**Fishery Manuscript Series No. 17-02**

# Spawner-Recruit Analyses and Escapement Goal Recommendations for Kenai River Chinook Salmon

**by**

**Steven J. Fleischman**

**and**

**Adam M. Reimer**

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

# *FISHERY MANUSCRIPT SERIES NO. 17-02*

# SPAWNER-RECRUIT ANALYSES AND ESCAPEMENT GOAL RECOMMENDATIONS FOR KENAI RIVER CHINOOK SALMON

by
Steven J. Fleischman
and
Adam M. Reimer

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

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

*and*

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

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# ABSTRACT

Age-structured state-space spawner-recruit models were fit to 1986–2015 data on abundance, harvest, and age composition for early and late runs of Kenai River Chinook salmon (*Oncorhynchus tshawytscha*), 75 cm mid eye to tail fork (METF) and longer. Historical annual run abundance, stock recruitment parameters, and fishery management reference points were estimated from these models. Sustainable Escapement Goals of 2,800–5,600 (early run) and 13,500–27,000 (late run) Chinook salmon 75 cm METF and longer are recommended, and their attributes and limitations discussed. Fish 75 cm METF (approximately 33.3 in total length) and longer can be assessed directly by imaging sonar in the Kenai River at river mile 13.7.

Key words: Chinook salmon, *Oncorhynchus tshawytscha*, Kenai River, spawning abundance, sustainable escapement goal, run reconstruction, spawner-recruit analysis, maximum sustained yield

# INTRODUCTION

## FISHERY MANAGEMENT

Two stocks of Chinook salmon (*Oncorhynchus tshawytscha*) return to the Kenai River (Figure 1) to spawn. Chinook salmon bound for tributaries of the Kenai River (tributary spawners) enter the river from late April through early July, whereas Chinook salmon that spawn in the Kenai River itself (mainstem spawners) enter the river from mid-June through mid-August (Burger et al. 1985; Bendock and Alexandersdottir 1992; Reimer 2013). In 1988, the Alaska Board of Fisheries (BOF) adopted management plans for Kenai River Chinook salmon that defined fish entering the river prior to 1 July to represent the early run and fish entering the river after 30 June to represent the late run (McBride et al. 1989).

### Early Run

Early-run Kenai River Chinook salmon are harvested primarily in 3 fisheries: an inriver sport fishery, an educational gillnet fishery occurring near the river mouth, and a marine sport fishery along the eastern shore of Cook Inlet from Anchor Point to Cape Ninilchik.[1]

In the 1988 Alaska Department of Fish and Game (ADF&G) management plan, the targeted spawning escapement for early-run Chinook salmon was set at 9,000 fish, with management directives centered on projected escapement levels of less than 5,300 fish, 5,300 to 9,000 fish, and greater than 9,000 fish (McBride et al. 1989). In 1999, ADF&G revised this to an escapement goal range of 7,200 to 14,400 Chinook salmon. Prior to the 2005 season, ADF&G established a biological escapement goal (BEG; definition in Alaska Administrative Code 5 AAC 39.222 [f][3]) of 4,000 to 9,000 early-run Chinook salmon (Hasbrouck and Edmundson 2007), while the BOF elected to set an optimal escapement goal (OEG; definition in 5 ACC 39.222 [f][25]) of 5,300 to 9,000 fish. Prior to the 2013 season, ADF&G adopted a sustainable escapement goal (SEG; definition in 5 ACC 39.222 [f][36]) of 3,800 to 8,500 early-run Chinook salmon (McKinley and Fleischman 2013), while the BOF elected to maintain the OEG of 5,300 to 9,000 fish.

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[1] Occasionally, small numbers of early-run fish are also caught during very early openings of the commercial eastside setnet (ESSN) fishery and in an ADF&G cost-recovery program.

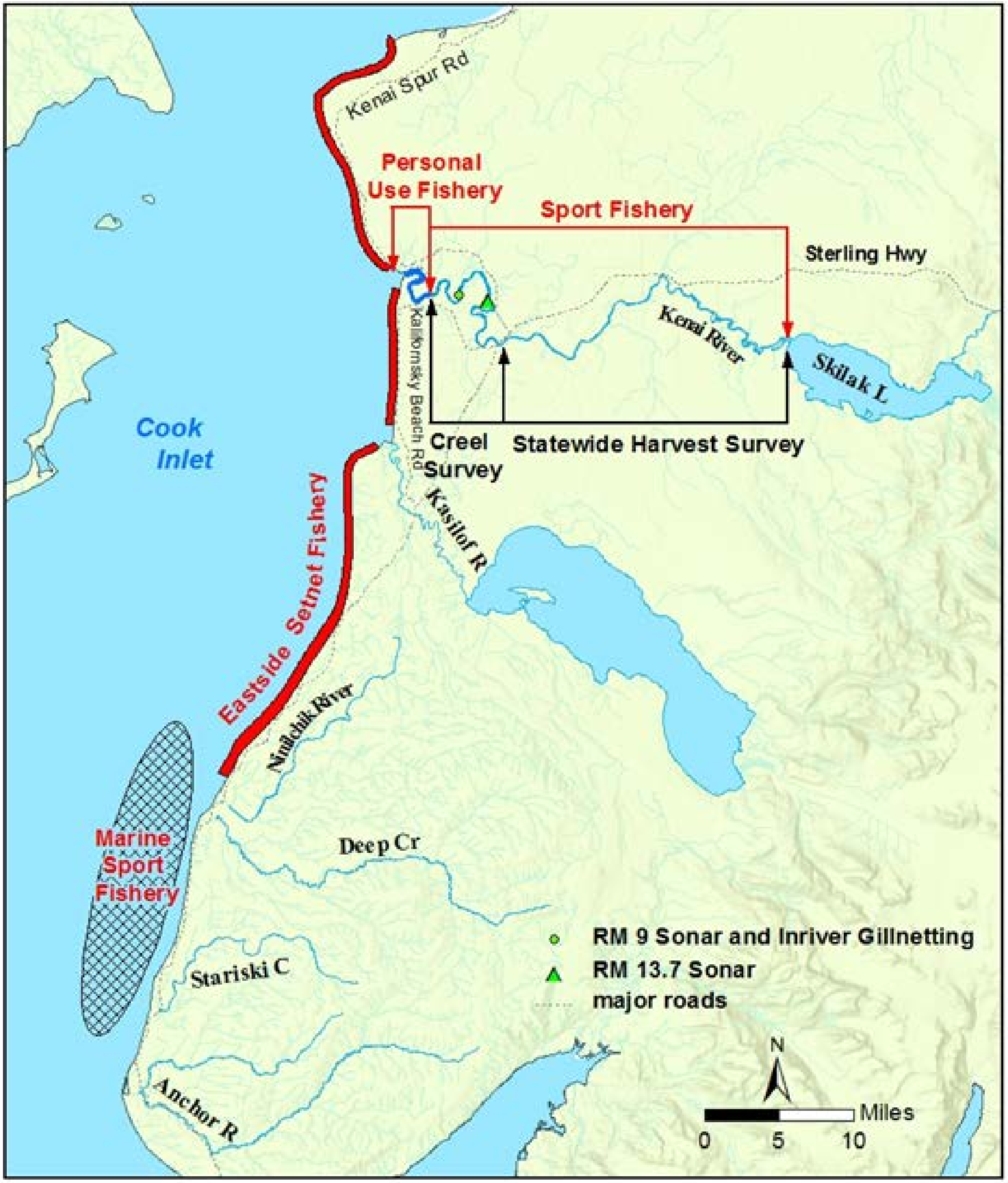

Figure 1.–Major fisheries and sampling programs included in the Kenai River Chinook salmon stock assessment.

*Note*: Red text, arrows, and shading denote major fisheries harvesting Kenai River Chinook salmon. Black text and arrows denote inriver sampling programs for Kenai River Chinook salmon.

The *Kenai River and Kasilof River Early-run King salmon Management Plan* (Alaska Administrative Code 5 AAC 57.160) contains management strategies for this stock. A slot-limit regulation was enacted in 2002 in response to a declining number of age-7 (ocean-age-5) early-run Chinook salmon. The original slot limit allowed retention of Chinook salmon with total length (TL) less than 40 inches or greater than 55 inches. The lower limit was changed to 44 inches in 2003, 46 inches TL in 2008, and 42 inches in 2014. The slot limit is in effect 1 January to 30 June from the mouth of the Kenai River upstream to Slikok Creek (approximately river mile [RM] 18.7), and 1 January to 14 July from RM 18.7 to Skilak Lake.

Other sport fishing regulations for this stock, which are among the most restrictive in Alaska, are detailed in the management plan, and include a daily bag and possession limit of 1 and a seasonal limit of 2 Chinook salmon, closed areas, and partial restrictions on fishing from guided boats.

### Late Run

Late-run Kenai River Chinook salmon are primarily harvested in 4 fisheries: an inriver sport fishery, a personal use fishery occurring near the river mouth, a commercial set gillnet fishery on the east side of Cook Inlet, and a marine sport fishery occurring along the eastern shore of Cook Inlet[2].

In the 1988 management plan, the targeted spawning escapement for late-run Chinook salmon was set at 22,300 fish, with management directives centered on 3 projected escapement levels: less than 15,500 fish; 15,500 to 22,300 fish; and greater than 22,300 fish (McBride et al. 1989). In 1999, ADF&G revised this to a BEG of 17,800 to 35,700 Chinook salmon. The current goal, implemented in 2013, is an SEG of 15,000 to 30,000 Chinook salmon (Fleischman and McKinley 2013).

The *Kenai River Late-Run King Salmon Management Plan* (Alaska Administrative Code 5 AAC 21.359) contains management strategies designed to achieve the SEG. Regulations for the Kenai River late-run Chinook salmon sport fishery are similar to those in place during the early-run fishery except that bait is allowed and the slot limit occurs in limited times and areas. If the inriver fishery is restricted, other Cook Inlet sport fisheries, personal use fisheries, and Cook Inlet commercial fisheries may also be restricted.

## STOCK ASSESSMENT

Commercial harvest of Chinook salmon by the set gillnet fishery on the east side of Cook Inlet (ESSN) has been reported since 1966. This information is available to ADF&G via commercial fish tickets that document commercial landings and provides an index of late-run Kenai River Chinook salmon abundance. Age, sex, and length information has been collected from the ESSN harvest since 1983 (Tobias and Willette 2002). Stock composition of Chinook salmon harvested in the ESSN fishery has been estimated using genetic mixed stock analysis since 2010 (Eskelin et al. 2013; Eskelin and Barclay 2015, 2016).

Onsite creel surveys have provided estimates of harvest, catch, and angler effort, as well as age, sex, and length data from the inriver sport harvest since 1976 (Perschbacher 2015b). Catch per unit effort from the sport fishery provides an index of Chinook salmon abundance.

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[2] Smaller harvests occur in a commercial drift fishery, an educational fishery near the river mouth, and a subsistence fishery located within the Kenai National Wildlife Refuge.

Assessment of Kenai River Chinook salmon abundance was initiated in the mid-1980s using 2 methods: capture-recapture (CR) experiments and riverine sonar (McKinley and Fleischman 2010). Traditional CR estimates of early-run abundance were produced in 1986 and 1987. Thereafter the CR project was simplified to an inriver gillnetting project that used catches from a 7.5-inch mesh gillnet to estimate age, sex, and length composition of returning Chinook salmon. Additionally, late-run Chinook salmon abundance was estimated as a function of harvest and exploitation rate in 1996 and 1997 (Hammarstrom and Hasbrouck 1998, 1999). Beginning in 1986, dual-beam sonar at river mile 8.6 (RM 8.6) used target strength (TS, a measure of echo loudness) and range (distance from sonar transducer) thresholds to classify fish as Chinook salmon versus other species (Eggers et al. 1995). At the RM 8.6 sonar site, Chinook salmon were believed to primarily migrate midriver, whereas other salmon species were believed to primarily migrate nearshore. Split-beam sonar replaced dual-beam sonar in 1995, allowing direction of travel to be determined for sonar targets (Burwen et al. 1998). While TS and range thresholds remained in use for species classification through 2010, alternative methodologies continued to be evaluated. Tethered fish experiments found that echo length standard deviation (ELSD, variability in the duration of the returning echo) was a better predictor of fish size than TS in the Kenai River (Burwen and Fleischman 1998; Burwen et al. 2003). A statistical “mixture model” technique was also introduced that combined ELSD measurements from tethered fish of known length with netting data to estimate the species composition of fish counted by sonar (Fleischman and Burwen 2003).

During the late 1990s, the inriver netting program was standardized with respect to drift location (midriver and just downstream of the RM 8.6 sonar site), timing (low tide), and procedures (Reimer et al. 2002). In 2002, a 5-inch mesh gillnet was added, the type of mesh twine was changed from cable-lay nylon to multi-monofilament, and the drift location was further restricted to closely match the cross section of the river that was insonified by the RM 8.6 sonar. These changes were implemented so that net catches would better reflect the actual distribution of fish size, thereby making it possible to estimate species composition from the netting data (Reimer 2004). Species composition estimates from the inriver gillnetting program were paired with RM 8.6 sonar counts to provide an alternative sonar estimate (net-apportioned sonar) beginning in 2002 (Miller et al. 2004). Daily catch rates from the standardized netting program have provided an important index of inriver run strength since 2002.

In 2002, ADF&G began testing dual-frequency identification sonar (DIDSON) in the Kenai River. DIDSON uses a lens system that provides high resolution images that approach the quality achieved with conventional optics (Simmonds and MacLennan 2005), with the added advantage that images can be obtained in dark or turbid waters. DIDSON allows direct length measurements for individual sonar targets. Studies using live tethered Chinook and sockeye salmon confirmed a close relationship ($r^2 = 0.90$) between DIDSON fish image length and true fish length (Burwen et al. 2011). Mixture model estimates derived from DIDSON length measurements provided improved species discrimination over those derived from split-beam sonar ELSD. The wider field of view and improved image quality provided by the DIDSON also allowed for improved identification of individual fish targets even during periods of high fish passage. In 2010, DIDSON and split-beam sonars operated side by side confirmed that TS-based estimates were biased high due to misclassified sockeye salmon, and the first successful DIDSON-based abundance estimates were produced (Miller et al. 2013). DIDSON sonar became the default technology soon after; TS-based estimates were discontinued after 2010 (Miller et al. 2013) and split-beam sonar was discontinued after 2011 (Miller et al. 2014).

With the advent of DIDSON (2010 late run, 2011 early run), it became possible to generate direct estimates of abundance for fish of specific length categories. Over time, it became evident that fish measured as 75 cm or longer by imaging sonar were composed almost entirely of Chinook salmon (Figure 2). Later, based on tethered fish and other data, Miller et al. (2016b) concluded that a fish measured 75 cm by imaging sonar is also approximately 75 cm mid eye to tail fork (METF).

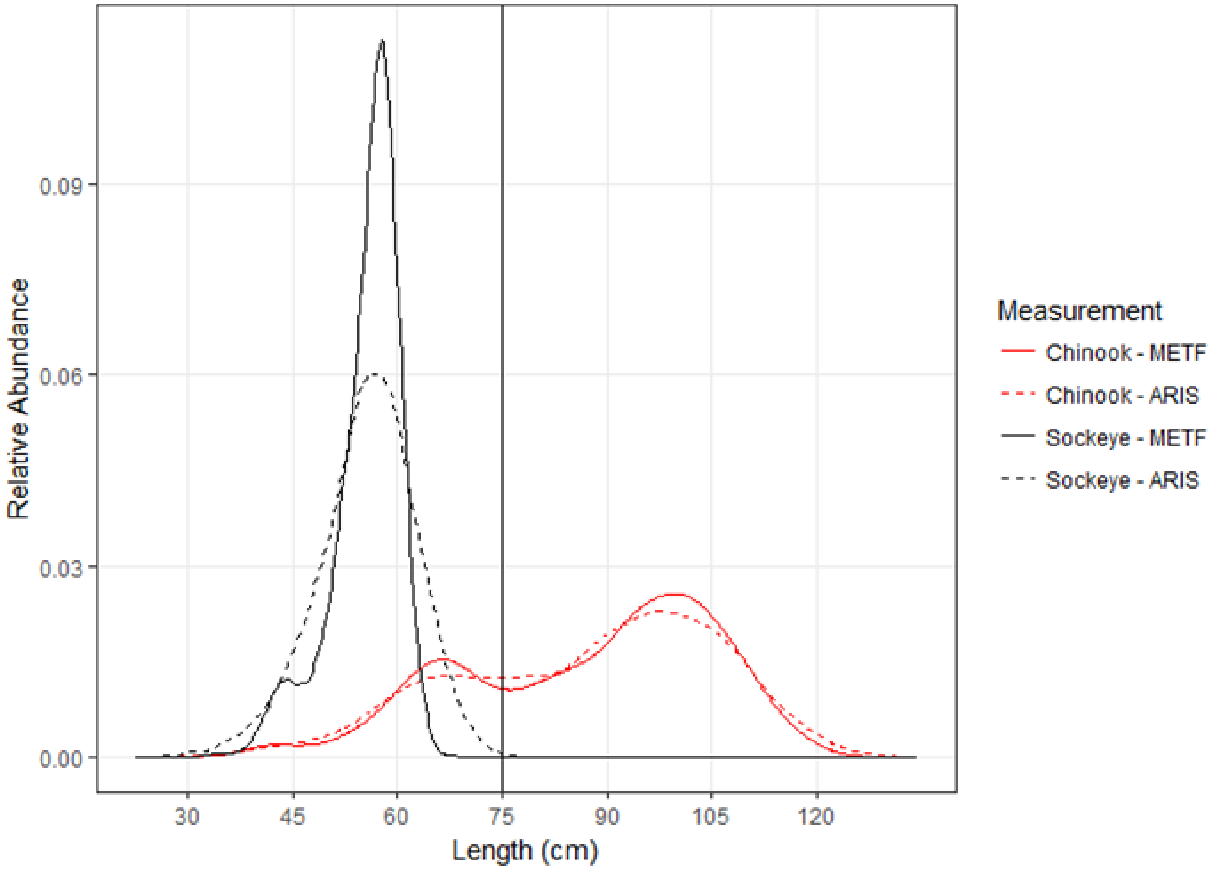

Figure 2.–Length distributions of Kenai River sockeye salmon captured in fish wheels and Chinook salmon sampled by inriver gillnets between 2002 and 2015.

*Note*: Dashed lines reflect the length distributions after accounting for error associated with measuring the fish using imaging sonar.

From 2010 to 2014, ADF&G modified the work of Bromaghin et al. (2010) to produce stock-specific abundance and run timing (SSART) estimates for Kenai River Chinook salmon. The SSART model uses genetic stock identification (GSI) data from the inriver netting and creel programs to estimate stock composition of the inriver run and harvest respectively. Other model inputs include estimates of passage from tributary weirs (Funny, Killey, and Russian rivers, and Slikok, Quartz, and Grant creeks), estimates of inriver harvest from the onsite creel survey and the ADF&G statewide harvest survey (SWHS), and daily CPUE from the inriver netting project. SSART model estimates of abundance for all Chinook salmon regardless of size for the years 2007 to 2012 are detailed in Reimer et al. (2016). The SSART model analysis was revised and updated to provide estimates of Chinook salmon 75 cm METF and longer for the years 2007 to 2014 in support of the analysis herein (Reimer and Fleischman 2016).

In 2011 and 2012, ADF&G staff found substantial numbers of Chinook salmon migrating between the transducer and the shoreline at the RM-8.6 sonar site (Miller et al. 2014; Miller et al. 2015). Further evidence that the DIDSON was missing some Chinook salmon came from SSART estimates of abundance that were consistently larger than the comparable DIDSON-based sonar estimates. Unfortunately, tidally induced fluctuations of water level at RM 8.6 precluded counting fish migrating near shore with conventional placement of transducers. Comprehensive analyses of all relevant stock assessment data (Fleischman and McKinley 2013; McKinley and Fleischman 2013) estimated that an average of approximately 35% of early-run and 22% of late-run Chinook salmon went undetected by sonar and nets at the RM-8.6 site between 1986 and 2012. SEGs of 3,800 to 8,500 and 15,000 to 30,000 were recommended for the early- and late-run stocks, assessed by expanding RM-8.6 DIDSON estimates by 1.55 (early run) and 1.28 (late run) to account for these missed fish. Fisheries were managed based on the spatially-expanded DIDSON-based estimates in 2013 and 2014.

In 2013, Adaptive Resolution Imaging Sonar (ARIS)[3] was first installed at RM 13.7 and operated concurrently with DIDSON at RM 8.6. Because water level is not influenced by tides at RM 13.7, an array of multiple ARIS units was able to count migrating fish across nearly the entire cross section of the river. Sonar estimates of Chinook salmon 75 cm METF and longer from the RM 13.7 site have compared favorably with the corresponding SSART estimates and do not require an expansion factor to account for fish escaping detection by passing behind the transducers. DIDSON-based estimates at RM 8.6 were discontinued after 2014, and fisheries were managed using ARIS-based estimates at RM 13.7 in 2015 and 2016.

During the 2013 season, experimental drifts were conducted near shore 2 days per week and it became evident that Chinook salmon migrating near shore, behind the RM 8.6 sonar transducers, tended to be smaller in size than fish migrating midriver. Such size-stratified migration behavior had the potential to bias the sonar estimates at RM 13.7 because the RM 8.6 midriver netting program was the source of length composition information needed for mixture model estimates of Chinook salmon abundance (Miller et al. 2016b). When large numbers of Chinook salmon migrate nearshore, *and* their size composition differs from those that migrate midriver, failure to sample the nearshore migrants can lead to biased estimates of small Chinook salmon. Therefore, beginning in 2014, nearshore and midriver areas were sampled with equal frequency and the data combined for stock assessment purposes, thereby providing length measurements that more accurately reflected the size distribution of migrating Chinook salmon.

With the benefit of data from the revised netting sample design, we can now assess the degree to which size-stratified migration occurs at RM 8.6 in a given year. During the 2013–2016 early and late runs, nearshore migrants were composed of smaller fish (to varying degrees) than midriver migrants (Appendix E1). However, only during the 2013 early run did a large difference in size composition occur simultaneously with a large fraction of Chinook salmon migrating nearshore, which are the conditions required to create substantial bias. Evidently the migratory behavior of “small” versus “large” Chinook salmon at RM 8.6 can differ among years and runs. These differences make it difficult to reconstruct historical abundance of small Chinook salmon because it is unknown the extent to which the abundance of small Chinook salmon was underestimated in any given year prior to 2013. This has hampered ongoing efforts

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[3] ARIS is the next generation of multi-beam imaging sonar technology. It produces images comparable to or better than a DIDSON.

to revise and update 1986–2012 run reconstructions for Kenai River Chinook salmon of all sizes (e.g., Fleischman and McKinley 2013; McKinley and Fleischman 2013).

Mixture model estimates of small Chinook salmon can be sensitive to details of how the netting data were used (Miller et al. 2016b). In 2015, inseason estimates used for managing the fishery required substantial postseason revisions, largely because inseason procedures adopted to accommodate sparse netting data proved biased under some circumstances (Miller et al. *In prep*). Shortcomings such as these prompted discussions about the potential benefits of basing inseason Kenai River Chinook salmon stock assessment and management on direct sonar counts of "large" fish only. In this report, we define large fish as 75 cm METF and longer[4].

# OBJECTIVES

This report is part of an ongoing transition toward management of Kenai River Chinook salmon stocks based on DIDSON–ARIS assessment technology. Thus far, steps in this transition have included the commencement of DIDSON-based abundance estimates in 2010 (Miller et al. 2013), discontinuation of TS-based estimates in 2011 (Miller et al. 2014), discontinuation of split-beam sonar in 2012 (Miller et al. 2015), run reconstruction and spawner-recruit analysis to develop DIDSON-based escapement goals in 2013 (Fleischman and McKinley 2013; McKinley and Fleischman 2013), and commencement of ARIS-based abundance estimates measured across nearly the entire cross section of the river at RM 13.7 in 2013 (Miller et al. 2016a). This report provides the foundation for the next step in the transition, which is assessment and management based on ARIS estimates of Chinook salmon 75 cm METF and longer obtained at RM 13.7 beginning in 2017. Specific objectives are as follows:

1) Reconstruct historical annual run abundance, escapement, harvest, and age composition of Kenai River early- and late-run Chinook salmon 75 cm METF and longer for 1986–2015.
2) Estimate stock recruitment parameters and fishery reference points for Kenai River early- and late-run Chinook salmon 75 cm METF and longer.
3) Recommend escapement goals for Kenai River early- and late-run Chinook salmon 75 cm METF and longer.

# METHODS

Comprehensive analyses were conducted of all relevant stock assessment data in the context of integrated state-space models of historical run abundance and stock dynamics. The models, patterned closely after those of Fleischman and McKinley 2013; McKinley and Fleischman 2013), assume a Ricker spawner-recruit relationship and time-varying productivity. They are age-structured, which enables a realistic depiction of observation error in inriver abundance, age composition, and harvest. The models are 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

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[4] This definition differs from that used in the RM 13.7 sonar reports (Miller et al. 2016a, 2016b; Miller et al. *In prep*), in which large fish are 90 cm and longer, as measured by the ARIS. "Large" fish in this report are inclusive of both "medium" and "large" fish from those sonar reports.

that provide maximum sustained yield ($S_{MSY}$) and recruitment ($S_{MSR}$). The current analyses differ from the 2013 analyses in that they consider only Chinook salmon 75 cm METF and longer and include 3 additional years of data.

