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Stock Assessment of Early-Run Chinook Salmon in the Kenai River, 2002-2006

by

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and

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March 2010

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

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Weights and measures (metric)

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

Weights and measures (English)

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

Time and temperature

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

Physics and chemistry

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

General

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

Measures (fisheries)

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

Mathematics, statistics

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

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ABSTRACT

The status and escapement goal of early-run Chinook salmon *Oncorhynchus tshawytscha* in the Kenai River was assessed using information from creel surveys, an inriver sonar project, an age-structure spawner-recruit analysis, educational harvests, an inriver gillnetting project, and Alaska Statewide Harvest Surveys. This report updates stock assessment statistics with data from 2002–2006.

The estimated total runs of early-run Kenai River Chinook salmon were 7,226 (SE = 169) in 2002, 13,371 (SE = 199) in 2003, 15,587 (SE = 261) in 2004, 20,526 (SE = 295) in 2005, and 23,401 (SE = 394) in 2006. The estimated inriver sport fishery harvest was 12% of the run in 2002, 21% in 2003, 22% in 2004, 19% in 2005, and 20% in 2006. Spawning escapement estimates of early-run Chinook salmon were 6,185 fish (SE = 221) in 2002, 10,097 (SE = 540) in 2003, 11,855 (SE = 487) in 2004, 16,387 (SE = 412) in 2005, and 18,428 (SE = 495) in 2006. Spawning escapement estimates for 2002–2006 were all within or above the current optimal escapement goal of 5,300–9,000 Chinook salmon.

Hook-and-release mortality estimates for early-run Kenai River Chinook salmon ranged from 78 (SE = 54; 2002) to 389 (SE = 276; 2003). Return-per-spawner estimates ranged from 0.53 (SE = 0.28) to 3.89 (SE = 0.71). Estimated sibling ratios averaged 4.27 (SD = 2.67) for age 5 to age 4, 2.27 (SD = 1.16) for age 6 to age 5, and 0.06 (SD = 0.04) for age 7 to age 6. Results suggest there is an increasing trend in the runs of ocean-age-2 fish. The mean age estimates of the escapement from the last two complete brood returns (1998 and 1999) were the lowest in the last 20 years; however, the mean age estimates of the return from 1998 were above average and 1999 were average. Mean length-at-age estimates have not changed since 1986.

A slot limit imposed in 2003 decreased the selective harvest for ocean-age-4 and ocean-age-5 fish, and increased the selective harvest for ocean-age-3 fish. However, because of low harvest rates, the slot limit has not substantially affected the age composition of the escapement. Estimated runs of ocean-age-5 fish from 2002–2006 ranged from 129 (SE = 49; 2003) to 865 (SE = 284; 2006).

Based on an age-structured Bayesian spawner-recruit analysis, spawning escapement at maximum sustained yield S_{MSY} is, with 95% probability, between 3,592 and 6,073 (posterior median = 4,579). Spawning escapement at maximum return S_{MAX} is, with 95% probability, between 4,443 and 9,755 (posterior median = 6,189). Active research is underway to develop improved sonar estimates of inriver run. Preliminary results indicate that the current published estimates are subject to substantial measurement error. No immediate change is recommended to the current optimal escapement goal of 5,300–9,000 fish.

Key words: Kenai River, Chinook salmon, total run, spawning escapement, sibling ratios, brood tables, slot limit, spawner-recruit analysis, maximum sustained yield, Bayesian statistics, Markov Chain Monte Carlo, *Oncorhynchus tshawytscha*.

INTRODUCTION

Two stocks of Chinook salmon *Oncorhynchus tshawytscha* return to the Kenai River (Figures 1 and 2) to spawn, both of which are highly prized by anglers for their size, relative to other Chinook salmon stocks (Roni and Quinn (2007)). The early run enters the river from late April through June, and the late run enters the river from late June through early August (Burger et al. 1985; Bendock and Alexandersdottir 1992). Early-run Kenai River Chinook salmon migrate through Cook Inlet with stocks from other streams of the Kenai Peninsula (Anchor River, Deep Creek, Ninilchik River, Stariski Creek, and Kasilof River) and the Susitna River drainage (Figure 1). Early-run Kenai River Chinook salmon spawn primarily in tributary streams (Bendock and lexandersdottir 1992) and are the focus of this report; late-run fish are destined almost exclusively for mainstem spawning locations and are the focus of a companion report[1].

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[1] Stock Assessment of Late-run Kenai River Chinook Salmon, Project Leader T. McKinley, ADF&G Sport Fish Biologist, Soldotna.

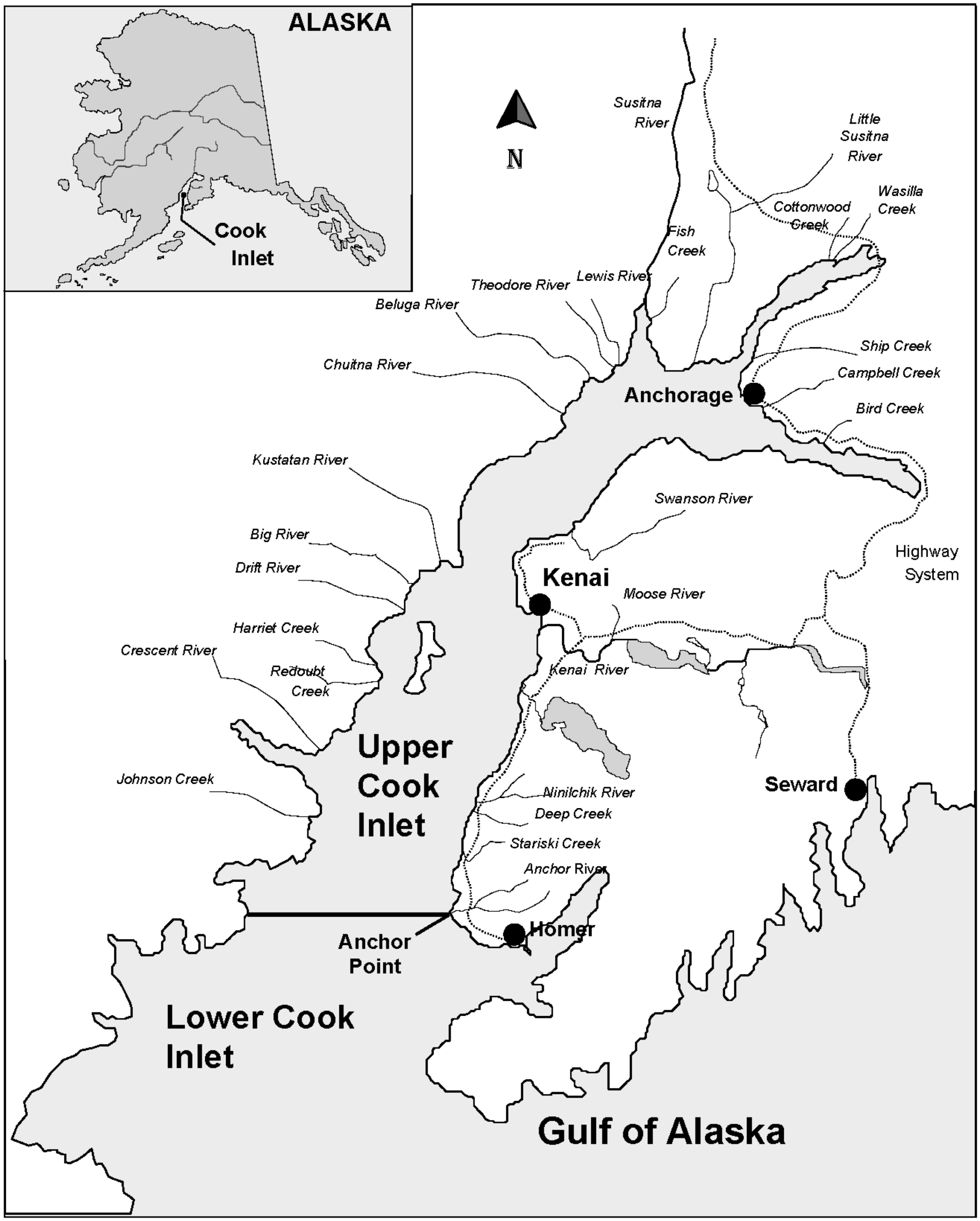

Figure 1.–Location of Kenai River and other rivers in the Cook Inlet area.

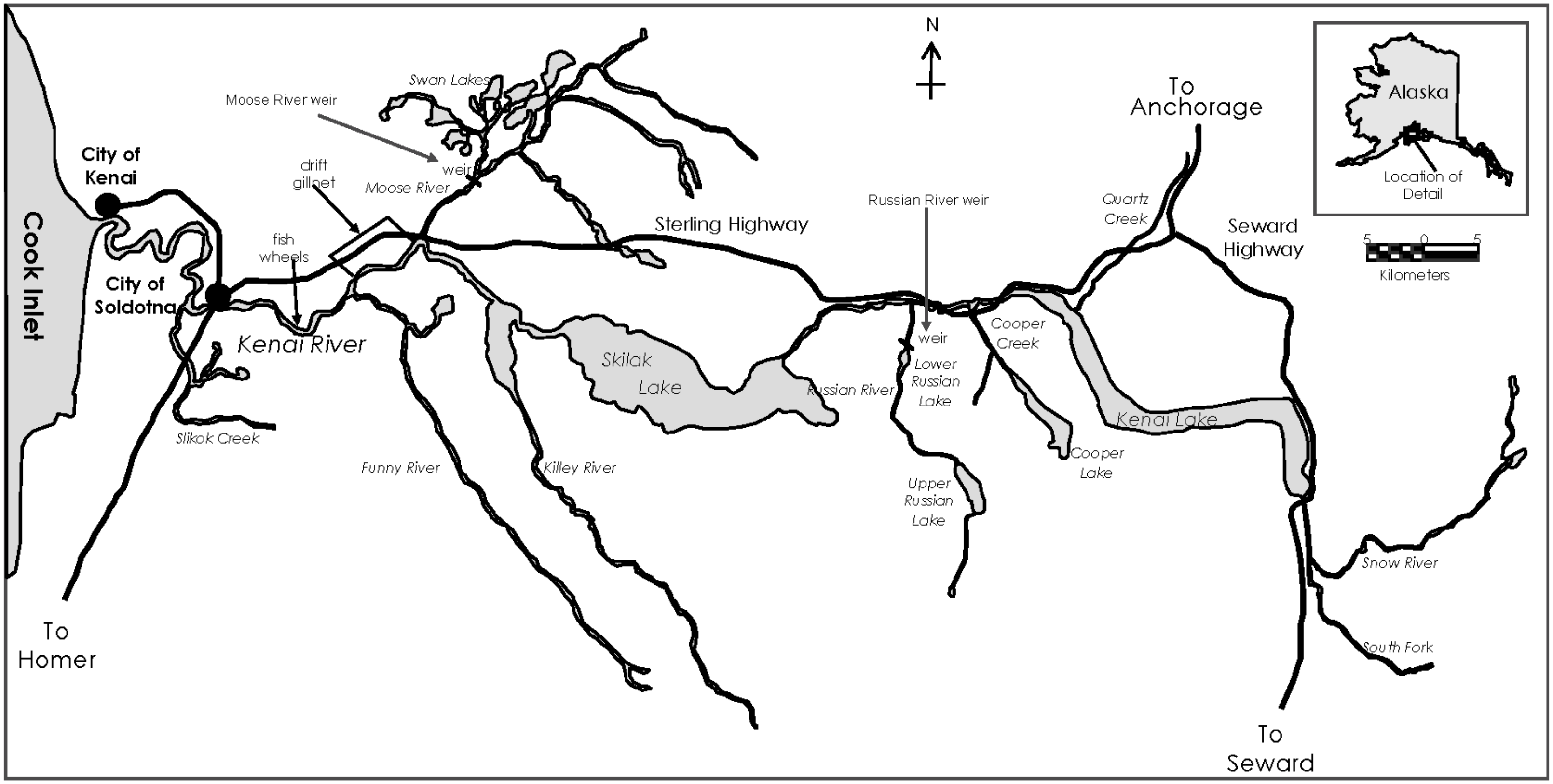

Figure 2.–Map of Kenai River drainage.

Chinook salmon of Kenai River origin are harvested primarily in three fisheries. The first is a recreational marine fishery near Ninilchik Village along the eastern shore of Cook Inlet, which accounts for the only substantial marine harvest of early-run stocks. The second is an educational gillnet fishery operated in the Kenai River by the Kenaitze Indian tribe. This gillnet fishery was established by the Alaska Board of Fisheries (BOF) and generally accounts for less than 200 fish harvested annually (Nelson et al. 1999). Chinook salmon were harvested in this fishery in 1992 and 1994, which was prosecuted as a personal use fishery in 1995. The third fishery is a major sport fishery in the Kenai River itself.

Prior to 1970, the sport fishery in the Kenai River was limited to shorebased anglers targeting sockeye salmon *O. nerka* in July and coho salmon *O. kisutch* in August and early September. In 1973, anglers began experimenting with a fishing method used in the Pacific Northwest of bouncing brightly colored terminal gear along the river bottom from a drifting boat. It proved to be very effective for catching Chinook salmon in the Kenai River, and the fishery expanded rapidly during the late 1970s and 1980s.

The Alaska Department of Fish and Game (ADF&G) and public concerns about overexploitation began to grow during the early 1980s as fisheries targeting both the early and late runs of Chinook salmon increased. In 1988, the BOF adopted management plans for the early and late runs (McBride et al. 1989). These plans defined the early run as prior to 1 July and the late run as after 30 June. Currently, the *Kenai River and Kasilof River Early-Run King Salmon Management Plan* (*5 AAC 57.160*) mandates that the inriver sport fishery be managed to achieve an optimal escapement goal (OEG) of 5,300–9,000 Chinook salmon. In brief, bait, multiple hooks and fishing from boats on Mondays are prohibited unless the projected spawning escapement exceeds 9,000 fish. If the projected spawning escapement is below 5,300, ADF&G restricts the sport fishery in order to achieve a spawning escapement of at least 5,300 fish.

A slot limit regulation was enacted in 2002 and revised in 2003 in response to a declining number of ocean-age-5 Chinook salmon in the early run. The Department has specific direction to address changes in the Department's *Policy for the Management of Sustainable Salmon Fisheries 5 AAC 39.222*(*c*)(*2*)(*D*). The policy states that "salmon escapement should be managed in a manner to maintain genetic and phenotypic characteristics of the stock by assuring appropriate geographic and temporal distribution of spawners as well as consideration of size range, sex ratio, and other population attributes." The original 2002 slot limit was 40–55 inches TL. The 2003 slot limit allows Chinook salmon less than 44 inches TL or 55 inches TL and greater to be retained (note: the slot limit was changed to 46–55 inches in 2008). The slot limit is in effect January 1-June 30 from the mouth of Kenai River to the Soldotna Bridge, and January 1-July 14 from the Soldotna Bridge upstream to Skilak Lake. The 2003 slot limit was enacted to protect a portion of the ocean-age-5 Chinook salmon from being harvested. Other sport fishing regulations for this stock, which are among the most restrictive in Alaska, are also detailed in the management plan, and include a daily bag and possession limit of one and a seasonal limit of two Chinook salmon, closed areas, and restrictions on boats, guides, and guided anglers.

