Fishery Data Series No. 25-07

Mortality of Chinook Salmon Caught and Released Using Sport Tackle in the Nushagak River, 2017–2018

by

Lee K. Borden

and

Jason E. Dye

March 2025

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figures or figure captions.

Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

FISHERY DATA SERIES NO. 25-07

MORTALITY OF CHINOOK SALMON CAUGHT AND RELEASED USING SPORT TACKLE IN THE NUSHAGAK RIVER, 2017–2018

by
Lee K. Borden
Alaska Department of Fish and Game, Division of Sport Fish, Dillingham
and
Jason E. Dye
Alaska Department of Fish and Game, Division of Sport Fish, Dillingham

Alaska Department of Fish and Game
Division of Sport Fish, Research and Technical Services
333 Raspberry Road, Anchorage, Alaska, 99518-1565

March 2025

This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C.777-777K) under Project F-10-33, Job No. S-2-44.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

Lee K. Borden,
Alaska Department of Fish and Game, Division of Sport Fish,
P.O. Box 230, Dillingham, AK 99576-0230, USA

and

Jason E. Dye,
Alaska Department of Fish and Game, Division of Sport Fish,
P.O. Box 230, Dillingham, AK 99576-0230, USA

This document should be cited as follows:
Borden, L. K., and J. E. Dye. 2025. Mortality of Chinook salmon caught and released using sport tackle in the Nushagak River, 2017–2018. Alaska Department of Fish and Game, Fishery Data Series No. 25-07, Anchorage.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDICES

ABSTRACT

The common practice of catch-and-release fishing for Chinook salmon (*Oncorhynchus tshawytscha*) in the Nushagak River (Bristol Bay Management Area) has led to concerns over the rate of mortality in released fish. These concerns prompted the Alaska Department of Fish and Game to initiate a multi-year investigation of mortality associated with the practice. During the 2017 and 2018 seasons, short-term (5-day) hooking survival for Chinook salmon that were caught and released in the Nushagak River sport fishery was assessed using radio telemetry. Biological and fishery related variables were recorded for each of 109 fish caught, released, and tracked in 2017, and for each of 209 fish caught, released, and tracked in 2018. Overall survival estimates were 92.7% and 93.8% for the 2017 and 2018 seasons, respectively, with a pooled survival rate of 93.4%. Hazard ratio analysis of the pooled data found that the hazard for dying is significantly greater for fish that were hooked in any location other than the mouth, specifically the body, gills, esophagus, and eye. The 5-day survival for fish hooked in the mouth was 96%, whereas the survival rate for fish hooked elsewhere was 85%.

Keywords: king salmon, Chinook salmon, *Oncorhynchus tshawytscha*, hook-and-release, catch-and-release, mortality, radio telemetry, Nushagak River, Bristol Bay Management Area

INTRODUCTION

The Nushagak River is located in Southwestern Alaska and flows approximately 390 km from its headwaters into Bristol Bay (Figure 1). The Nushagak River drainage has 2 main tributaries: the Nuyakuk River, draining the Tikchik Lakes from the west, and the Mulchatna River, which flows into the Nushagak River from the east. The Nushagak River supports one of the largest Chinook salmon runs in Alaska, with an average (1989–2016) annual total run of approximately 178,000 fish and a spawning escapement of approximately 117,000 fish (Table 1).

The abundance of Chinook salmon stocks in the Nushagak–Mulchatna Rivers drainage has been variable in recent years. The 2009, 2010, 2011, and 2014 runs were well below average and did not achieve the inriver goal of 95,000 fish. The 2012, 2013, 2015, and 2016 runs were above average and exceeded the inriver goal. Total runs of Chinook salmon from the Nushagak and Mulchatna Rivers averaged 128,417 fish from 2011 through 2016, ranging from 90,717 to 166,006 fish (Table 1).

Total harvest by commercial, subsistence, and sport fisheries averaged 40,811 Chinook salmon from 2011 through 2016 (calculated from Table 1). The majority of the harvest (54%) was taken by the commercial fishery, 30% was taken by the subsistence fishery, and 16% was taken by sport anglers (Table 1). Sport harvest and catch (total harvested and released) of Chinook salmon averaged 6,904 and 35,869 fish, respectively, from 2011 through 2016 (calculated from Table 1).

Based on Statewide Harvest Survey (SWHS[1]) data, annual sport fishing effort on the Nushagak River averaged 18,940 angler-days from 2011 to 2016. Based on freshwater logbook data from 2006 through 2016 (Powers and Sigurdsson 2016; ADF&G freshwater logbook database, accessed October 20, 2017), guided effort downstream of the Mulchatna River has been variable, with a low of 3,920 angler-days in 2010 and a high of 8,559 angler-days in 2006. From 2011 through 2016, effort averaged 6,647 angler-days.

[1] Alaska Sport Fishing Survey database [Internet]. 1996– . Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited March 20, 2025). Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

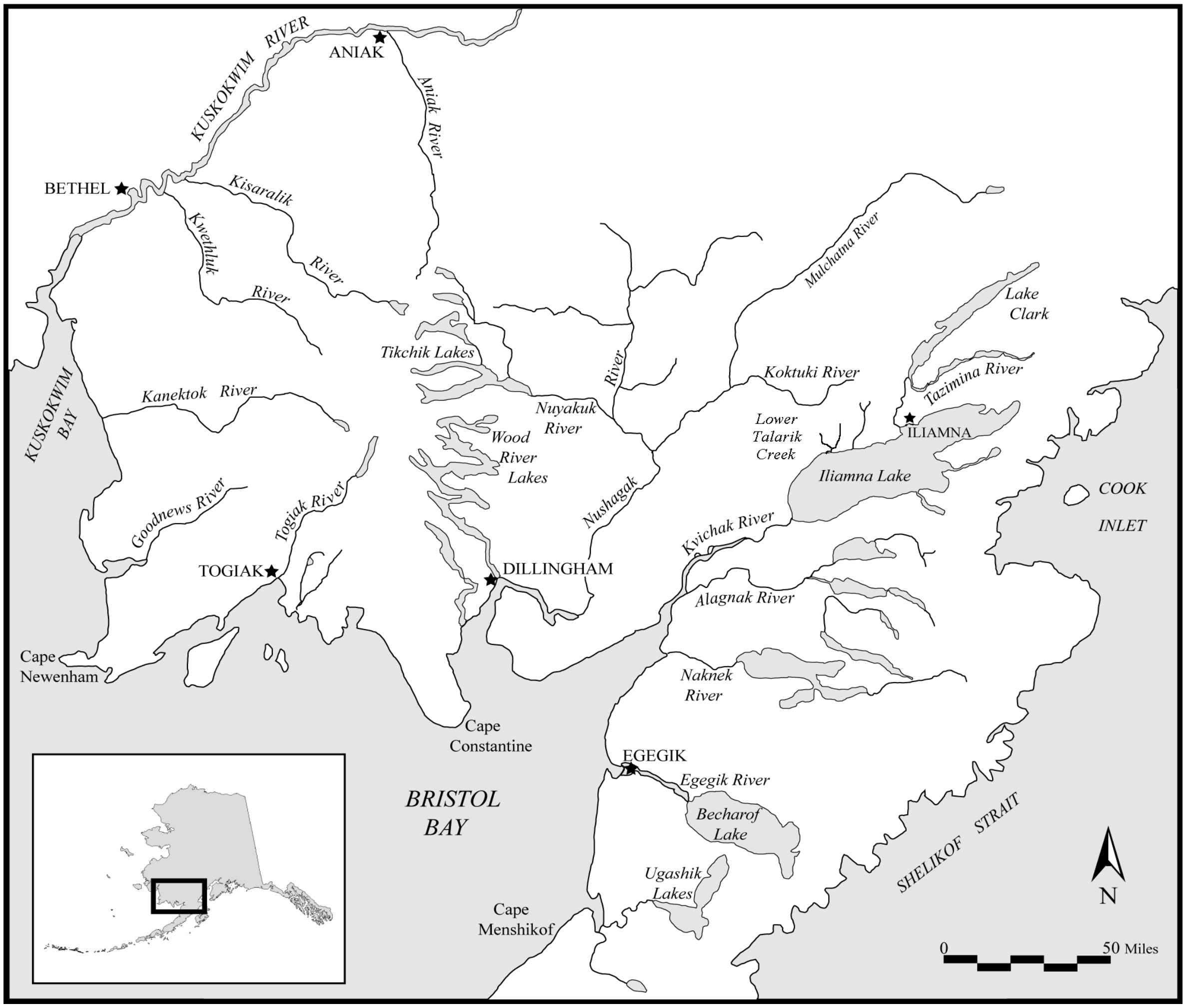

Figure 1.–Nushagak–Mulchatna Rivers drainage.

Table 1.–Chinook salmon harvest and escapement (1989–2016) and sport catch (2004–2016) for the Nushagak–Mulchatna Rivers drainage.

		Harvests below sonar			Inriver	Harvests above sonar		Sonar estimate	
Year	Total run[a]	Commercial[b]	Subsistence[c]	Sport[d]	sonar estimate	Subsistence[e]	Sport[f]	of escapement[g]	Sport catch
1989	102,241	17,637	4,898	1,404	78,302	2,217	2,210	73,875	NA
1990	85,792	14,812	6,228	797	63,955	3,325	2,689	57,941	NA
1991	132,769	19,718	6,907	1,793	104,351	3,127	3,758	97,466	NA
1992	139,943	47,563	7,688	1,844	82,848	2,499	2,911	77,438	NA
1993	173,747	62,976	10,552	2,408	97,812	2,919	3,492	91,401	NA
1994	332,388	119,480	8,829	4,436	199,643	6,661	6,191	186,792	NA
1995	268,137	79,943	7,810	2,238	178,146	5,891	2,713	169,542	NA
1996	192,011	72,123	9,086	2,346	108,456	6,855	3,045	98,557	NA
1997	156,052	64,390	8,731	931	170,610	6,587	2,567	[h]	NA
1998	370,908	117,820	6,987	1,640	244,461	5,271	4,188	235,003	NA
1999	147,530	11,178	5,732	934	129,686	4,325	3,304	122,058	NA
2000	136,194	12,120	5,398	1,389	117,288	4,072	4,628	108,588	NA
2001	212,037	11,746	6,703	1,600	191,988	5,057	4,299	182,632	NA
2002	228,969	40,039	6,430	1,193	181,307	4,851	2,500	173,956	NA
2003	222,846	43,485	10,651	2,203	166,507	8,035	3,752	154,720	NA
2004	350,407	96,759	8,898	2,567	242,183	6,712	4,339	231,132	69,278
2005	306,892	62,764	7,142	2,863	234,123	5,387	5,702	223,034	65,089
2006	218,413	84,881	5,683	3,166	124,683	4,288	4,307	116,088	50,756
2007	121,959	51,831	7,598	3,581	60,464	5,732	6,088	48,644	53,633
2008	126,301	18,968	7,387	3,305	96,641	5,573	3,395	87,673	45,181
2009	115,884	24,693	7,260	2,451	81,480	5,477	3,903	72,100	33,102
2010	69,556	26,056	5,216	1,659	36,625	3,935	2,248	30,443	18,572
2011	95,300	26,927	7,103	1,542	59,728	5,358	3,302	51,068	40,139
2012	129,282	11,952	7,711	1,833	107,786	2,639	4,098	101,049	37,476
2013	133,246	10,213	6,613	1,971	113,709	4,989	4,714	104,746	32,154
2014	90,717	11,448	6,418	2,369	70,482	4,842	3,891	61,749	26,158
2015	155,948	48,803	6,612	2,514	98,019	4,352	4,720	88,947	32,952
2016	166,006	23,783	13,802	3,053	125,368	1,933	5,358	118,077	46,333

-continued-

Table 1.–Page 2 of 2.

		Harvests below sonar			Inriver	Harvests above sonar		Sonar estimate	
Year	Total run[a]	Commercial[b]	Subsistence[c]	Sport[d]	sonar estimate	Subsistence[e]	Sport[f]	of escapement[g]	Sport catch
1989-2016									
Average	177,910	44,075	7,503	2,144	127,380	4,747	3,868	117,212	42,371
Percent	NA	70%	12%	3%	NA	8%	6%	NA	NA
2011-2016									
Average	128,417	21,188	8,043	2,214	95,849	4,019	4,347	87,606	35,869
Percent	NA	54%	20%	5%	NA	10%	11%	NA	NA
2017	98,689	NA	NA	NA	56,961	NA	NA	NA	NA

Source: Commercial harvest (total Nushagak District): 1989-1993 Jones et al. (2012: Appendix A19); 1994–2014 Elison et al. (2015: Appendix A19). Subsistence harvests above and below sonar: ADF&G Subsistence Division, Subsistence Database from Charles Utermohle, Program Coordinator, Subsistence Division, Region II, Anchorage, Nov. 20, 2000. Data for 2000–2008 provided by James Fall, Subsistence Division, Region II, Anchorage. Sport harvests above and below the sonar: Alaska Sport Fishing Survey database [Internet]. 1996– . Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited March 20, 2025). Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/. Prior sport harvest data can be found in Mills (1990–1994) and Howe et al. (1995, 1996). Sonar estimates: 1989–1993 Jones et al. (2012: Appendix A19); 1994–2014 Elison et al. (2015: Appendix A19).

Note: NA = not applicable or not available.

[a] Run refers to an aggregation of salmon of all ages returning from ocean feeding grounds to spawn in any given calendar year.

[b] Total Nushagak District commercial harvest.

[c] Includes Nushagak Bay and Igushik.

[d] Sport harvest total for 1989 to 1996 is 50% of the Nushagak River system sport harvest. Sport harvest total for 1997 to 2016 is Nushagak River sport harvest from Black Point to sonar (Figure 2).

[e] Includes Ekwok area, Iowithla River, Klutuk River, Koliganek area, New Stuyahok area, Portage Creek area, Kokwok area, Mulchatna River, and an unknown Nushagak River watershed site.

