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Effects of Holding Time in a Fish Wheel Live Box on Upstream Migration of Kuskokwim River Chum Salmon

by

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

FISHERY DATA SERIES NO. 11-34

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by
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ABSTRACT

The need for accurate whole-river chum salmon *Oncorhynchus keta* abundance estimates is integral to management of the commercial and subsistence fisheries on the Kuskokwim River. Direct main river counts are not possible, so indirect methods such as mark–recapture must be used to estimate chum salmon abundance in the Kuskokwim River. Previous mark–recapture studies have been unsuccessful due to a geographically disproportionate number of recovered tags that is likely linked to a delayed mortality effect from tagging and handling stresses. Advances in tagging techniques and new holding time standards, which have proven effective for more recent studies of Chinook, coho, and sockeye salmon, spurred this initiative to explore the cumulative effects of the current Kuskokwim River tagging methods on tagging success of chum salmon. In this study, radiotelemetry techniques were used to measure differences in upriver migration between 2 treatment groups of Kuskokwim River chum salmon, each experiencing different levels of holding time in a fish wheel live box. The 2 levels of holding time represented the extremes of the current holding time standard: immediate release and 1 hour holding. Fish that were held in the fish wheel live box for 1 hour displayed markedly lower survival times, travel speed, upriver extent traveled, upriver retention, and tributary escapement than fish that were released immediately after capture and tagging. Fish that were released immediately displayed similar levels of tagging success compared to other species of salmon for which the Kuskokwim River mark–recapture platform has proven successful. Any future mark–recapture study of Kuskokwim River chum salmon should consider releasing all tagged fish immediately after capture and tagging. A prudent next step toward a full-scale study would be a feasibility study exploring the potential for this improved methodology to satisfy the spatial assumptions of mark–recapture.

Key words Fish wheel, holding time, tagging stress, chum salmon, *Oncorhynchus keta*, Kuskokwim River, radiotelemetry, mark–recapture, survival time, travel time, dropout, fallback, abundance estimation, run reconstruction.

INTRODUCTION

The need for accurate whole-river chum salmon abundance estimates is integral to management of subsistence and commercial fisheries on the Kuskokwim River, and to put into context broader issues such as the significance of marine interception from locations outside the Kuskokwim River. From 2002 to 2005, two sample mark–recapture methods were used to estimate abundance of chum salmon returning to the Kuskokwim River (Kerkvliet et al. 2003 and 2004; Pawluk et al. 2006; Schaberg et al. 2010). Fish wheels operated in mainstem Kuskokwim River were used to capture and tag chum salmon, and weirs located on select upriver spawning tributaries were used as tag recapture sites. During each year of study, investigators observed a pattern of decreasing tag recovery with increasing distance from the tag site, indicating that the assumptions required for an unbiased estimate of abundance had been violated.

Likely explanations for the observed mark–recapture bias include disproportionate capture probabilities at the tag site for spatially distinct spawning stocks, and a delayed stress response to capture, handling, and tagging (e.g., Schaberg et al. 2010). The data do not support the disproportionate capture hypothesis; however, that source of bias cannot be entirely dismissed (Schaberg et al. 2010). Research has linked holding time and crowding in fish wheel live boxes to physiological and behavioral changes in chum salmon, specifically, reduced travel speeds and elevated mortality (e.g., Kerkvliet et al. 2004 and Bromaghin et al. 2007). Stress incurred while held in the fish wheel live box has been suggested as the most likely mechanism leading to the previously unsuccessful efforts to estimate chum salmon abundance in the Kuskokwim River (Schaberg et al. 2010).

Advances in tagging techniques and new holding time standards have proven the current Kuskokwim River mark–recapture platform to be effective in recent studies of Kuskokwim River Chinook *O. tshawytscha*, coho *O. kisutch*, and sockeye *O. nerka* salmon (e.g., Stuby 2007; Gilk

et al. 2011; Schaberg et al. 2010). The current mark–recapture platform attempts to strike a balance between minimizing fish stress and maximizing capture and tagging efficiency. The capture and tagging process is likely as streamlined as possible given the type of project objectives being addressed. The current standard of holding fish for no more than 1 hour represents a considerable improvement over earlier years; although, a shift toward eliminating holding time altogether would likely minimize the negative effects of the capture and tagging process. Prior to pursuing any new initiative using mark–recapture methods to estimate total chum salmon abundance, the current tagging platform should be tested to gauge the potential for improved success over efforts from previous years.

This study represents a first step toward evaluating and mitigating the biases associated with estimating abundance of Kuskokwim River chum salmon using the existing mark–recapture platform. The results could be incorporated into a future full-scale effort to estimate abundance. If successful, that effort would provide the "missing link" needed for completing the existing retrospective salmon run reconstruction model developed by Bue et al. (2008). Completing that modeling effort would have broad ramifications for management of Kuskokwim River chum salmon. For example, model results would yield reliable estimates of total annual returns by age dating back to approximately 1988. This data set would provide the foundation for establishing whole-river escapement goals and forecasting future returns.

BACKGROUND

Chum salmon are an important cultural and economic resource throughout the Kuskokwim Area. The subsistence salmon fishery is one of the largest and most important in Alaska, accounting for approximately 20% of the annual statewide subsistence chum salmon harvest (Brown et al. 2005; Fall et al. 2007a, 2007b). The commercial harvest, although modest compared to other areas of the state (e.g., Eggers et al. 2010), helps support the local economy and provides monies in support of subsistence activities.

The *Policy for the Management of Sustainable Salmon Fisheries* (5AAC 39.222) in Alaska states: "salmon fisheries shall be managed to allow escapement within ranges necessary to conserve and sustain salmon production…" Currently there are escapement goals for Aniak River and Kogrukluk River chum salmon stocks, but no drainage-wide goal has been established for Kuskokwim River chum salmon. A major shortcoming has been the lack of whole-river abundance estimates upon which to base an analysis of productivity.

OBJECTIVES

1. Evaluate the effects of no holding time and 1 hour holding time in a fish wheel live box on chum salmon tagging success. The following metrics were used to index the level of tagging success expressed by each treatment group:
    a. Survival time post tagging;
    b. Travel time between each upriver tracking station;
    c. Percent of fish migrating past each upriver tracking station;
    d. Percent of fish that passed and remained upriver of each tracking station; and
    e. Percent of fish that entered a spawning tributary.

METHODS

PROJECT DATES

The start and end dates were selected to target chum salmon bound for extreme upriver spawning locations as it was believed that these fish would experience the greatest negative behavioral effects. The majority of Kuskokwim River chum salmon bound for the upper drainage pass the fish wheel tagging site before July 15 (Schaberg et al. 2010). As such, the start and end dates for tag deployment were June 24 and July 6 respectively. Ground-based tracking began on June 24 and continued until August 16. Aerial tracking surveys were flown on July 14, July 27, and August 16.

CAPTURE

Chum salmon were captured using 2 bank-mounted fish wheels, one located along each bank near river kilometer (rkm) 270. The fish wheel location was upstream from where commercial and most subsistence harvest occurred but downstream of the majority of spawning tributaries. Each fish wheel consisted of 3 baskets measuring 2.4 x 3.0 m (length x width) constructed of aluminum. Baskets were fitted with 7.62 cm stretched nylon webbing. A chute constructed of plywood was incorporated into each basket to allow captured fish to slide into a plywood live box. The live box measured 2.4 x 1.2 x 0.6 m (length x width x depth) and was fastened to the offshore side of the fish wheel. The live box was partitioned, and a small section (measuring 0.5 x 1.2 x 0.6 m) was designated for use in this study as a way to simulate live box crowding. The sides and bottom of the live box were perforated to allow river water to flow through. Fish wheel performance was adjusted daily to maintain near constant fishing effort by positioning each so they fished in water depths of 1–2 m, maintained 2–4 basket revolutions per minute, and so the distance between the baskets and substrate was minimized.

FISH SELECTION

A total of 169 radio tags were available to be deployed. Tags were deployed in fish that met the following criteria: 1) capture time was known; 2) fish displayed no major wounds or signs of pre-capture stress; 3) fish had not spawned prior to capture; and 4) length was ≥400 mm from mid eye to fork of tail (MEF). Tagging crews attempted to select an equal number of fish each day from each fish wheel.

