Fishery Data Series No. 23-13

Stock Assessment of Rainbow Trout in the Upper Kenai River, Alaska, 2018

by

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and

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June 2023

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

A multiple-event mark–recapture study was conducted on rainbow trout (*Oncorhynchus mykiss*) in the upper Kenai River in 2018. The objectives of this study were to estimate the abundance and fork length (FL) composition of rainbow trout in the most heavily fished section of the upper Kenai River (river miles 69.6–73.2) and to compare these estimates to those from previous surveys conducted in 1986, 1987, 1995, 2001, and 2009 on the same stretch of river. There were an estimated 10,568 (SE 608) rainbow trout at least 200 mm FL and 8,482 (SE 495) rainbow trout at least 300 mm FL in the study area. Abundance of fish at least 200 mm FL was 79% higher than in 2009 and 24% higher than in 2001. Abundance of fish at least 300 mm FL was 66% higher than in 2009, 33% higher than in 2001, and 52% higher than in 1995. Most of the rainbow trout were between 250 mm and 449 mm FL, accounting for 88% of the population. Approximately 75% of the population was less than 400 mm FL, which is the approximate upper length (16 inches total length) of fish allowed to be harvested by regulation. Overall, rainbow trout abundance in 2018 was considerably higher than in any other study year, but the number of fish more than 450 mm FL was only 743 (SE 71), which was less than half of what was observed in 1995, 2001, and 2009.

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

INTRODUCTION

The Kenai River (Figure 1) supports a higher number of angler-days per year than any other river in the state of Alaska, averaging 379,749 angler-days between 2009 and 2018 (Lipka et al. 2020). Although many anglers participate in Kenai River salmon fisheries, the drainage also supports a major rainbow trout (*Oncorhynchus mykiss*) fishery. The Alaska Department of Fish and Game (ADF&G) statewide harvest survey (SWHS) estimated the average annual rainbow trout catch for the past 10 years (2009–2018) exceeded 175,000 fish (Table 1).

Participation and catch in the rainbow trout fishery have been highest in the river section between Skilak Lake and Kenai Lake (henceforth referred to as the upper Kenai River) with approximately half of estimated catch occurring in that section annually. The most recent 10-year average annual catch estimate in the upper Kenai River was approximately 85,000 fish and was as high as 123,411 fish in 2015 (Table 1).

Fishing regulations governing the upper Kenai River have a long history and have generally become more conservative through time to the point of not allowing harvest (no retention, catch-and-release only) from 1997 to 2004 (Table 2). However, in 2005, the Alaska Board of Fisheries liberalized the upper Kenai River rainbow trout sport fishery, allowing harvest of 1 rainbow trout less than 16 inches daily with no annual limit for individual anglers (Alaska Administrative Code 5AAC 57.120 [6] [c]). Harvest estimates of rainbow trout in the upper Kenai River have averaged 412 fish since 2005 and have been as high as 941 fish in 2008 (calculated from Table 1). In 2018, estimated harvest of rainbow trout in the upper Kenai River was 351 fish.

The area of the upper Kenai River between Sportsman's Landing and the boat launch at river mile (RM) 73.7 and Jim's Landing (RM 69.6; Figure 2) is highly popular with anglers due to ease of access and easily fishable waters. Midsummer abundance of rainbow trout in this area (hereafter referred to as the "index area") was estimated in 1986, 1987, 1995, 2001, and 2009 as an index of abundance and length composition for the entire upper Kenai River rainbow trout population (Lafferty 1989; Hayes and Hasbrouck 1996; King and Breakfield 2007; Eskelin and Evans 2013).

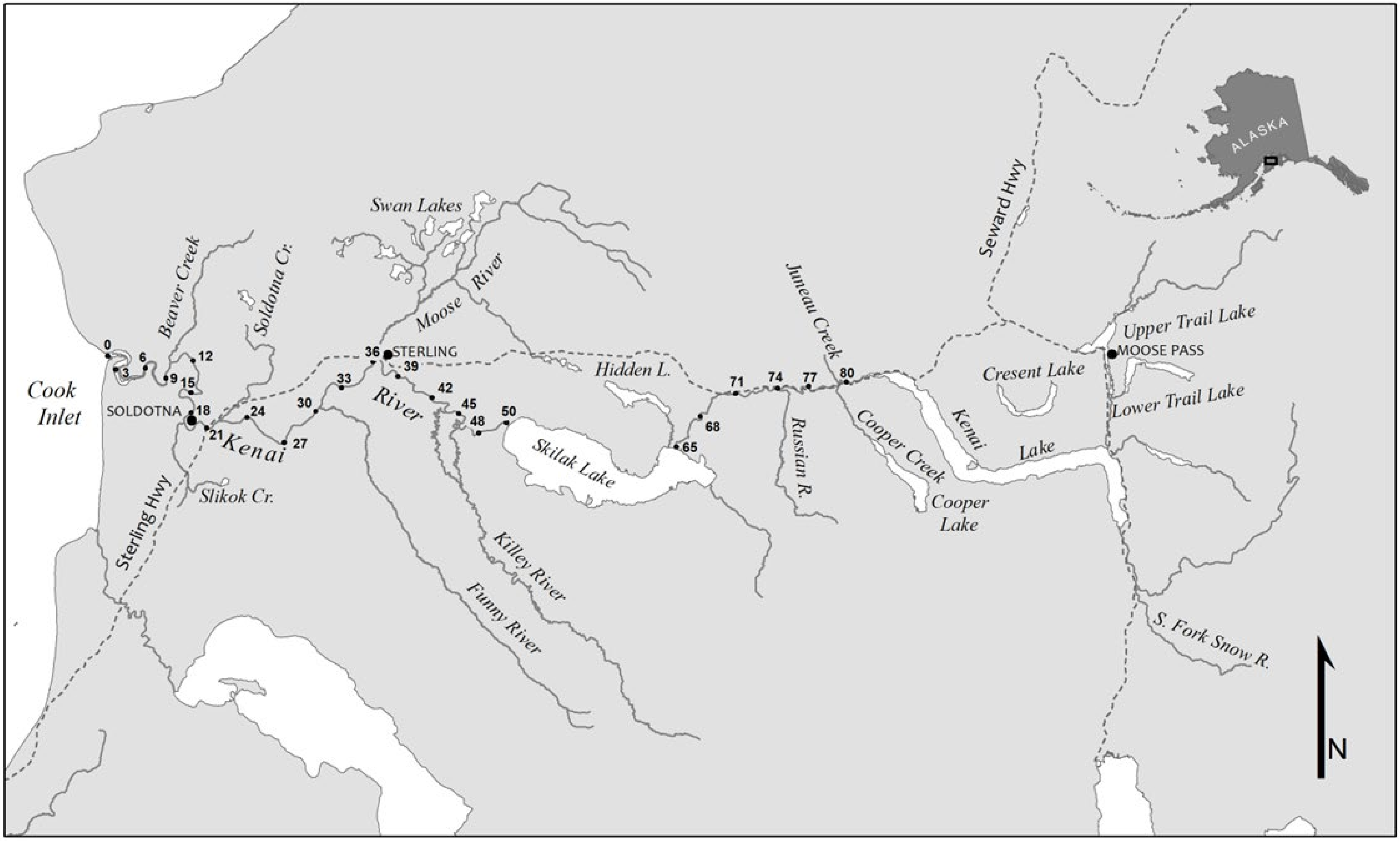

Figure 1.–Map of Kenai River drainage.

Note: Numbers represent river miles.

Table 1.–Number of Kenai River rainbow trout caught and harvested by river section as estimated by the Statewide Harvest Survey, 1984–2018.

	Cook Inlet to Soldotna Bridge			Soldotna Bridge to Moose River confluence			Moose River confluence to Skilak Lake outlet			Skilak Lake inlet to Kenai Lake outlet			Kenai River total[a]		
	Catch[b]	Harvest		Catch[a]	Harvest		Catch[b]	Harvest		Catch[b]	Harvest[c]		Catch[b]	Harvest	
Year	No.	No.	%	No.	No.	%	No.	No.	%	No.	No.	%	No.	No.	%
1984[d]	3,464	766	22.1	2,911	644	22.1	5,112	1,130	22.1	4,200	928	22.1	15,687	3,468	22.1
1985[d]	3,398	880	25.9	2,653	850	32.0	5,410	1,500	27.7	3,520	710	20.2	14,981	3,940	26.3
1986	2,570	623	24.2	2,380	168	7.1	1,750	901	51.5	2,020	733	36.3	8,720	2,425	27.8
1987	2,220	522	23.5	3,450	670	19.4	6,430	629	9.8	3,870	364	9.4	15,970	2,185	13.7
1988	2,780	295	10.6	1,560	216	13.8	5,880	1,063	18.1	7,580	559	7.4	17,800	2,133	12.0
1989	2,020	481	23.8	2,230	354	15.9	6,470	829	12.8	6,870	253	3.7	17,590	1,927	11.0
1990	2,624	510	19.4	3,571	943	26.4	5,366	937	17.5	11,995	1,145	9.5	23,556	3,535	15.0
1991	3,672	516	14.1	3,844	1,123	29.2	7,930	940	11.9	18,108	740	4.1	33,585	3,329	9.9
1992	4,448	427	9.6	3,879	411	10.6	15,127	736	4.9	28,702	403	1.4	52,156	1,977	3.8
1993	6,190	1,149	18.6	5,556	580	10.4	12,651	653	5.2	37,755	192	0.5	62,152	2,574	4.1
1994	3,796	506	13.3	3,980	364	9.1	10,968	543	5.0	35,089	163	0.5	53,833	1,576	2.9
1995	4,516	620	13.7	4,087	440	10.8	13,072	780	6.0	33,475	310	0.9	55,150	2,150	3.9
1996	5,513	304	5.5	4,777	646	13.5	8,650	373	4.3	45,471	237	0.5	64,411	1,560	2.4
1997	7,411	739	10.0	6,641	539	8.1	20,047	632	3.2	61,053	0	0.0	95,152	1,910	2.0
1998	5,502	608	11.1	5,380	670	12.5	12,158	737	6.1	42,224	0	0.0	65,264	2,015	3.1
1999	11,415	1,516	13.3	8,325	695	8.3	32,050	1,573	4.9	50,189	0	0.0	101,979	3,784	3.7
2000	16,477	1,292	7.8	9,428	1,083	11.5	18,990	1,084	5.7	78,836	0	0.0	123,731	3,459	2.8
2001	11,216	987	8.8	7,473	868	11.6	22,392	567	2.5	51,130	0	0.0	92,211	2,422	2.6
2002	12,641	995	7.9	8,157	944	11.6	19,355	864	4.5	71,753	0	0.0	114,175	3,019	2.6
2003	12,844	1,026	8.0	10,913	700	6.4	41,204	372	0.9	54,552	0	0.0	123,049	2,278	1.9
2004	15,080	1,452	9.6	13,310	978	7.3	34,026	831	2.4	91,443	0	0.0	159,510	3,311	2.1
2005	14,119	953	6.7	11,585	647	5.6	34,675	607	1.8	57,936	267	0.5	126,264	2,517	2.0
2006	13,168	588	4.5	13,683	1,109	8.1	33,222	472	1.4	67,741	289	0.4	131,819	2,499	1.9
2007	11,829	542	4.6	18,832	769	4.1	52,701	684	1.3	90,757	661	0.7	178,970	2,666	1.5
2008	26,385	696	2.6	20,943	794	3.8	47,956	772	1.6	103,095	941	0.9	202,875	3,214	1.6
2009	11,502	625	5.4	16,165	543	3.4	67,940	828	1.2	102,745	399	0.4	201,632	2,454	1.2
2010	9,397	553	5.9	16,944	786	4.6	63,655	696	1.1	79,663	237	0.3	173,301	2,403	1.4
2011	19,849	571	2.9	27,305	464	1.7	80,908	318	0.4	71,088	374	0.5	199,765	1,727	0.9

-continued-

Table 1.–Page 2 of 2.

