Regional Operational Plan SF.2A.2018.17

Operational Plan: Stock Assessment of Upper Kenai River Rainbow Trout, 2018

by

Tony Eskelin

June 2018

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

REGIONAL OPERATIONAL PLAN SF.2A.2018.17

OPERATIONAL PLAN: STOCK ASSESSMENT OF UPPER KENAI RIVER RAINBOW TROUT, 2018

by
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June 2018

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SIGNATURE/TITLE PAGE

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Approval

Title	Name	Signature	Date
Project leader	Tony Eskelin		
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ABSTRACT

A multiple event mark–recapture study will be conducted on rainbow trout (*Oncorhynchus mykiss*) in the upper Kenai River in 2018. The objectives of this study will be to estimate the abundance and fork length (FL) composition in the most heavily fished section of the upper Kenai River (rivermiles 69.6–73.2) and to compare those estimates to those from previous surveys conducted in 1986, 1987, 1995, 2001, and 2009 on the same stretch of river. Abundances of rainbow trout at least 200 mm FL and at least 300 mm FL will also be estimated.

Key words: rainbow trout, *Oncorhynchus mykiss*, abundance, MARK, RMark, Huggins models, fork length, Kenai River, mark–recapture

INTRODUCTION

PURPOSE

It is estimated that over 170,000 rainbow trout (*Oncorhynchus mykiss*) are caught in the Kenai River drainage every year, and approximately half of this catch occurs in the upper Kenai River. The section of the upper Kenai River most heavily fished for rainbow trout is between rivermiles (RM) 69.6 and 73.2. Large estimated catches and more liberal harvest regulations that allow harvest warrant a mark–recapture project in 2018 to index the upper Kenai River rainbow trout population by estimating the abundance and length composition of the rainbow trout population in the most heavily fished section of the upper Kenai River and to compare these estimates to those from mark–recapture studies in 1986, 1987, 1995, 2001, and 2009 which were conducted in the same area and during the same time of year.

BACKGROUND

The Kenai River drainage (Figure 1) is the most heavily utilized system for freshwater sport fishing in Alaska. Although many anglers participate in the river's salmon fisheries, the Kenai River drainage also supports a major rainbow trout fishery. In 1984, an estimated 15,687 rainbow trout were caught in the drainage (Table 1). Annual catch remained relatively stable until the 1990s when it increased dramatically despite gear and harvest restrictions. Annual catch of rainbow trout has been variable since 2000 but in some years the estimated catch exceeds 200,000 fish drainage-wide, including over 100,000 rainbow trout caught in the upper river section between Skilak and Kenai lakes (referred to as the "upper Kenai River" henceforth). In 2015, it was estimated that over 240,000 rainbow trout were caught in the entire drainage of which over 120,000 fish were estimated caught in the upper Kenai River. The most recent 5-year average estimated drainage-wide catch was 178,345 in 2012–2016, and an estimated 88,574 fish were caught on average in the upper Kenai River during the same time (Table 1). Estimated catch of rainbow trout in 2016 (the latest available estimate) was 173,397 drainage-wide, including 78,149 in the upper Kenai River.

The section of the upper Kenai River between the Ferry Crossing (RM 73.5) and Jim's Landing (RM 69.6.) is highly popular with anglers due to ease of access and fishing success rate. The mid-summer abundance of rainbow trout from near the Ferry Crossing to Jim's Landing has been estimated 5 times (1986, 1987, 1995, 2001, and 2009) by ADF&G and used as an index of the entire upper Kenai River rainbow trout population.

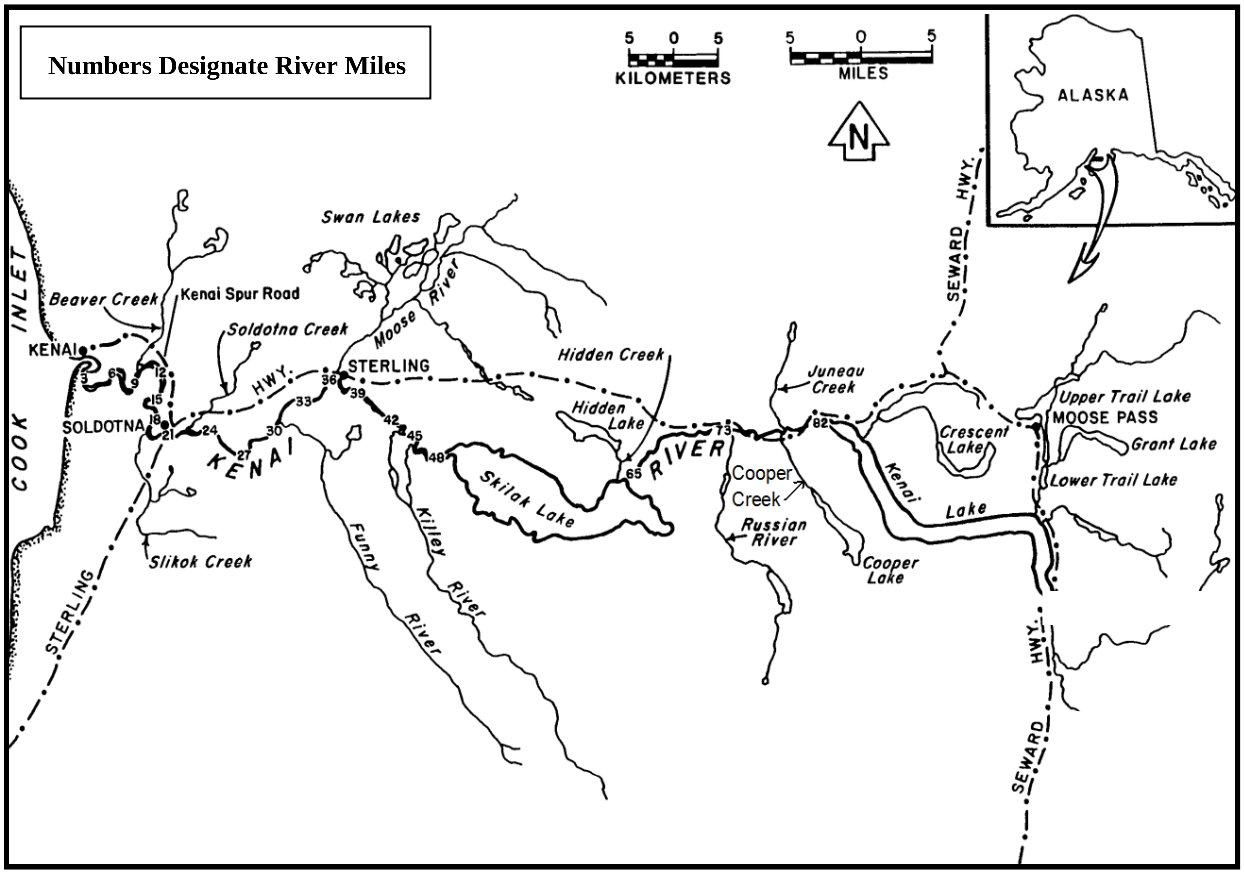

Figure 1.–Map of the Kenai River drainage.

