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Stock Specific Abundance and Run Timing of Chinook Salmon in the Kenai River, 2007–2012

by

Adam M. Reimer

Adam St. Saviour

and

Steven J. Fleischman

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

Symbols and Abbreviations

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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Adam M. Reimer
Adam St. Saviour
and
Steven J. Fleischman

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

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Adam M Reimer,
Alaska Department of Fish and Game, Division of Sport Fish,
43961 Kalifornsky Beach Rd., Ste B, Soldotna, AK 99669, USA

Adam St. Saviour,
Alaska Department of Fish and Game, Division of Sport Fish,
333 Raspberry Road, Anchorage, AK 99518, USA

and

Steven J. Fleischman,
Alaska Department of Fish and Game, Division of Sport Fish,
333 Raspberry Road, Anchorage, AK 99518, USA

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ABSTRACT

A stock-specific abundance and run timing model (SSART) was fit to relative and absolute estimates of abundance, genetic stock identification data, radiotelemetry data, and creel survey estimates of harvest for Kenai River Chinook salmon (*Oncorhynchus tshawytscha*) from 2007 to 2012. Bayesian statistical methods were employed to estimate inriver abundance and run timing by stock at river mile 8.6 of the Kenai River. Abundance of early-run Chinook salmon ranged from 6,739 (SE 819) in 2012 to 12,300 (SE 2,087) in 2007. Abundance of late-run Chinook salmon ranged from 22,190 (SE 3,815) in 2010 to 48,370 (SE 8,641) in 2007. Tributary stocks had greater relative abundance within the run before 15 June, and the Mainstem–Juneau Creek stock had greater relative abundance after 15 June. Fish from Killey River–Benjamin Creek, Funny River–Slikok Creek, and Quartz–Crescent creeks migrated upstream primarily during the first 3 of 6 time strata; fish from Grant Creek and Russian River migrated upstream primarily during the third through fifth time strata; and fish from Mainstem Kenai River–Juneau Creek migrated upstream primarily during the last 3 time strata.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, Kenai River, abundance, Bayesian statistics, genetic stock identification, OpenBUGS, SSART

INTRODUCTION

The Kenai River watershed encompasses approximately 2,200 square miles of the Kenai Peninsula, including diverse landscapes such as glaciers, large lakes, high mountains, and vast lowlands. The Kenai River mainstem is approximately 82 miles long, including a 15-mile stretch where it flows through Skilak Lake (Figure 1). Tidal influence extends up to river mile (RM) 12. Populations of Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), sockeye salmon (*O. nerka*), pink salmon (*O. gorbuscha*), Dolly Varden (*Salvelinus malma*), and rainbow trout (*O. mykiss*) live in the Kenai River and support valuable commercial and recreational fisheries, including the largest recreational Chinook salmon fishery in Alaska (Jennings et al. 2015). The Kenai River fishery will probably support substantial angler effort into the foreseeable future due to its reputation, easy accessibility, and location near major Alaska population centers.

KENAI RIVER CHINOOK SALMON BIOLOGY

Kenai River Chinook salmon are separated into tributary and mainstem spawning populations. Most populations of tributary spawning Chinook salmon arrive from late April to early July (Burger et al. 1983; Bendock and Alexandersdottir 1992; Reimer 2013), although some tributaries (Russian River and Grant Creek) have demonstrated later run timing. Tributaries of the Kenai River that support populations of Chinook salmon include Slikok Creek, Funny River, Killey River, Benjamin Creek, Russian River, Juneau Creek, Quartz Creek, Crescent Creek, Daves Creek, Ptarmigan Creek, and Grant Creek (Burger et al. 1983; Bendock and Alexandersdottir 1992; Reimer 2013). Funny River, Killey River, and Benjamin Creek support the largest populations of tributary-spawning Chinook salmon. Mainstem-spawning Chinook salmon arrive from late June to mid-August (Burger et al. 1983; Hammarstrom et al. 1985; Bendock and Alexandersdottir 1992; Reimer 2013). The entire Kenai River mainstem upstream of the intertidal area (RM 12) is suitable spawning habitat for Chinook salmon.

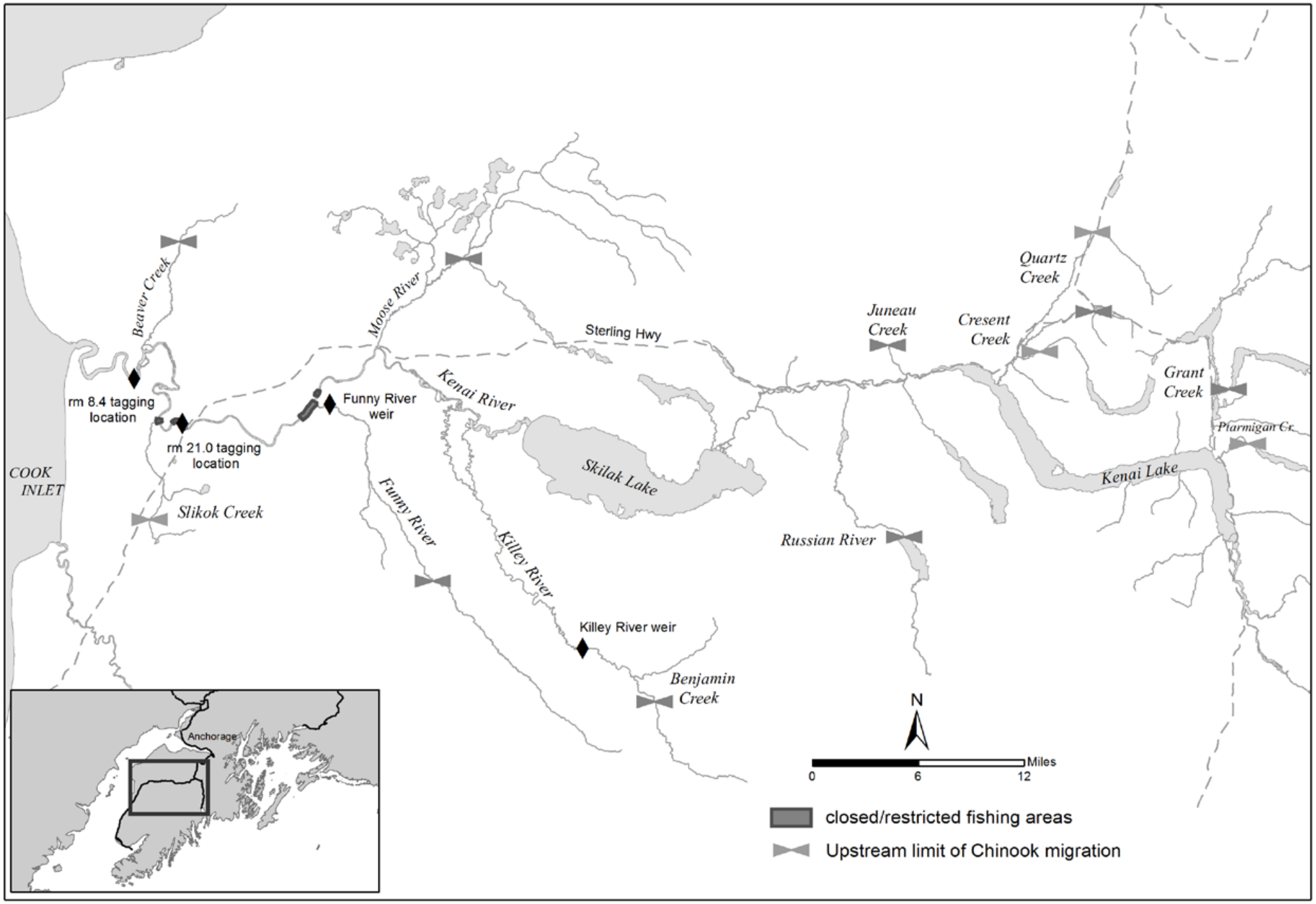

Figure 1.–The Kenai River drainage.

Note: Although not indicated in the figure, the Kenai River upstream of Skilak Lake and all tributaries to the Kenai River are also closed to sport fishing.

FISHERIES MANAGEMENT

Kenai River Chinook salmon are managed using plans first adopted by the Alaska Board of Fisheries in 1988 (McBride et al. 1989). These plans defined the early run as fish entering the Kenai River prior to 1 July and the late run as fish entering after 30 June. At the time of this study, the early run was managed to achieve an optimal escapement goal (OEG; defined in Alaska Administrative Code 5 ACC 39.222 [f][25]) of 5,300–9,000 Chinook salmon as described in the *Kenai River and Kasilof River Early-Run King Salmon Management Plan* (5 AAC 57.160). Early-run fish are harvested primarily by the inriver sport fishery but also by a marine sport fishery in Cook Inlet and a small subsistence fishery in the estuary.

At the time of this study, the late run was managed to achieve a sustainable escapement goal (SEG; defined in 5 ACC 39.222 [f][36]) of 17,800–35,700 Chinook salmon as described in the *Kenai River and Kasilof River Late-Run King Salmon Management Plan* (5 AAC 21.359). Late-run fish are harvested primarily by an inriver sport fishery and a marine commercial set gillnet fishery in Cook Inlet but also by marine sport, commercial drift gillnet, subsistence, and personal use fisheries. The regulations associated with each plan were designed to consider the unique characteristics of tributary and mainstem spawning Chinook salmon. Sport fishing regulations for these stocks are detailed in the management plan and include a daily bag and possession limit of 1 and an annual limit of 2 Chinook salmon, a slot limit of 46 to 55 inches for specific times and areas, closed areas, and partial restrictions on fishing from guided boats.

STOCK ASSESSMENT HISTORY

The size of the inriver run is a key component for estimating spawning escapement and implementing management plans. Daily and seasonal estimates of Kenai River Chinook salmon abundance at RM 8.6 have been generated since 1987 using hydroacoustic (sonar) techniques. Sonar assessment of Chinook salmon abundance in the Kenai River is complicated by the presence of more abundant sockeye salmon, which overlap in size and migrate concurrently with Chinook salmon. Sonar technology and methods have undergone nearly continuous refinement in an effort to improve fish species classification. From 2002 to 2011, split-beam sonar provided abundance estimates based on how much the duration of returning sound ("echo length") varied among echoes from the same fish (echo length was more variable for large than small fish). An age-structured mixture model, fit to echo length standard deviation, was used for the 2007–2009 assessments of Chinook salmon abundance (Miller et al. 2011-2012). Improved abundance estimates based on DIDSON[1] imaging sonar, which provided more precise measurements of fish size, were available starting in 2010 (Miller et al. 2013-2015).

The Kenai River Creel Survey (established in 1974) and Inriver Gillnetting Project (established in 1979) are operated annually by the Alaska Department of Fish and Game (ADF&G) on the lower Kenai River (Perschbacher 2014). The creel survey is used to estimate harvest by age of Chinook salmon from the fishery that occurs in the mainstem Kenai River. The Inriver Gillnetting Project occurs near RM 8.6 and provides age composition data used for stock assessment and length data from captured Chinook and sockeye salmon to inform the sonar mixture model, which provides estimates of Chinook salmon passage. Catch per unit effort

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[1] Dual-frequency Identification Sonar, manufactured by Sound Metrics Corporation. Product names used in this publication are included for completeness but do not constitute product indorsement.

(CPUE) was calculated and used as an index of Chinook salmon abundance. Lastly, the Inriver Gillnetting Project provided a platform to deploy radio tags as part of this study.

In the 2000s, genetic stock identification (GSI) technology (Adams et al. 1994) was implemented to address important Kenai River Chinook salmon stock assessment issues such as stock-specific run timing and catch allocation. GSI is used to determine the stock composition of a “mixture” of fish of unknown origin by comparing the allele frequency information in the mixture to allele frequencies from fish of known stock origin (the “baseline”) and assigning proportions of the mixture to the known stocks. Collection of tissue samples for development of a GSI baseline within the Kenai River drainage began in 2005 (Begich et al. 2010). Collection of mixture samples by the Inriver Gillnetting Project began in 2003 and by the Kenai River Creel Survey downstream of the Soldotna Bridge (RM 21) in 2006. Beginning in 2007, this was supplemented by mixture samples from the sport fish harvest upstream of the Soldotna Bridge. In 2011, a preliminary Kenai River drainage Chinook salmon baseline was developed from a subset of populations and the same set of genetic markers reported in Barclay et al. (2012) for a Cook Inlet–wide baseline. The preliminary baseline included more than 2,000 Chinook salmon collected over 11 spawning locations between 2003 and 2009.

Several weirs have been operated by ADF&G and United States Fish and Wildlife Service (USFWS) in Kenai River tributaries to measure salmon escapement. ADF&G has operated weirs on the Russian River since 1969 (Begich and Pawluk 2007, 2010; Begich et al. 2013; Pawluk 2015) and in Slikok Creek between 2008 and 2012. The USFWS has operated weirs on the Funny River since 2006 (Gates and Boersma 2009a-b, 2011; Boersma and Gates 2013) and on the Killey River near Benjamin Creek since 2012 (Gates and Boersma 2013).

Here we synthesize data from multiple sources to obtain annual estimates of Chinook salmon inriver abundance for the years 2007–2012. The data include catch rates and GSI allele counts from the inriver gillnets; harvest estimates from the creel survey; escapement counts from Funny, Killey, and Russian rivers, and Slikok Creek; and radiotelemetry data from fish instrumented at RM 8.6 and RM 21. To obtain these estimates, we fit a statistical model modified from that of Bromaghin et al. (2010), who modeled radiotelemetry mark–recapture data to produce stock-specific abundance and run-timing estimates of coho salmon in the Kasilof River. The Bromaghin et al. (2010) model was modified to include GSI data to estimate stock composition, and to include harvest upstream of the marking event. The modified model is termed the stock-specific abundance and run timing (SSART) model. The analysis was conducted within a Bayesian statistical framework.

This report documents the data sources, the SSART model and associated statistical methodology, and the resulting estimates of abundance and run timing by stock group. Preliminary versions of SSART abundance estimates have been used to anchor run reconstructions and inform escapement goal analyses for early- and late-run stocks (Fleischman and McKinley 2013; McKinley and Fleischman 2013). Abundance numbers reported herein supplant those estimates.

METHODS

SSART Model Overview

The conceptual framework for the Stock-Specific Abundance and Run Timing model (SSART) was originally developed by the USFWS (Bromaghin et al. 2010)[2]. The model stratifies Chinook salmon abundance by space and time, where genetic reporting groups (Killey River–Benjamin Creek, Funny River–Slikok Creek, Grant Creek, Mainstem Kenai River–Juneau Creek, Quartz Creek–Crescent Creek, and Russian River) represent the spatial stratification and approximately 2-week intervals (16–31 May, 1–15 June, 16–30 June, 1–15 July, 16–31 July, and 1–15 August) represent the time strata. The first 3 time strata compose the early run and the last 3 strata the late run. Information about relative abundance by spatial stratum is provided by GSI data from inriver gillnetting samples and by final destinations of fish captured and radiotagged in the lower Kenai River. Information about relative abundance by temporal stratum is derived from CPUE of the Inriver Gillnetting Project located near RM 8.6. Tributary weir data anchor the analysis by providing known escapements from 1 or more of the stocks. Harvest by stock group is accounted for by collecting genetic samples from harvested fish and weighting by estimates of harvest by time strata (Figure 2).

This approach has 3 advantages over traditional mark–recapture experiments. A primary advantage is that stock composition estimates from GSI are produced using tissue samples collected at the time of capture and thus the estimates are unaffected by fish behavior after capture and handling. In contrast, traditional mark–recapture experiments must recapture marked fish and thus handling effect is a large source of potential (and often unknown) bias. Another benefit of the SSART approach is the ability to combine information from multiple data sources. For instance, the precision of stock composition estimates can be improved by supplementing stock identity probabilities produced by GSI with known spawning destinations from radiotagged Chinook salmon[3]. A third feature of the SSART model is that the entire run is reconstructed through space and time, resulting in estimates of stock-specific abundance and harvest by time period and by river reach. Such information is valuable for formulating management strategies.

Required Data Sources

The SSART model requires input data from several different projects in the Kenai River system. These projects are briefly described in the following sections with reference to their respective comprehensive reports. Data used in the SSART model that are not readily available in published reports are included in Appendices A1–A7.

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2 The current methods differ from those of Bromaghin et al. (2010) in the use of GSI allele frequency data, the inclusion of harvest, and in the adoption of a Bayesian, rather than maximum likelihood, framework.

3 Use of radiotelemetry information in this way introduces minimal bias related to handing because severely affected fish fail to reach a spawning destination, and the stock identities of the radiotagged fish are derived exclusively from GSI data.

