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Estimation of Pacific Salmon Distribution and Abundance in the Matanuska River Watershed, Southcentral Alaska, 2009

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Abstract

The Matanuska River is a major physical feature of northern Cook Inlet, yet little is known about salmon distribution, run timing, or abundance. This project was implemented to provide fishery managers with baseline data regarding the relative run strength and spawning distribution of Chum *Oncorhynchus keta*, Coho *O. kisutch*, and Sockeye salmon *O. nerka* in the Matanuska River watershed. In 2009, a fish wheel was used to capture and mark fish for a spawning distribution and abundance estimate study. Radiotelemetry was used to identify and track individual Chum, Coho, and Sockeye salmon to spawning destinations upstream of the tagging site on the Matanuska River. Recapture events for the mark-recapture component of the study consisted of 48 carcass surveys at spawning beds between 26 August and 16 October (11,223 carcasses examined). A Bayesian implementation of a time-stratified Lincoln-Petersen model provided abundance estimates. A total of 433 Chum, 424 Coho, and 318 Sockeye salmon were captured and marked at the fish wheel from 24 June through 12 September. A total of 291 radio transmitters were deployed in a subset of healthy Chum, Coho, and Sockeye salmon between 24 June and 3 September 2009, of which 257 fish were successfully tracked to spawning areas. Over 75% of Chum (n = 68) and 82% of Sockeye salmon (n = 95) selected spawning locations in the main-stem braid plain of the Matanuska River, whereas 54% of Coho Salmon (n = 45) selected spawning locations in tributary watersheds. Clearwater side channels associated with the main-stem braid plain provide important spawning habitat for Pacific salmon in the Matanuska watershed. Abundance estimates of spawning Chum, Coho, and Sockeye salmon populations upstream of our capture site were 54,720, 11,430, and 13,750 fish, respectively, demonstrating that glacial river systems have the potential to support substantial Pacific salmon runs.

Introduction

The human population of the Matanuska-Susitna (Mat-Su) Borough is one of the fastest growing in the U.S., with a growth rate of 49% from 1990 to 2000 (U.S. Census Bureau 2001). The city of Palmer and the communities of Sutton and Chickaloon are the major population centers in the Matanuska River watershed. Rapid population growth and the accompanying pressures for development will increasingly challenge the ability of fisheries and land managers to balance fish habitat conservation with these changes over time. Maintaining healthy fish habitat, including water quality and quantity, is critical to maintaining healthy fish populations in the Matanuska River watershed.

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Major human activities that affect fish habitat in the Matanuska River watershed are associated with residential and urban development, including land clearing and residential and commercial building construction. The primary effects of housing and urban development on salmon and their habitat are the loss of wetlands, alteration of riparian habitat, degraded water quality, creation of impervious surfaces, and disconnected fish passages (MSBSHP 2013). The Glenn Highway provides access along most of the length of the Matanuska River and secondary road construction for housing, urban, and industrial development and for the development of natural resources will continue as the population in the area continues to grow.

The Matanuska watershed is rich in coal and other natural resources, and coal mining was historically important to the economy of the area. In the 1910s, the U.S. Navy's need for coal for its Pacific Fleet led to the Development of the coal towns of Sutton and Chickaloon. Coal mining activity waned in the 1920s but continued in the watershed until the mid-1980s. Although there are no active coal mines in the Matanuska River watershed, coal mining in the watershed may again become economically feasible in the future. In addition to coal resources, sand and gravel mining occurs today in numerous areas of the watershed, with increased interest from the gravel industry to mine within the Matanuska River braid plain.

The Matanuska River is a major feature of northern Cook Inlet, yet little is known about salmon distribution, timing, or abundance. Pacific salmon *Oncorhynchus* spp. from the Matanuska River contribute to commercial fisheries in the Upper Cook Inlet; mainly in mixed stock set and drift gillnet fisheries for Sockeye *O. nerka* and Coho *O. kisutch* salmon. Most Upper Cook Inlet commercial Sockeye Salmon fisheries target stocks returning to the Kasilof and Kenai rivers, although the contribution of Matanuska stocks is unknown. Total commercial harvest of Coho Salmon in Upper Cook Inlet averaged nearly 250,000 fish per year from 1994 to 2003 (Fox and Shields 2005), but the portion of those fish bound for the Matanuska River was unknown. Previous research indicates that the Central District drift net and Northern District west-side set net fisheries harvest mainly Coho Salmon bound for northern Cook Inlet, particularly the Susitna River (Vincent-Lang and McBride 1989). Willette et al. (2003) estimated that the Matanuska River Coho Salmon escapement was about 20,000 fish, which comprised 8% of the Knik Arm escapement and about 2% of the overall upper Cook Inlet escapement. However, until 2008 there were no direct measures of Matanuska River Chum *O. keta*, Coho, or Sockeye salmon run timing or escapements (Anderson and Bromaghin 2009). Sport harvest of salmon in the Matanuska River is low (Sweet et al. 2003).

Concerns for how to effectively protect and restore salmon production in the face of rapid development of these drainages led to the creation of the Mat-Su Basin Salmon Habitat Partnership (MSBSHP). The MSBSHP is one of the fish habitat partnerships approved nationwide under the National Fish Habitat Action Plan (NFHAP). The NFHAP is a national effort to protect and restore the nation's waterways and fisheries through science-based partnerships of affected stakeholders. The MSBSHP has developed a Strategic Action Plan, which identifies objectives, actions, and research necessary to protect salmon and salmon habitat in the Mat-Su basin (MSBSHP 2008, 2013).

This was the second year of a project that was implemented to provide fishery and land managers with baseline data regarding the relative run strength, run timing, and spawning distribution of Chum, Coho, and Sockeye salmon in the Matanuska River watershed and to provide baseline data regarding relative run strength of other anadromous species.

Objectives for the project were to:

1. Estimate the sex, age, and length compositions of Chum, Coho, and Sockeye salmon in the Matanuska River.
2. Estimate the migratory timing profiles of Chum, Coho, and Sockeye salmon in the Matanuska River at the point of capture from mid-June through October.
3. Estimate the abundance of Chum, Coho, and Sockeye salmon such that the estimate will have a 90% probability of being within +/-10% of the true abundance.
4. Detect the ultimate spawning destination upstream of the capture site, via the presence of at least one tagged fish, of a population comprising 10% or more of all the Chum Salmon passing the capture site during each temporal stratum with probability 0.85..
5. Detect the ultimate spawning destination upstream of the capture site, via the presence of at least one tagged fish, of a population comprising 10% or more of all the Coho Salmon passing the capture site during each temporal stratum with probability 0.85.
6. Detect the ultimate spawning destination upstream of the capture site, via the presence of at least one tagged fish, of a population comprising 10% or more of all the Sockeye Salmon passing the capture site during each temporal stratum with probability 0.85.
7. Map Chum, Coho, and Sockeye salmon spawning areas of the main-stem Matanuska River and its tributaries.

Fish wheels have been successfully used to capture fish for tagging and estimation of migratory timing in projects for the Copper (Savereide 2005, Wade et al. 2007), Yukon (Apodaca and Daum 2006, Cleary and Hamazaki 2007), Kuskokwim (Pawluk et al. 2006), and Nass (Link and English 1996, 2000) rivers. Anderson and Bromaghim (2009) demonstrated that fish wheels can successfully capture migrating salmon in the Matanuska River.

Study Area

The Matanuska River watershed drains over 5,300 km^2 within the Cook Inlet drainage basin of Southcentral Alaska (Figure 1). The headwaters of the Matanuska River originate at over 3,000 m in the Chugach Mountains and the river flows westward for more than 120 km to its terminus in Knik Arm of Cook Inlet. The watershed is bound to the north by the Talkeetna mountain range and to the south by the Chugach mountain range. The Chickaloon River, with its headwaters in the Talkeetna Mountains, is the largest tributary to the Matanuska River. Most of the larger tributary streams of the Matanuska River originate in the Talkeetna Mountains.

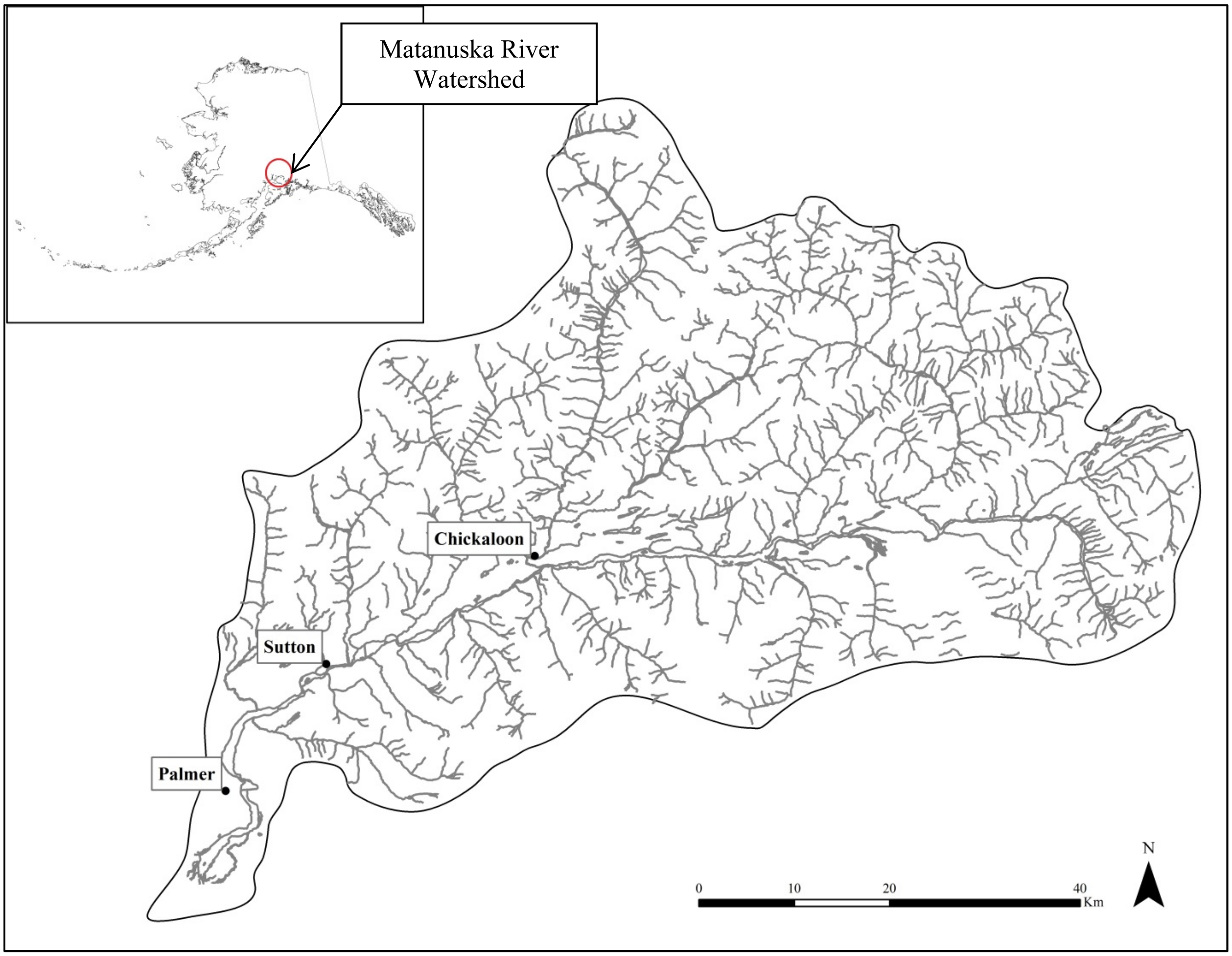


Figure 1. Map of the Matanuska River watershed, southcentral Alaska.

The Matanuska River is a typical glacial river with braided channels, shifting substrates, an overall lack of pool habitat, and is generally less stable than snowmelt or rain dominated systems (Milner and Petts 1994). These physical characteristics are thought to make glacial rivers unsuitable for fish habitat (Milner and Petts 1994), and high turbidity in glacial systems also contributes to reduced survival and growth of salmonids (Lloyd et al. 1987). The Matanuska River carries tremendous amounts of sediment creating high turbidity, with typical mid-summer peak flows exceeding 30,000 cubic feet per second as it flows to Cook Inlet (USGS gage data). Although the main channels of glacial rivers may be too swift and unstable to provide much fish habitat, off-channel and side channel habitats can provide important spawning and rearing habitat for salmonids in glacial rivers (Lorenz and Eiler 1989; Murphy et al. 1989; Eiler et al. 1992). Recent work on the Matanuska River indicates that juvenile salmonids utilize clearwater side channels for rearing habitat (USGS, Chickaloon Native Village, unpublished data), and side channels are thought to provide much of the available spawning habitat for anadromous salmonids in the Matanuska River watershed (Anderson and Bromaghin 2009).

Five species of Pacific salmon spawn and rear in the Matanuska River and its tributaries. The Alaska Department of Fish and Game (ADF&G) has documented Chinook *O. tshawytscha* and Sockeye salmon in the main-stem Matanuska River and four tributary streams; Coho Salmon in 13 tributary streams and the main-stem Matanuska River; Chum Salmon in the main-stem river and six tributary streams; and Pink Salmon *O. gorbuscha* in the main-stem Matanuska River (Table 1). These distribution data are thought to be incomplete, and little is known about the abundance of these species. The Matanuska River is a significant physical feature of northern Cook Inlet, yet little is known about salmon distribution, timing, or abundance.

Table 1. Distribution of Pacific salmon species in the Matanuska River watershed based on data reported in Johnson and Weiss (2007). p = present; s = spawning; r = rearing.

	Salmon Species				
Waterbody	Chinook	Coho	Chum	Sockeye	Pink
Upper Matanuska River	p	p	s	s	
Caribou Creek			s		
Coal Creek		s			
Tatondan Lake & outlet stream		p		s	
Chickaloon River		r	s		
Lower Matanuska River	p	p,s	p,s	p,s	p
Carbon Creek		s			
Carpenter Creek		s			
Kings River	s	p,s,r	s		
Granite Creek	s	s	s		
Little Granite Creek & tributary		r	s	s,r	
Eska Creek		p	s		
Stream 1220-2098 & tributary		s			
Wolverine Lake & outlet tributary		s,r		p,s	
Wolverine Creek	p	s		p	
Moose Creek	s	s			

Methods

Marking event—Two fish wheels were deployed in 2009 to capture fish in the Matanuska River for our spawning distribution and abundance estimate study. The fish wheels were designed and constructed by ADF&G and each one consisted of two 7.3-m-long aluminum floats connected by two 3.7-m-long aluminum catwalks and a four-spoke, height-adjustable rotating axle. The overall radius of the basket assembly was 2.3 m and we connected two 2.3-m-deep by 1.8-m-wide baskets and two 2.3-m by 1.8-m paddle frames to the axle. The maximum effective fishing radius of the basket assembly was 1.5 m based on the height of the axle above the water. We adjusted the basket assembly to fish as close to the stream bottom as possible to maximize capture efficiency and moved the axle and the fish wheel as necessary to optimize water flow and depth. We attempted to maintain a basket rotation speed between 2 and 3.5 rpm. Captured fish were passed from the basket via an aluminum slide mechanism into a 0.6-m-wide by 2.4-m-long by 1.2-m-deep plywood live box that was perforated with holes and slits on the sides and bottom to allow water circulation and to prevent sediment build up. One live-capture fish wheel was staged for operation on the right bank of the Matanuska River at a constricted site approximately 1.7 km upriver from the bridge on the Old Glenn Highway (Figure 2), the same location used in 2008. The second fish wheel was staged adjacent to the first fish wheel on the river left side, near the Bartko channel mouth.