# DATA

The state-space models were fit to historical data for Kenai River Chinook salmon 75 cm METF and longer. The following input data were required for each run: 1) estimates of annual harvest below (downstream of) and above (upstream of) the location of the inriver stock assessment, 2) estimates of total run age composition, and 3) estimates of relative and absolute annual abundance, with coefficients of variation (CVs) for the absolute measures (Appendices B1–B5). Sources of these data components are described in the following sections.

## Annual Harvest

Kenai River Chinook salmon are harvested in marine recreational, commercial set and drift gillnet fisheries, as well as inriver personal use, subsistence-educational, and sport fisheries. Estimates of harvest in the Cook Inlet marine recreational fishery were obtained from the SWHS (Jennings et al. 2015; Alaska Sport Fishing Survey database [Internet]. 1996– . Anchorage, AK: Alaska Department of Fish and Game, Division of Sport Fish [cited January 2017), available from: http://www.adfg.alaska.gov/sf/sportfishingsurvey/). Commercial harvest estimates were obtained from mandatory fish tickets issued at the fish processors (Shields and Dupuis 2016) and GSI estimates of stock composition (Eskelin and Barclay 2016). Personal use harvests were estimated from returned harvest reports (Dunker 2013; K. Dunker, ADF&G, Fishery Biologist, personal communication). Annual harvests in the subsistence-educational fishery were reported directly to Division of Sport Fish (Begich et al. 2013). Inriver sport harvests were estimated by an onsite creel survey for harvest downstream of the Soldotna Bridge (Perschbacher 2012 a-b) and with the SWHS for harvest upstream of Soldotna Bridge (Jennings et al. 2015; Alaska Sport Fishing Survey database). It is assumed that some Chinook salmon that were hooked and then released by anglers in the inriver sport fishery subsequently die. A hook-and-release mortality rate for Kenai River Chinook salmon of 6.4% was applied to estimates of released fish (Bendock and Alexandersdottir 1992).

### *Early Run*

Harvesters of early-run Kenai River Chinook salmon downstream of RM 8.6 include the marine and inriver sport fisheries, the ESSN fishery, and an educational gillnet fishery. Harvests in the ESSN fishery prior to 25 June were assumed to be 68% Kenai River early-run Chinook salmon (2013–2015 late June–early July average; Eskelin et al. 2013; Eskelin and Barclay 2015, 2016). The contribution of Kenai River Chinook salmon to Cook Inlet marine recreational fishery harvests was unknown at the time of this analysis but is thought to be small. Begich (2010) concluded that Kenai River early-run Chinook salmon made up less than 10% of the marine recreational harvest; for this analysis, we assumed 5%[5]. Harvests downstream of RM 8.6 were multiplied by the percentage of the inriver sport harvest that was 75 cm METF and longer during the same year. We assumed a CV of 0.2 for harvest downstream of RM 8.6. Fleischman and McKinley (2013) found that key parameter estimates were not sensitive to CV assumptions.

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[5] Subsequent GSI analysis from this fishery indicated that the contribution of Kenai fish to the marine recreational harvest is probably less than 5%.

Sport harvest estimates upstream of RM 8.6 were multiplied by the proportion of the sport harvest that was 75 cm METF and longer during the same year. The estimates of sampling error from the onsite creel survey and SWHS were squared, summed, square rooted, and divided by the sum of the harvest estimates to obtain CVs for the total harvest above RM 8.6.

### *Late Run*

Kenai River late-run Chinook salmon are harvested by marine and inriver sport anglers, commercial set and drift gillnet fisheries in Cook Inlet marine waters, and personal use and educational fisheries near the river mouth. GSI estimates of the stock composition of fish harvested in the ESSN fishery were obtained for the years 2010 to 2015 (Eskelin et al. 2013; Eskelin and Barclay 2015, 2016). The 2010–2015 average percentage of Kenai River late-run Chinook salmon (69%) was applied to ESSN harvests for the years 1986–2009 and 2016. The CV of ESSN harvests was assumed to be 0.1.

Stock compositions of fish harvested in the marine recreational fishery and the marine drift gillnet commercial fishery are unknown. Because these fisheries are, on average, more distant from the mouth of the Kenai River than the ESSN fishery, we assumed that 60% of Chinook salmon harvested in these fisheries were destined for the Kenai River and that the CV for these harvest estimates was 1.0.

Sport harvests downstream of RM 8.6 were multiplied by the proportion of the inriver sport harvest that was 75 cm METF and longer during the same year. Commercial, personal use, and educational harvests downstream of RM 8.6 were multiplied by the proportion of the ESSN commercial harvest that was 75 cm METF and longer during the same year. Coefficients of variation for commercial set and drift gillnet, personal use and inriver sport harvests downstream of RM 8.6 were assumed to be 0.1. The CV for the educational harvest was assumed to be 0.05. Estimates of sampling error were squared, summed, square rooted, and divided by the sum of the reduced harvest estimates to obtain CVs for the total harvest below RM 8.6. Fleischman and McKinley (2013) found that key parameter estimates were not sensitive to CV assumptions.

Sport harvests upstream of RM 8.6 were multiplied by the proportion of the sport harvest that was 75 cm METF and longer during the same year. Estimates of sampling error from the onsite creel survey and SWHS were squared, summed, square rooted, and divided by the sum of the harvest estimates to obtain CVs for the total harvests above RM 8.6.

## Age Composition

Age and length data exist from fish sampled at the RM 8.6 inriver gillnetting project, with annual sample sizes of 34 to 1,063 during the early run and 149 to 1,647 during the late run. Additional age and length data exist from fish sampled (annual sample sizes 142 to 3,651) from the ESSN fishery (Tobias et al. 2013). Age was estimated by counting scale annuli.

The model requires annual data on the age composition of the total run of Chinook salmon 75 cm METF and longer. For the early run, when harvests downstream of RM 8.6 were small, we used age composition data from the inriver run as a proxy for total run age data (Appendix B1). For the late run, when harvests downstream of RM 8.6 were large, annual age composition of the total run was reconstructed from the weighted age compositions of the sampled run components (ESSN harvest, inriver run; Appendix B4).

Historically, all age-3, all age-4, and some age-5 Kenai River Chinook salmon were shorter than 75 cm METF, whereas most age-5 and all age-6 and age-7 Chinook salmon were longer than 75 cm METF (Figure 3). Age composition of fish 75 cm METF and longer was obtained by omitting age-3 and age-4 fish and by multiplying the estimated abundance of age-5 fish in each run component by the proportion of age-5 Chinook salmon that were 75 cm METF and longer in the associated length sample.

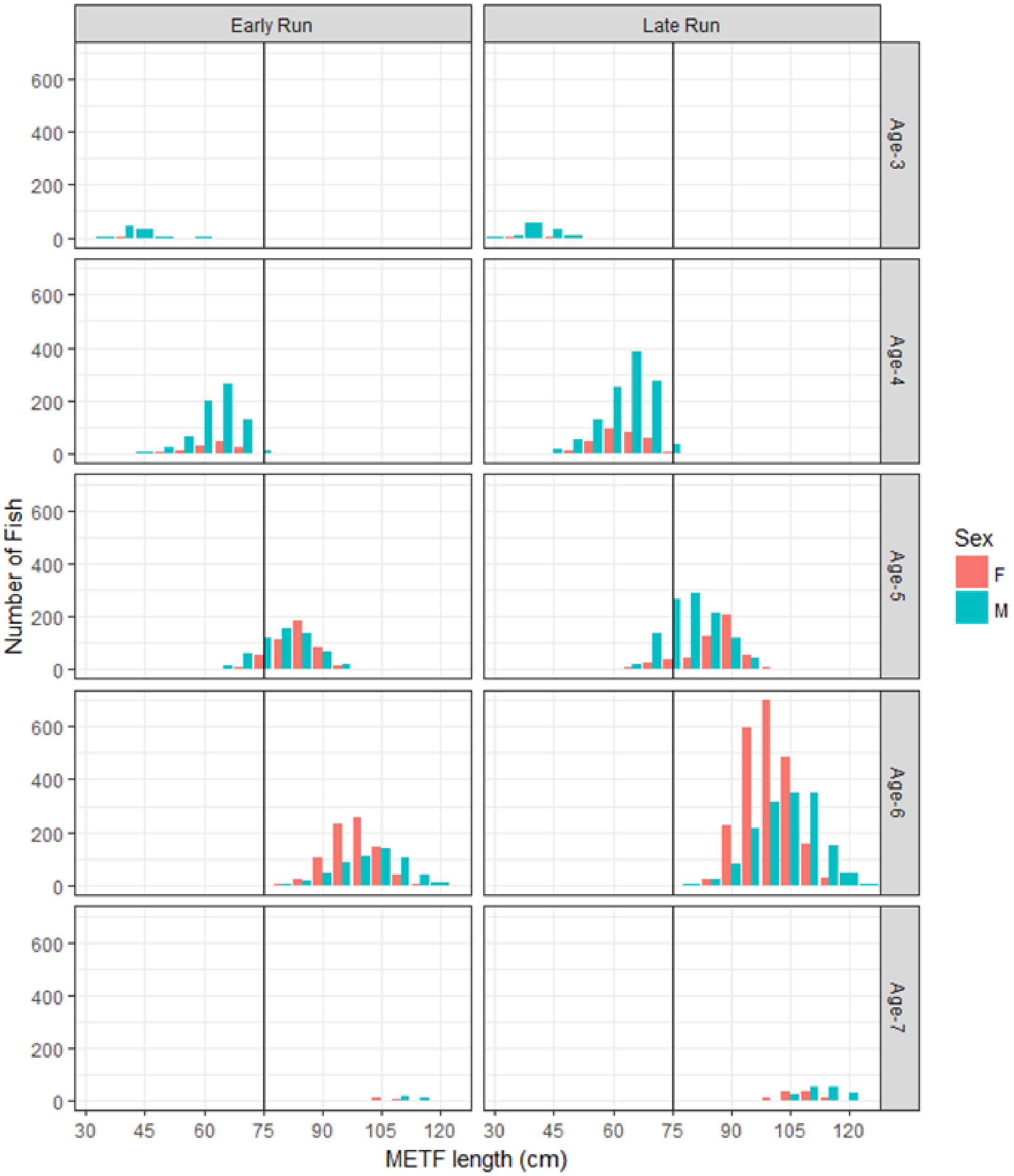

Figure 3.–Frequency distributions of early- and late-run Chinook salmon lengths (METF) sampled by an onsite netting project, 2002–2015.

*Note*: Vertical lines are at 75 cm METF.

## Measures of Abundance

ARIS-based estimates of net upstream[6] passage and their CVs are direct sonar estimates of Chinook salmon 75 cm METF and longer at RM 13.7 (Miller et al. 2016a, 2016b, *In prep*). These estimates are available from 2013 to 2015 for both runs.

DIDSON-based estimates are direct sonar estimates of upstream-bound[7] Chinook salmon measured 75 cm METF and longer by the DIDSON and migrating midriver between the sonar transducers at RM 8.6 (Key et al. 2016a, 2016b; Miller et al. 2013, 2014; Miller et al. 2015)[8]. These estimates are available for 2011–2014 in the early run and for 2010–2014 in the late run. Because DIDSON estimates at RM 8.6 represent a fraction of inriver passage, they constitute an index of relative abundance.

Estimates of inriver run abundance are available from a variety of capture-recapture (CR) studies. Traditional 2-event CR experiments of Kenai River early-run Chinook salmon inriver abundance were conducted in 1986 and 1987 (Conrad 1988; Conrad and Larson 1987). The CR estimates for these 2 years were multiplied by annual estimates of the proportion of Chinook salmon sampled with inriver netting that were 75 cm METF and longer (0.79 and 0.93, respectively). Radiotelemetry-based CR experiments of Kenai River late-run Chinook salmon inriver abundance were conducted in 1996 and 1997 (Hammarstrom and Hasbrouck 1998, 1999). Because radiotelemetry-based CR estimates were germane to 1–31 July only, they were expanded to include 1–10 August based on daily values of ESSN CPUE in those years. Radiotelemetry-based CR estimates were multiplied by annual estimates of the proportion of Chinook salmon sampled with inriver netting that were 75 cm METF and longer in each year (0.90 and 0.91, respectively). Finally, genetic CR experiments of inriver abundance of Chinook salmon 75 cm METF and longer were available for the 2007–2014 early runs and the 2013–2014 late runs from fitting the SSART model to genetic allele frequency, radiotelemetry, harvest, and weir data, all specific to fish 75 cm METF and longer (Reimer and Fleischman 2016).

The following indices of relative abundance were available for both runs. Annual catch rates from the inriver test gillnet study (NCPUE) were available from 2002 to 2015 (e.g., Perschbacher 2015a). Daily catch rates were summed and multiplied by the proportion of the catch that was 75 cm METF and longer to provide index values for each run and year. Net apportioned split-beam sonar estimates of Chinook salmon passage (NASB) were available for the early run from 2002 to 2014 and for the late run from 2002 to 2013 (e.g., Miller et al. 2014). NASB estimates were multiplied by the annual proportions of Chinook salmon netted inriver that were 75 cm METF and longer. Annual catch rates (guided anglers only) from the inriver sport fishery (SCPUE) were available for the early run from 1989 to 2012 and for the late run from 1986 to 2011 (e.g., Perschbacher 2015a). SCPUE values were multiplied by proportions of Chinook salmon sampled from the harvest that were 75 cm METF and longer.

For the late run only, an additional index of relative abundance was available from annual harvest rates in the ESSN fishery (CCPUE; obtained from a maximum likelihood analysis of daily catch rates; personal communication, Xinxian Zhang, Biometrician, ADF&G, Anchorage).

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[6] For ARIS-based estimates at the RM 13.7 site, upstream migrants were decremented by downstream migrants.

[7] For DIDSON-based estimates at the RM 8.6 site, upstream migrants were not decremented by downstream migrants.

[8] In the cited DIDSON reports, such estimates were termed "threshold" or "large fish" estimates and were tabulated in appendices.

For the early run only, an additional index of relative abundance was constructed from model-derived estimates of late-run total run abundance of Chinook salmon 75 cm METF and longer ($N_{LR}$), which exhibited positive relationships with early-run indices of abundance. Early- and late-run Kenai River Chinook salmon share freshwater and perhaps early marine habitat as juveniles, and these commonalities are borne out in correlated annual abundance measures.

## STATE-SPACE MODEL

The state-space model (Appendix A1) specifies precisely how population parameters lead to the data that are observed. The process model component describes how natural population processes generate true annual abundance by age, and the observation model component describes how the observed data are generated.

### Process Model

Abundance of Kenai River Chinook salmon is generated by a spawner-recruit[9] (SR) relationship, which describes the number of fish expected to return (the "recruitment") from a given "escapement" (number of spawning fish). The total recruitment *R* produced from fish spawning in year *y* follows the Ricker (1975) formulation:

$$R_y = S_y \alpha e^{-\beta S} \tag{1}$$

where *S* is the number of spawners, parameter $\alpha$ (number of recruits per spawner in the absence of density dependence) is a measure of productivity, and parameter $\beta$ is a measure of density dependence.

In the model, productivity is allowed to vary among brood years, fluctuating around a central tendency. Time-varying productivity often manifests as serially correlated model residuals, so an autoregressive lognormal error term with a lag of one year (AR[1]) was included in the linearized form of the spawner-recruit relationship (Noakes et al. 1987)

$$\ln(R_y) = \ln(S_y) + \ln(\alpha) - \beta S_y + \phi \nu_{y-1} + \varepsilon_{Wy} \tag{2}$$

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

$$\nu_y = \ln(R_y) - \ln(S_y) - \ln(\alpha) + \beta S_y \tag{3}$$

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

Age at maturity is also allowed to fluctuate annually around a central tendency, to a specified extent. Age-at-maturity vectors[10] $\underline{\boldsymbol{p}}_{\boldsymbol{y}} = (p_{y5}, p_{y6}, p_{y7})$ from year *y* returning at ages 5–7 were drawn from a *Dirichlet*($\gamma_5$,$\gamma_6$,$\gamma_7$) distribution. The Dirichlet parameters can also be expressed in an alternate form where

$$D = \sum_a \gamma_a \tag{4}$$

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[9] Often termed "stock-recruit" in the fisheries literature.

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

is the (inverse) dispersion[11] of the annual age-at-maturity vectors, reflecting consistency of age at maturity among brood years. The location parameters

$$\pi_a = \frac{\gamma_a}{D} \tag{5}$$

are proportions that sum to 1, reflecting the age-at-maturity central tendencies.

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

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

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

$$N_y = \sum_a N_{ya} \, . \tag{7}$$

Annual harvest $H$ of Kenai-origin Chinook salmon below (downstream of) the stock assessment projects at RM 8.6 was modeled as the product of the annual harvest rate below RM 8.6 and total run:

$$H.below_y = \mu.below_y N_y \, . \tag{8}$$

Inriver run $IR$ at RM 8.6 was modeled as follows:

$$IR_y = N_y - H.below_y \, . \tag{9}$$

Annual harvest above RM 8.6 was the product of the annual harvest rate above RM 8.6 and inriver run abundance:

$$H.above_y = \mu.above_y IR_y \, . \tag{10}$$

Finally, spawning escapement $S$ was inriver run abundance minus harvest above RM 8.6:

$$S_y = IR_y - H.above_y \, . \tag{11}$$

## Observation Model

Observed data include estimates of annual harvest and age composition below and above RM 8.6 (Appendices B1–B5), plus CR estimates of inriver run, sonar estimates of midriver run at RM 8.6 and inriver run at RM 13.7, and indices of relative abundance (NCPUE, NASB, SCPUE, CCPUE, $N_{LR}$). Sampling distributions for the data follow.

Estimated inriver runs of Chinook salmon from capture-recapture and RM-13.7 sonar were

$$I\hat{R}_y = IR_y e^{\varepsilon_{IRy}} \tag{12}$$

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

where the $\{\varepsilon_{IRy}\}$ were normal ($0,\sigma^2_{IRy}$) and

$$\sigma^2_{IRy} = \ln\left(CV^2\left(\widehat{IR}_y\right)+1\right). \tag{13}$$

Estimated annual harvest of Kenai River Chinook salmon below RM 8.6 was

$$\hat{H}.below_y = H.below_y e^{\varepsilon_{HBy}} \tag{14}$$

where the $\{\varepsilon_{HBy}\}$ were normal ($0,\sigma^2_{HBy}$) and the variances followed Equation 13.

Estimated annual harvest of Kenai River Chinook salmon above RM 8.6 was

$$\hat{H}.above_y = H.above_y e^{\varepsilon_{HAy}} \tag{15}$$

where the $\{\varepsilon_{HAy}\}$ were normal ($0,\sigma^2_{HAy}$) and the variances followed Equation 13.

Estimated abundance of Chinook salmon migrating midriver by the DIDSON at RM 8.6 was

$$DS_y = MR_y e^{\varepsilon_{DSy}}, \tag{16}$$

$$MR_y = p_{MR}\, IR_y \tag{17}$$

where $MR_y$ is the number of Chinook salmon migrating midriver between the transducers and therefore detectable by the RM-8.6 DIDSON, $p_{MR}$ is the fraction migrating midriver, the $\{\varepsilon_{DSy}\}$ were normal ($0,\sigma^2_{DSy}$), and the variances followed Equation 13.

Five indices of abundance were available. Each comprised an independent measure of relative abundance:

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

where subscript $i$ indicates 1 of the 5 indices of abundance, $q_i$ is a factor of proportionality relating true abundance to index $I_i$, $X_y$ is the generic true abundance (midriver run $MR$ for NCPUE and NASB; inriver run $IR$ for SCPUE; and total run $N$ for $N_{LR}$ and CCPUE) and the $\{\varepsilon_{iy}\}$ are independently and normally distributed process errors with variance $\sigma^2_{Ii}$. Parameters $q_i$ and $\sigma^2_{Ii}$ were estimated from the data.

The model predicts the age composition of the total run; however, the data originated from 2 major components of the run: the harvest downstream of RM 8.6 and the inriver run at RM 8.6. During the early run, inriver run accounts for more than 95% of the total run, and we used inriver run age composition as a surrogate for total run age composition. For the late run, estimates of the age composition of the total run were obtained by weighting the age composition estimates from each component by the relative abundance of each component, obtained using an approximate spreadsheet version of the run reconstruction.

Actual scale-age counts, summing to annual sample sizes $n_y$ of Chinook salmon 75 cm METF and longer, were used for the early-run model. Because age composition estimates during the late run were a weighted average of 2 samples, an "effective sample size" of $n_{Ey}$ = 100 was used and surrogate scale-age counts $x_{ya}$ were obtained that summed to $n_{Ey}$. The scale-age counts ($x_{ya}$) were modeled as multinomially distributed, with order parameter $n_{Ey}$ and proportion parameters as follows:

$$q_{y,a} = \frac{N_{ya}}{N_y}. \qquad (19)$$

Previous analyses have found that key results from state-space analyses of Pacific salmon data are generally not sensitive to choice of $n_{Ey}$ (e.g., Fleischman and McKinley 2013).

The inriver netting project operated solely with 7.5-inch mesh nets until 2002, when 5.0-inch nets were added and twine type was changed. McKinley and Fleischman (2013) included age-specific net selectivity parameters in the model to account for this change. Net selectivity was assumed to be equal across ages in this analysis because preliminary analyses indicated that selectivity differed little before and after 2002 among Chinook salmon 75 cm METF and longer.

## MODEL FITTING

Model fitting involves finding the values of the population parameters that could have plausibly resulted in the data that were observed. To do so, Markov Chain Monte Carlo (MCMC) methods were employed using the package RJAGS (Plummer 2013) within R (R Core Team 2016). 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).

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 the “prior” probability distribution. The output of the Bayesian analysis is called the “posterior” probability distribution, which is a synthesis of the prior information and the information contained in the data. See Fleischman et al. (2013) and Staton et al. (2016) for similar applications of the methods used in this report.

### Prior Distributions

Non-informative priors (chosen to have a minimal effect on the posterior) were used for most parameters. Initial recruitments $R_{1979}$-$R_{1985}$ (those with no linked spawner abundance) were modeled as drawn from a common lognormal distribution with median $\mu_{logR}$ and variance $\sigma^2_{logR}$. Normal priors with mean zero, very large variances, and constrained to be positive, were used for $\ln(\alpha)$ and $\beta$ (Millar 2002), as well as for $\mu_{logR}$ and $p_{MR}$, and coefficients of proportionality $q_i$ (log transformed). The initial model residual $v_0$ was given a normal prior with mean zero and variance $\sigma^2_W/(1-\phi^2)$. Annual harvest rates $\left\{\mu.below_y \text{ and } \mu.above_y\right\}$ were given beta(0.1,0.1) prior distributions. Diffuse conjugate inverse gamma priors were used for $\sigma^2_W$, $\sigma^2_{logR}$ and $\sigma^2_{Ii}$ (index uncertainty parameters).

### Sampling from the Posterior Distribution

MCMC samples were drawn from the joint posterior probability distribution of all unknowns in the model. Two chains were initiated, the first 10,000 samples from each were discarded and 2,000,000 additional samples were generated. After thinning by a factor of 1,000, the remaining 4,000 samples (2,000 samples per chain) were used to estimate the marginal posterior means, standard deviations, and percentiles. The diagnostic tools of RJAGS (Plummer 2013) and ShinySTAN (Stan Development Team 2016) were used to assess mixing and convergence, and no major problems were encountered. Interval estimates were constructed from the percentiles of the posterior distribution.

## REFERENCE POINTS AND OPTIMAL YIELD PROFILES

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

$$S_{MSY} \cong \frac{\ln(\alpha')}{\beta}\left[0.5 - 0.07\ln(\alpha')\right]. \tag{20}$$

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

$$Y_S = R - S = Se^{\ln(\alpha') - \beta S} - S\,. \tag{21}$$

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

$$U_{MSY} \cong \ln(\alpha')\left[0.5 - 0.07\ln(\alpha')\right], \tag{22}$$

escapement leading to maximum sustained recruitment (*MSR*)

$$S_{MSR} = \frac{1}{\beta}, \tag{23}$$

and equilibrium spawning abundance, where recruitment exactly replaces spawners:

$$S_{EQ} = \frac{\ln(\alpha')}{\beta}\,. \tag{24}$$

The quantity

$$\ln(\alpha') = \ln(\alpha) + \frac{\sigma_W^2}{2\left(1 - \phi^2\right)} \tag{25}$$

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

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

OYPs (and, for the early run, 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 $S_{MSY}$

For purposes of comparing escapement goals across stocks, we divided the lower and upper bounds of 22 published goals for Alaska Chinook salmon (Munro and Volk 2016) by point estimates of $S_{MSY}$ for each stock, thereby expressing all goal ranges in terms of multiples of $S_{MSY}$. These values were multiplied by estimates of $S_{MSY}$ for early- and late-run Kenai Chinook salmon 75 cm METF and longer to provide a graphical comparison of the recommended goals with those from other stocks.

## 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 of fisheries scientists and regional research coordinators from both fisheries divisions.

# RESULTS

***All results detailed below apply to Chinook salmon 75 cm METF and longer, unless otherwise stated.*** Note that the results of McKinley and Fleischman (2013) and Fleischman and McKinley (2013) applied to all Chinook salmon, regardless of size.

## EARLY RUN

Appendix B1 summarizes empirical (data-based) estimates of early-run harvest and age composition for Chinook salmon 75 cm METF and longer. Appendix B2 summarizes annual empirical measures of relative and absolute abundance. Estimates in Appendices B1 and B2 compose the data that inform the parameters of the state-space model, yielding the results below.