	Cook Inlet to Soldotna Bridge			Soldotna Bridge to Moose River confluence			Moose River confluence to Skilak Lake outlet			Skilak Lake inlet to Kenai Lake outlet			Kenai River total[a]		
	Catch[b]	Harvest		Catch[a]	Harvest		Catch[b]	Harvest		Catch[b]	Harvest[c]		Catch[b]	Harvest	
Year	No.	No.	%	No.	No.	%	No.	No.	%	No.	No.	%	No.	No.	%
2012	16,119	843	5.2	23,866	878	3.7	47,253	396	0.8	81,349	386	0.5	169,443	2,540	1.5
2013	11,140	464	4.2	13,174	461	3.5	52,992	400	0.8	90,301	446	0.5	168,042	1,771	1.1
2014	12,123	616	5.1	14,216	502	3.5	43,059	273	0.6	69,629	135	0.2	139,193	1,619	1.2
2015	29,097	797	2.7	22,093	534	2.4	67,020	648	1.0	123,441	286	0.2	241,651	2,265	0.9
2016	23,241	834	3.6	25,492	860	3.4	43,042	599	1.4	78,149	169	0.2	170,935	2,462	1.4
2017	18,206	1,526	8.4	17,967	918	5.1	53,884	303	0.6	103,437	830	0.8	193,494	3,577	1.8
2018	10,132	323	3.2	15,302	259	1.7	27,538	219	0.8	48,373	351	0.7	101,485	1,210	1.2
Historical averages															
1984–2018	10,460	747	10.5	10,631	669	10.1	29,168	711	6.9	54,501	357	3.5	105,987	2,511	5.6
2009–2018	16,081	715	4.7	19,252	621	3.3	54,729	468	0.9	84,818	361	0.4	175,894	2,203	1.3
2014–2018	18,560	819	4.6	19,014	615	3.2	46,909	408	0.9	84,606	354	0.4	169,352	2,227	1.3

Source: 1996–present: Statewide Harvest Survey searchable database [Internet]. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited April 2022). Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey. 1984–1995: Mills (1985–1994); Howe et al. (1995, 1996). Catch estimates for 1984–1989 are unpublished estimates from the Statewide Harvest Survey (M Mills, ADF&G, Division of Sport Fish, Research and Technical Services, Anchorage).

[a] For data from 2002 to 2018, numbers by section may not sum to total. Catch and harvest estimates from these years include unspecified reaches.

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

[c] Retention of rainbow trout was prohibited from 1997 through 2004.

[d] In 1984 and 1985, catch estimates were mistakenly reported as harvest in Mills (1985, 1986). Numbers for harvest presented here are correct.

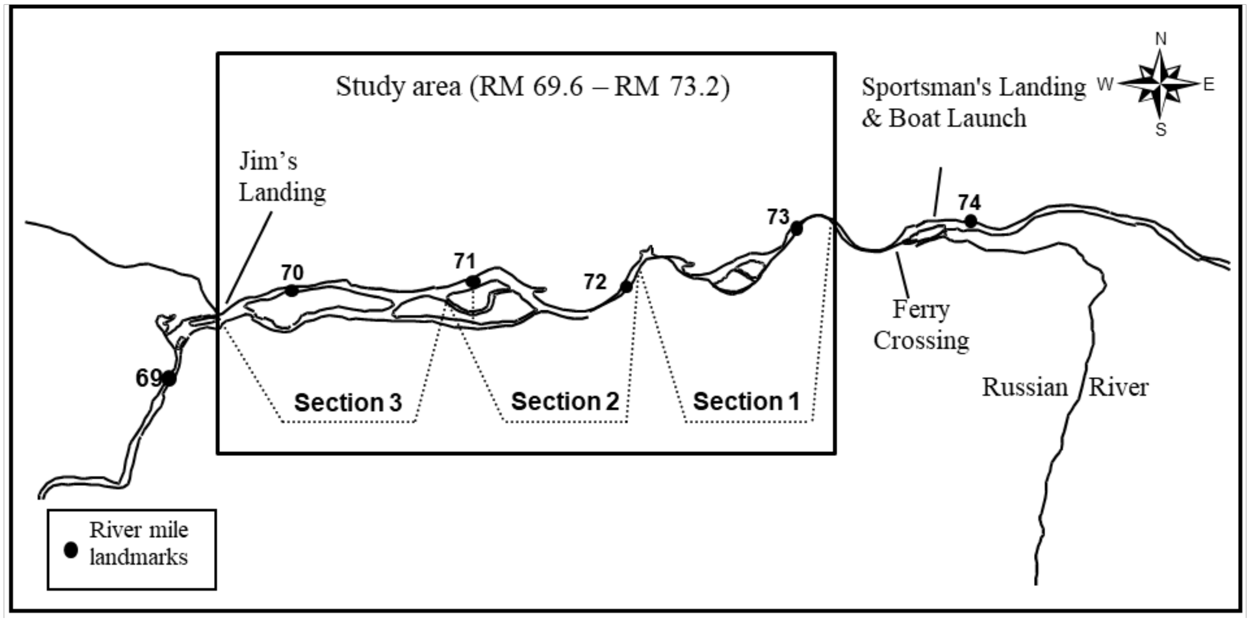

Figure 2.–Rainbow trout stock assessment study area of the upper Kenai River, Alaska.

Table 2.–Regulation summary for the upper Kenai River rainbow trout fishery, 1977–2018.

		Bag limit		
Year	Open season	Daily	Seasonal	Gear restrictions
1977	Entire year	10; Only 2 ≥20 inches	No limit	None
1978	Entire year	10; Only 1 ≥20 inches	No limit	None
1979	Entire year	10; Only 1 ≥20 inches	2 ≥20 inches	None
1980–1981	Entire year	10; Only 1 ≥20 inches	5 ≥20 inches	Artificial lures (1 Jan–31 May)
1982	15 Jun–31 Dec	5; Only 1 ≥20 inches	5 ≥20 inches	None
1983	15 Jun–31 Dec	5; Only 1 ≥20 inches	2 ≥20 inches	None
1984–1986	15 Jun–31 Oct	3; Only 1 ≥20 inches	2 ≥20 inches	Artificial lures only
1987–1988	15 Jun–31 Oct	2; Only 1 ≥20 inches	2 ≥20 inches	Artificial lures only
1989–1990	15 Jun–31 Oct	1; Must be ≥20 inches	2 ≥20 inches	Single hook, artificial lures only
1991–1992	15 Jun–31 Oct	1; Must be ≥24 inches	2 ≥24 inches	Single hook, artificial lures only
1993–1996	15 Jun–31 Oct	1; Must be ≥30 inches	2 ≥30 inches	Single hook, artificial lures only
1997–1998	15 Jun–14 Apr	No retention	No retention	Single hook, artificial lures only
1999–2001	11 Jun–14 Apr	No retention	No retention	Single hook, artificial lures only
2002–2004	11 Jun–1 May	No retention	No retention	Single hook, artificial lures only
2005–2016	11 Jun–1 May	1; Must be <16 inches	No limit	Single hook, artificial lures only
2017–2018	11 Jun–30 Apr	1; Must be <16 inches	No limit	Single hook, artificial lures only

Note: Text with grey shading indicates a new regulation from the previous year. Additional restrictions include the following: 1997–1999 fishing closure between Kenai Lake and Sterling Hwy mile 53 bridge, January 1–June 14; 1999–2001 attractors must be free sliding on leader; 2000–2004 fishing closure between Kenai Lake and Sterling Hwy mile 53 bridge, December 31–June 11; 2002–2018 attractors must be free sliding on leader or fixed on leader within 2 inches of hook.

The rainbow trout population in the index area was evaluated for the first time in 1986 and 1987 (Lafferty 1989) as 1 element of a larger assessment of Kenai River rainbow trout population dynamics for a master's thesis. Hook-and-line techniques and a mark–recapture estimator were used in 1986, whereas boat electrofishing techniques were employed in 1987. Abundance of rainbow trout at least 200 mm fork length (FL) in the index area was estimated to be 3,640 fish (SE 456) in 1986 and 4,950 fish (SE 376) in 1987 (Lafferty 1989). A companion creel survey estimated the exploitation rate to be low and found that catch-and-release angling for rainbow trout was a common practice in that area. The 1986–1987 fishing season was considerably shorter than in previous years (1977–1983), but harvest of fish 20 inches or greater was still allowed (Table 2). Following increasingly restrictive regulations at intervals of every 2–3 years, Hayes and Hasbrouck (1996) estimated the 1995 abundance of rainbow trout at least 300 mm FL in the index area to be 5,598 fish (SE 735) using hook-and-line techniques for fish capture. The authors also reanalyzed the data from 1986 and 1987 (Lafferty 1989) to generate estimates of abundance of rainbow trout at least 300 mm FL during those years. The estimates of rainbow trout at least 300 mm FL were 2,520 fish (SE 363) in 1986 and 3,472 fish (SE 482) in 1987. Estimated population abundance 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 class than in 1987.

Using hook-and-line techniques as well, King and Breakfield (2007) estimated the abundance of rainbow trout at least 300 mm FL in the index area in 2001. The data were reanalyzed by Eskelin and Evans (2013) using modeling techniques that had been unavailable before, revising this estimate to 6,365 (SE 625)[1]. This estimate represented a 14% increase in this size class from 1995 and a 153% and 83% increase from 1986 and 1987, respectively. Abundance of rainbow trout at least 200 mm FL in the index area was 8,553 fish (SE 806). This estimate was 73% larger for this size class than in 1987. Abundance of rainbow trout between 200 mm and 299 mm FL was not assessed in 1995, so no comparison of that size class can be made between 1995 and 2001.

Following the 2001 study, Eskelin and Evans (2013) estimated the abundance of rainbow trout at least 300 mm FL in the index area was 5,106 (SE 431) in 2009. This represented a 20% decrease in this size class from 2001, but this abundance was only 9% lower than the 1995 estimate. The estimate of fish at least 200 mm FL was 5,916 (SE 481) compared to 8,553 (SE 806) in 2001, which represented a 31% decline.

Several indicators warranted another assessment of upper Kenai River rainbow trout. First, the population had declined from 2001 to 2009 for all sizes of fish less than 500 mm. Second, assuming catch-and-release mortality rates remained relatively constant, rainbow trout mortality resulting from catch-and-release fishing was near an all-time high. Third, in recent years, counts of spawning rainbow trout have decreased during ADF&G stream surveys on the lower Russian River, where there is an important spawning aggregate for rainbow trout in the Kenai River watershed (Palmer 1998). Lastly, harvest of rainbow trout less than 16 inches total length (TL) in the upper Kenai River had been allowed for the past 13 years (since 2005; 5AAC 57.120 [6] [c]), which could have impacted the population.