TREATMENT GROUPS

Chum salmon selected for tagging were partitioned into 2 equally sized treatment groups: “No Holding Time” and “1 Hour Holding Time”. Treatment group assignment followed a systematic approach that assumed each fish passing upstream of the capture site had an equal probability of being captured. All fish meeting the selection criteria were assigned to the 1 Hour Holding Time group until half of the daily tag allotment was deployed, and all subsequent fish that met the selection criteria were assigned to the No Holding Time group until the remainder of daily tag allotment was deployed. Because not all selected fish were captured at the exact same time, time differences within and between treatment groups could not be avoided. However, daily sampling goals were typically achieved within a few hours. Holding time was a function of the treatment group to which the fish was assigned and was independent of capture time.

A crowding effect in the fish wheel live box was simulated. Chum salmon assigned to the 1 Hour Holding Time group were placed in the designated subsection of the live box which forced fish into close proximity. The crowding effect was held near constant over the course of the study by selecting an equal number of fish each day and placing all selected fish in the live box as close together in time as possible. Fish that were captured by the fish wheel but not selected for tagging were allowed to fall into the larger "undesignated" portion of the live box simulating a disturbance effect.

TAGGING AND HANDLING

The primary tag was a pulse encoded esophageal radio tag (Advanced Telemetry Systems-ATS-Model F1840B[1]). Radio tags were inserted through the esophagus and into the upper portion of the stomach so that the antenna end of the tag was seated 0.5 cm anterior to the base of the pectoral fin. Tag insertion was accomplished using a 45 cm piece of polyvinyl chloride tubing with an outside diameter of 1.27 cm. In addition, chum salmon were tagged with a uniquely numbered external t-bar anchor tag (Floy model FD-68BC) and an adipose fin clip. The sex of tagged fish was determined using external characteristics. Length (MEF) was measured to the nearest mm using a straight-edge meter stick. Chum salmon were tagged and measured while restrained in an aluminum cradle suspended in a large tub of re-circulating river water. Fish were handled without the use of anesthesia. Fish assigned to the No Holding Time group were tagged measured and released as quickly as possible following capture. Fish assigned to the 1 Hour Holding Time group were t-tagged and placed in the designated holding portion of the live box for 1 hour before being processed, and released. The time of release was recorded to the nearest minute for all tagged fish.

TRACKING

Ground-Based Tracking

A series of 12 ground-based tracking towers was positioned along the mainstem Kuskokwim River (Figure 1). A steel box contained an ATS Model R4500 receiver-data logger powered by two 12-volt batteries wired to a solar array. Tag signals were received by two 4-element Yagi antennas elevated by a telescoping mast. One antenna was pointed downriver and the other upriver so that direction of travel could be determined. The receiver was programmed to scan through the available frequencies using both antennas simultaneously at 2-second intervals. When a signal of sufficient strength was detected, the receiver paused for up to 12 seconds on each antenna, and the tag frequency, code, signal strength, date, time (hour/minute), and antenna number were recorded. Stored data were downloaded to a laptop computer every 2–3 weeks. A single tracking tower (designated as -1) was positioned downstream of the tagging site to count the number of fish that went back downstream after being tagged and released. The remaining 11 tracking towers (designated sequentially as 1–11) were located upriver between rkm 297 and 890 (Figure 1).

Aerial Tracking

A total of 3 aerial tracking surveys were flown along the mainstem Kuskokwim River between each tracking tower location to determine if tagged fish remained in the mainstem or escaped into a spawning tributary. Aerial surveys were conducted with a PA-18 fixed-wing aircraft, a

[1] Product names used in this report are included for scientific completeness, but do not constitute a product endorsement.

pilot, and a surveyor who operated the R4500 data logger. All available frequencies were programmed into the data logger prior to each flight. Scan time for each frequency was 2 seconds. A single H-antenna was mounted on each wing strut such that the antennas detected peak signals perpendicular to the direction of travel. Surveys were flown at approximately 120 km/hr at an altitude between 100 and 300 m above the center of the river. Once a tag was detected, the operator would prompt the receiver to record the frequency, code, and location.

ANALYSIS

Movement Monitoring

Each ground-based tracking tower archived a comprehensive record of signal strengths for both the downriver and upriver antennas, which when evaluated together represented the history of relative distance and direction from the tracking tower for each of the radiotagged chum salmon that neared the tower. A typical detection record representing a 2-antenna tower can be visualized as 2 broadly overlapping approximately normal distributions of relative signal strengths where one distribution represents the downriver antenna and the other distribution represents the upriver antenna. In this way, a fish passing upriver of the tracking tower would be detected at low signal strength first by the downriver and then by the upriver antenna. Signal strength would increase concurrent on both antennas before it reached a climax on the downriver followed by the upriver antenna. Finally, the signal would decrease concurrent on both antennas with the final records recorded by the upriver antenna. A fish passing downriver would have the reverse pattern. The date and time of passage was determined by identifying the data point in the record where the relative signal strength switched between antennas. In the case where a fish crossed the tower multiple times, the first upriver passage record was used for fish traveling upstream, and the last downriver passage record was used for fish traveling downstream.

Statistical Inference

Because the behavior of untagged fish was unknown, it was not possible to establish a standard for comparison of results among the various metrics; instead, simple comparisons between the 2 treatment groups were performed. It was assumed that the level of tagging success representing the No Holding Time treatment group was the best that could be achieved given the current capture and tagging procedures. Because timing and method of capture, handling, and tagging was held constant between both treatments, any differences in the selected metrics were attributed to the effect of holding time in the fish wheel live box.

Metric 1: Survival Time Post Tagging

We were interested in comparing the mean survival times between the 2 treatment groups as a convenient method for comparing the post tagging life expectancies in a statistically meaningful way. In this analysis, we refer to “failure” rather than “mortality” because we generally could not differentiate between true mortality, tag loss, or tag failure.

For each tagged fish, an event history was constructed representing all observations from the time of tagging/release until the time of failure. Since the exact time of failure was not observed the data was viewed as interval-censored. All event histories were summarized into 2 critical time intervals. The first interval t_1^* represents the time elapsed from tagging/release until the last observation for which the fish was known to be alive. The second interval t_2^* represents the time elapsed from tagging/release until the first observation for which the fish was known to have

failed. In this way, we create a "failure interval" (t_1^*, t_2^*) that includes the unknown true failure time and is indicative of our level of uncertainty in the exact timing of that event.

Calculation of t_1^* and t_2^* was determined from known tagging/release times recorded at the tagging site and combined data from the array of telemetry tracking stations, mainstem aerial surveys flights, weirs, and volunteer tag recoveries. It was assumed that all fish that did not move into a spawning tributary failed. Failure was evidenced by dropping out of the study area or permanent cessation of movement. For fish that were not observed as having failed (e.g., fish that escaped into spawning tributaries), a general failure date of September 30 was used. Historical daily chum salmon passage and carcass data collected at Kuskokwim River salmon escapement monitoring weir projects suggest that by September 30 the chum salmon run is largely over and most individuals have spawned and expired.

A Bayesian survival analysis was used to model the distribution of failure times for the 2 holding time treatments (Congdon 2003). We assumed that, for each treatment, the failure times *t* have a Weibull distribution (Congdon 2003): a parametric probability distribution commonly used for modeling event duration data. The form of this distribution is:

$$f(t_i) = \kappa \lambda_i t^{\kappa-1} e^{-(\lambda_i t)^{\kappa}} I\left(t_{1i}^*, t_{2i}^*\right) \qquad 1$$

where:

i represents an individual fish.

$I\left(t_{1i}^*, t_{2i}^*\right)$ is an indicator function showing that the unobserved t_i falls between t_{1i}^* and t_{2i}^* which are observed.

κ is a scale parameter and was assumed to be common to both treatments.

λ_i is a location parameter and was a function of the covariate treatment, such that:

$$\log(\lambda_i) = \beta_0 + \beta_1 TRT_i \qquad 2$$

where:

β_0 and β_1 are the regression coefficients that relate the effects of the treatment to λ_i

TRT_i is a dummy variable taking a value of 1 for the second treatment, and zero otherwise. This specification allows the two treatments to have different means (life-expectancies).

