Fishery Data Series No. 09-52

Stock Assessment of Rainbow Trout in the Gulkana River, 2004 and 2005

by

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and

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

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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by

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ABSTRACT

A two-year study was conducted on rainbow trout in the Gulkana River. In 2004 a feasibility study was conducted to evaluate proposed sampling gear and protocols for a mark-recapture experiment performed in 2005 to estimate abundance of rainbow trout. In 2004, the effectiveness of hook-and-line gear and hoop traps baited with salmon roe were tested within a 50-mile segment of the Upper Gulkana River from 12 to 18 August and again from 24 to 28 August. Hook-and-line effort was deployed systematically throughout the study area, and hoop traps were set as often as possible within study sections. Mean CPUE for hook-and-line gear was 2.20 fish per man-hour of angling. Hoop traps captured 0.065 rainbow trout per hour, roughly 1.5 rainbow trout per overnight set, and were more effective at capturing smaller fish when compared to hook-and-line gear. In conclusion, the results demonstrated that the two gear types in combination should be used in 2005 to achieve desired sample sizes for the mark-recapture experiment.

In 2005, a mark-recapture experiment was performed in the 50-mile section of the Gulkana River. The first event occurred from 10 to 24 August, the second from 20 September to 6 October, and fish were captured with the recommended combination of hook-and-line gear and baited hoop traps. A stratified Bailey-modified Petersen estimator was used to estimate the abundance of rainbow trout. Estimated abundance for small fish (160-274 mm FL) was 6,850 (95% CI = 4,845-8,885) and for large fish (≥275 mm FL) was 5,238 (95% CI = 3,888-6,588). The combined estimate for rainbow trout ≥160 mm FL was 12,088 fish (95% CI = 9,671-14,505). Diagnostic tests suggested that the abundance estimate for small fish might be slightly biased low because a small portion of these fish may have been isolated from the experiment.

Key words: rainbow trout, *Oncorhynchus mykiss*, Gulkana River, abundance, mark-recapture, hook-and-line, hoop traps, CPUE, length distribution

INTRODUCTION

The Gulkana River drainage supports the largest known fisheries for rainbow trout *Oncorhynchus mykiss*, Chinook salmon *O. tshawytscha* and Arctic grayling *Thymallus arcticus* within the Upper Copper/Upper Susitna Management Area (UCUSMA; Figure 1), accounting for as much as half of the angler effort annually since 1977 (Taube 2006). Estimated annual angler effort directed at all species on the Gulkana River peaked in the mid-to-late 1990s, and has recently leveled off at about 18,000 angler days (Figure 2). Angler catch of rainbow trout in the Gulkana River has been estimated since 1990. Estimated annual catch showed an increasing trend from 1990 to 1996 and has since stabilized with the latest five year average (2000–2004) of annual catch being about 5,700 trout (Figure 2). Most of the rainbow trout catches in the Gulkana River drainage occur in a section of the mainstem Gulkana River between the outlet of Paxson Lake and a boat launch and campground at Sourdough Creek (Figure 3). This approximately 50-mile long section of river is particularly popular because it lies within the portion of the Gulkana River designated as a National Wild River (popular among rafters and kayakers) and is believed to contain the highest densities of mature-sized rainbow trout within the drainage.

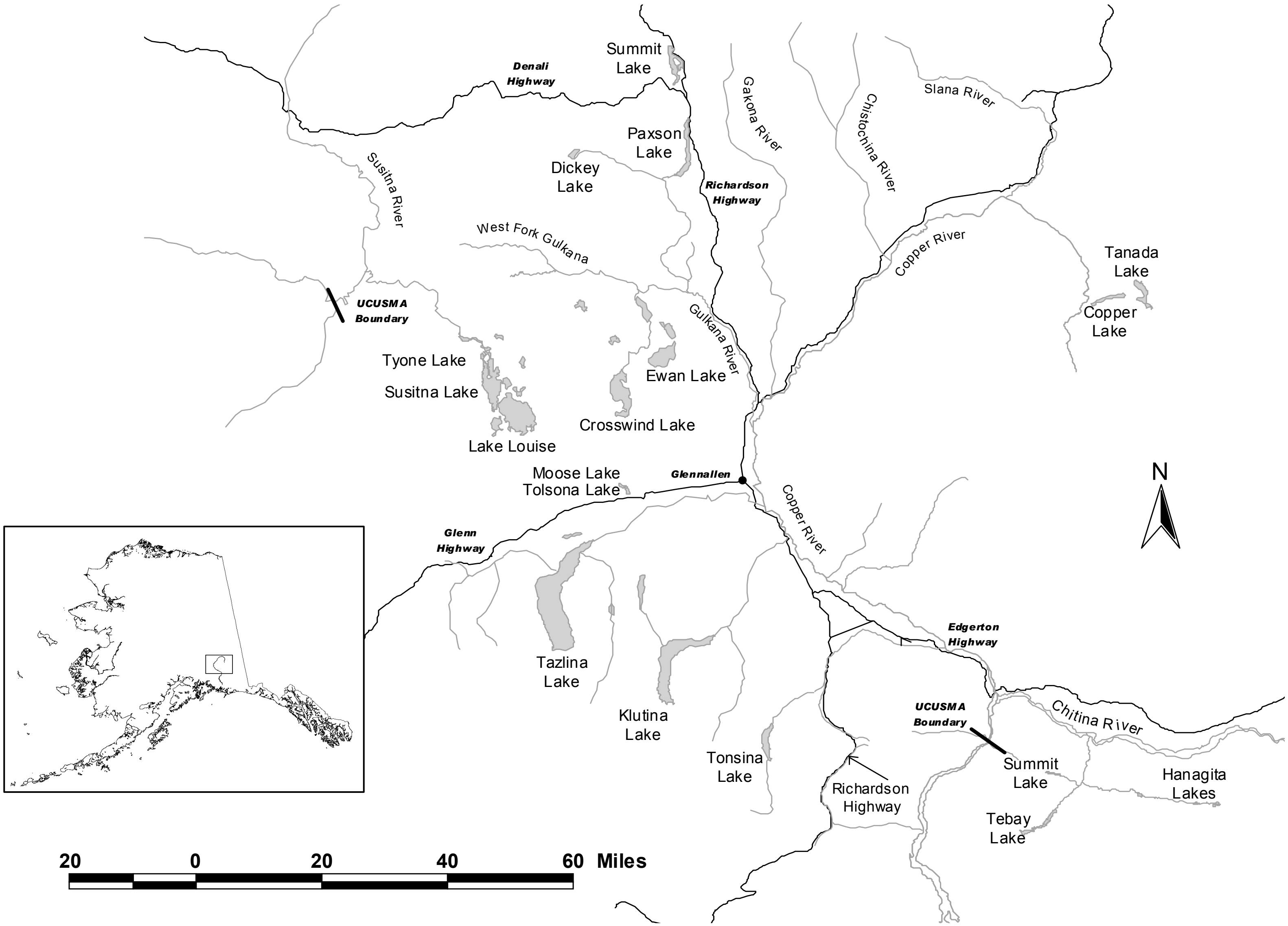


Figure 1.–Map of the Upper Copper/Upper Susitna Management Area.

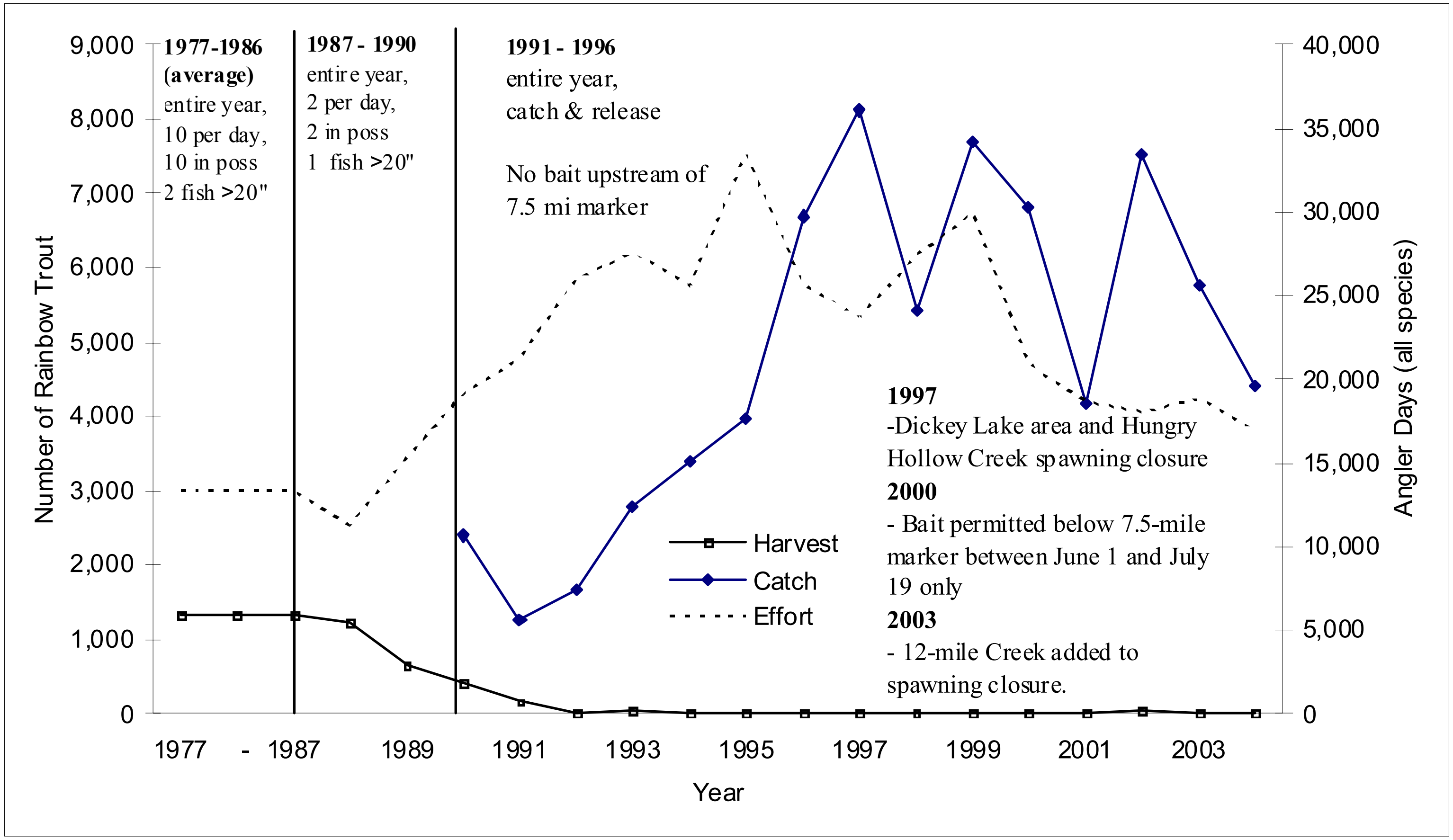


Figure 2.–Estimated angler effort (all species) and number of rainbow trout caught and harvested in the Gulkana River drainage from 1977 to 2004. Values reported by Taube (2006). Vertical lines delineate major changes in regulation.

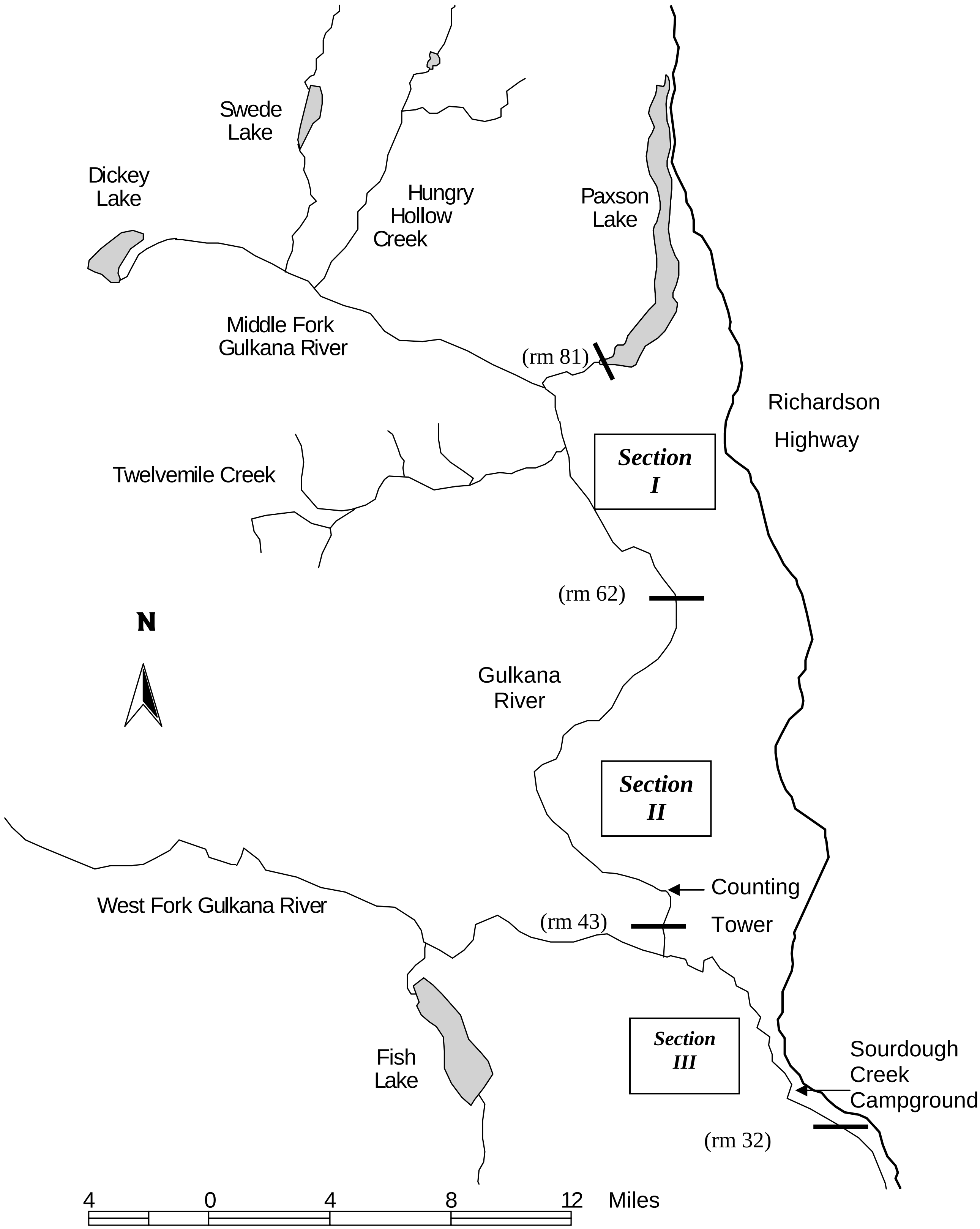


Figure 3.–Gulkana River study area with demarcations of section boundaries for the feasibility study, 2004.