A comprehensive stock assessment program was initiated in the mid-1980s which included creel surveys and estimation of inriver run by sonar to implement the management plan. The objectives of this continuing program are 2-fold: 1) to estimate inriver abundance and fishery mortality to effectively manage the fishery inseason; and 2) to develop brood tables for long-term stock assessment.

This report presents a long-term stock assessment of early-run Kenai River Chinook salmon. It summarizes previously published historical statistics and compiles updated information from 2002 through 2006. Included are estimates of inriver and total run by age, hook-and-release mortality by age, and spawning escapement by age. These are used to produce estimates of return by brood year. An age-structured Ricker spawner-recruit model is fit to the historical data, using Markov Chain Monte Carlo (MCMC) methods. This methodology reduces bias caused by measurement error, and provides a more realistic assessment of uncertainty than is possible with other statistical methods. The overall status of early-run Kenai River Chinook salmon stock is also assessed.

METHODS

Historical assessment begins with the 1986 run, the first year for which age data are available for all components of the run. Fishery and stock parameter estimates are derived from multiple sources; some are estimated directly and some indirectly (Table 1). Formulas for point estimates and variances are detailed in Appendix A1.

Table 1.–Summary of how stock parameter estimates are derived for early-run Kenai River Chinook salmon.

Stock parameter	Estimated directly (D) or indirectly (I)	How estimated
Inriver return	D	Sonar at river mile 8.6
Personal use and Kenaitze educational harvest	D	Reported directly to ADF&G
Total return	I	Inriver return plus reported harvest in personal use and Kenaitze Educational fishery
Age composition of inriver return	D	Netting project near sonar site at river mile 8.6
Age composition of total return	I	Age composition of inriver return used as a surrogate
Sport catch, harvest, and effort below Soldotna Bridge	D	Onsite creel survey
Age composition of sport harvest below Soldotna Bridge	D	Collection of age samples in onsite creel survey
Age composition of hook-and-released fish above and below Soldotna Bridge	I	Age composition of inriver return used as a surrogate
Sport catch and harvest above Soldotna Bridge	D and I	Most recently: estimated by attributing a portion of the harvest in the SWHS to the early run stock
Age composition of sport harvest above Soldotna Bridge	I	Age composition of sport harvest below Soldotna Bridge used as a surrogate
Age composition of hook-and-released fish above and below Soldotna Bridge	I	Age composition of inriver return used as a surrogate
Hook-and-release mortalities	I	Multiplication of average of direct estimates of mortality rate from 1990 and 1991 (rate not specific to age or size), and the estimated number of released fish above and below the Soldotna Bridge
Escapement	I	Subtraction of all known inriver mortalities from the inriver return
Age composition of the escapement	I	Subtraction of all known inriver mortalities (by age) from the inriver return (by age)

INRIVER RUN

Inriver runs of Kenai River Chinook salmon have been estimated using two methods: a capture-recapture program from 1985 through 1990 (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and Marsh 1990), and a hydroacoustic (sonar) program from 1984 through 2006 (Eggers et al. 1995; Burwen and Bosch 1995a-b, 1996, 1998; Bosch and Burwen 1999-2000; Miller and Burwen 2002; Miller et al. 2003-2005, 2007a-b, *In prep*). The sonar program was exploratory during the first four years of the study, and the two programs were conducted simultaneously from 1985 to 1990 to determine the best method for estimating inriver run. Abundance estimates from the capture-recapture program are not available for 1990 because of closures to the inriver sport fishery (Sonnichsen and Alexandersdottir 1991). The capture-recapture program was terminated after 1990 because estimates from the two methods were similar, the sonar estimates were more precise, and redundancy was cost prohibitive. In addition, the management plan implemented in 1989 required inseason estimates of abundance, which could not be provided by the capture-recapture method. Continued evaluation of the sonar project has resulted in improvements to inriver abundance estimates. Therefore, for inriver run estimates for this stock assessment, we used capture-recapture estimates for 1986–1987, and sonar estimates of passage for 1988–2006.

The age/sex composition of the inriver run was sampled in 1986–2006 to estimate inriver run by age. Scale samples collected from Chinook salmon prior to 1991 were obtained with cable-lay 7¼-inch (stretched measure) mesh gillnets during capture-recapture studies (Sonnichsen and Alexandersdottir 1991). Although the capture-recapture program was discontinued in 1991, age, sex, and length samples were still collected using gillnets from 1991 through 2001 (Hammarstrom 1992-1994; King 1995-1997; Marsh 1999-2000; Reimer et al. 2002). Beginning in 2002, the gillnets were constructed of multi-monofilament mesh, increasing the catch rate by approximately 3-fold (Reimer 2003, 2004a-b, 2007; Eskelin 2007, *In prep*). Also, a second mesh size (5-inch stretched mesh) was added in 2002 to reduce size selectivity of the gillnetting program. Age composition estimates from 2002–2006 reported here are from the pooled catch (both 5-inch and 7¼-inch mesh).[2]

SUBSISTENCE, EDUCATIONAL AND PERSONAL USE HARVEST

Harvests in subsistence, educational, and personal use fisheries for early-run Chinook salmon were compiled annually by ADF&G, Division of Sport Fish in Soldotna. These harvests are small, and standard errors are not available.

TOTAL RUN

Total run was estimated as the sum of inriver run (estimated by mark-recapture or sonar) and subsistence, personal use, and educational harvest (for equations see Appendices A1 and A2). Inriver estimates of age composition from the gillnetting program were applied to the total run to estimate total run by age (Appendix A3).

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[2] Technically, these estimates are not exactly comparable to pre-2002 estimates; however, the differences are small and they have a negligible effect on the spawner-recruit analysis.

SPORT HARVEST

The number of early-run Kenai River Chinook salmon harvested in the marine sport fishery is not known. Catch and harvest of Chinook salmon in the Kenai River sport fishery were estimated with an onsite creel survey (Conrad and Hammarstrom 1987; Hammarstrom 1988-1994; King 1995-1997; Marsh 1999-2000; Reimer et al 2002; Reimer 2003, 2004a-b, 2007; Eskelin 2007, *In prep*) and in the Statewide Harvest Survey (SWHS; Mills 1987-1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b). The creel survey provided estimates for the entire inriver sport fishery for 1986-1989, and downstream of Naptowne Rapids to Cook Inlet in 1990. In those years, catch and harvest were estimated for three river sections (two in 1990): Cook Inlet to the Soldotna Bridge, Soldotna Bridge to Naptowne Rapids, and Naptowne Rapids to the outlet of Skilak Lake. In 1991 and 1992, catch and harvest were only estimated for the Cook Inlet to Soldotna Bridge section because of restrictions and closures to the fishery upstream of the Soldotna Bridge. Beginning in 1993, catch and harvest were only estimated from Cook Inlet to Soldotna Bridge because of logistical problems with sampling the fishery upstream of the Soldotna Bridge. However, some sport fishing occurs upstream of the Soldotna Bridge.

Estimates of harvest and catch from creel surveys for Cook Inlet to Soldotna Bridge area were used for all years. Estimates from the SWHS (Mills 1987-1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009 a-b) were used to estimate harvest upstream of the Soldotna Bridge.

The SWHS provided estimates of harvest and catch of Chinook salmon from the following sections of the Kenai River: Cook Inlet to the Soldotna Bridge, the Soldotna Bridge to Moose River, Moose River to the outlet of Skilak Lake, and the inlet of Skilak Lake to the outlet of Kenai Lake. However, using these estimates to account for harvest and catch upstream of the Soldotna Bridge was complicated because prior to 1996, catch, harvest, and their variances were estimated for the entire year rather than by run. Beginning in 1996, these SWHS estimates were stratified into an early (before July 1) and late (after June 30) run. In addition, catch was not estimated in the SWHS prior to 1990.

Historically, the early run accounted for about half the total harvest upstream of the Soldotna Bridge based on creel surveys (Conrad and Hammarstrom 1987; Hammarstrom 1988-1991) and the SWHS (Howe et al. 2001a-d). Therefore, we used 50% of the SWHS estimates from upstream of the Soldotna Bridge to account for harvest upstream of the Soldotna Bridge for 1986–1995. Catch was accounted for in the same manner for 1990–1995. For 1986–1989 we used estimates of harvest to account for catch upstream of the Soldotna Bridge, assuming that catch equaled harvest. Our estimates of hook-and-release mortality are therefore biased low for those years because some fish were released alive. For 1996–2006, we used early-run (before July 1) estimates of harvest and catch upstream of the Soldotna Bridge from the SWHS (Howe et al. 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009 a-b).

Total sport harvest was estimated as the sum of harvest from Cook Inlet to the Soldotna Bridge (from onsite creel surveys) and harvest upstream of the Soldotna Bridge (from SWHS). Scale samples obtained from harvested fish sampled during the onsite creel surveys were used to estimate age composition of the total sport harvest (Appendix A3).

HOOK-AND-RELEASE MORTALITY

Hook-and-release mortality for Kenai River Chinook salmon was estimated in 1990 (8.8%, SE = 2.5%) and 1991 (4.0%, SE = 2.0%; Bendock and Alexandersdottir 1991, 1992). The mean of the two annual estimates (6.4%, inter-annual prediction error = 4.1%) was used as an estimate of hook-and-release mortality for the remaining years (Appendix A2). Hook-and-release mortality by age was estimated by applying age composition estimates from the inriver run to annual estimates of hook-and-release mortality (Appendix A3).

SPAWNING ESCAPEMENT

Spawning escapement was estimated by subtracting total inriver mortality (sport harvest and hook-and-release mortality) from the inriver run for each age class (Appendix A3).

RETURN PER SPAWNER

Within each calendar year, the individual age components of the total run corresponding to the same age were summed (e.g., total run estimates for ages 0.5, 1.4, and 2.3 were summed for age 6), and then total run by age corresponding to the same brood year were summed across calendar years (Appendix A4). Returns per spawner were estimated by dividing the total number of fish returning for each brood year by the number of spawners for that brood year (Appendix A4).

SIBLING RATIOS

The distribution of Chinook salmon returning in each age class within a brood year can be a stable, heritable characteristic of a stock (Hard et al. 1985; Ricker 1972; Withler et al. 1987; Hankin et al. 1993). Sibling ratios, which can be used to project future returns, were estimated as the ratio of the return at one age to the return at one or more younger ages (Appendix A4).

SPAWNER-RECRUIT ANALYSIS

A Ricker spawner-recruit function[3] (Ricker 1975) was chosen to model the relationship between escapement and recruitment, and to estimate optimal spawning escapement and other reference points. We employed Markov Chain Monte Carlo (MCMC) methods in a Bayesian framework, which are especially well-suited for modeling complex population and sampling processes. The Bayesian MCMC analysis considers all the data simultaneously in the context of an age-structured spawner-recruit statistical model, detailed in Appendix B1.

RESULTS

TOTAL RUN

Early-run Kenai River Chinook salmon ranged from 7,226 to 23,401 fish between 2002 and 2006 (Table 2, Figure 3). The total run during 2002–2006 was comprised of 1–4% three-year-old fish (ages 0.2, 1.1), 12–32% four-year-old fish (ages 0.3, 1.2, 2.1), 19–37% five-year-old fish (ages 0.4, 1.3, 2.2), 40–53% six-year-old-fish (ages 0.5, 1.4, 2.3), 1–4% seven-year-old-fish (ages 1.5, 2.4) (Table 3). Age-1.5 fish represented 1.0–4.3% of the total run between 2002 and 2006 (Appendix C1). The sex composition of the run has exhibited no obvious trend in the last 20 years (Figure 4).

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[3] The Ricker spawner-recruit function was chosen because it is capable of modeling overcompensation (a decline in absolute production with increasing escapement).

Table 2.–Abundance, harvest, and escapement of early-run Kenai River Chinook salmon, 1986–2006.

Year	Deep Creek marine harvest	Eastside set net harvest	Drift gillnet harvest	Subsis., P.U., and Educ. harvest	Inriver run	SE	Total run	Inriver sport harvest	SE	Hook-and-release mortality	SE	Spawning escapement	SE	Total harvest rate	SE
1986	Unknown	0	0	0	27,080	9,799	27,080	8,156	474	242	160	18,682	9,812	0.31	0.11
1987	Unknown	0	0	0	25,643	5,928	25,643	13,557	912	306	208	11,780	6,001	0.54	0.13
1988	Unknown	0	0	0	20,880	449	20,880	15,209	815	340	225	5,331	958	0.74	0.04
1989	Unknown	0	0	73	17,992	389	18,065	8,394	517	149	103	9,449	655	0.48	0.03
1990	Unknown	0	0	40	10,768	242	10,808	1,807	227	378	115	8,583	351	0.21	0.03
1991	Unknown	0	0	2	10,939	269	10,941	1,945	209	152	78	8,842	349	0.19	0.02
1992	Unknown	0	0	73	10,087	255	10,160	2,241	177	236	152	7,610	346	0.25	0.02
1993	Unknown	0	0	118	19,669	386	19,787	9,342	419	286	186	10,041	600	0.49	0.02
1994	Unknown	0	0	56	18,403	288	18,459	8,171	363	285	185	9,947	499	0.46	0.02
1995	Unknown	0	0	37	21,884	396	21,921	10,217	448	357	231	11,310	641	0.48	0.02
1996	Unknown	0	0	14	23,505	376	23,519	6,623	354	287	188	16,595	550	0.29	0.02
1997	Unknown	0	0	141	14,963	236	15,104	6,429	643	349	232	8,185	723	0.46	0.05
1998	Unknown	0	0	122	13,103	230	13,225	1,170	123	254	164	11,679	308	0.12	0.01
1999	Unknown	0	0	114	25,666	370	25,780	8,129	478	261	171	17,276	628	0.33	0.02
2000	Unknown	0	0	124	12,479	234	12,603	1,818	198	185	121	10,476	329	0.17	0.02
2001	Unknown	0	0	198	16,676	285	16,874	2,399	230	204	134	14,073	390	0.17	0.02
2002	Unknown	0	0	64	7,162	169	7,226	899	132	78	54	6,185	221	0.14	0.02
2003	Unknown	0	0	46	13,325	199	13,371	2,839	419	389	276	10,097	540	0.24	0.04
2004	Unknown	0	0	89	15,498	261	15,587	3,386	376	257	168	11,855	487	0.24	0.03
2005	Unknown	0	0	76	20,450	295	20,526	3,810	359	253	167	16,387	494	0.20	0.02
2006	Unknown	0	0	75	23,326	394	23,401	4,693	444	205	136	18,428	609	0.21	0.02

Table 3.–Total run of early-run Kenai River Chinook salmon by age and calendar year, 1986–2006.

