Fishery Manuscript Series No. 13-02

Run Reconstruction, Spawner–Recruit Analysis, and Escapement Goal Recommendation for Late-Run Chinook Salmon in the Kenai River

by

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and

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March 2013

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

fork length	FL
mideye to fork	MEF
mideye to tail fork	METF
standard length	SL
total length	TL

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, ^{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)	
probability of a type II error (acceptance of the null hypothesis when false)	
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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March 2013

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This document should be cited as:
Fleischman, S. J., and T. R. McKinley. 2013. Run reconstruction, spawner–recruit analysis, and escapement goal recommendation for late-run Chinook salmon in the Kenai River. Alaska Department of Fish and Game, Fishery Manuscript Series No. 13-02, Anchorage.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

ABSTRACT

An age-structured state-space spawner–recruit model was fit to estimates of relative and absolute abundance, harvest, and age composition for Kenai River late-run Chinook salmon (*Oncorhynchus tshawytscha*) from 1986 to 2012. Bayesian statistical methods were employed, which assessed uncertainty in the presence of measurement error, serial correlation, and missing data. It is recommended that an interim sustainable escapement goal of 15,000 to 30,000 fish be adopted for Kenai River late-run Chinook salmon, evaluated by multiplying DIDSON-based estimates of inriver abundance by 1.28 to account for undetected Chinook salmon passing the sonar site at river mile 9, and subtracting harvest and catch-and-release mortality above the current sonar site. It is recommended this goal be considered for revision after the sonar site is moved upriver. Annual runs of Kenai River late-run Chinook salmon are expected to remain below average in the near future.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, Kenai River, late run, spawning abundance, age composition, escapement goal, run reconstruction, spawner–recruit analysis, maximum sustained yield, measurement error, serial correlation, missing data, Bayesian statistics, OpenBUGS.

INTRODUCTION

Two stocks of Chinook salmon (*Oncorhynchus tshawytscha*) return to the Kenai River (Figure 1) to spawn. An early run enters the river from late April through June and spawns primarily in tributaries of the Kenai River. A late run enters the river from late June through early August, destined almost exclusively for mainstem spawning locations (Burger et al. 1985; Bendock and Alexandersdottir 1992).

Chinook salmon of Kenai River origin are harvested in several fisheries. The first measured harvest occurs in a recreational marine fishery near Deep Creek. A commercial set gillnet fishery along the eastern shore of Cook Inlet and, to a lesser degree, a commercial drift gillnet fishery also harvest late-run Chinook salmon while targeting sockeye salmon (*O. nerka*). Two single-net educational fisheries for the Kenaitze Indian tribe and the Village of Ninilchik have been authorized since 1989 and 1994, respectively. A personal use dip net fishery at the mouth of the Kenai River also harvests late-run Chinook salmon while targeting sockeye salmon. Finally, a Chinook salmon sport fishery occurs in the Kenai River itself.

FISHERIES MANAGEMENT

In 1988, the Board of Fisheries (BOF) adopted management plans for the early and late runs (McBride et al. 1989). These plans defined the early run as fish entering the river prior to 1 July and the late run as fish entering the river after 30 June. The dates and regulations associated with each management plan were designed to manage the unique characteristics of tributary-spawning Chinook salmon and mainstem-spawning Chinook salmon.

The Kenai River late-run Chinook salmon fishery is managed according to provisions of the *Kenai River Late-Run King Salmon Management Plan* (Alaska Administrative Code 5 AAC 21.359). In the original plan developed in 1988, the optimum spawning escapement was set at 22,300 fish, with management directives centered around 3 projected escapement levels: less than 15,500 fish; 15,500 to 19,000 fish; and greater than 22,300 fish. In 1999, the management plan was revised with a biological escapement goal (BEG) established as a range of 17,800 to 35,700 Chinook salmon. In 2011, the BEG was redefined as a sustainable escapement goal (SEG) because of uncertainty in escapement estimates due to the measurement error associated with split-beam target-strength-based (TS-based) sonar passage estimates of the number of Chinook salmon entering the river. The current management objective, as outlined in the plan, is to achieve adequate escapement defined as an SEG from 17,800 to 35,700 Chinook salmon.

Regulations for the Kenai River late-run Chinook salmon sport fishery include a daily bag and possession limit of one and a seasonal limit of two. Also, multiple hooks are prohibited, several areas of the drainage are closed to fishing for Chinook salmon, fishing from a motorized vessel is prohibited on Mondays, and guided anglers are restricted to fishing 5 days per week (Tuesday through Saturday) 12 hours per day (6:00 AM to 6:00 PM).

HISTORY OF RESEARCH ON KENAI RIVER LATE-RUN CHINOOK SALMON

A comprehensive stock assessment program was initiated by the Alaska Department of Fish and Game (ADF&G) in the mid-1980s to provide information for use in management of the Chinook salmon fisheries. Initially (1987–1994), dual-beam sonar technology was deployed at river mile 8.6 (herein referred to as RM 9) to estimate migrating fish. Target strength (TS) and range (distance from sonar transducer) were used to classify fish as Chinook salmon versus other species (Eggers et al. 1995). Split-beam sonar replaced dual-beam sonar in 1995 (Burwen et al. 1998). Considerable research has been conducted on Kenai River Chinook salmon since that time.

Investigations conducted in the 1990s began to indicate that target strength and range alone were ineffective for distinguishing between Chinook and sockeye salmon (Eggers 1994). Tethered fish and netting studies (Burwen et al. 1998) showed that many sockeye salmon exceeded the minimum TS threshold and migrated midriver, thus creating the potential for misclassifying sockeye salmon as Chinook salmon. Burwen et al. (1998) concluded that the TS-based sonar passage estimates were not accurate and recommended that the estimates be treated as an index rather than as an absolute number of fish. Subsequently, the TS-based sonar passage estimates were considered along with other indices of Chinook salmon abundance, such as catch rates in the inriver netting program and the inriver sport fishery, to assess run strength and to manage the fishery.

Radio-telemetry projects were conducted in 1996 and 1997 to estimate sport-fishery exploitation rates. These estimates, combined with creel survey estimates of harvest, provided independent estimates of inriver Chinook salmon abundance during the late run, when the potential to misclassify sockeye salmon was assumed to be the greatest (Hammarstrom and Hasbrouck 1998, 1999). An inriver gillnetting program was standardized in 1998 with respect to drift location, timing, and procedures (Reimer et al. 2002). In 2001, a pilot netting study investigated size selectivity and several other aspects of the netting program (Reimer 2003). Experiments conducted by tethering fish in front of the sonar (Burwen and Fleischman 1998; Burwen et al. 2003) found that duration of the returning echo ("echo length") was a better predictor of fish size than TS (a measure of echo loudness).

In 2002, as a result of the above research findings, 3 improvements to the sonar and inriver netting programs were implemented. The first improvement was to modify an existing inriver gillnetting program just downstream of the RM 9 sonar site. A 5-inch mesh gillnet was added, and drifted alternately with the existing 7.5-inch mesh gillnet, to capture a more representative sample of the size composition of fish entering the river (Reimer 2004). All gillnets were replaced with nets constructed of multi-fiber mesh, which captures fish more effectively than the original cable-lay nylon. Catch rates from the standardized inriver netting program have provided an important index of inriver run strength since 2002. The second improvement was to develop an alternative "*ELSD*" estimate of inriver abundance, based on the standard deviation of split-beam sonar echo length measurements and length measurements of Chinook and sockeye salmon from the inriver

gillnetting program. This information was combined to estimate the fraction of migrating fish that were Chinook salmon (Fleischman and Burwen 2003), which was then multiplied by total (all species) upstream fish passage estimates from the split-beam sonar ("total upstream passage"). The third improvement was to develop a second alternative estimate of inriver abundance based on sonar and netting data. The "*net-apportioned split-beam sonar"* estimate is the product of Chinook salmon catch proportions from the inriver netting program (Reimer 2004) and total upstream fish passage (all species) from the sonar program (Miller et al. 2005).

In addition to split-beam sonar, ADF&G began testing dual-frequency identification sonar (DIDSON) in the Kenai River in 2002. DIDSON uses a lens system that provides high resolution images that approach the quality achieved with conventional optics (Simmonds and MacLennan 2005), with the added advantage that images can be obtained in dark or turbid waters. Fish size measured from DIDSON images enabled discrimination of large Chinook salmon from smaller fish in the Kenai River (Burwen et al. 2007). In 2008, when high-resolution and long-range models of DIDSON became available (Burwen et al. 2010), DIDSON was deployed side-by-side with split-beam sonar on the south bank of the river. Beginning in 2010, DIDSON was deployed on both banks and produced estimates of inriver Chinook salmon abundance at a frequency sufficient for inseason management use. The 2010 DIDSON findings confirmed that TS-based estimates were subject to contamination by misclassified sockeye salmon (Miller et al. *In prep* a[1]). In 2011, limited onsite experiments found substantial numbers of large Chinook salmon migrating behind the left-bank transducer (Miller et al. *In prep* b[2]), and these findings were confirmed in 2012 (Burwen et al. *In prep*[3]). Tidally induced fluctuations of water level precluded counting these fish, and investigations of alternative sites were conducted in 2011and 2012 (personal communication, D. Burwen, ADF&G Anchorage).

In the mid-1990s, it became apparent that advances in genetic stock identification (GSI) technology (Adams et al. 1994) had potential for resolving some 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 for a "mixture" of fish of unknown origin (e.g., when there is a "mixture" of fish migrating upstream in a river or harvested in a fishery) by comparing the genetically-coded information from "the mixture" to the genetically-coded information from fish of known origin (the "baseline"). 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 netting project began in 2003, and by the inriver creel survey downstream of the Soldotna Bridge in 2006. Beginning in 2007, this was supplemented by mixture samples from the 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 SNPs markers reported in Barclay et al. (2012) for a Cook Inlet–wide baseline. The preliminary baseline includes more than 2,000 Chinook salmon collected over 11 spawning locations between 2003 and 2009, representing 10 populations.

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[1] Miller, J. D., D. L. Burwen, and S. J. Fleischman. *In prep* a. Estimates of Chinook salmon abundance in the Kenai River using split-beam and imaging sonars, 2010. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

[2] Miller, J. D., D. L. Burwen, and S. J. Fleischman. *In prep* b. Estimates of Chinook salmon abundance in the Kenai River using split-beam and imaging sonars, 2011. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

[3] Burwen, D. L., J. D. Miller, and S. J. Fleischman. *In prep*. Estimates of Chinook salmon abundance in the Kenai River using DIDSON imaging sonar, 2012. Alaska Department of Fish and Game, Fishery Data Series, Anchorage.

In 2010, Bromaghin et al. (2010) developed a new approach for modeling radiotelemetry, catch per unit effort (CPUE), and weir count data, fitting a stock-specific abundance and run-timing (SSART) model to obtain estimates of coho salmon abundance in the Kasilof River. ADF&G modified the model to utilize genetic stock identification (GSI) data from the inriver netting program and inriver creel survey, estimates of passage from weirs on the Funny and Russian rivers and Slikok Creek, estimates of harvest from the inriver creel survey and statewide mail survey (SWHS), and daily CPUE from the inriver netting project. Preliminary SSART model estimates (referred to in this report as CRGEN estimates, for genetic capture–recapture) have been produced for the years 2007–2012. More information on the SSART model is provided in Appendix D.

OBJECTIVES

ADF&G is currently transitioning to management of Kenai River Chinook salmon based on DIDSON/ARIS[4] assessment technology. Ultimately, this assessment will take place upstream of the current site where there is little or no tidal influence. Thus far, steps in this transition have included the commencement of DIDSON-based abundance estimates in 2010 (Miller et al. *In prep* a[1]), discontinuation of TS-based estimates in 2011 (Miller et al. *In prep* b[2]), and discontinuation of split-beam sonar in 2012 (Burwen et al. *In prep*[3]). TS-based abundance estimates were unavailable during the years 2011–2012 so Kenai Chinook salmon stocks were managed conservatively based on multiple indices of abundance. This report provides the foundation for the next step in the transition, which is management based on DIDSON estimates obtained at RM 9, beginning in 2013. Objectives of this report are as follows:

1) Conduct a comprehensive analysis of all relevant stock assessment data in the context of an integrated state-space model of historical run abundance and stock dynamics. The model assumes a Ricker spawner–recruit relationship and time-varying productivity. It has an age-structured framework, which enables a realistic depiction of observation error in inriver abundance, age composition, and harvest. The model is fit to multiple sources of information on historical abundance, as well as data on age composition and harvest, permitting simultaneous reconstruction of historical abundance and estimation of stock productivity and capacity. By constructing an integrated model, uncertainty associated with the run reconstruction flows through to the spawner–recruit analysis and to management reference points such as spawning escapement providing maximum yield (SMSY). Sensitivity analyses are conducted to assess robustness of the results to assumptions of the run reconstruction and spawner–recruit analyses.
2) Recommend an interim SEG based on DIDSON estimates of inriver abundance at RM 9. Normally, such a recommendation would be timed to coincide with a regularly scheduled BOF meeting. Optimally, a new escapement goal would not be developed until transition to a new sonar site is complete. However, the difficulty of managing recent large runs of sockeye salmon in the face of declining Chinook salmon abundance has created an urgent need for a goal based on the best available information, and one that can be implemented inseason using the best available stock assessment (DIDSON). These circumstances have necessitated an out-of-cycle escapement goal review.
3) Provide an updated summary of abundance, harvest, and age composition statistics for this stock for the years 1986–2012.

4 ARIS is the next generation of multi-beam imaging sonar technology. It produces images comparable to DIDSON or better.

METHODS

DATA SOURCES

The state-space model requires the following input data: 1) estimates and associated coefficients of variation (CV) of annual harvest downstream of ("below") and upstream of ("above") RM 9; 2) estimates of annual age composition for harvest below RM 9 and for the inriver run at RM 9 (Table 1–2); and, (3) estimates of annual relative and absolute abundance, with CVs for the absolute measures (Tables 3–4). Sources of these data components are described in the following sections.

Annual Harvest

Harvest Below RM 9

Kenai River late-run Chinook salmon are harvested by recreational anglers and by commercial set gillnet and commercial drift gillnet fisheries in Cook Inlet marine waters, by personal use and educational fisheries near the river mouth, and by sport anglers inriver. Commercial harvests were obtained from mandatory fish tickets issued at the fish processors (Shields and Dupuis 2012). Personal use harvests were estimated from returned harvest reports (Dunker 2010). Annual harvests in the subsistence-educational fishery are reported directly to Division of Sport Fish staff (Begich and Pawluk 2010). Sport harvests between the river mouth and RM 9 were estimated with an onsite creel survey (Perschbacher 2012a-b). Some Chinook salmon that are hooked and then released by anglers subsequently die. Hook-and-release mortality rates for Kenai River Chinook salmon were estimated to be 6.4% by Bendock and Alexandersdottir (1991, 1992). This rate was applied to estimates of released fish from the onsite creel survey (Perschbacher 2012a-b). Estimates of harvest in the Cook Inlet marine recreational fishery were obtained from the SWHS (Jennings et al. 2011).

Stock composition of fish harvested in the Upper Subdistrict Set Gillnet fishery ("eastside setnet fishery") was estimated by GSI in 2010 and 2011 (Appendix B). Estimates of the proportion of Kenai River fish in the harvest (0.647 in 2010; 0.727 in 2011) were applied to eastside setnet harvests for those years. The 2010–2011 average (0.687) was applied to eastside setnet fishery harvests for the years 1986–2009 and 2012.

Stock compositions of fish harvested in the marine recreational fishery and the marine drift gillnet commercial fishery are unknown. Because these fisheries are, on average, more distant from the mouth of the Kenai River than the eastside setnet fishery, we assumed that 60% of Chinook salmon harvested in these fisheries were bound for the Kenai River. We tested for sensitivity of the results to this assumption (see below, page 12).

Commercial, personal use, and educational harvests are known with relatively high precision. Estimates of sampling error were available from the onsite creel survey and statewide mail survey. Uncertainty associated with imputing the proportion of Kenai River fish in the eastside setnet fishery was not quantified directly, however for the state-space model, CVs of total harvests below RM 9 were assumed to be 0.15.

Harvest Above RM 9

Sport harvests between RM 9 and Soldotna Bridge were estimated with an onsite creel survey (Perschbacher 2012a-b). Estimates of sport harvest upstream of Soldotna Bridge were obtained with a statewide mail survey (Jennings et al. 2011). Estimates of sampling error from the onsite

creel survey and statewide mail survey were squared, summed, and divided by the summed harvest estimates to obtain CVs for the total harvests above RM 9.

Age Composition

The largest components of the total run were sampled for age composition (McKinley and Fleischman 2010). Age composition of the harvest below RM 9 was estimated by counting scale annuli (Mosher 1969) from fish sampled (annual sample size n_y ranged from 167 to 3,651 fish) from the commercial eastside set gillnet fishery (Tobias and Willette 2012). Age composition of the inriver run at RM 9 was estimated from fish sampled (n_y ranged from 206 to 1,647 fish) at the RM-9 inriver gillnetting project.

Measures of Abundance

DIDSON-based estimates of late-run Chinook salmon passage during 2010 through 2012 reported here are preliminary estimates from Miller et al. (*In prep* a-b[1-2]) and Burwen et al (*In prep*[3]). The DIDSON estimates are germane to all ages and sizes of Chinook salmon passing upstream between the sonar transducers at the RM-9 site. Annual catch rates from the inriver test gillnet fishery (NCPUE; Perschbacher 2012a-b) were obtained by summing daily catch rates from 1 July through 10 August. Net apportioned split-beam sonar estimates of Chinook salmon passages (NASB), and estimates based on ELSD during 2002 through 2009 were obtained from Miller et al. (*In prep* b[2]). Annual catch rates (guided anglers only) from the inriver sport fishery (SCPUE; Perschbacher 2012a-b) were obtained by summing daily estimates during 1–31 July. Values used for daily CPUE on unsampled days were the mean of sampled days from the same time strata. Annual catch rates from the commercial eastside set gillnet fishery (CCPUE; Shields and Dupuis 2012) were obtained from a Bayesian hierarchical analysis of daily catch rates, (personal communication, Xinxian Zhang, ADF&G Anchorage).

Radiotelemetry-based capture–recapture estimates of inriver run were available for 1996 and 1997 (CRTLM; Hammarstrom and Hasbrouck 1998, 1999). Because CRTLM estimates were germane to 1–31 July only, they were expanded to include 1–10 August based on daily values of CCPUE in those years. Preliminary estimates of inriver run were also available for 2007 through 2012 from genetic capture–recapture experiments (CRGEN) by fitting the SSART model to genetic allele frequency, radiotelemetry, harvest, and weir data (Appendix D).

Details of the annual measures of abundance are provided in Table 3; values of these measures are listed in Table 4.

STATE-SPACE MODEL

The state-space model serves to integrate all relevant information, and all parameters are estimated simultaneously, including historical abundance, stock productivity, and capacity. However it can be helpful to think of the model as having 2 components, a run reconstruction (RR) sub-model that synthesizes multiple sources of information on annual run abundance and a stock dynamics (SD) sub-model that synthesizes production, age at maturity, and harvest. The RR sub-model depends on 5 "index" measures (NCPUE, NASB, SCPUE, CCPUE, ELSD; defined in Table 3) to quantify the relative abundance among years. The time series of relative measures is anchored with recent sonar (DIDSON) and capture–recapture (CR) estimates of absolute abundance. DIDSON provides 3 precise annual estimates of a spatial subset of inriver abundance (fish migrating in the middle section of the river; see below) and CR (CRTLM and CRGEN) provides 8 annual estimates on the magnitude of total inriver abundance (Table 3).

For illustrative purposes, we ran the RR sub-model separately from the stock-recruit (SR) sub-model to produce intermediate run reconstruction estimates of inriver run abundance (Figure 2). In the RR model, each index has a linear relationship through the origin with true (midriver, inriver, or total) abundance (Figure 3). Estimates of these relationships were used to scale the individual indices in Figure 2.

The RM-9 sonar site is subject to tidal influence and the sonar transducers must be placed such that they remain submerged during the lowest tides. At high tide they are distant from shore and unable to sample the entire cross section of the river. Because of this constraint, some Chinook salmon swim behind the transducers and go undetected by the sonar.[5] The fraction $p_{MR,}$ of Chinook salmon that migrate "midriver" and are detected by the sonar at RM 9 cannot be estimated directly, because fluctuating water levels at the site would require continual re-deployment of transducers to ensonify the entire width of river. For this reason, reconstruction of Chinook salmon historical abundance requires one or more unbiased estimates of Chinook salmon inriver run. The current analysis relies on telemetry-based capture–recapture estimates in 1996 and 1997 (CRTLM) and preliminary estimates from genetic capture–recapture in 2007 through 2012 (CRGEN) to provide these estimates of inriver run.

In the full state-space model, abundance of Kenai River late-run Chinook salmon is driven by a Ricker (1975) spawner–recruit[6] (SR) function, which defines the number of fish expected to return (the "recruitment") from a given "escapement" (number of spawning fish). The Ricker SR relationship is the most common choice for modeling Pacific salmon stocks in Alaska. Productivity varies over time, fluctuating around a central tendency. Age at maturity is also allowed to fluctuate annually around a central tendency. Specifics of how model parameters (quantities) explain (predict) the observed data (abundance, harvest, age composition) are described below.