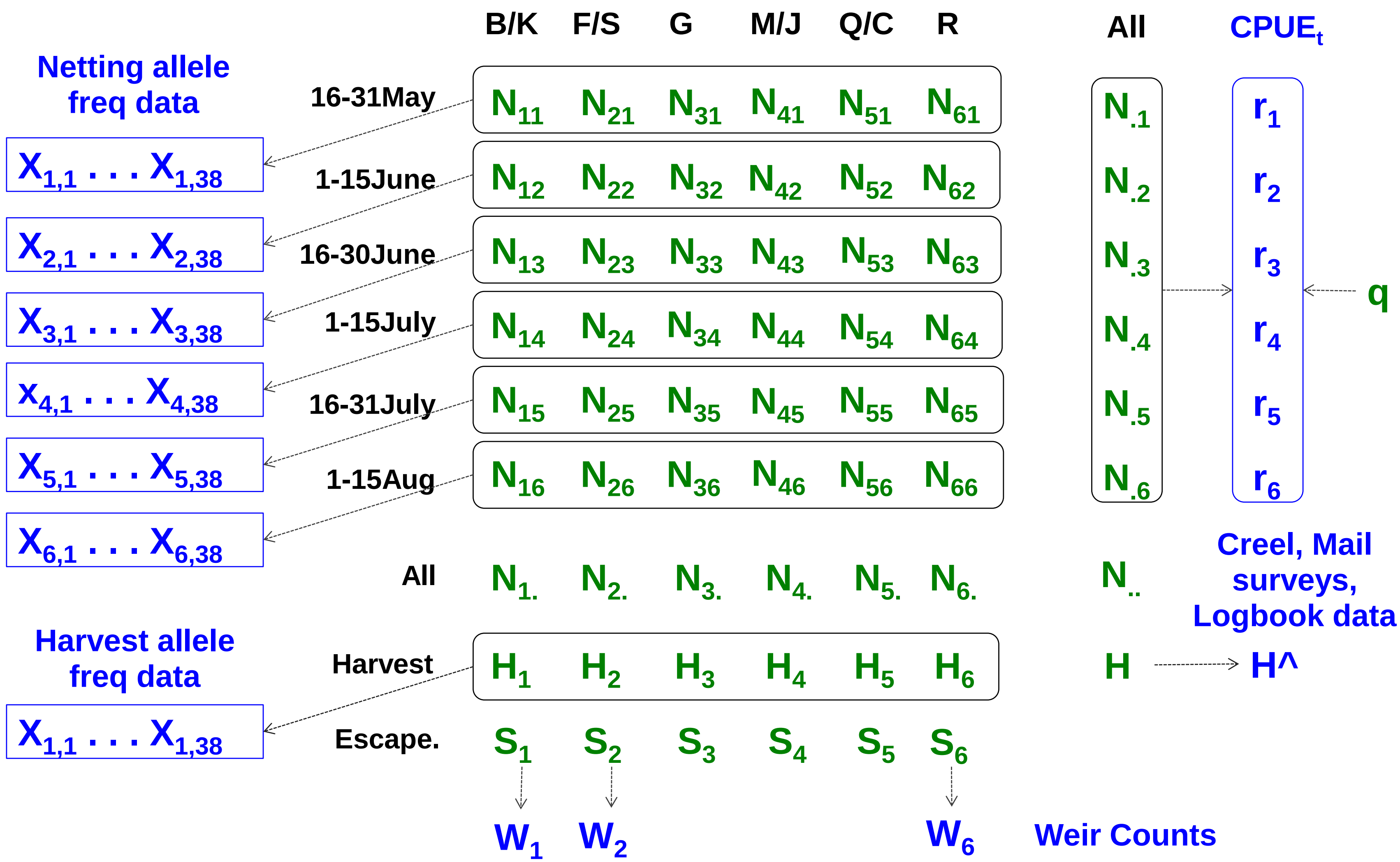

Figure 2.–The SSART model.

Note: Annual quantities of parameters N_{it} (abundance), H_i (harvest), S_i (escapement), and q (catchability) are shown in green and data $X_{m,h}$, r_t, $\hat{H}$, and W_i are shown in blue. Subscripts index individual fish (m), time (t), stock (i), and allele (h). B/K is Killey River–Benjamin Creek, F/S is Funny River–Slikok Creek, G is Grant Creek, M/J is Mainstem Kenai River–Juneau Creek, Q/C is Quartz Creek–Crescent Creek, and R is Russian River.

CPUE

The CPUE of Chinook salmon by the Inriver Gillnetting Project near RM 8.6 provides an index of abundance that is assumed to be proportional to Chinook salmon abundance migrating past RM 8.6 (Eskelin 2010; Perschbacher 2012a-d, 2014). Sampling began on 16 May in all years and continued through 10 August in years 2007–2011. In 2012, the sampling schedule continued until 17 August due to late run timing. These dates were assumed inclusive of the run of Kenai River Chinook salmon. Chinook salmon were captured with 2 sizes of gillnet (stretched mesh 5.0 in and 7.5 in) in colors that match Kenai River water. The netting project sampling area is approximately 0.3 mi long. Nets were drifted midriver while alternating between mesh size and the north and south sides of the thalweg. Gillnetting occurred once per day for 6 consecutive hours beginning 5 hours before low tide. A full description of methods and daily CPUEs are detailed in Eskelin (2010) and Perschbacher (2012a-d, 2014). CPUE data (Eskelin 2010: Appendices D3, D6; Perschbacher 2012a-b: Appendices D3, D6; Perschbacher 2012c-d, 2014: Appendices D2, D4) were reduced by summing the daily values within each time stratum.

Stock Composition of the Inriver Run

Genetic samples used to produce estimates of inriver run stock identification were collected from Chinook salmon captured by the Inriver Gillnetting Project near RM 8.6 (Eskelin 2010; Perschbacher 2012a-d, 2014; Appendix A1). Tissue samples for genetic analysis were removed from every Chinook salmon that was captured. A half-inch square piece of tissue was removed from the dorsal fin and immediately transferred to a 2 mL cryovial containing reagent grade 95% alcohol buffer solution and stored until DNA extraction. Laboratory analysis followed methods described in McKinley et al. (2013).

Harvest Estimates

Lower Kenai River (below the Soldotna Bridge [RM 21]; Figure 1) Chinook salmon sport harvests were estimated with an onsite creel survey (Eskelin 2010; Perschbacher 2012a-d, 2014). Harvest estimates were summed over each of 5 time strata (16–31 May, 1–15 June, 16–30 June, 1–15 July, and 16–31 July) (Appendix A2). Variability of the harvest estimate within each time stratum was summarized by the coefficient of variation (CV).

Estimates of middle Kenai River sport harvest (Soldotna Bridge to Skilak Lake [RM 21–50]; Figure 1) were obtained by multiplying the Statewide Harvest Survey (Jennings et al. 2010a-b, 2011a-b, 2015) estimate for Kenai River Chinook salmon harvested in each run (16 May–30 June and 1–31 July) by the proportion of reported harvest occurring between Soldotna Bridge and Skilak Lake in mandatory guide logbooks (Appendix A3). This combined estimate was preferred over the use of just the SWHS estimates because we noted some instances when the SWHS estimated substantial harvest upstream of the Soldotna Bridge even when the area was closed to harvest. We suspect SWHS participants misreported their location[4] because of unfamiliarity with the area, and the time lag between the fishing season and the SWHS mailing in the following winter, rather than reporting illegal harvest. In contrast, guide logbook data is filled out by professional fishing guides at the end of each fishing day. Estimates of middle Kenai River sport harvests used in the SSART model are reported in Appendix A3. Variability of the harvest estimates within each run was summarized by the CVs.

[4] Harvest from below the Soldotna Bridge was reported as above the Soldotna Bridge.

Total harvest was included by summing estimates of lower and middle river harvests and calculating the associated CVs.

Stock composition of the Harvest

Samples of harvested Chinook salmon from the lower Kenai River (below RM 21) encountered by the Kenai River Creel Survey (Appendix A1) were considered representative of the Kenai River Chinook salmon harvest downstream of the Soldotna Bridge. A full description of methods are detailed in Eskelin (2010) and Perschbacher (2012a-d, 2014). Sampling procedures were similar to those employed by the inriver gillnetting crew except that a half-inch piece of the auxiliary process was collected as the tissue sample. Laboratory analyses were also conducted in the same fashion as for the inriver run.

Tissue samples were also collected by a Middle Kenai River Chinook Salmon Harvest Sampling Study (Appendix A1). A full description of methods are detailed in McKinley et al. (2013). This survey was conducted by roving crews to sample fish between the Soldotna Bridge (RM 21.0) and the Moose River (RM 36.3). Tissue samples were used to estimate the stock composition of fish harvested upstream of the Soldotna Bridge.

Weir Counts

Weir counts provided known escapements for some stocks and anchored abundance estimates for the entire analysis. Knowledge of absolute abundance for a subset of the run that composed a quantifiable fraction of the total run provided inference about total abundance. Annual summaries of weir data are tabulated in Appendix A4.

Funny River–Slikok Creek

The Slikok Creek weir was operated as a double aluminum picket weir by ADF&G between 2008 and 2010. In 2011, the weir was redesigned to minimize migration disruption by utilizing a single weir with a motion-activated digital video recording device and underwater camera. Fish passage was recorded as video footage and reviewed to determine net upstream passage. This weir provided escapement estimates for the Slikok Creek component within the Funny River–Slikok Creek stock group. During 2007, when no weir count was available, the average of the 2008–2012 Slikok Creek escapements was used as an imputed value[5]. The weir was located approximately 0.31 miles upstream from the Slikok Creek confluence with the Kenai River. Little to no spawning is known to occur downstream of the weir.

The USFWS has operated a resistance board weir on the Funny River since 2006 (Gates and Boersma 2009a-b, 2011; Boersma and Gates 2013). This weir provides an escapement estimate for the Funny River component of the Funny River–Slikok Creek stock group for the SSART model. Upstream migrating fish are allowed to swim freely through the fish pass where they are recorded by a motion activated digital video recording device. The video footage from the site is reviewed by a technician to determine net upstream passage. The weir is located approximately 0.75 miles upstream from the Funny River confluence with the Kenai River. A minor amount of spawning occurs downstream of the weir (Boersma and Gates 2013; Reimer 2013). Escapement estimates were obtained by summing daily estimates.

[5] The SSART model only accepts the sum of the Funny and Slikok weir counts; thus, the average is used as an imputed value.

Killey River

The USFWS operated a resistance board weir on the Killey River for the first season in 2012 (Gates and Boersma 2013). This weir provided a partial escapement estimate for the Benjamin Creek–Killey River stock group for the SSART model. Upstream migrating fish swam freely through a fish pass and were recorded by a motion-activated digital video recorder. The video footage from the site was reviewed to determine net upstream passage. This weir was located approximately 2 miles downstream from the confluence of Benjamin Creek with the Killey River. Significant spawning occurs both upstream and downstream of the weir. Radio tags were used to estimate the fraction of Killey River fish that migrated upstream of the weir.

Russian River

ADF&G has operated a weir on the Russian River near the outlet of Lower Russian Lake since 1969 in order to estimate escapement of sockeye salmon (Begich and Pawluk 2007, 2010; Begich et al. 2013). Other species are recorded as they pass through the Russian River weir (Pawluk 2015), and thus data on Chinook salmon passage provided an escapement estimate for the Russian River stock in the SSART model. Fish were counted by direct observation as they swam through a fish trap. The weir was located approximately 3 miles upstream from the Russian River confluence with the Kenai River.

Chinook salmon are known to spawn between the weir and the confluence. The magnitude of downstream spawning was assessed by a stream survey conducted annually in late August. The survey count of Chinook salmon spawning downstream of the Russian River weir has ranged from 7% to 53% of the annual weir passage from 2007 to 2012 (Jason Pawluk, Fishery Biologist, ADF&G, Soldotna, personal communication). No effort was made to include fish spawning below the weir into the escapement estimate because fish that spawn downstream of the weir are in close proximity to the mainstem Kenai River and do not ascend a substantial waterfall downstream of the weir. Consequently, we are uncertain of their appropriate genetic reporting group. However, SSART model abundance estimates are negligibly affected by not including them as Russian River escapement.

SUPPLEMENTARY DATA SOURCES

The projects listed above provided all the necessary data to fit the SSART model for years 2007–2012. The following projects provided additional data that improved the precision of SSART model estimates.

Radiotagging

Esophageal implant radio tags were administered to a subset of the Chinook salmon captured by the Inriver Gillnetting Project beginning in 2010 (Reimer 2013). In 2010 and 2011, every Chinook salmon greater than 550 mm from mid eye to tail fork (METF) captured between 16 May and 5 July was radiotagged. In 2012, every Chinook salmon greater than 550 mm METF captured between 16 May and 5 July and every third Chinook salmon greater than 550 mm METF captured between 6 July and 15 August received a radio tag. Radiotagged Chinook salmon were actively located by foot, boat, and airplane and were passively located by fixed-location radiotelemetry receiving stations.

In order to be considered a migrant and provide spawning destination data for the SSART model, the behavior of each fish had to satisfy 5 criteria believed to represent minimum behavior[6] for successfully spawning Chinook salmon. Spawning locations could be determined for 35–55% of the radiotagged Chinook salmon, annually.

Radiotelemetry final destinations were used to improve the precision of stock composition estimates in 2010–2012. GSI provides a vector of (generally non-zero) probabilities of belonging to each stock group, whereas radiotagged fish with known spawning locations could be assigned a probability of 1.0 for the stock group identified by radiotelemetry and 0 for the other stock groups.

Additional radio tags were implanted in Chinook salmon caught in gillnets fished on the Kenai River near RM 21(Figure 1) in 2011 and 2012. This project used the same methods as the RM 8.6 Kenai River Inriver Gillnetting Project except gillnetting occurred 1 day per week from early June to mid-July (Reimer 2013; Appendix A5). Chinook salmon tagged at this site had a much higher likelihood of being located at a final spawning destination (80% compared to 38% of radio tags deployed at RM 8.6 in 2011 and 92% compared to 55% in 2012) and providing stock composition data about the inriver run for the SSART model (Reimer 2013). The improved proportion of successful migrants tagged at RM 21 was attributed to higher survival and less potential for harvest.

Additional GSI Samples

As part of this project, a harvest sampling program was conducted downstream of the Soldotna Bridge during 2010–2012 (Appendix A6) to augment the number of tissue samples collected by the Kenai River Creel Survey. In 2010, 161 samples were collected during both runs. In 2011 and 2012, 23 and 43 samples, respectively, were collected during the earlier time strata, when samples from the inriver creel survey were lacking. Sampling methods follow Perschbacher (2012a-d, 2014).

A limited number of professional fishing guides participated in a voluntary program run by ADF&G to collect tissue samples from harvested Chinook salmon in 2012. This program provided 56 GSI samples that were used to improve the stock composition estimates of harvest during the early run, when samples from the inriver creel survey were lacking (Appendix A7).

MODEL DETAILS

In Bayesian modeling, a full probability model is constructed that describes the joint probability distribution of the observed data and the population parameters of interest. Inference is based on the posterior probability distribution of key population parameters given the observed data. Our interest centers on the parameters N_y^{early}, which is the abundance of Chinook salmon that entered the Kenai River during the early run in year *y*, and N_y^{late}, which is the abundance of Chinook salmon that entered the Kenai River during the late run in year *y*. In this section, we describe the SSART probability model in 2 steps: first, the probability structures of key population parameters are described and then the sampling distributions for the observed data are described. The complete SSART model is provided in Appendices B1–B4.

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[6] Fish were censored if they were harvested, failed to migrate upstream of RM 13, died prior to 1 July, failed to display 6 days of site fidelity prior to mortality, or died within 18 days of freshwater entry. Reimer (2013) discusses assignment of radiotag fates at length.

Probability Structures of Key Parameters

To determine the early- and late-run abundance parameters, the total number of Chinook salmon of stock group *i* that pass by the netting project at RM 8.6 during year *y* is described as follows:

$$N_{iy} = N_y \theta_{iy}^0 \tag{1}$$

where N_y, total abundance in year *y*, is lognormally distributed with mean μ_N and standard deviation σ_N. The vector ($\theta_{1y}^0, \theta_{2y}^0, \theta_{3y}^0, \theta_{4y}^0, \theta_{5y}^0, \theta_{6y}^0$) where θ_{iy}^0, is the proportion of N_y from stock group *i* in year *y*, follows a Dirichlet($\gamma_1, \gamma_2, \gamma_3, \gamma_4, \gamma_5, \gamma_6$) distribution.

