Fishery Data Series No. 15-41

Stock Assessment of Rainbow Trout in the Kisaralik River, 2011

by

Corey J. Schwanke

November 2015

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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ABSTRACT

A 2-event mark–recapture experiment was conducted for the Kisaralik River rainbow trout population in 2011. Sampling took place in a 68-rkm section starting from Golden Gate Falls and continuing downstream to the lower boundary of the Yukon Delta National Wildlife Refuge. The first event occurred from 16 July to 22 July and the second event from 6 August to 12 August. A Bailey-modified Petersen estimator was used to estimate the abundance of rainbow trout ≥350 mm fork length (FL). The estimate omitted the bottom 13 rkm of the planned study area due to inadequate sample sizes attributed to poor water conditions during the recapture event. The estimated abundance of rainbow trout ≥350 mm FL for a 55-rkm section of the river immediately below Golden Gate Falls was of 3,959 (SE=651; 95% CI=2,683-5,235). Although the abundance estimate of this study ended up not being directly comparable to the 1997 estimate, they appear to be similar in terms of densities. Estimated length composition for the truncated study area had no dominant 25-mm FL length categories with 5 length categories (350–374, 375–399, 400–424, 425–449 and 450–474) all comprising between 14% and 20% of the population. Cumulative length frequencies of fish sampled in 1997 and 2011 were significantly different ($P<0.001$), with larger fish being sampled in 1997.

Key words: rainbow trout, *Oncorhynchus mykiss,* Kisaralik River, abundance, mark–recapture, length distribution

INTRODUCTION

OVERVIEW

The Kisaralik River (Figure 1) is located in southwest Alaska. It originates in the Kilbuck Mountains and flows northwesterly from Kisaralik Lake (elevation 480 m) into the Kuskokwim River approximately 47 km upstream from Bethel. The Kisaralik River drainage is 2,771 km^2, and the river (excluding tributaries) is approximately 180 river kilometers (rkm) in length. Multiple tributaries flow into the mainstem, most of which drain from the east. The Kisaralik River shares an intermittent connection with the Kasigluk River approximately 50 rkm from the Kuskokwim River. In some years as much as 50% of the flow from the Kisaralik can be diverted down this intermittent channel due to log jams (USFWS 1997). From Kisaralik Lake to the Kuskowkim River, the river drops about 473 m, averaging roughly 2.7 m/rkm. Gradient is highest in the upper river where many Class III and IV rapids occur. The U.S. Geological Survey operated a gauging station (15304200) between 1979 and 1987 at the Upper Falls (rkm 145) and reported a mean annual discharge of 878 cfs, a maximum of 1,379 cfs, and a minimum of 546 cfs. Boulder and bedrock substrates are typical down to Golden Gate Falls (located about 115 rkm above the Kuskokwim River). Below Golden Gate Falls, the river slows its pace, braids out in many places, woody debris becomes more common, and substrate changes to more gravel and silt as the river widens. Approximately 98.5 rkm (rkm 47.5–146) of the Kisaralik River flows through the Yukon Delta National Wildlife Refuge (Figure 1).

The Kisaralik River is the natal stream for 5 species of anadromous Pacific salmon: Chinook *Oncorhynchus tshawytscha*, chum *O. keta*, sockeye *O. nerka*, pink *O. gorbuscha*, and coho salmon *O. kisutch*. Anadromous Dolly Varden *Salvelinus malma* also reside in the system. Resident fish species inhabiting the Kisaralik River watershed (including lakes) include rainbow trout *O. mykiss*, Arctic char *Salvelinus alpinus*, Dolly Varden, northern pike *Esox lucius*, Arctic grayling *Thymallus arcticus*, burbot *Lota lota,* lake trout *Salvelinus namaycush*, whitefish *Coregonus* spp., longnose sucker *Catostomus catostomus*, blackfish *Dallia pectoralis*, and slimy sculpin *Cottus cognatus.*

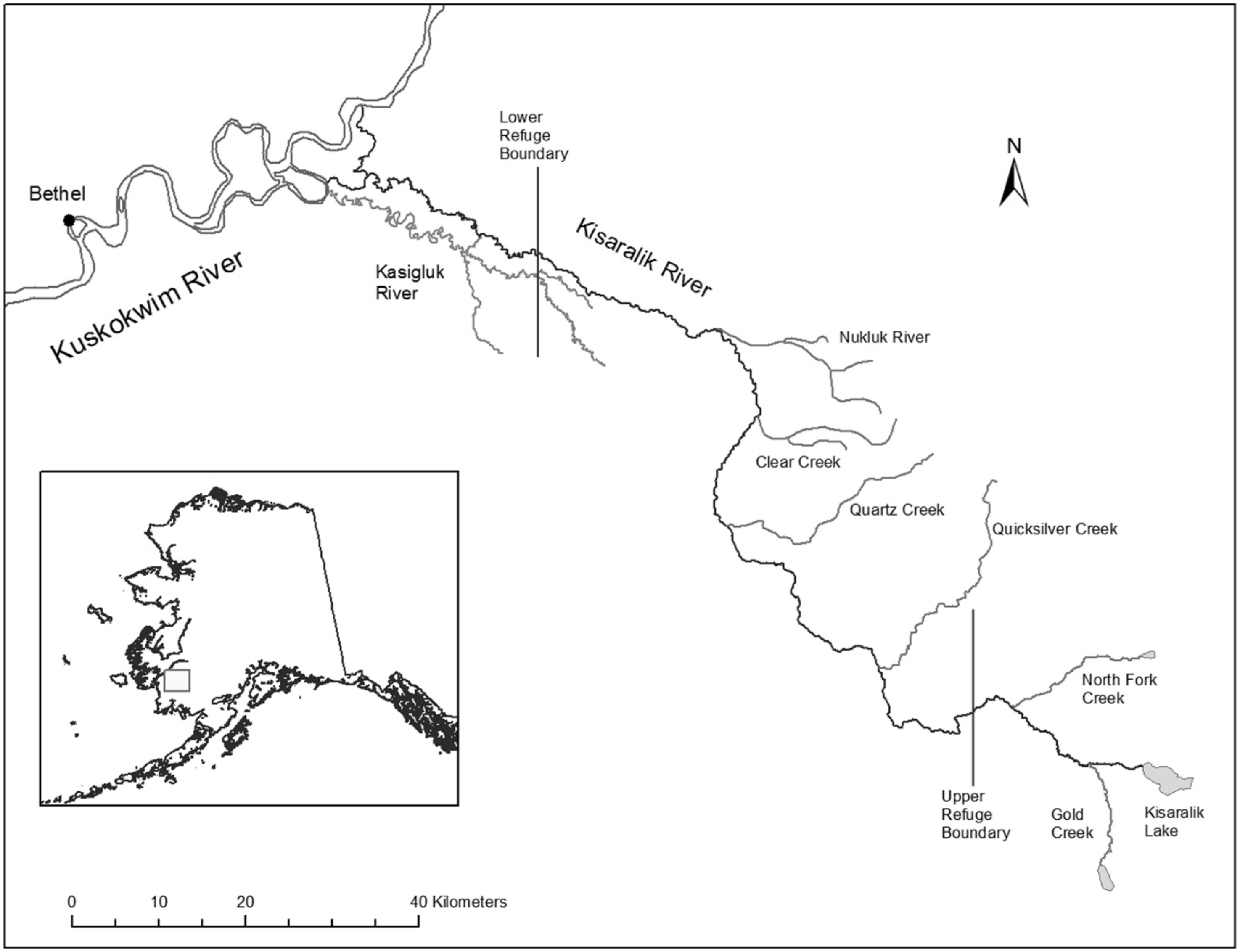

Figure 1.–Map of the Kisaralik River drainage.