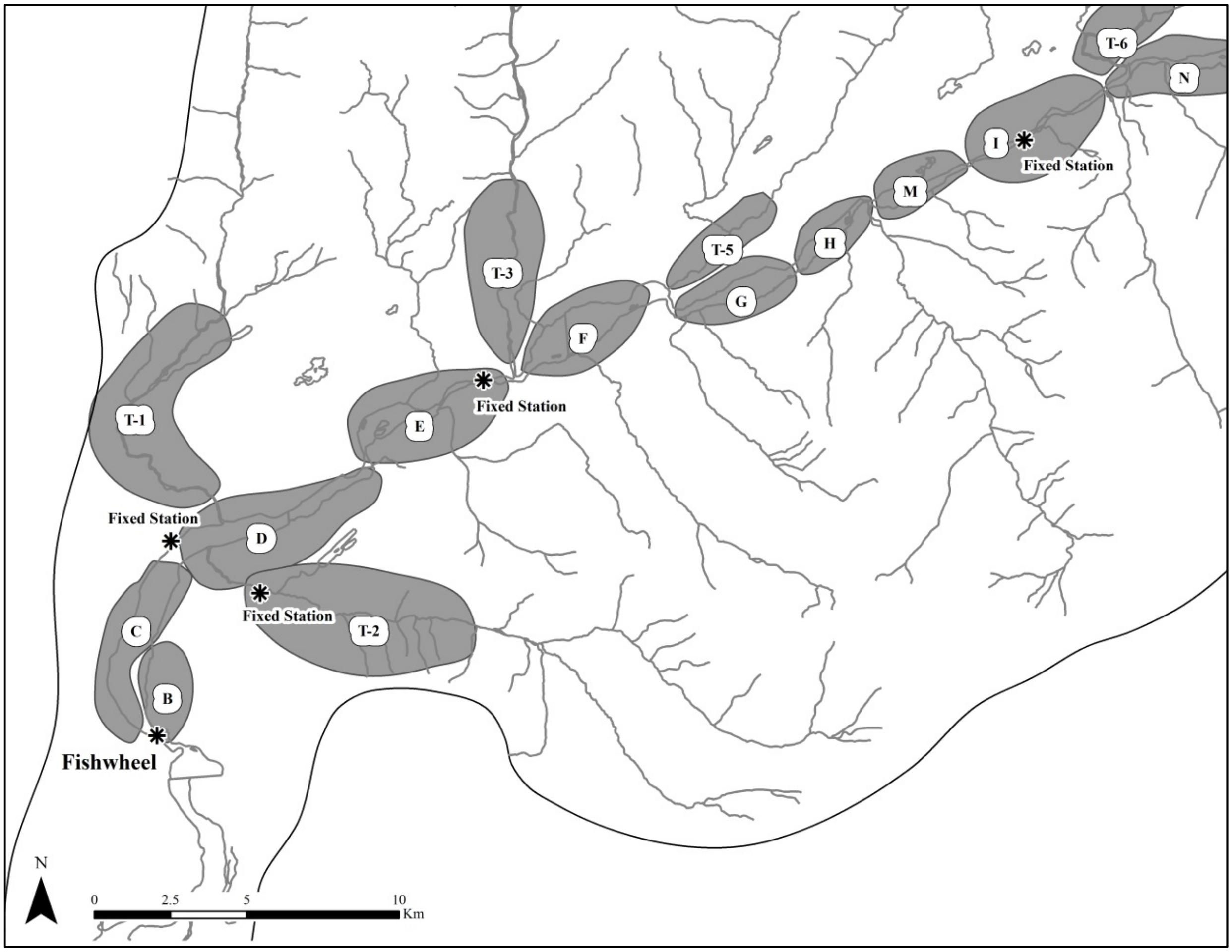


Figure 2. Map with locations of the fish wheel and the four fixed telemetry stations annotated with heavy asterisks, Matanuska River watershed, 2009. The fish wheel was located at coordinate 61.61245, -149.08803 (NAD83).

Captured Chum, Coho, and Sockeye salmon were netted from the live box and either included in the radiotelemetry study or marked to indicate the time strata of its capture. All fish captured at the fish wheel were identified to species and counted. We minimized the time that fish were held in the live tank to limit effects of capture and handling that can lead to increased mortality and changes in migration timing (Bromaghin et al. 2007). Catch per unit effort (CPUE, fish per hour) was calculated by dividing the total number of fish of each species captured by the length of time the fish wheel was operational.

A subset of healthy Chum, Coho, and Sockeye salmon longer than 450 mm (mid-eye to fork of tail length) was tagged with radio transmitters developed by Advanced Telemetry Systems, Inc. (ATS; Model No. F1840B). An additional 15 radio transmitters were reserved to deploy opportunistically in Chinook Salmon, if captured in the fish wheel. Transmitters were encapsulated in a biologically inert polypropylene copolymer and equipped with a 346-mm stainless steel nylon coated whip antenna. Transmitters weighed 26 g, which never exceeded 2% of the fish's body weight (Winter 1983), and measured 56 mm in length and 19 mm in diameter. Radio transmitters were gastrically implanted through the esophagus using methods similar to those used by Burger et al. (1985) and radio-tagged salmon were immediately released into the river. Three hundred radio tags, consisting of 4–25 unique pulse digital codes dispersed over 21 radio frequencies between 160 and 165 MHz, were used. The combination of codes on each frequency allowed for the identification of individual fish. A mortality code was transmitted after 8 hours of inactivity. A matrix of tag frequency codes was developed to select individual tags to deploy to minimize the number of same-frequency tags being deployed on a single day.

Radio transmitters were scheduled for deployment over five strata between 15 June and 31 August for Chum and Sockeye salmon, and five strata between 15 July and 20 September for Coho Salmon (Table 2). In a coarse sense, stratum length was inversely related to the expected abundance of salmon. Assuming that capture and tagging of salmon does not cause them to change their ultimate spawning locations, fish destined for the various spawning locations had an equal probability of capture within each stratum, and assuming tagged fish behaved independently, the binomial probability distribution (Johnson et al. 1992) provides a useful model for the number of fish to be observed at a particular spawning location for each species. Using a binomial model, 19 tagged fish minimally satisfied the criteria of Objectives 2, 3, and 4; therefore, 20 radio transmitters were allocated to each stratum as outlined in Table 2.

Table 2. Sampling strata (time frames) for distribution of Sockeye and Coho salmon radio transmitters, 2009.

Stratum	Strata Dates	Transmitter Allocation
	Chum and Sockeye salmon	
1	15 June – 15 July	20
2	16 – 30 July	20
3	31 July – 9 Aug	20
4	10 – 19 Aug	20
5	20 – 31 Aug	20
	Coho Salmon	
1	15 – 30 July	20
2	31 July – 9 Aug	20
3	10 – 19 Aug.	20
4	20 – 31 Aug.	20
5	1 – 20 Sept	20

Radio transmitters were deployed in as short of a time period as possible within each stratum. This was the most efficient deployment strategy given our limited knowledge of the abundance and run timing of Chum, Coho, and Sockeye salmon at this location. Tagging fish as quickly as we could capture them increased the likelihood that all tags were deployed within each stratum. If the target number of tags could not be deployed within a particular stratum, we attempted to deploy remaining tags in the subsequent stratum. Although pulse sampling admits the possibility that the tagged fish are not fully representative of all fish passing during an entire stratum, any resulting bias was expected to be small and should not compromise our ability to achieve the objectives of this investigation.

Stream flow (discharge, ft^3/s) was monitored by a USGS gaging station at the bridge on the Old Glenn Highway (gage number 15284000). The gage reports staff height and discharge, and historical data are available since 1949.

Biological sampling—All salmon implanted with radio transmitters were measured to the nearest mm (mid-eye to fork of tail), and the sex of the fish was determined from external characteristics when possible. A fin clip was collected from the caudal fin of each radio-tagged fish following protocols of the Conservation Genetics Laboratory. For all radio-tagged fish, three scales from each Sockeye and Coho salmon and one scale from each Chum Salmon was removed from the preferred area on the left side (Jearld 1983). Scales were pressed and aged following the field season by U.S. Fish and Wildlife Service (USFWS) personnel using the standards and guidelines of Mosher (1968). Salmon ages are reported according to the European method described by Jearld (1983) and Mosher (1968), where the number of winters the fish spent in fresh water and in the ocean are separated by a decimal. Age, sex, and length data, along with genetic samples, were also collected from a subsample of fish marked with fin clips or opercula punches in each temporal tagging stratum. Sample size goals were established such that simultaneous 90% confidence interval estimates of the age composition for each stratum have maximum widths of 0.20 (Bromaghin 1993). Calculated sample sizes were increased to account for an expectation that 15% of the scales would be unreadable. The adjusted sample size goals for 2009 were n = 128 for Sockeye and Chum salmon (3 major age categories) and n = 75 for Coho Salmon (2 major age categories).

Recapture Event—Carcass surveys were conducted opportunistically in spawning areas that were accessible by foot or raft. Carcass surveys were conducted in clearwater side channels, and marked and unmarked carcasses of each species were tallied. Ground surveys were conducted with a crew of two observers beginning in mid-August and ending in late October. Surveys continued throughout the spawning period. Surveys began at the mouth of selected clearwater side channels and proceeded upstream, covering all areas accessible to adult salmon. Surveyors wore polarized glasses to reduce water surface glare. All carcasses were identified to species and examined for marks. The following data were recorded for each ground survey: side channel name; GPS coordinates (NAD83 datum); count of marked and unmarked fish of each species, including numbers of each of the five marks; time; water clarity (excellent, good, or poor); lighting conditions (sun, partial overcast, overcast); and wind generated surface turbulence (calm, moderate, rough). If there was any uncertainty about whether a fish was marked, it was excluded from both counts. We believed that all carcasses in the survey area were visible and accessible to survey crews. Once a carcass had been sampled, the caudal fin was removed to avoid double counting in future surveys. Otoliths were collected from Sockeye salmon carcasses for a separate microchemistry analysis conducted by USGS.

Radio Tracking—Radiotelemetry receivers and data loggers manufactured by ATS were used for all mobile and fixed station tracking to automatically identify and record fish movements. Three fixed receiver stations were established at the same sites used in 2008, and a fourth site was established on Wolverine Creek near its confluence with the Matanuska River in 2009 (Figure 2). The new station on Wolverine Creek was chosen based on the large number of transmitters located in that watershed in 2008 and to help discriminate signals in the Moose Creek/Wolverine Creek Mouth area. The lowest fixed site was located below the confluence of Moose and Wolverine creeks, a second site was on the main-stem Matanuska River near Sutton, and a third site was on the main-stem Matanuska River below the mouth of the Chickaloon River. Fixed receiver stations included either a single data logging receiver or a separate receiver and data logger, a single Yagi antenna, antenna mast, 12-volt deep cycle battery, solar panel, voltage regulator, and strongbox. Data from fixed receiver stations were downloaded weekly to a notebook computer throughout the project.

Mobile surveys were employed to identify specific spawning locations in the Matanuska River and its tributaries. Aerial surveys were scheduled biweekly from mid-August through November as fish migrated to their spawning areas. Aerial surveys were conducted from fixed-wing aircraft equipped with two H-antennas, one mounted on each wing strut. Aerial surveys were conducted at approximately 200–300 m above ground along the Matanuska River and tributary watersheds. A global positioning system (GPS) built in to the data logging receiver was used during all mobile tracking surveys to identify the latitude and longitude coordinates of each located fish. Ground-based tracking followed aerial surveys to help refine spawning areas. Ground-based tracking was conducted from rafts, highway vehicles, all-terrain vehicles (ATV), and on foot.

Data Analysis

Marking event—Hourly fish wheel catches by species were entered each day into a spreadsheet. Run timing was estimated for each species based on CPUE over the course of the field season. We also investigated whether there were relationships between CPUE and river discharge. Age, sex, and length characteristics of Chum, Coho, and Sockeye salmon were summarized.

Abundance and run timing—Systematic capture heterogeneity was a concern for mark-recapture data. Thus, we implemented a time-stratified Lincoln-Petersen estimator in a Bayesian framework in order to explicitly model tag availability for detection and tag detection separately, thereby accommodating potential capture heterogeneity induced during marking or recapture sampling (see Sethi and Tanner 2013 for details). Primary features of the model include: *i*) deconstruction of the probability of capture at recovery sites into availability for detection and probability of detection, *ii*) time stratification of parameters, and *iii*) specification of both “fixed” and “random” effects parameterizations of the model. The assumptions of the time-stratified Lincoln-Petersen estimator as applied in this study are as follows: 1) additions to the population between the release and recovery site are not possible, and any mortality or emigration between the release and recovery sites is randomly distributed throughout the marked and unmarked population, 2) tags are not shed or misidentified, 3) all animals (i.e., marked and unmarked) that arrive at a given recovery stratum have the same probability of being detected, 4) all animals that pass the release site in a given stratum have the same probability of arriving at each of recovery strata, and finally 5) fish from the same release strata behave independently with respect to movement and fish in the same recovery strata are detected independently.

Radiotelemetry—Radiotelemetry information collected with various tracking methods were integrated into one database that archived the dates, locations, and fate of radio-tagged salmon. Locations were recorded as latitude and longitude coordinates and displayed on a geographic coverage of the Matanuska River watershed using ArcMap® software.

Each radio-tagged salmon was assigned 1 of 6 possible fates based on information collected from mobile and fixed radio receivers (Table 3; Figure 3). Spawning locations were defined based on the tracking results. A tagged fish that migrated to a particular location and remained for an extended period of time without activating the mortality sensor was considered to have identified a potential spawning location. An area in which two or more tagged fish were detected was considered to be a confirmed spawning location with reasonable certainty for the purposes of this investigation. Fish assigned a fate of harvested or dead/regurgitated were excluded from the sample. Fish whose spawning location could not be determined with reasonable certainty were placed into an unknown category.

Table 3. Fates assigned to radio transmitters for analysis purposes (see Figure 3).

Fate	Description
Lower Watershed Spawner	A fish that spawns in the Matanuska River or its tributaries between spawning enclaves B and D, including enclaves T-1 and T-2.
Middle Watershed Spawner	A fish that spawns in the Matanuska River or its tributaries between spawning enclaves E and I, including enclaves T-3 and T-5.
Upper Watershed Spawner	A fish that spawns in the Matanuska River or its tributaries in spawning enclave N or above, including enclaves T-6 and T-4.
Dead/Regurgitated	A fish that did not complete its spawning migration because it either died or regurgitated its radio transmitter.
Harvested	A fish harvested in the sport fishery.
Unknown	A fish that has a loss of contact with mobile or fixed radio receivers or cannot be assigned another fate with reasonable certainty.

