Fishery Data Series No. 21-14

Karluk River Steelhead Population Assessment, 2017–2019

by

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and

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December 2021

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

The Karluk River steelhead (*Oncorhynchus mykiss*) population was studied between 2017 and 2019. In 2017 and 2018, age, sex, and length information were collected from steelhead at 2 points in their life history: spawning (steelhead) and emigration (kelts). Steelhead were sampled near holding and spawning areas within the Karluk River drainage before, during, and after the annual spawning event. Kelts were also counted at the Karluk River weir near Karluk Lagoon, and a fraction of those counted were sampled. In 2017, age was determined for 60 steelhead and 345 kelts. In 2018, age was determined for 114 steelhead and 154 kelts. In 2019, a mark–recapture experiment was implemented by tagging fish during the spawning area sampling event and recovering tags passing through the weir during emigration. In 2019, 133 steelhead were sampled and tagged, and 49 tagged fish were recovered at the Karluk River weir among 2,877 kelts. The abundance of Karluk River steelhead during this spawning event was estimated to be 7,952 (95% confidence interval [CI] 7,451–9,666). Spawning survival was 37% (95% CI 29–45%).

Keywords: steelhead, *Oncorhynchus mykiss*, mark–recapture, abundance, Karluk River, age-sex-length

INTRODUCTION

The Karluk River (Figure 1) on the southwest side of Kodiak Island is approximately 24 miles in length from the outlet of Karluk Lake through the Karluk Lagoon to its mouth in the Shelikof Strait (Figure 1). It supports the largest steelhead (*Oncorhynchus mykiss*) sport fishery in the Kodiak Management Area (KMA) by both catch as well as popularity for anglers, and is the only steelhead fishery in the KMA large enough to be included in the Alaska Department of Fish and Game (ADF&G) Alaska Sport Fishing Survey, commonly known as the Statewide Harvest Survey (SWHS; Table 1). There is a long history of anglers targeting steelhead in the Karluk River drainage, but the fishery has recently become more popular with anglers seeking a remote and less crowded steelhead fishing destination. Anglers primarily target steelhead in the Karluk River during the month of October at a location known as “the Portage” (Figure 1).

In addition to the steelhead fishery, the Karluk River drainage also supports sport fisheries for sockeye (*O. nerka*) and coho (*O. kisutch*) salmon and has historically supported a Chinook salmon (*O. tschawytscha*) fishery, although Chinook salmon runs have been severely depressed since 2005. Rainbow trout (the nonanadromous form of steelhead) and Dolly Varden (*Salvelinus malma*) are also caught incidentally to other species. The Karluk River drainage supports large commercial fisheries in the KMA targeting primarily sockeye and pink salmon (*O. gorbuscha*), but coho and Chinook salmon are also harvested. Subsistence fisheries occur mostly in Karluk Lagoon and primarily consist of harvests of sockeye and coho salmon; however, harvests do occur in other areas of the Karluk River and other species, such as steelhead and rainbow trout, are harvested in smaller numbers. A winter subsistence steelhead fishery has also occurred historically in the Karluk River; however, effort in this fishery has declined in the last 30 years.

Karluk River steelhead return to freshwater in the fall beginning in September and continuing into November, with peak run timing typically occurring in mid-October. There are no spring-run steelhead in the Karluk River. Overwintering and migration of steelhead in the Karluk River has been documented by Chatto (1987) and indicates that more than 75% of overwintering can occur in river miles (RM) 12–20, surrounding the area known as “the Portage.” Other areas of possible overwintering include RM 22–24 near the lake outlet and some areas of the river below RM 12, where spawning also occurs. Spawning primarily occurs in May and surviving steelhead migrate to the ocean following spawning from late May through July (these fish are called kelts). A portion of the kelts survive to return to the Karluk River the next fall and spawn the following spring (repeat spawning). A smaller portion can survive to spawn multiple times. Survival from initial spawning to repeat spawning has previously been documented to be generally low, ranging between 24% and 31% (Begich 1999).

Begich (1992, 1993, 1995a, 1995b, 1997, 1999) conducted a series of studies to estimate the Karluk River steelhead spawning population size. Using a mark–recapture tagging experiment, estimated population sizes from the 1992–1997 studies ranged from 4,107 fish to 10,802 fish. Since then, the only indicators of abundance have been weir counts of the kelts that survived spawning. Kelt counts are obtained beginning annually in May when a weir is installed by the ADF&G Division of Commercial Fisheries (CF) to enumerate early-run sockeye salmon migrating to the freshwater, and as a result, the early portion of the kelt emigration is not enumerated in some years because the weir is not yet installed before kelts begin to move. From 2010 to 2019, kelt counts at the Karluk River weir have averaged 2,281 and ranged from 836 to 4,624 (Table 2).

In 2017 and continuing through 2019, a study was initiated by the ADF&G Division of Sport Fish (SF) in cooperation with CF to estimate the spawning abundance of Karluk River steelhead (*Oncorhynchus mykiss*) by means of mark–recapture experiments. This project, based on the successful mark–recapture study design used in the 1990s (Begich 1999), was meant to provide updated estimates of abundance for the population, and the results are presented herein.

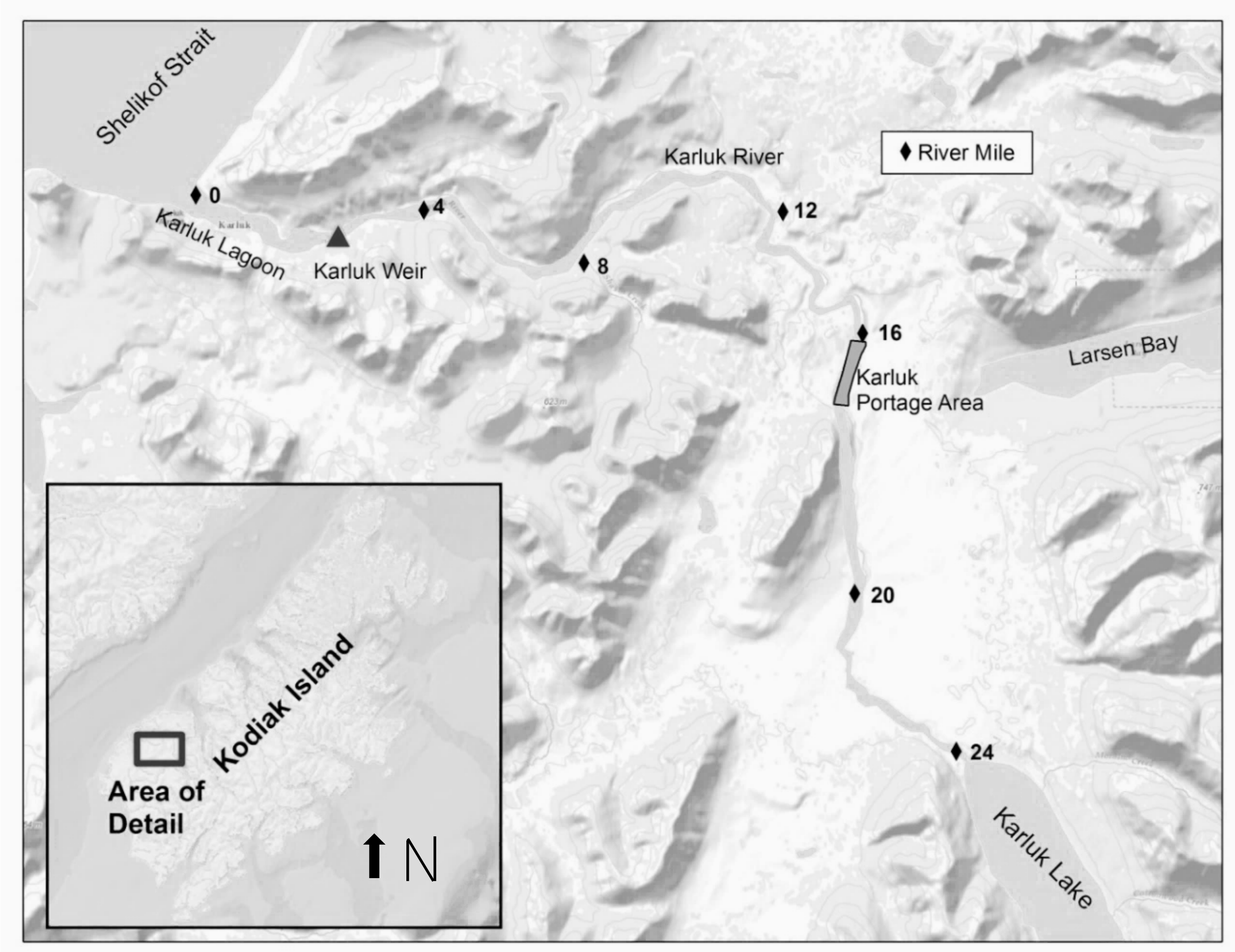

Figure 1.–Map of the Karluk River drainage showing the locations of river miles (RM) along the Karluk River and "the Portage" (labeled Karluk Portage Area), which is the primary staging area for Karluk River fish studies and the location of the majority of sport fishing effort for steelhead.

Table 1.– Steelhead catch (harvest plus release) in the Karluk River, 2009–2018.

Year	Reported guided angler catch[a]	SWHS estimated total catch[b]
2009	751	859
2010	667	216
2011	506	1,556
2012	504	236
2013	250	22
2014	488	108
2015	742	1,005
2016	824	2,709
2017	NA	74
2018	NA	120
Average 2009–2018	569	672

Source: Freshwater Logbook Database (Alaska Department of Fish and Game, Division of Sport Fish. 2006 to present. Accessed April 2020. [URL not publicly available as some information is confidential. Contact Research and Technical Services for data requests.]); Statewide Harvest Survey (SWHS) estimates from the Alaska Sport Fishing Survey database [Internet]. 1996–present. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish (cited April 2020). Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/.

[a] As reported by freshwater logbook data. Only available through 2016.

[b] As estimated by the Statewide Harvest Survey.

Table 2.–Steelhead kelt counts at the Karluk River weir, 2010–2019.

Year	Steelhead kelts
2010	2,203
2011	3,688
2012	836
2013	1,605
2014	1,381
2015	1,278
2016	1,168
2017	4,624
2018	3,148
2019	2,877
Average 2010–2019	2,281

Source: ADF&G Division of Commercial Fisheries Westward Region Escapement Database.