[f] Sport harvest total for 1989 to 1996 is 50% of the Nushagak River system sport harvest plus the Mulchatna River system, Tikchik–Nuyakuk Rivers, and Koktuli River sport harvests. Sport harvest total for 1997 to 2001 is 50% of the Nushagak River harvest plus the Nushagak River upstream of Iowithla River, Mulchatna River system, Tikchik–Nuyakuk Rivers, and the Koktuli River harvests. Sport harvest total for 2002 to 2016 is Nushagak River excluding Black Point to sonar.

[g] Sonar estimates for 1989 to 1996 and 1998 to 2016 are sonar estimates minus subsistence and sport harvest above sonar.

[h] No sonar estimate. Aerial survey estimate of escapement was 82,000 fish.

Nushagak River Chinook salmon are managed under guidelines of the *Nushagak-Mulchatna King Salmon Management Plan* (5AAC 06.361; Appendix A1) adopted into regulation in 1992. This plan was modified in the mid- and late 1990s and again in 2012 to account for the conversion of Bendix sonar counts to dual-frequency identification sonar (DIDSON) counts and applied to historical escapement numbers (Maxwell et al. 2011). The current sustainable escapement goal is 55,000 to 120,000 fish with an inriver goal of 95,000 (Fair et al. 2012).

ADF&G estimates inriver abundance of Chinook salmon at the Portage Creek sonar site located on the lower Nushagak River, approximately 53 km upstream from the terminus of the Nushagak commercial fishing district and 5 km downstream from the village of Portage Creek (Figures 1 and 2). Although the sonar project was not designed to assess Chinook salmon, it does produce an index of abundance that is used for inseason management of commercial and sport fisheries. The Chinook salmon sonar count has always been considered an index of abundance rather than a measure of total abundance because an unknown proportion of Chinook salmon are presumed to migrate upriver in the midchannel area beyond the range of the sonar.

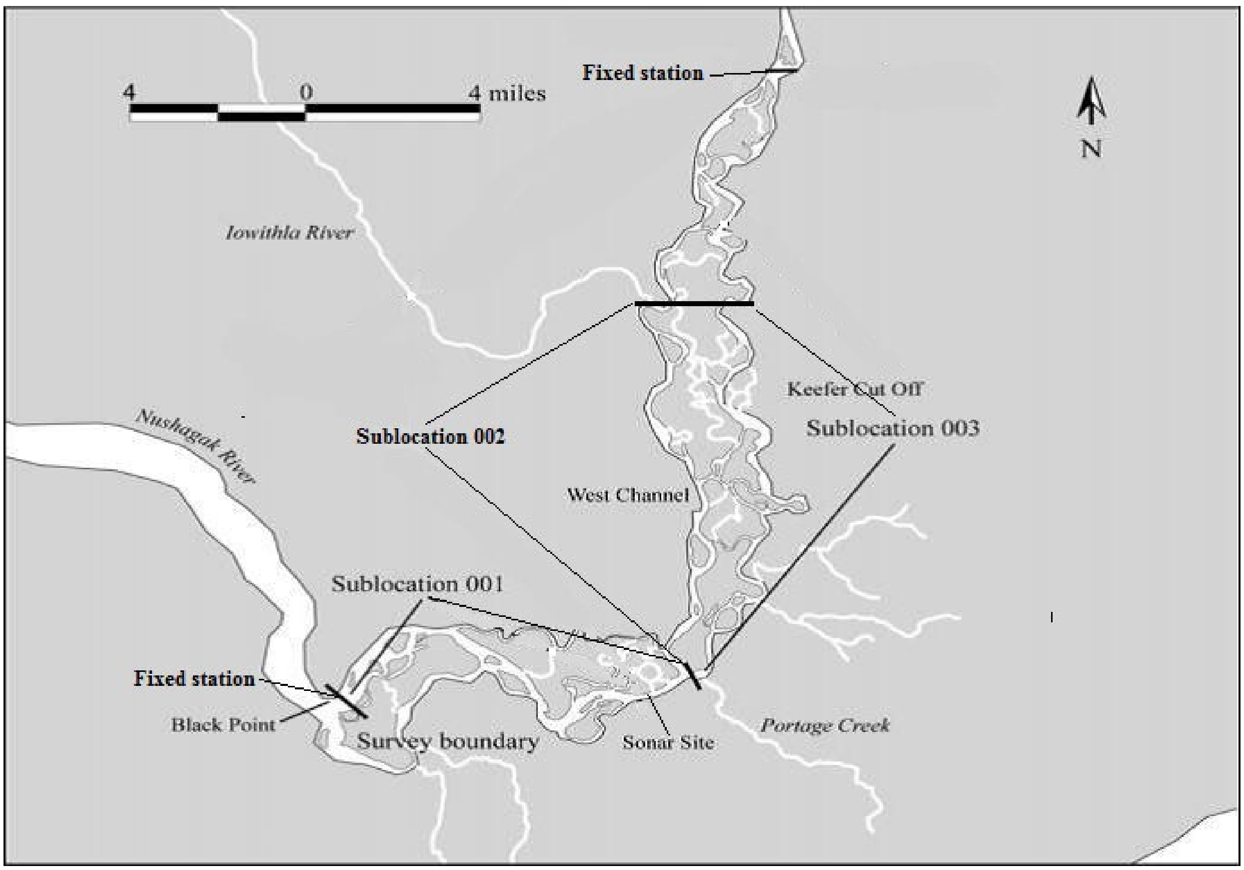

Figure 2.–Map of the lower Nushagak River drainage demarcating capture sublocations and locations of fixed tracking stations.

Due to the relatively large Chinook salmon return to the Nushagak River and relatively conservative sport fishing harvest regulations, the practice of catch-and-release fishing is common in the Nushagak River drainage. From 2011 through 2016, 28,110 fish were released on average from an average catch of 35,869 Chinook salmon, representing about 22% of the 2011–2016 average enumerated total run (calculated from Table 1). The number of fish released has raised concerns from users regarding the fate of Chinook salmon caught and released in the sport fishery.

Few catch and release mortality studies have been conducted on Chinook salmon sport fisheries in freshwater. Exceptions include Bendock and Alexandersdottir (1993), who estimated the survival rate of Chinook salmon caught and released in the Kenai River sport fishery averaged 91.2% and 94.1% for early and late runs, respectively, and Lindsay et al. (2004), who estimated the overall mortality rate of wild Chinook salmon caught and released in the Willamette River sport fishery at 12.2%. However, there are substantial differences between the Kenai River, Willamette River, and Nushagak River Chinook salmon stocks and associated sport fisheries. If a substantial portion of previously caught Nushagak River Chinook salmon do not proceed to spawn, estimates of escapement, as currently calculated, could be biased high. Concern over the fate of released fish and the need to evaluate catch-and-release restrictions as a management tool prompted this multi-year project with the goal of estimating the short-term survival rate of Chinook salmon caught and released in the lower Nushagak River sport fishery. The results of this project will be used to assist fisheries managers with future management strategies and assessment of harvest and escapement goals for Nushagak River Chinook salmon.

OBJECTIVES

PRIMARY OBJECTIVE

Estimate the short-term (5-day) survival rate for Chinook salmon ≥500 mm mid eye to tail fork (METF) length caught and released in the lower Nushagak River.

SECONDARY OBJECTIVES

1) Estimate the effects of selected biological and sport fishery related variables on survival rates of Chinook salmon caught and released in the lower Nushagak River.
2) Estimate length and sex composition of Chinook salmon captured in the lower Nushagak River.
3) Examine all captured Chinook salmon for previously applied marks from other studies.

METHODS

STUDY DESIGN

This study estimates the short-term (5-day) mortality rate[2] of Chinook salmon ≥500 mm METF caught and released in the Nushagak River during the period when the sport fishery was taking place in 2017 and 2018. Chinook salmon were captured with hook-and-line gear in the lower Nushagak River from Black Point upstream to its confluence with the Iowithla River, where most of the sport fishery occurs (Figure 2). Capture was conducted during the peak of the run from June 21 through July 10 in 2017 and June 17 through July 10 in 2018. Gear and terminal tackle common in the sport fishery were used to capture Chinook salmon ≥500 mm METF, which were implanted with an esophageal radio tag. Length, sex, and other biological and fishery-related variables were collected for all captured and tagged Chinook salmon. The "fates" (as a function of survival and movement) of radiotagged salmon were monitored by daily aerial surveys, boat surveys, and 2 stationary tracking stations. Tracking continued for at least 5 days beyond the date of the last tag deployment. The 5-day tracking period was chosen to ensure this study is comparable

---

2 Note an estimate of 5-day survival after hooking is the preferred study length because it gives sufficient length of time for potential impacts to manifest while not too long to be confounded by other influences on mortality.

to previous Chinook salmon catch-and-release mortality studies (e.g., Bendock and Alexandersdottir 1993).

Capture

Two 2-person crews captured Chinook salmon in the lower Nushagak River (Figure 2) during the 2017 field season, and three 2-person crews captured Chinook salmon during the 2018 field season. Captures occurred 6 days per week. The capture area for each year was divided into 3 sublocations (Figure 2):

1) Black Point to the downstream confluence of the west channel and the Keefer Cutoff[3], near Portage Creek (recorded as sublocation 001)
2) The western channel from its confluence with the Keefer Cutoff near Portage Creek to its confluence with the Iowithla River (recorded as 002)
3) The 25 km section of the Keefer Cutoff upstream from its confluence with the western channel near Portage Creek (recorded as 003).

Chinook salmon were captured using catch-and-release techniques commonly practiced by the sport fishery on the Nushagak River. Strong test monofilament or braided line (25–40 lb) was used along with a heavy spinning and/or casting rod and reel to bring the catch in quickly in a manner similar to that encouraged by guides. Landing time was varied to emulate the sport fishery.

Four combinations of terminal tackle and angling methods, common in the Nushagak Chinook salmon sport fishery, were used to capture fish: backtrolling plugs such as Kwikfish, drifting salmon eggs with Spin-n-Glos, downtrolling spinners such as T-spoons, and setting sideplaners from shore with either salmon eggs or plugs. Past creel surveys conducted on the lower Nushagak River Chinook salmon sport fishery have estimated that approximately 60% of anglers used bait and that sport fishing effort was equally distributed between the sublocations described above (Dye 2005; Cappiello and Dye 2006; Dye 2012). Therefore, to distribute the catch by terminal tackle in a similar proportion to the sport fishery, the study was designed such that 60% of the radio tags would be implanted in fish caught using bait, and the remaining 40% would be implanted in fish caught without the use of bait. The overall Chinook salmon sport fishery catch using sideplaners from shore is likely much lower than the other angling methods; therefore, no more than 10 percent of the overall total deployed tags (making up part of the 60% bait-designated radio tags) were to be implanted in fish caught with the use of sideplaners from shore. Finally, to ensure fish were caught and released proportionally to the sport fishery by location, approximately 33% of the total deployed tags were to be implanted in fish caught in each of the 3 capture sublocations.

Captured Chinook salmon were restrained in a tagging cradle or landing net. The tagging cradle or landing net was positioned alongside the boat to allow the fish to be processed without removal from the water. The tagging cradle was a rigid, padded device that immobilized captured fish. Landing nets were of typical design and comparable to those used in the sport fishery. All captured Chinook salmon were examined for previous marks (i.e., the radiotag antenna).

[3] The west channel and Keefer Cutoff (colloquially the "eastern channel") are the western and eastern waterways, respectively, between the Nushagak River–Portage Creek confluence and the northernmost fixed station depicted in Figure 2. Little to no angling occurs in the sloughs between the two waterways.

Tagging and Telemetry

Over the two field seasons, 321 esophageal radio tags (110 tags in 2017 and 211 tags in 2018) were inserted into Chinook salmon captured by hook and line in 3 capture sublocations in the lower Nushagak River from Black Point to the confluence with the Iowithla River, approximately 28 km upstream of the Portage Creek sonar site (Figure 2). A handheld GPS was used to identify the exact tagging locations. All Chinook salmon over 500 mm METF received a radio tag unless the fish was severely injured or bleeding profusely and therefore clearly a mortality. However, it was important that such fish were recorded and included in the study analysis as "angling-induced mortalities." Chinook salmon less than 500 mm METF were deemed too small to carry an esophageal radio transmitter and were not tagged. According to Winter (1983), transmitters should weigh no more than 2% of the body weight of a fish in air or 1.25% of the weight in water. With these criteria, Chinook salmon needed to weigh at least 1 kg to be safely tagged; the 500 mm METF cutoff generally meets this criterion.

Advanced Telemetry Systems (ATS) high frequency pulse encoded radio transmitters were used for tagging. The tags were 5.5 cm long, 1.9 cm in diameter, and weighed 26 g in air, with a 41 cm external whip antenna. Each radio tag was distinguishable by a unique frequency and encoded pulse pattern. Fifteen frequencies spaced approximately 30 kHz apart in the 151 and 153 MHz range with approximately 12 encoded pulse patterns per frequency were used for a total of up to 180 uniquely identifiable tags per season. Transmitters had a mortality option that changed the pulse rate of the signal when transmitter had been sedentary for 4 hours. This was used to identify mortalities.

Radio tags were inserted through the esophagus and into the upper stomach using a 41 cm plastic tube with a diameter equal to that of the radio tags. The radio transmitters were pushed through the esophagus such that the antenna end of the radio tag was seated approximately 0.5 cm posterior to the posterior base of the pectoral fin. Tagging was performed without the use of anesthesia. To simulate proper catch-and-release practices, except insertion of radio tags, handling was kept to a minimum. Sex was only recorded if it could be easily determined from external appearance. A measurement of METF length was taken of each Chinook salmon while it was in the holding cradle or landing net. No scales were taken to determine age. For each fish that received a radio tag, river location, tag frequency, tag code, and several biological and fishery-related variables were recorded as described in the following section.