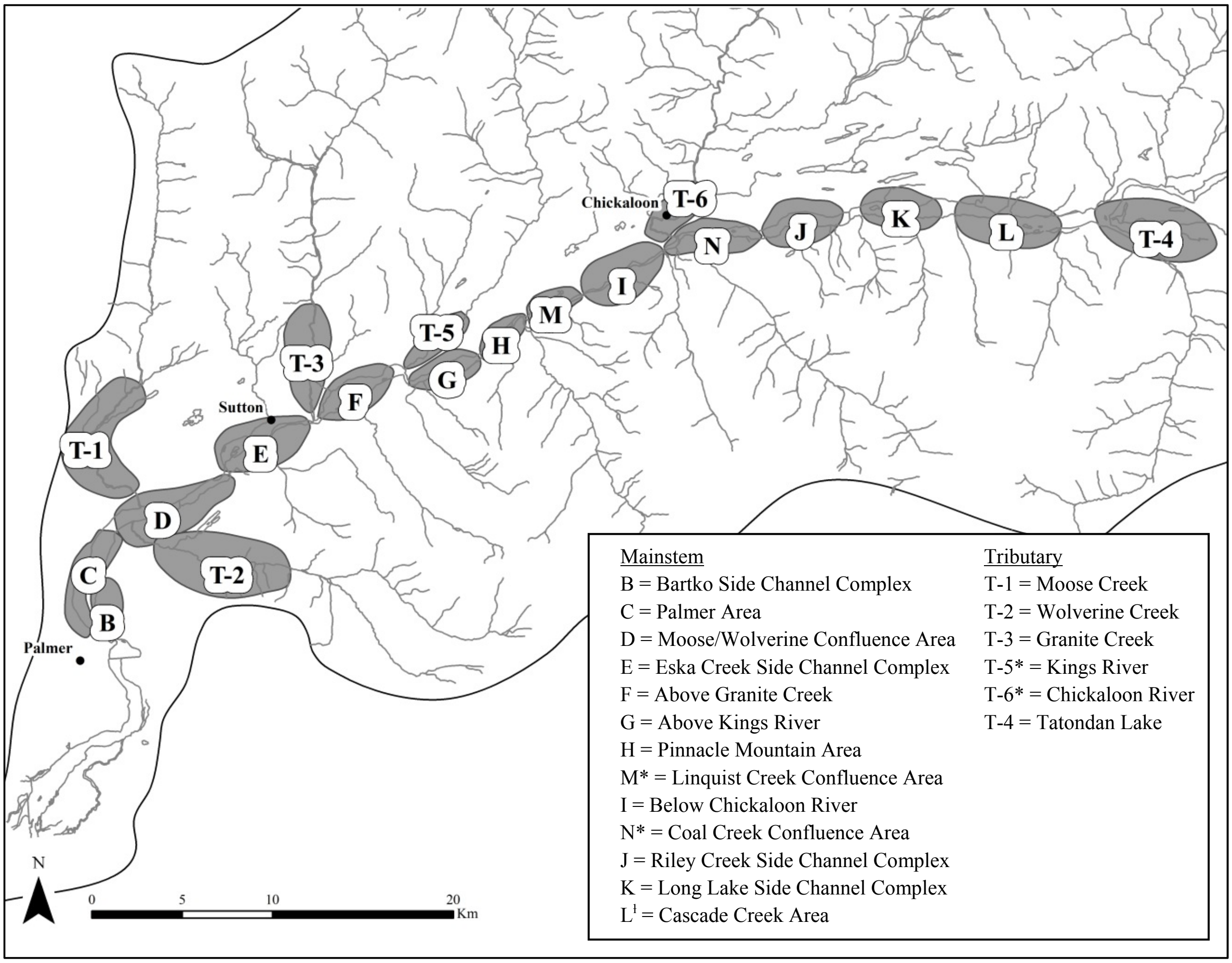


Figure 3. Map of the designated spawning enclaves within the Matanuska River watershed. * Enclaves were added in 2009 to supplement those designated in 2008. [1] Enclave L remains in the same position as 2008, but was extended and re-described for 2009.

Results

Marking event and run timing—For our marking event, only the fish wheel on the river-right bank was operated. Changes in stream bed morphology from 2008 affected our ability to effectively or safely position, anchor, and operate the fish wheel along the left river bank (Bartko side) in 2009. We operated the river right fish wheel for 538.6 hours from 24 June through 12 September, for a total of 64 days. High water events delayed operation of the fish wheel for 6 days within the season. Fish wheel run time varied between approximately 6-12 hours per day during daylight hours, depending on river conditions. Capture effort for tagging was approximately standardized across time, and catch per unit effort at the marking sites provides an index for species-specific run timing. A total of 433 Chum, 424 Coho, and 318 Sockeye salmon were captured (Figure 4; Appendix 1), with 50th percentile passage dates of 21 August for Chum, 20 August for Coho, and 18 August for Sockeye salmon. Chinook Salmon were captured on the first day of fish wheel operation (n = 9 on 24 June), but the first day of capture for Sockeye Salmon (n = 1) was not until 14 July, 23 July for Coho Salmon (n = 1), and 29 July for Chum

Salmon (n = 2; Figure 5). Captured salmon received unique marks by strata (Chum: n = 431; Coho: n = 415; Sockeye: n = 316). Other species captured included Pink Salmon *O. gorbuscha* (n = 1), Rainbow Trout *O. mykiss* (n = 4) and char *Salvelinus* spp. (n = 1), all of which were captured 15–28 August.

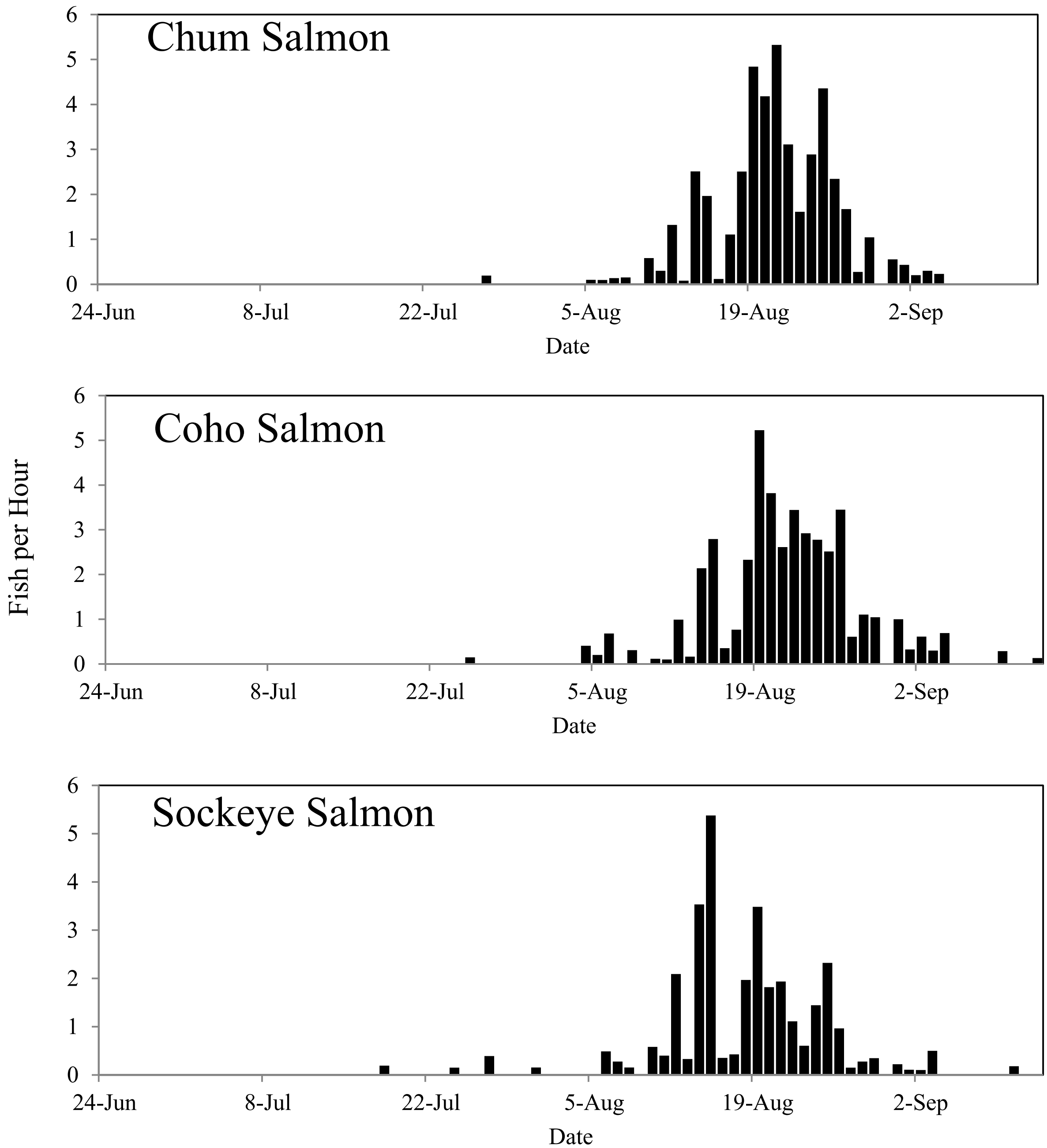


Figure 4. Catch per unit effort for Chinook, Chum, Coho, and Sockeye salmon expressed as the number of fish captured per hour at the Matanuska River fish wheel, operated 24 June – 12 September 2009.

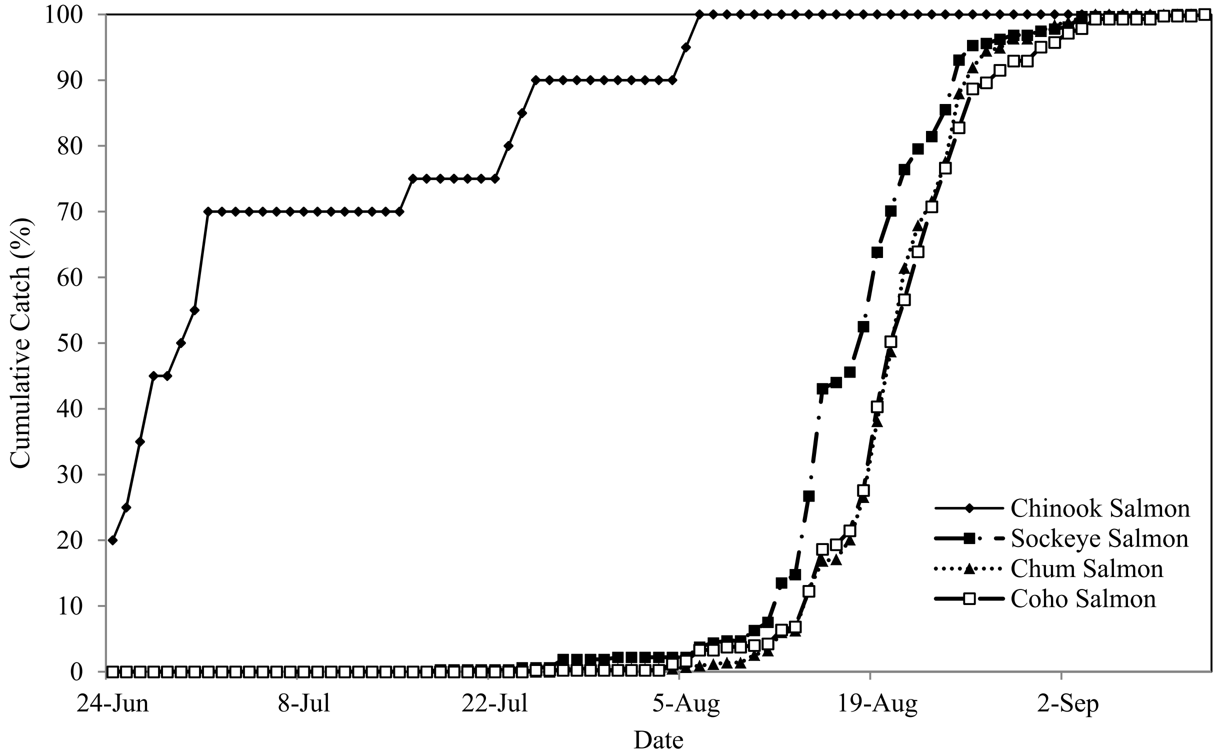


Figure 5. Cumulative total catch of Chinook (*n* = 20), Chum (*n* = 433), Coho (*n* = 424), and Sockeye (*n* = 318) salmon caught in the Matanuska River, 2009.

Mean daily stream discharge peaked at15,850 ft^3/s on 11 July and exceeded the historical values on six different occasions while the fish wheel was in operation (Figure 6).

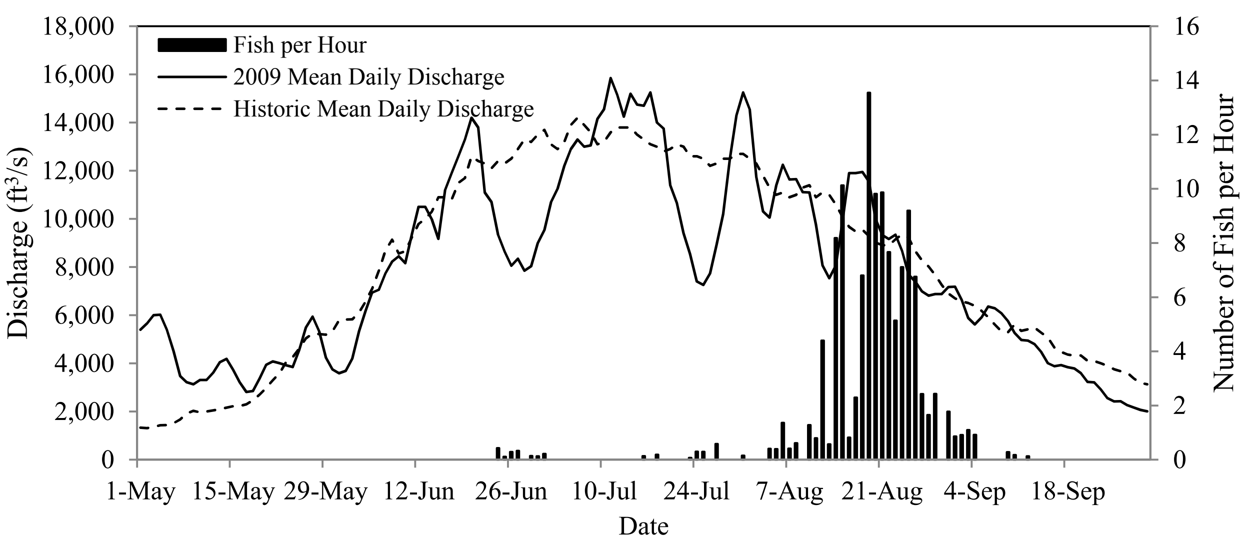


Figure 6. Summary of fish wheel catch per unit effort in relation to the mean daily discharge on the Matanuska River near Palmer, Alaska, 2009 and historical (1949 to 2007) daily discharge, USGS gage number 15284000. The fish wheel was operated 24 June – 14 September 2009.