MODEL DETAILS

The total recruitment R produced from fish spawning in year y follows a Ricker (1975) formulation:

$$R_y = S_y \; e^{\;S} \tag{1}$$

where S is the number of spawners, parameter (number of recruits-per-spawner in the absence of density dependence) is a measure of productivity, and parameter is a measure of density dependence. The inverse of is the number of spawners that produces the theoretical maximum recruitment (S_{MAX}).

To account for time-varying productivity, which manifests as serially correlated model residuals, an autoregressive lognormal error term with a lag of 1 year (AR(1)) was included in the linearized form of the spawner–recruit function (Noakes et al. 1987).

$$\ln\left(R_y\right) = \ln\left(S_y\right) + \ln(\;\;) \qquad S_y + \; v_{y\;1} + \; _{Wy} \tag{2}$$

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[5] The existence of Chinook salmon passing behind the transducers was investigated multiple times, but not confirmed until an additional DIDSON was deployed to sample behind the left-bank transducer in 2011 (Miller et al. *In prep* b[2]).

[6] Often termed "stock–recruit" in the fisheries literature.

where is the lag-1 autoregressive coefficient, $\{v_y\}$ are model residuals

$$_y = \ln(R_y) \quad \ln(S_y) \quad \ln(\ ) + \quad S_y, \tag{3}$$

and $\{ _{Wy}\}$ are independently and normally distributed process errors with "white noise" variance ^2_W.

Age at maturity was modeled hierarchically; i.e., it was allowed to vary, to a specified extent, among cohorts. Age at maturity vectors[7] $\underline{\boldsymbol{p}}_{\boldsymbol{y}} = (p_{y4}, p_{y5,} p_{y6}, p_{y7})$ from year y returning at ages 3–7 were drawn from a *Dirichlet(* $_3$, $_4$, $_5$, $_6$, $_7$*)* distribution. The Dirichlet parameters can also be expressed in an alternate form, where

$$D = \quad _a \quad ^a \tag{4}$$

is the (inverse) dispersion[8] of the annual age-at-maturity vectors, reflecting consistency of age-at-maturity among brood years. The location parameters

$$_a = \frac{^a}{D} \tag{5}$$

are proportions that sum to one, reflecting the age-at-maturity central tendencies.

The abundance N of age-a Chinook salmon in calendar year y is the product of the age proportion scalar p and the total return (recruitment) R from year y-a:

$$N_{ya} = R_{y\ a} p_{y\ a,a}. \tag{6}$$

Total run during calendar year y is the sum of abundance at age across ages:

$$N_y = \quad _a N_{ya}. \tag{7}$$

Annual harvest H of Kenai-origin Chinook salmon below (downstream of) the stock assessment projects at RM 9 was modeled as the product of the annual harvest rate below RM 9 and total run:

$$H_{By} = \quad _{By} N_y. \tag{8}$$

Inriver run IR at RM 9 was calculated as follows:

$$IR_y = N_y \quad H_{By}. \tag{9}$$

---

[7] These age proportions are maturity and survival schedules for a given brood year (cohort), across calendar years. In contrast, Equation 19 describes age proportions in a given calendar year, across brood years.

[8] A low value of D is reflective of a large amount of variability of age-at-maturity vectors $\underline{\boldsymbol{p}}_{\boldsymbol{y}}$ among brood years, whereas a high value of D indicates more consistency in $\underline{\boldsymbol{p}}_{\boldsymbol{y}}$ over time.

Midriver run *MR* (number of fish migrating between the sonar transducers at RM 9) was the product of inriver run and the fraction p_{MR} of Chinook salmon migrating midriver and therefore detectable by the sonar:

$$MR_y = IR_y p_{MR}. \tag{10}$$

Annual harvest above RM 9 was the product of the annual harvest rate above RM 9 and inriver run abundance:

$$H_{Ay} = \quad_{Ay} IR_y. \tag{11}$$

Finally, spawning escapement *S* was inriver run abundance minus harvest above RM 9:

$$S_y = IR_y \quad H_{Ay}. \tag{12}$$

Sampling Distributions of Observed Data

Observed data included estimates of annual harvest below and above RM 9 (1986–2012), direct estimates of inriver run (CRTLM 1996–1997 and CRGEN 2007–2011), direct estimates of midriver run (DIDSON 2010–2012), 5 indices of inriver run relative abundance (NCPUE, NASB, SCPUE, CCPUE, and ELSD), and age composition estimates. Sampling distributions (likelihood functions) for the data follow.

Estimated midriver run of Chinook salmon from the DIDSON (Table 4) was calculated as follows:

$$DS_y = MR_y e^{\ DSy} \tag{13}$$

where $\{\ _{DSy}\}$ were normal (0, $^2_{DSy}$), and

$$^2_{DSy} = \ln\left(CV^2\left(DS_y\right)+1\right). \tag{14}$$

Estimated inriver runs of Chinook salmon from CRTLM and CRGEN (Table 4) were calculated as follows:

$$\hat{IR}_y = IR_y e^{\ IRy} \tag{15}$$

where $\{\ _{IRy}\}$ were normal (0, $^2_{IRy}$) and the variances followed Equation 14.

Estimated annual harvest of Kenai River Chinook salmon below RM 9 (Table 1) was calculated as follows:

$$\hat{H}_{By} = H_{By} e^{\ HBy} \tag{16}$$

where $\{\ _{HBy}\}$ were normal (0, $^2_{HBy}$). Coefficients of variation $\{CV_{HBy}\}$ were assumed to be 15%.

Estimated annual harvest of Kenai River Chinook salmon above RM 9 (Table 1) was calculated as follows:

$$\hat{H}_{Ay} = H_{Ay} e^{\varepsilon_{HAy}} \tag{17}$$

where the $\{\varepsilon_{HAy}\}$ were normal (0, σ^2_{HAy}). Point estimates $\{\hat{H}_{Ay}\}$ and CVs were obtained from inriver creel surveys and SWHS.

Five indices of abundance were available (Table 4). Each comprised an independent measure of relative abundance:

$$I_{iy} = q_i X_y \varepsilon_{iy} \tag{18}$$

where q_i is a factor of multiplication relating true abundance to index i, X_y is the generic true abundance (midriver run *MR* for NCPUE, NASB, and ELSD; inriver run *IR* for SCPUE; and total run *N* for CCPUE) and $\{\varepsilon_{iy}\}$ are independently and normally distributed process errors with variance σ^2_{Ii}. Parameters q_i and σ^2_{Ii} are estimated from the data.

The model predicts the age composition of the total run, however the data originated from 2 major components of the run: the harvest downstream of RM 9 and the inriver run at RM 9 (Table 2). Estimates of the age composition of the total run were obtained by weighting the age composition estimates from each component by the relative abundance of each component, obtained by running a stand-alone version of the run reconstruction submodel. Because the precision of age composition estimates is often overstated, an "effective sample size" of n_{Ey} = 100 was used. Surrogate scale-age counts x_{ya} were obtained that summed to n_{Ey} rather than n_y. The x_{ya} (listed in Appendix A2) were modeled as multinomially distributed, with order parameter n_{Ey} and proportion parameters as follows:

$$q_{y,a} = \frac{N_{y,a}}{\sum_a N_{y,a}}. \tag{19}$$

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, serially correlated process errors, and missing data in the analysis; and provides a more realistic assessment of uncertainty than is possible with classical statistical methods. By properly specifying process variation, measurement error, and time-dependent linkage separately in the model, biases in the analysis can be reduced (Su and Peterman 2012).[9]

Bayesian statistical methods employ the language of probability to quantify uncertainty about model parameters. Knowledge existing about the parameters outside the framework of the current analysis is the "prior" probability distribution. The output of the Bayesian analysis is called the "posterior" probability distribution, which is a synthesis of the prior information and the information contained in the data. See Fleischman et al. (*In press*), as well as Ericksen and

[9] It is not uncommon for Bayesian and traditional analyses to produce similar results. In that case, the benefit of the Bayesian analysis is in confirming that uncertainty in the analysis does not invalidate the results.

Fleischman (2006), Szarzi et al. (2007), Fleischman and Borba (2009), Fleischman and Evenson (2010), Fleischman et al. (2011), and Hamazaki et al. (2012) for similar applications of the methods used in this paper.

Prior Distributions

Non-informative priors (chosen to have a minimal effect on the posterior) were used for most parameters. Initial recruitments R_{1979}–R_{1985} (those with no linked spawner abundance) were modeled as drawn from a common lognormal distribution with median $_{logR}$ and variance $^{2}_{logR}$. Normal priors with mean zero, very large variances, and constrained to be positive, were used for ln( ) and (Millar 2002), as well as for $_{logR}$ and p_{MR}. The initial model residual $_{0}$ was given a normal prior with mean zero and variance $^{2}_{W}/(1-\ ^{2})$. Diffuse conjugate inverse gamma priors were used for $^{2}_{W}$ and $^{2}_{logR}$. Annual harvest rates ($_{By}$ and $_{Ay}$) were given beta (0.1, 0.1) prior distributions.

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 3rd sample from a single Markov chain was written to disk. Of these, the first 5,000 samples were discarded and 40,000 additional samples were used to estimate the marginal posterior medians, standard deviations, and percentiles. The diagnostic tools of OpenBUGS assessed mixing and convergence, and no major problems were encountered. Interval estimates were constructed from the percentiles of the posterior distribution.

REFERENCE POINTS, OPTIMAL YIELD PROFILE, 2013 FORECAST

Reference points were calculated for each individual MCMC sample. Spawning abundance providing maximum sustained yield S_{MSY} was approximated by (Hilborn 1985):

$$S_{MSY} \quad \frac{\ln(\quad)}{\quad}(0.5 \quad 0.7\ln(\quad)). \tag{20}$$

Sustained yield at a specified level of S was obtained by subtracting spawning escapement from recruitment:

$$Y_S = R \quad S = Se^{\ln(\quad) \ S} \quad S\ . \tag{21}$$

Other relevant quantities include harvest rate leading to maximum sustained yield, approximated by (Hilborn 1985)

$$U_{MSY} \quad \ln(\quad)(0.5 \quad 0.7\ln(\quad)), \tag{22}$$

escapement leading to maximum production

$$S_{MAXR} = \frac{1}{\quad}, \tag{23}$$

and equilibrium spawning abundance, where recruitment exactly replaces spawners

$$S_{EQ} = \frac{\ln(\quad)}{\quad}. \tag{24}$$

The quantity

$$\ln(\quad) = \ln(\quad) + \frac{\frac{2}{R}}{2(1 \quad ^2)} \tag{25}$$

in equations 20, 21, 22, and 24 adjusts for the difference between the median and the mean of a right-skewed lognormal error distribution from an AR(1) process.

The probability that a given spawning escapement S would produce average yields exceeding X% of *MSY* was obtained by calculating Y_S at incremental values of S (1,000 to 100,000 by 1,000) for each MCMC sample, then comparing Y_S with X% of the value of *MSY* for that sample. The proportion P_Y of samples in which Y_S exceeded X% of *MSY* is an estimate of the desired probability, and the plot of P_Y versus S is termed an optimal yield probability profile (Fleischman et al. *In press*).

The probability that recruitment would be reduced to less than X% of *MSY* by supplying too few spawners S was obtained by calculating Y_S at incremental values of S and tallying the number of MCMC samples for which Y_S was less than X% of *MSY* and S was less than S_{MSY}. A plot of the fraction of samples in which this condition occurred versus S is termed an overfishing profile (Bernard and Jones III 2010).

SENSITIVITY TO ASSUMPTIONS

There were 6 alternative configurations of the analysis conducted to test for robustness of the results (Table 5). For example, it is unlikely that all relative abundance indices are linearly related to abundance as shown in Figure 3. In alternative configuration model 1a, we relaxed the linearity assumption for CCPUE and allowed it to have an allometric relationship with true abundance. In alternative configuration 1b we allowed 4 of 5 (all except NASB) to have allometric relationships:

$$I_{iy} = q_i I R_y^{r_i} \quad _{iy} \tag{26}$$

where q_i and r_i are parameters of an allometric relationship between true abundance and index i, and $\{ \quad _{iy} \}$ are independently and normally distributed process errors with variance $^2_{Ii}$. Parameters q_i , r_i , and $^2_{Ii}$ were estimated from the data. We were unable to estimate allometric relationships for all five indices simultaneously due to mixing and convergence problems. Index CCPUE was perhaps most likely to depart from linearity because Chinook salmon from other stocks are represented in the marine commercial catch and the fishery targets sockeye salmon. Index NASB is more likely to be linearly related because 2010 daily sonar and netting data did not reveal any major departure from this assumption (Miller et al. *In prep* a[1]).

In alternative configurations 2a and 2b, acknowledging that the choice of $n_E = 100$ was arbitrary, we repeated the analysis with $n_E = 50$ and $n_E = 200$. In alternative configurations 3a and 3b, we repeated the analysis with the CVs of harvest below RM 9 assumed to be 0.10 and 0.20, respectively. In alternative configurations 4a and 4b, we repeated the analysis with marine recreational and drift commercial catches composed of 0% and 100% Kenai late-run-origin fish.

Alternative configuration 5 omitted data from the years 1986–2001, when abundance data were sparse and estimates depended solely upon 2 indices of relative abundance (SCPUE and CCPUE) and 2 annual CRTLM estimates of absolute abundance.

Alternative configuration 6 used a modified version of the base model that allowed for trending age at maturity (TAM). The TAM model was developed in an effort to produce forecasts of run size and age composition in 2013.[10] In the TAM model, the assumption of constant age at maturity was relaxed, by allowing expected age proportion parameters $_{3}$- $_{7}$ (Equation 5) to trend across brood years, as governed by a multivariate logistic (ML) function (Congdon 2003: p. 99):

$$_{ay} = \frac{\exp(_{ay} + _{ay}t)}{\sum_{a} \exp(_{ay} + _{ay}t)}. \quad (27)$$

Age at maturity of fish from individual brood year y was allowed to vary from the expected proportions following a *Dirichlet(* $_{3y}$, $_{4y}$, $_{5y}$, $_{6y}$, $_{7y}$*)* distribution, where

$$_{ay} = D \; _{ay}, \quad (28)$$

and inverse dispersion parameter D governed the degree that annual age at maturity departed from the ML model.

ESCAPEMENT GOAL REVIEW PROCESS

The recommended escapement goal was selected by an ADF&G departmental escapement goal review team with 4 staff from Soldotna and 6 from Anchorage (see Acknowledgements). The team met weekly from September 2012 through January 2013 to plan the escapement goal analyses and to interpret and discuss the results. The escapement goal recommendation was reached by consensus.

RESULTS AND DISCUSSION

HARVEST AND AGE COMPOSITION

Annual harvests of Kenai River late-run Chinook salmon below the sonar and netting stock assessments at RM 9 ranged from 630 fish in 2012 to nearly 20,000 fish in 2004 (Table 1). Annual harvests above RM 9 ranged from 101 fish in 2012 to nearly 20,000 fish in 1988. Age composition of the inriver run was predominately age-5 (1.3) and age-6 (1.4) fish, although fish harvested below RM 9 had greater proportions of age-3 (1.1) and age-4 (1.2) fish than the inriver run (Table 2).

The quantities above were estimated directly from stock assessment data, whereas those that follow were estimated by fitting the state-space model as described in the Methods section.

ABUNDANCE, TIME-VARYING PRODUCTIVITY, HARVEST RATES, AND AGE AT MATURITY

Abundance measures had positive relationships with one another (Figure 4) and showed common trends through time (Figure 2). Reconstructed estimates of inriver run abundance (*IR*; black line with error bars in Figure 2) synthesized information from all abundance measures, generally passing through the center of the scaled individual measures. Inriver runs were relatively large during the years 1986–1988, 1993–1995, and 2003–2005; but underwent a persistent decline starting in 2006. There were moderate year to year deviations from this trend among individual

[10] Forecasts are not included in this report.

abundance indices, but generally the indices were in agreement. Estimates of abundance from the RR were more precise in 1996, 1997, and 2002–2012 when direct estimates or multiple indices or both were available. Estimates were less certain in the years 1986–1995 and in 1998–2001, when the only information available was derived from 2 relative abundance indices (*SCPUE* and *CCPUE*).

The ratio p_{MR} of midriver abundance *MR* to inriver abundance *IR* is a key quantity because it is also the fraction of Chinook salmon detectable by the sonar at the RM-9 site. To date, we have no direct estimate of this quantity. The fitted model provides an indirect estimate of p_{MR} (0.78; 90% CI: 0.68–0.90) because it contains some overlapping data for *MR* and *IR*. The inverse of p_{MR} (p_{MR}^{-1} = 1.28; 90% CI: 1.11–1.48) can be applied as a correction factor to expand DIDSON-based estimates of midriver run to the full river cross section.

There is a great deal of uncertainty about escapement *S* in years without direct estimates of run abundance, with error CVs of up to 24% (Table 6, Figure 5a). Reconstructed total run abundance *N* (Figure 5c) and brood year recruitments *R* (Figure 5b) were more precise because they contain a harvest component, which was relatively well-estimated. Error CVs for *N* and *R* were 8–15% except for *R* at the beginning and end of the data series, when one or more age classes were missing (Table 6, Figure 5b,c). Productivity residuals show a persistent, though variable, decrease in productivity starting with the 2004 brood year (Figure 5d). Harvest rates on Kenai River late-run Chinook salmon ranged from 0.25 to 0.52 until 2012, when fishery restrictions reduced the harvest rate to 0.03 (Figure 5e).

Age at maturity has fluctuated moderately from brood year to brood year, likewise age composition has fluctuated from calendar year to calendar year (Figure 6). There is evidence of a trend toward earlier maturation in more recent years as shown in Figure 6 (top panel). See Sensitivity Analyses and Remaining Uncertainties for more discussion of this topic.

State-space model estimates of total run abundance by age class are tabulated in Appendix C.

STOCK PRODUCTIVITY, CAPACITY, AND YIELD

Ricker SR relationships that could have plausibly generated the observed data are varied (Figure 7), some deviating substantially from the "point estimate" of the Ricker relationship, constructed from the posterior medians of ln( ) and (Figure 7, heavy dashed line). The results from the state-space model take into account the measurement error in both *S* and *R* as depicted by the error bars in Figure 7, essentially weighting the individual data pairs depending on how precisely each one is estimated.

Compared to other Alaskan Chinook salmon stocks, productivity of Kenai River late-run Chinook salmon is moderate (= 4.9), although note the wide 90% credibility interval (CI 2.1–9.6; Table 7). Productivity of the stock has fluctuated over time, as evidenced by the moderately high serial correlation (= 0.51; 90% CI 0.04–0.88; Table 7) in the spawner–recruit residuals (Figure 5d). Imprecise estimates of the productivity parameter are typical of stocks with time-varying productivity and lower than optimal harvest rates.

The uncertainty about is evident in the large variation in slope at the origin among the individual curves (Figure 7). Similarly, uncertainty about is reflected in variability in the values of *S* leading to maximum recruitment S_{MAXR} = 1/ , and uncertainty about equilibrium abundance S_{EQ} is reflected by variability in where the curves intersect the replacement line. S_{EQ}

is estimated with reasonably high certainty (CI 41,790–83,840), as is spawning escapement leading to maximum sustained yield S_{MSY} (CI 15,140–32,590; Table 7). Posterior medians of S_{EQ} and S_{MSY} are 53,200 and 20,260, respectively.

Given the wide diversity of plausible spawner–recruit relationships (SRRs; Figure 7), it is important to choose an escapement goal that is robust to this uncertainty, rather than one tailored to any single SRR. The optimal yield probability profiles in Figure 8 were generated by tallying, across plausible SRRs, the success or failure of a given number of spawners to achieve stated percentages of maximum sustained yield (*MSY*). The profiles display the probability of achieving 70%, 80%, and 90% of *MSY* for specified levels of escapement. These probabilities, which are maximized near 20,000 spawning Chinook salmon (Figure 8), can be used to quantify the yield performance of prospective escapement goals, taking into consideration the uncertainty about the true abundance, productivity, and capacity of the stock.

Expected sustained yield (numbers of fish over and above those necessary to replace spawners for the 1986–2008 brood years) is also maximized near 20,000 spawners (Figure 9). Under reduced levels of productivity experienced during recent (2004–2008) brood years, expected yield is reduced to about one half of 1986–2008 average levels (Figure 9).

Expected recruitment (numbers of fish returning from a escapement, as specified by the Ricker relationship, for the 1986–2008 brood years) is maximized near S_{MAXR} = 32,120 spawners (Figure 10). Under 2004–2008 levels of productivity, expected recruitment is reduced to about 75% of the 1986–2008 average levels (Figure 10).

SENSITIVITY ANALYSES AND REMAINING UNCERTAINTIES

Lacking a complete time series of direct estimates of historical abundance, this investigation of the stock dynamics of late-run Kenai River Chinook salmon relied on indirect reconstruction of past quantities. The reconstruction was designed to extract maximum information from the available data, being careful to preserve, assess, and acknowledge the associated uncertainty. The statistical methods employed were well suited to fitting complex models. Nevertheless, several sources of uncertainty remain unquantified, and these are discussed below in the context of sensitivity to modeling assumptions.