Following radio tag insertion, inriver migrations of salmon were tracked by aerial and boat surveys and 2 fixed stations. Fixed stations were located at the upstream confluence of the mainstem and Keefer Cutoff, approximately 50 km upstream of the Portage Creek sonar site, and at Black Point, approximately 15 km downstream of the sonar site (Figure 2). Each tracking station recorded all transmitter signals of sufficient strength. Stations recorded date, time, frequency, code, signal strength, and antenna number for each time a signal of sufficient strength was encountered. Data from each station were downloaded to a laptop computer at least once every 7–10 days with use of PROCOM PLUS software provided by ATS. Each station included 2 deep cycle batteries, an ATS Model 5041 Data Collection Computer (DCC II), an ATS Model 4000 receiver, a housing box, and 1 Yagi antenna. The receiver and DCC were programmed to scan through the frequencies at 3 s intervals. When a signal of sufficient strength was encountered, the receiver would pause for 5 s, and tag frequency, tag code, signal strength, date, and time were recorded on the data logger. The relatively short cycle helped minimize the chance that a radiotagged fish swam past the receiver site without being detected. Aerial tracking surveys of the mainstem were conducted daily from 18 June through 17 July in 2017 and 19 June through 16 July in 2018. During each aerial survey, date, tag frequency, GPS coordinates, and signal type (alive or mortality) were recorded. A reference tag was placed at a location chosen at random along the river within the tagging area to help verify that the tracking equipment was working properly during each aerial survey. The location of the tag was unknown to the surveyor, and it was moved to a new location every other day. Boat surveys were conducted periodically as needed during the study to locate tags. This level of coverage allowed for the determination of the number of tagged fish that died within 5 days of release, exited the survey area downriver, or travelled upstream of the confluence.

Fishery Recoveries

Recoveries of tagged Chinook salmon harvested in various fisheries were obtained by voluntary tag returns from subsistence, commercial, and sport fishers. The local and visiting public and commercial sport fishing operations were made aware of the study via guide meetings, email, and news releases, and were asked to turn in any tags they encountered and note the date of harvest. Tag numbers linked the fish to the original capture data. Imprinted on each radio tag was the Dillingham office address and a contact phone number.

Biological and Sport Fishery Related Variables

Biological and fishery related variables were recorded for each capture event. All Chinook salmon captured during the project were sampled for sex and length. Sex was determined, when possible, based on external sexual characteristics. METF length was recorded to the nearest 5 mm. Additionally, several fishery-related variables were recorded including water temperature (handheld thermometer about 30 cm below surface), landing time, handling time, angling method, and terminal tackle (see *Capture* section for details on angling method and tackle). Hooking location, bleeding severity, "swimming away" characteristics, and external condition of fish at release were also measured (Appendix B1).

Fates of Radiotagged Chinook Salmon:

All radiotagged salmon were assigned 1 of 4 distinct fates (Table 2). These fates defined whether caught-and-released Chinook salmon had died from injuries associated with capture and handling or were harvested or lost completely. Fate designations allowed us to assign tracked fish to censused (included in study) or noncensused (censored from study) status.

Censused fish fit one of the following definitions:

a) survived the 5-day tracking period
b) tracked within the 5-day study period but then lost
c) tracked within the 5-day study period and then detected as a mortality only after the 5-day study period was over
d) any fish detected as a mortality within the 5-day study period, including untagged mortalities at the tagging boat

Fate 1 fish (hooking survivors; Table 2) were assigned censused status with a 5-day survival time. Fate 2 fish (hooking mortalities) were assigned censused status along with the determined time of death. Fate 3 fish (fishery mortality or partial detection) were assigned a time of harvest or time of lost contact but were removed from the study. Fate 4 fish (unknown) were also dropped from the analysis.

Table 2.–List of possible fates of radiotagged Chinook salmon from the Nushagak River, 2017–2018.

Code	Fate	Description
1	Hooking survivor	Fish that moved upstream past the upstream tracking station (near upstream confluence of mainstem and Keefer Cutoff) at any time after release or Fish that were located with their transmitter in active mode at least 5 days after release.
2	Hooking mortality	Fish that died immediately after capture (these fish were not radiotagged) or Fish that never passed the upstream tracking station and whose carcasses were found dead within 5 days of release or Fish that never passed the upstream tracking station and were located either upstream or downstream of the tagging site with their transmitter in inactive mode on 2 consecutive aerial surveys within 5 days of release or Fish that never passed the upstream tracking station, moved downstream past the lower tracking station near Black Point, and are never located again
3	Fishing mortality or partial detection	Fish that were harvested in either the sport, commercial, or subsistence fishery within 5 days of release or Fish that were detected in the study area with transmitter in active mode within 5 days of tagging but were not detected again, or only as mortalities after the 5-day study period
4	Unknown	Fish that were never located after release. Such fish were not used for estimation of hooking mortality.

The aerial surveys, boat surveys, and fixed tracking stations monitored the movements that defined the fates of radiotagged Chinook salmon. Aerial tracking took place throughout and after the tagging period to determine whether the tags were working, whether the fish had recovered from handling, where they were located, and whether fish had survived for 5 days following release. The first aerial tracking survey commenced 1 day after the first tag had been deployed and continued daily until 5 days after the last tag was deployed. Tracking continued for an additional day in both 2017 and 2018 to observe any tagged fish with uncertain fates. Following completion of aerial surveys on the lower river, 1 aerial tracking survey was used to locate tags upstream of the upper tracking station. These flights helped locate fish that the tracking stations failed to record, and further validated that fish recorded by a station migrated past and remained upstream of the station.

Based on historical aerial surveys, nearly all Chinook salmon spawning occurs upstream of the confluence of the Nushagak and Iowithla Rivers, and the commencement of spawning has not been documented prior to July 25. Therefore, there should not have been any issues with tagged Chinook salmon spawning within the tagging area and possibly signaling a false mortality.

DATA ANALYSIS

For this study, we defined hook-and-release mortality as a failure event and the time to that event as the failure time. Censored individuals were those removed from the study by a fate other than hook-and-release mortality (e.g., removals by sport fishery). Five days after release, all fish still surviving were automatically censored (removed) from the experiment.

The following assumptions were made with respect to unbiased estimation of catch-and-release survival rates:

1) There was no natural mortality within the 5-day study period.
2) Radio tagging did not affect survivability during the 5-day study period.
3) There was no tag loss during the 5-day study period.
4) Tags were identifiable throughout the 5-day study period.
5) Censoring was independent[4].
6) Tagged fish were a representative sample of the sport-fish exploited population.

Assumption 1 is not directly testable; however, the life history of Chinook salmon, the lack of known predation, and the lack of spawning within the study area attests to the validity of assumption 1. Regarding assumptions 2, 3, and 4, ADF&G has extensive institutional knowledge on the use of esophageal radio tag implants in Chinook salmon and we are confident these assumptions are valid. Assumption 5, that censorship (removal from the experiment) by factors other than hook-and-release mortality is a random subset of the total sample, was tested using contingency table analysis with table dimensions 2 by s, where s denotes the number of variables—in this case, "censored" vs. "not censored" from the study and the variables under investigation (e.g., sex, where $s = 2$; see section pertaining to biological and fishery variables above for other variables of interest). Chi-square tests of independence in the 2 by s tables were conducted. The size distributions of tagged fish censored by factors other than hook-and-release mortality was also compared to the distribution of uncensored tagged fish using the nonparametric Kolmogorov–Smirnov statistic (Conover 1980). All statistical tests were conducted at the Type-1 error rate (alpha) of 0.1, unless otherwise noted.

Assumption 6 was met through careful study design. Creel survey information (Dye 2005; Cappiello and Dye 2006; Dye 2012) was used to distribute effort spatially and among gear types such that we have confidence in the validity in Assumption 6, which is crucial for the estimations of survival made in this study.

Catch and Release 5-Day Survival

Overall 5-day Survival

Careful study design (see above) allows us to assume that the sample of fish that were tagged is representative of the sport fishery catch in each year; therefore, 1 overall (pooled over biological and fishery variables) Kaplan-Meirer estimate of survival is valid for each year. The assessment of the effect of fishery and other explanatory variables on survival is described in the next section.

The nonparametric Kaplan-Meier estimator (Kaplan and Meier 1958; also known as the product limit estimator) was used to estimate the survivor function $F(t)$, which is the probability of surviving to time t and is estimated as follows:

[4] Within a subgroup of interest, radiotagged fish that are censored at time t are representative of all radiotagged fish in that subgroup that remain at risk at time t with respect to their survival experience; see Kleinbaum and Klein (2012) for details.

$$\hat{F}(t) = \prod_{j<t} 1 - \hat{h}_j \quad (1)$$

where $\hat{h}_j$ is the hazard function, or the probability of dying at time j, and is estimated by

$$\hat{h}_j = \frac{d_j}{r_j} \quad (2)$$

where

d_j = number of individuals dying at time j, and

r_j = number available or alive just before time j, including those individuals censored at time j.

The variance for the survivor function is estimated using Greenwood's formula (Collet 2003):

$$\text{var}(\hat{F}(t)) = \hat{F}(t)^2 \sum_{j<t} \frac{d_j}{r_j(r_j - d_j)} \quad (3)$$

The LIFETEST procedure of the SAS/STAT software component of Version 9.4 of the SAS System (SAS Institute Inc., Cary, NC, USA) for Windows was used to conduct the Kaplan-Meier analysis. Example SAS software code needed for Kaplan-Meier estimates and associated standard errors, survival plots, and confidence intervals is presented in Appendix C1.

Effect of Biological and Fishery Variables on 5-Day Survival

Cox Proportional Hazards Model

The strategy outlined in section 5.2 of Chapter 5 of Hosmer et al. (2008) was used to develop a Cox proportional hazards model that best described variability in catch-and-release survival rates. The strategy is summarized below. Example SAS/STAT software code needed for the analyses presented in this section is given in Appendix C1.

It is noted that the variable that denoted the level of bleeding, the variable describing the alacrity with which fish swam away after tagging, and handling time, were *not* included in the model development (Appendices C1 and C2). These variables were considered side-effects of the other variables. An independent Kaplan-Meier analysis for the effect of each of these 3 variables was, however, conducted.

1) Bivariate analyses.

A stratified Kaplan-Meier analysis was conducted for each of the biological and fishery variables in the study. Continuous variables were entered into the model categorized into 2 levels based on their median value. The log-rank test (via STRATA statement in the SAS LIFETEST procedure) was used to test whether the Kaplan-Meier survival curves were equivalent over strata. A univariate proportional hazards model was also used in the case of the continuous variables. A significance cut-off of 0.2 for the P-value was used to determine which variables were considered further. For example, if the P-value in the log-rank test for the sex variable in the Kaplan-Meier analysis was 0.18, then sex would be considered as a candidate variable in the steps described below.

2) Main-effects model

A full, main-effects Cox proportional hazards model (Cox and Oakes 1984) containing all variables whose *P*-values were <0.2 in the bivariate analysis (1) was then considered.

Cox's proportional hazards model is described as follows:

$$h(t,\underline{X}_j) = h_0(t)e^{\sum_{i=1}^{p}\beta_i X_{ij}} \quad (4)$$

where

$h(t,\underline{X}_j)$	=	hazard at time t for individual j with vector of covariates $\underline{X}_j$ (instantaneous potential per unit time for mortality to occur, given the fish has survived to time t; the hazard function has a 1:1 relationship with the survivor function).
$h_0(t)$	=	baseline hazard function, independent of covariates.
p	=	number of terms in the proportional hazards model
β_i	=	coefficient for ith covariate in the model
X_{ij}	=	realized values of the p covariates for individual j

The PHREG procedure of the SAS/STAT software component was used to fit the proportional hazards models by maximum likelihood methods. A backwards model-selection type analysis was conducted, in which variables with a *P*-value > 0.05 in Type-III SS tests (Wald statistics) were considered for deletion. The variable was only deleted if coefficients of variables remaining in the model did not change by more than 20%. This process led to a tentative final main effects model.

3) Reassess variables dropped in step 1

Variables dropped in the bivariate analysis (1) were added back to the tentative final model one at a time and their contribution reassessed.

4) Interactions

Two-factor interaction terms were assessed among all remaining main effects surviving model selection in steps 1–3.

5) Test of Cox proportional hazards assumption

The Cox proportional hazards model assumes that the hazard ratio comparing any 2 specifications of the predictors is constant over time. Three tests of the Cox proportional hazard assumption were conducted:

a) Test on Martingale residuals (Lin et al. 1993). The ASSESS statement in the PHREG procedure of the SAS/STAT software was used to conduct this test. Observed scores associated with the Martingale residuals were compared with simulated scores assuming proportional hazards.

b) Test on Schoenfeld residuals (Schoenfeld 1982). Schoenfeld residuals were created under PROC PHREG in the SAS/STAT software. Under the null hypothesis that the proportional hazards assumption is met, the correlation between the Schoenfeld residuals and various functions of time (log and square) is zero. PROC CORR in the SAS/STAT software was used to assess the correlations for each variable in the model.

c) Log-log survival curves. The log(−log(Survival(t)) was plotted versus time (t) for each covariate under analysis. Parallel curves indicated the proportional hazards assumption was met.

In the event that the Cox-proportional hazards assumption was violated for a particular covariate, or combination thereof, a stratified Cox proportional hazards model was used. The STRATA statement in the PHREG procedure was used for this purpose.

Effect Estimation

Hazard ratios were estimated as follows:

$$\widehat{HR} = e^{\sum_{i=1}^{p} \beta_i (X_i^* - X_i)} \quad (5)$$

where

X_i, X_i^* = values of covariates for predictor i for individuals for which hazard ratio is desired.

Estimated standard errors and confidence limits for hazard ratios were derived from the variance–covariance matrix of the maximum likelihood estimation. These statistics were provided by the PHREG procedure of the SAS/STAT software.