Wild rainbow trout in the Gulkana River are managed under the Cook Inlet and Copper River Basin Rainbow/Steelhead Trout Management Policy (CICRRTMP; ADF&G 1987). The document details specific management policies and recommended research objectives. The stated policies are:

Policy I: native rainbow trout populations will be managed to maintain historical size and age composition and stock levels; and,

Policy II: a diversity of sport fishing opportunities for wild and hatchery rainbow/steelhead trout will be provided through establishment of special management areas by regulation.

The recommended research needs of the policy are:

1. developing adequate methodologies to estimate rainbow trout abundance and fishing mortality;
2. developing an index of the relative abundance for rainbow/steelhead trout in selected waters;
3. examining spatial and seasonal distribution of rainbow trout in selected waters;
4. characterizing size and age composition of rainbow/steelhead trout in selected waters;
5. developing information on the harvest of rainbow trout/steelhead trout; and,
6. developing angler-preference information pertaining to the management of rainbow trout fisheries.

Since approval of this 1987 management policy, fishing regulations for rainbow trout, as well as steelhead in the Gulkana River, have become increasingly restrictive because of perceptions that harvest levels were not sustainable. These perceptions were not based on any rainbow trout specific stock assessments, but rather on angler reports and low incidental catches of rainbow trout during research activities directed at other species (e.g., Arctic grayling). The chronology of the regulatory changes for rainbow trout/steelhead in the Gulkana River was:

Prior to 1987: Ten fish per day, 10 in possession (only 2 of which could be 20 inches or longer);

1987: Two rainbow trout per day and 2 in possession (only 1 fish over 20 inches or longer). Bait and multiple hooks still allowed;

1991: Catch-and-release in entire Gulkana River drainage; fishing gear restricted to the use of unbaited, artificial lures in all waters of the Gulkana River upstream of a departmental marker located 7.5 miles upstream of the West Fork. Below this location, anglers could use bait all year;

1997: Spawning closures (15 April–14 June) were instituted on a three-mile section immediately downstream of Dickey Lake and all of Hungry Hollow Creek;

2000: Only unbaited, single hook artificial lures were permitted in all flowing waters of the Gulkana River. Bait and multiple hooks were permitted downstream of the 7.5-mile marker to the Richardson Highway bridge between 1 June and 19 July to accommodate anglers targeting chinook salmon; and,

2003: Twelvemile Creek was added to the listing of spawning area closures (15 April–14 June).

The Gulkana River has been the focus of several steelhead and rainbow trout studies. The most significant findings have resulted from 1) a pair of radiotelemetry studies that identified spawning locations (Burger et al. 1983; Fleming 2004); 2) stock assessments conducted from 2001 to 2002 on two of these spawning areas (Wuttig et al. 2004); and, 3) a compilation of directed and non-directed efforts to catch and sample rainbow trout for length, weight and age information, and determine fish distributions (ADF&G *Unpublished*; Fleming 1999, 2000 and 2004). In the early 1980s, 24 steelhead radiotagged in the Copper River near Copperville led to the documentation of two spawning areas in the Middle Fork Gulkana River where both rainbow trout and steelhead were observed spawning together: Hungry Hollow Creek and a 3-mile reach of river below the outlet of Dickey Lake. Fleming (2004) radiotagged 23 rainbow trout and identified Twelvemile Creek as a spawning area for both steelhead and rainbow trout and one suspected spawning area in the mainstem Gulkana River. Baseline genetic and abundance information collected during studies on the Dickey Lake and Hungry Hollow Creek spawning stocks from 2001 to 2003 demonstrated that: 1) the two spawning areas are genetically distinct; 2) within a spawning area both steelhead and rainbow trout are genetically interdependent; and, 3) the spawning stock of rainbow trout in each area is relatively small (e.g., approximately 250 fish; Wuttig et al. 2004). The compilation of the directed and non-directed sampling efforts have demonstrated that most of the mature-sized (e.g., >400 mm FL) rainbow trout inhabit the mainstem of the Gulkana River between the outlet of Paxson Lake and Sourdough Creek.

All steelhead and rainbow trout investigations in the Gulkana River drainage have, however, failed to provide a meaningful measure of the status (i.e., abundance and length composition) of the rainbow trout population that supports the directed rainbow trout fishery in the Gulkana River. There appears to be strong indications that the rainbow trout population has recovered, or is still recovering, from overexploitation that occurred prior to 1991 based on angler reports and the marked increases in catches provided by the Statewide Harvest Survey.

The goal of this project was to collect information on the abundance and length composition of rainbow trout in the mainstem of the Gulkana River between the outlet of Paxson Lake and Sourdough Creek Campground using a mark-recapture experiment in the fall of 2005. The primary benefits of this goal were to: 1) obtain information to adequately address regulatory proposals, such as gear restrictions; 2) obtain information to adequately address public concerns or perceptions about the population's status; 3) provide a measure or standard for comparisons with future evaluations of Gulkana River rainbow trout, as well as with other rainbow trout populations within the State of Alaska; and, 4) ensure consistency with policies and research needs identified in the CICRRTMP. Because no population assessments of rainbow trout in the mainstem Gulkana River had been performed, a feasibility study was conducted in 2004 to collect information on gear capture efficiencies, fish distributions and logistics needed to formulate and implement a successful mark-recapture experiment in 2005.

OBJECTIVES

The research objectives for 2004 were to:

1. estimate mean CPUE (number of rainbow trout captured per hour) for both baited hoop traps and hook-and-line gear for a 50-mile long reach of the mainstem Gulkana River between a position two miles downstream from the outlet of Paxson Lake and a position two miles downstream of Sourdough Creek (Figure 3);
2. estimate mean CPUE for both baited hoop traps and hook-and-line gear for each of the three sections of a 50-mile long reach of the mainstem Gulkana River between a position two miles downstream from the outlet of Paxson Lake and a position two miles downstream of Sourdough Creek (Figure 3);
3. describe and compare length compositions of rainbow trout captured using hook-and-line gear and baited hoop traps; and,
4. characterize the availability of effective hoop trap sites within each section.

The research objectives for 2005 were to:

1. estimate the abundance of rainbow trout ≥150 mm FL in a 50-mile index section of the Gulkana River during September such that the estimate was within 35% of the true abundance 95% of the time; and,
2. estimate length composition (in 25-mm FL length categories) of rainbow trout ≥150 mm FL in a 50-mi index section of the Gulkana River during September such that the estimates were within 10 percentage points of the true value 95% of the time.

METHODS

STUDY AREA

The Gulkana River is a non-glacial, runoff stream that flows southward out of the Alaska Range for approximately 112 mi before reaching the Copper River near Glennallen (Figures 1 and 3). The East Fork Gulkana River begins above timberline at Gunn Creek, a tributary to Summit Lake and continues until it enters Paxson Lake. The mainstem of the Gulkana River begins at the outlet of Paxson Lake and has two major tributary drainages: the West Fork Gulkana (185 mi in length including major tributaries) and the Middle Fork Gulkana (25 mi in length including major tributaries). A floatplane, or combinations of canoeing and overland portaging are necessary for access to either the West Fork or Middle Fork drainages. The Bureau of Land Management (BLM) manages much of the land bordering the river and much of the river drainage was designated as a National Wild River through the 1980 Alaska National Interest Lands Conservation Act (ANILCA). AHTNA Inc., a native corporation, owns most of the land downstream of Sourdough, which borders the lower 37 mi of the watershed. Stream habitats within the Gulkana River drainage range from slow meandering reaches to high gradient sections of Class III rapids in small, incised canyons. Much of the habitat has been described by Albin (1977) and more recently by Brink (1995) and was later classified by Stark (1999).

An approximately 50-mile long index section was selected as the study area encompassing the mainstem Gulkana River from a point two miles below Sourdough Creek campground upstream to Paxson Lake, including the lower half-mile of the Middle Fork Gulkana River. These boundaries were selected because this is where nearly all the sport fishing effort directed at rainbow trout occurs, and previous research and angler reports indicated that, except during spawning, a large majority (i.e., >75%) of the adult population appears to inhabit this reach of river year round. The most comprehensive sampling for rainbow trout in the Gulkana River was conducted in the summer of 2000 in an effort to distribute radio tags in proportion to perceived relative densities of mature-sized rainbow trout (Fleming 2004). In this study, the mainstem Gulkana, Middle Fork Gulkana, and portions of the West Fork Gulkana rivers were sampled using hook-and-line gear (no bait) during late July and early August. Of the 60 rainbow trout sampled, 48 (80%) were captured within the 50-mile study area, eight fish downstream of the study area, three fish from the Upper Middle Fork Gulkana River and one fish in the West Fork Gulkana River.

The river mileage delineated in Shelby et al. (1990), which starts at zero at the confluence of the Gulkana and Copper rivers and progresses upstream, was used in this study. The study area extended from river mile (rm) 32 to rm 80, and included the lower half-mile of the Middle Fork Gulkana River.

FEASIBILITY STUDY 2004

STUDY DESIGN AND FISH CAPTURE

This study was designed to provide a reasonable expectation of the number and size composition of rainbow trout that could be caught throughout the study area given a predefined amount of effort. More specifically, the study was designed to determine relative fish density in the 50-mile study area, as well as catch rates using two capture gears fished systematically: baited (salmon roe) hoop traps and hook-and-line gear. The measure to assess relative fish density and capture rates was CPUE. Effort was distributed evenly across the study area on the scale of one river mile. Within each river mile, the choices of fishing locations were made by the biologists and technicians using their knowledge and experience to target locations most likely to yield fish. For logistical and data analysis purposes, the study area was divided into three sections named Section I (upper; rm 63-80 and the lower half mile of the Middle Fork Gulkana), Section II (middle; rm 43-62) and Section III (lower; rm 32-42; Figure 3).

The terminal hook-and-line gear consisted of a salmon colored bead "pegged" approximately 2 in above a single hook baited with shrimp or salmon roe. A unit of effort was one man-hour of angling (two people angling for 0.5 h each). One unit of effort was deployed within each rm except two, in which no effort was deployed. In some rms, angling longer than one unit (30 min for two people) occurred. When this happened, angling beyond the 30 minute interval was considered "extra effort" and was not used in the CPUE calculations. Additionally, three rms were angled for one unit of time during two separate occasions. When this occurred, only the occasion during which the entire section was sampled was used for the CPUE calculations.

Hoop traps used were 4 ft long and had 4 steel hoops. Each trap had 2 throats (positioned at the 2nd and 3rd hoop), which narrowed to a diameter of 3-4 inches. The hoop netting was constructed of a 3/8-in knottless nylon mesh, bound with #15 cotton twine, and treated with an asphaltic compound. Each trap was erected, or "stretched," using two approximately 6-ft long pieces of ¾-in polyvinyl chloride pipe with snap clips at each end of the pipe, which were clipped to the distal hoops of the trap. Salmon roe was placed in a perforated plastic container that was inserted into the cod end of the trap. A baited hoop trap fished or "soaked" for an overnight period that ranged from 12 to 20 h. Effort was enumerated by hour.

Section I (upper section) was sampled by a two-person crew from 12 to 18 August. Originally, a jet-powered boat was to be used to sample all one-mile reaches of this section, but low water levels dictated the use of a raft instead, which greatly restricted the amount of area sampled using hoop traps. Hoop traps were set only within walking distance (0.5 mi) of camping areas; however, care was taken to place traps far enough apart (i.e., >150 yards) to minimize competition among them. All rms were sampled with hook-and-line except two due to time constraints.

Section III (lower section) was sampled from 16 to 18 August. A crew of two people sampled this area using a jet-powered boat. In each rm, two traps were set and one unit of angling effort was expended. This crew also sampled rm 43 during this time period, the lower most rm in the middle section.

Section II (middle section) was sampled from 24 to 28 August. Originally, two rafts were going to be used to float this section, and two traps were to be set in every river mile. One crew was to set traps in a pre-determined section (i.e., 4-5 rm), and the other raft was to float down and check the traps the next day, which would have resulted in hoops traps being set every rm. After sampling the upper and lower sections, this approach was deemed infeasible given time constraints. Instead, two crews split up and each angled a 4- to 5-mi stretch of river a day and set 4-7 traps near (within 1 mi) their campsites with sufficient separation to minimize competition. All rms were angled for at least one-man hour of effort in the middle section.

Data Collection

For each fish captured, data collected included:

1. measurement of fish length to the nearest mm FL;
2. type of capture gear and terminal gear used;
3. location (approximate river mile and GPS coordinate);
4. the number printed on the internal-anchor tag; and,
5. date.

For each hoop trap set, data collected included:

1. number of fish captured in each hoop trap set;
2. set number;
3. time set and time pulled or soak time;
4. location of each hoop trap set using a handheld GPS;
5. date; and,
6. description of set location (e.g., outside cut bank, depth = 5 ft, behind submerged tree).

For each unit of hook-and-line effort, data collected included:

1. location(s) where unit was expended using a handheld GPS unit;
2. number of fish captured per unit; and,
3. date.

Each rm was evaluated for potential hoop trap suitability based on water conditions. Rms were ranked on the following scale:

1. 0 suitable spots;
2. < 5 suitable spots;
3. 5-10 suitable spots; and,
4. ample suitable spots (>10).

Each rm was also evaluated for rainbow trout habitat on a relative scale of one (poor) to five (excellent). Rankings were determined based on catch rates while angling and river morphology (riffles, holding water, cover, etc.) within each rm.

Data was later summarized and entered into Microsoft Excel spreadsheets for analysis and archival (Appendix A1).