The number of Chinook salmon from stock group *i* that pass by the netting project at RM 8.6 during year *y*, time period *t* is described as follows:

$$N_{iyt} = N_{iy} \pi_{iyt} \tag{2}$$

where π_{iyt}, the run-timing proportions at time *t*, describe the proportion of N_{iy} that pass by the netting project at RM 8.6 during time period *t*.

The numbers of Chinook salmon that pass by the netting project at RM 8.6 during the early and late runs in year *y* are the sums of N_{iyt} across all stocks and appropriate time strata:

$$N_y^{early} = \sum_{t=1}^{3} \sum_{i=1}^{6} N_{iyt} = \sum_{t=1}^{3} N_{yt} \text{ and } N_y^{late} = \sum_{t=4}^{6} \sum_{i=1}^{6} N_{iyt} = \sum_{t=4}^{6} N_{yt}\,. \tag{3}$$

The run timing proportions are assumed bell shaped with respect to time strata. That is, the expected abundance passing RM 8.6 at time $t = \{1,2,3,5,6\}$ are proportional to a normal probability density function T_{iyt}:

$$\mathrm{T}_{iyt} = e^{-z_{iyt}^2/2} \tag{4}$$

where

$$z_{iyt} = \left(t - \bar{t}_{iy}\right) / \sigma_{RT1tributary} \tag{5}$$

for tributary stocks $i = \{1,2,3,5,6\}$, and

$$z_{4yt} = \left(t - \bar{t}_{iy}\right) / \sigma_{RT1mainstem/Juneau} \tag{6}$$

for the mainstem Kenai River–Juneau Creek stock $i = \{4\}$.

Thus the SSART model allows different run timing standard deviations σ_{RT1} for mainstem and tributary stocks. The model also allows different run timing means $\bar{t}_{iy}$ for 3 groups of stocks:

1) Killey River–Benjamin Creek, Funny River–Slikok Creek and Quartz–Crescent creeks, $i = \{1,2,5\}$
2) Grant Creek and Russian River, $i = \{3,6\}$
3) Mainstem Kenai River–Juneau Creek, $i = \{4\}$

Run timing means $\bar{t}_{iy}$ are assumed to vary among years as a normal distribution with standard deviation σ_{RT2}.

Actual run timing τ_{iyt} is corrupted (i.e., abundance by time period deviates from a perfect bell shape) by lognormal multiplicative errors $e^{\varepsilon_{RT3}}$ with standard deviation σ_{RT3}:

$$\tau_{iyt} = \mathrm{T}_{iyt} e^{\varepsilon_{RT3}} . \tag{7}$$

Run timing proportions are calculated as follows:

$$\pi_{iyt} = \tau_{iyt} / \sum_t \tau_{iyt} . \tag{8}$$

Run timing proportions describe how the number of Chinook salmon that pass by the netting project at RM 8.6 from stock *i* in year *y* are distributed across time strata, whereas stock composition proportions describe how the number of Chinook salmon that pass by the netting project at time *t* in year *y* are distributed across stocks:

$$\theta_{yti} = N_{iyt} / \sum_i N_{iyt} = N_{iyt} / N_{yt} . \tag{9}$$

Another parameter of interest for the SSART model is H_{iy}, the harvest by stock group *i* in year *y*.

Fish from stock group *i* were exposed to harvest rate h_{iy} in year *y*, resulting in harvest H_{iy} :

$$H_{iy} = N_{iy} h_{iy} . \tag{10}$$

Stocks assigned similar mean run timing were assumed to have similar harvest rates such that the same harvest rate h_{iy} was used within each run-timing group, though it differed between groups:

1) Killey River–Benjamin Creek, Funny River–Slikok Creek and Quartz–Crescent creeks, $i = \{1,2,5\}$
2) Grant Creek and Russian River, $i = \{3,6\}$
3) Mainstem Kenai River–Juneau Creek, $i = \{4\}$

The proportion of stock group *i* in the harvest of year *y* was

$$\theta_{Hyi} = H_{iy} / H_y \tag{11}$$

where H_y is the total harvest above RM 8.6, across all stocks, in year *y*.

Sampling Distributions of Observed Data

Observed data utilized by the SSART model consist of annual weir counts, annual estimates of harvest, netting CPUE by time period, allele counts from fish sampled by the RM 8.6 netting project, spawning destinations of radiotagged fish by the RM 8.6 netting project, and multinomial count pseudo-data constructed as a surrogate for stock composition information from GSI sampling of the harvest.

Annual weir counts for the Funny River–Slikok Creek, Quartz–Crescent creeks, and Russian River stock groups are modeled as follows:

$$\hat{S}_{iy} = S_{iy} e^{\varepsilon_{Siy}} \tag{12}$$

where S_{iy} is the number of fish from stock group *i* that escaped the fishery on year *y* and have the opportunity to spawn:

$$S_{iy} = N_{iy} - H_{iy} \, , \tag{13}$$

and the ε_{Siy} are normal $(0,\sigma^2_{Siy})$. The value of σ^2_{Siy} is calculated from the CV_{Siy}[7], which is set to 0.1 to reflect good precision in the weir-based escapement estimates. Annual weir counts for the portion of the Killey River–Benjamin Creek stock group that migrated upstream of the Killey River weir are modeled as follows:

$$\hat{S}_{By} = S_{By} e^{\varepsilon_{SBy}} \tag{14}$$

where S_{By} is the number of fish from the Benjamin Creek–Killey River stock group that escaped the fishery on year *y* and migrated past the Killey River weir:

$$S_{By} = \rho_y S_{1y} \, , \tag{15}$$

and the ε_{SBy} are normal $(0,\sigma^2_{SBy})$. The value of σ^2_{Siy} is calculated from the CV_{SBy}, which is set to 0.1 to reflect good precision in the weir-based escapement estimates. The number of radio tags observed above the Killey River weir is modeled as having a binomial (ρ_y, bk_y) distribution, where bk_y is the total number of radio tags observed in the Killey River drainage in year *y* and ρ_y is the proportion of radio tags entering the Killey River that migrated upstream of the Killey River weir.

Annual estimates of inriver harvest above RM 8.6, combined from the creel, mail survey, and guide logbook data, are modeled as follows:

$$\hat{H}_y = H_y e^{\varepsilon_{Hy}} \tag{16}$$

where ε_{Hy} is normal $(0,\sigma^2_{Hy})$, and σ_{Hy} approximately equal to the coefficient of variation of the harvest estimate.

Catch per unit effort in the netting project during time period *t* in year *y* is modeled as linearly related to abundance:

$$CPUE_{yt} = q_y N_{yt} e^{\varepsilon_{Nyt}} \tag{17}$$

where q_y is the constant of proportionality between abundance and standardized netting catch specific to year *y*, and the ε_{Nyt} are normal $(0,\sigma^2_I)$.

Allele counts at multiple (*h* = 1 to 38) genetic loci were observed for each of the M^8_{yt} fish sampled from the run at RM 8.6 during year *y* and time stratum *t*. Separately for each year and time stratum, each allele count *x* for fish *m* at locus *h* is modeled as having a binomial $(q_{z(m),h},2)$ distribution[8], where q_{ih} is the frequency of allele *h* in stock group *i*. The integer quantity *z(m)*, the stock identity index (1 to 6) for fish *m*, has a categorical prior distribution[9] with stock

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[7] If $x \sim N(0,\sigma^2)$ then $y = e^x \sim LogN(0,\sigma^2)$ and $CV_y = \sqrt{e^{\sigma^2} - 1} \sim \sigma$ when σ is small.

[8] The specified allele is present on either 0, 1, or both of the homologous chromosomes, thus the possible values of *x* are 0, 1, or 2, respectively.

[9] The categorical distribution is the multivariate analogue of the Bernoulli distribution, or alternatively a multinomial distribution with order 1. If z has a categorical$(\theta_1,\theta_2,\theta_3,\theta_4,\theta_5,\theta_6)$ distribution, it can assume values 1 to 6 with probabilities θ_1, θ_2, θ_3, θ_4, θ_5, and θ_6.

composition proportions (θ_{yt1}, θ_{yt2}, θ_{yt3}, θ_{yt4}, θ_{yt5}, θ_{yt6}). For radiotagged fish with known spawning destinations, the stock identity index was directly included as data.

Allele counts were also observed for each of the M_{yt}^{21} fish sampled from the run at RM 21 during year *y* and time stratum *t*. Fish sampled at RM 21 provided information about the stock composition of the run at RM 8.6 as described above except that the time stratum index when they were present at RM 8.6 is treated as a random variable. The vector of probabilities that fish *m* was present at RM 8.6 in time strata *t* (1 to 6) was given a categorical prior distribution with proportions $\left(tp_{v1}, tp_{v2}, tp_{v3}, tp_{v4}, tp_{v5}, tp_{v6}\right)$ where tp_{vt} is the probability of migrating past RM 8.6 in time stratum *t* given that it was captured at RM 21 in time stratum *v*. Fish radiotagged at RM 8 and later observed at RM 21 during time stratum *v* were modeled as multinomial(tp_{vt},$c21_v$) where $c21_v$ is the number of radiotagged fish detected at RM 21 during time stratum v. A noninformative Dirichlet prior was used for tp_{vt}.

Information on stock composition of the harvest was included in the SSART model in the form of surrogate multinomial count data constructed from a separate analysis of allele frequency data (Appendix B3) sampled from harvested fish[10]. Two geographic strata, upstream and downstream of the Soldotna Bridge, were used to model harvest stock composition. Harvest of fish downstream of the Soldotna Bridge was modeled with harvest timing proportions as described in Equations 2 and 4–9 after replacing abundance parameters (*N*) with harvest parameters (*HL*). Allele counts were observed for each of the $M2_{yt}$ fish sampled from the harvest downstream of the Soldotna Bridge. Separately for each year and time period, each allele count *x2* for fish *m2* at locus *h* is modeled as having a binomial($q_{z(m2),h}$,2) distribution, where q_{ih} is the frequency of allele *h* in stock group *i*. The integer quantity *z*(*m2)*, the stock identity index (1 to 6) for fish *m2*, has a categorical prior distribution with stock composition proportions (θ_{HLyt1},θ_{HLyt2},θ_{HLyt3},θ_{HLyt4},θ_{HLyt5},θ_{HLyt6}).

Allele counts were also observed for each of the $M3_{yt}$ fish sampled from the harvest upstream of the Soldotna Bridge. Separately for each year and time period, each allele count *x3* for fish *m3* at locus *h* is modeled as having a binomial($q_{z(m3),h}$, 2) distribution, where q_{ih} is the frequency of allele *h* in stock group *i*. The integer quantity *z*(*m3)*, the stock identity index (1 to 6) for fish *m3*, has a categorical prior distribution with stock composition proportions (θ_{HMyt1},θ_{HMyt2},θ_{HMyt3},θ_{HMyt4},θ_{HMyt5},θ_{HMyt6}). Harvest timing for fish harvested upstream of the Soldotna Bridge followed directly from the allele frequency data without the harvest timing assumptions described above.

Stock composition of the entire harvest where θ_{Hyi} equals (θ_{Hy1},θ_{Hy2},θ_{Hy3},θ_{Hy4},θ_{Hy5},θ_{Hy6}) was the weighted average of the stratum stock group proportions. This information was transferred to the SSART model using surrogate multinomial "data" that were constructed such that the number of counts (effective sample size) would supply stock composition information with precision equivalent to that contained in harvest allele frequency data.

Auxiliary information about the allele frequencies (q_{ih}) was available from baseline genetic samples collected on the spawning grounds of each stock (Rogers Olive et al. 2013). For each

[10] We supplied the harvest stock composition information in simplified multinomial form because it was not computationally feasible to integrate the two GSI mixture analyses into a single model.

stock group i, the baseline allele count Y at locus h is modeled as having a binomial(q_{ih},n_{ih}) distribution, where n_{ih} is the maximum number of possible instances[11] of allele h in fish sampled from the baseline of stock group i.

Prior Distributions

Bayesian analyses require that prior probability distributions be specified for all unknown parameters in the model. Annual abundance N_{iy} was hierarchical and lognormally distributed among years, independently by stock group. An inverse gamma(100,1) prior distribution was given to σ^2_I, which is equivalent to assuming that CPUE is related to true abundance with a CV of 0.1. All other root parameters of the model were assigned noninformative priors, designed to have minimal effects on the posterior.

MODEL FITTING

Markov Chain Monte Carlo (MCMC) methods, which are well-suited for modeling complex population and sampling processes, were employed. The MCMC algorithms were implemented in OpenBUGS (Lunn et al. 2009), which is a Bayesian software program. This methodology allows for inclusion of the effects of measurement error and missing data in the analysis, improves the ability to tease out process variation from observation error, and provides a more complete assessment of uncertainty than is generally possible with classical statistical methods.

Sampling from the Posterior Distribution

MCMC samples were drawn from the joint posterior probability distribution of all unknowns in the model. For results presented here, every sample from a single Markov chain was written to disk. Of these, the first 25,000 samples were discarded, and 50,000 additional samples were used to estimate the marginal posterior medians, standard deviations, and percentiles. The diagnostic tools of OpenBUGS were used to assess mixing and convergence, and no major problems were encountered. Interval estimates were constructed from the percentiles of the posterior distribution.

RESULTS

Point estimates reported below are posterior means; standard errors are posterior standard deviations.

INRIVER ABUNDANCE

Early Run and Late Run Inriver Abundance

Estimated Chinook salmon inriver abundance during the early run, defined as 16 May–30 June, declined from a high of 12,010 (SE 2,262) in 2007 to a low of 6,666 (810) in 2012 (Table 1). Estimated Chinook salmon inriver abundance during the late run, defined as 1 July–15 August, ranged from 47,280 (SE 9,505) in 2007 to 21,760 (SE 3,773) in 2010 (Table 1).

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[11] Two times the number of fish included in genetic baseline for each stock.

Table 1.–Early- and late-run abundance estimates of Kenai River Chinook salmon at RM 8.6.

	Early run		Late run	
Year	Mean (SD)	95% CI	Mean (SD)	95% CI
2007	12,010 (2,262)	8,382–17,340	47,280 (9,505)	31,970–69,990
2008	8,213 (948)	6,492–10,190	45,610 (6,026)	34,960–58,150
2009	9,848 (1,860)	6,866–14,050	41,650 (7,968)	29,160–58,890
2010	8,450 (1,258)	6,372–11,200	21,760 (3,773)	15,550–29,770
2011	9,179 (1,619)	6,663–12,880	27,030 (5,115)	19,140–38,750
2012	6,666 (810)	5,288–8,461	28,140 (3,885)	21,600–36,700

Note: A 95% credibility interval is reported as 2.5 and 97.5 percentiles from the posterior distribution.

Run Timing by Stock and Year

The SSART model structure also provides estimates of inriver abundance by stock and time strata (Appendix C1). The proportion of the run migrating past RM 8.6 varied in a consistent pattern from year to year. Most stock groups were present in 4 time strata, with over 90% of the total run returning in 3 time strata that encompass a period of approximately 6 weeks (Table 2). For fish from Killey River–Benjamin Creek, Funny River–Slikok Creek, and Quartz–Crescent creeks, over 88% of upstream passage occurred during the first 3 time strata, from 15 May to 30 June. For fish from Grant Creek and Russian River, over 92% of the upstream passage occurred during the third to fifth time strata, from 16 June to 31 July. For fish from Mainstem Kenai River–Juneau Creek, over 88% of the upstream passage occurred during the last 3 time strata, from 1 July to 17 August.

Stock Composition of the Run by Time Stratum and Year

Stock composition of the run varied annually but also changed in a predictable pattern over the course of the run (Table 3). Between 2007 and 2012, tributary-bound Chinook salmon composed most of the inriver run prior to 15 June. During the 16–31 May time stratum, the Killey River–Benjamin Creek fish were the largest percentage of the run (65–90%), followed by Funny River–Slikok Creek (8–31%) and Quartz Creek (2–5%). Similarly, during the 1–15 June time stratum, Killey River–Benjamin Creek fish composed 62–75% of the run and Funny River–Slikok Creek made up 16–32% of the run; Mainstem Kenai River–Juneau Creek followed with 2–9%. Together, the Killey River–Benjamin Creek and Funny River–Slikok Creek fish contributed over 87% of the inriver run during the first 2 time strata every year.

During the 16–30 June time stratum, several stocks made substantial contributions to the inriver run. Mainstem Kenai River–Juneau Creek fish were between 28% and 74% of the inriver run, Killey River–Benjamin Creek fish were between 17% and 49% of the inriver run, and Funny River–Slikok Creek fish were between 5% and 25% of the inriver run (Table 3). In 5 of 6 years, Mainstem Kenai River–Juneau Creek fish contributed the largest percentage of the inriver run during the 16–30 June time stratum.