The Kisaralik River supports a popular sport fishery for salmon, rainbow trout, Dolly Varden, and Arctic grayling. Although the majority of the effort is not specifically directed at rainbow trout, effort towards rainbow trout is assumed to track with total sport fishing effort (Table 1). Estimated annual sport fishing effort has ranged between 757 and 2,576 angler days since 1996, and annual effort has averaged 1,758 angler days the last 5 years (2006–2010). Catch of rainbow trout spiked in 1997 at 7,068 rainbow trout, leveled off until 2008 when it grew to 9,237, and remained high in 2009 (10,006) and 2010 (9,490; Table 1). Estimated sport harvest has been much lower than catch, averaging about 50 fish the last 10 years.

Significant sport fishery regulations changes for rainbow trout include the following:

Prior to 1998: 2 fish per day, only one over 20”, no gear restriction.

1998: Single hook, artificial lure, catch and release only above Akiak Village Lodge.

2001: Bag limit of one fish 14” or less below Akiak Village Lodge.

2004: Bag limit changed to 2 fish, only one over 20” below Akiak Village Lodge, and implementation of an annual limit of 2 fish over 20”.

Subsistence fishing for rainbow trout takes place on the Kisaralik River, although much of it has remained unquantified. Simon et al. (2007) attempted to estimate the harvest of non-salmon species by drainage for residents of Bethel but were unable to attain river-specific harvests. Subsistence harvests of 127 (2001), 357 (2002), and 185 (2003) rainbow trout were reported by residents of Bethel, the vast majority of which were harvested with hook and line. It is unknown what proportion of these fish came from the Kisaralik River, but it is assumed that the majority of the harvests came from a combination of the Kisaralik and Kwethluk rivers given that the next nearest system with harvestable numbers of rainbow trout is the Aniak River over 100 km upstream.

This study was intended to provide comparable information to a study conducted in 1997 (Harper et al. 2004). That study was a 2-event Petersen mark-–recapture experiment in which abundance and length composition were estimated. The first event of this study took place from 8 July to 19 July, 1997, and 1,115 trout were captured. The second event occurred 6 August to 16 August, 1997, and 1,146 trout were examined, 103 of which were marked in the first event. The data were length-stratified with abundance estimates of 1,873 (SE=735) rainbow trout 300–349 mm FL and 7,390 (SE=693) rainbow trout ≥350 mm FL.

OBJECTIVES

The research objectives were as follows:

1) estimate the abundance of rainbow trout ≥350 mm FL in a 68-km index section of the Kisaralik River during summer 2011 such that the estimate was within 25% of the actual abundance 95% of the time; and,

2) estimate length composition (in 25-mm FL length categories) of rainbow trout ≥350 mm FL in a 68-km index section of the Kisaralik River during summer 2011 such that the estimates were within 10 percentage points of the true value 95% of the time.

Additionally, a research task was to collect genetic tissue samples of rainbow trout from the Kisaralik and Kasigluk rivers.

Table 1.–Sport angler effort, harvest and catch of rainbow trout in the Kisaralik River, 1996–2010.

Year	Effort (days fished) [a]	Harvest	Catch
1996	1,173	211	2,470
1997	1,189	218	7,067
1998	1,021	0	1,289
1999	1,283	0	1,877
2000	2,084	47	3,076
2001	1,304	0	1,002
2002	2,410	29	5,520
2003	1,439	21	1,241
2004	2,071	99	3,134
2005	1,282	78	3,378
2006	1,168	0	4,339
2007	757	21	1,457
2008	2,576	136	9,237
2009	2,235	136	10,006
2010	2,056	0	9,490
2001–2010 average	1,730	52	4,880
2006–2010 average	1,758	59	6,906

[a] Effort is for all species

Data from Alaska Sport Fishing Survey database [Internet]. 2003–2013. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited February 16, 2015). Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/

Relative to Objectives 1 and 2, the 350-mm length criterion was important because it provided comparable results to the 1997 study. Fish 300–349 mm FL were of secondary importance but were still tagged in the event that they could be estimated, even with relatively poor precision.

METHODS

STUDY AREA

The study area was a 68-km section of the mainstem Kisaralik River starting at the lower boundary of the Yukon Delta National Wildlife Refuge, located approximately 47.5 rkm upstream from Kuskokuak Slough and extending upstream to Golden Gate Falls, located at approximately rkm 115.5 (Figure 2). These are the same boundaries that were used in the 1997 study (Harper et al. 2004).

EXPERIMENTAL AND SAMPLING DESIGN

This study was designed to estimate length composition and abundance of rainbow trout within the Kisaralik River study area (Figure 2) using 2-event Petersen mark–recapture techniques (Bailey's modification of the Petersen estimator) for a closed population (Seber 1982). The following assumptions applied to the model:

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

Failure to satisfy these assumptions may result in a biased estimate; therefore, the experiment was designed to allow the validity of these assumptions to be ensured or tested. Sufficient data were collected to perform diagnostic tests to identify heterogeneous capture probabilities (violations of Assumption 2), and prescribed model selection procedures were followed in the event of such violations. Diagnostic tests were not available to evaluate Assumptions 1, 3, 4, and 5; instead, the experiment was designed to ensure that these assumptions were met, thereby avoiding potential biases. In addition, the level of sampling effort used in 1997 was exceeded to help ensure sample sizes would be adequate to meet objective precision criteria and to perform reliable diagnostic tests.

The study area was divided into 7 geographic strata (hereafter referred to as river sections), with each river section being sampled by all crews for an entire day (Figure 2). River section size was based on the density of fish observed in 1997, where lower-density areas were composed of larger river sections and high-density areas were composed of smaller river sections. River sections ranged from 7.5–13.0 rkm, with the following rkm designations: A (rkm 47.5–60.5), B (rkm 60.5–68.0), C (rkm 68.0–75.5), D (rkm 75.5–83.0), E (rkm 83.0–90.5), F (rkm 90.5–103.0), and G (rkm 103.0–115.5). These 7 strata were used as the initial geographic strata for performing diagnostic tests (i.e., examine movement and capture probabilities) as well.