Return year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Total return
1986 Est.	0	4,191	11,384	9,349	2,156	0	27,080
SE	0	1,537	4,133	3,399	788	0	9,799
Prp	0.000	0.155	0.420	0.345	0.080	0.000	
SE	0.000	0.010	0.013	0.013	0.007	0.000	
1987 Est.	0	393	9,859	14,709	682	0	25,643
SE	0	134	2,312	3,417	187	0	5,928
Prp	0.000	0.015	0.384	0.574	0.027	0.000	
SE	0.000	0.004	0.016	0.016	0.005	0.000	
1988 Est.	0	373	3,302	14,914	2,237	53	20,880
SE	0	99	281	466	236	38	449
Prp	0.000	0.018	0.158	0.714	0.107	0.003	
SE	0.000	0.005	0.013	0.016	0.011	0.002	
1989 Est.	0	749	2,791	12,819	1,706	0	18,065
SE	0	137	254	415	203	0	389
Prp	0.000	0.041	0.155	0.710	0.094	0.000	
SE	0.000	0.008	0.014	0.017	0.011	0.000	
1990 Est.	0	782	2,874	6,462	690	0	10,808
SE	0	130	230	284	123	0	242
Prp	0.000	0.072	0.266	0.598	0.064	0.000	
SE	0.000	0.012	0.020	0.023	0.011	0.000	
1991 Est.	0	802	2,452	7,121	566	0	10,941
SE	0	189	306	385	160	0	269
Prp	0.000	0.073	0.224	0.651	0.052	0.000	
SE	0.000	0.017	0.027	0.031	0.015	0.000	
1992 Est.	0	826	2,891	5,906	537	0	10,160
SE	0	179	302	353	146	0	255
Prp	0.000	0.081	0.285	0.581	0.053	0.000	
SE	0.000	0.017	0.029	0.032	0.014	0.000	
1993 Est.	0	782	5,593	12,690	722	0	19,787
SE	0	213	506	590	205	0	386
Prp	0.000	0.040	0.283	0.641	0.036	0.000	
SE	0.000	0.011	0.025	0.026	0.010	0.000	
1994 Est.	0	651	3,741	13,173	894	0	18,459
SE	0	160	354	450	188	0	288
Prp	0.000	0.035	0.203	0.714	0.048	0.000	
SE	0.000	0.009	0.019	0.021	0.010	0.000	
1995 Est.	0	1,072	4,482	15,296	1,072	0	21,921
SE	0	316	596	727	318	0	396
Prp	0.000	0.049	0.204	0.698	0.049	0.000	
SE	0.000	0.014	0.027	0.031	0.014	0.000	
1996 Est.	0	1,847	6,750	14,424	497	0	23,519
SE	0	350	595	671	186	0	376
Prp	0.000	0.079	0.287	0.613	0.021	0.000	
SE	0.000	0.015	0.025	0.027	0.008	0.000	
1997 Est.	0	638	5,260	9,046	159	0	15,104
SE	0	157	379	406	79	0	236
Prp	0.000	0.042	0.348	0.599	0.011	0.000	
SE	0.000	0.010	0.025	0.025	0.005	0.000	

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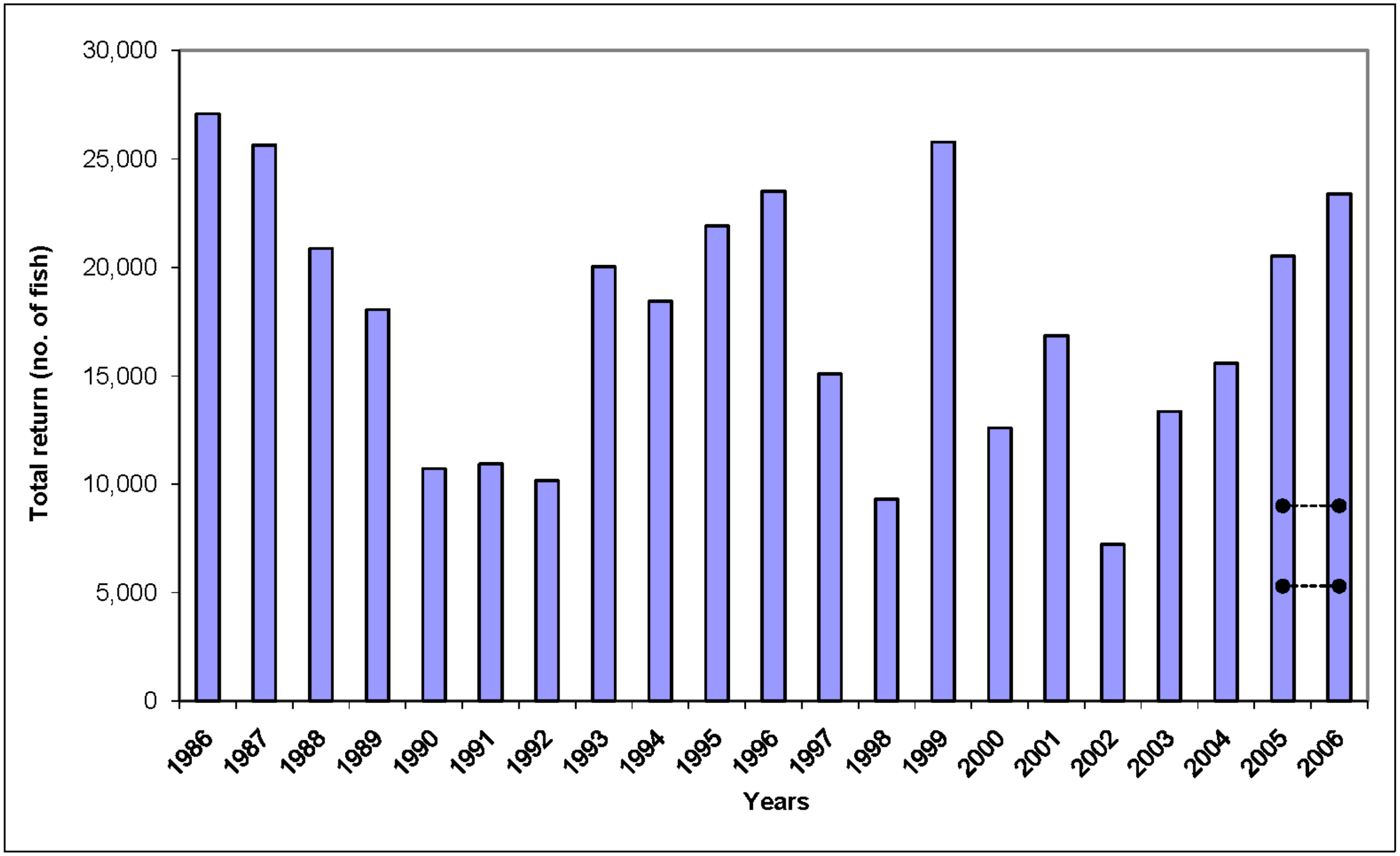
Table 3.–Page 2 of 2.

Return Year	Age 3	Age 4	Age 5	Age 6	Age 7	Age 8	Total Return
1998 Est.	0	2,506	4,872	5,429	418	0	13,225
SE	0	311	388	397	137	0	230
Prp	0.000	0.189	0.368	0.411	0.032	0.000	
SE	0.000	0.023	0.029	0.029	0.010	0.000	
1999 Est.	0	2,069	13,845	9,787	80	0	25,780
SE	0	391	742	713	80	0	370
Prp	0.000	0.080	0.537	0.380	0.003	0.000	
SE	0.000	0.015	0.028	0.027	0.003	0.000	
2000 Est.	0	1,160	5,505	5,865	73	0	12,603
SE	0	268	453	452	73	0	234
Prp	0.000	0.092	0.437	0.465	0.006	0.000	
SE	0.000	0.021	0.035	0.035	0.006	0.000	
2001 Est.	0	2,898	4,687	8,948	341	0	16,874
SE	0	461	544	619	169	0	285
Prp	0.000	0.172	0.278	0.530	0.020	0.000	
SE	0.000	0.027	0.032	0.036	0.010	0.000	
2002 Est.	260	1,133	2,692	2,881	260	0	7,226
SE	78	153	210	214	77	0	169
Prp	0.036	0.157	0.373	0.399	0.036	0.000	
SE	0.011	0.021	0.028	0.028	0.011	0.000	
2003 Est.	129	4,211	2,641	6,261	129	0	13,371
SE	49	240	202	265	49	0	199
Prp	0.010	0.315	0.198	0.468	0.010	0.000	
SE	0.004	0.017	0.015	0.019	0.004	0.000	
2004 Est.	133	2,309	5,196	7,283	666	0	15,587
SE	77	298	402	435	169	0	261
Prp	0.009	0.148	0.333	0.467	0.043	0.000	
SE	0.005	0.019	0.025	0.027	0.011	0.000	
2005 Est.	233	2,541	6,196	10,829	726	0	20,526
SE	134	404	557	610	223	0	295
Prp	0.011	0.124	0.302	0.528	0.035	0.000	
SE	0.007	0.020	0.027	0.029	0.011	0.000	
2006 Est.	196	7,150	4,540	10,650	865	0	23,401
SE	138	690	591	756	284	0	394
Prp	0.008	0.306	0.194	0.455	0.037	0.000	
SE	0.006	0.029	0.025	0.031	0.012	0.000	

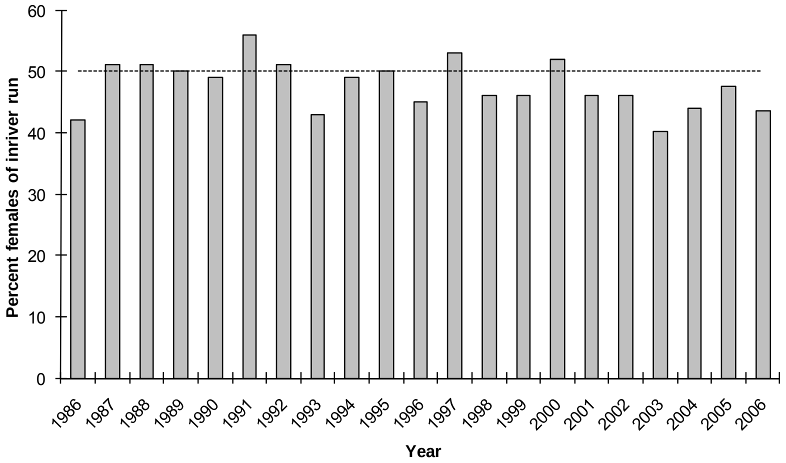
Note: Age 3 Chinook salmon includes: ages 0.2 and 1.1 fish; Age 4 includes: ages 0.3, 1.2, and 2.1 fish; Age 5 includes: ages 0.4, 1.3, and 2.2 fish; Age 6 includes: ages 0.5, 1.4, and 2.3 fish; Age 7 includes: ages 1.5, and 2.4 fish; and Age 8 includes: ages 1.6, and 2.5 fish.



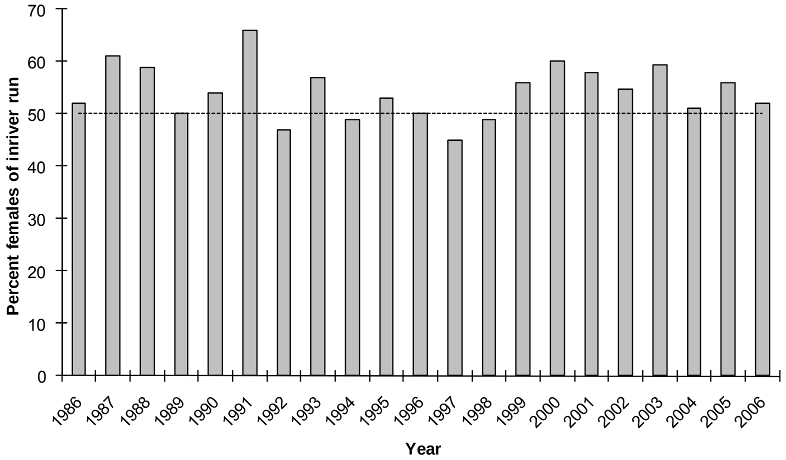
Note: Dashed line = lower and upper values of the optimum escapement goal (OEG) range established in 2005.

Figure 3.–Total return of early-run Kenai River Chinook salmon, 1986–2006.

Inriver run



Inriver harvest



Escapement

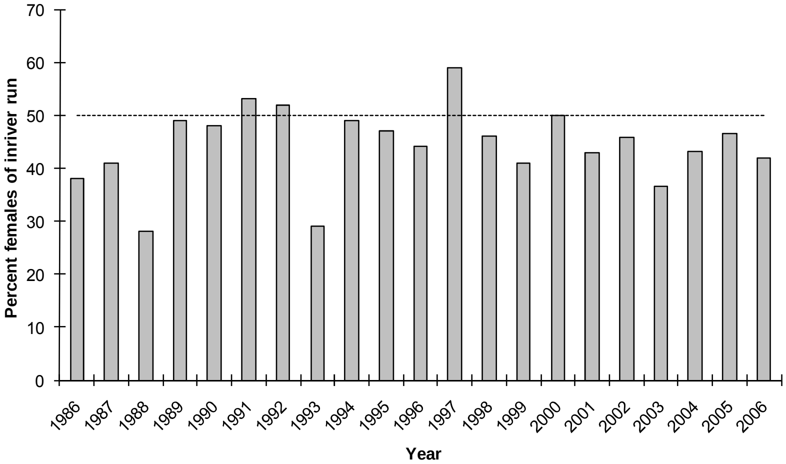


Figure 4.–Estimates of the percent of females in the inriver return, inriver harvest, and escapement of early-run Kenai River Chinook salmon, 1986–2006.

SPORT HARVEST AND CATCH

During 2002–2006, the annual estimated total sport harvest of early-run Kenai River Chinook salmon ranged from 899 to 4,693 fish, including 376 to 3,397 fish estimated by the creel survey downstream of the Soldotna Bridge and 523 to 1,296 fish estimated by the SWHS survey upstream of the bridge (Table 4). The sport harvest consisted primarily of age-1.3 and -1.4 fish; no age-1.5 fish were harvested after 2001 (Table 5).