OBJECTIVES

The objectives of this project were to document the current spawning population size of the Karluk steelhead run and compare this to previous estimates. Population estimates and spawning survival rates will be used to aid in management of the Karluk steelhead fishery by allowing managers increased understanding of the population size and structure and trends in abundance and survival rates over time. Specific objectives were as follows:

1) Estimate the number of spawning steelhead in the Karluk River during the spring of 2017–2019.
2) Estimate the age, sex, and length composition of the spawning population of steelhead in the Karluk River during the spring of 2017–2019.
3) Count kelts emigrating through the Karluk River weir from approximately 16 May through 15 July, 2017–2019.
4) Estimate the age, sex, and length composition of kelts emigrating through the Karluk River weir during the 2017–2019 spring emigrations.

METHODS

STUDY DESIGN

Steelhead overwinter in the upper Karluk River and concentrate in the Portage area where they can be captured with hook and line and then sampled (Chatto 1987). After spawning, kelts emigrate through a weir located in the lower river just above Karluk Lagoon (Figure 1). Using this knowledge, 2-event, mark–recapture experiments were implemented during 2017–2019 to estimate the abundance of spawning steelhead at the time of tagging. The first event (marking) occurred primarily in RM 12–20 but effort was also directed in areas throughout the drainage where fish are known to congregate prior to and during spawning, such as near the outlet of Karluk Lake and some of the lower reaches of the river below RM 12. Fish tagged during the first event were also sampled to collect age, sex, and length (ASL) data from the spawning population. The second event (recapture) was conducted at the Karluk River weir and ASL data were collected at this location as well; these ASL data were collected in all 3 years. Although mark–recapture experiments were meant to estimate population size for all 3 years, counting procedures at the weir proved insufficient to estimate abundance in 2017 and 2018.

First Event: Tagging

During each year of the project, steelhead were sampled between mid-April and mid-May during 2 sampling trips with the goal of tagging 150 steelhead to estimate the number of spawning steelhead in the Karluk River such that the estimate was within 25% of the actual abundance 95% of the time (Polum and Reimer 2018). Fish were caught by hook-and-line techniques by 1 or 2 crews of 3 people each, with effort spread in different areas when 2 crews were available. Timing of sampling trips attempted to target fish after they became more active as they left their wintering areas but before peak spawning. In the first year of the project, sampling was attempted early enough to occur entirely before spawning, when fish were still in their overwintering stage; however, it was found that these holding steelhead are much more difficult to catch and are very lethargic compared to those captured just prior to or during spawning. Spawning also commences very quickly when springtime water temperatures increase even slightly in the Karluk River, leaving little time to sample fish prior to spawning. For 2018 and 2019, sampling was attempted prior to peak spawning but because spawning commences quickly, it was not reasonable to expect samples composed of only prespawning fish, and many postspawning fish were encountered. To reduce handling mortality, effort was directed at waters that were thought to have fish holding rather than actively spawning, and any fish encountered on redds were avoided. Sampling trips of about 3 days were also most productive because catch rates tended to drop substantially after the second day of fishing, although the reason for this is unknown.

All captured steelhead were tagged with an individually numbered Floy T-Bar anchor tag with contact information for the project leaders included on each tag, and the tag number was recorded. Pink, green, and yellow tags were used in 2017, 2018, and 2019, respectively. Tags were placed on the left side of the fish near the posterior insertion of the dorsal fin when possible, or on the right side in the same location if needed. As a secondary mark, a portion of the right pectoral fin was clipped on each fish released with a tag, or the left pectoral fin was clipped if injury was observed to the right pectoral fin.

Age, sex, and length data were collected from all tagged fish and included fork length (FL) measurements from the tip of the snout to tail fork to the nearest millimeter; sex as determined by head shape, girth to length ratio, and the presence of ovipositor, eggs, or milt; and scales were collected for age determination. Steelhead scales develop first along the lateral line and spread most rapidly in the middle and posterior part of the body (Paget 1920). The annulus marking the first year of growth is most likely to be visible on scales from this preferred scale area. Scales from this area also tend to be oval-shaped and symmetrical (Maher and Larkin 1955) and relatively easy to interpret. Four scales were removed from each fish and mounted on a gum card. Scale impressions were made into cellulose plastic and read for age determination. Scale analysis was conducted using the methods of Mosher (1969), Jones (*Unpublished*),[1] Wallis (*Unpublished*)[2] and Love (2016). In addition to ASL samples, fish were examined for injuries occurring during the hooking and reeling process. A sample size goal of 138 was selected with an objective to estimate the age, sex, and length composition of the spawning population of steelhead in the Karluk River such that the estimates were within 11.5 percentage points of the actual proportions 90% of the time (Polum and Reimer 2018).

Second Event: Weir Sampling

A steelhead trap was installed in the Karluk River salmon weir and operated by CF to capture kelts for ASL sampling from approximately mid-May through mid-July annually (Appendix B1). SF personnel assisted with installation of this trap and any design modifications and training of CF personnel in steelhead capture and sampling. The trap captured downstream migrating steelhead (kelts) passively through a gate installed into one of the side panels that allowed kelts swimming along the front of the weir to enter the trap. The trap gate was closed nightly and opened each morning to prevent bears from eating kelts in the trap overnight. Because sockeye salmon enumeration occurred concurrently as a function of the normal weir operation, kelts could also pass the weir through a separate gate designed to allow upstream passage of sockeye salmon.

During earlier mark–recapture studies on this population (Begich 1992, 1993, 1995a, 1995b, 1997, 1999), all kelts passing the weir were examined for tags, fin clips, and ASL information. This study

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[1] Jones, D. E. *Unpublished*. Handbook for interpretation of steelhead trout scales in Southeast Alaska. Alaska Department of Fish and Game, Juneau.

[2] Wallis, J. *Unpublished*. Handbook for interpretation of steelhead trout scales from Anchor River. Alaska Department of Fish and Game, Homer.

deviated from that practice in several important ways. During 2017 and 2018, due to miscommunication between SF and CF staff, only marked kelts encountered in the sampling trap were recorded as such, whereas marked kelts passing through the sockeye salmon gate were not reliably recorded. This error resulted in an insufficient second event sample and made abundance estimation in 2017 and 2018 impossible. In 2019, all marked kelts passing the weir were recorded (49 fish), although tag number and ASL information were only recorded from fish encountered in the sampling trap (20 fish). Abundance estimation was possible in 2019 although assumption testing and estimation of abundance by sex was complicated because we lacked individual identifications for a majority of the kelts.

Sampling goals were to collect age, sex, and length data from the first 10 of every 30 kelts that passed the weir in 2017 and the first 10 of 40 kelts in 2018 and 2019 up to 138 fish from each third of the run to meet Objective 4 such that the estimates of age, sex, and length are within 11.5 percentage points of the actual proportions 90% of the time. ASL samples were collected from a portion of the kelts captured in the trap, although all tagged kelts that migrated through the trap were sampled for tag number, tag color, and fin clip status (secondary mark). Because some kelts pass through the weir during salmon counting operations, a portion of tagged kelts can pass through the weir without the chance to sample them (although tag color and the number of tagged fish were recorded in 2019), whereas all tagged kelts caught in the trap were sampled and each fish entering the trap was examined for tags.

Other Tag Recoveries

Tagged steelhead were also recovered in sport and commercial fisheries after the marking event. Information about the project was disseminated by word of mouth from conversations with anglers, guides, commercial fishing participants, and other stakeholders of the Karluk River area. Tags included contact information for the project leaders so that tags could be returned and information about harvest location collected.

DATA ANALYSIS

Abundance Estimate

Assumptions

In order for the spawning population estimate produced by this mark–recapture study to be unbiased, certain standard assumptions had to be met (Seber 1982). Assumptions of the model are as follows:

1) There was no recruitment, immigration, or emigration from the population over the duration of the experiment.

   This assumption was addressed by the study design and life history of steelhead in the Karluk River drainage: steelhead immigrate into the study area in the fall prior to the marking event, marking occurs prior to emigration, and fish are recaptured during emigration from the study area. We must also assume that spawning mortality is equal among tagged and untagged fish.

2) Marking and handling did not affect the probability of recapture.

   There is no explicit test for this assumption, and we assume mortality after tagging is attributable to the spawning event rather than the tagging event, although every effort was made to maximize the probability of survival after capture. Holding and handling time was minimized to reduce stress on tagged fish. Once hooked, fish were reeled in and captured in a rubber holding net as quickly as possible and were released gently from the net quickly after tagging and sampling.

3) No marks were lost between events and all marks were reported at the second event.

   Tagged fish received a fin clip in addition to a visual tag to ensure tag loss could be detected at the weir. Weir personnel individually inspected kelts for marks when captured in the weir trap although the loss of a colored tag would only be detected in fish sampled for ASL.

4) One of the following 3 conditions was met:
   a) All fish had an equal probability of being marked.
   b) All fish had an equal probability of being captured in the second event.
   c) Marked and unmarked fish mixed completely between sampling events.

   These conditions had a reasonable chance of being satisfied with this experimental design. Equal probability of capture during the marking event was possible because effort was distributed throughout known overwintering and spawning areas, the areas of overwintering and spawning were relatively concentrated, and multiple trips were made to capture fish in each area. In addition, sport fishing gear is not thought to be size selective amongst fish of spawning size. During the recapture event, it was possible for the weir to census emigrating individuals, provided monitoring occurred prior to the start of emigration. Mixing between events was also highly likely given that several weeks elapsed between the marking and recapture events, and marking occurred prior to spawning and emigration. These conditions were evaluated by time, size, and sex.

Equal probability of capture by size and sex were evaluated for both capture events using the procedures described in Appendix A1. Probability of capture tests by size and sex were conducted using observed sex compositions for captured and recaptured fish as opposed to the estimated sex compositions used for estimating abundance and described in methods below. If capture probability differed by size or sex, the data were stratified into groups where equal probability of capture was demonstrated within each group and separate abundance estimates were produced for each size–sex stratum using the procedures described in Appendix A1. Temporal violations of the probability of capture assumptions were tested using the procedures described in Appendix A2.

During the marking event, each sampling trip was used as a time stratum, and the recapture event was split into 4 time strata where each stratum represented 1 quartile of the annual emigration. Two temporal probability of capture tests requiring marking stratum information used only the 20 recaptured fish for which we had associated tag numbers. This limitation introduced a nuisance variable (associated with the probability of the tag number being recorded during the recapture event) into the hypothesis tests but because the probability of entering the sampling trap (and therefore recording a tag number) was very likely random with respect to marking stratum, this complication did not affect the hypothesis being tested, although the reduction in sample size certainly lowered the power of both tests.