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[1] King and Breakfield's (2007) original 2001 estimate was 6,167 (SE 625).

OBJECTIVES

The 2018 study was conducted to update the stock assessment of upper Kenai River rainbow trout and to evaluate the efficacy of the current management strategy. Results were compared to past surveys. Study objectives were as follows:

1) Estimate the abundance of rainbow trout ≥200 mm FL in the upper Kenai River between Highway Hole (RM 73.2) and Jim's Landing (RM 69.6) from July 2 through August 7, 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 mm FL in the upper Kenai River between the Highway Hole (RM 73.2) and Jim's Landing (MR 69.6) from July 2 through August 7, such that the estimates are within 5 percentage points of the true value 95% of the time.

In addition, the study had the following tasks:

1) Estimate the abundance of rainbow trout ≥200 mm and ≤400 mm FL (approximate harvestable size) in the upper Kenai River between the Highway Hole (RM 73.2) and Jim's Landing (RM 69.6) from July 2 through August 7.

2) Estimate the abundance of rainbow trout ≥300 mm FL in the upper Kenai River between the Highway Hole (RM 73.2) and Jim's Landing (RM 69.6) from July 2 through August 7 for comparison with past studies of abundance.

METHODS

FISH CAPTURE AND SAMPLE SIZE

Rainbow trout were captured in the upper Kenai River between RM 73.2 ("Highway Hole") and RM 69.6 ("Jim's Landing") from 2 July through 7 August 2018. Two 3–4-person crews working from drift boats captured fish using hook-and-line gear and bait. Each crew conducted a single drift per day, fishing with gear (bait, flies, or plugs) from boat or shore and stopping at locations likely to maximize capture. Crews captured and sampled rainbow trout for 3 consecutive days (Monday, Tuesday, Wednesday) per week (event) except during event 1, which coincided with the 4th of July holiday, so sampling was conducted during Tuesday, Wednesday, and Friday during that week. Other than during event 1, no sampling occurred on Fridays, weekends, or holidays to minimize disruption of the sport fishery and to create a 4-day (3 days between events 1 and 2) hiatus to allow mixing of fish between sampling events.

The study area was divided into 3 adjacent sections: Section 1, Highway Hole (RM 73.2) downstream to and including Windy Point area (RM 72.0); Section 2, downstream of Windy Point area to and including Whirlpool Hole area (RM 70.8); and Section 3, downstream of Whirlpool Hole area to Jim's Landing (RM 69.6; Figure 2). Geographic sections from previous rainbow trout studies (1986, 1987, 1995, 2001, and 2009) were used, although there were very slight differences in the boundaries between each study. Time and effort were spread as evenly as possible between sections, but no sampling goals were set for particular sections. An overall weekly sampling goal of 250 fish was determined by simulating mark–recapture estimates over a range of historical abundances (3,000–9,000 fish ≥200 mm).

Upon capture, each fish was guided into a landing net, the hook was removed, and the fish was transferred to a tote of river water, restrained in a tagging cradle (Larson 1995), inspected for previous tags or marks, and measured for fork length (FL; tip of snout to fork of tail). Rainbow trout at least 200 mm FL were marked (tagged) with individually numbered Floy T-Bar Anchor tags, inserted on the left side between the basal rays of the dorsal fin. In addition, the adipose fin was excised on all tagged fish as a secondary mark to assess tag loss. Tagged fish were released immediately near the capture location. Fish were monitored upon release to ensure they were healthy and had gained full mobility to swim away. If a fish did not recover from tagging, was bleeding from the gills, or otherwise deemed unlikely to survive, the marked fish was released, and the tag number was censored (removed from analysis) from the dataset.

Capture and recapture data were recorded on handheld computers. The tag number, fishing hole location, geographic section (1, 2, or 3), fork length, and suspected previous hooking injuries (i.e., mouth or eye damage) were recorded. Time spent fishing in each geographic section was recorded for each crew daily and monitored to distribute fishing effort approximately proportional to area for each event.

Environmental Variables

Daily gauge height (ft), river discharge (CFS), and temperature (ºC) were downloaded from the U.S. Geological Survey (USGS) website at https://waterdata.usgs.gov/nwis/uv?15258000 for use in modeling and also compared to the historical records during years with similar studies (1986, 1987, 1995, 2001, and 2009).

Fish Abundance

Assumptions

The assumptions used with the Schnabel closed population model (Williams et al. 2002) were as follows:

1) *Closed population*: The population was closed to additions (via birth, immigration, or growth) and losses (via death and emigration) during the study period.
2) *No mark loss*: Marks (tags) were not lost between events.
3) *Adequate quality control*: All fish marked and recaptured were correctly identified and recorded, and marking effects were minimized.
4) *Proper model specification*: Abundance estimates from possible unequal capture probabilities by time, length, location, and (or) handling were modeled appropriately and accurately.

Closed Population

Closure violations associated with growth (into or out of size classes) or natural mortality were not expected due to the short study duration. Fisheries-related mortality was likely but expected to have a negligible impact on population size because harvest numbers were likely to be small and catch-and-release mortality should have been low relative to the size of the population. Study dates were chosen to coincide with the summer feeding period of rainbow trout, and the population was expected to be stationary during the study. Several previous studies of rainbow trout in this area have concluded that a closed population assumption was reasonable.

Violations due to immigration and (or) emigration are possible in several forms: migration through the study area, permanent immigration, permanent emigration, and random temporary immigration and emigration. The POPAN modeling framework was used to directly assess the closed population assumption by estimating probability of entrance (describing emigration and recruitment) and survival (describing both mortality and emigration) in addition to the capture probabilities found in a closed population model (see *Proper Model Specification* below). Probability of entrance is defined as a multinomial where each value is the proportion of the total population that entered the study area prior to the second through final events. A suite of models was considered, and Akaike information criterion (AIC) model selection was used to determine if models consistent with the closed population assumption were preferred. For all models considered, capture probabilities were allowed to vary temporally within each of 3 length groups because these factors were found to influence probability of capture in previous studies (Eskelin and Evans 2013).

Two survival relationships were considered: one with an estimated constant survival, and a second with survival assumed to be 100%. The second model is consistent with the closure assumption. Five models were considered for entrance probability: one with probability of entrance varying with time, a second with probability of entrance varying with time and length group, a third with probability of entrance constant, a fourth with fish only entering the study area during the last event (this model was considered biologically likely by ADF&G staff), and one with all fish assumed to be within the study area prior to the first event. The last assumption is consistent with the closed population assumption. Preseason simulation results showed model selection based on standard AIC within an open population modeling framework would successfully detect permanent immigration or emigration rates in excess of 10% whereas 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 have a home range that is larger than the study area and fish move freely within their home range while crossing the study area boundaries essentially at random. In 3 similar studies, results showed moderate movement of fish, with on average about 21% of recaptures occurring in a different subsection from where they were tagged (Hayes and Hasbrouck 1996; King and Breakfield 2007; Eskelin and Evans 2013). Additionally, Palmer (1998) found that of 9 radiotagged fish that were present in the study area from June 25 to August 15, 2 exited the study area from the lower section, and 2 fish also entered the study area on the upper section. In this scenario a closed population estimator is acceptable, but the estimate will be germane to the entire population that used the study area rather than the size of the population within the study area[2].

No Mark Loss

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

Adequate Quality Control

Crews were diligent in looking for previous tags and adipose-finclipped fish prior to tagging or releasing fish. Tag numbers were read closely and spoken clearly by the tagging crew member to the crew member recording the data. To double-check recorded data, the recording crewmember

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[2] 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 $N_0\tau$.

read the tag number back to the tagging crewmember to ensure tag numbers were recorded accurately because this was vital for quality control of accurate assessment.

Captured fish were carefully handled and marked to minimize these effects on the probability of capture in subsequent periods. Fish were processed carefully but also rapidly to minimize stress and potential marking effects.

Proper Model Specification

Closed population mark–recapture models with i capture events use at least 2 descriptive parameters: $\mathbf{p}$, a vector of length i describing the probability of capture during each sampling event, and $\mathbf{c}$, a vector of length $i-1$ describing the probability of recapture during each sampling event. The appropriate model structure was assessed by a combination of past experiences, diagnostic tests, and AIC model selection. The resulting properly specified model is presented in the *Results* section.

Temporal variation in probability of capture

Temporal variability in probability of capture has been found in previous research on this population (Eskelin and Evans 2013) and is indicated by variation in the number of fish caught during each event. Models allowing the probability of capture to vary by capture event were included in our pool of candidate models.

Variation in probability of capture due to size

Size-based variability has been found in previous research on this population (Eskelin and Evans 2013). Differences in size selectivity among time intervals were tested using an Anderson–Darling test (Conover 1999) and by visual examination of cumulative length probability plots over events. We included models commonly referred to as "Huggins models" (Huggins 1989) in our pool of candidate models, which allowed for individual-based variation in probability of capture by length with and without temporal variation.

Geographic variation in probability of capture

Geographic variation in the probability of capture was examined by considering the recapture rate of fish tagged among the 3 sections (3×2 chi-square test: location versus recaptured or not recaptured). If the probability of capture among locations is constant or if fish mix, then the recapture rates among locations should not vary. Mixing of fish among locations was also tested by a 3×3 chi-square test (location versus location). A model where the probability of capture is allowed to vary over sections was included in the candidate pool.

Marking Effects

Catch-and-release mortality was anticipated to be very low during the study because fish were handled with care and obviously stressed or injured fish were censored from the dataset even if they were tagged. Marking effects were included in the candidate model pool by estimating a separate probability of recapture.

LENGTH COMPOSITION

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

$$\hat{\emptyset}_j = \frac{n_j}{n} \tag{1}$$

and

$$\text{var}(\hat{\emptyset}_j) = \frac{\hat{\emptyset}_j(1 - \hat{\emptyset}_j)}{n - 1} \tag{2}$$

where

n_j = the number of rainbow trout ≥200 mm of length class j.

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

When a length-based model (Huggins model with length covariate) was chosen for abundance estimation, estimated length composition was adjusted to account for the implied length selectivity. The proportion of the population in length category j for event i was calculated after weighting each sampled length by the inverse of its estimated probability of capture:

$$\hat{\emptyset}_{ij} = \frac{\sum_{k=1}^{n_i} {}^{1}/_{\hat{p}_{ik}} I(j)}{\sum_{i=1}^{n_i} {}^{1}/_{\hat{p}_{ik}}} \tag{3}$$

where

$\hat{p}_{ik}$ = probability of capture of the kth fish in the sample from event i.

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

The estimated probability of capture ($\hat{p}_{ik}$) was back-calculated from the fitted logit model that described effects of length and time on probability of capture (see Equations 3 and 4, below). The $\hat{\emptyset}_{ij}$ were then combined over events as follows:

$$\hat{\emptyset}_j = \sum_{i=1}^{5} w_i \hat{\emptyset}_{ij} \tag{4}$$

where w_i is the proportion of the total sample taken in event i (5 events total).