The analysis was conducted in the program OpenBUGS Version 3.2.1 (Thomas et al. 2011). Three chains of 100,000 iterations (allowing for a 50,000 iteration burn in period) were run, each assuming different initial values of failure time. The 3 initial values of failure time represented t_{1i}^*, t_{2i}^*, and the midpoint between those points.

Once the probability distribution *f(t)* of failure times was estimated for a particular treatment, the probability of survival up to time *t* was estimated as:

$$S(t) = 1 - \int_0^t f(u)du = 1 - F(t) \qquad 3$$

Metric 2: Travel Time between Each Upriver Tracking Station

Individual travel times were calculated for each radiotagged chum salmon for all applicable tower intervals as determined by the upstream extent of travel (e.g., tag site–tower 1, tower 1–tower 2…, and so on until upstream mainstem travel ceased). Travel time was calculated using the available date and time records from the receiver-data logger located at each tower (*j*), such that:

$$Travel\ Time_{j,\ ix} = t_{jix} - t_{(j-1)ix} \qquad 4$$

where:

Travel Time$_{j,\ ix}$ = length of time of an ith fish of treatment *x* traveling from j-1th to jth tower.

Travel time was reported in fractions of a day (e.g., 12 hours equals 0.5 days). Average travel times were calculated for both treatment groups. A series of 2-sample *t*-tests assuming unequal sample size and variance were conducted to test the hypotheses that travel times were equal among treatments for each tower interval.

Metric 3: Percent of Fish Migrating Past Each Upriver Tracking Station

Percent passage upstream of each upriver tower was determined for each treatment group by dividing the total number of radiotagged fish determined to have passed a given tower by the total number of tags deployed, such that:

$$Percent\ Passage_{xj} = \frac{n_{xj}}{N_x} \qquad 5$$

where:

Percent Passage $_{xj}$ = the percentage of fish from treatment *x* that successfully passed tower *j*.

n_{xj} = the number of tagged fish from treatment *x* that passed tower *j*.

N_x = the number of tagged fish exposed to treatment *x*.

A series of 2-sample *z*-tests for equal proportions were conducted to test the hypotheses that percent passage upstream of each tower was equal among treatments.

Metric 4: Percent of Fish That Passed and Remained Upriver of Each Tracking Station

Percent retention upstream of each tower was determined for each treatment group by dividing the total number of radiotagged fish that passed and remained upriver of a given tower by the total number of tagged fish that passed that tower, such that:

$$Percent\ Retention_{xj} = \frac{n^*_{xj}}{n_{xj}} \qquad 6$$

where:

Percent Retention $_{xj}$ = the percentage of fish from treatment *x* that passed and remained upriver of tower *j* until the end of the project operational period.

n^*_{xj} = the number of fish from treatment x that passed tower j and stayed upriver until the end of the project operational period.

N_{xj} = the number of tagged fish from treatment x that passed tower j.

A series of 2-sample z-tests for equal proportions were conducted to test the hypotheses that percent retention upstream of each tower was equal among treatments.

Metric 5: Percent of Fish That Entered a Spawning Tributary

Ground-based tracking tower data was used to determine the final mainstem reach for each tagged fish. If the fish was not located within that mainstem reach during aerial survey flights, then it was assumed that the fish had moved into a spawning tributary that drained into that mainstem reach. Moderate aerial tracking efforts within the Holitna River, a major chum salmon spawning tributary, were conducted during the July 27 flight to verify that this approach appropriately assigned fates. Percent tributary escapement was determined for each treatment group by dividing the number of tagged fish assumed to have moved into any tributary by the total number of tags deployed, such that:

$$\textit{Percent Tributary Escapement}_x = \frac{n_x}{N_x} \qquad 7$$

where:

Percent Tributary Escapement $_x$ = the percentage of fish from treatment x that were assumed to have moved from the mainstem into any tributary.

n_x = the number of fish from treatment x that were assumed to have moved from the mainstem into any tributary.

N_x = the number of tagged fish exposed to treatment x.

A series of 2-sample z-tests for equal proportions were conducted to test the hypotheses that percent tributary escapements were equal among treatments.

RESULTS

TAGGING SUMMARY

All 169 chum salmon tagged as part of this study were captured prior to the mid-point of the chum salmon catch at the tag site (Table 1). A total of 85 chum salmon were assigned to the No Holding Time treatment group, and 84 fish were assigned to the 1 Hour Holding Time treatment group. The number of fish tagged by bank of capture was near equal. All selected fish were successfully radiotagged and released alive. The mean length and sex composition did not differ significantly between treatment groups (Table 2). On average, total processing time for the 1 Hour Holding Time group was 63 minutes (range: 55–72). It was estimated that it took approximately 3 minutes to handle, inspect, tag, measure, and release a single fish.

METRICS OF TAGGING SUCCESS

Survival Time Post Tagging

On average, the No Holding Time group survived 1.58 times longer than the 1 Hour Holding Time group (p = 0.035). Estimates of mean survival for each treatment group were 66.54 and

43.56 days respectively for the No Holding Time and 1 Hour Holding Time groups (Table 3). Relatively low sample sizes and our uncertainty in actual time of failure resulted in insufficient resolution to clearly define the tail of the failure distribution (Figure 2). As such, the model produced estimates of mean group survival time that are believed to be longer than the unknown "true" survival time. The level of uncertainty around the estimated probability of survival over time was large (Figure 3).

Travel Time between Each Upriver Tracking Station

On average the 1 Hour Holding Time group traveled slower than the No Holding Time group through each upriver interval (Table 4; Figure 4). The difference was only significant between the tag site and tower 1 (p <0.0001) and between tower 1 and tower 2 (p = 0.0394). There were no significant differences in mean travel time between any of the more distant upriver intervals.

Percent of Fish Migrating Past Each Upriver Tracking Station

The percent of tagged fish that passed upstream of tower 1 was high for both treatment groups. The percentages of fish from the 1 Hour Holding Time group that passed each tower from tower 2 through tower 5 were significantly lower than in the No Holding Time group. Only one fish from each treatment group successfully passed upriver of tower 6 (Table 5; Appendix A).

Percent of Fish That Passed and Remained Upriver of Each Tracking Station

The percentage of passing fish that remained upstream of each successive tower was significantly lower for the 1 Hour Holding Time group compared to the No Holding Time group. Within each treatment group, the percentages of fish retained above each tower from tower 1 through tower 5 were similar (i.e., the rate that fish fell back below individual tracking stations did not change with increasing distance from the tag site). Retention above tower 6 could not be estimated because only one tagged fish was detected at tower 6 and above (Table 6; Appendix A).

Percent of Fish That Entered a Spawning Tributary

The percentage of fish that was assigned to a spawning tributary was significantly lower for the 1 Hour Holding Time group (31%) compared to the No Holding Time group (67%) (z-score: 4.69, p-value: <0.0001; Appendix A).

DISCUSSION

Radio tagged Kuskokwim River chum salmon that were held in a fish wheel live box for 1 hour performed poorly compared to fish that were not held prior to release (Appendix A). The observed reduction in survival, travel speed, upriver travel extent, upriver retention, and tributary escapement suggest that held fish experienced stress related to the cumulative effects of capture, tagging, and holding. Clearly, this experiment showed that holding chum salmon for 1 hour after tagging in a fish wheel live box would result in a violation of assumptions in a two-sample mark–recapture experiment, specifically, the assumption that the tagging process does not affect the behavior of marked fish (Seber 1982).

SURVIVAL TIME POST TAGGING

The survival analysis indicated that holding Kuskokwim River chum salmon in a fish wheel live box resulted in a considerable reduction in the probability of survival over time. On average,

Kuskokwim River chum salmon require 1–3 weeks to travel from the tag site to the recapture sites that would be used in a full-scale mark–recapture study (Schaberg et al. 2010). Holding fish in the fish wheel live box resulted in approximately a 10% decrease in probability of survival to 20 days. The implication is that recapture probability of tagged fish varies negatively as a function of holding time and distance (i.e., travel time) from the tag site.