Table 1.–Historical catch and retention estimates for Kenai River rainbow trout (1984–2016).

	Upper Kenai River				Kenai River Total			
Year	Number caught [a]	C & R mort. [b]	Number retained [c]	Fishing mortality	Number caught [a]	C & R mort. [b]	Number retained [c]	Fishing mortality
1984	4,200	164	930	1,094	15,687	611	3,470	4,081
1985	3,520	141	710	851	14,981	552	3,940	4,492
1986	2,020	64	733	797	8,720	315	2,425	2,740
1987	3,870	175	364	539	15,970	689	2,185	2,874
1988	7,580	351	559	910	17,800	783	2,133	2,916
1989	6,870	331	253	584	17,590	784	1,917	2,701
1990	11,995	543	1,145	1,688	23,556	1,001	3,535	4,536
1991	18,108	868	740	1,608	33,554	1,512	3,319	4,831
1992	28,702	1,415	403	1,818	52,156	2,509	1,977	4,486
1993	37,755	1,878	192	2,070	62,152	2,979	2,574	5,553
1994	35,089	1,746	163	1,909	53,833	2,613	1,576	4,189
1995	33,475	1,658	310	1,968	55,150	2,650	2,150	4,800
1996	45,471	2,262	237	2,499	64,411	3,143	1,560	4,703
1997	61,053	3,053	0	3,053	95,152	4,662	1,910	6,572
1998	42,224	2,111	0	2,111	65,264	3,162	2,015	5,177
1999	50,189	2,509	0	2,509	101,979	4,910	3,784	8,694
2000	78,836	3,942	0	3,942	123,731	6,014	3,459	9,473
2001	51,130	2,557	0	2,557	92,211	4,489	2,422	6,911
2002	71,753	3,588	0	3,588	114,175	5,558	3,019	8,577
2003	54,552	2,728	0	2,728	123,049	6,039	2,278	8,317
2004	91,443	4,572	0	4,572	159,510	7,810	3,311	11,121
2005	57,936	2,883	267	3,150	126,264	6,187	2,517	8,704
2006	67,741	3,373	289	3,662	131,819	6,466	2,499	8,965
2007	90,757	4,505	661	5,166	178,970	8,815	2,666	11,481
2008	103,095	5,155	941	6,096	202,875	10,144	3,214	13,358
2009	102,745	5,137	399	5,536	201,632	10,082	2,454	12,536
2010	79,663	3,983	237	4,220	173,301	8,665	2,403	11,068
2011	71,088	3,554	374	3,928	199,765	9,988	1,727	11,715
2012	81,349	4,067	386	4,453	169,443	8,472	2,540	11,012
2013	90,301	4,515	446	4,961	168,042	8,402	1,771	10,173
2014	69,629	3,481	135	3,616	139,193	6,960	1,619	8,579
2015	123,441	6,172	286	6,458	241,651	12,083	2,265	14,348
2016	78,149	3,907	169	4,076	173,397	8,670	2,462	11,132
Average								
1984–2016	53,204	2,648	343	2,991	103,545	5,082	2,518	7,600
2012–2016	88,574	4,429	284	4,713	178,345	8,917	2,131	11,049

Source: Mills 1985-1994; Howe et al. 1995, 1996; Alaska Sport Fishing Survey database [Internet]. 1996– . Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited April 2018). Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

[a] Catch estimates for 1984–1989 are unpublished estimates from the ADF&G Statewide Harvest Survey (M Mills, ADF&G Division of Sport Fish, Research and Technical Services, Anchorage).

[b] Catch and release (C & R) mortality assumed 5% (Schill and Scarpella 1997).

[c] Retention (harvest) of rainbow trout prohibited during 1997–2004.

Using a mark–recapture estimator, Lafferty (1989) estimated the abundance of rainbow trout greater than 200 mm fork length (FL[1]) in the study area to be 3,640 trout in 1986 and 4,950 in 1987. A creel survey revealed that the exploitation rate was low and that catch-and-release of rainbow trout was a common practice. Based on these findings, Lafferty (1989) concluded that the rainbow trout population in the upper Kenai River was healthy.

Hayes and Hasbrouck (1996) estimated the population of the Ferry Crossing to Jim's Landing section of the upper Kenai River in 1995 to be 5,598 rainbow trout ≥300 mm FL (Table 2). The authors also analyzed 1986 and 1987 data to estimate abundance of trout ≥300 mm during those years. The estimates of rainbow trout ≥300 mm were 2,520 in 1986 and 3,472 in 1987. The population in 1995 had increased since 1987 and had a more uniform distribution of fish among size classes, with a greater proportion of fish in the 450–550 mm size range.

Table 2.–Historical abundance estimates of rainbow trout in the upper Kenai River index area, 1986–2009.

	Number of rainbow trout			
Year	≥200 mm FL	SE	≥300 mm FL	SE
1986	3,640	456	2,520	363
1987	4,950	376	3,472	482
1995	N/A	N/A	5,598	735
2001	8,553	806	6,365	625
2009	5,916	481	5,106	431

Note: "N/A" means data not available.

King and Breakfield (2007) estimated the population in 2001 between Highway Hole (RM 73.2; note that the Ferry Crossing is at approximately RM 73.5) and Jim's landing in 2001 was 6,167 rainbow trout greater than 300 mm, which was a slight increase from the 1995 estimate. Eskelin and Evans (2013) estimated the abundance of rainbow trout greater than 300 mm was 5,106 fish in 2009.