The standard error of the adjusted population was estimated through simulation. M bootstrap capture histories were selected and for each, the preferred model was fit to the bootstrapped dataset. The adjusted length compositions (Equation 4) were then calculated for each bootstrap realization. The standard error of the length composition for category j was then calculated as follows:

$$\text{var}(\hat{\emptyset}_j) = \frac{\sum_{l=1}^{M} (\hat{\emptyset}_{jl}^{*} - \bar{\hat{\emptyset}}_j^{*})^2}{M - 1} \tag{5}$$

where

$\widehat{\emptyset}^{*}_{jl}$ = the proportion of the population in length category *j* estimated from bootstrap replicate *l*

and

$$\widehat{\emptyset}_j = \sum_{l}^{M} \widehat{\emptyset}^{*}_{jl} \tag{6}$$

The abundance of rainbow trout by length class was estimated as a product of 2 random variables:

$$\widehat{N}_j = \widehat{N}\widehat{\emptyset}_j \tag{7}$$

and its variance was estimated by Goodman (1960):

$$\text{var}(\widehat{N}_j) = \widehat{N}^2\text{var}(\widehat{\emptyset}_j) + \widehat{\emptyset}_j^2\text{var}(\widehat{N}) - \text{var}(\widehat{\emptyset}_j)\text{var}(\widehat{N}) \tag{8}$$

ABUNDANCE AND LENGTH COMPOSITION COMPARISON TO PAST STUDIES

Overall abundance and abundance by length were compared to results from previous studies in 1986, 1987, 1995, 2001, and 2009 (Lafferty 1989; Hayes and Hasbrouck 1996; King and Breakfield 2007; Eskelin and Evans 2013) to assess the health of the population and to determine effects from regulatory changes.

HOOKING INJURIES

Rainbow trout captured during the last 2 weeks of this study were examined for old healed-over external scars or deformities, especially damage around the head that may be related to previous hooking injuries (e.g., missing maxilla, missing or damaged eye). Only previous healed-over hooking injuries were recorded.

RESULTS

FISH CAPTURE AND SAMPLE SIZE

A total of 2,652 rainbow trout at least 200 mm FL were captured. Tags were applied to 2,387 fish; additionally, 265 previously marked fish were recaptured (Table 3). Among the recaptures, 256 fish were recaptured only once and 9 were recaptured twice. The number of captures was lowest in Event 1 (344 fish), and highest in Event 3 (531 fish) and Event 4 (526 fish). The recapture-to-capture rate showed a steady increase from 0.03 in Event 2 to 0.17 in Event 5, then a similar rate at 0.16 in Event 6 (Table 3). Proportion of recaptures from the tagged fish population "at large" and available for recapture during an event increased from 0.03 in Event 2 to 0.06 in Event 3 and then steadily declined back down to 0.03 by Event 6.

Table 3.–Capture history of upper Kenai River rainbow trout at least 200 mm FL in the upper Kenai River index area, 2 July–8 August 2018.

	Event[a]						
Statistic	1	2	3	4	5	6	Total
Captures	344	419	531	526	397	435	2,652
New tags	344	407	484	459	328	365	2,387
Recaptures		12	47	67	69	70	265
At large[b]		344	751	1,235	1,694	2,022	2,022
Recapture per capture		0.03	0.09	0.13	0.17	0.16	
Recapture per at large		0.03	0.06	0.05	0.04	0.03	

[a] Dates sampled during event: (1) 2–3 July and 6 July, (2) 9–11 July, (3) 16–18 July, (4) 23–25 July, (5) 30 July–1 Aug, (6) 6–8 August.

[b] "At large" is the number of tagged fish available for recapture during an event.

Section 1 had the most captures (1,153) followed by Section 2 (846) and Section 3 (653; Table 4). The proportion of all recaptures followed this same pattern (Table 4). The proportion recaptured in each section with respect to the number captured in each section was also highest for Section 1 (0.11), followed by Section 2 (0.10) and Section 3 (0.07; Table 4).

Table 4.–Number and proportion of rainbow trout at least 200 mm FL, tagged and recaptured by river section in the upper Kenai River index area, 2 July–8 August 2018.

River section[a]	Captures	New tags	Recaptures	Proportion recaptured	Proportion of all recaptures	Proportion of all captures
1	1,153	1,022	131	0.11	0.49	0.43
2	846	760	86	0.10	0.32	0.32
3	653	605	48	0.07	0.18	0.25

[a] Section 1 = RM 72.0–73.2; Section 2 = RM 70.8–72.0; Section 3 = RM 69.6–70.8.

ENVIRONMENTAL VARIABLES

River discharge (U.S. Geological Survey gauging station at Cooper Landing) varied about 33% during the 6-week study. Discharge was near the historical 1948–2017 mean at the beginning of the study, increased and peaked in Event 2, then decreased to below average for Events 3 and 4, and went back near the historical average for Events 5 and 6 (Figure 3).

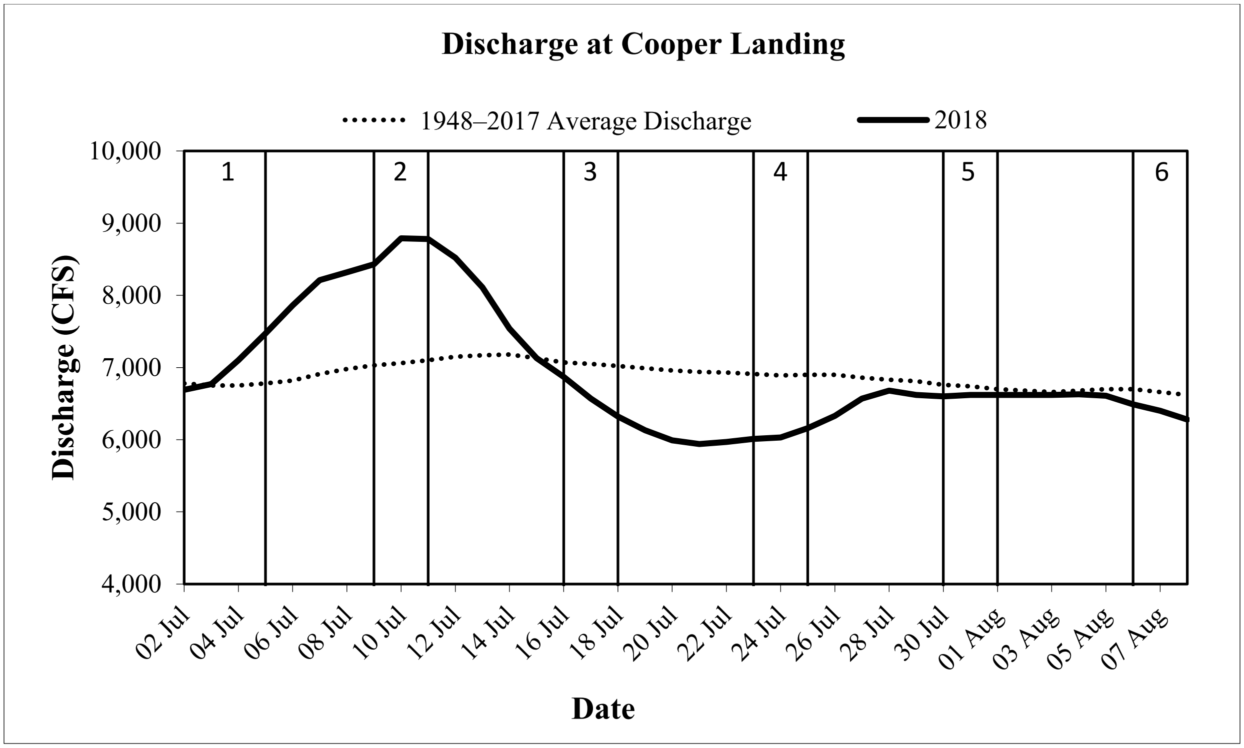

Figure 3.–Kenai River discharge at Cooper Landing, 2 July–8 August 2018.

ASSUMPTIONS

Closed Population

The proportion of recaptures with respect to captures increased through most of the study, except the recapture rate for Event 5 (0.17) was slightly higher than for Event 6 (0.16; Table 3). A general increase through time in the recapture rate supports the closed population assumption. A chi-square test of the hypothesis that the recapture rate was equal among the three river sections was not rejected ($\chi^2 = 3.3$, df = 2, $P = 0.20$) despite decreasing downstream recapture rates by river section (Table 4). In addition, there was some migration between river sections. The proportions of recaptures that occurred outside the original capture section were 0.10, 0.27, and 0.17, respectively, for Sections 1–3 (Table 5). In total, 17% of recaptures were of fish outside the river section they were tagged (Table 5).

The POPAN modeling framework was used to directly assess the closed population assumption using a suite of 10 candidate models. Four models accounted for more than 98% of AIC weight. The first (40% of the AIC weight) and third (15% of the AIC weight) were consistent with the closed population assumption, whereas the second- (34% of the AIC weight) and fourth- (10% of the AIC weight) ranked models both included small amounts of immigration. In the second-ranked model, 75% of the population was in the study area prior to the first event and 5% entered the study area prior to each subsequent event. Estimated abundance for the second-ranked model was 7.5% higher than the estimated abundance for the highest-ranked model. In the fourth-ranked model, the largest and smallest size classes were closed populations but 74% of the middle size class (300–399 mm FL) was in the study area prior to the first event and 26% entered the study area prior to the final event. Estimated abundance for the fourth-ranked model was 11.5% higher than estimated abundance for the highest-ranked model. Considering that 55% of the AIC weight is on models consistent with the closed population assumption and that models inconsistent with closure contain modest violations, it was justified to consider the population closed.

Table 5.–Movement of rainbow trout at least 200 mm FL between river sections in the upper Kenai River index area, 2 July–8 August 2018.

River section of capture[a]	River section of recapture			Total recaptures	Number outside original capture section	Proportion outside original capture section
	1	2	3			
1	118	10	3	131	13	0.10
2	9	63	14	86	23	0.27
3	1	7	40	48	8	0.17
Total	128	80	57	265	44	0.17

[a] Section 1 = RM 72.1–73.2; Section 2 = RM 71.0–72.1; Section 3 = RM 69.6–71.0.

No Mark Loss

Nearly all recaptures in the study had an attached Floy tag. There were a few (7) instances where fish were observed with freshly clipped adipose fins and holes where the tag was inserted but the fish did not bear a tag. In those cases, the fish either lost the tag naturally or the tag was pulled out by an angler (which anglers have reported doing in this fishery). Fish that were determined to have lost the tag were retagged and considered a new capture in the analysis.

Adequate Quality Control

There were a few (19) marked fish where length was either not recorded accurately at the time of tagging or not recorded accurately when recaptured and it was not possible to determine in which event this phenomenon happened. In these instances, the sample average length was used as a surrogate. Fish were released shortly after capture to minimize any handling effects.

Proper Model Specification

The number of rainbow trout captured during each event varied between 344 in event 1 and 531 in event 3, which is a strong indication that probability of capture varied between capture events (Table 3).

The proportion recaptured was not significantly different among 100 mm FL length categories (Table 6; $\chi^2 = 6.1$, df = 3, $P = 0.11$). For the entire study, the proportion recaptured increased with each increasing length group from 0.066 for fish in the 200–299 mm FL range to 0.137 for fish greater than 500 mm FL (Table 6). Although the recapture rates for different length categories were not significantly different, the increasing trend was similar to the 2009 study, which did document selective capture towards larger fish via recapture rate by length group.

Table 6.–Number of rainbow trout captured, number recaptured, and proportion recaptured by length category (100 mm increments) in the upper Kenai River study area, 2 July–8 August 2018.