Biological sampling—Age, sex, and length data were collected from 20 Chinook Salmon from 30 June to 6 August; 433 Chum Salmon from 27 July to 4 September; 424 Coho Salmon from 25 July to 12 September; and 318 Sockeye Salmon from 18 July to 10 September. Of the fish that could be reliably identified to sex at the capture event, 46% of the Chinook Salmon were female, as were 47% of the Chum Salmon, 51% of the Coho Salmon, and 55% of the Sockeye Salmon (Table 4).

Six age classes were identified from 10 Chinook Salmon scale samples in 2009, ranging from 1.2 to 2.4, with 3 of those being age 2.2. Due to reabsorption, scales from 5 other Chinook Salmon could not be read. Lengths of Chinook Salmon sampled in 2009 ranged from 520 to 925 mm (Table 5). Six age classes were identified from 218 Chum Salmon scale samples. Age-0.3 fish made up the majority of the Chum Salmon run (63%), with age 0.4 making up another 24% of the run. Length of Chum Salmon sampled in 2009 ranged from 500 to 680 mm (Table 6). Eight age classes were identified from 239 Coho Salmon scale samples. Age-2.1 fish made up most of the Coho Salmon run (81%), with age 1.1 making up another 10% of the run. Length of Coho Salmon sampled ranged from 420 to 650 mm (Table 7). Eight age classes were identified from 275 Sockeye Salmon scale samples. Age-1.2 fish made up most of the Sockeye Salmon run (40%), with ages 2.2 and 1.1 making up another 40% of the run (21% and 19%, respectively. Length of Sockeye Salmon sampled ranged from 480 to 680 mm (Table 8).

Table 4. Number[a] and proportions of female and male Chinook, Chum, Coho, and Sockeye salmon sampled at the Matanuska River, 2009.

Sex	*n*[a]	%
	Chinook Salmon	
Female	6	43
Male	8	57
Total	*14*	
	Chum Salmon	
Female	155	47
Male	176	53
Total	*331*	
	Coho Salmon	
Female	131	51
Male	124	49
Total	*255*	
	Sockeye Salmon	
Female	171	55
Male	142	45
Total	*313*	

[a]Number sampled does not include fish whose sex could not be determined (*n* = 6 for Chinook; *n* = 102 for Chum; *n* = 169 for Coho; and *n* = 5 for Sockeye salmon).

Table 5. Mean mid-eye to fork length (mm), SE, range, and sample size by age[a] of Chinook Salmon sampled at the Matanuska River fish wheel, 2009.

Age	1.2	1.3	1.4	1.5	2.2	2.4
			Female			
Mean	-	520	830	925	-	908
SE	-	-	-	-	-	-
Minimum	-	520	830	925	-	908
Maximum	-	520	830	925	-	908
n	0	1	1	1	0	1
			Male			
Mean	615	-	-	-	600	-
SE	-	-	-	-	-	-
Minimum	570	-	-	-	600	-
Maximum	660	-	-	-	600	-
n	2	0	0	0	2	-

[a]Number sampled does not include fish whose length or age could not be determined (n = 10).

Table 6. Mean mid-eye to fork length (mm), SE, range, and sample size[a] by age of Chum Salmon sampled at the Matanuska River fish wheel, 2009.

Age	0.2	0.3	0.4	0.5	1.2	1.3
				Female		
Mean	548	576	579	598	-	570
SE	10	3	5	17	-	6
Minimum	510	500	530	550	-	560
Maximum	630	630	650	620	-	580
N	11	75	29	4	0	3
				Male		
Mean	547	589	570	-	530	590
SE	15	5	8	-	-	20
Minimum	500	515	480	-	530	570
Maximum	620	680	660	-	530	610
N	7	62	23	0	1	2

[a]Number sampled does not include fish whose length or age could not be determined (n = 215).

Table 7. Mean mid-eye to fork length (mm), SE, range, and sample size[a] by age of Coho Salmon sampled at the Matanuska River fish wheel, 2009.

Age	1.1	1.2	1.3	2.1	2.2	2.3	3.1	3.2
				Female				
Mean	563	580	530	544	503	550	-	-
SE	5	-	-	4	27	-	-	-
Minimum	540	580	530	425	420	550	-	-
Maximum	595	580	530	620	592	550	-	-
N	10	1	1	103	7	1	0	0
				Male				
Mean	520	600	-	556	558	590	538	530
SE	11	-	-	5	22	-	31	-
Minimum	470	600	-	424	500	590	490	530
Maximum	600	600	-	650	620	590	630	530
N	13	1	0	90	5	1	4	1

[a]Number sampled does not include fish whose length or age could not be determined (n = 185).

Table 8. Mean mid-eye to fork length (mm), SE, range, and sample size[a] by age of Sockeye Salmon sampled at the Matanuska River fish wheel, 2009.

Age	0.3	1.1	1.2	1.3	1.4	2.1	2.2	2.3
				Female				
Mean	500	510	530	542	540	520	520	563
SE	-	11	5	8	-	14	8	8
Minimum	500	430	410	495	540	460	440	555
Maximum	500	550	620	610	540	578	600	570
n	1	11	75	15	1	8	35	2
				Male				
Mean	-	480	538	565	-	471	521	610
SE	-	10	9	5	-	11	16	-
Minimum	-	380	420	560	-	350	370	610
Maximum	-	630	635	570	-	540	620	610
n	0	40	35	2	0	23	21	1

[a]Number sampled does not include fish whose length or age could not be determined (n = 42).

Recapture events—For the recapture event, we conducted opportunistic carcass surveys at known spawning locations that were accessible by foot or raft (Figure 7). In total, 48 carcass surveys for Chum, Coho, and Sockeye salmon were conducted over 34 days from 26 August to 16 October. Within the lower watershed, 25 survey events were completed in enclaves B, C, D, T-1, and T-2; 19 survey events were conducted in enclaves E, F, G, and T-5; and four survey events done in enclaves J and T-5. A total of 11,223 carcasses were identified to species and examined for strata-specific marks (Table 9; Appendix 2).

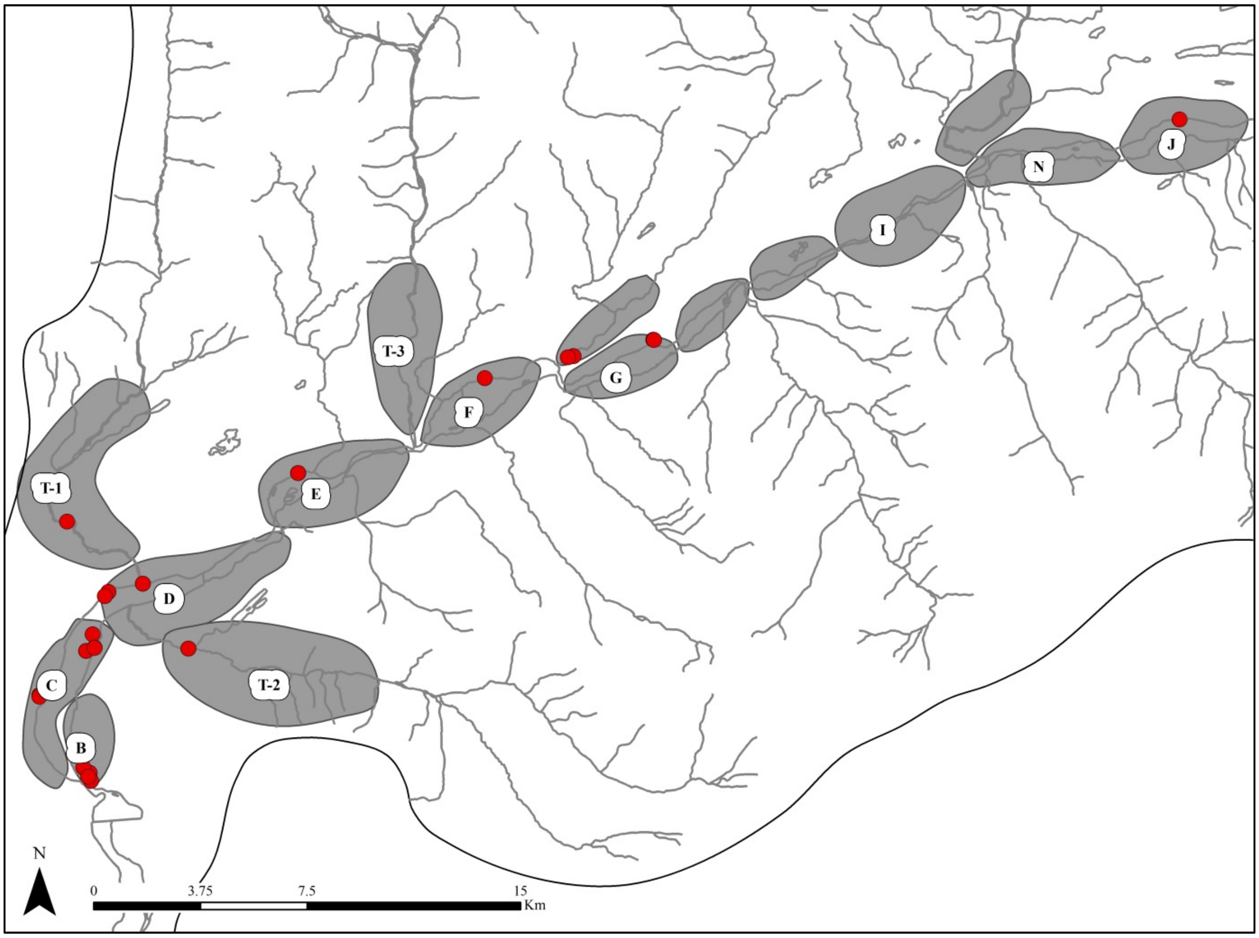


Figure 7. Map of opportunistic carcass survey locations, symbolized by red circles, conducted 26 August – 16 October within the Matanuska River drainage, 2009.

Table 9. Mark and recovery data for Matanuska River Pacific salmon used to calculate abundance estimates, 2009 (from Sethi and Tanner 2013).

Chum		Tag recoveries by recovery stratum		
Marking stratum	Tag releases	8.26.09 - 9.18.09	9.19.09 - 10.1.09	10.2.09 - 10.16.09
8.5.09 - 8.8.09	4	2	0	0
8.9.09 - 8.15.09	66	9	3	2
8.16.09 - 8.22.09	221	17	11	3
8.23.09 - 9.4.09	139	5	4	6
	Unmarked captures:	*1888*	*2800*	*2060*
Coho		Tag recoveries by recovery stratum		
Marking stratum	Tag releases	8.26.09 - 9.18.09	9.19.09 - 10.1.09	10.2.09 - 10.16.09
8.4.09 - 8.8.09	12	1	0	2
8.9.09 - 8.15.09	60	0	0	5
8.16.09 - 8.22.09	190	2	4	13
8.23.09 - 9.4.09	149	1	3	9
	Unmarked captures:	*42*	*295*	*676*
Sockeye		Tag recoveries by recovery stratum		
Marking stratum	Tag releases	8.26.09 - 9.18.09	9.19.09 - 10.1.09	10.2.09 - 10.16.09
7.27.09 - 8.1.09	5	1	1	1
8.2.09 - 8.8.09	8	0	1	3
8.9.09 - 8.15.09	121	12	12	13
8.16.09 - 8.22.09	116	6	14	5
8.23.09 - 9.3.09	63	1	2	5
	Unmarked captures:	*749*	*1438*	*1096*

Mark-recapture abundance—The time-stratified Lincoln-Peterson abundance models highlighted capture heterogeneity for Chum and Coho salmon, resulting in model averaged abundance estimates that were 17% and 8% higher, respectively, than the potentially biased pooled Lincoln-Petersen estimates. The time-stratified model averaged estimate for Chum Salmon spawner abundance was 54,720 salmon upstream of the capture site, with a 95% credibility interval of 40,860 to 79,073 fish (also see Sethi and Tanner 2013). The model averaged estimate of spawner abundance for Coho Salmon upstream of the capture site was estimated at 11,430 with a 95% credibility interval of 8,170 to 17,011. The model averaged estimate of spawner abundance for Sockeye Salmon upstream of the capture site was estimated at 13,750 with a 95% credibility interval of 10,470 to 18,010.

Radiotelemetry—All four fixed telemetry stations were operational in time to capture upstream movement by radio-tagged salmon. Fixed stations were operated 30 June – 22 October, with the lower three stations downloaded 11 times through the season and the single highest fixed station downloaded 5 times. Three float trip searches were conducted between 15 September and 14 October and seven aerial searches were conducted between 22 August and 15 October.

A total of 291 radio transmitters were deployed in healthy Chum, Coho, and Sockeye salmon between 24 June and 3 September 2009 (Table 10). Of the 291 radio-tagged fish, 257 fish were successfully tracked to spawning areas, 11 fish were determined to have regurgitated their tags or died, and 23 fish were not located with sufficient confidence to determine a spawning fate (Table

11). No radio-tagged fish were reported as harvested in 2009. Over 75% of Chum (*n* = 68) and 82% of Sockeye salmon (*n* = 95) selected spawning locations in the main-stem braid plain of the Matanuska River, whereas 54% of Coho Salmon (*n* = 45) selected spawning locations in tributary watersheds (Tables 12, 13; Appendices 3 - 5). Of the six identified tributary enclaves, the Wolverine Creek (T-2) and Tatondan Lake (T-4) enclaves were more heavily used by radio-tagged fish (8% each of the combined species; Table 12).

Table 10. Distribution of radio transmitters by species and tagging strata for Chum, Sockeye and Coho salmon in the Matanuska River, 2009.

Stratum	Strata Dates	Transmitter Deployment	
		Chum Salmon	*Sockeye Salmon*
1	15 June – 15 July	1	6
2	16–30 July	4	7
3	31 July – 9 Aug	48	60
4	10–19 Aug	19	24
5	20–31 Aug	19	19
		Coho Salmon	
1	15–30 July	1	
2	31 July–9 Aug	9	
3	10–19 Aug.	13	
4	20–31 Aug.	32	
5	1–20 Sept	29	

Only 14 Chinook Salmon received radio tags early in the field season (24 June – 3 July; Appendix 6). Of these, two fish either died or regurgitated their radio tags and 12 Chinook Salmon spawned in the lower river, primarily using the Moose Creek enclave area.

Table 11. Number (percentages in parentheses) of transmitters for each salmon species assigned to fate categories within the Matanuska River drainage, 2009.

Fate	Chinook	Chum	Coho	Sockeye	All CH, CO, S*
Lower Watershed Spawner	12 (86)	59 (65)	42 (50)	38 (33)	139 (48)
Middle Watershed Spawner	0	16 (18)	15 (18)	44 (38)	75 (26)
Upper Watershed Spawner	0	0	19 (23)	24 (21)	43 (15)
Unknown	0	11 (12)	4 (5)	8 (7)	23 (8)
Dead/Regurgitation	2 (14)	5 (5)	4 (5)	2 (2)	11 (4)
Total	14	91	84	116	291

*CH = Chum Salmon; CO = Coho Salmon; S = Sockeye Salmon

Table 12. Distribution of radio-tagged salmon identified by spawning enclaves within the Matanuska River, 2009.