5-day Survival: Kenai Study Sex-Length Strata

In their study of Chinook salmon catch-and-release mortality on the Kenai River, Alaska, Bendock and Alexandersdottir (1993) stratified their data according to 2 time periods (1989 and 1990–1991) and 3 sex-length combinations (small males [<750 mm METF], large males [≥750 mm METF], and females) to accommodate different levels of censoring in their data. They reported survival estimates for each of these sex-length-period strata.

We report Kaplan-Meier (product limit) survival estimates for similar sex-length strata in this study for comparison. It is noted, however, that in the Kenai River study, fish as small as 405 mm METF were tagged, whereas in this study, tagging was restricted to 500 mm METF and above.

Length and Sex Composition

Mean length and variance of Chinook salmon captured in the Nushagak River was estimated using standard sample summary statistics (Cochran 1977).

The proportion (p_i) of Chinook salmon of length or sex class i will be estimated as a binomial proportion as follows:

$$\hat{p}_i = \frac{x_i}{x} \quad (6)$$

where

x_i = number of Chinook salmon of length or sex class i, and

x = total number of Chinook salmon sampled.

The variance of the estimated proportion was estimated as follows:

$$\text{var}(\hat{p}_i) = \frac{\hat{p}_i(1 - \hat{p}_i)}{x - 1} \quad (7)$$

RESULTS

CAPTURE AND TAGGING

2017

In 2017, tagging commenced on 21 June and continued through 10 July. During this time, 111 Chinook salmon ≥500 mm METF were caught, and 110 of these were tagged and released. Fifty-eight fish were tagged in sublocation 1, 9 fish were tagged in sublocation 2, and 43 were tagged in sublocation 3 (Table 3). The number of fish tagged per day ranged from 2 to 11. Daily water temperature ranged from 12°C to 16°C and averaged 14°C.

All 58 fish caught in sublocation 1 were radiotagged. However, the paperwork for 1 tagged fish was lost and another radiotagged fish was never detected again. These 2 fish from sublocation 1 were dropped from the study. Another captured fish from sublocation 3 was killed upon capture; this fish was not tagged but nevertheless entered the survival study as a catch-induced mortality. The number of fish entering the survival study in 2017 was therefore 109, consisting of 108 valid radiotagged fish plus 1 boat-mortality fish (Table 3).

Table 3.–Catch and radiotagging summary (≥500 mm METF), 2017 and 2018.

Year	Sublocation	Caught	Radiotagged	Tag data lost	Never detected	Valid radio tags	Boat mortality (not tagged)	Tracked fish
2017	1	58	58	1	1	56	0	56
	2	9	9	0	0	9	0	9
	3	44	43	0	0	43	1	44
	Total	111	110	1	1	108	1	109
2018	1	80	78	0	3	75	2	77
	2	95	93	0	2	91	1	92
	3	40	39	0	0	39	1	40
	Total	215	210	0	5	205	4	209

2018

In 2018, tagging commenced on 17 June and continued through 10 July. During this time, 215 Chinook salmon ≥500 mm METF were caught, and 210 of these were tagged and released. Seventy-eight were tagged in sublocation 1, 93 were tagged in sublocation 2, and 39 were tagged in sublocation 3 (Table 3). The number of fish tagged per day ranged from 1 to 27. Daily water temperature ranged from 10°C to 14°C and averaged 11.4°C.

Four fish were killed on capture in 2018, 2 from sublocation 1, 1 from sublocation 2, and 1 from sublocation 3. These fish were not tagged but nevertheless entered the survival study as catch-induced mortalities. Five radiotagged fish were never detected again, and these fish were dropped from the study. Adding the former and subtracting the latter, the number of fish entering the survival study in 2018 was therefore 209, consisting of 205 valid radiotagged fish plus 4 boat-mortalities (Table 3).

LENGTH AND SEX COMPOSITION

2017

There were 109 fish included in the 2017 survival study that were measured for METF length (Figure 3). Length ranged from 500 mm (by design) to 940 mm, with an average of 668 mm (SE 11 mm). Sex was also estimated for the 109 fish included in the survival study. Of these, 83 were male (76.6%, SE 4%), averaging 631 mm (SE 12 mm), and 26 were female (23.4%, SE 4%), averaging 792 mm (SE 12 mm).

2018

There were 209 fish followed in the 2018 survival study that were measured for METF length (Figure 4). Length ranged from 500 mm (by design) to 1,100 mm with an average of 640 mm (SE 7 mm). Sex was estimated for all 209 of the fish included in the survival study; 165 were male (78.9%, SE 2.8%), averaging 613 mm (SE 7 mm), and 44 were female (21.1%, SE 2.8%), averaging 739 mm (SE 13 mm).

Overall

A total of 318 Chinook salmon were measured for length in the 2017 and 2018 survival studies (Figure 5). Of these, length ranged from 500 to 1100 mm and averaged 649 mm (SE 6 mm). Sex was estimated for all 318 fish included in the 2017 and 2018 survival studies. Of these, 248 were male (78.2%, SE 2.3%), averaging 619 mm (SE 6 mm) and 70 were female (21.8%, SE = 2.3%), averaging 758 mm (SE 10 mm).

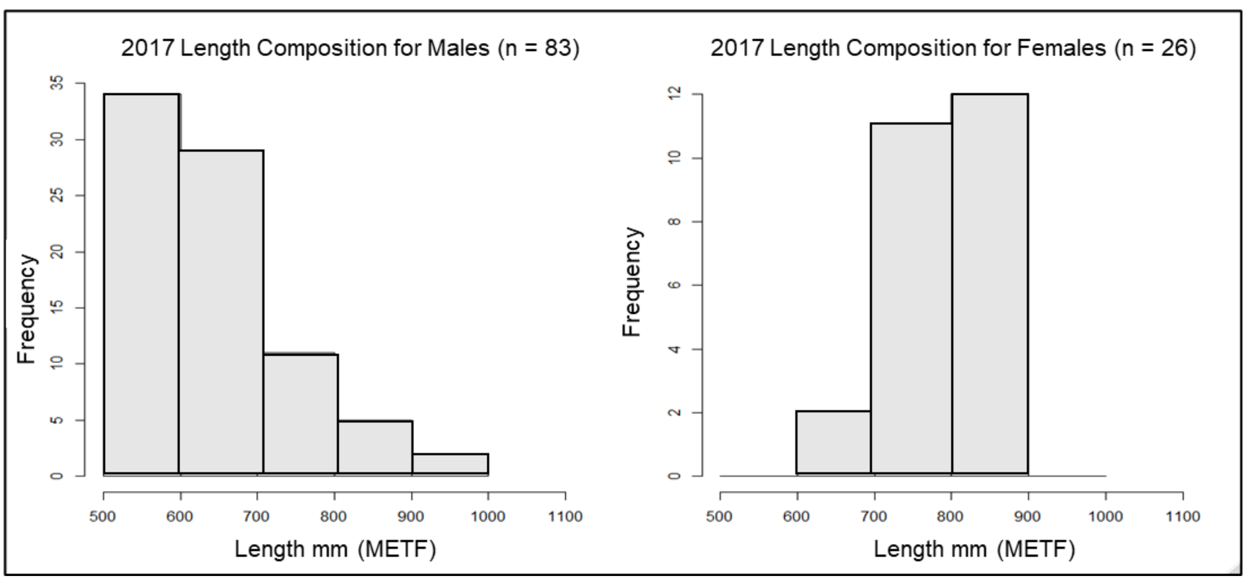

Figure 3.–Length distribution by sex for Nushagak River Chinook salmon ≥500 mm METF that were included in the 2017 survival study.

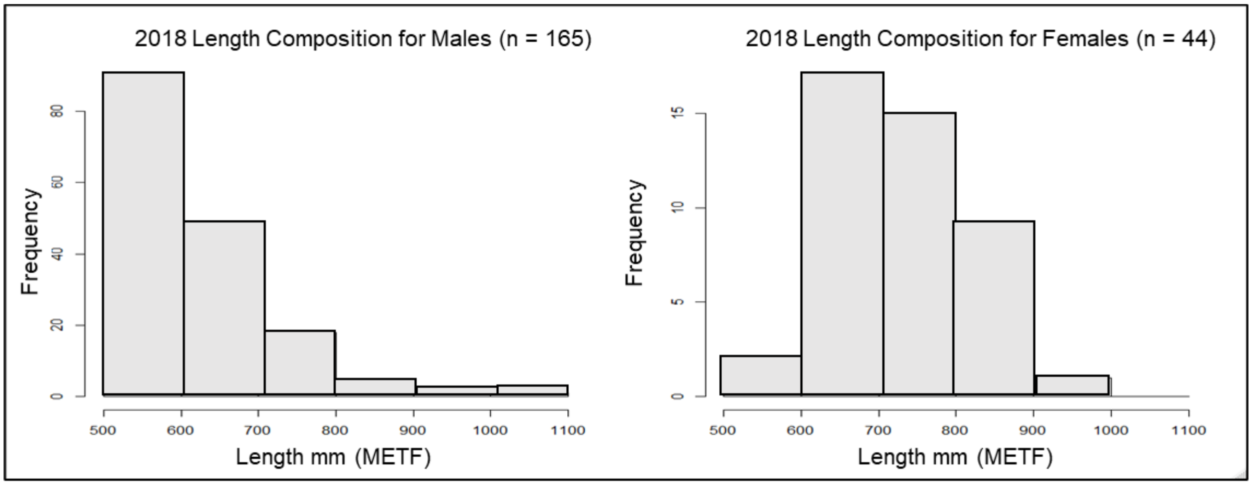

Figure 4.–Length distribution by sex for Nushagak River Chinook salmon ≥500 mm METF that were included in the 2018 survival study.

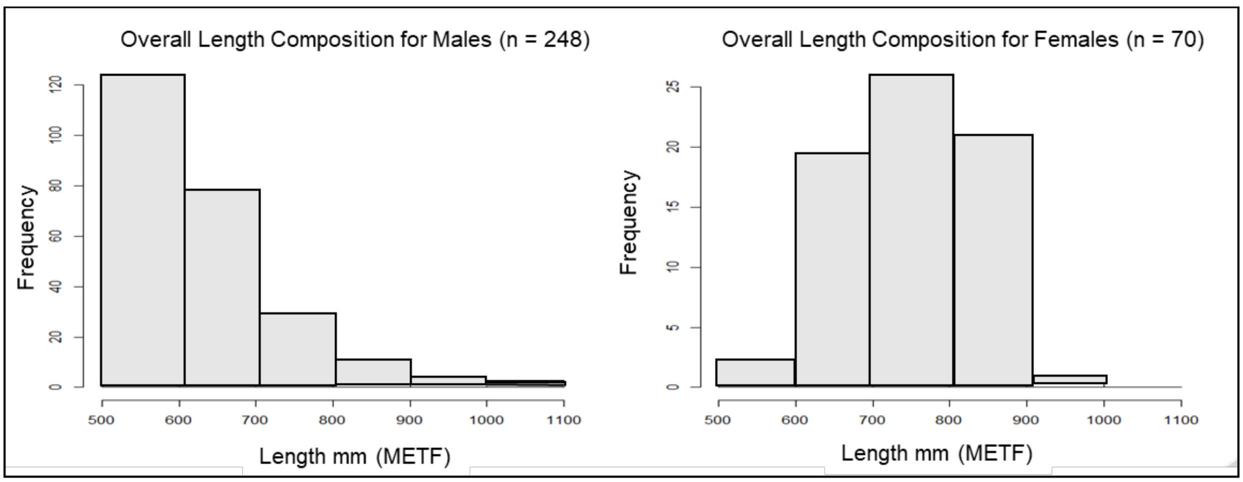

Figure 5.–Length distribution by sex for Nushagak River Chinook salmon ≥500 mm METF that were included in the 2017 or 2018 survival studies.

A Kolomogorov–Smirnoff test of year on the lengths of fish included in the survival studies was significant at the 0.1 Type-1 error level ($P = 0.07$); lengths in 2017 tended to be larger than those in 2018. In a similar test for just males, no significant difference in length distributions was found ($P = 0.19$), but there was a significant difference for females ($P = 0.005$), indicating the lengths in 2017 were larger and that female lengths appeared to drive the difference observed between years when pooled over sex. The difference in mean lengths for females between years was 53 mm. A chi-square test of independence between years on sex composition of fish included in the survival studies was not significant ($P = 0.74$).

Catch-and-Release 5-day Survival

2017

In 2017, 100 of 109 fish included in the study survived through their fifth day after capture, whereas 8 were mortalities and 1 was censored within the 5 days (contact was lost for this fish until it was discovered as a mortality on the 7th day; Table 4). Mortalities consisted of 7 tagged fish and 1 fish that died upon capture. No fish dropped downstream of Black Point and no tags were returned by anglers in 2017. Given only 1 fish was censored within the 5-day study period and only 1 fish was removed from the study at the outset due to our inability to relocate the tag, no tests of the censoring assumption (assumption 5) were made.

The Kaplan–Meier estimate for 2017 of Chinook salmon survival at 5 days after capture was 92.7% (SE 2.5%), with a 95% confidence interval of 85.8% to 96.3%. The product-limit survival curve showing survival probability over time is given in Figure 6.

Table 4.–Distribution of tracked fish and fates by sex for Nushagak River Chinook salmon, 2017 and 2018.

Year	5-day fates	Mortality location	Females	Males	Total
2017					
	Trackeda		25	82	109
	Mortality		4	4	8
		Downstream of Black Point	0	0	0
		Within study area (tracked)	3	4	7
		Within study area (at boat)	1	0	1
	Harvested		0	0	0
	Censored (<5 days)		0	1	1
	Survivors (≥ 5 days)		21 (84.0[b])	77 (93.9[b])	100
2018					
	Tracked		44	165	209
	Mortality		3	10	13
		Downstream of Black Point	1	0	1
		Within study area (tracked)	1	7	8
		Within study area (at boat)	1	3	4
	Harvested[c]		0	0	0
	Censored (<5 days)		2	1	3
	Survivors (≥ 5 days)		40 (90.1[b])	153 (92.7[b])	

[a] Sex of 2 tagged fish not recorded.

