also calculated: 1) pooling sections 1-21 (i.e. excluding section 22), and 2) section 22 alone, each using the Bailey-modified Petersen estimator.

Table 1.–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 Delta Clearwater River study area, 2006.

	Comparison and Test Statistic		
Length strata	**M vs. R**	**C vs. R**	**Result**
≥ 270 mm FL	D = 0.13 P-value = 0.27 Fail to reject H_0	D = 0.08 P-value = 0.86 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis
≥ 330 mm FL	D = 0.15 P-value = 0.22 Fail to reject H_0	D = 0.10 P-value = 0.69 Fail to reject H_0	Case I, do not stratify, use lengths from both events for composition analysis

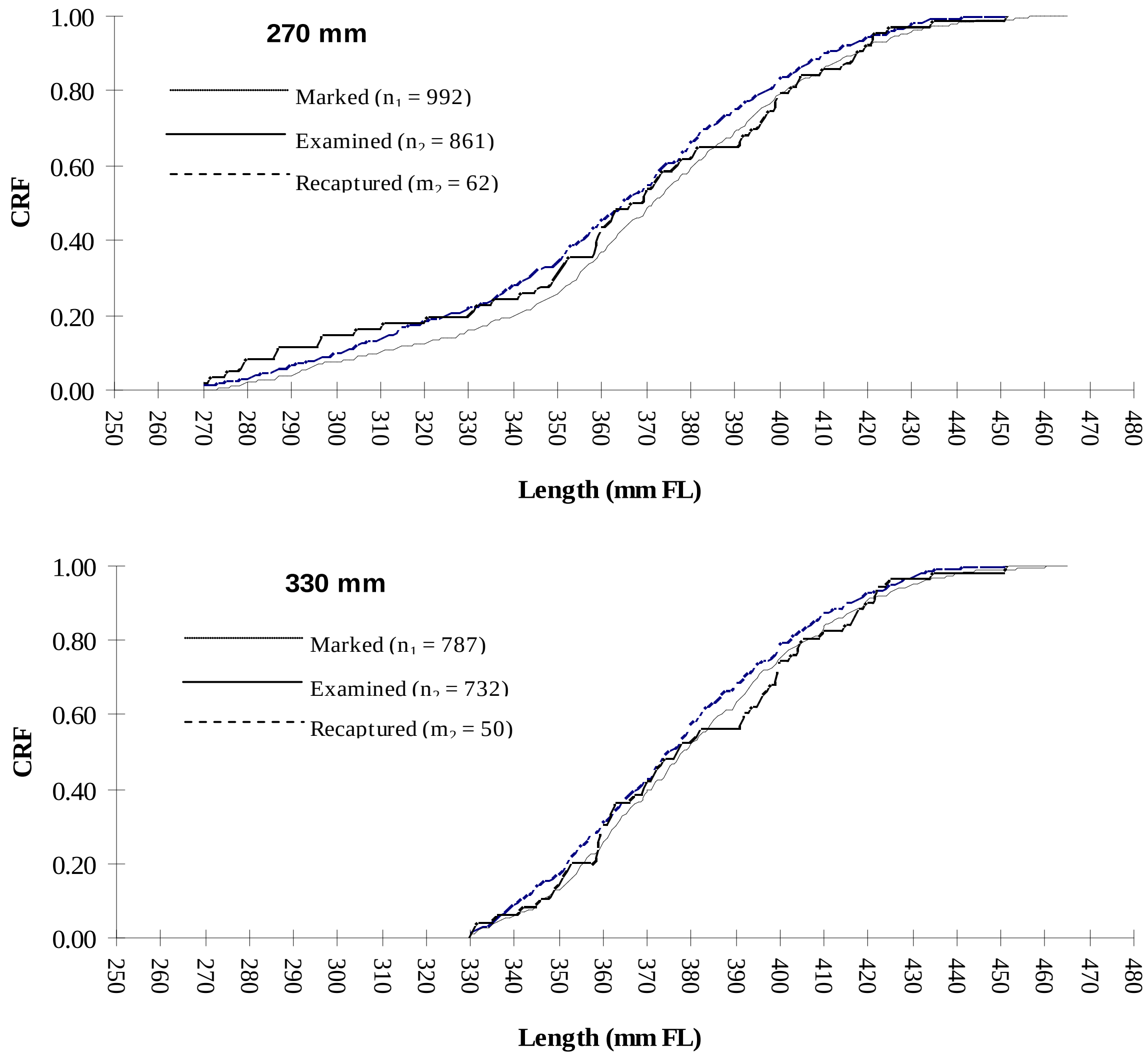

Figure 6.–Cumulative relative frequency (CRF) of Arctic grayling ≥270 and ≥330 that were marked, examined and recaptured in the Delta Clearwater River study area, 2006.

Table 2.–Results of consistency tests for the Petersen estimator (Appendix A3) for estimating abundance of Arctic grayling in the Delta Clearwater study area, 2006.