Estimated abundance of rainbow trout ≥300 mm between the Ferry Crossing and Jim's Landing increased consistently from 1986 through 2001 but the estimate was lower in 2009 (Table 2). Because of this drop in the estimated abundance of fish ≥300 mm and because the number of fish between 200 mm and 300 mm dropped steeply in 2009 (Table 2), ADF&G became concerned about the mortality of rainbow trout from harvest and catch-and-release fishing. Assuming a 5% mortality rate for released trout (Schill and Scarpanella 1997), the average total fishing mortality (including harvest) in the upper Kenai River fishery over the most recent 5 years is 45% more than the long-term average total fishing mortality (Table 1). In addition, the estimated harvest of small rainbow trout (those less than 16 inches or 406 mm) has declined from an average of over 500 fish from 2005 through 2010 to less than 300 from 2012 through 2016.

The Russian River is known to be an important spawning area for rainbow trout in the Kenai River watershed (Palmer 1998). Anectodal evidence from ADF&G stream count data on the Russian River suggests a decline in spawning rainbow trout since 1996 (Figure 2). This decline, in combination with high estimated catches and more liberal regulations that allow harvest, has

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[1] All references to fish length in this document will be reported as fork length which is measured tip of nose to fork of tail.

warranted a mark–recapture project in 2018 to index the upper Kenai River rainbow trout population.

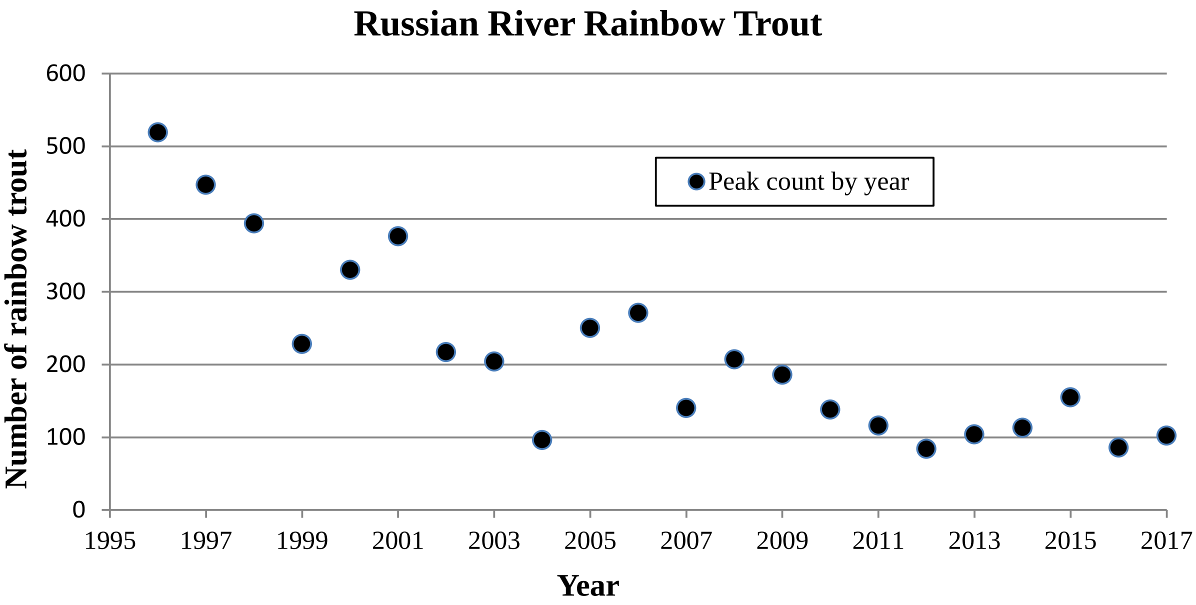

Figure 2.–Peak stream survey counts of spawning rainbow trout in the Russian River, 1991–2017.

It is important for ADF&G to reassess the stock status of the upper Kenai River rainbow trout resource in order to evaluate the effectiveness of the current management strategy. In 2018, we plan to assess the mid-summer population of rainbow trout inhabiting the mainstem Kenai River from Highway Hole (RM 73.2) to Jim's Landing (RM 69.6). Results of this study will be compared to those conducted in 1986, 1987, 1995, 2001, and 2009.

OBJECTIVES

PRIMARY OBJECTIVES

1) Estimate the abundance of rainbow trout ≥200 mm in the upper Kenai River between Highway Hole (RM 73.2) and Jim's Landing (RM 69.6) from June 26 through August 2, such that the estimate is within 25% of the true abundance 95% percent of the time.
2) Estimate the length composition of rainbow trout ≥200 millimeters in the upper Kenai River between Highway Hole (RM 73.2) and Jim's Landing (RM 69.6) from June 26 through August 2, such that the estimates are within 5 percentage points of the true value 95% of the time.

SECONDARY OBJECTIVES

1) Estimate the abundance of rainbow trout ≥200 mm and ≤400 mm in the upper Kenai River between Highway Hole (RM 73.2) and Jim's Landing (RM 69.6) from June 30 through August 7. It is noted that current regulations allow harvest of 1 rainbow trout ≤16 inches (about 400 mm) per day.
2) Estimate the abundance of rainbow trout ≥300 millimeters in the upper Kenai River between Highway Hole (RM 73.2) and Jim's Landing (RM 69.6) from June 30 through

August 7. It is noted that past studies have estimated abundance of fish ≥200 mm and ≥300 mm.

METHODS

STUDY DESIGN

Abundance

A closed mark–recapture model will be used to estimate abundance. Rainbow trout will be captured in the upper Kenai River in 3 sections between Highway Hole and Jim's Landing (Figure 3) from June 25 through August 2. Two 3–5 person crews working from drift boats will capture fish using hook and line gear. Fish ≥200 mm in length will be marked with an individually numbered Floy T-anchor tag[2] and an adipose fin clip and released near the location of capture.