Spawning Locations	Chinook		Chum		Coho		Sockeye		All CH, CO, & S	
	2008	2009	2008	2009	2008	2009	2008	2009	2008	2009
<u>*Lower Watershed*</u>										
B	-	0	12	13	12	6	15	10	39	29
C	-	4	1	29	3	3	2	20	6	52
T-1	-	8	3	3	3	5	0	1	6	9
T-2	-	0	0	2	25	21	1	0	26	23
D	-	0	26	12	16	7	21	7	63	26
Subtotal	*-*	*12*	*42*	*59*	*59*	*42*	*39*	*38*	*140*	*139*
<u>*Middle Watershed*</u>										
E	-	0	2	6	4	9	17	14	23	29
T-3	-	0	1	2	2	0	0	2	3	4
F	-	0	0	7	6	1	7	4	13	12
T-5*	-	0	-	0	-	1	-	1	-	2
G	-	0	1	1	9	2	4	21	14	24
H	-	0	0	0	5	1	7	1	12	2
M*	-	0	-	0	-	1	-	1	-	2
I	-	0	0	0	2	0	0	0	2	0
Subtotal	*-*	*0*	*4*	*16*	*28*	*15*	*35*	*44*	*67*	*75*
<u>*Upper Watershed*</u>										
T-6*	-	0	-	0	-	1	-	0	-	1
N*	-	0	-	0	-	0	-	2	-	2
J	-	0	0	0	2	1	5	10	7	11
K	-	0	0	0	0	0	2	1	2	1
L	-	0	0	0	1	0	1	4	2	4
T-4	-	0	0	0	45	17	0	7	45	24
Subtotal	*-*	*0*	*0*	*0*	*48*	*19*	*8*	*24*	*56*	*43*
Total	-	12	46	75	135	76	82	106	263	257

* Enclaves added in 2009 to supplement those designated in 2008.

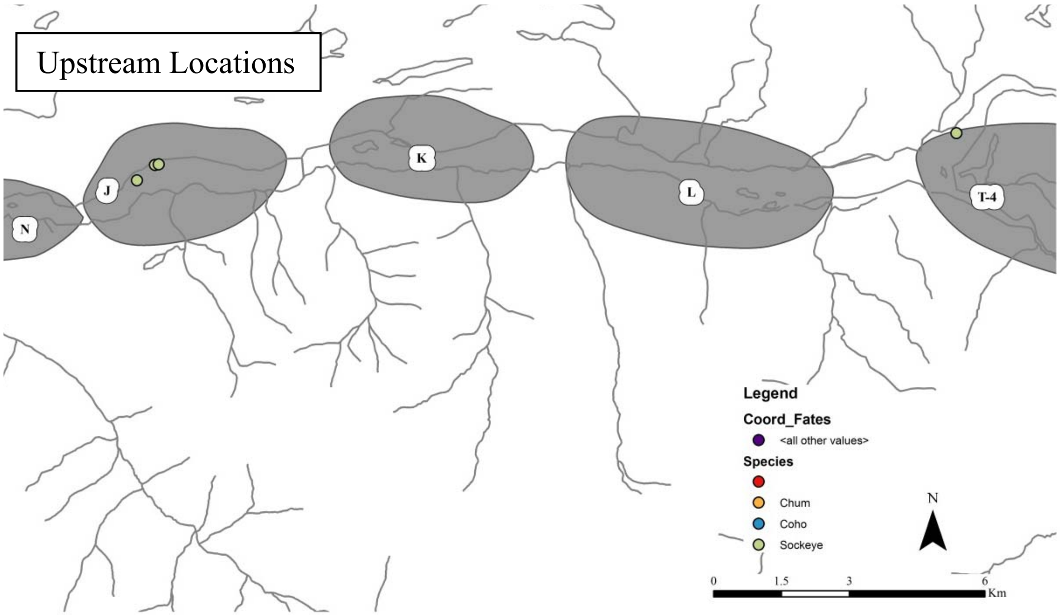
Table 13. Number of radio-tagged Chum, Coho, and Sockeye salmon tracked by strata to spawning enclaves in the Matanuska River drainage, 2009.

	Spawning Location		
Tagging Stratum	Lower Watershed	Middle Watershed	Upper Watershed
		Chum Salmon	
1	1	0	0
2	1	3	0
3	27	10	0
4	14	2	0
5	16	1	0
		Coho Salmon	
1	1	0	0
2	8	1	0
3	5	4	3
4	13	4	11
5	15	6	5
		Sockeye Salmon	
1	2	3	1
2	0	4	3
3	15	29	14
4	9	6	5
5	12	2	1

Note: All Chinook salmon were radio-tagged during tagging stratum 1 (n = 14).

Persistent clearwater side channels were identified in the Matanuska main stem by the U.S. Geographical Survey in 2007 (Curran et al. 2011). Through mobile tracking (foot and raft) at accessible locations, we were able to confirm that 13 groups of the USGS delineated side channels were selected for spawning by radio-tagged fish. Radio-tagged Chum Salmon (n = 22, 15% of spawners) were tracked to 7 of the USGS-identified channels in enclaves B – G. Radio-tagged Coho Salmon (n = 4, 3% of spawners) were tracked to 3 of the USGS-identified channels in enclaves D, G, and J. Radio-tagged Sockeye Salmon (n = 52, 25% of spawners) were tracked to 12 of the USGS-identified channels in all enclaves except enclaves H, M, I, and K.

A radio-tagged fish was considered to have a fine scale spawning fate designated if it was either 1) tracked and located to a gain of 1 with signal strength 100 or greater during time periods of active spawning, or 2) visually sighted amongst spawning activity or at redds. Using these criteria, we confidently identified 24 specific spawning sites for Chum, 7 sites for Coho, and 40 sites for Sockeye salmon within foot accessible areas of the spawning enclaves (Figure 8; Appendix 7).



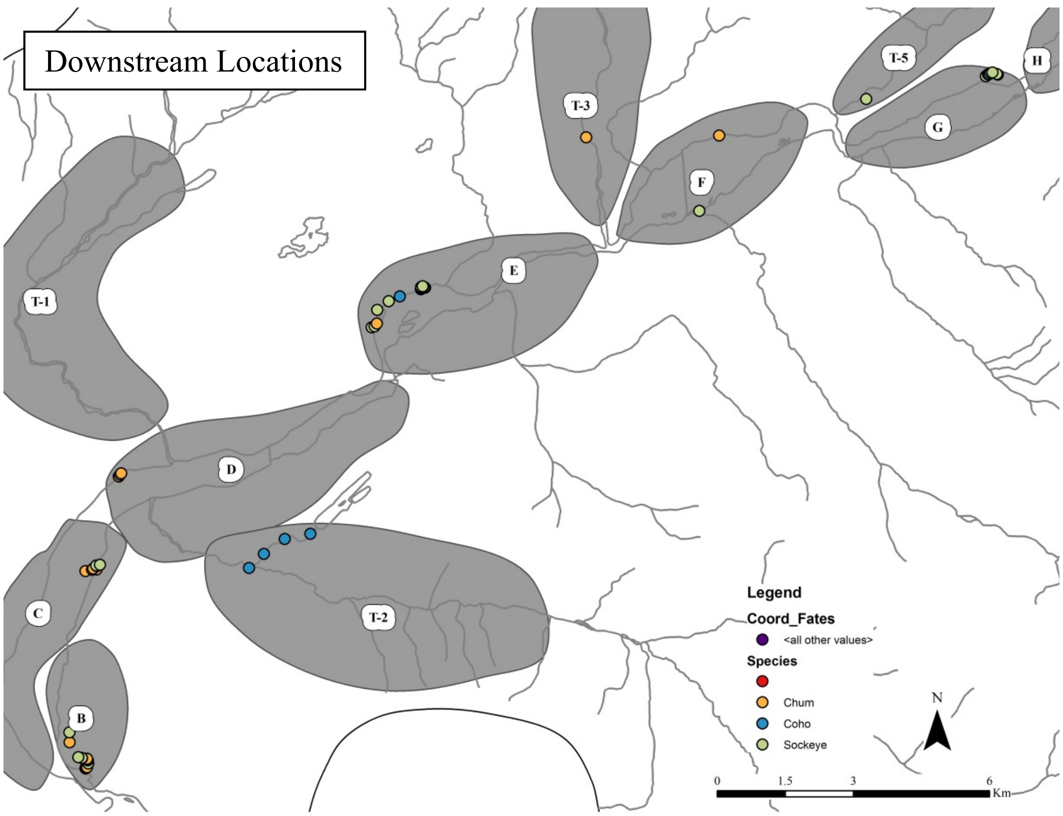


Figure 8. Fine-scale spawning locations for individual fish (Chum Salmon *n* = 24; Coho Salmon *n* = 7; Sockeye Salmon *n* = 40) radio tracked within accessible upstream areas (above) and downstream areas (below) of the Matanuska River drainage, 2009.

Discussion

We were successful in operating a fish wheel to capture migrating salmon on the Matanuska River in 2009, and we believe that we effectively captured both tails of the spawning runs, from early to late, for Chum, Coho, and Sockeye salmon. We began operating the fish wheel on 24 June, and while we captured a few Chinook Salmon on the first day, we did not capture Sockeye Salmon until mid-July or Chum or Coho salmon until late-July, which leads us to believe we captured the early run timing for those species. We continued to operate the fish wheel until 12 September, a full 2 weeks beyond the point where we reached the 95th percentile for capture of all three of the species of interest (Appendix 1). Our run timing for Sockeye Salmon was about 3 weeks later compared to Fish Creek in upper Cook Inlet, but was consistent with the timing reported from the Matanuska River in 2008. Run timing for Coho Salmon observed at the fish wheel occurred within a week of the runs reported for Deshka River and Fish Creek, but was nearly 2 weeks earlier than the Little Susitna River; whereas in 2008, Coho Salmon runs on the Matanuska River were markedly later than those of the Deshka River (Table 14; Anderson and Bromaghin 2009). No escapement project in upper Cook Inlet reported Chum Salmon run timing in 2008 or 2009.

Table 14. Summary of the 50th percentile passage dates and spawning population estimates[b]/counts[c] (*N*) for Chinook, Chum, Coho, and Sockeye salmon in northern Cook Inlet watersheds, 2009.

		Chinook Salmon		*Chum Salmon*		*Coho Salmon*		*Sockeye Salmon*	
Watershed	Method	Date	*N*	Date	*N*	Date	*N*	Date	*N*
Matanuska River	Fish wheel[b]	-	-	21-Aug	54,720	20-Aug	11,430	18-Aug	13,750
Deshka River[a]	Weir[c]	20-Jun	11,960	-	-	15-Aug	27,348	-	-
Little Susitna River[a]	Weir[c]	-	-	-	-	3-Sep	9,523	-	-
Fish Creek[a]	Weir[c]	-	-	-	-	24-Aug	8,214	30-Jul	83,480

[a]Alaska Department of Fish and Game, unpublished data.
[b]Abundance estimated using mark-recapture data described in this report.
[c]Fish count data.
'-' is no data.

The streambed morphology of the river at the capture site, i.e., shifting substrate and sediment deposition, affected the fish wheel placement on the river left bank (Bartko side), preventing us from operating both fish wheels concurrently, one on each side of the river. In 2008, Anderson and Bromagin (2009) operated a fish wheel on the left bank, but had to move their fish wheel to the river right side because low water flow did not support fish wheel spinning at a consistent and effective fishing rate after 6 August 2008.

We suspect that the right bank location provided an effective site to intercept migrating salmon. It is unlikely that the upriver spawning distribution of salmon on the Matanuska River was related to bank of capture because the main channel of the river is less than 100 m wide at our fish wheel capture site. In-season changes in the streambed morphology and river discharge affected the fish wheel efficiency on the right bank; however, we were able to compensate on most days by adjusting the axle height or fish wheel position along the bank. We were limited in safe and effective alternate locations to place the fish wheel.

Of the 20 Chinook Salmon captured in the fish wheel, only 10 provided legible scales. We only caught the end of the run for migrating Chinook Salmon, and as a result, reabsorption affected our ability to collect and age scales from Chinook Salmon. We were unable to collect intact scales from 5 of the 20 fish, and another 5 fish had scales that were unreadable. Due to the small sample size, we cannot adequately describe the age composition of Chinook Salmon in the Matanuska River.

In 2008, Anderson and Bromaghin (2009) were unable to collect enough readable scales to adequately describe the age composition of radio-tagged Chum Salmon. In 2009, we were able to collect readable scales from almost half of our captured Chum Salmon, allowing us to determine that most of the Chum Salmon captured at the fish wheel did not rear in fresh water, but instead emigrated out to a marine environment after emergence. Contrary to the Chum Salmon life history, most adult Sockeye Salmon captured at the fish wheel spent at least one winter in fresh water as juveniles and most Coho Salmon spent 2 years in fresh water before emigrating out to sea. Similar freshwater rearing ages were reported for Sockeye and Coho salmon captured in 2008 (Anderson and Bromaghin 2009).

The Lincoln-Peterson time-stratified estimators allowed for capture heterogeneity in the observed data. However, the complexity of the models raised several disadvantages relative to the straightforward pooled Lincoln-Petersen estimator. First, Bayesian implementation of time-stratified models requires knowledge of complex programs to implement MCMC algorithms. Second, Bayesian model fitting is time consuming, requiring custom programming of model structures and validation procedures, as well as substantial computing time to run multiple parallel chains in an MCMC routine. Finally, the more complicated time-stratified models result in less precise, albeit potentially more accurate, abundance estimates compared to the simple pooled estimator. The pooled estimator on the other hand is trivial to calculate. For these reasons, design-based approaches to satisfy the Lincoln-Petersen model assumptions and control for capture heterogeneity in the field, such as attempts to tag in proportion to abundance (e.g., Sethi and Tanner 2014) or conducting separate abundance estimates stratified by sex or some other demographic characteristic associated with tagging or recovery behavior, will continue to be important tools to estimate salmon abundance. In cases where the sources of capture heterogeneity are unknown, and when field-based controls of capture heterogeneity are not feasible, or when accuracy is of primary importance (e.g., when ground-truthing an abundance index such as sonar counts for salmon), more complicated time-stratified estimators are a good choice.

When we compared our abundance estimates of salmon to fish counts reported in other drainages, the portion of upper Cook Inlet Sockeye Salmon spawning in the Matanuska River was a fraction of what was counted at Fish Creek (Table 16). Although not reported for 2009, the Yentna River sonar estimate in 2008 (ADF&G, unpublished data) was more than six times higher than our Sockeye Salmon estimate for 2009. The Coho Salmon abundance estimate for the Matanuska River was higher than the runs counted on either Little Susitna River or Fish Creek, but was approximately one-half of the escapement counted in the Deshka River (Table 16). No escapement data in upper Cook Inlet were reported for Chum Salmon in 2008 or 2009.

Radio-tagged Chinook Salmon primarily spawned in Moose Creek; however, the small sample and bias towards later-run fish did not allow us to adequately describe the spawning distribution of the Chinook Salmon in the Matanuska River system. Although our results are similar to the spawning information presented by Johnson and Weiss (2007), they also reported spawning in the Kings River and Granite Creek. To adequately describe spawning aggregations of Chinook Salmon in the Matanuska River system, it is necessary to increase the sample size by capturing and tagging fish in proportion to the entire run. Based on the run timing of Chinook Salmon in the Deshka River (23 May – 29 Aug 2009, Table 16), the capture event would need to operate on the Matanuska River much earlier in the season.