	Consistency Test		
	I	II	III
Length and Geographic Strata	Complete Mixing	Equal probability of Capture, 1st Event	Equal Probability of Capture, 2nd Event
≥ 270 mm FL	χ^2 = 212.06 P-value = 0.000	χ^2 = 20.25 P-value = 0.001	χ^2 = 10.87 P-value = 0.054
≥ 330 mm FL	χ^2 = 124.33 P-value = 0.000	χ^2 = 8.21 P-value = 0.145	χ^2 = 4.67 P-value = 0.457

Table 3.–Number of Arctic grayling ≥270 mm FL marked (n 1), examined (n2), and recaptured (m2) by section(s) in the Delta Clearwater River study area, 2006.

		Section(s) where examined								
		1 - 4	5 - 8	9 - 12	13 - 16	17 - 21	22	m_2	n_1	$(m_2/n_1)^b$
Section(s) where marked	1 - 4	6	1	3	1	1	0	12	205	0.06
	5 - 8	0	9	0	0	0	0	9	122	0.07
	9 - 12	0	0	3	4	0	0	7	89	0.08
	13 - 16	0	0	1	10	3	0	14	212	0.07
	17 - 21	0	0	0	0	10	2	12	311	0.04
	22	0	0	0	0	2	6	8	53	0.15
	m_2	6	10	7	15	16	8	62		
	n_2	181	115	115	181	237	32			
	$(m_2/n_2)^a$	0.03	0.09	0.06	0.08	0.07	0.25			

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Table 4.–Number of Arctic grayling ≥330 mm FL marked (n_1), examined (n_2), and recaptured (m_2) by section(s) in the Delta Clearwater River study area, 2006.

		Section(s) where examined								
		1 - 4	5 - 8	9 - 12	13 - 16	17 - 21	22	m_2	n_1	$(m_2/n_1)^b$
Section(s) where marked	1 - 4	6	1	2	1	1	0	11	194	0.06
	5 - 8	0	9	0	0	0	0	9	114	0.08
	9 - 12	0	0	3	4	0	0	7	67	0.10
	13 - 16	0	0	1	9	2	0	12	162	0.07
	17 - 21	0	0	0	0	9	2	11	242	0.05
	22	0	0	0	0	0	0	0	8	0.00
	m_2	6	10	6	14	12	2	50		
	n_2	173	105	98	157	189	10			
	$(m_2/n_2)^a$	0.03	0.10	0.06	0.09	0.06	0.20			

[a] Probability of capture during first event.

[b] Probability of capture during second event.

Using the Darroch estimator the estimated abundance of Arctic grayling ≥ 270 mm FL in the DCR study area was 14,799 (SE = 2,204) with a stratum estimate for section 22 of 66 (SE = 165) fish. Using the Bailey-modified Peterson estimator, the estimated abundance for sections 1-21 pooled was 14,705 (SE = 1,830), and for section 22, was 250 fish (SE = 37). The combined study area estimate was 14,955 (SE = 1830).

For fish ≥ 330 mm FL, first and second event capture probabilities were similar among the six strata and the Bailey-modified Petersen estimator was used to calculate abundance (Tables 2 and 4). For fish ≥ 330 mm FL, the estimated abundance of Arctic grayling in the DCR study area was 11,311 (SE = 1,513).

LENGTH AND AGE COMPOSITION

Relative to Objectives 2–5, inferences were constrained to fish ≥ 270 mm FL. For Objectiv e 2, the proportion of the estimated population ≥ 270 mm FL that was ≥ 330 mm FL was 0.82 (SE = 0.01), and therefore, the null hypothesis was rejected (P-value < 0.01). Fish between 350 and 400 mm FL comprised the largest (0.50, SE = 0.01) segment of the population (Figure 7, Appendix C2). The proportion of the population ≥ age -7 was 0.72 (SE = 0.01; Appendix C3). The mean length of an age-6 fish was 328 mm FL (Table 5), and corresponded to the 330-mm management objective (Table 5).