Although the survival analysis was insightful, we believe that the reported estimates of mean survival time and the expected survival probabilities should not be used for representing Kuskokwim River chum salmon outside the context of this study. The time interval encompassing the "true" failure time was wide for most fish, often ranging between a few days to a month or more. Consequently, random sampling from the probability distribution of failure times resulted in at least some very large values. This combined with relatively small sample sizes resulted in estimates of mean survival and probability of survival that are likely biased high and are characterized by a high degree of uncertainty (Figure 3).

Our rational for including this analysis in this report was in part to illustrate that a formal survival analysis could be done using radiotelemetry data. With larger sample sizes and a more fine scale methodology for tracking movement and determining failure times, we believe this approach could result in reliable estimates of survival probability as a function of time. Knowledge of how the proportion of the tagged population that is available for recapture varies over time would be extremely valuable for evaluating and possibly correcting bias, specifically bias related to differential probability of recapture over space and time.

TRAVEL TIME BETWEEN EACH UPRIVER TRACKING STATION

Holding radiotagged Kuskokwim River chum salmon for 1 hour lengthened upriver travel time compared to tagged fish that were not held. On average, it took held fish 12 hours longer to swim from the tagging site to tower 1. Upstream of tower 1, held fish continued to travel at a rate slower, albeit similar, to fish released immediately after tagging.

Our results were consistent with a well documented sulking behavior and reduction in upriver migration rate for adult salmon handled in riverine studies. For example, Bernard et al. (1999) documented radiotagged adult Chinook salmon often drop downstream several kilometers after being handled before continuing their upstream migration. Bromaghin et al. (2007) documented an increased travel time in spaghetti-tagged Yukon River fall chum salmon as a result of holding time and crowding in fish wheel live boxes. A 6-year study addressing migration timing and travel time of Kuskokwim River coho, chum, sockeye, and Chinook salmon showed that median arrival date of t-tagged fish on the spawning grounds was 9, 4, 6, and 3 days later than that of untagged fish (Schaberg et al. 2010).

It is likely that a reduction in migration rate could in turn increase the rate of upriver mortality via predation and harvest, because slower migrating fish would have a protracted exposure time in harvest areas and they would orient themselves closer to the bank, presumably to access shallower calmer waters. Increased holding time (Bromaghin et al. 2007) and crowding in fish wheel live boxes (Kerkvliet et al. 2004) have both been linked to an increased probability of recapture at nearby fish wheel recapture sites, suggesting that as holding conditions deteriorate fish become stressed (e.g., Clements et al. 2002; Frank et al. 2009) and their ability to evade capture is diminished for at least some time after release. In practice, holding time and live box crowding are positively related.

PERCENT OF FISH MIGRATING PAST EACH UPRIVER TRACKING STATION

Holding time had little effect on the percentage of tagged fish that successfully passed tower 1, but upstream of tower 1 differences between the treatment groups were apparent suggesting the effect of holding time on upstream extent traveled was a delayed response. This result was particularly relevant, because previous researchers have used this tower location as a benchmark by which radiotagged fish must pass before the tagging event was considered "successful" and the fish was included in the marked population (e.g., Stuby 2007; Kevin Schaberg, ADF&G Kuskokwim Area Fisheries Research Biologist, personal communication). Results of this study indicate that use of this "entrance point" in earlier studies could be misleading, because if the cumulative tagging process does result in a delayed stress response, then project objectives would be better served by increasing the distance between the tag site and the entrance point.

The lack of radiotagged chum salmon upstream of tower 6 in this study was most likely a function of the relative abundance of Holitna River chum salmon compared to other Kuskokwim River stocks, not a response to tagging. The Holitna River joins the Kuskokwim River between towers 5 and 6. On average the Holitna supports approximately 45% of the Chinook salmon, 70% of the sockeye salmon, and 40% of the coho salmon (Gilk et al. 2011; Kevin Schaberg, ADF&G Kuskokwim Area Fisheries Research Biologist, personal communication) that spawn in the Kuskokwim River upstream of Kalskag. The percentage of chum salmon returning to the Holitna River is unknown but believed to be of a similar magnitude (e.g., Bue et al 2008). Historically, migration timing of Holitna River chum salmon past the tagging site overlaps broadly with more distant upriver stocks (Schaberg et al. 2010). Consequently, the probability of tagging Holitna River chum salmon during the operational period of this study was likely very high and expected. Inseason assessment of tracking data showed that many fish from both treatments did pass tower 5 but not tower 6, but very few were located in that mainstem reach during aerial surveys. Modest additional aerial survey efforts confirmed that the nearly all of the tagged fish that remained upstream of tower 5 traveled into the Holitna drainage.

PERCENT OF FISH THAT PASSED AND REMAINED UPRIVER OF EACH TRACKING STATION

Most tagged fish that passed a given tower were expected to remain upriver from that location for the duration of the study, presumably because the fish would spawn and die within an upriver tributary. Still, some percentage of fish traveling back downriver was expected due to natural straying behavior, inriver flow conditions, exhaustion, mortality, etc. The precision of homing and degree of straying in Kuskokwim River chum salmon are not known, but work conducted in other areas hints that the homing tendency is likely strong (e.g., Salo 1991). As such, exhaustion or mortality in the mainstem and subsequent "flushing" downriver was expected to be the dominant mechanism behind any observed "fallback".

The retention rate upstream of tower 1 for both treatments was particularly relevant because previous studies have used radio telemetry and tower 1 to model the percentage of Kuskokwim River Chinook, coho, and sockeye salmon that eventually fall back and drop out of the "marked" population (Gilk et al. 2011; Kevin Schaberg, ADF&G Kuskokwim Area Fisheries Research Biologist, personal communication). Dropout in these studies was defined as a marked fish that did not pass or passed but fell back downstream of tower 1 where it would presumably be unavailable for recapture at upriver tributary weirs. In this study, the 24% dropout experienced by the No Holding Time group was high but likely acceptable compared to the average dropout

documented for Chinook (9%), sockeye (12%) and coho salmon (23%). The 57% drop out for the 1 Hour Holding Time group was especially noteworthy because it was more than twice as high as any dropout rate observed for any other species of Kuskokwim River salmon that has been successfully studied using radiotelemetry mark–recapture.

Although the percent of upstream retention differed notably between treatment groups, the percent retention within each treatment group was consistent across tower locations (Table 5). By the nature of the analysis, it seemed reasonable to expect that percent retention would decrease as the distance from the tag site increased, simply because the watershed area being considered was smaller as the fish moved upriver. The observed pattern was only possible if tagged fish that ceased upstream movement prior to escaping into a spawning tributary were flushed downriver of tower 1 rather than being retained in the mainstem by natural features such as deep pools, eddies, side channels, and large woody debris. Tower records confirm that this was indeed the case. Regardless of treatment group, many fish were recorded traveling upstream of several tower locations only to eventually fall back downstream of tower 1. It is unlikely that many of the fish that fell back downstream of tower 1 had successfully spawned in an upriver tributary. On average fish spent 5 days upstream of the upper most passed tower prior to falling back downriver. These results suggest that any upriver tower location would be sufficient for estimating drop out of tagged fish. However, retention of salmon carcasses in the mainstem would certainly be affected by changes in water level and river morphology, and the pattern observed in this study may not be consistent across a range of flow conditions.

PERCENT TRIBUTARY ESCAPEMENT

The current Kuskokwim River mark–recapture platform relies on an existing array of salmon escapement monitoring weirs to function as tag recapture sites, and no effort is made to recapture tagged fish in the mainstem Kuskokwim River. Telemetry data from this and past studies clearly showed that not all tagged fish successfully escaped into spawning tributaries upriver of the tag site, and were therefore not available for recapture (e.g, Gilk et al. 2011: Kevin Schaberg, ADF&G Kuskokwim Area Fisheries Research Biologist, personal communication). The exact fate of radio tags located in the mainstem is largely unknown for this and other Kuskokwim River telemetry studies. The most common interpretation has been that tags located in the mainstem indicate that the tagged fish died during its upstream migration, but mainstem spawning and tag loss are alternate hypotheses. Currently there is no evidence to support major chum salmon spawning activity in the mainstem Kuskokwim River between the tag site and the uppermost tower location. Radiotagged salmon have been known to regurgitate their tag, but it is generally not possible to distinguish a regurgitated tag from an expired fish lying on the substrate. Formal estimates show that esophageal radio tag loss in freshwater salmon studies is on average very low, 2–3% over time periods and distances relevant to Kuskokwim River tagging initiatives (e.g., Ramstad and Woody 2003; Keefer et al. 2004). Given the relatively large number of radio tags located in the mainstem Kuskokwim River during this and previous mark–recapture efforts, it is unlikely that tag loss is the driving mechanism. Rather, mortality of tagged fish remains the most likely explanation.