[b] Percent of tagged fish.

[c] One fish harvested after the 5-day study period.

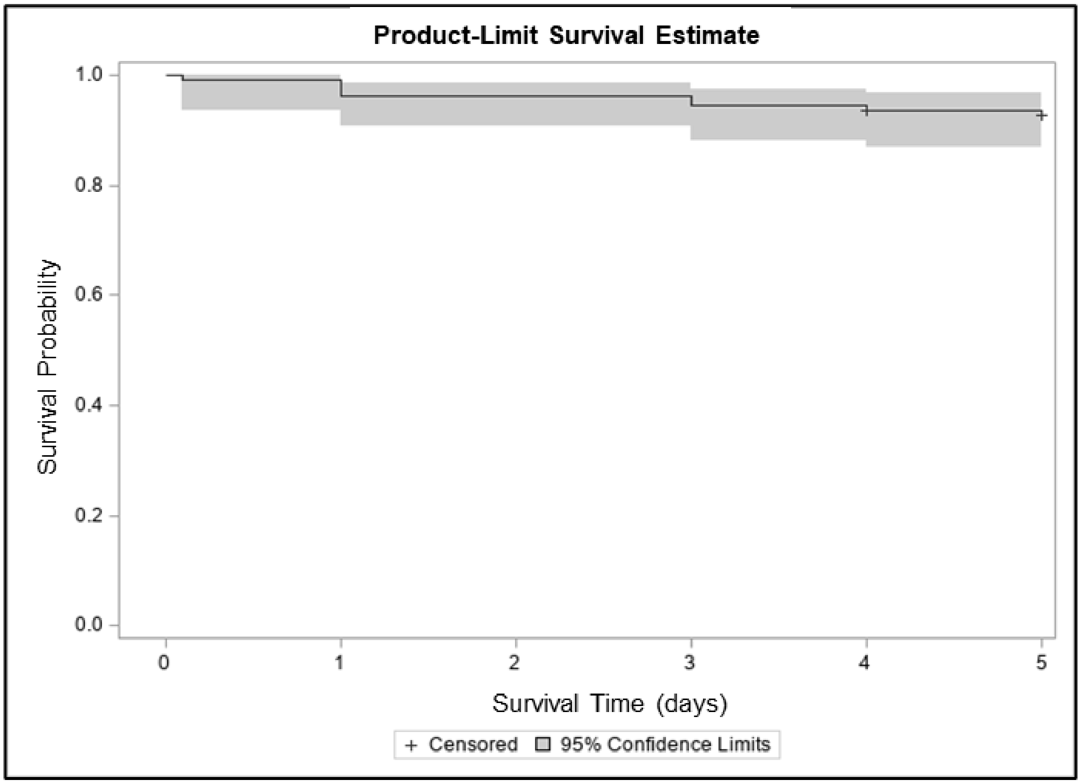

Figure 6.–Survival rates over time for Nushagak Chinook salmon, 2017.

2018

In 2018, 193 of 209 fish included in the study survived through their fifth day after capture, whereas there were 13 mortalities and 3 were censored within the 5 days (Table 4). Two of the censored fish (at 3 and 4 days after capture) were last detected downstream of the fixed station but above the confluence of the west channel and the Keefer cutoff; the third was last detected 3 days after capture in the west channel. The mortalities consisted of 8 fish tracked within the study area, 4 fish that died upon capture, and 1 fish that moved downstream of Black Point. One tag from a fish harvested by an angler was redeployed on 29 June 2018. Only 3 fish were censored within the 5-day study period and no tests of the censoring assumption (assumption 5) were carried out. Five fish were removed from the study at the outset due to our inability to locate them. Chi-square tests of independence for sex and length categories between censored fish and those included in the study were not significant ($P = 0.99$ for both factors).

The Kaplan-Meier estimate for 2018 of Chinook salmon survival at 5 days after capture was 93.7%, (SE 1.7%), with a 95% confidence interval of 89.5% to 96.3%. The product-limit survival curve, showing survival probability over time is given in Figure 7.

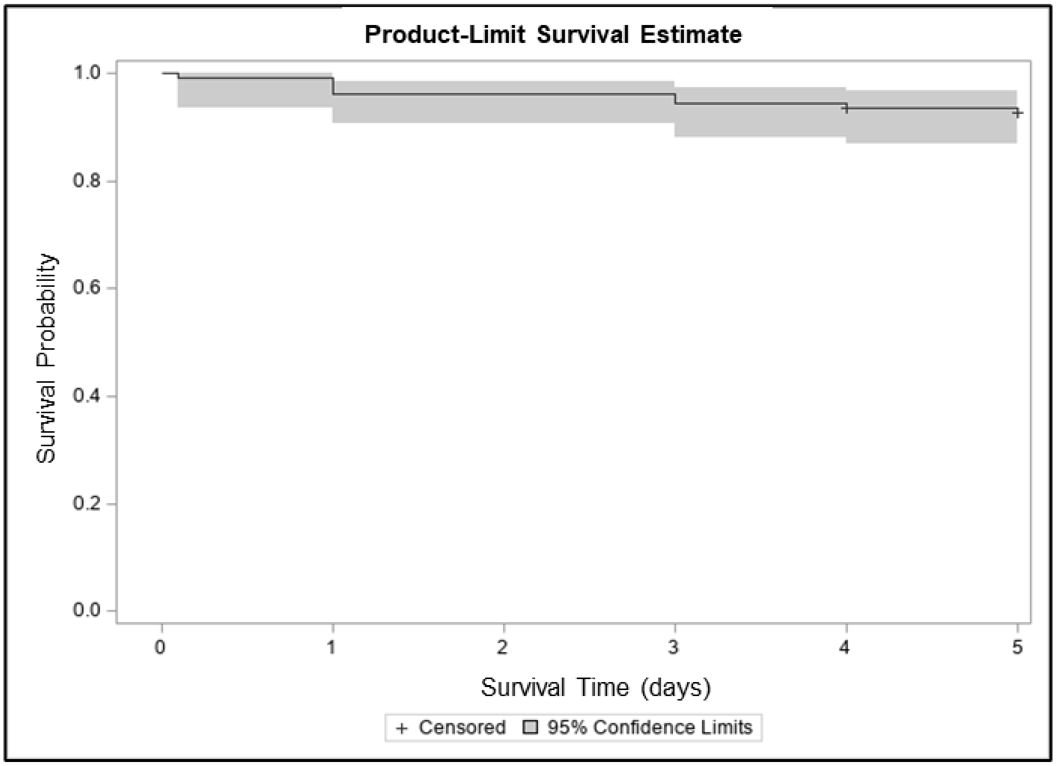

Figure 7.–Survival rates over time for Nushagak Chinook salmon, 2018.

Comparison of 5-day Survival: 2017 vs 2018

In total, 293 of 318 fish included in the 2017 and 2018 studies survived through their fifth day after capture. There were 21 mortalities and 4 were censored within 5 days. One fish was detected downstream of Black Point and 1 tag was returned by an angler.

A stratified (by year) Kaplan-Meier analysis was conducted to examine whether 5-day survival was different between years. No significant difference was found in 5-day survival rates between years ($P = 0.71$).

Pooled (2017–2018) 5-day Survival

Data were pooled over years and an overall Kaplan Meier analysis was conducted. The 5-day survival for the pooled analysis was 93.4 % (SE 1.4%) with a 95% confidence interval of 90.0% to 95.6% (Figure 8). Very similar results were obtained when year-specific estimates were combined by weighting each annual estimate by the inverse of the respective variances. The weighted estimate was 93.4% with a 95% confidence interval of 90.6% to 96.1%.

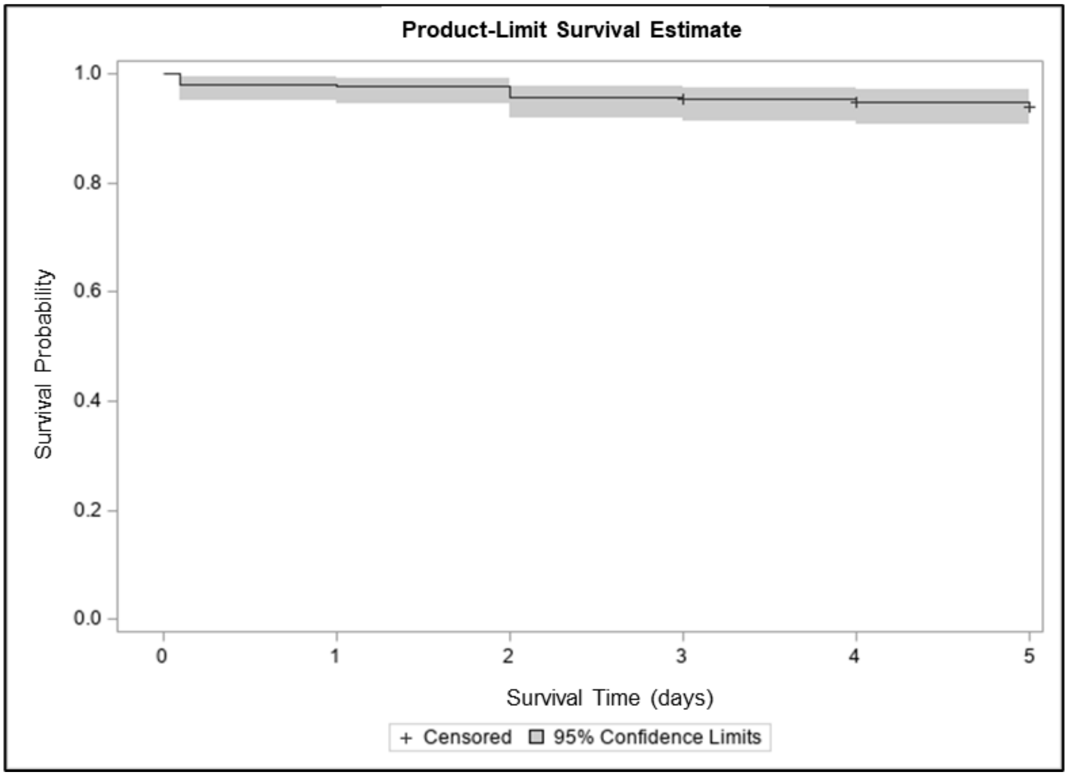

Figure 8.–Survival rates over time for Nushagak Chinook salmon, pooled 2017–2018 data.

EFFECT OF BIOLOGICAL AND FISHERY RELATED VARIABLES ON 5-DAY SURVIVAL

2017

Statistical analysis of the influence of certain biological variables required aggregation of the data into categories broader than those at which the data were collected. The aggregation of the hook-location, overall condition, bleeding-severity, and swim-away variables (described in Appendix B1) is presented in Table 5.

Table 5.–Aggregation of categories of hooking and bleeding severity variables for analysis.

Variable	Original categories[a]	Aggregated category
Hook Location	1,2,6,7	MOUTH-SNAG[b]
	3,4,5,8	OTHER[c]
Overall Condition	0	NO SLIME OR SCALE LOSS
	1,2,3	SLIME OR SCALE LOSS
Bleeding Severity	0,1	NONE OR LIGHT BLEED
	2,3	OTHER
Swimming Away	0	NO APPARENT STRESS
	1,2,3	OTHER

[a] See Appendix B1 for definitions.

[b] Original category aggregation consistent with that used by Bendock and Alexandersdottir (1993) and deemed “noncritical” with respect to survivability.

[c] Original category aggregation consistent with that used by Bendock and Alexandersdottir (1993) and deemed “critical” with regard to survivability.

Tracked fish were summarized by selected biological and fishery-related variables (Table 6). We planned on equal tagging among sublocations in 2017, but only 9 fish (8%) were tagged in sublocation 2 (this imbalance was addressed in 2018). About 97% of effort in 2017 was meted out using either back-troll or down-troll techniques, and with 1 of 3 terminal tackle types. Bait was used about 58% of the time and 74% of hooking locations were in noncritical areas. Fish were generally released with little bleeding (88%) and in generally good overall condition (73%).

Table 6.–Fish tracked in 2017 and 2018 by selected biological and fishery variables.

Variable	Level	2017	2018	Total
Sublocation				
	1	56	77	133
	2	9	92	101
	3	44	40	84
Sex				
	F	25	44	69
	M	82	165	247
Angling method				
	Back troll	14	71	85
	Down troll	92	132	224
	Side bounce	3	–	3
	Shore	–	5	5
	Side drift	–	1	1
Terminal tackle				
	Kwikfish	14	13	27
	Spin-n-Glo	47	82	129
	T-Spoon	48	109	157
	Spinner	–	3	3
	Fly	–	2	2
Bait				
	No	46	88	134
	Yes	63	121	184
Hooking category				
	Mouth snag	79	167	246
	Other	28	39	67
Bleed category				
	None or light bleed	95	187	282
	Other	13	22	35
Overall condition				
	No slime or scale loss	79	168	247
	Slime or scale loss	29	41	70

Note: An en dash indicates there were no fish in this category.

Cox Proportional Hazards Model

Following the methods outlined in the *Data Analysis* section, the following Cox proportional hazards model[5] (see Equation 4) was chosen:

$$h(t, \underline{X}_j) = h_0(t)e^{2.75 \times Sex_j + 3.95 \times T_{1j} + 1.99 \times T_{2j} - 2.28 \times HK_j} \quad (8)$$

where *j* is a particular fish at time *t* and

Sex	=	1 if female; 0 if male
T_1	=	1 if Kwikfish terminal tackle; 0 if otherwise (T-spoon only in 2017)
T_2	=	1 if Spin-n-Glo terminal tackle; 0 if otherwise (T-spoon only in 2017)
HK=	=	1 if mouth-snag hooking location; 0 if other hooking location

For example, the hazard at time *t* for a fish *j* that was female and caught in the mouth or snagged while using a Kwikfish as terminal tackle was

$$h(t, \underline{X}_j) = h_0(t)e^{2.75(1) + 3.95(1) + 1.99(0) - 2.28(1)} \quad (9)$$

Alternatively, the hazard at time *t* for a fish *j* that was male and caught in the eye while using terminal tackle other than a Kwikfish or Spin-n-Glo (i.e., a T-Spoon) was

$$h(t, \underline{X}_j) = h_0(t)e^{2.75(0) + 3.95(0) + 1.99(0) - 2.28(0)} = h_0(t) \quad (10)$$

Hazard ratios were calculated for each parameter in the final model using PROC PHREG (Table 7).