From 2002 through 2006, the estimated total sport catch of early-run Kenai River Chinook salmon ranged from 2,123 to 8,912 fish annually, including 419–4,523 fish estimated by creel survey downstream of the Soldotna Bridge and 1,704–6,095 fish estimated by the SWHS survey upstream of the bridge (Table 4).

HOOK-AND-RELEASE MORTALITY

During 2002–2006, annual estimates of the number of Chinook salmon released in the inriver sport fishery ranged from 1,224 to 6,073. By applying the 1990–1991 average mortality rate of 6.4%, the estimated hook-and-release mortality ranged from 78 (SE = 54) in 2002 to 389 (SE = 276) in 2003 (Table 6).

SPAWNING ESCAPEMENT

In 2002, the estimated Chinook salmon spawning escapement was 6,185 (SE = 221), the second lowest ever recorded for the early run. Although this was below the low end of the escapement goal in 2002 (7,200), it was above the current low end goal of 5,300 (Table 7). Spawning escapement was within or above the goal in all other years: 2003 was 10,097 (SE = 540, within the goal); 2004 was 11,855 (SE = 487, within the goal); 2005 was 16,387 (SE = 412, above the goal); 2006 was 18,428 (SE = 495, above the goal). The majority of the spawners in 2002, 2004, and 2005 were age-1.3 and -1.4; and in 2003 and 2006 the majority of spawners were age-1.2 and -1.4 (Table 7).

The proportion of female Chinook salmon in the spawning escapement has been stable, with no clear trend in the last 20 years, and no discernible change since the inception of the 2003 slot limit (Figure 4).

Table 4.–Sport harvest and catch for early-run Kenai River Chinook salmon, 1986–2006.

	Harvest						Catch						
	CI-SB[a]		SB-KL[b]		Total		CI-SB[a]		SB-KL[b]		Total		
Year	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Source
1986	6,337	459	1,819	117	8,156	474	10,122	684	1,819	233	11,941	723	Conrad and Hammarstrom 1987
1987	11,224	836	2,333	366	13,557	912	16,007	1,103	2,333	366	18,340	1,162	Hammarstrom 1988
1988	11,949	697	3,260	423	15,209	815	17,266	839	3,260	423	20,526	940	Hammarstrom 1989
1989	6,711	490	1,683	165	8,394	517	9,034	603	1,683	165	10,717	625	Hammarstrom 1990
1990	723	167	1,084	154	1,807	227	3,285	389	2,818	208	6,103	441	Hammarstrom 1991
1991	891	169	1,054	122	1,945	209	3,716	426	2,030	150	5,746	452	Hammarstrom 1992
1992	1,365	151	876	92	2,241	177	3,901	307	2,028	182	5,929	357	Hammarstrom 1993
1993	6,846	382	2,496	173	9,342	419	9,906	523	3,910	272	13,816	589	Hammarstrom 1994
1994	4,722	300	3,449	205	8,171	363	6,399	404	6,230	389	12,629	561	Schwager and King 1995
1995	7,733	420	2,484	155	10,217	448	11,360	541	4,434	313	15,794	625	King 1996
1996	4,166	290	2,457	203	6,623	354	5,552	320	5,562	687	11,114	758	King 1997
1997	4,942	619	1,487	173	6,429	643	6,782	775	5,093	871	11,875	1,166	Marsh 1999
1998	648	89	522	85	1,170	123	1,869	239	3,274	499	5,143	554	Marsh 2000
1999	5,534	393	2,595	272	8,129	478	7,186	475	5,015	442	12,201	649	Reimer et al. 2002
2000	1,149	157	669	121	1,818	198	2,309	229	2,397	432	4,706	489	Reimer et al. 2002
2001	1,428	190	971	129	2,399	230	1,837	216	3,755	546	5,592	588	Reimer 2003
2002	376	85	523	102	899	132	419	84	1,704	373	2,123	382	Reimer 2004a
2003	1,948	399	891	128	2,839	419	2,817	484	6,095	2,377	8,912	2,425	Reimer 2004b
2004	2,285	338	1,101	164	3,386	376	3,534	435	3,862	516	7,396	675	Reimer 2007
2005	2,876	329	934	143	3,810	359	4,430	735	3,327	419	7,757	846	Eskelin 2007
2006	3,397	412	1,296	164	4,693	444	4,523	441	3,378	410	7,901	602	Eskelin *in prep*

[a] CI-SB = Cook Inlet to Soldotna Bridge. From creel survey; areas surveyed were: entire area open to fishing 1986–1989; mid and lower sections in 1990; lower only 1991–2006.

[b] SB-KL = Soldotna Bridge to Kenai Lake. From Alaska Statewide Harvest Surveys (Mills 1987–1994; Howe et al. 1995, 1996, 2001a-d; Walker et al. 2003; Jennings et al. 2004, 2006; Jennings et al. 2007, 2009a-b); 50% of published harvest and catch estimates for 1986–1992. Catch for 1986-1995 not available, so we used 50% of harvest estimate.

Table 5.–Estimated sport harvest of early-run Kenai River Chinook salmon by age class, 1986–2006.

	Age Class															
Year	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
1986																	
Harvest	0	0	0	0	15	583	2,957	3,874	728	0	0	0	0	0	0	0	8,156
SE Harvest	0	0	0	0	15	95	238	283	107	0	0	0	0	0	0	0	474
1987																	
Harvest	0	0	0	0	0	116	4,220	8,498	636	0	0	0	0	87	0	0	13,557
SE Harvest	0	0	0	0	0	58	406	647	139	0	0	0	0	50	0	0	912
1988																	
Harvest	0	0	0	0	26	291	1,855	11,950	1,033	0	0	0	0	53	0	0	15,209
SE Harvest	0	0	0	0	26	88	230	691	169	0	0	0	0	37	0	0	815
1989																	
Harvest	0	0	0	0	92	275	2,202	5,275	550	0	0	0	0	0	0	0	8,394
SE Harvest	0	0	0	0	65	112	305	442	157	0	0	0	0	0	0	0	517
1990																	
Harvest	0	0	0	0	0	102	102	1,349	255	0	0	0	0	0	0	0	1,807
SE Harvest	0	0	0	0	0	51	51	193	81	0	0	0	0	0	0	0	227
1991																	
Harvest	0	0	0	0	0	0	166	1,573	207	0	0	0	0	0	0	0	1,945
SE Harvest	0	0	0	0	0	0	82	202	91	0	0	0	0	0	0	0	209
1992																	
Harvest	0	0	0	0	0	94	377	1,698	71	0	0	0	0	0	0	0	2,241
SE Harvest	0	0	0	0	0	47	91	167	41	0	0	0	0	0	0	0	177
1993																	
Harvest	0	0	0	0	0	290	1,868	6,636	483	0	0	0	0	64	0	0	9,342
SE Harvest	0	0	0	0	0	96	235	388	123	0	0	0	0	46	0	0	419
1994																	
Harvest	0	0	0	0	0	303	675	6,960	233	0	0	0	0	0	0	0	8,171
SE Harvest	0	0	0	0	0	83	124	346	73	0	0	0	0	0	0	0	363
1995																	
Harvest	0	0	0	0	0	0	378	8,451	1,387	0	0	0	0	0	0	0	10,217
SE Harvest	0	0	0	0	0	0	216	569	396	0	0	0	0	0	0	0	448
1996																	
Harvest	0	0	0	0	0	414	1,288	4,760	161	0	0	0	0	0	0	0	6,623
SE Harvest	0	0	0	0	0	97	169	309	61	0	0	0	0	0	0	0	354
1997																	
Harvest	0	0	0	0	0	200	679	5,271	280	0	0	0	0	0	0	0	6,429
SE Harvest	0	0	0	0	0	90	170	562	107	0	0	0	0	0	0	0	643
1998																	
Harvest	0	0	0	0	0	15	228	851	76	0	0	0	0	0	0	0	1,170
SE Harvest	0	0	0	0	0	15	58	107	34	0	0	0	0	0	0	0	123
1999																	
Harvest	0	0	0	0	36	677	2,948	4,202	230	0	0	36	0	0	0	0	8,129
SE Harvest	0	0	0	0	36	151	304	359	88	0	0	36	0	0	0	0	478
2000																	
Harvest	19	0	0	0	19	19	303	1,401	57	0	0	0	0	0	0	0	1,818
SE Harvest	19	0	0	0	19	19	77	171	33	0	0	0	0	0	0	0	198
2001																	
Harvest	34	0	0	0	0	304	405	1,622	34	0	0	0	0	0	0	0	2,399
SE Harvest	34	0	0	0	0	99	114	205	34	0	0	0	0	0	0	0	230
2002																	
Harvest	0	0	0	0	0	116	377	406	0	0	0	0	0	0	0	0	899
SE Harvest	0	0	0	0	0	57	97	100	0	0	0	0	0	0	0	0	132

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Table 5.–Page 2 of 2.

	Age Class																
Year	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
2003																	
Harvest	0	0	0	0	0	506	1,212	1,121	0	0	0	0	0	0	0	0	2,839
SE Harvest	0	0	0	0	0	189	273	262	0	0	0	0	0	0	0	0	419
2004																	
Harvest	0	0	0	0	0	372	1,693	1,287	0	0	0	0	34	0	0	0	3,386
SE Harvest	0	0	0	0	0	114	253	218	0	0	0	0	34	0	0	0	376
2005																	
Harvest	0	0	0	0	56	252	1,681	1,821	0	0	0	0	0	0	0	0	3,810
SE Harvest	0	0	0	0	40	85	227	237	0	0	0	0	0	0	0	0	359
2006																	
Harvest	0	0	0	0	62	781	1,738	2,112	0	0	0	0	0	0	0	0	4,693
SE Harvest	0	0	0	0	44	161	244	273	0	0	0	0	0	0	0	0	444

Table 6.–Estimated mortality of early-run Kenai River Chinook salmon due to hook-and-release fishing, 1986–2006.

	Sport		Released		Mortality			
Year	Catch	Harvest	Number [a]	SE	Proportion [b]	SE Prop.	Hook-and-release	SE
1986	11,941	8,156	3,785	864	0.064	0.041	242	160
1987	18,340	13,557	4,783	1,477	0.064	0.041	306	208
1988	20,526	15,209	5,317	1,244	0.064	0.041	340	225
1989	10,717	8,394	2,323	811	0.064	0.041	149	103
1990	6,103	1,807	4,296	496	0.088	0.025	378	115
1991	5,746	1,945	3,801	497	0.040	0.020	152	78
1992	5,929	2,241	3,688	399	0.064	0.041	236	152
1993	13,816	9,342	4,474	723	0.064	0.041	286	186
1994	12,629	8,171	4,458	668	0.064	0.041	285	185
1995	15,794	10,217	5,577	769	0.064	0.041	357	231
1996	11,114	6,623	4,491	836	0.064	0.041	287	188
1997	11,875	6,429	5,446	1,331	0.064	0.041	349	232
1998	5,143	1,170	3,973	567	0.064	0.041	254	164
1999	12,201	8,129	4,072	806	0.064	0.041	261	171
2000	4,706	1,818	2,888	527	0.064	0.041	185	121
2001	5,592	2,399	3,193	631	0.064	0.041	204	134
2002	2,123	899	1,224	404	0.064	0.041	78	54
2003	8,912	2,839	6,073	2,461	0.064	0.041	389	276
2004	7,396	3,386	4,010	773	0.064	0.041	257	168
2005	7,757	3,810	3,947	919	0.064	0.041	253	167
2006	7,901	4,693	3,208	748	0.064	0.041	205	136

[a] Units = number of fish.

[b] Estimated experimentally in 1990 and 1991; average used in all remaining years.

Table 7.–Estimates of early-run Kenai River Chinook salmon spawning escapement by age class, 1986–2006.

	Age Class																
	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
1986																	
Inriver return	0	0	0	0	0	4,191	11,384	9,349	2,116	0	0	0	0	40	0	0	27,080
SE return	0	0	0	0	0	1,537	4,133	3,399	788	0	0	0	0	30	0	0	9,799
Harvest	0	0	0	0	15	583	2,957	3,874	728	0	0	0	0	0	0	0	8,156
SE harvest	0	0	0	0	15	95	238	283	107	0	0	0	0	0	0	0	474
Hook-and-release mortality	0	0	0	0	0	37	102	84	19	0	0	0	0	0	0	0	242
SE hook-and-release	0	0	0	0	0	25	67	55	13	0	0	0	0	0	0	0	160
Escapement[a]	0	0	0	0	0	3,571	8,326	5,391	1,368	0	0	0	0	40	0	0	18,682
SE escapement	0	0	0	0	0	1,540	4,141	3,411	795	0	0	0	0	30	0	0	9,812
1987																	
Inriver return	0	0	0	0	0	393	9,859	14,683	577	0	0	0	26	105	0	0	25,643
SE return	0	0	0	0	0	134	2,312	3,417	178	0	0	0	26	56	0	0	5,928
Harvest	0	0	0	0	0	116	4,220	8,498	636	0	0	0	0	87	0	0	13,557
SE harvest	0	0	0	0	0	58	406	647	139	0	0	0	0	50	0	0	912
Hook-and-release mortality	0	0	0	0	0	5	118	175	7	0	0	0	0	1	0	0	306
SE hook-and-release	0	0	0	0	0	3	80	119	5	0	0	0	0	1	0	0	208
Escapement[a]	0	0	0	0	0	273	5,521	6,009	0	0	0	0	26	17	0	0	11,780
SE escapement	0	0	0	0	0	146	2,349	3,480	0	0	0	0	26	76	0	0	6,001
1988																	
Inriver return	0	0	0	0	0	373	3,302	14,888	2,237	53	0	0	27	0	0	0	20,880
SE return	0	0	0	0	0	99	281	465	236	38	0	0	27	0	0	0	449
Harvest	0	0	0	0	26	291	1,855	11,950	1,033	0	0	0	0	53	0	0	15,209
SE harvest	0	0	0	0	26	88	230	691	169	0	0	0	0	37	0	0	815
Hook-and-release mortality	0	0	0	0	0	6	54	243	36	1	0	0	0	0	0	0	340
SE hook-and-release	0	0	0	0	0	4	36	161	24	1	0	0	0	0	0	0	225
Escapement[a]	0	0	0	0	0	75	1,394	2,695	1,167	52	0	0	26	0	0	0	5,331
SE escapement	0	0	0	0	0	133	365	849	291	38	0	0	27	0	0	0	958
1989																	
Inriver return	0	0	0	0	0	746	2,780	12,767	1,699	0	0	0	0	0	0	0	17,992
SE return	0	0	0	0	0	137	253	414	202	0	0	0	0	0	0	0	389
Harvest	0	0	0	0	92	275	2,202	5,275	550	0	0	0	0	0	0	0	8,394
SE harvest	0	0	0	0	65	112	305	442	157	0	0	0	0	0	0	0	517
Hook-and-release mortality	0	0	0	0	0	6	23	105	14	0	0	0	0	0	0	0	149
SE hook-and-release	0	0	0	0	0	4	16	73	10	0	0	0	0	0	0	0	103
Escapement[a]	0	0	0	0	0	465	555	7,386	1,134	0	0	0	0	0	0	0	9,449
SE escapement	0	0	0	0	0	177	397	610	257	0	0	0	0	0	0	0	655
1990																	
Inriver return	0	0	0	0	0	779	2,864	6,438	687	0	0	0	0	0	0	0	10,768
SE return	0	0	0	0	0	130	229	283	122	0	0	0	0	0	0	0	242
Harvest	0	0	0	0	0	102	102	1,349	255	0	0	0	0	0	0	0	1,807
SE harvest	0	0	0	0	0	51	51	193	81	0	0	0	0	0	0	0	227
Hook-and-release mortality	0	0	0	0	0	27	101	226	24	0	0	0	0	0	0	0	378
SE hook-and-release	0	0	0	0	0	9	32	69	8	0	0	0	0	0	0	0	115
Escapement[a]	0	0	0	0	0	650	2,661	4,863	409	0	0	0	0	0	0	0	8,583
SE escapement	0	0	0	0	0	140	237	350	147	0	0	0	0	0	0	0	351
1991																	
Inriver return	0	0	0	0	0	802	2,452	7,120	566	0	0	0	0	0	0	0	10,939
SE return	0	0	0	0	0	189	306	385	160	0	0	0	0	0	0	0	269
Harvest	0	0	0	0	0	0	166	1,573	207	0	0	0	0	0	0	0	1,945
SE harvest	0	0	0	0	0	0	82	202	91	0	0	0	0	0	0	0	209
Hook-and-release mortality	0	0	0	0	0	11	34	99	8	0	0	0	0	0	0	0	152
SE hook-and-release	0	0	0	0	0	6	18	51	4	0	0	0	0	0	0	0	78
Escapement[a]	0	0	0	0	0	790	2,252	5,448	351	0	0	0	0	0	0	0	8,842
SE escapement	0	0	0	0	0	189	317	438	184	0	0	0	0	0	0	0	349