The first event spanned from 16 July to 22 July, and the second event spanned from 6 August to 12 August. The intent of the long hiatus (i.e., 3 weeks for each strata sampled) was to alleviate potentially large negative biases associated with isolating pockets of fish from sampling. The 3-week hiatus was planned to coincide with an influx of spawning salmon, when localized mixing should occur due to rainbow trout feeding on eggs. The potential for violating the closure assumption due to the duration and timing of the hiatus is addressed in the "Evaluation of Assumptions" subsection.

Given the constraints imposed by sampling fish in a river and the sampling protocol selected to accommodate them, the Bailey-modified Petersen estimator (Bailey 1951 and 1952), which is based on the binomial model and assumes sampling with replacement, was the appropriate abundance estimator. The sampling strategy for this project was to 1) sample the entire study area, attempting to subject all fish to an equal probability of capture during the first event (i.e., to the extent possible, distribute marks in proportion to abundance throughout the study area); 2) rely on mixing (i.e., seasonal migrations of 1–15 km as was observed in 1997) to produce a uniform n_1/N (where n_1 equaled the number of marked fish and N equaled true abundance) at that scale and to mitigate potential bias due to pockets of fish isolated from sampling; and, 3) repeat sampling strategy item1 for the second event.

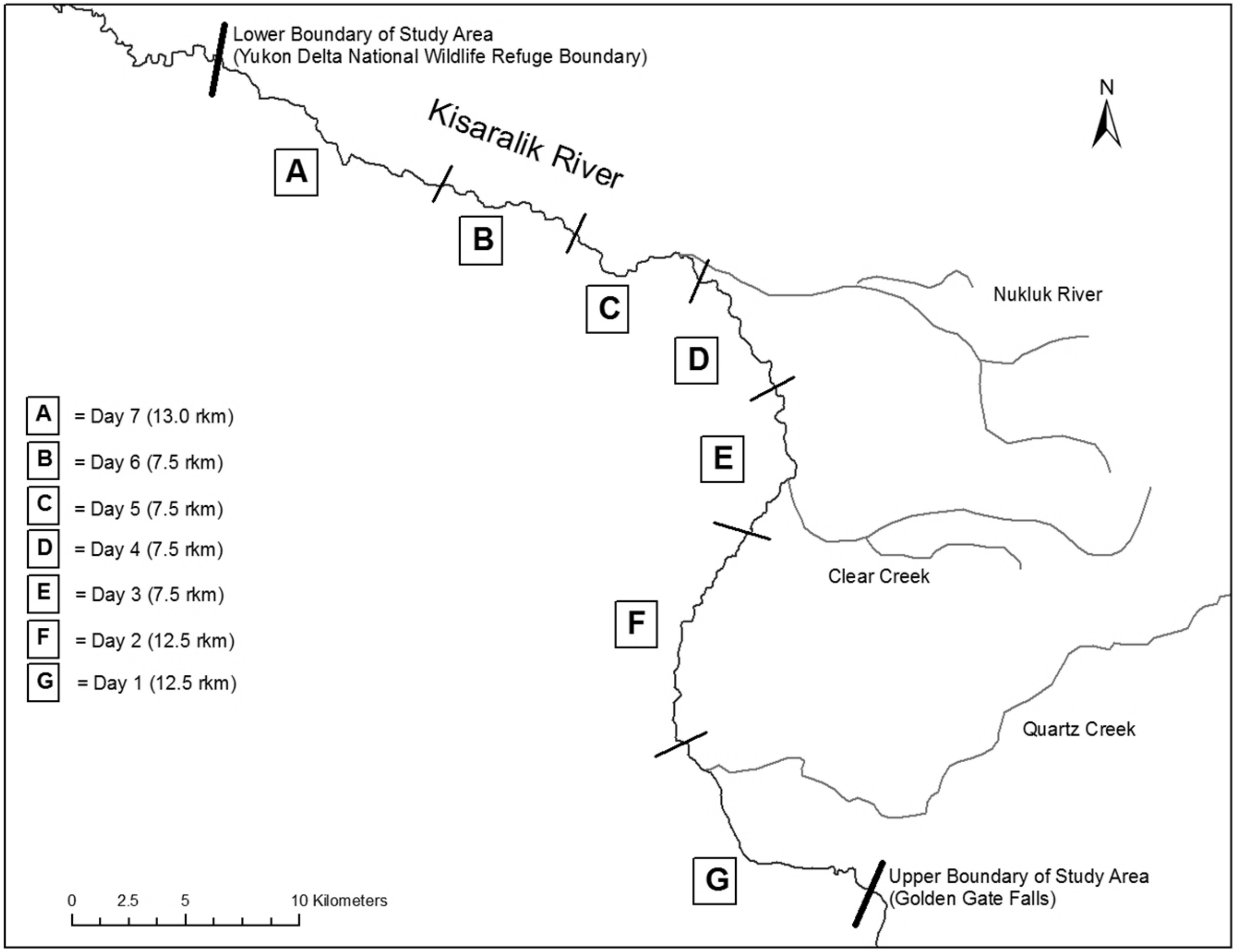

Figure 2.–Map of the study area with daily sampling segments and strata used for spatial selectivity diagnostic tests.

SAMPLING METHODS

For each event, a party of 10–11 people sampled rainbow trout with the use of 5 rafts. Personnel and gear were flown to Kisaralik Lake and floated downstream ~66 rkm to Golden Gate Falls, the upper boundary of the study area. Here, the party was divided into 4 crews of 2 people and 1 crew of 3 people. One section (Figure 2) was sampled each day and crews were assigned to a portion of the daily section. Crews rendezvoused each evening to camp together and compare observations. This was repeated for 7 days until 68 rkm were thoroughly sampled. Each crew sampled roughly 2.5 rkm per day in the low-density areas and roughly 1.5 rkm per day in the high-density areas.

All sampling was done with hook-and-line. Angling tackle was extensive but primarily consisted of dressed spinners, lead head jigs with marabou or rubber grub tails, egg imitation beads, and various flies. Bait in the form of shrimp was often used to increase catch rates.

Capture locations of all fish caught during the first event and examined during the second event were recorded using a GPS. During the first event, each captured rainbow trout ≥300 mm FL was tagged with an individually numbered Floy™ FD-94 internal anchor tag and given a secondary mark in the form of a partial left pectoral fin clip to evaluate tag loss between events. To prevent double counting of fish sampled during the second event, fish captured in this event received a partial right-pectoral fin clip. All captured fish were sampled and released within 50 m of their capture location. If a fish appeared unhealthy due to previous injury or recent capture injury, and it appeared it may not live until the second capture event, it was not tagged. All pertinent recorded data were summarized and entered into Microsoft Excel spreadsheets for analysis and archival (Appendix A1).