Length group (mm)	Number captured	Number recaptured	Total	Proportion recaptured
200–299	398	28	426	0.066
300–399	1,267	134	1,401	0.096
400–499	659	77	736	0.105
≥500	44	7	51	0.137
Total	2,368	246	2,614	0.094

An Anderson–Darling *k*-sample test was used to test the hypothesis that the length distribution across the 6 events was similar. The test was significant ($t = 7.3$; $P \approx 0$), suggesting that capture selectivity due to length changed during the study. Overall, fish were smaller in the last event than in any other event and fish were largest in Event 2 (Figure 4). Given that fish size distribution varied by event, any effect of size on the probability of capture may have also varied throughout the experiment.

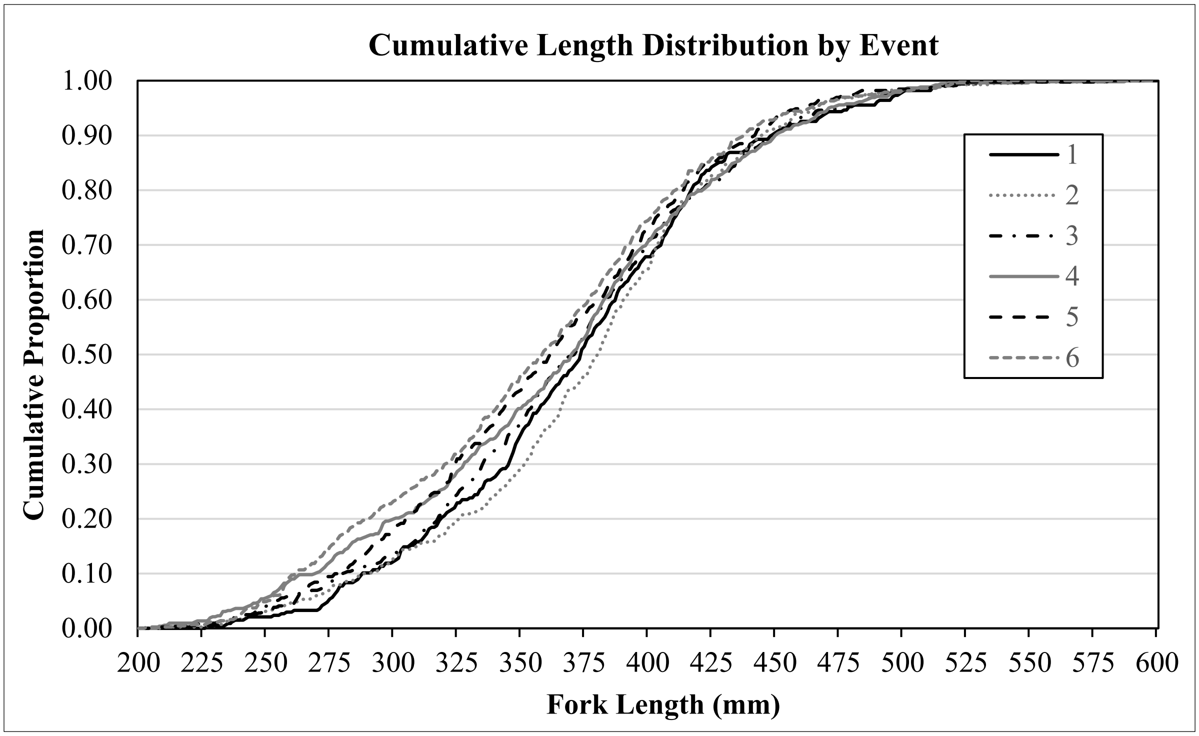

Figure 4.–Cumulative length distributions of captured rainbow trout during each event in the upper Kenai River index area, 2 July–8 August 2018.

Based on the results above, we estimated 6 candidate closed population models: constant probability of capture p(~1), time varying probability of capture p(~time), probability of capture as a function on length p(~lg), probability of capture as a function of length and time without interactions p(~time + lg), probability of capture as a function of length and time with interactions p(~time * lg), and p(~loc2 + loc3) different probabilities of capture based on the initial capture location (Table 7). The model including probability of capture as a function of length and time with interactions p(~time * lg) carried nearly 100% of the AIC weight. These results were similar to those in the 2009 study by Eskelin and Evans (2013).

Table 7.–Model selection criteria for 6 closed population models used to estimate the abundance of rainbow trout in the Upper Kenai River, 2018.

Model rank	Model description	Number of parameters	AICc	DeltaAICc	Weight	Deviance
1	p(~time * lg)	12	10,664.43	0	1	10,640.40
2	p(~time + lg)	7	10,680.68	16.26	<0.00	10,666.67
3	p(~time)	6	10,683.97	19.54	<0.00	32,414.47
4	p(~loc2 + loc3)	3	10,725.28	60.85	<0.00	10,719.28
5	p(~lg)	2	10,734.88	70.45	<0.00	10,730.88
6	p(~1)	1	10,738.16	73.74	<0.00	32,478.67

Note: AICc is the Akaike information criterion for small sample sizes.

The selected model (rank 1 in Table 7) described the relationships between probability of capture, length, and event explicitly using logistic regression. Equation 8 was the probability of capture for fish *i* during the first event (p_{1i}) as dictated by the chosen model:

$$\log\left(\frac{p_{1i}}{1-p_{1i}}\right) = \alpha_1 + \beta_1(L_i) \tag{8}$$

where L_i is the length of fish *i*. Equation 9 was the probability of capture for fish *i* during the event *j* (where *j* = 2 to 6) as dictated by the chosen model:

$$\log\left(\frac{p_{ji}}{1-p_{ji}}\right) = \alpha_1 + \alpha_j + \left(\beta_1 + \beta_j\right)(L_i) \tag{9}$$

Logistic regression parameter estimates are shown in Table 8. The fitted model indicated that length had a positive effect on capture probability for the first 4 events but declined to a negligible effect for the fifth and sixth events (Figure 5).

Table 8.–Parameter estimates for model chosen to estimate rainbow trout abundance ≥200 mm in the upper Kenai River index area, 2 July–8 August 2018.

Parameter	Estimate	SE	95% CI Lower	95% CI Upper
α_1	−4.7631	0.4720	−5.6883	−3.8380
α_2	−0.0365	0.4425	−0.9037	0.8307
α_3	0.7704	0.4184	−0.0497	1.5905
α_4	1.2004	0.4172	0.3827	2.0181
α_5	1.1502	0.4401	0.2876	2.0129
α_6	1.7628	0.4300	0.9201	2.6056
β_1	0.0038	0.0012	0.0013	0.0062
β_2	0.0006	0.0012	−0.0016	0.0029
β_3	−0.0009	0.0011	−0.0030	0.0013
β_4	−0.0021	0.0011	−0.0042	0.0001
β_5	−0.0027	0.0012	−0.0051	−0.0004
β_6	−0.0042	0.0012	−0.0065	−0.0019

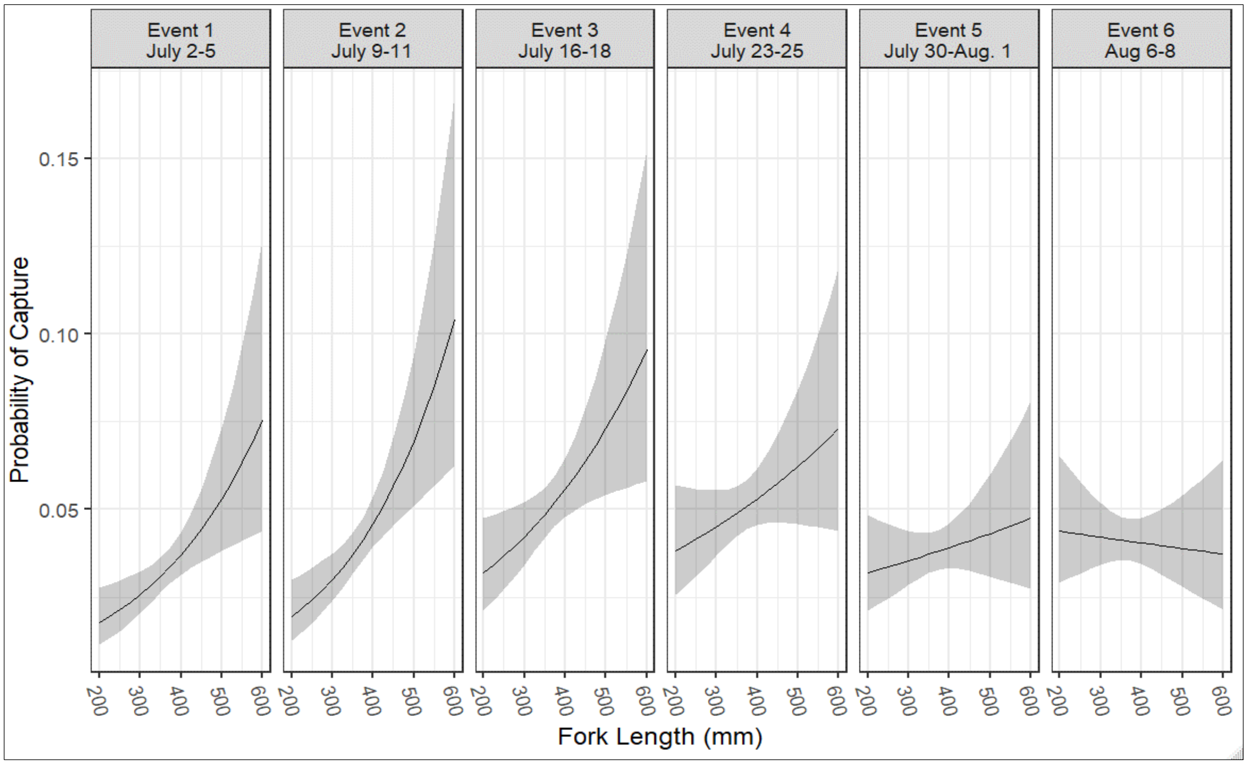

Figure 5.–Predicted probability of rainbow trout capture vs. fork length for each event of initial capture in the upper Kenai River index area, 2 July–8 August 2018.

Note: Shaded grey areas show predicted 90% credibility intervals of predicted probability of capture by length.

LENGTH COMPOSITION

Length compositions are presented as raw and adjusted proportions (Table 9); the adjustment was needed to account for differences in probability of capture based on fish length. Sampling was slightly selective towards larger-sized fish, so adjustments were required to account for that selectivity. The resulting adjustments increased the estimated number and proportion of rainbow trout less than 350 mm FL and conversely decreased the estimated number and proportion of fish at least 350 mm FL in the population. Only adjusted abundance and length statistics are reported hereafter.

Table 9.–Estimated abundance and proportion of rainbow trout by fork length group in the upper Kenai River study area, 2 July–8 August 2018.

Length category (mm)	Number caught	Raw proportion[a] Estimate	Raw proportion[a] SE	Adjusted proportion[b] Estimate	Adjusted proportion[b] SE	Abundance[c] Estimate	Abundance[c] SE
200–249	94	0.04	0.00	0.05	0.00	526	52
250–299	304	0.13	0.01	0.15	0.01	1,560	115
300–349	515	0.22	0.01	0.23	0.01	2,450	167
350–399	771	0.32	0.01	0.32	0.01	3,340	217
400–449	494	0.21	0.01	0.18	0.01	1,949	142
450–499	165	0.07	0.01	0.06	0.01	594	65
500–549	40	0.02	0.00	0.01	0.00	138	29
550–599	4	0.00	0.00	0.00	0.00	11	9
Totals							
≥200	2,387	1.000	–	1.000	–	10,568	–
≥300	1,989	0.833	0.008	0.802	0.017	8,482	–
<400[d]	1,684	0.705	0.009	0.746	0.028	7,876	–

[a] Raw proportions represent actual catch.