Data Analysis

All collected data was entered electronically into a Microsoft Excel workbook. Data was summarized by section, date, gear and effort.

CPUE was calculated for each unit of gear-specific effort as

$$\mathrm{CPUE}_{\mathrm{hoop}} = \mathrm{n}_{\mathrm{rt,hoop}} / \mathrm{e}_{\mathrm{soak}} \quad (1)$$

where:

$n_{rt,hoop}$ = number of rainbow captured in a trap set;

e_{soak} = duration (h) hoop trap fished; and,

$$\mathrm{CPUE}_{\mathrm{hook}} = \mathrm{n}_{\mathrm{rt,angle}} / \mathrm{e}_{\mathrm{hook}} \quad (2)$$

where:

$n_{rt,angle}$ = number of rainbow captured by hook-and-line; and,

e_{hook} = time (h) angled

Hoop trap data within each rm was pooled for analysis.

Average CPUE for the entire study area was estimated as a ratio (Thompson 2002) for each gear type:

$$\overline{CPUE} = \sum_{i=1}^{n} c_i \Big/ \sum_{i=1}^{n} e_i \quad (3)$$

with variance:

$$\hat{V}(\overline{CPUE}) = \frac{\sum_{i=1}^{n} \left(c_i - \overline{CPUE} \times e_i\right)^2}{\bar{e}^2 n(n-1)} \quad (4)$$

where:

c_i = catch of rainbow trout in river mile i;

e_i = effort expended in river mile i;

$\bar{e} = \frac{1}{n}\sum_{i=1}^{n} e_i$; and,

n = number of subsections (rms) sampled in the entire study area.

Average CPUE for each section (I-III) of the study area was estimated for each gear type using Equations 3 and 4 with n defined as the number of rms sampled in the section under consideration. Hoop trap data within each rm was pooled for Objectives 1 and 2 analyses. Although simple random samples were not taken, Equations 3 and 4 sufficed for meeting our goal of obtaining a reasonably unbiased expectation for the number and size composition of rainbow trout that can be caught throughout the study area given a defined amount of effort.

Relative to Objective 3, histograms of fish lengths grouped by gear type and river section were prepared and examined visually. Differences in length composition among groups were tested for using Anderson-Darling k-sample tests (Scholz and Stephens 1987) and two-sample Kolmogorov-Smirnov tests.

MARK-RECAPTURE 2005

Study Design and Fish Capture

In 2005, a two-event mark-recapture experiment was designed to estimate abundance and length compositions of rainbow trout within the 50-mile index area. The study area was divided into five sections prior to sampling to help distribute effort evenly throughout the study area and serve as initial strata for performing diagnostic tests (i.e., examine movement and capture probabilities). Based on the river's hydrology, access, and known rainbow trout distribution, the following sections were originally selected: A (rm 72–80 and the lower half-mile of the Middle Fork Gulkana River), B (rm 62–71), C (rm 53–61), D (rm 43–52) and E (rm 32–42; Figure 4). Sampling gear (i.e., baited hoop traps and hook-and-line) was consistent with what was used in the 2004 feasibility study. One exception was the use of weighted jig heads fitted with a rubber bodied grub tails tipped with shrimp or roe by some samplers, primarily during the second event.

The sampling strategy for this experiment 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 between events due to seasonal migrations and dispersal after salmon spawning to produce a uniform marked proportion on a local scale of 1–8 miles to mitigate potential bias due to pockets of fish isolated from sampling; and, 3) repeat step "1" for the second event.

The first event spanned 11–24 August and consisted of two segments. The first eight days were spent sampling the upper 39 miles of the study area (Sections A–D) using five two-person crews each with an inflatable raft. Four crews were each assigned to a section of river and sampled approximately two miles per day. A typical sampling day consisted of angling for six to seven hours along the entire reach of water sampled and setting/checking hoop traps for two to three hours. Approximately six to eight traps were set each evening, dispersed within a 0.5 to 1.0 mile radius from camp, and checked the following morning. The fifth crew (E) sampled the entire upper 39-mile river segment during the same time period using the same gear types, attempting to increase sample sizes and ensure that the combined effort of all crews was distributed in proportion to fish densities (i.e., it was anticipated that high density areas might be underfished

in order to cover daily assignments). Crew E typically angled the higher density areas in a five-mile reach daily and attempted to set hoop traps each night in areas the other crews did not (i.e.,camped in a different location). The 5th crew was used in this manner, as opposed to assigning them to one-fifth of the 39-mile section, because this approach was believed to: 1) be more effective in increasing the sample size by increasing effort in the higher density areas; 2) serve to fill gaps in scheduled sampling left by the other crews resulting from unforeseen events such as equipment failures and poor weather conditions; and, 3) offer logistical support for crews A–D (i.e., replacing lost or damaged gear).

The second segment of the first event took place from 21 to 24 August 2005 and sampling was conducted in the lower 11 miles of the study area (Section E). Four people using two jet-powered boats sampled this section with identical sampling equipment as the upper 39 miles. The jet boats permitted a complete and uniform coverage of Section E with both gear types with approximately eight traps set in each rm. As with the upper section, two people sampled approximately two rms with hook-and-line each day.

A major departure from a more typical two-event mark-recapture experiment was the inclusion of a relatively long (6-week) sampling hiatus as opposed to a shorter hiatus (i.e., 1–2 weeks), which is typically used to help ensure closure. The selection of a longer hiatus was made to alleviate potential large negative biases associated with pockets of fish being isolated from the experiment. The large study area and the limitations of sampling from a raft or shore combined with limited mixing during a short hiatus makes it difficult to ensure all fish will be subjected to some probability of capture. The six week hiatus helped to ensure at least partial mixing of marked and unmarked fish because the hiatus was planned to coincide with movement of rainbow trout from summer feeding areas to overwintering areas. The potential for violating the closure assumption due to the duration and timing of the hiatus is addressed below under the subheading "Assumption 1."

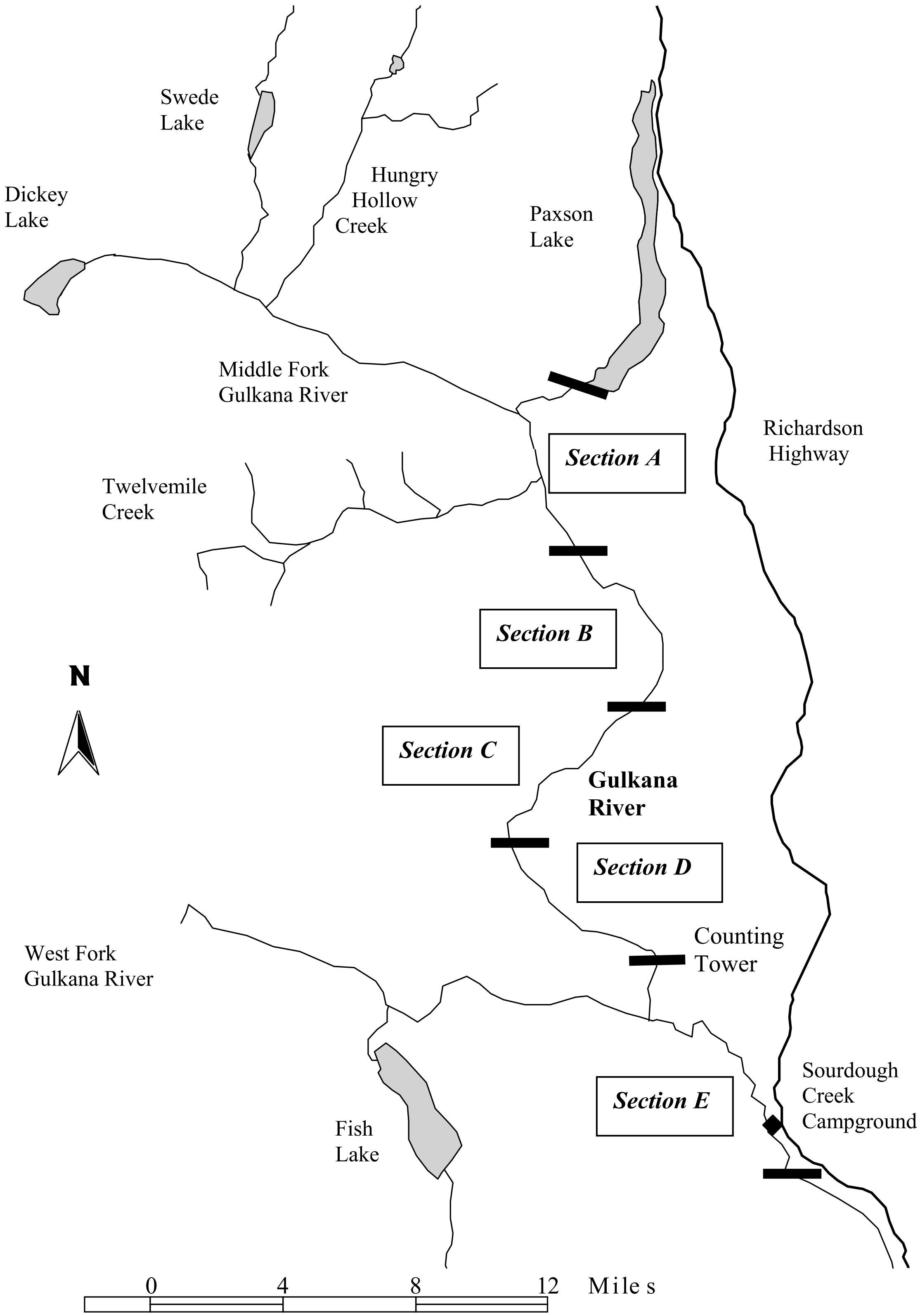


Figure 4.–Gulkana River study area with demarcations of section boundaries for the mark-recapture experiment, 2005.

The second event spanned from 22 September to 6 October and like the first event, the first eight days were spent sampling sections A–D by ten people paired among five inflatable rafts. However, unlike the first event, each of the five crews was assigned to an approximately 8-mile reach of river. This was done so each crew only had to sample approximately 1.5 rms a day. It was assumed sampling up to two miles per day would be problematic with less daylight and colder temperatures typical of late September. It also ensured no overlapping of hoop trap sets by Crew E.

The second segment of the second event took place from 3 to 6 October. The sampling area (Section E; Figure 4) and procedures were identical to that of the first event, except one person was added to each crew in anticipation of more fish being in Section E than during the first event.

During the second event, limited sampling occurred outside of the study area boundaries looking for evidence of emigration (i.e., capturing a tagged fish). A 0.5-mile reach above the Middle Fork Gulkana River boundary, the lower 0.25 mile of Twelvemile Creek, the lower half mile of the West Fork Gulkana River and a mile reach below the lower study area boundary in the mainstem (rm 31) were sampled.

Abundance was estimated using a two-event Petersen mark-recapture experiment (Seber 1982) designed to satisfy the following assumptions:

1. the population was closed (rainbow trout did 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 in the first event did not affect the probability of capture in the second event;
4. marked rainbow were identifiable during the second event; and,
5. all marked rainbow trout were reported when examined during the second event.

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

$$\hat{N} = \frac{n_1 n_2}{m_2}, \tag{5}$$

where:

n_1 = the number of rainbow trout marked and released during the first event;

n_2 = the number of rainbow trout examined for marks during the second event; and,

m_2 = the number of marked rainbow trout recaptured during the second event.

The specific form of the estimator was determined from the experimental design and the results of diagnostic tests performed to evaluate whether the assumptions were satisfied (see Data Analysis Section). The experiment was designed to allow the validity of these assumptions to be ensured or tested because failure to satisfy these assumptions could result in biased estimates.

Assumption 1: The selection of the study area boundaries served to minimize biases associated with closure violations due to large and small scale fish movements. The relatively large study area and its boundaries were chosen to mitigate the potential, and the effects, of any large scale movements of rainbow trout during the study period. Fleming (2004) had 13 radio-tagged rainbow trout within the study area in 2001. During the time period corresponding to the mark-recapture hiatus, movements documented by Fleming (2004) ranged from 1 to 8 mi and all were confined to within the study area. The Paxson Lake boundary is considered closed because no rainbow trout have ever been documented in the lake. It is unlikely many fish will cross the Middle Fork Gulkana or West Fork Gulkana boundaries because rainbow trout habitat above these boundaries is relatively poor (deep and slow moving). Rainbow trout habitat in the Middle Fork Gulkana River is limited to the lower half mile (included in the study area) and areas upstream of Hungry Hollow Creek (approximately 16 miles upstream of the boundary), which is used almost exclusively for juvenile fish (Stark 1999). Similarly for the West Fork, there is virtually no rainbow trout habitat in its lower 40 miles. The lower boundary was chosen for several reasons, the primary reason being to reduce the chance of fish moving long distances and crossing it. The lower boundary is approximately 10 miles below the confluence of the West Fork Gulkana River. The water hydrology remains similar from the West Fork Gulkana confluence to the lower boundary below Sourdough Campground, all of which is suitable for overwintering rainbow trout (i.e., deep runs, pools, minimal riffles), but not necessarily summertime feeding areas. Below the lower boundary, the river changes and becomes wider and shallower (not as good wintertime habitat) and it was believed that few fish would move downstream of the lower boundary. Therefore, it was anticipated that any positive bias resulting from the combined emigration and immigration at the study area boundaries would be inconsequential because the movements and numbers of fish at the boundaries would be small relative to the size of the study area and the overall abundance.

It was recognized that growth recruitment would likely occur during the six-week hiatus needed to promote mixing. Marking fish with individually-numbered tags permitted an evaluation of growth using lengths of recaptured fish. The growth data was used to determine whether adjustments to the abundance estimate or the population of inference were needed to eliminate related bias.

Natural mortality was assumed to be negligible because rainbow trout are most fit during this time of year. Angling induced mortality was assumed to be insignificant because the fishery is closed to the retention of rainbow trout and negligible hooking mortality was expected because angling effort diminishes greatly in August and September. Any mortality experienced would affect marked and unmarked fish equally.