EVALUATION OF ASSUMPTIONS

Assumption 1

The timing of sampling and selection of the study area boundaries helped to ensure that the assumptions of closure were not violated or that undetectable biases were inconsequential. The short duration of the experiment helped to ensure mortality and growth recruitment were insignificant. Rainbow trout are at their healthiest during midsummer, the study area was closed to the retention of rainbow trout, and in 1997, growth was negligible during a similar 3-week hiatus between sampling events. The sampling dates were similar to Harper et al. (2004), when no discernible concerns associated with closure were evident: most movements were <5 rkm, no fish moved >12 rkm, and all movement appeared to be confined within the boundaries. The relatively large size (68 rkm) of the study area, coupled with the knowledge that the upper and lower ends of the study had low densities of rainbow trout, helped mitigate potential movements across the study area boundaries. The upper boundary, Golden Gates Falls, is a partial fish barrier, and the preferred habitat ends near the lower boundary.

Assumption 2

To a feasible extent, this study was designed to subject all fish to an equal probability of capture during each event by allowing enough time for localized mixing to occur (i.e., individual movements of 1–5 rkm). It was anticipated that as the availability of food items changed (i.e., the increase of spawning salmon), rainbow trout would mix at a local level and eliminate any isolated pockets of fish. Because complete mixing of the entire study area was not expected to occur, efforts to sample fish in proportion to their relative densities during both events were important in meeting this assumption. Therefore, based on results of the 1997 study, effort was increased where relative densities appeared high and less effort was placed in areas where relative densities appeared low, particularly when associated with poor trout habitat on the ends of the study area. Diagnostic tests were performed to determine if capture probabilities varied by size, location, or time and whether stratification was necessary (Appendices B1 and B2).

Assumption 3

The 3-week hiatus was assumed to be sufficient to allow marked fish to recover from the effects of handling and any marking induced behavioral effects during the first event. Fish captured in the first event that exhibited signs of injury, excessive stress, or imminent death were not marked and censored from the experiment.

Assumption 4

This assumption was addressed by double-marking each rainbow trout captured during the first event. Tag loss was noted when a fish was recovered during the second event with a first-event fin clip but without a Floy™ tag. In addition, tag placement was standardized, which allowed the fish handler to verify tag loss by locating recent tag wounds.

Assumption 5

All fish were thoroughly examined for tags or recent fin clips. All markings (i.e., tag number, tag color, fin clip and tag wound) for each fish were recorded.

Genetic Sampling

Genetic material was collected from 193 random rainbow trout from the study area. Genetic tissue was collected by clipping a ~5 mm portion of the left pectoral fin and preserving the samples in 90% ethyl alcohol. Samples were preserved in individual uniquely-numbered vials that were issued to samplers pre-numbered. Genetic material and fish data were provided to the USFWS Conservation Genetics Laboratory in Anchorage, Alaska.

Data Analysis

Abundance Estimate (Objective 1)

Relative to Assumption 1, closure was not tested directly but inferred from the movements of fish recaptured within the study area and their tendency to move away from or towards study area boundaries as evidence of immigration and emigration. The analysis of movement also aided in determining whether the population of inference should be that during the first event, second event, or both.

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

Temporal and spatial violations of Assumption 2 were tested using consistency tests described by Seber (1982; Appendix B2). If all 3 of these tests rejected the null hypothesis, then a partially or completely stratified estimator would be used. If movement of marked fish between strata was observed (incomplete mixing), the methods of Darroch (1961) would be used to compute a partially stratified abundance estimate. If no movement of marked fish between geographic strata was observed, a completely stratified abundance estimate would be computed using the methods of Bailey (1951, 1952). Otherwise, at least 1 of the 3 consistency tests would fail to reject the null hypothesis, and it would be concluded that at least 1 of the conditions in Assumption 2 was satisfied.

If no assumptions were violated, the number of rainbow trout ≥350 mm FL in the described section of the Kisaralik River would be estimated using Bailey's modification of the Petersen estimator (Bailey 1951, 1952). The modified Petersen estimator and its variance were

$$\hat{N} = \frac{n_1(n_2+1)}{(m_2+1)}; \text{ and,} \tag{1}$$

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

where

n_1 = the number of fish marked during the first sampling event,

n_2 = the number of fish examined during the second sampling event, and,

m_2 = the number of fish captured during the second sampling event with marks from the first sampling event.

Length Composition (Objective 2)

Kolmogorov–Smirnov 2-sample tests were performed to test for size-selective sampling, and test outcomes were used to determine if stratification was necessary and if data from the first, second, or both events were to be used. For cases I-III (Appendix B1), stratification would not be necessary and length proportions and variances of proportions for rainbow trout ≥350 mm FL would be estimated using samples from the event(s) without size-selectivity using

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

where

$\hat{p}_k$ = the proportion of rainbow trout that were within length category *k*,

n_k = the number of rainbow trout sampled that were within length category *k*, and,

n = the total number of rainbow trout sampled.

The unbiased variance of this proportion would then be estimated as (Cochran 1977)

$$\hat{V}[\hat{p}_k] = \frac{\hat{p}_k(1-\hat{p}_k)}{n-1}. \tag{4}$$

If diagnostic tests indicate case IV, there was size-selectivity during both events and data must be stratified to eliminate variability in capture probabilities within strata for at least one or both sampling events. Formulae to adjust length composition estimates are presented in Appendix B1.

RESULTS

SUMMARY OF FISH CAPTURED

Sampling dates for the first event spanned from 16 July to 22 July, and 1,180 unique fish were captured, with 797 being ≥350 mm FL. The second event spanned from 6 August to 12 August, and 259 unique fish were captured, with 187 being ≥350 mm FL. A total of 37 fish from the second event were marked in the first event, with 31 being ≥350 mm FL. One fish had experienced tag loss between events. The entire first event was characterized by average water levels and good visibility. The second event had deteriorating water conditions due to persistent rains, and the river was bank-full and muddy by the last day of sampling.

ABUNDANCE ESTIMATION AND DIAGNOSTIC TESTING

As expected, insufficient numbers of rainbow trout <350 mm FL were captured to reliably perform diagnostic tests or estimate abundance. Therefore, the remainder of the report focuses on rainbow trout ≥350 mm FL.