[b] Adjusted proportions account for length selectivity (see Equation 3).

[c] Estimates of abundance are based on adjusted proportions.

[d] 400 mm FL is a close approximation of 16 inches total length (TL). Rainbow trout less than 16 inches TL are susceptible to harvest.

FISH ABUNDANCE

For the upper Kenai River study area in 2018, the preferred model gave an abundance estimate for rainbow trout at least 200 mm FL as 10,568 fish (SE 608; 95% CI 9,458–11,851 fish; Table 10). The estimated density of rainbow trout at least 200 mm FL in the study area was approximately 1,824 fish/RKM or 2,935 fish/RM.

Abundance of rainbow trout at least 300 mm FL was estimated to be 8,482 fish (SE 495; 95% CI 7,516–9,572 fish; Table 10). Abundance of fish at least 300 mm FL was calculated as the product of the estimated proportion of fish at least 300 mm FL (0.802; Table 9) and the overall abundance of fish at least 200 mm FL (Table 10). The estimated density of rainbow trout at least 300 mm FL in the study area was approximately 1,463 fish/RKM or 2,356 fish/RM.

ABUNDANCE AND LENGTH COMPOSITION COMPARISON TO PAST STUDIES

Estimated abundance of fish in 2018 was considerably higher than results from any previous study for both fish at least 200 mm and those at least 300 mm FL (Table 10 and Figure 6). For rainbow trout at least 200 mm FL, the 2018 abundance estimate (10,568 fish) was between 24% (8,553 in 2001) and 190% (3,640 in 1986) larger than previous studies (Table 10). Abundance of fish in the 200–299 mm length range was not estimated in 1995. For rainbow trout at least 300 mm FL, the 2018 abundance estimate (8,482 fish) was between 33% (6,365 in 2001) and well over 200% (2,520 in 1986) larger than previous studies (Table 10).

Table 10.–Historical abundance estimates of rainbow trout in the upper Kenai River index area, 1986–2018.

	Number of rainbow trout			
Year	≥200 mm	SE	≥300 mm	SE
1986	3,640	456	2,520	363
1987	4,950	376	3,472	482
1995	NA	NA	5,598	735
2001	8,553	806	6,365	625
2009	5,916	481	5,106	431
2018	10,568	608	8,482	495

Source: 1986, 1987, 1995: Hayes and Hasbrouck (1996); 2001, 2009: Eskelin and Evans (2013).

Note: NA means not available.

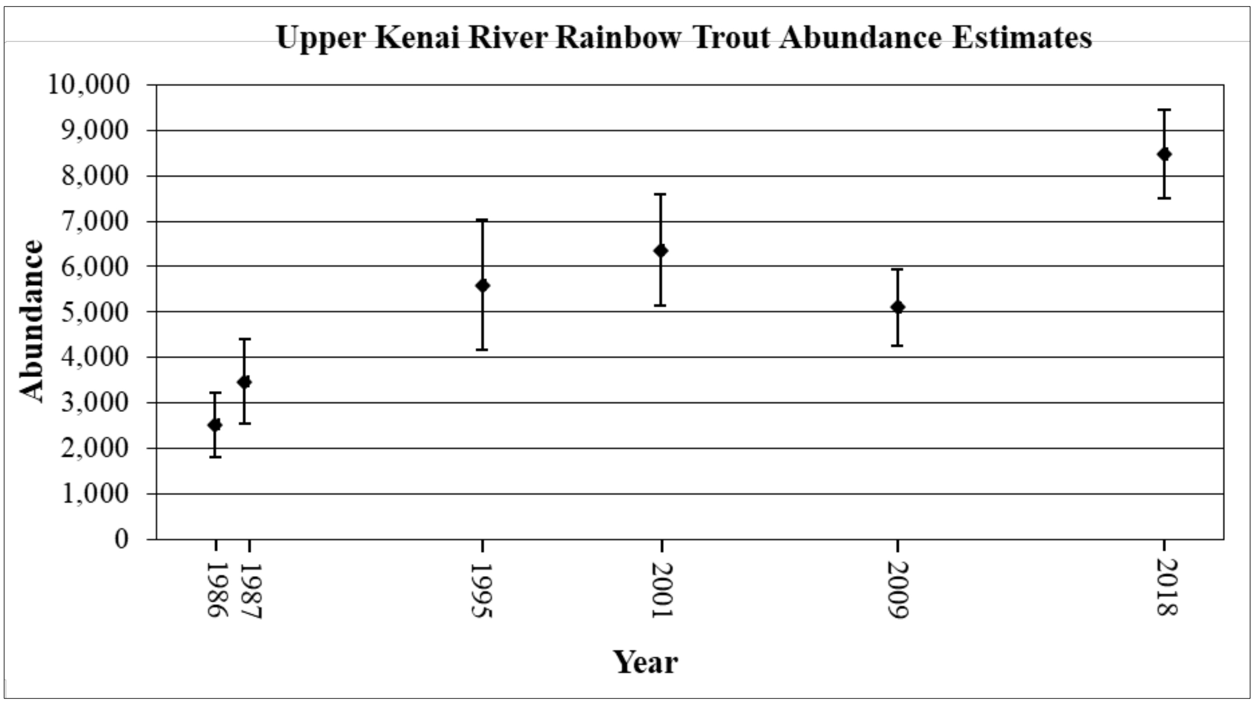

Figure 6.–Historical rainbow trout abundance estimates for fish ≥300 mm in the upper Kenai River index area, 1986–2018.

Note: Error bars show 95% confidence intervals.

Considering only fish ≥300 mm, the 2018 length composition was similar to the 1986 and 1987 studies but skewed towards smaller fish compared to the 1995, 2001, and 2009 studies (Figure 7). In 2018, a large proportion (0.39) were in the 350–399 mm length category, which was higher than in any other study (Table 11). Conversely, the proportion 450 mm and longer was only 0.09 in 2018, compared to the prior minimum of 0.18 in 1986; the proportion of fish 450 mm and longer was as large as 0.34 in 2009 (Table 11). The proportion of fish 500 mm and longer estimated in 2018 was only 0.02, whereas that proportion was 0.08 or larger in all other study years (Table 11).

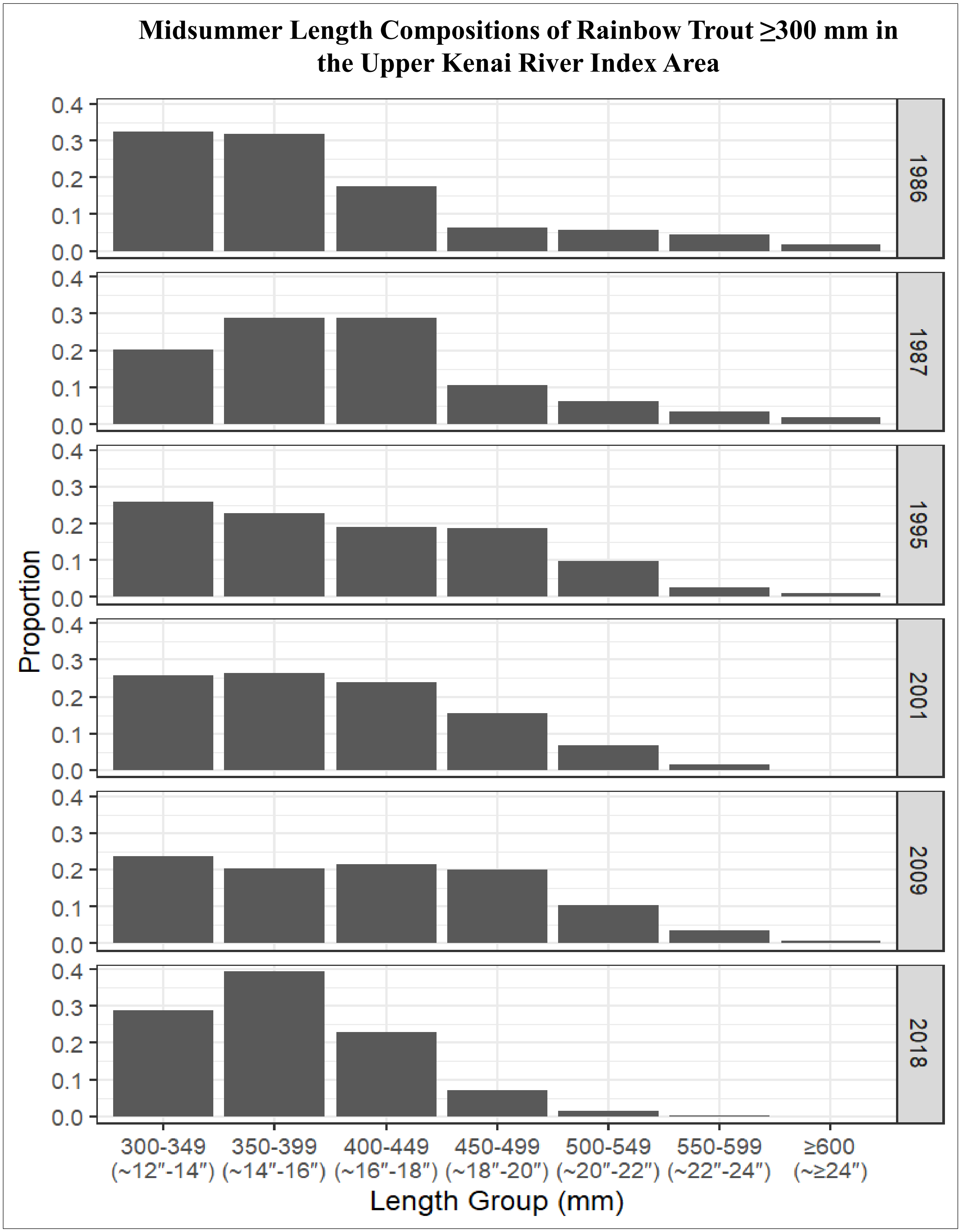

Figure 7.–Length composition estimates of rainbow trout ≥300 mm by category in 50 mm length increments for the upper Kenai River index area, 1986, 1987, 1995, 2001, 2009, and 2018.

Table 11.–Estimated abundance of rainbow trout (≥200 mm) and proportion by year and length group (≥300 mm) in the upper Kenai River index area, 1986–2018.