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Table 7.–Page 2 of 4.

	Age Class																
	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
1992																	
Inriver return	0	0	0	0	0	820	2,870	5,864	533	0	0	0	0	0	0	0	10,087
SE return	0	0	0	0	0	177	300	351	145	0	0	0	0	0	0	0	255
Harvest	0	0	0	0	0	94	377	1,698	71	0	0	0	0	0	0	0	2,241
SE harvest	0	0	0	0	0	47	91	167	41	0	0	0	0	0	0	0	177
Hook-and-release mortality	0	0	0	0	0	19	67	137	12	0	0	0	0	0	0	0	236
SE hook-and-release	0	0	0	0	0	13	43	88	8	0	0	0	0	0	0	0	152
Escapement[a]	0	0	0	0	0	707	2,426	4,028	450	0	0	0	0	0	0	0	7,610
SE escapement	0	0	0	0	0	184	316	398	151	0	0	0	0	0	0	0	346
1993																	
Inriver return	0	0	0	0	0	777	5,500	12,435	717	0	0	60	179	0	0	0	19,669
SE return	0	0	0	0	0	212	499	578	204	0	0	60	103	0	0	0	386
Harvest	0	0	0	0	0	290	1,868	6,636	483	0	0	0	0	64	0	0	9,342
SE harvest	0	0	0	0	0	96	235	388	123	0	0	0	0	46	0	0	419
Hook-and-release mortality	0	0	0	0	0	11	80	181	10	0	0	1	3	0	0	0	286
SE hook-and-release	0	0	0	0	0	8	52	118	7	0	0	1	2	0	0	0	186
Escapement[a]	0	0	0	0	0	476	3,552	5,618	224	0	0	59	177	0	0	0	10,041
SE escapement	0	0	0	0	0	233	554	706	239	0	0	60	103	0	0	0	600
1994																	
Inriver return	0	0	0	0	0	649	3,689	13,012	770	0	0	41	122	122	0	0	18,403
SE return	0	0	0	0	0	160	351	443	174	0	0	41	70	70	0	0	288
Harvest	0	0	0	0	0	303	675	6,960	233	0	0	0	0	0	0	0	8,171
SE harvest	0	0	0	0	0	83	124	346	73	0	0	0	0	0	0	0	363
Hook-and-release mortality	0	0	0	0	0	10	57	202	12	0	0	1	2	2	0	0	285
SE hook-and-release	0	0	0	0	0	7	37	131	8	0	0	1	1	1	0	0	185
Escapement[a]	0	0	0	0	0	336	2,956	5,850	525	0	0	40	120	120	0	0	9,947
SE escapement	0	0	0	0	0	180	374	577	189	0	0	41	70	70	0	0	499
1995																	
Inriver return	0	0	0	0	0	1,070	4,474	15,270	973	0	0	0	0	97	0	0	21,884
SE return	0	0	0	0	0	316	595	726	302	0	0	0	0	97	0	0	396
Harvest	0	0	0	0	0	0	378	8,451	1,387	0	0	0	0	0	0	0	10,217
SE harvest	0	0	0	0	0	0	216	569	396	0	0	0	0	0	0	0	448
Hook-and-release mortality	0	0	0	0	0	17	73	249	16	0	0	0	0	2	0	0	357
SE hook-and-release	0	0	0	0	0	12	48	161	11	0	0	0	0	2	0	0	231
Escapement[a]	0	0	0	0	0	1,052	4,023	6,570	0	0	0	0	0	96	0	0	11,310
SE escapement	0	0	0	0	0	316	635	936	0	0	0	0	0	97	0	0	641
1996																	
Inriver return	0	0	0	0	0	1,846	6,746	14,415	497	0	0	0	0	0	0	0	23,505
SE return	0	0	0	0	0	349	595	671	186	0	0	0	0	0	0	0	376
Harvest	0	0	0	0	0	414	1,288	4,760	161	0	0	0	0	0	0	0	6,623
SE harvest	0	0	0	0	0	97	169	309	61	0	0	0	0	0	0	0	354
Hook-and-release mortality	0	0	0	0	0	23	82	176	6	0	0	0	0	0	0	0	287
SE hook-and-release	0	0	0	0	0	15	54	115	4	0	0	0	0	0	0	0	188
Escapement[a]	0	0	0	0	0	1,410	5,376	9,479	330	0	0	0	0	0	0	0	16,595
SE escapement	0	0	0	0	0	363	621	748	196	0	0	0	0	0	0	0	550
1997																	
Inriver return	0	0	0	0	0	632	5,211	8,962	158	0	0	0	0	0	0	0	14,963
SE return	0	0	0	0	0	155	376	403	79	0	0	0	0	0	0	0	236
Harvest	0	0	0	0	0	200	679	5,271	280	0	0	0	0	0	0	0	6,429
SE harvest	0	0	0	0	0	90	170	562	107	0	0	0	0	0	0	0	643
Hook-and-release mortality	0	0	0	0	0	15	121	209	4	0	0	0	0	0	0	0	349
SE hook-and-release	0	0	0	0	0	10	81	139	3	0	0	0	0	0	0	0	232
Escapement[a]	0	0	0	0	0	417	4,411	3,482	0	0	0	0	0	0	0	0	8,185
SE escapement	0	0	0	0	0	180	420	705	0	0	0	0	0	0	0	0	723

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Table 7.–Page 3 or 4.

	Age																
	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
1998																	
Inriver return	0	0	0	0	0	2,483	4,827	5,379	414	0	0	0	0	0	0	0	13,103
SE return	0	0	0	0	0	308	384	394	136	0	0	0	0	0	0	0	230
Harvest	0	0	0	0	0	15	228	851	76	0	0	0	0	0	0	0	1,170
SE harvest	0	0	0	0	0	15	58	107	34	0	0	0	0	0	0	0	123
Hook-and-release mortality	0	0	0	0	0	48	94	104	8	0	0	0	0	0	0	0	254
SE hook-and-release	0	0	0	0	0	31	61	68	6	0	0	0	0	0	0	0	164
Escapement[a]	0	0	0	0	0	2,419	4,506	4,424	330	0	0	0	0	0	0	0	11,679
SE escapement	0	0	0	0	0	310	394	414	140	0	0	0	0	0	0	0	308
1999																	
Inriver return	0	0	0	0	0	2,060	13,784	9,664	79	0	0	0	79	0	0	0	25,666
SE return	0	0	0	0	0	389	739	706	79	0	0	0	79	0	0	0	370
Harvest	0	0	0	0	36	677	2,948	4,202	230	0	0	36	0	0	0	0	8,129
SE harvest	0	0	0	0	36	151	304	359	88	0	0	36	0	0	0	0	478
Hook-and-release mortality	0	0	0	0	0	21	140	98	1	0	0	0	1	0	0	0	261
SE hook-and-release	0	0	0	0	0	14	92	65	1	0	0	0	1	0	0	0	171
Escapement[a]	0	0	0	0	0	1,362	10,696	5,364	0	0	0	0	78	0	0	0	17,276
SE escapement	0	0	0	0	0	418	805	794	0	0	0	0	79	0	0	0	628
2000																	
Inriver return	0	103	34	0	0	1,046	5,417	5,808	72	0	0	0	0	0	0	0	12,479
SE return	0	59	34	0	0	259	448	447	72	0	0	0	0	0	0	0	234
Harvest	19	0	0	0	19	19	303	1,401	57	0	0	0	0	0	0	0	1,818
SE harvest	19	0	0	0	19	19	77	171	33	0	0	0	0	0	0	0	198
Hook-and-release mortality	0	2	1	0	0	15	80	86	1	0	0	0	0	0	0	0	185
SE hook-and-release	0	1	1	0	0	11	53	56	1	0	0	0	0	0	0	0	121
Escapement[a]	0	101	34	0	0	1,011	5,034	4,320	14	0	0	0	0	0	0	0	10,476
SE escapement	0	59	34	0	0	260	458	482	79	0	0	0	0	0	0	0	329
2001																	
Inriver return	0	168	0	0	0	2,695	4,632	8,843	337	0	0	0	0	0	0	0	16,676
SE return	0	119	0	0	0	440	538	612	167	0	0	0	0	0	0	0	285
Harvest	34	0	0	0	0	304	405	1,622	34	0	0	0	0	0	0	0	2,399
SE harvest	34	0	0	0	0	99	114	205	34	0	0	0	0	0	0	0	230
Hook-and-release mortality	0	2	0	0	0	33	57	108	4	0	0	0	0	0	0	0	204
SE hook-and-release	0	2	0	0	0	22	38	71	3	0	0	0	0	0	0	0	134
Escapement[a]	0	166	0	0	0	2,358	4,170	7,113	299	0	0	0	0	0	0	0	14,073
SE escapement	0	119	0	0	0	451	551	649	171	0	0	0	0	0	0	0	390
2002																	
Inriver return	47	0	0	0	211	1,123	2,668	2,832	257	0	0	0	23	0	0	0	7,162
SE return	33	0	0	0	69	151	208	211	77	0	0	0	23	0	0	0	169
Harvest	0	0	0	0	0	116	377	406	0	0	0	0	0	0	0	0	899
SE harvest	0	0	0	0	0	57	97	100	0	0	0	0	0	0	0	0	132
Hook-and-release mortality	1	0	0	0	2	12	29	31	3	0	0	0	0	0	0	0	78
SE hook-and-release	0	0	0	0	2	9	20	21	2	0	0	0	0	0	0	0	54
Escapement[a]	46	0	0	0	208	995	2,262	2,395	255	0	0	0	23	0	0	0	6,185
SE escapement	33	0	0	0	69	162	231	235	77	0	0	0	23	0	0	0	221
2003																	
Inriver return	0	18	0	0	129	4,178	2,632	6,239	129	0	0	0	0	0	0	0	13,325
SE return	0	18	0	0	49	238	201	264	49	0	0	0	0	0	0	0	199
Harvest	0	0	0	0	0	506	1,212	1,121	0	0	0	0	0	0	0	0	2,839
SE harvest	0	0	0	0	0	189	273	262	0	0	0	0	0	0	0	0	419
Hook-and-release mortality	0	1	0	0	4	122	77	182	4	0	0	0	0	0	0	0	389
SE hook-and-release	0	1	0	0	3	87	55	129	3	0	0	0	0	0	0	0	276
Escapement[a]	0	18	0	0	125	3,550	1,343	4,936	125	0	0	0	0	0	0	0	10,097
SE escapement	0	18	0	0	49	316	343	394	49	0	0	0	0	0	0	0	540

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Table 7.–Page 4 of 4.