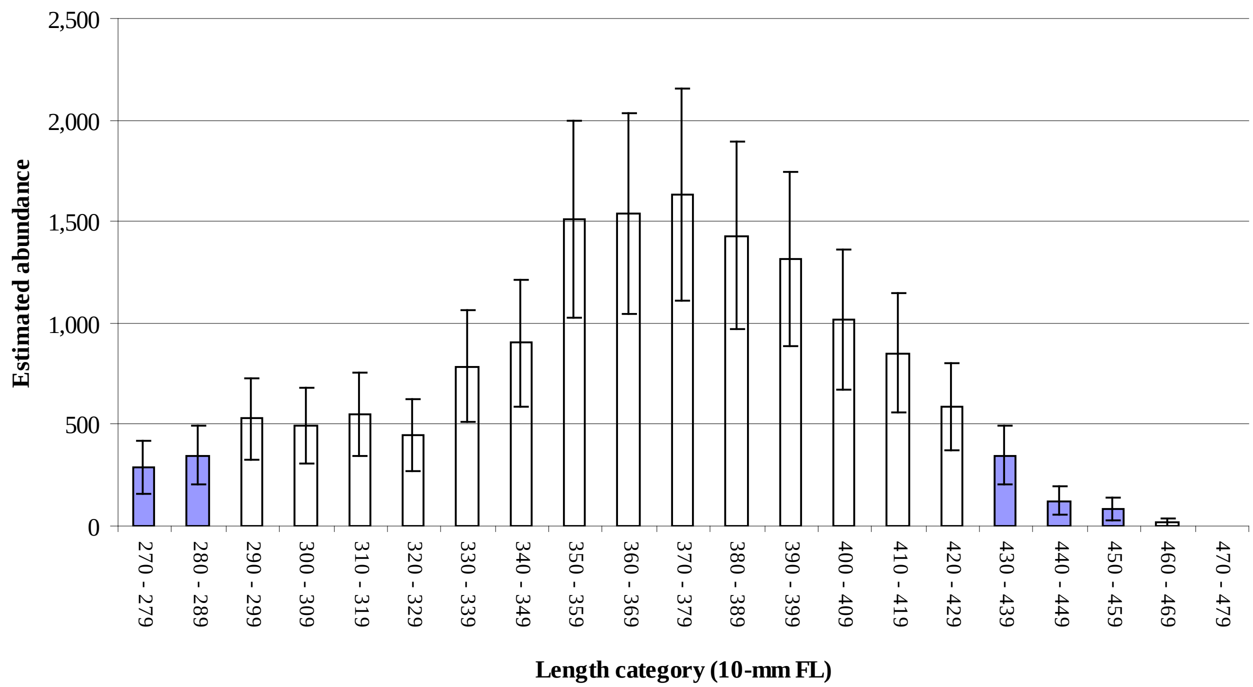

Figure 7.–Estimated size composition of Arctic grayling ≥ 270 mm FL in the Delta Clearwater River study area, 2006.

Table 5.–Mean length-at-age of Arctic grayling sampled from the Delta Clearwater River study area, 2006.

Age	Sample size n	Average length (mm FL)	SD (mm FL)
2	1	195	-
3	28	249	23
4	54	279	29
5	129	305	22
6	56	328	18

DISCUSSION

The presence of the radio-tagged Arctic grayling in the DCR during the mark-recapture experiment provided a unique opportunity to independently examine the movements of the assessed population. Their movements reaffirmed the assumption that the summer feeding population (i.e. late June to early August) in the DCR is functionally closed because the magnitude of bias associated with combined immigration and emigration over a two to three week window of sampling is insignificant (i.e. <5%).

The results demonstrated that the population size of Arctic grayling in section 22 was negligible relative to the remainder of the study area and was likely bounded between the 95% confidence intervals of the "Darroch" stratum estimate ($\hat{N}_{22}$ = 65, SE = 164) and the "Bailey" estimate ($\hat{N}_{22}$ = 250, SE = 37). To help alleviate this uncertainty in future studies, the amount of fishing effort within section 22 should be adjusted to help equalize capture probabilities among all sections. In 2006, one crew disproportionately targeted the single most obvious habitat in section 22, which was an obvious, single and large hole in the middle portion of the section. In future studies, it is recommended that only 1/3 of the fishing effort in section 22 be directed at this location to help control this sampling problem.

The abundance of fish in 2006 was significantly greater than in previous studies (Figure 8). To assess if changes in the size composition had occurred (i.e. more larger-sized fish), the abundance of two length strata were examined, 270–339 and ≥ 340 mm FL. In previous mark-recapture experiments (1996–2000) estimates of length composition were constrained to the relative stock density length categorization system defined by Gablehouse (1984) by apportioning the estimated abundance of fish ≥ 270 mm FL into defined groups: Quality = 270-339, Preferred = 340–449, and Memorable = 450–559 mm FL (Memorable and Preferred categories were combined because the proportion of Memorable fish was <0.01 during 1996–2000, and 2006). The comparison of the two length groups indicates the change in overall abundance was due to a marked increase in the abundance of fish ≥ 340 mm FL (Figure 8, Appendix C4).

It is evident from this study, that the management objectives for the DCR have been achieved. This has also been supported by reports from anglers very satisfied with their catch rates of relatively large fish. However it is recommended that the management objective of maintaining a fishery in which at least 40% of the assessed population of Arctic grayling exceeds 14 inches in length (i.e. 330 mm FL) be eliminated. This objective is problematic because the lower length limit of the assessed population was not defined and can vary from year to year (e.g. ≥240 mm FL to ≥300 mm FL) based on the outcome of sampling effort. If the intent of the management objective remains unchanged (i.e. good catch rates of larger-sized fish), it is recommended that an abundance-based management objective be established (e.g. maintain a minimum abundance of 7,000 Arctic grayling ≥ 330 fish) that can be clearly translated into measurable research objectives.