Assumption 2: Efforts were made to subject all fish to an equal probability of capture during each event by distributing more effort in areas of perceived higher densities using CPUE information attained in 2004 and adjusting effort based on catch rates during sampling in 2005. This approach was taken with hook-and-line gear, but was not possible for the hoop traps, which had a demonstrated tendency to select for smaller-sized rainbow trout (Bartlett and Hansen 2000; Bradley 1990 and 1991). As planned the distribution of hoop traps in each event left unsampled reaches of approximately 0.5 to 1.5 miles in length in Sections A–D. In Section E the use of a powerboat allowed traps to be placed uniformly throughout the section. Therefore, in regards to Sections A–D, the study design relied on localized mixing during the six-week hiatus to ensure that Assumption 2 was met, particularly for small fish. Sufficient movement was anticipated due to fish moving to different habitats related to changes in forage (i.e., cessation of Chinook salmon spawning) and overwintering preferences.

It was unknown if rainbow trout ≥150 mm FL would have equal probability of capture by length given that hoop traps and hook-and-line gear select for different size fish and given the amount and distribution of fishing effort applied by each. Diagnostic tests to identify and correct for potential biases due to size selectivity and spatio-temporal variability in capture probabilities have been presented in the Data Analysis section. Diagnostic tests were also performed to elicit details as to how the gear combination and distribution lead to the observed capture probabilities.

Assumption 3: The hiatus of six weeks between the first and second events for a given river section permitted marked fish to recover from handling and marking induced behavioral effects during the first event. In addition, multiple gear types served to mitigate marking induced behavioral effects.

Assumptions 4 and 5: Rainbow trout captured during the first event were double marked with an individually-numbered Floy™ FD-67 internal anchor tag and the removal of the tip of the left pectoral fin. In the second event, the tip of the right pectoral fin was removed from all fish and served as an identifying mark to prevent resampling. All fish were carefully examined for all marks.

Data Collection

For each captured rainbow trout, the following information was recorded: date, FL (mm), location (GPS coordinates and approximate rm), tag number and color (if tagged or already had a tag), secondary fin clip, recaptured status (Y or N), capture gear, fate and any pertinent comments. All fish were sampled and released within 100 yards of the capture location. If a fish captured during the first event appeared unhealthy due to previous injury or recent injury from capturing, and it appeared it may not live until the second capture event, it was not tagged and not used in the abundance estimation.

GPS coordinates were recorded for all hoop trap sets, regardless of whether rainbow trout were captured or not.

Data Analysis

Abundance Estimate

Relative to determining the population of inference, the cumulative length frequency distribution curve and length frequency histograms were examined to see if a length class representing age-1 could be defined. If so, the lower length limit of the population estimate would be adjusted to exclude the vast majority of age-1 fish, while still including most age-2 fish. Adjusting the lower length limit in this manner would serve to more clearly define the population of inference.

Relative to Assumption 1, closure could not be tested directly but was inferred from examination of the movement of recaptured fish within the study area and sampling outside of the study area during the second event. The movement data was examined for evidence of a tendency to move away from or towards study area boundaries to provide evidence of immigration and emigration. The presence of overwintering fish near or beyond the study area boundaries and the capture of marked fish beyond the study area were also used to imply or indicate emigration. The analysis of movement aided in determining whether the population of inference should be adjusted to the first or second event.

Relative to Assumption 2, variations in capture probability related to size, location and time were examined. Violations of Assumption 2 relative to size-selective sampling were tested by using two Kolmogorov-Smirnov (K-S) tests. There were four possible outcomes of these two tests relative to evaluating size selectivity (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 B1. Because of the duration of the hiatus, growth was anticipated to be significant enough to influence K-S tests and decision(s) regarding the need to stratify. To help mitigate the effects of growth on the K-S test diagnostics, lengths of recaptured fish, as measured during the first event, (as opposed to the second event lengths) were used in testing for significant differences in capture probabilities by size. The potential for growth recruitment to have biased the abundance estimate was also examined using techniques of Robson and Flick (1965).

Temporal and spatial violations of Assumption 2 were tested using consistency tests described by Seber (1982; Appendix B2). The documentation of release locations for each fish permitted the examination of multiple geographic stratification schemes and capture probabilities. Criteria considered when defining geographic strata included number of recaptures per stratum, hydrology, and stratum length relative to anticipated movements. If at least one of the three consistency tests resulted in a failure-to-reject the null hypothesis, then it would be concluded that at least one of the conditions in Assumption 2 was satisfied. If all three of these tests reject the null hypothesis, then depending on the extent of movement, a partially or completely stratified estimator would be used. If movement of marked rainbow trout 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 rainbow trout between geographic strata was observed, a completely stratified abundance estimate would be computed using the methods of Bailey (1951, 1952) or Darroch (1961).

Because the combination of gears and their distribution affect the probabilities of capture by size or by location/time in a potentially complicated manner, diagnostic tests were performed to aid in understanding gear effects. These tests were not intended to result in stratification by gear but instead to aid in understanding the diagnostics test results and adjustments made relative to size and spatiotemporal factors. K-S tests were performed to compare the length distributions of fish caught using each gear to aid in interpreting size related variability in probability of capture. Contingency table analyses were performed to 1) assess whether the probability of recapture during the second event was independent of gear of marking event; 2) determine whether recapture gear was independent of marking gear (essentially examines mixing between gears); and, 3) assess whether the recapture rate was independent of recapture gear.

Length Composition

Length composition of the population was estimated using the procedures outlined in Appendices B1 and B3.

RESULTS

FEASIBILITY STUDY 2004

Angling CPUE

A total of 156 rainbow trout were captured with angling gear in 2004. For simplification purposes, fish captured during the time period that the entire section was sampled (99 rainbow trout) were used in the CPUE calculations by section. For example, any opportunistic sampling effort in Section I from 24 to 28 August was not used in the CPUE calculation for Section I. Forty-four fish were captured after one unit of effort was expended within a river mile, and another 13 were captured in sections outside of their respective sampling times. Relative to CPUE calculations, 45 total units of effort were used with a corresponding estimated CPUE of 2.20 fish/man hr (Table 1). Four river mile sections were not sampled due to time constraints (rm 70, 69, 54 and 44). Section I (early sampling period) had a mean CPUE of 2.94, the largest of the three sections, while the mean CPUE for Section II (late sampling period) of 1.53 was the smallest (Table 1).

Hoop Trap CPUE

A total of 79 rainbow trout were captured with hoop traps, 65 of which were used for CPUE calculations. As with angling, only the fish captured during the time period the entire section was sampled were used in the CPUE calculations. Total CPUE among all sections was 0.065 fish/h (1,033 hr soak time; Table 1). Mean CPUE in Section II (late sampling period) was 0.108 fish/h and was the highest among sections. Section I (early sampling period) had the second highest mean CPUE (0.067 fish/h). Only 9 fish were captured in hoop traps in Section III resulting in a mean CPUE of 0.023 (Table 1).

Table 1.–CPUE estimates for rainbow trout from three sections of the Gulkana River using hook and line gear and hoop traps, 2004 feasibility study.

Section	Date	Units of Effort (h)	Catch	CPUE	SE
Hook-and-Line					
I	12–18 Aug	17	50	2.94	0.51
II	24–28 Aug	17	26	1.53	0.26
III	16–18 Aug	11	23	2.09	0.28
Total		45	99	2.20	0.24
Hoop Traps					
I	12–18 Aug	345	23	0.067	0.021
II	24–28 Aug	305	33	0.108	0.019
III	16–18 Aug	383	9	0.023	0.010
Total		1,033	65	0.065	0.012

Length Comparisons

The mean length of rainbow trout captured with hook-and-line was 347 mm (SD = 78.6), while the mean length of trout captured with hoop traps was 299 mm (SD = 88.1; Table 2).

Table 2.–Catch and length information of rainbow trout using hook-and-line gear and hoop traps from three sections of the Gulkana River, 2004 feasibility study.

Section	Date	Catch	Mean Length	SD
		Hook-and-Line		
I	12–18 Aug	78	346	72.4
II	24–28 Aug	58	346	89.7
III	16–18 Aug	20	358	69.5
Total	Both periods	156	347	78.6
		Hoop Traps		
I	12–18 Aug	36	291	99.1
II	24–28 Aug	34	296	75.7
III	16–18 Aug	9	343	80.5
Total	Both periods	79	299	88.1

Examination of length frequency distributions revealed that the lengths of fish captured by hook-and-line were significantly larger than those captured by hoop traps (K-S test result: $P < 0.001$, D-statistic = 0.25; Figure 5). Size distributions of rainbow trout captured with hook-and-line were similar across the three sections: cumulative length frequencies were not statistically different (Anderson-Darling test: $P = 0.50$, D-statistic = 1.74; Figure 6). Hoop trap caught fish also had similar cumulative length frequency distributions among the three sections (Anderson-Darling test: $P = 0.13$, D-statistic = 3.12; Figure 6).

Hoop Trap Suitability and Rainbow Trout Habitat

Despite efforts to standardize the ranking of rms according to their suitability for setting hoop traps and as habitat for rainbow trout, the results were deemed too subjective to present in detail because ranking guidelines were not specific enough to prevent substantial variability in ranking among crewmembers. Also, complications occurred when habitat changed drastically within a mile. For example, when a long slow moving section turned into good habitat at the lower tenth of the rm, it was difficult to rank the entire rm accordingly. Notwithstanding these limitations, ranks were ultimately assigned to each rm and results were archived (Appendix A1).

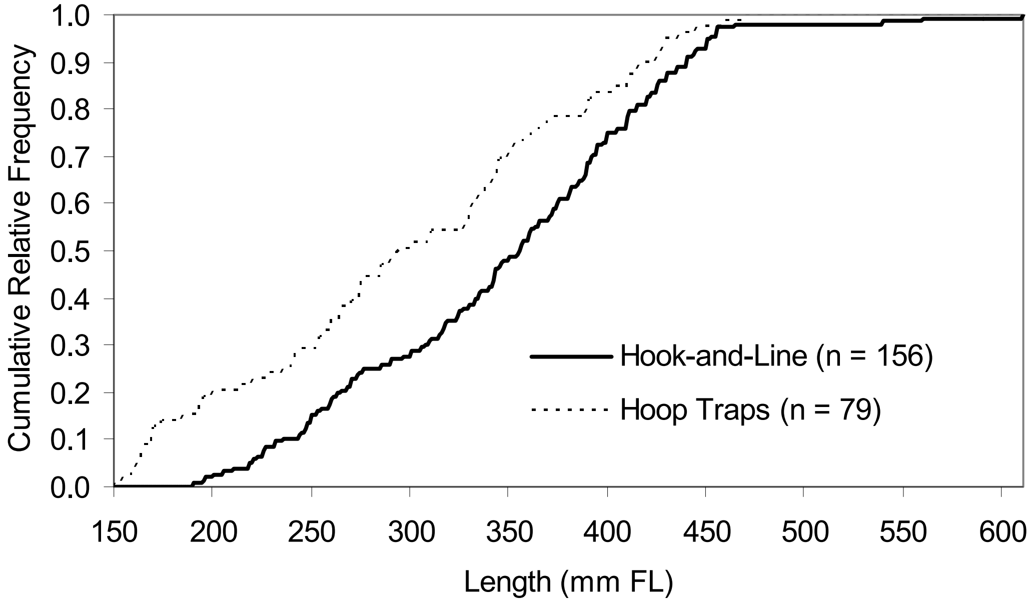
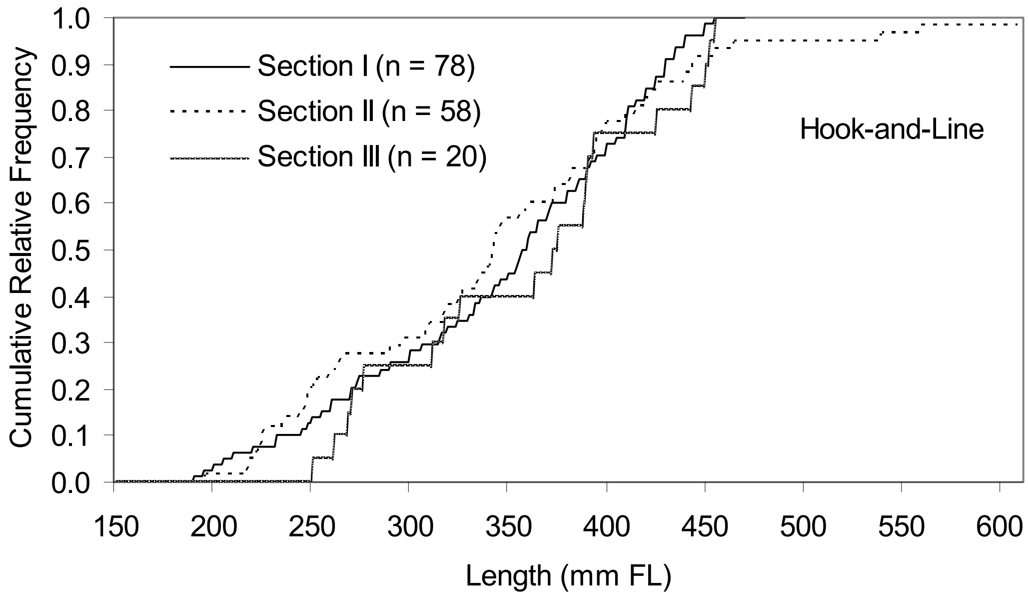


Figure 5.–Comparison of cumulative length frequency distributions of rainbow trout captured with hook-and-line gear and hoop traps, Gulkana River 2004 feasibility study.