We used a 2-sample mark–recapture experiment to estimate spawning abundance in the Karluk River. Spawning abundance of sex i was estimated using Chapman's version of the Peterson abundance estimator (Seber 1982) as follows:

$$N_i = \frac{(M_i + 1)(C_i + 1)}{R_i + 1} - 1 \,, \tag{1}$$

where

N_i	=	Spawning abundance of sex *i*,
M_i	=	number of fish marked and released in the first event of sex *i*,
R_i	=	number of marked fish recaptured in the second event of sex *i*, and
C_i	=	number of fish examined for marks in the second event of sex *i*.

Sex was determined for all fish during the marking event; however, sex was only determined for a sample of the total number of fish examined or recaptured at the weir. To estimate abundance separately for each sex, we needed estimates of $\widehat{R}_i$ (number of sex *i* recaptured) and $\widehat{C}_i$ (number of sex *i* examined for marks at the weir). We estimated $\widehat{R}_i$ as

$$\widehat{R_{male}} = R\rho_{maleR} \text{ and } \widehat{R_{female}} = R - \widehat{R_{male}} \quad (2)$$

Where R is the total number of recaptured fish and ρ_{maleR} (the probability of being a recaptured male) was estimated assuming a binomial distribution with sex composition data from fish recaptured and sampled for sex at the weir (r^*):

$$r^*_{male} \sim \text{binomial}(\rho_{maleR}, r^*) \quad (3)$$

where

r^*_{male}	=	number of male recaptures sampled at the weir,
r^*	=	number of recaptured fish sampled for sex at the weir.

Estimates of $\widehat{C}_i$ were handled similarly. $\widehat{R}_i$ and $\widehat{C}_i$ were estimated using Markov Chain Monte Carlo (MCMC) method through the package RJAGS (Plummer 2013) within R (R Core Team 2016). A noninformative prior was used for ρ_{maleC} whereas ρ_{maleR} used a uniform$\left({}^{4}/_{49}, 1\right)$ prior to ensure $\widehat{R_{male}} > r^*_{male}$. Equation 1 was used to estimate spawning abundance for each sex[3] and total abundance was the sum of the estimated male and female abundances. The analysis was initiated with 5 chains and 10,000 samples were generated per chain. The first 5,000 samples from each chain were discarded to reduce the effect of initial conditions resulting in 25,000 samples that were used to estimate the marginal posterior means, standard deviations, and percentiles. Trace plots, $\widehat{R}$, and effective sample sizes were used to assess convergence and no problems were encountered. Interval estimates were constructed from the percentiles of the posterior distribution.

[3] We also tried a more satisfying model where a hypergeometric distribution was used to model the probability of recapturing a marked fish. This model required a weakly informative prior for male abundance which defined a maximum spawning population of males. The hypergeometric model is not presented here because the prior limitation was somewhat arbitrary; however, reasonable choices provided similar abundance estimates as presented herein.

Spawning Survival

The survival of tagged fish to emigration $\widehat{S}$ was calculated using weir recapture information. Survival was estimated as a proportion (Cochran 1977):

$$\widehat{S} = \frac{R}{M} \tag{4}$$

with variance

$$\mathrm{var}\left(\widehat{S}\right) = \frac{\widehat{S}\left(1 - \widehat{S}\right)}{M - 1} \tag{5}$$

Wilson confidence interval (Hollander et al. 2014, page 24) was used to calculate the 95% CI. Samples sizes were too small to provide reliable estimates for spawning survival by sex or spawning history.

Age, Sex, and Length

Sex and age composition were tested for differences between temporal strata prior to estimating composition using likelihood ratio tests. When differences were found, age and sex were estimated and presented separately for each stratum to demonstrate changes in composition through time. In 2019, we had an estimate of spawning abundance and temporal differences in composition on the spawning grounds but assumed our spawning ground sampling was proportional to total abundance to produce estimates of abundance by age and sex for the entire spawning event.

We also tested for differences in the sex composition relative to age determination (successfully aged and unsuccessfully aged) for fish sampled at the weir. When differences were found, we first estimated composition by sex using all sample fish and then used estimates of abundance by sex to produce composition estimates as described below. Spawning ground data were too sparse to perform this adjustment.

The proportion of steelhead ($\hat{p}_{ti}$) in each age or sex class i during stratum t was estimated as follows (Cochran 1977):

$$\hat{p}_{it} = \frac{n_{it}}{n_t} \tag{6}$$

with variance

$$\mathrm{var}\left(\hat{p}_{it}\right) = \frac{\hat{p}_{it}\left(1 - \hat{p}_{it}\right)}{n_t - 1} \tag{7}$$

where n_{it} is the number of fish sampled during stratum t that were classified as age or sex class i and n_t is the total number of fish sampled during stratum t. Wilson confidence interval (Hollander et al. 2014, page 24) was used to calculate the 95% CI.

Abundance (A_{ti}) in each age or sex class i during stratum t and its variance (Goodman 1960) was estimated as follows:

$$\widehat{A}_{it} = \widehat{A}_t \hat{p}_{it} \,, \tag{8}$$

with variance

$$\text{var}(\widehat{A}_{it}) \approx \widehat{A}_t^2 \text{var}(\hat{p}_{it}) + \hat{p}_{it}^2 \text{var}(\widehat{A}_t) - \text{var}(\hat{p}_{it})\text{var}(\widehat{A}_t) \tag{9}$$

The variable A can represent the mark–recapture estimate of spawning abundance or weir count of kelts.[4] Total abundance was estimated by summation, and its variance was estimated by assuming independence between the stratum estimates. Composition estimates for total abundance were calculated as follows:

$$\widehat{p}_i = \sum_{i=1}^{I} \frac{\widehat{A}_i}{\widehat{A}} \widehat{p}_{it} \tag{10}$$

$$\text{var}(\hat{p}_i) \approx \frac{1}{\widehat{A}^2} \sum_i \left(\widehat{A}_i^2 \text{var}(\widehat{p}_{it}) + \left(\widehat{p}_{it} - \widehat{p}_i\right)^2 \text{var}(\widehat{A}_i) \right) \tag{11}$$

RESULTS

2017

Spawning Composition

In 2017, 2 trips were made to Karluk River to sample the spawning population of steelhead. The first trip included 2 days of sampling from 24 to 25 April, and the second trip included 3 days of sampling from 8 to 10 May. A total of 76 steelhead were sampled, 33 during the first sampling trip and 43 during the second sampling trip; age was determined for 26 (Table 3) and 34 (Table 4) steelhead, respectively. Sex composition differed between the 2 sampling trips (G = 7.1, df = 1, $P = 0.01$), whereas age composition (G = 7.2, df = 4, $P = 0.12$) and initial versus repeat spawning (G = 2.0, df = 2, $P = 0.36$) did not.

Kelt Composition

The Karluk River weir was installed on 24 May and 4,624 kelts were counted for the season, a record count for the Karluk River weir (Appendix B1). Weir operational dates included the entire kelt emigration (Figure 2). During this time, 410 kelts were sampled for age, sex, and length between 31 May and 14 July; age was determined for 345 (Table 5). Sex composition (G = 2.2, df = 3, $P = 0.53$), age composition (G = 14.12, df = 9, $P = 0.12$), and spawning history (G = 5.97, df = 6, $P = 0.43$) did not differ between time strata. The sex composition of unaged and aged fish differed (G = 12.51, df =1, p = 0.00).

[4] Note $\text{var}(A_t) = 0$ for weir counts.

Table 3.–Age, sex, and length (mm) composition of steelhead sampled in the first tagging trip, 2017.

		Age classes			
Sex	Information type	2-Initial	3-Initial	3-Repeat	All ages
Females	Sample size	16	2	4	22
	Proportion (SE)	0.615 (0.097)	0.077 (0.053)	0.154 (0.072)	0.846 (0.072)
	95% CI of proportion	0.425–0.776	0.021–0.241	0.062–0.335	0.665–0.938
	Mean length (SE)	609.8 (13.8)	592.0 (16.0)	624.0 (27.6)	610.8 (11.1)
	Range of length	505–710	576–608	570–687	505–710
Males	Sample size	4	0	0	4
	Proportion of samples (SE)	0.154 (0.072)	0	0	0.154 (0.072)
	95% CI of proportion	0.062–0.335	NA	NA	0.062–0.335
	Mean length (SE)	698.0 (22.1)	NA	NA	698.0 (22.1)
	Range of length	640–735	NA	NA	640–735
All	Sample size	20	2	4	26
	Proportion of samples (SE)	0.769 (0.084)	0.077 (0.053)	0.154 (0.072)	1.000 (0)
	95% CI of proportion	0.579–0.890	0.021–0.241	0.062–0.335	NA
	Mean length (SE)	627.5 (14.2)	592.0 (16.0)	624.0 (27.6)	624.2 (11.6)
	Range of length	505–735	576–608	570–687	505–735

Note: "Initial" means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. "Repeat" means this fish has spawned more than once as evidenced by spawning checks in the scale samples. "NA" means not applicable. "Proportion" is from Equation 6.

Table 4.–Age, sex, and length (mm) composition of steelhead sampled in the second tagging trip, 2017.

		Age classes						
Sex	Information type	1-Initial	2-Initial	3-Initial	3-Repeat	4-Repeat	5-Repeat	All ages
Females	Sample size	0	12	3	7	0	0	22
	Proportion (SE)	NA	0.353 (0.083)	0.088 (0.049)	0.206 (0.070)	NA	NA	0.647 (0.083)
	95% CI of proportion	NA	0.215–0.521	0.030–0.230	0.103–0.368	NA	NA	0.479–0.785
	Mean length (SE)	NA	611.2 (11.2)	666.7 (50.9)	632.6 (19.2)	NA	NA	625.5 (11.0)
	Range of length	NA	559–685	588–762	560–701	NA	NA	559–762
Males	Sample size	3	7	0	0	1	1	12
	Proportion (SE)	0.088 (0.049)	0.206 (0.070)	0	0	0.029 (0.029)	0.029 (0.029)	0.353 (0.083)
	95% CI of proportion	0.030–0.230	0.103–0.368	NA	NA	0.005–0.149	0.005–0.149	0.215–0.521
	Mean length (SE)	515.3 (19.2)	577.0 (22.9)	NA	NA	759.0 (NA)	805.0 (NA)	595.8 (29.7)
	Range of length	479–544	509–662	NA	NA	759–759	805–805	479–805
All	Sample size	3	19	3	7	1	1	34
	Proportion (SE)	0.088 (0.049)	0.559 (0.086)	0.088 (0.049)	0.206 (0.070)	0.029 (0.029)	0.029 (0.029)	1.000 (0)
	95% CI of proportion	0.030–0.230	0.395–0.711	0.030–0.230	0.103–0.368	0.005–0.149	0.005–0.149	NA
	Mean length (SE)	515.3 (19.2)	598.6 (11.3)	666.7 (50.9)	632.6 (19.2)	759.0 (NA)	805.0 (NA)	615.0 (12.6)
	Range of length	479–544	509–685	588–762	560–701	759–759	805–805	479–805

Note: "Initial" means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. "Repeat" means this fish has spawned more than once as evidenced by spawning checks in the scale samples. "NA" means not applicable. "Proportion" is from Equation 6.