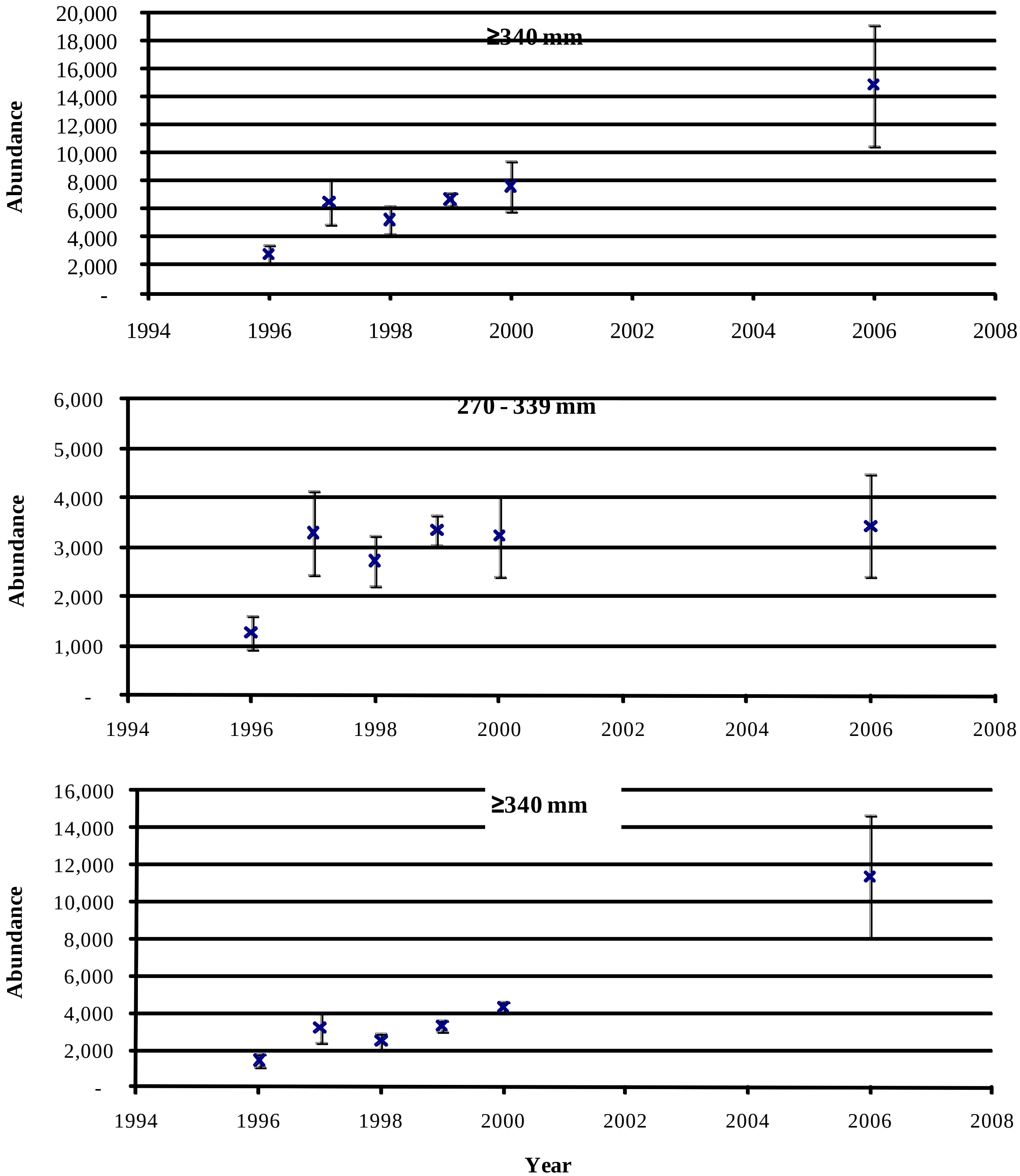

Figure 8.–Estimated abundances of Arctic grayling≥270, 270 –339 and ≥340 mm FL (±95% C.I.) in the Delta Clearwater study area 1996–2000 and 2006. Data from 1996–2000 reported in Ridder and Gryska (2000) and Gryska (2001).

Selection of a minimum threshold abundance is difficult because it is uncertain if the observed abundance in 2006 reflects a population at or nearing carrying capacity or simply a temporary spike in abundance due a few large cohorts that stayed from nearby systems. Therefore, an interim management objective should be developed that uses all assessments during 1996 to 2006, predicated on conducting an additional assessments (e.g. at 3-5 years intervals) to help identify natural variation for what is functionally catch-and-release fishery.

