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Susitna River Chinook Salmon Run Reconstruction and Escapement Goal Analysis

by

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and

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Mathematics, statistics

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

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ABSTRACT

The Susitna River drains approximately 52,000 square kilometers of the southern slopes of the Alaska Range and the Talkeetna mountains. This watershed supports wild populations of all 5 species of Pacific salmon and vibrant sport fisheries when production allows. Chinook salmon spawning escapements have been monitored since the late 1970s by aerial survey and a weir has been used to count returning adults on the Deshka River (a tributary) since 1995. The Deshka River is currently managed by an escapement goal based on weir passage whereas several other spawning populations are managed using escapement goals based only on once-per-year aerial surveys. Other fishery data, such as inriver and marine harvest estimates, age estimates, recent mark–recapture abundance estimates, and spawner distribution data are also available. We present a state-space model that incorporates all available datasets to generate annual inriver and spawning escapement abundance estimates of 4 stocks of Susitna River Chinook salmon. These stocks were created by dividing the drainage into geographical units similar to existing management units used in Alaska Department of Fish and Game sport fishing regulations: Deshka River, Eastside Susitna, Talkeetna River, and Yentna River. The state-space model estimates a spawner-recruitment (S-R) relationship for each stock that is used in developing escapement goal recommendations based on the number of spawners that provide maximum sustained yield (S_{MSY}). S_{MSY} was estimated for each stock: 12,564 for Deshka River; 12,971 for Eastside Susitna; 10,570 for Talkeetna River; and 13,614 for Yentna River. We used a decision matrix to choose escapement goals based on the probability of achieving maximum sustained yield for the 4 stocks. We recommend discontinuing escapement goals for individual spawning populations within these stocks and replacing them with stock-based escapement goals of 9,000–18,000 for Deshka River, 13,000–25,000 for Eastside Susitna, 9,000–17,500 for Talkeetna River, and 13,000–22,000 for Yentna River stocks.

Key words: Susitna River, Eastside Susitna, Deshka River, Talkeetna River, Yentna River, Chinook salmon, *Oncorhynchus tshawytscha*, state-space model, spawner-recruit relationship, maximum sustained yield, escapement goal

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) runs to the Northern Cook Inlet Management Area (NCIMA[1]) are made up of many spawning populations and collectively contribute the largest proportion of the Chinook salmon runs into Cook Inlet. The Chinook salmon run into the Susitna River drainage is the largest within the management area, and the fourth largest in Alaska, smaller only than runs into the Yukon, Kuskokwim, and Nushagak river drainages (Delany and Vincent-Lang, unpublished[2]). Until recently, estimates of the total Chinook salmon run into the Susitna River drainage have not been available, although it has long been assumed to number from 100,000 to 200,000 fish (Delaney and Vincent-Lang *unpublished*). Since 2014, Susitna River Chinook salmon mark–recapture studies have estimated an inriver run of Susitna River Chinook salmon of between 63,340 and 136,995 fish annually.

Current management units (Figure 1) used by the Alaska Department of Fish and Game (ADF&G) Division of Sport Fish (SF) are described in the annually published Southcentral Alaska Sport Fishing Regulations Summary (http://www.adfg.alaska.gov/index.cfm?adfg=fishregulations.sc_sportfish). The units are defined as Unit 1, the Susitna River from its mouth to and including the Deshka River; Unit 2, the Susitna River and tributaries upstream of the Deshka River to the Talkeetna River confluence; Unit 3, the Susitna River upstream from the

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[1] The NCIMA includes all freshwater drainages and adjacent marine waters of Upper Cook Inlet (UCI) between the southern tip of Chisik Island and the Eklutna River, excluding the upper Susitna River drainage upstream of the Oshetna River confluence.

[2] Delaney, K. and D. Vincent-Lang. Unpublished. Current status and recommendations for the future management of the Chinook salmon stocks of Northern Cook Inlet. A report to the Alaska Board of Fisheries, Anchorage, Alaska, November 1992. Alaska Department of Fish and Game, Division of Sport Fish, Anchorage. Subsequently referred to as Delaney and Vincent-Lang *unpublished*.

Talkeetna River confluence to the Oshetna River; Unit 4, the Yentna River drainage; Unit 5, the Talkeetna River drainage; and Unit 6, the Chulitna River drainage.

Unit 1 includes the Deshka River and Alexander Creek. The Deshka River supports one of the largest sport fisheries in the Susitna River drainage and is accessible only by boat, typically from the town of Willow. Alexander Creek once supported a popular Chinook salmon sport fishery until the mid-2000s when the population crashed, most likely due to northern pike (*Esox lucius*) predation (St. Saviour 2017). Both the Deshka River and Alexander Creek currently have escapement goals; the Deshka River has a weir-based goal, and the Alexander Creek goal is based on once-per-year ("single") aerial surveys. Alexander Creek has not met its aerial survey escapement goal since 2005 (Oslund et al. 2017: page 98).

Unit 2 includes streams accessible from the Parks Highway from the community of Willow to Trapper Creek. Popular Chinook salmon fisheries take place on Willow, Little Willow, Sheep, and Montana creeks, and the Kashwitna River. Goose Creek once supported a Chinook salmon fishery but has been closed by regulation since 2011 due to poor runs. Goose, Willow, Little Willow, Montana, and Sheep creeks each have single aerial-survey-based escapement goals. Presently, Goose and Sheep creeks have been designated by the Alaska Board of Fisheries (BOF) as stocks of management concern, and Willow Creek a stock of yield concern. Deception Creek, a tributary of Willow Creek, is stocked with hatchery Chinook salmon although hatchery fish are a small component of the run to the Willow Creek drainage (3–27% annually).

Unit 3 includes the Susitna River drainage, excluding the Chulitna River, upstream of the confluence of the Talkeetna River. In this unit, Indian River and Portage Creek tributaries support spawning populations of Chinook salmon. These are remote areas with difficult access that support little, if any, sport fishing. Both tributaries are downstream of Devil's Canyon, above which there are no known spawning areas. There are no escapement goals in this unit; however, single aerial surveys are flown to monitor escapements on both Indian River and Portage Creek as budgets allow.

Unit 4 comprises the entire Yentna River drainage. The Yentna River is a large, remote river accessible only by boat or small aircraft. It supports multiple sport fisheries, the largest of which are on Lake Creek and the Talachulitna River (a tributary of the Skwentna River). These 2 systems have single aerial-survey-based escapement goals. The Kahilitna River drainage also supports spawning populations in its tributaries Cache Creek and Peters Creek, which have escapement goals based on annual single aerial surveys. There are several smaller spawning populations in the remainder of the Yentna River drainage. For example, the Upper Yentna River and the Skwentna River all support spawning Chinook salmon populations, and most of them are only occasionally surveyed as budget allows.

Unit 5 includes the entire Talkeetna River, including Clear and Prairie creeks. Each of these creeks have escapement goals assessed with annual single aerial surveys. Clear Creek supports a popular Chinook salmon fishery. Both creeks are remote and require boat access.

Unit 6 includes the Chulitna River. The East Fork Chulitna River has an escapement goal assessed with an annual single aerial survey. This is a remote area but with some road access supporting a small catch-and-release fishery.

In total, there are 13 aerial-survey–based escapement goals within the Susitna River drainage. Surveyed streams are flown once per year during the peak spawning period and the resultant count provides an index of escapement. This assessment program includes most Susitna River Chinook salmon populations and provides multiple annual indices of Chinook salmon abundance from throughout the drainage. Goals based on aerial survey data are formed around percentiles of historical counts, which are used as a proxy for S_{MSY} in the absence of stock-specific productivity information (Bue et al. 2002). Most of the surveyed populations also support sport fisheries, and harvests from these have been monitored by the ADF&G Statewide Harvest Survey (SWHS) program (http://www.adfg.alaska.gov/sf/sportfishingsurvey/).

In general, management actions are applied to all Chinook salmon fisheries within a management unit even though most units are assessed with multiple goals. This system has been an effective management tool but can present managers with conundrums. For example, in Unit 5 (Talkeetna River) during 2012 and 2014, Clear Creek aerial survey counts achieved the escapement goal, whereas the Prairie Creek aerial survey counts were below the escapement goal. In Unit 2 (Eastside Susitna) between 2010 and 2012, aerial survey counts were below the escapement goal on Montana Creek and Willow Creek but achieved the escapement goal on Little Willow Creek.

The Sustainable Salmon Fisheries Policy defines a stock as an aggregation of 2 or more salmon populations that occur in the same geographic area and are managed as a unit (Alaska Administrative Code 5 AAC 39.222[f][34]). In this report, 4 Chinook salmon stocks are considered: Deshka River, Eastside Susitna, Talkeetna River, and Yentna River. We will use the term management **area** when referring the geographic areas in which the stocks occur. The stocks (Figure 2) include all Chinook salmon in management units 1, 2, 5, and 4, respectively, except that the Deshka River stock omits Alexander Creek Chinook salmon and thus the Deshka River management area is smaller than management unit 1. Chinook salmon in management units 3 and 6 were not considered due to a lack of data.

Until recently, ADF&G lacked stock assessment data that applied directly to these stocks. However, mark–recapture abundance projects implemented between 2012 and 2017 (AEA 2014, 2015[3]; Yanusz et al. 2018; DeCovich et al. *In prep*) consisted of an abundance estimation component and a distribution study component. Abundance was estimated for the mainstem Susitna River, defined as the entire drainage above the confluence of the Yentna River, and for the Yentna River. Radiotelemetry data were used to estimate the spawning distribution of Chinook salmon, and the distribution data were used to partition drainagewide abundance estimates into estimates of abundance for each stock. Radiotelemetry data also provided information about the relative composition of spawning populations within each stock. In this report, mark–recapture estimated abundance by stock was related to indices of abundance (such as aerial or weir counts) for spawning populations within each stock. This relationship, available for 5 years of this study, and other aerial survey index counts going back to the late 1970s enabled reconstruction of Susitna River Chinook salmon runs for each stock.

OBJECTIVES

1) Reconstruct historical annual run abundance, escapement, harvest, and age composition for Chinook salmon spawning within Susitna River Chinook salmon management areas from 1979 to 2017.
2) Estimate stock-recruit relationships for each Susitna River Chinook salmon stock.

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[3] These documents are available at Alaska Resources Library and Information Services (ARLIS).

3) Recommend escapement goals for each Susitna River Chinook salmon stock.

METHODS

Comprehensive analyses of all relevant stock assessment data were conducted in the context of an integrated state-space model of historical run abundance and stock dynamics. The state-space model, patterned closely after those of Fleischman and McKinley (2013), assumes a Ricker spawner-recruit relationship and time-varying productivity. This model is age-structured, which enables a realistic depiction of observation error in 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 yield. By constructing an integrated model, uncertainty associated with the run reconstruction is assimilated directly into the spawner-recruit analysis and estimates of the spawning escapements that provide maximum sustained yield (S_{MSY}), maximum sustained recruitment (S_{MSR}), and equilibrium (S_{EQ}).

DATA

The data available for this analysis (Figure 3) come from multiple projects, none of which were designed to answer the objectives of this report. Details regarding these data follow.

Inriver Run Size

Mark–recapture abundance estimates of Susitna River Chinook salmon are available for the mainstem Susitna River upstream of RM 34 for the years 2013–2017, and for the Yentna River upstream of RM 6 for years 2014–2017 (AEA 2014, 2015; Yanusz et al. 2018; DeCovich et. al. *In prep*) (Appendix A1). Because mark–recapture abundance estimates were germane to fish greater than 500 mm mid eye to tail fork length (METF) and aerial survey counts include all Chinook salmon, observed length-at-age data from the Deshka River weir were used to estimate the proportion of age-3 (1.1) and age-4 (1.2) fish less than or equal to 500 mm METF during years with mark–recapture estimates. The age-length data can be represented by 5-element vectors representing years 2013–2017 where (5, 17, 19, 15, 13) is the number of age-3 fish less than or equal to 500 mm METF and (13, 21, 36, 70, 21) is the total number of age-3 fish sampled for age. Thus 5 of the 13 age-3 fish sampled for age in 2013 were less than or equal to 500 mm METF. Likewise, (2, 15, 3, 0, 0) is the number of age-4 fish less than or equal to 500 mm METF and (64, 96, 92, 187, 28) is the number of age-4 fish sampled for age. All age-5+ fish are assumed to exceed 500 mm METF.

Spawning Abundance

Spawning escapements are indexed annually using helicopter surveys or weirs on 13 populations nested within the Deshka River, Eastside Susitna, Talkeetna River and Yentna River stocks. (Appendices A2 and A3) (Oslund 2016). To provide consistent annual index counts, spawning streams are flown in their entirety from mouth to headwaters to avoid shifts in spawning distribution and in case the survey is not flown during peak spawning. Aerial counts between 2 surveyors, each counting the same stream, were also paired in 1993–1996 on several Northern Cook Inlet streams. Paired aerial counts revealed an average of 93% agreement between surveyors, ranging from 91% to 98% agreement (Lafferty 1997).

Deshka River Stock

Prior to 1995, the Deshka River Chinook salmon escapement was monitored using a single aerial survey conducted yearly after the sport fishery had taken place (Appendix A2). Due to the popularity of the fishery and declining escapement indices in the early and mid-1990s, a weir was installed in 1995 to give ADF&G managers accurate inseason data about the escapement and the biological composition of the escapement (Lescanec 2017; Appendix A3), although aerial surveys were continued in some years.

Eastside Susitna Stock

Aerial survey data are available for 6 populations within the Eastside Susitna stock. Surveyed areas cover the known major spawning areas for this stock (Appendix A2).

For this analysis, Willow Creek survey counts were combined with Deception Creek (a tributary of Willow Creek) counts. Chinook salmon that spawn in the mainstem of Willow Creek are predominantly wild fish, whereas runs to Deception Creek include hatchery-reared fish. Deception Creek represents the only hatchery component to the Susitna River drainage Chinook salmon runs. Our run reconstruction requires pairing mark–recapture derived abundance estimates with aerial survey counts from the same stock. Mark–recapture estimates were germane to both hatchery and wild Chinook salmon, and radiotelemetry data used to estimate stock composition did not distinguish between Willow and Deception creeks, so aerial survey counts from both streams must be pooled in this analysis. Hatchery fish are allowed to spawn and contribute to returns in each brood year.

A weir located between the Parks Highway and the Willow Creek–Deception Creek confluence was operated on Willow Creek as part of a coded wire tag study from 2000 through 2002, and escapement counts of Chinook salmon were recorded (Suzanne Hayes, ADF&G Fishery Biologist, unpublished data; Appendix A3).

A weir was operated on Montana Creek in 2013 and 2014 as part of Susitna River mark-recapture studies, and Chinook salmon escapement was counted in both years (unpublished data from Cleary et al. 2014a; Cleary et al. 2014b) (Appendix A3).

Talkeetna River Stock

Aerial survey data are available for 2 populations—Clear and Prairie creeks—in the Talkeetna River stock (Appendix A2). Survey conditions are often favorable for these 2 creeks and they represent the major spawning areas for Chinook salmon in the Talkeetna River drainage. Two other tributaries—Iron Creek and Sheep River—have been shown to support some spawning habitat, but these are glacial and therefore not flown during annual survey flights.

Yentna River Stock

Aerial survey data are available for 4 populations within the Yentna River stock (Appendix A2). Lake Creek and the Talachulitna River are popular sport fishing destinations. Two other populations are surveyed (Cache and Peters creeks). Numerous small spawning populations, which together are a significant portion of the total, are too diffuse to be enumerated by aerial survey. Survey conditions are often favorable in the tributaries flown, with no counts missed in the last 28 years (1990–2017) for Lake Creek and the Talachulitna River. Cache Creek has substantial mining activity and complete counts are sometimes not available because of cloudy water from holding ponds draining into the main channel.

Stock Composition Data

Spawning distribution studies using radiotelemetry methods were conducted from 2013 through 2017 in the Susitna River drainage and from 2014 through 2017 in the Yentna River drainage (Cleary and Campbell 2016; Cleary et al. 2014a, 2014b, 2015, 2017; Yanusz et al. 2018; DeCovich et al. *In prep*). Radiotagged Chinook salmon were tracked with a combination of fixed station receivers and aerial tracking via small aircraft. For this analysis, final tag locations were arranged as multinomial count data relative to geographic areas covered by aerial surveys within each stock (Appendix A4). Final locations within an aerial survey footprint were associated with the surveyed population whereas final locations that fell outside of the areas covered by surveys were added to an "other" category for each stock (e.g., Other Eastside Susitna). The "other" category describes the unsurveyed portion of each stock.

Age Data

Age of returning adults was estimated from scale pattern analysis. Scale age data for Susitna River Chinook salmon come primarily from inriver harvest sampling and weir projects. These age data were available as total sample size and proportion in each age class. For this analysis, age data were converted into multinomial counts, and the sum of those counts was reported as the sample size. Small differences sometimes result between the sample sizes reported here and those reported in source publications due to the rounding error associated with this conversion.

Scales were collected from 1995 to 2017 in a systematic sampling program at the Deshka River weir and in each of the 3 years of operation (2000–2002) of the Willow Creek weir. No scale collection was done at the Montana Creek weir. Data from roaming harvest sampling surveys of the Susitna River drainage are also available for the years 1979–2000. We present data from these studies as 4 appendices corresponding to the stocks defined above (Appendices A5–A8). When reported data included harvest samples from more than 1 stock, the sample was assigned to the stock that contained the largest number of sampling locations.

Marine Harvest

Susitna River Chinook salmon migrate through numerous mixed-stock marine fisheries in Cook Inlet, and their contribution to many of these fisheries has been examined using genetics. Genetics studies show that Susitna River Chinook salmon do not make up a significant proportion of the harvest in Central Cook Inlet fisheries. For example, in the Eastside set gillnet fishery in Upper Cook Inlet, the reported harvest of "other Cook Inlet" reporting group, which includes the Susitna River, ranged between 4 and 211 fish, during 2010–2015 (Eskelin and Barclay 2016). These estimates are a maximum because there are more stocks included in the "other" reporting group than just the Susitna River. Susitna River Chinook salmon harvested in the marine sport fisheries of Cook Inlet is also small. The sport harvest of Northern Cook Inlet Chinook salmon (which includes Knik and Turnagain Arm stocks in addition to Susitna River stocks)ranged from 143 (2017) to 259 (2015) for the years 2014–2017 (Barclay et al. 2019). A drift gillnet fishery targeting sockeye salmon (*O. nerka*) in Cook Inlet also harvests some Chinook salmon (1966–2016 annual average was 954 Chinook salmon; Shields and Frothingham 2018); however, no stock composition information is available for Chinook salmon harvested in this fishery. We assume it is not significant for the purpose of this study because the fishery largely takes place after Susitna River Chinook salmon have migrated through the area.

Numbers of Chinook salmon harvested in the Northern District set gillnet fishery were obtained from mandatory fish tickets issued at fish processors (Shields and Frothingham 2018). Genetic stock composition analysis of the Northern District set gillnet harvest estimated Susitna River Chinook salmon composed 48% (SE 2.4%) of the harvest in 2016 and 55% (SE 2.5%) of the harvest in 2017 (Andrew Barclay, Fishery Biologist, ADF&G, Division of Commercial Fisheries, personal communication). Stock composition estimates are probably biased for years prior to 1986 because the fishery occurred later in the season, although the effect of this bias on the run reconstruction is negligible because total harvest during this period (725–2,716 fish) was small relative to the run of Susitna River Chinook salmon. Annual estimates were used to apportion the total commercial harvest for 2016 and 2017 but for all other years (1979–2015), the average proportion of 0.52 was used to estimate the number of Susitna River Chinook salmon harvested in the Northern District set gillnet fishery.

Numbers of Chinook salmon harvested in the Tyonek Subsistence fishery were obtained from survey data (Jones and Koster 2018). Genetic stock composition analysis of the Tyonek subsistence harvests estimated Susitna River Chinook salmon composed 56% (SE 4.7%) of the harvest in 2016 and 66% (SE 5.1%) of the harvest in 2017 (Andrew Barclay, Fishery Biologist, ADF&G, Division of Commercial Fisheries, personal communication). Annual estimates were used to apportion the total subsistence harvest for 2016 and 2017 but for all other years (1980–2015), the average proportion of 0.61 was used to estimate the number of Susitna River Chinook salmon harvested in the Tyonek subsistence fishery.

Total marine harvest of Susitna River Chinook salmon was estimated as the sum of the Northern District set gillnet harvest (years 1979–2017) and the Tyonek subsistence harvest (years 1980–2017) although this quantity contains harvest of Susitna River Chinook salmon not belonging to the Deshka, Eastside Susitna, Talkeetna and Yentna stocks. Mark–recapture abundance estimates between 2014 and 2017 contain information about the proportion of the total run of Susitna River Chinook salmon represented by the 4 stocks considered in this analysis (75%–90% annually, 85% average). Annual estimates were used to apportion the total marine harvest for 2014–2017 but for all other years (1979–2013), the average proportion (85%) was used to estimate marine harvest originating from the 4 stocks considered in the analysis. Marine harvest from each stock was assumed to be proportional to stock specific abundance. We assumed a large CV (15%) for these harvest estimates to account for uncertainty regarding apportionment (Appendix A9).

Inriver Harvest

Inriver harvest of Susitna River Chinook salmon prior to 1996 is obtained from published ADF&G SWHS estimates (Mills 1979–1980, 1981a–b, 1982–1994; Howe et al. 1995, 1996). Harvest estimates for individual fisheries were summed within each management area for this analysis. Because fisheries are proximate to spawning destinations, harvest within each management area is assumed to represent the stock that spawns within the management area. The design of the SWHS changed beginning in 1996, providing standard errors for SWHS estimates. SWHS estimates beginning in 1996 to present are now available in an online database (Alaska Sport Fishing Survey database [Internet]. 1996–present. Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish. Available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/). A “novel query” of this database was designed by ADF&G Sport Fish Research and Technical Services (RTS) staff to obtain post-1996 SWHS estimates and standard errors within each management area. Estimates were calculated for the Deshka River, both below and above the weir site, Eastside Susitna, Talkeetna River, and Yentna River (Appendix A10). Actual CVs were calculated for inriver harvest estimates between 1996 and 2017. For years prior to 1996, CVs for each management area were assumed to equal the 75th percentile of the CVs from the post-1996 harvest estimates.

STATE-SPACE MODEL

A state-space model (Appendix B1) was developed to generate annual abundance estimates for Susitna River Chinook salmon stocks and fit spawner-recruitment (S-R) relationships for use in developing escapement goal recommendations based on maximum sustained yield. State-space models contain 2 components: process equations and observation equations. Process equations describe population dynamics that are unobserved but of research or harvest management interest. In this application we focus on spawning escapements, recruitment from those escapements, and parameters that describe the S-R relationship. Observation equations describe how observed data are generated conditional on population parameters and latent recruitment states estimated by the process equations. We lack a robust time series of observed abundance and instead model the relationship between abundance and aerial survey data to reconstruct historical abundances while incorporating the uncertainty in historical abundance estimates into the S-R parameter estimates.

Many parameters are estimated in this state-space model. Parameters with similar function or interpretation often use the same symbol, distinguished by a subscript capital letter. Subscript lower-case letters denote parameter indices. For example, all harvest rates use the symbol μ where μ_{By} is the harvest rate below (downstream of) both Susitna RM 34 and Yentna RM 6 in year y, and μ_{Ays} is the harvest rate of stock s above either Susitna RM 34 or Yentna RM 6 in year y. Year indices y range from 1 to 39 representing 1979 to 2017, respectively. Age indices a range from 3 to 6, representing total age of Chinook salmon, where $a = 6$ represents fish with a total age of 6 or larger. Stock indices s range from 1 to 4, representing the Deshka River, Eastside Susitna, Talkeetna River, and Yentna River stocks, respectively (Figure 2). Some data and parameters are nested within stocks. When this occurs the stock index is moved into the object name and one such object exists for each stock. For example, radio telemetry data vectors are called $\mathbf{r.s}$ for stock s and each vector is a different length depending on the number of populations that compose the stock .

Process Component

Abundance of Susitna River Chinook salmon for each stock is generated by a S-R relationship that describes the number of fish expected to return (the “recruitment”) from a given number of spawning fish (the “escapement”). The total expected recruitment R_{cs} produced from fish spawning in brood year c by stock s follows the Ricker (1975) formulation:

$$R_{cs} = S_{cs}\alpha_s exp(-\beta_s S_{cs}) \tag{1}$$

where S_{cs} is the number of spawners, α_s (number of recruits per spawner in the absence of density dependence) is a measure of productivity for each stock, and β_s is a measure of density dependence for each stock.

However, productivity varies among brood years, fluctuating around a central tendency. Time-varying productivity often manifests as serially correlated model residuals, so a lognormal error term with a lag of 1 year was included in the linearized form of the S-R relationship (Noakes et al. 1987) to represent realized recruitment.

$$ln(R_{cs}) = ln(S_{cs}) + ln(\alpha_s) - \beta_s S_{cs} + \phi_s v_{(c-1)s} + \epsilon_{Ws} \tag{2}$$

where ϕ_s is the lag-1 serial correlation coefficient, v_{cs} are model residuals defined as

$$v_{cs} = ln(R_{cs}) - ln(S_{cs}) - ln(\alpha_s) + \beta_s S_{cs} \tag{3}$$

and the ϵ_{Ws} are independently and normally distributed process errors with "white noise" variance σ^2_{Ws}. The productivity parameters for each stock are drawn from a common distribution, $\ln(\alpha_s) \sim \text{Normal}(\mu_{ln\alpha}, \sigma^2_{ln\alpha})$. The density dependence parameter (β_s) was estimated independently for each stock because it was assumed to be correlated with the amount of habitat available for each stock within its respective management area. Initial recruitments $R_{1973} - R_{1978}$ (those lacking linked spawner abundance) were modeled as drawn from a common lognormal distribution with median μ_{lnR} and variance σ^2_{lnR}.

Age at maturity, which is needed to distribute recruitment across calendar years, is allowed to trend through time and fluctuate annually. Age-at-maturity vectors[4] $\mathbf{p_c} = (p_{c3} \quad p_{c4} \quad p_{c5} \quad p_{c6})$ from brood year c returning at ages 3–6 were drawn from a $\text{Dirichlet}(\gamma_{c3}, \gamma_{c4}, \gamma_{c5}, \gamma_{c6})$ distribution. The sum of the Dirichlet parameters is the (inverse) dispersion[5] of the age-at-maturity vectors, reflecting consistency of $\mathbf{p_c}$ among brood years:

$$D_{age} = \sum_{a=3}^{6} \gamma_{ca} \text{ for all } c \tag{4}$$

The location parameters were estimated using a baseline category logit model where

$$\pi_{ca} = \frac{\gamma_{ca}}{D_{age}} = \frac{exp(ML1_a + ML2_a c)}{\sum_{k=3}^{6} exp(ML1_k + ML2_k c)} \tag{5}$$

are proportions that sum to 1 for each brood year and the age-at-maturity central tendency can trend with brood year through the logistic regression coefficients $ML1_a$ and $ML2_a$. Age 6 Chinook salmon were used as the baseline category.

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[4] These proportions are maturity and survival schedules for a given brood year (cohort) across calendar years. In contrast, Equation (25) describes age proportions of returning fish in a given calendar year across brood years.

[5] A low value of D is reflective of a large amount of variability in age-at-maturity proportions $\mathbf{p_c}$ among brood years, whereas a high value of D indicates more consistency in $\mathbf{p_c}$ over time.

The abundance N_{yas} in stock s of age a Chinook salmon in calendar year y is the product of the age at maturity scalar p_{ca} and the total return (recruitment) R_{cs} for stock s from brood year $c = y - a$:

$$N_{yas} = p_{(y-a)a} R_{(y-a)s} \tag{6}$$

Total run N_{ys} for stock s during calendar year y is the sum of abundance at age across all ages:

$$N_{ys} = \sum_{a=3}^{6} N_{yas} \tag{7}$$

Annual harvest of Susitna-origin Chinook salmon below (downstream of) both Susitna RM 34 and Yentna RM 6, H_{By}, was modeled as the product of the annual harvest rate in the downstream area μ_{By}, and total run N_y:

$$H_{By} = \mu_{By} \sum_{s=1}^{4} N_{ys} \tag{8}$$

Inriver run IR_{ys} of stock s during calendar year y at either Susitna RM 34 or Yentna RM 6 was modeled as the product of stock-specific total run N_{ys} and the annual survival rate in the area downstream:

$$IR_{ys} = N_{ys}(1 - \mu_{By}) \tag{9}$$

Annual harvest of stock s above either Susitna RM 34 or Yentna RM 6, H_{Ays}, was the product of the annual harvest rate for each stock in the upstream area μ_{Ays} and the inriver run of stock s:

$$H_{Ays} = \mu_{Ays} IR_{ys} \tag{10}$$

Annual harvest of Deshka River Chinook salmon (s = 1) upstream of the Deshka River weir, $H_{DESHKAy}$, was a proportion $p_{DESHKAy}$ of the total inriver harvest of Deshka River Chinook salmon H_{Ay1}:

$$H_{DESHKAy} = p_{DESHKAy} H_{Ay1} \tag{11}$$

The $p_{DESHKAy}$ are drawn from a Beta$(b1_D, b2_D)$ distribution. The beta parameters are expressed in an alternate form where $B_D = b1_D + b2_D$ is the (inverse) dispersion and the location $(b1_D/B_D)$ is drawn from a noninformative beta prior.

Spawning escapement S_{ys} was inriver run abundance minus harvest above Susitna RM 34 or Yentna RM 6:

$$S_{ys} = IR_{ys} - H_{Ays} \tag{12}$$

Finally, Chinook salmon passage at the Deshka River weir was the sum of the spawning escapement in the Deshka River, S_{y1}, and harvest upstream of the weir:

$$IR_{DESy} = S_{y1} + H_{DESy} \tag{13}$$

Multiple populations ($p = 1,2,\dots,P_s$) contribute to the spawning escapement in the Eastside Susitna, Talkeetna, and Yentna stocks. The relative composition of spawning populations within each stock is of interest because some observed data is germane to the population scale. Composition of the $P_s - 1$ populations within stock s that are monitored[6] by aerial survey are allowed to fluctuate annually around a trending central tendency. A set of equations analogous to Equations (4) and (5) were used to define stock composition vectors $\boldsymbol{\rho}.\mathbf{s}^{*}{}_{y} = (\rho.s^{*}_{y1} \quad \rho.s^{*}_{y2} \quad \dots \quad \rho.s^{*}_{y(P_s-1)})$ for the surveyed populations in each stock s. Willow Creek, Prairie Creek, and Talachulitna Creek were used as the baselines for the Eastside Susitna, Talkeetna, and Yentna stocks respectively. The composition vectors $\boldsymbol{\rho}.\mathbf{s}^{*}{}_{y}$ are therefore allowed to fluctuate annually and trend through time, the (inverse) dispersion of the annual stock composition vectors being represented by $D.s_{COMP}$.

The annual proportion of fish from stock s that spawned in populations not monitored by aerial survey, $\rho.s'_{y}$, are drawn from a Beta$(b1.s, b2.s)$ distribution. The beta parameters are expressed in an alternate form where $B.s_{SURVEY} = b1.s + b2.s$ is the (inverse) dispersion and the location is drawn from a non-informative beta prior.

Stock composition was calculated as follows:

$$\boldsymbol{\rho}.\mathbf{s}_{\mathbf{y}} = \left[\rho.s^{*}_{y1}(1-\rho.s'_{y}) \quad \rho.s^{*}_{y2}(1-\rho.s'_{y}) \quad \dots \quad \rho.s^{*}_{y(P_s-1)}(1-\rho.s'_{y}) \quad \rho.s'_{y}\right] \tag{14}$$

Observation Component

Observed data (Appendices A1–A10) include mark–recapture estimates of inriver run, estimates of annual marine commercial and subsistence harvests below both Susitna RM 34 and Yentna RM 6, freshwater sport harvests above Susitna RM 34 or Yentna RM 6 and freshwater sport harvest above the Deshka weir, radiotelemetry data, aerial survey data for 13 populations, weir counts for 3 populations, age composition data from throughout the Susitna River drainage, and length composition data from the Deshka weir. Assumed sampling distributions for the observed data are given below.

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[6] Populations not monitored by aerial survey are grouped, hence $P_s - 1$ populations are monitored.

Inriver Run and Length Composition

Estimated annual inriver runs of Chinook salmon for stock s, $\widehat{IR}_{500ys}$, from mark–recapture data were

$$\widehat{IR}_{500ys} = IR_{500ys} exp(\epsilon_{IR500ys}) \tag{15}$$

where IR_{500ys} is the inriver run of fish 500 mm mid eye to tail fork (METF) length or larger, $\epsilon_{IR500ys} \sim \text{Normal}(0, \sigma^2_{\widehat{IR}500ys})$, and $\sigma^2_{\widehat{IR}500ys}$ is calculated from the coefficient of variation (CV) of $\widehat{IR}_{500ys}$:

$$\sigma^2_{\widehat{IR}_{500ys}} = \ln(\text{CV}(\widehat{IR}_{500ys})^2 + 1) \tag{16}$$

The number of age a (where $a = 3,4$) fish that were less than 500 mm METF in year y, $x_{lt500ya}$, was

$$x_{lt500ya} \sim \text{Binomial}(p_{lt500ya}, n_{ya}) \tag{17}$$

where n_{ya} is the total number of fish sampled for age and length in age class a during year y and $p_{lt500ya}$ is the proportion of fish less than 500 mm METF in age class a (3 or 4) during year y.

Inriver runs of fish 500 mm METF or greater, IR_{500ys}, were

$$IR_{500ys} = IR_{ys}[1 - (q_{y3}p_{lt500y3} + q_{y4}p_{lt500y4})] \tag{18}$$

where q_{ya} is the proportion of the run that is age a in calendar year y.