Table 5.–Age, sex, and length (mm) composition of steelhead kelts passing the Karluk River weir, 2017.

		Age classes					
		1-Initial	2-Initial	3-Initial	3-Repeat	4-Repeat	All ages
Females	Sample size	5	193	1	14	4	217
	Proportion (SE)	0.014 (0.010)	0.525 (0.025)	0.003 (0.004)	0.038 (0.016)	0.011 (0.009)	0.590 (0.016)
	Kelts (SE)	63 (31)	2,426 (116)	13 (14)	176 (52)	50 (28)	2,728 (107)
	Mean length (SE)	518.4 (11.5)	624.4 (2.9)	655.0 (0.0)	672.8 (14.0)	696.8 (18.9)	626.6 (3.1)
	Range of length	478–547	493–728	655–655	592–775	649–737	478–775
Males	Sample size	5	109	4	9	1	128
	Proportion (SE)	0.016 (0.017)	0.349 (0.042)	0.013 (0.015)	0.029 (0.022)	0.003 (0.008)	0.410 (0.033)
	Kelts (SE)	74 (38)	1,613 (115)	59 (34)	133 (50)	15 (17)	1,894 (107)
	Mean length (SE)	515.0 (0.8)	608.4 (5.9)	633.0 (26.3)	646.8 (18.3)	644.0 (0.0)	608.5 (5.6)
	Range of length	512–517	465–726	591–709	523–700	644–644	465–726
All	Sample size	10	302	5	23	5	345
	Proportion (SE)	0.030 (0.019)	0.874 (0.037)	0.016 (0.016)	0.067 (0.027)	0.014 (0.012)	1.000 (0)
	Kelts (SE)	137 (49)	4,039 (163)	72 (37)	309 (72)	65 (33)	4,622 (0)
	Mean length (SE)	516.6 (5.4)	618.0 (2.9)	636.9 (21.7)	661.6 (11.6)	684.8 (15.5)	619.2 (2.9)
	Range of length	478–547	465–728	591–709	523–775	644–737	465–775

Note: "Initial" means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. "Repeat" means this fish has spawned more than once as evidenced by spawning checks in the scale samples. "NA" means not applicable. "Proportion" is from Equation 10. "Kelts" is the estimated abundance by age-sex class.

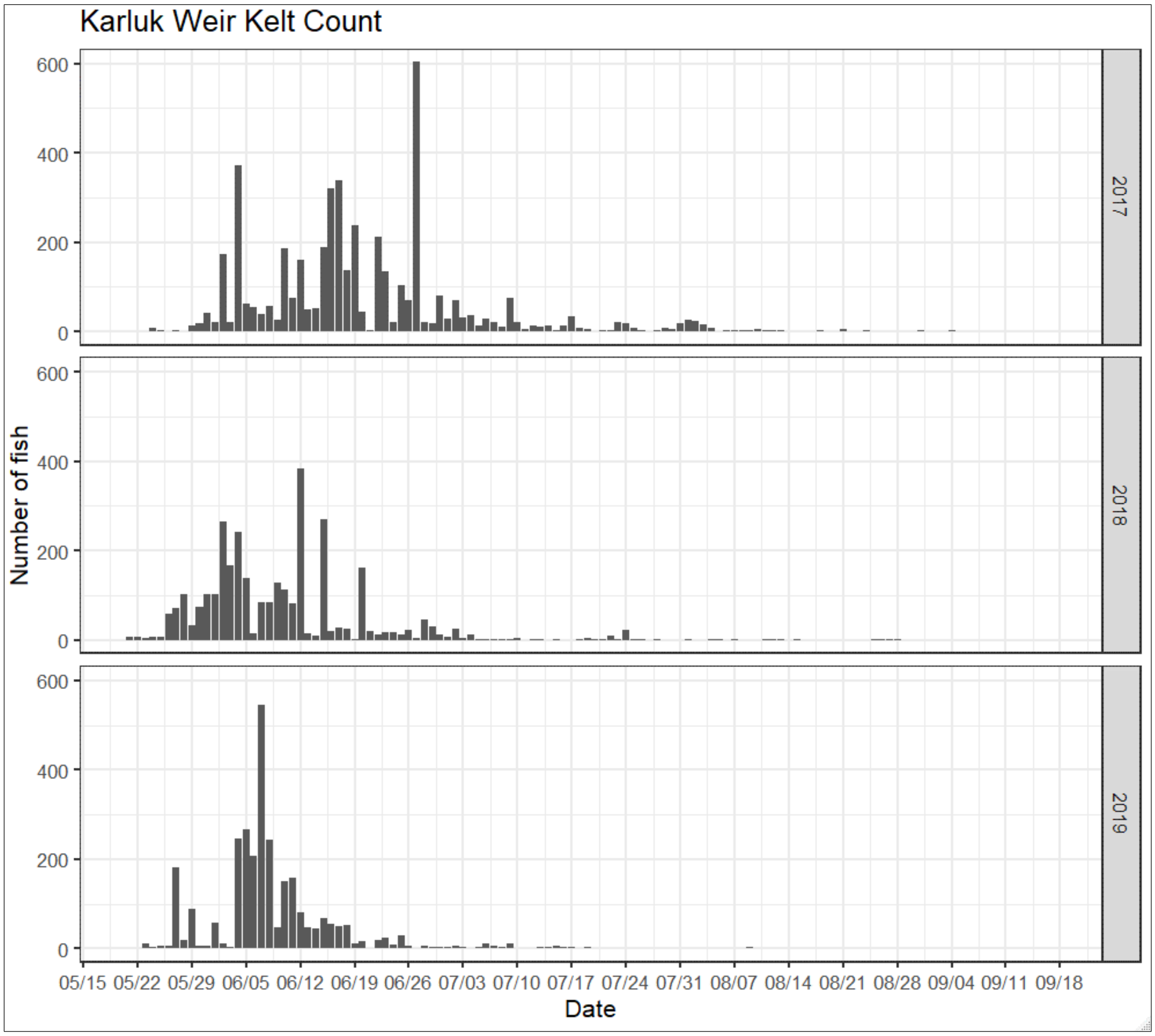

Figure 2.–Daily steelhead kelt counts at the Karluk River weir, 2017–2019.

2018

Spawning Composition

Two sampling trips were conducted in 2018: one for 7 days from 1 to 8 May and another for 2 days from 18 to 19 May. A total of 141 steelhead were tagged, 91 during the first sampling trip and 50 during the second sampling trip; age was determined for 114 (Table 6). Sex composition (G = .09, df = 1, P = 0.77), age composition (G = 3.31, df = 3, P = 0.37), and spawning history (G = 2.03, df = 2, P = 0.36) did not differ between sampling trips.

Kelt Composition

The Karluk River weir was installed on 21 May and 3,148 kelts were counted for the season (Appendix B1). From 22 May through 13 July, 176 kelts were sampled for age, sex, and length; age was determined for 154 (Table 7). Sex composition (G = 2.2, df = 3, P = 0.53), age composition (G = 14.12, df = 9, P = 0.12), and spawning history (G = 5.97, df = 6, P = 0.43) did not differ between time strata. The sex composition of unaged and aged fish did not differ (G = 0.96, df =1, P = 0.32).

Table 6.–Age, sex, and length (mm) composition of steelhead sampled during tagging, 2018.

		Age classes					
		1-Initial	2-Initial	3-Initial	3-Repeat	4-Repeat	All ages
Females	Sample size	5	59	6	8	2	80
	Proportion (SE)	0.044 (0.019)	0.518 (0.047)	0.053 (0.021)	0.070 (0.024)	0.018 (0.012)	0.702 (0.043)
	95% CI of proportion	0.019–0.099	0.427–0.607	0.024–0.110	0.036–0.132	0.005–0.062	0.612–0.778
	Mean length (SE)	546.4 (19.0)	640.2 (6.9)	705.7 (18.9)	649.1 (16.0)	713.0 (112.0)	642.0 (6.9)
	Range of length	517–620	540–800	643–760	555–689	601–825	517–825
Males	Sample size	5	26	3	0	0	34
	Proportion (SE)	0.044 (0.019)	0.228 (0.039)	0.026 (0.015)	0	0	0.298 (0.043)
	95% CI of proportion	0.019–0.099	0.161–0.313	0.009–0.075	NA	NA	0.222–0.388
	Mean length (SE)	508.7 (10.1)	630.9 (15.2)	705.7 (95.9)	NA	NA	619.5 (16.2)
	Range of length	482–533	511–725	518–834	NA	NA	482–834
All	Sample size	10	85	9	8	2	114
	Proportion (SE)	0.088 (0.026)	0.746 (0.041)	0.079 (0.025)	0.070 (0.024)	0.018 (0.012)	1.000 (0)
	95% CI of proportion	0.048–0.154	0.659–0.817	0.042–0.143	0.036–0.132	0.005–0.062	NA
	Mean length (SE)	527.6 (11.9)	637.3 (6.6)	705.7 (30.3)	649.1 (16.0)	713.0 (112.0)	635.2 (6.9)
	Range of length	482–620	511–800	518–834	555–689	601–825	482–834

Note: "Initial" means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. "Repeat" means this fish has spawned more than once as evidenced by spawning checks in the scale samples. "NA" means not applicable. "Proportion" is from Equation 6.

Table 7.–Age, sex, and length (mm) composition of steelhead kelts passing the Karluk River weir, 2018.