Regardless of the driving mechanism, holding chum salmon in a fish wheel live box for 1 hour resulted in fewer tagged fish escaping into spawning tributaries, compared to fish with no holding time. Only 27% of the tagged chum salmon that were held in the live box were assigned to a spawning tributary compared to 66% of the fish that were tagged and released immediately

after capture. The percentage of the 1 Hour Holding Time group that escaped to tributaries in this investigation was far less than that observed for other salmon species tagged at the Kuskokwim River tag site: Chinook salmon 75%; sockeye salmon 73%; and coho salmon 62% (Gilk et al. 2011, Kevin Schaberg, ADF&G Kuskokwim Area Fisheries Research Biologist, *personal communication*). In contrast, the No Holding Time group performed within the range of expectation given what has been previously observed in other studies. When only fish that remained upstream of tower 1 are considered, 89% of the No Holding Time group was assigned to a spawning tributary (a higher percentage compared to most other Kuskokwim River salmon mark–recapture studies).

APPLICATION TO FUTURE STUDIES

Results of this study support observations made during previous mark–recapture studies (Kerkvliet et al. 2003, 2004; Pawlik et al. 2006); specifically, that holding fish in a fish wheel live box contributed to the pattern of decreasing tag recoveries with increasing distance from the tag site. In these earlier studies, chum salmon were held for up to 2 hours when the wheels were staffed, and 4 or more hours between shifts (Schaberg et al. 2010). In addition, fish were often crowded in the live box, literally overflowing during periods of extremely high catch rates. Regardless of the conditions, all but the most visibly stressed fish were tagged and released, and all tagged fish were considered in the final analysis.

Other studies have also link holding time and live box crowding to reduced success of chum salmon mark–recapture studies conducted in the Kuskokwim and Yukon Rivers (e.g., Kerkvliet et al. 2003, 2004; Bromaghin et al. 2007). For example, holding time and crowding in fish wheel live boxes resulted in reduced probability of recapture at distant upriver sites for spaghetti-tagged Yukon River fall chum salmon (Bromaghin et al. 2007). Those investigators speculated that a stress response due to holding conditions resulted in an elevated mortality rate, thus some fish simply died before reaching more distant spawning grounds.

Within the Kuskokwim River, the effect of holding time on upstream migration appears unique to chum salmon. The Kuskokwim River mark–recapture platform has been used successfully for Chinook (e.g., Stuby 2007), sockeye (e.g., Gilk et al. 2011), and coho salmon (e.g., Schaberg et al. 2010), as evidenced by the statistical similarity in the mark-to-unmarked ratios across upriver recapture weirs. It is possible that chum salmon migrating past the tag site are at a critical stage in their physiological transition and are more susceptible to stressors than other species. Unfortunately, alternate downriver tagging sites have proven unsuccessful due to inadequate flow characteristics (Schaberg et al. 2010), and upriver sites would exclude major spawning tributaries or would likely have unequal probability of capture for discrete spawning stocks (e.g., Stuby 2007).

We recommend that investigators planning to use the existing Kuskokwim River mark–recapture platform to estimate chum salmon abundance strongly consider eliminating holding time altogether, thereby helping to minimize the tagging effects. Unfortunately, even releasing fish immediately after capture and tagging will likely not completely mitigate bias due to handling and tagging effects. For example, Bromaghin et al. (2007) showed that Yukon River fall chum salmon that were tagged and released immediately after capture with fish wheels still displayed a negative relationship between recapture probability and distance from the tag site, although the effect was not as strong compared to fish that were held in the fish wheel live box prior to release.

The underlying question clouding any future effort to use mark–recapture to estimate abundance of Kuskokwim River chum salmon is: will eliminating the stress of holding fish in a live box reduce the magnitude of the bias to an acceptable level? At a first look, it appears that with proper precaution it could. The most promising indication of potential success was that radiotagged chum salmon that were released immediately after capture and tagging displayed similar dropout and tributary escapement rates compared to other species of Kuskokwim River salmon for which mark–recapture has proven successful.

It may be necessary to consider alternate modeling strategies to correct any biases associated with disproportionate marking or recovery. For example, as described briefly in this report, we may be able to use telemetry data to model the probability that a tagged chum salmon will fail as a function of time. Knowledge of the failure rate could be combined with existing run timing data to adjust tag recoveries across a range of temporal/spatial scales. Bromaghin et al. (2010) present another option. They have developed a new temporally stratified mark–recapture model that permits capture probabilities and migratory timing to vary. Their model, which incorporates radio telemetry, appears to have considerable application for Kuskokwim River chum salmon. At this time we are not able to recommend a "best" approach, but we recognize the need to consider alternative methods.

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TABLES AND FIGURES

Table 1.–Summary of daily chum salmon radiotagging efforts at the Kuskokwim River fish wheel tagging location (rkm 270).

Date	Fish Tagged						Cumulative tagged (%)	Percentage of total cumulative catch (%) [c]
	No Holding Time [a]			1Hr. Holding Time [b]				
	Right Bank	Left Bank	Subtotal	Right Bank	Left Bank	Subtotal		
24 Jun	3	3	6	3	3	6	7	5
25 Jun	0	6	6	1	5	6	14	6
26 Jun	2	4	6	2	5	7	22	6
27 Jun	3	4	7	3	4	7	30	9
28 Jun	0	9	9	2	6	8	40	11
29 Jun	4	4	8	4	5	9	50	13
30 Jun	Fish wheels did not operate						50	13
1 Jul							50	14
2 Jul	4	4	8	4	4	8	60	21
3 Jul	4	4	8	4	4	8	69	26
4 Jul	4	4	8	4	4	8	79	33
5 Jul	4	4	8	4	4	8	88	39
6 Jul	6	5	11	4	5	9	100	43
Total	34	51	85	35	49	84		

[a] Fish were processed and released without being held in the fish wheel live box.

[b] Fish were processed and released after being held in the fish wheel live box for 1 hour.

[c] Percentage of seasonal cumulative chum salmon catch at the Kalskag fish wheels. This illustrates the portion of the annual run that was being represented by tagging efforts.

Table 2.–Descriptive statistics representing radiotagged Kuskokwim River chum salmon exposed to either no holding time or a 1-hour holding time in a fish wheel live box.

Statistic	No Holding Time [a]			1Hr. Holding Time [b]			p-value
	n	Mean	SD	n	Mean	SD	
Processing Time (min)	85	3 [c]		84	63	2.83	
Mean Length (mm MEF)	85	553	29.55	83	556	34.12	0.2745 [d]
	Trials [e]	Success [f]	Percent	Trials [e]	Success [f]	Percent	
% Female	85	48	56%	84	46	55%	0.8231 [g]

[a] Fish were processed and released without being held in the fish wheel live box.

[b] Fish were processed and released after being held in the fish wheel live box for 1 hour.

[c] Estimated.

[d] Based on a 2-tailed *t*-test assuming unequal variance, $\alpha = 0.05$.

[e] Number of fish exposed to a treatment.

[f] Number of fish from each treatment meeting the specific criterion.

[g] Based on a 2-sample z-test of equal proportions, $\alpha = 0.05$.

Table 3.–Survival times of radiotagged Kuskokwim River chum salmon exposed to either no holding time or a 1-hour holding time in a fish wheel live box.