Harvest

Estimated annual harvest of Susitna River Chinook salmon below both Susitna RM 34 and Yentna RM 6, $\widehat{H}_{By}$, was

$$\widehat{H}_{By} = H_{By} exp(\epsilon_{HBy}) \tag{19}$$

where the $\epsilon_{HBy} \sim \text{Normal}(0, \sigma^2_{\widehat{H}By})$ and the variances followed Equation (16). Estimated annual harvest of Susitna River Chinook salmon above either Susitna RM 34 or Yentna RM 6, $\widehat{H}_{Ays}$ for stock s, was modeled according to Equation (19) after substituting H_{Ays} and ϵ_{HAys} for H_{By} and ϵ_{HBy}, respectively, where the $\epsilon_{HAys} \sim \text{Normal}(0, \sigma^2_{\widehat{H}Ays})$ and the variances followed Equation (16). Similarly, estimated annual harvest of Deshka River Chinook salmon upstream of the Deshka weir, $\widehat{H}_{DESy}$, was generated according to Equation (19) after substituting $H_{DESHKAy}$ and $\epsilon_{H_{DESHKA}y}$ for H_{By} and ϵ_{HBy}, respectively, where the $\epsilon_{H_{DESHKA}y} \sim \text{Normal}(0, \sigma^2_{\widehat{H}_{DESHKA}y})$ and the variances followed Equation (16).

Radiotelemetry

Radio telemetry data (counts of radiotagged fish) within each stock, where $\mathbf{r.s}_y = (r.s_{y1} \quad r.s_{y2} \quad \cdots \quad r.s_{yP_s})$, were partitioned into P_s categories with $P_s - 1$ categories representing populations that are counted during aerial surveys and 1 category (P_s) representing Chinook salmon belonging to stock s but not belonging to the $P_s - 1$ populations monitored by aerial survey. The number of radio tags from populations that were not counted during aerial surveys was

$$r.s_{yP_s} \sim \text{Binomial}\left(\rho.s'_y, \sum_{p=1}^{P_s} r.s_{yp}\right) \tag{20}$$

The number of radio tags belonging to populations that were counted during aerial surveys, $r.s_{y[p=1:(P_s-1)]}$, was as follows:

$$r.s_{y[p=1:(P_s-1)]} \sim \text{Multinomial}\left(\rho.s^*_{y[p=1:(P_s-1)]}, \sum_{p}^{P_s-1} r.s_{yp}\right) \tag{21}$$

where $\rho.s^*_{yp}$ estimates the annual proportion of radiotagged fish from surveyed population p within stock s.

Abundance Indices

Annual aerial survey counts of population p within stock s, $a.s_{yp}$, are related to stock s abundance S_{ys} after accounting for survey observability θ_i and stock composition $\rho.s_{yp}$:

$$a.s_{yp} = \theta_{i(s,p)}\rho.s_{yp}S_{ys}exp(\epsilon_{ASi(s,p)}) \tag{22}$$

where $\epsilon_{ASi} \sim \text{Normal}(0, \sigma^2_{ASi})$. A total of 13 populations were monitored by aerial survey and $i(s,p)$ is a function that maps stock and population indices to an index $i = 1{:}13$ allowing hierarchical treatment of survey observability and survey error. Thus, the proportion of the spawning escapement counted during aerial surveys θ_i was $\text{logit}(\theta_i) \sim \text{Normal}(\mu_\theta, \sigma^2_\theta)$.

Survey-specific residual standard deviations were $\sigma_{ASi} \sim \text{half\_Cauchy}(0, C_{AS})$ where C_{AS} is the median of the distribution of σ_{ASi} (Lunn et al. 2013). Because modeled observability of spawning Chinook salmon θ_i is treated as constant through time, the annual variability in observability is confounded with annual variability in stock composition, $\rho.s_{yp}$. Also note that stock composition was only observed late in the time series (2012–2017) and modeled trends in stock composition in early years result from changes in the relative magnitude of aerial survey counts. Thus, the relative magnitude of survey counts is assumed to reflect stock composition[7].

Weirs counts were available for 3 of the populations. Each weir count is related to the abundance of the stock where it was located after accounting for stock composition $\rho.s_{yp}$:

$$w.s_{yp} = \begin{cases} IR_{DESHKAy} exp(\epsilon_w), & \text{if } s = 1 \\ \rho.s_{yp} S_{ys} exp(\epsilon_w), & \text{if } s \neq 1 \end{cases} \tag{23}$$

where the $\epsilon_w \sim \text{Normal}(0, \sigma_w^2)$ and the variances followed Equation (16) with an assumed CV of 0.05 reflecting good precision associated with weir counts.

Age Composition

A total of 76 age composition datasets were collected from stock-specific locations between 1979 and 2017. The Deshka River stock is represented throughout the time series, but most other stocks are represented only early in the time series (Figure 3). We deemed this resolution insufficient to model age composition independently for each stock and focused on modeling the age composition of the run to the entire Susitna River drainage. The model assumes fish were harvested in proportion to their abundance (by age and by stock), though this assumption is likely not critical because harvest rates are small. Age composition may differ between stocks, and multinomial logistic regression was used to include a correction for the stock that was sampled when estimating annual age composition for the entire drainage. Thus, age counts x_{ja} were modeled as multinomially distributed

$$x_{j[a=3:6]} = \text{Multinomial}\left(q^*_{j[a=3:6]}, \sum_{a=3}^{6} x_{ja}\right) \tag{24}$$

where j = 1:76. The location parameters were

$$q^*_{ja} = \frac{exp\left[\ln\left(\frac{N_{y(j)a}}{N_{y(j)(a=3)}}\right) + b_{s(j)a}\right]}{\sum_{k=3}^{6} e\,xp\left[\ln\left(\frac{N_{y(j)k}}{N_{y(j)(k=3)}}\right) + b_{s(j)k}\right]} \tag{25}$$

where $y(j)$ is a function that maps the row index j to the year y in which the data were collected. Hence, $N_{y(12)}$ is the abundance during the year in which the 12th age composition dataset was collected. Similarly, $s(j)$ is a function that maps the row index j to the stock s from which the data were collected. Equation (25) represents a multinomial logistic regression where the intercept is a function of annual abundance of all 4 stocks in each age class and the categorical

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[7] While trending stock-specific observability could result in similar data we believe consistent survey procedures utilized throughout the time series make this possibility less likely.

covariates b_{sa} account for age composition differences between the stocks. The categorical covariates were parameterized with a sum to zero constraint. Because $\sum_s b_{sa} = 0$, the quantity

$$q_{ya} = \frac{N_{ya}}{\sum_{k=3}^{6} N_{yk}} \tag{26}$$

estimates age composition for the entire Susitna River Chinook salmon run.

MODEL FITTING

Bayesian statistical methods employ the language of probability to quantify uncertainty about model parameters. Knowledge existing about the parameters outside the framework of this analysis is reflected in 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. This methodology allows for inclusion of the effects of measurement error, serially correlated productivity, and missing data into 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 in the model, biases in the estimates can be reduced (Su and Peterman 2012). Model fitting involves finding the values of the population parameters of the model that could have plausibly resulted in the observed data. To do so, Markov Chain Monte Carlo (MCMC) methods were employed using the package RJAGS (Plummer 2013) within R (R Core Team 2016). See Fleischman et al. (2013) and Staton et al. (2017) for similar applications of the methods used in this report.

Prior Distributions

Noninformative priors (chosen to have minimal effect on the posterior) were used for most parameters. Truncated normal priors with mean zero, very large variances, and constrained to be positive were used for $\mu_{ln\alpha}$, β, and μ_{lnR}. Initial model residuals ν_s were given a truncated normal prior with mean zero and variance $\sigma_{Ws}^2/(1-\phi_s^2)$ between –3 and +3. Annual harvest rates μ_{By}, μ_{Ays} were given $\text{beta}(0.5{,}0.5)$ priors. Diffuse conjugate inverse gamma priors were used for σ_{Ws}^2 and σ_{lnR}^2. In some cases, the prior support was limited within a range that did not truncate the eventual posterior to aid in convergence. For example, Dirichlet dispersion parameters for age, stock, and harvest compositions use a $\text{Uniform}(0.07{,}1)$ prior on the $1/\sqrt{D}$ scale where the lower bound aids convergence by constraining the posterior densities for D to realistic Dirichlet parameter sums. The prior on C_{AS} was also $\text{Uniform}(0{,}1)$ but while C_{AS} could exceed 1, the limited prior support did not truncate the posterior. A weakly informative conjugate inverse gamma prior [$\text{gamma}(2{,}1)$] was used for $\sigma_{ln\alpha}^2$ which also aided convergence while minimally affecting the posterior.

Sampling from the Posterior Distribution

MCMC samples were drawn from the joint posterior probability distribution of all unknowns in the model. The model was initiated with 3 chains and 200,000 samples were generated per chain. Initial values were generated randomly although some parameters were generated from a uniform distribution truncated to plausible values within the parameter's support. The first

50,000 samples from each chain were discarded and the remaining samples were thinned by a factor of 200, resulting in 2,250 samples that were used to estimate the marginal posterior means, standard deviations, and percentiles. Convergence was assessed using Rhat and examination of trace plots and density plots. Approximately 97% of the monitored parameters had a Rhat of less than 1.1. Among the parameters with a Rhat that exceeded 1.1, most were less than 1.15. None of the main stock recruit parameters ($\alpha_s, \beta_s, S_{MSYs}$) converged poorly. Poor convergence was often associated with estimates near zero that occasionally sampled briefly away from zero, although these sampling divergences were small enough to have little practical significance. Other poor convergence cases were associated with chains converging to very slightly different means. In these cases, density plots were marginally wider but still clearly unimodal. Dirichlet dispersion parameters converged most poorly, displaying high levels of autocorrelation within each chain although the chains sampled from the same range of values. Thus, effective sample sizes for Dirichlet dispersion parameters were less than 30. The model required approximately 3 hours to run when parallel processed on a multi-core 3.8 GHz processor. Interval estimates were constructed from the percentiles of the posterior distribution.

REFERENCE POINTS AND OPTIMAL YIELD PROFILES

Reference points were calculated from S-R parameter estimates for each individual MCMC sample. Sustained yield is the number of fish in the expected recruitment over and above that needed to replace the spawners when population dynamics are stable. Spawning abundance that provides maximum sustained yield (MSY), S_{MSY}, which is the theoretical number of spawners that will result in the largest difference between recruitment and replacement, was approximated as follows:

$$S_{MSYs} \cong \frac{\ln(\alpha'_s)}{\beta_s}[0.5 - 0.07\ln(\alpha'_s)] \tag{27}$$

The quantity

$$\ln(\alpha'_s) = \ln(\alpha_s) + \frac{\sigma^2_{Ws}}{2(1-\phi_s^2)} \tag{28}$$

in Equation (27) adjusts for the difference between the median and the mean of a right-skewed lognormal error distribution with autocorrelation.

Sustained yield at a specified escapement $Y(S)$ was obtained by subtracting spawning escapement from recruitment:

$$Y(S)_s = R_s - S = S\exp(\ln(\alpha'_s) - \beta_s S) - S \tag{29}$$

The harvest rate leading to maximum sustained yield, is approximated by (Hilborn 1985):

$$U_{MSYs} \cong \ln(\alpha'_s)[0.5 - 0.07\ln(\alpha'_s)] \tag{30}$$

Fishery managers may want to evaluate existing and proposed goal ranges with respect to other indicators of fishery performance. The escapement leading to maximum sustained recruitment (MSR) is as follows:

$$S_{MSRs} = \frac{1}{\beta_s} \tag{31}$$

Equilibrium spawning abundance, where recruitment exactly replaces spawners is

$$S_{EQs} = \frac{\ln(\alpha'_s)}{\beta_s} \tag{32}$$

For each stock, the probability that a given spawning escapement S would produce an average yield $Y(S)$ exceeding X% of MSY was obtained by calculating $Y(S)$ at incremental values of S for each MCMC sample, then comparing $Y(S)$ with X% of the value of MSY for that sample. The proportion of samples in which $Y(S)$ exceeds X% of MSY is an estimate of the desired probability, and the plot of this proportion versus S is termed an optimal yield profile (OYP; Fleischman et al. 2013).

The probability that yield 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).

The probability that a given spawning escapement S would produce average recruitment R exceeding X% of MSR was obtained by calculating R from Equation (1) at incremental values of S for each MCMC sample, then comparing R with X% of the value of MSR for that sample. The proportion of samples in which R exceeded X% of MSR is an estimate of the desired probability, and the plot of this proportion versus S is termed an optimal recruitment profile (ORP; Fleischman et al. 2013).

OYPs, overfishing profiles, and ORPs were used to quantify the yield (or recruitment) performance of prospective escapement goals, taking into consideration the uncertainty about the true abundance, productivity, and capacity of the stock.

ESCAPEMENT GOALS STANDARDIZED TO S_{MSY}

To compare escapement goals from this study to goals for other Alaska stocks, we divided the lower and upper bounds of 21 published goals for Alaska Chinook salmon (Munro 2019) by point estimates of S_{MSY} associated with each goal range, thereby expressing all goal ranges in terms of multiples of S_{MSY}. These values were multiplied by estimates of S_{MSY} presented in this report to provide a graphical comparison of the recommended goals with exisitng goals for Alaskan Chinook salmon.

ESCAPEMENT GOAL REVIEW PROCESS

An interdivisional escapement goal review team was convened to review the available data, discuss analyses and results, and make escapement goal recommendations. The escapement goals recommended in this report are the product of several collaborative meetings of the review team and other ADF&G staff. The final recommendation was reached by consensus.

RESULTS

DESHKA RIVER STOCK

Measures of Chinook salmon abundance for the Deshka River stock displayed a common trend through time when more than one measure was available (Figure 4). Estimated escapement closely tracked weir counts, which are assumed to be very precise, starting in 1995. Prior to 1995, only aerial survey data are available to index abundance. Runs were large prior to 1991, underwent a decline during 1991–1994, rebounded during 1995–2004, declined again starting in 2005, and remained at a lower level during 2008–2017. Escapement estimates ranged between 7,259 in 2008 and 56,198 in 2004, and inriver run estimates ranged from 8,081 in 1994 to 65,237 in 2004 (Appendix C1).

Total and inriver run estimates (Appendix C1) are more precise than escapement estimates prior to 1995 because harvest is well estimated compared to the abundance estimates based on single annual aerial surveys. Coefficients of variation for total and inriver run ranged from 0.18 to 0.39 prior to 1995 whereas coefficients of variation for escapement ranged from 0.23 to 0.50. After 1995, all estimates have coefficients of variation ranging from 0.04 to 0.14 because weir estimates are very precise. Coefficients of variation for recruitment from complete brood years were highly variable both before (0.14–0.56) and after (0.09–0.52) the weir was installed and associated with considerable variation in realized recruitment around the S-R relationship (σ_W = 0.84; 95% CI 0.55–1.27; Table 1).

The model-estimated proportion of the escapement observed during single aerial surveys of the Deshka River, θ_i, was 0.44 (95% CI 0.38–0.55; Table 2). Empirical estimates of observability (survey count/weir count) exist for 12 years and range from 0.21 to 0.54. There was average agreement between Deshka River aerial survey counts (expanded by inverse observability) and Deshka River weir counts. The lognormal standard deviation for the Deshka River aerial survey regression, σ_{ASi}, was 0.29 (95% CI 0.20–0.47; Table 2), which is similar to the median value for the distribution of σ_{AS} (0.28; 95% CI 0.13–0.55).

Estimated Ricker parameters from the state-space model take uncertainty in estimated escapement S and recruitment R (Figure 5 error bars) into account. The individual data pairs are weighted depending upon the certainty with which the individual values of S and R are known. Because escapement and recruitment are poorly known for many brood years, and due to other sources of uncertainty, Ricker S-R relationships that could have plausibly generated the observed data are diverse (Figure 5: light lines), often deviating substantially from the mean Ricker relationship (Figure 5: heavy dashed line).

Median productivity (recruits per spawner in the absence of density effects) of the Deshka River Chinook salmon stock during 1979–2017 was moderate (α = 3.4; 95% CI 1.42–8.4; Table 1). There is a great deal of uncertainty about productivity, as evident in the extent to which the plausible S-R relationships differ with respect to their slope at the origin (Figure 5). Similarly, uncertainty about β is reflected in variability in the escapements leading to maximum recruitment S_{MSR}, and uncertainty about equilibrium abundance S_{EQ} is reflected by variability in the escapements where the curves intersect the replacement line. Variability in spawning escapements associated with maximum sustained yield S_{MSY} is harder to visualize. Graphically, sustained yield is greatest at the escapement that maximizes the length of a vertical line drawn from the Ricker curve downward to the replacement line. Given the diversity of plausible S-R relationships (Figure 5), it is important to choose an escapement goal that is robust to this uncertainty rather than one tailored solely to the median S-R relationship. To address this uncertainty, we tallied the success or failure of a given number of spawners in achieving biological reference points across plausible S-R relationships in the optimal yield, optimal recruitment, and overfishing profiles (Figure 6).

The model-estimated escapement leading to maximum sustained yield S_{MSY} for the Deshka River Chinook salmon stock was 12,737 (95% CI 9,197–22,568; Table 1). The optimal yield profiles (Figure 6, top panel) show the probability of a given number of spawners achieving 70%, 80%, and 90% of MSY. These probabilities, which are greatest near S_{MSY}, can be used to quantify the yield performance of prospective escapement goals (Figure 6 pink-shaded areas), taking into consideration all uncertainty about the true abundance and productivity of the stock. The overfishing profiles (Figure 6 middle panel) show the probability that sustained yield would be reduced to less than 70%, 80%, or 90% of MSY by fishing too hard and supplying too few spawners. For this stock, these probabilities are nearly the exact complements of the probabilities in the left-hand limbs of the optimal yield profiles.

Expected sustained yield (number of fish over and above that necessary to replace the number of spawners, averaged over brood years 1973–2014) is maximized at S_{MSY} (Figure 7). Actual yield in any single year has varied widely (Figure 5), in part because the S-R relationship is noisy and in part because many escapements have been near S_{EQ}. Annual median return per spawner has ranged between 0.05 and 6.5 for Deshka River Chinook salmon with 14 of 36 complete brood years failing to replace themselves (Figure 5, Appendix C1).

The model-estimated escapement leading to maximum recruitment S_{MSR} was 20,303 (95% CI 12,093–47,048; Table 1). Analogous to the optimum yield profiles discussed above, optimum recruitment profiles tally the success or failure of a given number of spawners to maximize recruitment across plausible S-R relationships. The optimal recruitment profiles in Figure 6 (bottom panel) show the probability of a given number of spawners achieving 70%, 80%, and 90% of MSR. Optimum recruitment probabilities, which are highest near S_{MSR}, reach maximums at larger spawning abundances than optimum yield probabilities and decrease more slowly as spawning abundance increases.

EASTSIDE SUSITNA STOCK

Measures of Chinook salmon abundance for the Eastside Susitna stock displayed a common trend through time (Figure 8). Runs were small prior to 1983, increased during 1983–1997, underwent a decline during 1998–2012, rebounded slightly after 2012, but were low again in 2017. Escapement estimates ranged between 10,046 in 2012 and 41,112 in 1997, and inriver run estimates ranged from 10,086 in 2012 to 48,187 in 1997 (Appendix C2).

Total and inriver run estimates (Appendix C2) have similar precision as escapement estimates. Coefficients of variation for total and inriver run ranged from 0.07 to 0.29, and coefficients of variation for escapement ranged from 0.07 to 0.31. Coefficients of variation for recruitment from complete brood years were moderate (0.14–0.23) and reflect low variation in realized recruitment around the S-R relationship (σ_W = 0.29; 95% CI 0.17–0.53).

Among the surveyed streams within the Eastside Susitna stock, Chinook salmon in Little Willow and Willow creeks increased in relative abundance between 1979 and 2017 whereas those in Goose, Kashwitna, Montana, and Sheep creeks decreased in relative abundance (Figure 9, Appendix D1). In the baseline logistic regression used to describe these trends, Willow Creek was used as the baseline and all of the regression slopes were negative and the 95% CIs on the regression slopes for Goose, Kashwitna, Montana, and Sheep creeks did not contain zero. Most recently, Willow Creek was the largest component of the Eastside Susitna stock spawning abundance followed by Little Willow Creek, Montana Creek, Sheep Creek, Kashwitna River, and Goose Creek. The inverse dispersion for the Eastside Susitna stock is moderate (D_{comp} = 116; 95% CI 61.3– 200; Table 1), but poorly estimated, indicating moderate variability around the composition expected from the multinomial logistic regression model with a calendar-year covariate. There are minor differences between estimated stock composition and empirical stock composition estimates in some years, which represent situations where weighted relative survey counts and telemetry data disagree.

Because Chinook salmon in unsurveyed streams in the Eastside Susitna stock lack relative composition information early in the time series, no trend in the relative abundance of unsurveyed streams can be estimated. “Other” fish from unsurveyed streams composed 16.9–31.2% (Figure 9, Appendix D1) of the Eastside Susitna stock. Inverse dispersion is small (B_{survey} = 28.6; 95% CI 6.2– 138; Table 1), indicating high variability in the proportion of the Eastside Susitna stock that spawns within the 6 surveyed streams. High variability was documented with telemetry data (Figure 9).

The model-estimated proportion of the escapement observed during an aerial survey (Table 2) of the Eastside Susitna stock ranged from 0.24 (95% CI 0.16–0.38) for Kashwitna River to 0.59 (95% CI 0.47–0.72) for Montana Creek. There was good agreement between the Goose Creek, Little Willow Creek, Montana Creek, and Willow Creek aerial survey counts (expanded by inverse observability and stock composition) and other indices of abundance in the Eastside Susitna stock, all of which had lognormal standard deviations that were smaller than the median value for the distribution of σ_{AS} (0.28; 95% CI 0.13–0.55). The lognormal standard deviation for the Kashwitna River and Sheep Creek aerial survey regressions were larger than the median value for the distribution of σ_{AS}, indicating these surveys were more variable abundance indicators.

Uncertainty in estimated escapement S and recruitment R (Figure 10 error bars[8]) is incorporated into variability in the underlying stock-recruit relationship. The Eastside Susitna stock has produced a yield for most broods, although not for a prolonged period in the early part of this century. Annual median return per spawner has ranged between 0.39 and 3.8 for the Eastside Susitna Chinook salmon stock with 11 of 36 complete brood years failing to replace themselves (Figure 10, Appendix C2).

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[8] The interpretation of Figures 10–12 is explained more fully in the Deshka River stock section

Median productivity (recruits per spawner in the absence of density effects) of the Eastside Susitna Chinook salmon stock during 1979–2017 was moderate (α = 3.7; 95% CI 1.78–7.4; Table 1). The model-estimated escapement leading to maximum sustained yield S_{MSY} for the Eastside Susitna Chinook salmon stock was 12,868 (95% CI 8,602–24,227; Table 1). Both quantities have wide credibility intervals, as do the other reference points for the stock. Profiles (Figure 11) are used to evaluate the performance of various escapements relative to reference points while considering the underlying uncertainly. The probability that a given number of spawners achieves a high percentage of MSY is maximized near S_{MSY}. Expected sustained yield (number of fish over and above that necessary to replace the number of spawners, averaged over brood years 1973–2014) is also maximized at S_{MSY} (Figure 12). Optimum recruitment probabilities (Figure 11), which are highest near S_{MSR}, reach maximums at larger spawning abundances than optimum yield probabilities and are very wide relative to yield profiles, limiting their management utility.

TALKEETNA RIVER STOCK

Measures of Chinook salmon abundance for the Talkeetna River stock are few but displayed a common trend through time (Figure 13). Runs increased through 1988, underwent a decline during 1989–1994, rebounded until 1997, and gradually declined thereafter. Escapement estimates ranged between 5,982 in 2011 and 40,872 in 1988, and inriver run estimates ranged from 6,999 in 2017 to 42,688 in 1988 (Appendix C3).

Total and inriver run estimates (Appendix C3) have similar precision as escapement estimates. Coefficients of variation for total and inriver run ranged from 0.10 to 0.32, and coefficients of variation for escapement ranged from 0.10 to 0.33. Coefficients of variation for recruitment from complete brood years were highly variable (0.22–0.59) and associated with considerable variation in realized recruitment around the S-R relationship (σ_W = 0.74; 95% CI 0.40–1.19).

Between the 2 surveyed streams within the Talkeetna River stock, Clear Creek Chinook salmon increased in relative abundance between 1979 and 2017 whereas fish in Prairie Creek decreased in relative abundance (Figure 9, Appendix D2). In the baseline logistic regression used to describe these trends, Prairie Creek was used as the baseline and about 97% of the posterior density for the Clear Creek regression slope was positive. Clear and Prairie Creeks are similar-sized components of the spawning abundance for the Talkeetna River stock in recent years. The inverse dispersion for the Talkeetna River stock is small (D_{comp} = 43.0; 95% CI 20.3– 162; Table 1), but poorly estimated, indicating larger variability around the composition expected from the multinomial logistic regression model with a calendar-year covariate. There is considerable divergence between estimated stock composition and empirical stock composition estimates in some years, which represent situations where weighted relative survey counts and telemetry data disagree.

Because fish in unsurveyed streams in the Talkeetna River stock lack relative composition data early in the time series, no trend in the relative abundance of unsurveyed streams can be estimated. “Other” fish from unsurveyed streams composed 24.9–44.8% (Figure 9, Appendix D2) of the Talkeetna River stock. Inverse dispersion is small (B_{survey} = 23.4; 95% CI 3.9– 149; Table 1), indicating high variability in the proportion of the Talkeetna River stock spawning within the 2 surveyed streams. High variability was also documented with telemetry data (Figure 9).

The model-estimated proportion of the escapement observed during an aerial survey (Table 2) of the Talkeetna stock ranged from 0.32 (95% CI 0.25–0.43) for Clear Creek to 0.70 (95% CI 0.56–0.87) for Prairie Creek (Table 2). There was very good agreement between both aerial survey counts (expanded by inverse observability and stock composition) and mark–recapture estimated abundance for the Talkeetna River stock. The lognormal standard deviation for the aerial survey regressions was 0.10 (95% CI 5.2e-03–0.28) for Clear Creek and 0.17 (95% CI 0.01–0.33) for Prairie Creek, both of which are smaller than the median value for the distribution of σ_{AS} (0.28; 95% CI 0.13–0.55).

Uncertainty in estimated escapement S and recruitment R (Figure 14[9] error bars) is incorporated into variability in the underlying stock-recruit relationship. The Talkeetna stock has frequently failed to produce a yield; this may be partially due to the escapements being near S_{eq} and partially due to the low productivity of the stock. Annual median return per spawner has ranged between 0.26 and 4.6 for Talkeetna River Chinook salmon, with 15 of 36 complete brood years failing to replace themselves (Figure 14, Appendix C3).

Median productivity (recruits per spawner in the absence of density effects) of the Talkeetna River Chinook salmon stock during 1979–2017 was low (α = 2.8; 95% CI 1.34–5.8; Table 1). Model-estimated escapement leading to maximum sustained yield S_{MSY} for the Talkeetna River Chinook salmon stock was 10,669 (95% CI 7,186–22,330; Table 1). Both quantities have wide credibility intervals, as do the other reference points for the stock. Profiles (Figure 15) are used to evaluate the performance of various escapements relative to reference points while considering the underlying uncertainly. The probability that a given number of spawners achieves a high percentage of MSY is maximized near S_{MSY}. Expected sustained yield (number of fish over and above that necessary to replace the number of spawners, averaged over brood years 1973–2014) is also maximized at S_{MSY} (Figure 16). Optimum recruitment probabilities (Figure 15), which are highest near S_{MSR}, reach maximums at larger spawning abundances than optimum yield probabilities and are very wide relative to yield profiles, limiting their management utility.

YENTNA RIVER STOCK

Some of the measures of abundance for the Yentna River Chinook salmon stock displayed a common trend through time (Figure 17). Runs increased through 1984, underwent a decline during 1985–1994, and rebounded until 2004, declined through 2009, increased through 2015, and declined to historically low levels in 2017. Escapement estimates ranged between 12,693 in 2017 and 65,457 in 2004, and inriver run estimates ranged from 13,947 in 2017 to 70,456 in 2004 (Appendix C4).

Total and inriver run estimates (Appendix C4) have similar precision as escapement estimates. Coefficients of variation for total and inriver run ranged from 0.08 to 0.38, and coefficients of variation for escapement ranged from 0.09 to 0.40. Coefficients of variation for recruitment from complete brood years were moderate (0.17–0.39), reflecting moderate variation in realized recruitment around the S-R relationship (σ_W = 0.44; 95% CI 0.25–0.71).

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[9] The interpretation of Figures 14-16 is explained more fully in the Deshka River stock section

Among the surveyed streams within the Yentna River stock, Chinook salmon in Peters Creek increased in relative abundance between 1979 and 2017 whereas those in Cache Creek decreased in relative abundance, and the relative abundances of the Chinook salmon in Lake Creek and Talachulitna River have remained similar across years (Figure 9, Appendix D3). In the baseline logistic regression used to describe these trends, the Talachulitna River was used as the baseline and 96% of the posterior density for the Cache Creek regression slope was negative, 95% of the posterior density for the Peters Creek regression slope was positive, and the posterior density for the Peters Creek regression slope was centered on zero. Lake Creek Chinook salmon are the largest component of the Yentna River stock spawning abundance in recent years followed by Talachulitna River, Peters Creek, and Cache Creek. The inverse dispersion for the Yentna River stock is small (D_{comp} = 53.4; 95% CI 26.5– 126; Table 1), indicating larger variability around the composition expected from the multinomial logistic regression model with a calendar year covariate. Estimated stock composition and empirical stock composition estimates are similar.

Because fish in unsurveyed streams in the Yentna River stock lack relative composition data early in the time series, no trend in the relative abundance of unsurveyed streams can be estimated. “Other” fish in unsurveyed streams compose 34.8–51.0% (Figure 9, Appendix D3) of the Yentna River stock. Inverse dispersion is moderate (B_{survey} = 56.2; 95% CI 3.6– 192; Table 1), indicating moderate variability in the proportion of the Yentna River stock spawning within the 4 surveyed streams. Moderate variability was documented with telemetry data (Figure 9).

The model-estimated proportion of the escapement observed during an aerial survey (Table 2) in the Yentna River stock ranged from 0.50 (95% CI 0.40–0.62) for Lake Creek to 0.65 (95% CI 0.50–0.84) for Talachulitna River. There was good agreement between the Lake Creek and Talachulitna River aerial survey counts (expanded by inverse observability and stock composition) and mark–recapture estimated abundance in the Yentna River stock, both of which had lognormal standard deviations that were less than or equal to the median value for the distribution of σ_{AS} (0.28; 95% CI 0.13–0.55). The lognormal standard deviation for the Cache Creek and Peters Creek aerial survey regressions were larger than the median value for the distribution of σ_{AS} indicating these surveys were poorly correlated with mark–recapture abundance. These regressions are based on only 4 years of mark–recapture data.

Uncertainty in estimated escapement S and recruitment R (Figure 18[10] error bars) is incorporated into variability in the underlying stock-recruit relationship. Many brood years from the Yentna River stock have produced a yield, with most exceptions coming from escapement at or above S_{EQ}. Annual median return per spawner ranged between 0.14 and 2.5 for the Yentna River Chinook salmon stock with 14 of 36 complete brood years failing to replace themselves (Figure 18, Appendix C4).

Median productivity (recruits per spawner in the absence of density effects) of the Yentna River Chinook salmon stock during 1979–2017 was moderate (α = 4.4; 95% CI 2.2–8.0; Table 1). Model-estimated escapement leading to maximum sustained yield S_{MSY} for the Yentna River Chinook salmon stock was estimated to be 13,768 (95% CI 9,311–20,085; Table 1). Both quantities have wide credibility intervals, as do the other reference points for the stock. Profiles (Figure 19) are used to evaluate the performance of various escapements relative to reference

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[10] The interpretation of Figures 18–20 is explained more fully in the Deshka River stock section

points while considering the underlying uncertainly. The probability that a given number of spawners achieves a high percentage of MSY is maximized near S_{MSY}. Expected sustained yield (number of fish over and above that necessary to replace the number of spawners, averaged over brood years 1973–2014) is also maximized at S_{MSY} (Figure 20). Optimum recruitment probabilities (Figure 19), which are highest near S_{MSR}, reach maximums at larger spawning abundances than optimum yield probabilities and are very wide relative to yield profiles, limiting their management utility.

AGE COMPOSITION

Between 1979 and 1985, annual age composition datasets exist from sport harvested Chinook salmon in the Deshka River, Eastside Susitna, and Yentna River stocks. In general, the Eastside Susitna Chinook salmon stock contained larger proportions of older fish (Figure 21, middle panel). Between 1986 and 1996, annual age composition datasets exist for the sport harvest of Chinook salmon in the Eastside Susitna, Deshka River and Talkeetna River stocks. The Deshka River Chinook salmon stock contained smaller proportions of older fish in paired annual samples.

Chinook salmon in the Susitna River drainage are composed of age-3 (1.1), age-4 (1.2), age-5 (1.3), and age-6 (1.4) fish (Figure 21 middle panel, Table 3). Throughout the time series age-5 fish have been the dominant age class whereas the relative abundance of age-6 fish has steadily decreased and the relative abundance of age-3 fish has increased (dramatically in recent years).

Age-at-maturity of Susitna River drainage Chinook salmon varied across years (Figure 21 top panel, Table 4) from 5.9e-04 to 9.4% for age 3, from 10.3 to 43.4% for age 4, from 25.1 to 62.9% for age 5, and from 6.6 to 51.4% for age 6. Age-at-maturity has trended strongly toward increasing contributions of age-3, age-4, and age-5 fish and decreasing contributions of age-6 fish.

DISCUSSION

The current Chinook salmon escapement goals established for 11 populations within the Susitna River drainage (except the Deshka River) are based on once-per-year “single” aerial surveys. Mark–recapture abundance projects implemented between 2013 and 2017 (AEA 2014, 2015[11]; Yanusz et al. 2018; DeCovich et al. *In prep*) provide abundance estimates for Susitna River Chinook salmon stocks and allowed us to reconstruct historical abundances based on aerial survey counts. When reconstructing abundance, we chose to aggregate populations into stocks that match existing Chinook salmon management units. This resolution is used for management because fisheries within each management area are similar with respect to access and fishing methods.

Our approach offers some fundamental improvements over existing stock assessment practices. Instead of the current method of using a single aerial survey to assess the escapement of each creek of interest, our approach uses multiple single aerial surveys to estimate run size for each stock. For example, the Eastside Susitna stock has 6 aerial survey counts available to index annual abundance.

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[11] These documents are available at Alaska Resources Library and Information Services (ARLIS).