		Age classes					
		1-Initial	2-Initial	2-Repeat	3-Repeat	4-Repeat	All ages
Females	Sample size	5	80	1	10	3	99
	Proportion (SE)	0.032 (0.014)	0.519 (0.039)	0.006 (0.006)	0.065 (0.019)	0.019 (0.011)	0.643 (0.038)
	95% CI of proportion	0.014–0.074	0.441–0.597	0.001–0.036	0.036–0.115	0.007–0.056	0.565–0.714
	Kelts (SE)	102 (44)	1,635 (124)	20 (20)	204 (61)	61 (34)	2,024 (119)
	Mean length (SE)	521.0 (26.6)	618.8 (5.5)	685.0 (0.0)	668.5 (11.8)	751.0 (15.9)	623.7 (6.0)
	Range of length	457–612	503–724	685–685	619–720	723–778	457–778
Males	Sample size	18	37	0	0	0	55
	Proportion (SE)	0.117 (0.025)	0.240 (0.034)	0	0	0	0.357 (0.038)
	95% CI of proportion	0.075–0.177	0.180–0.314	NA	NA	NA	0.286–0.434
	Kelts (SE)	368 (80)	756 (106)	NA	NA	NA	1,124 (119)
	Mean length (SE)	543.6 (8.0)	586.9 (11.3)	NA	NA	NA	572.7 (8.4)
	Range of length	478–591	495–735	NA	NA	NA	478–735
All	Sample size	23	117	1	10	3	154
	Proportion (SE)	0.149 (0.028)	0.760 (0.034)	0.006 (0.006)	0.065 (0.019)	0.019 (0.011)	1.000 (0)
	95% CI of proportion	0.102–0.214	0.686–0.820	0.001–0.036	0.036–0.115	0.007–0.056	NA
	Kelts (SE)	470 (88)	2,392 (106)	20 (20)	204 (61)	61 (34)	3,148 (0)
	Mean length (SE)	538.7 (84)	608.5 (5.3)	685.0 (0.0)	668.5 (11.8)	751.0 (15.9)	605.2 (5.3)
	Range of length	457–612	495–735	685–685	619–720	723–778	457–778

Note: “Initial” means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. “Repeat” means this fish has spawned more than once as evidenced by spawning checks in the scale samples. “NA” means not applicable. “Proportion” is from Equation 10. “Kelts” is the estimated abundance by age-sex class.

2019

Spawning Abundance

Two sampling trips of 3 days each were made in 2019 to capture and tag spawning steelhead on 6–8 May and 14–16 May. A total of 134 steelhead were tagged and sampled for ASL, 101 during the first sampling trip and 33 during the second sampling trip; age was determined for 89 (Table 8) and 28 (Table 9) steelhead, respectively.

Kelts were counted at the Karluk River weir between 23 May and 17 September. A total of 2,877 kelts were counted (Appendix B1), 49 of which were observed to be tagged and 20 of which had the tag number recorded. There were 245 kelts sampled for ASL; age and sex were determined for 185 fish. In 2019, the weir captured most if not all of the steelhead emigration, with only 3 of the first 12 days when the weir was operational recording a daily passage in excess of 1% of the season's total emigration (Figure 2).

Table 8.–Age, sex, and length (mm) composition of steelhead sampled during the first tagging trip, 2019.

		Age classes				
		1-Initial	2-Initial	3-Repeat	4-Repeat	All ages
Females	Sample size	2	53	14	2	71
	Proportion (SE)	0.022 (0.016)	0.596 (0.052)	0.157 (0.039)	0.022 (0.016)	0.798 (0.043)
	95% CI of proportion	0.006–0.078	0.492–0.691	0.096–0.247	0.006–0.078	0.703–0.868
	Mean length (SE)	543.5 (87.5)	622.8 (5.8)	684.0 (8.0)	722.0 (12.0)	635.8 (6.3)
	Range of length	456–631	544–745	620–730	710–734	456–745
Males	Sample size	6	10	2	0	18
	Proportion (SE)	0.067 (0.027)	0.112 (0.034)	0.022 (0.016)	0	0.202 (0.043)
	95% CI of proportion	0.031–0.139	0.062–0.195	0.006–0.078	NA	0.132–0.297
	Mean length (SE)	522.7 (14.5)	673.3 (19.2)	727.5 (12.5)	NA	626.5 (22.1)
	Range of length	470–563	564–755	715–740	NA	470–755
All	Sample size	8	63	16	2	89
	Proportion (SE)	0.090 (0.030)	0.708 (0.048)	0.180 (0.041)	0.022 (0.016)	1.000 (0)
	95% CI of proportion	0.046–0.167	0.606–0.792	0.114–0.272	0.006–0.078	NA
	Mean length (SE)	527.9 (19.9)	630.4 (6.1)	689.4 (8.0)	722.0 (12.0)	634.0 (6.6)
	Range of length	456–631	544–755	620–740	710–734	456–755

Note: "Initial" means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. "Repeat" means this fish has spawned more than once as evidenced by spawning checks in the scale samples. "NA" means not applicable. "Proportion" is from Equation 6.

Table 9.–Age, sex, and length (mm) composition of steelhead sampled during the second tagging trip, 2019.

		Age classes			
		1-Initial	2-Initial	3-Repeat	All ages
Females	Sample size	3	15	1	19
	Proportion (SE)	0.107 (0.059)	0.536 (0.096)	0.036 (0.036)	0.679 (0.090)
	95% CI of proportion	0.037–0.272	0.358–0.705	0.006–0.177	0.493–0.821
	Mean length (SE)	518.3 (4.3)	616.2 (6.4)	724.0 (NA)	606.4 (11.8)
	Range of length	511–526	573–654	724–724	511–724
Males	Sample size	4	5	0	9
	Proportion (SE)	0.143 (0.067)	0.179 (0.074)	0	0.321 (0.090)
	95% CI of proportion	0.057–0.315	0.079–0.356	NA	0.179–0.507
	Mean length (SE)	526.5 (11.0)	655.4 (22.2)	NA	598.1 (25.9)
	Range of length	502–551	600–718	NA	502–718
All	Sample size	7	20	1	28
	Proportion (SE)	0.250 (0.083)	0.714 (0.087)	0.036 (0.036)	1.000 (0)
	95% CI of proportion	0.127–0.434	0.529–0.847	0.006–0.177	NA
	Mean length (SE)	523.0 (6.3)	626.0 (8.0)	724.0 (NA)	603.8 (11.3)
	Range of length	502–551	573–718	724–724	502–724

Note: "Initial" means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. "Repeat" means this fish has spawned more than once as evidenced by spawning checks in the scale samples. "NA" means not applicable. "Proportion" is from Equation 6.

Three likelihood ratio tests (Tables 10–12) were conducted to test for sex selectivity in either sampling event using numbers of males and females determined from ASL sampling at the first event (spawning grounds) and at the second event (weir). Test statistics were insignificant when comparing the sex composition of all fish sampled at the weir (captures) to marked fish sampled at the weir (recaptures; G = 1.72, df = 1, P = 0.19; Table 10) and when comparing the sex composition of fish marked on the spawning grounds to marked fish recaptured at the weir (G = 0.10, df = 1, P = 0.75; Table 11). These test results indicate the first and second events, respectively, were not sex selective (Appendix A1). However, a significant difference between the sex composition of fish sampled at the weir and fish marked on the spawning grounds (G = 4.72, df = 1, P = 0.03; Table 12) suggests the tests with recaptured fish may have lacked power to identify significant differences when they exist. We interpreted these tests as indicative of possible sex selectivity in the marking event.

Table 10.–Number of kelts sampled for ASL at the Karluk River weir (captured) and those that were marked (recaptured) by sex, 2019.

Fish sampled for ASL	Male	Female	Total
Captured at weir	80	157	237
Recaptured at weir	4	16	20
Test	G = 1.72, df = 1, P = 0.19; fail to reject H_o		

Note: Test statistic tests the hypothesis that sex composition of each sample is similar.

Table 11.–Number of steelhead marked on the spawning grounds and those that were recaptured during ASL sampling at the Karluk River weir by sex, 2019.

Fish sampled for ASL	Male	Female	Total
Marked on spawning grounds	31	103	134
Recaptured at weir	4	16	20
Test	G = 0.10, df = 1, P = 0.75, fail to reject H_o		

Note: Test statistic tests the hypothesis that sex composition of each sample is similar.

Table 12.–Number of steelhead marked on the spawning grounds and kelts captured during ASL sampling at the Karluk River weir by sex, 2019.

Fish sampled for ASL	Male	Female	Total
Captured at weir	80	157	237
Marked on spawning grounds	31	103	134
Test	G = 4.72, df = 1, P = 0.03, reject H_o		

Note: Test statistic tests the hypothesis that sex composition of each sample is similar.

Three Kolomgorov-Smirnov tests (Figure 3) were conducted to test for size selectivity in either sampling event using numbers of ASL-sampled fish where 131 marked steelhead were measured for length in the first event and 244 captured kelts were measured for length in the second event. Test statistics were insignificant when comparing the length distribution of fish captured at the weir to fish recaptured at the weir (D = 0.22, P = 0.33) and when comparing the length distribution of fish marked on the spawning grounds to fish recaptured at the weir (D = 0.27, P = 0.16). These test results indicate the marking and recapture events, respectively, were not size selective and were supported by a test comparing the size composition of fish captured at the weir and fish marked on the spawning grounds (D = 0.11, P = 0.23). These test results all support the idea that neither event was size selective.

Three likelihood ratio tests (Tables 13–15) were conducted to test for equal probability of capture across temporal strata. The test statistic was insignificant when comparing the number of fish with recorded tag information recaptured at the weir by run quartile that were marked and released during each first event sampling trip (G = 3.49, df = 4, P = 0.48; Table 13), indicating emigratory timing was similar between sampling trips. Similarly, a test of recaptured to not-recaptured ratios amongst marking strata for fish with recorded tag information (G = 0.80, df = 1, P = 0.37; Table 15) was also insignificant. However, a test of equality for marked to unmarked ratios of enumerated kelts amongst weir run strata (G = 4.3, df = 3, P = 0.22; Table 14) was significant. Although these test results indicate temporal strata can be pooled without bias, we note the insignificant tests are based on small sample sizes and may have lacked power to detect significant differences.

The test results suggest a single pooled Chapman estimator will produce an unbiased estimate of abundance. However, our test results lacked statistical power and sex composition differed between marking events and weir capture events (males were relatively more common in the weir capture events [80/237 = 0.34] than the marking events [31/134 = 0.23]; Table 12). Further, we have interest in the age and sex composition during both sampling events, and would like to estimate the age composition during the spawning event using fish sampled during the spawning event. For these reasons, we estimated abundance separately for each sex.