### Abundance, Harvest Rates, and Age at Maturity

Measures of abundance exhibited common trends through time, and reconstructed estimates of run abundance generally passed through the center of the scaled individual measures (Figure 4). Runs were largest during 1986–1988 and 2003–2005, underwent a decline during 2006–2013, and rebounded slightly in 2014–2015. There were moderate year-to-year deviations from this trend among individual abundance indices, but generally the indices were in agreement. Estimates of abundance became more precise with time as more data sources became available. They were least precise before 2001 when only 2 indices were available, and very precise after 2011 when imaging (DIDSON and ARIS) sonar became operational (Appendix B2 and Figure 4).

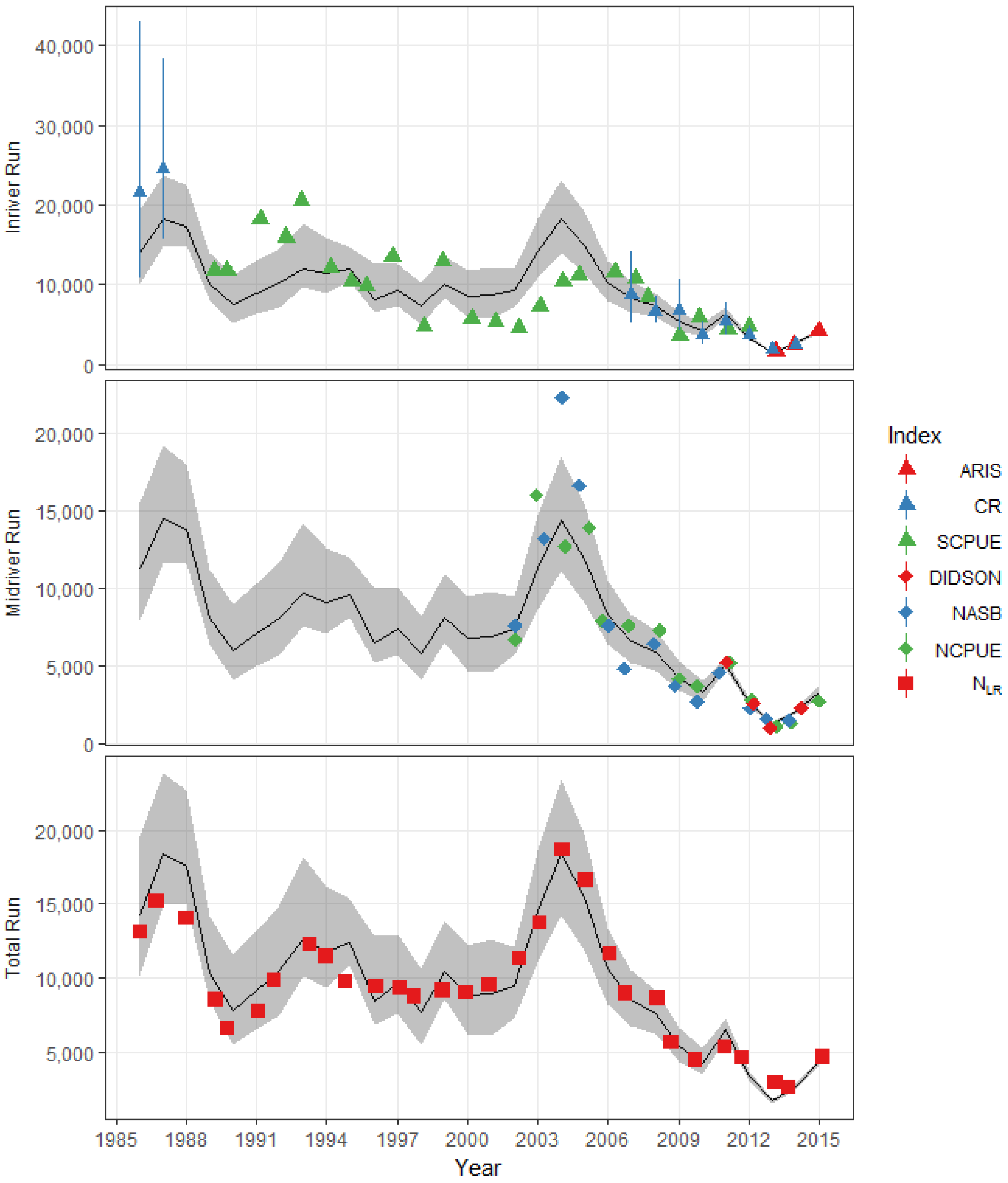

Figure 4.–Inriver, midriver, and total run abundance (dark black lines show the median; shaded areas show 95% credibility intervals) of **early-run** Kenai River Chinook salmon 75 cm METF and longer as reconstructed from 4 indices of relative abundance: inriver gillnet catch rate (NCPUE), split-beam sonar salmon abundance apportioned by Chinook salmon fraction in test gillnets (NASB), catch rate in the lower-river sport fishery (SCPUE), and late-run Chinook salmon abundance ($N_{LR}$); plus direct sonar estimates of midriver run at RM 8.6 (DIDSON), direct sonar estimates of inriver run at RM 13.7 (ARIS), and capture-recapture estimates of inriver run (CR, 95% credibility interval bounds plotted).

*Note*: For plotting, each relative abundance index was expanded by the inverse of its scaling factor *q* (see Equation 18). Points are jittered along the *x*-axis.

There is a great deal of uncertainty about escapement estimates before the year 2000, with CVs of up to 0.67 (Table 1; Figure 5 top panel). Reconstructed total run abundance (Figure 5 second panel) and brood year recruitment (Figure 5 middle panel) were more precise because they contain a harvest component that was relatively well-estimated. Coefficients of variation for total run and recruitment were less than 0.20 except for recruitment at the beginning and end of the data series, when one or more age classes were missing (Table 1). Harvest rates on early-run Chinook salmon longer than 75 cm METF exceeded $U_{MSY}$ during 1987–1989, 1993, 1995–1996, and 1999 but were considerably lower during other years (Figure 5 fourth panel).

Table 1.–Annual abundance estimates for **early-run** Kenai River Chinook salmon 75 cm METF and longer obtained by fitting a state-space model to data from 1979 to 2015.

| Year | Total run (CV) | Inriver run (CV) | Escapement (CV) | Recruitment (CV) |
|---|---:|---:|---:|---:|
| 1979 | – | – | – | 16,436 (0.82) |
| 1980 | – | – | – | 10,115 (0.23) |
| 1981 | – | – | – | 19,686 (0.11) |
| 1982 | – | – | – | 21,437 (0.09) |
| 1983 | – | – | – | 10,862 (0.12) |
| 1984 | – | – | – | 7,199 (0.17) |
| 1985 | – | – | – | 9,158 (0.16) |
| 1986 | 14,177 (0.17) | 14,051 (0.17) | 6,562 (0.37) | 9,853 (0.16) |
| 1987 | 18,340 (0.13) | 18,167 (0.13) | 4,660 (0.49) | 12,076 (0.14) |
| 1988 | 17,531 (0.11) | 17,325 (0.11) | 2,668 (0.59) | 13,297 (0.13) |
| 1989 | 10,341 (0.14) | 10,102 (0.14) | 2,663 (0.51) | 11,700 (0.09) |
| 1990 | 7,813 (0.20) | 7,552 (0.20) | 5,523 (0.28) | 8,607 (0.14) |
| 1991 | 9,178 (0.18) | 8,941 (0.19) | 6,830 (0.24) | 8,933 (0.12) |
| 1992 | 10,539 (0.18) | 10,190 (0.18) | 7,902 (0.23) | 7,439 (0.13) |
| 1993 | 12,600 (0.16) | 12,097 (0.17) | 3,108 (0.59) | 7,889 (0.12) |
| 1994 | 11,766 (0.15) | 11,374 (0.15) | 3,448 (0.48) | 11,105 (0.12) |
| 1995 | 12,437 (0.09) | 11,992 (0.09) | 1,692 (0.53) | 10,206 (0.15) |
| 1996 | 8,454 (0.17) | 8,147 (0.18) | 1,940 (0.67) | 7,933 (0.13) |
| 1997 | 9,716 (0.14) | 9,313 (0.14) | 2,898 (0.44) | 15,639 (0.11) |
| 1998 | 7,730 (0.17) | 7,309 (0.18) | 5,918 (0.22) | 15,516 (0.12) |
| 1999 | 10,474 (0.13) | 10,156 (0.13) | 2,808 (0.44) | 17,518 (0.12) |
| 2000 | 8,879 (0.17) | 8,521 (0.18) | 6,580 (0.23) | 11,673 (0.11) |
| 2001 | 8,992 (0.18) | 8,654 (0.19) | 6,455 (0.25) | 7,286 (0.11) |
| 2002 | 9,487 (0.13) | 9,308 (0.13) | 8,489 (0.15) | 8,103 (0.10) |
| 2003 | 14,491 (0.13) | 14,247 (0.13) | 11,735 (0.17) | 7,390 (0.09) |
| 2004 | 18,397 (0.13) | 18,188 (0.13) | 15,319 (0.15) | 3,262 (0.13) |
| 2005 | 15,452 (0.13) | 15,021 (0.13) | 11,529 (0.17) | 6,444 (0.08) |
| 2006 | 10,638 (0.12) | 10,361 (0.12) | 6,072 (0.22) | 4,875 (0.08) |
| 2007 | 8,514 (0.12) | 8,313 (0.12) | 5,151 (0.21) | 2,279 (0.10) |
| 2008 | 7,637 (0.10) | 7,438 (0.10) | 4,138 (0.19) | 1,406 (0.15) |
| 2009 | 5,465 (0.11) | 5,357 (0.11) | 4,034 (0.15) | 3,955 (0.10) |
| 2010 | 4,288 (0.10) | 4,163 (0.11) | 3,012 (0.15) | 6,100 (0.28) |
| 2011 | 6,564 (0.05) | 6,433 (0.05) | 5,196 (0.07) | – |
| 2012 | 3,391 (0.05) | 3,324 (0.05) | 2,977 (0.07) | – |
| 2013 | 1,702 (0.04) | 1,602 (0.04) | 1,601 (0.04) | – |
| 2014 | 2,702 (0.04) | 2,622 (0.04) | 2,621 (0.04) | – |
| 2015 | 4,317 (0.03) | 4,199 (0.04) | 4,198 (0.04) | – |

*Note*: Point estimates are posterior medians, CVs are posterior standard deviations divided by posterior means, and recruitment values are listed by brood year.

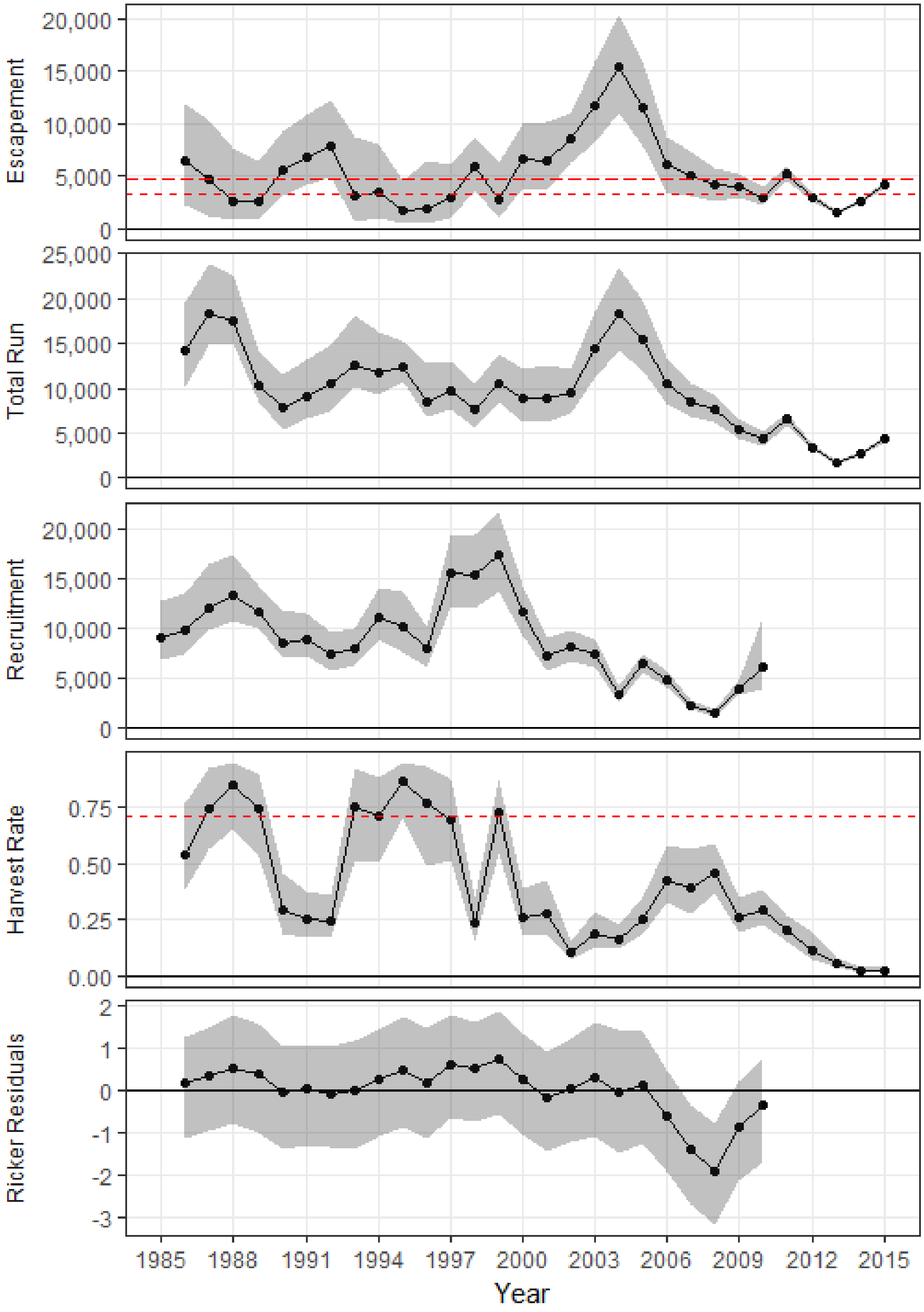

Figure 5.–Point estimates (posterior medians; solid lines) and 95% credibility intervals (shaded areas) of spawning escapement, total run abundance, recruitment by brood year, harvest rate, and Ricker productivity residuals from a state-space model of Kenai River **early-run** Chinook salmon 75 cm METF and longer, 1986–2015.

*Note*: Posterior medians of $S_{MSY}$ and $U_{MSY}$ are plotted as short dash horizontal reference lines; the posterior median of $S_{MSR}$ is plotted as a long dash horizontal reference line.

Chinook salmon 75 cm METF and longer were composed primarily of age-5 (1.3) and age-6 (1.4) fish (Table 2, Figure 6 middle and bottom panels). Early-run Chinook salmon matured at age-5 (20–50%), age-6 (45–75%), and age-7 (0–10%; Figure 4 top panel). The early-run stock trended sporadically toward earlier maturation during 1986–2015 (Figure 6 top panel).

Table 2.–Total run abundance by age class obtained by fitting a state-space model to data from Kenai River **early-run** Chinook salmon 75 cm METF and longer, 1986–2015.

| Year | Age-5 (CV) | Age-6 (CV) | Age-7 (CV) |
|---|---:|---:|---:|
| 1986 | 6,648 (0.17) | 6,108 (0.17) | 1,387 (0.19) |
| 1987 | 6,874 (0.13) | 11,037 (0.13) | 437 (0.24) |
| 1988 | 2,226 (0.14) | 13,367 (0.11) | 1,944 (0.15) |
| 1989 | 1,267 (0.17) | 8,020 (0.14) | 1,072 (0.18) |
| 1990 | 1,901 (0.21) | 5,354 (0.20) | 570 (0.26) |
| 1991 | 2,042 (0.22) | 6,556 (0.19) | 526 (0.35) |
| 1992 | 2,624 (0.20) | 7,243 (0.18) | 647 (0.29) |
| 1993 | 3,235 (0.19) | 8,824 (0.16) | 509 (0.31) |
| 1994 | 1,873 (0.19) | 9,349 (0.15) | 555 (0.27) |
| 1995 | 2,268 (0.17) | 9,570 (0.10) | 609 (0.31) |
| 1996 | 2,099 (0.20) | 6,157 (0.18) | 229 (0.38) |
| 1997 | 3,139 (0.16) | 6,429 (0.14) | 131 (0.46) |
| 1998 | 3,188 (0.19) | 4,214 (0.18) | 317 (0.35) |
| 1999 | 5,846 (0.14) | 4,566 (0.14) | 59 (0.71) |
| 2000 | 3,791 (0.19) | 4,956 (0.18) | 65 (0.73) |
| 2001 | 2,754 (0.21) | 5,943 (0.19) | 240 (0.48) |
| 2002 | 4,108 (0.15) | 4,902 (0.15) | 432 (0.32) |
| 2003 | 3,783 (0.15) | 10,469 (0.13) | 229 (0.38) |
| 2004 | 6,249 (0.15) | 11,092 (0.14) | 994 (0.27) |
| 2005 | 4,131 (0.16) | 10,672 (0.13) | 611 (0.30) |
| 2006 | 2,709 (0.17) | 7,331 (0.13) | 565 (0.33) |
| 2007 | 3,923 (0.14) | 4,412 (0.14) | 150 (0.58) |
| 2008 | 3,457 (0.13) | 4,012 (0.13) | 135 (0.58) |
| 2009 | 1,474 (0.18) | 3,835 (0.12) | 126 (0.58) |
| 2010 | 2,534 (0.13) | 1,648 (0.16) | 73 (0.70) |
| 2011 | 2,621 (0.12) | 3,812 (0.09) | 110 (0.58) |
| 2012 | 1,138 (0.16) | 2,168 (0.10) | 70 (0.71) |
| 2013 | 548 (0.21) | 1,069 (0.12) | 71 (0.67) |
| 2014 | 1,881 (0.09) | 754 (0.19) | 55 (0.70) |
| 2015 | 2,324 (0.13) | 1,897 (0.15) | 82 (0.72) |

*Note*: Point estimates are posterior medians; CVs are posterior standard deviations divided by posterior means.

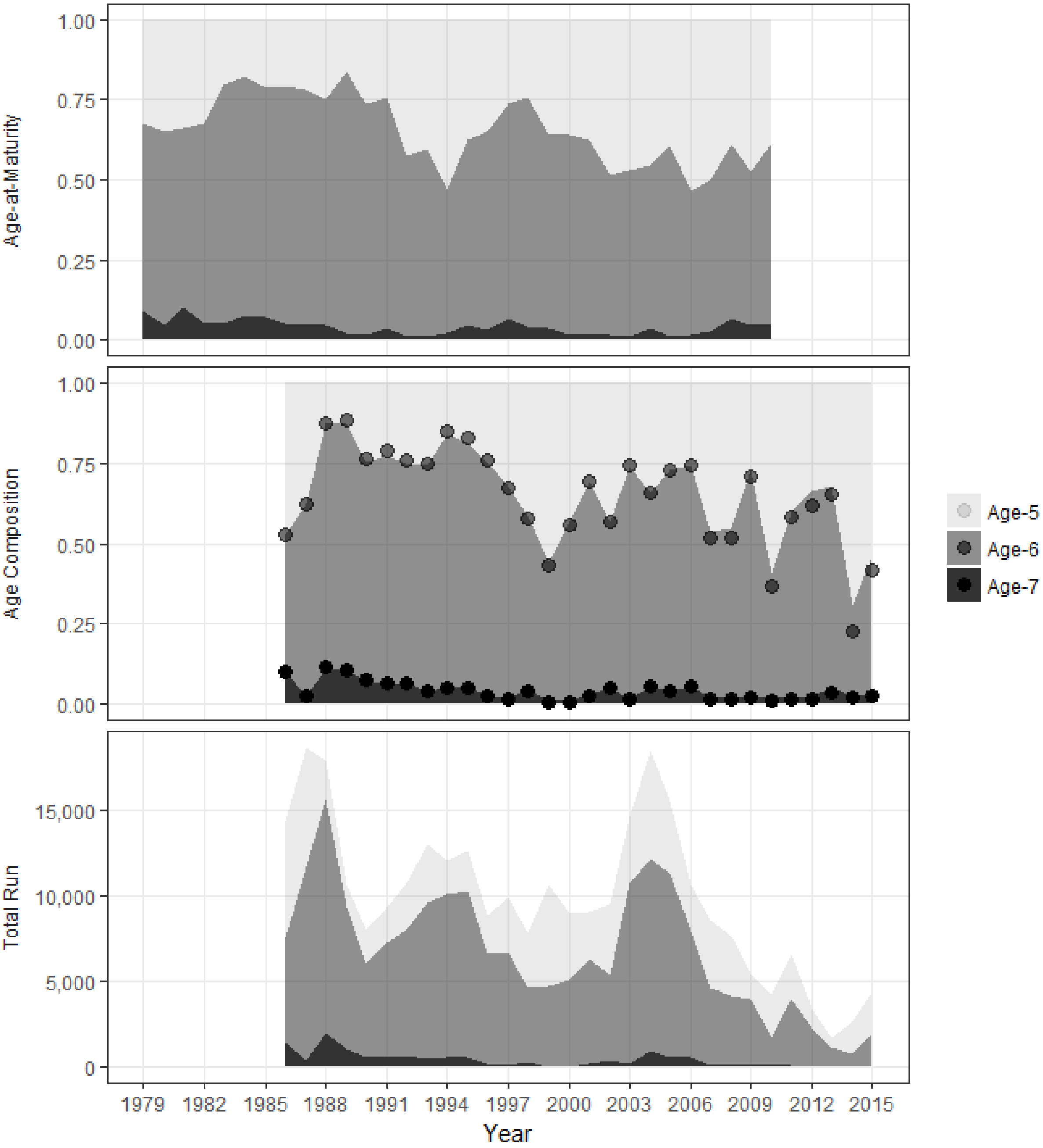

Figure 6.–Estimated age-at-maturity proportions by brood year (top), age composition proportions by calendar year (middle), and total run by age (bottom), from state-space model fitted to data from Kenai River **early-run** Chinook salmon 75 cm METF and longer.

*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 from Appendix B1.

## Productivity, Yield, and Recruitment

Estimates of population parameters from the state-space model take the measurement errors in escapement *S* and recruitment *R* (Figure 7 error bars) into account. The individual data pairs are weighted differentially, depending upon the certainty with which the individual values of *S* and *R* are known. Because measurement error is substantial for many brood years, and due to other sources of uncertainty, Ricker SR relationships that could have plausibly generated the observed data are diverse (Figure 7: light lines), often deviating substantially from the median Ricker relationship (Figure 7: heavy dashed line).

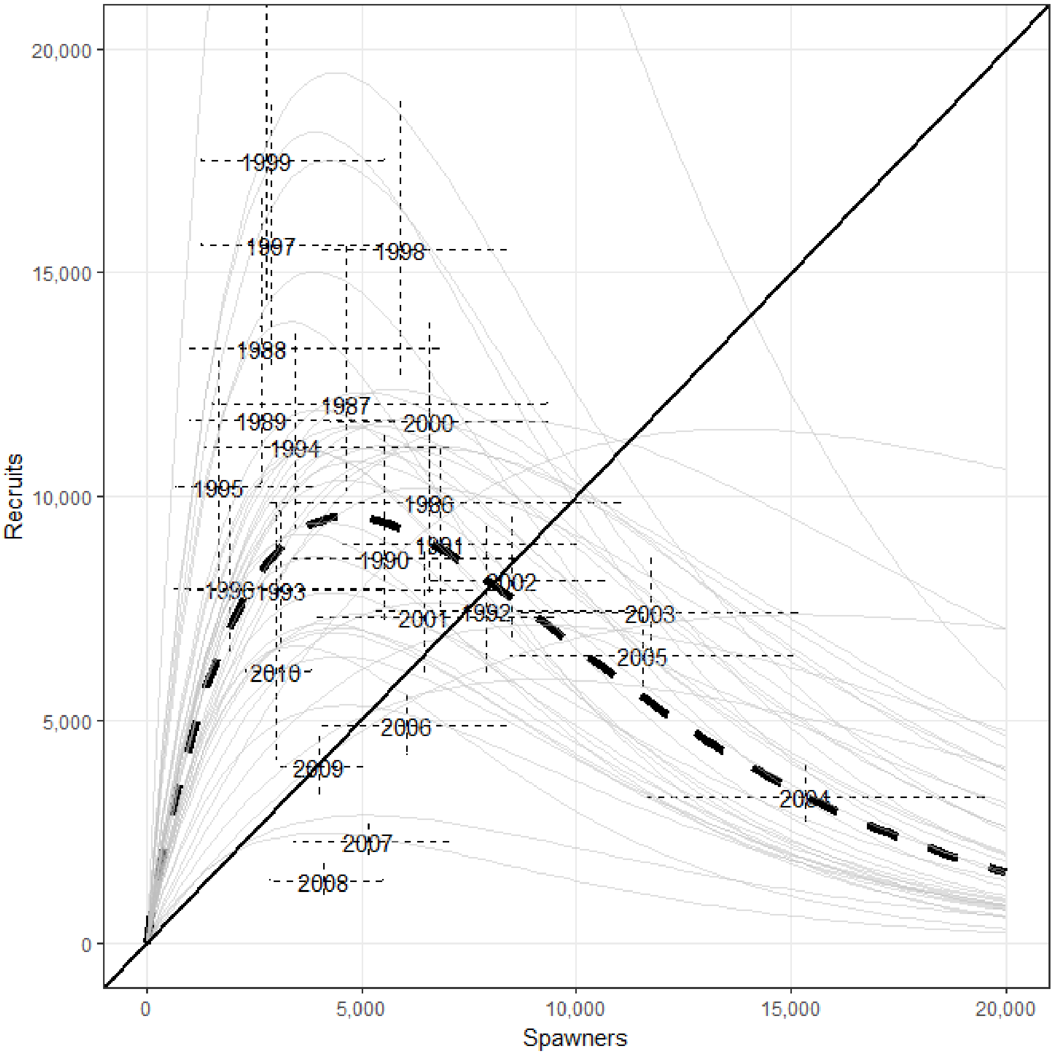

Figure 7.–Plausible spawner-recruit relationships for Kenai River **early-run** Chinook salmon 75 cm METF and longer, as derived from an age-structured state-space model fitted to abundance, harvest, and age data for 1986–2015.