Treatment	Mean	CV	sd	95% Credible Interval			Ratio of Means	p-value [a]
1 Hour Holding Time	43.56	37%	16.1	21.35	–	83.22	1.58	0.035
No Holding Time	66.54	36%	24.07	32.70	–	125.00		

[a] $\alpha = 0.05$.

Table 4.–Mean upriver travel speed of radiotagged Kuskokwim River chum salmon exposed to either no holding time or a 1-hour holding time in a fish wheel live box.

Interval	Interval Distance (rkm)	No Holding Time [a]				1Hr. Holding Time [b]				p-value [c]
		n [d]	Mean Travel Time (days)	Stdev	rkm / day	n [d]	Mean Travel Time (days)	Stdev	rkm / day	
Tag Site–Tower #1	27.36	83	0.82	0.28	33.48	79	1.30	0.74	21.04	<0.0001
Tower #1–Tower #2	56.33	73	1.62	0.32	34.82	56	1.75	0.47	32.25	0.0394
Tower #2–Tower #3	43.45	72	1.07	0.15	40.74	50	1.11	0.24	39.23	0.1457
Tower #3–Tower #4	49.89	66	1.21	0.26	41.37	40	1.25	0.27	39.91	0.2094
Tower #4–Tower #5	35.41	60	1.82	0.20	19.40	32	1.87	0.32	18.97	0.2538
Tower #5–Tower #6	82.08	1	1.10		74.62					
Tower #6–Tower #7	53.11	1	1.05		50.35					
Tower #7–Tower #8	48.28	1	1.09		44.28					
Tower #8–Tower #9	37.01	1	0.96		38.46					
Tower #9–Tower #10	69.20	1	2.36		29.27					
Tower #10–Tower #11	117.48									

[a] Fish were processed and released without being held in the fish wheel live box.

[b] Fish were processed and released after being held in the fish wheel live box for 1 hour.

[c] Based on a 2-tailed t-test assuming unequal variance, $\alpha = 0.05$.

[d] Number of tags identified at each tower used to estimate travel times.

Table 5.–Percentage of radiotagged Kuskokwim River chum salmon that passed each upriver tower, after exposure to either no holding time or a 1-hour holding time in a fish wheel live box.

Tower	Distance From Tag Site (rkm)	No Holding Time [a] (Tagged = 85)		1Hr. Holding Time [b] (Tagged = 84)		p-value [c]
		Success [d]	Percent Passage	Success [d]	Percent Passage	
1	27	84	99%	79	94%	N/A
2	84	74	87%	57	68%	0.0028
3	127	72	85%	51	61%	0.0005
4	177	66	79%	41	49%	<0.0001
5	212	60	71%	32	38%	<0.0001
6	295	1	1%	1	1%	N/A
7	348	1	1%	0	0%	N/A
8	396	1	1%	0	0%	N/A
9	433	1	1%	0	0%	N/A
10	502	1	1%	0	0%	N/A
11	620	0	0%	0	0%	N/A

Note: N/A denotes that a test of significance could not be performed because one or both of the independent samples failed to meet the minimum required 5 successes and failures.

[a] Fish were processed and released without being held in the fish wheel live box.

[b] Fish were processed and released after being held in the fish wheel live box for 1 hour.

[c] Based on a 2-sample z-test of equal proportions, $\alpha = 0.05$.

[d] Number of fish that passed upstream of the specified tower.

Table 6.–Percentage of radiotagged Kuskokwim River chum salmon that remained above each upriver tower, after exposure to either no holding time or a 1-hour holding time in a fish wheel live box.

Tower	Distance From Tag Site (rkm)	No Holding Time [a] (Tagged = 85)			1Hr. Holding Time [b] (Tagged = 84)			p-value [c]
		Trials [d]	Success [e]	Percent Retention	Trials [d]	Success [e]	Percent Retention	
1	27	84	65	77%	79	36	46%	<0.0001
2	84	74	52	70%	57	25	44%	0.0023
3	127	72	51	71%	51	17	33%	<0.0001
4	177	66	46	70%	41	14	34%	0.0003
5	212	60	45	75%	32	11	34%	0.0001
6	295	1	1	100%	1	1	100%	N/A
7	348	1	1	100%	0			N/A
8	396	1	1	100%	0			N/A
9	433	1	1	100%	0			N/A
10	502	1	1	100%	0			N/A
11	620	0			0			N/A
			p-value [f]	0.9916		p-value [f]	0.8367	

Note: N/A denotes that a test of significance could not be performed because 1 or both of the independent samples failed to meet the minimum required 5 successes and failures.

[a] Fish were processed and released without being held in the fish wheel live box.

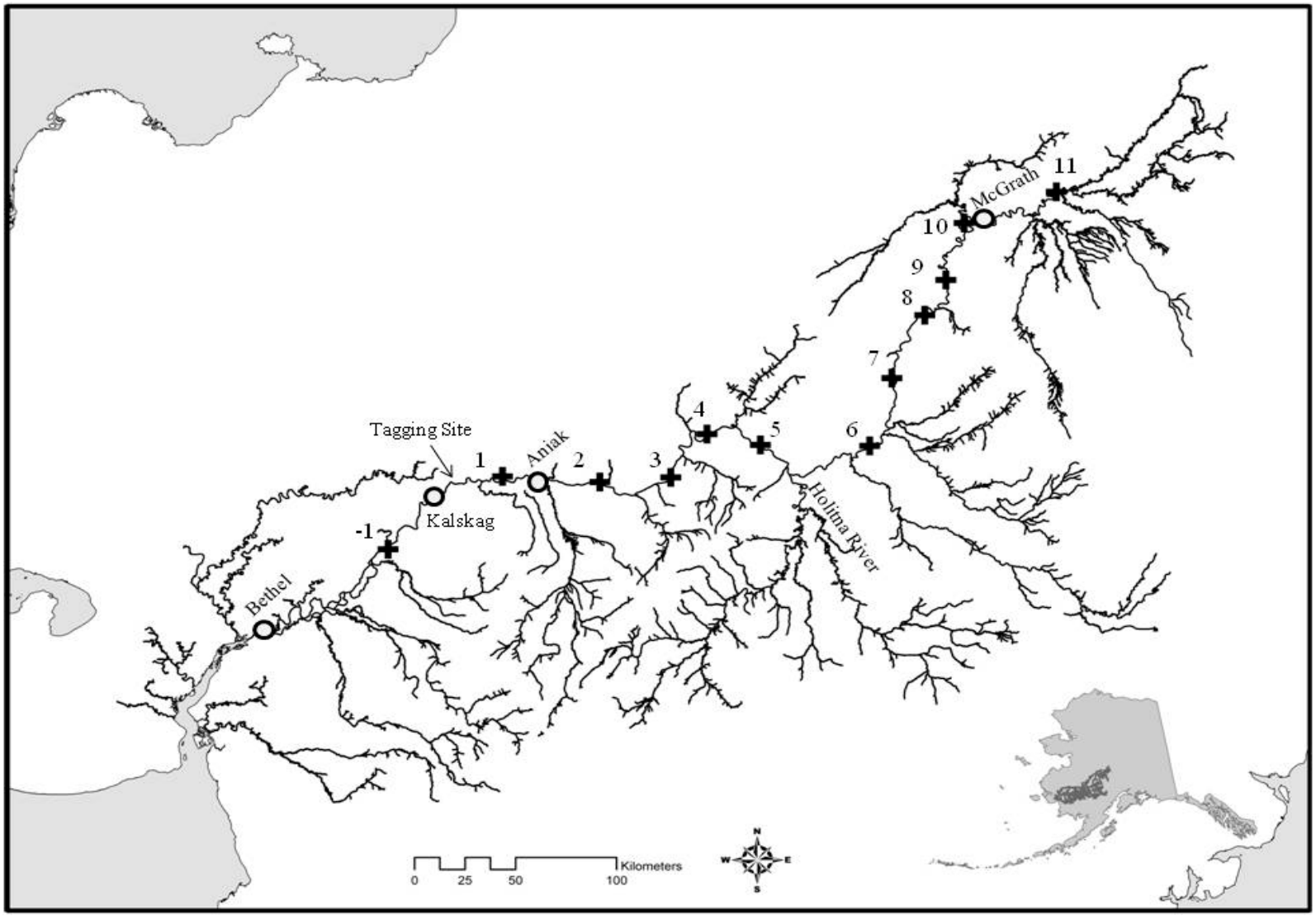
[b] Fish were processed and released after being held in the fish wheel live box for 1 hour.