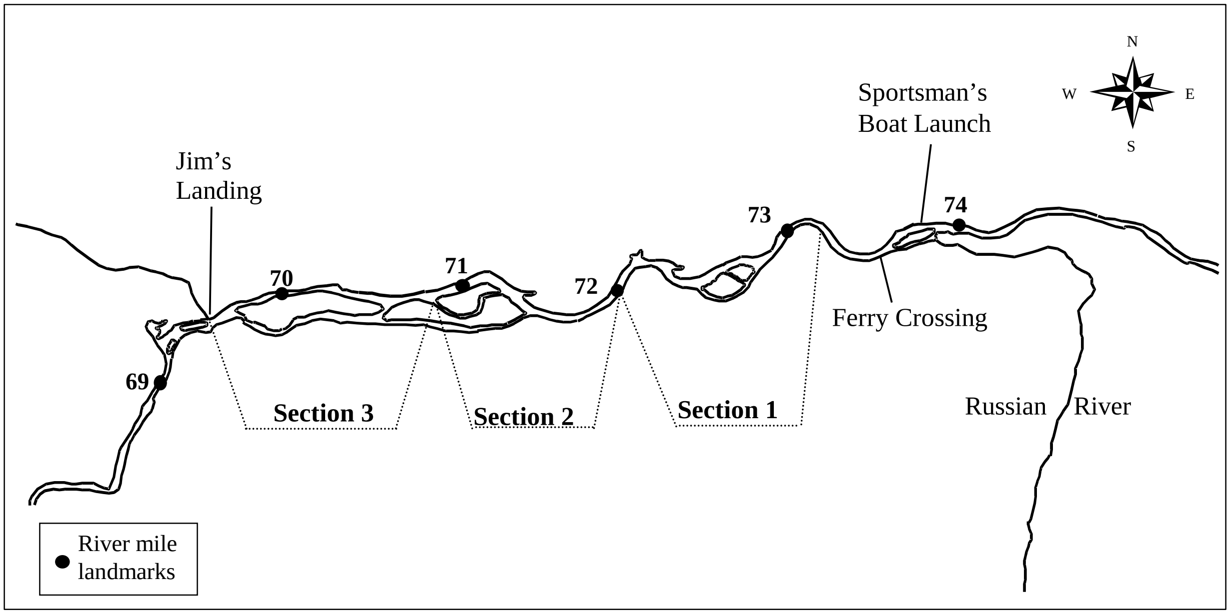

Figure 3.–Upper Kenai River study area with 3 subsections.

Each week will represent a separate sampling event. Sampling will be conducted at least 3 days per week (i.e., Monday, Tuesday, and Wednesday). Sampling may occur on Thursday depending on catch during the three scheduled sampling days that week. No sampling will occur on Fridays, weekends, or holidays. Avoiding those days will minimize impact on the sport fishery, and create at least a 3-day hiatus to allow mixing of fish between sampling events.

The study area will be divided into 3 adjacent sections: Section 1, which includes Highway Hole (RM 73.2) to and including Windy Point (RM 72.0), Section 2, which includes the area downstream of Windy Point to and including Whirlpool Hole (RM 70.8), and Section 3, which includes the area downstream of Whirlpool Hole to Jim's Landing (RM 69.6) (Figure 3). Each section will be approximately 1.2 RM in length. Sampling effort during each event will be

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

approximately equal. Increases in catch per unit effort in sections with higher abundance should help equalize capture probabilities over sections with different population densities.

Sample Size

Simulation was used to estimate relative precision under all combinations of 4 true abundances (3000, 5000, 7000, and 9000 fish) and 3 samples sizes (200, 250, and 300) in fish captured per week, assuming a closed population. These abundance levels span the range of abundances observed in the area during previous experiments (Table 2). Our relative precision goal (within 25% of true abundance 95% of the time) should be achieved under all abundance levels with catches of at least 250 fish per week. Catches of 200 fish per week should achieve relative precision goals for true abundances of 7,000 or less (Table 3). In the most recent upper Kenai River study (Eskelin and Evans 2013), at least 264 rainbow trout ≥200 mm were sampled each week using similar gear and effort as planned in this study.

Table 3.–Mean estimated abundance and relative precision of 25 simulations at 3 weekly catch levels and 4 true abundance levels.

		True abundance			
Weekly catch	Statistic	*N* = 3,000	*N* = 5,000	*N* = 7,000	*N* = 9,000
300					
	Estimated abundance	3,034	4,946	7,019	9,204
	Relative precision	10%	13%	16%	19%
250					
	Estimated abundance	3,027	5,162	6,911	8,935
	Relative precision	12%	17%	20%	22%
200					
	Estimated abundance	3,012	5,107	7,196	8,936
	Relative precision	15%	21%	25%	28%

The abundance of rainbow trout ≥200 mm and ≤400 mm will be estimated by multiplying the proportion of fish ≥200 mm and ≤400 mm in the length sample by the abundance of fish ≥200 mm from the mark–recapture estimate. We anticipate sampling at least 1,200 fish (6 weeks × 200 fish/week) during the study for lengths. Given the extremely large length sample, our estimated abundance of fish ≥200 mm and ≤400 mm will be negligibly increased from the simulated relative precisions in Table 3.

Assumptions Necessary to Estimate Abundance

The assumptions necessary to estimate abundance with a closed population model are as follows (Seber 1982):

1) The population is closed with no additions or losses between sampling events (through recruitment, death, immigration, or emigration).
2) All rainbow trout have an equal capture probability in the first capture event or in the subsequent capture events, or marked rainbow trout mix completely with unmarked rainbow trout prior to subsequent capture events.
3) Marking does not affect capture probability in subsequent capture events.
4) Marks (tags) are not lost between events.

5) All marked rainbow trout recaptured during subsequent capture events are correctly identified and recorded.

Closed Population Assumption

Closure violations associated with growth or natural mortality are not expected due to the short study duration. Fisheries-related mortality is likely but expected to have a negligible impact on population size and affect marked and unmarked fish equally. Violations due to immigration and emigration are possible in several forms: migration through the study area, permanent immigration, permanent emigration, and random temporary immigration and emigration. Study dates were chosen to coincide with the summer feeding period of rainbow trout so that the population is expected to be stationary during the study. In the event permanent immigration or emigration occurs, simulation results show standard Akaike information criterion (AIC) based model selection within an open population modeling framework would successfully detect migration rates in excess of 10% and additionally, rates of less than 10% would minimally bias a closed population estimator.

A more likely scenario is that the population of fish within the study area has a home range that is larger than the study area. Fish would be expected to move freely within their home range while crossing the study area boundaries essentially at random. In this scenario, a closed population estimator will estimate the entire population that used the study area rather than the size of the population within the study area[3]. In 3 similar studies, about 21% of recaptures on average were not from the same subsection in which they were tagged (Hayes and Hasbrouck 1996; King and Breakfield 2007; Eskelin and Evans 2013). Movement between sections may be representative of movement from Section 1 and from Section 3 to outside of the study area because habitat quality is similar for short sections both upstream and downstream of the boundaries. Movement probabilities within the study area can be estimated using a multi-state Cormack Jolly Seber (CJS) model in which the states are equivalent to the three study sections.