*Note*: Posterior medians of R and S are plotted as brood year labels with 90% credibility intervals plotted as light dashed lines. The heavy dashed line is the Ricker relationship constructed from ln($\alpha$) and $\beta$ posterior medians. Ricker relationships are also plotted (light grey lines) for 40 paired values of ln($\alpha$) and $\beta$ 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.

Median productivity (recruits per spawner, in the absence of density effects) of early-run Chinook salmon during 1986–2015 has been moderately high ($\alpha = 5.5$; Table 3). There is a great deal of uncertainty about $\alpha$ (CV = 0.63; Table 3), as evident in the extent to which the plausible SR relationships differ with respect to their slope at $S = 0$ (Figure 7). Similarly, uncertainty about $\beta$ is reflected in variability in the values of $S$ leading to maximum recruitment $S_{MSR} = 1/\beta$, and uncertainty about equilibrium abundance $S_{EQ}$ is reflected by variability in the values of $S$ where the curves intersect the replacement line.

Table 3.–State-space model parameter estimates for Kenai River **early-run** Chinook salmon 75 cm METF and longer for calendar years 1986–2015.

| Parameter | Median | 0.05 percentile | 0.95 percentile | CV |
|---|---|---|---|---|
| $\ln(\alpha)$ | 1.7 | 0.78 | 2.7 | 0.39 |
| $\alpha$ | 5.5 | 2.2 | 14.7 | 0.63 |
| $\beta$ | 2.12e-04 | 1.30e-04 | 3.10e-04 | 0.27 |
| $\phi$ | 0.76 | 0.48 | 0.96 | 0.21 |
| $\sigma_w$ | 0.47 | 0.35 | 0.67 | 0.20 |
| $S_{MSR}$ | 4,728 | 3,226 | 7,664 | 0.27 |
| $S_{EQ}$ | 9,324 | 6,333 | 18,197 | 0.33 |
| $S_{MSY}$ | 3,283 | 2,262 | 4,981 | 0.24 |
| $U_{MSY}$ | 0.71 | 0.47 | 0.88 | 0.19 |
| D | 21.6 | 14.4 | 31.4 | 0.24 |
| $\pi_1$ | 0.34 | 0.31 | 0.37 | 0.06 |
| $\pi_2$ | 0.61 | 0.58 | 0.64 | 0.03 |
| $\pi_3$ | 0.05 | 0.04 | 0.06 | 0.17 |
| $p_{MR}$ | 0.80 | 0.74 | 0.86 | 0.04 |
| $q_{NCPUE}$ | 2.24e-04 | 1.97e-04 | 2.57e-04 | 0.08 |
| $q_{NASB}$ | 0.61 | 0.53 | 0.72 | 0.10 |
| $q_{SCPUE}$ | 5.18e-06 | 4.34e-06 | 6.16e-06 | 0.11 |
| $q_{N^{LR}}$ | 4.9 | 4.4 | 5.4 | 0.06 |
| $\sigma_{NCPUE}$ | 0.22 | 0.15 | 0.34 | 0.24 |
| $\sigma_{NASB}$ | 0.26 | 0.18 | 0.41 | 0.25 |
| $\sigma_{SCPUE}$ | 0.44 | 0.34 | 0.59 | 0.17 |
| $\sigma_{N^{LR}}$ | 0.21 | 0.16 | 0.29 | 0.18 |

*Note*: Posterior medians are point estimates, 5th and 95th percentiles define 90% credibility intervals for the parameters. Parameter definitions are in the Methods section.

The Ricker recruitment residuals in Figure 5 (bottom panel) are deviations in recruitment from that predicted by the Ricker SR relationship, reflecting time-varying changes in productivity after controlling for density-dependent effects. Early-run productivity was relatively stable through the 2005 brood year, declined sharply from 2006 to 2008, and increased in 2009 and 2010, perhaps reflecting rapid changes in density-independent marine survival.

Escapement leading to maximum sustained yield $S_{MSY}$ was estimated to be between 2,262 and 4,981 (posterior median 3,283, CV 0.24; Table 3). Given the diversity of plausible SR relationships (Figure 7), it is important to choose an escapement goal that is robust to this uncertainty rather than one tailored solely to the median SR relationship. To address this uncertainty we tallied the success or failure of a given number of spawners to achieve biological reference points across plausible SR relationships. Sustained yield is the number of fish in the expected recruitment over and above that needed to replace the spawners. The optimal yield profiles in Figure 8 (top panel) show the probability of a given number of spawners achieving 70%, 80%, and 90% of *MSY*. These probabilities, which are highest near $S_{MSY}$, can be used to quantify the yield performance of prospective escapement goals (Figure 8 shaded areas), taking into consideration all of the uncertainty about the true abundance and productivity of the stock. The overfishing profiles (Figure 8 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 ($1 - p$) of the probabilities ($p$) 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 1986–2010) is also maximized at $S_{MSY}$ (Figure 9). Under reduced levels of productivity experienced during the 5 most recent brood years for which we have data (2006–2010; Figure 5 bottom panel), expected yield declined to approximately 20% of the historical average (Figure 9).

Early-run Chinook salmon are taken primarily by a sport fishery with limited harvest (due to a slot limit and other restrictions), and thus large run sizes and high catch rates are an important priority. Run size is associated with large recruitments. Therefore, we constructed optimal recruitment profiles by tallying, across plausible SR relationships, the success or failure of a given number of spawners to achieve stated percentages of *MSR*. The profiles, which are highest near $S_{MSR}$ = 4,728 (CV 0.27; Table 3), display the probability of achieving 70%, 80%, and 90% of *MSR* for specified levels of early-run escapement (Figure 8 bottom panel).

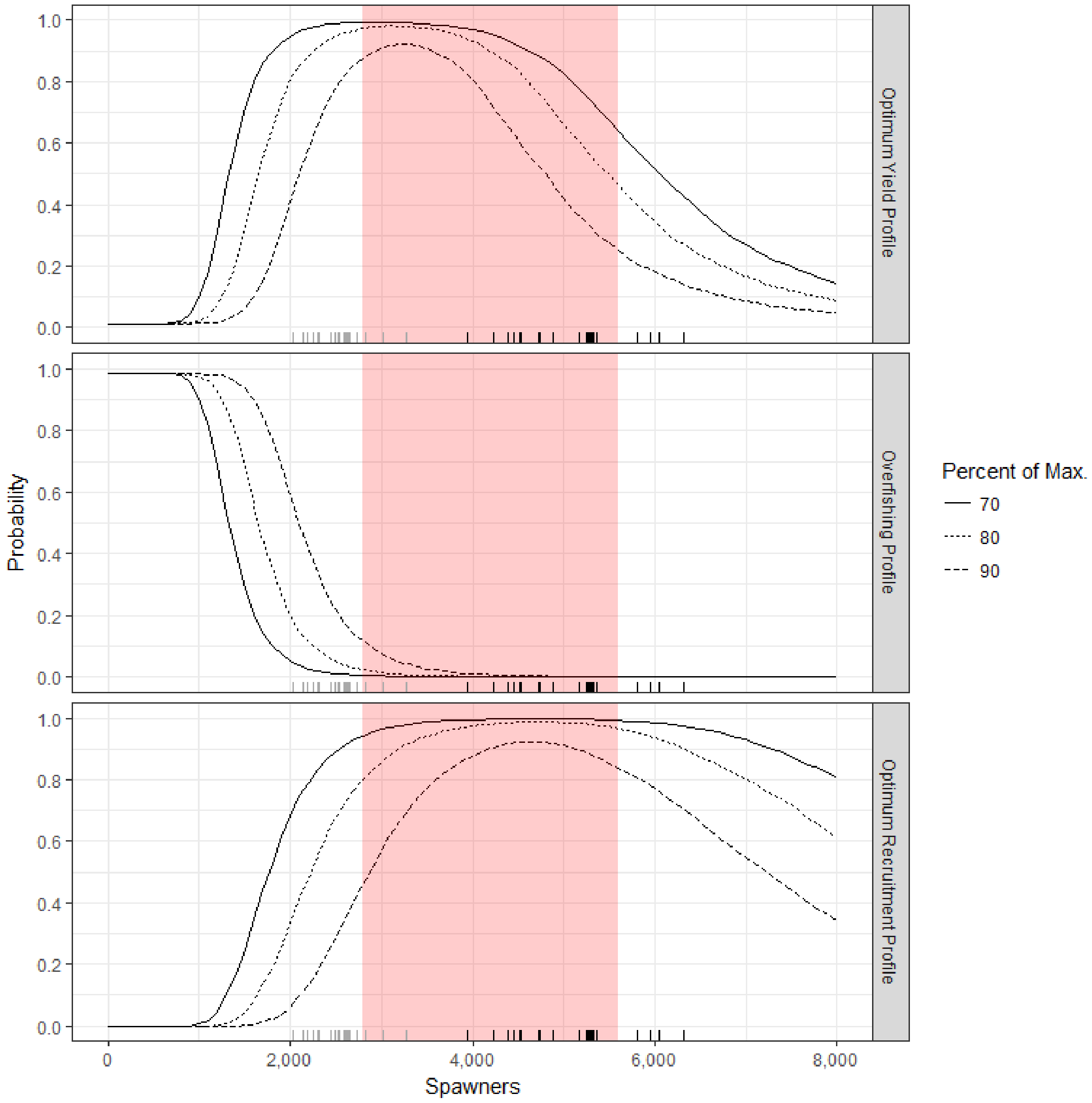

Figure 8.–Optimal yield profiles (OYPs), overfishing profiles (OFPs), and optimal recruitment profiles (ORPs) for Kenai River **early-run** Chinook salmon 75 cm METF and longer.

*Note*: OYPs and ORPs show probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield or maximum recruitment. OFPs show probability that reducing escapement to a specified spawning abundance will result in less than specified fractions of maximum sustained yield. Shaded areas bracket the recommended goal ranges; grey and black marks along the *x*-axis show comparable lower and upper bounds for other Alaskan Chinook salmon stocks scaled by $S_{MSY}$ ratios (see Methods).

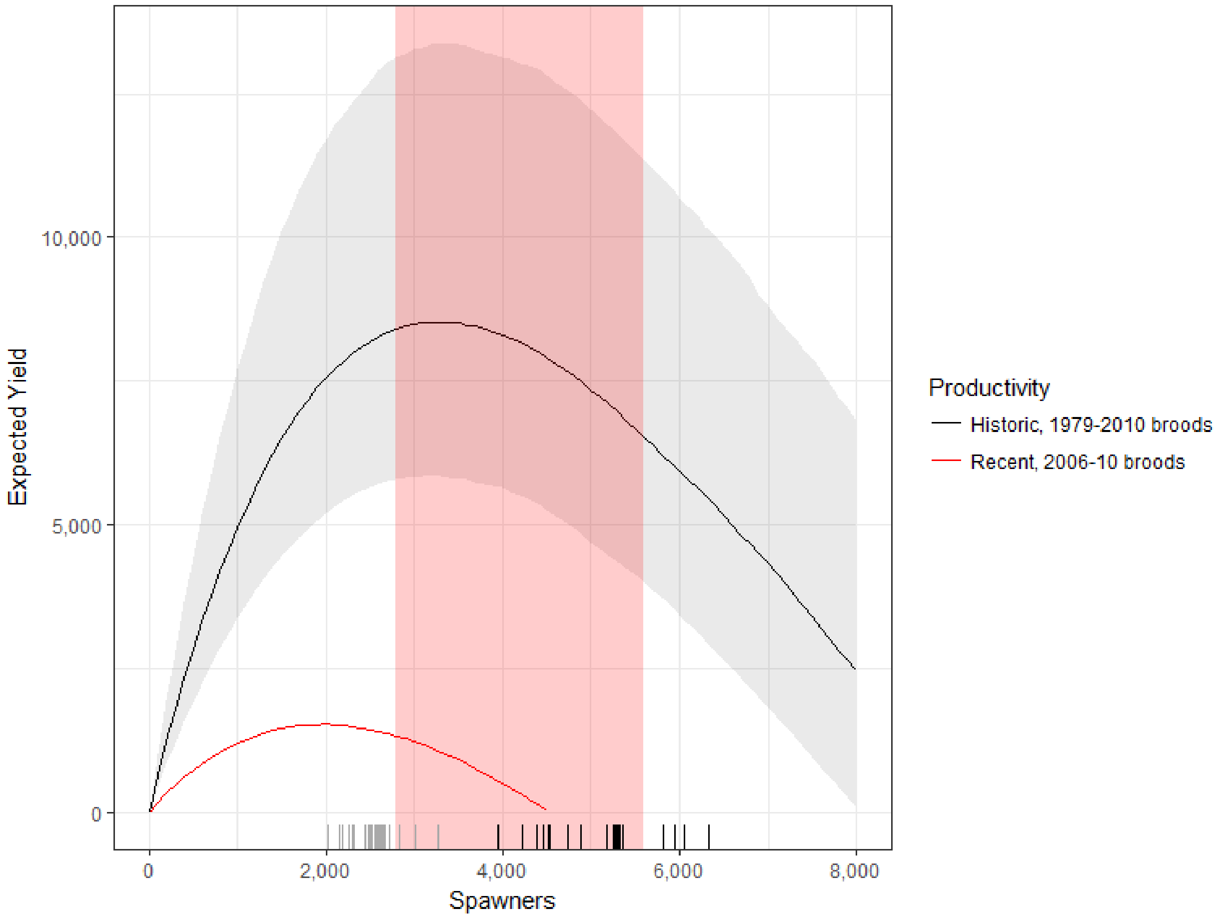

Figure 9.–Expected sustained yield (ESY) plots for Kenai River **early-run** Chinook salmon 75 cm METF and longer.

*Note*: ESY median (solid black line) and 50% interval (shaded area around the line) assume average productivity for brood years 1979–2010. Median ESY under recent, reduced productivity (brood years 2006–2010) is also shown (solid red line). The shaded vertical area brackets the recommended goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds for other Alaskan Chinook salmon stocks scaled by $S_{MSY}$ ratios (see Methods).

## LATE RUN

Appendices B3 and B4 summarize empirical estimates of late-run harvest and age composition for Chinook salmon 75 cm METF and longer. Appendix B5 summarizes annual empirical measures of relative and absolute abundance. Estimates in Appendices B3–B5 compose the data that inform the parameters of the state-space model, yielding the results below.

### Abundance, Harvest Rates, and Age at Maturity

As with the early run, measures of late-run abundance exhibited common trends through time, and reconstructed estimates of run abundance generally passed through the center of the scaled individual measures (Figure 10). Runs were largest during 1986–1988 and 2003–2005, and have declined in size since 2004. From 2010 through 2015, when multiple indices and absolute assessments were available, estimates of total run, inriver run, and escapement were precise (CV = 0.03–0.06, Table 4). Before 2010, CVs were 0.12–0.22 for total run, 0.14–0.25 for inriver run, and 0.18–0.37 for escapement (Table 4). Coefficients of variation for recruitment were 0.20 or lower except at the beginning and end of the data series, when one or more age classes were missing (Table 4; Figure 11 third panel).

The harvest rate on late-run Chinook salmon 75 cm METF and longer ranged mostly between 30% and 50% of total run abundance from 1986 to 2011, but was less than 30% thereafter (Figure 11 fourth panel).

Chinook salmon 75 cm METF and longer were composed primarily of age-5 (1.3) and age-6 (1.4) fish (Table 5, Figure 12 middle and bottom panels). Late run Chinook salmon 75 cm METF and longer matured at age 5 (15–45%), age 6 (50–75%), and age 7 (0–10%; Figure 12 top panel). The trend toward earlier maturation was less evident in the late run (Figure 12 top panel) than in the early run (Figure 6 top panel).

### Stock Productivity and Yield

Plausible Ricker SR relationships for the late run are depicted in Figure 13. The late-run stock was less productive during 1986–2015, on average, ($\alpha$ = 3.5; Table 6) than the early-run stock ($\alpha$ = 5.5; Table 3).

The Ricker recruitment residuals (Figure 11 bottom panel) are deviations in recruitment from that predicted by the Ricker SR relationship, reflecting time-varying changes in productivity after controlling for density-dependent effects. Late-run productivity reached a high for the 1999 brood year, then declined steadily until rebounding slightly for the 2009–2010 brood years.

Escapement leading to maximum sustained yield $S_{MSY}$ was estimated to be between 11,731 and 31,832 (posterior median 18,477, CV 0.31; Table 6). Late-run $S_{MSY}$ was estimated with somewhat less certainty than early-run $S_{MSY}$ (CV = 0.24; Table 3). The optimal yield profiles (Figure 14 top panel) are slightly less steep and reach lower maxima than the early run, indicating less certainty about yield dynamics.

Expected sustained yield (number of fish over and above that necessary to replace the number of spawners, averaged over brood years 1986–2010) is also maximized near $S_{MSY}$ (Figure 15). Under the reduced levels of productivity experienced during the most recent brood years for which we have data (2006–2010; Figure 11 bottom panel), expected yield declined to approximately 25% of the historical average (Figure 15).

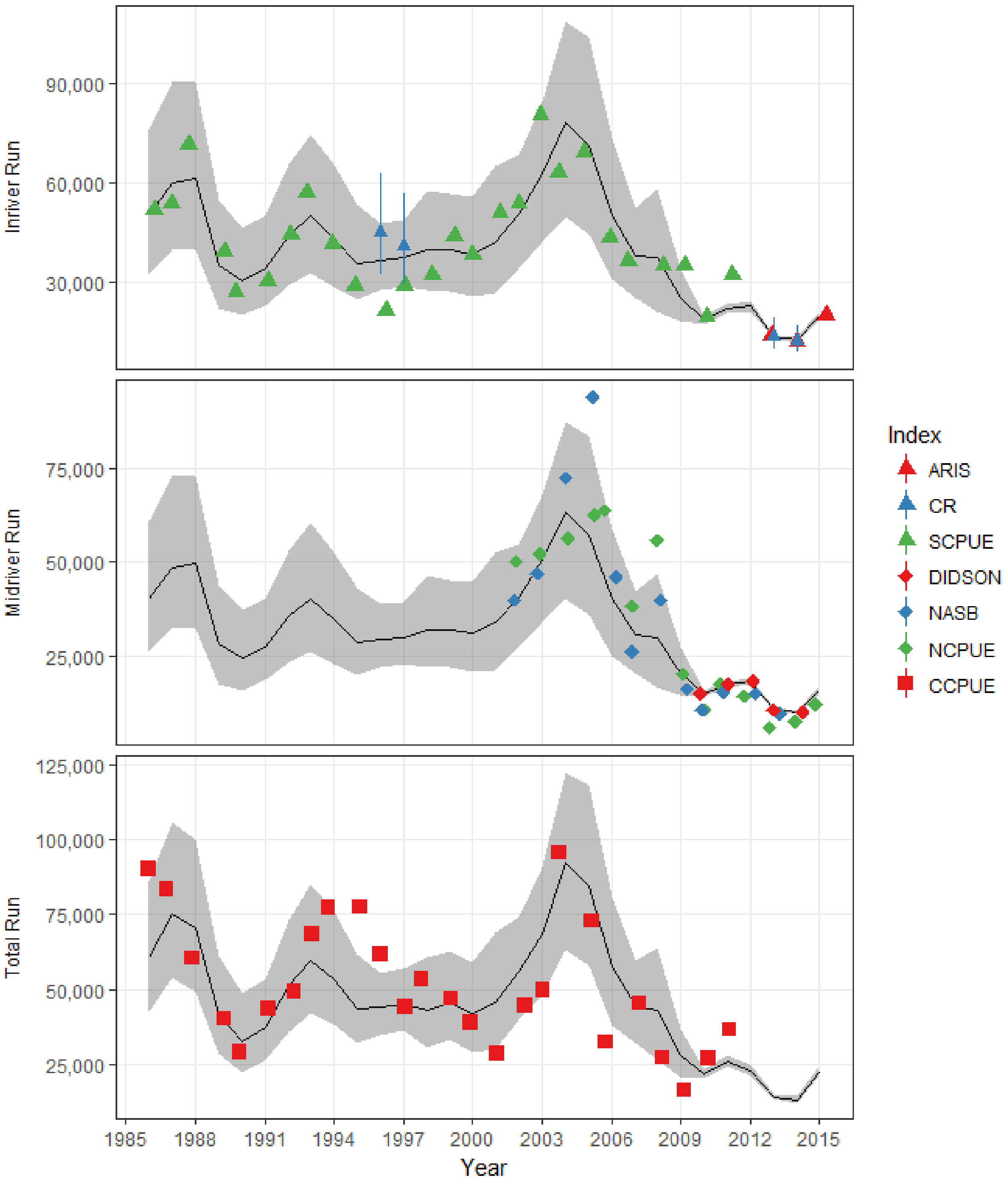

Figure 10.–Inriver, midriver, and total run abundance (dark black lines show the median; shaded areas show 95% credibility intervals) of **late-run** Kenai River Chinook salmon 75 cm METF and longer as reconstructed from 4 indices of relative abundance: inriver gillnet catch rate (NCPUE), split-beam sonar salmon abundance apportioned by Chinook salmon fraction in test gillnets (NASB), catch rate in the lower-river sport fishery (SCPUE), and catch rate in the commercial fishery (CCPUE); plus direct sonar estimates of midriver run at RM 8.6 (DIDSON), direct sonar estimates of inriver run at RM 13.7 (ARIS), and capture-recapture estimates of inriver run (CR, 95% credibility interval bounds plotted).

*Note*: For plotting, each relative abundance index was expanded by the posterior median of the inverse of its scaling factor $q$ (see Equation 18). Points are jittered along the $x$-axis.