Our approach also considers variability in “observability” of surveyed populations within each stock and variability of stock composition within each stock to effectively weight each survey count by its relative accuracy. Aerial surveys conducted only once per year are subject to many possible sources of error. The ability to see spawning Chinook salmon from the air varies daily based on water depth and clarity, ambient light conditions, and the location of spawning Chinook salmon at the time of the survey. The term “observability” captures all these effects. ADF&G has standardized the aerial survey program for the Susitna River drainage in a way that attempts to minimize variability due to these factors and provide consistency throughout the time series (Oslund 2016). Remaining annual variability is confounded with variability in stock composition and quantified by the lognormal error term from the relationship between survey counts and estimated escapement in Equation (23). By evaluating escapement at the stock level, annual variation in stock composition and observability of aerial surveys can be considered when evaluating annual abundance.

This analysis also estimates the relationship between spawners and recruits in each stock to inform escapement goal recommendations. The current goals are based on ranges of observed aerial survey counts without considering the underlying stock-recruit relationship. Both the current method and our approach can produce useful management advice, although by estimating stock-recruit relationships, we can provide biological and management perspectives not available from survey counts alone.

Escapement goals proposed using our method are also robust to missed aerial surveys. It is common to miss a survey count for a single stream in a given year for a variety of reasons (weather, funding, etc.). When managers are evaluating each population individually, missed surveys result in a failure to assess escapement relative to the goal. By aggregating populations into stocks, escapement goals can still be evaluated based on the survey counts available. Thus, stock assessment would continue to rely upon aerial surveys of individual spawning populations within each stock, which allows monitoring, and if necessary, management at the population level to avoid localized depletion.

TEMPORAL TRENDS IN HARVEST RATE, ABUNDANCE, AND PRODUCTIVITY

Four stocks of Susitna River Chinook salmon are included in this assessment. The model presented herein considers each stock mostly independently except for hierarchical productivity and observability parameters and shared age composition estimates, although stocks may share other patterns of biological of harvest management interest.

The largest historical harvest rates (Figure 22) occurred on the Eastside Susitna stock, followed by the Deshka River, Yentna River, and Talkeetna River stocks. None of these stocks have historically been fished at rates that would theoretically maximize yield. This result suggests that yield from Susitna River Chinook salmon fisheries could be improved at higher harvest rates.

Our analysis suggests biological differences exist between the stocks we have assessed. One such indicator is differences in temporal patterns of annual abundance (Figure 23). For example, although all stocks have been near historical minimums in the last 10 years, the Deshka River stock was also near historical minimums in the middle 1990s at a time when the Eastside Susitna stock was doing well. A second example can be seen in 2004 when the Deshka and Yentna stocks were at historical maximums, the Eastside Susitna stock was very abundant, and the Talkeetna River stock was middling.

Productivity differences between stocks are less distinct. Although there are differences in point estimates for stock specific productivity, α_s, these estimates are imprecise and credibility intervals overlap. Productivity patterns differ throughout the time series. Ricker recruitment residuals (Figure 24) are deviations in recruitment of Chinook salmon for each stock from that predicted by the Ricker S-R relationship, reflecting time-varying changes in productivity after controlling for density-dependent effects. A general pattern exists for all stocks; above-average productivity was more frequent until about the 2002 brood year and below average productivity was more frequent thereafter, although differences between the stocks exist. For example, the Deshka River stock had an extended period of below-average productivity between the 1987 and 1991 brood years that was less pronounced or absent in the other stocks. Furthermore, low productivity in the recent broods of the Eastside Susitna stock was more frequent and more consistent than for the other stocks. Examination of the Ricker residuals in conjunction with the horsetail plot for the Eastside Susitna stock (Figure 10) suggests 2 productivity regimes, with recent productivity considerably lower than average productivity, although a mechanism driving this pattern is unknown. Finally, residual correlation is strong for the Eastside Susitna stock (Table 1), supporting the concept of time-varying productivity, but is weak or nonexistent for the other stocks.

ESCAPEMENT GOAL RECOMMENDATIONS

Escapement goal recommendations were developed for Susitna River Chinook salmon stocks by a committee composed of ADF&G staff from the divisions of Sport Fish and Commercial Fisheries. Although optimum yield profiles were used to identify escapement goal bounds with the desired yield performance, those bounds were refined based on factors specific to each stock. As a framework for considering qualitative criteria, the committee developed a decision matrix with 5 important factors (Table 5). Although this matrix is not a formula for calculating upper and lower goal bounds, it did help guide staff in deciding whether a goal should be more or less conservative in relation to S_{MSY}. The following are rationales for using each criterion. In some cases, criteria provided conflicting advice for the same stock. In those situations, managers used their knowledge of the fisheries to prioritize.

Escapement Goal Decision Matrix

Inseason Management

Whether or not a fishery can be managed inseason may affect the width of an escapement goal. We recommend using a wider goal range in the absence of inseason management. The Deshka River is the only stock we considered with inseason management capability (Table 5).

Harvest Rate

In general, harvest rates within the Susitna River drainage are low, reflecting low fishing power and limited ability to control Chinook salmon escapements. Wider goal ranges were considered for these stocks, particularly when the stock also lacks inseason management. The Eastside Susitna stock has more road accessibility and was considered the only stock to have a medium harvest rate (Table 5).

Data Quality and Quantity

This is a subjective measure of the error and bias associated with the 3 available methods for collecting abundance data for each stock. The most accurate and precise data available for this modeling effort are the Deshka River weir counts, which enumerate Chinook salmon escapement in that river with very little error (high data quality; Table 5). Stock specific mark–recapture estimates of abundance are available for all stocks but are less precise. Finally, aerial survey data, also available for all stocks, are only indices of abundance and are germane to individual populations within most stocks.

The proportion of the escapement within each stock assessed by aerial surveys is highly variable. For example, aerial surveys cover the entirety of the Deshka River stock and a large majority of the Eastside Susitna stock. In the Talkeetna River stock, both major populations are surveyed and account for a slight majority of the escapement. In the Yentna River, coverage of aerial surveys is less. The major Yentna River populations of Lake Creek and the Talachulitna River are surveyed each year, but there are many smaller populations that have no annual assessment and so is considered to have low data quantity (Table 5). The number of aerial surveys flown in each stock is also a consideration because more surveys represent more datapoints for the annual run size estimate of each stock.

One advantage of the state-space modeling approach is that data quality and quantity are accounted for and reflected in the variability associated with parameter estimates. The quality of our abundance data is reflected in the widths of the grey areas in Figures 4, 8, 13 and 17. In general, we recommended more conservative goal ranges when poor quality and quantity of data resulted in less precise estimates.

Issues with Age, Sex, and Length Data

Results from the age, sex, and length (ASL) data of adult returns were considered. In the case of this analysis, the main result was the increasing proportion of younger age classes (ages 3 and 4) and corresponding decrease of older age classes (age 6 and above). In general, younger Chinook salmon tended to be male (Ivey 2014; Lescanec 2017). While the effect of changing ASL composition was not explicitly modeled, these concerns resulted in shifting the escapement goal bounds towards larger escapements in relation to S_{MSY}. This approach attempts to protect future production against insufficient eggs during annual spawning.

Deshka River Stock Escapement Goal

Deshka River Chinook salmon have an existing goal range of 13,000–27,000 Chinook salmon. Escapements at the low end of the existing range have 98% probability of producing a yield greater than 80% of MSY whereas escapements at the upper end of the existing range have 10.8% probability of producing yields greater than 80% of MSY. The proposed escapement goal of 9,000–18,000 fish has 91.5% probability of achieving 80+% of MSY at the lower bound and 78% probability of achieving 80+% MSY at the upper bound.

The Deshka River is unique among the 4 stocks in that it has inseason management capability due to daily counts from the weir. Therefore, if escapements are projected to exceed the upper goal bound based on run-timing curves, harvest rate can be increased via increased fishing time and (or) allowing more efficient gear types (e.g., bait) to be used. Because realized harvest rate is low relative to the estimated median harvest rate leading to MSY (U_{MSY}, Figure 22), liberalizing the sport fishery early in the fishing season can be an effective strategy to keep the escapement within the escapement goal. Conversely, if escapements are projected to not attain the lower bound, the sport fishery can be restricted or closed. For this reason, a narrow goal, focused on optimizing yield, is possible because management action can be taken inseason to better attain escapements to produce desired yields.

Eastside Susitna Stock Escapement Goal

Goose Creek, Little Willow Creek, Montana Creek, Sheep Creek, and Willow Creek each have existing goals based on single aerial survey data. ADF&G uses these 5 single aerial survey counts to make 5 run size determinations without considering the variability associated with aerial counts. This analysis leverages the 6 pieces of information[12] to make 1 run-size estimate (for the stock) while accounting for correlation in run sizes between the spawning populations and variability in survey observability.

We recommend the 5 escapement goals within the East Susitna management area be discontinued and replaced by a single goal. The proposed escapement goal of 13,000–25,000 fish has 96% probability of achieving 80+% of MSY at the lower bound and 19% probability of achieving 80+% of MSY at the upper bound.

Although there are no weirs with a long time series of accurate counts for this stock, the majority of the stock is monitored with aerial surveys; unsurveyed waters in the Eastside Susitna management unit average less than 25% of the spawning abundance (Figure 9). Because this stock lacks inseason escapement information, assessments of stock performance relative to the goal happens after the spawning run is over. Decisions on the management strategy for the next spring's fisheries are made by considering recent years' performance, and once the fishery begins inseason, changes based on other indices (boat or aerial surveys) are likely to be few. Because of this lag between the fishery and final run assessment, we chose a conservative escapement goal range that was near the actual estimate of S_{MSY} for the lower bound, and a higher upper bound that has a decreased probability of achieving MSY when compared to the Deshka River goal.

Talkeetna River Stock Escapement Goal

Clear Creek and Prairie Creek have existing goals based on single aerial survey data. ADF&G uses these 2 single aerial survey counts to make 2 run size determinations without considering the variability associated with aerial counts. This analysis leverages the same 2 pieces of information to make 1 run size estimate (for the stock) while accounting for correlation in run sizes between spawning populations and variability in survey observability.

We recommend the 2 escapement goals within the Talkeetna management area be discontinued and replaced by a single goal. The proposed escapement goal 9,000–17,500 fish has 93.8% probability of achieving 80+% of MSY at the lower bound and 42.7% probability of achieving 80+% of MSY at the upper bound. With respect to recruitment, the proposed escapement goal has 47.6% probability of achieving 80+% of MSR at the lower bound and 91% probability of achieving 80+% of MSR at the upper bound.

Because there are only 2 single aerial surveys flown for the Talkeetna River stock (Clear and Prairie creeks) and estimated productivity is the lowest of the 4 stocks (Table 1), we

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[12] Kashwitna River is surveyed but does not have an existing goal range.

recommended a goal that was more conservative (higher) than the Deshka River stock while forgoing some probability of achieving MSY.

Yentna River Stock Escapement Goal

Lake Creek, Peters Creek, and Talachulitna River have existing goals based on single aerial survey data. ADF&G uses these 3 single aerial survey counts to make 3 run size determinations without considering the variability associated with aerial counts. This analysis leverages 4[13] pieces of information to make 1 run size estimate (for the stock) while accounting for correlation in run sizes between the spawning populations and variability in survey observability.

We recommend the 3 escapement goals within the Yentna management area be discontinued and replaced by a single goal. The proposed escapement goal of 13,000–22,000 fish has 98.9% probability of achieving 80+% of MSY at the lower bound and 51% probability of achieving 80+% of MSY at the upper bound. With respect to recruitment, the proposed escapement goal has 78.5% probability of achieving 80+% of MSR at the lower bound and 97.3% probability of achieving 80+% of MSR at the upper bound.

The Yentna River stock is unique among the 4 stocks because it contains the largest proportion of escapement unmonitored by aerial survey (“other”), about 40% on average (Figure 9). Because of this large unsurveyed proportion, we recommended a conservative goal, which will probably sacrifice some yield. The goal recommended for the Yentna River stock was similar to the Eastside Susitna stock in relation to probability of achieving MSY, although it was slightly less conservative at the upper bound.

REMAINING CONSIDERATIONS

The recommended goals omit some Susitna River drainage Chinook salmon: Alexander Creek, upstream tributaries (notably Chulitna River but also Indian Creek and Portage Creek), and the mainstem of the Susitna River are not included in the recommended escapement goals. These areas are excluded because we lack quality data to inform the model. Mark–recapture estimates of abundance were only germane to the Susitna River upstream of the confluence with Alexander Creek, so we lack an absolute abundance estimate for the Alexander Creek drainage. Weir estimates of Alexander Creek Chinook salmon are available in recent years, but the stock-recruit relationship was probably different early in the time series, prior to the introduction of invasive northern pike. Mark–recapture estimates do exist for upstream tributaries and the mainstem Susitna River although we could not identify a relationship between mark–recapture estimates and aerial survey data in those areas.

The recommended goals are for Chinook salmon of all sizes: Current escapement goals are based on aerial surveys that count Chinook salmon of all sizes, so the goals are applied to fish of all sizes. The proposed goals are based on these same aerial surveys and also apply to fish of all sizes. This report (Figure 21), describes a strong trend of Susitna River drainage Chinook salmon maturing at younger ages in recent years, based primarily on samples from the Deshka River weir. Smaller, younger Chinook salmon may be less productive that their larger, older counterparts and this relationship may need to be accounted for in the future. Proposed goals are

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[13] Cache Creek is surveyed but does not have an existing goal range.

all shifted toward higher escapements relative to S_{MSY} to buffer the effect of the increased presence of younger and potentially less productive age classes.

The recommended goals will delay run size assessment: Run size assessments relative to the proposed escapement goals will rely on the run reconstruction model. Because the model requires age composition and harvest data, run size assessments will be delayed relative to current practices. Final estimates of spawning abundance will depend on SWHS data, which are not released until 18 months after the fishing season has ended. A preliminary assessment will be available between successive runs. The exception to this is the Deshka River, where escapement relative to the goal will be assessed with the weir.

Susitna River Chinook salmon stock assessment will continue to be refined: This analysis represents the first attempt to consolidate all relevant Susitna River Chinook salmon stock assessment data into 1 analysis. This framework will be reviewed and revised prior to future Alaska Board of Fisheries meetings and used as a basis for future stock assessment efforts. Specifically, the relationship between mark–recapture abundance estimates and other indices will need to be periodically re-evaluated. In recent years, a mark–recapture project has been done for the mainstem Susitna River, but not for the Yentna River. A mark–recapture project for the Yentna River would simultaneously add to the 4 years of data already collected there, and could be used to evaluate performance of the stock relative to the escapement goal. For these reasons, we recommend a Yentna River mark–recapture project be conducted within the next 3 years.

SUMMARY AND CONCLUSIONS

Proposed escapement goals coincide with existing management units. This analysis considers aerial survey error and variability in stock composition to combine multiple indices of stock composition into a single estimate of abundance for major management units. Run sizes, productivity, and harvest rates differ between existing management units.

Proposed escapement goals include the major Susitna River Chinook salmon spawning areas and fisheries. Between 2014 and 2017, between 75% and 90% of the estimated spawning abundance in the Susitna River drainage was attributable to the 4 management units included in this stock assessment (Yanusz et al. 2018; DeCovich et al. *In prep*). Management units 3 and 6, which are excluded from this stock assessment, contain negligible sport fisheries. Between 1996 and 2017, between 97% to 100% of the SWHS-estimated sport harvest in the Susitna River drainage came from management units included in this stock assessment.

Escapement goals for the Susitna River drainage will be periodically reviewed. All Pacific salmon escapement goals in the state of Alaska are subject to review to allow for consideration of recent data, changes in stock productivity, and revised assessment and analysis. The run reconstruction and stock-recruit analysis described herein will be revised and improved between Alaska Board of Fisheries 3-year cycles.

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TABLES

Table 1.–State-space model parameter estimates for Susitna River Chinook salmon by stock, calendar years 1979–2017.

Parameter	Deshka River (95% CI)	Eastside Susitna (95% CI)	Talkeetna River (95% CI)	Yentna River (95% CI)
$\ln(\alpha)$	1.22 (0.35–2.1)	1.30 (0.58–2.0)	1.04 (0.29–1.75)	1.47 (0.79–2.1)
α	3.4 (1.42–8.4)	3.7 (1.78–7.4)	2.8 (1.34–5.8)	4.4 (2.2–8.0)
β	4.9e-05 (2.1e-05–8.3e-05)	4.4e-05 (1.8e-05–7.1e-05)	5.1e-05 (1.6e-05–9.1e-05)	4.5e-05 (2.4e-05–7.7e-05)
ϕ	0.32 (-0.30–0.80)	0.80 (0.39–0.94)	0.18 (-0.41–0.77)	0.41 (-0.24–0.88)
σ_w	0.84 (0.55–1.27)	0.29 (0.17–0.53)	0.74 (0.40–1.19)	0.44 (0.25–0.71)
D_{age}	28.5 (20.3–40.7)	28.5 (20.3–40.7)	28.5 (20.3–40.7)	28.5 (20.3–40.7)
D_{comp}	NA	116 (61.3–200)	43.0 (20.3– 162)	53.4 (26.5– 126)
B_{survey}	NA	28.6 (6.2–138)	23.4 (3.9– 149)	56.2 (3.6– 192)
S_{MSR}	20,303 (12,093–47,048)	22,667 (14,162–54,281)	19,479 (11,021–60,945)	22,225 (12,927–41,790)
S_{EQ}	33,696 (24,151–60,191)	32,644 (20,831–60,437)	26,616 (18,127–55,109)	35,518 (24,607–50,837)
S_{MSY}	12,737 (9,197–22,568)	12,868 (8,602–24,227)	10,669 (7,186–22,330)	13,768 (9,311–20,085)
U_{MSY}	0.64 (0.37–0.84)	0.57 (0.34–0.76)	0.55 (0.29–0.76)	0.62 (0.42–0.78)

Note: Posterior medians are point estimates and 95% credibility intervals are shown in parentheses. Parameter definitions are in the Methods section.

Table 2.–Aerial survey observability and lognormal standard deviation with 95% confidence interval for each population in the Susitna River drainage, calendar years 1979–2017.

Stock	Population	θ_i(95% CI)	σ_{ASi}(95% CI)
Deshka River	Deshka	0.44 (0.38–0.55)	0.29 (0.20–0.47)
Eastside Susitna	Goose	0.38 (0.22–0.65)	0.19 (0.01–0.44)
Eastside Susitna	Kashwitna	0.24 (0.16–0.38)	0.42 (0.23–0.61)
Eastside Susitna	Little Willow	0.28 (0.22–0.38)	0.20 (0.02–0.34)
Eastside Susitna	Montana	0.59 (0.47–0.72)	0.19 (0.05–0.33)
Eastside Susitna	Sheep	0.30 (0.18–0.51)	0.44 (0.09–0.71)
Eastside Susitna	Willow	0.45 (0.38–0.52)	0.21 (0.11–0.32)
Talkeetna River	Clear	0.32 (0.25–0.43)	0.10 (5.2e-03–0.28)
Talkeetna River	Prairie	0.70 (0.56–0.87)	0.17 (0.01–0.33)
Yentna River	Cache	0.56 (0.32–0.85)	0.73 (0.13–1.12)
Yentna River	Lake	0.50 (0.40–0.62)	0.15 (0.02–0.31)
Yentna River	Peters	0.61 (0.42–0.85)	0.57 (0.34–0.83)
Yentna River	Talachulitna	0.65 (0.50–0.84)	0.29 (0.17–0.44)

Table 3.–Age composition estimates obtained by fitting a state-space model to data from Susitna River drainage Chinook salmon, calendar years 1979–2017.

Calendar year	Age 3 (SD)	Age 4 (SD)	Age 5 (SD)	Age 6+ (SD)
1979	1.3e-05 (9.5e-05)	0.12 (9.7e-03)	0.36 (0.01)	0.52 (0.02)
1980	1.8e-05 (1.2e-04)	0.29 (0.02)	0.36 (0.02)	0.35 (0.02)
1981	1.8e-05 (9.9e-05)	0.19 (0.01)	0.45 (0.02)	0.36 (0.02)
1982	1.0e-05 (6.1e-05)	0.15 (9.8e-03)	0.31 (0.01)	0.54 (0.01)
1983	8.4e-06 (4.8e-05)	0.23 (0.01)	0.39 (0.01)	0.37 (0.01)
1984	9.2e-06 (5.0e-05)	0.14 (7.8e-03)	0.44 (0.01)	0.42 (0.01)
1985	1.6e-05 (7.8e-05)	0.16 (0.01)	0.33 (0.01)	0.51 (0.01)
1986	3.6e-05 (2.2e-04)	0.28 (0.02)	0.37 (0.02)	0.35 (0.02)
1987	6.5e-03 (4.7e-03)	0.20 (0.02)	0.46 (0.02)	0.33 (0.02)
1988	7.2e-03 (4.6e-03)	0.14 (9.6e-03)	0.36 (0.01)	0.49 (0.01)
1989	0.01 (7.5e-03)	0.20 (0.01)	0.25 (0.01)	0.54 (0.01)
1990	2.1e-04 (8.7e-04)	0.30 (0.02)	0.22 (0.02)	0.49 (0.02)
1991	7.0e-05 (2.5e-04)	0.11 (0.01)	0.40 (0.02)	0.49 (0.02)
1992	0.02 (0.01)	0.22 (0.01)	0.38 (0.02)	0.38 (0.02)
1993	1.2e-04 (4.6e-04)	0.16 (0.01)	0.43 (0.02)	0.42 (0.02)
1994	1.9e-04 (6.2e-04)	0.12 (0.01)	0.34 (0.02)	0.54 (0.02)
1995	3.1e-03 (2.7e-03)	0.27 (0.02)	0.29 (0.02)	0.44 (0.02)
1996	1.4e-04 (4.1e-04)	0.37 (0.02)	0.36 (0.02)	0.27 (0.02)
1997	1.4e-04 (4.4e-04)	0.16 (0.01)	0.62 (0.02)	0.23 (0.02)
1998	1.7e-04 (4.8e-04)	0.23 (0.02)	0.42 (0.02)	0.35 (0.02)
1999	1.8e-04 (4.6e-04)	0.27 (0.02)	0.41 (0.02)	0.32 (0.02)
2000	2.1e-04 (5.0e-04)	0.10 (0.01)	0.67 (0.02)	0.23 (0.02)
2001	4.9e-03 (3.4e-03)	0.22 (0.01)	0.46 (0.02)	0.32 (0.02)
2002	6.3e-03 (4.4e-03)	0.20 (0.01)	0.57 (0.02)	0.23 (0.02)
2003	5.1e-03 (3.7e-03)	0.35 (0.02)	0.46 (0.02)	0.18 (0.02)
2004	4.5e-03 (3.4e-03)	0.18 (0.02)	0.63 (0.02)	0.19 (0.02)
2005	5.3e-03 (3.9e-03)	0.28 (0.02)	0.55 (0.02)	0.16 (0.02)
2006	3.4e-04 (6.4e-04)	0.21 (0.02)	0.51 (0.02)	0.27 (0.02)
2007	8.9e-04 (1.7e-03)	0.10 (0.02)	0.65 (0.03)	0.25 (0.03)
2008	9.2e-04 (1.7e-03)	0.14 (0.02)	0.34 (0.03)	0.52 (0.03)
2009	7.4e-04 (1.5e-03)	0.62 (0.03)	0.25 (0.02)	0.13 (0.02)
2010	5.1e-03 (4.5e-03)	0.23 (0.02)	0.66 (0.03)	0.11 (0.02)
2011	0.01 (7.9e-03)	0.27 (0.02)	0.62 (0.03)	0.10 (0.02)
2012	0.02 (0.01)	0.51 (0.03)	0.26 (0.03)	0.21 (0.03)
2013	0.02 (0.01)	0.23 (0.03)	0.55 (0.03)	0.20 (0.03)
2014	0.04 (0.02)	0.40 (0.03)	0.39 (0.03)	0.17 (0.03)
2015	0.05 (0.03)	0.28 (0.03)	0.49 (0.03)	0.17 (0.02)
2016	0.08 (0.04)	0.45 (0.03)	0.37 (0.03)	0.10 (0.02)
2017	0.05 (0.03)	0.15 (0.03)	0.68 (0.03)	0.13 (0.02)

Table 4.–Age-at-maturity estimates obtained by fitting a state-space model to data from Susitna River drainage Chinook salmon, brood years 1973–2014.

Brood year	Age 3 (SD)	Age 4 (SD)	Age 5 (SD)	Age 6+ (SD)
1973	5.6e-04 (4.3e-03)	0.15 (0.07)	0.33 (0.09)	0.51 (0.08)
1974	5.7e-04 (3.4e-03)	0.18 (0.07)	0.44 (0.07)	0.38 (0.06)
1975	6.5e-04 (4.6e-03)	0.16 (0.03)	0.41 (0.06)	0.43 (0.05)
1976	1.1e-05 (8.3e-05)	0.22 (0.04)	0.34 (0.04)	0.44 (0.05)
1977	1.7e-05 (1.1e-04)	0.18 (0.03)	0.31 (0.03)	0.51 (0.03)
1978	1.3e-05 (7.2e-05)	0.12 (0.01)	0.40 (0.03)	0.48 (0.03)
1979	5.9e-06 (3.5e-05)	0.18 (0.02)	0.38 (0.03)	0.44 (0.03)
1980	8.5e-06 (4.9e-05)	0.17 (0.02)	0.37 (0.03)	0.46 (0.03)
1981	1.0e-05 (5.5e-05)	0.17 (0.02)	0.45 (0.03)	0.38 (0.03)
1982	1.1e-05 (5.5e-05)	0.22 (0.02)	0.34 (0.02)	0.44 (0.03)
1983	3.2e-05 (2.0e-04)	0.17 (0.02)	0.37 (0.03)	0.46 (0.03)
1984	7.7e-03 (5.6e-03)	0.19 (0.02)	0.29 (0.03)	0.50 (0.03)
1985	0.01 (7.2e-03)	0.27 (0.03)	0.25 (0.03)	0.47 (0.03)
1986	0.02 (9.2e-03)	0.31 (0.03)	0.34 (0.03)	0.34 (0.03)
1987	2.7e-04 (1.1e-03)	0.12 (0.02)	0.44 (0.03)	0.44 (0.03)
1988	6.9e-05 (2.5e-04)	0.22 (0.02)	0.41 (0.02)	0.37 (0.02)
1989	0.03 (0.02)	0.19 (0.02)	0.29 (0.02)	0.49 (0.03)
1990	2.0e-04 (7.5e-04)	0.14 (0.02)	0.45 (0.03)	0.42 (0.03)
1991	1.4e-04 (4.7e-04)	0.27 (0.02)	0.36 (0.02)	0.38 (0.03)
1992	1.6e-03 (1.4e-03)	0.19 (0.01)	0.54 (0.02)	0.27 (0.02)
1993	1.0e-04 (3.1e-04)	0.20 (0.02)	0.47 (0.03)	0.33 (0.03)
1994	2.0e-04 (6.1e-04)	0.28 (0.02)	0.47 (0.03)	0.25 (0.02)
1995	1.5e-04 (4.1e-04)	0.22 (0.02)	0.52 (0.02)	0.26 (0.02)
1996	2.2e-04 (5.7e-04)	0.12 (0.01)	0.57 (0.02)	0.31 (0.02)
1997	1.8e-04 (4.5e-04)	0.20 (0.02)	0.59 (0.02)	0.21 (0.02)
1998	4.6e-03 (3.3e-03)	0.20 (0.02)	0.53 (0.03)	0.26 (0.03)
1999	4.6e-03 (3.2e-03)	0.28 (0.02)	0.60 (0.02)	0.11 (0.01)
2000	5.6e-03 (4.1e-03)	0.23 (0.02)	0.53 (0.03)	0.24 (0.02)
2001	6.6e-03 (4.9e-03)	0.30 (0.02)	0.49 (0.02)	0.20 (0.02)
2002	5.7e-03 (4.1e-03)	0.20 (0.02)	0.53 (0.03)	0.26 (0.02)
2003	1.1e-03 (2.0e-03)	0.27 (0.04)	0.54 (0.04)	0.18 (0.03)
2004	3.2e-03 (6.0e-03)	0.30 (0.04)	0.46 (0.04)	0.24 (0.04)
2005	7.2e-04 (1.3e-03)	0.42 (0.02)	0.51 (0.02)	0.07 (0.01)
2006	7.1e-04 (1.5e-03)	0.24 (0.03)	0.58 (0.03)	0.17 (0.02)
2007	7.5e-03 (6.5e-03)	0.34 (0.03)	0.29 (0.03)	0.37 (0.04)
2008	7.4e-03 (5.3e-03)	0.31 (0.02)	0.55 (0.02)	0.14 (0.02)
2009	0.02 (0.01)	0.28 (0.03)	0.43 (0.03)	0.27 (0.03)
2010	0.02 (0.01)	0.32 (0.02)	0.57 (0.03)	0.09 (0.02)
2011	0.05 (0.03)	0.42 (0.03)	0.45 (0.03)	0.09 (0.02)
2012	0.06 (0.03)	0.43 (0.04)	0.37 (0.03)	0.13 (0.06)
2013	0.09 (0.04)	0.10 (0.04)	0.63 (0.09)	0.17 (0.08)
2014	0.02 (0.02)	0.31 (0.09)	0.53 (0.10)	0.14 (0.07)

Table 5.–Decision criteria and scores (numeric, yes/no, or rated low, medium, high) used to develop escapement goals for Susitna River drainage Chinook salmon stocks.

Stock	Inseason assessment?	Harvest rate	Data quality	Data quantity	Issues with ASL?
Deshka River	Yes	low	high	high	yes
Eastside Susitna	No	medium	medium	high	yes
Talkeetna River	No	low	medium	high	yes
Yentna River	No	low	medium	low	yes

Note: "ASL" means age-sex-length data. Scoring is discussed in detail in the Discussion section under the Escapement Goal Decision Matrix header.

FIGURES

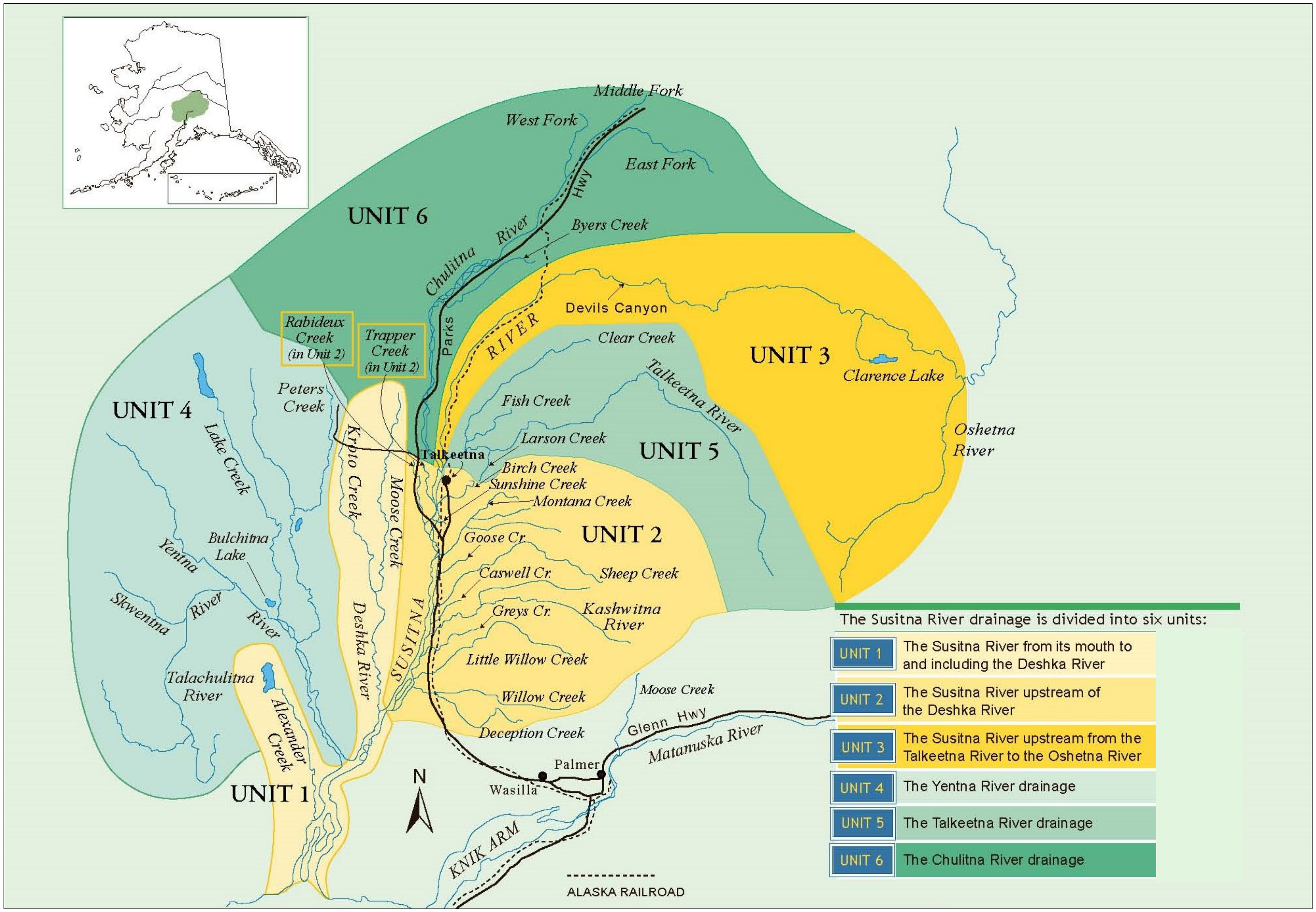


Figure 1.–Susitna River Chinook salmon management units.

Source: Adapted from Southcentral Alaska Sport Fishing Regulations Summary (http://www.adfg.alaska.gov/index.cfm?adfg=fishregulations.sc_sportfish).