During the 1–15 July time stratum, Mainstem Kenai River–Juneau Creek fish were at least 93% of the inriver run in every year with minor measurable contributions from most other stock groups (Table 3). After 15 July, Mainstem Kenai River–Juneau Creek fish were the only measurable contributor to the inriver run.

Table 2.–Run timing proportions $\{\pi_{iyt}\}$ and standard deviations (in parentheses) for Kenai River Chinook salmon at RM 8.6 by stock group, year, and time strata.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian
2007	May 16–31	0.12 (0.02)	0.08 (0.05)	0.00 (0.01)	0.00 (0.00)	0.12 (0.08)	0.00 (0.01)
	June 1–15	0.61 (0.06)	0.33 (0.12)	0.06 (0.07)	0.01 (0.00)	0.40 (0.13)	0.05 (0.06)
	June 16–30	0.24 (0.05)	0.46 (0.11)	0.30 (0.16)	0.04 (0.01)	0.41 (0.14)	0.27 (0.14)
	July 1–15	0.03 (0.02)	0.11 (0.09)	0.43 (0.14)	0.26 (0.03)	0.07 (0.06)	0.48 (0.14)
	July 16–31	0.00 (0.00)	0.01 (0.01)	0.19 (0.14)	0.58 (0.03)	0.00 (0.01)	0.17 (0.11)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.02 (0.04)	0.11 (0.01)	0.00 (0.00)	0.02 (0.03)
2008	May 16–31	0.12 (0.02)	0.11 (0.05)	0.00 (0.01)	0.00 (0.00)	0.14 (0.09)	0.00 (0.00)
	June 1–15	0.46 (0.05)	0.54 (0.10)	0.05 (0.06)	0.00 (0.00)	0.43 (0.14)	0.04 (0.04)
	June 16–30	0.37 (0.05)	0.29 (0.08)	0.29 (0.15)	0.02 (0.01)	0.36 (0.14)	0.28 (0.12)
	July 1–15	0.05 (0.03)	0.06 (0.05)	0.45 (0.14)	0.16 (0.02)	0.07 (0.06)	0.49 (0.12)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.19 (0.13)	0.41 (0.03)	0.00 (0.01)	0.18 (0.11)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.02 (0.03)	0.41 (0.03)	0.00 (0.00)	0.02 (0.02)
2009	May 16–31	0.26 (0.04)	0.09 (0.07)	0.00 (0.01)	0.00 (0.00)	0.15 (0.11)	0.00 (0.01)
	June 1–15	0.30 (0.05)	0.37 (0.13)	0.05 (0.06)	0.00 (0.00)	0.44 (0.14)	0.05 (0.05)
	June 16–30	0.34 (0.06)	0.42 (0.12)	0.33 (0.15)	0.07 (0.01)	0.34 (0.15)	0.33 (0.15)
	July 1–15	0.10 (0.07)	0.11 (0.10)	0.44 (0.14)	0.47 (0.03)	0.07 (0.07)	0.44 (0.14)
	July 16–31	0.00 (0.00)	0.01 (0.02)	0.16 (0.12)	0.34 (0.03)	0.00 (0.01)	0.16 (0.12)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.02 (0.03)	0.11 (0.01)	0.00 (0.00)	0.02 (0.02)
2010	May 16–31	0.12 (0.02)	0.12 (0.05)	0.00 (0.01)	0.00 (0.00)	0.16 (0.10)	0.00 (0.00)
	June 1–15	0.61 (0.05)	0.52 (0.09)	0.06 (0.06)	0.01 (0.01)	0.51 (0.13)	0.03 (0.03)
	June 16–30	0.25 (0.04)	0.31 (0.09)	0.38 (0.15)	0.08 (0.01)	0.28 (0.13)	0.24 (0.09)
	July 1–15	0.02 (0.02)	0.04 (0.03)	0.40 (0.14)	0.34 (0.03)	0.05 (0.05)	0.59 (0.10)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.14 (0.11)	0.42 (0.03)	0.00 (0.00)	0.13 (0.07)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.14 (0.01)	0.00 (0.00)	0.01 (0.02)
2011	May 16–31	0.16 (0.03)	0.27 (0.08)	0.00 (0.00)	0.00 (0.00)	0.16 (0.11)	0.00 (0.01)
	June 1–15	0.65 (0.04)	0.52 (0.09)	0.05 (0.05)	0.01 (0.00)	0.46 (0.14)	0.05 (0.05)
	June 16–30	0.17 (0.04)	0.19 (0.07)	0.30 (0.14)	0.11 (0.01)	0.31 (0.14)	0.29 (0.15)
	July 1–15	0.02 (0.02)	0.02 (0.02)	0.48 (0.13)	0.38 (0.03)	0.06 (0.06)	0.45 (0.13)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.16 (0.10)	0.43 (0.03)	0.00 (0.01)	0.19 (0.13)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.02 (0.02)	0.07 (0.01)	0.00 (0.00)	0.02 (0.03)
2012	May 16–31	0.32 (0.04)	0.23 (0.10)	0.00 (0.01)	0.00 (0.00)	0.18 (0.12)	0.00 (0.01)
	June 1–15	0.42 (0.04)	0.47 (0.10)	0.07 (0.07)	0.01 (0.00)	0.48 (0.13)	0.05 (0.06)
	June 16–30	0.24 (0.04)	0.26 (0.10)	0.40 (0.15)	0.04 (0.01)	0.29 (0.14)	0.29 (0.15)
	July 1–15	0.02 (0.01)	0.04 (0.04)	0.38 (0.13)	0.17 (0.02)	0.05 (0.05)	0.45 (0.14)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.14 (0.10)	0.45 (0.03)	0.00 (0.00)	0.18 (0.13)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.33 (0.03)	0.00 (0.00)	0.02 (0.03)

Table 3.–Stock composition $\{\theta_{yti}\}$ and standard deviations (in parentheses) of the inriver run for Kenai River Chinook salmon at RM 8.6 by stock group, year, and time stratum.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian
2007	May 16–31	0.74 (0.12)	0.19 (0.12)	0.00 (0.00)	0.01 (0.02)	0.05 (0.04)	0.00 (0.00)
	June 1–15	0.75 (0.06)	0.16 (0.06)	0.00 (0.00)	0.05 (0.04)	0.03 (0.02)	0.00 (0.00)
	June 16–30	0.32 (0.08)	0.25 (0.08)	0.02 (0.01)	0.36 (0.09)	0.04 (0.03)	0.01 (0.01)
	July 1–15	0.02 (0.01)	0.02 (0.02)	0.01 (0.01)	0.94 (0.03)	0.00 (0.00)	0.01 (0.00)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2008	May 16–31	0.67 (0.11)	0.28 (0.11)	0.00 (0.00)	0.00 (0.00)	0.05 (0.04)	0.00 (0.00)
	June 1–15	0.62 (0.06)	0.32 (0.06)	0.00 (0.00)	0.02 (0.02)	0.04 (0.02)	0.00 (0.00)
	June 16–30	0.49 (0.07)	0.17 (0.05)	0.01 (0.01)	0.28 (0.06)	0.03 (0.02)	0.02 (0.01)
	July 1-15	0.03 (0.02)	0.02 (0.01)	0.01 (0.01)	0.93 (0.03)	0.00 (0.00)	0.02 (0.01)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2009	May 16–31	0.90 (0.06)	0.08 (0.06)	0.00 (0.00)	0.01 (0.01)	0.02 (0.02)	0.00 (0.00)
	June 1–15	0.67 (0.07)	0.20 (0.07)	0.01 (0.01)	0.08 (0.04)	0.04 (0.02)	0.01 (0.01)
	June 16–30	0.33 (0.06)	0.10 (0.04)	0.01 (0.01)	0.52 (0.07)	0.01 (0.01)	0.02 (0.01)
	July 1–15	0.03 (0.02)	0.01 (0.01)	0.00 (0.00)	0.95 (0.02)	0.00 (0.00)	0.01 (0.00)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.99 (0.01)	0.00 (0.00)	0.00 (0.00)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2010	May 16–31	0.71 (0.09)	0.23 (0.09)	0.00 (0.00)	0.01 (0.01)	0.05 (0.03)	0.00 (0.00)
	June 1–15	0.69 (0.04)	0.19 (0.04)	0.00 (0.00)	0.09 (0.03)	0.03 (0.01)	0.00 (0.00)
	June 16–30	0.31 (0.06)	0.13 (0.04)	0.01 (0.01)	0.51 (0.07)	0.02 (0.01)	0.02 (0.01)
	July 1–15	0.01 (0.01)	0.01 (0.01)	0.01 (0.00)	0.94 (0.01)	0.00 (0.00)	0.03 (0.01)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.99 (0.00)	0.00 (0.00)	0.00 (0.00)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2011	May 16–31	0.65 (0.08)	0.31 (0.08)	0.00 (0.00)	0.01 (0.01)	0.02 (0.02)	0.00 (0.00)
	June 1–15	0.73 (0.05)	0.16 (0.04)	0.00 (0.00)	0.08 (0.03)	0.02 (0.01)	0.00 (0.00)
	June 16–30	0.17 (0.04)	0.05 (0.02)	0.02 (0.01)	0.74 (0.05)	0.01 (0.01)	0.01 (0.00)
	July 1–15	0.01 (0.01)	0.00 (0.00)	0.01 (0.01)	0.97 (0.01)	0.00 (0.00)	0.00 (0.00)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	August 1–10	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
2012	May 16–31	0.84 (0.06)	0.14 (0.06)	0.00 (0.00)	0.00 (0.00)	0.02 (0.02)	0.00 (0.00)
	June 1–15	0.71 (0.05)	0.18 (0.04)	0.01 (0.01)	0.08 (0.04)	0.03 (0.02)	0.00 (0.00)
	June 16–30	0.38 (0.07)	0.09 (0.04)	0.03 (0.02)	0.47 (0.08)	0.02 (0.01)	0.01 (0.00)
	July 1–15	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.96 (0.02)	0.00 (0.00)	0.00 (0.00)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)
	August 1–17	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.00)	0.00 (0.00)	0.00 (0.00)

HARVEST BY STOCK

Harvest Timing by Stock and Year

The SSART model structure also provides estimates of harvest by stock and time stratum (Appendices C2–C3). Like run timing, timing of harvest downstream of the Soldotna Bridge also varied in a consistent pattern. The largest stock groups were harvested in appreciable numbers in 4 time strata, with over 80% of the total harvest occurring in 2 time strata over a period of 1 month (Table 4). Harvest of fish from Killey River–Benjamin Creek, Funny River–Slikok Creek, and Quartz–Crescent creeks stock groups occurred primarily during the second and third time strata during 1–30 June. Harvest of fish from Mainstem Kenai River–Juneau Creek stock occurred during the fourth and fifth time strata during 1–31 July.

Table 4.–Harvest timing proportions and standard deviations (in parentheses) for Kenai River Chinook salmon harvested downstream of the Soldotna Bridge (RM 21) by stock group, year, and time strata.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian
2007	May 16–31	0.01 (0.01)	0.04 (0.02)	0.00 (0.00)	0.00 (0.00)	0.07 (0.14)	0.00 (0.01)
	June 1–15	0.48 (0.11)	0.63 (0.18)	0.01 (0.04)	0.00 (0.00)	0.39 (0.34)	0.01 (0.06)
	June 16–30	0.49 (0.11)	0.30 (0.18)	0.41 (0.35)	0.07 (0.03)	0.43 (0.34)	0.21 (0.29)
	July 1–15	0.02 (0.03)	0.03 (0.05)	0.35 (0.31)	0.27 (0.03)	0.09 (0.18)	0.53 (0.35)
	July 16–31	0.00 (0.01)	0.00 (0.01)	0.23 (0.30)	0.66 (0.04)	0.01 (0.07)	0.24 (0.31)
2008	May 16–31	0.05 (0.02)	0.09 (0.04)	0.00 (0.00)	0.00 (0.00)	0.07 (0.14)	0.00 (0.00)
	June 1–15	0.62 (0.07)	0.59 (0.10)	0.01 (0.06)	0.00 (0.00)	0.51 (0.33)	0.00 (0.02)
	June 16–30	0.29 (0.06)	0.29 (0.10)	0.17 (0.26)	0.02 (0.01)	0.35 (0.32)	0.24 (0.20)
	July 1–15	0.04 (0.05)	0.03 (0.05)	0.48 (0.35)	0.37 (0.04)	0.06 (0.14)	0.39 (0.25)
	July 16–31	0.00 (0.01)	0.00 (0.01)	0.34 (0.35)	0.61 (0.04)	0.00 (0.03)	0.37 (0.25)
2009	May 16–31	0.16 (0.04)	0.02 (0.04)	0.00 (0.00)	0.00 (0.00)	0.09 (0.18)	0.00 (0.00)
	June 1–15	0.38 (0.10)	0.73 (0.23)	0.01 (0.03)	0.00 (0.00)	0.42 (0.34)	0.01 (0.03)
	June 16–30	0.45 (0.09)	0.19 (0.20)	0.17 (0.25)	0.01 (0.01)	0.37 (0.33)	0.08 (0.15)
	July 1–15	0.02 (0.02)	0.05 (0.11)	0.47 (0.34)	0.55 (0.04)	0.10 (0.20)	0.71 (0.29)
	July 16–31	0.00 (0.01)	0.00 (0.03)	0.36 (0.35)	0.44 (0.04)	0.01 (0.05)	0.20 (0.27)
2010	May 16–31	0.18 (0.06)	0.02 (0.03)	0.00 (0.00)	0.00 (0.00)	0.10 (0.20)	0.00 (0.00)
	June 1–15	0.01 (0.01)	0.01 (0.01)	0.00 (0.02)	0.00 (0.00)	0.11 (0.17)	0.00 (0.01)
	June 16–30	0.80 (0.06)	0.94 (0.07)	0.43 (0.35)	0.03 (0.01)	0.71 (0.30)	0.33 (0.20)
	July 1–15	0.02 (0.03)	0.03 (0.05)	0.36 (0.31)	0.29 (0.04)	0.08 (0.16)	0.51 (0.21)
	July 16–31	0.00 (0.02)	0.00 (0.02)	0.21 (0.28)	0.69 (0.04)	0.01 (0.04)	0.16 (0.18)
2011	May 16–31	0.11 (0.04)	0.02 (0.03)	0.00 (0.00)	0.00 (0.00)	0.05 (0.11)	0.00 (0.00)
	June 1–15	0.41 (0.13)	0.16 (0.18)	0.00 (0.02)	0.00 (0.00)	0.37 (0.30)	0.00 (0.03)
	June 16–30	0.41 (0.12)	0.75 (0.21)	0.15 (0.24)	0.03 (0.01)	0.51 (0.32)	0.12 (0.19)
	July 1–15	0.07 (0.08)	0.07 (0.12)	0.52 (0.35)	0.46 (0.04)	0.06 (0.13)	0.66 (0.28)
	July 16–31	0.00 (0.02)	0.01 (0.03)	0.33 (0.35)	0.52 (0.04)	0.01 (0.04)	0.21 (0.26)
2012	May 16–31	0.26 (0.17)	0.07 (0.12)	0.00 (0.00)	0.00 (0.00)	0.10 (0.19)	0.00 (0.00)
	June 1–15	0.70 (0.17)	0.80 (0.23)	0.01 (0.05)	0.00 (0.00)	0.54 (0.34)	0.00 (0.01)
	June 16–30	0.02 (0.03)	0.05 (0.08)	0.09 (0.18)	0.00 (0.01)	0.22 (0.27)	0.07 (0.15)
	July 1–15	0.02 (0.05)	0.08 (0.18)	0.76 (0.28)	0.99 (0.02)	0.13 (0.25)	0.83 (0.24)
	July 16–31	0.00 (0.00)	0.00 (0.01)	0.13 (0.23)	0.01 (0.02)	0.00 (0.03)	0.10 (0.19)

Timing of harvest upstream of the Soldotna Bridge also varied in a consistent pattern from year to year. The majority of harvest of Killey River–Benjamin Creek fish occurred prior to 1 July (Table 5). The majority of harvest of Mainstem Kenai River–Juneau Creek fish occurred after 1 July. For the other stock groups, harvest timing was more varied from year to year as a result of very small and imprecise harvest estimates (Appendix C3).