Most Chum Salmon selected main-stem spawning areas lower in the watershed, which also reflects the telemetry results from 2008 (Anderson and Bromaghin 2009). The farthest upstream we observed radio-tagged Chum Salmon in 2009 was the side channel complex in enclave G, upstream of the Kings River. Spawning Chum Salmon have been reported upstream as far as lower Caribou Creek (Johnson and Weiss 2007); however, no radio-tagged fish from 2008 or 2009 were detected spawning further upriver than spawning enclave G.

The distribution of radio-tagged Coho Salmon was similar among main-stem and tributary spawning areas in 2008 (55%) and 2009 (59%). More Coho Salmon selected spawning areas in the Wolverine Creek and Tatondan Lake watersheds than any other area (Table 14). We detected Coho Salmon spawning in Chickaloon River in 2009, which was not documented in 2008, though our sample size of radio-tagged Coho Salmon tracked to spawning enclaves was small in 2009 (n = 76) compared to 2008 (n = 135; Anderson and Bromaghin 2009).

Nearly all Sockeye Salmon selected spawning areas on the main-stem Matanuska braid plain, similar to 2008. In 2008, radio-tagged Sockeye Salmon spawned in three primary areas: the Bartko and Eska creek side channel complexes and the Moose Creek/Wolverine Creek mouth area. Although those three areas were also selected in 2009, radio-tagged fish were fated more often to spawning enclaves C and G, in the side channels within the Palmer area (19%) and the side channels above the Kings River (20%). Our findings confirm the telemetry results in 2008 and verify that Sockeye Salmon in the Matanuska River system employ an alternate life history by selecting spawning areas within the main-stem braid plain rather than selecting spawning sites in the lake watersheds, as originally reported (Anderson and Bromaghin 2009; Johnson and Weiss 2007). In other systems, overwintering river-type life histories for Sockeye Salmon fry have been reported in spring areas, side channels, and sloughs (Bugaev 1987; Wood et al. 1987; Burgner 1991).

We describe the spawning distributions of three Pacific salmon in the Matanuska River system upstream of our capture site, and found a close association of spawning habitat selection with the stable clearwater side channels along the main-stem braid plain. However, work done by the USGS in 2006 and 2007 identified and mapped more clearwater side channels within the main-stem braid plain below our fish wheel (72 km) than were identified above it (56 km). Curran et al. (2011) reported that side channels can shift appreciably across decades, but the relative abundance of clearwater side channels remains fairly stable, with some side channels (e.g., the Bartko side channel complex), persisting for decades before actively migrating. Not all clearwater side channel habitat provides suitable spawning habitat for salmon, but it is likely that more spawning habitat is available downstream of our capture site than upstream of it.

We increased our mobile ground tracking efforts in 2009 to verify the exact spawning locations of our radio-tagged fish. We were able to identify fine-scale spawning site selections for 71 of 257 radio-tagged Chum, Coho, and Sockeye salmon, but this required access to the spawning reaches and considerable effort.

We could not conclusively identify spawning areas in more turbid, glacial stream reaches with the same specificity as the clearwater side channels and tributaries due to access issues and lack of visual spawning indicators. That is, the presence of spawning pairs or redds was occluded from visual confirmations. Salmon spawning in glacially turbid habitats has been documented (Burger et al. 1985; Lorenz and Eiler 1989; Barton 1992; Eiler et al. 1992; Burger et al. 1995; Savereide 2003; Young and Woody 2007), but we were unable to estimate the proportion of fish that spawned in clearwater side channels compared to fish that spawned in turbid waters of the main-stem braid plain.

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References

Anderson, J. L., and Bromaghin, J. F. 2009. Estimating the spawning distribution of Pacific salmon in the Matanuska river watershed, Southcentral Alaska, 2008. U.S. Fish and Wildlife Service Data Series Report 2009-12.

Apodaca, C. K., and D. W. Daum. 2006. Estimated abundance of adult fall Chum Salmon in the middle Yukon River, Alaska, 2005 – Final Report. U.S. Fish and Wildlife Service, Fairbanks Fish and Wildlife Field Office, Alaska Fisheries Technical Report Number 89, Fairbanks, Alaska.

Barton, L. H. 1992. Tanana River, Alaska, fall Chum Salmon radio telemetry study. Alaska Department of Fish and Game, Fishery Research Bulletin 92-01, Anchorage, Alaska.

Bromaghin, J. F. 1993. Sample size determination for interval estimation of multinomial probabilities. The American Statistician 47:203-206.

Bromaghin, J. F., T. J. Underwood, and R. F. Hander. 2007. Residual effects from fish wheel capture and handling of Yukon River fall Chum Salmon. North American Journal of Fisheries Management 27:860-872.

Bugaev, V. F. 1987. Scale patterns and biology of juvenile Sockeye Salmon (*Onchorhynchus nerka*) in Kamchaka River. Pages 36-43 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, VanCouver, British Columbia.

Burger, C. V., R. L. Wilmot, and D. B. Wangaard. 1985. Comparison of spawning areas and times for two runs of Chinook Salmon *Oncorhynchus tshawytscha* in the Kenai River, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 42: 693-700.

Burger, C. V. J. E. Finn, and L. Holland-Bartels. 1995. Patterns of shoreline spawning by Sockeye Salmon in a glacially turbid lake: evidence for population differentiation. Transactions of the American Fisheries Society 124:1-15.

Burgner, R. L. 1991. Life history of Sockeye Salmon (*Onchorhynchus nerka*). Pages 2-117 *in* C. Groot and L. Margolis, editors. Pacific salmon life histories. University of British Columbia Press, VanCouver, British Columbia.

Cleary, P. M., and T. Hamazaki. 2007. Fall Chum Salmon mark-recapture abundance estimation on the Tanana and Kantishna rivers, 2007. Alaska Department of Fish and Game, Fishery Data Series Number 07-45, Anchorage, Alaska.

Curran, J. H., McTeague, M. L., Burril, S. E., Zimmerman, C. E. 2011. Distribution, persistence, and hydrologic characteristics of salmon spawning habitats in clearwater side channels of the Matanuska River, Southcentral Alaska. U.S. Geological Survey Scientific Investigations Report 2011-5102.

Eiler, J. H., B. D. Nelson, and R. F. Bradshaw. 1992. Riverine spawning by Sockeye Salmon in the Taku River, Alaska and British Columbia. Transactions of the American Fisheries Society 121:701-708.

Fox, J., and P. Shields. 2005. Upper Cook Inlet commercial fisheries annual management report, 2004. Alaska Department of Fish and Game, Report to the Board of Fisheries, 2005, Anchorage.

Jearld, A. 1983. Age determination. Pages 301-324 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Johnson, N. L., S. Kotz, and N. Balakrishnan. 1992. Univariate discrete distributions. John Wiley & Sons, New York, New York.

Johnson, J. and E. Wiess. 2007. Catalog of waters important for spawning, rearing, or migration of anadromous fishes – Southcentral Region, Effective June 1, 2007. Alaska Department of Fish and Game, Special Publication No. 07-05, Anchorage, Alaska.

Link, M. R., and K. K. English. 1996. The 1993 fishwheel project on the Nass River and an evaluation of fishwheels as an inseason management and stock assessment tool for the Nass River. Canadian Technical Report of Fisheries and Aquatic Sciences 2130. 103 p.

Link, M. R., and K. K. English. 2000. Long-term sustainable monitoring of Pacific salmon populations using fishwheels to integrate harvesting, management, and research. Pages 667 to 674 *in* E. E. Knudsen, C. R. Steward, D. D. MacDonald, J. E. Williams, and D. W. Reiser, editors. Sustainable fisheries management: Pacific salmon. Lewis Publications, Boca Raton, Florida.

Lloyd, D. S., Koenings, J. P., and J. D. La Perriere. 1987. Effects of turbidity in fresh waters of Alaska. North American Journal of Fisheries Management 7:18-33.

Lorenz, J. M., and J. H. Eiler. 1989. Spawning habitat and redd characteristics of Sockeye Salmon in the glacial Taku River, British Columbia and Alaska. Transactions of the American Fisheries Society 118:495-502.

Matanuska-Susitna Basin Salmon Habitat Partnership (MSBSHP). 2008. Conserving salmon in the Mat-Su basin: the Strategic Action Plan of the Mat-Su Basin Salmon Habitat Partnership. URL http://conserveonline.org/workspaces/MatSuSalmon (accessed May 2012).

Mat-Su Basin Salmon Habitat Partnership (MSBSHP). 2013. Conserving salmon in the Mat-Su basin: the Strategic Action Plan of the Mat-Su Basin Salmon Habitat Partnership. URL http://www.fishhabitat.org/partnership/matanuska-susitna-basin-salmon-habitat-partnership (accessed December 2014).

Milner, A. M., and G. E. Petts. 1994. Glacial rivers: physical habitat and ecology. Freshwater Biology 32:295-307.

Mosher, K. H. 1968. Photographic atlas of Sockeye Salmon scales. Fishery Bulletin 67:243-280.

Murphy, M. L., J. Heifetz, J. F. Thedinga, S. W. Johnson, and K. V. Koski. 1989. Habitat utilization by juvenile Pacific salmon (*Oncorhynchus*) in the glacial Taku River, Southeast Alaska. Canadian Journal of Fisheries and Aquatic Sciences 46:1677-1685.

Pawluk, J., J. Baumer, T. Hamazaki, and D. Orabutt. 2006. A mark-recapture study of Kuskokwim River Chinook, Sockeye, Chum and Coho salmon, 2005. Alaska Department of Fish and Game, Fishery Data Series Number 06-54, Anchorage, Alaska.

Savereide, J. W. 2003. Inriver abundance, spawning distribution, and run timing of Copper River Chinook Salmon, 2002–2004. Alaska Department of Fish and Game, Fishery Data Series Number 05-50, Anchorage, Alaska.

Savereide, J. W. 2005. Inriver abundance, spawning distribution, and run timing of Copper River Chinook Salmon, 2002. Alaska Department of Fish and Game, Fishery Data Series Number 03-21, Anchorage, Alaska.

Sethi, S. and T. Tanner. 2013. Bayesian implementation of a time-stratified Lincoln-Petersen estimator for salmon abundance in the upper Matanuska River, Alaska, USA. Fisheries Research 145:90-99.

Sethi, S. and T. Tanner. 2014. Spawning distribution and abundance of a northern Chinook Salmon population. Fisheries Management and Ecology 21:427-438.

Sweet, D., S. Ivey, and D. Rutz. 2003. Area management report for the recreational fisheries of Northern Cook Inlet, 2001 and 2002. Alaska Department of Fish and Game, Fishery Management Report No. 03-10, Anchorage, Alaska.

U.S. Census Bureau. 2001. Counties ranked by percent population change: 1990-2000. Census 2000 Gateway, Population Distribution Branch. Available: http://www.census.gov/population/www/cen2000/phc-t4.html.

Vincent-Lang, D., and D. McBride. 1989. Stock origins of Coho salmon in the commercial harvests from Upper Cook Inlet, Alaska. Alaska Department of Fish and Game, Fishery Data Series Number 93, Anchorage.

Wade, G. D., K. M. van den Broek, J. W. Savereide, and J. J. Smith. 2007. Spawning distribution and run timing of Copper River Sockeye salmon, 2006 annual report. U.S. Fish and Wildlife Service, Office of Subsistence Management, Fisheries Resource Monitoring Program (Study No. 05-501), Anchorage, Alaska.

Willette, T. M., R. DeCino, and N. Gove. 2003. Mark-recapture population estimates of Coho, Pink, and Chum salmon runs to upper Cook Inlet in 2002. Alaska Department of Fish and Game, Regional Information Report 2A03-20, Anchorage, Alaska.

Winter, J. D. 1983. Underwater Biotelemetry. Pages 371-395 *in* L. A. Nielsen and D. L. Johnson, editors. Fisheries Techniques. American Fisheries Society, Bethesda, MD.

Wood, C. C, B. E. Riddell, and D. T. Rutherford. 1987. Alternative life histories of Sockeye Salmon (*Onchorhynhus nerka*) and their contribution to production in the Sitkine River, northern British Columbia. Pages 12-24 *in* H. D. Smith, L. Margolis, and C. C. Wood, editors. Sockeye Salmon (*Onchorhynhus nerka*) population biology and future management. Canadian Special Publication of Fisheries and Aquatic Sciences 96.

Young, D. B., Woody, C. A., 2007. Spawning distribution of Sockeye Salmon in a glacially influenced watershed: the importance of glacial habitats. Transactions of the American Fisheries Society 136: 452-459.

Appendix 1. Daily summary of fish wheel effort and catch for Chinook, Chum, Coho, and Sockeye salmon in the Matanuska River, 2009.

Date	Effort (h)	Chinook Salmon	Chum Salmon	Coho Salmon	Sockeye Salmon
24-Jun	9.17	4	0	0	0
25-Jun	8.58	1	0	0	0
26-Jun	6.92	2	0	0	0
27-Jun	6	2	0	0	0
28-Jun	0	0	0	0	0
29-Jun	7	1	0	0	0
30-Jun	7.58	1	0	0	0
1-Jul	13.75	3	0	0	0
2-Jul	5.25	0	0	0	0
3-Jul	0	0	0	0	0
4-Jul	0	0	0	0	0
5-Jul	0	0	0	0	0
6-Jul	0	0	0	0	0
7-Jul	7.5	0	0	0	0
8-Jul	8.33	0	0	0	0
9-Jul	0	0	0	0	0
10-Jul	0	0	0	0	0
11-Jul	0	0	0	0	0
12-Jul	0	0	0	0	0
13-Jul	5.25	0	0	0	0
14-Jul	7.58	0	0	0	0
15-Jul	7.17	0	0	0	0
16-Jul	7.17	1	0	0	0
17-Jul	10.33	0	0	0	0
18-Jul	5.17	0	0	0	1
19-Jul	0	0	0	0	0
20-Jul	5.67	0	0	0	0
21-Jul	6.92	0	0	0	0
22-Jul	13.08	0	0	0	0
23-Jul	13.67	1	0	0	0
24-Jul	6.58	1	0	0	1
25-Jul	6.75	1	0	1	0
26-Jul	0	0	0	0	0
27-Jul	10.25	0	2	0	4
28-Jul	8.5	0	0	0	0
29-Jul	7.25	0	0	0	0
30-Jul	7.25	0	0	0	0
31-Jul	6.5	0	0	0	1
1-Aug	6.33	0	0	0	0
2-Aug	0	0	0	0	0
3-Aug	4.08	0	0	0	0
4-Aug	9.83	0	0	4	0
5-Aug	10	1	1	2	0

Appendix 1, Continued.