We will also test the null hypothesis that the ratio of marked to unmarked fish declines during the study or stays constant over sampling events (1-tailed test) against the alternative hypothesis that it increases. A declining or constant ratio is consistent with immigration or growth recruitment. Occurrence of growth recruitment will be examined by comparing length of marked versus recaptured fish.

The closure tests of Otis et al. (1978) and Stanley and Burnham (1999) will not be used because it is known that we will have fishing mortality during the study and significant test results would be hard to interpret.

Probability of Capture and Mixing Assumption

Variation in probability of capture due to size

It is possible that rainbow trout ≥200 mm will have different probabilities of capture due to size. Therefore, 2 approaches will be taken to assess size selectivity. The first approach involves testing size distributions. This approach will be used if the experiment is for some reason reduced to 2 events (i.e., there are a low number of recaptures); the procedures outlined in

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[3] If the population using the study area (N_0) is found within the study area with probability τ, then closed population estimates of the probability of capture (p) estimate the product $p\tau$ and the closed population estimator of population size estimates N_0 (Williams et al. 2002). The expected value of the population within the study area would equal $N_0\tau$.

Appendices A1 and A2 will be followed to detect and correct for selectivity in this case. The second approach will use a group of models commonly referred to as "Huggins models" (Huggins 1989) to test whether length affected probability of capture and to incorporate the length effect in the abundance estimation, should it be significant.

Variation in probability of capture over sections and mixing

The CJS model referenced above will provide estimates of probability of capture by section within each sampling event. We will use Program MARK and AIC to compare CJS models where the probability of capture is allowed to vary over sections within a sampling event versus models where the capture probability is forced to be equal over sections within a sampling event.

This assumption can also be tested by examining the recapture rate of fish tagged among the 3 locations (3 × 2 chi-square test: location versus recaptured or not recaptured). If the probability of capture among locations is constant or if fish mixed, then the recapture rates among locations should not vary. Mixing of fish among locations will also be tested by a 3 × 3 chi-square test (location versus location).

Marking Effects on Capture Probability Assumption

Careful and rapid processing by the marking crew when capturing and handling fish will minimize stress and violation of this assumption. This assumption can also be tested within the closed population modeling frameworks by considering models including a behavior effect.

Mark Loss Assumption

The assumption of no tag loss will be tracked by clipping the adipose fin from all rainbow trout (≥200 mm) caught and tagged. This secondary mark will allow testing of the assumption of no tag loss.

Data Collection Assumption

Careful examination and recording of data by the crew of each fish caught will negate problems of marked fish not being properly detected and recorded.

Length Composition

To attain the desired precision of ±5 percentage points 95% of the time for fork length (FL) composition, a minimum of 480 rainbow trout need to be sampled (Thompson 1987; with finite population correction factor based on a population size of 6,000). These criteria will be easily achieved because all captured rainbow trout will be measured for length and we anticipate sampling at least 1,200 fish in the abundance estimation component (6 weeks × 200 fish per week).

DATA COLLECTION

Rainbow trout will be captured with hook and line from 2 drift boats. A minimum of 4 people will be assigned to each boat. Crewmembers will complete the following tasks for all fish captured:

1) Identify the section and river mile of capture to the nearest one-quarter mile (or fishing hole).
2) Examine all captured rainbow trout for tags and adipose fin clips.

3) Measure FL to the nearest millimeter and identify sex if possible of all rainbow trout captured.
4) Tag rainbow trout ≥200 mm with individually numbered Floy T-Anchor tag and remove the adipose fin (Appendix C1). A recaptured recently fin-clipped fish with no tag present will be recorded as a tag loss and given a new tag.
5) Record all field data associated with activities 1–5 above on handheld computers or data sheets (Appendices C1–C3).

DATA REDUCTION

All mark–recapture and biological data will be recorded on field forms or handheld computers. The crew leader is responsible for ensuring the data are complete and accurate. At the end of each day of sampling, the crew leader will go over the data and correct obvious errors. The crew leader will also tally the number of rainbow trout caught, the number of tags released, the number of recaptured fish, note the time fished per subsection, total hours worked, and any equipment problems. Daily tallies provided by the tagging crews will be used to track crew and project inseason performance. Additionally, these data will allow staff to keep a running tally, in the form of a contingency table, of tags deployed and recovered on a daily basis.

Field forms will be given to the project biologist and the data will be downloaded onto the project biologist's computer. The project biologist will create an ASCII text file and capture history file for analysis in Program MARK and R. An Excel file will also be created for volunteer tag returns. The project biologist will retain final edited copies of the field forms and will create an electronic tag database file.

DATA ANALYSIS

Abundance

Abundance will be estimated using the R package RMark. Initially, open population models will be used to compare models. For example, in the POPAN parametrization (Schwarz and Arnason 1996) 4 parameters describe a mark–recapture experiment with i capture events: **N**, the total number of animals to enter the study area and survive until the next sampling event, **b**, a vector of length i which sums to 1 and describes the percentage of the population entering the study area prior to sampling event i, **phi**, a vector of length $i-1$ describing apparent survival between sampling events, and **p**, a vector of length i describing the probability of capture during each sampling event. Popan models that fix parameters **b** = c(1,0,0,…)[4] and **phi** = 1 assume closure, whereas models that allow **b** and **phi** to vary through time will estimate the magnitude of any closure violations. Akaike's information criterion (AIC; e.g., Burnham and Anderson [1998]) will be used to compare models. Simulation was used to test the reliability of this procedure and showed AIC model selection would successfully detect migration rates greater than 10% and any rates of less than 10% will minimally bias a closed population estimator. In conjunction with open population modeling, temporal changes in the marked proportion and movement of marked fish within the study area will be considered as described in pervious sections. We anticipate satisfying the closure assumption based on past experiments.

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[4] **b** = c(1,0,0,…) implies 100% of the population was inside the study area prior to the first event.