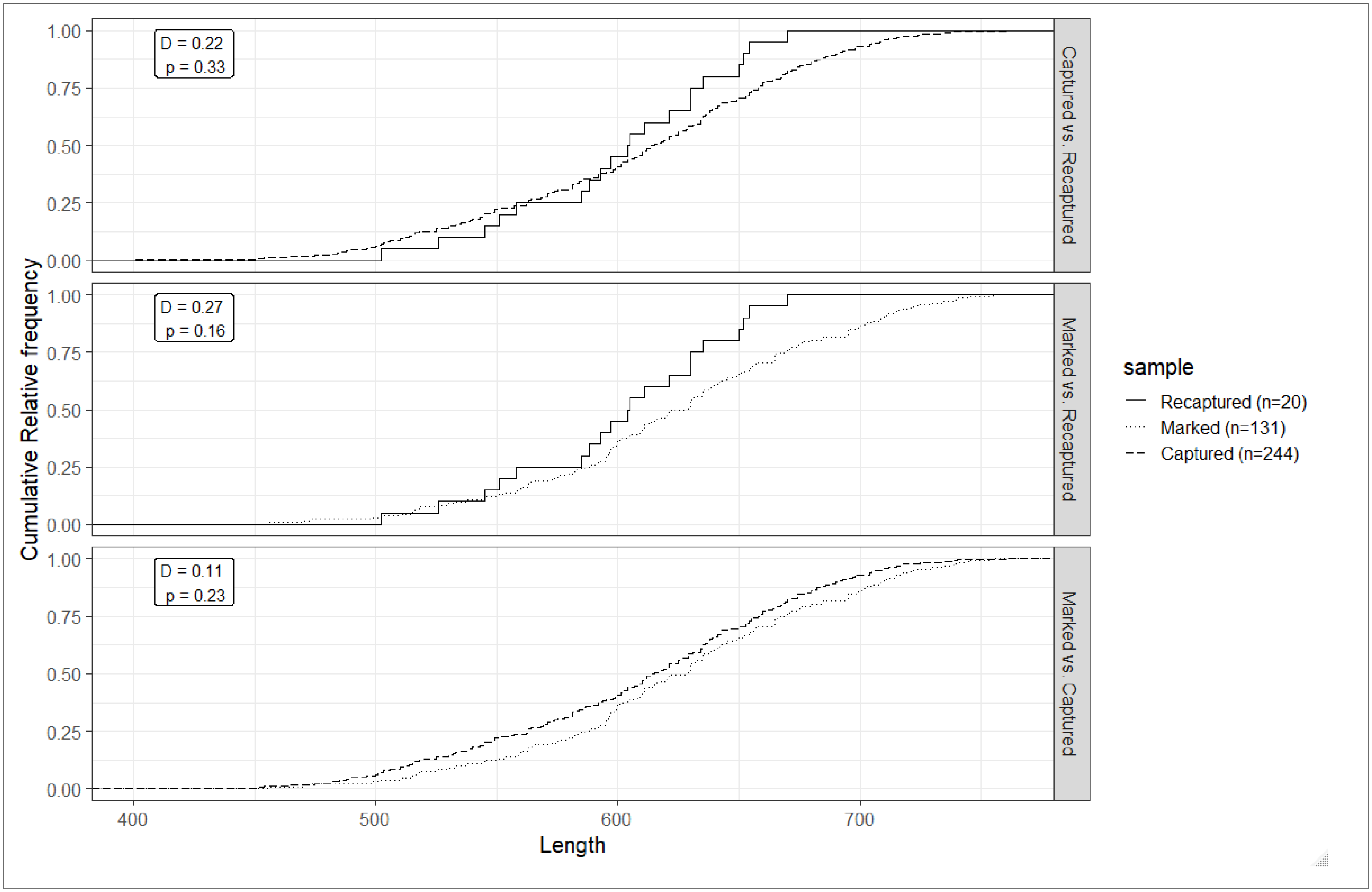

Figure 3.–Kolomgorov-Smirnov tests for size selectivity in the first and second sampling events, 2019.

Table 13.–Number of recaptured steelhead marked during each sampling trip and recaptured during each run quartile at the Karluk River weir, 2019.

	Recapture stratum				Marked fish not recaptured and	
Marking stratum	May 23–Jun 4	Jun 5–Jun 6	Jun 7–Jun 11	Jun 12–Sep 2	sampled	Total
May 6–8	0	2	2	9	88	101
May 14–16	1	1	1	4	26	33
Total	1	3	3	13		
Test	G = 3.49, df = 4, p = 0.48, fail to reject H_o					

Note: Test statistic tests the hypothesis that movement probabilities are independent of marking stratum (Appendix A2).

Table 14.–Number of marked and unmarked steelhead observed during each run quartile at the Karluk River weir, 2019.

	Recapture stratum				
Sample	May 23–Jun 4	Jun 5–Jun 6	Jun 7–Jun 11	Jun 12–Sep 2	Total
Recaptured	5	7	11	26	49
Unmarked	638	467	976	747	2,828
Examined	643	474	987	773	2,877
Pcapture 1st event	0.008	0.015	0.011	0.034	0.017
Test	G = 16.53, df = 3, *P* = 0.00, reject H_o				

Note: Test statistic tests the hypothesis that marked to unmarked ratio is constant amongst recapture strata (Appendix A2).

Table 15.–Number of marked steelhead that were recaptured as kelts during ASL sampling at the Karluk River weir and number of marked steelhead that were not for each marking trip, 2019.

	Marking stratum		
Sample	May 6–8	May 14–16	Total
Recaptured and sampled	13	7	20
Not (recaptured and sampled)	88	26	114
Marked	101	33	134
Pcapture/sample 2nd event	0.13	0.21	0.15
Test	G = 1.28, df = 1, *P* = 0.25, fail to reject H_o		

Note: Test statistic tests the hypothesis that the probability of resighting a marked steelhead is independent of its marking stratum (Appendix A2). "Pcapture" = probability of capture.

The numbers of marked male and female kelts recaptured during ASL sampling were used to estimate the sex composition of marked fish observed passing the weir ($\widehat{R}_i$; Equations 2 and 3). We estimated 11 (95% CI 5–20) of the 49 marked fish passing the weir were males, whereas the remaining 38 (95% CI 29–44) were female. Similarly, the numbers of male and female kelts passing the weir ($\widehat{C}_i$ or "captures") were estimated using the sex composition from the 237 captures that were sampled for ASL. We estimated 975 (95% CI 802–1,158) of the 2,877 kelts were males, whereas the remaining 1,902 (95% CI 1,719–2,075) were female. Spawning abundance during 2019 was estimated as 2,804 (95% CI 1,395–5,380) male steelhead and 5,148 (95% CI 4,186–6,706) female steelhead. Total abundance of spawning steelhead was estimated from the sum to be 7,952 (95% CI 7,451–9,666). The estimate of total spawning abundance met the preseason precision objective.

Overall spawning survival (Equation 4) was 37% (SE 4%; 95% CI 29–45%) with 49 tags sighted at the weir from 134 tags released during the spawning event. Age and sex composition data amongst recaptured tags were insufficient to identify different spawning survival rates for each sex or spawning history.

Spawning Composition

Likelihood ratio tests found that sex composition did not differ between sampling trips (G = 1.25, df = 1, *P* = 0.27), but that age composition (G = 8.77, df = 3, *P* = 0.03) and spawning history (G = 5.78, df = 2, *P* = 0.06) were significantly different. Age, sex, and length composition by sampling trip in 2019 was presented in Tables 8 and 9. However, we assumed ASL samples were taken in proportion to abundance and used pooled samples to estimate the age and sex composition (proportions) of the spawning population, which along with the mark–recapture estimate of spawning abundance during the marking (first) event, was used to estimate spawner abundance by age and sex (Table 16).

Kelt Composition

Sex composition (G = 4.32, df = 3, p = 0.23), age composition (G = 10.46, df = 12, p = 0.56), and spawning history (G = 6.23, df = 9, p = 0.72) did not differ between time strata at the weir and no temporal strata were used to estimate the sex and age composition of the kelt emigration (Table 17). The sex of unaged and aged fish differed (G = 9.44, df =1, *P* = 0.00) so sex composition was estimated first using all fish sampled for sex prior to estimate age by sex using the fish with valid ages.

Table 16.–Estimated age, sex, and length (mm) composition and abundance of spawning steelhead during the marking event, 2019.

		Age classes				
		1-Initial	2-Initial	3-Repeat	4-Repeat	All ages
Females	Sample size	5	68	15	2	90
	Proportion (SE)	0.036 (0.024)	0.489 (0.056)	0.108 (0.040)	0.014 (0.016)	0.647 (0.045)
	Spawners (SE)	286 (197)	3,890 (612)	858 (333)	114 (125)	5,148 (652)
	Mean length (SE)	528.4 (28.4)	621.3 (4.7)	686.7 (7.9)	722.0 (12.0)	629.5 (5.7)
	Range of length	456–631	544–745	620–730	710–734	456–745
Males	Sample size	10	15	2	0	27
	Proportion (SE)	0.131 (0.129)	0.196 (0.164)	0.026 (0.054)	0	0.353 (0.239)
	Spawners (SE)	1,038 (676)	1,558 (812)	208 (312)	NA	2,804 (1,035)
	Mean length (SE)	524.2 (9.3)	666.9 (14.4)	727.5 (12.5)	NA	616.7 (17.0)
	Range of length	470–563	564–755	715–740	NA	470–755
All	Sample size	15	83	17	2	117
	Proportion (SE)	0.167 (0.124)	0.685 (0.118)	0.134 (0.068)	0.014 (0.016)	1.000 (0)
	Spawners (SE)	1,324 (704)	5,447 (1,017)	1,066 (456)	114 (125)	7,952 (584)
	Mean length (SE)	525.1 (9.6)	634.4 (7.4)	694.6 (12.0)	722.0 (12.0)	625.0 (7.1)
	Range of length	456–631	544–755	620–740	710–734	456–755

Note: "Initial" means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. "Repeat" means this fish has spawned more than once as evidenced by spawning checks in the scale samples. "NA" means not applicable. "Proportion" is from Equation 10 and "Spawners" is estimated abundance by age-sex class.

Table 17.–Estimated age, sex, and length composition of kelts passing the Karluk River weir, 2019.

		Age classes						
		1-Initial	2-Initial	2-Repeat	3-Repeat	4-Repeat	5-Repeat	All ages
Females	Sample size	5	105	2	17	2	1	132
	Proportion (SE)	0.025 (0.016)	0.527 (0.036)	0.010 (0.010)	0.085 (0.028)	0.010 (0.010)	0.005 (0.007)	0.662 (0.015)
	Kelts (SE)	72 (35)	1,516 (100)	29 (22)	245 (62)	29 (22)	14 (16)	1,906 (85)
	Mean length (SE)	502.6 (17.2)	629.4 (4.0)	651.5 (30.5)	686.9 (10.1)	668.0 (57.0)	690.0 (0.0)	633.4 (4.5)
	Range of length	465–545	520–724	621–682)	610–762	611–725	690–690	465–762
Males	Sample size	20	31	1	1	0	0	53
	Proportion (SE)	0.127 (0.069)	0.197 (0.075)	0.006 (0.018)	0.006 (0.018)	0	0	0.338 (0.058)
	Kelts (SE)	366 (82)	568 (91)	18 (21)	18 (21)	NA	NA	971 (85)
	Mean length (SE)	516.9 (11.0)	599.8 (10.6)	557.0 (0.0)	502.0 (0.0)	NA	NA	565.8 (9.3)
	Range of length	401–636	501–705	557–557	502–502	NA	NA	401–705
All	Sample size	25	136	3	18	2	1	185
	Proportion (SE)	0.152 (0.070)	0.724 (0.076)	0.016 (0.021)	0.092 (0.034)	0.010 (0.010)	0.005 (0.007)	1.000 (0)
	Kelts (SE)	439 (89)	2,084 (135)	47 (31)	264 (65)	29 (22)	14 (16)	2,877 (0)
	Mean length (SE)	514.5 (9.7)	621.3 (4.2)	614.8 (25.4)	674.1 (9.9)	668.0 (57.0)	690.0 (0.0)	610.6 (4.6)
	Range of length	401–636	501–724	557–682	502–762	611–725	690–690	401–762

Note: “Initial” means this is the first spawning event for this fish as evidenced by spawning checks in the scale samples. “Repeat” means this fish has spawned more than once as evidenced by spawning checks in the scale samples. “NA” means not applicable. “Proportion” is from Equation 10 and “Kelts” is the estimated abundance by age-sex class.