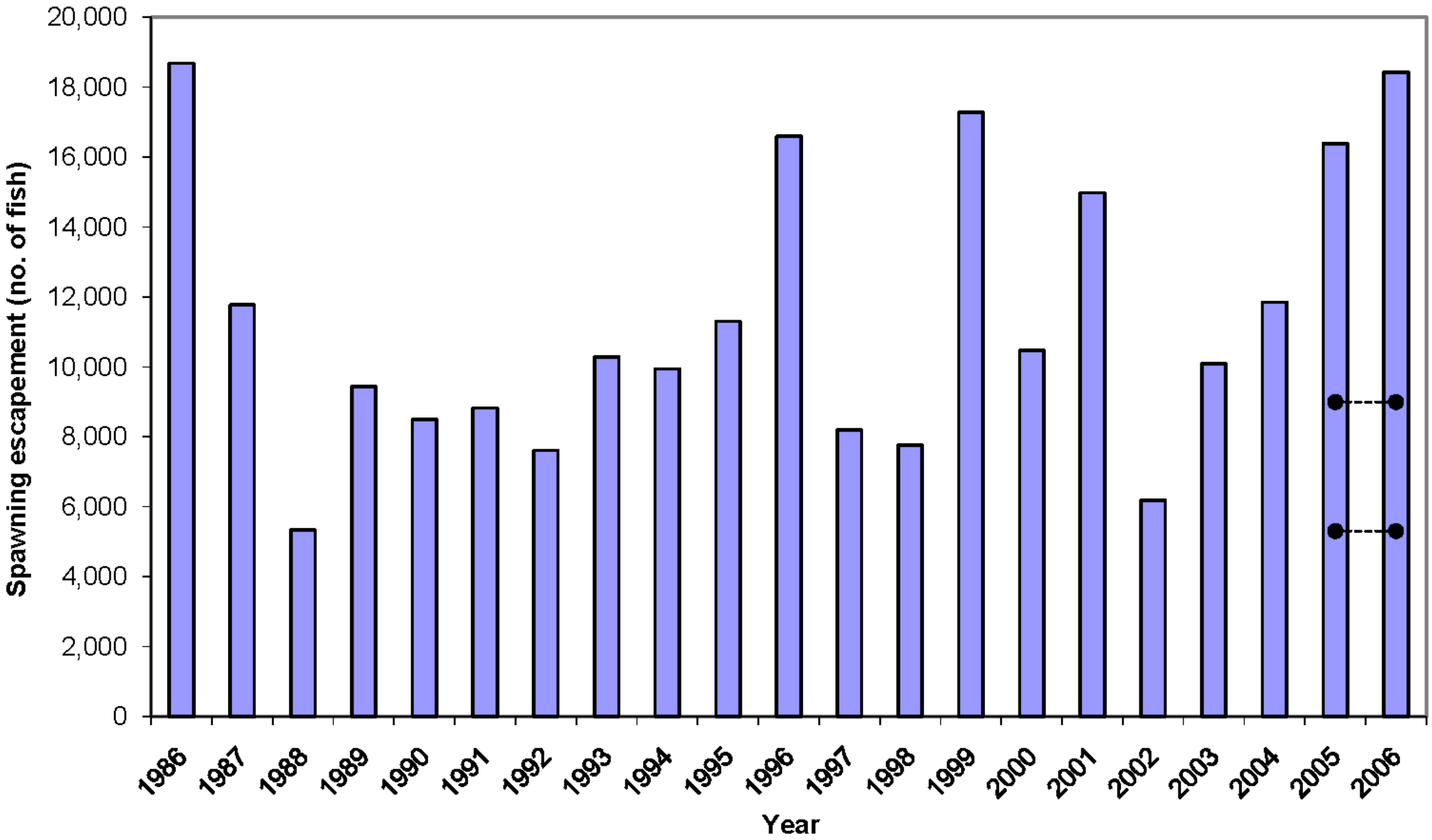
	Age															
	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
2004																	
Inriver return	0	0	0	0	132	2,296	5,166	7,197	662	0	0	0	44	0	0	0	15,498
SE return	0	0	0	0	76	297	400	431	168	0	0	0	44	0	0	0	261
Harvest	0	0	0	0	0	372	1,693	1,287	0	0	0	0	34	0	0	0	3,386
SE harvest	0	0	0	0	0	114	253	218	0	0	0	0	34	0	0	0	376
Hook-and-release mortality	0	0	0	0	2	38	86	119	11	0	0	0	1	0	0	0	257
SE hook-and-release	0	0	0	0	2	25	56	78	7	0	0	0	1	0	0	0	168
Escapement[a]	0	0	0	0	130	1,886	3,387	5,791	651	0	0	0	10	0	0	0	11,855
SE escapement	0	0	0	0	76	319	477	489	168	0	0	0	56	0	0	0	487
2005																	
Inriver return	0	0	0	0	233	2,532	6,173	10,789	723	0	0	0	0	0	0	0	20,450
SE return	0	0	0	0	0	71	131	164	51	0	0	0	0	0	0	0	295
Harvest	0	0	0	0	56	252	1,681	1,821	0	0	0	0	0	0	0	0	3,810
SE harvest	0	0	0	0	40	85	227	237	0	0	0	0	0	0	0	0	359
Hook-and-release mortality	0	0	0	0	3	31	76	133	9	0	0	0	0	0	0	0	253
SE hook-and-release	0	0	0	0	2	21	51	88	6	0	0	0	0	0	0	0	167
Escapement[a]	0	0	0	0	174	2,249	4,416	8,835	714	0	0	0	0	0	0	0	16,387
SE escapement	0	0	0	0	40	113	267	301	51	0	0	0	0	0	0	0	494
2006																	
Inriver return	0	0	0	0	195	7,127	4,526	10,518	862	0	0	0	98	0	0	0	23,326
SE return	0	0	0	0	0	261	293	358	82	0	0	0	0	0	0	0	394
Harvest	0	0	0	0	62	781	1,738	2,112	0	0	0	0	0	0	0	0	4,693
SE harvest	0	0	0	0	44	161	244	273	0	0	0	0	0	0	0	0	444
Hook-and-release mortality	0	0	0	0	2	63	40	93	8	0	0	0	1	0	0	0	205
SE hook-and-release	0	0	0	0	1	42	27	62	5	0	0	0	1	0	0	0	136
Escapement[a]	0	0	0	0	131	6,284	2,748	8,314	855	0	0	0	97	0	0	0	18,428
SE escapement	0	0	0	0	44	310	382	455	82	0	0	0	1	0	0	0	609

[a] For some age classes in some years, estimated harvest in the sport fishery was greater than the estimated inriver return. When this occurred, spawning escapement for that age class was set to zero, and spawning escapement by age class will not sum to total escapement.

Spawning escapements have not exhibited an upward or downward trend in the last 20 years. Estimated spawning escapements since 1986 have always been above the low end of the current OEG (5,300 Chinook salmon), and in 14 of the last 20 years have been above the upper end of the current OEG (9,000; Figure 5).

EFFECT OF SLOT LIMIT

The 2003 slot limit prohibits retention of Chinook salmon from 44 to 55 inches TL. This regulation was designed to minimize the harvest of ocean-age-5 fish for conservation purposes. Although mean length-at-age of Kenai River Chinook salmon differs by age class and appears stable across years (Figure 6), there is considerable overlap in the length distributions of each age class, especially between ages 1.4 and 1.5 (Figure 7). Using information similar to that presented in Figure 8, the BOF discerned that a slot limit from 44 to 55 inches TL was the best compromise for minimizing the harvest of ocean-age-5 fish and maximizing the harvest of ocean-age-4 fish, which is the predominant age class in the stock and the fishery.



Note: Dashed lines = lower and upper values of the optimal escapement goal (OEG) range established in 2005.

Figure 5.–Estimated spawning escapements of early-run Kenai River Chinook salmon, 1986–2006.

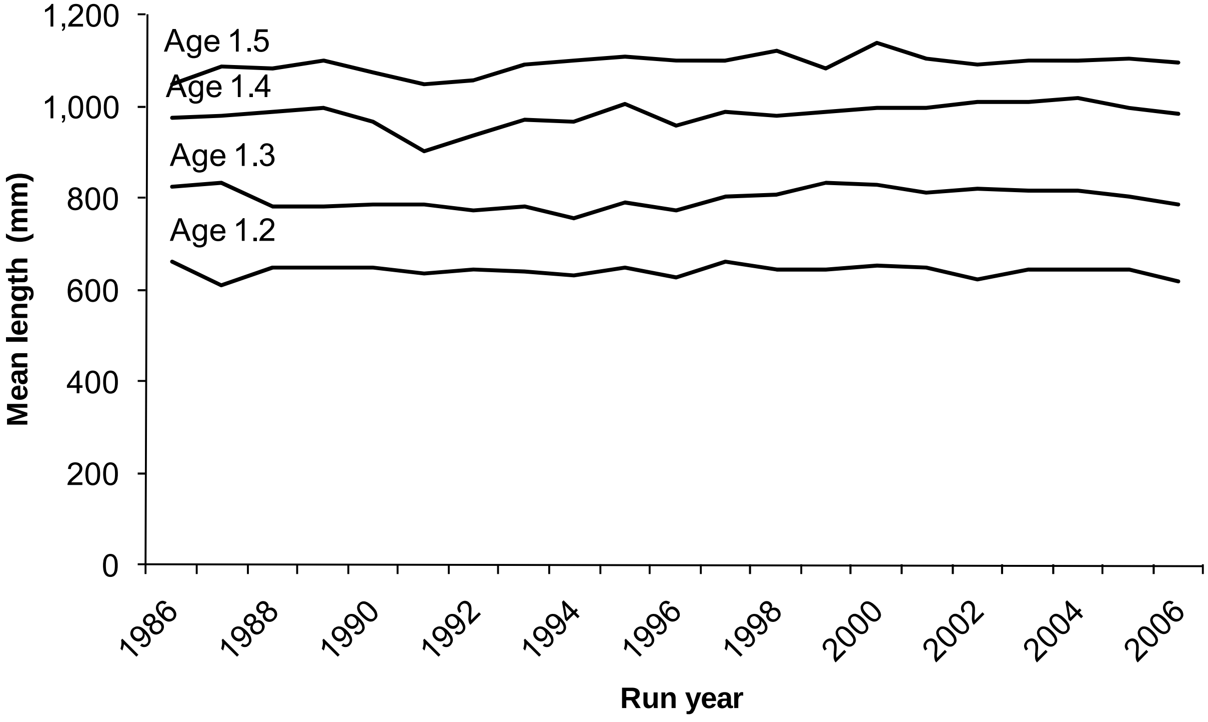
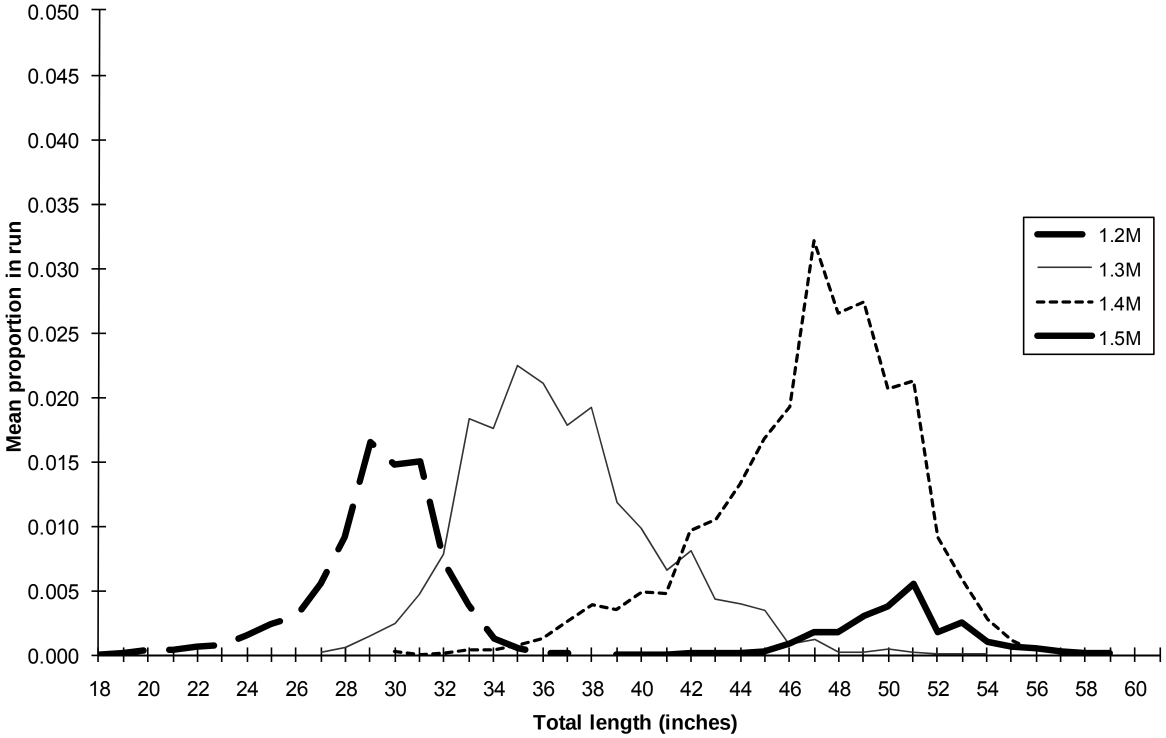
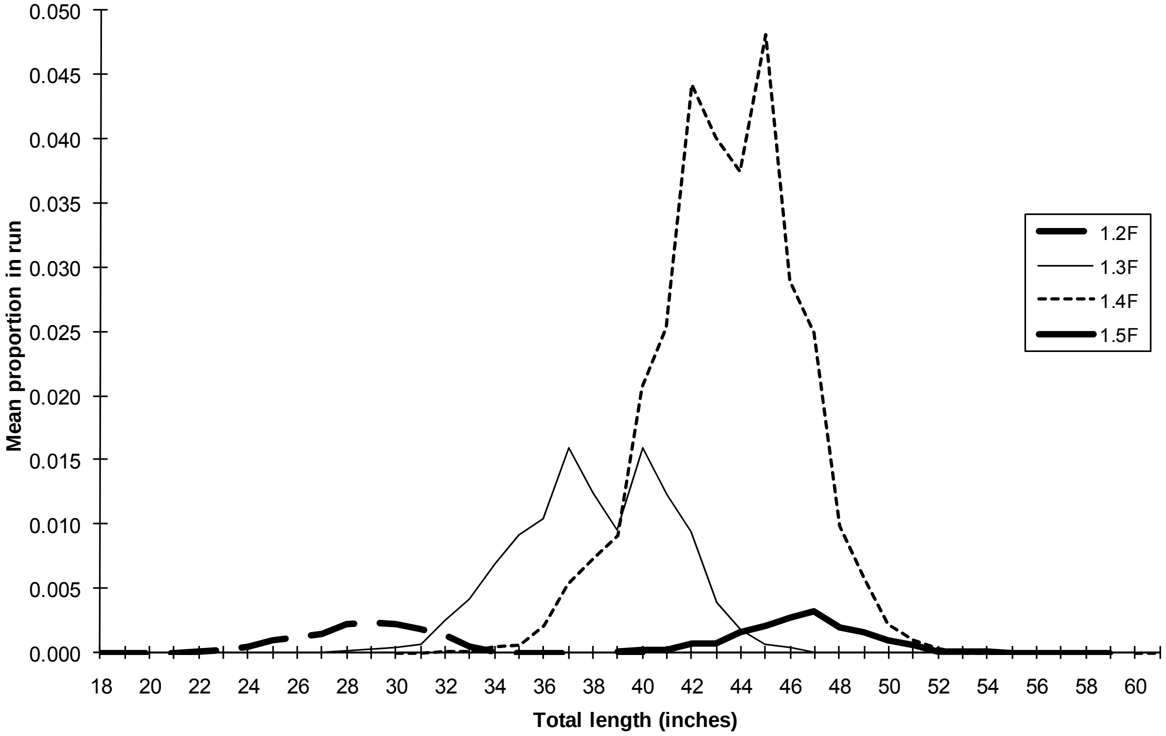


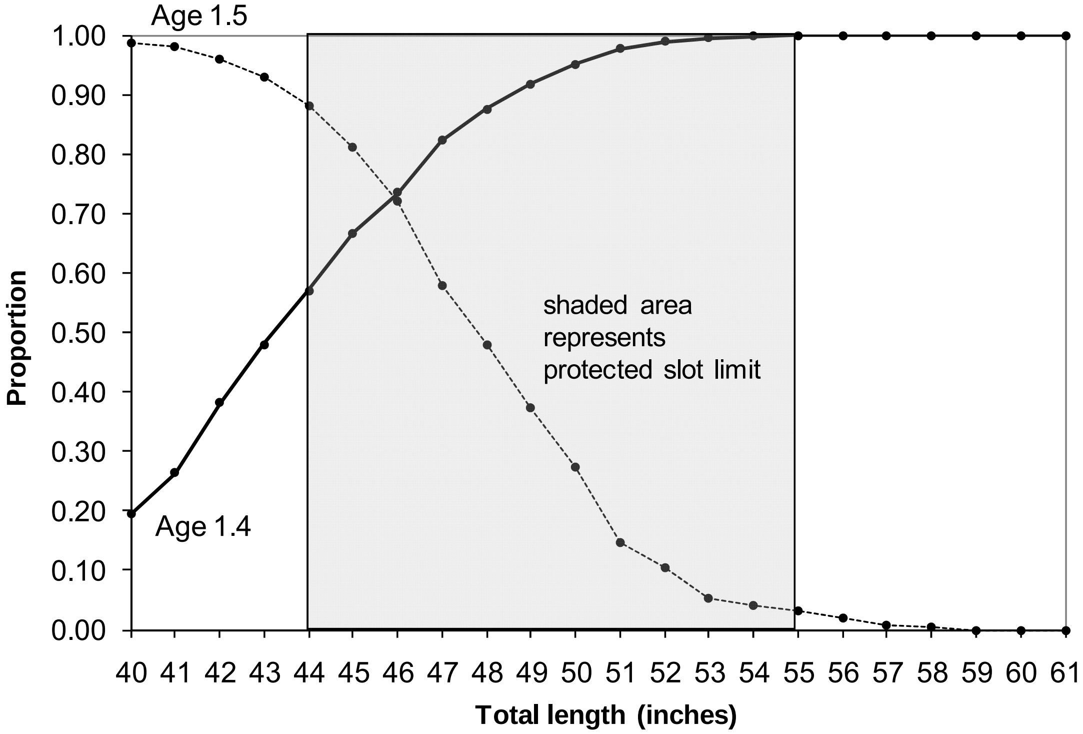
Figure 6.–Mean length-at-age estimates by year for early-run Kenai River Chinook salmon, 1986–2006.