Section A was culled from the experiment due to inadequate effort and sample sizes in the first and second events and coupled with only localized mixing between events. This was ascribed to incomplete information on fish densities during the planning phase and deteriorating water levels during the rainy second event. When designing the sampling schedule based on the catch rates observed by Harper et al. (2004), it was assumed that that fish densities in Section A would be half that of Sections B, C, D, and E. Consequently, Section A was made larger (i.e., 13 versus 7.5 rkm; Figure 2). However, during the first event, the sampling crews experienced rainbow trout densities in the majority of Section A that were consistent with Sections B–D, and adequate time was not given to mark fish at the same rates as the other sections. To satisfy Assumption 2, more time was allocated to Section A during the second event, hoping that all fish would have an equal probability of capture during at least the second event. Unfortunately, consistent rains dominated the second event and deteriorating water conditions affected catch rates as the crew progressed downstream. By the time the crews reached Section A, the water clarity was not conducive for sampling. Essentially, sampling ceased as the crew entered Section A. Because first event capture probabilities could not be assessed for Section A and mixing was insufficient to allow for a pooled abundance estimate, Section A was omitted relative to the project objectives of estimating abundance and length composition.

A total of 642 rainbow trout ≥350 mm FL were captured during the first event within the truncated 55-km study area (Sections B–G). Another 184 rainbow trout ≥350 mm FL were examined in the second event and 29 of these were marked from the first event.

Kolmogorov–Smirnov tests indicated that size stratification was not necessary for rainbow trout ≥350 mm FL (Case I; Appendix B1), with the truncated study area meaning there was no size selectivity in either event and that stratification by length was not needed (Figure 3).

Consistency tests indicated that geographic stratification was not necessary for the truncated study area (Tables 2 and 3; Appendix B2). These tests indicated that fish did have equal probability of capture during both the first and second events. Therefore, the data from all sections were pooled for the abundance estimate.

Biases due to closure violations related to growth and fish movement across the boundaries of the truncated study area appeared negligible. Mean growth between events was not meaningful and was calculated at 2.4 mm (SE=4.0) when considering all recaptured fish ≥350 mm FL (Table 4). Truncating the study area resulted in a lower boundary within a high-density area and increasing the likelihood of significant immigration or emigration occurring between events. Examination of the movement distance and patterns of recaptured fish indicated that associated biases, if any, were inconsequential. Mean movement of recaptured fish was short (1,286 m; SE=625; Table 4) relative to the study area (55 rkm), a large majority (78%) moved ≤500 m, and there was no trend in direction moved (Figure 4). Of the 155 fish marked in Section A, 1 fish was recaptured in section B during the second event, providing evidence of limited immigration. This particular fish was originally tagged 600 meters below the Section B lower boundary. Since documented movements of recaptured fish were fairly random, with 16 fish moving upstream and 12 fish moving downstream (Table 4), it is likely that both limited immigration and emigration occurred. This would result in an abundance estimate with a positive bias; however, this bias was likely insignificant. Movements across the upper boundary were not a concern because of the very low densities in the upper section (Section G) and the river above there. The lower boundary also had low densities of rainbow trout and it was believed that densities remained low below there. During both events, less than 10 fish were captured while transiting to and away from the study area.

The abundance estimate for the truncated study area (Sections B–G) of rainbow trout ≥350 mm FL was 3,959 (SE=651; 95% CI=2,683-5,235). The relative precision of this estimate (0.32) fell short of the objective (0.25).

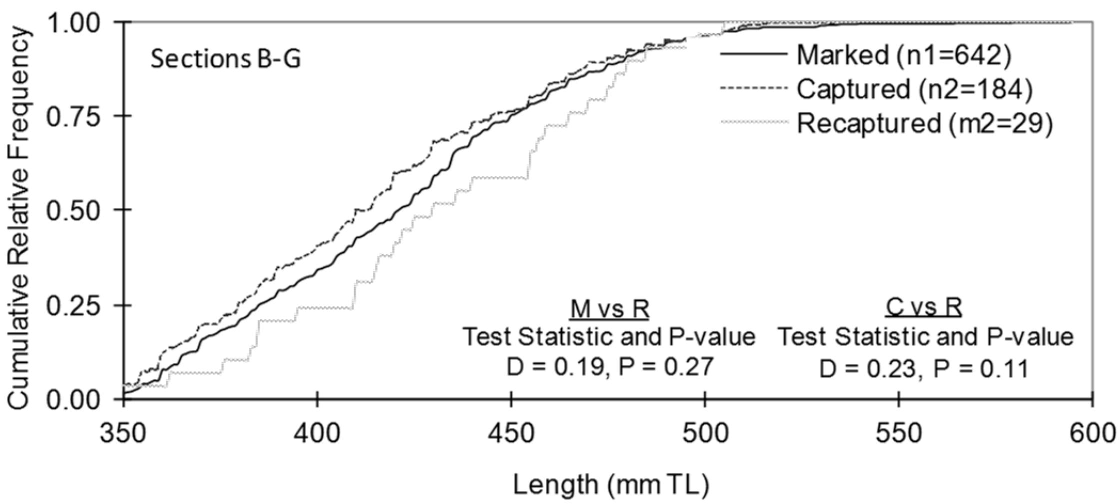

Figure 3.–Cumulative relative length frequency distributions of rainbow trout ≥350 mm FL, Kisaralik River.

Table 2.–Test for equal probability of capture during the first event for rainbow trout ≥350 mm FL. Number of marked and unmarked rainbow trout examined during the second event by section (B–G) of the Kisaralik River, 2011.

Category	Section Where Examined						
	B	C	D	E	F	G	All Sections
Marked (m_2)	3	15	3	4	4	0	29
Unmarked (n_2-m_2)	33	44	20	21	24	13	155
Examined (n_2)	36	59	23	25	28	13	184
$P_{capture}$ 1st event (m_2/n_2)	0.08	0.25	0.13	0.16	0.14	0.00	0.15

χ^2 = 8.25, df = 5, P-value = 0.14, fail to reject H_0.

Table 3.–Test for equal probability of capture during the second event for rainbow trout ≥350 mm FL. Number of rainbow trout marked by section (B–G) during the first event that were recaptured and not recaptured during the second event, Kisaralik River, 2011. One fish was recaptured that had lost its tag and could not be assigned the section where it was marked

	Section Where Marked						
Category	B	C	D	E	F	G	All Sections
Recaptured (m_2)	5	13	3	4	3	0	28
Not Recaptured (n_1-m_2)	169	154	126	60	77	28	614
Marked (n_1)	174	167	129	64	80	28	642
$P_{capture}$ 2nd event (m_2/n_1)	0.03	0.08	0.02	0.06	0.04	0.00	0.04

χ^2 = 8.79, df = 5, P-value = 0.12, fail to reject H_0.

Table 4.–Mean length (mm FL), dates of capture, growth and movement of rainbow trout ≥350 mm FL (n=28) captured during both sampling events at the Kisaralik River (section B–G), 2011.