Table 7.–Hazard ratios calculated for 2017 hazards model parameters using PROC PHREG in SAS.

Parameter	df	Estimate	SE	Pr>Chi Sq	Hazard ratio
Sex(F)	1	2.75	0.9	0.002	15.6
T1(Kwikfish)	1	3.95	1.3	0.002	52.2
T2(Spin-n-Glo)	1	1.99	1.2	0.09	7.4
HK(Mouth-Snag)	1	−2.28	0.8	0.006	0.1

The 3 tests of the Cox-proportional hazards assumption outlined in the *Data Analysis* section were carried out for each of the effects in the final model. No problems were detected.

The estimated hazard ratio for sex was 15.6, which is significantly different from 1.0 (P = 0.002), with a 95% confidence interval of 2.7 to 91.9. These results indicate that the hazard for dying for females was greater than that for males. It is very important to note, however, that the confidence interval for the hazard ratio is very wide, and we have little idea of its true value.

There also appears to be an effect of terminal tackle on mortality. Among the tackle types, the Kwikfish variety appears to induce a hazard ratio of 52.2. However, the confidence interval for the hazard ratio (4.5, 610) was extremely large and we have little idea of the true magnitude of the effect. Hook location was the other significant variable in the analysis. The estimated hazard ratio for hook location was 0.1 (CI 0.02, 0.59), indicating the hazard for dying for fish hooked in the

[5] Upon dropping the sublocation variable (Step 2), the Angling Method parameter estimate changed by 28%; this value is greater than the specified 2015 cutoff. The model containing sublocation became uncompromisingly complicated, and one that we felt could not be supported by the limited data. Therefore, we dropped sublocation from the model.

mouth or being snagged in the body was lower than that for fish hooked in the esophagus, gills, or eyes.

Two-factor interaction terms were assessed among main effects. The estimated hazard ratio for the Kwikfish lure versus the Spin-n-Glo lure was lower than the main effect, at 7.1 (CI 1.3, 38.9), whereas no significant effect was found for the Spin-n-Glo lure versus the T-Spoon lure, with the confidence interval including 1.0 (CI 0.71, 76.2).

5-day Survival Using Kenai Study Strata

The Kaplan-Meier estimates of survival at 5 days for small males (<750 mm METF), large males (≥750 mm METF) and females were 95.7% (SE 2.4%), 91.7% (SE 8.0%) and 84.0% (SE 7.3%), respectively. The stratified Kaplan-Meier analysis found no differences in survival among strata ($P = 0.15$), although individual bivariate comparison found that the survival rate for small males (95.7%) was significantly different to that of females (84.0%; $P = 0.05$). No other bivariate tests were significant among these strata.

5-day Survival for Bleeding, Handling Time, and Swim-Away Variables

The bleeding and handling time variables and the variable describing the alacrity with which fish swam away after tagging were *not* included in the Cox regression model. These variables were considered side effects of the other variables. An independent Kaplan-Meier analysis for the effect of each of these 3 variables was, however, conducted.

For the bleeding variable, the test of equality between the 2 categories was highly significant ($P < 0.001$). The 5-day survival estimate for the high bleeding category was 61.5% (CI 30.8%, 81.8%), whereas the estimate for the none–light bleeding category was 96.8% (CI 90.8%, 98.9%). For the handling time variable, which was categorized into 2 levels based on the median, the test of equality between the 2 categories was not significant ($P = 0.28$). For the swim-away variable, the test of equality between the "no apparent stress" and "other" categories was significant ($P = 0.03$). The 5-day survival estimate for the swim category representing an effect of capture was 84.4% (CI 66.4%, 93.2%), whereas the estimate for the category representing no effect was 96.1% (CI 88.3%, 98.7%).

2018

Tracked fish were summarized by selected biological and fishery-related variables (Table 6). Distribution of tagged fish among sublocations was more even in 2018 than in 2017. About 97% of effort was meted out using either back-troll or down-troll techniques, similar to the rate in 2017. Five terminal tackle types were used in 2018, but 98% of tagged fish were caught on tackle similar to that used in 2017. Bait was used about 58% of the time, similar to the rate in 2017, and 81% of hooking locations were in noncritical areas. Fish were generally released with little bleeding (89%) and in good overall condition (80%), similar to rates seen in 2017.

Cox Proportional Hazards Model

Following the methods outlined in the *Data Analysis* section, the following Cox proportional hazards model (see Equation 4) was chosen:

$$h(t, \underline{X}_j) = h_0(t)e^{-1.12 \times HK_j} \tag{11}$$

where j is a particular fish at time t and

HK = 1 if mouth-snag hooking location; 0 if other hooking location.

Thus, the hazard at time *t* for a fish *j* that is caught in the mouth or is snagged is

$$h(t, \underline{X}_j) = h_0(t)e^{-1.12(1)} \quad (12)$$

and the hazard at time *t* for a fish *j* that is caught in the eye ("other" categorization) is

$$h(t, \underline{X}_j) = h_0(t)e^{-1.12(0)} \quad (13)$$

Hazard ratios were calculated for each parameter in the final model (in this case, only 1) using PROC PHREG (Table 8).

Table 8.–Hazard ratios calculated for 2018 hazards model parameters using PROC PHREG in SAS.

Parameter	df	Estimate	SE	Pr>Chi Sq	Hazard ratio
HK(Mouth)	1	-1.12	1	0.049	0.325

The 3 tests of the Cox-proportional hazards assumption outlined in the *Data Analysis* section were carried out for the hooking category variable. No problems were detected.

The estimated hazard ratio for hook location was 0.33 (CI 0.11, 0.99), indicating the hazard for dying for fish hooked in the mouth or being snagged was about 0.33 of that for fish hooked elsewhere.

5-day Survival Using Kenai Study Strata

The Kaplan-Meier estimates of survival at 5 days for small males (<750 mm METF), large males (≥750 mm METF), and females were 93.1% (SE 2.1%), 1.00 (no mortalities were detected), and 93.2% (3.8%), respectively. The stratified Kaplan-Meier analysis found no differences in survival among strata ($P = 0.24$); individual bivariate comparisons were also not significant ($P > 0.24$).

5-day Survival for Bleeding, Handling Time, and Swim-Away Variables

As described earlier, the bleeding and handling time variables and the variable describing the alacrity with which fish swam away after tagging were *not* included in the Cox regression model. These variables were considered side effects of the other variables. An independent Kaplan-Meier analysis for the effect of each of these variables was, however, conducted.

For the bleeding variable, the test of equality between the 2 categories was highly significant ($P < 0.0001$). The 5-day survival estimate for the high bleeding category was 54.6% (CI 32.1%, 72.4%), whereas the estimate for the none–light bleeding category was 98.4% (CI 95.1%, 99.5%). For the handling time variable, which was categorized into 2 levels based on the median, the test of equality between the 2 categories was not significant ($P = 0.22$). For the swim-away variable, the test of equality between the 2 categories was significant ($P = 0.0001$). The 5-day survival estimates for the swim category representing an effect of capture was 70.6% (CI 52.2%, 82.9%), whereas the 5-day survival estimate for the category representing no effect was 98.3% (CI 94.8%, 99.4%).

Pooled (2017–2018) Analysis

Bivariate Analyses

We conducted bivariate analyses for the pooled data for comparison with previous studies on the Kenai River (Bendock and Alexandersdottir 1993). Each bivariate analysis consisted of a stratified Kaplan-Meier test in the case of a dichotomous variable (e.g., use of bait or tackle type) or a univariate proportional hazards model in the case of a continuous variable (e.g., temperature or handling time; Table 9). The main analysis pertaining to the biological and fishery variables is presented in the Cox model section below.

Table 9.–Results of bivariate analyses on pooled 2017 and 2018 biological and fishery variables.

Variable	Level	5-day survival (%)	*P*-value[a]
Sublocation			0.66
	1	94.7	NA
	2	93.0	NA
	3	91.7	NA
Sex			0.18
	M	94.3	NA
	F	89.3	NA
Length[b]	NA	NA	0.94
Angling method			0.56
	Back troll	91.6	NA
	Down troll	93.8	NA
Terminal tackle			0.16
	Quickfish	85.2	NA
	Spin n Glo	95.3	NA
	T-Spoon	93.1	NA
Temperature[b]	NA	NA	0.76
Bait			0.93
	Yes	93.4	NA
	No	93.3	NA
Hook location			0.002
	Mouth-Snag	95.5	NA
	Other	84.9	NA
Landing time[b]	NA	NA	0.96
Overall condition			0.07
	Good	94.7	NA
	Other	88.5	NA

Note: NA means not applicable.

[a] H_o: No difference among levels for categorical variables; no effect for continuous variables.

[b] Continuous variable; univariate Cox regression used to assess relevance.

Cox Proportional Hazards Model

Following the methods outlined in the *Data Analysis* section (Equation 4), the following Cox proportional hazards model was chosen:

$$h(t, \underline{X}_j) = h_0(t)e^{-1.27 \times HK_j} \tag{14}$$

where *j* is a particular fish at time *t* and

HK = 1 if mouth-snag hooking location; 0 if other hooking location.

Thus, the hazard at time *t* for a fish *j* that is caught in the mouth or snagged is

$$h\left(t, \underline{X}_j\right) = h_0(t)e^{-1.27(1)} \quad (15)$$

and the hazard at time *t* for a fish *j* which is caught in the eye ("other" categorization) is

$$h\left(t, \underline{X}_j\right) = h_0(t)e^{-1.27(0)} \quad (16)$$

Hazard ratios were calculated for each parameter in the final model (in this case, only 1) using PROC PHREG (Table 10).

Table 10.–Hazard ratios calculated for pooled 2017–2018 hazards model parameters using PROC PHREG in SAS.

Parameter	df	Estimate	SE	Pr>Chi Sq	Hazard ratio
HK(Mouth)	1	-1.27	0.4	0.004	0.28

The 3 tests outlined in the *Data Analysis* section of the Cox-proportional hazards assumption were carried out for the hooking category variable. No problems were detected.

The estimated hazard ratio for hook location was 0.28 (CI 0.12, 0.66), indicating the hazard for dying for fish hooked in the mouth or being snagged was about 0.28 of that for fish hooked elsewhere. The 5-day survival for fish hooked in the mouth or those snagged was 95.5% (CI 93.0%, 98.2%), whereas that for fish hooked elsewhere was 84.9% (CI 76.9%, 94.0%). The distribution of fates was determined by hooking category (Table 11), and survivor functions are given in Figure 9.

Table 11.–Distribution of fates over hooking location variable, pooled (2017–2018) data.

	Fate		
Hook location	Hooking survivor	Hooking mortality	Fishery mortality or partial detection
Mouth snag	231	11	4
Other	57	10	0

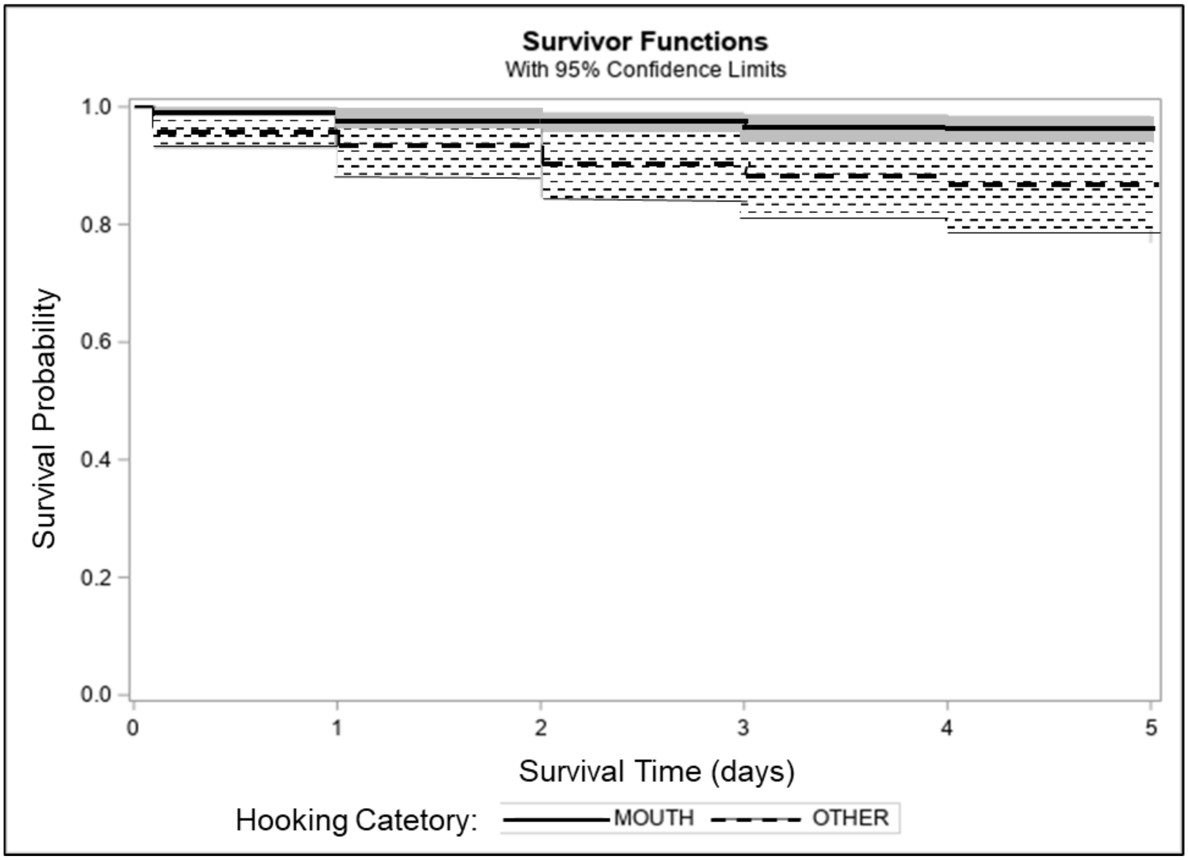

Figure 9.–Survival rates over time for Nushagak Chinook salmon hooked in the mouth or snagged versus hooked in other areas for pooled 2017 and 2018 data.