Note: legend codes–numbers (freshwater.saltwater age); letters (sex where M = male, F = female).

Figure 7.–Estimated age-length-sex frequency relationships for early-run Kenai River Chinook salmon, 1986–2006.

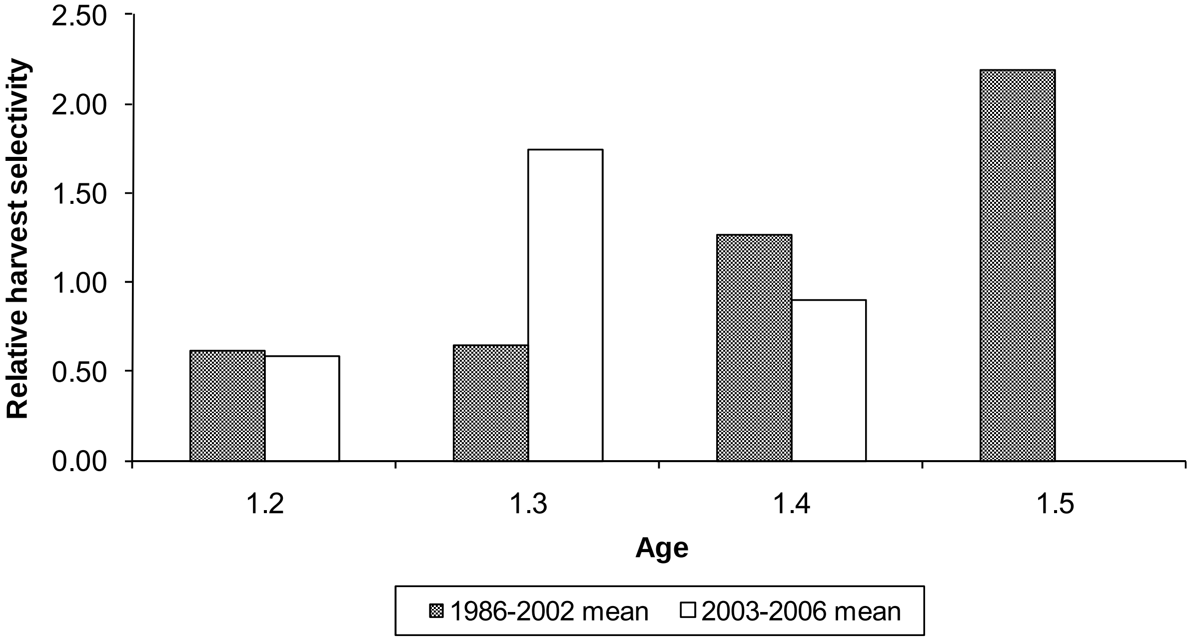


Note: Solid line = age-1.4 Chinook salmon; dashed line = age-1.5 Chinook salmon.

Figure 8.–Estimated cumulative proportion of age-1.4 and -1.5 early-run Kenai River Chinook salmon in 1-inch increments from 40 to 60 inches total length.

Before the 2003 slot limit, estimated harvest of ocean-age-5 fish in the early run ranged from 0 in 2002 to 1,387 (14% of the harvest) in 1995. Since the 2003 slot limit, creel surveys have detected no harvest of ocean-age-5 fish in the early run (Table 5).

Harvest selectivity (the proportion of each age class in the harvest divided by the proportion of each age class in the inriver return) changed dramatically following the implementation of the 2003 slot limit (Figure 9). A harvest selectivity equal to one indicates neutral selectivity (age class harvested in proportion to its abundance), whereas age classes with harvest selectivity greater than one are selected *for* (harvested disproportionately more) and age classes with harvest selectivity less than one are selected *against* (harvested disproportionately less). Prior to the slot limit, age-1.5 Chinook salmon were strongly selected for and age-1.4 fish were weakly selected for. After the slot limit (2003–2006), age-1.3 fish were selected for, age-1.4 fish experienced approximately neutral selectivity, and harvest selectivity for age-1.5 fish was estimated to be zero. Harvest selectivity for age-1.2 fish did not change as a result of the slot limit (Figure 9). The proportion of female Chinook salmon harvested in the sport fishery has been stable (i.e., about 50% of the harvest) since 1986 (Figure 4). Implementation of the 2003 slot limit has not changed the proportion of female Chinook salmon in the sport harvest.



Note: Selectivity estimates <1 = no selectivity for that age class; *selectivity estimates =1* indicates no selectivity or neutral; *selectivity estimates >1* equates to selectivity for that age class.

Figure 9.–Relative harvest selectivity estimated by age for early-run Kenai River Chinook salmon, pre- (1986–2002) and implementation (2003–2006) of the 2003 slot limit.

Along with the slot limit in 2003, a sealing requirement for Kenai River Chinook salmon harvested that are 55 inches TL or longer was enacted. Fish 55 inches TL or longer are required to be examined by ADF&G staff in the Soldotna Office, and a yellow, plastic, individually numbered strap attached to the fish. As part of the sealing process, biological samples, and angler information including location are collected. Through 2006 only one fish 55 inches TL or longer was harvested and sealed from the Kenai River in May or June and this was an age-1.4 fish. In contrast, there were 31 sealed fish harvested in the month of July; 16 were age-1.4, 12 were age-1.5, and ages from 3 were not determined.

SIBLING RELATIONSHIPS AND TRENDS IN AGE OF RETURN

Estimated mean sibling ratios were 4.26 (SD = 2.67) for Chinook salmon age 5 to age 4, 2.24 (SD = 1.13) for age 6 to age 5, and 0.063 (SD = 0.041) for age 7 to age 6 (Table 8). The age 5 to age 4 sibling ratio has been well below average for the last 5 brood years (Table 8, Figure 10).

The mean age of the escapements for brood years 1998 and 1999 (i.e., the last two years that we have complete brood returns) were the lowest in the last 20 years (Figure 11). However, the mean age of the return from escapements was above average in 1998 and average in 1999 (Figure 11).

Table 8.–Estimated sibling return ratios for early-run Kenai River Chinook salmon for brood years 1980–2001.

Brood year	Age 5/ Age 4	Age 6/ Age 5	Age 6/ Age 4+5	Age 7/ Age 6	Age 7/ Age 5+6	Age 7/ Age 4+5+6
1980	ND	ND	ND	0.07	ND	ND
1981	ND	1.29	ND	0.15	0.09	ND
1982	2.35	1.51	1.06	0.11	0.07	0.06
1983	8.40	3.88	3.47	0.05	0.04	0.04
1984	7.49	2.32	2.04	0.09	0.06	0.06
1985	3.84	2.48	1.97	0.08	0.05	0.05
1986	3.14	2.41	1.83	0.12	0.09	0.08
1987	3.61	4.39	3.44	0.07	0.06	0.05
1988	6.77	2.36	2.05	0.08	0.06	0.05
1989	4.78	4.09	3.38	0.03	0.03	0.03
1990	6.89	3.22	2.81	0.01	0.01	0.01
1991	6.30	1.34	1.16	0.05	0.03	0.02
1992	2.85	1.03	0.76	0.01	0.01	0.01
1993	7.64	2.01	1.78	0.01	0.00	0.00
1994	5.53	0.42	0.36	0.06	0.02	0.02
1995	2.66	1.63	1.18	0.03	0.02	0.02
1996	4.04	0.61	0.49	0.04	0.02	0.01
1997	0.93	2.33	1.12	0.11	0.07	0.06
1998	2.33	2.76	1.93	0.10	0.07	0.07
1999	1.23	2.08	1.15	0.08	0.05	0.04
2000	2.68	1.72	1.25	-	-	-
2001	1.79	-	-	-	-	-
Mean	4.26	2.24	1.75	0.063	0.042	0.038
Std. Dev.	2.67	1.13	0.98	0.041	0.030	0.026
% Coeff. Var.	63%	50%	56%	66%	71%	70%
Maximum	8.40	4.39	3.47	0.15	0.09	0.08
Minimum	0.93	0.42	0.36	0.01	0.00	0.00

Note: ND = no data because no attempts were made to collect it; "-" = value cannot be computed because of data limitations.

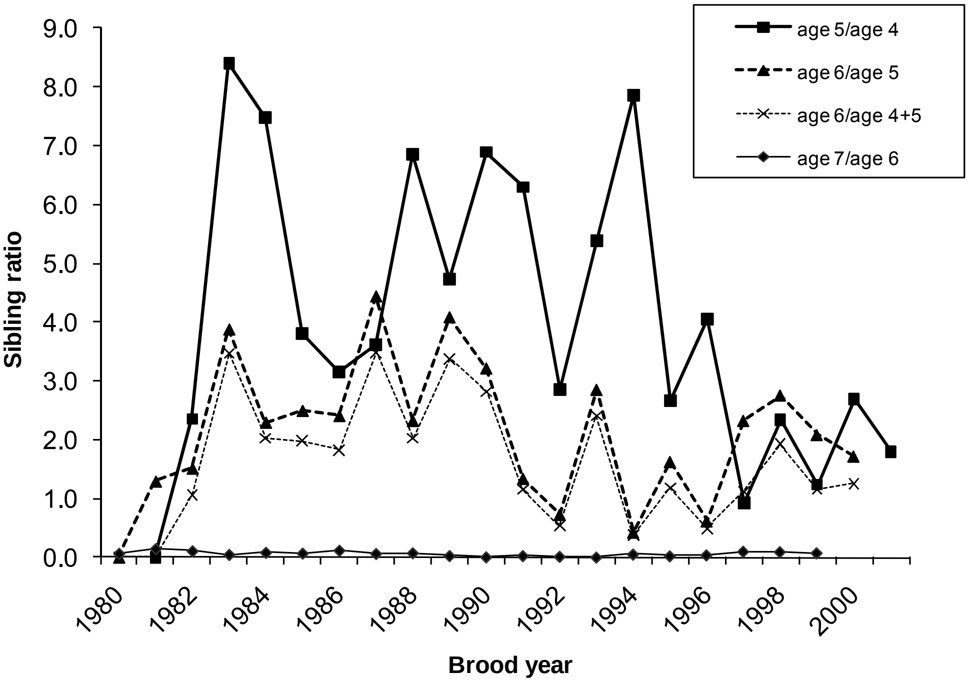


Figure 10.–Estimated sibling ratios by brood year for early-run Kenai River Chinook salmon.

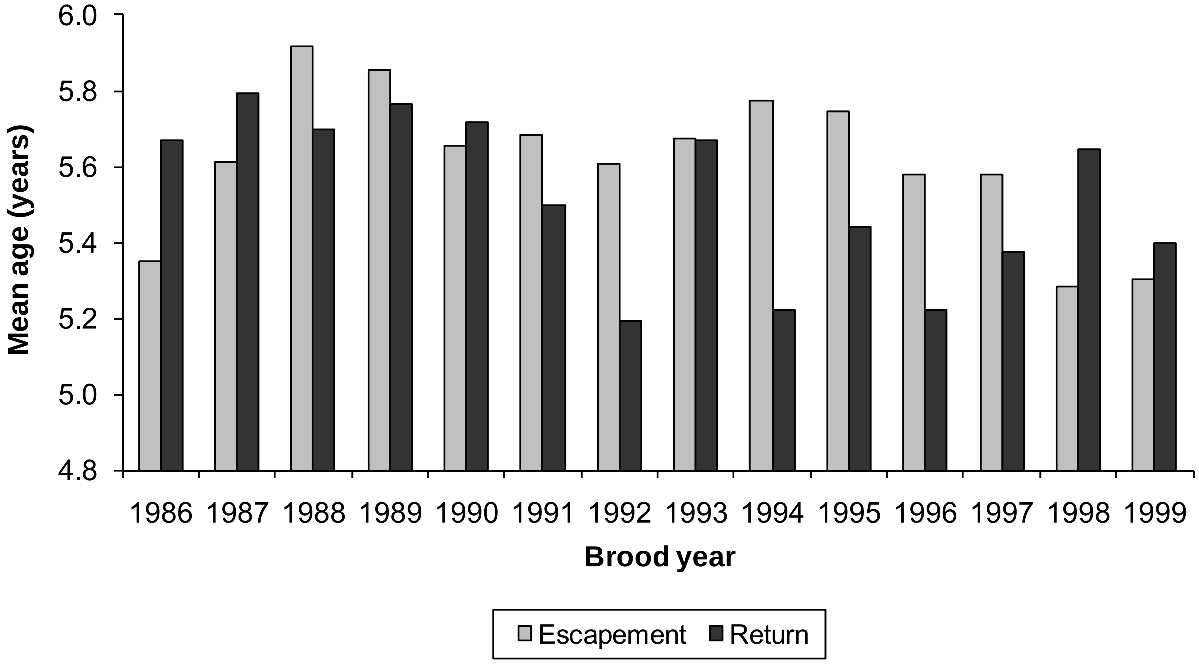


Figure 11.–Estimated mean age of escapement and return by brood year for early-run Kenai River Chinook salmon, 1986–1999.