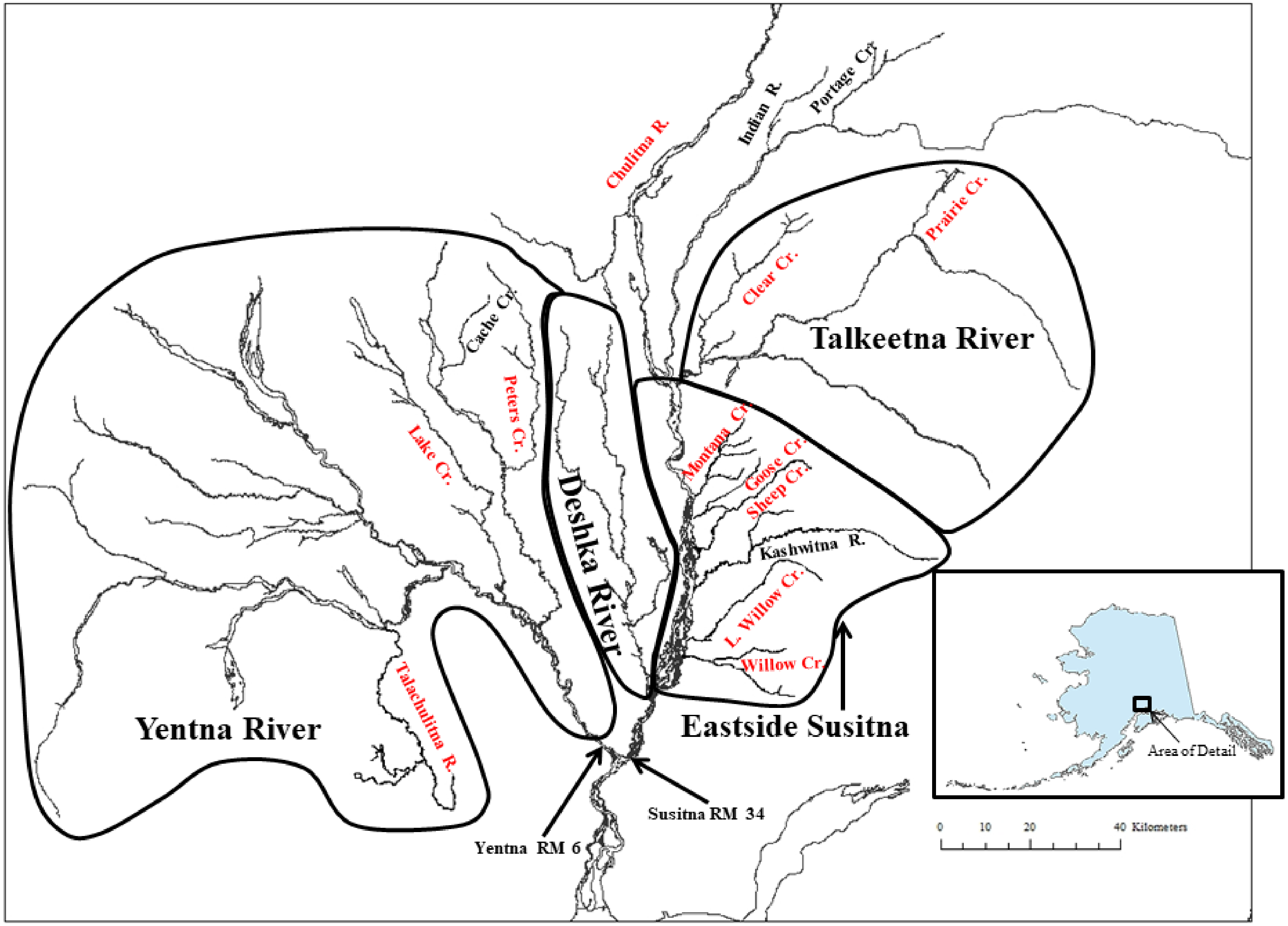
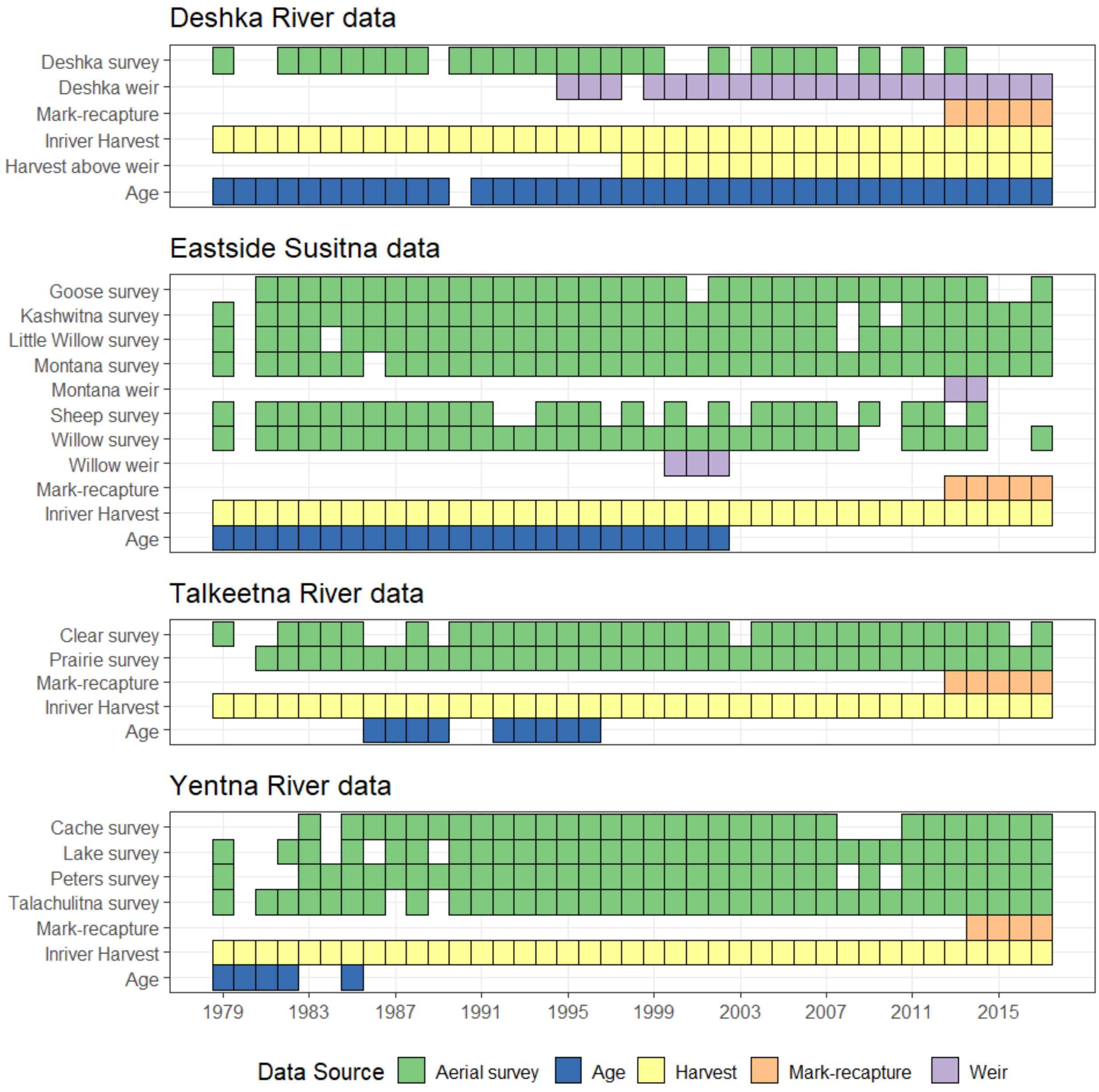


Figure 2.–Susitna River Chinook salmon stocks (large bold text) for run reconstruction and escapement goal analysis.

Note: Labeled tributaries are flown during annual single aerial surveys. Red labels indicate the population has an existing SEG.


Deshka River data

Eastside Susitna data

Talkeetna River data

Yentna River data

Figure 3.–Susitna River Chinook salmon data by stock, 1979–2017.

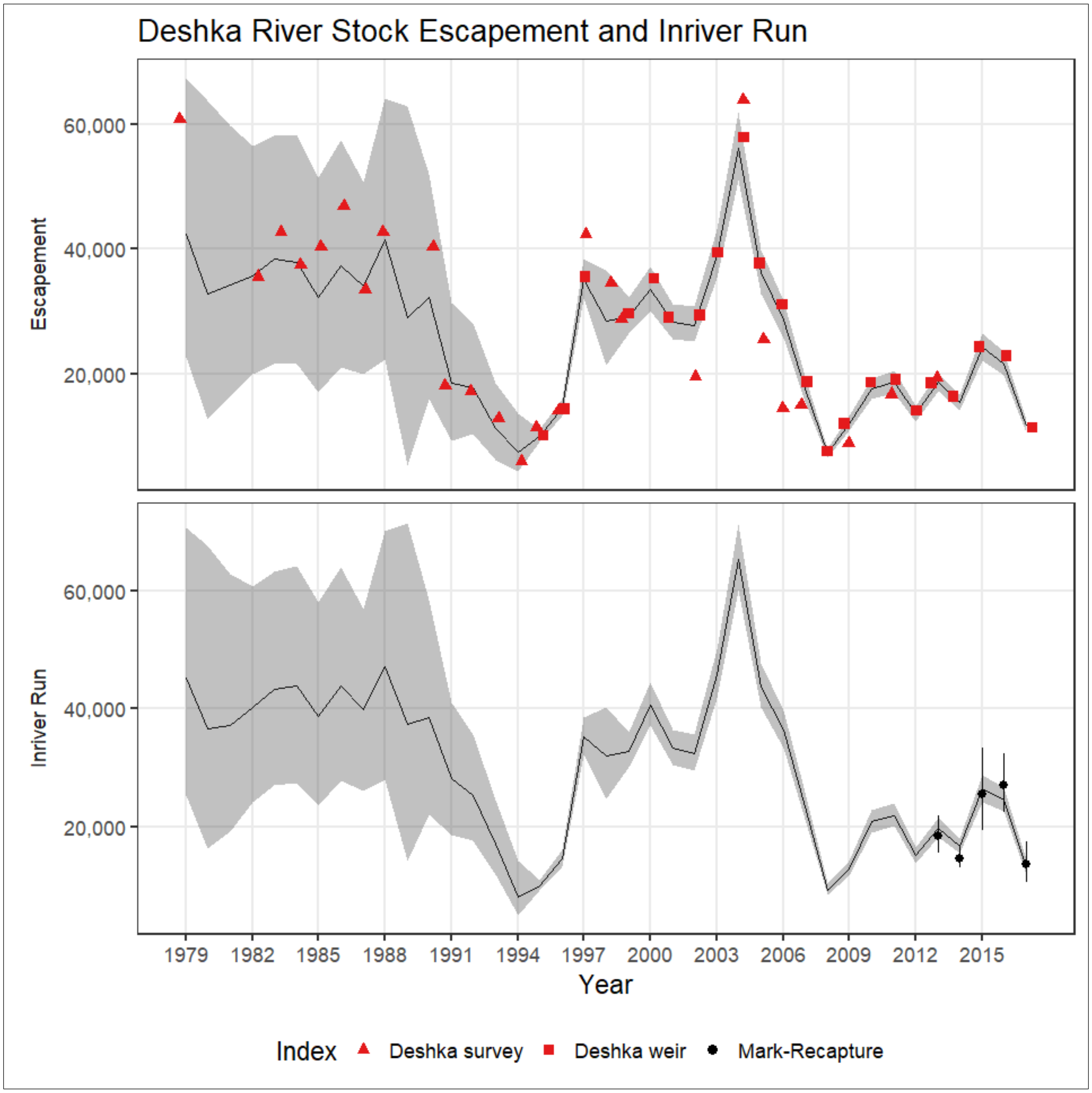


Figure 4.–Model-estimated escapement (top) and inriver run abundance (bottom) of the Deshka River Chinook salmon stock by year (black lines show the median and shaded areas show 95% credibility intervals) as reconstructed from aerial survey counts, weir counts, and mark–recapture estimates.

Note: For plotting, aerial survey counts were expanded by the inverse of survey detectability. Points are jittered along the *x*-axis.

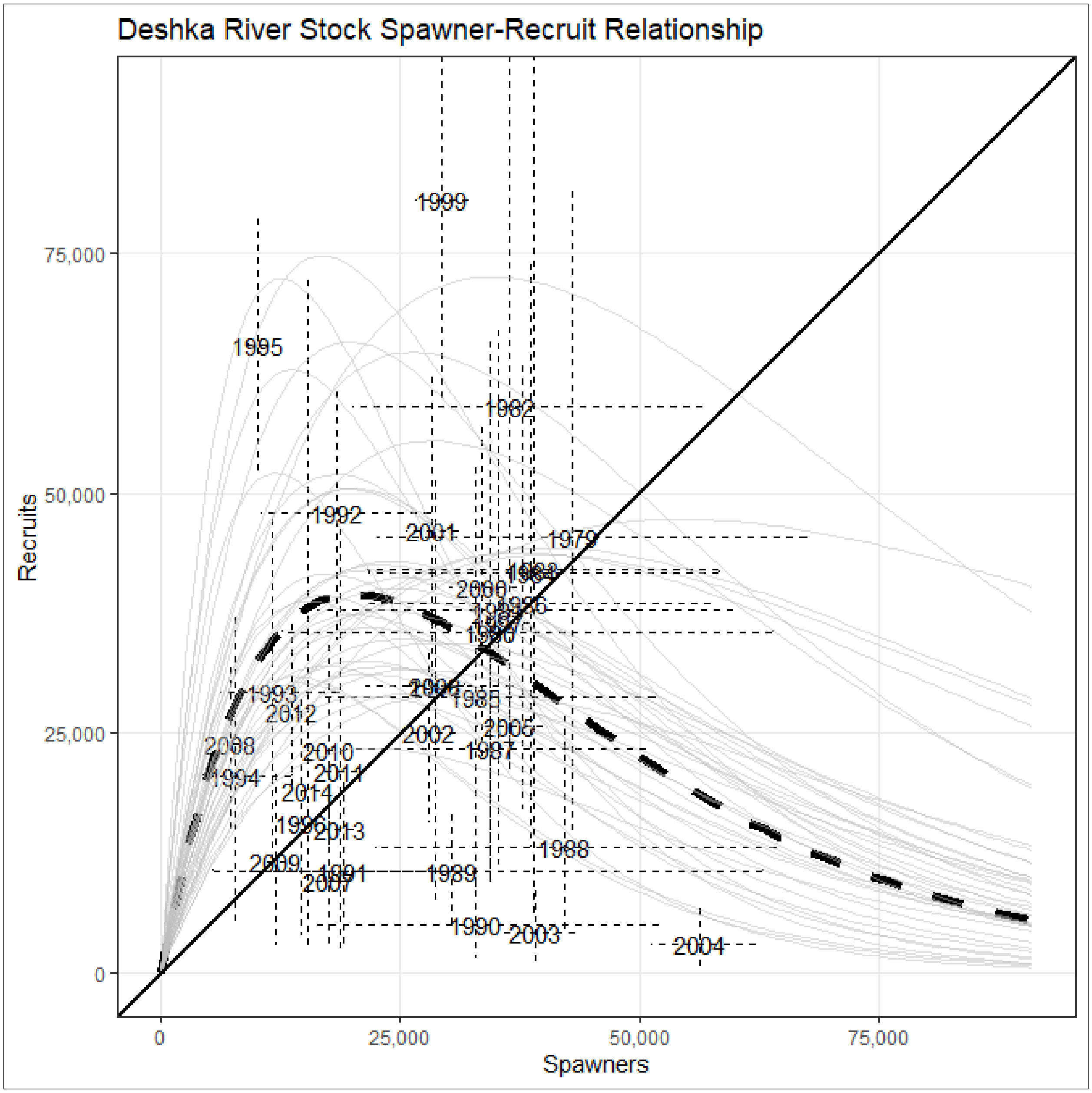


Figure 5.–Plausible spawner-recruit relationships for the Deshka River Chinook salmon stock as derived from an age-structured state-space model fitted to abundance, harvest, and age data for 1979–2017.

Note: Posterior means of R and S are plotted as brood year labels with 95% credibility intervals plotted as light dashed lines. The heavy dashed line is the Ricker relationship constructed from $\ln(\alpha')$ and β posterior medians. Ricker relationships are also plotted (light grey lines) for 40 paired values of $\ln(\alpha')$ and β sampled from the posterior probability distribution, representing plausible Ricker relationships that could have generated the observed data. Recruits replace spawners (R = S) on the diagonal line.

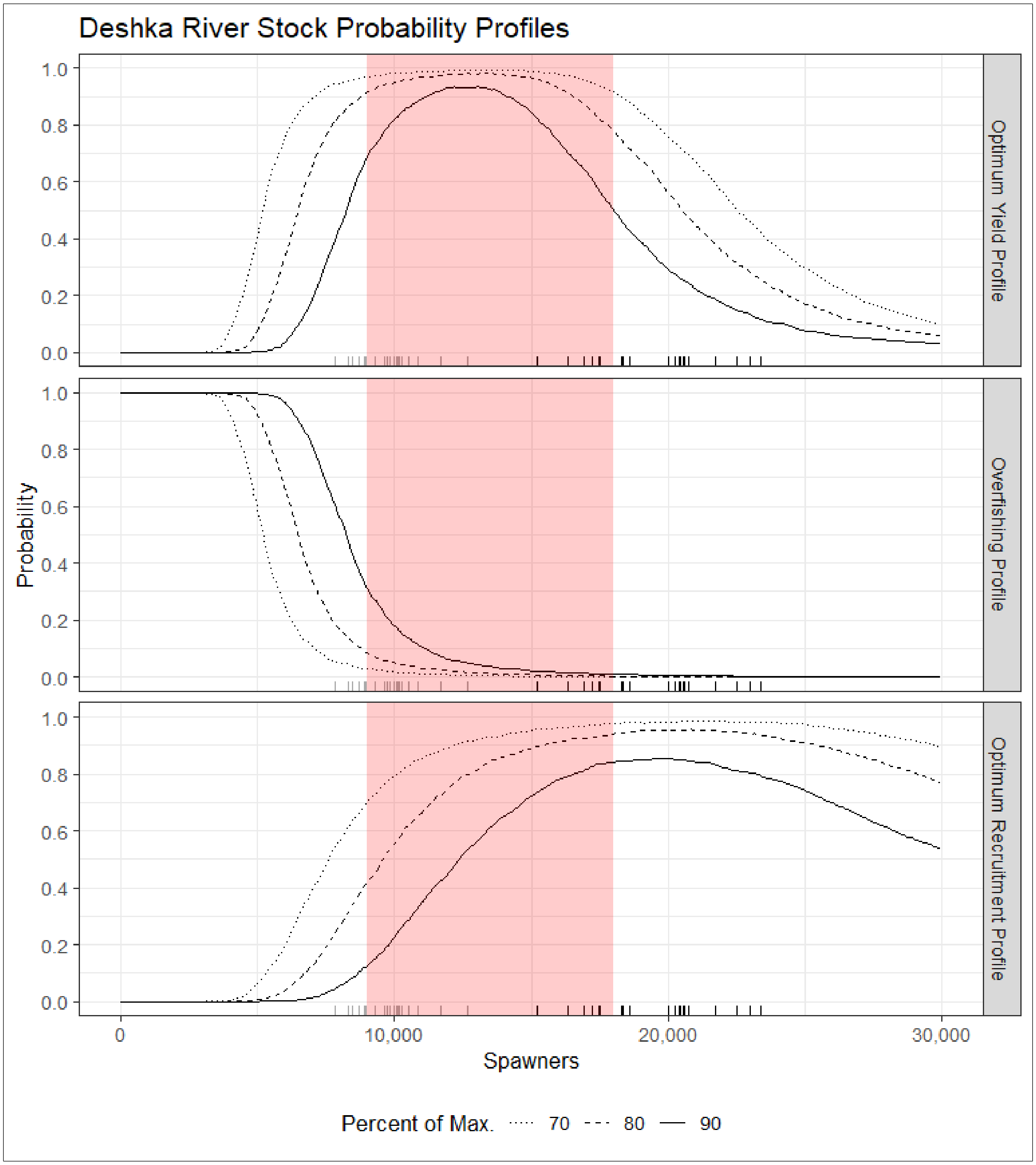


Figure 6.–Optimal yield (OYP), overfishing, and optimum recruitment (ORP) profiles for the Deshka River Chinook salmon stock. Profiles show the probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield (OYP and overfishing) or maximum sustained recruitment (ORP).

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

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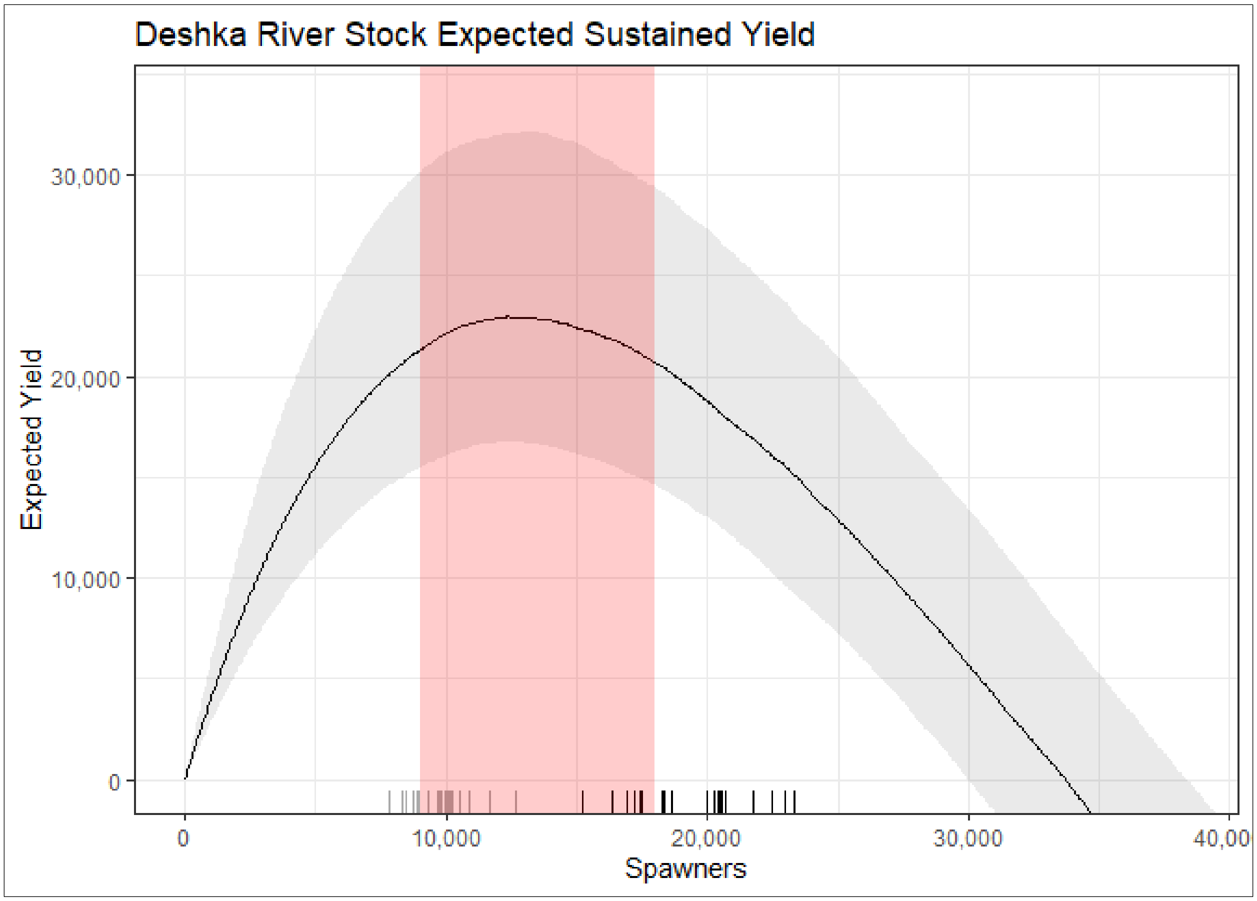

Figure 7.–Expected sustained yield (ESY) plots for the Deshka River Chinook salmon stock. ESY median (solid black line) and 50% interval (grey-shaded area around the line) assume average productivity for brood years 1979–2014.

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

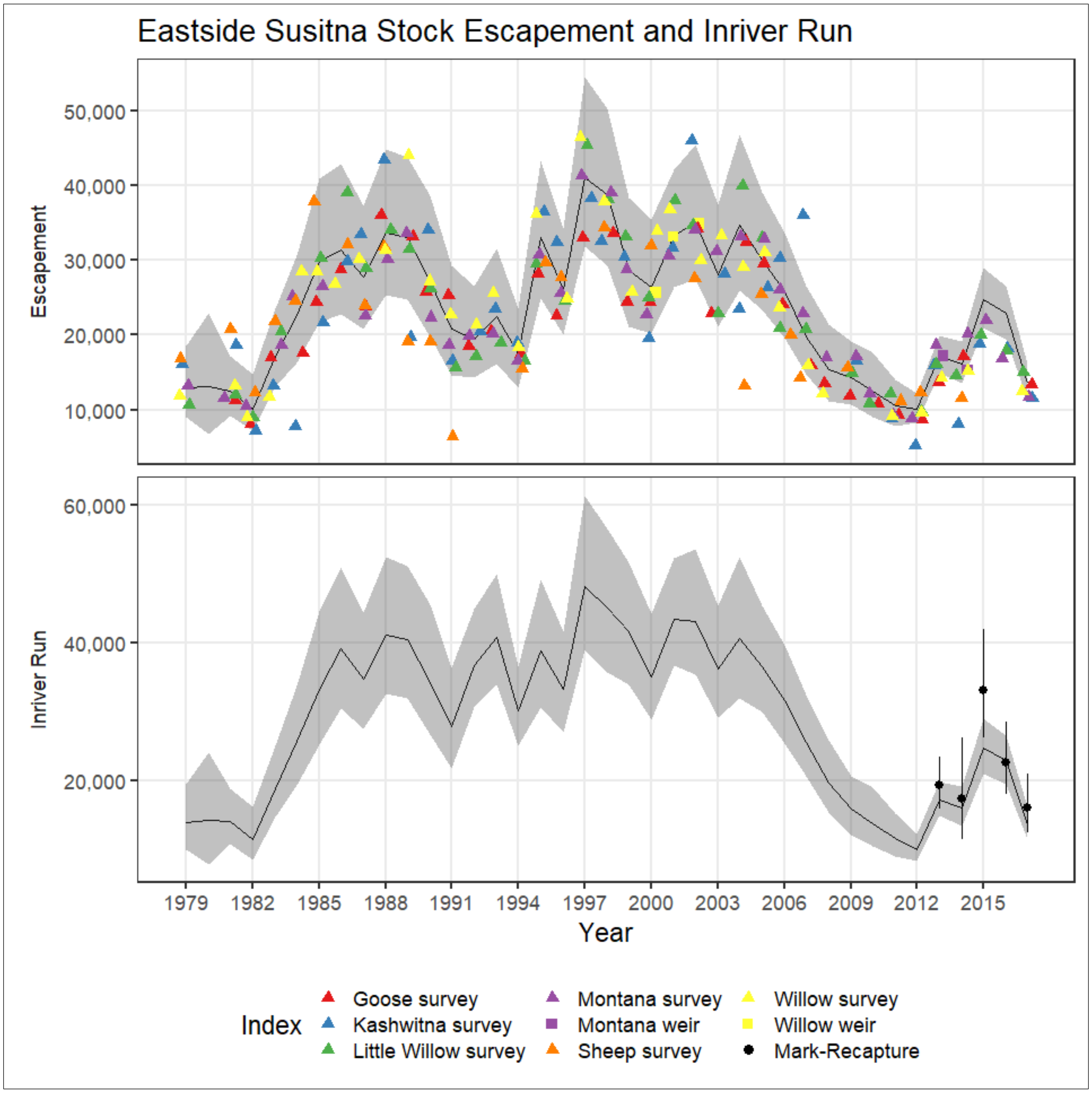

Figure 8.–Model-estimated escapement (top) and inriver run abundance (bottom) of the Eastside Susitna Chinook salmon stock by year (black lines show the median and shaded areas show 95% credibility intervals) as reconstructed from aerial survey counts, weir counts, and mark–recapture estimates.

Note: For plotting, aerial survey counts were expanded by the inverse of survey detectability and stock composition whereas weir counts were expanded by the inverse of stock composition. Points are jittered along the *x*-axis.

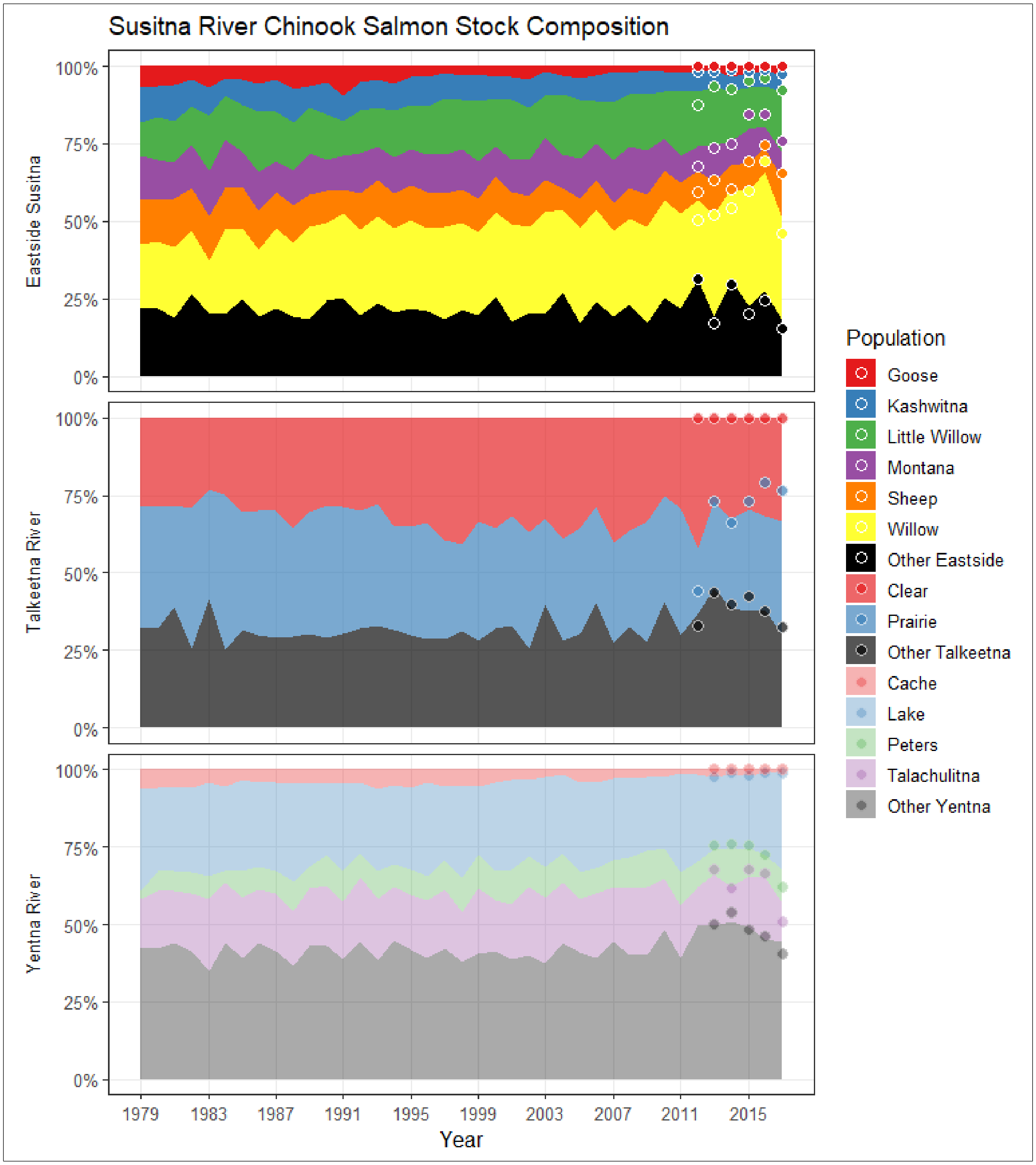

Figure 9.–Estimated stock composition estimates by calendar year from the state-space model fitted to data from Susitna River drainage Chinook salmon in the Eastside Susitna, Talkeetna River, and Yentna River stocks.

Note: Each panel is an area graph in which distances between lines represent stock composition proportions. Dots are telemetry-based estimates of stock composition.

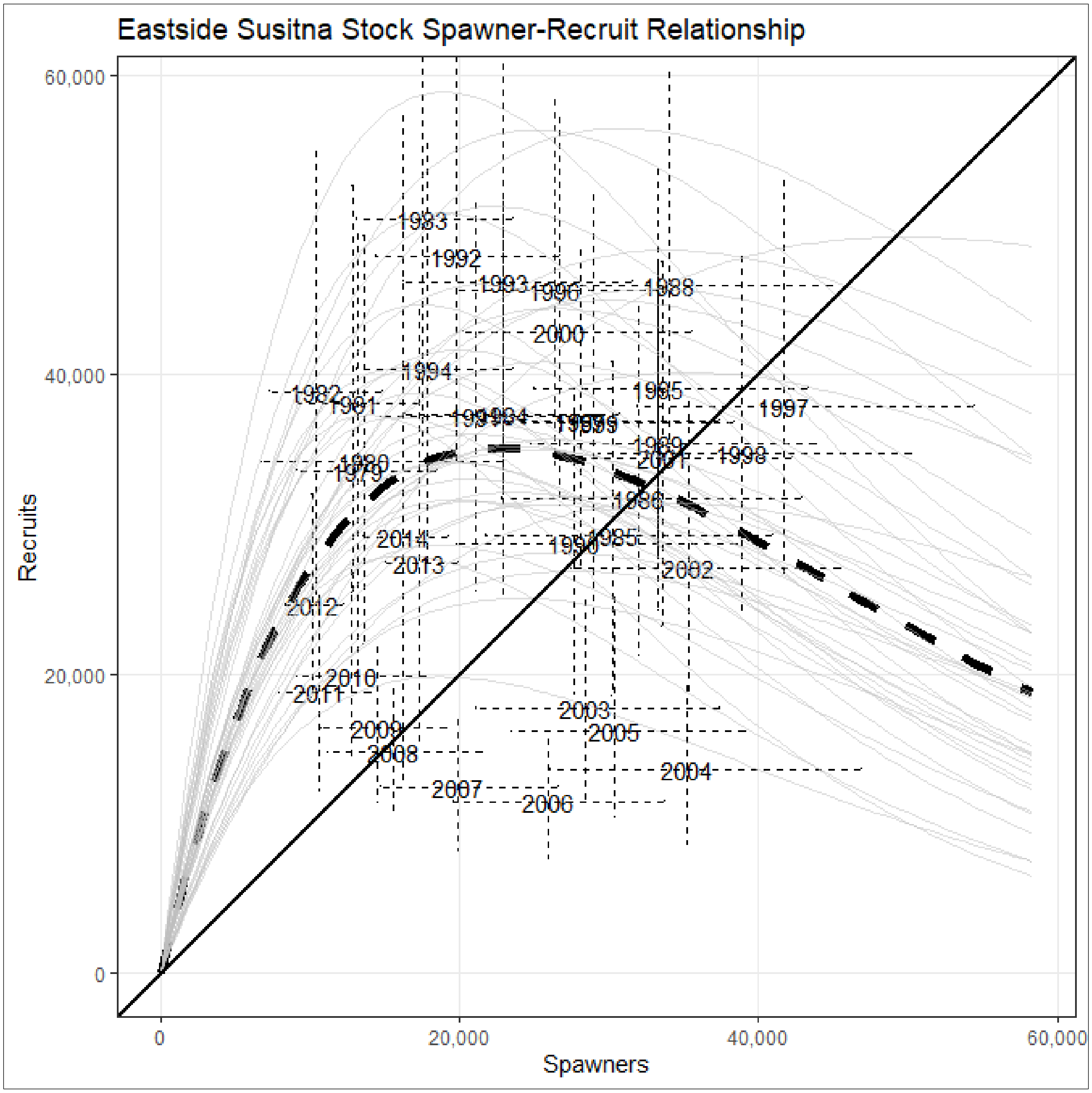

Figure 10.–Plausible spawner-recruit relationships for the Eastside Susitna Chinook salmon stock as derived from an age-structured state-space model fitted to abundance, harvest, and age data for 1979–2017.