5-day Survival Using Kenai Study Strata

The Kaplan-Meier estimates of survival at 5 days for small males (<750 mm METF), large males (≥750 mm METF), and females were 93.9% (SE 1.6%), 96.9% (SE 3.1%), and 89.8% (SE 3.6%), respectively. The stratified Kaplan-Meier analysis found no differences in survival among strata ($P = 0.34$); individual bivariate comparisons were also not significant ($P > 0.22$).

5-Day Survival for Bleeding, Handling Time, and Swim-Away Variables

As described earlier, the bleeding and handling time variables and the variable describing the alacrity with which a fish swam away after tagging were *not* included in the Cox regression model. These variables were considered side effects of the other variables. An independent Kaplan-Meier analysis for the effect of each of these variables was, however, conducted.

For the bleeding variable, the test of equality between the 2 categories was highly significant ($P < 0.0001$). The 5-day survival estimate for the high bleeding category was 57.1% (CI 39.2%, 71.5%), whereas the estimate for the none–light bleeding category was 97.9% (CI 95.3%, 99.0%). For the handling time variable, which was categorized into 2 levels based on the median, the test of equality between the 2 categories was not significant ($P = 0.76$). For the swim-away variable, the test of equality between the 2 categories was significant ($P = 0.0001$). The 5-day survival estimates for the swim category representing an effect of capture was 77% (CI 65%, 87%), whereas the 5-day survival estimate for the category representing no effect was 97.6% (CI 94.8%, 98.9%).

DISCUSSION

CATCH AND RELEASE 5-DAY SURVIVAL

We found overall survival from our catch and release events (pooled estimate of 93.4%; Table 12) was slightly higher than the tolerance level of approximately 92% that had been previously assumed for Nushagak River Chinook salmon. However, the estimated survival in this study is likely an underestimation of the true value due to 2 factors. First, increased handling with respect to normal angling practice is necessary to apply radio tags. This increased handling time likely increased the probability of mortality by a small but unknown amount. Second, it is likely a small number of tags dropped out of the esophagus of a tagged fish. A tag that is dropped from the esophagus of a fish after tagging will trigger the mortality indicator in the tag and will signal a false positive for a mortality, therefore resulting in possible overestimation of mortality.

Table 12.–Overall 5-day survival estimates for 2017, 2018, and pooled data.

Year	5-day survival estimate (%)	Lower 95% Bound	Upper 95% Bound
2017	92.7	85.8	96.3
2018	93.8	89.5	96.3
Pooled	93.4	90.0	95.6

Compared to the results from the Kenai study (Bendock and Alexandersdottir 1993), the catch and release survival of 93.4% for Nushagak River Chinook salmon is within a similar range to the early run (91.2%) and late run (94.1%) 5-day survival rates for Chinook salmon found on the Kenai River. Although the rate of tag drop in the Nushagak study is unknown, the added stress involved in additional handling required to apply the “backpack” style tags deployed in the Kenai study could possibly account for the similar rates of survival if the additional mortality (backpack) were equivalent to drop rate (esophageal). Nevertheless, consistency between the Nushagak study and the Kenai study is encouraging because the effects of catch-and-release activity appear relatively uniform between the 2 drainages.

The Nushagak River study was designed to apply tags proportional to the type of angling that occurs in the sport fishery by using the same terminal gear, angling techniques, and handling methods. This allowed the data to be pooled regardless of biological or fishery variables to give an overall survival rate germane to the sport fishery. The only proportional design element that was not met was the undersampling of sublocation 2 in 2017. The fact that there were no significant sublocation effects in the survival rate suggests the undersampling of sublocation 2 in 2017 was not likely to have been problematic.

On August 8 and August 11 of 2017, postseason aerial surveys of spawning Chinook salmon were conducted by the Alaska Department of Fish and Game on a selection of spawning tributaries of the Nushagak River. It was deemed prudent to bring a radio receiver to locate fish that had been tagged by the sampling crew in June and July. Surveys were conducted with the assistance of Tom Tucker from Tucker Aviation in a Robinson R44 rotary wing aircraft. Several weeks after tagging, 15 fish were located higher in the drainage on the spawning grounds and up to about 130 miles from where they were tagged (Figure 10). This information serves to confirm that the catch-and-release tagging process and the presence of an esophageal tag did not prevent fish from proceeding to the spawning grounds and surviving long enough to have the opportunity to spawn.

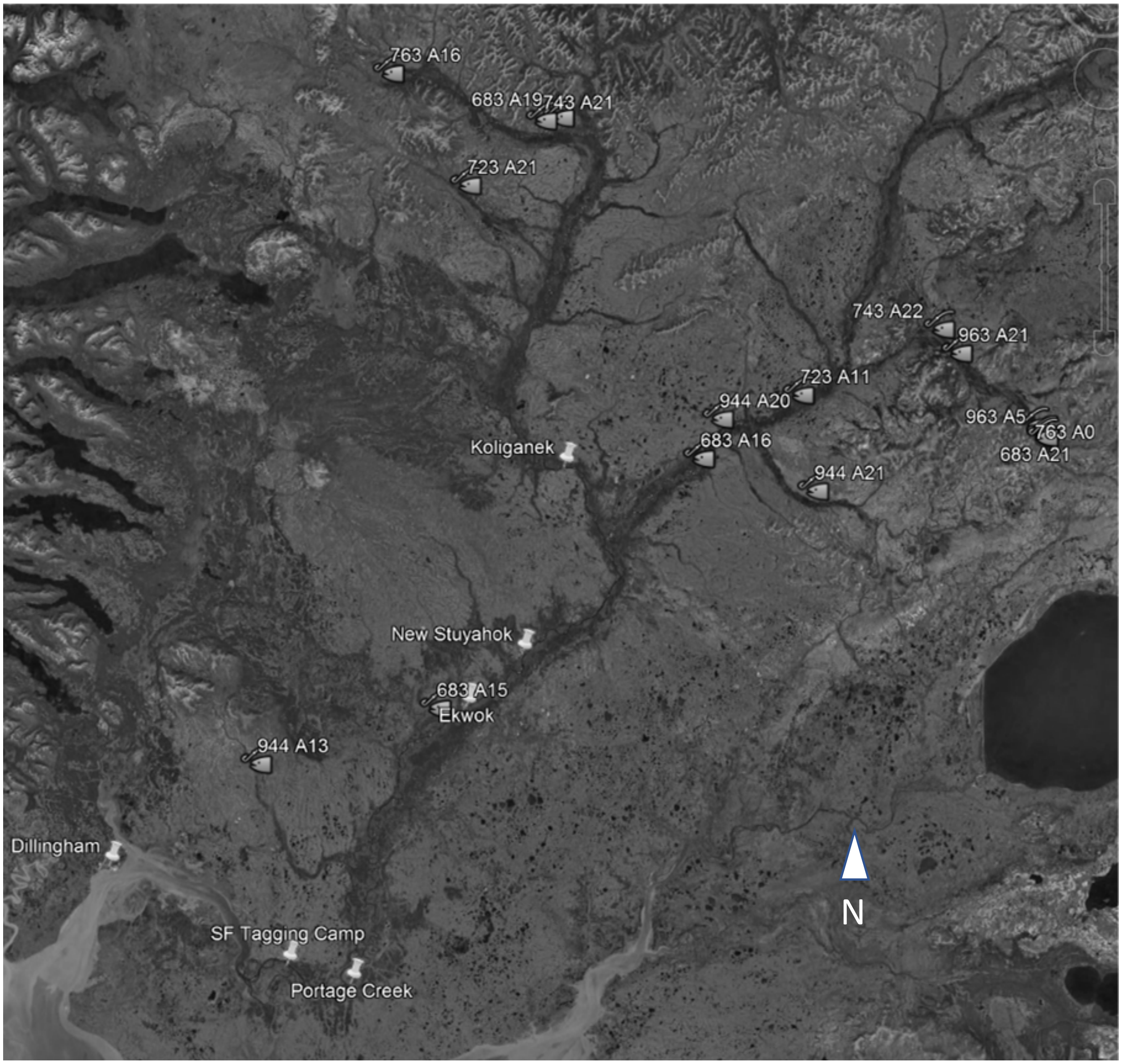

Figure 10.–Radiotagged Chinook salmon relocated on August 8 and 11 on spawning grounds in tributaries of the Nushagak River.

Note: Image comparable to Figure 1.

SECONDARY BIOLOGICAL AND FISHERY RELATED VARIABLES:

In the 2017 and 2018 Nushagak River studies, hooking location was consistently a significant variable in the Cox proportional hazard modelling and the single most important factor in the pooled data analysis. A similar finding was made in the Kenai study, but the predicted hooking effect varied widely among the sex-length strata. The 5-day survival rate for fish hooked in the mouth was 96%, whereas the survival rate for fish hooked elsewhere was 85%. Our results for noncritical (mouth) and critical (elsewhere) hooking locations fell within the range found among the strata used in the Kenai study. It is very likely that more than just the hooking variable is responsible for explaining catch-and-release mortality. Both our study and the Kenai study lacked sample sizes large enough to tease out variables that had smaller effects on survivability than hooking location. Although the relatively low observed mortality rates are good from a management perspective, they make it difficult to tease out effects of the secondary biological and fishery-related variables of interest. Although not included in the model building process for reasons explained earlier, fish that bled heavily or swam away laboriously suffered higher mortality than those that did not bleed heavily and those that swam away in a normal manner. This is a commonsense indicator of reduced survival and is not particularly surprising. We found no differences in 5-day survival rates among the sex–length strata used in the Kenai study (small males, large males, and females); part of this inconsistency may lie in the fact that the Kenai study tagged fish as small as 405 mm METF, whereas our study on the Nushagak River was restricted to fish ≥500 mm METF.

MANAGEMENT IMPLICATIONS

Estimating the mortality of Chinook salmon caught and released in the sport fishery on the Nushagak River is valuable to the management of the stock because it factors into escapement estimates. Along with sport and subsistence harvest estimates upriver of the sonar, the number of estimated mortalities due to catch-and-release practices in the sport fishery must be subtracted from the number of fish that are estimated to have passed the sonar to arrive at the actual escapement estimate.

Prior to conducting this study, an assumed rate of 8% was used to calculate catch-and-release mortality in the Nushagak River Chinook salmon sport fishery. This rate was based on the Kenai River study (Bendock and Alexandersdottir, 1993) because it seemed most applicable to the Nushagak River (based on similarities in the fisheries and geographic distance) compared to other Chinook salmon in catch-and-release mortality studies conducted in other states (e.g., Lindsay et al. 2011). Given that an assumed 8% mortality rate has been used for Nushagak River Chinook salmon, the 6.6% mortality rate found in this study makes it unlikely that escapements in the past have been badly underestimated. Taking the recent 5-year annual average from 2012 to 2016 of 28,136 Nushagak River Chinook salmon released in the sport fishery, the difference between using an 8% mortality rate and a 6.6% mortality rate would result in 393 more fish in the escapement on average than had previously been assumed. Given the low rate of catch-and-release mortality for Chinook salmon in the Nushagak River Chinook salmon sport fishery, catch-and-release would appear to be a potentially effective management practice when necessary to achieve the escapement goal.

ACKNOWLEDGMENTS

The authors would like to thank Stephen Warta, who acted as crew leader and was responsible for acquiring and tagging the Chinook salmon used in this study. James Bryant, Steve Licavoli, Ryan Luiten, Kristen Flowers, and Kraig Hammond contributed as department technicians and assisted with the tagging of fish and data collection. Bristol Bay Native Association (BBNA) Intern Program contributed to the successful execution of this study with 2 interns, Nick Jacuk and Peter Egrass, who also assisted with tagging fish and data collection. Pilots Tom Tucker with Tucker Aviation and Gabe Davis with Sunday Air Taxi flew the daily telemetry tracking flights without which this study wouldn't have been possible. Choggiung Limited manages most of the land adjacent to the Nushagak River and provided ADF&G with land use access in order to place fixed station receivers as well as set up a tagging field camp that was vitally important to the operations of the study.

REFERENCES CITED

Bendock, T. N., and M. Alexandersdottir. 1993. Hooking mortality of Chinook salmon released in the Kenai River, Alaska. North American Journal of Fisheries Management 13(3):540-549.

Cappiello, T., and J. E. Dye. 2006. Survey of the Chinook salmon sport fishery in the lower Nushagak River, Alaska, 2001. Alaska Department of Fish and Game, Fishery Data Series No. 06-68, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds06-68.pdf

Cochran, W. G. 1977. Sampling techniques. 3rd edition. John Wiley and Sons, New York.

Collet, D. 2003. Modelling survival data in medical research. 2nd edition. Chapman and Hall, London.

Conover, W. J. 1980. Practical nonparametric statistics. 2nd edition. John Wiley and Sons, New York.

Cox, D. R., and Oakes, D. 1984. Analysis of survival data. Chapman and Hall, London.