TAGS RECOVERED IN COMMERCIAL AND SPORT FISHERIES

A few tagged steelhead were reported caught in commercial and sport fisheries in the KMA. Four tagged steelhead were recovered from commercial salmon fisheries in the KMA, 3 from seine vessels, and 1 from a set net site (Table 18). Several anglers reported catching tagged steelhead in the Karluk River, but they did not record or remember the tag color or number. Only 1 steelhead was reported from the Karluk River sport fishery where a tag color and number was recorded. Three of the tagged fish were caught in the same year as tagging and 2 were caught the year after being tagged. All were caught late in summer through the fall, with the earliest being in early July.

Tag recoveries in these fisheries provided some information about migration patterns and encounter rates with different fishing gear; however, it is certain that some unknown number of tags were caught but never reported. Tags recovered other than at the Karluk River weir were not used for generating estimates of abundance or survival rates but were useful in gathering additional information about Karluk River steelhead as well as generating some level of public interest in the project because anglers and commercial fishermen were aware of the tagged fish.

Table 18.–Tags recovered in commercial and sport fisheries, 2017–2019.

Date	Tagging year	Tag color	Location	Fishery
8/28/2018	2018	Pink	Rocky Point, Uyak Bay	Commercial salmon seine
9/29/2018	2017	Green	West Point, Uganik Bay	Commercial salmon seine
October 2018	2018	Pink	Karluk Portage	Sport fishery
7/7/2019	2019	Yellow	Cape Uyak	Commercial salmon seine
9/5/2019	2018	Pink	Uyak Bay	Commercial salmon set net

DISCUSSION

This project was designed to replicate early Karluk River steelhead work conducted in the mid-1990s (Begich 1992, 1993, 1995a, 1995b, 1997, 1999) at a reduced cost by reduced sampling of marked kelts as they passed the weir. Unfortunately, during the first 2 years of the study, we were unable to produce spawning abundance estimates because tagged fish were not reliably recorded as they passed the weir, meaning we did not know the number of recaptured fish. During the last season (2019), further training of the weir crew and revised recapture procedures at the weir resulted in a census of the tagged fish passing the weir; however, tag numbers were recorded from an insufficient number of these fish because a portion of the kelts passed the weir through the salmon counting gates and not through the trap, and tag numbers were not able to be collected. As a result, sample sizes for equal probability of capture and temporal stratification tests were small and may have lacked power to identify important differences. To some extent, the project was robust to these considerations because the weir was a census of emigrating fish, guaranteeing equal probability of capture during at least 1 event. However, in 2019 we desired a stratified estimate to use age information from the first event but the incomplete sample from recaptured fish and resulting small sample sizes made the estimation difficult. A possible solution to this problem in future steelhead research on the Karluk River would be to conduct passive recapture at the weir using passive integrated transponder (PIT) tags. Steelhead could be tagged in the first event with PIT tags and for the second event at the weir, receivers could be installed at each counting gate and the trap to record every tagged fish passing the weir automatically. This could reduce the potential for bias discussed above as well as increase the power of the probability of capture tests.

Both temporal stratification tests which failed to reject the null hypothesis lacked statistical power due to small sample sizes, and the results of these tests, had tag numbers been recovered from all 49 recaptured kelts, remain unknown. Because a pooled estimate is generally believed to induce a positive bias under our closure and consistency results (Arnason et al. 1996), it is possible our estimate is biased high. Although we were unable to assess the size of this bias, we did observe partial mixing in the tags that were read, which may mitigate the potential for a large positive bias due to a pooled estimate.

Because fish sampled at the weir were checked for both a tag and a secondary mark in 2019, tag loss could be detected and the size of a potential positive bias due to tag loss could be examined. In 2017, checks of sampled fish found 2 of 21 marked kelts had lost their tag, although in 2018 and 2019, none were observed (out of 13 and 20, respectively) to have lost their tag, and we feel improved handling and tagging procedures resulted in better retention in later years. It is unlikely we would have observed 0 tag losses from the 33 fish observed in 2018 and 2019 if tag loss had stayed at the 2017 rate of 2/21 (~9.5%), and because the size of a positive bias grows negligible as the tag loss rate decreases, tag loss is unlikely to have biased the estimate in 2019.

The 2017 season was considered a pilot study and the tagging goal was not met. It became apparent that marked fish also experienced significant handling-induced mortality because only 1 tagged male was recovered at the weir in this season. For the 2018 and 2019 studies, handling practices were changed to reduce stress on tagged fish by shortening the fight time after hooking, minimizing the time the fish were held, and having all tagging and sampling gear ready prior to fish being caught. Despite difficulties in estimating spawning survival for 2017 and 2018, these efforts allowed us to estimate spawning survival in 2019, which was within the range of estimates obtained for all 6 seasons (1992–1997) of the previous research studies (Begich 1999).

Table 19.–Comparison of results from Begich (1992, 1993, 1995a, 1995b, 1997, 1999) with Karluk steelhead results and population estimate for 2019.

Year	Number marked	Recaptured	% Recaptured	Abundance estimate	SE or CI
1992	415	277	67	4,107	134
1993	350	204	58	7,026	308
1994	285	143	50	9,116	522
1995	353	220	62	10,802	437
1996	196	70	36	7,252	674
1997	490	322	66	10,377	329
2019	134	49	37	7,952	7,451–9,666

Source: 1992–1997 data found in Begich (1999, Table 2, page 36).

The results of the 2019 mark–recapture experiment showed that there is a relatively large run of steelhead in the Karluk River (Table 19), similar to most estimates previously reported (Begich 1992, 1993, 1995a, 1995b, 1997, 1999). It was previously assumed by Kodiak SF staff that the annual Karluk River steelhead kelt run was between 3,000 and 5,000 fish based on kelt counts at the Karluk River weir and that previous population estimates had likely been conducted at a peak steelhead abundance in the 1990s. It is possible, given the 2019 results, that the run is larger than previously assumed, aligning with the previous mark–recapture estimates, and may be similar in size to some of the larger Southeast Alaska steelhead runs, although is likely quite variable in size over time.

Management of the steelhead run is unlikely to change given this new information because anglers are limited to an annual harvest of only 2 steelhead or rainbow trout over 20 inches. The existing sport fishery is relatively limited in size due to the remote nature of the river and private ownership of the uplands surrounding the river; the sport fishery is unlikely to have a significant impact on the run given the run size and relatively low catch and release mortality rates (Bendock and Alexandersdottir 1993; Vincent-Lang et al. 1993). The fishery is not anticipated to grow in terms of the number of anglers or effort due to the difficult access to the river; however, the run could support increased effort if that were to happen in the future.

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APPENDIX A: MARK–RECAPTURE TESTING PROCEDURES

Size- and sex-selective sampling may cause bias in 2-event mark–recapture estimates of abundance and size and sex composition. Kolmogorov-Smirnov (KS) 2-sample tests are used to detect size-selective sampling and contingency table analyses (chi-square tests of independence) are used to detect evidence of sex-selective sampling.

Results of the KS and chi-square (χ^2) tests dictated whether the data needed to be stratified to obtain an unbiased estimate of abundance. The nature of the detected selectivity also determined whether the first, second, or both event samples were used for estimating size and sex compositions.

DEFINITIONS

M = Lengths or sexes of fish marked in the first event.

C = Lengths or sexes of fish inspected for marks in the second event.

R = Lengths or sexes of fish marked in the first event and recaptured in the second event.

SIZE-SELECTIVE SAMPLING: KS TESTS

Three KS tests are used to test for size-selective sampling:

KS Test 1	C vs R	Used to detect size selectivity during the 1st sampling event. H_o: Length distributions of populations associated with C and R are equal.
KS Test 2	M vs R	Used to detect size selectivity during the 2nd sampling event. H_o: Length distributions of populations associated with M and R are equal.
KS Test 3	M vs C	Used to corroborate the results of the first 2 tests. H_o: Length distributions of populations associated with M and C are equal.

SEX-SELECTIVE SAMPLING: CHI-SQUARE TESTS

Three contingency table analyses (χ^2 tests on 2 × 2 tables) are used to test for sex-selective sampling:

χ^2 Test 1	C vs R	Used to detect sex selectivity during the 1st sampling event. H_o: Sex is independent of the C–R classification.
χ^2 Test 2	M vs R	Used to detect sex selectivity during the 2nd sampling event. H_o: Sex is independent of the M–R classification.
χ^2 Test 3	M vs C	Used to corroborate the results of the first 2 tests. H_o: Sex is independent of the M–C classification.

Several actions can be taken depending on the results of selectivity testing (Table A1-1).

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Table A1-1.–Possible results of selectivity testing, interpretation, and action.

	KS or χ^2 Test			
Case	M vs. R (2nd event test)	C vs. R (1st event test)	M vs. C (1st vs. 2nd event)	Interpretation and action
I	Fail to reject H_o	Fail to reject H_o	Fail to reject H_o	**Interpretation**: No selectivity during either sampling event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use all data from both sampling events.
II	Reject H_o	Fail to reject H_o	Reject H_o	**Interpretation:** No selectivity during the 1st event but there is selectivity during the 2nd event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use data from the 1st sampling event without stratification. 2nd event data only used if stratification of the abundance estimate is performed, with weighting according to Equations 1–3 (Appendix A1).
III	Fail to reject H_o	Reject H_o	Reject H_o	**Interpretation:** No selectivity during the 2nd event but there is selectivity during the 1st event. **Action**: Abundance: Use a Petersen-type model without stratification. Composition: Use data from the 2nd sampling event without stratification. 1st event data may be incorporated into composition estimation only after stratification of the abundance estimate and appropriate weighting according to Equations 1–3 (Appendix A1).
IV	Reject H_o	Reject H_o	Either result	**Interpretation:** Selectivity during both 1st and 2nd events. **Action**: Abundance: Use a stratified Petersen-type model, with estimates calculated separately for each stratum. Sum stratum estimates for overall abundance. Composition: Combine stratum estimates according to Equations 1–3 (Appendix A1).
V	Fail to reject H_o	Fail to reject H_o	Reject H_o	**Interpretation:** The results of the 3 tests are inconsistent. **Action:** Need to determine which of Cases I–IV best fits the data. Inconsistency can arise from high power of the M vs. C test or low power of the tests involving R. Examine sample sizes (generally M or C from <100 fish and R from <30 are considered small), magnitude of the test statistics (D_{max}), and the *P*-values of the 3 tests to determine which of which of Cases I–IV best fits the data.