Note: Posterior means of R and S are plotted as brood year labels with 95% credibility intervals plotted as light dashed lines. The heavy dashed line is the Ricker relationship constructed from $\ln(\alpha')$ and β posterior medians. Ricker relationships are also plotted (light grey lines) for 40 paired values of $\ln(\alpha')$ and β sampled from the posterior probability distribution, representing plausible Ricker relationships that could have generated the observed data. Recruits replace spawners (R = S) on the diagonal line.

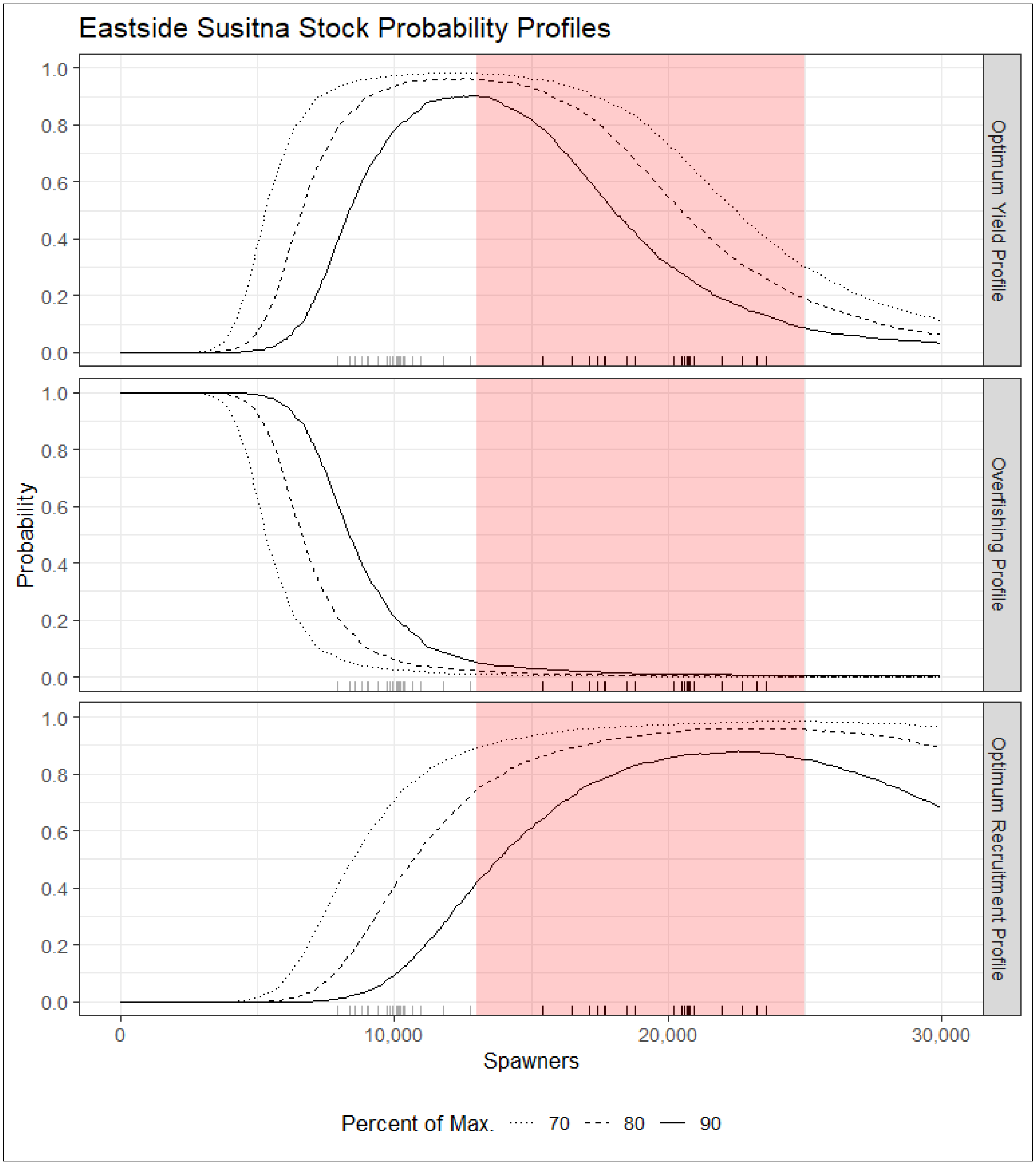

Figure 11.–Optimal yield (OYP), overfishing, and optimum recruitment (ORP) profiles for the Eastside Susitna Chinook salmon stock. Profiles show the probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield (OYP and overfishing) or maximum sustained recruitment (ORP).

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

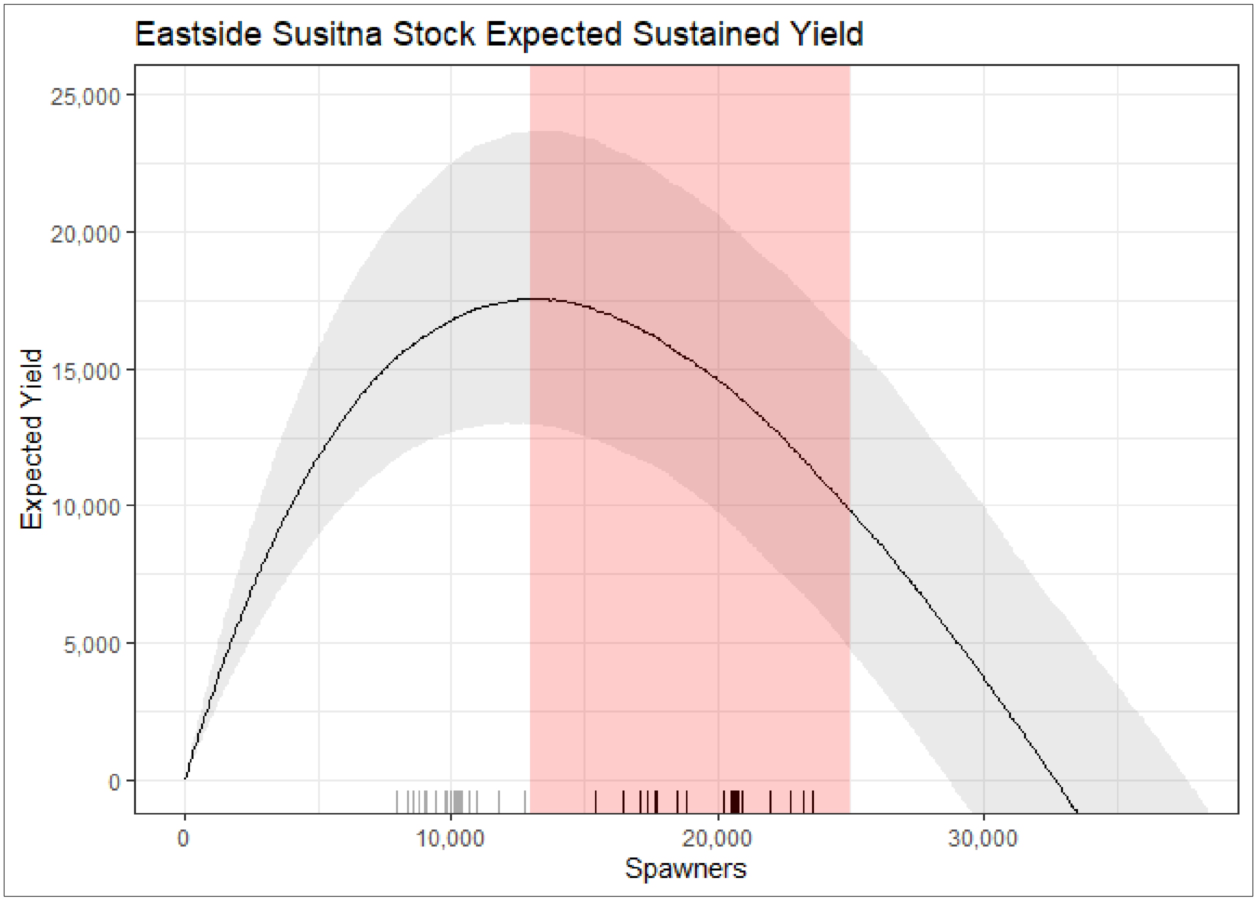

Figure 12.–Expected sustained yield (ESY) plots for the Eastside Susitna Chinook salmon stock. ESY median (solid black line) and 50% interval (grey-shaded area around the line) assume average productivity for brood years 1973–2014.

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

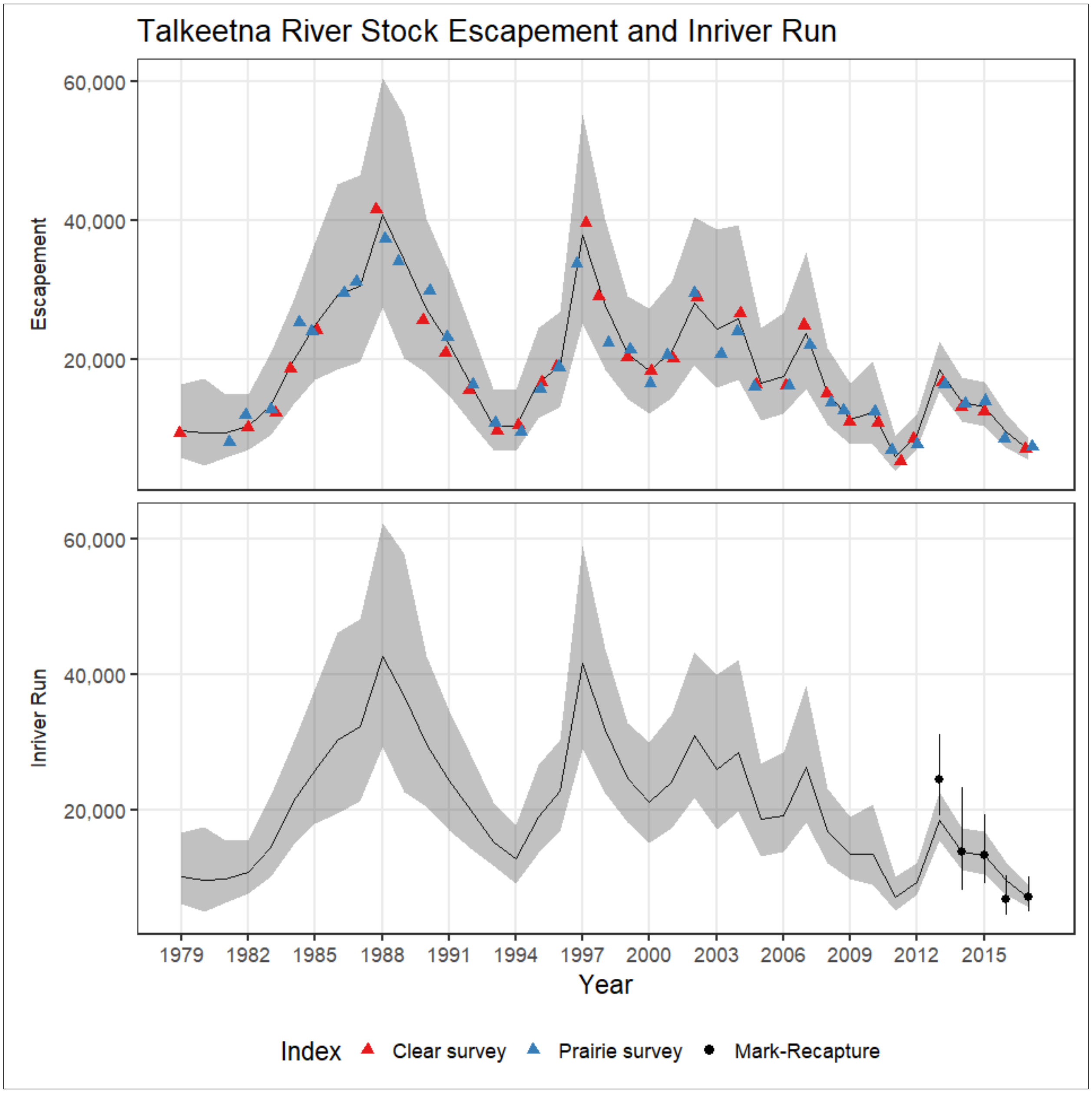

Figure 13.–Model-estimated escapement (top) and inriver run abundance (bottom) of the Talkeetna River Chinook salmon stock by year (black lines show the median while shaded areas show 95% credibility intervals) as reconstructed from aerial survey counts and mark–recapture estimates.

Note: For plotting, aerial survey counts were expanded by the inverse of the product of survey detectability and stock composition. Points are jittered along the *x*-axis.

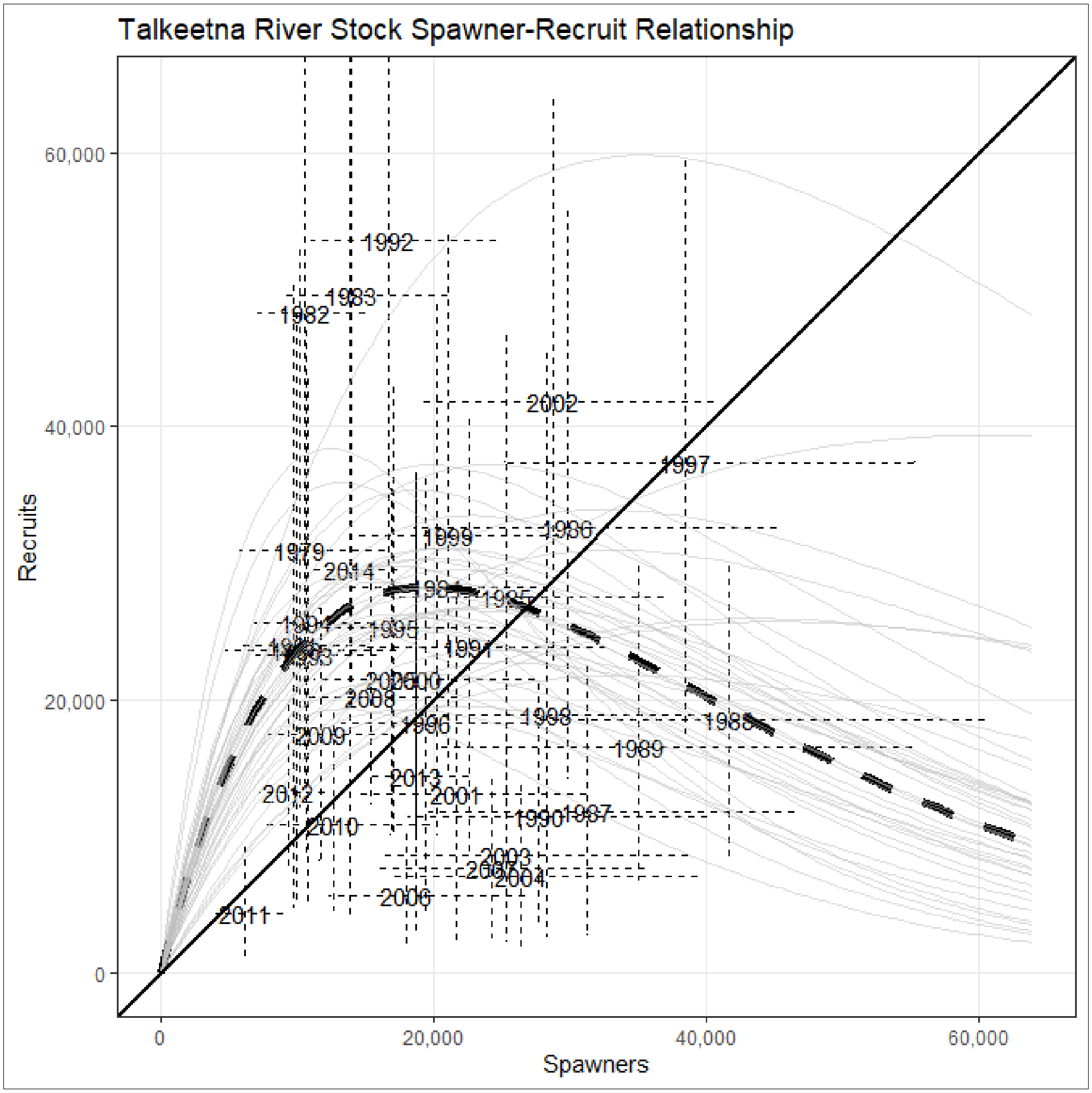

Figure 14.–Plausible spawner-recruit relationships for the Talkeetna River Chinook salmon stock as derived from an age-structured state-space model fitted to abundance, harvest, and age data for 1979–2017.

Note: Posterior means of R and S are plotted as brood year labels with 95% credibility intervals plotted as light dashed lines. The heavy dashed line is the Ricker relationship constructed from $\ln(\alpha')$ and β posterior medians. Ricker relationships are also plotted (light grey lines) for 40 paired values of $\ln(\alpha')$ and β sampled from the posterior probability distribution, representing plausible Ricker relationships that could have generated the observed data. Recruits replace spawners (R = S) on the diagonal line.

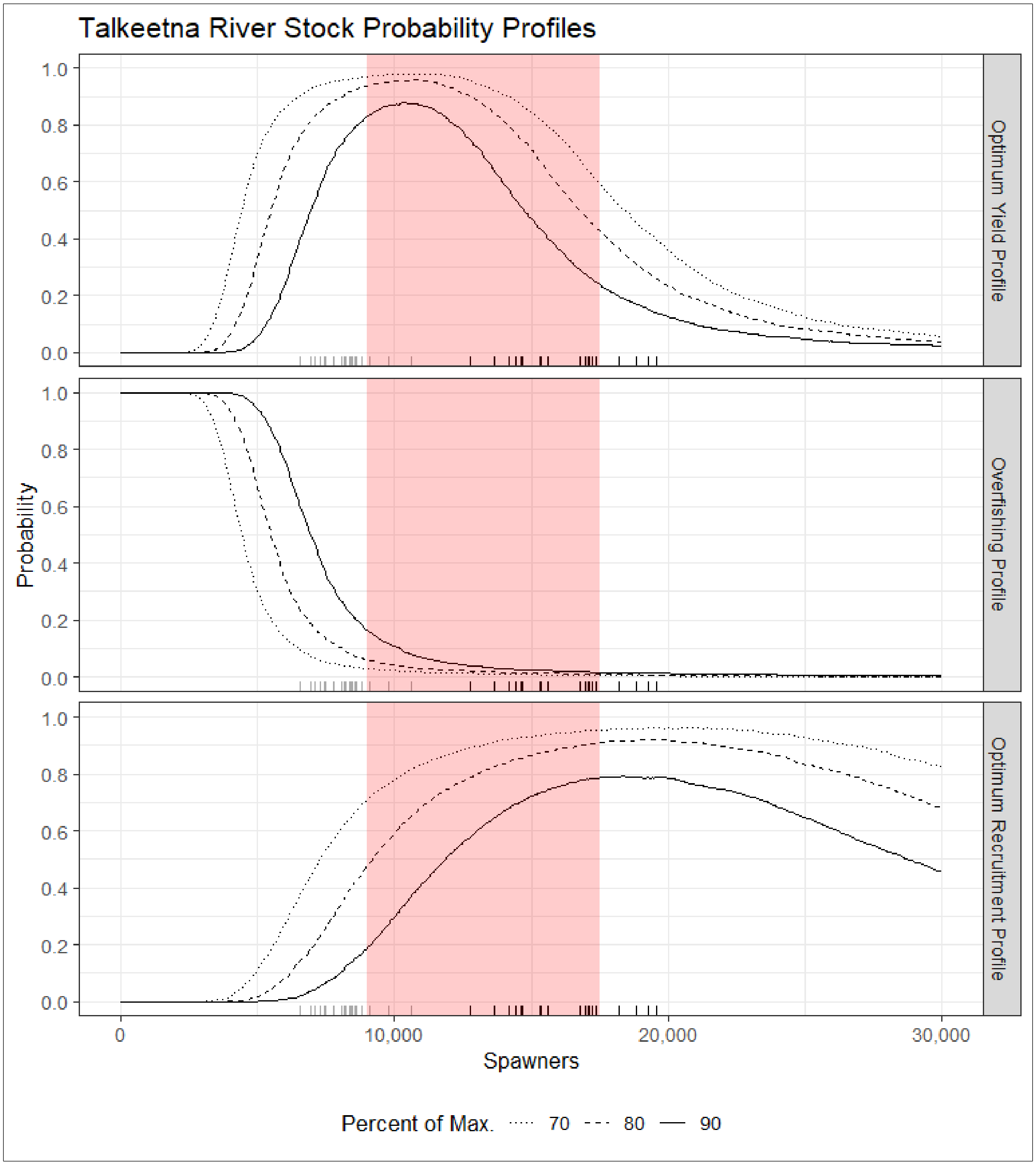

Figure 15.–Optimal yield (OYP), overfishing, and optimum recruitment (ORP) profiles for the Talkeetna River Chinook salmon stock. Profiles show the probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield (OYP and overfishing) or maximum sustained recruitment (ORP).

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

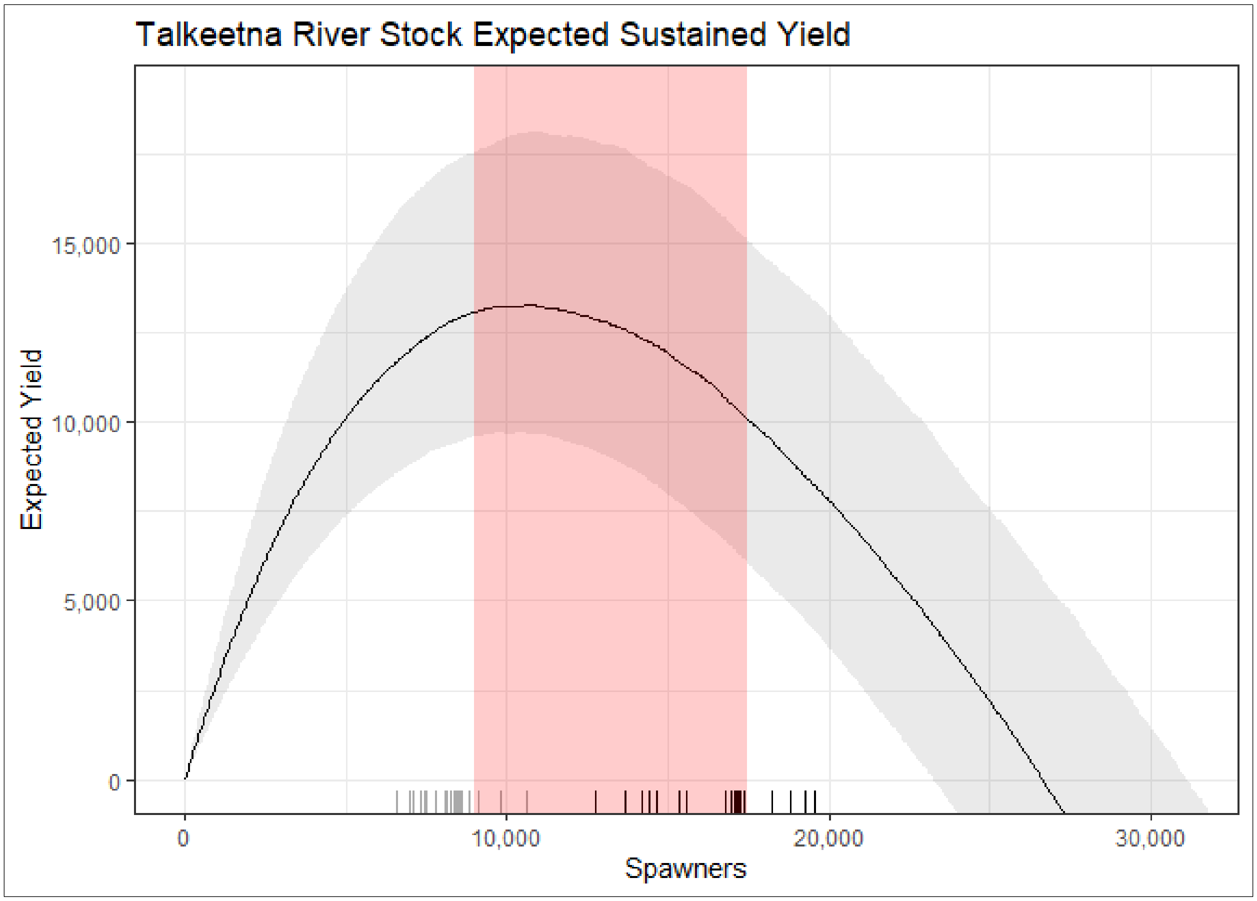

Figure 16.–Expected sustained yield (ESY) plots for the Talkeetna River Chinook salmon stock. ESY median (solid black line) and 50% interval (grey-shaded area around the line) assume average productivity for brood years 1979–2014.

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

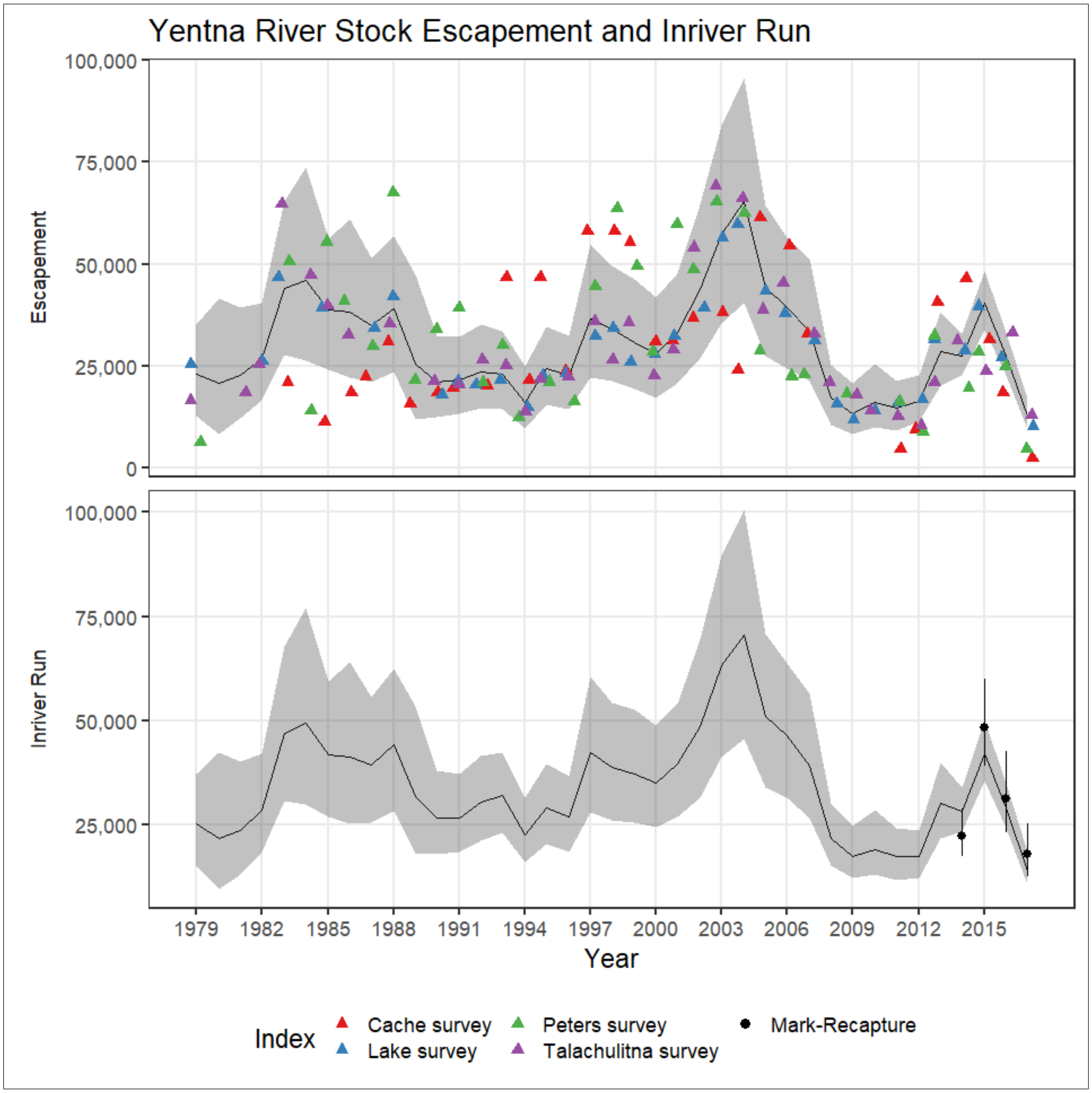

Figure 17.–Model-estimated escapement (top) and inriver run (bottom) abundance of the Yentna River Chinook salmon stock by year (black lines show the median while shaded areas show 95% credibility intervals) as reconstructed from aerial survey counts and mark–recapture estimates.

Note: For plotting, aerial survey counts were expanded by the inverse of the product of survey detectability and stock composition. Points are jittered along the *x*-axis.

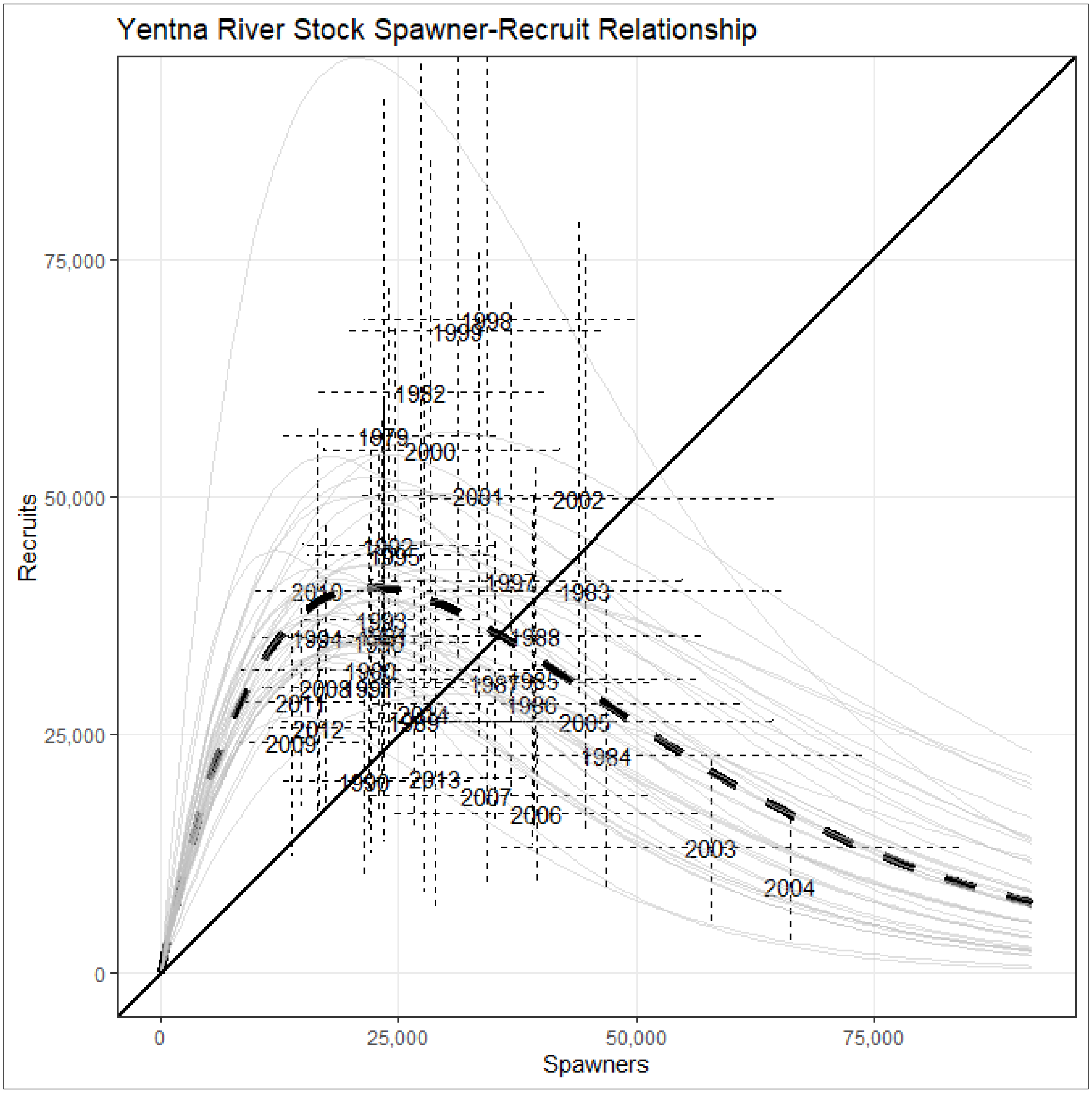

Figure 18.–Plausible spawner-recruit relationships for the Yentna River Chinook salmon stock as derived from an age-structured state-space model fitted to abundance, harvest, and age data for 1979–2017.