Dye, J. E. 2005. Survey of the Chinook salmon sport fishery in the lower Nushagak River, Alaska, 2000. Alaska Department of Fish and Game, Fishery Data Series No. 05-23, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds05-23.pdf

Dye, J. E. 2012. Monitoring the Chinook salmon sport fishery on the Nushagak River drainage, Alaska, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 12-67, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS12-67.pdf

Elison, T., P. Salomone, T. Sands, M. Jones, C. Brazil, G. Buck, F. West, T. Krieg, and T. Lemons. 2015. 2014 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 15-24, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMR15-24.pdf

Fair, L. F., C. E. Brazil, X. Zhang, R. A. Clark, and J. W. Erickson. 2012. Review of salmon escapement goals in Bristol Bay, Alaska, 2012. Alaska Department of Fish and Game, Fishery Manuscript Series No. 12-04, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMS12-04.pdf

Falk, M. R., and F. V. Gillman. 1975. Mortality data for angled Arctic grayling and northern pike from the Great Slave Lake area, Northwest Territories. Data Report Series No: CEN/D-75-1, Resource Management Branch, Central Region, Fisheries and Marine Service, Environment Canada.

Hosmer, D.W., S. May, and S. Lemeshow. 2008. Applied survival analysis: Regression modeling of time-to-event data. Wiley Series in Probability and Statistics. John Wiley & Sons, New York.

Howe, A. L., G. Fidler, A. E. Bingham, and M. J. Mills. 1996. Harvest, catch, and participation in Alaska sport fisheries during 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-32, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds96-32.pdf

Howe, A. L., G. Fidler, and M. J. Mills. 1995. Harvest, catch, and participation in Alaska sport fisheries during 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-24, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds95-24.pdf

Jones, M., T. Sands, S. Morstad, T. Baker, G. Buck, F. West, P. Salomone, and T. Krieg. 2012. 2011 Bristol Bay area annual management report. Alaska Department of Fish and Game, Fishery Management Report No. 12-21, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMR12-21

Kaplan, E. L., and P. Meier. 1958. Nonparametric estimation from incomplete observations. Journal of the American Statistical Association 53(282):457-481.

Lin D.Y., L. J. Wei, Z. Ying. 1993. Checking the Cox model with cumulative sums of martingale-based residuals. Biometrika 80:557–572.

Lindsay, R.B., R. K. Schroeder, K. R. Kenaston, R. N. Toman, and M. A. Buckman. 2011. Hooking mortality by anatomical location and its use in estimating mortality of spring Chinook salmon caught and released in a river sport fishery. North American Journal of Fisheries Management 24(2):367-378.

REFERENCES CITED (Continued)

Maxwell, S. L., A. V. Faulkner, L. Fair, and X. Zhang. 2011. A comparison of estimates from 2 hydroacoustic systems used to assess sockeye salmon escapement in 5 Alaska Rivers. Alaska Department of Fish and Game, Fishery Manuscript Series No. 11-02, Anchorage. http://www.adfg.alaska.gov/FEDAIDpdfs/FMS11-02.pdf

Mills, M. J. 1990. Harvest and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-44, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds90-44.pdf

Mills, M. J. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-58, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds91-58.pdf

Mills, M. J. 1992. Harvest, catch, and participation in Alaska sport fisheries during 1991. Alaska Department of Fish and Game, Fishery Data Series No. 92-40, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds92-40.pdf

Mills, M. J. 1993. Harvest, catch, and participation in Alaska sport fisheries during 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-42, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds93-42.pdf

Mills, M. J. 1994. Harvest, catch, and participation in Alaska sport fisheries during 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-28, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds94-28.pdf

Powers, B., and D. Sigurdsson. 2016. Participation, effort, and harvest in the sport fish business/guide licensing and logbook programs, 2014. Alaska Department of Fish and Game, Fishery Data Series No. 16-02, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS16-02.pdf

Schoenfeld, D. 1982. Partial Residuals for The Proportional Hazards Regression Model. Biometrika 69(1): 239–241. https://doi.org/10.2307/2335876

Stuby, L., and T. Taube. 1998. Mortality of sheefish captured and released on sport fishing gear in the Kobuk River, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-15, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds98-15.pdf

Winter, J. D. 1983. Underwater telemetry. Pages 371-395 [*In*] L. A. Nielsen and D. L. Johnson, editors. Fisheries techniques. American Fisheries Society, Bethesda, Maryland.

APPENDIX A: NUSHAGAK–MULCHATNA CHINOOK SALMON MANAGEMENT PLAN

5 AAC 06.361. *Nushagak–Mulchatna King Salmon Management Plan*[6]

(a) The purpose of this management plan is to ensure biological spawning escapement requirements of king salmon into the Nushagak-Mulchatna river systems. It is the intent of the Alaska Board of Fisheries (board) that Nushagak-Mulchatna king salmon be harvested in the fisheries that have historically harvested them. This management plan provides guidelines to the department in an effort to preclude allocation conflicts between the various users of this resource. The department shall manage Nushagak-Mulchatna king salmon stocks in a conservative manner consistent with sustained yield principles and the subsistence priority.

(b) The department shall manage the commercial fishery in the Nushagak District as follows:

(1) to achieve an inriver goal of 95,000 king salmon present in the Nushagak River upstream from the department sonar counter; the inriver goal provides for

(A) a biological escapement goal of 55,000–120,000 fish;

(B) reasonable opportunity for subsistence harvest of king salmon; and

(C) a king salmon sport fishery guideline harvest level of 5,000 fish 20 inches or greater in length;

(2) in order to maintain a natural representation of age classes in the escapement, the department shall attempt to schedule commercial openings to provide pulses of fish into the river that have not been subject to harvest by commercial gear.

(3) the department may close the commercial drift or set gillnet fishery if the harvest in the directed commercial king salmon fishery for either gear group is more than two sockeye salmon for every one king salmon.

(c) If the total inriver king salmon return in the Nushagak River is projected to exceed 95,000 fish, the guideline harvest level described in (b)(1)(C) of this section does not apply.

(d)[7] If the spawning escapement of king salmon in the Nushagak River is projected to be more than 55,000 fish and the projected inriver return is less than 95,000 fish, the commissioner

(1) shall close, by emergency order, the directed king salmon commercial fishery in the Nushagak District; during a closure under this paragraph, the use of a commercial gillnet with webbing larger than five and one-half inches in another commercial salmon fishery is prohibited;

(2) repealed 5/31/2019;

(3) repealed 5/31/2019;

(e) If the spawning escapement of king salmon in the Nushagak River is projected to be less

than 55,000 fish, the commissioner

(1) shall close, by emergency order, the sockeye salmon commercial fishery in the Nushagak District until the projected sockeye salmon escapement into the Wood River exceeds 100,000 fish;

(2) shall close, by emergency order, the sport fishery in the Nushagak River to the taking of salmon and prohibit the use of bait for fishing for all species of fish until the end of the king salmon season specified in 5 AAC 67.020 and 5 AAC 67.022(g); and

-continued-

6 Note: King salmon means Chinook salmon and department means ADF&G in the regulatory language.

7 The triggers to implement restrictions on the sport fishery, (d) (2) and (3), were removed from the plan at the 2018 Alaska Board of Fisheries (BOF) meeting pending potential changes to the plan that may be adopted at the Statewide BOF meeting in 2020.

(3) shall establish, by emergency order, fishing periods during which the time or area is reduced for the inriver king salmon subsistence fishery in the Nushagak River.

(f) Notwithstanding 5 AAC 06.200, in a directed king salmon commercial fishery, the southern boundary of the Nushagak District is a line from an ADF&G regulatory marker located at Etolin Point at 58°39.37′N lat., 158°19.31′W long., to 58°33.92′N lat., 158°24.94′W long. to Protection Point at 58°29.27′N lat., 158°41.78′ W long.

(g) During a directed king salmon commercial fishery in the Nushagak District, drift gillnet and set gillnet fishing periods will be of equal length, but do not have to be open concurrently.

APPENDIX B: HOOKING AND HANDLING CODES

Appendix B1.–Codes for Nushagak River Chinook salmon hooking and handling mortality data form, 2017–2018.

Hook location		Bleeding severity			Swimming away		Overall external appearance	
Body part	Code	Severity	Description	Code	Description	Code	Description	Code
Upper jaw	1	None	No evidence of external bleeding.	0	No apparent effects from handling. Fish easily and readily swam away.	0	Fish shows no apparent handling effects. Loses little slime and scales still intact.	0
Roof of mouth	2	Slight	A small amount of bleeding generally localized near the point of hook entry.	1	Fish shows some handling stress, but swims off soon after release.	1	Some slime loss, scales remain intact.	1
Esophagus	3	Moderate	A greater amount of external bleeding generally localized around the point of hook entry.	2	Fish held in quiet water for a while. Takes some time to recover, but finally swims away.	2	Slime and some scale loss.	2
Gills	4	Severe	Copious amounts of blood, staining the water in the holding tub and generally surrounding and obscuring the point of hook entry.	3	Assumed mortality.	3	Heavy slime and scale loss.	3
Tongue	5	–	–	–	–		–	
Lower jaw	6	–	–	–	–		–	
Snag	7	–	–	–	–		–	
Eye	8	–	–	–	–		–	

Source: Adapted from Stuby and Taube (1998) and Falk and Gillman (1975).

APPENDIX C: EXAMPLE SAS CODE USED TO ESTIMATE SURVIVAL RATES

Appendix C1.–Example SAS code used in Kaplan-Meier and Cox proportional hazards estimation of survival rates.

SAS CODE[8]

```
*SAS code: Overall Kaplan Meier Estimation;
title "OVERALL KM-2017 ";
proc lifetest data=NUSH17 outsurv=KM17_OVERALL ALPHA=0.05 stderr Method=KM Plots=S (CL); *Kaplan Meier estimates, 95% confidence limits, survivor function plot with confidence bands;
Time SURVT*STATUS(0);
run;
proc print data=KM17_OVERALL;
run;

* SAS code: Stratified Kaplan Meier Estimates for variable Sub-Location-used in Bivariate analysis;
title "SUB-KM-2017";
proc lifetest data=NUSH17 method=KM Plots=(S);
Time SURVT*STATUS(0);
STRATA SUB;
run;

* SAS code: Cox Proprotional hazard model with Sex, Terminal Tackle and Hook Category as model inputs;
data TMcovals; * Sets TMTACK covariate values for baseline statement;
input SEX $ TMTACK $ HKCAT $;
datalines;
M TSp MOUTH
M QuickF MOUTH
M SpinG MOUTH
;
run;
title "FINAL MODEL-2017";
proc phreg data=NUSH17 plots(cl)=(s cumhaz) outest=ESTBET covout; * Output covariances for check;
class SEX TMTACK HKCAT;
```

-continued-

[8] Variables listed in Appendix C2.

```
model SURVT*STATUS(0)=      SEX TMTACK  HKCAT;
baseline out=a covariates=TMcovals survival=sTM LOWER=lTMcl UPPER=uTMcl; * Obtian lower and upper limits for specified TMTACK levels;
hazardratio TMTACK ;
run;
title "ESTBETA";
proc print data=ESTBET;
run;
title "Data a";
proc print data=a;run;
```

*** Matringale residuals;**

```
proc phreg data=NUSH17  ;
class                  SEX TMTACK HKCAT ;
model SURVT*STATUS(0)=      SEX TMTACK HKCAT ;
Assess PH/resample;
run;
* Schoenfeld residuals;
proc phreg data=NUSH17  ;
class                  SEX TMTACK HKCAT ;
model SURVT*STATUS(0)=      SEX TMTACK HKCAT ;
OUTPUT OUT=b RESSCH= schsex schTMTACK schHKCAT;
run;
data c;
set b;
lsurvt=LOG(survt);
survtsq=survt**2;
run;
proc corr data=c;
var survt lsurvt survtsq schsex schTMTACK schHKCAT;
run;
* Log-Log Survival Curves;
proc phreg data=NUSH17;
class                  SEX HKCAT ;
model SURVT*STATUS(0)=      SEX HKCAT ;
strata TMTACK;
```

-continued-

```
baseline out=out2 survival=s2 loglogs=LS2;
run;
proc print data=out2; run;
symbol1 value=dot   color=black;
symbol2 value=triangle color=black;
symbol3 value=square color=black;
proc gplot data=out2;
plot ls2*survt=TMTACK;
run;
```

Appendix C2.–Data subset example and list of input variables for SAS code in Appendix C1.

DATA SUBSET

Obs	AMETH	YEAR	SURVT	STATUS	FATE	SUB	SEX	MEF	TEMP	TMTACK	BAIT	LTIM	BLD	SW	OV	HKCAT	BLDCAT	SWCAT	OVCAT
1	Backtroll	2017	3	1	2	2	M	545	15	QuickF	Y	77	2	0	0	OTHER	HIGHBLEE	NOSWEFFE	GOODEXT
2	Downtroll	2017	5	0	1	3	M	570	14	TSp	Y	112	0	0	0	OTHER	NO_LTBLE	NOSWEFFE	GOODEXT
3	Downtroll	2017	5	0	1	1	M	670	14	TSp	N	162	1	1	0	OTHER	NO_LTBLE	SWEFFECT	GOODEXT
4	Downtroll	2017	5	0	1	1	M	620	15	SpinG	N	107	1	0	0	OTHER	NO_LTBLE	NOSWEFFE	GOODEXT

LIST OF VARIABLES

AMETH	Method of capture
YEAR	Year of study
SURVT	Survival time *t* (days)
STATUS	Alive vs mortality
FATE	Fate category (1–4)
SUB	Sublocation
SEX	Sex (M = male, F = female)
MEF	Mid eye to tail fork length
TEMP	Water temperature
TMTACK	Terminal tackle
BAIT	Captured with bait (yes or no)
LTIM	Landing time
BLD	Bleeding category
SW	Swim away category
OV	Overall condition category
HKCAT	Hooking location aggregated category
BLDCAT	Bleeding severity aggregated category
SWCAT	Swimming away aggregated category
OVCAT	Overall condition aggregated category