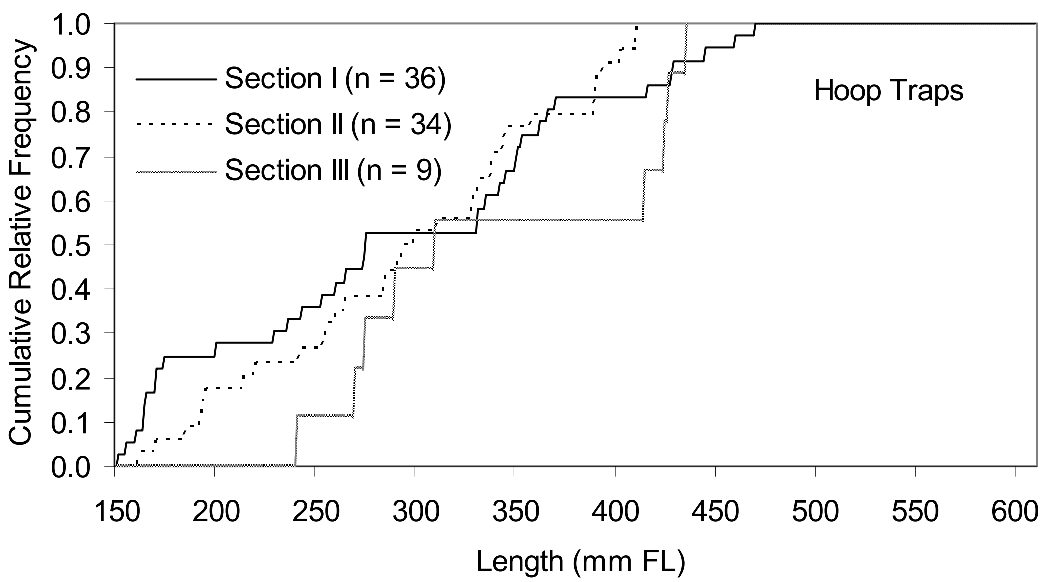


Figure 6.–Comparison of cumulative length frequency distributions of rainbow trout captured in three sections of the Gulkana River using hook-and-line (upper graph) and hoop traps (lower graph), 2004 feasibility study.

MARK-RECAPTURE 2005

Summary of Fish Captured

A total of 2,086 rainbow trout ≥160 mm were captured during this study and used in the mark-recapture analysis. In the first event 1,117 rainbow trout were captured and marked and 969 were captured and examined during the second event, 89 of which were marked during the first event. Rainbow trout as small as 89 mm FL were captured; however, fish <160 mm FL but were not included in the analyses. The largest rainbow trout captured was 600 mm FL. The smallest recaptured fish was 163 mm FL and the largest was 445 mm FL. Nine additional rainbow trout were captured during the first event that were either sampling mortalities or not tagged because they appeared too stressed (e.g., had a potential mortal wound such as a festering sore or were hooked in the gills).

Abundance Estimation and Diagnostic Testing

Population of Inference

First, based on examination of length frequency histograms, the lower length limit of rainbow trout was increased from 150 to 160 mm because it appears to eliminate most of the age-1 cohort from the abundance estimate (Figure 7). This lower length limit also closely corresponded to the smallest recaptured fish at 163 mm FL. Second, there were some relatively large gaps (e.g., 1-2 miles) between some groupings of hoop traps throughout the length of the study area when compared to the observed small scale movements (e.g., 0.25-1.0 mi) for the smaller sized rainbow trout between events. This led to the possibility that some rainbow trout ≤274 mm FL in Sections A-D were isolated (i.e., not sampled) from the experiment during both events, which would violate Assumption 2 (Figure 8). The visual pattern was more formally examined with a Bayesian change point analysis using the software WinBUGs (Spiegelhalter 1999). This analysis identified a change in the distances moved beginning at 275 mm FL.

Concern over the representativeness of the second event sample of rainbow trout ≤274 mm FL, combined with diagnostic tests providing only marginal support for equal probability of capture by size during the second event, led to further evaluating the sampling of small fish. The K-S test result for equal probability of capture during the second event for rainbow trout ≥160 mm FL was marginal (P-value = 0.08; D-statistic = 0.14). In addition, the greatest separation between the curves occurred just below the 275 mm FL break associated with movement. This, coupled with results of the diagnostic tests for equal probability of capture by size for the first event being somewhat compromised by growth led to even further investigation of the sampling of small fish.

To address this issue, movement data from recaptured rainbow trout 160-274 mm FL were compared with the distribution of hoop traps during the second event. Specifically, hoop trap locations from both events were tabulated and compared to average distance moved by the smaller class fish to determine if fish could have been isolated from the gear during both events. The study area was divided into 0.05 mile long cells (264 ft) and GPS and map locations were used to delineate 1st event hoops. With movement between events restricted to being within the 0.05 mi cells, the proportion of 2nd event hoops matching the location of first event hoops was0.26, while the proportion of the study area sampled by hoops in the first event was 0.20, an oversampling of previously sampled cells. Conversely, 74% of the second event hoop traps sampled waters likely without marks (gaps), the gaps being somewhat undersampled. Movement between events was then accounted for by increasing the number of cells associated with the mark location symmetrically up and downstream. As the degree of movement increased the sampling of gaps became increasingly representative. At the median movement distance of ±0.3 mi (±6 cells) the proportion of gaps present before the 2nd event decreased to 0.29, while the proportion of gaps sampled during the 2nd event was 0.25. For movement distances corresponding to ±0.5 mi (±10 cells) the proportions were essentially the same at ~0.15.

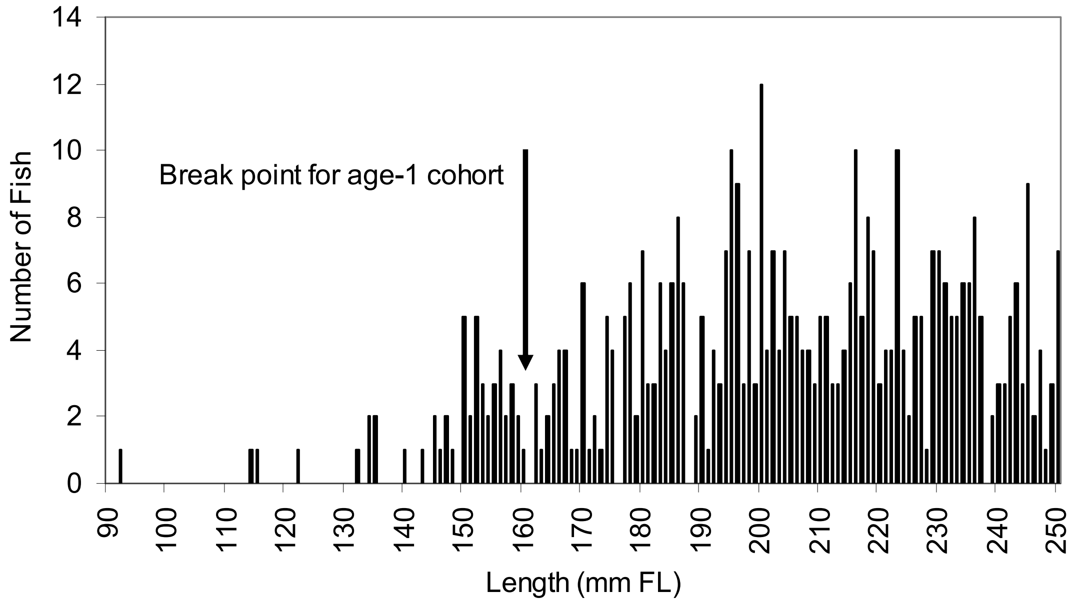


Figure 7.–Length frequency distributions of rainbow trout ≤250 mm FL from the recapture event, Gulkana River, 2005.

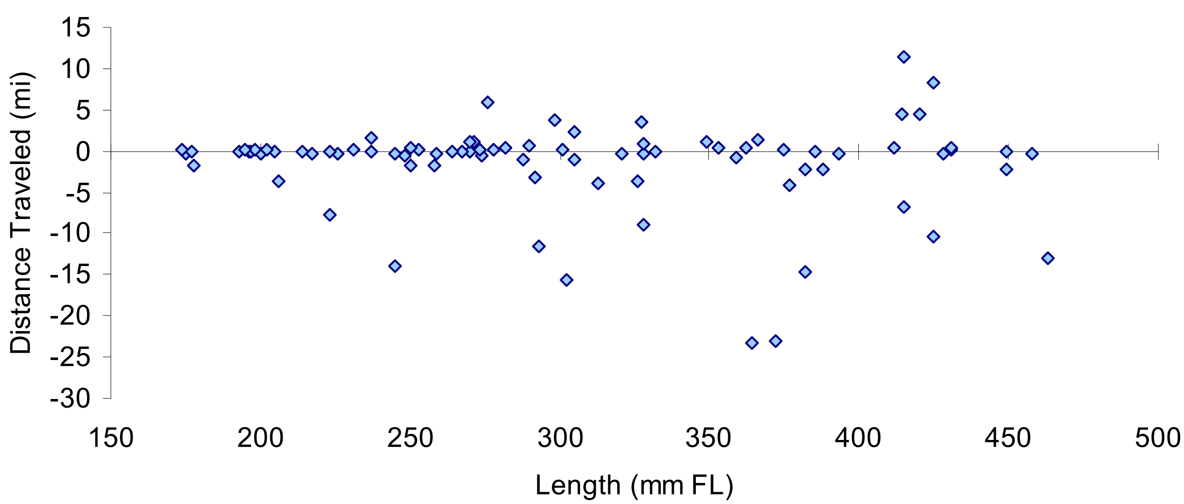


Figure 8.–Distance traveled between sampling events relative to length of recaptured rainbow trout, Gulkana River, 2005.

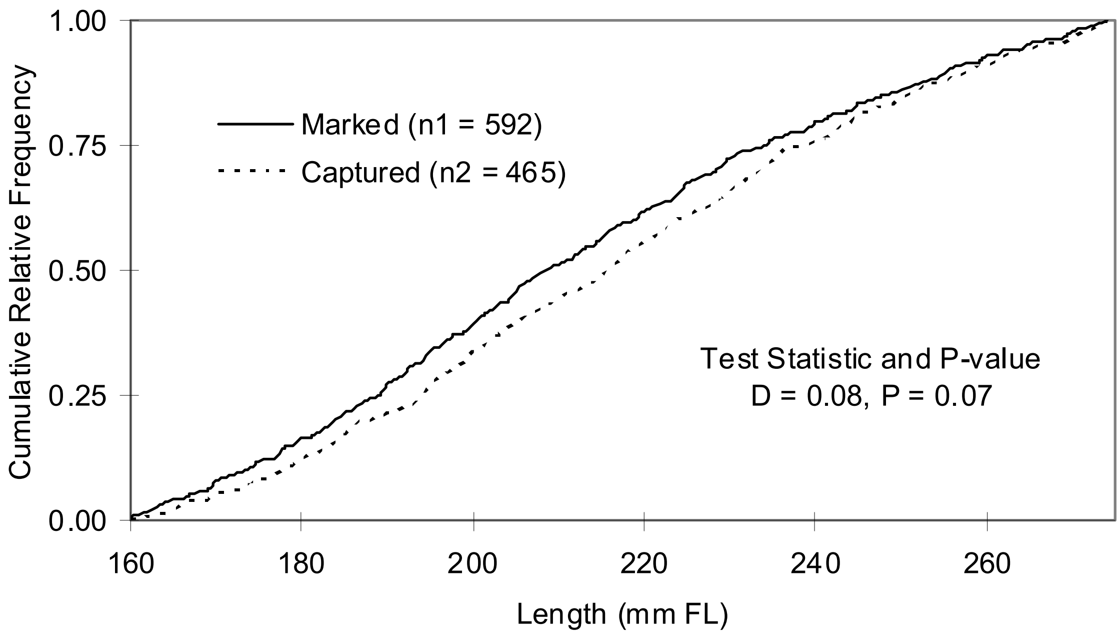
A more sophisticated analysis, which addressed the relative densities of small rainbow trout within the river and the actual gap distances faced by individual fish released at specific locations, suggested that the distribution of hoops in the second event was such that 28% of the fishing power was expected to have occurred within gaps during the second event (virtually the same as the 29% gaps existing after median movement). In this analysis the number of marked fish expected to bridge the gap between their mark location and the closest 2nd event hoop was determined by using the movements of recaptured fish to calculate the probability of moving the specified gap distance.

These results suggest that the abundance estimate for small fish in Sections A-D will have a relatively small (i.e., as compared to the estimated standard error) negative bias. Gaps between adjacent hoop traps in the lowest section (Section E) were small relative to small fish movements and the possibility of bias was considered insignificant; however, very few small fish were caught in Section E ($n_{1,E}$=4 $n_{2,E}$=1) and this section contributed little to the overall abundance. The potential for negative bias in Sections A-D was somewhat mitigated by hook-and-line effort for fish >200 mm (Figure 5) but to what extent is poorly constrained. To isolate the small potential for bias in the abundance estimate of small rainbow trout from the larger rainbow trout and to cleanly separate fish that exhibited limited movement from those that exhibited more substantial movements when addressing the assumption of closure, two size strata were identified for estimating abundance: 160-274 mm FL (small fish), and fish ≥275 mm FL (large fish). Each length strata was treated independently relative to diagnostic tests (Appendix B1 and B2) and assumptions of closure relative to growth and movement (emigration and immigration).

Diagnostic Tests Relative to Size and Spatio-Temporal Stratification

Within each length stratum, size stratification was not required when estimating abundance. For rainbow trout 160-274 mm FL, K-S tests indicated that the samples were Case I (Appendix B1; Figure 9): length compositions did not significantly differ at the 95% confidence level when M vs. C was tested (P-value = 0.07; D-statistic = 0.08) and when M vs. $R_{(\text{first event lengths})}$ was tested (P-value = 0.09; D-statistic = 0.20). Although these P-values were marginal (i.e., between 0.05 and 0.10), at least for the M vs. C test, accounting for growth would move the C curve closer to the M curve thus increase the P-value. Furthermore, the C vs. $R_{(\text{first event lengths})}$ test, which tests the hypothesis of equal probability of capture by size during the first event, indicated similar probabilities of capture by size (P-value = 0.40; D-statistic = 0.15). This test is not immune to growth effects; however, the combination of these results, the linearity of the empirical cumulative distribution function, and the failure of the M vs. C test to reject the null hypothesis despite growth support equal probability of capture by size in both events. For fish ≥275 mm FL, K-S tests indicated that the samples were also Case I (Appendix B1; Figure 10): length compositions did not significantly differ when M vs. C was tested (P-value = 0.88; D-statistic = 0.04) or when M vs. $R_{(\text{first event lengths})}$ was tested (P-value = 0.31; D-statistic = 0.15). Also, the C vs. $R_{(\text{first event lengths})}$ test indicated equal probabilities of capture by size in the first event (P-value = 0.20; D-statistic = 0.16).