Table 4.–Annual abundance estimates for **late-run** Kenai River Chinook salmon 75 cm METF and longer obtained by fitting a state-space model to data from 1979-2015.

| Year | Total run (CV) | Inriver run (CV) | Escapement (CV) | Recruitment (CV) |
|---|---|---|---|---|
| 1979 | – | – | – | 51,903 (0.60) |
| 1980 | – | – | – | 40,003 (0.22) |
| 1981 | – | – | – | 92,417 (0.16) |
| 1982 | – | – | – | 80,767 (0.17) |
| 1983 | – | – | – | 37,959 (0.19) |
| 1984 | – | – | – | 35,395 (0.19) |
| 1985 | – | – | – | 33,505 (0.18) |
| 1986 | 60,707 (0.18) | 49,957 (0.22) | 40,972 (0.26) | 52,117 (0.17) |
| 1987 | 75,072 (0.17) | 60,130 (0.21) | 47,070 (0.27) | 59,676 (0.17) |
| 1988 | 70,835 (0.18) | 61,342 (0.21) | 41,572 (0.30) | 55,907 (0.17) |
| 1989 | 41,725 (0.20) | 34,828 (0.23) | 25,336 (0.32) | 38,640 (0.17) |
| 1990 | 33,185 (0.20) | 30,253 (0.22) | 24,478 (0.27) | 40,111 (0.13) |
| 1991 | 37,783 (0.18) | 33,876 (0.20) | 26,303 (0.26) | 50,992 (0.11) |
| 1992 | 51,494 (0.18) | 44,071 (0.21) | 36,583 (0.25) | 45,463 (0.16) |
| 1993 | 59,897 (0.18) | 50,019 (0.21) | 32,448 (0.32) | 43,137 (0.16) |
| 1994 | 53,541 (0.18) | 43,010 (0.22) | 25,033 (0.37) | 40,287 (0.17) |
| 1995 | 43,622 (0.17) | 35,630 (0.21) | 24,016 (0.30) | 48,753 (0.19) |
| 1996 | 44,214 (0.12) | 36,457 (0.14) | 28,806 (0.18) | 52,404 (0.16) |
| 1997 | 45,388 (0.12) | 37,110 (0.14) | 24,822 (0.21) | 65,395 (0.15) |
| 1998 | 43,261 (0.17) | 39,527 (0.19) | 32,560 (0.23) | 85,907 (0.16) |
| 1999 | 45,948 (0.16) | 39,454 (0.19) | 28,520 (0.26) | 97,451 (0.17) |
| 2000 | 42,039 (0.18) | 38,432 (0.20) | 24,923 (0.31) | 60,123 (0.19) |
| 2001 | 45,973 (0.21) | 41,970 (0.23) | 28,442 (0.34) | 41,366 (0.17) |
| 2002 | 56,303 (0.15) | 50,372 (0.17) | 40,381 (0.22) | 45,349 (0.20) |
| 2003 | 68,512 (0.16) | 62,615 (0.17) | 48,278 (0.22) | 32,442 (0.15) |
| 2004 | 92,115 (0.16) | 78,280 (0.19) | 65,084 (0.23) | 17,445 (0.10) |
| 2005 | 84,751 (0.18) | 71,099 (0.21) | 54,669 (0.27) | 28,511 (0.06) |
| 2006 | 57,634 (0.19) | 50,067 (0.22) | 38,619 (0.29) | 21,369 (0.08) |
| 2007 | 44,736 (0.15) | 37,872 (0.18) | 29,461 (0.23) | 18,982 (0.07) |
| 2008 | 43,069 (0.22) | 37,329 (0.25) | 27,545 (0.34) | 13,110 (0.08) |
| 2009 | 28,244 (0.14) | 25,137 (0.16) | 17,992 (0.23) | 21,093 (0.07) |
| 2010 | 22,247 (0.04) | 18,531 (0.04) | 13,035 (0.06) | 23,513 (0.24) |
| 2011 | 26,412 (0.04) | 21,689 (0.04) | 15,742 (0.06) | – |
| 2012 | 23,311 (0.04) | 22,622 (0.04) | 22,455 (0.04) | – |
| 2013 | 14,413 (0.03) | 13,329 (0.03) | 12,308 (0.03) | – |
| 2014 | 13,445 (0.04) | 12,304 (0.03) | 11,972 (0.03) | – |
| 2015 | 22,861 (0.04) | 19,496 (0.04) | 16,830 (0.04) | – |

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

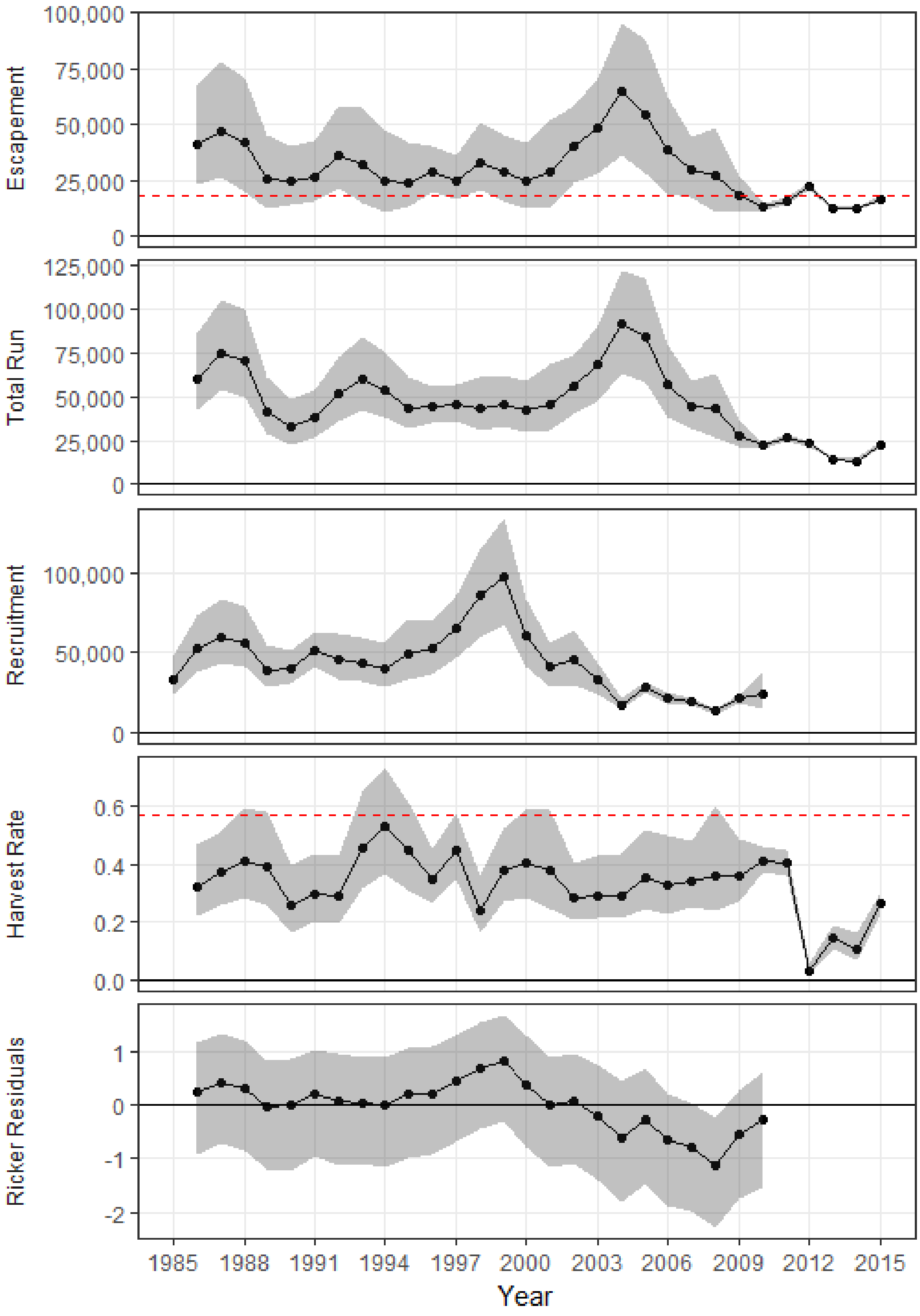

Figure 11.–Point estimates (posterior medians; solid lines) and 95% credibility intervals (shaded areas) of spawning escapement, total run abundance, recruitment by brood year, harvest rate, and Ricker productivity residuals from a state-space model of Kenai River **late-run** Chinook salmon 75 cm METF and longer, 1986-2015.

*Note*: Posterior medians of $S_{MSY}$ and $U_{MSY}$ are plotted as dashed horizontal reference lines.

Table 5.–Total run abundance by age class obtained by fitting a state-space model to data from Kenai River **late-run** Chinook salmon 75 cm METF and longer, 1986–2015.

| Year | Age 5 (CV) | Age 6 (CV) | Age 7 (CV) |
|---|---:|---:|---:|
| 1986 | 28,843 (0.20) | 28,643 (0.21) | 2,881 (0.44) |
| 1987 | 20,049 (0.22) | 53,373 (0.18) | 1,315 (0.57) |
| 1988 | 5,929 (0.31) | 55,173 (0.19) | 9,289 (0.28) |
| 1989 | 6,559 (0.27) | 29,895 (0.21) | 5,161 (0.31) |
| 1990 | 4,818 (0.28) | 26,277 (0.21) | 1,884 (0.39) |
| 1991 | 8,331 (0.24) | 26,933 (0.20) | 2,381 (0.37) |
| 1992 | 9,550 (0.25) | 39,956 (0.19) | 1,610 (0.47) |
| 1993 | 9,510 (0.26) | 46,669 (0.19) | 3,341 (0.39) |
| 1994 | 7,332 (0.27) | 42,680 (0.18) | 3,149 (0.38) |
| 1995 | 10,074 (0.23) | 30,070 (0.18) | 3,353 (0.35) |
| 1996 | 14,614 (0.17) | 28,372 (0.14) | 968 (0.56) |
| 1997 | 9,872 (0.20) | 34,222 (0.13) | 1,251 (0.48) |
| 1998 | 8,100 (0.24) | 33,132 (0.18) | 1,898 (0.42) |
| 1999 | 10,198 (0.23) | 33,151 (0.17) | 2,308 (0.40) |
| 2000 | 12,019 (0.23) | 28,189 (0.19) | 1,511 (0.46) |
| 2001 | 9,976 (0.27) | 34,200 (0.22) | 1,578 (0.47) |
| 2002 | 13,123 (0.22) | 40,530 (0.16) | 2,257 (0.42) |
| 2003 | 17,229 (0.22) | 49,350 (0.17) | 1,405 (0.57) |
| 2004 | 24,465 (0.22) | 64,462 (0.17) | 2,385 (0.50) |
| 2005 | 15,010 (0.25) | 65,599 (0.19) | 3,580 (0.43) |
| 2006 | 10,299 (0.26) | 40,112 (0.20) | 6,711 (0.31) |
| 2007 | 12,498 (0.21) | 27,552 (0.17) | 4,371 (0.31) |
| 2008 | 8,869 (0.26) | 30,653 (0.23) | 3,158 (0.38) |
| 2009 | 4,703 (0.22) | 21,594 (0.16) | 1,747 (0.38) |
| 2010 | 8,760 (0.12) | 11,719 (0.10) | 1,701 (0.29) |
| 2011 | 6,843 (0.15) | 18,636 (0.07) | 902 (0.44) |
| 2012 | 8,470 (0.13) | 13,681 (0.09) | 1,055 (0.39) |
| 2013 | 3,622 (0.15) | 9,994 (0.07) | 766 (0.35) |
| 2014 | 4,684 (0.13) | 8,225 (0.08) | 494 (0.43) |
| 2015 | 6,302 (0.15) | 15,302 (0.07) | 1,192 (0.35) |

*Note*: Point estimates are posterior medians; CVs are posterior standard deviations divided by posterior means.

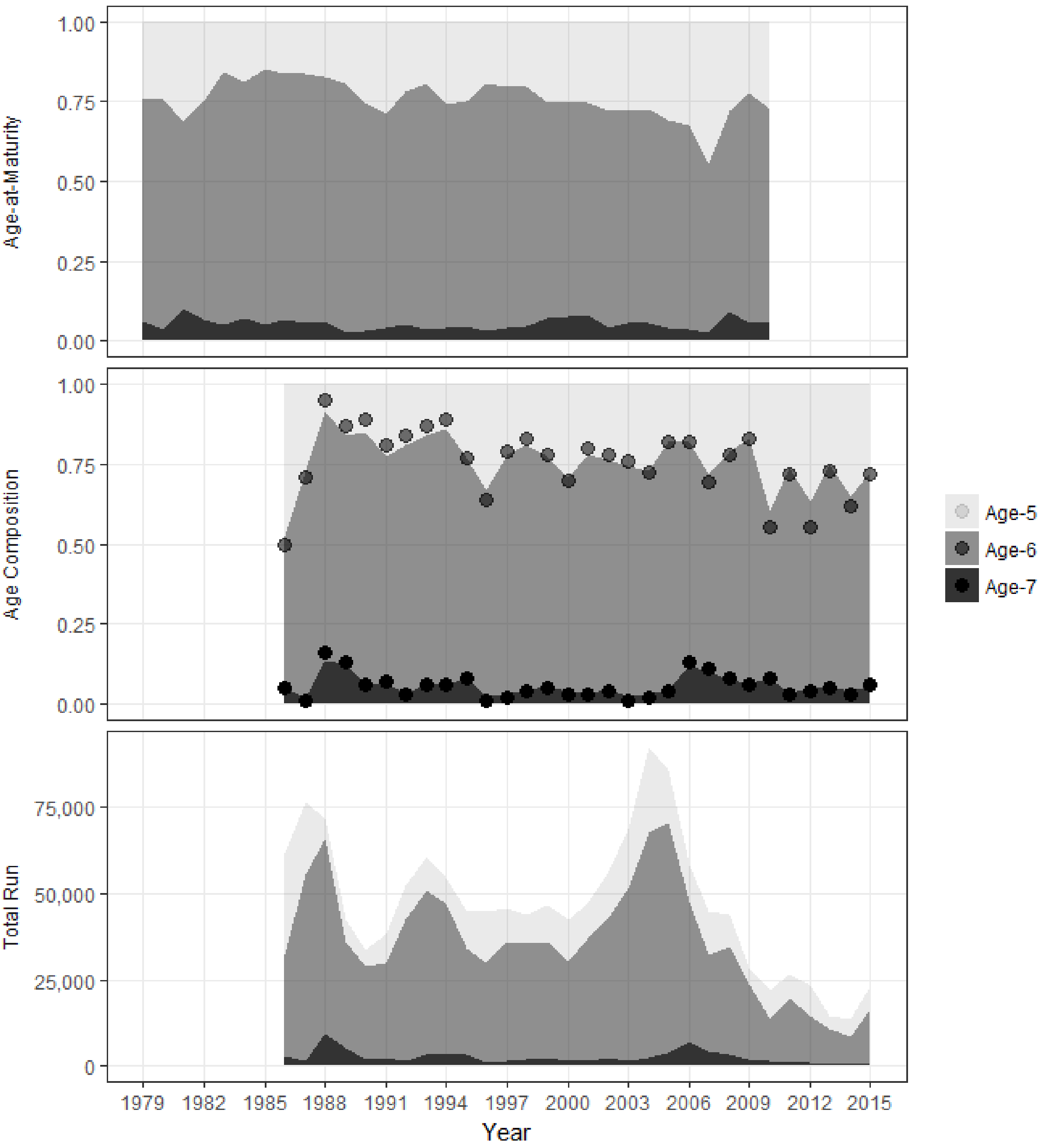

Figure 12.–Area graphs of estimated age-at-maturity proportions by brood year (top), age composition proportions by calendar year (middle), and total run by age (bottom), from state-space model fitted to data from Kenai River **late-run** Chinook salmon 75 cm METF and longer.

*Note*: Dots in middle plot are data-based estimates of age composition from Appendix B4.

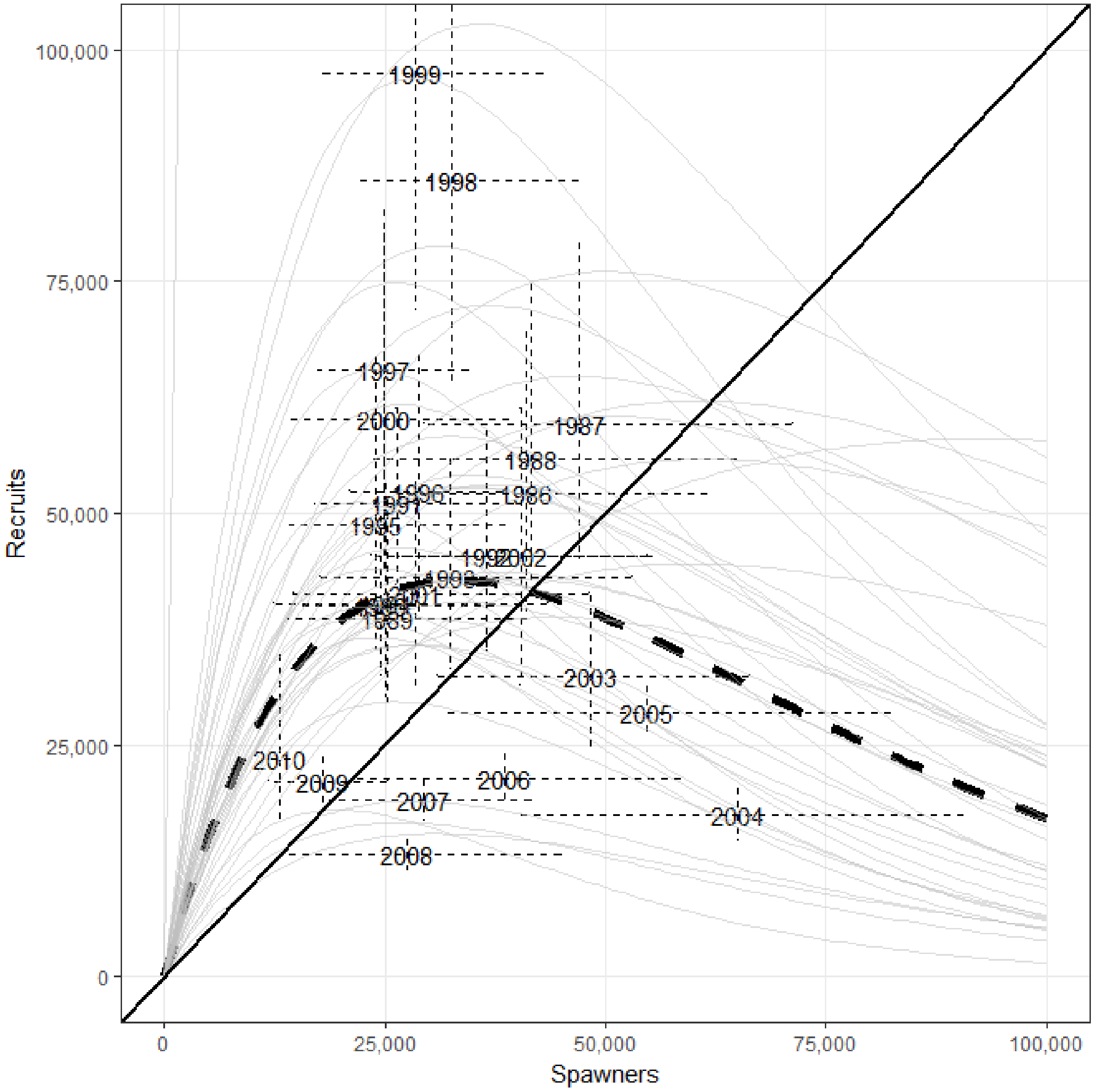

Figure 13.–Plausible spawner-recruit relationships for Kenai River **late-run** Chinook salmon 75 cm METF and longer, as derived from an age-structured state-space model fitted to abundance, harvest, and age data for 1986–2015.

*Note*: Posterior medians of R and S are plotted as brood year labels with 90% credibility intervals plotted as light dashed lines. The heavy dashed line is the Ricker relationship constructed from ln($\alpha$) and $\beta$ posterior medians. Ricker relationships are also plotted (light grey lines) for 40 paired values of ln($\alpha$) and $\beta$ 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.

Table 6.–State-space model parameter estimates for Kenai River **late-run** Chinook salmon 75 cm METF and longer, calendar years 1986–2015.

| Parameter | Median | 0.05 percentile | 0.95 percentile | CV |
|---|---|---|---|---|
| $\ln(\alpha)$ | 1.3 | 0.50 | 2.2 | 0.47 |
| $\alpha$ | 3.5 | 1.6 | 8.7 | 0.54 |
| $\beta$ | 3.03e-05 | 1.56e-05 | 4.89e-05 | 0.36 |
| $\phi$ | 0.81 | 0.57 | 0.97 | 0.16 |
| $\sigma_w$ | 0.31 | 0.22 | 0.44 | 0.21 |
| $S_{MSR}$ | 33,041 | 20,439 | 64,066 | 0.36 |
| $S_{EQ}$ | 47,252 | 29,651 | 99,947 | 0.38 |
| $S_{MSY}$ | 18,477 | 11,731 | 31,832 | 0.31 |
| $U_{MSY}$ | 0.57 | 0.31 | 0.81 | 0.30 |
| D | 43.4 | 27.4 | 69.7 | 0.29 |
| $\pi_1$ | 0.24 | 0.22 | 0.26 | 0.06 |
| $\pi_2$ | 0.70 | 0.68 | 0.73 | 0.02 |
| $\pi_3$ | 0.06 | 0.05 | 0.07 | 0.13 |
| $p_{MR}$ | 0.81 | 0.77 | 0.85 | 0.03 |
| $q_{NCPUE}$ | 1.91e-04 | 1.59e-04 | 2.51e-04 | 0.14 |
| $q_{NASB}$ | 0.79 | 0.66 | 1.0 | 0.13 |
| $q_{SCPUE}$ | 1.69e-06 | 1.39e-06 | 2.12e-06 | 0.13 |
| $q_{CCPUE}$ | 0.01 | 0.01 | 0.02 | 0.12 |
| $\sigma_{NCPUE}$ | 0.35 | 0.23 | 0.59 | 0.29 |
| $\sigma_{NASB}$ | 0.27 | 0.16 | 0.49 | 0.35 |
| $\sigma_{SCPUE}$ | 0.26 | 0.19 | 0.36 | 0.20 |
| $\sigma_{CCPUE}$ | 0.33 | 0.24 | 0.45 | 0.20 |

*Note*: Posterior medians are point estimates; 5th and 95th percentiles define 90% credibility intervals for the parameters. Parameter definitions are in the Methods section.

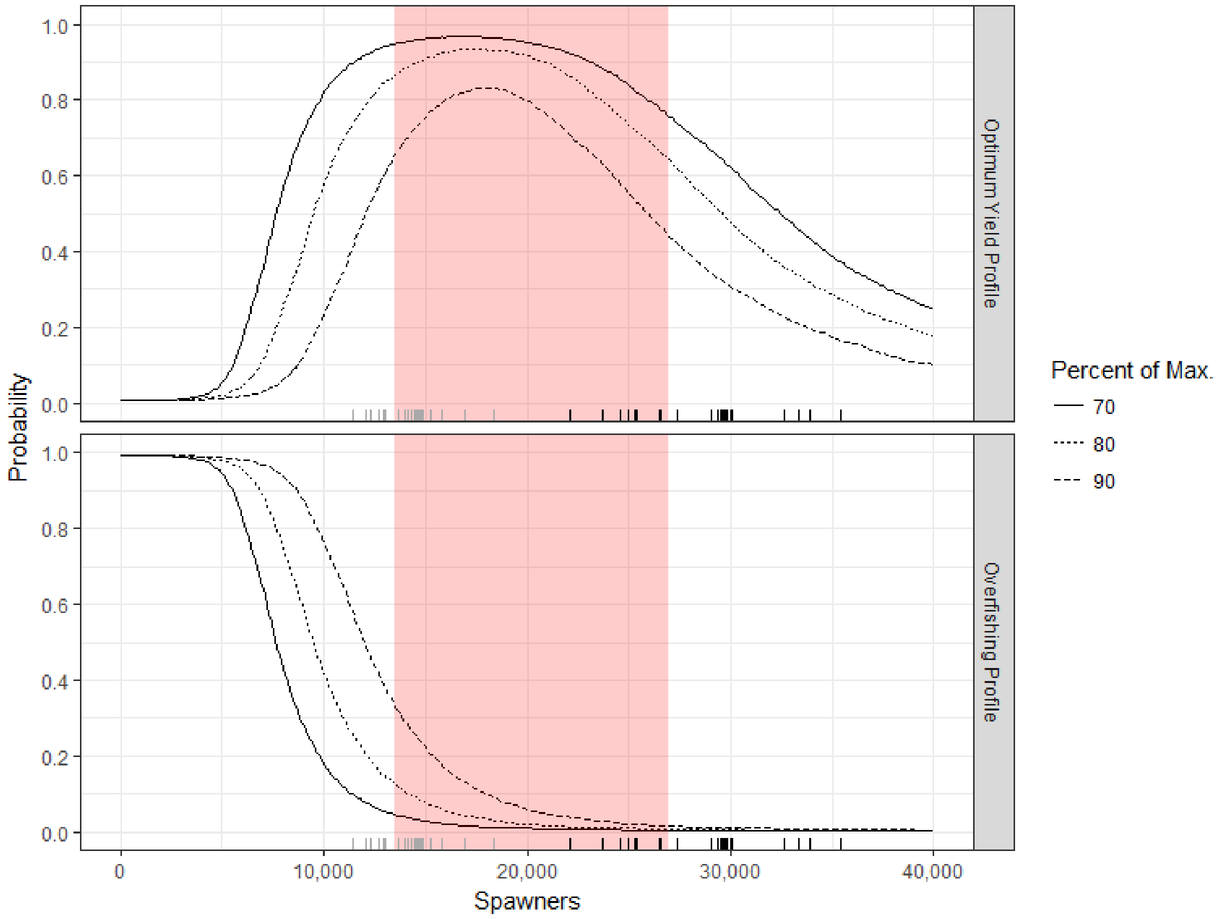

Figure 14.–Optimal yield profiles (OYP) plots for Kenai River **late-run** Chinook salmon 75 cm METF and longer. OYPs show probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield.

*Note*: Shaded areas bracket the recommended goal ranges; grey and black marks along the *x*-axis show comparable lower and upper bounds for other Alaskan Chinook salmon stocks scaled by $S_{MSY}$ ratios (see Methods).

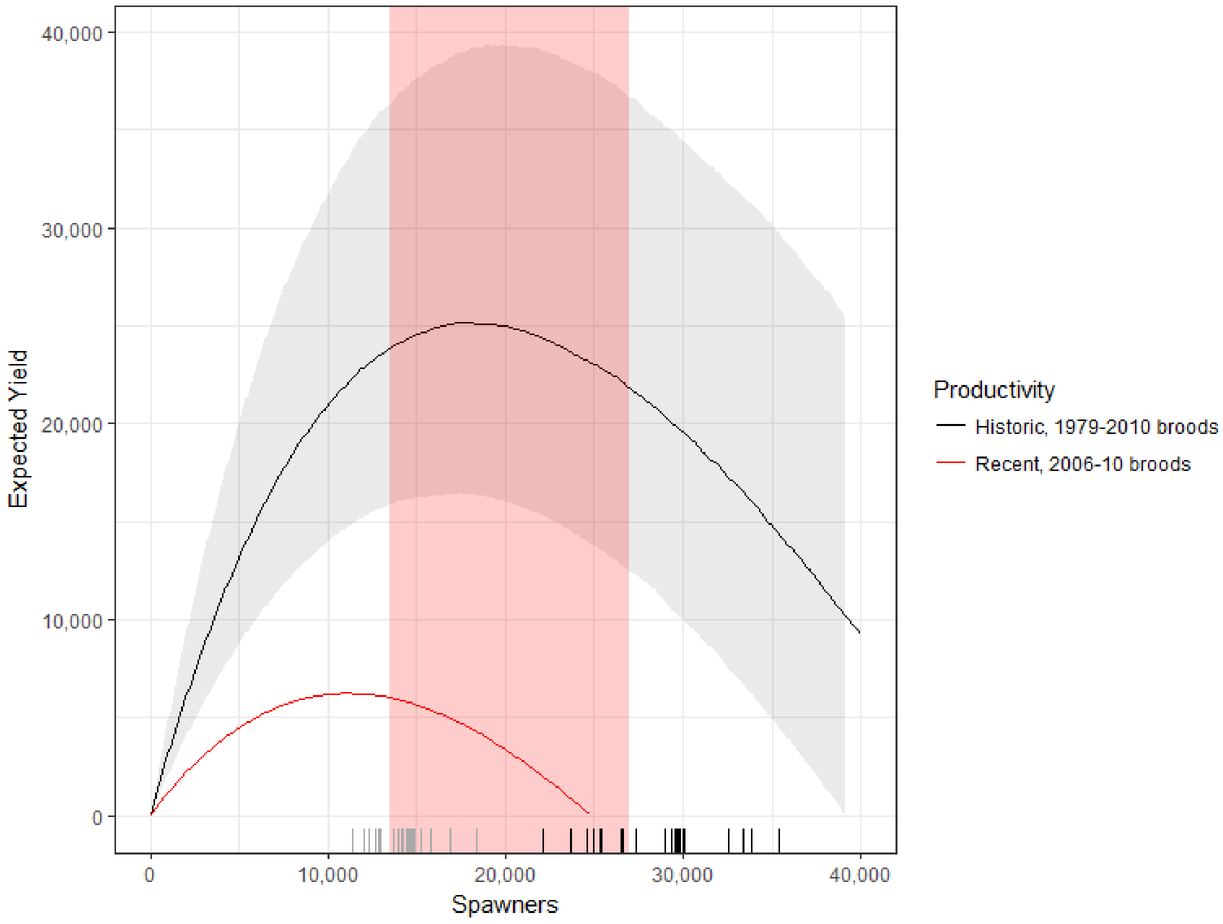

Figure 15.–Expected sustained yield (ESY) plots for Kenai River **late-run** Chinook salmon 75 cm METF and longer.