Table 5.–Harvest timing proportions and standard deviations (in parentheses) for Kenai River Chinook salmon harvested between the Soldotna Bridge and Skilak Lake (RM 21–50) by stock group, year, and time strata.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian
2007	May 16–June 30	0.90 (0.05)	0.68 (0.25)	0.36 (0.20)	0.22 (0.08)	0.72 (0.19)	0.55 (0.27)
	July 1–31	0.10 (0.05)	0.32 (0.25)	0.64 (0.20)	0.78 (0.08)	0.28 (0.19)	0.45 (0.27)
2008	May 16–June 30	0.84 (0.05)	0.81 (0.16)	0.40 (0.23)	0.07 (0.03)	0.40 (0.18)	0.16 (0.11)
	July 1–31	0.16 (0.05)	0.19 (0.16)	0.60 (0.23)	0.93 (0.03)	0.60 (0.18)	0.84 (0.11)
2009	May 16–June 30	0.76 (0.10)	0.48 (0.28)	0.34 (0.24)	0.05 (0.03)	0.65 (0.26)	0.39 (0.27)
	July 1–31	0.24 (0.10)	0.52 (0.28)	0.66 (0.24)	0.95 (0.03)	0.35 (0.26)	0.61 (0.27)
2010	May 16–June 30	0.92 (0.05)	0.63 (0.26)	0.36 (0.26)	0.06 (0.02)	0.40 (0.28)	0.10 (0.10)
	July 1–31	0.08 (0.05)	0.37 (0.26)	0.64 (0.26)	0.94 (0.02)	0.60 (0.28)	0.90 (0.10)

Stock Composition of the Harvest by Time Stratum and Year

The stock composition of the harvest downstream of the Soldotna Bridge [RM 21] during each time stratum was similar to, but more variable than, the composition of the inriver run. Much of the variability comes from small GSI sample sizes resulting in imprecise stock composition estimates. Tributary bound Chinook salmon composed the majority of the harvest downstream of the Soldotna Bridge prior to 15 June. During the 16–31 May time stratum[12], Killey River–Benjamin Creek fish were the largest percentage of the harvest downstream of the Soldotna Bridge (51–96%), followed by Funny River–Slikok Creek fish (3–48%) (Table 6). During the 1–15 June time stratum[13], Killey River–Benjamin Creek fish were the largest percentage of the harvest downstream of the Soldotna Bridge (62–89%), followed by Funny River–Slikok Creek fish (7–37%). Together, these 2 stock groups composed over 90% of the harvest downstream of the Soldotna Bridge every year during the first 2 time strata. During the 16–30 June time stratum, several stocks made substantial contributions to the harvest downstream of the Soldotna Bridge. Killey River–Benjamin Creek fish were between 44% and 79% of the harvest, Funny River–Slikok Creek fish were between 7% and 27% of the harvest, and the Mainstem Kenai River–Juneau Creek fish were between 10% and 39% of the harvest (Table 6). In all years the fish from Killey River–Benjamin Creek were the largest percentage of the harvest downstream of the Soldotna Bridge during the 16–30 June time stratum.

During the 1–15 July time stratum, Mainstem Kenai River–Juneau Creek fish were at least 91% of the harvest downstream of the Soldotna Bridge in every year with minor contributions from most other stock groups (Table 6). After 15 July, Mainstem Kenai River–Juneau Creek fish were the only measurable contributor to the harvest downstream of the Soldotna Bridge.

[12] Ignoring 2007, when low angler effort resulted in insufficient GSI samples.
[13] Ignoring 2010, when fishery restrictions resulted in insufficient GSI samples.

Table 6.–Stock composition and standard deviations (in parentheses) for Kenai River Chinook salmon harvested downstream of the Soldotna Bridge (RM 21) by stock group, year, and time strata.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian
2007	May 16–31	0.25 (0.23)	0.72 (0.23)	0.00 (0.00)	0.00 (0.00)	0.03 (0.06)	0.00 (0.01)
	June 1–15	0.62 (0.10)	0.37 (0.10)	0.00 (0.00)	0.00 (0.01)	0.01 (0.01)	0.00 (0.00)
	June 16–30	0.44 (0.11)	0.14 (0.11)	0.01 (0.02)	0.39 (0.10)	0.01 (0.01)	0.01 (0.01)
	July 1–15	0.01 (0.02)	0.01 (0.02)	0.01 (0.01)	0.97 (0.03)	0.00 (0.00)	0.01 (0.01)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	1.00 (0.01)	0.00 (0.00)	0.00 (0.00)
2008	May 16–31	0.51 (0.16)	0.48 (0.16)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.00 (0.00)
	June 1–15	0.67 (0.08)	0.32 (0.08)	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.00 (0.00)
	June 16–30	0.54 (0.10)	0.27 (0.10)	0.00 (0.01)	0.15 (0.09)	0.01 (0.02)	0.02 (0.02)
	July 1–15	0.02 (0.03)	0.01 (0.01)	0.00 (0.01)	0.95 (0.03)	0.00 (0.00)	0.01 (0.01)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.99 (0.01)	0.00 (0.00)	0.01 (0.01)
2009	May 16–31	0.96 (0.05)	0.03 (0.04)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.00 (0.00)
	June 1–15	0.69 (0.15)	0.30 (0.15)	0.00 (0.00)	0.00 (0.02)	0.02 (0.02)	0.00 (0.00)
	June 16–30	0.79 (0.11)	0.08 (0.09)	0.01 (0.02)	0.10 (0.08)	0.01 (0.02)	0.01 (0.01)
	July 1–15	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)	0.98 (0.02)	0.00 (0.00)	0.01 (0.01)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.01 (0.01)	0.99 (0.01)	0.00 (0.00)	0.00 (0.01)
2010	May 16–31	0.94 (0.09)	0.05 (0.08)	0.00 (0.00)	0.00 (0.00)	0.02 (0.04)	0.00 (0.00)
	June 1–15			Closed to harvest			
	June 16–30	0.47 (0.09)	0.26 (0.09)	0.02 (0.02)	0.19 (0.07)	0.03 (0.03)	0.04 (0.02)
	July 1–15	0.01 (0.01)	0.00 (0.01)	0.01 (0.01)	0.95 (0.02)	0.00 (0.00)	0.03 (0.02)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.99 (0.01)	0.00 (0.00)	0.00 (0.01)
2011	May 16–31	0.95 (0.06)	0.03 (0.05)	0.00 (0.00)	0.00 (0.00)	0.02 (0.03)	0.00 (0.00)
	June 1–15	0.89 (0.09)	0.07 (0.08)	0.00 (0.00)	0.00 (0.01)	0.04 (0.04)	0.00 (0.00)
	June 16–30	0.47 (0.11)	0.19 (0.10)	0.00 (0.01)	0.29 (0.10)	0.03 (0.04)	0.01 (0.02)
	July 1–15	0.02 (0.02)	0.00 (0.01)	0.00 (0.00)	0.97 (0.02)	0.00 (0.00)	0.01 (0.01)
	July 16–31	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.99 (0.01)	0.00 (0.00)	0.00 (0.01)
2012	May 16–31	0.95 (0.06)	0.04 (0.06)	0.00 (0.00)	0.00 (0.00)	0.01 (0.02)	0.00 (0.00)
	June 1–15	0.83 (0.06)	0.15 (0.06)	0.00 (0.00)	0.00 (0.01)	0.02 (0.01)	0.00 (0.00)
	June 16–30			Closed to harvest			
	July 1–15	0.01 (0.03)	0.01 (0.03)	0.02 (0.03)	0.91 (0.08)	0.00 (0.01)	0.04 (0.04)
	July 16–31			Closed to harvest			

The stock composition of the harvest upstream of the Soldotna Bridge was estimated for 2 time strata: 16 May—30 June and 1 July—31 July. Tributary-bound Chinook salmon were the majority of the harvest upstream of the Soldotna Bridge prior to 1 July. Killey River–Benjamin Creek fish were the largest percentage of the harvest (62–75%), and Mainstem Kenai River–Juneau Creek fish (9–19%) were the second largest contributor to the harvest (Table 7). After 1 July, the harvest upstream of the Soldotna Bridge was predominantly Mainstem Kenai River–Juneau Creek fish (75–91%), although significant contributions from tributary stock groups were present (Table 7).

Table 7.–Stock composition and standard deviations (in parentheses) for Kenai River Chinook salmon harvested between the Soldotna Bridge and Skilak Lake (RM 21–50) by stock group, year, and time strata.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian
2007	May 16–June 30	0.62 (0.09)	0.05 (0.05)	0.04 (0.03)	0.19 (0.08)	0.09 (0.06)	0.02 (0.02)
	July 1–31	0.08 (0.05)	0.02 (0.02)	0.09 (0.06)	0.75 (0.08)	0.04 (0.04)	0.02 (0.02)
2008	May 16–June 30	0.73 (0.05)	0.08 (0.04)	0.02 (0.01)	0.09 (0.04)	0.06 (0.03)	0.02 (0.01)
	July 1–31	0.09 (0.03)	0.01 (0.01)	0.02 (0.02)	0.76 (0.05)	0.07 (0.04)	0.05 (0.02)
2009	May 16–June 30	0.64 (0.13)	0.06 (0.07)	0.04 (0.04)	0.16 (0.11)	0.07 (0.06)	0.03 (0.03)
	July 1–31	0.06 (0.03)	0.02 (0.02)	0.02 (0.02)	0.88 (0.04)	0.01 (0.01)	0.01 (0.01)
2010	May 16–June 30	0.75 (0.06)	0.04 (0.04)	0.01 (0.01)	0.17 (0.06)	0.01 (0.01)	0.01 (0.01)
	July 1–31	0.02 (0.02)	0.01 (0.01)	0.01 (0.01)	0.91 (0.03)	0.01 (0.01)	0.05 (0.02)

DISCUSSION

The SSART model was developed in 2010 as a way to assess Chinook salmon abundance in the Kenai River that was independent of inriver sonar. Traditional mark–recapture was ruled out as an alternative method to sonar because there was no means to conduct recapture events capable of achieving the desired level of precision in a cost-effective manner. Abundance estimates based on sport fishery exploitation rates (Hammarstrom and Hasbrouck 1998, 1999) were also ruled out because the sport fishery was frequently restricted after 2010. Adapted from the pioneering work of Bromaghin et al. (2010), the SSART approach obtains stock identification information from GSI data collected at the time of sampling, thus avoiding bias introduced by tagging and handling effects. It also allows annual estimates to be generated for previous years (in this case, beginning in 2007) using data collected for other stock assessment purposes. After 2011, partnership with the United States Fish and Wildlife Service (USFWS) to operate weirs on tributary streams improved the precision of SSART-based estimates.

SSART estimates of Chinook salmon run size for 2007–2012 consistently exceed sonar-based estimates for both early and late runs (Figure 3). When McKinley and Fleischman (2013) and Fleischman and McKinley (2013) included SSART and sonar estimates in run reconstructions utilizing multiple data sources, the model estimated that the fraction of Chinook salmon that are detected by the normal DIDSON sonar configuration at RM 8.6 was only 65% of the early-run passage and only 78% of late-run passage. Experimental deployments of additional sonar in 2011 and 2012 for short trial periods identified up to 29% more Chinook salmon greater than or equal to 75 cm DIDSON length (34 inches total length) migrating between the standard locations of the DIDSON sonar transducers and the shore (Miller et al. 2014; Miller et al. 2015). Large tidal fluctuations at the RM 8.6 site provide opportunities for fish to swim behind the sonar transducers during high tides but prohibit moving the transducers nearshore to count a larger fraction of the run. Beginning in 2013, sonar was deployed 5 miles upstream (RM 13.7) where bank-to-bank coverage is feasible.

A major assumption of the SSART model is that the catchability of Chinook salmon by the Inriver Gillnetting Project is constant across time strata. This assumption is particularly important for estimates of late-run abundance. Abundance is monitored directly at tributary weirs, providing an anchor for SSART estimates of early arriving fish. Late arriving fish (which are more likely to be mainstem than tributary fish) are never directly monitored, and late-run abundance estimates rely on the assumption of constant catchability. Beginning in 2013, we will have an opportunity to test this assumption as sonar counts at RM 13.7 become available.

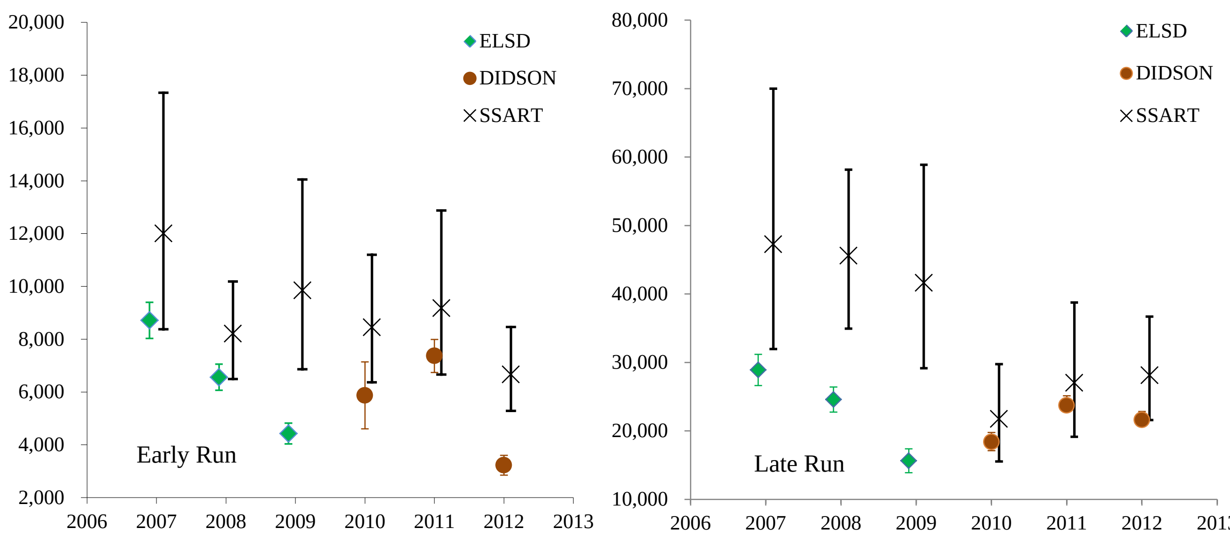

Figure 3.–A multiyear comparison of estimates of the number of Kenai River early- (left) and late-run (right) Chinook salmon passing RM 8.6 per year.

Note: Scales differ between graphs. ELSD means Echo-Length Standard Deviation from split beam sonar, DIDSON indicates multibeam imaging sonar, and SSART is the model described herein.

A second assumption of the SSART model is that, within each time stratum, Chinook salmon from all stocks have equal probabilities of being sampled. Length frequency distributions between fish sampled at tributary weirs and the Inriver Gillnetting Project (Figure 4) suggest that Funny and Killey River stocks differ in size distribution. Gillnets are known to sample fish selectively based on length (Hamley 1975). To test model sensitivity to gillnet sampling bias we reran the SSART model 2 times, once while omitting the 2012 Funny River weir count and again while omitting the 2012 Killey River weir count. If gillnet sampling resulted in biased stock composition estimates, SSART abundance estimates should change when weir counts from over- and undersampled stocks were used as an anchor. SSART estimates appeared to be minimally affected by gillnet sampling bias because early- and late-run abundance estimates changed by less than 3% when partial 2012 weir data were included. The model also estimated weir counts for the Funny and Killey Rivers when either weir count was omitted to within 2% of the actual count.

Our results with respect to stock composition are in general agreement with those of McKinley et al. (2013). McKinley et al. (2013) used 3 genetic reporting groups: lower tributary (comprising Benjamin Creek, Killey River, Funny River, and Slikok Creek), upper tributary (comprising Quartz Creek, Crescent Creek, Grant Creek, and Russian River), and mainstem (comprising upper Kenai mainstem and Juneau Creek). When grouped in this way, McKinley et al. (2013) found that the lower tributary group had the earliest run timing, the upper tributary group had intermediate run timing, and the mainstem group had the latest run timing.