Under the current 12-inch maximum size limit, the harvest of fish has been minimal. Based on the observed harvests and population size, the current seasonal restriction could be removed. This would serve to simplify the fishing regulation and provide for additional opportunity to harvest fish without any deleterious consequences toward meeting the management objectives.

Much has been learned about the life history of Arctic grayling based on tag recoveries, and in this study, several captured fish that were previously tagged in the Salcha and North Fork Goodpaster rivers have contributed to our understanding of the magnitude and complexity of Arctic grayling movements and their staying behaviors (Table 6). In waters such as the North Fork Goodpaster River, it is generally assumed that as Arctic grayling age, summer feeding areas become more established to which there is high degree of annual fidelity (Hughes 2000). Interestingly, the fish from the North Fork Goodpaster River, which were first tagged approximately 100 km upstream from the mouth of the Goodpaster River, at some point strayed to the DCR from what appeared to be very high-quality habitat for summer feeding. The tags from the Salcha River were unique because of their distance traveled between drainages (approximately 120 km), that a juvenile fish was tagged, and represents another fish that strayed from high-quality summer feeding habitat located approximately 60 km upstream from the mouth of the Salcha River. These observed movements of Arctic grayling to the DCR reinforces the concept that straying occurs at all ages and across large distances, and that straying from many systems likely contributes significantly to the recruitment of Arctic grayling to the DCR.

Table 6.–Movements of fish marked in the North Fork Goodpaster River (NF GPR) and the Salcha River recaptured in the DCR, 2006.

Date marked	River Marked	Length at capture (mm FL)	Date recovered	River recovered	Length at capture (mm FL)
7/11/2003	NF GPR	378	7/25/2006	DCR	359
7/11/2004	NF GPR	391	7/25/2006	DCR	410
7/10/2003	NF GPR	402	8/1/2006	DCR	445
7/9/2004	NF GPR	336	7/24/2006	DCR	387
7/10/2004	NF GPR	271	8/2/2006	DCR	335
7/9/2003	NF GPR	300	7/24/2006	DCR	366
6/28/2004	Salcha R.	321	7/31/2006	DCR	390
5/7/2004	Salcha R.	193	7/27/2006	DCR	305

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APPENDIX A

Appendix A1.–Estimated number of anglers, angler-days, harvest, and catch of Arctic grayling from the DCR, 1977–2006.

Year	Anglers[a]	Angler days[a]	Harvest	Catch
1977	na[b]	6,881	6,118	na
1978	na	7,210	7,657	na
1979	na	8,398	6,492	na
1980	na	4,240	5,680	na
1981	na	4,673	7,362	na
1982	na	4,231	4,779	na
1983	na	5,867	6,546	na
1984	2,024	5,139	4,193	na
1985	2,947	8,722	5,809	na
1986	3,693	10,137	2,343	na
1987[c]	3,068	5,397	2,005	na
1988	2,413	5,184	2,910	na
1989	2,845	5,368	3,016	na
1990	2,498	4,853	1,772	12,424
1991	3,171	5,594	2,165	7,998
1992	1,770	3,756	797	6,086
1993	1,491	4,909	437	5,712
1994	2,100	3,984	1,411	9,306
1995[d]	2,927	6,261	926	5,974
1996	2,286	3,424	1,210	8,978
1997[e]	1,680	2,161	54	6,089
1998	1,548	3,415	0	15,990
1999	1,859	5,705	0	11,772
2000	1,547	2,626	0	8,594
1997[f]	1,779	4,671	47	12,576
2002	2,034	4,580	51	12,913
2003	2,386	6,006	0	17,576
2004	1,943	3,357	111	14,212
2005	1,946	4,507	140	19,929
2006	2,137	4,850	85	12,542

Data provided by Parker (2008).

[a] Anglers and angler-days fished represents effort on all species.

[b] na = Estimate is not available.

[c] Regulations changed from no closed season and a five fish bag and a 10 fish possession limit to catch-and-release fishing from 1 April until the first Saturday in June, a 305 mm (12 inch) minimum length limit; a five fish bag and possession limit; and, a restriction of terminal gear to unbaited artificial lures.

[d] The daily bag and possession limits were reduced from five fish to two fish in July 1995.

[e] In June 1997, the DCR and its tributaries were closed to possession of Arctic grayling from 1 January through 31 December.

Appendix A2.-Sport fishing regulatory history of Delta Clearwater River

1959 Regulations before Statehood (Alaska Game Commission).

- Open season year-round and no bait or gear restrictions.
- Daily bag and possession limit is 10 in combination of trout, char, Arctic grayling and northern pike.
- With exception of northern pike, no more than two harvested fish may be over 20 inches in length.

1962–1964 Initial Regulations after Statehood (Alaska Department of Fish and Game).

- Open season year-round and no bait or gear restrictions.
- Daily bag and possession limit is 10 in total of trout, Arctic grayling, salmon, and lake trout, of which no more than 2 trout, Arctic grayling, or lake trout may be over 20 inches.