If the population can be assumed closed, we plan to use Huggins models (Huggins 1989) to estimate abundance. Huggins models use at least 2 parameters to describe a mark–recapture experiment with *i* capture events: **p** a vector of length *i*, describing the probability of capture during each sampling event, and **c**, a vector of length $i-1$ describing the probability of recapture during each sampling event. Abundance is calculated as a derived parameter. This parameterization allows the incorporation of a length selectivity effect directly into an abundance estimation model through generalized linear modeling of capture probabilities. In addition to length selectivity, we plan to examine models including other explanatory variables for probability of capture. For example, length selectivity may differ among events. Differences in size selectivity among time intervals will be tested using an Anderson-Darling test (Conover 1999) and by visual examination of cumulative length probability plots over events. River discharge may also be a covariate because probability of capture may change due to differing fishing conditions.

Because the probability of capture (**p**) and recapture (**c**) can be modeled separately, behavioral effects after marking can be accounted for in Huggins models. Heterogeneity in capture probabilities can also be included in a subclass of Huggins models called Pledger models, which model capture probabilities as a finite mixture of 2 or more distributions.

R Mark will be used to estimate a suite of five models with differing parameter structures: 1) probability of capture varies with time, 2) length selectivity varies with time, 3) behavioral effects, 4) heterogeneity in encounter probabilities, and 5) models that assume constant probability of capture among grouped subsets of contiguous events. After a variety of models have been identified and fit to the data, model selection will proceed using AIC (Equation 1) as an optimization criterion:

$$AIC = -2\log\left[L\left(\hat{\theta}\middle|y\right)\right] + 2K \tag{1}$$

where $L\left(\hat{\theta}\middle|y\right)$ is the likelihood of the parameter maximum likelihood estimates ($\hat{\theta}$) given the data (y), and K is the number of parameters in the model. The relative differences in AIC results between each model and the minimum AIC in the model set ($\Delta_i = AIC_i - AIC_{min}$) will be used to rank models where Akaike weights are calculated as follows:

$$w_i = \frac{\exp\left(^{-\Delta_i}/_2\right)}{\sum_{m=1}^{R}\exp\left(^{-\Delta_m}/_2\right)} \tag{2}$$

and provide a normalized measure of the evidence that model *i* is the most appropriate model out of the *R* models considered. Akaike weights close to 1 indicate 1 model is favored whereas several models with similar weights would indicate several different parameter structures explain the data equally well. In this case, model averaging may be appropriate (Williams et al. 2002).

A Z-test will be used to determine if abundance of rainbow trout ≥200 mm changed significantly between 2009 and 2018.

Length Composition

The proportion of rainbow trout in length class *j* and its variance will be estimated as a binomial proportion (Cochran 1977):

$$\hat{p}_j = \frac{n_j}{n} \tag{3}$$

and

$$\operatorname{var}(\hat{p}_j) = \frac{\hat{p}_j(1 - \hat{p}_j)}{n - 1} \tag{4}$$

where

n_j = the number of rainbow trout ≥200 mm of length class *j*, and

n = the total number of rainbow trout ≥200 mm measured for length.

The abundance of rainbow trout ≥200 mm by length class ($\hat{N}_j$) will be estimated as a product of 2 random variables(Goodman 1960):

$$\hat{N}_j = \hat{N}\hat{p}_j \tag{5}$$

and its variance by

$$\operatorname{var}(\hat{N}_j) = \hat{N}^2\operatorname{var}(\hat{p}_j) + \hat{N}^2\hat{p}_j^2\operatorname{var}(\hat{N}) - \operatorname{var}(\hat{p}_j)\operatorname{var}(\hat{N}) \tag{6}$$

If a length-based individual covariate is used (Huggins model) to estimate abundance, then the proportion of the population in length category *j* will be calculated after weighting each sampled length by the inverse of its estimated probability of capture:

$$\hat{p}_{ij} = \frac{\sum_{i=1}^{n_i} {}^{1}/_{\hat{c}_{ij}}\, I(j)}{\sum_{i=1}^{n_i} {}^{1}/_{\hat{c}_{ij}}} \tag{7}$$

where

$\hat{c}_{ij}$ = the estimated probability of capture of the *k*th fish in the sample from event *i*, and

$I(j)$ = an indicator function where $I(j) = 1$ for fish in length category *j* and $I(j) = 0$ otherwise.

The estimated probability of capture will be back-calculated from the fitted logit model that described the effects of length and time on probability of capture. The $\hat{p}_{ij}$ will then be combined over events as follows:

$$\hat{p}_j = \sum_{i=1}^{I} w_i\hat{p}_{ij} \tag{8}$$

where w_i is the proportion of the total sample taken in event *i* (*I* total events).

The standard error of the adjusted $\hat{p}_j$ will be estimated through simulation. *M* bootstrap capture histories will be selected and for each, the estimation model refit and the adjusted length compositions will be recalculated for each bootstrap realization. The standard error of the length composition for category *j* will be calculated as follows:

$$\operatorname{var}(\hat{p}_j) = \frac{\sum_{l=1}^{M}(\hat{p}_{jl} - \bar{\hat{p}}_j)}{M - 1} \tag{9}$$

where $\hat{p}_{jl}$ denotes the length composition for the *l*th bootstrap realization.

The proportion of tag loss and its variance will be estimated using (1) and (2) where the numerator of (1) will be the number of fin-clipped rainbow trout observed that had no tag and the denominator will be the total number of fin-clipped rainbow trout observed (both with and without tags).

SCHEDULE AND DELIVERABLES

Dates	Activity	Personnel
Mid to late June	Hiring and preseason training	Eskelin
Late June–early August	Mark–recapture events	Eskelin, 4 FWT II
Early to mid-August	Prepare equipment for winter storage	Eskelin, 4 FWT II
October	Tagging data edited and error checked	Eskelin
December	Data analysis and final population estimates	Eskelin and Reimer
March 2019	Fishery Data Series (FDS) report submitted	Eskelin and Reimer

RESPONSIBILITIES

Principal Investigator

Tony Eskelin, Fishery Biologist II

Duties: This position will serve as the overall supervisor for the project and personnel involved. Responsible for the procurement of equipment, provides daily supervision of tagging crew, supervises collection and processing of field data, edits project data, analyzes project data, and coauthors FDS report.

Consulting Biometrician

Adam Reimer, Biometrician II

Duties: Provides guidance on sampling design and data analysis, produces final population estimates and assists with preparation of operational plan and FDS report.