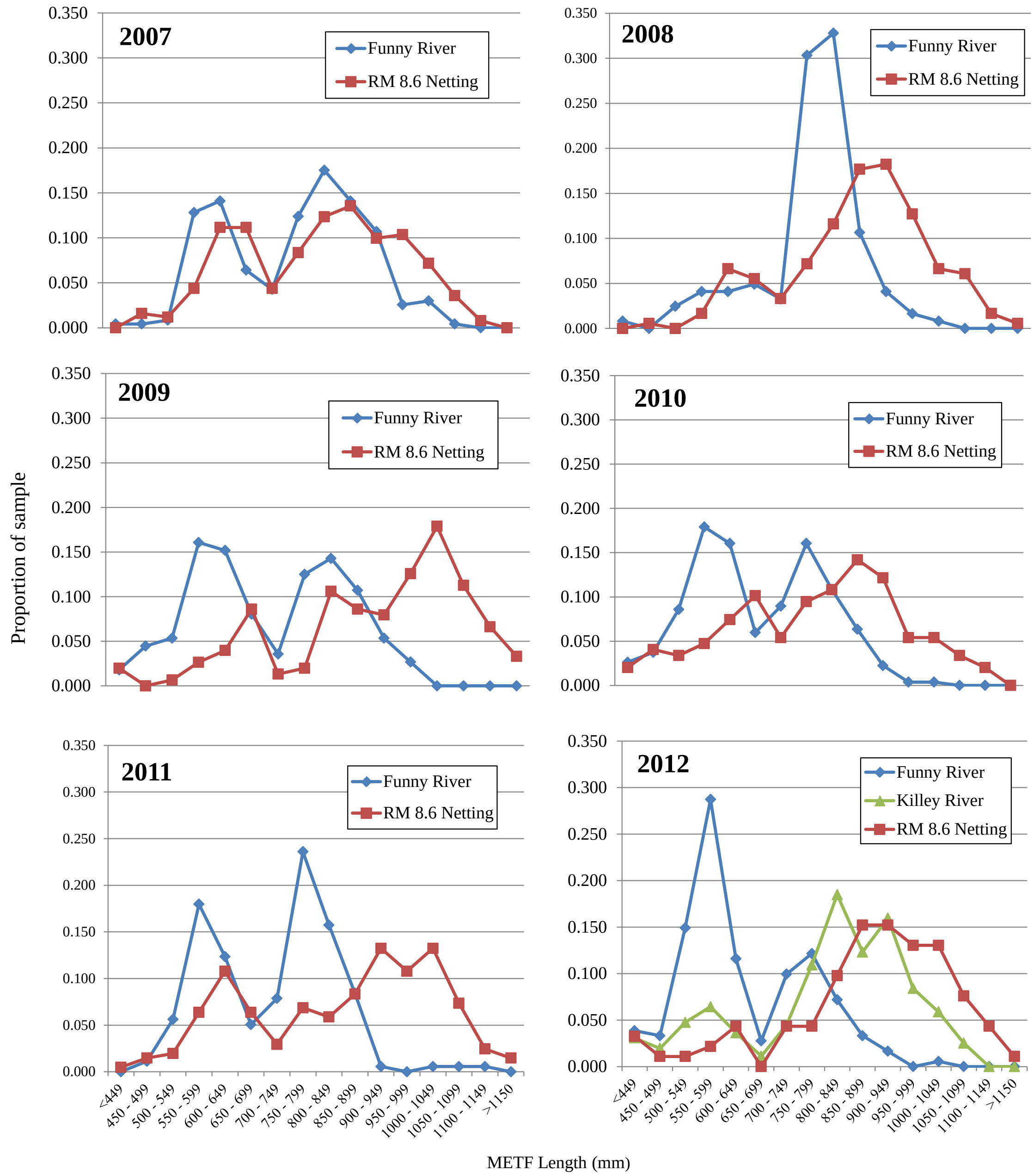

Figure 4.–Length distribution of Chinook salmon sampled at USFWS weirs on the Funny and Killey rivers and fish sampled by the RM 8.6 gillnetting project in 2007–2012.

The SSART model assumes that the Quartz–Crescent creeks stock group had similar mean run and harvest timing as the lower Kenai River tributaries. Both approaches appear to be reasonable. Posterior estimates for mean run timing of the Quartz–Crescent creeks stock group were intermediate to estimates for lower and upper tributary stocks when each stock was allowed a separate mean in an earlier version of the SSART model. Also, the date of capture for radiotagged Chinook salmon that eventually spawned in the Quartz Creek drainage spanned the dates of capture for other tributary stocks. In contrast, radiotelemetry data for Russian River and Grant Creek contradict the run timing estimates of either modeling approach. Of 9 fish eventually tracked to either the Russian River or Grant Creek between 2010 and 2014, the earliest was captured on 22 June and the latest was captured on 30 June. Run timing estimates for the Russian River and Grant Creek stocks produced by the SSART model (Table 2) and stock composition estimates for the upper tributary stock group from McKinley et al. (2013) suggest that the majority of fish from these stocks immigrate in July. The discrepancy between radiotelemetry data and GSI run timing information for upper Kenai River tributaries may be a sampling issue, because radio tag deployments were less frequent in July.

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APPENDIX A: PREVIOUSLY UNPUBLISHED DATA USED IN THE SSART MODEL

Appendix A1.–Genetic sample sizes used to produce the inriver run and harvest estimates of Kenai River Chinook salmon by year.

	Year					
Estimate	2007	2008	2009	2010	2011	2012
Run	369	469	516	512	699	436
Harvest lower [a]	386	379	368	443	340	142
Harvest middle [b]	147	359	191	356	0	0

[a] Below Soldotna Bridge, RM 0–21.

[b] Soldotna Bridge to Skilak Lake, RM 21–50.

Appendix A2.–Estimated Kenai River Chinook salmon harvest input data for the area downstream of the Soldotna Bridge (RM 21).

Year	Time stratum	Harvest	SE	CV [a]
2007				
	16–31 May	20	9	0.44
	1–15 June	959	176	0.18
	16–30 June	1,544	419	0.27
	1–15 July	2,184	311	0.14
	16–31 July	5,323	513	0.10
2008				
	16–31 May	144	38	0.27
	1–15 June	1,530	162	0.11
	16–30 June	895	140	0.16
	1–15 July	3,152	514	0.16
	16–31 July	5,109	457	0.09
2009				
	16–31 May	112	26	0.23
	1–15 June	387	113	0.29
	16–30 June	393	84	0.21
	1–15 July	3,494	324	0.09
	16–31 July	2,754	314	0.11
2010				
	16–31 May	79	22	0.28
	1–15 June[a]	1	1	1.00
	16–30 June	749	91	0.12
	1–15 July	1,465	266	0.18
	16–31 July	3,465	356	0.10
2011				
	16–31 May	59	18	0.30
	1–15 June	226	56	0.25
	16–30 June	518	144	0.28
	1–15 July	2,826	316	0.11
	16–31 July	3,174	411	0.13
2012				
	16–31 May	86	36	0.42
	1–15 June	227	86	0.38
	16–30 June [a]	1	1	1.00
	1–15 July	101	51	0.51
	16–31 July [a]	1	1	1.00

Source: Onsite creel surveys in Eskelin (2010) and Perschbacher (2012a-d, 2014)

[a] Because the fishery was closed or restricted downstream of the Soldotna Bridge, estimated harvest $N = 1$ and SE = 1 were used to keep the calculation from being undefined.

Appendix A3.–Estimated Kenai River Chinook salmon harvest input data for the area upstream of the Soldotna Bridge to Skilak Lake (RM 21–50) using guide logbook information and SWHS total harvest for the Kenai River, 2007–2012.

		SWHS total harvest		Reported guide logbook harvest			Harvest upstream of Soldotna Bridge		
Run	Year	Harvest	SE	Upstream[a]	Downstream[a]	Upstream/total	Harvest	SE	CV
Early run									
	2007	4,029	421	360	1,504	0.19	778	81	0.10
	2008	3,794	273	231	1,645	0.12	467	34	0.07
	2009	1,862	194	61	500	0.11	202	21	0.10
	2010	1,526	182	228	503	0.31	476	57	0.12
	2011	2,408	252	25	503	0.05	114	12	0.10
	2012	789	158	20	214	0.09	67	13	0.20
Late run									
	2007	14,039	679	239	5,001	0.05	640	31	0.05
	2008	12,314	601	310	4,693	0.06	763	37	0.05
	2009	8,569	489	285	3,108	0.08	720	41	0.06
	2010	7,686	467	566	2,177	0.21	1586	96	0.06
	2011	7,777	546	16	3,076	0.01	40	3	0.07
	2012 [b]						1	1	1.00

[a] Relative to the Soldotna Bridge.

[b] Because the fishery was closed upstream of the Soldotna Bridge, the estimated harvest $N = 1$ and SE = 1 were used to keep calculations from being undefined.

Appendix A4.–Kenai River drainage tributary Chinook salmon weir passages estimates, 2007–2012.

Year	Funny River [a]	Killey River [b]	Russian River	Slikok Creek
2007	2,075		88	
2008	1,246		110	68
2009	1,114		227	70
2010	1,187		164	28
2011	990		52	44
2012	879	1,602	43	27

[a] Boersma and Gates (2013); Gates and Boersma (2009a, 2009b, 2011).

[b] Gates and Boersma (2013).

Appendix A5.–Capture data for inriver gillnetting near RM 21, Kenai River, 2011–2012.

				Chinook salmon			Sockeye salmon					Water data	
Year	Date	Drifts (no.)	Minutes fishing	Capture (no.)	CPUE	SE (CPUE)	Capture (no.)	CPUE	SE (CPUE)	Eulachon	Dolly Varden	Clarity [a]	Temperature [b]
2011													
	2 Jun	16	86	7	0.055	0.055	11	0.086	0.086	0	0	37	0
	9 Jun	15	84	9	0.118	0.030	6	0.053	0.053	0	0	115	0
	15 Jun	15	56	8	0.145	0.042	2	0.037	0.037	0	0	150	9.4
	22 Jun	14	38	8	0.209		8	0.209		0	0	176	10
	29 Jun	16	57	8	0.241	0.156	1	0.011	0.011	0	0	60	11
	7 Jul	15	56	7	0.123	0.004	9	0.251	0.225	0	0	–	–
	13 Jul	9	32	8	0.330	0.131	0	0.000	0.000	0	0	92	11
2012													
	7 Jun	18	45	9	0.200	0.034	6	0.132	0.008	0	0	109	7.5
	13 Jun	15	36	9	0.322	0.236	2	0.080	0.080	0	0	82	8
	20 Jun	10	25	8	0.271	0.083	0	0.000	0.000	0	0	54	8.5
	27 Jun	20	74	3	0.048	0.028	1	0.010	0.010	0	0	44	9
	28 Jun	20	81	4	0.066	0.048	2	0.018	0.018	0	0	53	10.5
	4 Jul	14	36	11	0.394	0.232	0	0.000	0.000	0	0	–	–

Note: The symbol "–" indicates no samples taken.

[a] Visibility of a 12-inch Secchi disk in centimeters.

[b] Degrees Celsius.

Appendix A6.–Number of Kenai River Chinook salmon genetic samples included in the SSART model from supplementary harvest sampling by date, 2010–2012.

Year	Date	*n*
2010		
	18 May	1
	20 May	1
	26 May	1
	16 Jun	1
	18 Jun	3
	20 Jun	2
	22 Jun	9
	24 Jun	2
	25 Jun	2
	26 Jun	3
	29 Jun	6
	2 Jul	7
	3 Jul	7
	4 Jul	1
	6 Jul	13
	7 Jul	2
	13 Jul	7
	14 Jul	5
	16 Jul	4
	17 Jul	15
	20 Jul	32
	22 Jul	5
	23 Jul	9
	24 Jul	8
	27 Jul	8
	29 Jul	6
	31 Jul	1
2011		
	24 May	2
	27 May	3
	30 May	5
	17 Jun	3
	18 Jun	3
	21 Jun	2
	23 Jun	2
	29 Jun	1
	30 Jun	2

Year	Date	*n*
2012		
	29 May	2
	31 May	4
	1 Jun	1
	2 Jun	4
	4 Jun	6
	8 Jun	12
	9 Jun	2
	10 Jun	1
	11 Jun	5
	12 Jun	3
	4 Jul	2
	7 Jul	1

Appendix A7.–Number of Chinook salmon sampled by 14 professional fishing guides between 15 May and 30 June 2012.

Date	Number sampled	Comment
22 May	1	
23 May	1	
24 May	0	
25 May	0	
26 May	0	
27 May	0	
28 May	1	
29 May	1	
30 May	1	
31 May	5	
1 Jun	4	
2 Jun	6	
3 Jun	0	
4 Jun	0	
5 Jun	3	
6 Jun	2	
7 Jun	16	Samples from several guides during a charity fishing event
8 Jun	2	
9 Jun	2	
10 Jun	0	
11 Jun	0	
12 Jun	7	
13 Jun	3	
14 Jun	1	

APPENDIX B: OPENBUGS CODE

Appendix B1.–OpenBUGS code for Bayesian estimation of inriver abundance[14].

```
model{
# Prior information for run timing
  RT.mean.trib ~ dnorm(0,1.0E-2)I(0,5)
  RT.mean.i[4] ~ dnorm(0,1.0E-2)I(0,5)
  RT.mean.gr ~ dnorm(0,1.0E-2)I(0,5)
  RT.mean.i[1] <- RT.mean.trib
  RT.mean.i[2] <- RT.mean.trib
  RT.mean.i[3] <- RT.mean.gr
  RT.mean.i[5] <- RT.mean.trib
  RT.mean.i[6] <- RT.mean.gr
  RT.tau1.trib ~ dgamma(0.1,0.1)
  RT.tau1.mjgr ~ dgamma(0.1,0.1)
  RT.tau2 ~ dgamma(0.1,0.1)
  RT.tau3 ~ dgamma(0.1,0.1)
  log.HL.tau ~ dgamma(0.1,0.1)
  log.HM.tau ~ dgamma(0.1,0.1)
  RT.sigma1.trib <- 1 / sqrt(RT.tau1.trib)
  RT.sigma1.mjgr <- 1 / sqrt(RT.tau1.mjgr)
  RT.sigma2 <- 1 / sqrt(RT.tau2)
  RT.sigma3 <- 1 / sqrt(RT.tau3)
  HL.sigma <- 1 / sqrt(log.HL.tau)
  HM.sigma <- 1 / sqrt(log.HM.tau)

for(i in 1:C) {
    log.HLi.mean[i] ~ dnorm(0,1.0E-12)I(0,)
    log.HMi.mean[i] ~ dnorm(0,1.0E-12)I(0,)
    for(y in 1:Y) {
        log.HLiy[i,y] ~ dnorm(log.HLi.mean[i],log.HL.tau)I(1,)
        RT.mean.iy[i,y] ~ dnorm(RT.mean.i[i],RT.tau2)
        log.HMiy[i,y] ~ dnorm(log.HMi.mean[i],log.HM.tau)I(1,)
     }
}

for(y in 1:Y) {
     for(t in 1:T.L) {
          z[1,y,t] <- (t - RT.mean.iy[1,y]) / RT.sigma1.trib                    #Equations 5-6
          z[2,y,t] <- (t - RT.mean.iy[2,y]) / RT.sigma1.trib
          z[3,y,t] <- (t - RT.mean.iy[3,y]) / RT.sigma1.mjgr
          z[4,y,t] <- (t - RT.mean.iy[4,y]) / RT.sigma1.mjgr
          z[5,y,t] <- (t - RT.mean.iy[5,y]) / RT.sigma1.trib
          z[6,y,t] <- (t - RT.mean.iy[6,y]) / RT.sigma1.mjgr
    }
}

 for(y in 1:Y) {
     for(i in 1:C) {
          HL.iy[i,y] <- exp(log.HLiy[i,y])
          RT.sum[i,y] <- sum(RT[i,y,])
          HM.iy[i,y] <- exp(log.HMiy[i,y])
          D.sum[i,y] <- sum(D[i,y,])
    for(t in 1:T.L) {
        log.RunTiming[i,y,t] <- log(exp(- z[i,y,t]*z[i,y,t]/2))                 #Equation 4
        RT[i,y,t] ~ dlnorm(log.RunTiming[i,y,t],RT.tau3)                        #Equation 7
        pi[i,y,t] <- RT[i,y,t] / RT.sum[i,y]                                    #Equation 8
        HL.iyt[i,y,t] <- pi[i,y,t] * HL.iy[i,y]                                 #Equation 2
        theta.Lk[y,t,i] <- HL.iyt[i,y,t] / HL.yt[y,t]                           #Equation 9
```