Note: Posterior means of R and S are plotted as brood year labels with 95% credibility intervals plotted as light dashed lines. The heavy dashed line is the Ricker relationship constructed from $\ln(\alpha')$ and β posterior medians. Ricker relationships are also plotted (light grey lines) for 40 paired values of $\ln(\alpha')$ and β sampled from the posterior probability distribution, representing plausible Ricker relationships that could have generated the observed data. Recruits replace spawners (R = S) on the diagonal line.

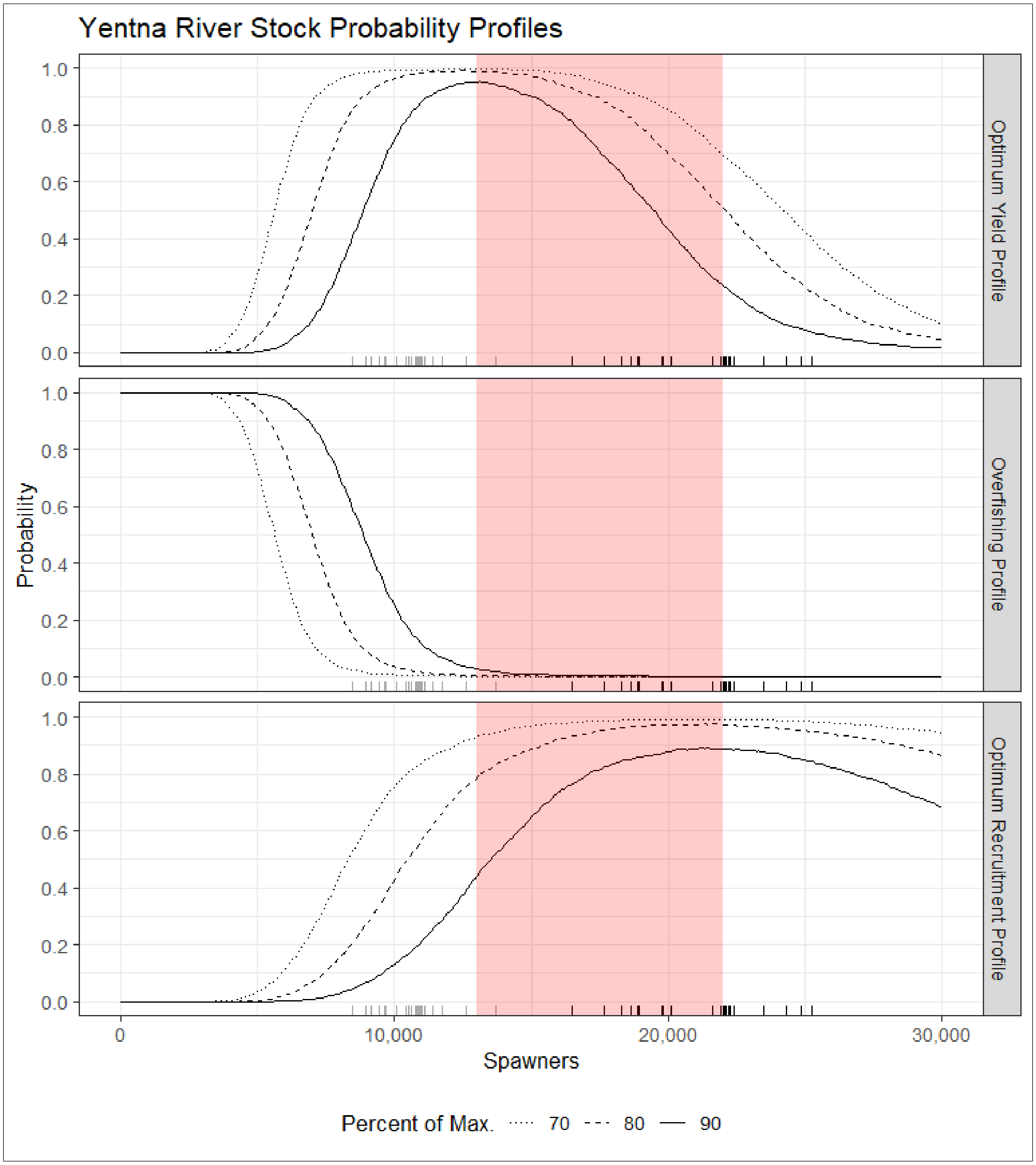

Figure 19.–Optimal yield (OYP), overfishing, and optimum recruitment (ORP) profiles for Yentna River Chinook salmon stock. Profiles show the probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield (OYP and overfishing) or maximum sustained recruitment (ORP).

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

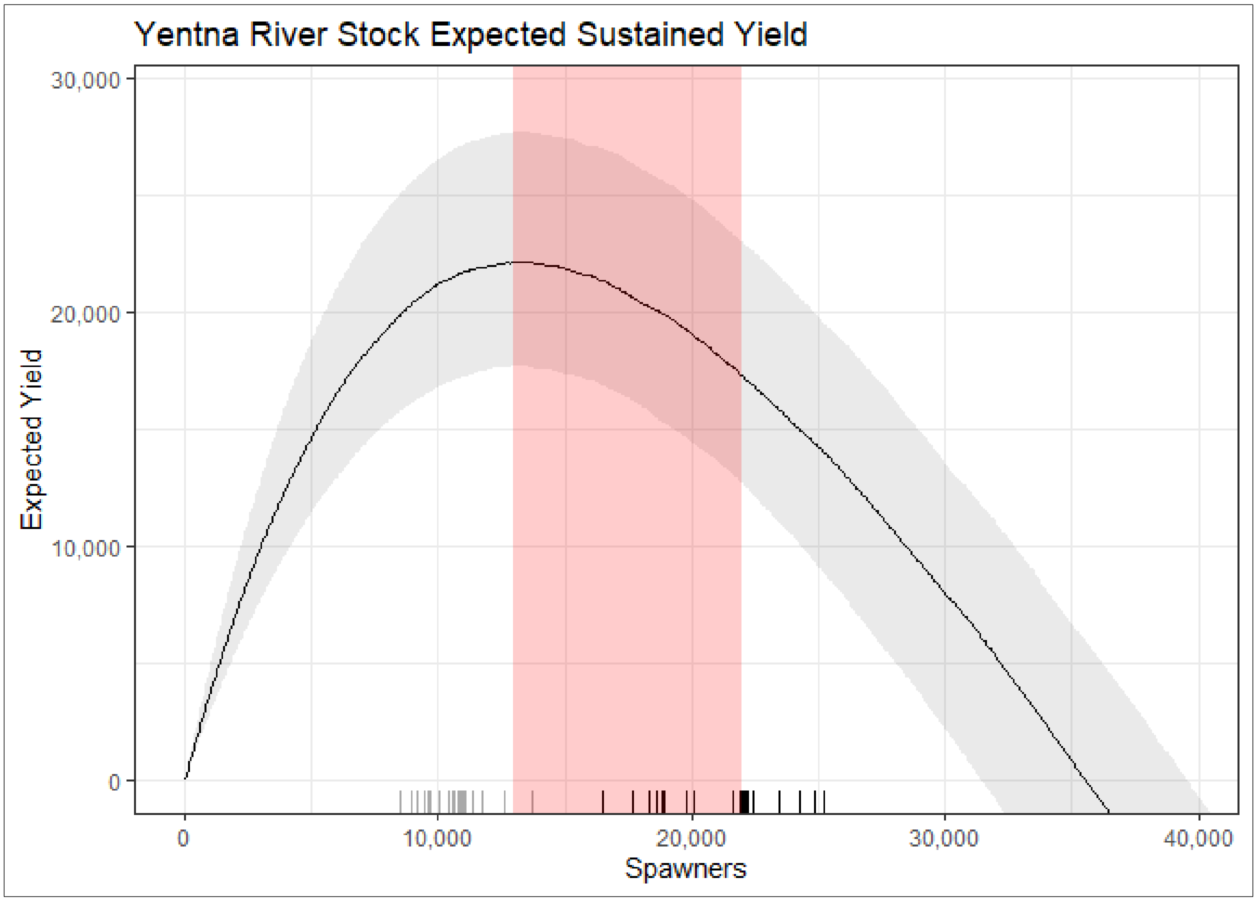

Figure 20.–Expected sustained yield (ESY) plots for the Yentna River Chinook salmon stock. ESY median (solid black line) and 50% interval (grey-shaded area around the line) assume average productivity for brood years 1979–2014.

Note: Pink shaded areas bracket the proposed goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds, respectively, scaled by S_{MSY} ratios for other Alaskan Chinook salmon stocks (see Methods).

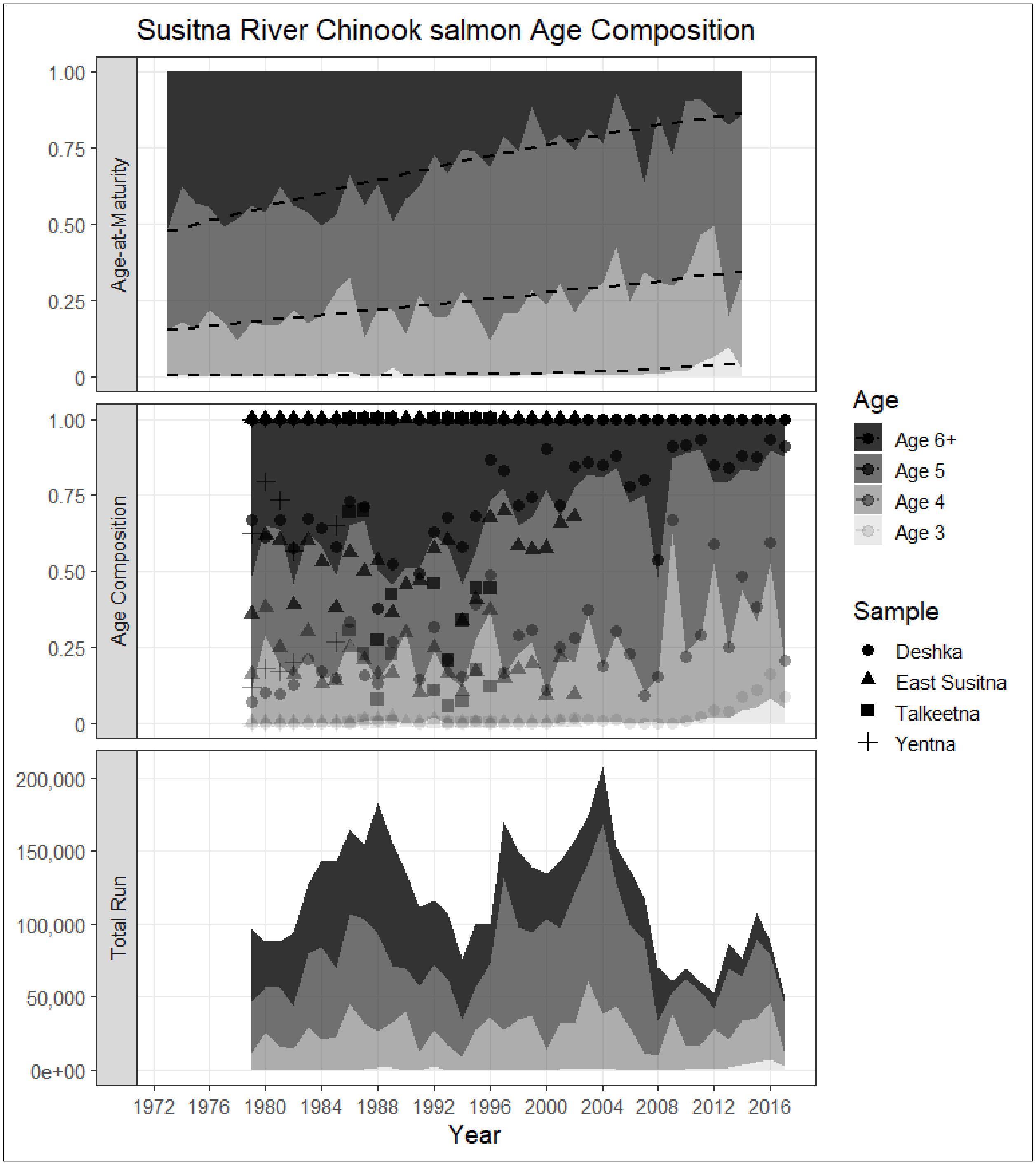

Figure 21.–Estimated age-at-maturity proportions by brood year (top), age composition proportions by calendar year (middle), and total run by age (bottom) from the state-space model fitted to data from Susitna River Chinook salmon.

Note: Top and middle are area graphs in which distance between lines represent age proportions. Dots in middle plot are data-based estimates of age composition.

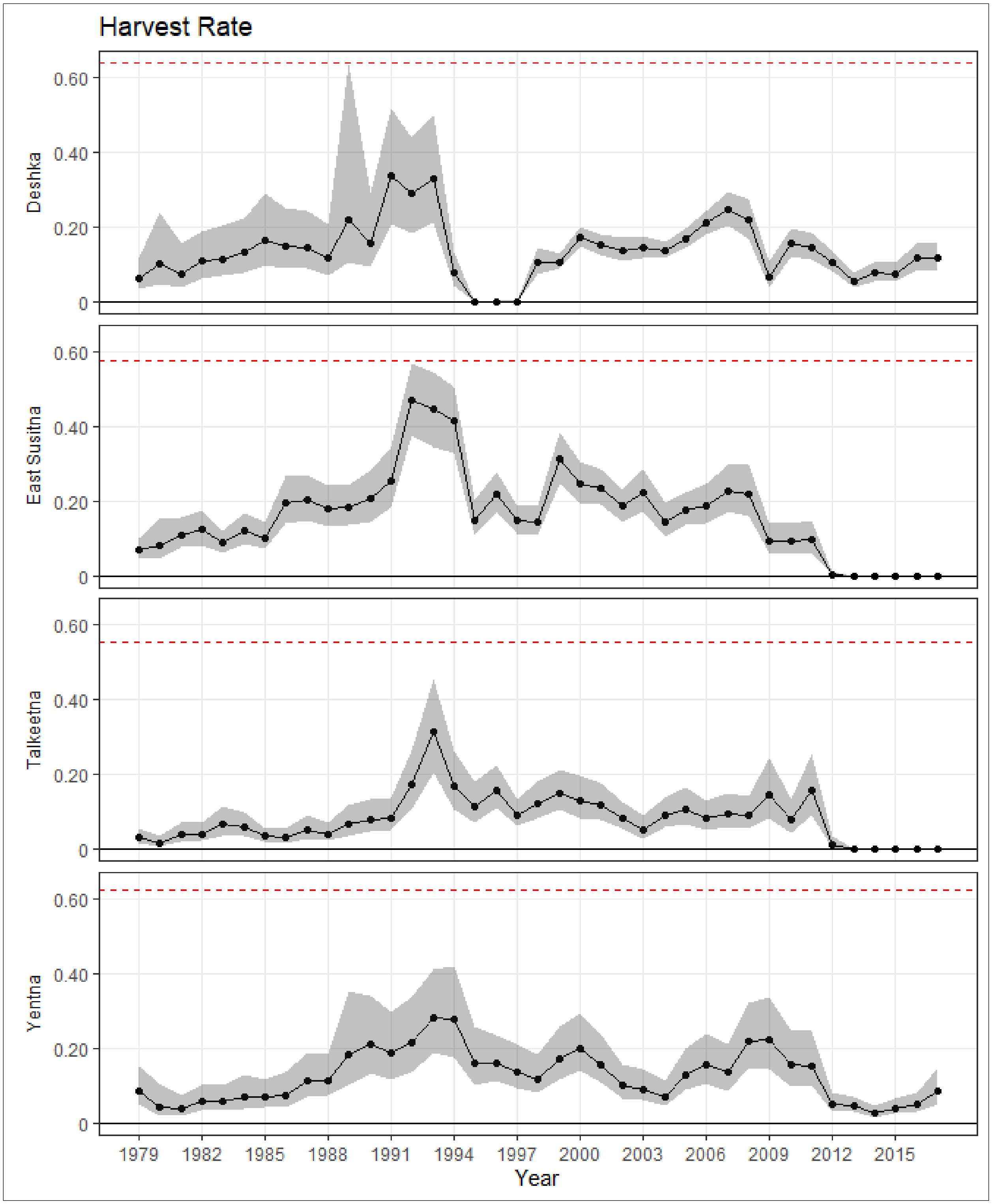

Figure 22.–Point estimates (posterior medians; solid lines) and 95% credibility intervals (shaded areas) of harvest rate from a state-space model by stock, 1979–2017.

Note: The posterior median of U_{MSY} is plotted as short-dash horizontal reference line.

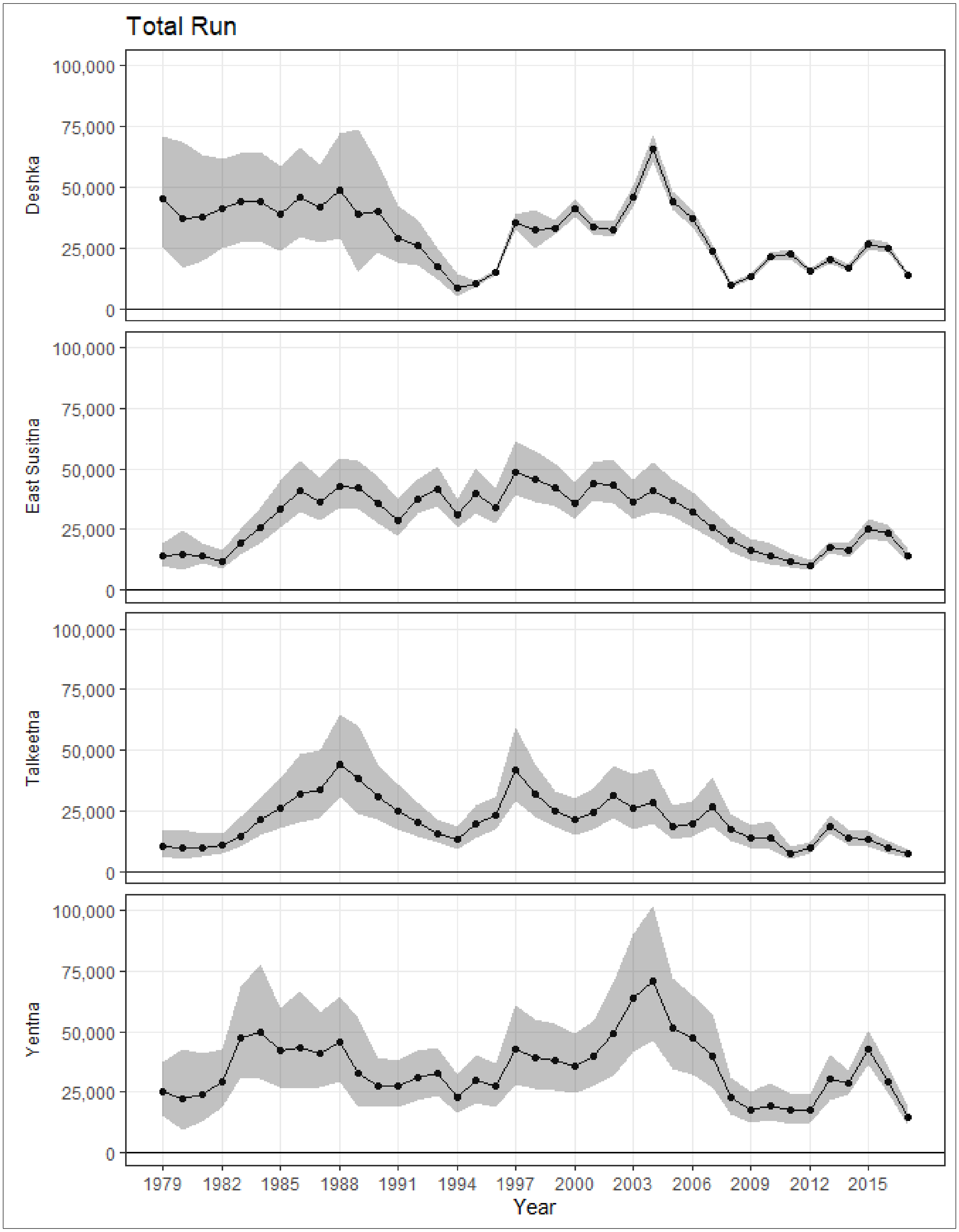

Figure 23.–Point estimates (posterior medians; solid lines) and 95% credibility intervals (shaded areas) of total run abundance from a state-space model by stock, 1979–2017.

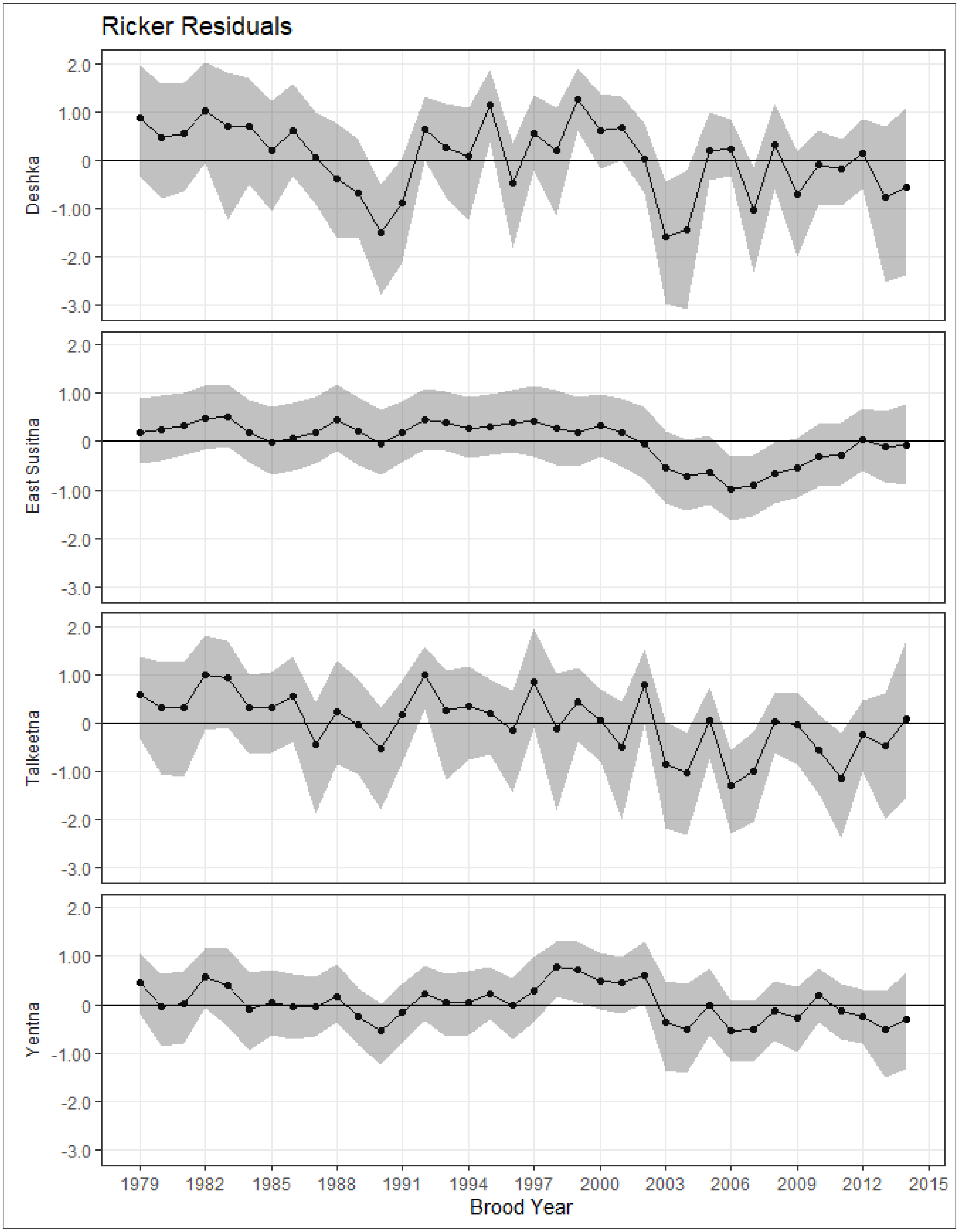

Figure 24.–Point estimates (posterior medians; solid lines) and 95% credibility intervals (shaded areas) of Ricker productivity residuals from a state-space model by stock, 1979–2014 brood years.

APPENDIX A: STOCK ASSESSMENT DATA

Appendix A1.–Mark–recapture abundance estimates for Susitna River stocks 2013–2017.

	2013		2014		2015		2016		2017	
Stock	$\widehat{IR}$	SE($\widehat{IR}$)	$\widehat{IR}$	SE($\widehat{IR}$)	$\widehat{IR}$	SE($\widehat{IR}$)	$\widehat{IR}$	SE($\widehat{IR}$)	$\widehat{IR}$	SE($\widehat{IR}$)
Deshka River	18,469	1,573	14,630	864	25,454	3,519	26,922	2,566	13,610	1,763
Eastside Susitna	19,299	1,891	17,343	3,709	33,090	3,984	22,676	2,652	16,104	2,156
Talkeetna River	24,408	3,008	13,746	3,782	13,236	2,566	6,779	1,465	7,044	1,287
Yentna River			22,267	2,871	48,415	5,326	31,339	4,971	17,838	3,202

Source: AEA 2014, 2015; Yanusz et al. 2018; DeCovich et. al. *In prep.*

Appendix A2.–Single aerial survey index counts of Susitna River Chinook salmon, 1979–2017.

	Deshka	East Susitna						Talkeetna		Yentna			
Year	Deshka	Goose	Kashwitna	Little Willow	Montana	Sheep	Willow–Deception Creek	Clear	Prairie	Cache	Lake	Peters	Talachulitna
1979	27,385		457	327	1,094	778	1,087	864			4,196	108	1,648
1980													
1981		262	558	459	814	1,013	1,357		1,875				2,025
1982	16,000	140	156	316	887	527	821	982	3,844		3,577		3,101
1983	19,237	477	297	1,042	1,641	975	898	938	3,200	497	7,075	2,272	10,014
1984	16,892	258	111		2,309	1,028	3,464	1,520	9,000			324	6,138
1985	18,151	401	457	1,305	1,767	1,634	2,900	2,430	6,500	206	5,803	2,901	5,145
1986	21,080	630	700	2,133		1,285	2,580		8,500	424		1,915	3,686
1987	15,028	416	872	1,320	1,320	895	3,460		9,138	556	4,898	1,302	
1988	19,200	1,076	1,159	1,515	2,016	1,215	3,286	4,850	9,280	818	6,633	3,927	4,112
1989		835	355	1,325	2,701	610	5,860		9,463	362		959	
1990	18,166	552	872	1,115	1,269	634	3,065	2,380	9,113	484	2,075	2,027	2,694
1991	8,112	968	340	498	1,215	154	2,753	1,974	6,770	499	3,011	2,458	2,457
1992	7,736	369	470	673	1,560		2,643	1,530	4,453	487	2,322	996	3,648
1993	5,769	347	525	705	1,281		3,238	886	3,023	1,690	2,869	1,668	3,269
1994	2,665	375	430	712	1,143	542	2,245	1,204	2,254	628	1,898	573	1,575
1995	5,150	374	836	1,210	2,110	1,049	4,626	1,928	3,884	1,601	3,017	1,041	2,521
1996	6,343	305	782	1,077	1,841	1,028	2,987	2,091	5,037	581	3,514	749	2,748
1997	19,047	308	761	2,390	3,073		6,181	5,100	7,710	1,774	3,841	2,637	4,494
1998	15,556	415	619	1,782	2,936	1,160	4,773	3,894	4,465	1,771	5,056	4,367	2,759
1999	12,904	268	644	1,837	2,088		3,081	2,216	5,871	1,720	2,877	3,298	4,890
2000		348	329	1,121	1,271	1,162	4,164	2,142	3,790	709	4,035	1,648	2,414
2001			604	2,084	1,930		5,163	2,096	5,191	624	4,661	4,226	3,309
2002	8,749	565	1,049	1,680	2,357	854	3,758	3,496	7,914	671	4,852	2,959	7,824
2003		175	546	879	2,576		4,878		4,095	558	8,153	3,998	9,573

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Appendix A2.–Page 2 of 2.

	Deshka	East Susitna						Talkeetna		Yentna			
Year	Deshka	Goose	Kashwitna	Little Willow	Montana	Sheep	Willow–Deception	Clear	Prairie	Cache	Lake	Peters	Talachulitna
2004	28,778	417	342	2,227	2,117	285	3,465	3,417	5,570	212	7,598	3,757	8,352
2005	11,495	468	454	1,784	2,600	760	4,269	1,924	3,862	1,460	6,345	1,508	4,406
2006	6,499	306	613	816	1,850	580	3,157	1,520	3,570	1,230	5,300	1,114	6,152
2007	6,712	105	895	1,103	1,936	400	1,977	3,310	5,036	551	4,081	1,225	3,871
2008		117			1,357		1,510	1,795	3,039		2,004		2,964
2009	3,954	65	317	776	1,460	500	1,133	1,205	3,500		1,394	1,283	2,608
2010		76		468	755		1,173	903	3,022		1,617		1,499
2011	7,522	80	134	713	494	350	1,241	512	2,038	27	2,563	1,103	1,368
2012		57	85	494	416	363	1,105	1,177	1,185	87	2,366	459	847
2013	8,686	62	234	858	1,304		2,102	1,471	3,304	582	3,655	1,643	2,285
2014		232	88	684	953	262	2,023	1,390	2,812	475	3,506	1,443	2,256
2015			224	788	1,416		2,046	1,205	3,290	363	4,686	1,514	2,582
2016			203	675	692		1,814		1,853	120	3,588	1,122	4,295
2017		148	161	840	603		1,829	780	1,930	9	1,601	307	1,087

Source: 1979–2015, Oslund et al. 2017; 2016–2017, ADF&G, Palmer, unpublished data.

Appendix A3.–Weir counts of Chinook salmon at the Deshka River, Montana Creek, and Willow Creek weirs, 1995–2017.

Year	Deshka	Montana	Willow
1995	10,048		
1996	14,349		
1997	35,587		
1998	36,310		
1999	29,088		
2000	33,965		7,026
2001	27,966		10,394
2002	28,535		9,743
2003	39,257		
2004	56,659		
2005	36,433		
2006	29,922		
2007	17,594		
2008	7,284		
2009	11,641		
2010	18,223		
2011	18,553		
2012	13,952		
2013	18,378	2,015	
2014	16,099	1,217	
2015	23,627		
2016	22,099		
2017	11,034		

Source: Deshka weir, Lescanec 2016; Montana Creek weir, unpublished data from Cleary et al. 2014, Cleary and Yanusz 2014); Willow Creek weir, unpublished data from ADF&G Northern Cook Inlet Chinook salmon coded wire tag project.

Appendix A4.–Number of transmitters tracked to final location by stock and population.

		Year					
Stock	Population	2012	2013	2014	2015	2016	2017
Eastside Susitna							
	Goose Creek	2	2	1	1	1	2
	Kashwitna River	12	5	4	2	2	4
	Little Willow Creek	22	21	12	7	9	13
	Montana Creek	9	11	10	10	8	8
	Sheep Creek	10	12	4	6	4	15
	Willow Creek	21	37	17	26	35	24
	Other Eastside Susitna	35	18	20	13	19	12
Talkeetna River							
	Clear Creek	29	38	18	7	5	8
	Prairie Creek	6	41	14	8	10	15
	Other Talkeetna River	17	61	21	11	9	11
Yentna River							
	Cache Creek	NA	15	2	5	2	3
	Lake Creek	NA	134	48	52	55	83
	Peters Creek	NA	48	29	19	12	25
	Talachulitna River	NA	106	16	45	42	23
	Other Yentna River	NA	304	112	113	95	92

Source: Cleary and Campbell 2016; Cleary et al. 2014a–b, 2015, 2017; Yanusz et al. 2018; DeCovich et al. *In prep.*

Note: Telemetry data were not used to estimate the stock composition of the Deshka River stock because it is considered a single stock.

Appendix A5.–Number of Chinook salmon sampled by total age for the Deshka River stock, 1979–2017.

Year	Type	Age 3	Age 4	Age 5	Age 6+	Total	Source
1979	Harvest	0	20	178	98	296	a
1980	Harvest	0	18	92	70	180	a
1981	Harvest	0	15	90	52	157	a
1982	Harvest	0	38	134	128	300	a
1983	Harvest	0	279	611	438	1,328	b
1984	Harvest	0	248	687	526	1,461	c
1985	Harvest	0	65	187	182	434	d
1986	Harvest	0	127	152	103	382	e
1987	Harvest	0	30	107	55	192	f
1988	Harvest	3	42	87	217	349	g
1989	Harvest	4	77	77	144	302	h
1991	Harvest	0	22	53	78	153	d
1992	Harvest	11	21	32	38	102	d
1993	Harvest	0	31	69	48	148	i
1994	Harvest	0	17	48	47	112	j
1995	Weir	3	128	98	108	337	k
1996	Weir	0	163	127	44	334	k
1997	Weir	0	82	324	82	488	k
1998	Weir	0	92	136	90	318	k
1999	Weir	0	136	194	114	444	k
2000	Weir	0	50	369	47	466	k
2001	Weir	7	128	253	153	541	k
2002	Weir	9	147	315	87	558	k
2003	Weir	5	176	238	69	488	k
2004	Weir	5	101	371	84	561	k
2005	Weir	5	142	283	58	488	l
2006	Weir	0	111	269	108	488	l
2007	Weir	0	21	165	46	232	l
2008	Weir	0	41	101	123	265	l
2009	Weir	0	258	92	35	385	l
2010	Weir	3	70	234	29	336	l
2011	Weir	7	92	222	23	344	l
2012	Weir	12	157	75	44	288	l
2013	Weir	9	53	145	40	247	l
2014	Weir	21	96	96	29	242	l
2015	Weir	36	91	165	42	334	d
2016	Weir	69	186	147	29	431	d
2017	Weir	21	28	168	22	239	d

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Note: Minor differences between Appendix A5 and the source data reflect rounding errors when reconstructing age composition data from reported age composition proportions.

[a] Delaney and Hepler 1983: p 67, Table 6.

[b] Hepler and Bentz 1984: p 52, Table 4.