1965–1974

- Open season year-round and no bait or gear restrictions.
- Daily bag and possession limit is 10 in total of trout, Arctic grayling, salmon, sheefish, and lake trout, of which no more than 2 trout, Arctic grayling, sheefish, or lake trout may be over 20 inches.

1975–1982

- Open season year-round and no bait or gear restrictions.
- Daily bag and possession limit is 10 in total of trout, Arctic grayling, salmon, sheefish, and lake trout, of which no more than 5 may be Arctic grayling and only 2 of those may be over 20 inches.
- Possession limit may be two daily bag limits of Arctic grayling.

1983–1984

- Open season year-round and no bait or gear restrictions.
- Daily bag is 5 Arctic grayling less than 20 inches and 2 Arctic grayling greater than 20 inches (possession limit 2 daily bag limits).

1985–1986

- Open season year-round and no bait or gear restrictions.
- Daily bag limit is 5 (possession limit 10) Arctic grayling, no size limit.

1988–1991

- All captured Arctic grayling must be immediately released from April 1 to the first Saturday of June.
- All harvested Arctic grayling must be a minimum of 12 inches in length.
- Only unbaited, artificial lures or flies may be used.

-continued-

1995

- Arctic grayling must be immediately released from April 1 through May 31.
- All harvested Arctic grayling must be a minimum of 12 inches in length.
- Only unbaited, artificial lures or flies may be used.
- **Emergency Order effective July 1995 –** bag and possession limit is 2 Arctic grayling.

1996–1997

- By emergency order, the daily bag and possession limit is 2 Arctic grayling.
- All captured Arctic grayling must be immediately released from April 1 through May 31.
- All harvested Arctic grayling must be a minimum of 12 inches in length.
- Only unbaited, artificial lures or flies may be used.
- **Emergency Order effective June 1997 –** Only catch-and-release fishing for Arctic grayling is allowed.

1998–2000

- Only catch-and-release fishing for Arctic grayling is allowed.
- Only unbaited, single-hook, artificial lures may be used from January 1 through August 31 and only unbaited, artificial lures may be used from September 1 through December 31.

2001–2006

- Only catch-and-release fishing for Arctic grayling is allowed from August 10 through July 9, and a bag and possession limit of one Arctic grayling less than 12 inches from July 10 through August 9.
- Only unbaited, single-hook, artificial lures may be used from January 1 through August 31 and only unbaited, **artificial** lures may be used from September 1 through December 31.

Appendix A3.-Summary of estimates of abundance and SE for Arctic grayling ≥150 mm FL, ≥ 240 mm FL, ≥ 270 mm FL, ≥ age-5, and for recruited fish (age-5), Delta Clearwater River, 1977–2000.

Year	$\hat{N}$ [150]	SE[$\hat{N}$ 150]	$\hat{N}$ [240]	SE[$\hat{N}$ 240]	$\hat{N}$ [270]	SE[$\hat{N}$ 270]	$\hat{N}$ [Age 5+][a]	SE[Age 5+]	Recruitment	
									$\hat{N}$ [Age 5][a]	SE[Age 5]
1977	nd	---	nd	---	nd	---	9,702	1,234	5,862	1,335
1978	nd	---	nd	---	nd	---	8,826	1,279	4,461	1,484
1979	nd	---	nd	---	nd	---	6,258	885	4,134	1,146
1980	nd	---	nd	---	nd	---	6,175	832	3,467	856
1981	nd	---	nd	---	nd	---	9,829	1,461	6,907	1,640
1982	nd	---	nd	---	nd	---	9,369	1,159	4,554	1,173
1983	nd	---	nd	---	nd	---	12,760	1,746	7,828	1,999
1984	nd	---	nd	---	nd	---	11,063	1,276	4,931	1,295
1985	nd	---	nd	---	nd	---	10,767	1,388	4,458	1,267
1986	nd	---	nd	---	nd	---	7,840	1,148	2,724	708
1987	nd	---	nd	---	nd	---	7,684	1,289	3,571	933
1988	nd	---	nd	---	nd	---	8,845	1,962	1,957	578
1989	nd	---	nd	---	nd	---	6,482	1,751	2,420	601
1990	nd	---	nd	---	nd	---	4,477	1,766	2,301	619
1991	nd	---	nd	---	nd	---	nd	---	1,754	686
1992	nd	---	nd	---	nd	---	nd	---	2,219	1,066
1993	nd	---	nd	---	nd	---	nd	---	945	692
1994	nd	---	nd	---	nd	---	nd	---	1,179	1,491
1995	nd	---	nd	---	nd	---	nd	---	Nd	---
1996	nd	---	3,000	370	2,750	340	2,490	310	670	100
1997	9,000	920	7,420	920	6,490	800	4,600	590	810	140
1998	nd	---	6,000	780	4,743	479	4,495	625	1,950	300
1999	nd	---	6,977	401	6,684	211.3	6,271	369	1,760	140
2000	nd	---	7,991	940	7,591	895	6,944	940	1,706	250
Average	9,000	---	6,203	---	5,660	---	7,622	---	3,153	---