Length	Date Marked	Date Recaptured	Growth (mm FL)[a]	Movement (m)	Absolute Movement (m)
351	7/19/2011	8/9/2011	-1	-500	500
375	7/20/2011	8/11/2011	41	-11,300	11,300
380	7/21/2011	8/11/2011	-4	60	60
381	7/21/2011	8/11/2011	4	-10	10
383	7/20/2011	8/10/2011	0	200	200
386	7/19/2011	8/10/2011	-24	4,100	4,100
398	7/21/2011	8/10/2011	24	-1,400	1,400
400	7/17/2011	8/7/2011	20	20	20
404	7/18/2011	8/8/2011	11	-60	60
410	7/21/2011	8/9/2011	-25	13,800	13,800
425	7/17/2011	8/7/2011	0	-1,100	1,100
425	7/20/2011	8/10/2011	32	70	70
425	7/20/2011	8/10/2011	5	-150	150
430	7/18/2011	8/8/2011	25	400	400
435	7/20/2011	8/10/2011	24	120	120
435	7/20/2011	8/10/2011	5	-1,700	1,700
435	7/20/2011	8/10/2011	-25	0	0
435	7/19/2011	8/9/2011	1	-30	30
436	7/20/2011	8/10/2011	-41	-120	120
457	7/18/2011	8/8/2011	8	-60	60
462	7/17/2011	8/7/2011	13	-220	220
463	7/20/2011	8/10/2011	7	50	50
465	7/20/2011	8/10/2011	15	200	200
478	7/18/2011	8/8/2011	20	-150	150
479	7/21/2011	8/11/2011	-2	20	20
500	7/20/2011	8/10/2011	-15	70	70
505	7/20/2011	8/10/2011	-50	-50	50
505	7/20/2011	8/10/2011	0	70	70
		Mean Growth	2.4	Mean Abs Mvt	1,286
		SE	4.0	SE	625

[a] Length measurements likely were not precise enough to accurately assess growth but are presented as a means to display that mean growth was negligible.

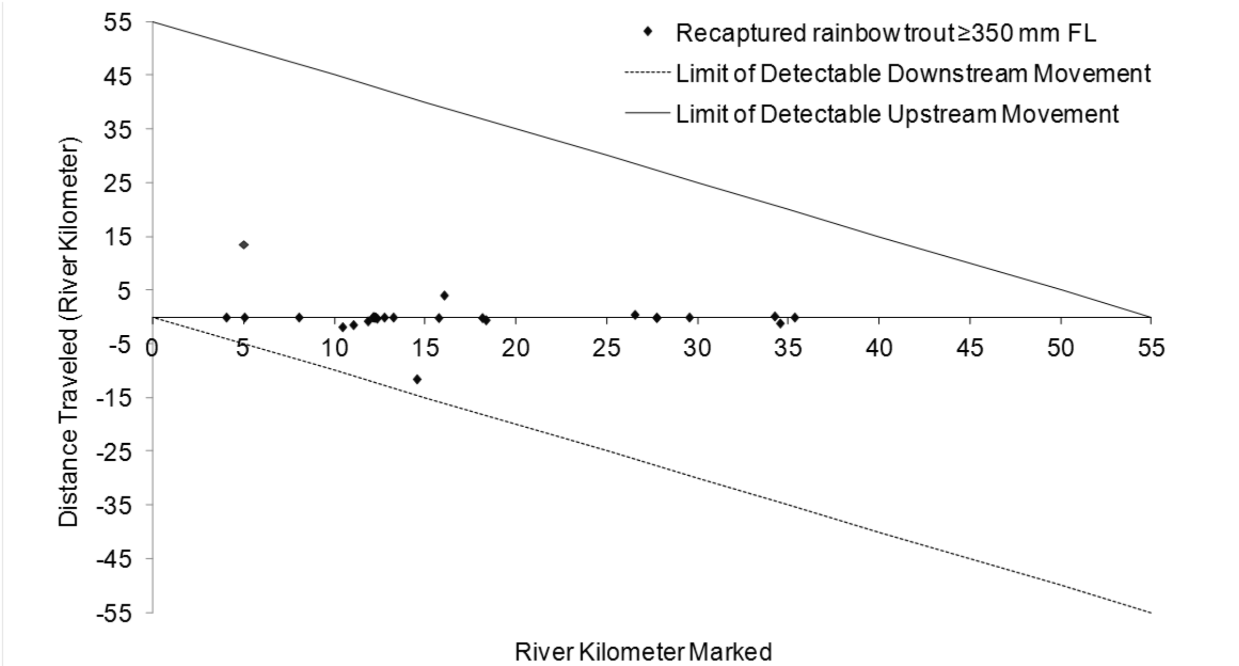

Figure 4.–Distance rainbow trout traveled from the time of tagging to the time of recapture, Kisaralik River, 2011. Negative distances correspond to downstream movements. River kilometer 0 was the downstream boundary of the study area with Golden Gate Falls being the upstream boundary.

LENGTH COMPOSITION

Mean length of rainbow trout ≥350 mm FL was 421 mm FL (SD=43) in the first event and 415 mm FL (SD=43) in the second event for fish in the truncated study area (Table 5).

Kolmogorov–Smirnov tests using lengths of rainbow trout ≥350 mm FL from Sections B–G indicated a case I scenario, meaning there was no size selectivity in either event, and lengths from both events were pooled for length distribution estimation (Figure 3; Appendix B1). The estimated length composition of rainbow trout ≥350 mm FL had no dominant 25-mm FL length categories (Figure 5), but 5 of them collectively comprised 87% of the estimated population of rainbow trout ≥350 mm FL: 350–374 (18%), 375–399 (16%), 400–424 (19%), 425–449 (20%) and 450–474 (14%).

DISCUSSION

This study attained the second abundance estimate for rainbow trout in the Kisaralik River. In 1997, an abundance of 7,390 (SE=693; 95% CI=6,032- 8,748) rainbow trout ≥350 mm FL was estimated during a similar 2-event mark–recapture experiment using the same study area as originally planned in this study (Sections A–G) and during similar sampling dates. The truncated study area in this study (Sections B–G) negated any direct comparisons between years relative to abundance.

However, sampling data from the first event in 2011 did provide some insight about densities that were likely present in Section A. Examination of capture probabilities showed that approximately 15% of the population in Sections B–G (Table 2) was sampled during the first event when crews generally sampled a specific area or “fishing hole” until it became unproductive. In the longer Section A, the crews marked 155 rainbow trout during the first event and believed that a substantially lower proportion of fish were marked because they were forced to leave an area that was still productive in order to sample all 13.5 rkm within 1 day. Assuming that the first event crew had a capture rate that was two-thirds to one-half that of the rest of the study area in Section A (between 10% and 7.5% capture rates), between 1,550 and 2,066 rainbow trout ≥350 mm FL may have been residing in Section A. Summing these numbers with the point estimate of 3,959 (SE=651) from the truncated area results equates to between 5,509 and 6,025 rainbow trout ≥350 mm FL in the 1997 study area (Sections A–G). This would bring the point estimate inside the boundaries of the 1997 study area within 1,365 (10.0% capture rate in Section A) and 1,881 (7.5% capture rate in Section A) fish of the 1997 abundance estimate. Considering reasonable levels of associated SE, these abundance estimates would be similar.