Date	Effort (h)	Chinook Salmon	Chum Salmon	Coho Salmon	Sockeye Salmon
6-Aug	10.25	1	1	7	5
7-Aug	7.25	0	1	0	2
8-Aug	6.5	0	1	2	1
9-Aug	0	0	0	0	0
10-Aug	8.58	0	5	1	5
11-Aug	10	0	3	1	4
12-Aug	9.08	0	12	9	19
13-Aug	12.17	0	1	2	4
14-Aug	10.75	0	27	23	38
15-Aug	9.67	0	19	27	52
16-Aug	8.5	0	1	3	3
17-Aug	11.75	0	13	9	5
18-Aug	11.17	0	28	26	22
19-Aug	10.33	0	50	54	36
20-Aug	11	0	46	42	20
21-Aug	10.33	0	55	27	20
22-Aug	9	0	28	31	10
23-Aug	9.92	0	16	29	6
24-Aug	9	0	26	25	13
25-Aug	10.33	0	45	26	24
26-Aug	7.25	0	17	25	7
27-Aug	6.58	0	11	4	1
28-Aug	7.25	0	2	8	2
29-Aug	5.75	0	6	6	2
30-Aug	0	0	0	0	0
31-Aug	9	0	5	9	2
1-Sep	9.25	0	4	3	1
2-Sep	9.83	0	2	6	1
3-Sep	10	0	3	3	5
4-Sep	8.67	0	2	6	0
5-Sep	0	0	0	0	0
6-Sep	0	0	0	0	0
7-Sep	0	0	0	0	0
8-Sep	7.5	0	0	0	0
9-Sep	7	0	0	2	0
10-Sep	5.58	0	0	0	1
11-Sep	6.5	0	0	0	0
12-Sep	7.5	0	0	1	0

Appendix 2. Table of carcass surveys for Chum, Coho, and Sockeye salmon by date and location within the Matanuska River drainage with survey conditions and counts by species, 2009.

Date	Spawning Enclave	Latitude	Longitude	Water Clarity[a]	Light Conditions[b]	Wind Turbidity[c]	Species	Marked	Unmarked
26-Aug	G	61.73711	-148.68521	E	O	C	Sockeye	0	1
							Chum	0	5
29-Aug	G	61.73711	-148.68521	E	P/O	M	Sockeye	0	2
							Chum	1	24
1-Sep	E	61.70407	-148.92839	V	O	C	Sockeye	1	3
							Chum	0	0
2-Sep	B	61.61504	-149.08186	E	O	C	Sockeye	0	0
							Chum	1	7
3-Sep	C	61.65833	-149.07289	P	S	M	Chum	0	10
3-Sep	C	61.65330	-149.07812	E	S	C	Sockeye	0	6
							Chum	1	222
4-Sep	E	61.70407	-148.92839	V	S	C	Sockeye	1	4
							Chum	0	1
5-Sep	G	61.73711	-148.68521	E/G	S	C	Sockeye	0	33
							Chum	2	163
7-Sep	C	61.65410	-149.07231	E	S	C	Coho	0	0
							Sockeye	0	38
							Chum	6	392
8-Sep	D	61.67308	-149.03717	P	S	C	Chum	3	94
8-Sep	T-1	61.67308	-149.03717	E	P/O	C	Coho	0	1
							Chum	0	5
9-Sep	T-5	61.73399	-148.73933	E	O	C	Sockeye	0	5
							Chum	0	4
10-Sep	G	61.73711	-148.68521	U	U	U	Sockeye	0	0
11-Sep	G	61.73711	-148.68521	U	U	U	Sockeye	0	0
14-Sep	B	61.61244	-149.08122	E	P/O	C	Coho	0	0
							Sockeye	1	34
							Chum	9	238
15-Sep	T-5	61.73399	-148.73933	E	S	C	Sockeye	0	10
							Chum	0	7
16-Sep	G	61.73711	-148.68521	E	P/O	C	Coho	0	1
							Sockeye	3	128
							Chum	3	206
16-Sep	T-2	61.65166	-149.01013	E	P/O	C	Coho	4	39
17-Sep	B	61.61504	-149.08186	E	S	C	Coho	0	0
							Sockeye	2	164
							Chum	2	325
18-Sep	E	61.70407	-148.92839	P	S	C	Coho	0	1
							Sockeye	12	321
							Chum	5	185

Appendix 2, Continued.

Date	Spawning Enclave	Latitude	Longitude	Water Clarity[a]	Light Conditions[b]	Wind Turbidity[c]	Species	Marked	Unmarked
19-Sep	C	61.65410	-149.07231	E	S	C	Sockeye	8	235
							Chum	6	586
22-Sep	G	61.73711	-148.68521	E	O	C	Coho	0	0
							Sockeye	4	180
							Chum	1	183
24-Sep	T-2	61.65166	-149.01013	E	O	C	Coho	6	259
25-Sep	F						Coho	0	3
							Sockeye	0	17
							Chum	2	801
25-Sep	B	61.61244	-149.08122	E	O	C	Coho	0	0
							Sockeye	5	322
							Chum	0	227
29-Sep	F	61.72930	-148.79939	E	O	C	Coho	0	0
							Sockeye	1	11
							Chum	0	101
29-Sep	G	61.7371	-148.6852	E	O	C	Coho	1	4
							Sockeye	2	72
							Chum	1	44
29-Sep	D	61.67127	-149.06035	V	O	M	Coho	0	5
							Sockeye	0	17
							Chum	3	489
30-Sep	D	61.67127	-149.06035	G	P/O	M	Coho	0	0
							Sockeye	1	65
							Chum	3	169
30-Sep	E	61.70407	-148.92839	G	P/O	M	Coho	0	8
							Sockeye	5	267
							Chum	0	17
30-Sep	C	61.65410	-149.07231	E	S	C	Coho	0	1
							Sockeye	3	135
							Chum	1	118
1-Oct	T-5	61.73399	-148.73933	E	S	C	Coho	0	1
							Sockeye	0	20
							Chum	0	9
1-Oct	E	61.70407	-148.92839	G	S	C	Coho	0	14
							Sockeye	1	97
							Chum	1	56
2-Oct	C	61.61805	-149.90329	G	S	C	Coho	0	3
							Sockeye	3	219
							Chum	7	983
5-Oct	T-2	61.65166	-149.01013	E	O	C	Coho	9	149

Appendix 2, Continued.

Date	Enclave	Latitude	Longitude	Water Clarity[a]	Light Conditions[b]	Wind Turbidity[c]	Species	Marked	Unmarked
5-Oct	C	61.64057	-149.11122	G	O	C	Coho	0	0
							Sockeye	1	40
							Chum	0	344
6-Oct	T-1	61.69432	-149.08432	E	O	C	Coho	0	18
6-Oct	G	61.73705	-148.68488	E-G	S	M	Coho	3	20
							Sockeye	3	44
							Chum	0	19
6-Oct	T-5	61.73381	-148.74313	E	P/O	C	Coho	0	3
							Sockeye	0	6
7-Oct	C	61.65406	-149.07233	E	O	M	Coho	0	0
							Sockeye	3	92
							Chum	1	18
7-Oct	D	61.67008	-149.06288	G-P	O	M	Coho	0	0
							Sockeye	1	15
							Chum	1	469
8-Oct	E	61.70407	-148.92839	G-P	O	C	Coho	3	80
							Sockeye	1	64
							Chum	0	5
9-Oct	B	61.62157	-149.08694	P	O	C	Coho	6	149
							Sockeye	0	69
							Chum	1	30
9-Oct	B	61.61681	-149.08571	G	O	M	Coho	0	50
							Sockeye	2	182
							Chum	0	58
13-Oct	C	61.64008	-149.11137	V	O	C	Coho	0	8
							Sockeye	1	33
							Chum	0	85
14-Oct	J	61.79253	-148.32291	E	S	C	Coho	1	0
							Sockeye	6	33
15-Oct	E	61.70407	-148.92839	E-G	S	C	Coho	5	74
							Sockeye	5	39
							Chum	0	8
16-Oct	B	61.61379	-149.08299	E	S	C	Coho	2	122
							Sockeye	1	260
							Chum	1	41

[a]Key: U = Unknown; E = Excellent; G = Good; P = Poor; V = Variable
[b]Key: U = Unknown; S = Sunny; P/O = Partially Overcast; O = Overcast
[c]Key: U = Unknown; C = Calm; M = Moderate

Appendix 3. Summary of biological data and spawning fate for radio-tagged Chum Salmon in the Matanuska River, 2009. See Table 3 and Figure 3 for explanation of spawning fate.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
1	27-Jul	CH1	2.1	U	520	T-2
2	5-Aug	CH2	0.3	M	640	G
2	6-Aug	CH3	-	M	610	F
2	7-Aug	CH4	-	M	620	E
2	8-Aug	CH5	0.5	F	620	T-1
3	10-Aug	CH10	-	F	630	F
3	10-Aug	CH6	-	M	630	D
3	10-Aug	CH7	-	F	650	Unknown
3	10-Aug	CH8	-	M	620	Unknown
3	10-Aug	CH9	-	M	610	F
3	11-Aug	CH11	0.3	M	640	C
3	11-Aug	CH12	0.4	M	480	D
3	11-Aug	CH13	0.4	F	650	D
3	12-Aug	CH14	0.4	M	590	B
3	12-Aug	CH15	-	M	610	C
3	12-Aug	CH16	-	M	620	C
3	12-Aug	CH17	0.4	M	580	B
3	12-Aug	CH18	0.3	F	590	C
3	12-Aug	CH19	-	M	530	T-3
3	12-Aug	CH20	0.4	M	600	C
3	12-Aug	CH21	0.3	F	620	C
3	12-Aug	CH22	-	M	520	Unknown
3	12-Aug	CH23	0.4	M	550	Dead/Regurgitation
3	12-Aug	CH24	0.4	F	590	Dead/Regurgitation
3	12-Aug	CH25	-	M	610	E
3	13-Aug	CH26	1.3	F	580	T-2
3	14-Aug	CH27	-	M	580	Dead/Regurgitation
3	14-Aug	CH28	0.3	F	590	Dead/Regurgitation
3	14-Aug	CH29	-	F	555	C
3	14-Aug	CH30	-	M	620	C
3	14-Aug	CH31	0.3	F	545	E
3	14-Aug	CH32	UR	M	620	Unknown
3	14-Aug	CH33	0.3	F	630	C
3	14-Aug	CH34	0.4	M	570	C
3	14-Aug	CH35	0.3	M	650	F
3	14-Aug	CH36	0.4	M	585	T-3
3	14-Aug	CH37	UR	F	615	C
3	14-Aug	CH38	-	M	600	F
3	14-Aug	CH39	0.4	F	590	Unknown
3	14-Aug	CH40	0.3	F	630	B
3	14-Aug	CH41	-	M	630	B
3	14-Aug	CH42	-	F	610	C

Appendix 3, continued.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
3	14-Aug	CH43	UR	F	570	D
3	14-Aug	CH44	-	M	620	Unknown
3	14-Aug	CH45	UR	F	565	C
3	14-Aug	CH46	UR	M	580	F
3	14-Aug	CH47	0.3	M	630	D
3	14-Aug	CH48	-	M	580	B
3	14-Aug	CH49	0.4	M	535	C
3	14-Aug	CH50	-	M	590	D
3	14-Aug	CH51	0.3	F	550	C
3	14-Aug	CH52	-	M	570	Dead/Regurgitation
3	14-Aug	CH53	-	M	610	E
4	16-Aug	CH54	1.2	M	530	F
4	17-Aug	CH55	-	M	550	B
4	17-Aug	CH56	UR	F	575	D
4	17-Aug	CH57	0.3	F	570	C
4	17-Aug	CH58	0.3	F	580	T-1
4	17-Aug	CH59	-	M	630	Unknown
4	17-Aug	CH60	-	M	640	T-1
4	17-Aug	CH61	-	M	595	B
4	17-Aug	CH62	0.3	M	550	D
4	17-Aug	CH63	0.3	M	605	Unknown
4	17-Aug	CH64	0.3	M	620	Unknown
4	17-Aug	CH65	0.2	M	530	C
4	17-Aug	CH66	-	M	590	D
4	17-Aug	CH67	UR	F	510	E
4	18-Aug	CH68	0.3	F	540	B
4	18-Aug	CH69	UR	F	580	C
4	18-Aug	CH70	0.3	F	570	D
4	18-Aug	CH71	0.2	M	620	C
4	22-Aug	CH72	0.4	F	577	C
5	23-Aug	CH73	-	M	615	D
5	23-Aug	CH74	-	M	560	D
5	23-Aug	CH75	0.3	M	640	B
5	23-Aug	CH76	0.5	F	600	B
5	23-Aug	CH77	-	M	620	Unknown
5	23-Aug	CH78	0.3	F	550	E
5	23-Aug	CH79	0.3	F	535	C
5	23-Aug	CH80	0.3	F	565	C
5	23-Aug	CH81	0.3	M	523	C
5	23-Aug	CH82	0.4	F	570	C
5	23-Aug	CH83	0.4	F	570	B
5	23-Aug	CH84	0.3	F	560	B
5	23-Aug	CH85	UR	F	-	C

Appendix 3, continued.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
5	23-Aug	CH86	0.3	M	600	C
5	23-Aug	CH87	0.3	M	550	C
5	23-Aug	CH88	0.4	F	580	Unknown
5	25-Aug	CH89	0.5	F	620	C
5	29-Aug	CH90	0.3	M	520	B
5	29-Aug	CH91	-	F	580	C

Appendix 4. Summary of biological data and spawning fate for radio-tagged Coho Salmon in the Matanuska River, 2009. See Table 3 and Figure 3 for explanation of spawning fate.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
1	25-Jul	CO1	2.1	F	600	D
2	4-Aug	CO2	2.1	M	650	B
2	4-Aug	CO3	2.1	F	610	B
2	4-Aug	CO4	2.1	M	580	T-2
2	4-Aug	CO5	2.2	F	420	E
2	6-Aug	CO6	2.1	M	580	T-2
2	6-Aug	CO7	2.1	M	550	T-2
2	6-Aug	CO8	2.1	F	600	T-1
2	8-Aug	CO10	1.1	F	550	T-1
2	8-Aug	CO9	2.1	M	590	T-2
3	10-Aug	CO11	3.1	U	640	T-5
3	11-Aug	CO12	3.2	M	530	E
3	12-Aug	CO13	2.3	M	590	T-2
3	12-Aug	CO14	1.1	F	560	E
3	12-Aug	CO15	2.1	F	580	T-4
3	12-Aug	CO16	2.1	M	510	M
3	12-Aug	CO17	2.2	M	600	T-2
3	12-Aug	CO18	2.2	F	590	T-2
3	12-Aug	CO19	2.3	F	550	T-4
3	12-Aug	CO20	2.1	F	610	T-4
3	12-Aug	CO21	2.1	F	490	Unknown
3	13-Aug	CO22	2.1	M	610	T-2
3	13-Aug	CO23	2.1	M	520	T-2
4	16-Aug	CO24	2.1	M	570	T-4
4	16-Aug	CO25	2.1	F	565	T-2
4	16-Aug	CO26	UR	M	610	T-2
4	17-Aug	CO27	2.1	F	590	T-4
4	17-Aug	CO28	2.1	M	560	T-2
4	17-Aug	CO29	2.1	M	560	Unknown
4	17-Aug	CO30	2.1	M	590	T-4
4	17-Aug	CO31	2.1	M	570	T-1
4	17-Aug	CO32	2.1	M	540	T-4
4	17-Aug	CO33	2.1	F	505	T-4
4	17-Aug	CO34	2.1	M	570	E
4	18-Aug	CO35	2.1	M	595	Dead/Regurgitation
4	18-Aug	CO36	2.1	M	590	D
4	18-Aug	CO37	UR	F	550	E
4	18-Aug	CO38	2.1	F	490	T-4
4	18-Aug	CO39	3.1	M	490	Unknown
4	18-Aug	CO40	1.1	F	560	T-2
4	18-Aug	CO41	2.1	M	520	T-4
4	18-Aug	CO42	1.1	F	570	D