*Note*: ESY median (solid black line) and 50% credibility interval (shaded area around the line) assume average productivity for brood years 1979–2010. Median ESY under recent, reduced productivity (brood years 2006–2010) is also shown (solid red line). The vertical shaded area brackets the recommended goal range; grey and black marks along the *x*-axis show comparable lower and upper bounds for other Alaskan Chinook salmon stocks scaled by $S_{MSY}$ ratios (see Methods).

# DISCUSSION

## WHY CHANGE TO SIZE-BASED ESCAPEMENT GOALS?

We propose that inseason management of Kenai River Chinook salmon fisheries be based on direct sonar estimates of Chinook salmon 75 cm METF and longer, primarily because such estimates constitute the most reliable information available. Since 2010, the deployment of imaging sonar (DIDSON and ARIS) in the Kenai River has made it possible to reliably distinguish large Chinook salmon from smaller fish of other species (Miller et al. 2013). ARIS length measurements from Chinook salmon 75 cm METF and longer do not overlap with ARIS measurements from sockeye and other small salmon (Figure 2), and thus these Chinook salmon can be identified and directly assessed by the sonar. Since 2013, when ARIS was first deployed at RM 13.7, it has been possible to count fish traversing nearly the entire cross section of the river, eliminating the need for spatial expansion (Miller et al. 2016b). In 2013 and 2014, paired sonar and capture-recapture (CR) estimates of Chinook salmon 75 cm METF and longer were in close agreement for both the early run (sonar 11% and 4% lower than CR in 2013 and 2014, respectively; Appendix B2) and the late run (sonar 1% higher and 2% lower, respectively; Appendix B5).

In contrast, accurate estimates of small Chinook salmon abundance are indirect, imprecise, time-consuming, and difficult to obtain inseason. Chinook salmon less than 75 cm METF cannot be distinguished from other salmon based solely on length measurements (Figure 2); therefore, their abundance cannot be assessed by the sonar alone. Complex statistical methods must be employed that require length measurements from known-identity Chinook and sockeye salmon captured in the inriver netting program. Because estimates of small Chinook salmon are indirect, they are less precise than estimates of larger Chinook salmon, especially when run sizes are small and netting catches are sparse. For instance in 2014, early- and late-run estimates of small Chinook salmon were 2–4 times more uncertain than corresponding estimates of larger Chinook salmon (Miller et al. 2016b). Such estimates of small Chinook salmon are problematic in other ways: they are sensitive to how the netting data are collected, and to details of how the netting data are used. For example, during the 2013 early run, size-stratified migration behavior at RM 8.6 skewed midriver netting data strongly toward larger fish, resulting in small Chinook abundance estimates that were far too low (Miller et al. 2016a). Then in 2014 and 2015, Chinook salmon age composition departed sharply from historical averages, prompting substantial postseason revisions to estimates of small Chinook salmon abundance (Key et al. 2016b, Miller et al. 2016b, Miller et al. *In prep*).

Chinook salmon 75 cm METF and longer include all fish aged 6 and 7 (1.4 and 1.5, respectively) and approximately 80% of those aged 5 (1.3). Their smaller counterparts include all fish aged 3 and 4 (1.1 and 1.2, respectively) plus 20% of those aged 5 (Figure 3). Because 3- and 4-year-old Chinook salmon are nearly all male, large Chinook salmon account for the great majority of the stock's potential egg deposition. In 2014–2016, 85% (early run) and 93% (late run) of netted female Chinook salmon were 75 cm METF and longer (Appendix E1). Also, larger females tend to bear more and larger eggs (e.g., Appendices C1–C2), so Chinook salmon 75 cm METF and longer account for even higher percentages of potential egg deposition.

Similar size-based escapement goals have also been implemented for several Chinook salmon stocks in southeast Alaska (SEAK; Heinl et al. 2014). The primary motivation for setting size-based goals in SEAK was to match them with the most reliable assessments, as is true for the Kenai River Chinook salmon stocks. The SEAK escapement goals target Chinook salmon 66 cm METF and longer[12] because smaller fish are more difficult to assess with aerial surveys and capture-recapture experiments. A secondary benefit of size-based goals is that they focus management on larger fish that are disproportionately female, which helps to maintain a baseline level of egg deposition and potential recruitment when productivity is low and runs are small. Note that size-based goals are not a remedy for the recent downturn in Chinook salmon productivity. Small improvements in potential egg deposition at the lower end of the escapement goal range are not likely to counteract large swings in factors like marine survival, such as those documented by Pahlke et al. (2010).

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[12] This threshold excludes age-1.1 and -1.2 Chinook salmon for SEAK stocks.

## ESCAPEMENT GOAL RECOMMENDATIONS

For the reasons detailed above, we recommend basing inseason management of Kenai River Chinook salmon fisheries on the abundance of Chinook salmon 75 cm METF and longer.

State of Alaska policy is to set escapement goals that provide for sustained yield (5 AAC 39.220). We fitted integrated spawner-recruit (SR) models to Kenai River Chinook salmon data in order to learn about the yield dynamics of these stocks. One key output from such an analysis is an estimate of the number of spawners that provide maximum sustained yield $S_{MSY}$. Goals chosen strictly to maximize yield would be centered on $S_{MSY}$ but factors other than maximum yield are also important to consider, including composition of user groups (commercial vs. sport vs. subsistence fisheries), value of the current goal (large changes undesirable), recent history of escapements and yields (affecting risk tolerance), and whether other stocks are affected by the goal (weak stock considerations).

The circumstances surrounding each individual stock are unique, and this is reflected in their respective escapement goals. We compiled published escapement goals for 22 Alaska Chinook salmon stocks, including the current goals for Kenai River early- and late-run stocks (all sizes) and standardized them by dividing by estimated values of $S_{MSY}$ for each stock (Appendix D1). These standardized values provide a useful way to compare the attributes of escapement goals across stocks. Among Alaska Chinook salmon stocks, lower bounds ranged from 62% to 100% (mean 77%) of $S_{MSY}$, and upper bounds ranged from 120% to 192% (mean 155%) of $S_{MSY}$ (Appendix D1). For Chinook salmon regardless of size, the current early-run SEG is 86% of $S_{MSY}$ at the lower bound and 192% of $S_{MSY}$ at the upper bound, and the current late-run SEG is 74% of $S_{MSY}$ at the lower bound and 148% of $S_{MSY}$ at the upper bound[13]. The current Kenai River Chinook salmon early-run SEG for Chinook salmon of all sizes is one of the highest in the state relative to $S_{MSY}$, with the lower bound ranking 3rd highest and the upper bound the highest among the 22 stocks. The current late-run SEG for Chinook salmon of all sizes is slightly lower than average, with lower and upper bounds ranked 7th and 9th lowest, respectively.

Information about the range of escapements that produce near-maximum yields is graphically summarized in the optimal yield profiles (Figures 8 and 14). Probability of achieving yields near *MSY* reaches a maximum at $S_{MSY}$ and declines for lower and higher escapements. For the early-run stock, which is harvested primarily by sport fisheries (marine and inriver), run size (calendar year abundance) is an important additional consideration because it affects catch rates. Run size is directly tied to recruitment (brood year return), which reaches a maximum *MSR* at $S_{MSR} = 1/\beta$. Information about the range of early-run escapements that lead to near-maximum recruitment is summarized in optimal recruitment profiles. Probability of achieving recruitment near *MSR* reaches a maximum at $S_{MSR}$ and declines for lower and higher escapements. Under a Ricker spawner-recruit model, $S_{MSR}$ is always higher than $S_{MSY}$.

**Based on the foregoing information and analyses, the Alaska Department of Fish and Game recommends sustainable escapement goals (SEG; definition in 5 ACC 39.222 [f][36]) of 2,800–5,600 Kenai River early-run Chinook salmon and 13,500–27,000 Kenai River late-run Chinook salmon 75 cm METF and longer.**

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[13] $S_{MSY}$ for Chinook salmon of all sizes was estimated to be 4,434 for early run (McKinley and Fleischman 2013), and 20,260 for the late run (Fleischman and McKinley 2013).

For the early run (Figure 8), the recommended goal brackets point estimates of both $S_{MSY}$ (3,283) and $S_{MSR}$ (4,728). At the lower bound of the recommended range there are high (99%, 97%, and 86%) probabilities of achieving yields that are at least 70%, 80%, and 90%, respectively, of *MSY*. At the upper end of the range, the probability of near-maximum yields is lower (65%, 47%, and 27% probability of 70%, 80%, and 90% of *MSY*); however, the probability of achieving at least 70%, 80%, or 90% of *MSR* is high (99%, 96%, and 85%). Across the entire escapement goal range, the average probability of achieving 80% of *MSY* is 83% and the average probability of achieving 80% of *MSR* is 95%.

For the late run (Figure 14), the recommended goal brackets the point estimate of $S_{MSY}$ (18,477). At the lower bound of the recommended range, there are high (94%, 87%, and 65%) probabilities of achieving yields that are 70%, 80%, and 90% of *MSY*. At the upper end of the range, probabilities of achieving yields that are 70%, 80%, and 90% of *MSY* are 76%, 65%, and 44% respectively. Across the entire escapement goal range, the average probability of achieving 80% of *MSY* is 85%.

The recommended escapement goals have the following attributes:

***The recommended goals preserve the original intent of the current Kenai Chinook salmon SEGs with respect to sustained yield.***

Multiple factors were considered when ADF&G recommended the 2013 escapement goals (Fleischman and McKinley 2013; McKinley and Fleischman 2013). Ultimately, the net effect of these considerations can be encapsulated and summarized in the relationship between the recommended lower and upper goal bounds and the 2013 estimates of $S_{MSY}$. Because this analysis is an update of the 2013 analysis using an improved dataset, the relationship between the current goal boundaries and $S_{MSY}$ factored heavily in our recommendations.

Relative to $S_{MSY}$, the lower bound (LB) of the recommended early-run goal (85% of $S_{MSY}$) is nearly the same as the current goal (86%), whereas the upper bound (UB) is lower (170%) than the current goal (192%; see also Appendix D1). The recommended late-run goal bounds (73% and 146% of $S_{MSY}$) remain nearly the same as the current goal (74% and 148%). Relative to $S_{MSY}$, the recommended early-run LB remains 3rd highest among 22 Alaska Chinook salmon stocks whereas the early-run UB moves down from highest to 4th highest. The late-run LB and UB remain 7th and 9th lowest, respectively, among the 22 stocks (Appendix D1)

Optimum yield profiles from the original (2013) analyses for all sizes of Chinook salmon are reproduced in Figures 16 and 17. At the early-run LB, the late-run LB, and the late-run UB, probabilities of near-maximum yield are slightly reduced from the status quo. For example, at the LB of the recommended early-run goal there is 97% probability of achieving 80% of *MSY*, compared to 99% for the current goal (Figure 16). At the LB and UB of the recommended late-run goal the probabilities of achieving 80% of *MSY* are 87% and 65% compared to 92% and 68%, respectively, for the current goal (Figure 17). The reductions are due to a slightly poorer statistical fit of the spawner-recruit model to the new dataset, which includes 3 new years of very precise data that reflect lower productivity than the original dataset (Figures 9 and 15).

At the early-run UB, probabilities of optimal yield are improved from the status quo. For example there is now 47% probability of achieving 80% of *MSY*, compared to only 17% for the current goal. The recommended early-run UB is now more consistent with other Alaska Chinook salmon stocks.

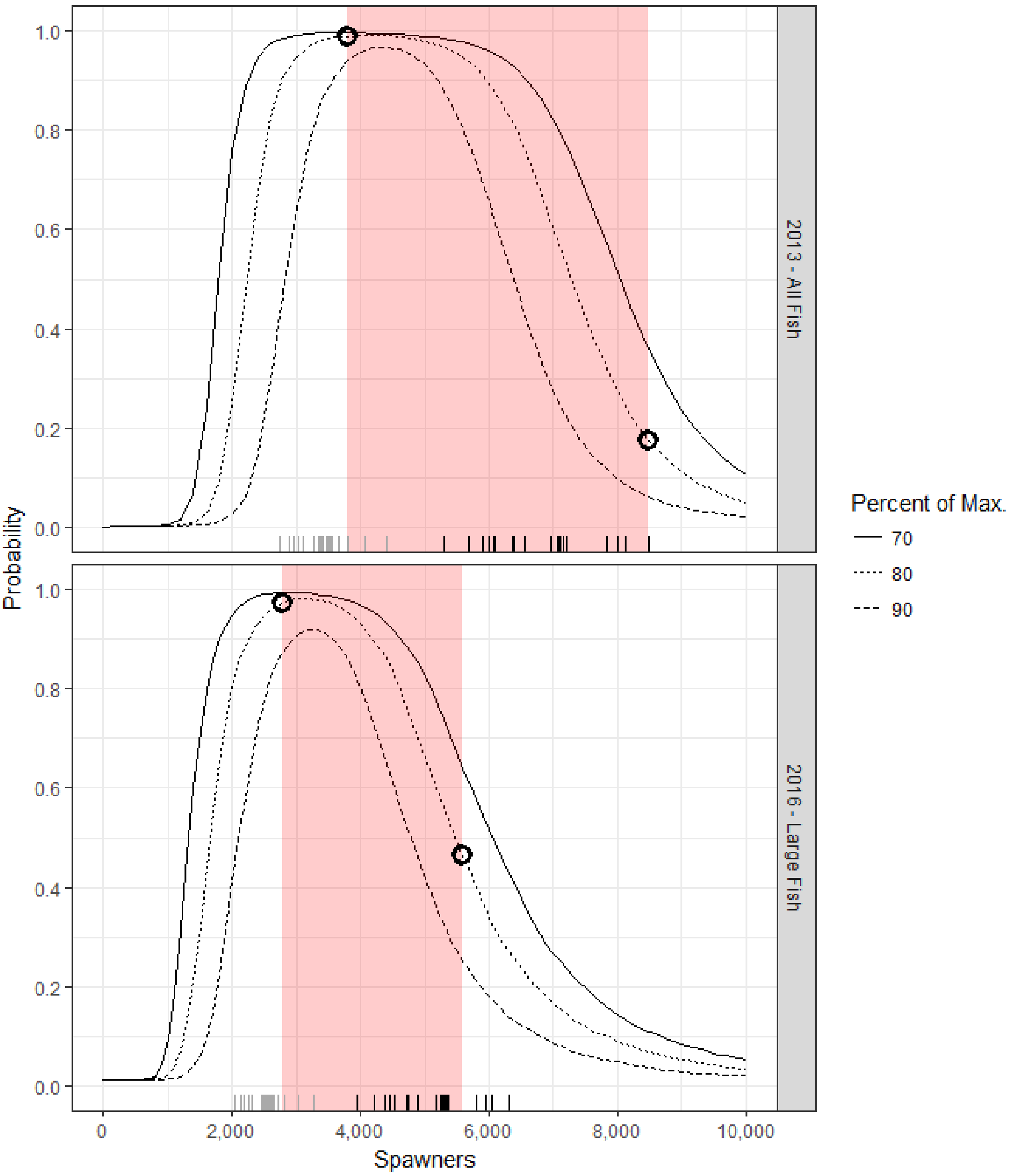

Figure 16.–Optimal yield profiles (OYP) plots for Kenai River **early-run** Chinook salmon of all sizes (top panel) and 75 cm METF and longer (bottom panel).

*Note:* OYPs show probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield. Shaded areas bracket the current and recommended goal ranges; grey and black marks along the *x*-axis show comparable lower and upper bounds for other Alaskan Chinook salmon stocks scaled by $S_{MSY}$ ratios (see Methods). Circled probabilities of attaining 80% of MSY at the lower and upper bounds of each goal are cited in the discussion.

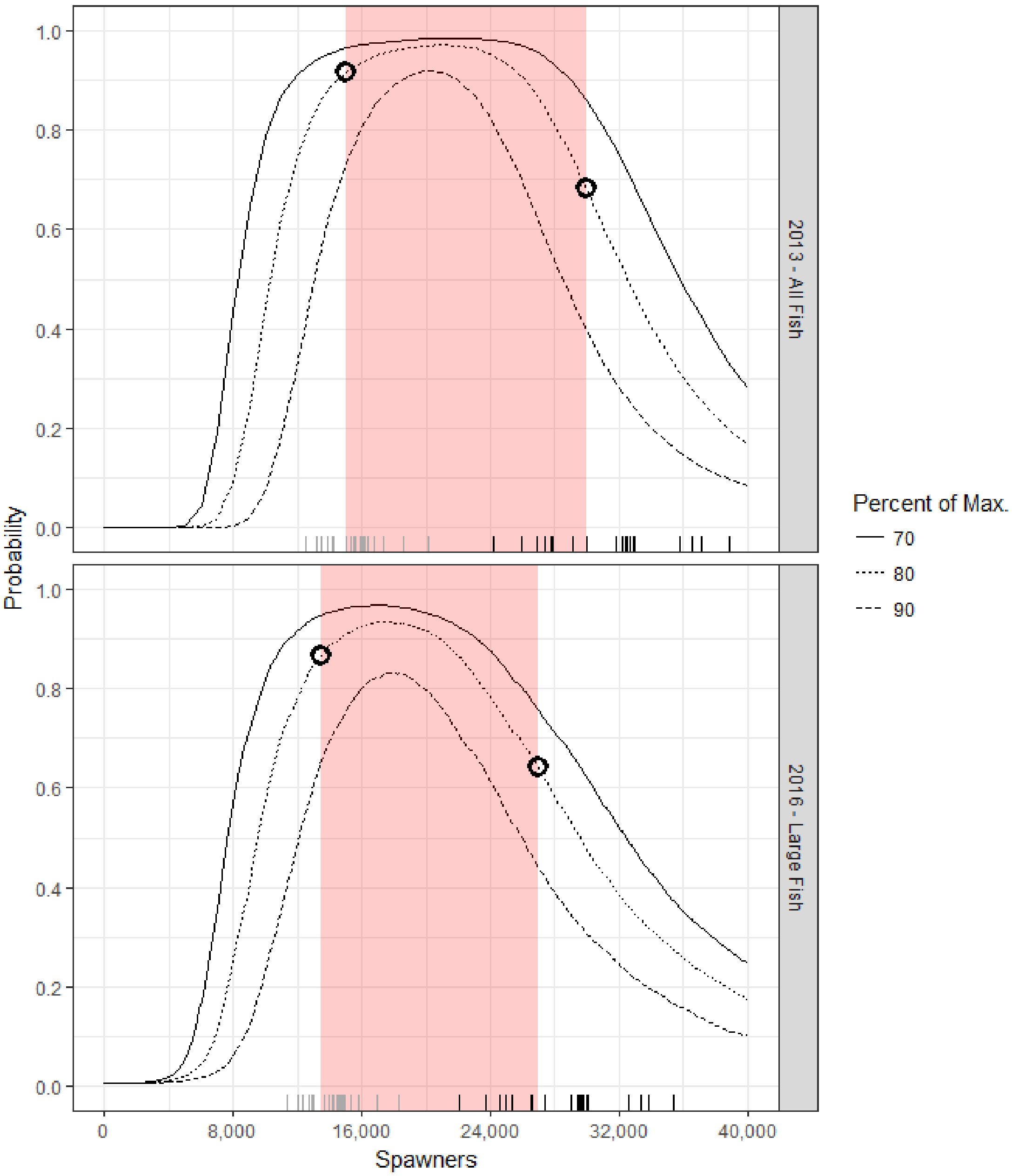

Figure 17.–Optimal yield profiles (OYP) plots for Kenai River **late-run** Chinook salmon of all sizes (top panel) and 75 cm METF and longer (bottom panel).

*Note*: OYPs show probability that a specified spawning abundance will result in specified fractions (70%, 80%, and 90% line) of maximum sustained yield. Shaded areas bracket the current and recommended goal ranges; grey and black marks along the *x*-axis show comparable lower and upper bounds for other Alaskan Chinook salmon stocks scaled by $S_{MSY}$ ratios (see Methods). Circled probabilities of attaining 80% of MSY at the lower and upper bounds of each goal are cited in the discussion.

***The late-run goal may represent a change from the status quo with respect to management of the stock.*** The lower and upper bounds of the recommended goal (13,500–27,000) for late-run Chinook salmon 75 cm METF and longer are both 90% of the current goal (15,000–30,000) for Chinook salmon of all sizes. Yet only 61-71% of Chinook salmon captured in the inriver netting project were 75 cm METF and longer during the 2014–2016 late runs (Appendix E1). Recent late runs have been unusually low in abundance (Figure 11) and small in body size (Appendix E1). If such runs persist, the recommended late-run goal may provide less fishing opportunity than might have occurred under the current goal[14].

## REMAINING CONSIDERATIONS AND FUTURE OUTLOOK

***The recommended goals do not directly address productivity of Chinook salmon less than 75 cm METF.*** Small Chinook salmon were intentionally omitted in the analyses presented in this report because we lack full confidence in assessments of their abundance, and the inclusion of unreliable small Chinook salmon assessments would introduce unwanted noise and bias into the spawner-recruit analysis. On the other hand, by omitting small fish we sacrifice some biological realism because small Chinook salmon undoubtedly provide yield and affect stock productivity by competing and spawning with large Chinook salmon. ADF&G is not recommending any changes to the historical harvest patterns of small Chinook salmon at this time. We will continue to collect data for postseason assessment of Chinook salmon of all sizes for both runs. As such assessments accumulate, they will support a fuller understanding of the production dynamics of the entire stock, including small fish.

***The recommended goals may result in reduced ability to project season-ending totals.*** During the late run, larger older fish generally arrive later than smaller younger fish. Thus, under the new goal, a smaller fraction of the run will have passed the RM 13.7 sonar by any given date. Depending on the volatility of large-fish run timing, this could increase the uncertainty of inseason projections of run abundance and escapement. A better understanding of run timing for large Chinook salmon at RM 13.7 will develop as more years of data accumulate.

***Our knowledge of Kenai River Chinook salmon stock dynamics will improve over time.*** Lacking a complete time series of absolute estimates of abundance, this investigation relied partially upon indirect reconstruction of past quantities. Stock assessment capabilities have improved greatly in recent years, and the resulting estimates of abundance have become more precise (Figures 5 and 11). For spawner-recruit analyses of Kenai River Chinook salmon, we employ statistical methods that accommodate varying levels of measurement error and give greater weight to more precise estimates. As precise, sonar-based estimates of abundance accumulate, they will contribute a greater share of the information about $S_{MSY}$ and $S_{MSR}$, while historical, indirect estimates of abundance will naturally have less influence.

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[14] The recommended lower bound for early-run Chinook salmon 75 cm METF and longer (2,800) is 74% of the current SEG lower bound (3,800) and 53% of the current OEG lower bound (5,300) for Chinook salmon of all sizes. From 37% to 57% of Chinook salmon captured in the inriver netting project were 75 cm METF and longer during the 2014–2016 early runs (Appendix E1). Recent early runs have also been unusually low in abundance (Figure 11) and small in body size (Appendix E1).