A key assumption associated with the run reconstruction model is that the five index variables are linearly related to the underlying and unknown true abundance. Because direct estimates of abundance were not available during the peak abundance years of 2003 through 2005, there was not sufficient information in the data to relax this assumption entirely and estimate non-linear allometric relationships for all five indices. Model estimates were only mildly sensitive to the choice of how many indices departed from a linear relationship (Table 5: configurations 1a,b). Neither were the results sensitive to sampling error CV for harvest below RM 9 (Table 5: 3a,b). Extreme values (0 and 1) for the proportion of Kenai fish in marine recreational and driftnet commercial fisheries caused a 7% change in the posterior median of S_{MSY} (Table 5: 4a,b). However, 0 and 1 are implausible values. In the base analysis, we assumed 60% Kenai fish in these fisheries; plausible deviations from this value would have produced much smaller changes. Alternate values of effective sample size for age composition affected the AR(1) coefficient , which reflects the degree to which productivity changes over time, and the interannual dispersion D of age at maturity, but not S_{MSY} or p_{MR} (Table 5: configurations 2a,b).

Alternate configuration 5 omitted data from 1986 to 2001, which were considerably more sparse than those that followed (Table 4). This reduced the time span of the analysis to only 11 years (2002–2012), and the number of complete brood years to 4 (2002–2005).[11] Remarkably, although this change greatly reduced the estimates of and , the estimate of S_{MSY} was similar to that from the base analysis (8% lower) and p_{MR} increased only slightly from 0.78 to 0.80 (Table 5: configuration 5). Further, because a lower value of S_{MSY} recommends management for greater amounts of fishing, and a higher value of p_{MR} (more fish counted by the RM-9 DIDSON) recommends management for less fishing, the discordant differences in S_{MSY} and p_{MR} partially offset one another. The short and long datasets were therefore roughly in agreement with respect to escapement goal considerations.[12]

An alternate configuration of the model designed to accommodate a trend in age at maturity (the TAM model) affected several model parameters (Table 5: configuration 6). The point estimate of (reflecting average productivity) was reduced from 4.9 to 2.9 and the estimate of AR(1) productivity coefficient increased from 0.52 to 0.77 (i.e., a stronger recent decline in productivity). Differences in S_{MSY} and p_{MR} between the base and TAM models were less extreme but still noteworthy (S_{MSY} 12% higher; p_{MR} increased from 0.78 to 0.87). These differences point out the need for further investigation of age-at-maturity trends in this stock (see below).

The model assumes that capture–recapture estimates of inriver run abundance are unbiased, thereby providing the basis for reconstructing absolute numbers of fish during the historical record. Hypothetically, if capture–recapture estimates of the inriver run are biased and low, then the current estimate of S_{MSY} would also be too low.[13] On the other hand, capture–recapture estimates that are too low would lead to an estimate of p_{MR} that is too high.[14] The opposite is true if capture–recapture estimates are too high (estimates of S_{MSY} and p_{MR} too high and too low, respectively). As explained above, discordant differences in S_{MSY} and p_{MR} such as these would partially offset one another in terms of their effects on inseason management advice. Furthermore, the CRGEN estimates (Appendix D) are generated using new, evolving methodology designed to minimize bias, and we have no information to indicate a consistent directional bias in the estimates.

The consistent disparity between DIDSON and CRGEN estimates suggests that the sonar at RM 9 misses some migrating Chinook salmon. Experiments conducted in 2011 and 2012 at RM 9 confirmed the presence of fish "behind" the south-bank transducer (between the transducer and the river shore; Miller et al. *In prep* b[2]; Burwen et al. *In prep*[3]*).*[15] At this point in time, we must rely on estimates of p_{MR} from the state-space model in order to account for undetected fish at RM 9. We are hopeful that improved information about true inriver abundance and p_{MR} will be available after the 2013 season, when ARIS imaging sonar will be deployed at a new site upstream near RM 14. Because tides do not influence water level at the new sonar site, we expect to detect and count a very large fraction of Chinook salmon there. The RM-9 site will also continue to be operated in 2013, thereby permitting a comparison of abundance estimates

[11] The age-structured state-space model is also able to extract information from the incomplete (2006–2009) brood years (Fleischman et al. *In press*).

[12] We attribute this agreement to the fact that the short dataset provided good information about S_{EQ} and therefore S_{MSY} because the data points were centered around equilibrium abundance. That is, 4 of 8 brood years failed to replace themselves (Table 6: columns 4 and 5, 2003–2006).

[13] This can be easily verified by reducing all values of N in a spreadsheet version of the reconstructed brood table and observing the effect on the estimate of S_{MSY}.

[14] This assumes that DIDSON estimates are held constant.

[15] Before 2011, similar experiments conducted with DIDSON on the north bank had failed to detect fish migrating behind the transducer.

between the two sites[16] and providing additional, and more precise, information about p_{MR}. In addition, production of improved CRGEN estimates in 2013[17] may help to clarify this issue.

The relative role of density-dependent and density-independent factors for late-run Kenai River Chinook salmon also remains uncertain. Most of the cohorts represented in recent small runs (Table 6, e.g., 2009–2012) have originated from large escapements (Table 6, e.g., 2003–2006), which is consistent with density dependence playing a large role. But these runs also coincide with a statewide decline in Chinook salmon productivity thought to be due to factors, like marine survival, not related to stock-specific Chinook salmon density (ADF&G Chinook Salmon Research Team 2013). Given that improved stock assessment capabilities are now in place, future runs will be accurately assessed. Knowledge of the size of these runs, which originated from recent, small escapements, will bolster our understanding of recent stock dynamics. A rebound in upcoming runs would be consistent with the importance of density-dependent factors, whereas continued small runs would be consistent with density-independent explanations.

Finally, there is evidence of a trend toward earlier age at maturity for Kenai River late-run Chinook salmon (Figure 6). When the state-space model was modified to accommodate a trend in age at maturity (TAM), forecast performance[18] was improved and several model parameters were affected (Table 5: configuration 6). As discussed above, the TAM model indicated lower average productivity and a stronger recent decline in productivity. Additionally, the expectation for future run sizes was reduced, as were the anticipated recruitments from recent incomplete brood years (2007, 2008, 2009; not shown). The TAM model is new and has not been fit to data from other Pacific salmon stocks, whereas the base model has been applied to many such cases (e.g., Figure 11; see also Figure 7 in Fleischman et al. *In press*). Development of the TAM model will continue, so that it can be evaluated as a tool for forecasting and escapement goal analysis.

CONCLUSIONS

Despite the important uncertainties discussed above, several results from the current analysis are clear. First, productivity of Kenai River late-run Chinook salmon has fluctuated over time (Figure 5d). Second, the resulting trends in abundance (Figure 5c) are well estimated from the historical data (Figure 2), despite the lack of a complete set of direct estimates. In particular, every version of the run reconstruction developed during the current analysis, including all of those referenced herein, are in agreement that recent runs of late-run Chinook salmon to the Kenai River have been the smallest in recent history. Third, despite the small runs of recent years, a comprehensive analysis of stock productivity, capacity, and yield (fitting of the state-space model) failed to find evidence that the stock has been over-exploited. Escapements have exceeded the lower end of the recommended goal every year (Figure 12) and in recent years they have exceeded S_{MSY} in all but 2010 and 2011 (Figure 5a). Harvest rates have generally been well below U_{MSY} (Figure 5e, Figure 13). Finally, as discussed on page 15 above, key results (estimates of S_{MSY} and p_{MR}, which are most relevant to the escapement goal) were robust to a wide variety of alternate model/data configurations (Table 5).

[16] Harvest and spawning between the sites will be factored in to this analysis.
[17] The CRGEN estimates will benefit from an additional weir installed on Quartz Creek in 2013.
[18] 2013 forecasts are not provided in this report.

ESCAPEMENT GOAL RECOMMENDATION

Information about the range of escapements that will lead to optimal yields is summarized in the optimal yield profile (OYP; Figure 8). The steeper the limbs of the OYP, and the greater the maximum probability, the better the information about sustained yield at different levels of escapement. Compared to other Alaska Chinook salmon stocks that have been analyzed in a similar manner, the OYP for Kenai River late-run Chinook salmon (Figure 8) has better than average information content (Figure 11).

Based on the foregoing analysis, the Alaska Department of Fish and Game recommends an interim sustainable escapement goal (SEG) of 15,000–30,000 Kenai River late-run Chinook salmon. At the lower bound of the recommended range, there is a high probability of achieving near-optimal yields. For example, there is greater than 95% probability of achieving greater than 70% of MSY, and 73% probability of achieving greater than 90% of MSY on average (Figure 8). Conversely, the risk of overfishing relative to attaining 90% or more of MSY is 27%. At the upper bound of the recommended goal range there is a 68% probability of achieving greater than 80% of MSY at escapements of 30,000 fish (Figure 8). The recommended goal is based on the actual escapement needed to sustain yields, so that it must be evaluated by accounting for undetected Chinook salmon passing the RM-9 sonar site. This is accomplished by multiplying DIDSON-based estimates of passage by a correction factor to reflect Chinook salmon passage in the entire cross-section of the river. We recommend a correction factor of 1.28, which is obtained from the state-space model as the inverse of p_{MR} (point estimate 0.78), the fraction of Chinook salmon detected by sonar at RM 9. Projections of harvest and release mortality[19] above RM 9 must be subtracted from expanded DIDSON inriver passage estimates to project escapement during the fishing season.

The recommended interim escapement goal has the following attributes:

The new goal is transferable. The goal is expressed in the "currency" of actual fish, accounting for imperfect detection at the RM-9 site. Although the goal will be subject to review and revision (see below), it will not require reformulation after the planned transition to an upriver sonar site is complete.

The new goal is consistent with previous practice. Assuming perfect knowledge of the spawner–recruit relationship (= 4.9, = 0.000031) an escapement goal range of 13,000 to 28,000 would provide expected yields of at least 90% of *MSY*. Alternatively, according to Eggers (1993), an escapement goal range of 16,200 (0.8 × $S\hat{}_{MSY}$ point estimate) to 32,400 (1.6 × $S\hat{}_{MSY}$) would provide robust yield performance. In reality, our knowledge of , , and S_{MSY} is uncertain, and uncertainty about the true status of the stock creates risk. Our analysis quantifies uncertainty about key parameters and begins to assess risk in an organized way. However, there is no recipe for selecting an escapement goal based on the results of such an analysis. For example, in Figure 11, optimal yield profiles from 5 other recently-reviewed Chinook salmon stocks are reproduced and rescaled for comparison with the Kenai River late-run OYP, and probabilities of achieving 90% of *MSY* are plotted versus the lower bound[20] of the escapement

[19] Release mortality is obtained by multiplying creel survey estimates of number of fish released by 0.064 (Bendock and Alexandersdottir 1992).

[20] Given that large runs are not expected in the near future, the lower bound of the goal is currently more relevant than the upper bound for Kenai River late-run Chinook salmon.

goal for each stock. These lower-bound probabilities range from 43% to 96% for the 5 stocks.[21] The Kenai River late-run stock has probability 73% of achieving optimal yield at the lower bound of the recommended goal, which is consistent (ranked 3 of 6) with the other goals.

The new goal will protect the Kenai River late-run Chinook salmon stock from overfishing. Because DIDSON–based assessment represents a large advancement over previous methods, the ability to detect a small run and manage appropriately has been greatly improved. After transition of sonar assessment operations upriver to a site with fewer detection issues, assessment will be further enhanced. By combining accurate assessment with an escapement goal based on up-to-date knowledge of stock dynamics, we will continue to prevent overfishing of the stock.

The new goal will benefit Cook Inlet fisheries. Better assessment capabilities facilitate the timely transfer of accurate information to fishery managers during the season. Combined with an escapement goal based on an improved understanding of stock productivity, capacity, and yield, the effect is to reduce the potential for unnecessary fishery restrictions. Short-term risk to fisheries is thus minimized to an extent consistent with our mandate to sustain yields into the future. Although not addressed in this report, uncertainty associated with projecting Chinook salmon run abundance in real time during the fishing season remains an important challenge to managing these fisheries during periods of low Chinook salmon abundance.

Small runs are expected for the near future. Results of the run reconstruction and spawner–recruit analysis suggest that the Kenai River late-run stock has been undergoing a decline in productivity. The 2012 total run (28,550) was the smallest on record (Table 6), representing nearly a 4-fold decline from peak abundance in 2004 (99,690; Table 6). Similar declines have been documented for other Chinook salmon stocks statewide (ADF&G Chinook Salmon Research Team *In prep*[18]). Thus far, there is little evidence that the decline will soon be reversed. Based on the current analysis of historical data, escapements of 15,000–30,000 Kenai River late-run Chinook salmon can provide yields of approximately 35,000 fish (Figure 9; 80% CI 18,000–60,000). However this expectation of yield performance is based on "average" stock dynamics across brood years 1986 to 2008. During the most recent five brood years (2004–2008), productivity residuals have been negative (Figure 5d), averaging −0.37 (natural logarithm) units, which is equivalent to a 31% decline in productivity ($1 - e^{-0.37}$). Figure 9 also shows revised yield expectations, should the reduced productivity of recent brood years continue into the future. Under this scenario, expected yield would be approximately 20,000 for escapements within the goal range (80% CI 5,000–40,000), a reduction in yield of nearly 50% from average conditions.[22]

[21] The divergent risk probabilities in Figure 11 are a consequence of the differing sets of considerations that are relevant to each individual stock. Some of these considerations include status quo (i.e., current goal), type of fishery (commercial, sport, subsistence), recent history of the stock (declining or increasing), fishing power (ability to harvest large runs), and accuracy and timeliness of inseason assessment. In all cases, including for Kenai River late-run Chinook salmon, the recommended goal represents a compromise between these competing considerations, one that was arrived at after careful deliberation by the escapement goal review team.

[22] Under a modified version of the state-space model developed for forecasting, yield expectations are reduced even further. The modified "TAM" model accommodates a trend in age at maturity. Yield projections from the TAM model are not shown in this report.

The escapement goal for Kenai River late-run Chinook salmon will be periodically reviewed. All Pacific salmon escapement goals in the state of Alaska are subject to triennial review. This goal will merit attention for the following reasons:

1) Sonar assessment methodology remains in transition. Until this transition is complete, there will be uncertainty about the absolute magnitude of inriver abundance.

2) Sonar and capture–recapture estimates remain preliminary at the time of preparation of this report. Although we do not anticipate major changes in these estimates, they are subject to revision until published.

3) The recruitment from recent small escapements has yet to be assessed.[23] As the 2007–2009 cohorts complete their return, a more comprehensive understanding of productivity and age at maturity will emerge for this stock.

ACKNOWLEDGEMENTS

The escapement goal review team (EGRT) included the authors, and Robert Begich, Jason Pawluk, and Mark Willette of ADF&G Soldotna; and Bob Clark, Jack Erickson, Lowell Fair, Jim Hasbrouck, and Tom Vania of ADF&G Anchorage. Drafts of this report were reviewed by Milo Adkison of University of Alaska Fairbanks; Jim Jasper, Andrew Munro, and Eric Volk of ADF&G Anchorage; as well as by members of the EGRT listed above. Adam Reimer (ADF&G Soldotna) reviewed an early draft and provided genetic capture–recapture estimates. Jim Jasper and Xinxian Zhang of ADF&G Anchorage provided statistical help.

[23] The lowest escapement from which the recruitment is complete was 27,760 in 1997, which produced 71,250 returning adults (Table 6). Returns from the small 2009 escapement (21,390) will commence as age-4 fish return in 2013, and from the smaller 2010 escapement (16,210) as age-4 fish return in 2014 (Table 6).

REFERENCES CITED

Adams, N. S., W. J. Spearman, C. V. Burger, K. P. Currens, C. B. Schreck, and H. W. Li. 1994. Variation in mitochondrial DNA and allozymes discriminates early and late forms of Chinook salmon (*Oncorhynchus tshawytscha*) in the Kenai and Kasilof Rivers, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 51 (Supplement 1): 172-181.

ADF&G Chinook Salmon Research Team. 2013. Chinook salmon stock assessment and research plan, 2013. Alaska Department of Fish and Game, Special Publication No. 13-01, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/SP13-01.pdf

Barclay, A. W., C. Habicht, R. A. Merizon, and R. J. Yanusz. 2012. Genetic baseline for Upper Cook Inlet Chinook salmon: 46 SNPs and 5,279 fish. Alaska Department of Fish and Game, Fishery Manuscript Series No. 12-02, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMS12-02

Begich, R. N., and J. A. Pawluk. 2010. 2008-2010 Recreational fisheries overview and historical information for North Kenai Peninsula: fisheries under consideration by the Alaska Board of Fisheries, February 2011. Alaska Department of Fish and Game, Fishery Management Report No. 10-51, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMR10-51.pdf

Begich, R. N., W. D. Templin, A. W. Barclay, and L. W. Seeb. 2010. Development of microsatellite genetic markers for Kenai River Chinook salmon. Alaska Department of Fish and Game, Fishery Data Series No. 10-38, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS10-38.pdf

Bendock, T. N., and M. Alexandersdottir. 1991. Hook-and-release mortality in the Kenai River Chinook salmon recreational fishery. Alaska Department of Fish and Game, Fishery Data Series No. 91-39, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds91-39.pdf

Bendock, T. N., and M. Alexandersdottir. 1992. Mortality and movement behavior of hooked-and-released Chinook salmon in the Kenai River recreational fishery, 1989-1991. Alaska Department of Fish and Game, Fishery Manuscript No. 92-02, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fms92-02.pdf

Bernard, D. R., and E. L. Jones III. 2010. Optimum escapement goals for Chinook salmon in the transboundary Alsek River. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-02, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMS10-02.pdf

Bromaghin, J. F., K. S. Gates, and D. E. Palmer. 2010. A likelihood framework for joint estimation of salmon abundance and migratory timing using telemetric mark–recapture. North American Journal of Fisheries Management 30(6):1385-1394.

Burger, C. V., R. L. Wilmot, and D. B. Wangaard. 1985. Comparison of spawning areas and times for two runs of Chinook salmon (*Oncorhynchus tshawytscha*) in the Kenai River, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 42(4):693-700.

Burwen, D. L., D. E. Bosch, and S. J. Fleischman. 1998. Evaluation of hydroacoustic assessment techniques for Chinook salmon on the Kenai River, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 98-3, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds98-03.pdf

Burwen, D. L., and S. J. Fleischman. 1998. Evaluation of side-aspect target strength and pulse width as hydroacoustic discriminators of fish species in rivers. Canadian Journal of Fisheries and Aquatic Sciences 55(11):2492-2502.

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2007. Evaluation of a dual-frequency imaging sonar for estimating fish size in the Kenai River. Alaska Department of Fish and Game, Fishery Data Series No. 07 44, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds07-44.pdf

Burwen, D. L., S. J. Fleischman, and J. D. Miller. 2010. Accuracy and precision of manual fish length measurements from DIDSON sonar images. Transactions of the American Fisheries Society, 139:1306-1314.

Burwen, D. L., S. J. Fleischman, J. D. Miller, and M. E. Jensen. 2003. Time-based signal characteristics as predictors of fish size and species for a side-looking hydroacoustic application in a river. ICES Journal of Marine Science 60:662-668.

REFERENCES CITED (Continued)

Congdon, P. 2003. Applied Bayesian Modelling. Wiley and Sons, New York.

Dunker, K. J. 2010. Upper Cook Inlet personal use salmon fisheries, 2007-2009. Alaska Department of Fish and Game, Fishery Data Series No. 10-89, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS10-89.pdf

Eggers, D. M. 1993. Robust harvest policies for Pacific salmon fisheries. Pages 85-106 [*in*] Proceedings of the International Symposium on Management Strategies for Exploited Fish Populations. Alaska Sea Grant Report No. 93-02, University of Alaska, Fairbanks, Alaska.

Eggers, D. M. 1994. On the discrimination of sockeye and Chinook salmon in the Kenai River based on target strength determined with 420 kHz dual-beam sonar. Alaska Fishery Research Bulletin 1(2):125-139. Alaska Department of Fish and Game, Juneau.

Eggers, D. M., P. A. Skvorc II, and D. L. Burwen. 1995. Abundance estimates of Chinook salmon in the Kenai River using dual-beam sonar. Alaska Fishery Research Bulletin 2(1):1-22. http://www.adfg.alaska.gov/FedAidpdfs/AFRB.02.1.001-022.pdf

Ericksen, R. P., and S. J. Fleischman. 2006. Optimal production of coho salmon from the Chilkat River. Alaska Department of Fish and Game, Fishery Manuscript No. 06-06, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fms06-06.pdf

Eskelin, T., and J. D. Miller. 2010. A qualitative evaluation of parameters used to assess Kenai River king salmon, 1986-2010. Alaska Department of Fish and Game, Special Publication No. 10-18, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/SP10-18.pdf

Fleischman, S. J., and B. M. Borba. 2009. Escapement estimation, spawner-recruit analysis, and escapement goal recommendation for fall chum salmon in the Yukon River drainage. Alaska Department of Fish and Game, Fishery Manuscript Series No. 09-08, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMS09-08.pdf

Fleischman, S. J., and D. L. Burwen. 2003. Mixture models for the species apportionment of hydroacoustic data, with echo-envelope length as the discriminatory variable. ICES Journal of Marine Science 60:592-598.