Appendix 4, continued.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
4	18-Aug	CO43	2.1	F	570	D
4	18-Aug	CO44	1.1	F	595	H
4	18-Aug	CO45	2.1	M	570	T-4
4	18-Aug	CO46	1.1	M	490	T-2
4	18-Aug	CO47	2.1	M	545	C
4	18-Aug	CO48	2.1	M	570	T-4
4	18-Aug	CO49	1.1	M	480	Dead/Regurgitation
4	18-Aug	CO50	1.2	F	580	B
4	18-Aug	CO51	1.1	F	540	E
4	18-Aug	CO52	2.1	F	600	D
4	18-Aug	CO53	1.1	M	550	T-6
4	18-Aug	CO54	2.1	F	560	T-2
4	18-Aug	CO55	2.1	M	570	T-4
5	23-Aug	CO56	2.1	M	590	F
5	23-Aug	CO57	2.1	M	575	T-2
5	23-Aug	CO58	2.1	F	500	T-4
5	23-Aug	CO59	2.1	F	562	T-2
5	23-Aug	CO60	2.1	F	495	E
5	23-Aug	CO61	2.1	M	550	G
5	23-Aug	CO62	2.1	M	580	T-4
5	23-Aug	CO63	2.1	F	520	Dead/Regurgitation
5	23-Aug	CO64	2.2	M	500	T-2
5	23-Aug	CO65	2.1	F	560	Unknown
5	23-Aug	CO66	1.1	F	560	B
5	23-Aug	CO67	2.1	F	590	T-2
5	23-Aug	CO68	2.1	F	555	G
5	23-Aug	CO69	UR	M	510	J
5	23-Aug	CO70	2.1	F	520	T-4
5	23-Aug	CO71	2.1	M	610	T-2
5	23-Aug	CO72	2.1	F	540	D
5	23-Aug	CO73	2.1	M	610	T-2
5	23-Aug	CO74	1.1	M	480	B
5	23-Aug	CO75	2.1	F	550	E
5	24-Aug	CO76	2.1	F	550	T-4
5	25-Aug	CO77	2.2	F	450	T-1
5	25-Aug	CO78	2.1	M	560	C
5	27-Aug	CO79	2.1	F	440	Dead/Regurgitation
5	31-Aug	CO80	2.1	M	485	T-1
5	1-Sep	CO81	2.1	F	490	D
5	2-Sep	CO82	2.1	F	520	B
5	2-Sep	CO83	2.1	F	560	E
5	3-Sep	CO84	UR	M	550	C

Appendix 5. Summary of biological data and spawning fate for radio-tagged Sockeye Salmon in the Matanuska River, 2009. See Table 3 and Figure 3 for explanation of spawning fate.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
1	18-Jul	S1	1.2	M	580	C
1	27-Jul	S2	1.2	F	535	J
1	27-Jul	S3	2.2	F	460	D
1	27-Jul	S4	2.2	U	520	E
1	27-Jul	S5	2.2	M	590	T-3
1	31-Jul	S6	2.3	F	555	G
2	6-Aug	S10	2.2	M	555	G
2	6-Aug	S7	-	M	580	J
2	6-Aug	S8	1.3	F	610	J
2	6-Aug	S9	2.2	M	520	G
2	7-Aug	S11	2.3	M	430	E
2	7-Aug	S12	UR	M	410	G
2	8-Aug	S13	2.2	F	480	J
3	10-Aug	S14	UR	M	620	E
3	10-Aug	S15	UR	M	580	G
3	10-Aug	S16	1.2	F	570	E
3	10-Aug	S17	2.1	M	530	J
3	10-Aug	S18	1.2	U	480	B
3	11-Aug	S19	2.2	M	540	C
3	11-Aug	S20	2.2	F	560	C
3	11-Aug	S21	-	M	560	K
3	11-Aug	S22	2.2	M	480	F
3	12-Aug	S23	1.2	F	620	E
3	12-Aug	S24	1.1	M	500	C
3	12-Aug	S25	2.2	M	510	T-4
3	12-Aug	S26	1.2	F	610	G
3	12-Aug	S27	UR	F	580	E
3	12-Aug	S28	2.2	F	600	G
3	12-Aug	S29	2.2	F	510	J
3	12-Aug	S30	2.2	F	550	T-4
3	12-Aug	S31	1.2	M	500	J
3	12-Aug	S32	1.2	M	520	G
3	12-Aug	S33	1.3	F	560	T-4
3	12-Aug	S34	2.2	M	610	T-4
3	12-Aug	S35	2.2	F	530	J
3	12-Aug	S36	1.2	F	450	T-5
3	12-Aug	S37	1.1	M	470	G
3	12-Aug	S38	1.1	M	450	G
3	12-Aug	S39	2.2	U	450	G
3	12-Aug	S40	2.2	F	410	C
3	12-Aug	S41	2.1	M	450	G
3	13-Aug	S42	1.2	F	570	N

Appendix 5, continued.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
3	13-Aug	S43	UR	M	580	G
3	13-Aug	S44	2.2	M	610	D
3	13-Aug	S45	2.2	F	490	C
3	14-Aug	S46	2.2	M	620	B
3	14-Aug	S47	1.2	M	580	G
3	14-Aug	S48	UR	M	600	J
3	15-Aug	S49	2.1	F	578	E
3	15-Aug	S50	1.2	F	500	E
3	15-Aug	S51	2.2	F	560	G
3	15-Aug	S52	1.2	F	515	E
3	15-Aug	S53	1.2	F	590	G
3	15-Aug	S54	2.1	M	540	M
3	15-Aug	S55	1.2	F	550	C
3	15-Aug	S56	1.2	F	510	C
3	15-Aug	S57	2.2	M	540	T-4
3	15-Aug	S58	1.2	F	500	E
3	15-Aug	S59	UR	F	570	E
3	15-Aug	S60	2.1	F	490	B
3	15-Aug	S61	1.2	F	490	C
3	15-Aug	S62	2.2	F	470	G
3	15-Aug	S63	1.2	F	485	E
3	15-Aug	S64	1.1	M	450	J
3	15-Aug	S65	1.1	M	444	H
3	15-Aug	S66	2.1	F	460	T-1
3	15-Aug	S67	2.1	M	470	Unknown
3	15-Aug	S68	1.2	M	480	D
3	15-Aug	S69	1.2	F	470	L
3	15-Aug	S70	2.1	M	435	D
3	15-Aug	S71	1.2	M	440	Unknown
3	15-Aug	S72	1.1	M	420	G
3	15-Aug	S73	2.2	F	480	T-3
4	16-Aug	S74	1.2	M	560	Unknown
4	16-Aug	S75	1.2	M	550	L
4	16-Aug	S76	1.1	M	470	C
4	17-Aug	S77	2.2	F	580	T-4
4	17-Aug	S78	1.3	F	530	N
4	17-Aug	S79	1.2	F	480	C
4	17-Aug	S80	UR	F	500	Unknown
4	17-Aug	S81	1.2	M	570	L
4	18-Aug	S82	1.3	M	570	E
4	18-Aug	S83	2.1	F	515	G
4	18-Aug	S84	1.2	F	535	B
4	18-Aug	S85	UR	F	510	C

Appendix 5, continued.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
4	18-Aug	S86	1.2	M	580	F
4	18-Aug	S87	1.2	F	525	G
4	18-Aug	S88	2.2	F	520	F
4	18-Aug	S89	1.2	F	550	F
4	18-Aug	S90	1.1	F	520	B
4	18-Aug	S91	1.1	M	500	Unknown
4	18-Aug	S92	1.2	F	520	D
4	18-Aug	S93	2.1	M	480	Unknown
4	18-Aug	S94	UR	F	490	T-4
4	18-Aug	S95	1.2	F	540	C
4	18-Aug	S96	1.2	M	580	D
4	18-Aug	S97	2.2	F	500	B
5	23-Aug	S100	2.2	F	450	C
5	23-Aug	S101	UR	F	550	C
5	23-Aug	S102	2.1	M	470	C
5	23-Aug	S103	-	F	475	C
5	23-Aug	S98	2.3	M	610	C
5	23-Aug	S99	2.2	F	545	Unknown
5	24-Aug	S104	2.2	F	540	Dead/Regurgitation
5	24-Aug	S105	1.1	M	490	B
5	24-Aug	S106	1.2	F	580	Dead/Regurgitation
5	24-Aug	S107	1.1	M	520	G
5	24-Aug	S108	1.2	M	550	Unknown
5	24-Aug	S109	1.1	F	545	B
5	24-Aug	S110	1.2	F	550	L
5	24-Aug	S111	1.2	F	520	B
5	24-Aug	S112	1.2	F	580	D
5	24-Aug	S113	1.1	M	605	C
5	24-Aug	S114	1.2	F	490	C
5	24-Aug	S115	2.2	M	540	B
5	25-Aug	S116	1.2	F	530	E

Appendix 6. Summary of biological data and spawning fate for radio-tagged Chinook Salmon in the Matanuska River, 2009. See Table 3 and Figure 3 for explanation of spawning fate.

Stratum	Tag Date	Fish ID	Age	Sex	Length (mm)	Spawning Fate
1	24-Jun	K1	2.2	U	611	T-1
1	24-Jun	K2	1.4	F	830	C
1	24-Jun	K3	2.4	F	908	C
1	26-Jun	K4	1.2	M	660	T-1
1	26-Jun	K5	-	M	950	T-1
1	27-Jun	K6	UR	F	920	T-1
1	27-Jun	K7	1.2	M	570	Dead/Regurgitation
1	29-Jun	K8	2.2	M	600	T-1
1	30-Jun	K9	1.3	F	520	Dead/Regurgitation
1	1-Jul	K10	UR	F	800	T-1
1	1-Jul	K11	UR	U	530	T-1
1	16-Jul	K12	1.5	M	630	T-1
1	23-Jul	K13	-	M	900	C
1	24-Jul	K14	-	M	965	C

Appendix 7. Fine-scale spawning locations for individual fish radio-tracked within accessible areas, Matanuska River, 2009. See Figure 3 for explanation of spawning enclave.

Species	Stratum	Tag Date	Fish ID	Spawning Enclave	Latitude	Longitude
Chum	2	5-Aug	CH2	G	61.7371	-148.6852
Chum	2	7-Aug	CH4	E	61.6975	-148.9480
Chum	3	10-Aug	CH10	F	61.7293	-148.7993
Chum	3	12-Aug	CH18	C	61.6541	-149.0723
Chum	3	12-Aug	CH19	T-3	61.7310	-148.8548
Chum	3	14-Aug	CH34	C	61.6534	-149.0741
Chum	3	14-Aug	CH36	T-3	61.7310	-148.8548
Chum	3	14-Aug	CH40	B	61.6161	-149.0819
Chum	3	14-Aug	CH41	B	61.6163	-149.0821
Chum	4	17-Aug	CH56	D	61.6719	-149.0590
Chum	4	18-Aug	CH68	B	61.6146	-149.0824
Chum	4	22-Aug	CH72	C	61.6536	-149.0737
Chum	5	23-Aug	CH73	D	61.6713	-149.0601
Chum	5	23-Aug	CH76	B	61.6198	-149.0888
Chum	5	23-Aug	CH79	C	61.6534	-149.0723
Chum	5	23-Aug	CH82	C	61.6532	-149.0769
Chum	5	23-Aug	CH85	C	61.6534	-149.0742
Coho	3	12-Aug	CO14	E	61.7025	-148.9375
Coho	4	18-Aug	CO54	T-2	61.6572	-148.9823
Coho	5	23-Aug	CO59	T-2	61.6540	-149.0022
Coho	5	23-Aug	CO61	G	61.7373	-148.6842
Coho	5	23-Aug	CO64	T-2	61.6566	-148.9931
Coho	5	23-Aug	CO69	J	61.7917	-148.3312
Coho	5	23-Aug	CO71	T-2	61.6514	-149.0088
Sockeye	1	18-Jul	S1	C	61.6541	-149.0717
Sockeye	1	27-Jul	S4	E	61.7041	-148.9276
Sockeye	2	6-Aug	S10	G	61.7369	-148.6811
Sockeye	2	7-Aug	S11	E	61.6970	-148.9490
Sockeye	2	6-Aug	S7	J	61.7889	-148.3409
Sockeye	2	6-Aug	S8	J	61.7916	-148.3328
Sockeye	3	10-Aug	S15	G	61.7370	-148.6851
Sockeye	3	10-Aug	S16	E	61.7041	-148.9277
Sockeye	3	10-Aug	S18	B	61.6160	-149.0818
Sockeye	3	11-Aug	S19	C	61.6541	-149.0718
Sockeye	3	12-Aug	S23	E	61.7036	-148.9285
Sockeye	3	12-Aug	S26	G	61.7374	-148.6833
Sockeye	3	12-Aug	S27	E	61.7038	-148.9283
Sockeye	3	12-Aug	S28	G	61.7367	-148.6861
Sockeye	3	12-Aug	S29	J	61.7917	-148.3312
Sockeye	3	12-Aug	S36	T-5	61.7342	-148.7368
Sockeye	3	12-Aug	S37	G	61.7370	-148.6815
Sockeye	3	13-Aug	S45	C	61.6540	-149.0718

Appendix 7, continued.

Species	Stratum	Tag Date	Fish ID	Spawning Enclave	Latitude	Longitude
Sockeye	3	14-Aug	S46	B	61.6153	-149.0817
Sockeye	3	15-Aug	S49	E	61.6968	-148.9502
Sockeye	3	15-Aug	S50	E	61.7002	-148.9474
Sockeye	3	15-Aug	S51	G	61.7371	-148.6848
Sockeye	3	15-Aug	S52	E	61.7040	-148.9284
Sockeye	3	15-Aug	S53	G	61.7367	-148.6861
Sockeye	3	15-Aug	S55	C	61.6541	-149.0723
Sockeye	3	15-Aug	S56	C	61.6541	-149.0723
Sockeye	3	15-Aug	S57	T-4	61.7840	-147.9960
Sockeye	3	15-Aug	S58	E	61.7038	-148.9267
Sockeye	3	15-Aug	S59	E	61.7040	-148.9270
Sockeye	3	15-Aug	S60	B	61.6542	-149.0708
Sockeye	3	15-Aug	S70	D	61.6716	-149.0596
Sockeye	4	18-Aug	S82	E	61.7018	-148.9422
Sockeye	4	18-Aug	S84	B	61.6145	-149.0830
Sockeye	4	18-Aug	S86	F	61.7148	-148.8101
Sockeye	4	18-Aug	S89	F	61.7148	-148.8101
Sockeye	4	18-Aug	S90	B	61.6218	-149.0886
Sockeye	4	18-Aug	S97	B	61.6168	-149.0857
Sockeye	5	24-Aug	S105	B	61.6165	-149.0842
Sockeye	5	24-Aug	S109	B	61.6165	-149.0841
Sockeye	5	24-Aug	S111	B	61.6144	-149.0829
Sockeye	5	24-Aug	S115	B	61.6146	-149.0828