[a] Estimates for 1977–1990 are from CAGEAN modeling (Clark and Ridder 1994) and reflect population at start of fishing season. Estimates for 1996–1999 are from mark-recapture experiments and reflect population in July (Ridder 1998b; 1999; Ridder and Gryska 2000; Gryska 2001).

nd = no data

Appendix A4–Allocation of fishing effort by two-person crews (Crews A – F) by approximately 1-km long sampling sections during the two-sample mark-recapture experiment in the Delta Clearwater River study area, 2006**.**

	Event 1					Event 2				
Section	Jul 24	Jul 25	Jul 26	Jul 27	Jul 28	Jul 31	Aug 1	Aug 2	Aug 3	Aug 4
1	A					A				
2	B					B				
3	C					C				
4	D					D				
5	E					E				
6		A					A			
7		B					B			
8		C					C			
9		D					D			
10		E					E			
11		F					F			
12			A					A		
13			B					B		
14			C					C		
15			D					D		
16			E					E		
17			F					F		
18				A					A	
19				B, C					B, C	
20				D, E					D, E	
21					A, B					A, B
22					C, D					C, D

APPENDIX B

Appendix B1.–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:

$$\hat{N} = \frac{n_1(n_2+1)}{m_2+1}, \tag{B1-1}$$

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):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \tag{B1-2}$$

Appendix B2.-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 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 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

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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 B3.–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 B4.-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:

$$\hat{p}_k = \frac{n_k}{n} \quad \text{(B4-1)}$$

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):

$$\hat{V}\left[\hat{p}_k\right] = \frac{\hat{p}_k\left(1-\hat{p}_k\right)}{n-1}. \quad \text{(B4-2)}$$

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

$$\hat{N}_k = \sum_{k=1}^{s} \hat{p}_k \hat{N}, \quad \text{(B4-3)}$$

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):

$$\hat{V}\left[\hat{N}_k\right] \approx \sum_{k=1}^{s}\left(\hat{V}\left[\hat{p}_k\right]\hat{N}^2 + \hat{V}\left[\hat{N}\right]\hat{p}_k^2 - \hat{V}\left[\hat{p}_k\right]\hat{V}\left[\hat{N}\right]\right). \quad \text{(B4-4)}$$

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:

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$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \qquad \text{(B4-5)}$$

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:

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk} \hat{N}_j \qquad \text{(B4-6)}$$

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):

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s} \left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right] \right). \qquad \text{(B4-7)}$$

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

$$\hat{p}_k = \hat{N}_k / \hat{N} \tag{B4-8}$$

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

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

$$\hat{V}\left[\hat{p}_k\right] \approx \sum_{j=1}^{s}\left\{\left(\frac{\hat{N}_j}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{jk}\right]\right\} + \frac{\sum_{j=1}^{s}\left\{\hat{V}\left[\hat{N}_j\right]\left(\hat{p}_{jk} - \hat{p}_k\right)^2\right\}}{\hat{N}^2}. \tag{B4-9}$$

APPENDIX C

Appendix C1.–Locations (river kilometers) of radio-tagged Arctic grayling during boat surveys of the DCR conducted prior to, during, and after the mark-recapture experiment (July 28 to August 3). For example, 14.20 represents a fish that was in section 15, approximately 0.2 km downstream of the 14/15 section boundary, and blank cells indicate no data.