Fleischman, S. J., M. J. Catalano, R. A. Clark, and D. R. Bernard. *In press.* An age-structured state-space stock-recruit model for Pacific salmon *Oncorhynchus* spp. Canadian Journal of Fisheries and Aquatic Sciences. Available at http://www.nrcresearchpress.com/journal/cjfas (Accessed 03/2013).

Fleischman, S. J., and D. Evenson. 2010. Run reconstruction, spawner-recruit analysis, and escapement goal recommendation for summer chum salmon in the East Fork of the Andreafsky River. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-04, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMS10-04.pdf

Fleischman, S. J., J. A. Der Hovanisian, and S. A. McPherson. 2011. Escapement goals for Chinook salmon in the Blossom and Keta rivers. Alaska Department of Fish and Game, Fishery Manuscript Series No. 11-05, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMS11-05.pdf

Hamazaki, T., M. J. Evenson, S. J. Fleischman, and K. L. Schaberg. 2012. Spawner-recruit analysis and escapement goal recommendation for Chinook salmon in the Kuskokwim River Drainage. Alaska Department of Fish and Game, Fishery Manuscript Series No. 12-08, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMS12-08

Hammarstrom, S. L., and J. J. Hasbrouck. 1998. Estimation of the abundance of late-run Chinook salmon in the Kenai River based on exploitation rate and harvest, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 98-6, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds98-06.pdf

Hammarstrom, S. L., and J. J. Hasbrouck. 1999. Estimation of the abundance of late-run Chinook salmon in the Kenai River based on exploitation rate and harvest, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-8, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds99-08.pdf

REFERENCES CITED (Continued)

Hilborn, R. 1985. Simplified calculation of optimum spawning stock size from Ricker's stock-recruitment curve. Canadian Journal of Fisheries and Aquatic Sciences 42:1833-4.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2011. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2010. Alaska Department of Fish and Game, Fishery Data Series No. 11-60, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS11-60

Lunn, D., D. Spiegelhalter, A. Thomas, and N. Best. 2009. The BUGS project: Evolution, critique and future directions. Statistics in Medicine 28(25):3049-3067.

McBride, D. N., M. Alexandersdottir, S. Hammarstrom, and D. Vincent-Lang. 1989. Development and implementation of an escapement goal policy for the return of Chinook salmon to the Kenai River. Alaska Department of Fish and Game, Fishery Manuscript No. 8, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fms-008.pdf

McKinley, T. R., and S. J. Fleischman. 2010. Stock assessment of early-run Chinook salmon in the Kenai River, 2002-2006. Alaska Department of Fish and Game, Fishery Data Series No. 10-19, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/Fds10-19.pdf

McPherson, S. A., E. L. Jones III, S. J. Fleischman, and I. M. Boyce. 2010. Optimal production of Chinook salmon from the Taku River through the 2001 year class. Alaska Department of Fish and Game, Fishery Manuscript Series No. 10-03, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/Fms10-03.pdf

Millar, R. B. 2002. Reference priors for Bayesian fisheries models. Canadian Journal of Fisheries and Aquatic Sciences 59:1492-1502.

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2005. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2003. Alaska Department of Fish and Game, Fishery Data Series No. 05-59, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds05-59.pdf

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2012. Estimates of Chinook salmon passage in the Kenai River using split-beam sonar, 2008-2009. Alaska Department of Fish and Game, Fishery Data Series No. 12-73, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS12-73.pdf

Mosher, K. H. 1969. Identification of Pacific salmon and steelhead trout by scale characteristics. U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries, Circular 317.

Noakes, D., D. W. Welch, and M. Stocker. 1987. A time series approach to stock-recruitment analysis: transfer function noise modeling. Natural Resource Modeling 2: 213-233.

Perschbacher, J. 2012a. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2008. Alaska Department of Fish and Game, Fishery Data Series No. 12-70, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS12-70

Perschbacher, J. 2012b. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2009. Alaska Department of Fish and Game, Fishery Data Series No. 12-61, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS12-61

Reimer, A. 2003. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2001. Alaska Department of Fish and Game, Fishery Data Series No. 03-01, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds03-01.pdf

Reimer, A. 2004. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 04-28, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds04-28.pdf

Reimer, A. M., W. W. Jones, and L. E. Marsh. 2002. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 1999 and 2000. Alaska Department of Fish and Game, Fishery Data Series No. 02-25, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds02-25.pdf

REFERENCES CITED (Continued)

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191:382.

Shields, P., and A. Dupuis. 2012. Upper Cook Inlet commercial fisheries annual management report, 2011. Alaska Department of Fish and Game, Fishery Management Report No. 12-25, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FMR12-25

Simmonds, J., and D. MacLennan. 2005. Fisheries acoustics: theory and practice. 2nd edition. Blackwell Science, Ames, Iowa.

Su, Z., and R. M. Peterman. 2012. Performance of a Bayesian state-space model of semelparous species for stock-recruitment data subject to measurement error. Ecological Modeling 224(1):76-89.

Szarzi, N. J., S. J. Fleischman, R. A. Clark, and C. M. Kerkvliet. 2007. Stock status and recommended escapement goal for Anchor River Chinook salmon. Alaska Department of Fish and Game, Fishery Manuscript No. 07-05, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/fms07-05

Tobias, T. M., and T. M. Willette. 2012. Abundance, age, sex, and size of Chinook, sockeye, coho and chum salmon returning to Upper Cook Inlet, Alaska, 2010. Alaska Department of Fish and Game, Fishery Data Series No. 12-14, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS12-14

TABLES

Table 1.–Estimated harvest below and above river mile 9 (RM 9) for Kenai River late-run Chinook salmon, 1986–2012.

	Harvest and other mortality										
	Below RM 9							Above RM 9			
Year	Deep Creek marine sport[a]	Comm setnet[b]	Comm driftnet[c]	Personal use	Subsistence	Sport	Total	Sport	Hook relative. mortality	Total	CV
1986	378	13,619	1,100				15,097	9,872	316	10,188	0.05
1987	731	14,536	2,731				17,998	13,100	123	13,223	0.06
1988	892	8,834	1,330				11,056	19,695	176	19,871	0.05
1989	821	7,498	0		22		8,341	9,691	88	9,779	0.06
1990	963	2,843	373	91	13		4,283	6,897	69	6,966	0.07
1991	1,023	3,361	145	130	288		4,947	7,903	16	7,919	0.05
1992	1,269	7,363	326	50	402		9,410	7,556	234	7,790	0.06
1993	1,700	9,672	451	129	27		11,979	17,775	478	18,253	0.04
1994	1,121	10,700	276	13	392		12,502	17,837	572	18,409	0.04
1995	1,241	8,291	314	36	646		10,528	12,609	472	13,081	0.05
1996	1,223	7,944	219	45	294		9,725	8,112	337	8,449	0.06
1997	1,759	7,780	293	339	26		10,197	12,755	570	13,325	0.06
1998	1,070	3,495	199	271	2		5,037	7,515	595	8,110	0.07
1999	602	6,501	345	488	4	1,170	9,110	12,425	682	13,107	0.08
2000	631	2,531	162	410	6	831	4,571	14,391	499	14,890	0.05
2001	552	4,128	371	638	8	1,336	7,034	15,144	825	15,969	0.07
2002	256	6,511	249	606	6	1,929	9,558	10,678	665	11,343	0.07
2003	120	10,174	744	1,016	11	823	12,888	16,120	1,803	17,923	0.09
2004	996	14,897	916	792	10	2,386	19,997	14,988	1,019	16,007	0.07
2005	624	15,183	1,103	775	11	2,287	19,984	15,927	1,267	17,194	0.08
2006	563	6,840	631	1,034	11	3,322	12,400	12,490	830	13,320	0.08
2007	478	8,445	547	1,509	6	1,750	12,735	9,690	670	10,360	0.07
2008	310	5,203	392	1,362	15	1,011	8,293	10,128	370	10,498	0.08
2009	154	3,839	515	1,189	4	1,132	6,833	7,904	626	8,530	0.07
2010	335	4,567	323	865	21	445	6,556	6,762	264	7,026	0.06
2011	528	5,596	356	1,243	5	458	8,186	6,894	479	7,373	0.07
2012	30	484	115	0	0	2	630	101	95	196	0.06

[a] Assumes 60% of Deep Creek marine sport harvest is of Kenai-origin fish.

[b] Kenai River fish only, based on 2010–2011 genetic sampling of commercial setnet fishery (Appendix B).

[c] Assumes 60% of commercial driftnet harvest is of Kenai-origin fish.

Table 2.–Estimated age composition of harvest below RM 9 and age composition of inriver run at RM 9 for Kenai River late-run Chinook salmon, 1986–2012.

	Age composition proportions									
	Harvest below RM 9					Inriver run at RM 9				
Year	3	4	5	6	7	3	4	5	6	7
1986	0.01	0.23	0.37	0.34	0.03	0	0.12	0.44	0.4	0.04
1987	0.02	0.13	0.33	0.51	0.01	0	0.02	0.28	0.69	0.01
1988	0.03	0.11	0.15	0.69	0.03	0	0.01	0.04	0.78	0.17
1989	0.01	0.15	0.21	0.53	0.09	0	0.1	0.12	0.65	0.12
1990	0.01	0.3	0.3	0.34	0.05	0	0.12	0.15	0.69	0.05
1991	0.01	0.25	0.33	0.39	0.02	0	0.07	0.16	0.7	0.07
1992	0.02	0.15	0.28	0.5	0.04	0	0.07	0.16	0.75	0.02
1993	0.03	0.13	0.21	0.59	0.04	0	0.08	0.14	0.72	0.06
1994	0.04	0.13	0.15	0.6	0.07	0	0.06	0.11	0.78	0.05
1995	0.03	0.24	0.31	0.35	0.06	0	0.22	0.21	0.5	0.06
1996	0.04	0.19	0.34	0.4	0.02	0	0.08	0.34	0.57	0.01
1997	0.08	0.15	0.3	0.45	0.02	0	0.04	0.22	0.72	0.02
1998	0.12	0.24	0.23	0.39	0.02	0	0.15	0.14	0.68	0.03
1999	0.02	0.26	0.25	0.44	0.03	0	0.12	0.21	0.61	0.05
2000	0.09	0.13	0.39	0.38	0.01	0	0.04	0.31	0.62	0.03
2001	0.12	0.4	0.15	0.32	0.01	0	0.12	0.19	0.66	0.03
2002	0.13	0.3	0.36	0.2	0.01	0.02	0.18	0.19	0.58	0.03
2003	0.04	0.52	0.24	0.19	0.02	0.01	0.3	0.2	0.49	0
2004	0.06	0.24	0.43	0.26	0.01	0.01	0.14	0.25	0.59	0.01
2005	0.03	0.27	0.21	0.48	0.02	0	0.07	0.18	0.7	0.04
2006	0.13	0.35	0.22	0.27	0.03	0.01	0.27	0.13	0.49	0.1
2007	0.05	0.43	0.23	0.29	0.01	0	0.2	0.29	0.42	0.09
2008	0.1	0.2	0.28	0.41	0.02	0.02	0.07	0.2	0.63	0.08
2009	0.14	0.51	0.12	0.22	0.01	0	0.29	0.11	0.55	0.04
2010	0.2	0.26	0.34	0.19	0.01	0.04	0.2	0.34	0.36	0.06
2011	0.05	0.34	0.25	0.35	0.01	0.02	0.3	0.19	0.46	0.02
2012	0.1	0.18	0.37	0.36	0	0.02	0.1	0.4	0.44	0.04

Table 3.–Annual measures of Kenai River Chinook salmon abundance used to reconstruct historical run sizes.

Measure	Acronym	Citation	Years	Definition	Strengths / Weaknesses
Multibeam imaging sonar estimate	DIDSON	Burwen et al. 2010	2010–2012	Upstream midriver passage of Chinook salmon between transducers placed at fixed distances from shore. Netting data provide length distributions for apportionment.	Provides precise fish length measurement and species classification, improved detection and tracking of migrating fish. Brief historical record.
Catch rate in inriver test fishery	NCPUE	Perschbacher 2012a, 2012b	2002–2012	Catch rate of Chinook salmon from gillnets drifted inriver at the sonar site.	Independent of sonar. Nets not deployed during rising tides.
Net-apportioned split-beam sonar	NASB	Miller et al. 2012	2002–2012	Total upstream fish passage from split-beam sonar multiplied by Chinook salmon proportions derived from inriver netting project.	Combines strengths of sonar and netting projects. Nets not deployed during rising tides.
Catch rate in lower river sport fishery	SCPUE	Perschbacher 2012a, 2012b	1986–2011	Mean daily catch rate of Chinook salmon from inriver sport fishery, from creel survey interviews.	Independent of sonar. Sensitive to changes in regulations and fishing conditions.
Catch rate in commercial east-side setnet fishery	CCPUE	Shields and Dupuis 2012	1986–2011	Sum of daily catch rates of Chinook salmon in the eastside Cook Inlet setnet fishery adjacent to Kenai River mouth.	Independent of sonar. Influenced by presence of non-Kenai stocks.
Estimated annual passage using sonar echo-length	ELSD	Miller et al. 2012	2002–2009	Upstream midriver passage as estimated by split-beam sonar, using echo length standard deviation to apportion species.	Best estimates available from split-beam sonar. Less accurate than DIDSON, available for only 8 years
Radio-telemetry capture–recapture estimates	CRTLM	Hammarstrom and Hasbrouck 1999	1996–1997	Harvest estimated by creel divided by radio-telemetry estimate of exploitation rate.	Provides some ability to quantify fraction of Chinook salmon detected by sonar in midriver. Possibly subject to bias.
Genetic capture–recapture estimates	CRGEN	Eskelin and Miller 2010	2007–2011	Stock-specific abundance and run-timing model fitted to weir, harvest, and genetic allele-frequency data.	Provides some ability to quantify fraction of Chinook salmon detected by sonar in midriver. Possibly subject to bias; methods currently under development.

Table 4.–Values of annual abundance measures used to reconstruct historical run size, Kenai River late-run Chinook salmon, 1986–2012.

Year	NCPUE	NASB	SCPUE	CCPUE	ELSD	DIDSON[a] (CV)	CRTLM (CV)	CRGEN[a] (CV)
1986			0.110	1,391				
1987			0.099	1,182				
1988			0.115	945				
1989			0.066	669				
1990			0.055	514				
1991			0.058	661				
1992			0.073	706				
1993			0.102	987				
1994			0.080	1,089				
1995			0.065	1,277				
1996			0.042	1,012			50,053 (0.17)	
1997			0.050	717			44,567 (0.17)	
1998			0.066	959				
1999			0.078	829				
2000			0.072	758				
2001			0.100	809				
2002	12.7	41,813	0.106	947	33,508			
2003	16.9	62,635	0.176	1,252	57,101			
2004	14.2	75,050	0.129	1,547	43,542			
2005	13.8	85,590	0.127	1,105	48,275			
2006	17.6	52,482	0.091	778	37,692			
2007	10.4	29,457	0.073	987	28,914			51,060 (0.20)
2008	12.2	36,011	0.060	560	24,589			47,460 (0.14)
2009	5.4	17,722	0.074	525	15,655			44,660 (0.23)
2010	3.0	12,501	0.039	535		19,000 (0.07)		21,330 (0.16)
2011	5.1	18,765	0.068	692		21,036 (0.02)		27,300 (0.18)
2012	3.0	13,896				21,914 (0.03)		25,080 (0.15)

Note: Abbreviations defined in Table 2. CV = coefficient of variation.

[a] DIDSON and CRGEN estimates are preliminary and subject to revision until published.

Table 5.–Posterior medians of key quantities from base and alternate configurations of a state-space model of the abundance of Kenai River late-run Chinook salmon.

		Alternative model (data configuration)									
	Base model	1a (CCPUE allometric)[a]	1b (indices allometric except NASB)[b]	2a ($n.E$ = 50)[c]	2b ($n.E$=200)[d]	3a ($CV(Hb)$=0.1)[e]	3b ($CV(Hb)$=0.2)[f]	4a (Rec, Drift p_K = 0%)[g]	4b (Rec, Drift p_K = 100%)[h]	5 (2002–2012 data only)[i]	6 (TAM)[j]
	4.9	4.5	4.6	4.9	4.6	5	4.8	4.9	4.9	**1.7**	**2.9**
10^5	3.1	3.1	2.8	3.0	3.1	3.0	3.2	3.0	3.2	**1.7**	3.0
$_w$	0.34	0.34	0.36	0.35	0.32	0.36	0.34	0.34	0.34	0.60	0.35
	0.52	0.55	0.5	**0.62**	**0.46**	0.49	0.52	0.5	0.5	0.52	**0.77**
S_{EQ}	53,200	56,190	52,510	53,710	54,110	52,880	52,920	51,100	54,880	**46,560**	56,820
S_{MSY}	20,260	21,630	20,240	20,330	20,850	20,010	20,230	19,510	20,920	**18,660**	**22,530**
D	56	53	56	**76**	**38**	54	58	50	54	**266**	**202**
p_{MR}	0.78	0.80	0.80	0.78	0.79	0.78	0.78	0.79	0.78	0.80	**0.87**
N_{2004}	99,690	104,800	89,580	101,400	99,000	99,290	99,350	96,600	102,500	100,300	99,030

Note: Noteworthy differences are in bold.

[a] CCPUE abundance index non-linear.

[b] All abundance indices non-linear (except NASB).

[c] Effective sample size = 50.

[d] Effective sample size = 200.

[e] CV for harvest below RM 9 = 0.1.

[f] CV for harvest below RM 9 = 0.2.

[g] 0% Kenai-origin fish in marine recreational and driftnet commercial fisheries.

[h] 100% Kenai-origin fish in marine recreational and driftnet commercial fisheries.

[i] 1986–2001 data omitted.

[j] Trending age at maturity model.

Table 6.–Parameter estimates for state-space model fitted to Kenai River late-run Chinook salmon data, calendar years 1986–2012. Posterior medians are point estimates, CVs are posterior standard deviations divided by posterior means.

Year	Total run *N* (CV)	Inriver run *IR* (CV)	Escapement *S* (CV)	Recruitment *R* (CV)
1979				61,230 (0.59)
1980				53,640 (0.21)
1981				111,500 (0.14)
1982				93,390 (0.13)
1983				40,540 (0.15)
1984				37,510 (0.15)
1985				42,450 (0.14)
1986	78,120 (0.14)	62,740 (0.17)	52,550 (0.20)	51,810 (0.13)
1987	82,190 (0.13)	63,550 (0.17)	50,280 (0.22)	59,950 (0.14)
1988	72,940 (0.14)	61,760 (0.16)	41,810 (0.24)	62,480 (0.13)
1989	44,800 (0.14)	36,370 (0.18)	26,550 (0.24)	43,520 (0.14)
1990	38,550 (0.15)	34,200 (0.16)	27,220 (0.21)	48,600 (0.12)
1991	44,000 (0.14)	38,940 (0.16)	31,000 (0.20)	64,470 (0.10)
1992	51,800 (0.14)	42,290 (0.17)	34,470 (0.20)	53,700 (0.12)
1993	62,130 (0.14)	50,210 (0.17)	31,930 (0.27)	44,930 (0.13)
1994	60,140 (0.13)	47,440 (0.17)	28,970 (0.27)	53,360 (0.13)
1995	55,660 (0.13)	44,770 (0.16)	31,660 (0.23)	63,300 (0.13)
1996	52,900 (0.11)	42,790 (0.13)	34,340 (0.16)	52,500 (0.12)
1997	51,640 (0.10)	41,120 (0.12)	27,760 (0.18)	71,250 (0.13)
1998	52,310 (0.13)	47,110 (0.15)	38,980 (0.18)	92,650 (0.11)
1999	52,840 (0.13)	43,670 (0.15)	30,520 (0.22)	130,000 (0.11)
2000	52,110 (0.14)	47,440 (0.15)	32,520 (0.22)	75,330 (0.12)
2001	60,700 (0.14)	53,610 (0.16)	37,580 (0.23)	53,570 (0.12)
2002	66,400 (0.10)	56,800 (0.12)	45,390 (0.15)	68,180 (0.10)
2003	97,690 (0.11)	85,110 (0.13)	66,900 (0.17)	44,870 (0.11)
2004	99,690 (0.10)	79,690 (0.12)	63,770 (0.15)	21,280 (0.13)
2005	96,970 (0.10)	77,440 (0.13)	60,060 (0.17)	38,680 (0.09)
2006	74,310 (0.11)	62,270 (0.13)	48,970 (0.16)	28,330 (0.11)
2007	60,100 (0.08)	47,370 (0.10)	36,950 (0.13)	51,660 (0.19)
2008	51,010 (0.08)	42,840 (0.10)	32,290 (0.13)	36,140 (0.32)
2009	36,890 (0.09)	29,940 (0.11)	21,390 (0.16)	40,490 (0.46)
2010	30,050 (0.08)	23,250 (0.09)	16,210 (0.13)	
2011	35,780 (0.07)	27,090 (0.09)	19,680 (0.12)	
2012	28,550 (0.09)	27,910 (0.09)	27,710 (0.09)	

Table 7.–Parameter estimates for a state-space model fitted to Kenai River late-run Chinook salmon data, calendar years 1986–2012. Posterior medians are point estimates, 5th and 95th percentiles define 90% credibility intervals for the parameters. Parameter definitions are in the methods section.