-continued-

[14] Prior distributions are specified in green font; sampling distributions of the data (the "likelihood") are specified in blue font.

```
        }
    for(t in 1:T.M) {
        D[i,y,t] ~ dgamma(1,0.1)
        piM[i,y,t] <- D[i,y,t] / D.sum[i,y]
        HM.iyt[i,y,t] <- piM[i,y,t] * HM.iy[i,y]                    #Equation 2
        theta.Mk[y,t,i] <- HM.iyt[i,y,t] / HM.yt[y,t]               #Equation 9
        }
    }
    for(t in 1:T.L) {
      HL.yt[y,t] <- sum(HL.iyt[,y,t])
    }
    for(t in 1:T.M) {
      HM.yt[y,t] <- sum(HM.iyt[,y,t])
    }
  }

for(y in 1:Y) {
    for(t in 1:T.L) {
       log.HLyt[y,t] <- log(HL.yt[y,t])
       tau.HLyt[y,t] <- 1 / cv.HLyt[y,t] / cv.HLyt[y,t]
       log.HLyt.hat[y,t] ~ dnorm(log.HLyt[y,t], tau.HLyt[y,t])
     }
     for(t in 1:T.M) {
       log.HMyt[y,t] <- log(HM.yt[y,t])
       tau.HMyt[y,t] <- 1 / cv.HMyt[y,t] / cv.HMyt[y,t]
       log.HMyt.hat[y,t] ~ dnorm(log.HMyt[y,t], tau.HMyt[y,t])
     }
     for(i in 1:C) {
       H.iy[i,y] <- HL.iy[i,y] + HM.iy[i,y]
       theta.H[i,y] <- H.iy[i,y] / H.y[y]
       theta.L[i,y] <- HL.iy[i,y] / HL.y[y]
       theta.M[i,y] <- HM.iy[i,y] / HM.y[y]
     }
}

for(y in 1:Y) {
    HL.y[y] <- sum(HL.yt[y,])
    HM.y[y] <- sum(HM.yt[y,])
    H.y[y] <- HL.y[y] + HM.y[y]
}

#GSI stock composition
for(i in 1:C) {
    for(h in 1:A) {
        qd[i,h] ~ dbeta(0.5,0.5)
        Yd[i,h] ~ dbin(qd[i,h],nd[i,h])                  #Baseline Allele Frequencies
    }
}
for(i in 1:C) {                                          # YEAR 2007 (i.e. y=1)
    for(t in 1:T.L) {
        theta.Lk.1[t,i] <- theta.Lk[1,t,i]
    }
    for(t in 1:T.M) {
        theta.Mk.1[t,i] <- theta.Mk[1,t,i]
    }
}
```

-continued-

```
for(m2 in 1:M2[1]) {
    z2.1[m2] ~ dcat(theta.Lk.1[tstrat.L.1[m2],1:C])            #Stock Identification, Lower Harvest
    for(h in 1:A) {
        Xd2.1[m2,h] ~ dbin(qd[z2.1[m2],h],2)                   #Allele Counts,  Lower Harvest
    }
}
for(m3 in 1:M3[1]) {
    z3.1[m3] ~ dcat(theta.Mk.1[tstrat.M.1[m3],1:C])            #Stock Identification, Middle Harvest
    for(h in 1:A) {
        Xd3.1[m3,h] ~ dbin(qd[z3.1[m3],h],2)                   #Allele Counts, Middle Harvest
    }
}
for(i in 1:C) {                                                # YEAR 2008 (i.e. y=2)
    for(t in 1:T.L) {
        theta.Lk.2[t,i] <- theta.Lk[2,t,i]
    }
    for(t in 1:T.M) {
        theta.Mk.2[t,i] <- theta.Mk[2,t,i]
    }
}
for(m2 in 1:M2[2]) {
    z2.2[m2] ~ dcat(theta.Lk.2[tstrat.L.2[m2],1:C])
    for(h in 1:A) {
        Xd2.2[m2,h] ~ dbin(qd[z2.2[m2],h],2)
    }
}
for(m3 in 1:M3[2]) {
    z3.2[m3] ~ dcat(theta.Mk.2[tstrat.M.2[m3],1:C])
    for(h in 1:A) {
        Xd3.2[m3,h] ~ dbin(qd[z3.2[m3],h],2)
    }
}
for(i in 1:C) {                                                # YEAR 2009 (i.e. y=3)
    for(t in 1:T.L) {
        theta.Lk.3[t,i] <- theta.Lk[3,t,i]
    }
    for(t in 1:T.M) {
        theta.Mk.3[t,i] <- theta.Mk[3,t,i]
    }
}
for(m2 in 1:M2[3]) {
    z2.3[m2] ~ dcat(theta.Lk.3[tstrat.L.3[m2],1:C])
    for(h in 1:A) {
        Xd2.3[m2,h] ~ dbin(qd[z2.3[m2],h],2)
    }
}
for(m3 in 1:M3[3]) {
    z3.3[m3] ~ dcat(theta.Mk.3[tstrat.M.3[m3],1:C])
    for(h in 1:A) {
        Xd3.3[m3,h] ~ dbin(qd[z3.3[m3],h],2)
    }
}
for(i in 1:C) {                                                # YEAR 2010 (i.e. y=4)
    for(t in 1:T.L) {
        theta.Lk.4[t,i] <- theta.Lk[4,t,i]
    }
```

-continued-

```
    for(t in 1:T.M) {
        theta.Mk.4[t,i] <- theta.Mk[4,t,i]
    }
}
for(m2 in 1:M2[4]) {
    z2.4[m2] ~ dcat(theta.Lk.4[tstrat.L.4[m2],1:C])
    for(h in 1:A) {
        Xd2.4[m2,h] ~ dbin(qd[z2.4[m2],h],2)
    }
}
for(m3 in 1:M3[4]) {
    z3.4[m3] ~ dcat(theta.Mk.4[tstrat.M.4[m3],1:C])
    for(h in 1:A) {
        Xd3.4[m3,h] ~ dbin(qd[z3.4[m3],h],2)
    }
}
for(i in 1:C) {                                    # YEAR 2011 (i.e. y=5)
    for(t in 1:T.L) {
        theta.Lk.5[t,i] <- theta.Lk[5,t,i]
    }
}
for(m2 in 1:M2[5]) {
    z2.5[m2] ~ dcat(theta.Lk.5[tstrat.L.5[m2],1:C])
    for(h in 1:A) {
        Xd2.5[m2,h] ~ dbin(qd[z2.5[m2],h],2)
    }
}
for(i in 1:C) {                                    # YEAR 2012 (i.e. y=6)
    for(t in 1:T.L) {
        theta.Lk.6[t,i] <- theta.Lk[6,t,i]
    }
}
for(m2 in 1:M2[6]) {
    z2.6[m2] ~ dcat(theta.Lk.6[tstrat.L.6[m2],1:C])
    for(h in 1:A) {
        Xd2.6[m2,h] ~ dbin(qd[z2.6[m2],h],2)
    }
}
}
```

Appendix B2.–Annotated dataset for Bayesian estimation of inriver abundance.

```
list(C=6, Y=6, T=6, ones=c(1,1,1,1,1,1), quarters=c(0.25,0.25,0.25,0.25),
M=c(369,469,516,512,699,436),

log.SB.hat=c(NA,NA,NA,NA,NA,7.38),
bk=c(0,0,0,50,60,51),
b=c(0,0,0,19,28,21),

#from SWHS recalc
log.H.hat=c(9.35,9.40,8.99,8.96,8.85,6.18),
cv.H=c(0.066,0.060,0.059,0.059,0.078,0.223),

#from Harvest GSi theta v2.5a
x=structure(.Data=c(23,8,2,112,1,1,…),.Dim=c(6,6)),

#describes timestrata during capture relative to timestrata when passing rm 21
c8=structure(.Data=c(7,0,0,0,0,0, 23,20,0,0,0,0, 4,71,22,0,0,0, 0,6,16,7,0,0),.Dim=c(4,6)),
c21=c(7,43,97,29),

log.Syi.hat=structure(.Data=c(NA,7.66,NA,NA,NA,4.48,…),.Dim=c(6,6)),

log.index=structure(.Data=c(-1.41, 0.21, 0.09, 1.06, 1.85, 0.14,…),.Dim=c(6,6)),

z4=c(NA,NA,NA,1,1,NA,NA,1,NA,1,NA,NA,NA,NA,1,1,2,NA,1,1,NA,NA,NA,1,1,1,NA,NA,NA,1,1,1,…),
z5=c(NA,1,1,NA,1,1,NA,NA,NA,NA,1,1,NA,2,NA,NA,1,NA,2,NA,NA,NA,NA,NA,2,NA,NA,2,1,NA,1,…),
z6=c(1,1,1,1,NA,1,1,NA,1,NA,NA,1,NA,NA,2,1,NA,NA,2,NA,1,1,1,NA,NA,1,1,1,NA,1,1,NA,1,NA,1,…),

Yd=structure(.Data=c(668,240,735,685,589,105,…),.Dim=c(6,38)),
nd=structure(.Data=c(914,908,902,906,906,906,…),.Dim=c(6,38)),

tstrat1=c(1,…,2,…,3,…,4,…,5,…,6,…),
Xd1=structure(.Data=c(2,1,2,2,2,0,0,2,0,2,2,2,2,0,0,0,0,0,2,1,1,2,2,0,0,1,1,0,0,…),.Dim=c(369,38)),

…

tstrat6=c(1,…,2,…,3,…,4,…,5,…,6,…,NA,…),
tstrat6_21=c(NA,…,2,…,3,…,4,…),
Xd6=structure(.Data=c(1,1,2,1,0,0,1,2,0,1,2,1,1,0,0,1,0,0,2,0,0,1,2,0,0,2,2,0,0,…),.Dim=c(436,38)))
)
```

Appendix B3.–OpenBUGS code for harvest stock composition [15].

```
model{
# Prior information for run timing
  RT.mean.trib ~ dnorm(0,1.0E-2)I(0,5)
  RT.mean.i[4] ~ dnorm(0,1.0E-2)I(0,5)
  RT.mean.gr ~ dnorm(0,1.0E-2)I(0,5)
  RT.mean.i[1] <- RT.mean.trib
  RT.mean.i[2] <- RT.mean.trib
  RT.mean.i[3] <- RT.mean.gr
  RT.mean.i[5] <- RT.mean.trib
  RT.mean.i[6] <- RT.mean.gr
  RT.tau1.trib ~ dgamma(0.1,0.1)
  RT.tau1.mjgr ~ dgamma(0.1,0.1)
  RT.tau2 ~ dgamma(0.1,0.1)
  RT.tau3 ~ dgamma(0.1,0.1)
  log.HL.tau ~ dgamma(0.1,0.1)
  log.HM.tau ~ dgamma(0.1,0.1)
  RT.sigma1.trib <- 1 / sqrt(RT.tau1.trib)
  RT.sigma1.mjgr <- 1 / sqrt(RT.tau1.mjgr)
  RT.sigma2 <- 1 / sqrt(RT.tau2)
  RT.sigma3 <- 1 / sqrt(RT.tau3)
  HL.sigma <- 1 / sqrt(log.HL.tau)
  HM.sigma <- 1 / sqrt(log.HM.tau)

for(i in 1:C) {
    log.HLi.mean[i] ~ dnorm(0,1.0E-12)I(0,)
    log.HMi.mean[i] ~ dnorm(0,1.0E-12)I(0,)
    for(y in 1:Y) {
        log.HLiy[i,y] ~ dnorm(log.HLi.mean[i],log.HL.tau)I(1,)
        RT.mean.iy[i,y] ~ dnorm(RT.mean.i[i],RT.tau2)
        log.HMiy[i,y] ~ dnorm(log.HMi.mean[i],log.HM.tau)I(1,)
     }
}

for(y in 1:Y) {
     for(t in 1:T.L) {
         z[1,y,t] <- (t - RT.mean.iy[1,y]) / RT.sigma1.trib
         z[2,y,t] <- (t - RT.mean.iy[2,y]) / RT.sigma1.trib
         z[3,y,t] <- (t - RT.mean.iy[3,y]) / RT.sigma1.mjgr
         z[4,y,t] <- (t - RT.mean.iy[4,y]) / RT.sigma1.mjgr
         z[5,y,t] <- (t - RT.mean.iy[5,y]) / RT.sigma1.trib
         z[6,y,t] <- (t - RT.mean.iy[6,y]) / RT.sigma1.mjgr
    }
}

 for(y in 1:Y) {
     for(i in 1:C) {
         HL.iy[i,y] <- exp(log.HLiy[i,y])
         RT.sum[i,y] <- sum(RT[i,y,])
         HM.iy[i,y] <- exp(log.HMiy[i,y])
         D.sum[i,y] <- sum(D[i,y,])
    for(t in 1:T.L) {
```

[15] Prior distributions are specified in green font, sampling distributions of the data (the “likelihood”) are specified in blue font.

```
  log.RunTiming[i,y,t] <- log(exp(- z[i,y,t]*z[i,y,t]/2))
        RT[i,y,t] ~ dlnorm(log.RunTiming[i,y,t],RT.tau3)
        pi[i,y,t] <- RT[i,y,t] / RT.sum[i,y]
        HL.iyt[i,y,t] <- pi[i,y,t] * HL.iy[i,y]
        theta.Lk[y,t,i] <- HL.iyt[i,y,t] / HL.yt[y,t]
        }
    for(t in 1:T.M) {
        D[i,y,t] ~ dgamma(1,0.1)
        piM[i,y,t] <- D[i,y,t] / D.sum[i,y]
        HM.iyt[i,y,t] <- piM[i,y,t] * HM.iy[i,y]
        theta.Mk[y,t,i] <- HM.iyt[i,y,t] / HM.yt[y,t]
        }
    }
    for(t in 1:T.L) {
      HL.yt[y,t] <- sum(HL.iyt[,y,t])
    }
    for(t in 1:T.M) {
      HM.yt[y,t] <- sum(HM.iyt[,y,t])
    }
  }

for(y in 1:Y) {
    for(t in 1:T.L) {
        log.HLyt[y,t] <- log(HL.yt[y,t])
        tau.HLyt[y,t] <- 1 / cv.HLyt[y,t] / cv.HLyt[y,t]
        log.HLyt.hat[y,t] ~ dnorm(log.HLyt[y,t], tau.HLyt[y,t])
     }
     for(t in 1:T.M) {
        log.HMyt[y,t] <- log(HM.yt[y,t])
        tau.HMyt[y,t] <- 1 / cv.HMyt[y,t] / cv.HMyt[y,t]
        log.HMyt.hat[y,t] ~ dnorm(log.HMyt[y,t], tau.HMyt[y,t])
     }
     for(i in 1:C) {
        H.iy[i,y] <- HL.iy[i,y] + HM.iy[i,y]
        theta.H[i,y] <- H.iy[i,y] / H.y[y]
        theta.L[i,y] <- HL.iy[i,y] / HL.y[y]
        theta.M[i,y] <- HM.iy[i,y] / HM.y[y]
     }
}

for(y in 1:Y) {
    HL.y[y] <- sum(HL.yt[y,])
    HM.y[y] <- sum(HM.yt[y,])
    H.y[y] <- HL.y[y] + HM.y[y]
}
```

-continued-

```
#GSI stock composition
for(i in 1:C) {
    for(h in 1:A) {
        qd[i,h] ~ dbeta(0.5,0.5)
        Yd[i,h] ~ dbin(qd[i,h],nd[i,h])
    }
}
for(i in 1:C) {                              # YEAR 2007 (i.e. y=1)
    for(t in 1:T.L) {
        theta.Lk.1[t,i] <- theta.Lk[1,t,i]
    }
    for(t in 1:T.M) {
        theta.Mk.1[t,i] <- theta.Mk[1,t,i]
    }
}
for(m2 in 1:M2[1]) {
    z2.1[m2] ~ dcat(theta.Lk.1[tstrat.L.1[m2],1:C])
    for(h in 1:A) {
        Xd2.1[m2,h] ~ dbin(qd[z2.1[m2],h],2)
    }
}
for(m3 in 1:M3[1]) {
    z3.1[m3] ~ dcat(theta.Mk.1[tstrat.M.1[m3],1:C])
    for(h in 1:A) {
        Xd3.1[m3,h] ~ dbin(qd[z3.1[m3],h],2)
    }
}
for(i in 1:C) {                                      # YEAR 2008 (i.e. y=2)
    for(t in 1:T.L) {
        theta.Lk.2[t,i] <- theta.Lk[2,t,i]
    }
    for(t in 1:T.M) {
       theta.Mk.2[t,i] <- theta.Mk[2,t,i]
    }
}
for(m2 in 1:M2[2]) {
    z2.2[m2] ~ dcat(theta.Lk.2[tstrat.L.2[m2],1:C])
    for(h in 1:A) {
        Xd2.2[m2,h] ~ dbin(qd[z2.2[m2],h],2)
    }
}
for(m3 in 1:M3[2]) {
    z3.2[m3] ~ dcat(theta.Mk.2[tstrat.M.2[m3],1:C])
    for(h in 1:A) {
        Xd3.2[m3,h] ~ dbin(qd[z3.2[m3],h],2)
    }
}
```