Tests of consistency were performed for each length stratum; however, a small adjustment was made to the geographic strata defined in the Methods Section prior to running the consistency tests (Appendix B3). After sampling the river two consecutive years, it became evident that the canyon area (rm 62.5) should be in the same geographic stratum as the nine-mile stretch below the canyon. Both the canyon and the waters below the canyon were more similar relative to hydrology and rainbow trout densities than the areas above the canyon. Moving the canyon area from Section B to Section C resulted in the following geographic strata for consistency tests: A (rm 72–80 and the lower half-mile of the Middle Fork Gulkana River), B (rm 63–71), C (rm 53–62), D (rm 43–52) and E (rm 32–42).



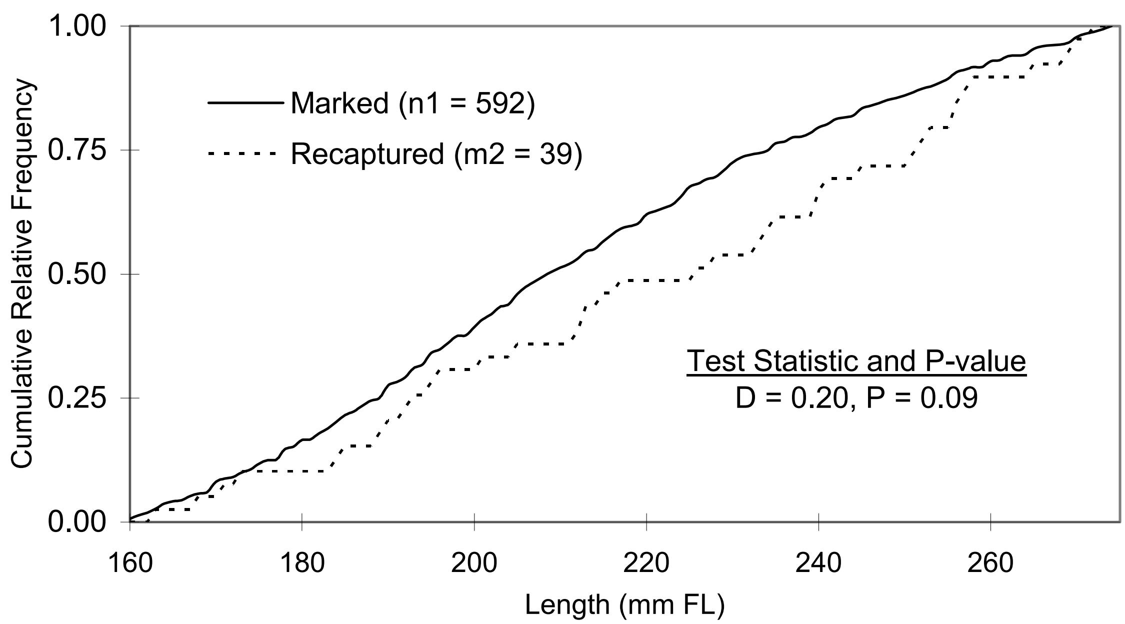
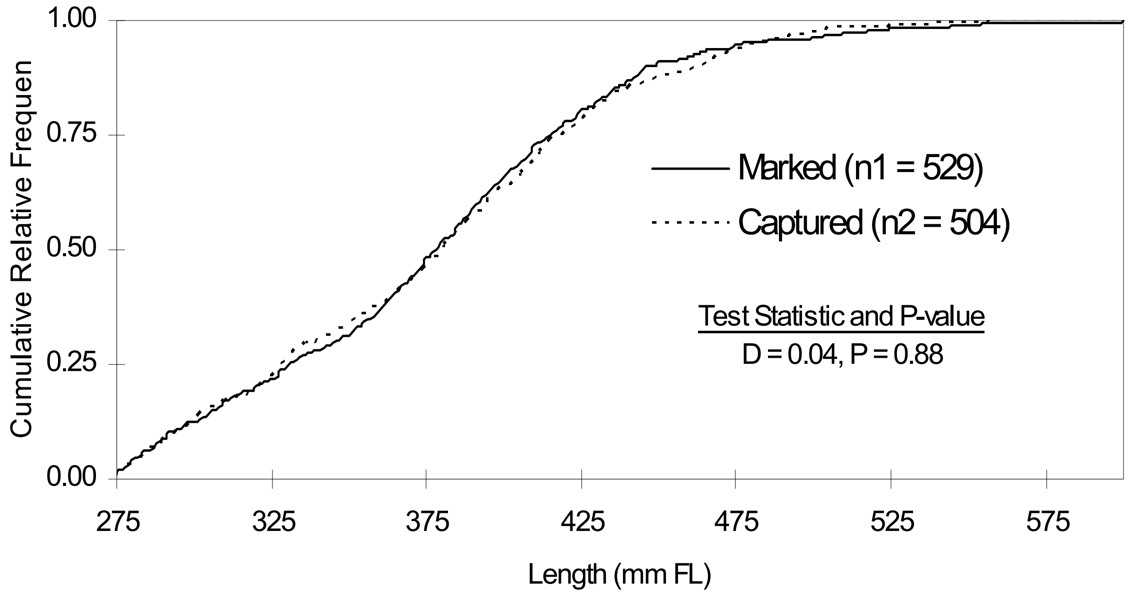


Figure 9.–Cumulative relative frequency of rainbow trout 160-274 mm FL marked and examined (top) and marked and recaptured (bottom), Gulkana River, 2005.



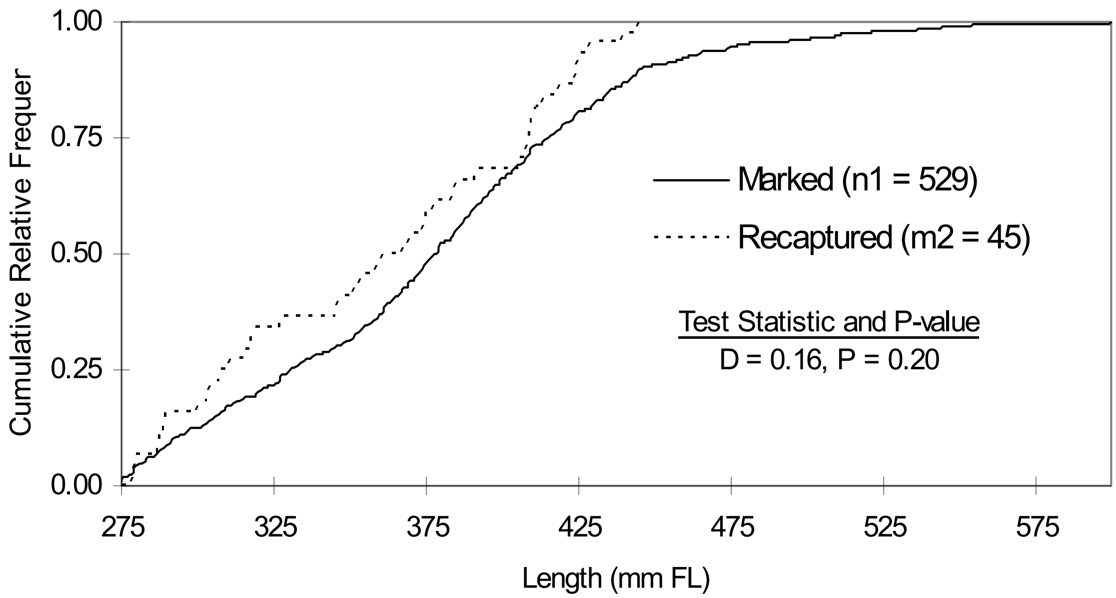


Figure 10.–Cumulative relative frequency of rainbow trout ≥275 mm FL marked and examined (top) and marked and recaptured (bottom), Gulkana River, 2005.

For fish 160-274 mm FL, geographic stratification was not necessary: although mixing among geographic strata was incomplete (P-value < 0.001; Table 3), capture probabilities during the first event were not significantly different (P-value = 0.48; Table 4) nor were capture probabilities during the second event (P-value = 0.48; Table 5). For fish ≥275 mm FL, geographic stratification was not necessary: although mixing among geographic strata was incomplete (P-value < 0.001; Table 6) and capture probabilities during the first event were significantly different (P-value = 0.009; Table 7), capture probabilities during the second event were not significantly different (P-value = 0.95; Table 8). Several other explorative testing schemes were evaluated, but the results are not presented. Geographic strata ranged from dividing the area into several different six section schemes (9–11 rm in length), all the way to dividing the area into 17 approximately 3 rm sections. The conclusion that geographic stratification was not necessary was also reached when tests were run using the original boundaries as well as the other possible stratification schemes.

Evaluating Closure Relative to Movement

Before estimating the abundances for each stratum, the closure assumption needed to be evaluated in light of the observed movements and potential for growth recruitment. For fish 160-274 mm FL, movement data of recaptured fish revealed that these fish generally did not make extensive movements (Figure 8) suggesting the population was closed to immigration and emigration resulting in an abundance estimate germane to both events. Movement of recaptured fish ≥275 mm FL was more extensive (Figure 8) and it was likely that emigration across the lower boundary occurred. Nine recaptured fish, all ≥275 mm FL, traveled >10 mi, eight traveled downstream (two fish traveled at least 23 mi) and one moved upstream. Two fish were recaptured within 5 mi of the lower boundary of the study area indicating that a small portion of the fish may have left the study between events via the lower boundary (Figure 11). No fish were recaptured within 1.5 mi of the upper boundary (Paxson Lake); this boundary is considered closed because rainbow trout have not been observed in or above Paxson Lake. In addition, there was no evidence of substantial movements of fish towards the Middle Fork Gulkana River. Because the movement data (from recaptured fish and previous studies) did not suggest concurrent immigration, the potential for a violation of closure at the lower boundary due to emigration (Figure 11) renders the abundance estimate germane to the first event. The potential for positive bias due to combined immigration and emigration at the boundaries due to local movements was deemed negligible because the study area was relatively large, the upper boundary appeared closed, the densities in Section E (the lowest section) were relatively low, and movement above the Middle Fork boundary were thought unlikely due to habitat constraints. Sampling outside the study area during the second event resulted in no previously tagged rainbow trout being captured. Sampling the one-mile stretch below the lower boundary (rm 31) resulted in a catch of four unmarked rainbow trout. No rainbow trout were captured while sampling the lower ½ mi of the West Fork Gulkana River. Ten unmarked rainbow trout were captured with baited hoop traps and hook-and-line gear within approximately 0.15 mi above the Middle Fork boundary. Only one fish was captured between 0.15 and 0.5 miles above the boundary. This, and the visual observance of lack of suitable habitat upstream, suggests the ten fish captured within 0.15 mi of the boundary may have been attracted to the bait from suitable habitat that exists at the boundary.

Table 3.–Test for complete mixing. Number of rainbow trout 160-274 mm FL marked in each river section (A–E) and recaptured or not recaptured in each section of the Gulkana River, 2005.

Section Where Marked	Section Where Recaptured					Not Recaptured	Total Marked
	A	B	C	D	E	(n_1-m_2)	(n_1)
A	11	1	0	0	0	135	147
B	0	3	1	0	0	77	81
C	0	1	17	1	1	275	295
D	0	0	0	1	0	48	49
E	0	0	0	0	2	14	16
Total	11	5	18	2	3	549	588

χ^2 = 108.56, df = 20, P-value < 0.0001, reject H_0.

Table 4.–Test for equal probability of capture during the first event for rainbow trout 160–274 mm FL. Number of marked and unmarked rainbow trout examined during the second event by section (A–E) of the Gulkana River, 2005.

Category	Section Where Examined					
	A	B	C	D	E	All Sections
Marked (m_2)	11	5	18	2	3	39
Unmarked (n_2-m_2)	144	36	214	19	13	426
Examined (n_2)	155	41	232	21	16	465
$P_{capture}$ 1st event (m_2/n_2)	0.07	0.12	0.08	0.10	0.19	0.084

χ^2 = 3.50, df = 4, P-value = 0.48, fail to reject H_0.

Table 5.–Test for equal probability of capture during the second event for rainbow trout 160-274 mm FL. Number of rainbow trout marked by section (A–E) during the first event that were recaptured and not recaptured during the second event, Gulkana River, 2005.

Category	Section Where Marked					
	A	B	C	D	E	All Sections
Recaptured (m_2)	12	4	20	1	2	39
Not Recaptured (n_1-m_2)	135	77	275	48	14	549
Marked (n_1)	147	81	295	49	16	588
$P_{capture}$ 2nd event (m_2/n_1)	0.08	0.05	0.07	0.02	0.13	0.066

χ^2 = 3.49, df = 4, P-value = 0.48, fail to reject H_0.

Table 6.–Test for complete mixing. Number of rainbow trout ≥275 mm FL marked in each river section (A-E) and recaptured or not recaptured in each section of the Gulkana River, 2005.

Section Where Marked	Section Where Recaptured					Not Recaptured	Total Marked
	A	B	C	D	E	(n_1-m_2)	(n_1)
A	5	3	0	0	0	82	90
B	1	7	2	1	1	106	118
C	1	4	6	2	2	179	194
D	0	0	0	5	3	92	100
E	0	0	0	0	2	25	27
Total	7	14	8	8	8	484	529

χ^2 = 50.30, df = 20, P-value = 0.0002, reject H_0.

Table 7.–Test for equal probability of capture during the first event for rainbow trout ≥275 mm FL. Number of marked and unmarked rainbow trout examined during the second event by section (A-E) of the Gulkana River, 2005.

Category	Section Where Examined					
	A	B	C	D	E	All Sections
Marked (m_2)	7	14	11	9	9	50
Unmarked (n_2-m_2)	133	54	99	64	104	454
Examined (n_2)	140	68	110	73	113	504
$P_{capture}$ 1st event (m_2/n_2)	0.05	0.21	0.10	0.12	0.08	0.10

χ^2 = 13.41, df = 4, P-value = 0.009, reject H_0.

Table 8.–Test for equal probability of capture during the second event for rainbow trout ≥275 mm FL. Number of rainbow trout marked by section (A–E) during the first event that were recaptured and not recaptured during the second event, Gulkana River, 2005.