Parameter	Posterior median	5th percentile	95th percentile	Posterior CV
ln( )	1.58	0.76	2.27	0.30
	4.9	2.1	9.6	0.73
	0.000031	0.000014	0.000049	0.34
	0.51	0.04	0.88	0.52
w	0.34	0.24	0.48	0.21
S_{MAXR}	32120	20430	69740	0.39
S_{EQ}	53200	41790	83840	0.21
S_{MSY}	20260	15140	32590	0.24
U_{MSY}	0.64	0.40	0.79	0.21
D	56	38	83	0.25
1	0.02	0.01	0.03	0.20
2	0.15	0.13	0.17	0.08
3	0.22	0.20	0.24	0.06
4	0.56	0.54	0.59	0.03
5	0.05	0.04	0.06	0.14
p_{MR}	0.783	0.678	0.901	0.09
p_{MR}^{-1}	1.28	1.11	1.48	0.09
$q_{NCPUE}\ 10^{-4}$	2.4	2.0	3.1	0.13
q_{NASB}	0.92	0.77	1.13	0.12
$q_{SCPUE}\ 10^{-6}$	1.7	1.4	1.9	0.09
q_{CCPUE}	0.02	0.01	0.02	0.1
q_{ELSD}	0.76	0.63	0.92	0.1
NCPUE	0.31	0.21	0.51	0.29
NASB	0.26	0.17	0.43	0.30
SCPUE	0.23	0.17	0.32	0.19
CCPUE	0.21	0.15	0.29	0.20
ELSD	0.11	0.04	0.24	0.54

FIGURES

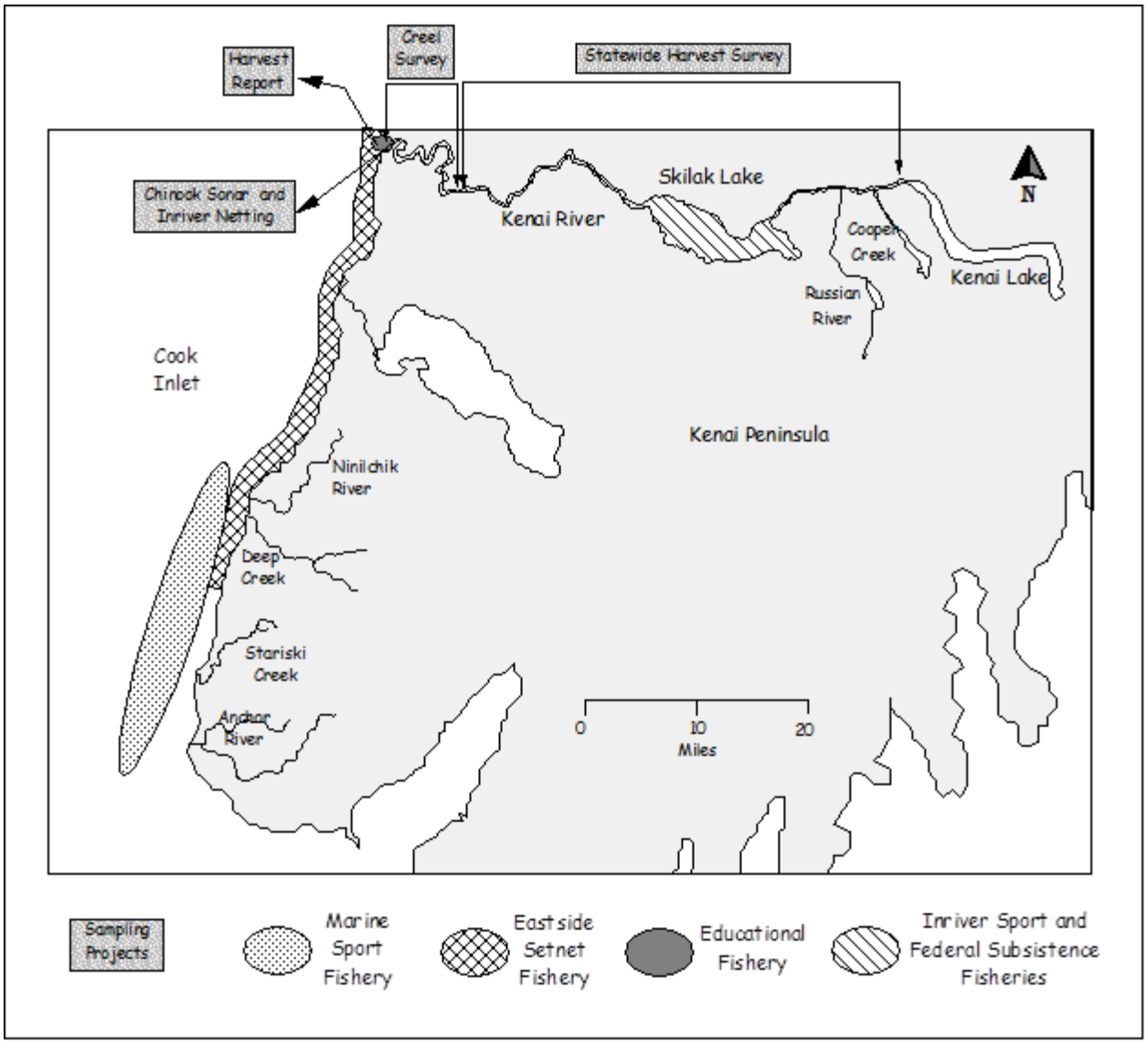

Figure 1.–Kenai River drainage.

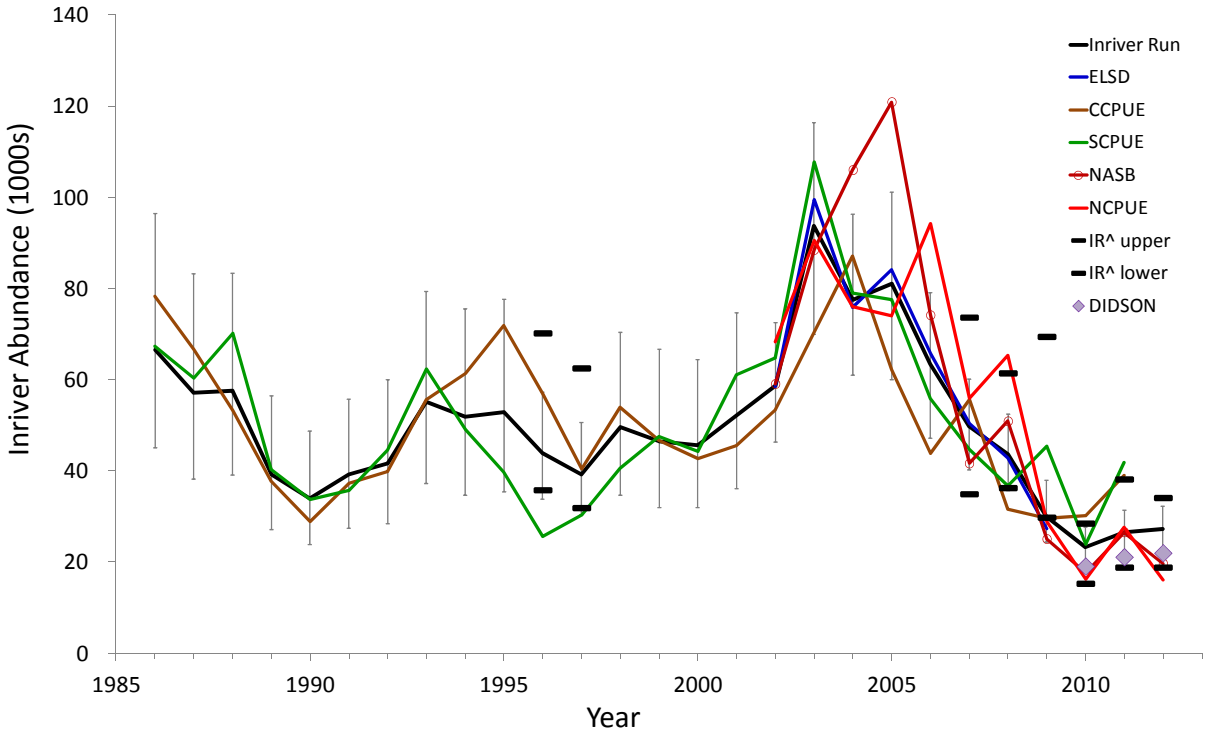

Figure 2.–Intermediate results from the run reconstruction component of the state-space model for Kenai River late-run Chinook salmon, illustrating how inriver run abundance (black line with error bars) was reconstructed from 5 measures of relative abundance: inriver gillnet catch rate (NCPUE), split-beam sonar salmon abundance apportioned by Chinook salmon fraction in test gillnets (NASB), catch rate in the lower-river sport fishery (SCPUE), catch rate in the marine commercial setnet fishery (CCPUE), and split-beam sonar estimates of Chinook salmon passage based on echo-length standard deviation (ELSD); plus 3 measures of absolute abundance (capture–recapture estimates [IR^] with lower and upper bounds of 95% interval based on telemetry (1996–1997), genetic stock identification (preliminary estimates subject to revision, 2007–2012), and direct estimates of midriver run from imaging sonar (DIDSON point estimates, 2010–2012). For plotting, relative abundance measures were converted to number of inriver Chinook salmon based on relationships in Figure 3. Values of inriver run plotted here differ slightly from final estimates, which are also subject to the influence of the population dynamics component of the state-space model.

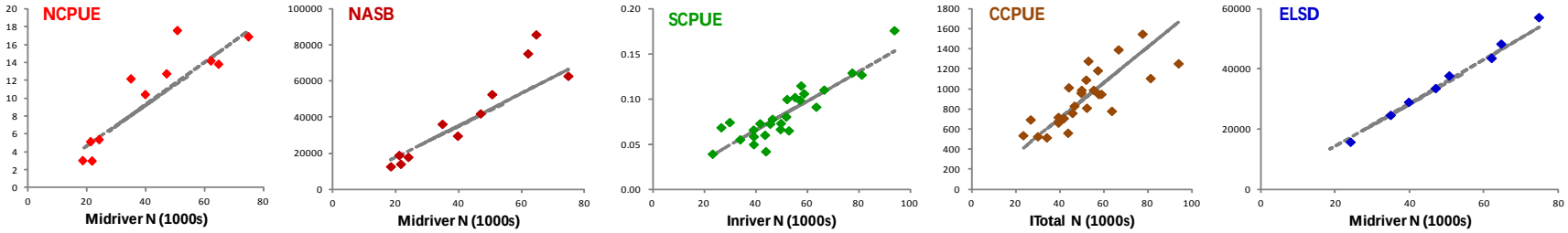

Figure 3.–Linear relationships between abundance measures and model-based point estimates of abundance, from a state-space model of Kenai River Chinook salmon data, 1986–2012. Slopes *q* and error standard deviations of these relationships are listed in Table 6.

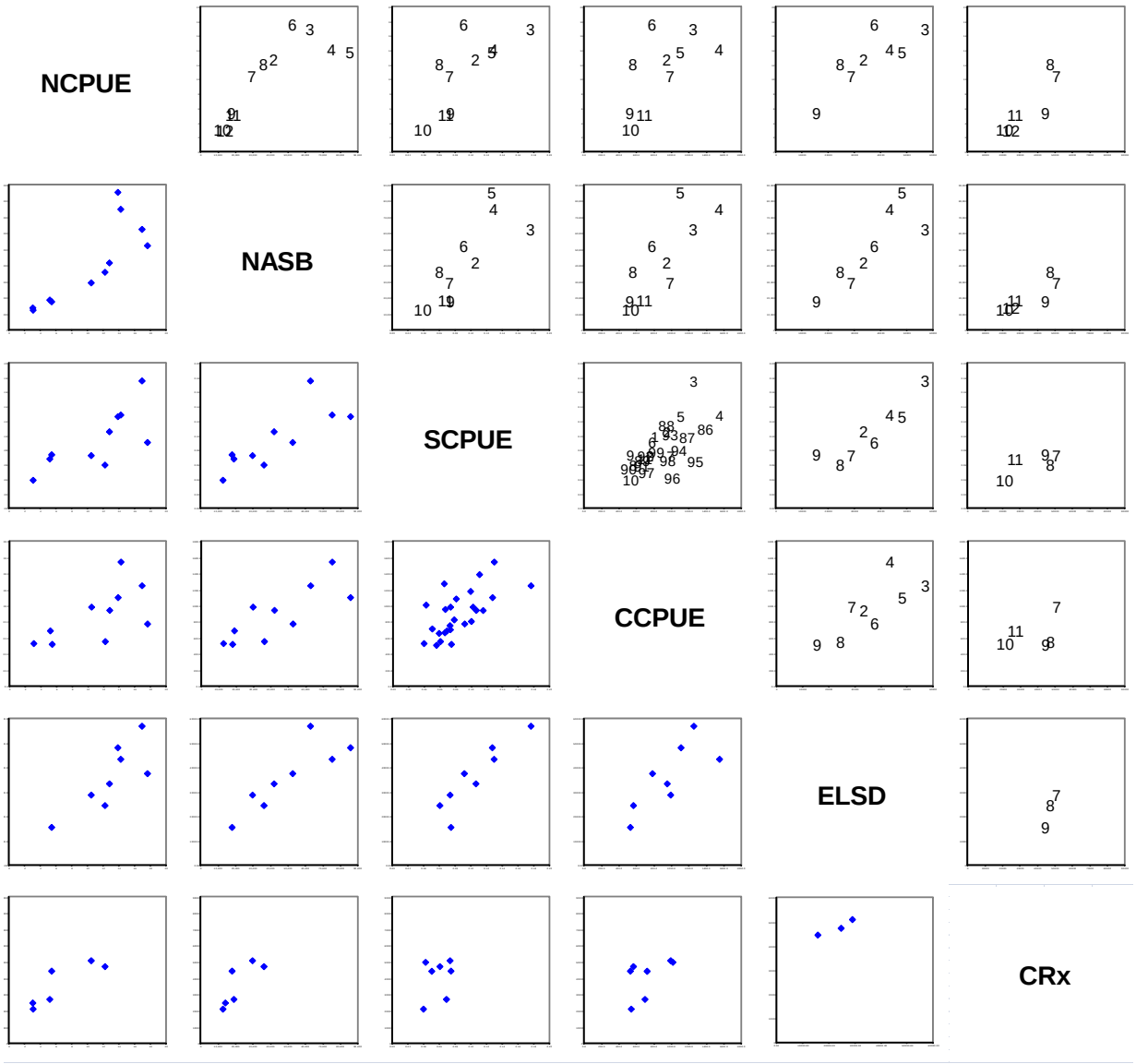

Figure 4.–Scatter plot matrix of key abundance measures for Kenai River late-run Chinook salmon, 1986–2012. Acronyms defined in Table 2. CRx includes CRTLM and CRGEN.

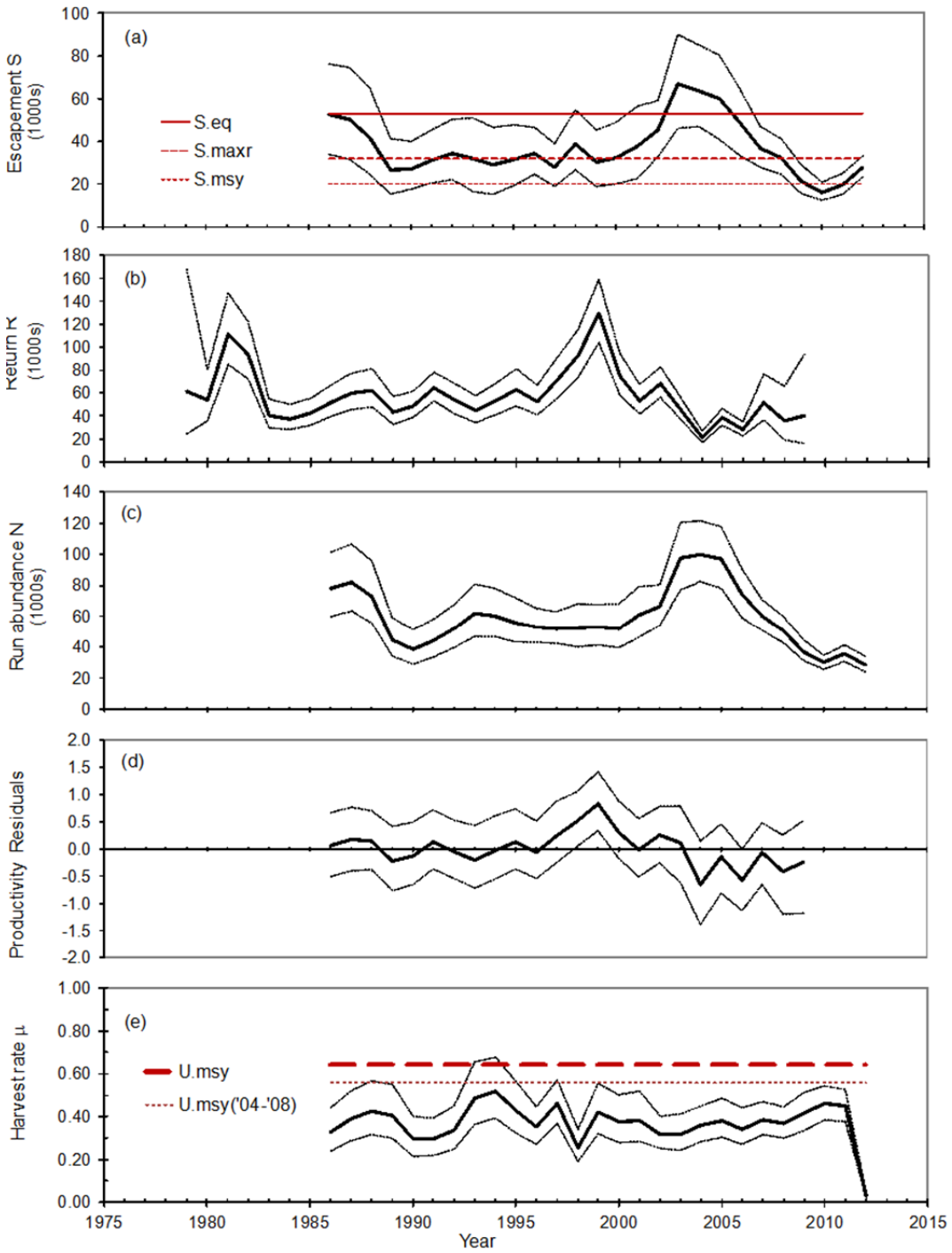

Figure 5.–Point estimates (posterior medians; solid lines) and 95% credibility intervals (lighter dashed lines) of (a) spawning escapement, (b) recruitment by brood year, (c) run abundance, (d) productivity residuals, and (e) harvest rate from a state-space model of Kenai River late-run Chinook salmon, 1986–2012. Posterior medians of S_{EQ}, S_{MAXR}, S_{MSY}, and U_{MSY} are plotted as horizontal reference lines in (a) and (e). U_{MSY} for recent brood years (2004–2008) is also plotted in (e).

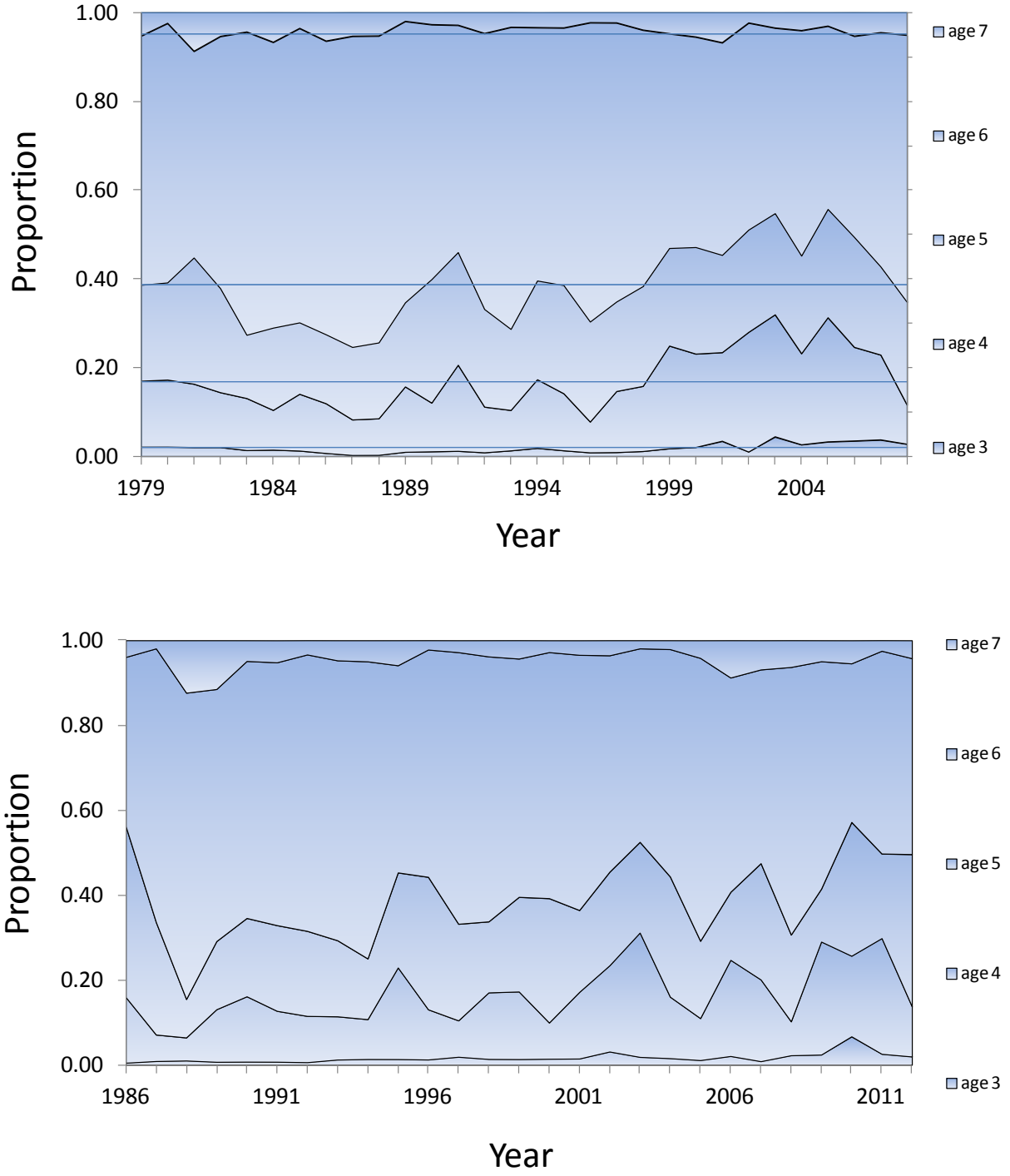

Figure 6.–Area graphs of age-at-maturity proportions by brood year (top) and age composition proportions by calendar year (bottom) from an age-structured state-space model fit to Kenai River late-run Chinook salmon data. Distances between the solid lines are posterior medians of proportions. Horizontal lines in top figure are posterior medians of age-at-maturity central tendency proportions $_{a}$.