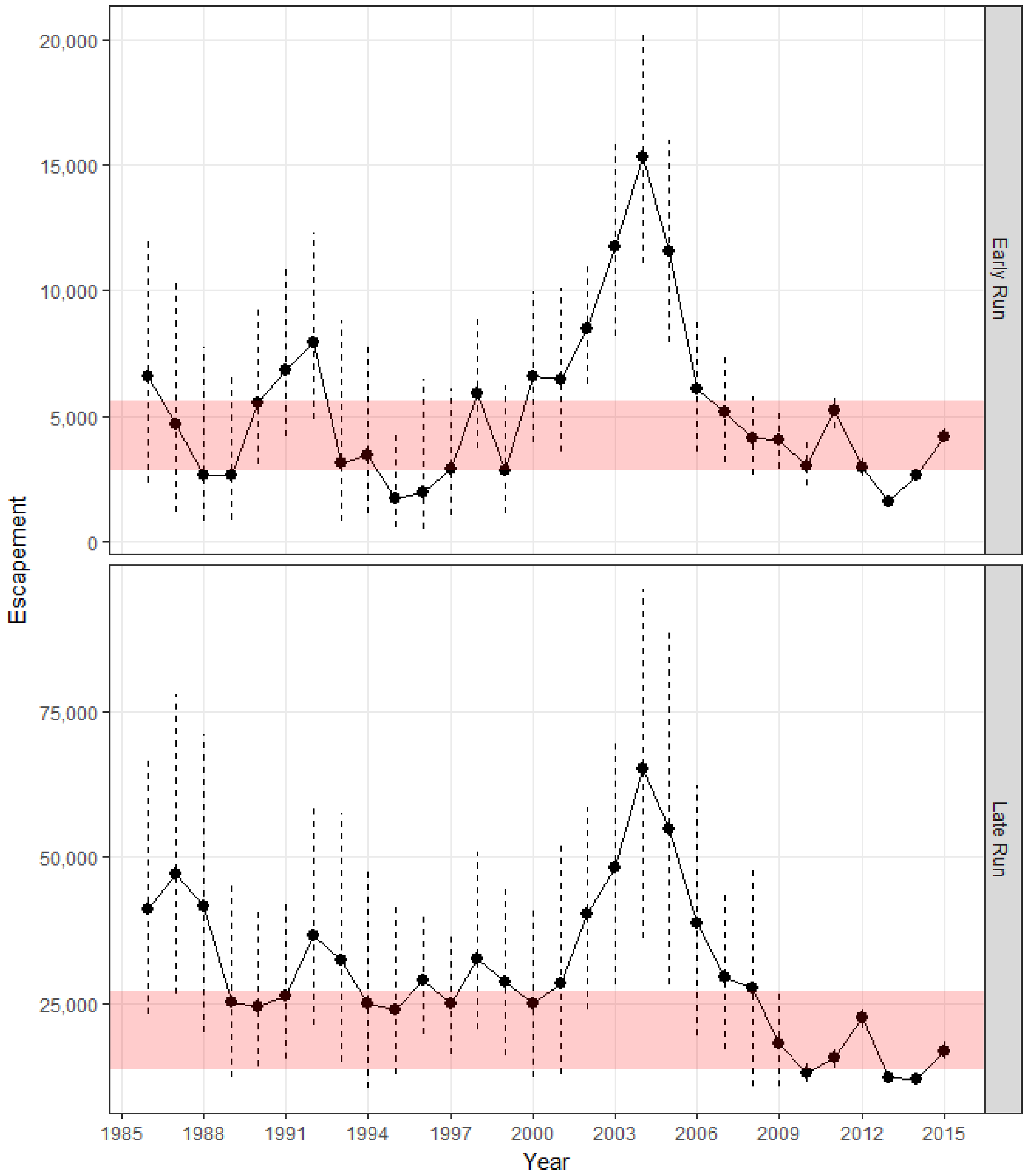

Figure 18.–Historical estimates of escapement and 95% credibility intervals for Chinook salmon 75 cm METF and longer obtained by fitting a state-space model to Kenai River early and late-run Chinook salmon data, 1986–2015.

*Note*: Shaded areas bracket the recommended goal ranges.

## SUMMARY AND CONCLUSIONS

***Revised escapement goals for Kenai River Chinook salmon based on fish 75 cm METF and longer will be implemented during the 2017 season.*** The recommended escapement goals will have approximately the same expected yield characteristics as the current goals for Chinook salmon of all sizes, except that expected yield performance at the upper bound of the early-run goal will be improved.

***Inseason assessments will be more accurate and more easily produced in a timely manner.*** Kenai River Chinook salmon 75 cm METF and longer can be assessed directly by the sonar at RM 13.7 and do not require netting data or complex statistical methods.

***The effect of the recommended goals on fishery management will depend upon total run abundance and the size composition of future runs.*** During years with small runs dominated by small Chinook salmon, the recommended goals may reduce fishing opportunities compared to the *status quo*.

***Implementation of the recommended goals will focus management on the largest, oldest segment of the population.*** Kenai River Chinook salmon 75 cm METF and longer include approximately 89% of all females.

***The escapement goals for Kenai River Chinook salmon will be periodically reviewed.*** All Pacific salmon escapement goals in the state of Alaska are subject to triennial review to allow for consideration of recent data and changes in stock productivity. By the next review, prior to the 2020 Upper Cook Inlet BOF meeting, we will have 3 more years of direct assessment data and it will be possible to quantify the recruitment from the low escapements of 2013 and 2014.

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# APPENDIX A: RJAGS CODE

Appendix A1.–RJAGS model code for state-space model of Kenai River early-run Chinook salmon data, 1986–2015.

```
mod=function(){
 for (y in (A+a.min):(Y+A-1)) {
  log.R[y] ~ dt(log.R.mean2[y],tau.white,500)
  R[y] <- exp(log.R[y])
  log.R.mean1[y] <- log(S[y-a.max]) + lnalpha - beta * S[y-a.max]
  log.resid[y] <- log(R[y]) - log.R.mean1[y]
  lnalpha.y[y] <- lnalpha + log.resid[y]
 }
 log.resid.vec <- log.resid[(A+a.min):(Y+A-1)]
 lnalpha.vec <- lnalpha.y[(A+a.min):(Y+A-1)]
 log.R.mean2[A+a.min] <- log.R.mean1[A+a.min] + phi * log.resid.0
 for (y in (A+a.min+1):(Y+A-1)) {
  log.R.mean2[y] <- log.R.mean1[y] + phi * log.resid[y-1]
 }
 lnalpha ~ dnorm(0,1.0E-6)%_%T(0,)
 beta ~ dnorm(0,1.0E-2)%_%T(0,)
 phi ~ dnorm(0,1.0E-4)%_%T(-1,1)
 tau.white ~ dgamma(0.001,0.001)
 log.resid.0 ~ dnorm(0,tau.red)
 alpha <- exp(lnalpha)
 tau.red <- tau.white * (1-phi*phi)
 sigma.white <- 1 / sqrt(tau.white)
 sigma.red <- 1 / sqrt(tau.red)
 lnalpha.c <- lnalpha + (sigma.white * sigma.white / 2 / (1-phi*phi) )
 S.max <- 1 / beta
 S.eq <- lnalpha.c * S.max
 S.msy <- S.eq * (0.5 - 0.07*lnalpha.c)
 U.msy <- lnalpha.c * (0.5 - 0.07*lnalpha.c)

 # BROOD YEAR RETURNS W/O SR LINK DRAWN FROM COMMON LOGNORMAL DISTN
 mean.log.R ~ dnorm(0,1.0E-4)%_%T(0,)
 tau.R ~ dgamma(0.1,0.1)
 R.0 <- exp(mean.log.R)
 sigma.R0 <- 1 / sqrt(tau.R)
 for (y in 1:a.max) {
  log.R[y] ~ dt(mean.log.R,tau.R,500)
  R[y] <- exp(log.R[y])
 }

 # GENERATE Y+A-1 MATURITY SCHEDULES, ONE PER BROOD YEAR
 D.scale ~ dunif(0,1)
 D.sum <- 1 / (D.scale * D.scale)
 pi.1  ~ dbeta(0.3,0.6)                          # ERv09
 pi.2p ~ dbeta(0.3,0.3)                           # ERv09
 pi[1] <- pi.1
 pi[2] <- pi.2p * (1 - pi[1])
 pi[3] <- 1 - pi[1] - pi[2]
 for (a in 1:A) {
  gamma[a] <- D.sum * pi[a]
  for (y in 1:(Y+A-1)) {
```

-continued-

```
    g[y,a] ~ dgamma(gamma[a],0.5)
    p[y,a] <- g[y,a]/sum(g[y,])
  }
}

# ASSIGN PRODUCT OF P AND R TO ALL CELLS IN N MATRIX
for (a in 1:A) {
  for (y in a:(Y + (a - 1))) {
    N.ta[y - (a - 1), (A + 1 - a)] <- p[y, (A + 1 - a)] * R[y]
  }
}

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

# INRIVER PASSAGE ESTIMATED, AS WELL AS HARVESTS BELOW AND ABOVE BORDER
p.MR ~ dnorm(0.5,1.0E-4)%_%T(0.01,0.99)
p.MR.inv <- 1 / p.MR

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

  #IN SOME YEARS, DIRECT ESTIMATES OF IR AVAILABLE
  log.IR[y] <- log(Inriver.Run[y])
  tau.log.IR[y] <- 1 / log(cv.IR[y]*cv.IR[y] + 1)
  IR.hat[y] ~ dlnorm(log.IR[y],tau.log.IR[y])

  tau.ARIS[y] <- 1 / log(cv.AR[y]*cv.AR[y] + 1)
  ARIS[y] ~ dlnorm(log.IR[y],tau.ARIS[y])

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

-continued-

```
   mu.Habove[y] ~ dbeta(0.5,0.5)
   H.above[y] <- mu.Habove[y] * Inriver.Run[y]
   log.Ha[y] <- log(H.above[y])
   tau.log.Ha[y] <- 1 / log(cv.Ha[y]*cv.Ha[y] + 1)
   Habove.hat[y] ~ dlnorm(log.Ha[y],tau.log.Ha[y])
   mu[y] <- (H.below[y] + H.above[y]) / N[y]
   S[y] <- max(Inriver.Run[y] - H.above[y], 1)
   log.S[y] <- log(S[y])
  }