Tag #	5-Jul	24-Jul	25-Jul	26-Jul	27-Jul	28-Jul	31-Jul	1-Aug	2-Aug	3-Aug	10 Aug
12	15.61	14.00	13.97	14.04	14.04	13.97	14.1	14.04	14.03	14.04	14.03
13	10.65	10.73	10.7	10.73	10.7	10.7	10.7	10.7	10.67	nd	11.12
14	-4.27	15.76	15.73	15.62	15.7	15.62	15.7	15.32	15.62	15.66	15.66
15	12.76	12.79	12.81	12.76	12.81	12.76	12.81	12.76	12.84	12.84	12.79
16	15.21	12.54	12.46	12.51	12.54	12.51	12.51	12.51	12.54	12.57	12.54
17	13.41	13.44	13.44	13.54	14.2	14.32	14.35	14.36	14.36	14.35	14.37
19	-0.82	-0.82	-0.82	-0.82	-0.82	-0.29	-0.82	-0.82	-0.82	-0.82	-0.82
23	19.94	19.94	19.94	19.94	19.94	19.94	19.94	19.94	19.94	nd	19.94
30	6.94	6.97	6.91	6.94	6.97	6.91	6.91	6.94	6.94	6.91	6.99
31	11.08	11.52	13.43	13.36	13.43	13.43	13.43	13.36	13.43	13.56	13.42
32	nd	19.18	19.18	19.18	19.18	19.18	19.18	19.18	19.18	19.02	19.18
34	12.55	12.6	12.6	12.6	12.6	12.6	12.55	12.55	12.55	9.72	8.12
35	12.51	12.23	12.23	12.16	12.19	12.23	12.07	12.07	12.07	12.1	12.1
41	18.3	16.75	16.82	16.75	16.75	16.82	16.75	16.72	16.82	16.75	16.82
42	-0.47	-0.47	-0.47	-0.47	-0.47	0.23	-0.47	-0.47	-0.47	-0.47	-0.47
43	15.35	15.39	15.39	15.39	15.39	15.39	15.3	15.35	15.39	15.43	15.39
50	17.56	17.56	17.63	17.56	17.63	17.63	17.56	17.56	17.63	17.56	17.63
56	23.11	18.13	18.06	18.13	17.86	18.04	17.78	17.78	17.78	17.82	17.72
60	3.72	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.37	1.35	1.37
61	20.15	19.97	19.97	19.97	19.97	19.97	20.00	20.00	19.97	20.58	20.29
66	20.55	20.02	20.02	19.99	20.02	20.02	19.99	19.99	20.02	19.99	18.85
73	3.19	3.19	3.19	3.19	3.87	4.63	9.93	10.32	10.32	10.32	10.32
74	18.71	18.71	18.71	18.71	18.71	18.71	18.71	18.71	18.64	18.71	18.71
81	15.99	12.98	14.08	13.79	13.82	13.85	13.85	13.82	13.9	13.85	13.79
83	1.99	1.99	1.99	1.99	1.99	5.83	5.76	5.76	5.8	5.76	nd
84	20.5	20.30	nd	20.30	20.02	19.91	20.02	19.96	20.02	20.02	19.93

[a] A negative sign indicates a fish upstream of the upper boundary of the study area.

Appendix C2.–Estimated length composition by 10-mm length (FL) categories of Arctic grayling ≥270 mm FL in the Delta Clearwater River study area, 2006.

Category	Sample size	Proportion	SE	Abundance	SE
270–279	35	0.020	0.003	289	64
280–289	42	0.023	0.004	347	74
290–299	64	0.036	0.004	529	102
300–309	60	0.034	0.004	496	97
310–319	67	0.037	0.004	554	105
320–329	54	0.030	0.004	446	89
330–339	95	0.053	0.005	785	140
340–349	109	0.061	0.006	901	158
350–359	183	0.102	0.007	1,512	248
360–369	186	0.104	0.007	1,537	252
370–379	198	0.111	0.007	1,636	267
380–389	173	0.097	0.007	1,429	236
390–399	159	0.089	0.007	1,314	219
400–409	123	0.069	0.006	1,016	175
410–419	103	0.058	0.006	851	150
420–429	71	0.040	0.005	587	110
430–439	42	0.023	0.004	347	74
440–449	15	0.008	0.002	124	37
450–459	10	0.006	0.002	83	29
460–469	2	0.001	0.001	17	12
470–479	0	0.000	0.000	0	0

Appendix C3.–Estimated age composition of Arctic grayling ≥270 mm FL in the Delta Clearwater River study area, 2006. It was assumed that all fish ≥350 mm FL were age 7 or greater.

Age	Sample size	Proportion	SE	Abundance	SE
1	0	0.000	0.000	0	0
2	0	0.000	0.000	0	0
3	12	0.007	0.002	97	31
4	78	0.043	0.005	640	119
5	280	0.156	0.009	2,310	366
6	129	0.072	0.006	1,067	183
≥7	1,293	0.722	0.011	10,683	1,599

Appendix C4.–Estimated abundance of Arctic grayling≥270, 270 –339 and 340 mm FL in the Delta Clearwater River study area, 1996–2000 and 2006. Data from 1996–2000 reported in Ridder and Gryska (2000) and Gryska (2001).

Year	Length strata	Abundance $\hat{N}$	SE ($\hat{N}$)	$\hat{N}_{\geq 340} / \hat{N}_{\geq 270}$
1996	>270	2755	342	
	270–339	1,281	170	
	>340	1,474	190	0.54
1997	>270	6,490	806	
	270–339	3,300	430	
	>340	3,190	420	0.49
1998	>270	5,227	473	
	270–339	2,734	257	
	>340	2,493	235	0.48
1999	>270	6,684	408	
	270–339	3,357	148	
	>340	3,327	151	0.50
2000	>270	7,591	895	
	270–339	3,236	413	
	>340	4,356	151	0.57
2006	>270	14,798	2,205	
	270–339	3,445	534	
	>340	11,353	1,698	0.77

Appendix C5.-Data files[a] for all Arctic grayling captured in the Delta Clearwater River, 2006.

File Name[a]
Delta Clearwater River grayling data files for archive-2006.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.