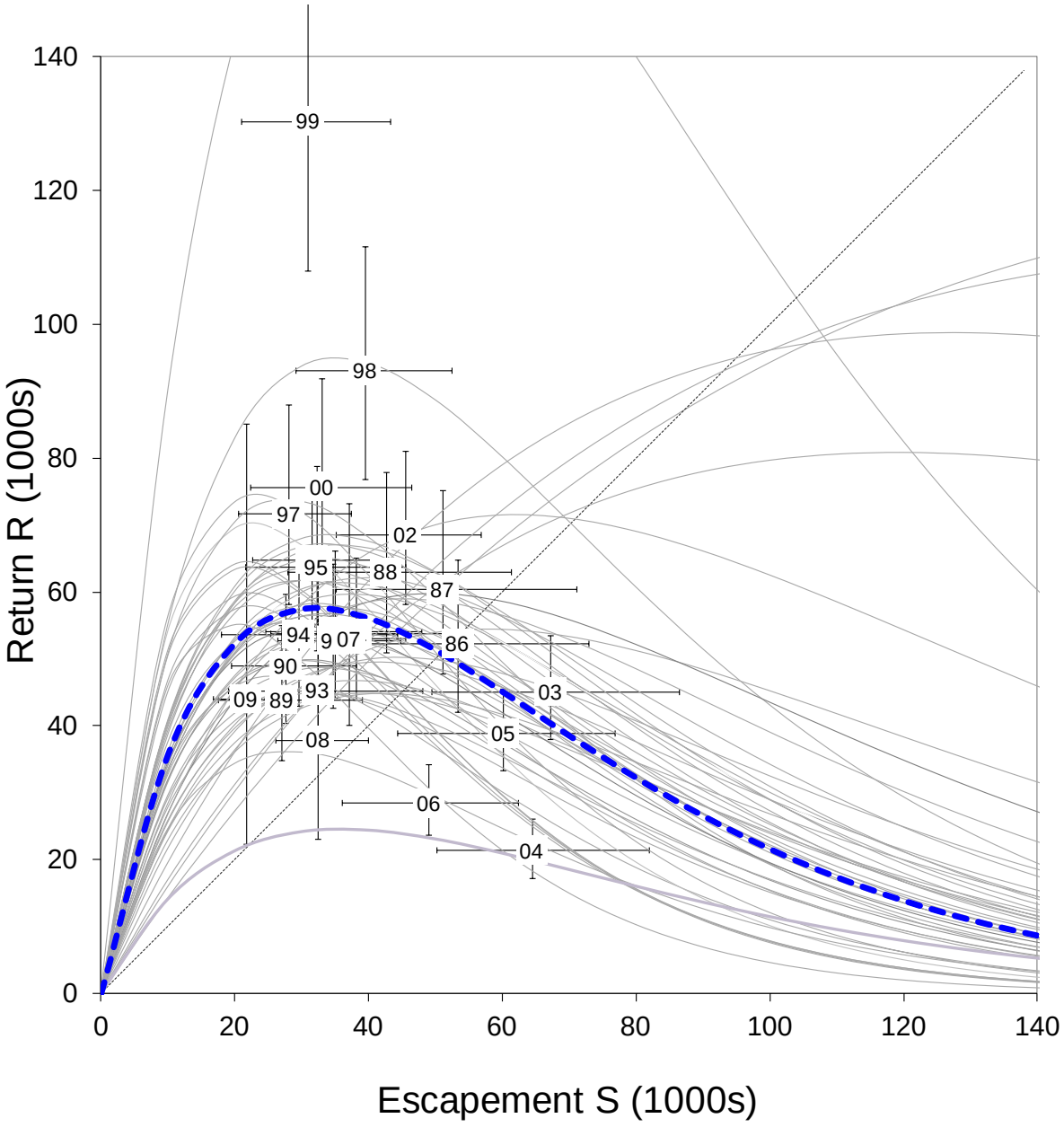

Figure 7.–Plausible spawner–recruitment relationships for Kenai River late-run Chinook salmon as derived from an age-structured state-space model fitted to abundance, harvest, and age data for 1986–2012. Posterior medians of *R* and *S* are plotted as brood year labels; error bars bracket 90% credibility intervals. The heavy dashed line is the Ricker relationship constructed from ln( ) and posterior medians. Ricker relationships are also plotted for 75 paired values of ln( ) and sampled from the posterior probability distribution, representing plausible Ricker relationships that could have generated the observed data. The diagonal dotted line is the replacement line (*R* = *S*).

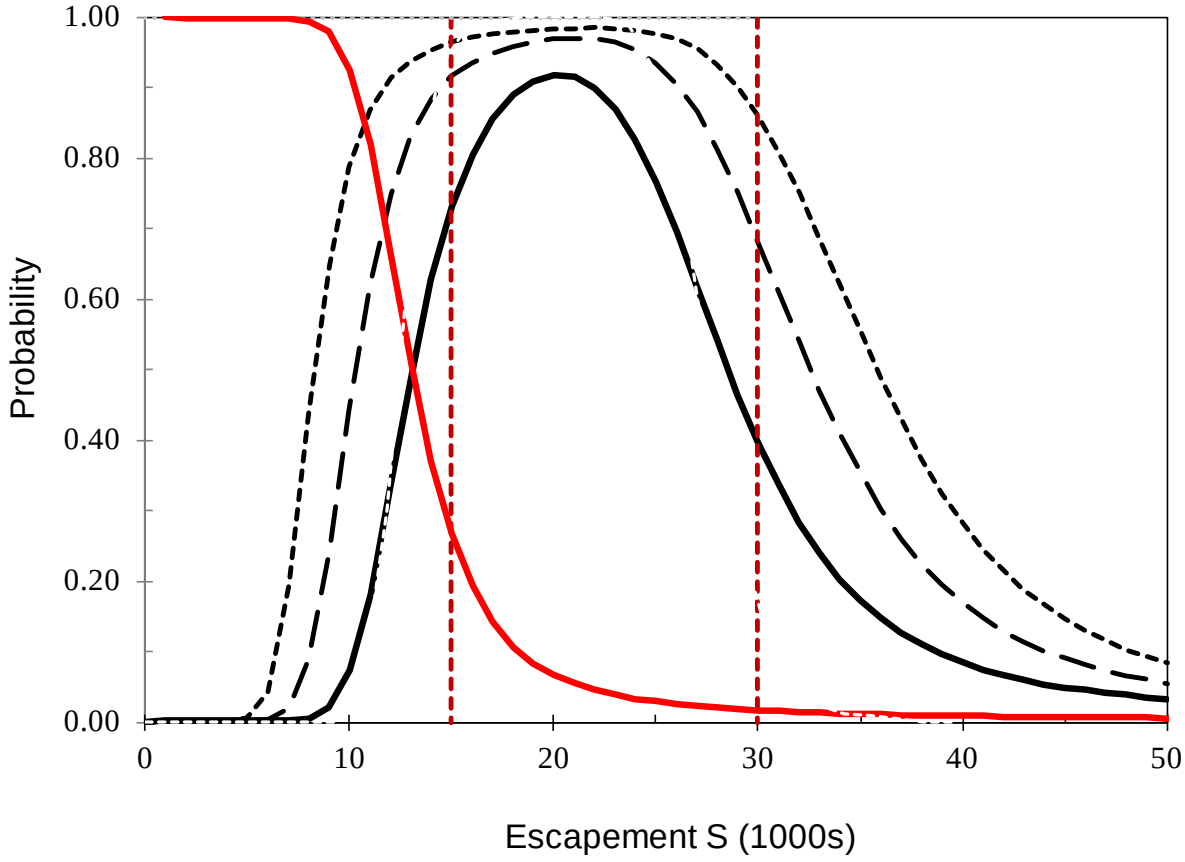

Figure 8.–Optimal yield profiles (OYPs) and overfishing profile (OFP) for Kenai River late-run Chinook salmon. OYPs (black dome-shaped profiles) show probability that a specified spawning abundance will achieve 70% (short dashes), 80% (long dashes), and 90% (solid line) of maximum sustained yield MSY. OFP (solid red declining line) is the probability that reducing the escapement to a specified spawning abundance will result in less than 90% of MSY. Vertical dashed red lines show the recommended escapement goal range.

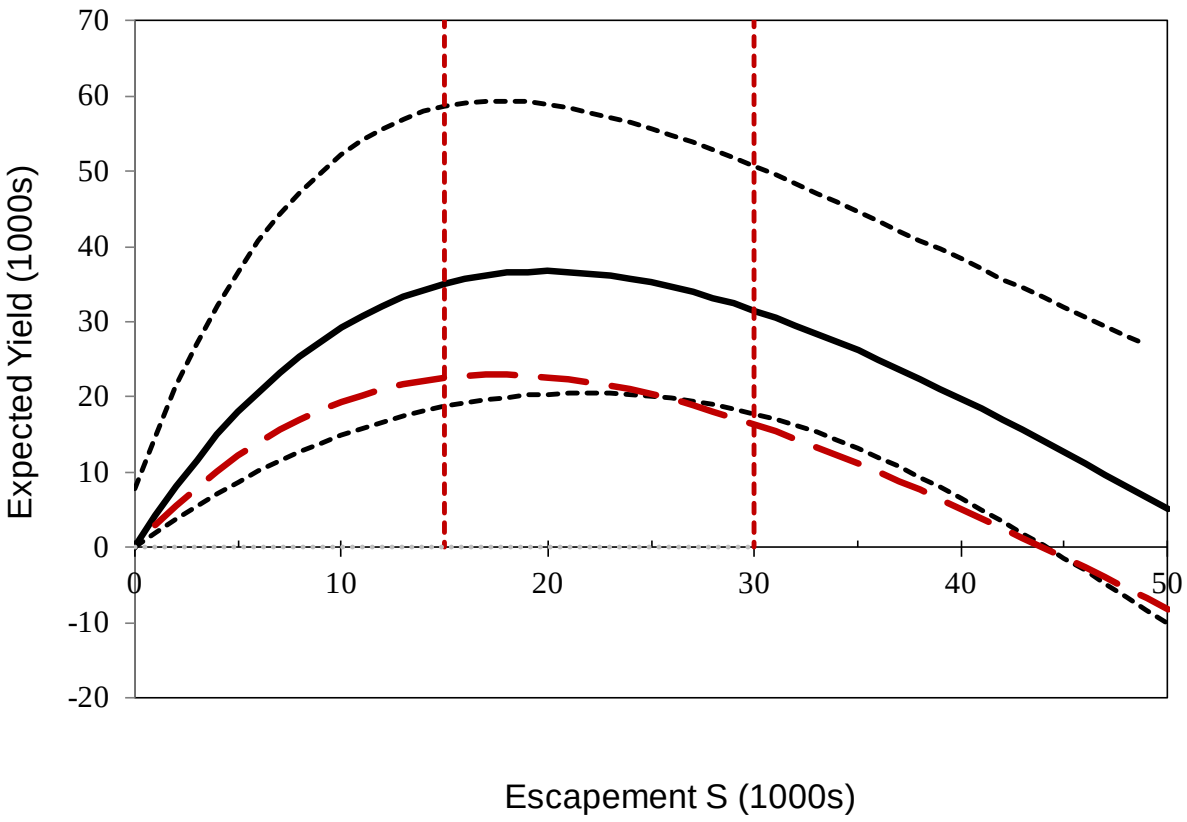

Figure 9.–Expected sustained yield (solid black line), and 80% interval (short dashed black lines) versus spawning escapement for Kenai River late-run Chinook salmon, assuming average productivity for brood years 1979–2008. Vertical lines bracket recommended escapement goal range. Expected sustained yield under recent, reduced productivity (brood years 2004–2008) is also shown (long dashed red lines).

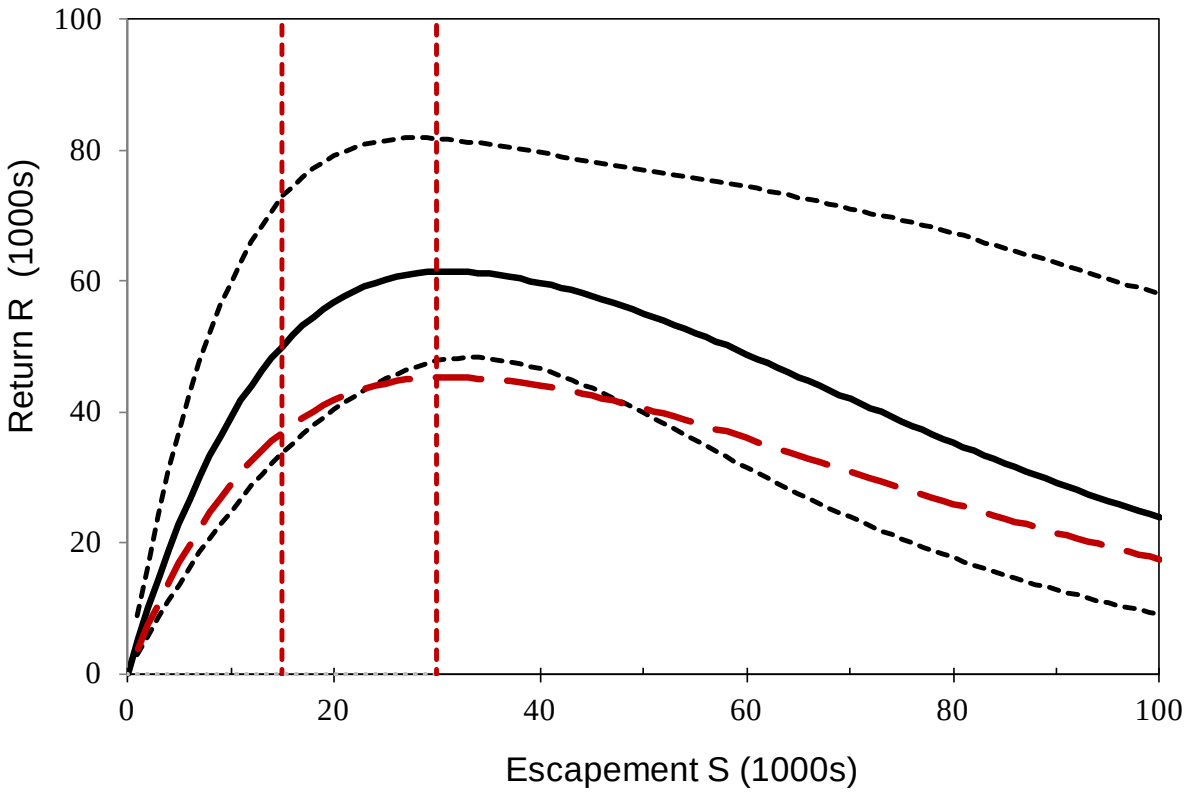

Figure 10.–Posterior median of expected recruitment (solid line), and 80% interval (dashed lines) as a function of spawning escapement for Kenai River late-run Chinook salmon. Model assumes average productivity for brood years 1979–2008. Expected recruitment under recent, reduced productivity (brood years 2004–2008) is also shown (long dashed red lines). Vertical lines bracket the recommended escapement goal range.

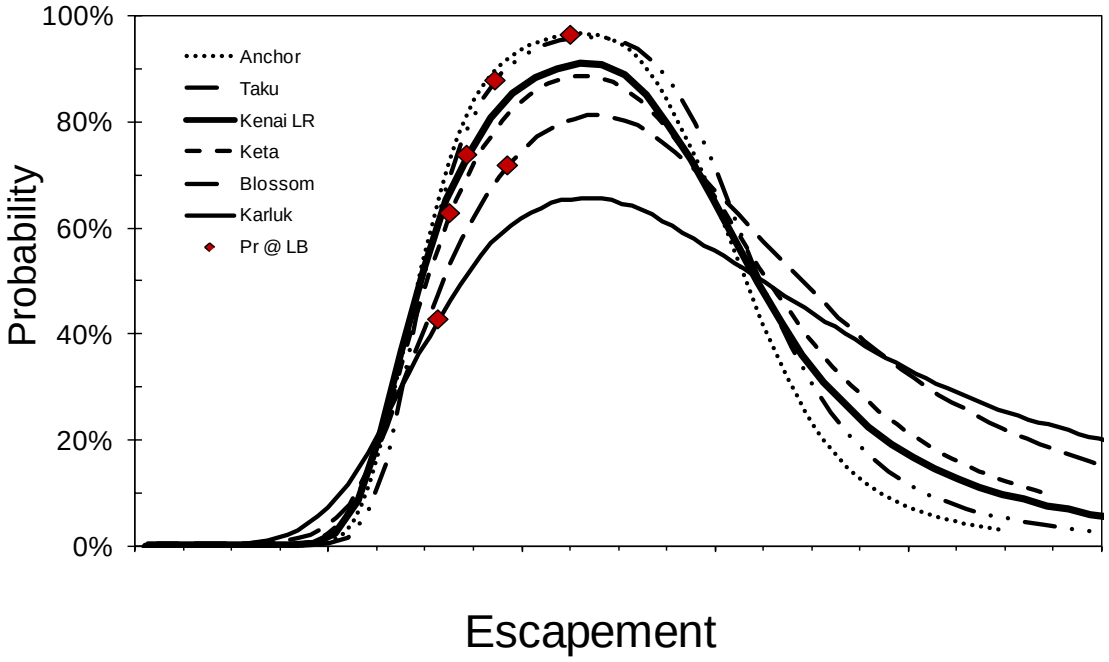

Figure 11.–Optimal yield profiles (probability of achieving 90% of MSY) from similar state-space analyses of data from Anchor River Chinook salmon (Szarzi et al. 2007), Blossom River Chinook salmon (Fleischman et al. 2011), Karluk River Chinook Salmon (Fleischman et al. *In press*), Keta River Chinook salmon (Fleischman et al. 2011), and Taku River Chinook salmon (McPherson et al. 2010). The 90% OYP for Kenai River late-run Chinook salmon from Figure 8 is in bold. Symbols represent probability of 90% yield at the lower bound of the escapement goal. Horizontal axis scales were adjusted to align profiles and facilitate comparisons.