Category	Section Where Marked					
	A	B	C	D	E	All Sections
Recaptured (m_2)	8	12	15	8	2	45[a]
Not Recaptured (n_1-m_2)	82	106	179	92	25	484
Marked (n_1)	90	118	194	100	27	529
$P_{capture}$ 2nd event (m_2/n_1)	0.09	0.10	0.08	0.08	0.07	0.085

χ^2 = 0.66, df = 4, P-value = 0.95, fail to reject H_0.

[a] Fifty rainbow trout ≥275mm FL were recaptured, but 5 had experienced tag loss and could not be assigned a river section where marked.

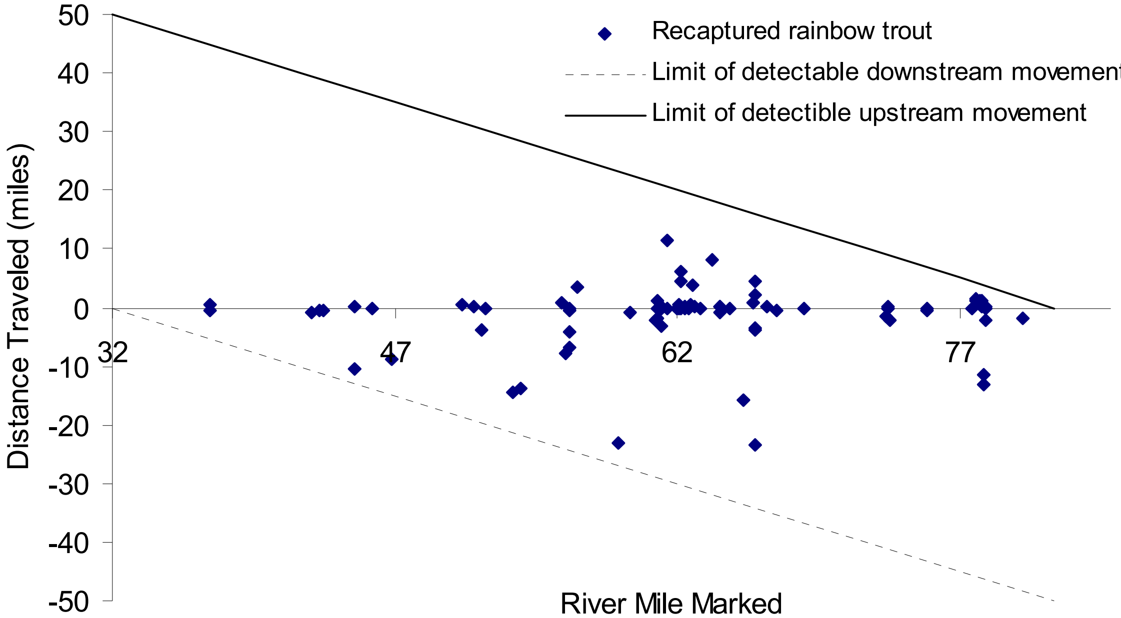


Figure 11.–Distance rainbow trout traveled from the time of tagging to the time of recapture, Gulkana River, 2005. Negative distances correspond to downstream movements and river mile 32 is the downstream boundary of the study area.

Evaluating Closure Relative to Growth

Based on lengths attained from the 84 recaptured fish, the sampled population grew on average 9.5 mm and growth occurred across all size classes of fish (Figure 12). Adjustments to the abundance estimates to account for biases due to growth recruitment were judged to be not necessary based on K-S test results and sensitivity analyses. The K-S tests (i.e., Appendix B1; Figures 9 and 10) demonstrated that length stratification was not required for either strata despite the observed growth. Because the marked:unmarked ratio for rainbow trout growing into the larger size stratum was similar to fish already in that stratum, the bias induced in the abundance estimate for large fish was close to zero and negligible. For the smaller size stratum methods of Robson and Flick (1965) were used to adjust abundance estimates for growth recruitment for a variety of lower bounds for the "penetration" of unmarked fish. All adjustments were negligible (i.e., <100 fish) and varied between positive and negative; therefore, the reported abundance estimate was not adjusted for growth recruitment.

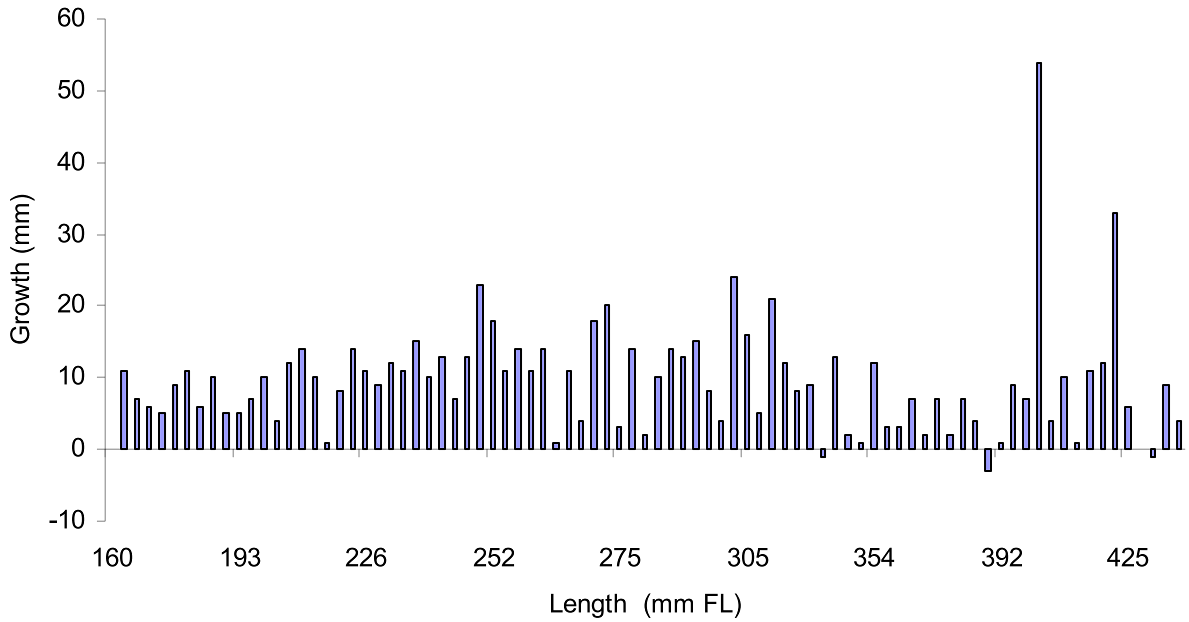


Figure 12.–Growth of rainbow trout captured between sampling events, Gulkana River, 2005. X-axis denotes length at time of marking (August).

The Effect of Gear on Diagnostic Test Results

There was no evidence that the distribution of gear strongly influenced the diagnostic test results described above. Despite differences in their length frequency distributions (P-value < 0.0001; D-statistic = 0.40; Figure 13), diagnostic test results indicate that using two different gear types did not induce significant spatiotemporal heterogeneities in probability of capture for either length strata.

Contingency table analysis indicated that mixing of rainbow trout 160-274 mm FL between gear types was complete (P-value = 0.10), that probabilities of capture in the second event were independent of gear used during the first event (P-value = 0.55), and that recapture rates did not differ by the gear used during the second event (P-value = 0.36; Tables 9–11). Likewise for larger fish, contingency table analysis indicated that mixing of rainbow trout between gear types was complete (P-value = 0.87), that probabilities of capture in the second event were independent of gear used during the first event (P-value = 0.92), and that recapture rates did not differ by the gear used during the second event (P-value = 0.64; Tables 12–14).

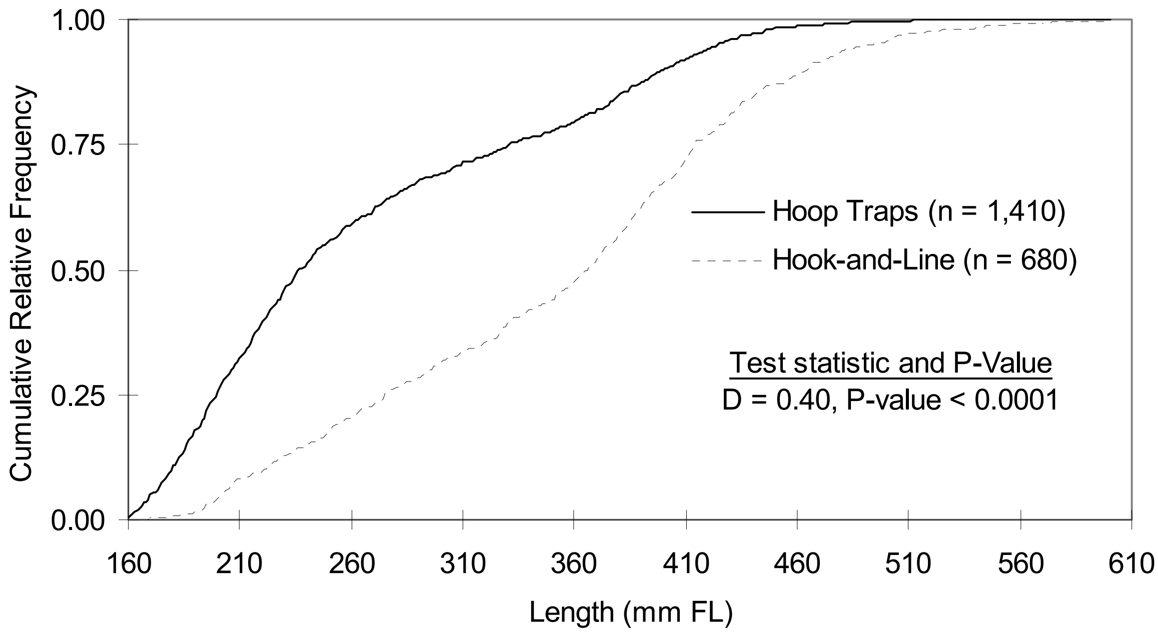


Figure 13.–Cumulative length frequency distributions of rainbow trout captured with hoop traps and hook-and-line gear in the Gulkana River, 2005.

Abundance Estimate

In conclusion, the study design and the diagnostic test results (Appendices B1 and B2) indicated that the abundance for each strata should be estimated using the Bailey modified Petersen estimator (Bailey 1951, 1952; Appendix B4). For rainbow trout ≥275 mm FL the estimated abundance was 5,238 fish (SE = 689; 95% CI = 3,888-6,588). For rainbow trout 160-274 mm FL, the estimated abundance was 6,850 fish (SE = 1,023; 95% CI = 4,845-8,855), with the potential for a relatively small negative bias (i.e., small compared to the estimated standard error). The combined estimate for rainbow trout ≥160 mm FL was 12,088 fish (SE = 1,233; 95% CI = 9,671-14,505). Interestingly, the abundance of rainbow trout ≥160 mm FL calculated without stratifying, and accepting the marginal diagnostic test result for equal probability by size, was 12,039 fish (SE = 1,202; 95% CI = 9.683-14,395), virtually the same. That said, the stratified approach is preferred because it provides an unbiased result for large rainbow trout and identifies the potential for a small negative bias associated with the abundance of small fish stemming from their limited movement and the distribution of hoop traps.

Table 9.–Contingency table used to determine whether recapture gear was independent of marking gear for rainbow trout 160–274 mm FL in the Gulkana River, 2005.

Marking Gear	Recapture Gear		
	H&L	Hoop	Total
H&L	2	3	5
Hoop	4	30	34
Total	6	33	39

$\chi^2 = 2.67$, df = 1, P-value = 0.10, fail to reject H_0

Table 10.–Test for equal probability of capture during the second event (by examining recapture rates). Number of rainbow trout 160–274 mm FL marked by gear type during the first event that were recaptured and not recaptured during the second event, Gulkana River, 2005.

Category	Gear Type		
	H&L	Hoop Trap	Total
Recaptured (m_2)	6	33	39
Not recaptured (n_1-m_2)	106	443	549
Marked (n_1)	112	476	588
$P_{capture}$ (m_2-n_1)	0.05	0.07	0.07

$\chi^2 = 0.36$, df = 1, P-value = 0.55, fail to reject H_0

Table 11.–Test for equal probability of capture during the first event (by examining recapture rates). Number of rainbow trout 160–274 mm FL examined by gear type during the second event that were marked and unmarked from the first event, Gulkana River, 2005.

Category	Gear Type		
	H&L	Hoop Trap	Total
Marked (m_2)	6	33	39
Unmarked (n_2-m_2)	45	381	426
Examined (n_2)	51	414	465
$P_{capture}$ (m_2-n_2)	0.17	0.08	0.08

$\chi^2 = 0.85$, df = 1, P-value = 0.36, fail to reject H_0

Table 12.–Contingency table used to determine whether recapture gear was independent of marking gear for rainbow trout ≥275 mm FL in the Gulkana River, 2005.

Marking Gear	Recapture Gear		
	H&L	Hoop	Total
H&L	11	10	21
Hoop	12	12	24
Total	23	22	45

$\chi^2 = 0.03$, df = 1, P-value = 0.87, fail to reject H_0

Table 13.–Test for equal probability of capture during the second event (by examining recapture rates). Number of rainbow trout ≥275 mm FL marked by gear type during the first event that were recaptured and not recaptured during the second event, Gulkana River, 2005.

Category	Gear Type		
	H&L	Hoop Trap	Total
Recaptured (m_2)	23	22	45
Not recaptured (n_1-m_2)	238	221	459
Marked (n_1)	261	243	504
$P_{capture}$ (m_2-n_1)	0.09	0.09	0.09

$\chi^2 = 0.01$, df = 1, P-value = 0.92, fail to reject H_0

Table 14.–Test for equal probability of capture during the first event (by examining recapture rates). Number of rainbow trout ≥275 FL examined by gear type during the second event that were marked and unmarked from the first event, Gulkana River, 2005.

Category	Gear Type		
	H&L	Hoop Trap	Total
Recaptured (m_2)	23	22	45
Not recaptured (n_1-m_2)	230	254	484
Marked (n_1)	253	276	529
$P_{capture}$ (m_2-n_1)	0.09	0.08	0.09

$\chi^2 = 0.21$, df = 1, P-value = 0.64, fail to reject H_0

Length Composition

Although K-S test results support pooling of lengths from both events (Case I; Appendix B1; Figures 9 and 10) to estimate length composition within each stratum, lengths from only the first event were used because growth, though not substantial, occurred between events and because the abundance estimate for the large size stratum was restricted to the first event. Samples sizes from the first event within each strata were well in excess of those estimated as necessary to satisfy objective criteria. For fish 160-274 mm FL, the largest proportion of the estimated population was between 200 and 224 mm FL (Table 15). For fish ≥275 mm FL, over 90% were < 450 mm FL.