[c] Based on a 2-sample z-test of equal proportions, $\alpha = 0.05$.

[d] Number of fish that passed upstream of the specified tower.

[e] Number of fish that remained upstream of the specified tower.

[f] Based on contingency table analysis of towers 1–5 only, $\alpha = 0.05$.



Note: Numbers corresponding to each telemetry tracking tower are consistent with those described in the text.

Figure 1.–Kuskokwim River drainage illustrating the location of the tag site and the 12 ground-based telemetry tracking towers.

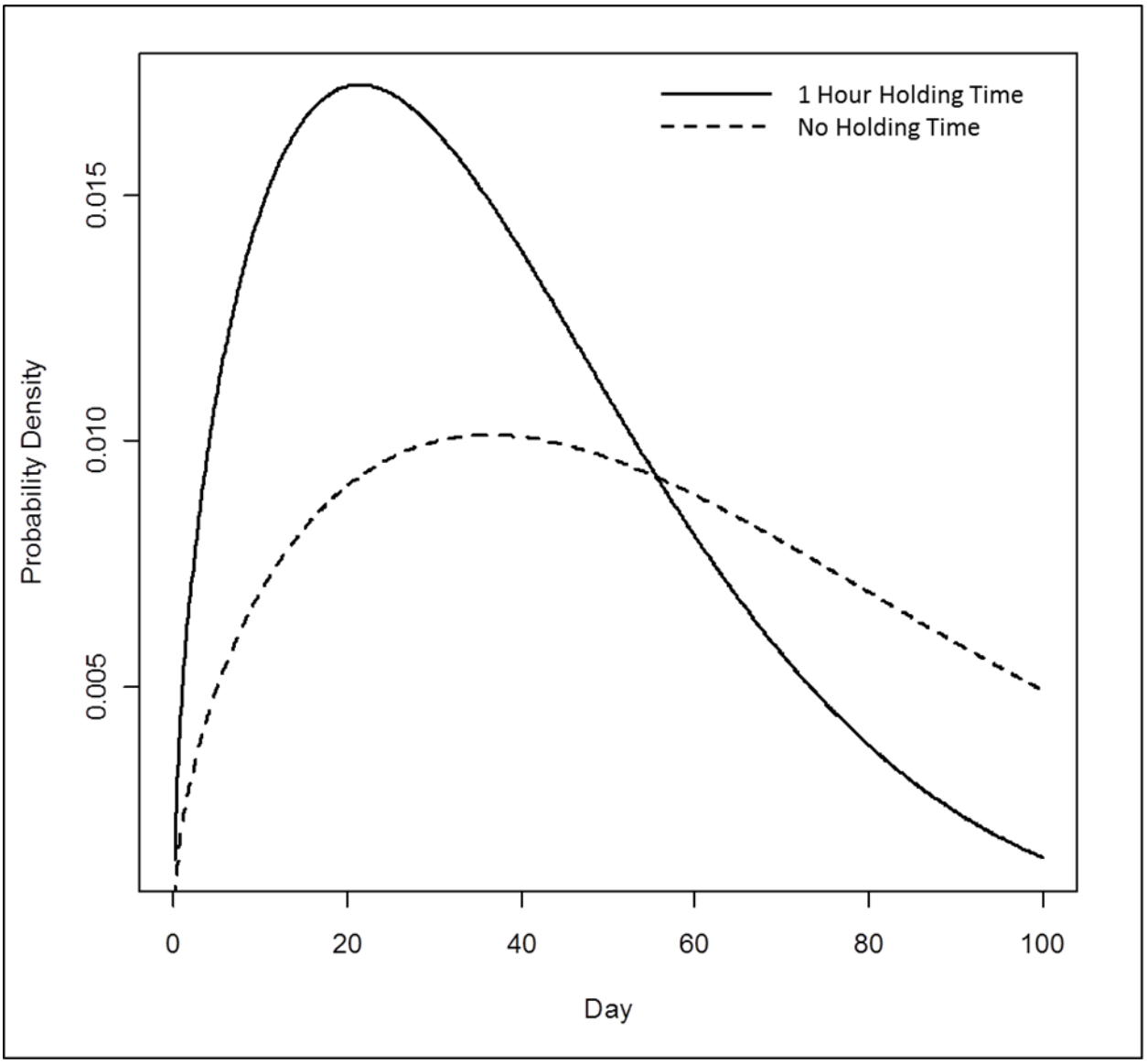


Figure 2.–Probability distribution of failure times of radiotagged Kuskokwim River chum salmon exposed to either no holding time or a 1 hour holding time in a fish wheel live box.