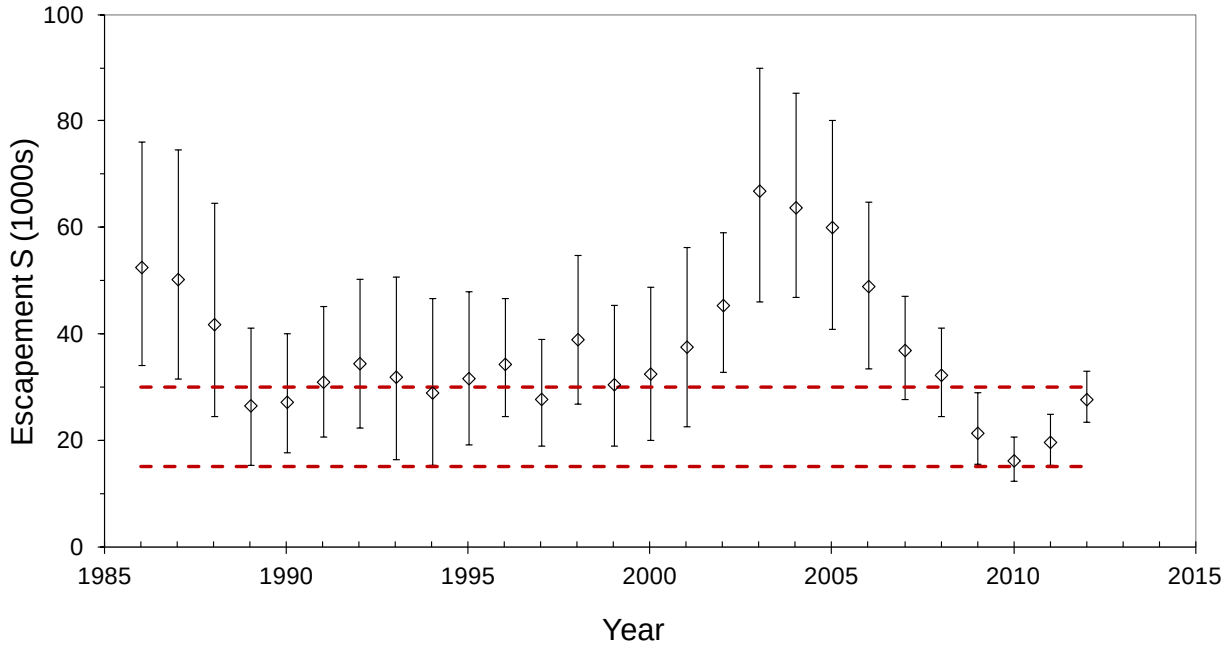

Figure 12.–Historical estimates of escapement and 95% credibility intervals obtained by fitting a state-space model to Kenai River late-run Chinook salmon data, 1986–2012. Horizontal dotted lines bracket the recommended escapement goal range of 15,000 to 30,000 fish.

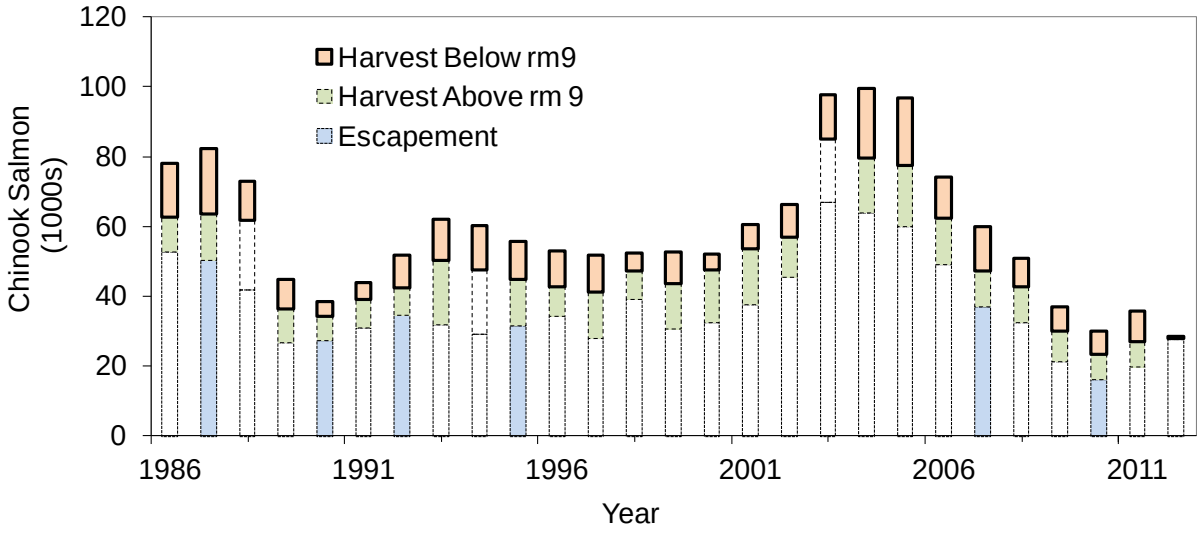

Figure 13.–Posterior medians of spawning escapement (bottom, blue bars, dotted outline), harvest above RM 9 (middle, green bars, dashed outline) and harvest below RM 9 (top, orange bars, solid outline) from 1986 to 2012 obtained from fitting a state-space model to Kenai River late-run Chinook salmon data.

APPENDIX A: OPENBUGS CODE AND DATA

Appendix A1.–OpenBUGS (Lunn et al. 2009) model code for a state-space model of Kenai River late-run Chinook salmon data, 1986–2012. Block updaters must be disabled prior to compiling. Prior distributions in green font; sampling distributions of the data in blue, intermediate hierarchical quantities in blue-green. Notation generally follows text of report, except where otherwise noted.

```
model{
  for (y in A+a.min:Y+A-1) {
    log.R[y] ~ dt(log.R.mean2[y],tau.white,500)
    R[y] <- exp(log.R[y])
    log.R.mean1[y] <- log(S[y-a.max]) + lnalpha - beta * S[y-a.max]
    log.resid[y] <- log(R[y]) - log.R.mean1[y]
    RS.resid[y] <- exp(log.resid[y])
    lnalpha.y[y] <- lnalpha + log.resid[y]
    alpha.y[y] <- exp(lnalpha.y[y])
    }
  log.R.mean2[A+a.min] <- log.R.mean1[A+a.min] + phi * log.resid.0
  for (y in A+a.min+1:Y+A-1) {
    log.R.mean2[y] <- log.R.mean1[y] + phi * log.resid[y-1]
    }

  lnalpha ~ dnorm(0,1.0E-6)I(0,)
  beta ~ dnorm(0,1.0E-1)I(0,)
  phi ~ dnorm(0,1.0E-4)I(-1,1)
  tau.white ~ dgamma(0.001,0.001)
  log.resid.0 ~ dnorm(0,tau.red)I(-3,3)
  alpha <- exp(lnalpha)
  tau.red <- tau.white * (1-phi*phi)
  sigma.white <- 1 / sqrt(tau.white)        # sigma_w in report text
  sigma.red <- 1 / sqrt(tau.red)
  lnalpha.c <- lnalpha + (sigma.white * sigma.white / 2 / (1-phi*phi) )
  S.max <- 1 / beta
  S.eq <- lnalpha.c * S.max
  S.msy <- S.eq * (0.5 - 0.07*lnalpha.c)
  U.msy <- lnalpha.c * (0.5 - 0.07*lnalpha.c)

# INITIAL RECRUITMENTS HIERARCHICAL
  mean.log.R ~ dnorm(0,1.0E-4)I(0,)
  tau.R ~ dgamma(0.1,0.1)
  R.0 <- exp(mean.log.R)
  sigma.R0 <- 1 / sqrt(tau.R)
  for (y in 1:a.max) {
    log.R[y] ~ dt(mean.log.R,tau.R,500)
    R[y] <- exp(log.R[y])
    }
```

-continued-

```
# GENERATE Y+A-1 MATURITY SCHEDULES, ONE PER BROOD YEAR
  D.scale ~ dunif(0,1)
  D.sum <- 1 / (D.scale * D.scale)          #D.sum is D in text
  pi[1] ~ dbeta(1,1)
  pi.2p ~ dbeta(1,1)
  pi.3p ~ dbeta(1,1)
  pi.4p ~ dbeta(1,1)
  pi[2] <- pi.2p * (1 - pi[1])
  pi[3] <- pi.3p * (1 - pi[1] - pi[2])
  pi[4] <- pi.4p * (1 - pi[1] - pi[2] - pi[3])
  pi[5] <- 1 - pi[1] - pi[2] - pi[3] - pi[4]
  for (a in 1:A) {
    gamma[a] <- D.sum * pi[a]
    for (y in 1:Y+A-1) {
       g[y,a] ~ dgamma(gamma[a],0.1)
       p[y,a] <- g[y,a]/sum(g[y,])
     }
    }

# ASSIGN PRODUCT OF P AND R TO ALL CELLS IN N MATRIX
# y SUBSCRIPT INDEXES BROOD YEAR
# y=1 IS THE BROOD YEAR OF THE OLDEST FISH IN YEAR 1 (upper right cell)
# y=Y IS THE BROOD YEAR OF THE YOUNGEST FISH IN YEAR Y (lower left cell, forecast year)
# ASSIGN PRODUCT OF P AND R TO ALL CELLS IN N MATRIX (Matt's code)
    for (a in 1:A) {
       for (y in a:(Y + (a - 1))) {
          N.ta[y - (a - 1), (A + 1 - a)] <- p[y, (A + 1 - a)] * R[y]
          }
       }

# MULTINOMIAL SCALE SAMPLING ON TOTAL ANNUAL RUN N
# INDEX t IS CALENDAR YEAR
for (t in 1:Y) {
  N[t] <- sum(N.ta[t,1:A])
  for (a in 1:A) {
    q[t,a] <- N.ta[t,a] / N[t]
    }
  n[t] <- sum(x[t,1:A])
  x[t,1:A] ~ dmulti(q[t,],n[t])
  }

# INRIVER RUN ESTIMATED, AS WELL AS HARVESTS BELOW AND ABOVE RM 9
 p.MR ~ dnorm(0.5,1.0E-4)I(0.01,0.99)  # proportion migrating midriver,
 p.MR.inv <- 1 / p.MR
```

-continued-

```
for (y in 1:Y) {
  mu.Hbelow[y] ~ dbeta(0.1,0.1)
  H.below[y] <- mu.Hbelow[y] * N[y]
  log.Hb[y] <- log(H.below[y])
  tau.log.Hb[y] <- 1 / log(cv.Hb[y]*cv.Hb[y] + 1)
  Hbelow.hat[y] ~ dlnorm(log.Hb[y],tau.log.Hb[y])
  Inriver.Run[y] <- max(N[y] - H.below[y], 1)

  log.IR[y] <- log(Inriver.Run[y])
  tau.log.IR[y] <- 1 / log(cv.IR[y]*cv.IR[y] + 1)
  IR.hat[y] ~ dlnorm(log.IR[y],tau.log.IR[y])
  #DIDSON detects fraction p.MR of total migrants
  Midriver.Run[y] <- p.MR * Inriver.Run[y]
  log.MR[y] <- log(Midriver.Run[y])
  tau.log.DS[y] <- 1 / log(cv.DS[y]*cv.DS[y] + 1)
  DIDSON[y] ~ dlnorm(log.MR[y],tau.log.DS[y])

  mu.Habove[y] ~ dbeta(0.1,0.1)
  H.above[y] <- mu.Habove[y] * Inriver.Run[y]
  log.Ha[y] <- log(H.above[y])
  tau.log.Ha[y] <- 1 / log(cv.Ha[y]*cv.Ha[y] + 1)
  Habove.hat[y] ~ dlnorm(log.Ha[y],tau.log.Ha[y])
  mu[y] <- (H.below[y] + H.above[y]) / N[y]
  S[y] <- max(Inriver.Run[y] - H.above[y], 1)
  log.S[y] <- log(S[y])
  }

  for(i in 1:5) {
    log.q[i] ~ dnorm(0,1.0E-4)
    tau.i[i] ~ dgamma(0.001,0.001)
    r.i[i] <- 1.0
    sigma.i[i] <- 1 / sqrt(tau.i[i])
    q.i[i] <- exp(log.q[i])                #q.i is theta in the text
    for (y in 1:Y) {
      index[y,i] ~ dlnorm(log.qiNri[y,i],tau.i[i])   #index is capital I in the text
      }
    }
  for (y in 1:Y) {
    log.qiNri[y,1] <- log(q.i[1] * pow(Midriver.Run[y],r.i[1]))
    log.qiNri[y,2] <- log(q.i[2] * pow(Midriver.Run[y],r.i[2]))
    log.qiNri[y,3] <- log(q.i[3] * pow(Inriver.Run[y],r.i[3]))
    log.qiNri[y,4] <- log(q.i[4] * pow(N[y],r.i[4]))
    log.qiNri[y,5] <- log(q.i[5] * pow(Midriver.Run[y],r.i[5]))
    }
```

-continued-

```
# CALCULATE SUSTAINED YIELD AT REGULAR INTERVALS OF S;
# FIND PROBABILITY S* WILL PROVIDE YIELDS WITHIN X% OF MSY;
# SY AT RECENT PRODUCTIVITY LEVELS EVALUATED;
R.msy <- S.msy * exp(lnalpha - beta * S.msy)*exp(sigma.red*sigma.red/2)
MSY <- R.msy - S.msy
nOF90[1] <- 0
nOF80[1] <- 0
nOF70[1] <- 0
  for (i in 1:100) {                  #LOOP TO FIND Pr(SY>XX%MSY)
    S.star[i] <- 1000*i
    R.star[i] <- min(S.star[i] * exp(lnalpha.c - beta * S.star[i]),1.0E6)
    R.recent[i] <- min(S.star[i] * exp(lnalpha.c.recent - beta * S.star[i]),1.0E6)
    SY[i] <- R.star[i] - S.star[i]
    SY.recent[i] <- R.recent[i] - S.star[i]
    I90[i] <- step(SY[i] - 0.9 * MSY)
    I80[i] <- step(SY[i] - 0.8 * MSY)
    I70[i] <- step(SY[i] - 0.7 * MSY)
    Exceed70Rmax[i] <- step(R.star[i] - 0.7 * R.max)
    Exceed80Rmax[i] <- step(R.star[i] - 0.8 * R.max)
    Exceed90Rmax[i] <- step(R.star[i] - 0.9 * R.max)
    OF90[i] <- 1 - nOF90[i]
    OF80[i] <- 1 - nOF80[i]
    OF70[i] <- 1 - nOF70[i]
    }
for (i in 2:100) {
    nOF90[i] <- max(I90[i],nOF90[i-1])
    nOF80[i] <- max(I80[i],nOF80[i-1])
    nOF70[i] <- max(I70[i],nOF70[i-1])
    }
# MEASURES OF REDUCED PRODUCTIVITY FOR 2004-2008
  lnalpha.recent    <- mean(lnalpha.y[27:31])
  lnalpha.c.recent <- mean(lnalpha.y[27:31]) + (sigma.white * sigma.white / 2 / (1-phi*phi) )
  U.msy.recent <- lnalpha.c.recent * (0.5 - 0.07*lnalpha.c.recent)
}
```

Appendix A2.–WinBUGS data objects for a state-space model of Kenai River Chinook salmon data, 1986–2012. Abundance indices are NCPUE, NASB, SCPUE, CCPUE, and ELSD.

list(Y=**27**, A=**5**, a.min=**4**, a.max=**7)**

index[,1]	index[,2]	index[,3]	index[,4]	index[,5]	DIDSON[]	cv.DS[]	IR.hat[]	cv.IR[]
NA	NA	0.110	1391	NA	NA	0.05	NA	0.01
NA	NA	0.099	1182	NA	NA	0.05	NA	0.01
NA	NA	0.115	945	NA	NA	0.05	NA	0.01
NA	NA	0.066	669	NA	NA	0.05	NA	0.01
NA	NA	0.055	514	NA	NA	0.05	NA	0.01
NA	NA	0.058	661	NA	NA	0.05	NA	0.01
NA	NA	0.073	706	NA	NA	0.05	NA	0.01
NA	NA	0.102	987	NA	NA	0.05	NA	0.01
NA	NA	0.080	1089	NA	NA	0.05	NA	0.01
NA	NA	0.065	1277	NA	NA	0.05	NA	0.01
NA	NA	0.042	1012	NA	NA	0.05	50053	0.17
NA	NA	0.050	717	NA	NA	0.05	44567	0.17
NA	NA	0.066	959	NA	NA	0.05	NA	0.01
NA	NA	0.078	829	NA	NA	0.05	NA	0.01
NA	NA	0.072	758	NA	NA	0.05	NA	0.01
NA	NA	0.100	809	NA	NA	0.05	NA	0.01
12.74	41813	0.106	947	33508	NA	0.05	NA	0.01
16.88	62635	0.176	1252	57101	NA	0.05	NA	0.01
14.18	75050	0.129	1547	43542	NA	0.05	NA	0.01
13.81	85590	0.127	1105	48275	NA	0.05	NA	0.01
17.58	52482	0.091	778	37692	NA	0.05	NA	0.01
10.42	29457	0.073	987	28914	NA	0.05	51060	0.20
12.17	36011	0.060	560	24589	NA	0.05	47460	0.14
5.38	17722	0.074	525	15655	NA	0.05	44660	0.23
3.03	12501	0.039	535	NA	19000	0.071	21330	0.16
5.14	18765	0.068	692	NA	21036	0.023	27300	0.18
2.98	13896	NA	NA	NA	21914	0.029	25080	0.15

END;

-continued-

Hbelow.hat[]	cv.Hb[]	Habove.hat[]	cv.Ha[]
15097	0.15	10188	0.05
17998	0.15	13223	0.06
11056	0.15	19871	0.05
8341	0.15	9779	0.06
4283	0.15	6966	0.07
4947	0.15	7919	0.05
9410	0.15	7790	0.06
11979	0.15	18253	0.04
12502	0.15	18409	0.04
10528	0.15	13081	0.05
9725	0.15	8449	0.06
10197	0.15	13325	0.06
5037	0.15	8110	0.07
9110	0.15	13107	0.08
4571	0.15	14890	0.05
7034	0.15	15969	0.07
9558	0.15	11343	0.07
12888	0.15	17923	0.09
19997	0.15	16007	0.07
19984	0.15	17194	0.08
12400	0.15	13320	0.08
12735	0.15	10360	0.07
8293	0.15	10498	0.08
6833	0.15	8530	0.07
6556	0.15	7026	0.06
8186	0.15	7373	0.07
630	0.15	196	0.06
END;			

-continued-

Appendix A2.–Page 3 of 3. Multinomial age counts summing to effective sample size of 100.

x[,1] x[,2] x[,3] x[,4] x[,5]
0 14 43 39 4
1 5 29 64 1
1 3 6 76 15
0 11 14 63 12
0 14 16 65 5
0 9 18 67 6
0 8 18 71 3
1 9 15 70 5
1 7 12 75 5
1 23 23 48 6
1 10 34 54 1
2 6 24 66 2
1 16 15 65 3
1 15 22 59 4
1 5 32 60 2
1 15 19 62 3
3 20 21 53 3
2 32 20 45 1
2 16 28 52 1
1 11 19 66 4
3 28 15 45 9
1 25 28 39 7
3 9 22 60 7
3 34 11 49 4
8 21 34 32 5
3 31 21 44 2
2 10 40 44 4
END;

APPENDIX B: GENETIC STOCK IDENTIFICATION OF CHINOOK SALMON HARVESTED IN THE EASTSIDE SETNET FISHERY IN 2010–2011

Appendix B1.–Genetic stock identification of Chinook salmon harvested in the eastside setnet fishery in 2010–2011.

MEMORANDUM *State of Alaska*

Department of Fish and Game

Division of Commercial Fisheries

TO: Jeff Regnart
Division of Commercial Fisheries
Director

And

Charles Swanton
Sport Fish Division
Director

DATE: November 30, 2012

THROUGH: William Templin
Fisheries Scientist I

PHONE NO: 267-2290

FROM: Andrew Barclay
Fishery Biologist III

SUBJECT: ESSN Chinook salmon MSA

From 2010 to 2012 genetic tissue samples were collected opportunistically from Chinook salmon harvested in the Upper Cook Inlet (UCI) Upper Subdistrict set gillnet fishery, commonly referred to as the East Side Set Net (ESSN) fishery. Tissue samples were collected from Chinook salmon during regular openings at receiving sites and occasionally from a fish processor the following day. The sampling goal for each fishing period was to sample as many Chinook salmon as possible during each tide from all areas of the ESSN fishery. Because there was only one dedicated person to collect these samples, some areas of the ESSN fishery could not be sampled during each tide. Additionally, some areas were targeted for sampling because they were expected to have larger Chinook salmon harvests, while some areas with lower harvests were not sampled. A total of 885, 1281, and 185 Chinook salmon genetic tissue samples were collected in 2010, 2011, and 2012, respectively.

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In 2012 the ESSN fishery was closed for much of the season to protect Chinook salmon returning to the Kenai River. In the fall of 2012, the Gene Conservation Laboratory was directed to proceed with analysis of the collected samples to determine the stock composition the ESSN during the three years. Based on discussions with biologists and biometricians from both Commercial Fisheries and Sport Fish divisions, the 2012 samples were excluded from the analysis because of the low sample size and restricted fishing periods from which they originated. The GCL generally does not release estimates that might have management or allocation implications until data are collected over a minimum of three years. However, due to the public interest in this question, the GCL has analyzed the 2010 and 2011 collections and the results are provided in this memo. These estimates should be viewed as preliminary until data from a more structured study plan from additional years are analyzed.

The current genetic baseline for UCI Chinook salmon contains a total of 66 individual collections representing 32 populations which have been analyzed for 40 single nucleotide polymorphism loci (Table 1; Figure 1)[ed. note: see Appendices B2 and B4]. This baseline contains the same set of loci and collections as the baseline reported in Barclay et al. (2012) with the exception of two additional Kenai River populations (Grant Creek and Lower Kenai River mainstem). The updated baseline was used in the analysis of the ESSN fishery samples; however, Slikok Creek (Kenai River) was removed from the baseline because it is a very small population and it is genetically similar to Crooked Creek (Kasilof River). Initial tests of the baseline (which included Slikok Creek) for mixed-stock analysis (MSA) indicated that a large portion of Crooked Creek fish misallocated to Slikok Creek. Once Slikok Creek was excluded, MSA tests of the baseline indicated that adequate genetic differentiation existed among all the reporting groups and that they could be used with high confidence (at least 90% correct allocations in 100% proof tests; see methods in Barclay et al. 2010). These reporting groups include: 1) all UCI Chinook population North and West of the Kenai River; *NorthwestCI*, 2) Kenai River tributary populations (excluding Juneau Creek); *KenaiTrib*, 3) Kenai River mainstem populations including Juneau Creek; *KenaiMainstem*, 4) the Kasilof River mainstem population; *KasilofMainstem*, and 5) Anchor River, Ninilchik River, Deep Creek, and Crooked Creek; *CoastalSKenaiPen* (Table 1; Figure 1). Although Juneau Creek is a tributary of the Kenai River it was included in the Kenai River mainstem reporting group because it is genetically similar to Kenai River mainstem populations.