  for(i in 1:4) {
   log.q[i] ~ dnorm(0,1.0E-4)
   tau.i[i] ~ dgamma(0.001,0.001)
   sigma.i[i] <- 1 / sqrt(tau.i[i])
   q.i[i] <- exp(log.q[i])
  }
  for (y in 1:Y) {
   log.qiN[y,1] <- log(q.i[1] * Midriver.Run[y])
   log.qiN[y,2] <- log(q.i[2] * Midriver.Run[y])
   log.qiN[y,3] <- log(q.i[3] * Inriver.Run[y])
   log.qiN[y,4] <- log(q.i[4] * N[y])
   index1[y] ~ dlnorm(log.qiN[y,1],tau.i[1])
   index2[y] ~ dlnorm(log.qiN[y,2],tau.i[2])
   index3[y] ~ dlnorm(log.qiN[y,3],tau.i[3])
   index4[y] ~ dlnorm(log.qiN[y,4],tau.i[4])
  }
  # MEAN LNA FOR 5 MOST RECENT BROOD YEARS
  lnalpha.recent    <- mean(lnalpha.y[(Y+A-5):(Y+A-1)])
  lnalpha.c.recent <- lnalpha.recent + (sigma.white * sigma.white / 2 / (1-phi*phi) )
  U.msy.recent <- lnalpha.c.recent * (0.5 - 0.07*lnalpha.c.recent)
  S.eq.recent <- lnalpha.c.recent * S.max
  S.msy.recent <- S.eq.recent * (0.5 - 0.07*lnalpha.c.recent)
}
```

*Note*: Not all notation corresponds directly to text of report.

# APPENDIX B: EMPIRICAL ESTIMATES OF HARVEST, AGE COMPOSITION, AND MEASURES OF ABUNDANCE FOR KENAI RIVER CHINOOK SALMON 75 CM METF AND LONGER

Appendix B1.–Empirical estimates of harvest below and above RM 8.6 and of age composition of run at RM 8.6 for Kenai River early-run Chinook salmon 75 cm METF and longer, 1986–2015.

| | Harvest and other mortality | | | | | | | | | Age composition of inriver run at RM 8.6 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Below RM 8.6 | | | | | Above RM 8.6 | | | | | | |
| Year | Cook Inlet marine rec.[a] | Misc. marine[b,c,d] | Kenaitize education | Total | CV | Sport | Hook-rel. mort. | Total | CV | Age 5 | Age 6 | Age 7 |
| 1986 | 128 | 0 | | 128 | 0.20 | 7,233 | 215 | 7,448 | 0.06 | 0.47 | 0.43 | 0.10 |
| 1987 | 175 | 0 | | 175 | 0.20 | 13,138 | 297 | 13,435 | 0.07 | 0.38 | 0.60 | 0.02 |
| 1988 | 201 | 0 | | 201 | 0.20 | 14,401 | 322 | 14,723 | 0.05 | 0.12 | 0.76 | 0.11 |
| 1989 | 169 | 0 | 64 | 233 | 0.20 | 7,334 | 130 | 7,464 | 0.06 | 0.12 | 0.78 | 0.10 |
| 1990 | 218 | 0 | 37 | 256 | 0.20 | 1,682 | 352 | 2,033 | 0.12 | 0.24 | 0.69 | 0.07 |
| 1991 | 238 | 0 | 2 | 240 | 0.20 | 1,920 | 150 | 2,070 | 0.11 | 0.21 | 0.73 | 0.06 |
| 1992 | 275 | 0 | 67 | 342 | 0.20 | 2,058 | 217 | 2,274 | 0.09 | 0.24 | 0.70 | 0.06 |
| 1993 | 377 | 0 | 109 | 487 | 0.20 | 8,666 | 266 | 8,931 | 0.05 | 0.25 | 0.71 | 0.04 |
| 1994 | 320 | 0 | 52 | 373 | 0.20 | 7,638 | 267 | 7,905 | 0.05 | 0.15 | 0.80 | 0.05 |
| 1995 | 408 | 0 | 37 | 444 | 0.20 | 10,118 | 353 | 10,472 | 0.05 | 0.17 | 0.78 | 0.05 |
| 1996 | 206 | 0 | 91 | 298 | 0.20 | 5,816 | 252 | 6,068 | 0.06 | 0.24 | 0.73 | 0.03 |
| 1997 | 269 | 0 | 116 | 385 | 0.20 | 6,121 | 332 | 6,453 | 0.10 | 0.32 | 0.66 | 0.01 |
| 1998 | 278 | 0 | 126 | 404 | 0.20 | 1,124 | 244 | 1,369 | 0.14 | 0.42 | 0.54 | 0.04 |
| 1999 | 216 | 0 | 100 | 317 | 0.20 | 7,161 | 230 | 7,390 | 0.06 | 0.57 | 0.43 | 0.00 |
| 2000 | 229 | 0 | 119 | 348 | 0.20 | 1,745 | 177 | 1,923 | 0.12 | 0.44 | 0.55 | 0.00 |
| 2001 | 154 | 0 | 166 | 320 | 0.20 | 2,010 | 171 | 2,181 | 0.10 | 0.31 | 0.67 | 0.03 |
| 2002 | 139 | 0 | 40 | 178 | 0.20 | 740 | 64 | 804 | 0.15 | 0.43 | 0.52 | 0.05 |
| 2003 | 151 | 0 | 94 | 245 | 0.20 | 2,120 | 290 | 2,410 | 0.16 | 0.26 | 0.73 | 0.02 |
| 2004 | 152 | 0 | 56 | 209 | 0.20 | 2,656 | 201 | 2,858 | 0.11 | 0.34 | 0.60 | 0.06 |
| 2005 | 156 | 194 | 63 | 414 | 0.20 | 3,182 | 211 | 3,393 | 0.10 | 0.27 | 0.69 | 0.04 |
| 2006 | 218 | 0 | 56 | 274 | 0.20 | 4,060 | 178 | 4,237 | 0.09 | 0.26 | 0.69 | 0.05 |
| 2007 | 167 | 23 | 13 | 203 | 0.20 | 2,902 | 183 | 3,085 | 0.14 | 0.48 | 0.50 | 0.01 |
| 2008 | 97 | 63 | 36 | 196 | 0.20 | 3,171 | 111 | 3,283 | 0.07 | 0.48 | 0.50 | 0.02 |
| 2009 | 59 | 9 | 41 | 109 | 0.20 | 1,226 | 81 | 1,307 | 0.12 | 0.29 | 0.69 | 0.02 |
| 2010 | 70 | 26 | 26 | 122 | 0.20 | 1,071 | 72 | 1,144 | 0.10 | 0.63 | 0.36 | 0.01 |
| 2011 | 93 | 0 | 35 | 128 | 0.20 | 1,127 | 78 | 1,205 | 0.14 | 0.42 | 0.57 | 0.02 |
| 2012 | 47 | 0 | 19 | 65 | 0.20 | 309 | 10 | 319 | 0.29 | 0.38 | 0.60 | 0.01 |
| 2013 | 86 | 0 | 9 | 95 | 0.20 | 0 | 0 | 0 | 1.00 | 0.41 | 0.56 | 0.03 |
| 2014 | 65 | 10 | 1 | 76 | 0.20 | 0 | 0 | 0 | 1.00 | 0.78 | 0.21 | 0.02 |
| 2015 | 66 | 41 | 8 | 115 | 0.20 | 0 | 0 | 0 | 1.00 | 0.61 | 0.36 | 0.03 |

[a] Assumes 5% of Deep Creek marine sport harvest is of Kenai-origin fish.

[b] For 2005, assumes 68% of ESSN catch before 25 June.

[c] For 2007–2010, assumes 68% of ADF&G cost recovery catch before 25 June.

Appendix B2.–Values of annual indices of abundance used to reconstruct historical run size, Kenai River early-run Chinook salmon 75 cm METF or longer, 1986–2015.

| Year | NCPUE | NASB | SCPUE | $N_{LR}$ | DIDSON (CV) | ARIS (CV) | CR (CV) |
|---|---|---|---|---|---|---|---|
| 1986 |  |  |  | 60,707 |  |  | 21,633 (0.36) |
| 1987 |  |  |  | 75,072 |  |  | 24,542 (0.23) |
| 1988 |  |  |  | 70,835 |  |  |  |
| 1989 |  |  |  | 41,725 |  |  |  |
| 1990 |  |  |  | 33,185 |  |  |  |
| 1991 |  |  |  | 37,783 |  |  |  |
| 1992 |  |  |  | 51,494 |  |  |  |
| 1993 |  |  |  | 59,897 |  |  |  |
| 1994 |  |  |  | 53,541 |  |  |  |
| 1995 |  |  |  | 43,622 |  |  |  |
| 1996 |  |  |  | 44,214 |  |  |  |
| 1997 |  |  |  | 45,388 |  |  |  |
| 1998 |  |  |  | 43,261 |  |  |  |
| 1999 |  |  |  | 45,948 |  |  |  |
| 2000 |  |  |  | 42,039 |  |  |  |
| 2001 |  |  |  | 45,973 |  |  |  |
| 2002 | 1.51 | 4,681 | 0.019 | 56,303 |  |  |  |
| 2003 | 3.60 | 8,147 | 0.049 | 68,512 |  |  |  |
| 2004 | 2.86 | 13,738 | 0.060 | 92,115 |  |  |  |
| 2005 | 3.13 | 10,260 | 0.070 | 84,751 |  |  |  |
| 2006 | 1.78 | 4,686 | 0.048 | 57,634 |  |  |  |
| 2007 | 1.71 | 2,986 | 0.049 | 44,736 |  |  | 8,637 (0.26) |
| 2008 | 1.64 | 3,969 | 0.040 | 43,069 |  |  | 6,645 (0.13) |
| 2009 | 0.94 | 2,290 | 0.021 | 28,244 |  |  | 6,692 (0.24) |
| 2010 | 0.83 | 1,662 | 0.026 | 22,247 |  |  | 3,672 (0.19) |
| 2011 | 1.18 | 2,813 | 0.027 | 26,412 | 5,248 (0.04) |  | 5,347 (0.19) |
| 2012 | 0.63 | 1,396 | 0.022 | 23,311 | 2,562 (0.05) |  | 3,718 (0.13) |
| 2013 | 0.25 | 1,006 |  | 14,413 | 999 (0.07) | 1,724 (0.05) | 1,940 (0.16) |
| 2014 | 0.30 | 932 |  | 13,445 | 2,281 (0.04) | 2,397 (0.05) | 2,507 (0.15) |
| 2015 | 0.62 |  |  | 22,861 |  | 4,212 (0.04) |  |

*Note*: Column abbreviations describe the inriver gillnet CPUE (NCPUE), net apportioned split-beam sonar (NASB), inriver sport fishery CPUE (SCPUE), late-run total run abundance ($N_{LR}$), DIDSON sonar estimates from RM 8.6 (DIDSON), ARIS sonar estimates from RM 13.7 (ARIS), and mark–recapture estimates (CR).

Appendix B3.–Empirical estimates of harvest below and above RM 8.6 for Kenai River late-run Chinook salmon 75 cm METF and longer, 1986–2015.

| | Harvest and other mortality | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Below RM 8.6 | | | | | | | | Above RM 8.6 | | | |
| Year | Cook Inlet marine rec. [a] | Comm. set gillnet [b] | Comm. drift gillnet [c] | Educ.-subsist. | Personal use | Inriver sport | Total | CV | Sport | Hook-rel. mort. | Total | CV |
| 1986 | 332 | 9,541 | 763 | 0 | 0 | 0 | 10,635 | 0.10 | 8,665 | 277 | 8,943 | 0.05 |
| 1987 | 711 | 11,638 | 2,163 | 0 | 186 | 0 | 14,699 | 0.09 | 12,743 | 120 | 12,863 | 0.06 |
| 1988 | 878 | 7,424 | 1,116 | 0 | 0 | 0 | 9,418 | 0.12 | 19,395 | 174 | 19,568 | 0.05 |
| 1989 | 795 | 6,005 | 0 | 17 | 0 | 0 | 6,817 | 0.15 | 9,387 | 86 | 9,472 | 0.06 |
| 1990 | 793 | 1,705 | 221 | 8 | 0 | 0 | 2,726 | 0.30 | 5,678 | 56 | 5,735 | 0.07 |
| 1991 | 967 | 2,380 | 103 | 202 | 0 | 0 | 3,653 | 0.27 | 7,474 | 15 | 7,489 | 0.05 |
| 1992 | 1,205 | 5,539 | 275 | 299 | 0 | 0 | 7,317 | 0.18 | 7,174 | 222 | 7,396 | 0.06 |
| 1993 | 1,629 | 7,775 | 365 | 21 | 0 | 0 | 9,791 | 0.18 | 17,034 | 458 | 17,492 | 0.04 |
| 1994 | 1,089 | 8,734 | 225 | 317 | 0 | 0 | 10,365 | 0.13 | 17,318 | 555 | 17,873 | 0.04 |
| 1995 | 1,102 | 5,945 | 253 | 2 | 505 | 0 | 7,808 | 0.16 | 11,197 | 419 | 11,617 | 0.05 |
| 1996 | 1,113 | 6,033 | 175 | 1 | 222 | 0 | 7,544 | 0.17 | 7,383 | 307 | 7,690 | 0.06 |
| 1997 | 1,613 | 5,868 | 281 | 15 | 272 | 0 | 8,049 | 0.21 | 11,698 | 523 | 12,221 | 0.06 |
| 1998 | 917 | 2,165 | 123 | 1 | 156 | 0 | 3,362 | 0.28 | 6,435 | 509 | 6,945 | 0.07 |
| 1999 | 502 | 4,402 | 231 | 3 | 327 | 976 | 6,441 | 0.10 | 10,360 | 569 | 10,929 | 0.08 |
| 2000 | 568 | 1,795 | 114 | 4 | 288 | 748 | 3,518 | 0.17 | 12,961 | 450 | 13,410 | 0.05 |
| 2001 | 465 | 1,905 | 170 | 4 | 291 | 1,125 | 3,959 | 0.13 | 12,748 | 695 | 13,443 | 0.07 |
| 2002 | 226 | 3,483 | 132 | 3 | 321 | 1,702 | 5,867 | 0.08 | 9,420 | 586 | 10,007 | 0.07 |
| 2003 | 95 | 4,375 | 317 | 5 | 432 | 649 | 5,872 | 0.08 | 12,704 | 1,421 | 14,125 | 0.09 |
| 2004 | 832 | 9,990 | 439 | 7 | 525 | 1,992 | 13,785 | 0.10 | 12,515 | 851 | 13,366 | 0.07 |
| 2005 | 583 | 9,501 | 744 | 7 | 632 | 2,136 | 13,602 | 0.08 | 14,875 | 1,183 | 16,058 | 0.08 |
| 2006 | 477 | 3,074 | 742 | 5 | 460 | 2,817 | 7,575 | 0.08 | 10,590 | 704 | 11,294 | 0.08 |
| 2007 | 387 | 4,055 | 260 | 3 | 717 | 1,417 | 6,838 | 0.08 | 7,845 | 543 | 8,388 | 0.07 |
| 2008 | 287 | 3,425 | 255 | 10 | 887 | 935 | 5,799 | 0.08 | 9,368 | 342 | 9,710 | 0.08 |
| 2009 | 128 | 1,410 | 187 | 1 | 432 | 940 | 3,099 | 0.07 | 6,563 | 520 | 7,083 | 0.07 |
| 2010 | 262 | 2,429 | 170 | 11 | 456 | 348 | 3,675 | 0.10 | 5,285 | 207 | 5,492 | 0.06 |
| 2011 | 425 | 3,006 | 208 | 3 | 726 | 369 | 4,737 | 0.11 | 5,552 | 385 | 5,937 | 0.07 |
| 2012 | 211 | 333 | 89 | 0 | 27 | 2 | 662 | 0.32 | 76 | 71 | 147 | 0.50 |
| 2013 | 229 | 687 | 89 | 2 | 3 | 23 | 1,033 | 0.23 | 955 | 48 | 1,003 | 0.19 |
| 2014 | 322 | 569 | 93 | 0 | 0 | 2 | 986 | 0.33 | 291 | 38 | 330 | 0.18 |
| 2015 | 354 | 2,583 | 143 | 4 | 28 | 277 | 3,390 | 0.13 | 2,478 | 162 | 2,640 | 0.11 |

[a] Assumes 60% of Deep Creek marine sport harvest is of Kenai-origin fish; uses inriver harvest fraction of large fish.

[b] Kenai River fish only, based on 2010–2015 genetic sampling of setnet fishery; uses ESSN harvest fraction of large fish.

[c] Assumes 60% of commercial driftnet harvest is of Kenai-origin fish; uses ESSN harvest fraction of large fish.

Appendix B4.–Empirical estimates of age composition of the harvest below RM 8.6 and the inriver run at RM 8.6 for Kenai River late-run Chinook salmon 75 cm METF and longer, 1986–2015.

| | Age composition | | | | | |
|---|---|---|---|---|---|---|
| | Harvest below RM 8.6 | | | Inriver run at RM 8.6 | | |
| Year | Age 5 | Age 6 | Age 7 | Age 5 | Age 6 | Age 7 |
| 1986 | 0.58 | 0.39 | 0.04 | 0.49 | 0.46 | 0.05 |
| 1987 | 0.37 | 0.61 | 0.01 | 0.27 | 0.71 | 0.01 |
| 1988 | 0.14 | 0.83 | 0.03 | 0.03 | 0.79 | 0.18 |
| 1989 | 0.21 | 0.67 | 0.11 | 0.11 | 0.74 | 0.14 |
| 1990 | 0.27 | 0.64 | 0.09 | 0.10 | 0.85 | 0.06 |
| 1991 | 0.42 | 0.55 | 0.03 | 0.17 | 0.76 | 0.07 |
| 1992 | 0.28 | 0.66 | 0.05 | 0.15 | 0.83 | 0.03 |
| 1993 | 0.19 | 0.75 | 0.06 | 0.11 | 0.82 | 0.06 |
| 1994 | 0.15 | 0.76 | 0.09 | 0.10 | 0.85 | 0.05 |
| 1995 | 0.35 | 0.55 | 0.10 | 0.21 | 0.71 | 0.08 |
| 1996 | 0.43 | 0.55 | 0.03 | 0.35 | 0.64 | 0.01 |
| 1997 | 0.34 | 0.63 | 0.03 | 0.19 | 0.79 | 0.02 |
| 1998 | 0.34 | 0.62 | 0.04 | 0.16 | 0.81 | 0.04 |
| 1999 | 0.30 | 0.66 | 0.04 | 0.21 | 0.74 | 0.06 |
| 2000 | 0.46 | 0.53 | 0.01 | 0.29 | 0.68 | 0.03 |
| 2001 | 0.28 | 0.70 | 0.03 | 0.19 | 0.77 | 0.03 |
| 2002 | 0.58 | 0.41 | 0.01 | 0.19 | 0.76 | 0.04 |
| 2003 | 0.47 | 0.49 | 0.05 | 0.23 | 0.76 | 0.01 |
| 2004 | 0.55 | 0.43 | 0.01 | 0.24 | 0.75 | 0.02 |
| 2005 | 0.25 | 0.72 | 0.03 | 0.17 | 0.79 | 0.05 |
| 2006 | 0.38 | 0.57 | 0.05 | 0.16 | 0.70 | 0.14 |
| 2007 | 0.36 | 0.61 | 0.03 | 0.30 | 0.58 | 0.12 |
| 2008 | 0.37 | 0.60 | 0.02 | 0.21 | 0.71 | 0.09 |
| 2009 | 0.35 | 0.63 | 0.02 | 0.16 | 0.78 | 0.06 |
| 2010 | 0.61 | 0.38 | 0.01 | 0.42 | 0.49 | 0.09 |
| 2011 | 0.38 | 0.60 | 0.02 | 0.26 | 0.71 | 0.03 |
| 2012 | 0.49 | 0.51 | 0.00 | 0.44 | 0.51 | 0.04 |
| 2013 | 0.46 | 0.54 | 0.00 | 0.26 | 0.68 | 0.05 |
| 2014 | 0.49 | 0.50 | 0.00 | 0.38 | 0.59 | 0.03 |
| 2015 | 0.43 | 0.56 | 0.01 | 0.26 | 0.67 | 0.06 |

Appendix B5.–Values of annual indices of abundance used to reconstruct historical run size, Kenai River late-run Chinook salmon 75 cm METF or longer, 1986–2015.

| Year | NCPUE | NASB | SCPUE | CCPUE | DIDSON (CV) | ARIS (CV) | CR (CV) |
|---|---|---|---|---|---|---|---|
| 1986 | | | 0.089 | 1296 | | | |
| 1987 | | | 0.092 | 1199 | | | |
| 1988 | | | 0.123 | 870 | | | |
| 1989 | | | 0.067 | 582 | | | |
| 1990 | | | 0.046 | 422 | | | |
| 1991 | | | 0.052 | 630 | | | |
| 1992 | | | 0.076 | 708 | | | |
| 1993 | | | 0.098 | 982 | | | |
| 1994 | | | 0.071 | 1109 | | | |
| 1995 | | | 0.049 | 1113 | | | |
| 1996 | | | 0.036 | 887 | | | 44,872 (0.17) |
| 1997 | | | 0.049 | 636 | | | 40,581 (0.17) |
| 1998 | | | 0.055 | 769 | | | |
| 1999 | | | 0.075 | 676 | | | |
| 2000 | | | 0.065 | 560 | | | |
| 2001 | | | 0.087 | 415 | | | |
| 2002 | 9.88 | 32,416 | 0.092 | 642 | | | |
| 2003 | 10.28 | 38,160 | 0.138 | 716 | | | |
| 2004 | 11.09 | 58,697 | 0.108 | 1371 | | | |
| 2005 | 12.31 | 76,322 | 0.119 | 1048 | | | |
| 2006 | 12.51 | 37,353 | 0.074 | 468 | | | |
| 2007 | 7.52 | 21,271 | 0.062 | 656 | | | |
| 2008 | 10.96 | 32,416 | 0.060 | 396 | | | |
| 2009 | 3.96 | 13,034 | 0.060 | 241 | | | |
| 2010 | 2.07 | 8,556 | 0.033 | 392 | 14,958 (0.03) | | |
| 2011 | 3.42 | 12,491 | 0.055 | 528 | 17,461 (0.02) | | |
| 2012 | 2.80 | 12,011 | | | 18,312 (0.02) | | |
| 2013 | 1.14 | 7,787 | | | 10,498 (0.03) | 13,657 (0.02) | 13,470 (0.17) |
| 2014 | 1.47 | | | | 10,062 (0.02) | 11,615 (0.02) | 11,870 (0.18) |
| 2015 | 2.37 | | | | | 19,645 (0.02) | |

*Note*: Column abbreviations describe the inriver gillnet CPUE (NCPUE), net apportioned split-beam sonar (NASB), inriver sport fishery CPUE (SCPUE), commercial eastside set gillnet fishery (CCPUE), DIDSON sonar estimates from RM 8.6 (DIDSON), ARIS sonar estimates from RM 13.7 adjusted for harvest and spawning below the sonar site (ARIS), and mark–recapture estimates (CR).

# APPENDIX C: KENAI RIVER CHINOOK SALMON FECUNDITY INFORMATION, 1981

Appendix C1.–Kenai River Chinook salmon fecundity data, 1981.

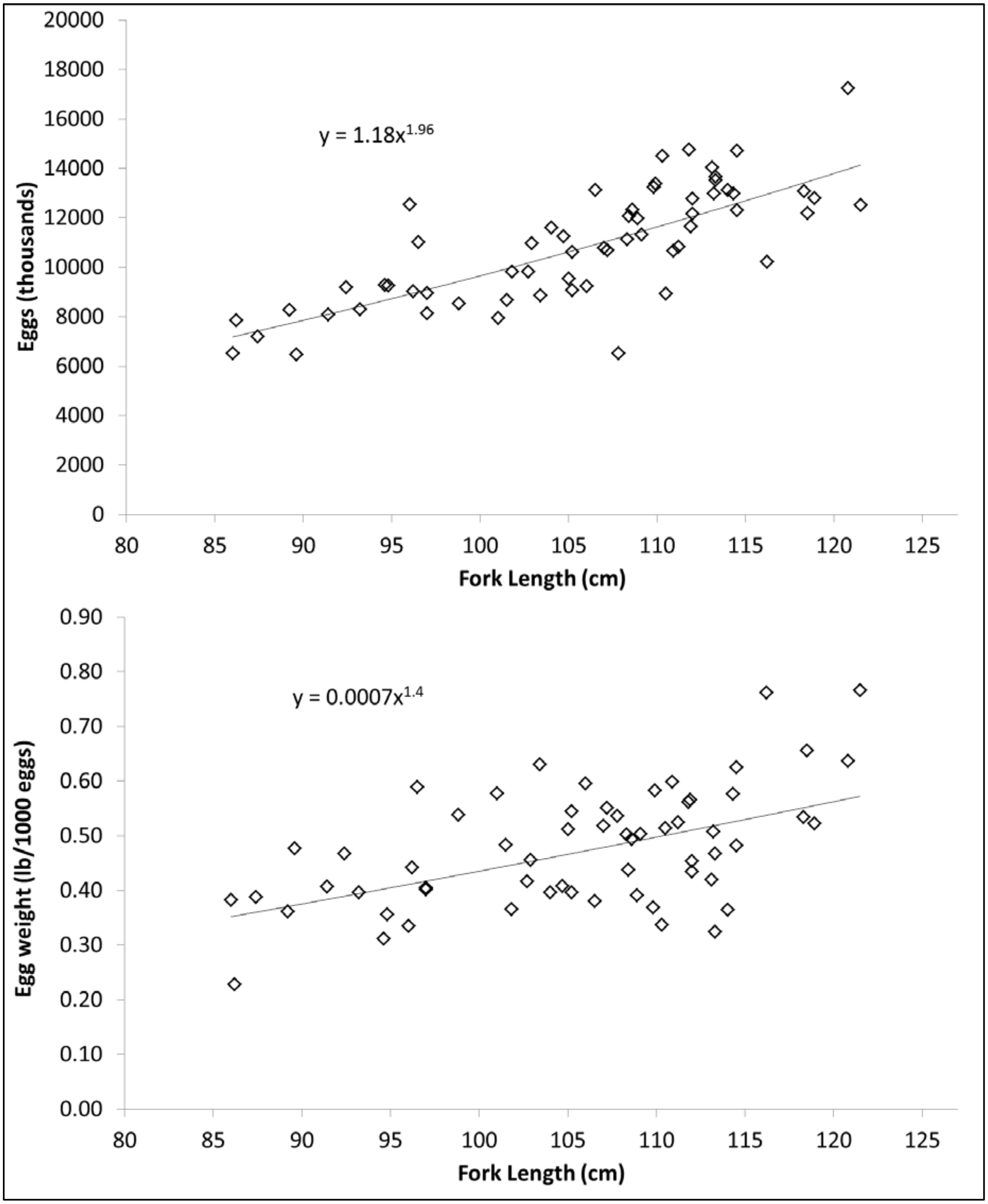
| | Chinook salmon | | Skein | | |
|---|---|---|---|---|---|
| Date | FL (mm) | Weight (lb) | Weight (lb) | Number of eggs | lb/1000 eggs |
| 5/28/1981 | 932 | 27.2 | 3.3 | 8315 | 0.40 |
| 5/29/1981 | 1015 | 31.2 | 4.2 | 8688 | 0.48 |
| 5/29/1981 | 892 | 22.4 | 3 | 8292 | 0.36 |
| 6/2/1981 | 970 | 25.9 | 3.3 | 8137 | 0.41 |
| 6/3/1981 | 1027 | 30 | 4.1 | 9825 | 0.42 |
| 6/4/1981 | 970 | 25.5 | 3.6 | 8963 | 0.40 |
| 6/6/1981 | 1029 | 28.1 | 5 | 10970 | 0.46 |
| 6/6/1981 | 946 | 25.8 | 2.9 | 9283 | 0.31 |
| 6/8/1981 | 914 | 21.9 | 3.3 | 8102 | 0.41 |
| 6/8/1981 | 1010 | 26.8 | 4.6 | 7965 | 0.58 |
| 6/9/1981 | 960 | 26.1 | 4.2 | 12541 | 0.33 |
| 6/9/1981 | 962 | 24.2 | 4 | 9033 | 0.44 |
| 6/9/1981 | | 29.4 | 5.1 | 8645 | 0.59 |
| 6/9/1981 | 1105 | 35 | 4.6 | 8936 | 0.51 |
| 6/9/1981 | 1018 | 31.3 | 3.6 | 9835 | 0.37 |
| 6/9/1981 | 1040 | 32.4 | 4.6 | 11605 | 0.40 |
| 6/10/1981 | 1070 | 36.5 | 5.6 | 10793 | 0.52 |
| 6/10/1981 | 1050 | 31.9 | 4.9 | 9559 | 0.51 |
| 6/10/1981 | 896 | 21.5 | 3.1 | 6490 | 0.48 |
| 6/10/1981 | 874 | 19.6 | 2.8 | 7202 | 0.39 |
| 6/11/1981 | 860 | 19.1 | 2.5 | 6532 | 0.38 |
| 6/11/1981 | 1073 | 36.6 | | | |
| 6/11/1981 | 1185 | 47 | 8 | 12198 | 0.66 |
| 6/11/1981 | 948 | 27.1 | 3.3 | 9263 | 0.36 |
| 6/13/1981 | 988 | 28.5 | 4.6 | 8537 | 0.54 |
| 6/15/1981 | 1052 | 32.1 | 5.8 | 10631 | 0.55 |
| 6/15/1981 | 924 | 24.3 | 4.3 | 9191 | 0.47 |
| 6/15/1981 | 1034 | 29.8 | 5.6 | 8869 | 0.63 |
| 6/15/1981 | 1072 | 35 | 5.9 | 10693 | 0.55 |
| 6/17/1981 | 1120 | 39.2 | 5.3 | 12181 | 0.44 |
| 6/17/1981 | 862 | 19 | 1.8 | 7873 | 0.23 |
| 6/23/1981 | 965 | 36 | 6.5 | 11029 | 0.59 |
| 6/23/1981 | 1078 | 23.5 | 3.5 | 6521 | 0.54 |
| 7/1/1981 | 1140 | 42.8 | 4.8 | 13136 | 0.37 |
| 7/1/1981 | 1089 | 35.8 | 4.7 | 11998 | 0.39 |

-continued-

Appendix C1.–Page 2 of 2.

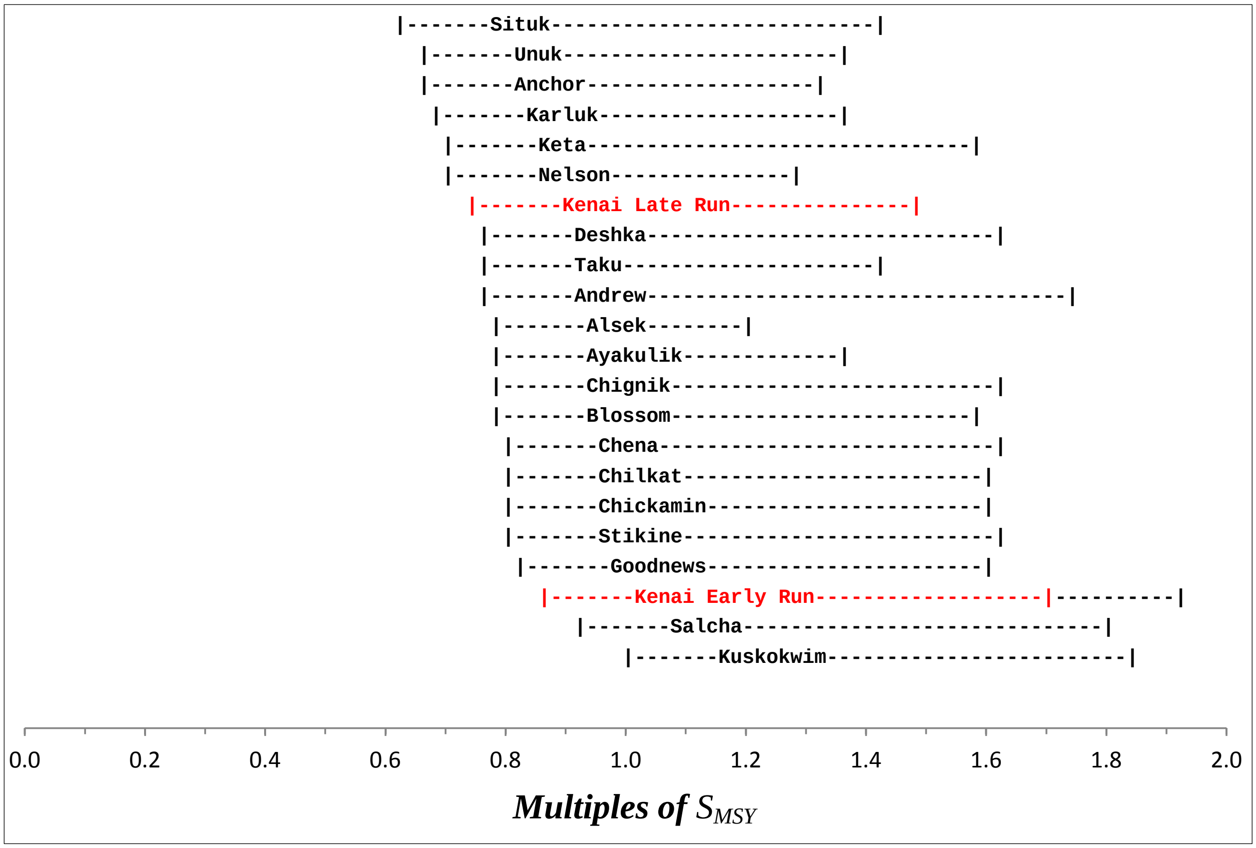
|  | Chinook salmon |  | Skein |  |  |
|---|---|---|---|---|---|
| Date | FL (mm) | Weight (lb) | Weight (lb) | Number of eggs | lb/1000 eggs |
| 7/2/1981 | 1052 | 31 | 3.6 | 9081 | 0.40 |
| 7/2/1981 | 1133 | 37.9 | 4.4 | 13540 | 0.32 |
| 7/2/1981 | 1103 | 35.6 | 4.9 | 14528 | 0.34 |
| 7/6/1981 | 1060 | 33.1 | 5.5 | 9236 | 0.60 |
| 7/7/1981 | 1091 | 33.8 | 5.7 | 11325 | 0.50 |
| 7/7/1981 | 1047 | 31.6 | 4.6 | 11252 | 0.41 |
| 7/8/1981 | 1132 | 41.9 | 6.6 | 12996 | 0.51 |
| 7/8/1981 | 1083 | 39 | 5.6 | 11149 | 0.50 |
| 7/9/1981 | 1118 | 46.8 | 8.3 | 14764 | 0.56 |
| 7/10/1981 | 1112 | 37.8 | 5.7 | 10847 | 0.53 |
| 7/15/1981 | 1145 | 42.6 | 7.1 | 14723 | 0.48 |
| 7/15/1981 | 1183 | 45 | 7 | 13096 | 0.53 |
| 7/15/1981 | 1098 | 36.5 | 4.9 | 13262 | 0.37 |
| 7/15/1981 | 1065 | 32.9 | 5 | 13132 | 0.38 |
| 7/15/1981 | 1086 | 35.4 | 6.1 | 12340 | 0.49 |
| 7/15/1981 | 1120 | 43.3 | 5.8 | 12773 | 0.45 |
| 7/16/1981 | 1208 | 55.1 | 11 | 17255 | 0.64 |
| 7/16/1981 | 1215 | 46.8 | 9.6 | 12522 | 0.77 |
| 7/20/1981 | 1189 | 46.6 | 6.7 | 12811 | 0.52 |
| 7/20/1981 | 1133 | 40.6 | 6.4 | 13682 | 0.47 |
| 7/20/1981 | 1162 | 40 | 7.8 | 10235 | 0.76 |
| 7/21/1981 | 1109 | 37.7 | 6.4 | 10687 | 0.60 |
| 7/21/1981 |  | 31.3 | 5.9 | 11328 | 0.52 |
| 7/21/1981 | 1099 | 38.8 | 7.8 | 13386 | 0.58 |
| 7/21/1981 | 1119 | 37.7 | 6.6 | 11664 | 0.57 |
| 7/23/1981 | 1145 | 42.4 | 7.7 | 12305 | 0.63 |
| 7/23/1981 | 1143 | 40.8 | 7.5 | 13001 | 0.58 |
| 7/23/1981 | 1084 | 35.4 | 5.3 | 12088 | 0.44 |
| 7/23/1981 | 1131 |  | 5.9 | 14055 | 0.42 |

Appendix C2.–Fecundity (top) and egg weight per 1000 eggs (bottom) vs. fork length, Kenai River Chinook salmon, 1981.



# APPENDIX D: ESCAPEMENT GOALS RELATIVE TO ESTIMATES OF SPAWNING ABUNDANCE PROVIDING MAXIMUM SUSTAINED YIELD FOR 22 ALASKA CHINOOK SALMON STOCKS

Appendix D1.–Escapement goal lower and upper bounds for 22 Alaska Chinook salmon stocks plotted as multiples of $S_{MSY}$. For the Kenai River stocks, the plotted bounds apply to both current (2013) and recommended (2017) escapement goals, except for the Kenai River early-run upper bound, which was 1.92 × $S_{MSY}$ for the 2013 goal (shown in black) but only 1.70 × $S_{MSY}$ for the 2017 goal (shown in red).



# APPENDIX E: KENAI RIVER CHINOOK SALMON INRIVER GILLNET CATCH COMPOSITION AT RM 8.6, 2002–2016

Appendix E1.–Proportion of Chinook salmon and female Chinook salmon 75 cm METF and longer and proportion of eggs originating from female Chinook salmon 75 cm METF and longer in midriver (MR), nearshore (NS) and full river (FR) inriver gillnet catches at Kenai River river mile 8.6, 2002–2016.

| | | Number of Chinook salmon sampled | | | Proportion ≥75 cm METF | | | | | | Proportion of eggs from females ≥75 cm METF | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | All Chinook | | | Female Chinook | | | | | |
| Run | Year | MR | NS | FR | MR | NS | FR | MR | NS | FR | MR | NS | FR |
| Early | 2002 | 338 | | | 0.76 | | | 0.92 | | | 0.96 | | |
| | 2003 | 797 | | | 0.64 | | | 0.87 | | | 0.94 | | |
| | 2004 | 414 | | | 0.76 | | | 0.87 | | | 0.93 | | |
| | 2005 | 446 | | | 0.83 | | | 0.99 | | | 0.99 | | |
| | 2006 | 275 | | | 0.63 | | | 0.79 | | | 0.90 | | |
| | 2007 | 251 | | | 0.66 | | | 0.83 | | | 0.91 | | |
| | 2008 | 181 | | | 0.82 | | | 0.95 | | | 0.97 | | |
| | 2009 | 151 | | | 0.81 | | | 0.97 | | | 0.99 | | |
| | 2010 | 148 | | | 0.63 | | | 0.92 | | | 0.95 | | |
| | 2011 | 204 | | | 0.70 | | | 1.00 | | | 1.00 | | |
| | 2012 | 92 | | | 0.84 | | | 0.88 | | | 0.93 | | |
| | 2013[a] | 50 | 17 | 67 | 0.68 | 0.29 | | 0.96 | 1.00 | | 0.98 | 1.00 | |
| | 2014 | 130 | 35 | 165 | 0.38 | 0.31 | 0.37 | 0.84 | 1.00 | 0.86 | 0.91 | 1.00 | 0.92 |
| | 2015 | 88 | 51 | 139 | 0.59 | 0.45 | 0.54 | 0.80 | 0.88 | 0.82 | 0.88 | 0.93 | 0.89 |
| | 2016 | 111 | 62 | 173 | 0.61 | 0.48 | 0.57 | 0.94 | 0.76 | 0.88 | 0.96 | 0.83 | 0.92 |
| Late | 2002 | 1064 | | | 0.78 | | | 0.87 | | | 0.94 | | |
| | 2003 | 1291 | | | 0.61 | | | 0.72 | | | 0.87 | | |
| | 2004 | 1051 | | | 0.78 | | | 0.87 | | | 0.94 | | |
| | 2005 | 594 | | | 0.89 | | | 0.98 | | | 0.99 | | |
| | 2006 | 784 | | | 0.71 | | | 0.81 | | | 0.91 | | |
| | 2007 | 511 | | | 0.72 | | | 0.89 | | | 0.94 | | |
| | 2008 | 551 | | | 0.90 | | | 0.96 | | | 0.98 | | |
| | 2009 | 378 | | | 0.74 | | | 0.99 | | | 0.99 | | |
| | 2010 | 244 | | | 0.68 | | | 0.94 | | | 0.97 | | |
| | 2011 | 326 | | | 0.67 | | | 0.98 | | | 0.99 | | |
| | 2012 | 258 | | | 0.86 | | | 0.97 | | | 0.98 | | |
| | 2013 | 170 | 18 | 188 | 0.64 | 0.44 | | 0.95 | 1.00 | | 0.97 | 1.00 | |
| | 2014 | 272 | 50 | 322 | 0.65 | 0.34 | 0.61 | 0.96 | 0.90 | 0.95 | 0.98 | 0.94 | 0.97 |
| | 2015 | 224 | 64 | 288 | 0.71 | 0.48 | 0.66 | 0.89 | 0.67 | 0.84 | 0.94 | 0.80 | 0.90 |
| | 2016 | 188 | 74 | 262 | 0.72 | 0.66 | 0.71 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | Average | | | | | | | | | | | | |
| Early | 2013–2016 | 95 | 41 | 136 | 0.57 | 0.39 | **0.49** | 0.88 | 0.91 | **0.85** | 0.93 | 0.94 | **0.91** |
| Late | 2013–2017 | 213 | 51 | 265 | 0.68 | 0.48 | **0.66** | 0.95 | 0.89 | **0.93** | 0.97 | 0.94 | **0.96** |

*Note*: Values cited in the text are in bold.

[a] Chinook salmon migrating nearshore were undersampled in 2013, when nearshore sampling occurred only 2 days per week.