[c] Hepler and Bentz 1985: p 166, Table 7.

[d] unpublished data, ADF&G, Palmer.

[e] Hepler and Bentz 1987: p 18, Table 6.

[f] Hepler et al. 1988: p 63, Table 29.

[g] Hepler et al. 1989: p 60, Table 23.

[h] Sweet and Webster 1990: p 60, Table 21.

[i] Whitmore et al. 1994: p 62, Table 26.

[j] Whitmore et al. 1995: p 76, Table 28.

[k] Ivey 2014: p 20, Table 5.

[l] Lescanec 2017: p 16, Table 5.

Appendix A6.–Number of Chinook salmon sampled by total age for the Eastside Susitna stock, 1979–2002.

Year	Type	Age 3	Age 4	Age 5	Age 6+	Total	Source
1979	Harvest	0	100	126	403	629	a
1980	Harvest	0	265	167	265	697	a
1981	Harvest	0	109	153	175	437	a
1982	Harvest	0	109	157	418	684	a
1983	Harvest	0	268	268	358	894	a
1984	Harvest	0	144	445	523	1,112	a
1985	Harvest	0	62	107	277	446	a
1986	Harvest	0	10	26	26	62	b
1986	Harvest	0	32	18	30	80	b
1986	Harvest	0	34	27	49	110	b
1986	Harvest	0	22	54	69	145	b
1987	Harvest	3	15	34	74	126	c
1987	Harvest	0	42	48	69	159	c
1988	Harvest	0	54	70	99	223	d
1988	Harvest	2	13	31	98	144	d
1988	Harvest	7	66	228	211	512	d
1989	Harvest	13	64	61	121	259	e
1989	Harvest	2	41	43	169	255	e
1989	Harvest	0	26	67	272	365	e
1990	Harvest	0	150	81	275	506	f
1991	Harvest	0	36	133	191	360	g
1992	Harvest	8	156	214	281	659	h
1993	Harvest	0	68	182	167	417	i
1994	Harvest	0	28	65	182	275	j
1995	Harvest	0	42	59	147	248	k
1996	Harvest	0	88	73	77	238	l
1997	Harvest	0	27	99	55	181	m
1998	Harvest	0	44	99	102	245	n
1999	Harvest	0	19	37	42	98	o
2000	Harvest	0	10	50	39	99	p
2000	Weir	0	14	81	75	170	p
2001	Weir	0	64	131	101	296	p
2002	Weir	0	29	179	98	306	p

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Note: Minor differences between Appendix A6 and the source data reflect rounding errors when reconstructing age composition data from reported age composition proportions.

[a] Hepler and Bentz 1986: p 191, Table 7.

[b] Hepler and Bentz 1987: p 18, Table 6.

[c] Hepler et al. 1988: p 63, Table 29.

[d] Hepler et al. 1989: p 60, Table 23.

[e] Sweet and Webster 1990: p 61, Table 21.

[f] Sweet et al. 1991: p 58, Table 19.

[g] Peltz and Sweet 1992: p 65, Appendix B6.

[h] Peltz and Sweet 1993: p 15, Table 2.

[i] Whitmore et al. 1994: p 62, Table 26.

[j] Whitmore et al. 1995: p 76, Table 28.

[k] Whitmore et al. 1996: p 64, Table 23.

[l] Whitmore and Sweet 1997: p 63, Table 27.

[m] Whitmore and Sweet 1998: p 63, Table 28.

[n] Whitmore and Sweet 1999: p 64, Table 29.

[o] Rutz and Sweet 2000: p 65, Table 29.

[p] unpublished data, ADF&G, Palmer.

Appendix A7.–Number of Chinook salmon sampled by total age for the Talkeetna River stock, 1986–1996.

Year	Type	Age 3	Age 4	Age 5	Age 6+	Total	Source
1986	Harvest	0	11	14	11	36	a
1987	Harvest	2	49	106	68	225	b
1988	Harvest	0	13	32	120	165	c
1989	Harvest	1	76	66	195	338	d
1992	Harvest	0	17	56	86	159	e
1993	Harvest	0	9	24	127	160	f
1994	Harvest	0	13	49	122	184	g
1995	Harvest	0	40	61	127	228	h
1996	Harvest	0	20	54	93	167	i

Note: Minor differences between Appendix A7 and the source data reflect rounding errors when reconstructing age composition data from reported age composition proportions.

[a] Hepler and Bentz 1987: p 18, Table 6.

[b] Hepler et al. 1988: p 63, Table 29.

[c] Hepler et al. 1989: p 60, Table 23.

[d] Sweet and Webster 1990: p 61, Table 21.

[e] unpublished data, ADF&G, Palmer.

[f] Whitmore et al. 1994: p 62, Table 26.

[g] Whitmore et al. 1995: p 76, Table 28.

[h] Whitmore et al. 1996: p 64, Table 23.

[i] Whitmore and Sweet 1997: p 63, Table 27.

Appendix A8.–Number of Chinook salmon sampled by total age for the Yentna River stock, 1979–1985.

Year	Type	Age 3	Age 4	Age 5	Age 6+	Total	Source
1979	Harvest	0	26	110	82	218	a
1980	Harvest	0	20	69	23	112	a
1981	Harvest	0	24	80	38	142	a
1982	Harvest	0	84	154	182	420	a
1985	Harvest	0	85	121	111	317	a

Note: Samples from Deshka River are included in the cited data. For this study, the count of Deshka fish from Appendix A5 is subtracted from the data in the cited report. Minor differences between Appendix A8 and the source data reflect rounding errors when reconstructing age composition data from reported age composition proportions.

[a] Hepler and Bentz 1986: p 190, Table 6.

Appendix A9.–Estimated harvest and coefficient of variation of harvest of Chinook salmon from the Deshka River, Eastside Susitna, Talkeetna River, and Yentna River stocks in the Northern District set gillnet fishery and the Tyonek subsistence fishery, 1979–2017.

Year	Harvest	CV
1979	751	0.15
1980	1,438	0.15
1981	1,355	0.15
1982	2,014	0.15
1983	1,836	0.15
1984	1,665	0.15
1985	1,847	0.15
1986	7,655	0.15
1987	6,441	0.15
1988	6,545	0.15
1989	6,254	0.15
1990	4,658	0.15
1991	3,485	0.15
1992	2,602	0.15
1993	2,261	0.15
1994	1,865	0.15
1995	2,656	0.15
1996	1,695	0.15
1997	1,041	0.15
1998	1,857	0.15
1999	2,072	0.15
2000	1,768	0.15
2001	1,545	0.15
2002	1,664	0.15
2003	1,455	0.15
2004	1,751	0.15
2005	2,091	0.15
2006	2,575	0.15
2007	2,464	0.15
2008	2,518	0.15
2009	1,138	0.15
2010	1,345	0.15
2011	1,448	0.15
2012	1,031	0.15
2013	1,282	0.15
2014	982	0.15
2015	1,445	0.15
2016	1,445	0.15
2017	1,771	0.15

Appendix A10.–Sport harvest of Susitna River Chinook salmon by stock, 1979–2017.

	Deshka				
Year	Total harvest	Harvest above weir	Eastside Susitna	Talkeetna	Yentna
1979	2,811 (0.18)	1 (0.50)	947 (0.11)	312 (0.20)	2,089 (0.18)
1980	3,685 (0.18)	1 (0.50)	1,153 (0.11)	172 (0.20)	896 (0.18)
1981	2,769 (0.18)	1 (0.50)	1,552 (0.11)	373 (0.20)	852 (0.18)
1982	4,307 (0.18)	1 (0.50)	1,393 (0.11)	450 (0.20)	1,645 (0.18)
1983	4,889 (0.18)	1 (0.50)	1,646 (0.11)	934 (0.20)	2,759 (0.18)
1984	5,699 (0.18)	1 (0.50)	3,044 (0.11)	1,272 (0.20)	3,417 (0.18)
1985	6,407 (0.18)	1 (0.50)	3,365 (0.11)	871 (0.20)	2,799 (0.18)
1986	6,490 (0.18)	1 (0.50)	7,625 (0.11)	908 (0.20)	2,982 (0.18)
1987	5,632 (0.18)	1 (0.50)	6,935 (0.11)	1,639 (0.20)	4,232 (0.18)
1988	5,474 (0.18)	1 (0.50)	7,330 (0.11)	1,762 (0.20)	4,971 (0.18)
1989	8,062 (0.18)	1 (0.50)	7,338 (0.11)	2,372 (0.20)	5,713 (0.18)
1990	6,161 (0.18)	1 (0.50)	6,999 (0.11)	2,358 (0.20)	5,435 (0.18)
1991	9,306 (0.18)	1 (0.50)	6,897 (0.11)	2,025 (0.20)	5,016 (0.18)
1992	7,256 (0.18)	1 (0.50)	17,778 (0.11)	3,338 (0.20)	6,299 (0.18)
1993	5,682 (0.18)	1 (0.50)	17,671 (0.11)	4,729 (0.20)	9,384 (0.18)
1994	624 (0.18)	1 (0.50)	12,591 (0.11)	2,144 (0.20)	6,009 (0.18)
1995	1 (0.18)	1 (0.50)	5,701 (0.11)	2,126 (0.20)	4,569 (0.18)
1996	11 (0.94)	1 (0.50)	7,254 (0.07)	3,585 (0.11)	4,280 (0.10)
1997	42 (0.60)	1 (0.50)	7,055 (0.06)	3,800 (0.08)	5,719 (0.09)
1998	3,397 (0.12)	392 (0.24)	6,423 (0.08)	3,872 (0.11)	4,567 (0.10)
1999	3,495 (0.09)	561 (0.21)	13,009 (0.06)	3,702 (0.10)	6,350 (0.09)
2000	7,075 (0.07)	1,277 (0.17)	8,643 (0.06)	2,740 (0.12)	6,990 (0.08)
2001	5,007 (0.10)	1,021 (0.19)	10,221 (0.07)	2,866 (0.12)	6,184 (0.09)
2002	4,508 (0.12)	896 (0.33)	7,933 (0.07)	2,616 (0.12)	4,732 (0.11)
2003	6,605 (0.10)	931 (0.17)	8,072 (0.07)	1,288 (0.22)	5,798 (0.12)
2004	9,050 (0.08)	1,364 (0.20)	5,780 (0.09)	2,589 (0.13)	4,901 (0.11)
2005	7,332 (0.08)	1,345 (0.19)	6,441 (0.09)	1,985 (0.15)	6,538 (0.10)
2006	7,753 (0.09)	1,266 (0.16)	5,818 (0.09)	1,561 (0.16)	7,265 (0.12)
2007	5,696 (0.12)	1,183 (0.30)	5,830 (0.11)	2,476 (0.17)	5,262 (0.11)
2008	2,036 (0.15)	256 (0.45)	4,261 (0.11)	1,479 (0.16)	4,704 (0.11)
2009	723 (0.29)	319 (0.46)	1,498 (0.20)	1,982 (0.24)	3,842 (0.14)
2010	3,381 (0.14)	382 (0.29)	1,223 (0.17)	1,013 (0.20)	2,909 (0.14)
2011	3,139 (0.13)	542 (0.25)	1,088 (0.20)	1,086 (0.24)	2,677 (0.16)
2012	1,650 (0.14)	155 (0.39)	34 (0.60)	113 (0.54)	806 (0.21)
2013	1,087 (0.18)	153 (0.57)	1 (0.50)	1 (0.50)	1,340 (0.18)
2014	1,329 (0.18)	236 (0.48)	1 (0.50)	1 (0.50)	689 (0.33)
2015	1,927 (0.18)	724 (0.35)	1 (0.50)	1 (0.50)	1,626 (0.24)
2016	2,890 (0.18)	799 (0.38)	1 (0.50)	1 (0.50)	1,455 (0.25)
2017	1,392 (0.19)	349 (0.42)	1 (0.50)	1 (0.50)	1,095 (0.23)

Source: Mills 1979-1980, 1981a-b, 1982-1994; Howe et al. 1995, 1996; Alaska Sport Fishing Survey database (novel query).

Note: Coefficients of variation are noted in parenthesis for years 1996–2017. Prior to 1996, the 75th percentile of the CV for each stock is used.

APPENDIX B: STATE-SPACE MODEL

Appendix B1.–RJAGS code for the Susitna River Chinook salmon run reconstruction and escapement goal analysis.

```
################################################################################
#
#  RJAGS model
#
################################################################################
model{
  for (s in 1:SG){
    tau.white[s] ~ dgamma(0.001,0.001)
    tau.red[s] <- tau.white[s] * (1-phi[s]*phi[s])
    sigma.white[s] <- 1 / sqrt(tau.white[s])
    sigma.red[s] <- 1 / sqrt(tau.red[s])
    log.resid.vec[1:(Y - a.min), s] <- log.resid[(A+a.min):(Y+A-1), s]
    lnalpha.vec[1:(Y - a.min), s] <- lnalpha.y[(A+a.min):(Y+A-1), s]
      for (c in (A+a.min):(Y+A-1)) {
        log.R[c, s] ~ dt(log.R.mean2[c, s],tau.white[s],500)
        R[c, s] <- exp(log.R[c, s])
        log.R.mean1[c, s] <- log(S[c-a.max, s]) + lnalpha[s] - beta[s] * S[c-a.max, s]  #Eq. 1
        log.resid[c, s] <- log(R[c, s]) - log.R.mean1[c, s]  #Eq. 3
        lnalpha.y[c, s] <- lnalpha[s] + log.resid[c, s]
        }
      log.R.mean2[A+a.min, s] <- log.R.mean1[A+a.min, s] + phi[s] * log.resid.0[s]  #Eq. 2
      for (c in (A+a.min+1):(Y+A-1)) {
        log.R.mean2[c, s] <- log.R.mean1[c, s] + phi[s] * log.resid[c-1, s]
        }
      lnalpha[s] ~ dnorm(mu.lnalpha, tau.lnalpha)T(0,)
      beta[s] ~ dnorm(0, 1.0E-2)T(0,)
      log.resid.0[s] ~ dnorm(0,tau.red[s])T(-3,3)
      alpha[s] <- exp(lnalpha[s])
      lnalpha.c[s] <- lnalpha[s] + (sigma.white[s] * sigma.white[s] / 2 / (1-phi[s]*phi[s]))  #Eq. 28
      phi[s] ~ dunif(-0.95, 0.95)
      S.max[s] <- 1 / beta[s]  #Eq. 31
      S.eq[s] <- lnalpha.c[s] * S.max[s]  #Eq. 32
      S.msy[s] <- S.eq[s] * (0.5 - 0.07*lnalpha.c[s])  #Eq. 27
      U.msy[s] <- lnalpha.c[s] * (0.5 - 0.07*lnalpha.c[s])  #Eq. 30

    # BROOD YEAR RETURNS W/O SR LINK DRAWN FROM COMMON LOGNORMAL DISTN
      mean.log.R[s] ~ dnorm(0,1.0E-4)T(0,)
      R.0[s] <- exp(mean.log.R[s])
      for (c in 1:a.max) {
        log.R[c, s] ~ dt(mean.log.R[s],tau.R,500)
        R[c, s] <- exp(log.R[c, s])
        }
    }
    #Hierarchical lnalpha
    mu.lnalpha ~ dnorm(0, 1E-6)T(0,)
    tau.lnalpha ~ dgamma(2,1)
    sigma.lnalpha <- 1 / sqrt(tau.lnalpha)
    tau.R ~ dgamma(0.001,0.001)
    sigma.R0 <- 1 / sqrt(tau.R)
```

-continued-

```
### GENERATE MATURITY SCHEDULES, ONE PER BROOD YEAR
# MULTIVARIATE LOGISTIC MODEL CONTROLS TIME-TREND OF EXPECTED MATURITY
# GIVEN EXPECTED MATURITY, ANNUAL MATURITY SCHEDULES DIRICHLET DISTRIB AT COHORT (BROOD YEAR) c
  Dscale.age ~ dunif(0.07,1)
  Dsum.age <- 1 / (Dscale.age * Dscale.age)
  ML1[A] <- 0
  ML2[A] <- 0
for (a in 1:(A-1)) {
  ML1[a] ~ dnorm(0,0.0001)
  ML2[a] ~ dnorm(0,0.0001)
  }

for (c in 1:(Y+A-1)) {
  for (a in 1:A) {
    logistic.a[c,a] <- exp(ML1[a] + ML2[a] * c) #Eq. 5.2
    pi[c,a] <- logistic.a[c,a] / sum(logistic.a[c,])
    gamma[c,a] <- Dsum.age * pi[c,a]  #Eq. 5.1
    g[c,a] ~ dgamma(gamma[c,a],0.1)
    p[c,a] <- g[c,a]/sum(g[c,])
    }
  }

# ASSIGN PRODUCT OF p AND R TO ALL CELLS IN N MATRIX
for (s in 1:SG){
    for (a in 1:A) {
        for (c in a:(Y + (a - 1))) {
            N.tas[c - (a - 1), (A + 1 - a), s] <- p[c, (A + 1 - a)] * R[c, s]  #Eq. 6
            }
        }
    }

### CALENDAR YEAR AGE COMPOSITION
  for (y in 1:Y) {
    for (a in 1:A) {
      N.ta[y,a] <- sum(N.tas[y,a, 1:SG])
      q[y,a] <- N.ta[y,a] / sum(N.ta[y, ])  #Eq. 26
      }
    }

# MULTINOMIAL SCALE SAMPLING ON TOTAL ANNUAL RETURN N
# INDEX y IS CALENDAR YEAR
# MULTIVARIATE LOGISTIC MODEL ADJUSTS FOR SAMPLE LOCATION
for (j in 1:J) {
  x.a[j, 1:A] ~ dmulti(q.star[j, ], n.a[j])  #Eq. 24
    for (a in 1:A) {
      q.star[j,a] <- rho[j,a] / sum(rho[j,1:A])  #Eq. 25
      log(rho[j,a]) <- log(N.ta[yr.a[j],a] / N.ta[yr.a[j], 1]) + b[x.stock[j], a]
      }
  }
for(a in 1:A){b0[1,a] <- 0} #Deshka baseline
for(s in 2:SG){b0[s,1] <- 0 for(a in 2:A){b0[s,a] ~ dnorm(0, 0.0001)}}
for(s in 1:SG){for(a in 1:A){b[s,a] <- b0[s,a] - mean(b0[,a])}}


# ANNUAL RETURN N
```

```
for (y in 1:Y) {
  for (s in 1:SG) {
    N[y, s] <- sum(N.tas[y,1:A, s])  #Eq. 7
  }
}


### STOCK COMPOSITION ###
### MULTIVARIATE LOGISTIC MODEL CONTROLS TIME-TREND OF STOCK COMPOSITION
### GIVEN EXPECTED COMPOSITION, ANNUAL COMPOSITION DIRICHLET DISTRIB AT YEAR y.
### note p.S# is rho.# in report
# East Susitna, T_s=7
  Dscale.S2 ~ dunif(0.07,1)
  Dsum.S2 <- 1 / (Dscale.S2 * Dscale.S2)
  ML1.S2[6] <- 0
  ML2.S2[6] <- 0
for (t in 1:5) {
  ML1.S2[t] ~ dnorm(0,0.0001)
  ML2.S2[t] ~ dnorm(0,0.0001)
  }

for (y in 1:Y) {
    for (t in 1:6) {
      logistic.S2[y, t] <- exp(ML1.S2[t] + ML2.S2[t] * y)
      pi.S2[y, t] <- logistic.S2[y, t] / sum(logistic.S2[y, ])
      gamma.S2[y, t] <- Dsum.S2 * pi.S2[y, t]
      g.S2[y, t] ~ dgamma(gamma.S2[y, t], 0.1)
      p.S2s[y, t] <- g.S2[y, t]/sum(g.S2[y, ])
      p.S2[y, t] <- p.S2s[y, t] * (1 - p.S2o[y]) #Eq. 14 elements 1:(T_s-1)
      }
      p.S2[y, 7] <- p.S2o[y]  #Eq. 14  element T_s
    }

# Talkeetna, T_s=3
  Dscale.S3 ~ dunif(0.07,1)
  Dsum.S3 <- 1 / (Dscale.S3 * Dscale.S3)
  ML1.S3[2] <- 0
  ML2.S3[2] <- 0
  ML1.S3[1] ~ dnorm(0,0.0001)
  ML2.S3[1] ~ dnorm(0,0.0001)

for (y in 1:Y) {
    for (t in 1:2) {
      logistic.S3[y, t] <- exp(ML1.S3[t] + ML2.S3[t] * y)
      pi.S3[y, t] <- logistic.S3[y, t] / sum(logistic.S3[y, ])
      gamma.S3[y, t] <- Dsum.S3 * pi.S3[y, t]
      g.S3[y, t] ~ dgamma(gamma.S3[y, t], 0.1)
      p.S3s[y, t] <- g.S3[y, t]/sum(g.S3[y, ])
      p.S3[y, t] <- p.S3s[y, t] * (1 - p.S3o[y])
      }
      p.S3[y, 3] <- p.S3o[y]
    }

# Yentna, T_s=5
  Dscale.S4 ~ dunif(0.07,1)
```

-continued-

```
 Dsum.S4 <- 1 / (Dscale.S4 * Dscale.S4)
  ML1.S4[4] <- 0
  ML2.S4[4] <- 0
for (t in 1:3) {
  ML1.S4[t] ~ dnorm(0,0.0001)
  ML2.S4[t] ~ dnorm(0,0.0001)
  }

for (y in 1:Y) {
    for (t in 1:4) {
      logistic.S4[y, t] <- exp(ML1.S4[t] + ML2.S4[t] * y)
      pi.S4[y, t] <- logistic.S4[y, t] / sum(logistic.S4[y, ])
      gamma.S4[y, t] <- Dsum.S4 * pi.S4[y, t]
      g.S4[y, t] ~ dgamma(gamma.S4[y, t], 0.1)
      p.S4s[y, t] <- g.S4[y, t]/sum(g.S4[y, ])
      p.S4[y, t] <- p.S4s[y, t] * (1 - p.S4o[y])
      }
      p.S4[y, 5] <- p.S4o[y]
    }

# MULTINOMIAL COUNTS OF RADIOS TRACKED TO SURVEYED AREAS
for (y in 1:Y) {
    tele.S2[y, 1:6] ~  dmulti(p.S2s[y, ], Ntele.S2[y] - tele.S2[y, 7])  #Eq. 21
    tele.S3[y, 1:2] ~  dmulti(p.S3s[y, ], Ntele.S3[y] - tele.S3[y, 3])
    tele.S4[y, 1:4] ~  dmulti(p.S4s[y, ], Ntele.S4[y] - tele.S4[y, 5])
}

for(s in 1:(SG - 1)){
  p.So.mean[s] ~ dbeta(1, 1)
  Bscale.So[s] ~ dunif(0.07, 1)
  Bsum.So[s] <- 1 / Bscale.So[s] / Bscale.So[s]
  B1.So[s] <- Bsum.So[s] * p.So.mean[s]
  B2.So[s] <- Bsum.So[s] - B1.So[s]
}

# MULTINOMIAL COUNTS OF RADIOS TRACKED TO UNSURVEYED AREAS
for (y in 1:Y) {
  p.S2o[y] ~ dbeta(B1.So[1], B2.So[1])
  p.S3o[y] ~ dbeta(B1.So[2], B2.So[2])
  p.S4o[y] ~ dbeta(B1.So[3], B2.So[3])
  tele.S2[y, 7] ~  dbinom(p.S2o[y], Ntele.S2[y])  #Eq. 20
  tele.S3[y, 3] ~  dbinom(p.S3o[y], Ntele.S3[y])
  tele.S4[y, 5] ~  dbinom(p.S4o[y], Ntele.S4[y])
}

### AIR SURVEY
#Observability
#index by i since observability and survey errors are modeled hierarchically.
# Theta set up as a glm although Iâ€™m not sure a good covariate is accessible.
for (i in 1:I) {b1.theta[i] ~ dnorm(mu_b1t, tau_b1t)}
mu_b1t ~ dnorm(0, 0.0001)
tau_b1t ~ dgamma(0.001,0.001)
```

-continued-

```
for (i in 1:I){
  for (y in 1:Y){
    logit(theta[i, y]) <- b1.theta[i]
    }
  }

# Hierarchical air survey errors
for (i in 1:I){
    sigma.air[i] <- abs(z.air[i]) / sqrt(g.air[i])
    z.air[i] ~ dnorm(0, invCsq)
    g.air[i] ~ dgamma(0.5, 0.5)
    tau.air[i] <- 1 / sigma.air[i] / sigma.air[i]
}
C_as ~ dunif(0,1)
invCsq <- 1 / C_as / C_as

#AIR SURVEY DATA
# Deshka
for(y in 1:Y){
    log.t1S1[y] <- log(theta[1, y] * S[y, 1])  #Eq. 22
    air.S1[y] ~ dlnorm(log.t1S1[y], tau.air[1])
    }
# East Susitna, T_s-1=6
for(t in 1:6) {
    for(y in 1:Y){
    log.tpS2[y, t] <- log(theta[(t + 1), y] * p.S2[y, t] * S[y, 2])  #Eq. 22
    air.S2[y, t] ~ dlnorm(log.tpS2[y, t], tau.air[t + 1])
    }
}
# Talkeetna Survey data
for(t in 1:2) {
    for(y in 1:Y){
    log.tpS3[y, t] <- log(theta[(t + 7), y] * p.S3[y, t] * S[y, 3])  #Eq. 22
    air.S3[y, t] ~ dlnorm(log.tpS3[y, t], tau.air[t + 7])
    }
}
# Yentna Survey data
for(t in 1:4) {
    for(y in 1:Y){
    log.tpS4[y, t] <- log(theta[(t + 9), y] * p.S4[y, t] * S[y, 4])  #Eq. 22
    air.S4[y, t] ~ dlnorm(log.tpS4[y, t], tau.air[t + 9])
    }
}

### WEIR COUNTS W (SMALL) LOGNORMAL ERRORS, DETECTABILITY = 1
# tau.weir=400 so cv.weir=0.05
  for (y in 1:Y) {
    log.11S1[y] <- log(IR_deshka[y])
      weir[y, 1] ~ dlnorm(log.11S1[y], 400)  #Eq. 23 when s=1, Deshka
    log.1p4S2[y] <- log(p.S2[y, 4] * S[y, 2])
      weir[y, 2] ~ dlnorm(log.1p4S2[y], 400)  #Eq. 23 when s=2, Montana
    log.1p6S2[y] <- log(p.S2[y, 6] * S[y, 2])
      weir[y, 3] ~ dlnorm(log.1p6S2[y], 400)  #Eq. 23 when s=2, Willow/Deception
    }
```

-continued-

```
p.HDeshka.mean ~ dbeta(1, 1)
Bscale.HDeshka ~ dunif(0.07, 1)
Bsum.HDeshka <- 1 / Bscale.HDeshka / Bscale.HDeshka
B1.HDeshka <- Bsum.HDeshka * p.HDeshka.mean
B2.HDeshka <- Bsum.HDeshka - B1.HDeshka
# INRIVER RUN AND HARVESTS ESTIMATED
for (y in 1:Y) {
  mu.Hmarine[y] ~ dbeta(0.5,0.5)
  Hmarine[y] <- mu.Hmarine[y] * sum(N[y, ])  #Eq. 8
  logHm[y] <- log(Hmarine[y])
  tau.logHm[y] <- 1 / log(cv.Hm[y]*cv.Hm[y] + 1)
  Hm.hat[y] ~ dlnorm(logHm[y],tau.logHm[y])  #Eq. 19
  # MR estimates gt 500mm fish, reduce IR to same size class
  p.small3[y] ~ dbeta(1,1)
  p.small4[y] ~ dbeta(1,1)
  small3[y, 1] ~ dbinom(p.small3[y], small3[y, 2])  #Eq. 17
  small4[y, 1] ~ dbinom(p.small4[y], small4[y, 2])
  for (s in 1:SG){
    IR[y, s] <- N[y, s] * (1 - mu.Hmarine[y])  #Eq. 9
    IR500[y, s] <- IR[y, s] * (1 - (q[y, 1] * p.small3[y] + q[y, 2] * p.small4[y]))  #Eq. 18
    logIR500[y, s] <- log(IR500[y, s])
    tau.logMR[y, s] <- 1 / log(cv.MR[y, s]*cv.MR[y, s] + 1)  #Eq. 16
    MR[y, s] ~ dlnorm(logIR500[y, s], tau.logMR[y, s])  #Eq. 15
    mu.Habove[y, s] ~ dbeta(0.5,0.5)
    Habove[y, s] <- mu.Habove[y, s] * IR[y, s]  #Eq. 10
    logHa[y, s] <- log(Habove[y, s])
    tau.logHa[y, s] <- 1 / log(cv.Ha[y, s]*cv.Ha[y, s] + 1)
    Ha.hat[y, s] ~ dlnorm(logHa[y, s], tau.logHa[y, s])
    S[y, s] <- max(IR[y, s] - Habove[y, s], 1)  #Eq. 12
  }
  # Harvest upstream of Deshka weir
  p.HDeshka[y] ~ dbeta(B1.HDeshka, B2.HDeshka)
  HDeshka[y] <- p.HDeshka[y] * Habove[y, 1]  #Eq. 11
  logHd[y] <- log(HDeshka[y])
  tau.logHd[y] <- 1 / log(cv.Hd[y]*cv.Hd[y] + 1)
  Hd.hat[y] ~ dlnorm(logHd[y], tau.logHd[y])
  IR_deshka[y] <- S[y, 1] + HDeshka[y]  #Eq. 13
}
}
```

APPENDIX C: ABUNDANCE ESTIMATES

Appendix C1.–Annual abundance estimates for the Deshka River Chinook salmon stock obtained by fitting a state-space model to data from 1979 to 2017.

Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
1973	–	–	–	49,277 (0.35)
1974	–	–	–	35,753 (0.36)
1975	–	–	–	29,235 (0.38)
1976	–	–	–	56,793 (0.28)
1977	–	–	–	35,225 (0.31)
1978	–	–	–	45,008 (0.32)
1979	45,610 (0.25)	45,242 (0.25)	42,400 (0.27)	44,756 (0.38)
1980	37,355 (0.35)	36,667 (0.35)	32,901 (0.39)	35,250 (0.41)
1981	37,814 (0.29)	37,239 (0.30)	34,339 (0.32)	37,464 (0.39)
1982	41,072 (0.23)	40,161 (0.23)	35,739 (0.25)	57,979 (0.37)
1983	44,004 (0.21)	43,353 (0.21)	38,368 (0.24)	39,133 (0.56)
1984	44,366 (0.21)	43,827 (0.21)	37,831 (0.24)	40,934 (0.37)
1985	39,209 (0.23)	38,715 (0.23)	32,295 (0.27)	27,998 (0.40)
1986	46,011 (0.21)	43,859 (0.21)	37,281 (0.24)	37,807 (0.31)
1987	41,562 (0.20)	39,754 (0.20)	34,061 (0.23)	23,322 (0.30)
1988	48,811 (0.22)	47,097 (0.22)	41,467 (0.25)	12,305 (0.44)
1989	38,923 (0.38)	37,315 (0.39)	29,040 (0.50)	10,625 (0.28)
1990	39,946 (0.24)	38,512 (0.24)	32,330 (0.29)	4,850 (0.44)
1991	29,015 (0.20)	28,073 (0.20)	18,549 (0.29)	10,199 (0.43)
1992	25,892 (0.18)	25,305 (0.18)	17,730 (0.25)	47,901 (0.14)
1993	17,389 (0.18)	17,012 (0.18)	11,334 (0.27)	28,885 (0.32)
1994	8,278 (0.27)	8,081 (0.27)	7,438 (0.29)	20,298 (0.41)
1995	10,345 (0.05)	10,062 (0.05)	10,060 (0.05)	65,480 (0.10)
1996	14,883 (0.05)	14,628 (0.05)	14,602 (0.05)	15,614 (0.41)
1997	35,549 (0.05)	35,317 (0.05)	35,266 (0.05)	36,076 (0.22)
1998	32,338 (0.12)	31,906 (0.12)	28,415 (0.14)	30,174 (0.39)
1999	33,316 (0.05)	32,809 (0.05)	29,242 (0.05)	80,332 (0.13)
2000	41,085 (0.04)	40,526 (0.04)	33,495 (0.05)	40,487 (0.22)
2001	33,778 (0.04)	33,408 (0.05)	28,333 (0.05)	45,915 (0.17)
2002	32,718 (0.05)	32,368 (0.05)	27,842 (0.05)	25,177 (0.18)
2003	46,112 (0.05)	45,711 (0.05)	39,033 (0.05)	4,059 (0.46)
2004	65,829 (0.04)	65,237 (0.04)	56,198 (0.05)	2,823 (0.52)
2005	44,337 (0.04)	43,715 (0.04)	36,336 (0.05)	25,828 (0.09)
2006	37,067 (0.04)	36,350 (0.04)	28,640 (0.05)	30,034 (0.09)
2007	23,872 (0.05)	23,359 (0.05)	17,561 (0.06)	9,193 (0.45)
2008	9,666 (0.05)	9,301 (0.05)	7,259 (0.05)	24,037 (0.18)
2009	13,057 (0.05)	12,805 (0.05)	11,938 (0.05)	11,574 (0.40)
2010	21,247 (0.05)	20,835 (0.05)	17,524 (0.05)	23,241 (0.23)

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Appendix C1.–Page 2 of 2.

Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
2011	22,464 (0.05)	21,911 (0.05)	18,664 (0.05)	21,227 (0.23)
2011	22,464 (0.05)	21,911 (0.05)	18,664 (0.05)	21,227 (0.23)
2012	15,492 (0.05)	15,177 (0.05)	13,547 (0.05)	27,027 (0.16)
2013	20,038 (0.04)	19,745 (0.04)	18,604 (0.04)	11,502 (0.81)
2014	16,917 (0.04)	16,693 (0.04)	15,385 (0.04)	13,800 (1.00)
2015	26,738 (0.04)	26,367 (0.04)	24,298 (0.05)	–
2016	24,904 (0.04)	24,499 (0.04)	21,620 (0.05)	–
2017	13,612 (0.05)	13,118 (0.05)	11,565 (0.05)	–

Note: Point estimates are posterior medians; CVs are posterior standard deviations divided by posterior means. Recruitment values are listed by brood year.

Appendix C2.–Annual abundance estimates for the Eastside Susitna Chinook salmon stock obtained by fitting a state-space model to data from 1979 to 2017.

Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
1973	–	–	–	11,971 (0.36)
1974	–	–	–	11,491 (0.37)
1975	–	–	–	17,116 (0.30)
1976	–	–	–	13,130 (0.32)
1977	–	–	–	13,307 (0.31)
1978	–	–	–	15,709 (0.35)
1979	14,074 (0.17)	13,955 (0.17)	13,019 (0.18)	33,129 (0.22)
1980	14,559 (0.28)	14,316 (0.29)	13,139 (0.31)	33,716 (0.20)
1981	14,393 (0.15)	14,152 (0.15)	12,580 (0.16)	37,842 (0.18)
1982	11,734 (0.17)	11,473 (0.17)	10,052 (0.19)	38,376 (0.19)
1983	19,143 (0.14)	18,863 (0.14)	17,236 (0.16)	49,732 (0.18)
1984	25,961 (0.14)	25,655 (0.14)	22,618 (0.16)	36,949 (0.18)
1985	33,685 (0.14)	33,222 (0.14)	29,841 (0.16)	29,040 (0.20)
1986	41,143 (0.13)	39,162 (0.13)	31,451 (0.16)	31,370 (0.19)
1987	36,326 (0.12)	34,774 (0.12)	27,818 (0.15)	36,870 (0.15)
1988	42,661 (0.12)	41,083 (0.12)	33,724 (0.14)	45,555 (0.14)
1989	42,212 (0.12)	40,428 (0.12)	33,006 (0.15)	35,100 (0.16)
1990	35,472 (0.14)	34,176 (0.14)	27,102 (0.17)	28,685 (0.18)
1991	28,764 (0.13)	27,809 (0.13)	20,745 (0.18)	36,602 (0.17)
1992	37,580 (0.10)	36,723 (0.10)	19,444 (0.16)	47,195 (0.17)
1993	41,598 (0.10)	40,721 (0.10)	22,548 (0.17)	45,667 (0.17)
1994	30,945 (0.10)	30,151 (0.10)	17,508 (0.15)	40,121 (0.17)
1995	39,901 (0.12)	38,810 (0.12)	32,985 (0.14)	38,432 (0.17)
1996	33,874 (0.11)	33,322 (0.11)	26,079 (0.14)	45,427 (0.14)
1997	48,502 (0.12)	48,187 (0.12)	41,112 (0.14)	37,370 (0.18)
1998	45,707 (0.12)	45,101 (0.12)	38,722 (0.14)	34,259 (0.18)
1999	42,301 (0.11)	41,673 (0.11)	28,673 (0.15)	36,473 (0.20)
2000	35,575 (0.11)	35,105 (0.11)	26,350 (0.14)	42,563 (0.15)
2001	43,978 (0.09)	43,462 (0.09)	33,301 (0.12)	34,173 (0.18)
2002	43,452 (0.10)	42,991 (0.10)	34,950 (0.13)	26,559 (0.18)
2003	36,524 (0.12)	36,221 (0.12)	28,038 (0.15)	17,570 (0.20)
2004	40,951 (0.13)	40,620 (0.13)	34,733 (0.15)	13,555 (0.19)
2005	36,988 (0.11)	36,470 (0.11)	30,043 (0.13)	15,663 (0.23)
2006	32,262 (0.11)	31,656 (0.11)	25,772 (0.14)	11,380 (0.18)
2007	26,068 (0.11)	25,525 (0.12)	19,693 (0.15)	12,363 (0.17)
2008	20,443 (0.13)	19,680 (0.13)	15,334 (0.17)	14,672 (0.15)
2009	16,191 (0.13)	15,880 (0.13)	14,362 (0.15)	16,242 (0.16)
2010	14,121 (0.16)	13,844 (0.16)	12,561 (0.17)	19,560 (0.16)

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Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
2011	11,899 (0.13)	11,601 (0.13)	10,474 (0.15)	18,828 (0.17)
2012	10,297 (0.10)	10,086 (0.10)	10,046 (0.10)	24,359 (0.14)
2013	17,455 (0.07)	17,202 (0.07)	17,201 (0.07)	26,567 (0.28)
2014	16,308 (0.09)	16,084 (0.09)	16,083 (0.09)	27,203 (0.40)
2015	25,032 (0.08)	24,700 (0.08)	24,699 (0.08)	–
2016	23,374 (0.08)	22,973 (0.08)	22,972 (0.08)	–
2017	14,140 (0.09)	13,616 (0.09)	13,615 (0.09)	–

Note: Point estimates are posterior medians; CVs are posterior standard deviations divided by posterior means. Recruitment values are listed by brood year.

Appendix C3.–Annual abundance estimates for the Talkeetna River Chinook salmon stock obtained by fitting a state-space model to data from 1979 to 2017.

Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
1973	–	–	–	9,586 (0.42)
1974	–	–	–	9,136 (0.41)
1975	–	–	–	7,208 (0.43)
1976	–	–	–	15,396 (0.29)
1977	–	–	–	8,549 (0.41)
1978	–	–	–	12,077 (0.41)
1979	10,171 (0.26)	10,088 (0.26)	9,767 (0.27)	30,083 (0.34)
1980	9,779 (0.32)	9,624 (0.32)	9,448 (0.33)	22,620 (0.46)
1981	9,971 (0.23)	9,823 (0.23)	9,436 (0.24)	22,971 (0.49)
1982	11,092 (0.18)	10,853 (0.18)	10,388 (0.19)	47,445 (0.39)
1983	14,603 (0.21)	14,389 (0.21)	13,421 (0.22)	47,917 (0.36)
1984	21,514 (0.18)	21,264 (0.18)	19,944 (0.19)	27,710 (0.35)
1985	26,130 (0.19)	25,800 (0.19)	24,908 (0.20)	27,117 (0.34)
1986	31,754 (0.22)	30,262 (0.22)	29,322 (0.23)	31,746 (0.33)
1987	33,780 (0.21)	32,281 (0.21)	30,636 (0.22)	11,631 (0.44)
1988	44,300 (0.19)	42,688 (0.19)	40,872 (0.20)	18,265 (0.30)
1989	38,444 (0.23)	36,826 (0.23)	34,392 (0.25)	15,965 (0.36)
1990	30,721 (0.19)	29,625 (0.19)	27,128 (0.20)	11,237 (0.41)
1991	25,052 (0.19)	24,274 (0.19)	22,068 (0.20)	23,587 (0.34)
1992	20,359 (0.17)	19,881 (0.18)	16,447 (0.21)	52,890 (0.27)
1993	15,693 (0.16)	15,337 (0.16)	10,455 (0.21)	22,997 (0.43)
1994	13,028 (0.17)	12,707 (0.17)	10,449 (0.21)	24,852 (0.38)
1995	19,437 (0.17)	18,888 (0.17)	16,713 (0.19)	24,574 (0.34)
1996	23,161 (0.15)	22,789 (0.15)	19,126 (0.18)	17,687 (0.44)
1997	41,950 (0.18)	41,674 (0.18)	37,843 (0.20)	36,852 (0.29)
1998	32,186 (0.17)	31,763 (0.18)	27,819 (0.20)	17,445 (0.59)
1999	24,961 (0.15)	24,592 (0.16)	20,867 (0.18)	31,014 (0.32)
2000	21,438 (0.18)	21,135 (0.18)	18,335 (0.21)	20,908 (0.32)
2001	24,385 (0.18)	24,110 (0.18)	21,189 (0.20)	12,180 (0.52)
2002	31,260 (0.18)	30,917 (0.18)	28,225 (0.19)	41,459 (0.25)
2003	26,124 (0.22)	25,902 (0.22)	24,453 (0.23)	8,158 (0.46)
2004	28,746 (0.20)	28,497 (0.20)	25,855 (0.21)	6,734 (0.44)
2005	18,801 (0.18)	18,543 (0.18)	16,535 (0.20)	21,093 (0.30)
2006	19,535 (0.18)	19,167 (0.18)	17,520 (0.20)	5,568 (0.37)
2007	26,868 (0.19)	26,287 (0.19)	23,741 (0.21)	7,437 (0.40)
2008	17,396 (0.17)	16,743 (0.17)	15,212 (0.18)	19,902 (0.22)
2009	13,662 (0.18)	13,395 (0.18)	11,378 (0.21)	17,527 (0.27)
2010	13,770 (0.22)	13,495 (0.22)	12,438 (0.24)	10,447 (0.34)

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Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
2011	7,328 (0.18)	7,133 (0.18)	5,982 (0.21)	4,091 (0.49)
2012	9,506 (0.13)	9,316 (0.13)	9,158 (0.13)	13,029 (0.24)
2013	18,801 (0.10)	18,501 (0.10)	18,500 (0.10)	12,689 (0.63)
2014	13,997 (0.12)	13,808 (0.12)	13,808 (0.12)	20,927 (1.01)
2015	13,366 (0.12)	13,196 (0.12)	13,195 (0.12)	–
2016	9,785 (0.13)	9,616 (0.13)	9,615 (0.13)	–
2017	7,269 (0.11)	6,999 (0.11)	6,998 (0.11)	–

Note: Point estimates are posterior medians; CVs are posterior standard deviations divided by posterior means. Recruitment values are listed by brood year.

Appendix C4.–Annual abundance estimates for the Yentna River Chinook salmon stock obtained by fitting a state-space model to data from 1979 to 2017.

Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
1973	–	–	–	24,661 (0.37)
1974	–	–	–	21,984 (0.39)
1975	–	–	–	19,175 (0.41)
1976	–	–	–	28,594 (0.37)
1977	–	–	–	34,409 (0.30)
1978	–	–	–	48,640 (0.32)
1979	25,437 (0.22)	25,239 (0.22)	23,095 (0.24)	55,252 (0.29)
1980	22,158 (0.38)	21,785 (0.38)	20,874 (0.40)	30,778 (0.35)
1981	23,912 (0.29)	23,521 (0.29)	22,673 (0.30)	34,804 (0.33)
1982	29,280 (0.21)	28,600 (0.21)	26,883 (0.22)	60,136 (0.28)
1983	47,603 (0.20)	46,960 (0.20)	44,183 (0.21)	38,400 (0.39)
1984	49,979 (0.24)	49,343 (0.24)	46,052 (0.26)	22,596 (0.34)
1985	42,443 (0.20)	41,873 (0.20)	38,944 (0.22)	30,495 (0.28)
1986	43,442 (0.23)	41,325 (0.23)	38,159 (0.25)	27,596 (0.30)
1987	41,246 (0.19)	39,436 (0.19)	34,993 (0.22)	30,537 (0.25)
1988	45,859 (0.19)	44,138 (0.20)	39,183 (0.22)	34,976 (0.23)
1989	32,981 (0.28)	31,688 (0.28)	25,649 (0.34)	25,845 (0.25)
1990	27,573 (0.19)	26,584 (0.19)	20,965 (0.24)	20,097 (0.27)
1991	27,525 (0.18)	26,627 (0.18)	21,586 (0.22)	29,624 (0.27)
1992	31,099 (0.17)	30,401 (0.17)	23,711 (0.21)	44,223 (0.27)
1993	32,871 (0.15)	32,146 (0.15)	23,016 (0.21)	36,770 (0.28)
1994	23,164 (0.17)	22,556 (0.17)	16,180 (0.23)	34,804 (0.28)
1995	29,845 (0.17)	29,045 (0.17)	24,393 (0.20)	43,276 (0.24)
1996	27,433 (0.17)	26,953 (0.17)	22,707 (0.20)	34,973 (0.27)
1997	42,508 (0.19)	42,229 (0.19)	36,497 (0.22)	40,391 (0.30)
1998	39,195 (0.18)	38,727 (0.18)	34,151 (0.21)	68,393 (0.25)
1999	37,859 (0.18)	37,295 (0.18)	30,914 (0.21)	66,977 (0.27)
2000	35,632 (0.18)	35,134 (0.18)	28,131 (0.22)	54,437 (0.25)
2001	39,931 (0.17)	39,496 (0.17)	33,332 (0.21)	50,149 (0.26)
2002	49,025 (0.19)	48,479 (0.19)	43,761 (0.21)	48,413 (0.26)
2003	63,733 (0.19)	63,196 (0.19)	57,417 (0.21)	13,050 (0.34)
2004	71,049 (0.19)	70,456 (0.19)	65,457 (0.21)	9,127 (0.37)
2005	51,817 (0.18)	51,098 (0.18)	44,430 (0.21)	25,499 (0.28)
2006	47,402 (0.17)	46,459 (0.18)	39,386 (0.21)	16,618 (0.24)
2007	39,832 (0.19)	38,967 (0.19)	33,653 (0.22)	18,511 (0.26)
2008	22,671 (0.17)	21,838 (0.18)	17,159 (0.22)	29,210 (0.25)
2009	17,610 (0.19)	17,266 (0.19)	13,407 (0.24)	24,156 (0.25)
2010	19,479 (0.20)	19,125 (0.20)	16,119 (0.24)	39,955 (0.17)

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Year	Total run (CV)	Inriver run (CV)	Escapement (CV)	Recruitment (CV)
2011	17,921 (0.18)	17,476 (0.18)	14,794 (0.21)	28,541 (0.20)
2012	17,668 (0.16)	17,326 (0.17)	16,465 (0.17)	25,262 (0.20)
2013	30,445 (0.15)	29,999 (0.15)	28,639 (0.16)	19,139 (0.44)
2014	28,654 (0.09)	28,269 (0.09)	27,550 (0.10)	24,550 (0.55)
2015	42,760 (0.08)	42,166 (0.09)	40,375 (0.09)	–
2016	29,448 (0.10)	28,943 (0.10)	27,409 (0.10)	–
2017	14,487 (0.14)	13,947 (0.14)	12,693 (0.16)	–

Note: Point estimates are posterior medians; CVs are posterior standard deviations divided by posterior means. Recruitment values are listed by brood year.

APPENDIX D: STOCK COMPOSITION ESTIMATES

Appendix D1.–Annual stock composition estimates for the Eastside Susitna Chinook salmon stock obtained by fitting a state-space model to data from 1979 to 2017.

Year	Goose (SD)	Kashwitna (SD)	Little Willow (SD)	Montana (SD)	Sheep (SD)	Willow (SD)	Other Eastside Susitna (SD)
1979	0.07 (0.03)	0.11 (0.03)	0.11 (0.03)	0.14 (0.03)	0.15 (0.05)	0.20 (0.04)	0.22 (0.09)
1980	0.06 (0.03)	0.10 (0.04)	0.14 (0.04)	0.13 (0.04)	0.13 (0.05)	0.22 (0.05)	0.22 (0.09)
1981	0.06 (0.02)	0.12 (0.03)	0.13 (0.03)	0.12 (0.03)	0.16 (0.05)	0.23 (0.04)	0.19 (0.08)
1982	0.04 (0.02)	0.09 (0.03)	0.12 (0.03)	0.14 (0.03)	0.14 (0.05)	0.21 (0.04)	0.26 (0.10)
1983	0.07 (0.02)	0.09 (0.03)	0.18 (0.04)	0.15 (0.03)	0.14 (0.04)	0.17 (0.04)	0.20 (0.08)
1984	0.04 (0.02)	0.06 (0.03)	0.14 (0.04)	0.15 (0.03)	0.13 (0.04)	0.27 (0.05)	0.20 (0.08)
1985	0.04 (0.02)	0.08 (0.03)	0.15 (0.03)	0.11 (0.03)	0.14 (0.04)	0.23 (0.04)	0.25 (0.09)
1986	0.06 (0.02)	0.09 (0.03)	0.19 (0.04)	0.13 (0.03)	0.13 (0.04)	0.22 (0.04)	0.19 (0.08)
1987	0.04 (0.02)	0.10 (0.03)	0.16 (0.03)	0.10 (0.03)	0.12 (0.04)	0.26 (0.04)	0.22 (0.08)
1988	0.08 (0.02)	0.11 (0.03)	0.16 (0.03)	0.11 (0.03)	0.12 (0.04)	0.23 (0.04)	0.19 (0.08)
1989	0.06 (0.02)	0.07 (0.03)	0.15 (0.03)	0.14 (0.03)	0.10 (0.04)	0.30 (0.05)	0.18 (0.08)
1990	0.05 (0.02)	0.10 (0.03)	0.15 (0.03)	0.10 (0.03)	0.11 (0.04)	0.25 (0.05)	0.24 (0.09)
1991	0.10 (0.03)	0.08 (0.03)	0.11 (0.03)	0.11 (0.03)	0.08 (0.04)	0.27 (0.05)	0.25 (0.09)
1992	0.05 (0.02)	0.09 (0.03)	0.14 (0.03)	0.13 (0.03)	0.12 (0.04)	0.28 (0.05)	0.20 (0.08)
1993	0.04 (0.01)	0.09 (0.03)	0.13 (0.03)	0.11 (0.02)	0.11 (0.04)	0.28 (0.05)	0.23 (0.09)
1994	0.05 (0.02)	0.09 (0.03)	0.15 (0.03)	0.12 (0.03)	0.11 (0.04)	0.27 (0.04)	0.20 (0.08)
1995	0.03 (0.01)	0.09 (0.03)	0.14 (0.03)	0.12 (0.02)	0.11 (0.03)	0.29 (0.05)	0.22 (0.08)
1996	0.03 (0.01)	0.10 (0.03)	0.15 (0.03)	0.12 (0.02)	0.12 (0.03)	0.27 (0.04)	0.21 (0.08)
1997	0.02 (9.6e-03)	0.08 (0.02)	0.18 (0.04)	0.12 (0.03)	0.11 (0.04)	0.30 (0.04)	0.18 (0.08)
1998	0.03 (0.01)	0.08 (0.02)	0.16 (0.03)	0.13 (0.03)	0.11 (0.03)	0.28 (0.04)	0.21 (0.08)
1999	0.03 (0.01)	0.08 (0.03)	0.19 (0.04)	0.12 (0.03)	0.11 (0.03)	0.27 (0.04)	0.20 (0.08)
2000	0.04 (0.01)	0.07 (0.02)	0.16 (0.03)	0.09 (0.02)	0.12 (0.03)	0.27 (0.04)	0.26 (0.09)
2001	0.03 (0.02)	0.08 (0.02)	0.19 (0.04)	0.11 (0.02)	0.10 (0.03)	0.31 (0.04)	0.18 (0.07)
2002	0.04 (0.01)	0.09 (0.03)	0.17 (0.03)	0.12 (0.02)	0.10 (0.03)	0.28 (0.04)	0.20 (0.08)
2003	0.02 (7.6e-03)	0.08 (0.02)	0.13 (0.03)	0.14 (0.03)	0.10 (0.03)	0.33 (0.05)	0.20 (0.08)
2004	0.03 (0.01)	0.06 (0.02)	0.19 (0.04)	0.11 (0.02)	0.07 (0.03)	0.27 (0.05)	0.27 (0.09)

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Year	Goose (SD)	Kashwitna (SD)	Little Willow (SD)	Montana (SD)	Sheep (SD)	Willow (SD)	Other Eastside Susitna (SD)
2005	0.04 (0.01)	0.07 (0.02)	0.19 (0.03)	0.13 (0.02)	0.10 (0.03)	0.31 (0.05)	0.17 (0.07)
2006	0.03 (0.01)	0.08 (0.03)	0.14 (0.03)	0.12 (0.02)	0.09 (0.03)	0.30 (0.05)	0.24 (0.08)
2007	0.02 (7.0e-03)	0.10 (0.03)	0.19 (0.03)	0.14 (0.03)	0.09 (0.03)	0.28 (0.05)	0.19 (0.08)
2008	0.02 (8.3e-03)	0.07 (0.03)	0.17 (0.04)	0.13 (0.03)	0.10 (0.03)	0.28 (0.05)	0.23 (0.09)
2009	0.01 (5.7e-03)	0.08 (0.02)	0.18 (0.03)	0.14 (0.03)	0.10 (0.03)	0.31 (0.05)	0.17 (0.07)
2010	0.02 (7.0e-03)	0.07 (0.03)	0.15 (0.03)	0.10 (0.02)	0.09 (0.03)	0.31 (0.06)	0.25 (0.09)
2011	0.02 (8.2e-03)	0.06 (0.02)	0.21 (0.04)	0.09 (0.02)	0.10 (0.03)	0.30 (0.05)	0.22 (0.08)
2012	0.02 (5.7e-03)	0.07 (0.02)	0.18 (0.03)	0.08 (0.02)	0.09 (0.02)	0.26 (0.03)	0.31 (0.04)
2013	0.01 (4.5e-03)	0.06 (0.02)	0.19 (0.02)	0.12 (9.7e-03)	0.10 (0.02)	0.33 (0.03)	0.19 (0.03)
2014	0.03 (0.01)	0.04 (0.01)	0.16 (0.03)	0.08 (8.1e-03)	0.07 (0.02)	0.30 (0.03)	0.31 (0.05)
2015	0.02 (0.01)	0.05 (0.01)	0.14 (0.03)	0.11 (0.02)	0.09 (0.02)	0.37 (0.04)	0.23 (0.04)
2016	0.02 (0.01)	0.04 (0.01)	0.13 (0.03)	0.07 (0.02)	0.08 (0.02)	0.39 (0.04)	0.28 (0.05)
2017	0.03 (8.5e-03)	0.06 (0.02)	0.20 (0.03)	0.09 (0.02)	0.13 (0.03)	0.33 (0.04)	0.18 (0.04)

Note: Point estimates are posterior means with posterior standard deviations in parentheses.

Appendix D2.–Annual stock composition estimates for the Talkeetna River Chinook salmon stock obtained by fitting a state-space model to data from 1979 to 2017.

Year	Clear (SD)	Prairie (SD)	Other Talkeetna River (SD)
1979	0.28 (0.07)	0.40 (0.10)	0.32 (0.12)
1980	0.29 (0.08)	0.39 (0.10)	0.32 (0.12)
1981	0.28 (0.09)	0.33 (0.08)	0.39 (0.12)
1982	0.29 (0.06)	0.45 (0.08)	0.25 (0.11)
1983	0.23 (0.05)	0.35 (0.08)	0.42 (0.11)
1984	0.25 (0.05)	0.50 (0.10)	0.25 (0.11)
1985	0.31 (0.06)	0.38 (0.07)	0.31 (0.11)
1986	0.30 (0.08)	0.40 (0.08)	0.30 (0.11)
1987	0.30 (0.08)	0.41 (0.09)	0.29 (0.11)
1988	0.36 (0.07)	0.35 (0.07)	0.29 (0.11)
1989	0.30 (0.08)	0.39 (0.09)	0.30 (0.11)
1990	0.28 (0.06)	0.43 (0.08)	0.29 (0.11)
1991	0.29 (0.06)	0.41 (0.08)	0.30 (0.11)
1992	0.30 (0.06)	0.38 (0.08)	0.32 (0.11)
1993	0.28 (0.06)	0.39 (0.08)	0.33 (0.11)
1994	0.35 (0.07)	0.33 (0.07)	0.32 (0.11)
1995	0.35 (0.07)	0.35 (0.07)	0.30 (0.11)
1996	0.34 (0.06)	0.38 (0.07)	0.29 (0.11)
1997	0.39 (0.08)	0.32 (0.07)	0.28 (0.11)
1998	0.41 (0.08)	0.28 (0.06)	0.31 (0.11)
1999	0.33 (0.06)	0.39 (0.07)	0.28 (0.11)
2000	0.36 (0.07)	0.32 (0.06)	0.32 (0.11)
2001	0.32 (0.06)	0.35 (0.07)	0.33 (0.11)
2002	0.37 (0.07)	0.38 (0.07)	0.25 (0.11)
2003	0.32 (0.09)	0.28 (0.07)	0.40 (0.12)
2004	0.39 (0.08)	0.33 (0.07)	0.28 (0.11)
2005	0.36 (0.07)	0.34 (0.07)	0.30 (0.11)
2006	0.29 (0.06)	0.31 (0.07)	0.40 (0.11)
2007	0.40 (0.08)	0.32 (0.06)	0.27 (0.11)
2008	0.36 (0.07)	0.31 (0.06)	0.32 (0.11)
2009	0.33 (0.06)	0.39 (0.08)	0.28 (0.11)
2010	0.25 (0.06)	0.34 (0.08)	0.41 (0.11)
2011	0.29 (0.06)	0.41 (0.08)	0.30 (0.11)
2012	0.42 (0.05)	0.21 (0.04)	0.37 (0.05)
2013	0.27 (0.03)	0.28 (0.03)	0.45 (0.04)
2014	0.32 (0.04)	0.29 (0.04)	0.39 (0.05)
2015	0.29 (0.04)	0.33 (0.05)	0.37 (0.06)
2016	0.32 (0.06)	0.30 (0.05)	0.38 (0.07)
2017	0.33 (0.04)	0.37 (0.05)	0.30 (0.06)

Note: Point estimates are posterior means with posterior standard deviations in parentheses.

Appendix D3.–Annual stock composition estimates for the Yentna River Chinook salmon stock obtained by fitting a state-space model to data from 1979 to 2017.

Year	Cache (SD)	Lake (SD)	Peters (SD)	Talachulitna (SD)	Other Yentna River (SD)
1979	0.06 (0.04)	0.33 (0.08)	0.03 (0.02)	0.15 (0.05)	0.43 (0.11)
1980	0.06 (0.04)	0.27 (0.07)	0.06 (0.03)	0.19 (0.06)	0.42 (0.11)
1981	0.06 (0.03)	0.27 (0.07)	0.07 (0.03)	0.17 (0.05)	0.44 (0.11)
1982	0.06 (0.03)	0.27 (0.06)	0.07 (0.04)	0.19 (0.05)	0.41 (0.11)
1983	0.04 (0.03)	0.30 (0.07)	0.07 (0.03)	0.24 (0.06)	0.35 (0.12)
1984	0.06 (0.03)	0.27 (0.07)	0.04 (0.02)	0.20 (0.05)	0.44 (0.11)
1985	0.03 (0.02)	0.29 (0.06)	0.09 (0.03)	0.20 (0.05)	0.39 (0.11)
1986	0.04 (0.02)	0.27 (0.07)	0.08 (0.03)	0.17 (0.05)	0.44 (0.11)
1987	0.04 (0.02)	0.28 (0.06)	0.07 (0.03)	0.19 (0.06)	0.41 (0.11)
1988	0.05 (0.02)	0.32 (0.07)	0.10 (0.04)	0.18 (0.05)	0.37 (0.12)
1989	0.04 (0.02)	0.27 (0.07)	0.07 (0.03)	0.19 (0.06)	0.43 (0.11)
1990	0.05 (0.02)	0.23 (0.06)	0.10 (0.04)	0.19 (0.05)	0.43 (0.11)
1991	0.04 (0.02)	0.28 (0.06)	0.10 (0.04)	0.18 (0.05)	0.39 (0.12)
1992	0.04 (0.02)	0.23 (0.05)	0.08 (0.03)	0.21 (0.05)	0.44 (0.10)
1993	0.06 (0.03)	0.26 (0.06)	0.09 (0.03)	0.20 (0.05)	0.38 (0.12)
1994	0.05 (0.02)	0.25 (0.06)	0.08 (0.03)	0.17 (0.04)	0.45 (0.10)
1995	0.06 (0.03)	0.26 (0.06)	0.08 (0.03)	0.18 (0.05)	0.42 (0.11)
1996	0.04 (0.02)	0.30 (0.06)	0.08 (0.03)	0.19 (0.05)	0.39 (0.11)
1997	0.05 (0.03)	0.24 (0.06)	0.10 (0.04)	0.19 (0.05)	0.42 (0.11)
1998	0.05 (0.03)	0.29 (0.06)	0.11 (0.04)	0.16 (0.04)	0.38 (0.12)
1999	0.05 (0.03)	0.22 (0.05)	0.11 (0.04)	0.21 (0.05)	0.41 (0.12)
2000	0.04 (0.02)	0.29 (0.06)	0.09 (0.03)	0.16 (0.04)	0.41 (0.11)
2001	0.04 (0.02)	0.29 (0.06)	0.12 (0.04)	0.17 (0.05)	0.39 (0.12)
2002	0.03 (0.02)	0.25 (0.06)	0.10 (0.04)	0.22 (0.06)	0.40 (0.12)
2003	0.03 (0.01)	0.29 (0.06)	0.10 (0.03)	0.21 (0.05)	0.38 (0.12)
2004	0.02 (0.01)	0.25 (0.06)	0.10 (0.03)	0.19 (0.05)	0.44 (0.10)
2005	0.04 (0.02)	0.29 (0.06)	0.09 (0.03)	0.17 (0.05)	0.41 (0.11)
2006	0.04 (0.02)	0.28 (0.06)	0.08 (0.03)	0.21 (0.05)	0.39 (0.11)
2007	0.03 (0.01)	0.26 (0.06)	0.09 (0.03)	0.18 (0.04)	0.44 (0.10)
2008	0.03 (0.02)	0.26 (0.06)	0.10 (0.04)	0.22 (0.06)	0.40 (0.11)
2009	0.03 (0.02)	0.24 (0.06)	0.11 (0.04)	0.22 (0.06)	0.40 (0.11)
2010	0.02 (0.02)	0.23 (0.05)	0.10 (0.04)	0.16 (0.04)	0.48 (0.10)
2011	0.01 (8.5e-03)	0.32 (0.07)	0.11 (0.04)	0.17 (0.04)	0.39 (0.11)
2012	0.02 (0.01)	0.28 (0.05)	0.09 (0.03)	0.12 (0.03)	0.50 (0.07)
2013	0.03 (5.6e-03)	0.23 (0.02)	0.08 (0.01)	0.17 (0.01)	0.49 (0.02)
2014	0.02 (6.8e-03)	0.24 (0.02)	0.12 (0.02)	0.11 (0.02)	0.51 (0.03)
2015	0.02 (7.4e-03)	0.24 (0.02)	0.09 (0.02)	0.17 (0.02)	0.49 (0.03)
2016	0.01 (5.3e-03)	0.26 (0.02)	0.07 (0.01)	0.20 (0.02)	0.45 (0.03)
2017	6.8e-03 (4.7e-03)	0.32 (0.03)	0.11 (0.02)	0.13 (0.02)	0.44 (0.03)

Note: Point estimates are posterior means with posterior standard deviations in parentheses.

APPENDIX E: EXTERNAL REVIEW QUESTIONS ADDRESSED

Two external peer reviews conducted before publication raised several technical concerns that were not specifically addressed in the published report. We are grateful for these reviews and they will certainly play a role in improving future revisions of the reported model. This appendix lists these concerns and some additional documentation providing context for the modeling decisions used in this report.

- There are only a few escapements below the lower bound of the recommended goal ranges.

This situation may be unsettling but is expected for stocks with low harvest rates like those in the Susitna River drainage. Consider the estimated stock-recruit relationship and associated spawner-recruit pairs in Figure 18. The point where the median stock-recruit relationship crosses the diagonal line is a stable population equilibrium. In the absence of fishing, observed spawner-recruit pairs will cluster around this point and produce little to no yield when averaged across years. ADF&G attempts to set goals that will maximize yield. Yield is maximized by spawning escapements associated with the greatest distance between the Ricker curve downward to the replacement line (S_{MSY}). Because a goal designed to maximize sustained yield contains S_{MSY}, and S_{MSY}, falls well below equilibrium spawning abundance (about 14,000 fish in Figure 18) such a goal would be expected to fall near the lower bound of observed escapements when the stock is exposed to low harvest rates.

- Should the 4 stocks be modeled in 1 stock assessment or in 4 separate stock assessments?

There are 3 parameters in the reported model that share information between stocks: the productivity parameter (α), observability parameters (θ and σ_{AS}), and age composition parameters. The productivity parameter is discussed in more detail below. Observability refers to the ability to observe Chinook salmon while flying an aerial survey, and depends on the characteristics of each spawning tributary, the survey staff, and the procedures followed. Because survey staff and procedures were common to all Chinook salmon populations in the Susitna River drainage in each survey year, hierarchical modeling was employed to reflect our belief that observability parameters come from a common distribution. Age composition data for Susitna River Chinook salmon is sparse relative to the size of the drainage and number of years of survey data. This limitation forced us to share age composition data between stocks.

- Age composition model

One issue raised about the age composition model was our use of actual sample sizes when it is common to use a smaller effective sample size. Our choice probably underestimates variability associated with our estimated age composition (Tables 3 and 4) but is unlikely to affect the main stock recruit parameters (α, β, S_{MSY}).

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The second issue raised with the age composition model involves use of age composition data from both harvest sampling programs (which were conducted mostly early in the time series) and escapement sampling programs (which were conducted mostly late in the time series). Our reviewer notes that if sport fisheries are selectively harvesting larger fish, some of the declining trend in age at maturity (Figure 21) could be an artifact of sampling rather than a change in stock demographics. Early versions of this model used a similar multinomial logistic regression as the current model (equation 25) but replaced the stock specific covariate with a covariate associated with the type of age sample (harvest or weir). Sample-based covariates were mostly nonsignificant, indicating that the estimated trend in age at maturity may reflect changing stock demographics.

- Should productivity (α) be modeled hierarchically?

Productivity estimates are central to calculating S_{MSY} (equation 27) and are therefore important to estimate accurately. Our choice to model productivity hierarchically was driven by theoretical concerns; i.e., productivity is generally considered to be species and regionally specific, which is descriptive of the 4 stocks within this stock assessment. That said, changing how we modeled productivity would not result in different management advice. We ran the model with productivity estimated independently and found productivity changed slightly (-4% to 3%) relative to the hierarchical estimates we reported (Table 1) and estimates of S_{MSY} were within 4% of the estimates we reported (Table 1).

- Are time trends in stock composition necessary?

Estimating time trending stock composition adds significant model complexity and is only informed by empirical stock composition estimates late in the time series. The model can be fit without a time trend and this model estimates very similar main stock recruit parameters (α, β, S_{MSY}). The static model is thus more parsimonious and may be a better choice. We fit a model with time trending composition because viability of the populations within each stock is of management concern.

- Marine mixed-stock harvest

Very sparse data (2 years) is available to estimate the proportion of Susitna River Chinook salmon in Northern district set gillnet and Tyonek Subsistence fisheries. Because total marine harvest is small relative to our annual estimates of the total run of Susitna River Chinook salmon, we do not believe this data limitation is critical. We tested model sensitivity to drastically underestimating the Susitna contribution to these fisheries by running the model with marine harvest estimates 90% larger than the estimates in Appendix A9. Under this increased harvest assumption, estimates of S_{MSY} were within 2.5% of the estimates presented in Table 1.