		Year					
Estimate	Length (mm)	1986	1987	1995	2001	2009	2018
Abundance (SE[a])							
	200–249	NA	NA	NA	570 (78)	172 (44)	526 (52)
	250–299	NA	NA	NA	1,284 (145)	639 (93)	1,560 (115)
	300–349	821	697	1,449	1,729 (186)	1,213 (136)	2,450 (167)
	350–399	801	1,009	1,277	1,771 (190)	1,029 (110)	3,340 (217)
	400–449	444	1,009	1,070	1,609 (175)	1,106 (111)	1,949 (142)
	450–499	158	368	1,050	1,032 (122)	1,018 (113)	594 (65)
	500–549	143	212	539	462 (67)	527 (73)	138 (29)
	550–599	112	117	146	96 (25)	177 (33)	11 (9)
	≥600	41	61	66	0 (0)	35 (12)	0 (0)
Abundance at length or larger							
	200–249	NA	NA	NA	8,553	5,916	10,568
	250–299	NA	NA	NA	7,983	5,744	10,043
	300	2,520	3,473	5,597	6,699	5,106	8,482
	350	1,699	2,776	4,148	4,970	3,893	6,032
	400	898	1,767	2,871	3,199	2,863	2,692
	450	454	758	1,801	1,590	1,757	743
	500	296	390	751	558	740	149
	550	153	178	212	96	213	11
	600	41	61	66	0	35	0
Proportion[b]							
	300–349	0.33	0.20	0.26	0.26	0.24	0.29
	350–399	0.32	0.29	0.23	0.26	0.20	0.39
	400–449	0.18	0.29	0.19	0.24	0.22	0.23
	450–499	0.06	0.11	0.19	0.15	0.20	0.07
	500–549	0.06	0.06	0.10	0.07	0.10	0.02
	550–599	0.04	0.03	0.03	0.01	0.03	0.00
	≥600	0.02	0.02	0.01	0.00	0.01	0.00
Proportion at length or larger[b]							
	300	1.00	1.00	1.00	1.00	1.00	1.00
	350	0.67	0.80	0.74	0.74	0.76	0.71
	400	0.36	0.51	0.51	0.48	0.56	0.32
	450	0.18	0.22	0.32	0.24	0.34	0.09
	500	0.12	0.11	0.13	0.08	0.14	0.02
	550	0.06	0.05	0.04	0.01	0.04	0.00
	600	0.02	0.02	0.01	0.00	0.01	0.00

[a] Standard error (SE) given in parentheses where available.

[b] Abundance for the 200–299 mm FL size categories were only estimated for 2001, 2009, and 2018. Therefore, proportions and proportions at length or larger are only presented for size categories 300 mm and larger for comparison among years.

In 2018, the abundances of fish in both the 300–349 mm and 350–399 mm size categories were considerably greater than any other year (Figures 8 and 9). Abundance of fish in the 300–399 mm length range in 2018 (5,790 fish) was over 150% higher than the 2009 study (2,242) and 65% higher than the 2001 study (3,500; calculated from Table 11). Abundance of fish 400 mm and longer in 2018 (2,692 fish) was comparable to the 3 other recent studies: 2,871 fish in 1995; 3,199 fish in 2001; and 2,863 fish in 2009 (Table 11). However, abundance of fish 450 mm and longer dropped greatly in 2018 (743 fish) compared to the 3 other recent studies: 1,801 fish in 1995; 1,590 fish in 2001; and 1,757 fish in 2009 (Table 11). Estimated abundance of fish 500 mm and longer was only 11 fish, which was approximately 95% less than what was observed in 1995 (212 fish) and 2009 (213 fish) and about 89% less than estimated abundance in 2001 (96 fish). Abundance of fish in the 200–299 mm length range in 2018 (2,086 fish) was considerably larger than the 2009 study (810 fish) but near the 2001 study (1,855 fish; calculated from Table 11).

A fork length of 400 mm is a close approximation to 16 inches TL, which is the length cutoff for harvest as defined in regulation. Approximately 75% (7,876 out of 10,568 fish) of the population of rainbow trout in 2018 fell into the 200–399 mm FL categories and were therefore susceptible to harvest (calculated from Table 11). The estimated proportion of the population between 200 and 399 mm was much larger in 2018 than in 2001 (0.63; 5,355 out of 8,554 fish) and 2009 (0.52; 3,053 out of 5,916 fish; calculated from Table 11).

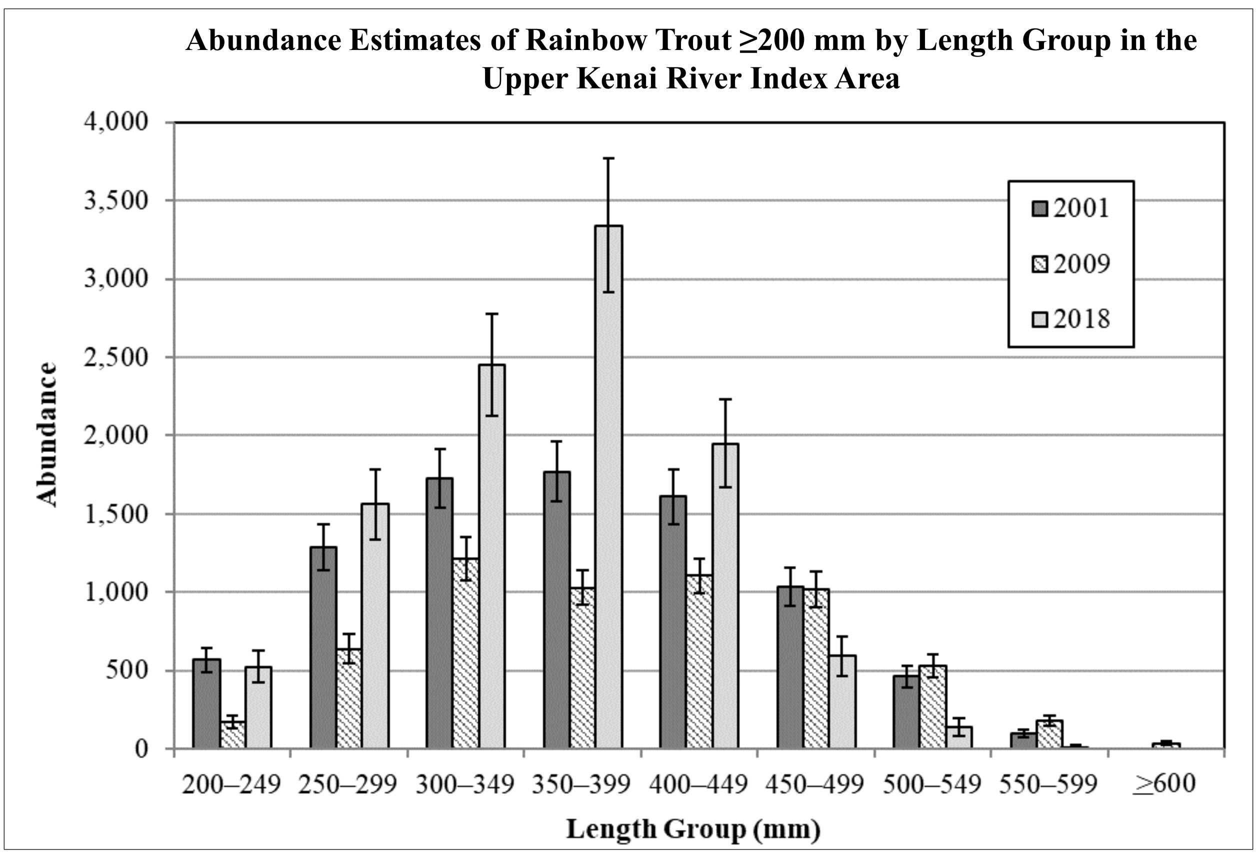

Figure 8.–Abundance of rainbow trout ≥200 mm by length group in the upper Kenai River index area, 2001, 2009, 2018.

Note: Error bars show 95% confidence intervals.

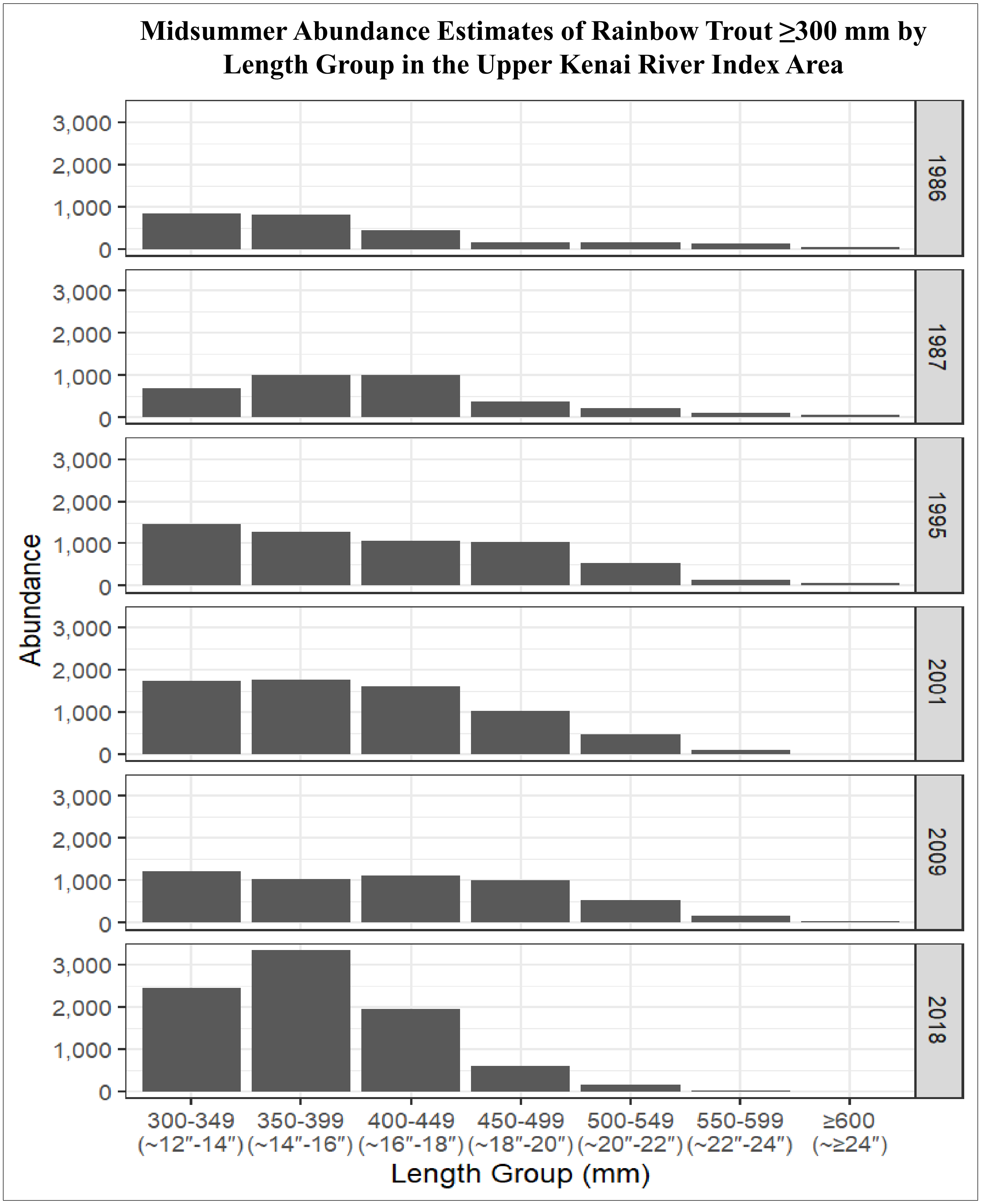

Figure 9.–Estimated abundance of rainbow trout ≥300 mm by length group in the upper Kenai River index area, 1986–2018.

HOOKING INJURIES

In 2018, a total of 849 rainbow trout at least 200 mm FL were examined for previous hooking injuries. Hooking injury was suspected in 524 fish (62% of the sample; Table 12). The proportion of rainbow trout observed with a hooking injury generally increased with fish size (Table 12).