For the 2010 and 2011 collections, tissues were subsampled in proportion to the harvest within statistical areas of the Upper Subdistrict (Ninilchik, Cohoe, South K. Beach, North K. Beach, South Salamatof, and North Salamatof), with a goal of 400 individuals per year. Some tissue samples in 2010 and 2011 were collected at processors which received deliveries from multiple statistical areas. Because the specific statistical area of these samples was not identified, these samples were excluded from analysis. A total of 376 and 347 samples were selected for analysis from 2010 and 2011, respectively. Several samples from 2010 (3) and 2011 (5) were excluded from the analysis because they failed to genotype at more than 20% of loci screened (see methods in Barclay et al. 2012). These individuals were removed because the inclusion of individuals with poor quality DNA might introduce genotyping error and reduce the accuracy of the MSA. The final number of successfully analyzed samples was 373 and 342 samples in 2010 and 2011, respectively.

-continued-

The MSA program BAYES was used to estimate the proportions of the 5 reporting groups (stocks; Figure 1) contributing to each fishery sample. The analysis employed a similar the BAYES protocol reported in Barclay et al. (2010) for baseline evaluation tests, except that each fishery sample was analyzed for 5 chains with 40,000 iterations per chain. Estimates and 90% credibility intervals for each fishery sample were tabulated from the combined set of the second half of each chain (100,000 iterations).

The stock composition estimates for 2010 and 2011 were similar. In both years the Kenai River mainstem reporting group had the greatest contribution followed by the Kasilof River mainstem reporting group. The combined contribution of all other reporting groups in both years did not exceed 2.4% (Table 2; Figure 2) [ed. note: see Appendices B3 and B5].

Please let me know if you have any questions regarding this analysis.

Appendix B2.–[ed. note: this is Table 1 from memorandum in Appendix B1] Tissue collections of Chinook salmon collected throughout Upper Cook Inlet including the year sampled, number of samples collected (N), the number of individuals analyzed from each collection included in the baseline and their assigned reporting group for the analysis of the East Side Set Net fishery collections. Unique population numbers represent all the analyzed collections that contribute to a single population.

Pop. No.	Reporting group	Location	Year collected	N	Analyzed
1	NorthwestCI	Straight Creek	2010	105	95
2		Chuitna River	2008	20	20
2			2009	122	122
3		Coal Creek	2009	42	42
3			2010	35	35
4		Middle Fork Chulitna River	2009	72	72
4			2010	97	97
5		Stephan Lake weir	2008	19	19
5		Prairie Creek	1995	52	52
5			2008	98	98
6		Chunilna Creek	2009	50	50
7		Montana Creek	2008	33	33
7			2009	155	155
7			2010	30	30
8		Deception Creek	2009	122	100
8		Willow Creek	2005	74	74
9		Moose Creek	1995	51	51
9		Deshka River weir	2005	200	200
10		Talachulitna River	1995	58	58
10			2008	74	72
10			2010	48	48
11		Sunflower Creek	2009	53	53
12		Little Susitna River	2009	3	3
12			2010	122	122
13		Moose Creek	1995	20	20
13			2008	33	33
13			2009	22	22
14		Ship Creek	2009	311	311
15		Chickaloon River	2008	2	2
15			2010	66	65

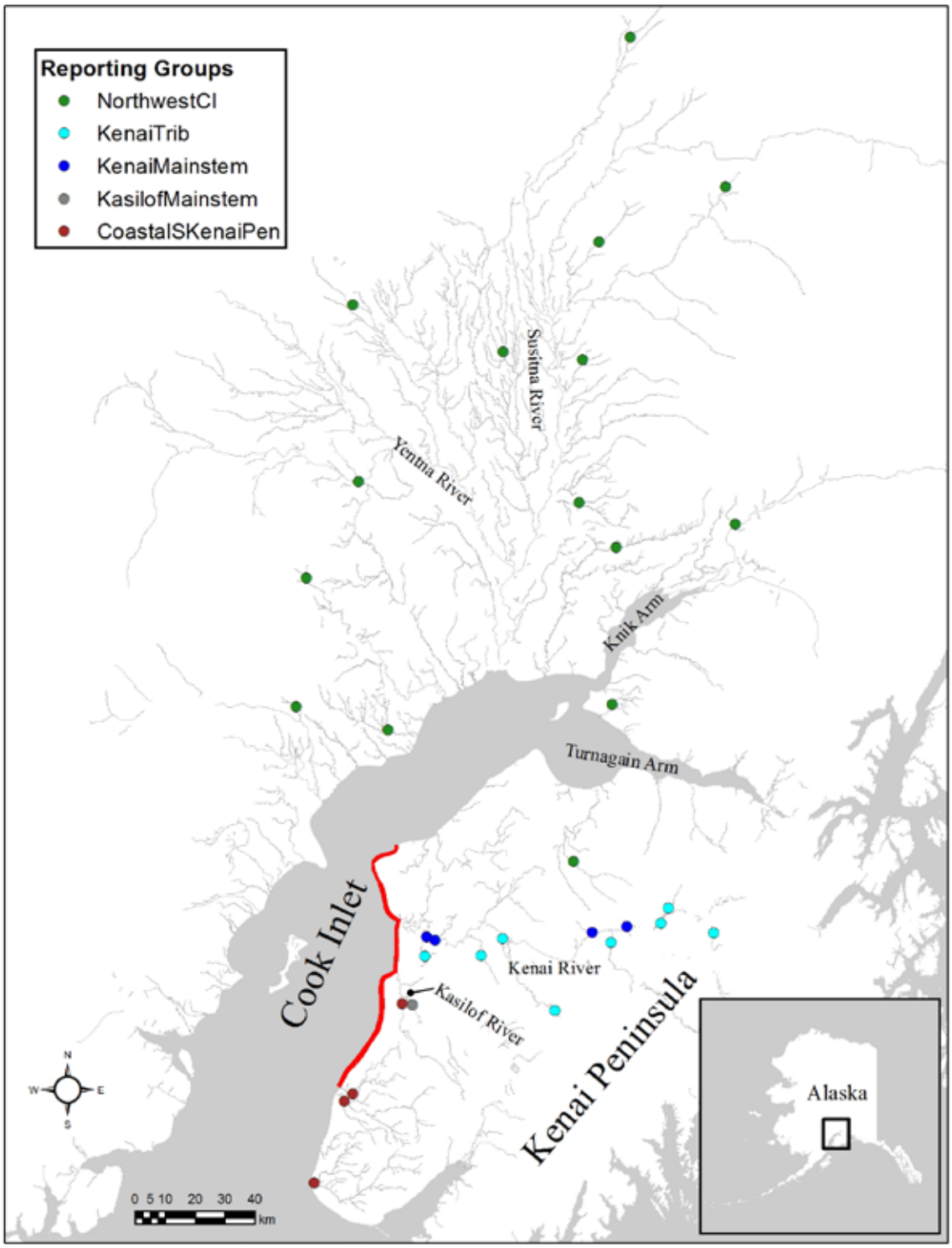
-continued-

Pop. No.	Reporting group	Location	Year collected	N	Analyzed
16	KenaiTrib	Grant Creek	2011	23	23
16			2012	32	32
17		Quartz Creek	2006	35	34
17			2008	34	34
17			2009	41	41
17		Dave's Creek	2007	8	8
17			2008	5	5
18		Crescent Creek	2006	165	165
19		Russian River	2005	24	24
19			2006	16	16
19			2007	84	83
19			2008	91	91
20		Benjamin Creek	2005	56	56
20			2006	150	150
21		Killey River	2005	68	68
21			2006	190	190
22		Funny River	2005	37	37
22			2006	183	183
23		Slikok Creek	2004	48	48
23			2005	100	95
23			2008	58	57
24	KenaiMainstem	Juneau Creek	2005	32	32
24			2006	100	91
24			2007	24	24
25		Upper Kenai River mainstem	2009	200	200
26		Middle Kenai River mainstem	2003	80	80
26			2004	39	39
26			2006	183	183
27		Lower Kenai River mainstem	2011	90	80
28	KasilofMainstem	Lower Kasilof River mainstem	2005	144	49
28		Middle Kasilof River mainstem	2005	273	273
29	CoastalSKenaiPen	Crooked Creek	1992	95	95
29			2005	212	212
30		Ninilchik River weir	2006	190	162
31		Deep Creek	2009	100	100
32		Anchor River weir	2006	200	200

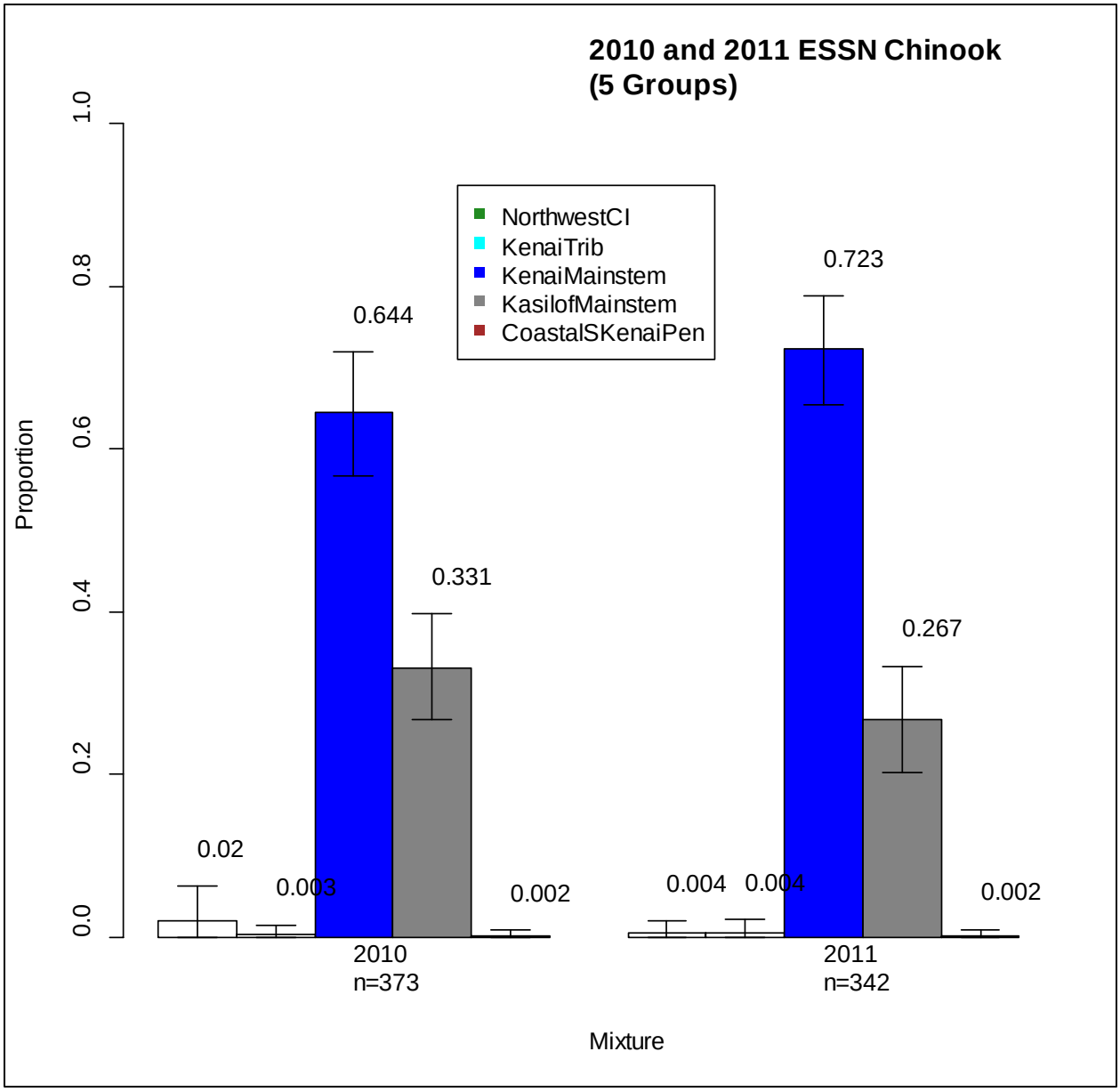
Appendix B3.–[ed. note: this is Table 2 from memorandum in Appendix B1] Stock proportion estimates, standard deviation (SD), sample size (n), and lower (5%) and upper (95%) bounds of the 90% credibility interval for mixtures of Chinook salmon harvested in the east side set net fishery in 2010 and 2011.

	2010 (n= 373)				2011 (n=342)			
Reporting Group	Mean	SD	5%	95%	Mean	SD	5%	95%
NorthwestCI	0.020	0.022	0.000	0.063	0.004	0.007	0.000	0.019
KenaiTrib	0.003	0.006	0.000	0.015	0.004	0.008	0.000	0.021
KenaiMainstem	0.644	0.046	0.566	0.719	0.723	0.041	0.654	0.788
KasilofMainstem	0.331	0.040	0.267	0.398	0.267	0.040	0.203	0.333
CoastalSKenaiPen	0.002	0.004	0.000	0.009	0.002	0.004	0.000	0.009

Appendix B4.–[ed. note: this is Figure 1 from memorandum in Appendix B1] Sampling locations (dots) for Chinook salmon used to compile a genetic baseline for Upper Cook Inlet. East Side Set Net fishery area is highlighted in red. Colors for each reporting group are indicated in the legend.



Appendix B5.–[ed. note: this is Figure 2 from memorandum in Appendix B1] Stock proportion estimates for Chinook salmon harvested in the East Side Set Net (ESSN) fishery of Upper Cook Inlet in 2010 and 2011. Numbers above the bars are the mean estimates, n is the sample size of the fishery sample for each year, and whiskers indicate the upper and lower bounds of the 90% credibility interval.



APPENDIX C: TOTAL RUN ABUNDANCE BY AGE CLASS

Appendix C1.–Total run abundance by age class obtained from fitting a state-space model to Kenai River late-run Chinook salmon data, 1986–2012.

Year	Age 3 (CV)	Age 4 (CV)	Age 5 (CV)	Age 6 (CV)	Age 7 (CV)
1986	453 (0.96)	12,150 (0.24)	31,680 (0.18)	31,430 (0.18)	3,110 (0.45)
1987	805 (0.71)	5,135 (0.31)	21,950 (0.19)	53,450 (0.15)	1,589 (0.55)
1988	803 (0.70)	3,977 (0.34)	6,655 (0.28)	53,170 (0.15)	9,096 (0.27)
1989	358 (0.95)	5,578 (0.26)	7,248 (0.24)	26,870 (0.17)	5,198 (0.29)
1990	323 (0.96)	5,977 (0.25)	7,181 (0.23)	23,590 (0.17)	1,902 (0.39)
1991	361 (0.95)	5,320 (0.27)	8,966 (0.22)	27,540 (0.16)	2,306 (0.36)
1992	367 (0.96)	5,676 (0.28)	10,460 (0.22)	34,030 (0.15)	1,754 (0.44)
1993	822 (0.70)	6,342 (0.27)	11,200 (0.23)	41,280 (0.16)	2,961 (0.39)
1994	873 (0.70)	5,674 (0.28)	8,661 (0.24)	42,510 (0.15)	3,020 (0.38)
1995	800 (0.70)	12,090 (0.21)	12,550 (0.20)	27,390 (0.16)	3,314 (0.36)
1996	709 (0.69)	6,274 (0.25)	16,610 (0.17)	28,500 (0.14)	1,174 (0.54)
1997	1,026 (0.57)	4,440 (0.28)	11,810 (0.18)	33,230 (0.12)	1,462 (0.48)
1998	770 (0.70)	8,248 (0.23)	8,814 (0.23)	32,930 (0.15)	2,016 (0.44)
1999	759 (0.70)	8,466 (0.23)	11,860 (0.20)	29,890 (0.15)	2,305 (0.40)
2000	791 (0.70)	4,473 (0.31)	15,400 (0.19)	30,460 (0.16)	1,469 (0.49)
2001	954 (0.69)	9,588 (0.24)	11,780 (0.22)	36,790 (0.16)	2,097 (0.45)
2002	2,134 (0.50)	13,500 (0.20)	14,650 (0.19)	33,890 (0.13)	2,366 (0.43)
2003	1,899 (0.58)	28,680 (0.18)	20,900 (0.20)	44,600 (0.15)	1,880 (0.55)
2004	1,646 (0.59)	14,480 (0.22)	28,370 (0.17)	53,670 (0.13)	2,101 (0.54)
2005	1,156 (0.69)	9,561 (0.25)	17,680 (0.20)	64,710 (0.12)	4,041 (0.40)
2006	1,597 (0.51)	16,820 (0.19)	11,900 (0.21)	37,540 (0.14)	6,543 (0.30)
2007	562 (0.71)	11,570 (0.19)	16,480 (0.16)	27,470 (0.13)	4,148 (0.33)
2008	1,191 (0.50)	4,069 (0.27)	10,450 (0.18)	32,250 (0.11)	3,232 (0.33)
2009	922 (0.50)	9,868 (0.17)	4,617 (0.23)	19,880 (0.13)	1,840 (0.40)
2010	2,043 (0.33)	5,714 (0.19)	9,489 (0.15)	11,250 (0.14)	1,642 (0.37)
2011	955 (0.51)	9,772 (0.16)	7,137 (0.18)	17,120 (0.12)	897 (0.48)
2012	585 (0.58)	3,376 (0.25)	10,280 (0.14)	13,220 (0.13)	1,214 (0.40)

APPENDIX D: GENETIC CAPTURE–RECAPTURE ESTIMATES OF INRIVER RUN

CRGEN estimates were generated by fitting a "Stock Specific Abundance and Run Timing" (SSART) statistical model to Kenai River Chinook salmon data. The SSART model is based on the work of Bromaghin et al. (2010), who developed a likelihood framework for joint estimation of salmon abundance and migratory timing using radio telemetry data. ADF&G modified the work of Bromaghin et al. (2010) to accommodate the use of GSI allele frequency data and data from the harvest after the first event, and by adopting a Bayesian framework for model fitting.

The SSART model (Appendix D2) was used to create a matrix of relative abundance by stock and by time period, where the stocks are the following genetic reporting groups: Killey River–Benjamin Creek, Funny River–Slikok Creek, Mainstem Kenai River, Quartz Creek–Crescent Creek, Russian River, and Grant Creek. Information about stock composition was provided by 1) genetic stock identification (GSI) methods applied to fish sampled with inriver gillnets, and 2) radio telemetry. Information about relative abundance across (15-day) time periods was provided by catch rates at the RM-9 inriver test gillnetting program. The matrix of relative abundance was anchored by independent estimates of escapement for Funny River and Slikok Creek, and Russian River reporting groups,[24] thereby permitting estimation of absolute abundance for the entire inriver run. Harvest by stock was accounted for by sampling GSI information from fish encountered in the lower river creel survey and a supplemental sampling program, and weighting by creel and mail survey estimates of harvest by time strata. Timing of each stock past the RM-9 capture site was assumed to be bell-shaped.[25]

Unlike traditional mark–recapture experiments, which must assume that behavior of marked fish is unaffected by handling, the SSART model experiment utilizes GSI information as the primary "mark." Because GSI data are derived solely from tissue samples collected at time of capture, fish behavior after the time of sampling has no bearing on the estimates.

Radiotransmitters were applied to a subsample of captured fish, and their spawning destinations were determined by radio telemetry methodology. Telemetry provides known stock identification for a subset of GSI-sampled fish, which strengthens the GSI information and improves the precision of abundance estimates.

The SSART capture–recapture model not only provides estimates of abundance of Kenai River Chinook salmon stocks but also their run timing, which is valuable for management purposes. Model structure is hierarchical among years with respect to total abundance, stock composition, and run-timing parameters.

Like the state-space model described in the main body of this report, the SSART model is implemented in OpenBUGS (Lunn et al. 2009), which provides the flexibility to combine information from multiple data sources.

Preliminary estimates of inriver abundance of late-run Chinook salmon during the years 2007–2012 are reported in Table 3. Because the model itself continues to undergo development, and because more years of data will be added, these estimates will change. A report detailing SSART model methods and results is planned for publication in 2014.

[24] The Benjamin and Killey rivers reporting group was also used in 2012.
[25] Expectation of run timing was based on the normal probability density function.

Appendix D2.–Flowchart of annual quantities (parameters N, H, and S in green; data x, y, r, H, and W in blue) from a stock-specific abundance and run timing (SSART) model. By fitting the SSART model to 2007–2012 Kenai River Chinook salmon data, CRGEN estimates of inriver run abundance by stock and time period are obtained. Two revisions to the model have occurred since this figure was produced: a sixth reporting group (Grant Creek) was added to the model; and the number of alleles was reduced from 40 to 38.