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COMPOSITION ESTIMATION FOR STRATIFIED ESTIMATES

An estimate of the proportion of the population in the *k*th size or sex category for stratified data with *I* strata is calculated as follows:

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

with variance estimated as

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

where

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

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

$\hat{N}$ = estimated total abundance

where

$$\hat{N} = \sum_{i=1}^{I} \hat{N}_i \, . \quad (3)$$

TESTS OF CONSISTENCY FOR PETERSEN ESTIMATOR

Three contingency table analyses are used to determine if the Petersen estimate can be used (Seber 1982). If any of the null hypotheses are not rejected, then a Petersen estimator may be used. If all 3 of the null hypotheses are rejected, a temporally or spatially-stratified estimator (Darroch 1961) should be used to estimate abundance.

Seber (1982) describes 4 conditions that lead to an unbiased Petersen estimate, some of which can be tested directly:

1) Marked fish mix completely with unmarked fish between events.
2) Equal probability of capture in event 1 and equal movement patterns of marked and unmarked fish.
3) Equal probability of capture in event 2.
4) The expected number of marked fish in recapture strata is proportional to the number of unmarked fish.

In the following tables, the terminology of Seber (1982) is followed, where *a* represents fish marked in the first event, *n* is the number of fish captured in second event, and *m* is the number of marked fish that were recaptured; $m_{\bullet j}$ and $m_{i\bullet}$ represent summation over the *i*th and *j*th indices, respectively.

I. **Mixing Test**

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

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

-continued-

II. Equal Proportions Test[1] (SPAS[2] terminology)

The Equal Proportions Test tests the hypothesis (condition 4) that the marked to unmarked ratio among recapture strata is constant: H_0: $\Sigma_i a_i \theta_{ij} / U_j = k$, where k is a constant, U_j is unmarked fish in stratum j at the time of 2nd event sampling, and a_i is the number of marked fish released in stratum i. Failure to reject H_0 means the Petersen estimator should be used only if the degree of closure among tagging strata is constant; i.e., $\Sigma_j \theta_{ij} = \lambda$ (Schwarz and Taylor 1998, page 289). A special case of closure is when all recapture strata are sampled, such as in a fishwheel to fishwheel experiment, where $\Sigma_j \theta_{ij} = 1.0$; otherwise, biological, and experimental design information should be used to assess the degree of closure.

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

III. Complete Mixing Test (SPAS terminology)

The Complete Mixing Test tests the hypothesis that the probability of resighting a released animal is independent of its stratum of origin: H_0: $\Sigma_j \theta_{ij} p_j = d$, where p_j is the probability of capturing a fish in recapture stratum j during the second event, and d is a constant.

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

[1] There is no 1:1 correspondence between Tests II and III and conditions 2–3 above. It is pointed out that equal probability of capture in event 1 will lead to (expected) nonsignificant Test II results, as will mixing, and that equal probability of capture in event 2 along with equal closure ($\Sigma_j \theta_{ij} = \lambda$) will also lead to (expected) nonsignificant Test III results.

[2] Stratified Population Analysis System (Arnason et al. 1996).

APPENDIX B: STEELHEAD KELT COUNTS, 2017–2019

Appendix B1.–Karluk River weir steelhead kelt counts, 2017–2019.

	2019		2018		2017	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
21 May	0	0	6	6	0	0
22 May	0	0	7	13	0	0
23 May	11	11	5	18	0	0
24 May	3	14	6	24	9	9
25 May	6	20	7	31	4	13
26 May	5	25	59	90	0	13
27 May	181	206	71	161	2	15
28 May	19	225	103	264	1	16
29 May	88	313	34	298	13	29
30 May	6	319	75	373	18	47
31 May	5	324	103	476	41	88
1 Jun	57	381	103	579	22	110
2 Jun	12	393	265	844	174	284
3 Jun	4	397	168	1,012	22	306
4 Jun	246	643	243	1,255	371	677
5 Jun	266	909	138	1,393	62	739
6 Jun	208	1,117	14	1,407	55	794
7 Jun	545	1,662	85	1,492	40	834
8 Jun	243	1,905	85	1,577	58	892
9 Jun	48	1,953	129	1,706	25	917
10 Jun	151	2,104	112	1,818	186	1,103
11 Jun	158	2,262	83	1,901	76	1,179
12 Jun	80	2,342	385	2,286	159	1,338
13 Jun	47	2,389	14	2,300	49	1,387
14 Jun	45	2,434	10	2,310	51	1,438
15 Jun	68	2,502	269	2,579	188	1,626
16 Jun	55	2,557	19	2,598	319	1,945
17 Jun	50	2,607	28	2,626	338	2,283
18 Jun	52	2,659	26	2,652	137	2,420
19 Jun	11	2,670	3	2,655	237	2,657
20 Jun	16	2,686	163	2,818	45	2,702
21 Jun	2	2,688	20	2,838	4	2,706
22 Jun	18	2,706	12	2,850	212	2,918
23 Jun	25	2,731	18	2,868	134	3,052
24 Jun	8	2,739	17	2,885	22	3,074
25 Jun	28	2,767	13	2,898	103	3,177
26 Jun	6	2,773	23	2,921	69	3,246
27 Jun	1	2,774	5	2,926	603	3,849
28 Jun	6	2,780	46	2,972	21	3,870
29 Jun	4	2,784	31	3,003	18	3,888
30 Jun	4	2,788	11	3,014	81	3,969

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	2019		2018		2017	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
1 Jul	3	2,791	6	3,020	28	3,997
2 Jul	6	2,797	24	3,044	69	4,066
3 Jul	3	2,800	4	3,048	31	4,097
4 Jul	1	2,801	12	3,060	37	4,134
5 Jul	4	2,805	3	3,063	13	4,147
6 Jul	10	2,815	3	3,066	28	4,175
7 Jul	5	2,820	2	3,068	22	4,197
8 Jul	4	2,824	2	3,070	10	4,207
9 Jul	12	2,836	3	3,073	75	4,282
10 Jul	0	2,836	4	3,077	22	4,304
11 Jul	2	2,838	0	3,077	6	4,310
12 Jul	0	2,838	1	3,078	12	4,322
13 Jul	4	2,842	1	3,079	11	4,333
14 Jul	3	2,845	0	3,079	13	4,346
15 Jul	5	2,850	1	3,080	3	4,349
16 Jul	3	2,853	0	3,080	14	4,363
17 Jul	3	2,856	0	3,080	35	4,398
18 Jul	2	2,858	2	3,082	8	4,406
19 Jul	3	2,861	4	3,086	5	4,411
20 Jul	2	2,863	1	3,087	1	4,412
21 Jul	1	2,864	3	3,090	3	4,415
22 Jul	0	2,864	9	3,099	2	4,417
23 Jul	0	2,864	3	3,102	21	4,438
24 Jul	2	2,866	23	3,125	19	4,457
25 Jul	0	2,866	3	3,128	9	4,466
26 Jul	0	2,866	2	3,130	4	4,470
27 Jul	1	2,867	0	3,130	1	4,471
28 Jul	0	2,867	1	3,131	2	4,473
29 Jul	1	2,868	0	3,131	9	4,482
30 Jul	1	2,869	0	3,131	5	4,487
31 Jul	0	2,869	0	3,131	17	4,504
1 Aug	1	2,870	1	3,132	25	4,529
2 Aug	0	2,870	0	3,132	24	4,553
3 Aug	1	2,871	0	3,132	16	4,569
4 Aug	0	2,871	3	3,135	8	4,577
5 Aug	0	2,871	3	3,138	0	4,577
6 Aug	0	2,871	0	3,138	2	4,579
7 Aug	0	2,871	1	3,139	2	4,581
8 Aug	0	2,871	0	3,139	3	4,584
9 Aug	3	2,874	0	3,139	3	4,587
10 Aug	0	2,874	0	3,139	6	4,593

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	2019		2018		2017	
Date	Daily	Cumulative	Daily	Cumulative	Daily	Cumulative
11 Aug	1	2,875	1	3,140	4	4,597
12 Aug	0	2,875	1	3,141	2	4,599
13 Aug	0	2,875	1	3,142	2	4,601
14 Aug	0	2,875	0	3,142	0	4,601
15 Aug	0	2,875	1	3,143	0	4,601
16 Aug	0	2,875	0	3,143	1	4,602
17 Aug	0	2,875	0	3,143	0	4,602
18 Aug	0	2,875	0	3,143	2	4,604
19 Aug	0	2,875	0	3,143	0	4,604
20 Aug	0	2,875	0	3,143	1	4,605
21 Aug	0	2,875	0	3,143	5	4,610
22 Aug	0	2,875	0	3,143	0	4,610
23 Aug	0	2,875	0	3,143	1	4,611
24 Aug	1	2,876	0	3,143	2	4,613
25 Aug	0	2,876	1	3,144	1	4,614
26 Aug	0	2,876	1	3,145	0	4,614
27 Aug	0	2,876	2	3,147	0	4,614
28 Aug	0	2,876	1	3,148	0	4,614
29 Aug	0	2,876	0	3,148	0	4,614
30 Aug	0	2,876	0	3,148	0	4,614
31 Aug	0	2,876	0	3,148	3	4,617
1 Sep	0	2,876	0	3,148	0	4,617
2 Sep	1	2,877	0	3,148	1	4,618
3 Sep	0	2,877	0	3,148	0	4,618
4 Sep	0	2,877	0	3,148	2	4,620
5 Sep	0	2,877	–	–	0	4,620
6 Sep	0	2,877	–	–	1	4,621
7 Sep	0	2,877	–	–	0	4,621
8 Sep	0	2,877	–	–	0	4,621
9 Sep	0	2,877	–	–	1	4,622
10 Sep	0	2,877	–	–	1	4,623
Total		2,877		3,148		4,624

Note: An en dash means the weir was not in use.