-continued-

```
for(i in 1:C) {                                    # YEAR 2009 (i.e. y=3)
     for(t in 1:T.L) {
          theta.Lk.3[t,i] <- theta.Lk[3,t,i]
     }
     for(t in 1:T.M) {
          theta.Mk.3[t,i] <- theta.Mk[3,t,i]
     }
}
for(m2 in 1:M2[3]) {
    z2.3[m2] ~ dcat(theta.Lk.3[tstrat.L.3[m2],1:C])
    for(h in 1:A) {
         Xd2.3[m2,h] ~ dbin(qd[z2.3[m2],h],2)
    }
}
for(m3 in 1:M3[3]) {
     z3.3[m3] ~ dcat(theta.Mk.3[tstrat.M.3[m3],1:C])
     for(h in 1:A) {
          Xd3.3[m3,h] ~ dbin(qd[z3.3[m3],h],2)
     }
}
for(i in 1:C) {                                    # YEAR 2010 (i.e. y=4)
    for(t in 1:T.L) {
         theta.Lk.4[t,i] <- theta.Lk[4,t,i]
    }
    for(t in 1:T.M) {
         theta.Mk.4[t,i] <- theta.Mk[4,t,i]
    }
}
for(m2 in 1:M2[4]) {
     z2.4[m2] ~ dcat(theta.Lk.4[tstrat.L.4[m2],1:C])
     for(h in 1:A) {
          Xd2.4[m2,h] ~ dbin(qd[z2.4[m2],h],2)
     }
}
for(m3 in 1:M3[4]) {
     z3.4[m3] ~ dcat(theta.Mk.4[tstrat.M.4[m3],1:C])
     for(h in 1:A) {
          Xd3.4[m3,h] ~ dbin(qd[z3.4[m3],h],2)
     }
}
for(i in 1:C) {                                    # YEAR 2011 (i.e. y=5)
     for(t in 1:T.L) {
          theta.Lk.5[t,i] <- theta.Lk[5,t,i]
     }
}
for(m2 in 1:M2[5]) {
     z2.5[m2] ~ dcat(theta.Lk.5[tstrat.L.5[m2],1:C])
     for(h in 1:A) {
          Xd2.5[m2,h] ~ dbin(qd[z2.5[m2],h],2)
     }
}
for(i in 1:C) {                                    # YEAR 2012 (i.e. y=6)
     for(t in 1:T.L) {
          theta.Lk.6[t,i] <- theta.Lk[6,t,i]
     }
}
```

Appendix B4.–Annotated dataset for Bayesian estimation of harvest stock composition.

```
list(C=6, Y=6, T.L=5, T.M=2, A=38, M2=c(386,379,368,443,340,142), M3=c(147,359,191,356,0,0),

log.HLyt.hat=structure(.Data=c(3.00, 6.87, 7.34, 7.69, 8.58,…),.Dim=c(6,5)),

cv.HLyt=structure(.Data=c(0.44, 0.18, 0.27, 0.14, 0.10,…),.Dim=c(6,5)),

log.HMyt.hat=structure(.Data=c(6.66, 6.46, 6.15, 6.64,…),.Dim=c(6,2)),

cv.HMyt=structure(.Data=c(0.10, 0.05, 0.07, 0.05, 0.10,…),.Dim=c(6,2)),

Yd=structure(.Data=c(668,240,735,685,589,105,…),.Dim=c(6,38)),
nd=structure(.Data=c(914,908,902,906,906,906,…),.Dim=c(6,38)),

tstrat.L.1=c(1,…,2,…,3,…,4,…,5,…),
Xd2.1=structure(.Data=c(1,1,1,2,0,1,1,2,0,2,2,2,2,0,0,0,0,… ),.Dim=c(386,38)),

tstrat.M.1=c(1,…,2,…),
Xd3.1=structure(.Data=c(2,0,2,1,1,0,0,2,0,2,2,2,0,0,0,1,0,… ),.Dim=c(147,38)),

…

tstrat.L.6=c(1,…,2,…,3,…,4,…),
Xd2.6=structure(.Data=c(2,1,1,1,0,0,0,2,0,2,2,2,1,0,0,1,0,),.Dim=c(142,38))
)
```

APPENDIX C: ESTIMATES BY STOCK GROUP, TIME STRATUM, AND YEAR

Appendix C1.–Kenai River Chinook salmon inriver run estimates (and standard deviations) at RM 8.6 by stock group, year, and time stratum.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian	Total by time stratum
2007	May 16–31	857 (243)	222 (138)	1 (3)	13 (19)	57 (47)	1 (2)	1,151 (253)
	June 1–15	4,268 (986)	896 (322)	16 (22)	318 (236)	189 (117)	10 (13)	5,697 (1,139)
	June 16–30	1,668 (543)	1,247 (326)	81 (65)	1,903 (747)	200 (132)	58 (37)	5,158 (1,040)
	July 1–15	220 (165)	306 (247)	120 (83)	12,540 (2,918)	32 (35)	105 (54)	13,320 (2,887)
	July 16–31	9 (14)	18 (29)	56 (65)	28,390 (6,045)	2 (3)	38 (31)	28,520 (6,042)
	August 1–10	0 (0)	0 (2)	8 (19)	5,432 (1,200)	0 (0)	4 (6)	5,445 (1,198)
	Total by stock	7,021 (1,516)	2,689 (257)	281 (166)	48,600 (10,160)	481 (246)	216 (86)	
2008	May 16–31	586 (138)	241 (98)	0 (1)	2 (3)	43 (34)	1 (1)	873 (137)
	June 1–15	2,261 (432)	1,139 (227)	5 (8)	81 (66)	140 (75)	11 (12)	3,638 (479)
	June 16–30	1,821 (368)	605 (188)	32 (28)	1,052 (317)	116 (68)	76 (37)	3,702 (517)
	July 1–15	234 (152)	125 (106)	53 (41)	7,321 (1,245)	22 (25)	138 (56)	7,893 (1,235)
	July 16–31	10 (15)	6 (10)	23 (25)	18,820 (2,886)	1 (2)	51 (37)	18,910 (2,881)
	August 1–10	0 (0)	0 (0)	2 (5)	18,800 (2,859)	0 (0)	5 (7)	18,810 (2,858)
	Total by stock	4,913 (722)	2,115 (194)	116 (78)	46,080 (6,220)	322 (136)	282 (81)	
2009	May 16–31	1,403 (315)	120 (92)	1 (2)	10 (11)	33 (31)	1 (2)	1,567 (333)
	June 1–15	1,683 (419)	503 (173)	13 (16)	205 (113)	101 (65)	15 (16)	2,520 (517)
	June 16–30	1,894 (539)	569 (176)	77 (60)	3,032 (839)	84 (69)	104 (52)	5,761 (1,152)
	July 1–15	555 (417)	157 (141)	104 (72)	20,640 (4,355)	17 (26)	137 (49)	21,610 (4,382)
	July 16–31	17 (28)	11 (24)	40 (40)	14,970 (3,131)	1 (3)	51 (38)	15,090 (3,128)
	August 1–10	0 (1)	0 (2)	4 (7)	4,946 (1,061)	0 (0)	5 (7)	4,956 (1,060)
	Total by stock	5,552 (1,182)	1,360 (130)	238 (136)	43,800 (8,629)	236 (139)	313 (53)	

-continued-

Appendix C1.–Part 2 of 2.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian	Total by time stratum
2010	May 16–31	557 (132)	177 (73)	1 (1)	11 (11)	35 (27)	1 (1)	782 (144)
	June 1–15	2,765 (493)	742 (143)	9 (11)	350 (155)	115 (57)	12 (10)	3,994 (614)
	June 16–30	1,124 (294)	447 (134)	54 (35)	1,897 (497)	64 (45)	88 (38)	3,674 (640)
	July 1–15	112 (76)	64 (48)	57 (35)	8,029 (1,593)	11 (13)	217 (57)	8,490 (1,613)
	July 16–31	5 (7)	3 (5)	21 (20)	9,899 (1,907)	0 (1)	47 (27)	9,974 (1,911)
	August 1–10	0 (0)	0 (0)	2 (3)	3,287 (636)	0 (0)	5 (6)	3,295 (637)
	Total by stock	4,563 (774)	1,433 (128)	144 (69)	23,470 (4,178)	226 (99)	370 (67)	
2011	May 16–31	683 (176)	322 (95)	0 (1)	13 (11)	25 (21)	0 (0)	1,044 (206)
	June 1–15	2,840 (616)	609 (121)	10 (11)	329 (146)	74 (48)	4 (5)	3,865 (705)
	June 16–30	723 (218)	220 (88)	69 (48)	3,179 (708)	52 (41)	27 (17)	4,270 (842)
	July 1–15	95 (73)	29 (29)	117 (86)	11,420 (2,350)	10 (15)	43 (22)	11,710 (2,375)
	July 16–31	3 (6)	1 (2)	38 (37)	13,100 (2,672)	1 (1)	18 (16)	13,160 (2,679)
	August 1–10	0 (0)	0 (0)	4 (7)	2,147 (448)	0 (0)	2 (3)	2,154 (448)
	Total by stock	4,343 (884)	1,181 (111)	239 (143)	30,190 (5,725)	162 (90)	95 (36)	
2012	May 16–31	1,311 (229)	222 (99)	1 (2)	4 (5)	28 (26)	0 (0)	1,567 (233)
	June 1–15	1,744 (289)	444 (105)	14 (16)	191 (104)	75 (48)	3 (3)	2,470 (338)
	June 16–30	989 (228)	244 (97)	80 (54)	1,254 (318)	47 (40)	15 (9)	2,629 (392)
	July 1–15	77 (58)	36 (36)	78 (57)	5,125 (855)	8 (11)	23 (9)	5,348 (861)
	July 16–31	2 (4)	1 (3)	28 (31)	13,090 (2,064)	0 (1)	9 (7)	13,130 (2,064)
	August 1–17	0 (0)	0 (0)	2 (4)	9,667 (1,547)	0 (0)	1 (2)	9,670 (1,546)
	Total by stock	4,124 (530)	947 (89)	203 (118)	29,330 (4,101)	159 (94)	51 (13)	

Note: Individual estimates and totals may differ slightly due to rounding.

Appendix C2.–Lower Kenai River (below Soldotna Bridge [RM 21]) Chinook salmon harvest estimates and standard deviations by stock group, year, and time stratum.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian	Total by year
2007	May 16–31	6 (7)	18 (10)	0 (0)	0 (0)	1 (2)	0 (0)	
	June 1–15	578 (141)	345 (111)	0 (2)	2 (8)	6 (9)	0 (2)	
	June 16–30	612 (228)	198 (164)	18 (26)	545 (216)	9 (16)	7 (14)	
	July 1–15	23 (36)	18 (35)	12 (18)	2,171 (312)	2 (6)	19 (23)	
	July 16–31	2 (11)	2 (10)	11 (26)	5,294 (532)	0 (6)	9 (17)	
	Total by stock	1,222 (274)	581 (213)	41 (46)	8,013 (653)	18 (21)	36 (29)	9,911 (738)
2008	May 16–31	75 (32)	71 (31)	0 (0)	0 (0)	1 (3)	0 (0)	
	June 1–15	1,003 (164)	476 (133)	0 (2)	1 (4)	13 (16)	0 (2)	
	June 16–30	472 (116)	238 (97)	4 (8)	133 (84)	12 (21)	21 (20)	
	July 1–15	67 (82)	25 (43)	12 (17)	3,056 (509)	2 (7)	43 (44)	
	July 16–31	5 (23)	3 (15)	11 (24)	5,025 (458)	0 (1)	38 (41)	
	Total by stock	1,623 (227)	812 (182)	27 (32)	8,215 (693)	28 (30)	103 (69)	10,810 (723)
2009	May 16–31	112 (27)	3 (5)	0 (0)	0 (0)	1 (2)	0 (0)	
	June 1–15	285 (106)	121 (69)	0 (1)	1 (6)	6 (9)	0 (1)	
	June 16–30	328 (84)	33 (40)	4 (8)	39 (35)	6 (8)	3 (6)	
	July 1–15	12 (20)	10 (24)	14 (21)	3,430 (316)	2 (7)	40 (38)	
	July 16–31	2 (11)	1 (7)	14 (27)	2,731 (304)	0 (1)	10 (18)	
	Total by stock	739 (139)	167 (83)	33 (38)	6,201 (442)	15 (14)	53 (43)	7,209 (462)
2010	May 16–31	75 (23)	4 (7)	0 (0)	0 (0)	1 (3)	0 (0)	
	June 1–15			Closed to harvest				
	June 16–30	344 (76)	188 (69)	13 (17)	142 (56)	19 (21)	26 (17)	
	July 1–15	8 (14)	5 (13)	9 (12)	1,438 (263)	2 (5)	43 (29)	
	July 16–31	2 (9)	1 (3)	6 (12)	3,449 (346)	0 (1)	16 (24)	
	Total by stock	431 (82)	199 (71)	28 (24)	5,029 (439)	23 (22)	86 (44)	5,795 (448)
2011	May 16–31	60 (19)	2 (3)	0 (0)	0 (0)	1 (2)	0 (0)	
	June 1–15	256 (131)	21 (27)	0 (0)	1 (3)	9 (12)	0 (1)	
	June 16–30	249 (92)	103 (59)	2 (5)	156 (74)	16 (19)	6 (10)	
	July 1–15	45 (59)	10 (23)	10 (12)	2,768 (313)	2 (6)	30 (24)	
	July 16–31	3 (12)	1 (7)	7 (13)	3,164 (413)	0 (2)	13 (23)	
	Total by stock	613 (172)	137 (69)	19 (18)	6,088 (526)	28 (26)	49 (35)	6,934 (559)
2012	May 16–31	124 (118)	5 (12)	0 (0)	0 (0)	1 (2)	0 (0)	
	June 1–15	318 (153)	58 (38)	0 (1)	0 (2)	5 (6)	0 (0)	
	June 16–30			Closed to harvest				
	July 1–15	9 (30)	10 (39)	15 (19)	831 (710)	2 (7)	28 (31)	
	July 16–31			Closed to harvest				
	Total by stock	459 (192)	76 (53)	18 (19)	836 (710)	10 (9)	31 (31)	1,429 (802)

Note: Individual estimates and totals may differ slightly due to rounding

[a] Totals by year differ from creel survey harvest estimates (Appendix A2) because posterior distributions from the SSART model are affected by the other components of the probability model. Differences are minor unless harvests were estimated imprecisely outside of the model (for example, all time strata in 2012).

Appendix C3.–Middle Kenai River (Soldotna Bridge to the outlet of Skilak Lake [RM 21–50]) Chinook salmon harvest estimates and standard deviations by stock group, year, and time stratum.

Year	Time stratum	Killey–Benjamin	Funny–Slikok	Grant	Mainstem–Juneau	Quartz–Crescent	Russian	Total by year
2007	May 16–June 30	475 (82)	36 (39)	32 (26)	143 (65)	67 (47)	12 (12)	
	July 1–31	53 (29)	12 (14)	58 (37)	482 (60)	24 (23)	10 (11)	
	Total by stock	528 (88)	48 (45)	90 (51)	626 (92)	91 (57)	21 (17)	1,404 (83)
2008	May 16–June 30	343 (35)	37 (21)	9 (7)	42 (19)	30 (15)	7 (6)	
	July 1–31	67 (22)	8 (9)	17 (14)	578 (50)	50 (28)	40 (17)	
	Total by stock	411 (42)	45 (24)	27 (17)	620 (54)	80 (34)	48 (18)	1,230 (50)
2009	May 16–June 30	133 (30)	12 (15)	9 (9)	34 (23)	13 (13)	5 (6)	
	July 1–31	43 (22)	12 (13)	17 (14)	633 (48)	6 (6)	9 (8)	
	Total by stock	176 (38)	24 (22)	26 (18)	667 (54)	20 (16)	14 (10)	926 (48)
2010	May 16–June 30	364 (53)	19 (17)	7 (7)	85 (30)	5 (6)	7 (7)	
	July 1–31	34 (24)	10 (12)	15 (15)	1,434 (101)	11 (13)	73 (37)	
	Total by stock	398 (58)	29 (23)	21 (18)	1,519 (106)	16 (14)	81 (39)	2,064 (111)
2011	May 16–June 30	30 (24)	12 (15)	12 (14)	38 (27)	13 (15)	12 (14)	
	July 1–31	9 (7)	5 (5)	6 (5)	9 (7)	6 (6)	6 (5)	
	Total by stock	39 (26)	17 (16)	17 (16)	47 (28)	19 (17)	18 (16)	157 (12)
2012	May 16–June 30	18 (15)	9 (9)	8 (9)	22 (16)	9 (10)	9 (9)	74 (14)
	July 1–31	Closed to harvest						

Note: Individual estimates and totals may differ slightly due to rounding.