Tagging Crew

(4) *Vacant, NP Fish and Wildlife Technician II, 25 June–10 August, 2018*

Duties: Collect field data as outlined in the operational plan. The crew is responsible for adhering to sampling schedules and will complete all data forms and review them for errors before submitting them to the project biologist.

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APPENDIX A: DETECTION OF SIZE OR SEX SELECTIVE SAMPLING

Appendix A1.–Detection of size or sex selective sampling during a 2-sample mark–recapture experiment and its effects on estimation of population size and population composition.

Size selective sampling: The Kolmogorov-Smirnov 2-sample test (Conover 1980) is used to detect size selective sampling during the first or second sampling events. The second sampling event is evaluated by comparing the length frequency distribution of all fish marked during the first event (M) with that of marked fish recaptured during the second event (R), using the null test hypothesis of no difference. The first sampling event is evaluated by comparing the length frequency distribution of all fish inspected for marks during the second event (C) with that of R. A third test, comparing M and C, is conducted and used to evaluate the results of the first 2 tests when sample sizes are small. Sample sizes are considered small if less than 30 for R and less than 100 for M or C.

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

Results of the KS and chi-square tests (χ^2) will dictate whether the data need to be stratified to obtain an unbiased estimate of abundance. The nature of the detected selectivity will also determine whether the first, second, or both event samples are used for estimating size and sex compositions (Appendix A2).

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

$$\hat{p}_k = \sum_{i=1}^{I} \frac{\hat{N}_i}{\hat{N}} \hat{p}_{ik} \tag{1}$$

with variance estimated as

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

where

I = the number of size or sex strata,

$\hat{p}_{ik}$ = estimated proportion of fish belonging to age or size category k in stratum i;

$\hat{N}_i$ = estimated abundance in stratum i; and

$\hat{N}$ = estimated total abundance

where

$$\hat{N} = \sum_{i=1}^{I} \hat{N}_i \ . \tag{3}$$

Appendix A2.–Possible results of selectivity testing, interpretation, and action.

	KS or χ^2 Test			
Case	M vs. R (2nd event test)	C vs. R (1st event test)	M vs. C (1st vs. 2nd event)	Interpretation and action
I	Fail to reject H_o	Fail to reject H_o	Fail to reject H_o	**Interpretation**: No selectivity during either sampling event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use all data from both sampling events.
II	Reject H_o	Fail to reject H_o	Reject H_o	**Interpretation:** No selectivity during the 1st event but there is selectivity during the 2nd event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use data from the 1st sampling event without stratification. 2nd event data only used if stratification of the abundance estimate is performed, with weighting according to Equations A1–A3 (Appendix A1).
III	Fail to reject H_o	Reject H_o	Reject H_o	**Interpretation:** No selectivity during the 2nd event but there is selectivity during the 1st event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use data from the 2nd sampling event without stratification. 1st event data may be incorporated into composition estimation only after stratification of the abundance estimate and appropriate weighting according to Equations A1–A3 (Appendix A1).
IV	Reject H_o	Reject H_o	Reject H_o	**Interpretation:** Selectivity during both 1st and 2nd events. **Action**: Abundance: Use a stratified Petersen-type model, with estimates calculated separately for each stratum. Sum stratum estimates for overall abundance. Composition: Combine stratum estimates according to Equations A1–A3 (Appendix A1).
V	Fail to reject H_o	Fail to reject H_o	Reject H_o	**Interpretation:** The results of the 3 tests are inconsistent. **Action:** Need to determine which of Cases I–IV best fits the data [a].

[a] There are 4 conditions to be considered: 1) if sample sizes for M vs. R and C vs. R tests are not small and sample sizes for the M vs. C test are very large, the M vs. C test is probably detecting small differences that have little potential to result in bias during estimation so use Case I; 2) if sample sizes for M vs. R are small, the M vs. R *P*-value is not large (about 0.20 or less), and the C vs. R sample sizes are not small and (or) the C vs. R *P*-value is fairly large (about 0.30 or more), the rejection of the null in the M vs. C test was likely the result of size and (or) sex selectivity during the second event which the M vs. R test was not powerful enough to detect so may use Case I but Case II is the recommended, conservative interpretation; 3) if sample sizes for C vs. R are small, the C vs. R *P*-value is not large (about 0.20 or less), and the M vs. R sample sizes are not small and (or) the M vs. R *P*-value is fairly large (about 0.30 or more), the rejection of the null in the M vs. C test was probably the result of size and (or) sex selectivity during the first event which the C vs. R test was not powerful enough to detect so may use Case I but Case III is the recommended, conservative interpretation; and 4) if sample sizes for C vs. R and M vs. R are both small and both the C vs. R and M vs. R *P*-values are not large (about 0.20 or less), the rejection of the null in the M vs. C test may be the result of size and (or) sex selectivity during both events which the C vs. R and M vs. R tests were not powerful enough to detect so may use Cases I, II, or III, but Case IV is the recommended, conservative interpretation.

APPENDIX B: TESTS OF CONSISTENCY FOR THE PETERSEN ESTIMATOR

Appendix B1.–Tests of consistency for the Petersen estimator.

Of the following conditions, at least 1 must be fulfilled to meet the 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.
3) Every fish has an equal probability of being captured and examined during Event 2.

To evaluate these 3 assumptions, the chi-square statistic will be used to examine the following contingency tables as recommended by Seber (1982: p. 438). At least 1 null hypothesis needs to be accepted for to satisfy the assumptions of the Petersen model (Bailey 1951, 1952; Chapman 1951) to be valid. If all 3 tests are rejected, a temporally or geographically stratified estimator (Darroch 1961) should be used to estimate abundance.

In the following tables, the terminology of Seber (1982) is followed, where *a* represents fish marked in the first event, *n* is the number of fish captured in second event, and *m* is the number of marked fish that were recaptured.

I. Mixing Test

Tests the hypothesis (condition 1) that movement probabilities (θ_{ij}), describing the probability that a fish moves from marking stratum *i* to recapture stratum *j*, are independent of marking stratum: H_0: $\theta_{ij} = \theta_j$ for all *i* and *j*. Note that

Area–Time marking stratum (*i*)	Area–Time recapture stratum (*j*) 1	2	…	t	Not recaptured $a_i - m_{i\bullet}$
1	m_{11}	m_{12}	…	m_{1t}	$a_1 - m_{1\bullet}$
2	m_{21}	m_{22}	…	m_{2t}	$a_2 - m_{2\bullet}$
…	…	…	…	…	…
s	m_{s1}	m_{s2}	…	m_{st}	$a_s - m_{s\bullet}$

II. Equal Proportions Test

Tests the hypothesis of homogeneity on the columns of the 2-by-*t* contingency table with respect to the marked to unmarked ratio among time or area designations: H_0: $\Sigma_i a_i \theta_{ij} / U_j = k$, where *k* total marks released per total unmarked in the population, U_j is unmarked fish in stratum *j* at the time of 2nd event sampling, and a_i is the number of marked fish released in stratum *i*.