Table 12.–Number of rainbow trout ≥200 mm FL sampled by length group (total sample), and number and proportions of sampled fish observed with suspected previous hooking injuries by length group, 2018.

	Injury			Proportion
Length group (mm)	No	Yes	Total sample	with injury
200–249	17	16	33	0.48
250–299	75	59	134	0.44
300–349	86	120	206	0.58
350–399	82	167	249	0.67
400–449	52	114	166	0.69
450–499	10	37	47	0.79
500–549	3	10	13	0.77
550–599	0	1	1	1.00
Total	325	524	849	0.62

DISCUSSION

This study assessed the stock status of upper Kenai River rainbow trout and involved estimating abundance and length composition. Possible relationships between abundance and length composition were examined, the proportion of the population susceptible to harvest under the current management strategy was estimated, and comparisons of abundance and length composition to past studies were made.

Abundance of rainbow trout in the upper Kenai River index area was the highest observed in any of the six studies conducted since 1986, although almost 90% of the population was composed of smaller-sized fish less than 450 mm (approximately 18 inches TL), and there were fewer larger-sized fish (450 mm or longer) than in any of the studies in 1995, 2001, and 2009. The very large portion of 350–399 mm fish (approximately 14–16 inches TL) was an anomaly compared to past studies. There were twice as many fish in that size range compared to 2001, and over 3 times as many compared to any of the other studies.

Overall, midsummer abundance in the upper Kenai River index area remains well above levels seen in the mid to late 1980s and the number of fish capable of spawning (generally 400 mm and longer) in 2018 was comparable to estimates from the 1995, 2001, and 2009 studies and was well above what was observed in 1986 and 1987. This is likely from regulation changes that reduced, then eliminated harvest of spawning-sized fish.

The high abundance of smaller-sized fish, especially those fish in the 300–399 mm length range could be an indication of a healthy robust population that will produce many large fish as the cohort ages. However, the low abundance of large fish 450 mm and longer and especially fish 500 mm and longer could be an indication that the population is impacted by fishing such that many fish do not survive to a large size due to the cumulative effects of catch-and-release mortality. This is further supported by the increase in the proportion of fish with hooking injuries seen on larger fish (Table 12).

The high proportion of fish with a suspected previous hooking injury is a sign of the substantial fishing effort exerted by the highly popular sport fishery. Based on ADF&G's statewide harvest survey estimates, the recent 10-year average annual catch of rainbow trout in the entire upper Kenai River between Kenai and Skilak Lakes was approximately 85,000 fish (Table 1). The population size of rainbow trout for the entire upper Kenai River is unknown and the population size for the index area has only been estimated during midsummer, so how catch relates to abundance is unknown. However, given that catch of rainbow trout is high, it is possible that the average rainbow trout in the upper Kenai River is caught multiple times every year. In 2018, almost half of fish less than 300 mm were observed with a suspected hooking injury, which is a further indication of high impact from fishing because those fish just recently recruited to the fishery and catch-and-release mortality is suspected to be low. However, the cumulative effects of catch-and-release mortality can become substantial even under a low "per event" rate. If we assume each catch-and-release event in an independent Bernoulli trial, the negative binomial distribution approximates the probability of survival as a function of catch-and-release mortality and the number of times a fish is captured and released (Figure 10).

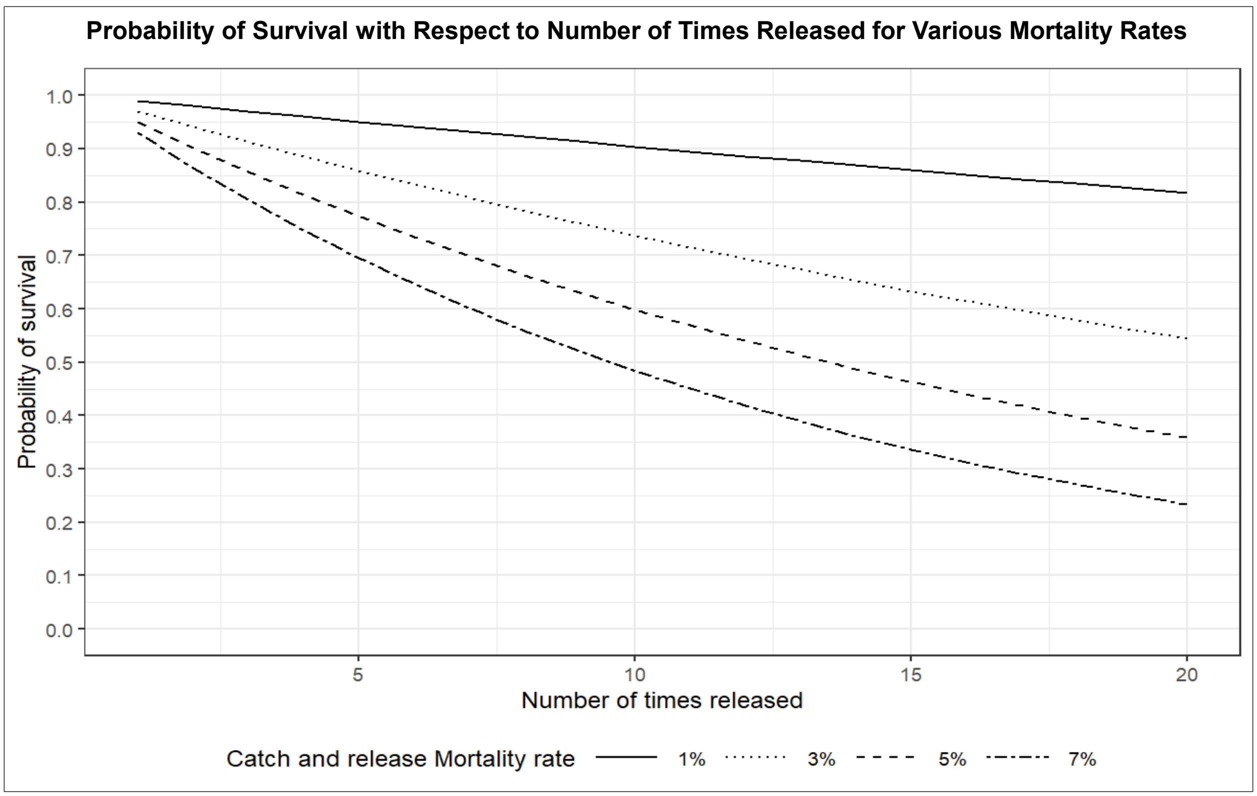

Figure 10.–Estimated probability of survival (negative binomial distribution) based on number of times a fish is caught and released based on 4 catch-and-release mortality rates.

The catch-and-release mortality rate of upper Kenai River rainbow trout is not known, and it is not known how the mortality rate may be different for fish of different sizes or how it changes due to other factors such as water temperature or time of year. Although catch-and-release mortality of rainbow trout in the upper Kenai River does not appear to be significantly impacting abundance, the effects of catch-and-release mortality may be impacting the size and age structure of the population (i.e., the low abundance of larger-sized fish). If fish have a high probability of being caught, and multiple catch-and-release events decrease probability of survival, it is plausible that few rainbow trout would survive to reach large trophy size. A Colorado study of postrelease hooking mortality for rainbow trout estimated a mortality rate between 1% and 14% for fly-caught fish (Schisler and Bergersen 1996). If catch-and-release mortality in the Kenai River study area was 3%, for example, and a fish was caught 10 times, then as estimated in Figure 10, it may only have a 75% chance of surviving the 10th hooking. If mortality was 7%, survival would be reduced to about 50% after the 10th hooking.

The regulatory change that has allowed harvest of fish less than 16 inches since 2005 does not appear to have caused a decline in population size. The recent 10-year average estimate of rainbow trout harvest in the upper Kenai River is 361 fish (Table 1). Impacts from catch-and-release mortality are probably much larger than directed harvest from sport fishing. Based on the statewide harvest survey estimates of catch, even a modest catch-and-release mortality rate of 3% would result in an average mortality of 2,700 fish annually in the upper Kenai River. Furthermore, nearly all harvest of spawning-sized fish (generally those about 400 mm and longer) is prevented by regulation because harvest is not allowed for fish 16 inches or longer in total length (392 mm), whereas catch-and-release mortality impacts fish of all sizes. In addition, a very high proportion of anglers practice catch-and-release angling for Kenai River rainbow trout regardless of imposed regulations. Because of this, it is doubtful that harvest would increase substantially even if catch increased and even though a high proportion of the population is susceptible to harvest because of the current size structure and liberal regulations (i.e., no annual limits of legal-sized fish). Furthermore, harvest may compensate for some catch-and-release mortality if some fish were harvested only because they were unintentionally harmed by the angler and were likely to die if released.

Due to the length of time between upper Kenai River rainbow trout assessments (the last 3 occurring almost a decade apart), determining the population dynamics and relationships between abundance and length composition of this stock is difficult. However, it is evident that the upper Kenai River rainbow trout population is healthy even though there were not many larger trophy-size fish in the population in midsummer at the time of the 2018 study. The degree to which natural processes such as floods, salmon escapements, water temperature, predation, and other factors affect survival and recruitment is unknown, further confounding a good fundamental understanding of the population dynamics of the upper Kenai River rainbow trout population. More similar studies are warranted in the next several years to increase understanding of the population dynamics of this highly popular and famed rainbow trout fishery. A multi-year study would garner much more pertinent information regarding the factors affecting population dynamics such as overwinter survival, recruitment, spawning abundance, and cohort-based relationships.

The sampling selectivity towards larger fish through time detected in this study was similar to the 2009 study except that size selectivity correlated with water level in 2009 but did not correlate with water level in 2018. Sampling selectivity toward larger fish was strong in the first 3 events, decreased in the 4th event, and was minimal to nonexistent in the 5th and 6th events. Whereas water level was average in the 1st, 5th, and 6th events, it was above average in the 2nd event and below average in the 3rd and 4th events. Eskelin and Evans (2013) surmised that selectivity for larger fish in 2009 occurred more during periods of low water when all fish were easily accessed and the selectivity of rod-and-reel gear for larger fish was more pronounced. Selectivity would then diminish when water levels increased, because it was more difficult to effectively fish the faster, deeper water and because smaller fish may be pushed closer to shore, making them more easily susceptible to capture from the bank or from boats close to the bank. In this study, selectivity for larger fish was still prevalent during the brief high-water event during Event 2.

Size selectivity detected in both the 2009 and 2018 studies could have been partly due to both angling techniques and areas fished. Attempts were made to sample all areas (nearshore, offshore, and side channels) representatively for the entire length of the study, but it is difficult to standardize methods because the habitat is too variable to have a clear definition of nearshore vs offshore and the definition would not apply to all sites. Crews may have tended to fish further offshore, possibly beyond some smaller fish located closer to the banks. In both the 2009 and 2018 studies, it seemed that areas near shore or up against cut banks were targeted more often later in the study once crews had learned more about where fish were distributed (T. Eskelin, personal observation). Further, some crew used larger gear (hooks and flies) at the beginning of the study, potentially targeting larger fish, and then later in the study began using smaller flies as heavily populated areas with low currents were discovered (T. Eskelin, personal observation). Due to the detected size selectivity in the 2009 and 2018 studies, future studies might benefit by adjusting sampling gear and techniques to capture a more representative sample of the population during all weekly strata. We suggest future studies make a concerted effort to fish with varying gear sizes and locations to avoid selectively fishing for larger fish.

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