DISCUSSION

FEASIBILITY STUDY 2004

The information collected during the 2004 feasibility study was beneficial for the design and implementation of the 2005 mark-recapture experiment as it related to sample sizes, indices of fish distribution and field logistics. Prior to this study, it was suspected that fishing hook-and-line gear with bait would be effective, but it was unknown how effective baited hoop traps would be in the Gulkana River relative to capture rates for all sizes of fish. The results demonstrated that hoop traps were moderately effective, and the combination of the two gear types would capture a broader size range of fish, similar to that observed at Willow Creek (Bartlett and Hansen 2000), at the Talachulitna River in 1990 (Bradley 1991) and at Lake Creek in 1989 (Bradley 1990). Using first hand familiarity with the river and known catch rates from the feasibility study, it was determined that desired sample sizes (i.e., 600 fish ≥150 mm FL per event) could be realistically attained by five two-person crews over an eight-day period in Sections I and II, and two two-person crews in Section III over a three-day period.

The angling CPUE indices attained in this study were suspect due to the amount of fishing effort applied to each one-mile reach, and therefore were interpreted as providing only very gross measures of fish densities. For example, it is our belief that the high value for the mean CPUE for Section III was an artifact of the relatively short angling duration spent in each rm. Most rm segments in Section III only supported one or two riffles that were easily targeted and angled during the allocated amount of time, and if the entire rm would have been angled, mean CPUE would have been much lower. Mean CPUE would have probably remained the same in Sections I and II if more time was allocated to angling because suitable habitat was much more consistent and consequently trout distributions appeared more uniform. Conversely, CPUE indices attained from hoop traps were believed to be a more reliable measure of fish densities because it was a passive gear and section estimates corresponded well to anecdotal information on distributions based on our observations, angler reports, previous studies and available habitat.

Study results and our observations indicated that gear effectiveness may have changed during the course of sampling, probably due to the presence/absence of spawning Chinook salmon and the choice of terminal gear (i.e., egg pattern). During the early sampling period when Sections I and III were sampled, rainbow trout were relatively easy to locate and catch because they were consistently found feeding on eggs behind spawning Chinook salmon that were easy to identify. During the second trip when Section II was sampled, Chinook salmon were initially sought but spawning activity had ceased reducing the ability to locate and catch rainbow trout, which required an adjustment to our methods and angling was conducted more "blindly". Evidence for a change in angling effectiveness is supported by a substantially larger CPUE observed in Section I versus Section II (Table 1) where higher densities of fish were expected based on previous studies and angler reports. It is unclear if the cessation of spawning affected the hoop traps. For example, the change in the availability of salmon eggs may have caused rainbow trout to more aggressively enter the hoop traps baited with salmon roe. To mitigate against temporal changes in capture probabilities, which could be problematic in mark-recapture experiments, it is recommended that future study designs ensure that Chinook salmon spawning neither begins nor ends during any sampling event.

Table 15.–Estimates of length composition and abundance by length group for rainbow trout 160–274 mm FL and for rainbow trout ≥275 mm FL, Gulkana River, 2005.

Length Strata (mm FL)	Length Class (mm FL)	Sample Size (n)	Proportion $\hat{p}_k$	$\hat{SE}[\hat{p}_k]$	$\hat{N}$	SE ($\hat{N}$)	CV
160-274							
	160 - 174	62	0.11	0.013	722	138	19%
	175 - 199	159	0.27	0.018	1,852	303	16%
	200 - 224	164	0.28	0.019	1,911	312	16%
	225 - 249	117	0.20	0.016	1,363	232	17%
	251 - 274	86	0.15	0.015	1,002	179	18%
Total		588			6,850	1,164	
≥275							
	275 - 299	65	0.12	0.014	649	113	17%
	300 - 324	49	0.09	0.013	489	92	19%
	325 - 349	51	0.10	0.013	509	95	19%
	350 - 374	80	0.15	0.016	798	133	17%
	375 - 399	96	0.18	0.017	958	153	16%
	400 - 424	77	0.15	0.015	768	129	17%
	425 - 449	56	0.11	0.013	559	102	18%
	450 - 474	20	0.04	0.008	200	51	25%
	475 - 499	10	0.02	0.006	100	34	34%
	500 - 524	11	0.02	0.006	110	36	32%
	525 - 549	5	0.01	0.004	50	23	46%
	550 - 574	2	0.00	0.003	20	14	71%
	575 - 599	1	0.00	0.002	10	10	100%
	600 - 624	2	0.00	0.003	20	14	71%
Total		525			5,238	999	

The qualitative knowledge gained from floating and sampling the river in 2004 greatly aided the planning of logistics for a successful mark-recapture experiment. Specifically, relative fish distribution was accurately assessed and effort was allocated accordingly, all potential camp locations were marked and recorded on GPS units, landmarks were denoted on maps to facilitate travel and sampling, and reliable estimates could be made for: the time needed to float and angle various river segments, the number of traps that could be retrieved and set each day, and the amount of bait needed.

MARK-RECAPTURE 2005

This was the first ever abundance estimate of rainbow trout in the Gulkana River. The precision criteria set for this study were exceeded with estimates of relative precision at the 95% confidence level of 0.26 and 0.29 for large and small fish, respectively. The success was attributed to favorable water conditions throughout the study period and higher than anticipated catch rates with hoop traps during both sampling events. It is not clear why hoop traps were more effective in 2005 than in 2004, but we believe it was a function of spawning Chinook salmon densities. Fewer than anticipated Chinook salmon were observed spawning during the marking event (11–24 August), and as discussed earlier, the presence of relatively few spawning salmon may have contributed to the increased effectiveness of the hoop traps. We had no prior insight as to how well the traps were going to work in late September/early October, but they worked as well as they did during the first event.

The study design for this project worked well, but there are several related items to consider in future studies. Focusing on fish ≥275 mm FL would help to simplify the project and possibly reduce cost by reducing the amount time allocated to setting hoop traps needed to satisfy Assumption 2. Hoop traps could still be used, but the movement/mixing of fish ≥275 was sufficient for relaxing the density and spacing of traps needed and the time saving could be applied to angling. If it were deemed necessary, estimating the abundance of small fish (age 2- and older) could be repeated and improved upon. Hook-and-line effort could be allocated the same way as in 2005 (i.e., 1.5 miles per day for a two-person crew above the West Fork Gulkana confluence), but hoop traps could be spatially balanced more effectively (fewer and smaller gaps).

Another item to consider is the benefits of reducing the hiatus between events. The six-week hiatus worked well and did not result in significant biases in 2005, however, a shorter hiatus (i.e., 2-3 week) would still provide for good localized mixing that is critical for the study design. A shorter hiatus could help mitigate potential closure violations associated with long distance emigration at the lower boundary and mitigate potential positive bias implications due to localized immigration/emigration (i.e., small-scale movements) at the study boundaries. Minimizing the potential for large-scale movements would also allow the option to reduce the study area to the mainstem above the West Fork Gulkana confluence, or even smaller. Densities were low below the West Fork Gulkana confluence prior to overwintering migrations, and could be excluded if the study concluded prior to these migrations taking place. It was believed that during the second event, overwintering migration had occurred, but was probably not complete. A shorter hiatus between sampling events would also alleviate growth implications.

In regard to allocation of sampling effort, the "clean-up crew" approach worked for the marking event in 2005; however, its design meant that the other four crews had to sample the upper 40 mile reach of the river independent of the fifth crew. Consequentially, each of the four crews had to sample approximately two rms a day, which amounted to very long days for the crews and hoop traps may not have been optimally dispersed throughout the study area. In the future, it is recommended that both events be designed like the second event in 2005, where each crew sampled approximately 1.5 rms in a day. This allowed time to break down camp, retrieve hoop traps, sample with hook-and-line, set hoop traps, and set camp back up in a 10-11 hour day. It would also provide opportunity for better coverage of hoop traps (i.e., camps would be closer together). Similarly, it was found that the approach taken to sample below the West Fork Gulkana during the second event was more appropriate. Water volume is typically much greater below the West Fork Gulkana making sampling more time consuming. Having two crews of three people (as opposed to two crews of two people), with each crew sampling 1.5–2 rms a day, allowed for more complete coverage. In the original design of the study a power boat was to be used to sample from the Middle Fork Gulkana confluence to the canyon area, but this approach may not be feasible in most years. There are many shallow runs and boulder patches in this stretch, and although it could be boated with moderate water conditions, the risk of damaging the boat would still be high.

All previously documented Gulkana River rainbow trout abundance estimates were from known spawning areas (Burger et al. 1983; Fleming 1999, 2000 and 2004; Stark 1999, Wuttig et al. 2004), and all indicated that relatively few rainbow trout (i.e., <300 fish) utilize these spawning areas and that fish appear to be become fully mature between 375 and 400 mm FL. Based on the abundance of fish ≥375 mm FL observed in this study, (Table 15) far more mature-sized rainbow trout exist than previously documented. It is recommended that a telemetry study, which coincides with spawning, be performed on the Gulkana River to identify all rainbow trout spawning areas, as well as their relative importance to the stock. A telemetry study prior to the next mark-recapture experiment would also be useful in determining optimal timing for future sampling events. For example, are there significant movements associated with the Chinook salmon spawning and when are overwintering migrations initiated and completed?

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APPENDIX A:
DATA FILE LISTING

Appendix A1.–Summary of data archives for the Gulkana River rainbow trout studies, 2004 and 2005.

Year	Data File[a]	Software
2004	2004GulkanaRTfeasibility.xls	Microsoft Excel
2005	2005GulkanaRTmark_recapture.xls	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.

APPENDIX B:
METHODS FOR TESTING ASSUMPTIONS OF THE PETERSEN ESTIMATOR AND ESTIMATING ABUNDANCE AND LENGTH COMPOSITION

Appendix B1.–Methodologies for alleviating bias due to size selectivity.

	Result of first K-S test[a]	Result of second K-S test[b]
Case I[c]		
	Fail to reject H_o	Fail to reject H_o
	Inferred cause: There is no size-selectivity during either sampling event.	
Case II[d]		
	Fail to reject H_o	Reject H_o
	Inferred cause: There is no size-selectivity during the second sampling event, but there is during the first sampling event.	
Case III[e]		
	Reject H_o	Fail to reject H_o
	Inferred cause: There is size-selectivity during both sampling events.	
Case IV[f]		
	Reject H_o	Reject H_o
	Inferred cause: There is size-selectivity during the second sampling event; the status of size-selectivity during the first event is unknown.	

Note: In addition to the tests outlined in Appendix B1, comparisons of length frequency distribution between fish captured during the second event (C) and fish recaptured in the second event from the first event (R) were conducted, which under some circumstances results in tests that are robust to growth.

[a] The first Kolmogorov-Smirnov (K-S) test is on the lengths of fish marked during the first event versus the lengths of fish recaptured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish recaptured during the second event.

[b] The second K-S test is on the lengths of fish marked during the first event versus the lengths of fish captured during the second event. H_o for this test is: The distribution of lengths of fish sampled during the first event is the same as the distribution of lengths of fish sampled during the second event.

[c] Case I: Calculate one unstratified abundance estimate, and pool lengths and ages from both sampling events for size and age composition estimates.

[d] Case II: Calculate one unstratified abundance estimate, and only use lengths and ages from the second sampling event to estimate size and age composition.

[e] Case III: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Pool lengths and ages from both sampling events and adjust composition estimates for differential capture probabilities.

[f] Case IV: Completely stratify both sampling events and estimate abundance for each stratum. Add abundance estimates across strata. Estimate length and age distributions from second event and adjust these estimates for differential capture probabilities.

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	Section Where Recaptured				Not Recaptured
Where Marked	**1**	**2**	**…**	**t**	(n_1-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-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-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.

From Appendix B1, Case I was found through inference testing and occurs when there is no size selectivity for either event. As stated earlier, only first event lengths were used to estimate length composition within each stratum because 1) growth, though not substantial, occurred between events; and, 2) the abundance estimate for the large size stratum was restricted to the first event.

To adjust estimates, the proportion of rainbow trout in a length category were calculated by summing independent stratum abundance estimates for the length category and then dividing by the summed abundances for all categories (i.e., total abundance). First the conditional proportions from the sample were calculated:

$$\hat{p}_{jk} = \frac{n_{jk}}{n_j} \tag{B3-1}$$

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 were in length category k; and,

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

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

$$\hat{V}\left[\hat{p}_{jk}\right] = \frac{\hat{p}_{jk}\left(1-\hat{p}_{jk}\right)}{n_j - 1}. \tag{B3-2}$$

The estimated abundance of rainbow trout in length category k in the population was then:

$$\hat{N}_k = \sum_{j=1}^{s} \hat{p}_{jk}\hat{N}_j \tag{B3-3}$$

where:

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

s = the number of size strata.

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

$$\hat{V}\left[\hat{N}_k\right] = \sum_{j=1}^{s}\left(\hat{V}\left[\hat{p}_{jk}\right]\hat{N}_j^2 + \hat{V}\left[\hat{N}_j\right]\hat{p}_{jk}^2 - \hat{V}\left[\hat{p}_{jk}\right]\hat{V}\left[\hat{N}_j\right]\right). \tag{B3-4}$$

Appendix B4.–Equations for calculating estimates of abundance and its variance using the Bailey-modified Petersen estimator.

For each length stratum, the Bailey-modified Petersen estimator (Bailey 1951 and 1952) was used because the sampling design was systematic in that sections A-D were fished simultaneously, and section E (downstream) was sampled afterward. Attempts were made 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 rainbow trout was estimated as:

$$\hat{N} = \frac{n_1(n_2+1)}{m_2+1}, \tag{B4-1}$$

where:

n_1 = the number of rainbow trout marked and released alive during the first event;

n_2 = the number of rainbow trout examined for marks during the second event; and,

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

The variance was estimated as (Seber 1982):

$$\hat{V}[\hat{N}] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)}. \tag{B4-2}$$