A significant difference was observed in the length composition of rainbow trout ≥350 mm FL between 1997 (both events) and 2011 (both events), with larger fish being sampled in 1997 (Figures 6 and 7). In 2011, there was not a difference in cumulative length distribution from fish sampled in Section A versus Sections B–G; therefore, lengths from Section A were included to ensure a consistent sampling area between the studies. Natural fluctuations in length composition are common in freshwater fish species (e.g., cohort effect). This study was just a "snap shot" of the population, and consecutive assessments would need to be conducted to better understand the difference between years.

It was unfortunate that high, and at times turbid, water during the second event constrained the results of this study. Even though sampling was rushed through parts of Section A, the crew did an exhaustive job sampling fish during the first event with good water conditions throughout the majority of the study area. Recapture rates from the second event suggested that the first event crew sampled about 15% of the population ≥350 mm FL. If the second event crew would have experienced good water conditions, the objective criteria for the planned study area would have been exceeded with excellent results. Also, an abundance estimate would likely have been attained for fish <350 mm FL, which would have been comparable to that of the 1997 study and would have provided useful information as to the overall length structure of the population. Instead, poor water conditions resulted in the second event crew sampling only 187 fish ≥350 mm FL for Sections A–G combined. If another abundance estimate is attempted on this river, consideration should be given to eliminating Section G from the study area (very few fish were sampled in this section during both studies) and allocating more time to the lowermost reach (i.e., Section A).

Table 5.–Mean length (mm FL) of rainbow trout ≥350 mm FL captured during sampling events at the Kisaralik River, 2011.

		Sections
Dates	Statistic	B-G
7/16–7/22	Mean	421
	SD	43
	Sample Size	642
8/6–8/12	Mean	415
	SD	43
	Sample Size	184
All	Mean	420
	SD	43
	Sample Size	826

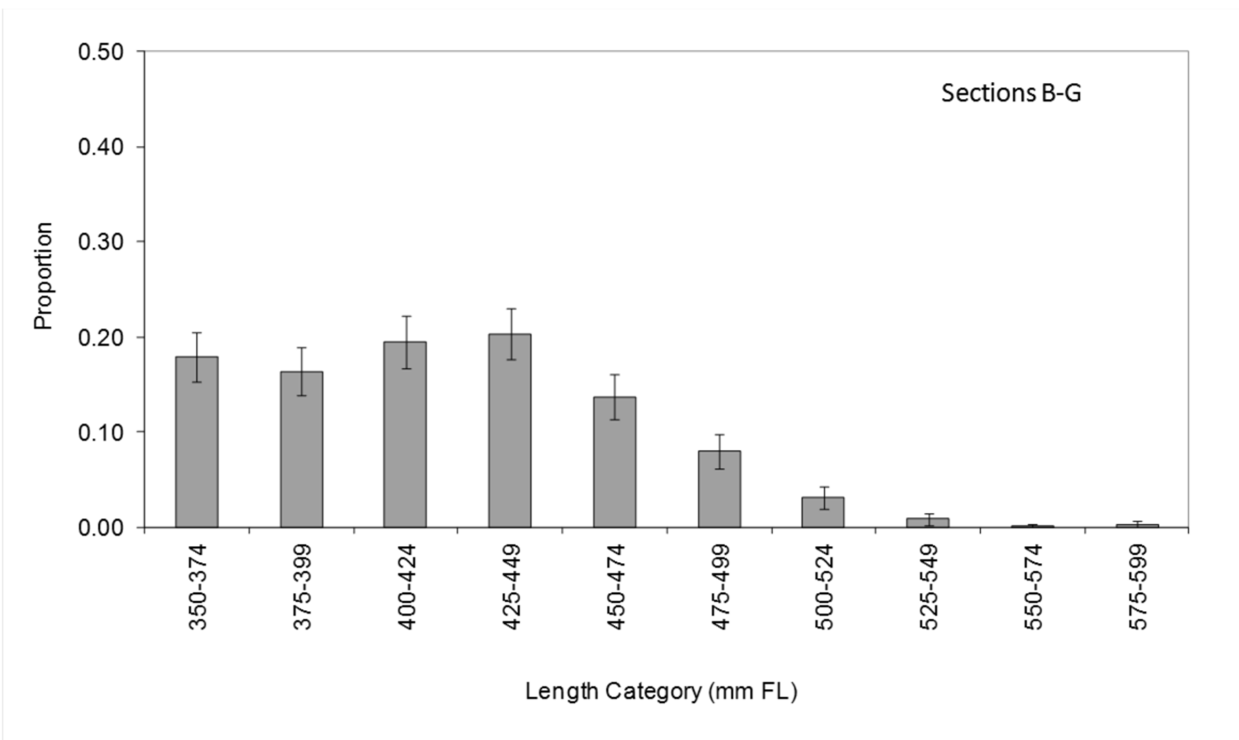

Figure 5.–Estimated length composition of rainbow trout ≥350 mm FL, Kisaralik River. Vertical bars represent 95% confidence intervals.