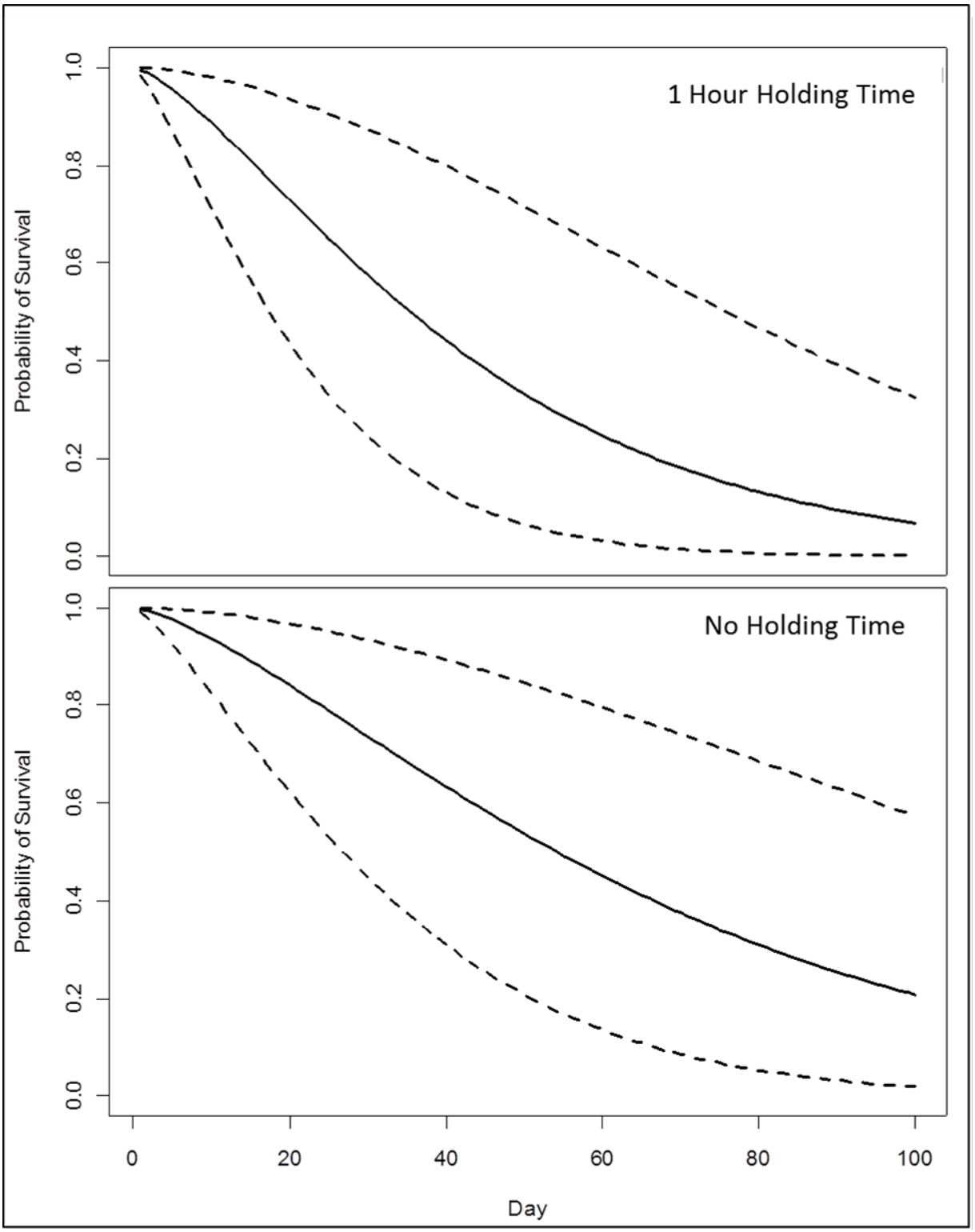
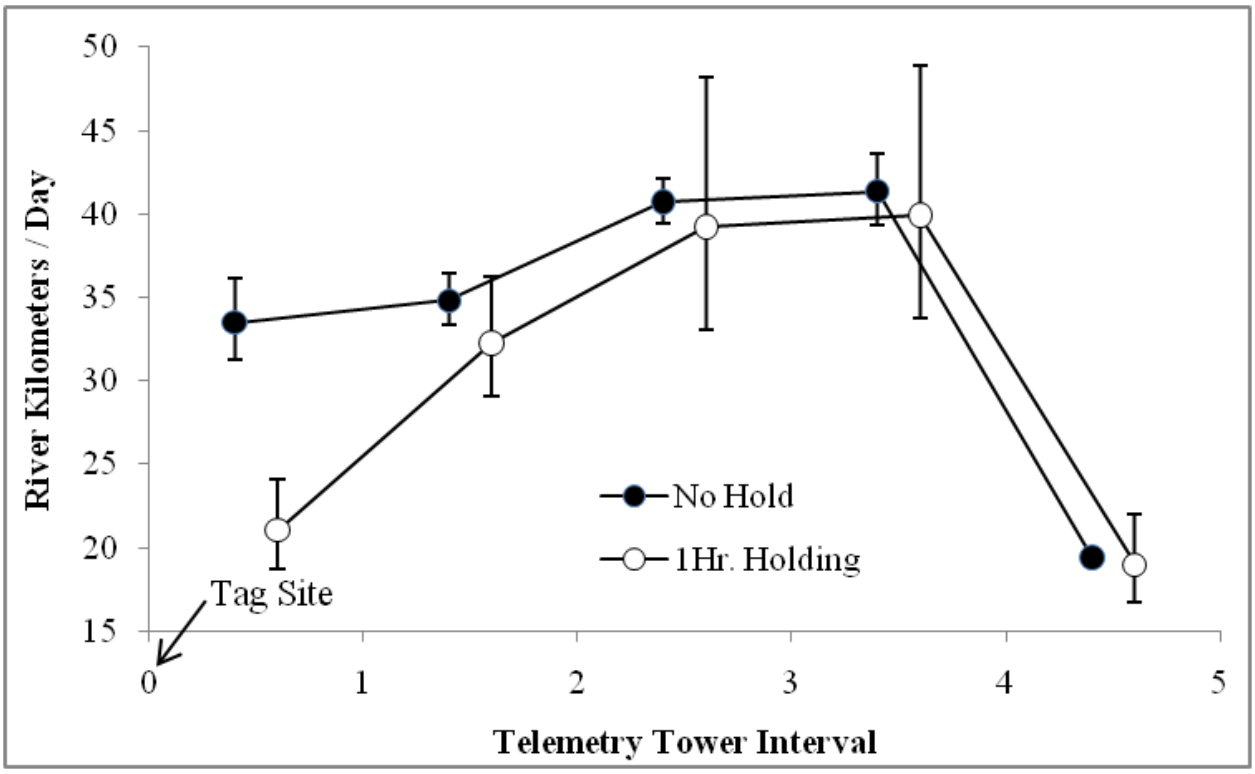


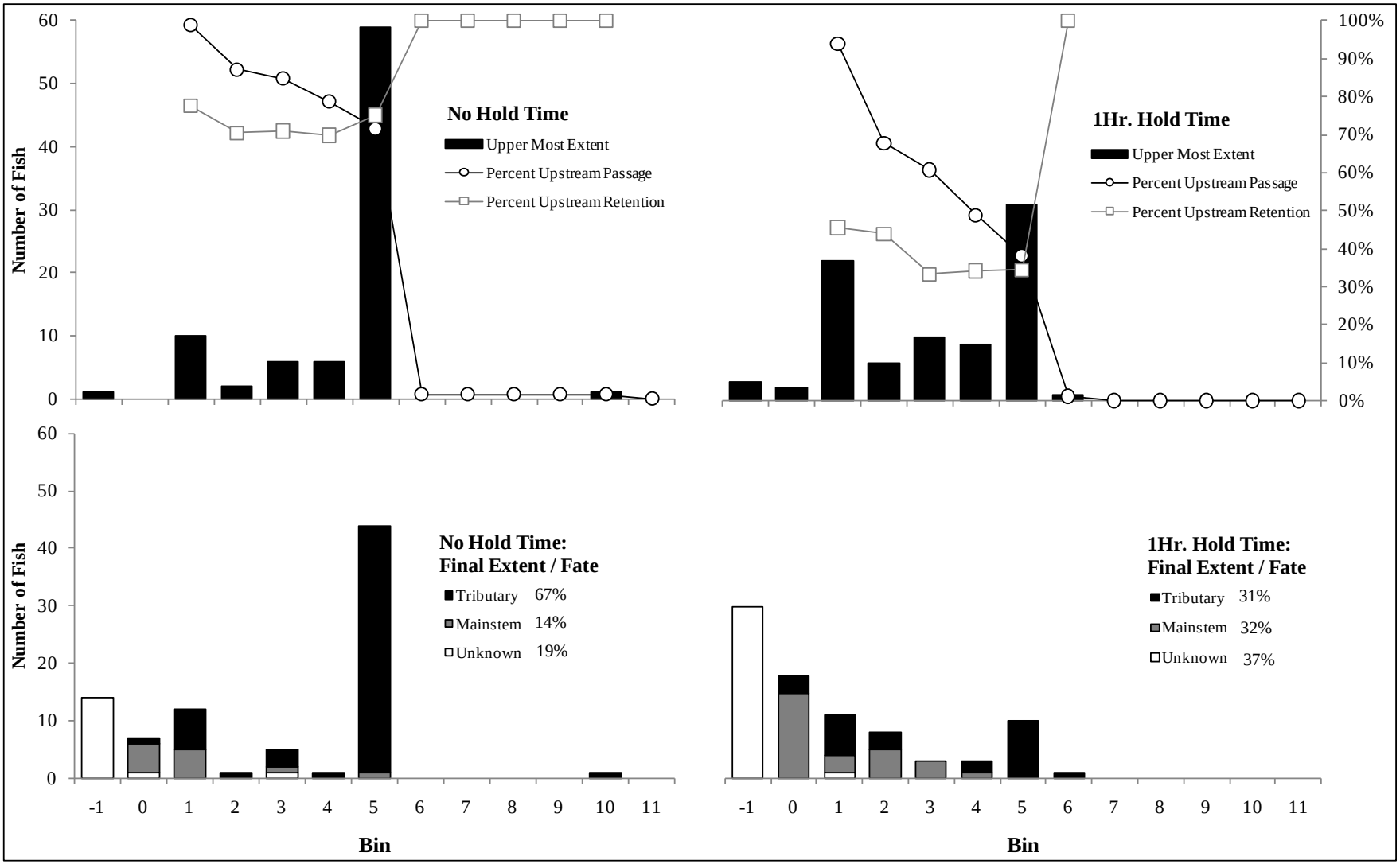
Figure 3.–Probability of survival of radiotagged Kuskokwim River chum salmon exposed to either no holding time or a 1 hour holding time in a fish wheel live box.



Note: 95% credible intervals are shown.

Figure 4.–Mean travel speed through each upriver tower interval for Kuskokwim River chum salmon exposed to either no holding time or a 1 hour holding time in a fish wheel live box.

APPENDIX A: SUPPLIMENTAL FIGURE



Note: Bin refers to the area between consecutive telemetry tracking towers. The tag site was located in bin #0.

Appendix A1.–Post release movement summary for Kuskokwim River chum salmon exposed to either no holding time or a 1-hour holding time in a fish wheel live box.