Status of sampled fish	Area–Time recapture stratum (*j*) 1	2	…	t
Recaptured ($m_{.j}$)	$m_{\bullet 1}$	$m_{\bullet 2}$	…	$m_{\bullet t}$
Unmarked ($n_j - m_{.j}$)	$n_1 - m_{\bullet 1}$	$n_2 - m_{\bullet 2}$	…	$n_t - m_{\bullet t}$

-continued-

III. Complete Mixing Test

Tests the hypothesis of homogeneity on the columns of the 2-by-*s* contingency table with respect to recapture probabilities among time or area designations: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in recapture stratum *j* during the second event, and *d* is a constant.

	Area–Time marking stratum (*i*)			
Status of sampled fish	1	2	…	s
Recaptured (m_i)	$m_{1\bullet}$	$m_{2\bullet}$	…	$m_{s\bullet}$
Not Recaptured (a_i - $m_{i\bullet}$)	$a_1 - m_{1\bullet}$	$a_2 - m_{2\bullet}$	…	$a_s - m_{s\bullet}$

APPENDIX C: TAGGING PROCEDURES FOR HANDLING AND INSERTING TAGS

Appendix C1.–Tagging procedures for handling and inserting tags.

Upon capture, rainbow trout will be landed as quickly as possible and placed in plastic tubs filled with river water. After fish are tagged and sampled, they will be placed back into the tub for observation. Sampled trout will be released unharmed as near as possible to the original location of capture.

The condition of all captured rainbow trout will be assessed. Rainbow trout with deep scars or lesions, damaged gill filaments, a lethargic condition, or otherwise appearing unlikely to survive will not be tagged. Rainbow trout less than 200 millimeters in length will be sampled for biological information but will not be tagged.

Rainbow trout that are 200 millimeters or greater in length and in suitable condition for tagging will have uniquely-numbered, Floy FD-68B, T-anchor tag inserted in the basal rays of the dorsal fin on the left side. To insert a tag, place needle of tag gun on left side of fish about one-eighth inch below the rear base of the dorsal fin. Push needle into the fish in a forward and slightly downward direction so that it penetrates between the basal rays of the fin. Once the needle is in the fish, squeeze the gun to insert the tag. Remove the needle from the fish and check that the tag is firmly installed in the fish. Use scissors to remove the adipose fin on all tagged rainbow trout.

Tags are easily placed in rainbow trout when tagging guns are kept clean, needles are sharp, and the tags are undamaged. Clean and lubricate tag guns at the end of each day. Replace needles immediately when dull or damaged. Keep tags in order and stored where they can't be bent or damaged (insect repellent can damage tags).

Appendix C2.–Instructions for filling the Kenai River rainbow trout mark–recapture form.

Date: Write in current date.

Location: Write in "Upper Kenai River." If sampling upstream of Sportman's Landing put "above Sportsman's;" if downstream of Jim's Landing put "Canyon."

Collectors: Crew leader's initials.

Water Temp: Take water temperature reading at 12:00 break (deg. C).

Time: Time when water temperature taken.

Page: Write in the number consecutively for each sampling day

Catch Location (RM or hole): Put in location of capture to nearest one-quarter mile or fishing hole (see descriptions below).

Catch location	Description
Highway Hole	Kenai River mile 73.0 to 73.2
Power Line	Kenai River mile 72.8 to 73, power line crossing downstream to 1st island
1st Island	Kenai River mile 72.5 to 72.8, North side of island
1st Island back Channel	Kenai River mile 72.5 to 72.8, South side of island
Across 1st Island	Kenai River mile 72.5 to 72.8, North bank
2nd Island	Kenai River mile 72.4 to 72.2, North bank
Windy Point	Kenai River mile 72 to 72.5
Two Trees	Kenai River mile 71.6 to 72
Rock Face	Kenai River mile 71.2 to 71.6
Upper Rainbow chute	Kenai River mile 71.5 to 71.0, South bank side channel
3rd Island	Kenai River mile 71.3 to 71.4, North bank
57 Hole	Kenai River mile 71.0 to 71.2
Whirlpool Hole	Kenai River mile 71.1 to 71.0
Upper Car Seat	Kenai River mile 70.8 to 70.9
Car Seat	Kenai River mile 70.6 to 70.7
Leaning Tree	Kenai River mile 70.4 to 70.5
Riprap	Kenai River mile 69.7 to 70.3
Old Reliable	Kenai River mile 69.6 to 70.5
Last Hole	Kenai River mile 69.7 to 70.0
Lower Rainbow Chute	Kenai River mile 70.9 to 70.6, South bank side channel
Upper Jim's Back Channel	Kenai River mile 70.2 to 70.5, South bank side channel
Lower Jim's Back Channel	Kenai River mile 69.8 to 70.1, South bank side channel

Length: Fork length to the nearest millimeter.

AD Clip: Put a checkmark when adipose fin is clipped or PRE, if adipose fin is already missing or clipped upon capture.

Sex: Mark only if absolutely known.

M = male
F = female

Recap: Put an 'R' if fish is already tagged and (or) adipose fin is missing upon capture.

Floy Tag#: Record Floy tag number.

Tag Loss: Put a checkmark when upon capture, adipose fin is clipped and no tag is present.

Fate: Released (R), Mortality (M), or Censor (C), Censor is one that may be alive but should be censored in the dataset.

Comments: Describe anything noteworthy.

Appendix C3.–Mark–recapture field form.

Page ______
of_______

Date: Water Temp:

Location:

Collectors:

Fish #	Catch Location	Length (mm)	AD Clip	Sex	Recap	Floy Tag #	Tag Loss	Fate	Comments
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

Tag Loss - √ if adipose fin is clipped and no tag is present when caught.

AD Clip - √ when adipose fin clipped, or pre for pre-existing clip.