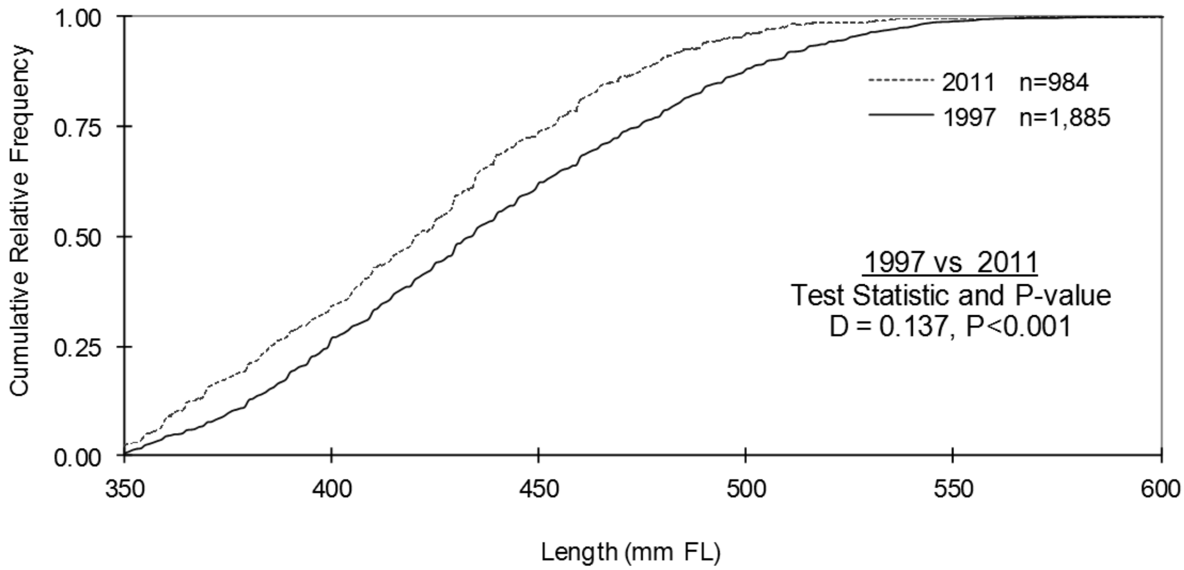

Figure 6.–Cumulative relative length frequency distributions of rainbow trout ≥350 mm FL sampled, Kisaralik River 1997 and 2011. Samples are from the sampling events (both events from both years) that did not have size selectivity. These data include fish captured from Section A in 2011.

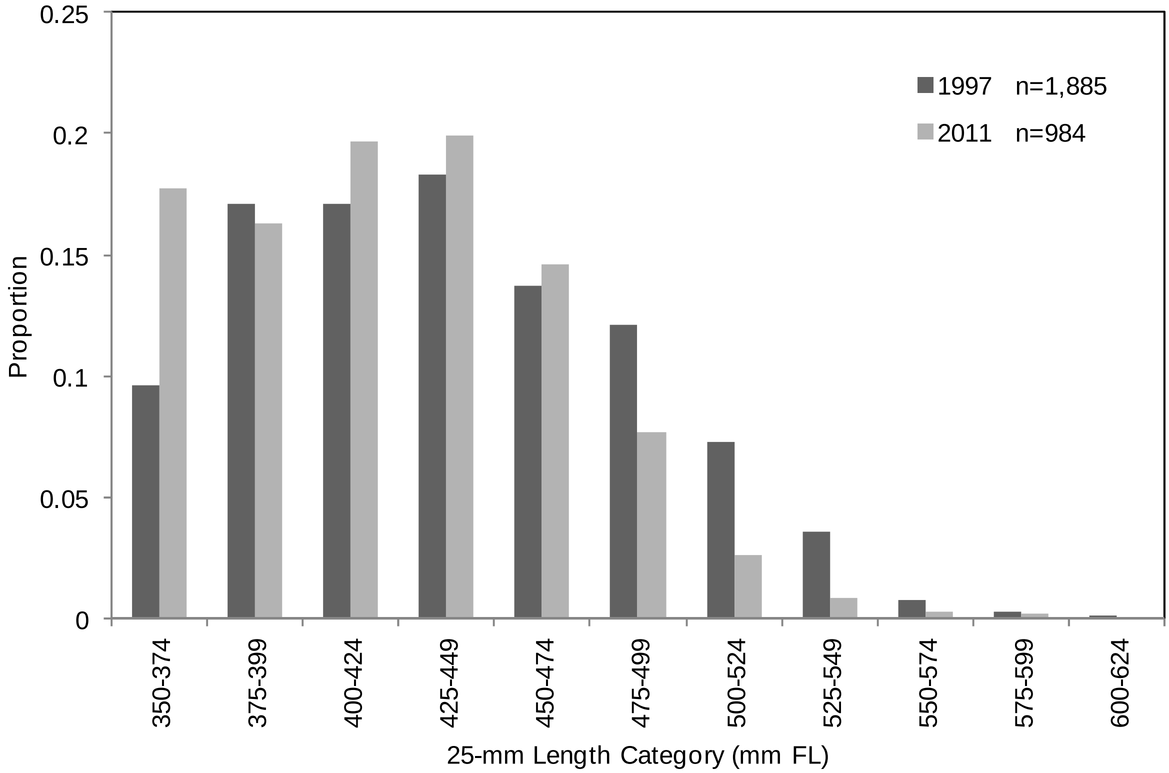

Figure 7.–Length histogram of rainbow trout sampled during events that were not size selective during 1997 and 2011 (both events from both years) Kisaralik River mark–recapture experiments. These data include fish captured from Section A in 2011.

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APPENDIX A:
SUMMARY OF DATA FILE ARCHIVES

Appendix A1.–Summary of data archives.

Project leader: Corey Schwanke; (907) 822-3309		
Year	Data File[a]	Software
2011	Kisaralik River rainbow trout 2011.dta[b]	Microsoft Excel

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

[b]The Excel file contains the following information for all captured rainbow trout: date, time, fork length, tag number and color, secondary mark type, recaptured status
(Y or N), and any other pertinent comments.

APPENDIX B:

METHODS FOR TESTING ASSUMPTIONS OF THE PETERSON ESTIMATOR AND ESTIMATING ABUNDANCE

Appendix B1.–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 using a two-sample test (e.g. Student's t-test).

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

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

Protocols given Adequate Power

Case I:

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

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

Case II:

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

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

-continued-

Overall composition parameters are estimated by combining stratum estimates weighted by estimated stratum abundance according to the formulae below.

Case III:

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

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

Case IV:

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

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

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

$$\hat{p}_k = \sum_{i=1}^{j} \frac{\hat{N}_i}{\hat{N}_\Sigma} \hat{p}_{ik} \text{, and} \tag{B1-1}$$

$$\hat{V}[\hat{p}_k] \approx \frac{1}{\hat{N}_\Sigma^2} \left(\sum_{i=1}^{j} \hat{N}_i^2 \hat{V}[\hat{p}_{ik}] + \left(\hat{p}_{ik} - \hat{p}_k \right)^2 \hat{V}[\hat{N}_i] \right) \tag{B1-2}$$

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*;

$\hat{N}_\Sigma$ = sum of the $\hat{N}_i$ across strata.

-continued-

Protocols when Power Suspect (re-classifying the experiment)

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

Case I:

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

Case II:

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

Case III:

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

-continued-

Guidelines for evaluating power:

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

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

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

Appendix B2.–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
	1	**2**	**…**	**t**	$(n_1\text{-}m_2)$
1					
2					
…					
s					

II.-Test For Equal Probability of capture during the first event[b]

	Section Where Examined			
	1	**2**	**…**	**t**
Marked (m_2)				
Unmarked $(n_2\text{-}m_2)$				

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

	Section Where Marked			
	1	**2**	**…**	**s**
Recaptured (m_2)				
Not Recaptured $(n_1\text{-}m_2)$				

[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 river sections: H_0: $\Sigma_i a_i \theta_{ij} = kU_j$, 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 the river 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.