Age composition has changed in the last decade, with age-1.2 fish showing an increasing trend, age-1.4 fish somewhat decreasing, and age-1.5 fish showing a decline through 2003 and an increase through 2006 (Figure 12, Appendix C1).

Age composition of the run varies consistently over time except during years with small runs (Figure 13). Most years, age-1.4 fish are the dominant age class during the month of May and the last two weeks in June. During the first two weeks of June there is no dominant age class. In years with the smallest runs (1992, 1998, and 2002, 1998), age-1.4 fish were not the predominant age class in May.

RETURN PER SPAWNER

To enable reconstruction of brood year returns for the spawner-recruit analysis, the numbers of fish by age were estimated by calendar year (Table 3) and by brood year (Table 9). For brood years 1986–1999 (i.e., years with complete return data), returns ranged from 8,857 (SE = 645) Chinook salmon in 1996 to 22,557 (SE = 938) in 1994. Return-per-spawner estimates ranged from 0.53 in brood years 1986 and 1996 (two of the highest escapements measured) to 3.88 for brood year 1988 (the lowest escapement measured with complete return data; Table 9). The lowest observed escapement with complete return data (1988; 5,331 fish) produced one of the largest returns (Figure 14), the largest returns per spawner (Figure 15), and the largest yield (return minus escapement) (Figure 16).

Table 9.–Adult returns for early-run Kenai River Chinook salmon by brood year and age, 1979–2006.

		Adult return						
Brood year	Spawning escapement	Age 4	Age 5	Age 6	Age 7	Age 8	Estimated return to date	Return per spawner
					(1986)	(1987)		
1979	ND	ND	ND	ND	2,156	0	2,156	-
SE	-	-	-	-	788	0	788	-
				(1986)	(1987)	(1988)		
1980	ND	ND	ND	9,349	682	53	10,084	-
SE	-	-	-	3,399	187	38	3,404	-
			(1986)	(1987)	(1988)	(1989)		
1981	ND	ND	11,384	14,709	2,237	0	28,331	-
SE	-	-	4,133	3,417	236	0	5,368	-
		(1986)	(1987)	(1988)	(1989)	(1990)		
1982	ND	4,191	9,859	14,914	1,706	0	30,670	-
SE	-	1,537	2,312	466	203	0	2,822	-
		(1987)	(1988)	(1989)	(1990)	(1991)		
1983	ND	393	3,302	12,819	690	0	17,204	-
SE	-	134	281	415	123	0	534	-
		(1988)	(1989)	(1990)	(1991)	(1992)		
1984	ND	373	2,791	6,462	566	0	10,192	-
SE	-	99	254	284	160	0	425	-
		(1989)	(1990)	(1991)	(1992)	(1993)		
1985	ND	749	2,874	7,121	537	0	11,282	-
SE	-	137	230	385.1	146	0	491	-
		(1990)	(1991)	(1992)	(1993)	(1994)		
1986	18,682	782	2,452	5,906	722	0	9,862	0.53
SE	9,812	130	306	353	205	0	527	0.28
		(1991)	(1992)	(1993)	(1994)	(1995)		
1987	11,780	802	2,891	12,690	894	0	17,277	1.47
SE	6,001	189	302	590	188	0	714	0.75
		(1992)	(1993)	(1994)	(1995)	(1996)		
1988	5,331	826	5,593	13,173	1,072	0	20,664	3.88
SE	958	179	506	450	318	0	768	0.71
		(1993)	(1994)	(1995)	(1996)	(1997)		
1989	9,449	782	3,741	15,296	497	0	20,316	2.15
SE	655	213	354	727	186	0	857	0.17
		(1994)	(1995)	(1996)	(1997)	(1998)		
1990	8,583	651	4,482	14,424	159	0	19,716	2.30
SE	351	160	596	671	79	0	915	0.14
		(1995)	(1996)	(1997)	(1998)	(1999)		
1991	8,842	1,072	6,750	9,046	418	0	17,286	1.95
SE	349	316	595	406	137	0	799	0.12

-continued-

Table 9.–Page 2 of 2.

Brood	Spawning	Adult return					Estimated return	Return per
year	escapement	Age 4	Age 5	Age 6	Age 7	Age 8	to date	spawner
		(1996)	(1997)	(1998)	(1999)	(2000)		
1992	7,610	1,847	5,260	5,429	80	0	12,617	1.66
SE	346	350	379	397	80	0	656	0.11
		(1997)	(1998)	(1999)	(2000)	(2001)		
1993	10,041	638	4,872	9,787	73	0	15,370	1.53
SE	600	157	388	713	73	0	830	0.12
		(1998)	(1999)	(2000)	(2001)	(2002)		
1994	9,947	2,506	13,845	5,865	341	0	22,557	2.27
SE	499	311	742	452	169	0	938	0.15
		(1999)	(2000)	(2001)	(2002)	(2003)		
1995	11,310	2,069	5,505	8,948	260	0	16,782	1.48
SE	641	391	453	619	16	0	861	0.11
		(2000)	(2001)	(2002)	(2003)	(2004)		
1996	16,595	1,160	4,687	2,881	129	0	8,857	0.53
SE	550	268	544	214	49	0	645	0.04
		(2001)	(2002)	(2003)	(2004)	(2005)		
1997	8,185	2,898	2,692	6,261	666	0	12,516	1.53
SE	723	461	210	265	169	0	596	0.15
		(2002)	(2003)	(2004)	(2005)	(2006)		
1998	11,679	1,133	2,641	7,283	726	0	11,783	1.01
SE	308	153	202	435	223	0	550	0.05
		(2003)	(2004)	(2005)	(2006)	(2007)		
1999	17,276	4,211	5,196	10,829	865	[a]	21,101	1.22
SE	628	240	402	610	284		820	0.06
		(2004)	(2005)	(2006)	(2007)	(2008)		
2000	10,476	2,309	6,196	10,650	[a]	[a]		
SE	329	298	557	756				
		(2005)	(2006)	(2007)	(2008)	(2009)		
2001	14,073	2,541	4,540	[a]	[a]	[a]		
SE	390	404	591					
		(2006)	(2007)	(2008)	(2009)	(2010)		
2002	6,185	7,150	[a]	[a]	[a]	[a]		
SE	221	690						
		(2007)	(2008)	(2009)	(2010)	(2011)		
2003	10,097	[a]	[a]	[a]	[a]	[a]		
SE	540							

Note: Age 4 Chinook salmon includes: ages 0.3, 1.2, and 2.1 fish; Age 5 includes: ages 0.4, 1.3, and 2.2 fish; Age 6 includes: ages 0.5, 1.4, and 2.3 fish; Age 7 includes: ages 1.5 and 2.4 fish; and Age 8 includes: ages 1.6 and 2.5 fish. ND = no data because no attempts were made to collect it; "-" = value cannot be computed because of data limitations.

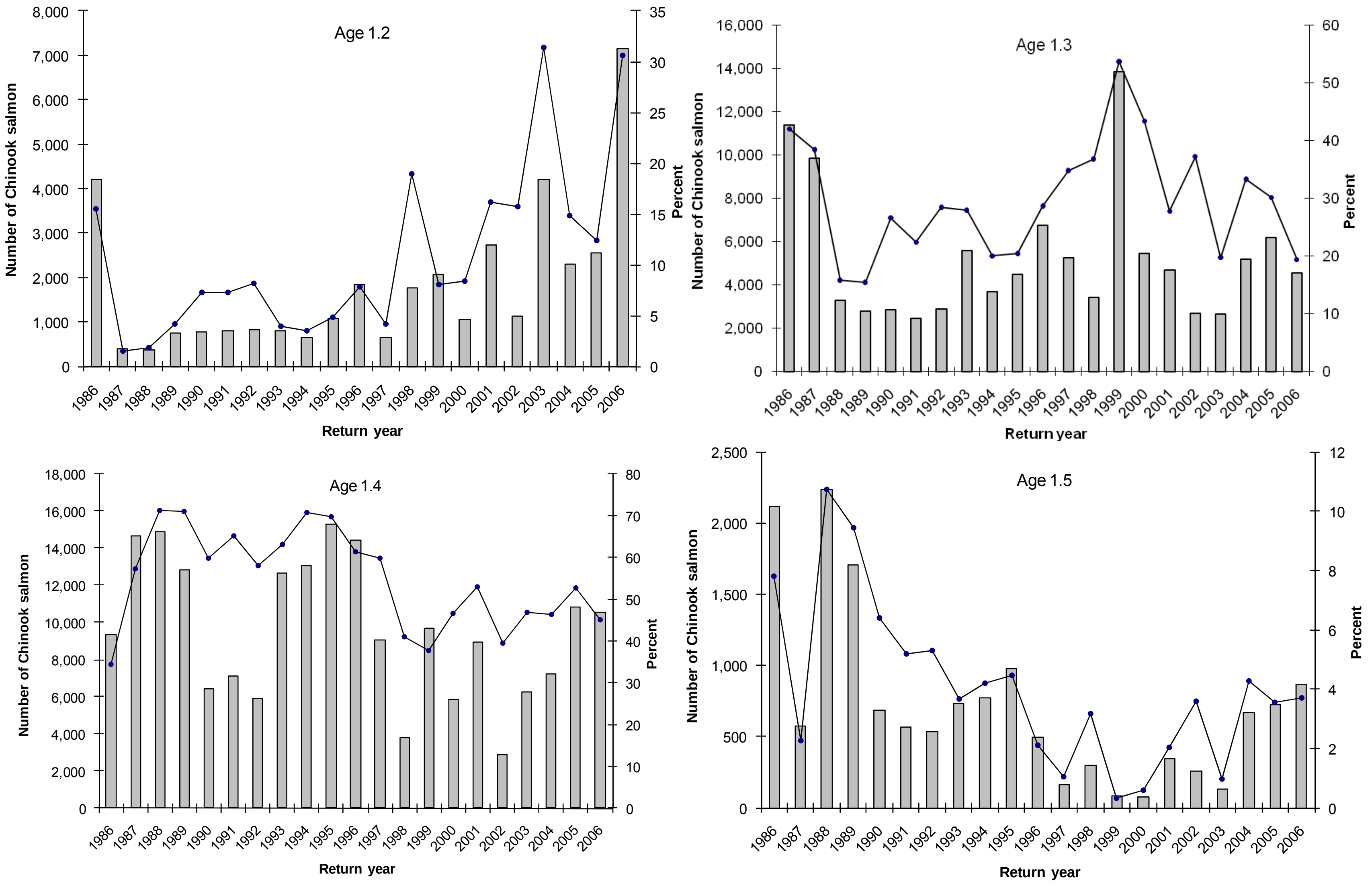
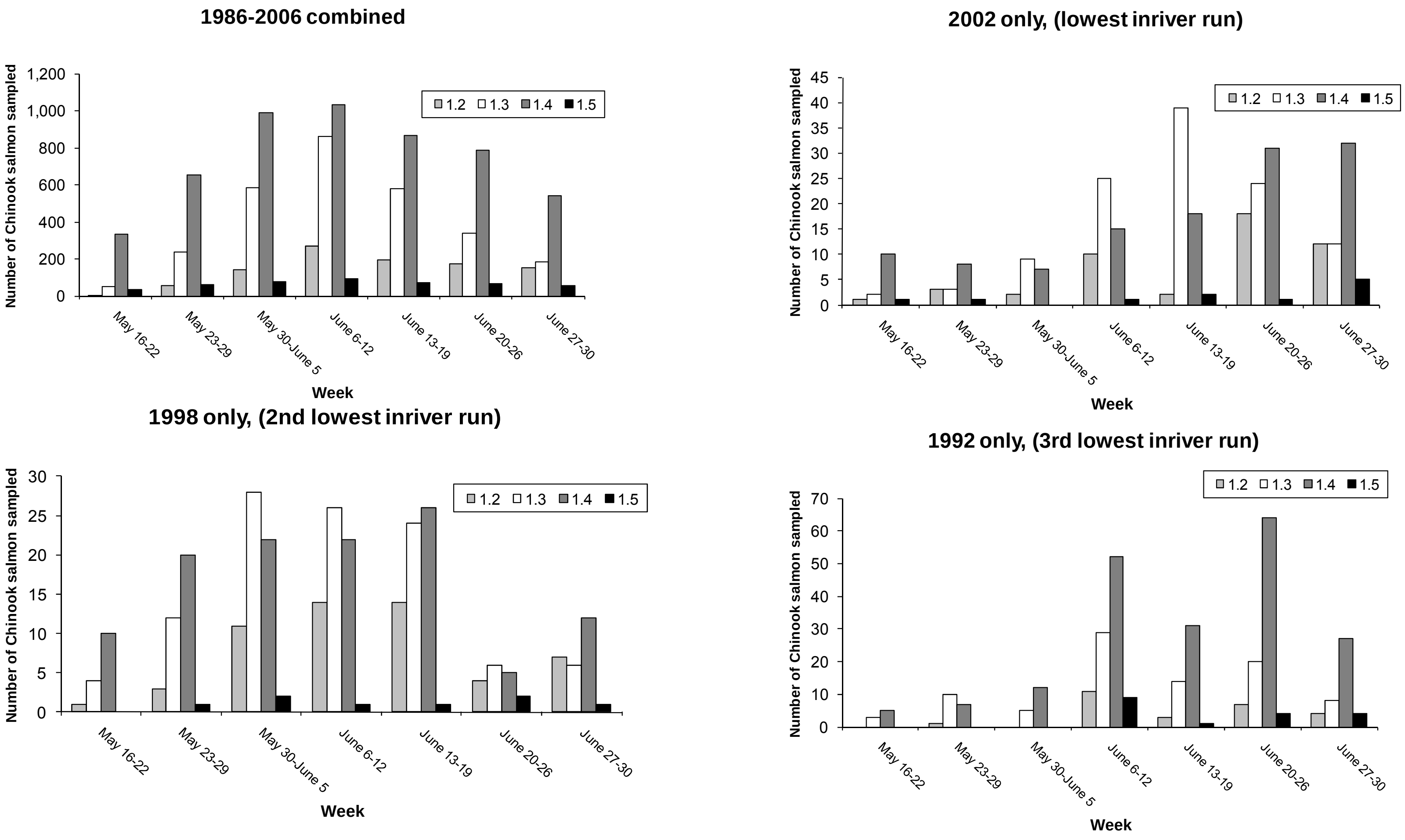


Figure 12.–Estimated number (*gray bars*) and percent (*lines*) of age-1.2, -1.3, -1.4, and -1.5 early-run Kenai River Chinook salmon in the total run.



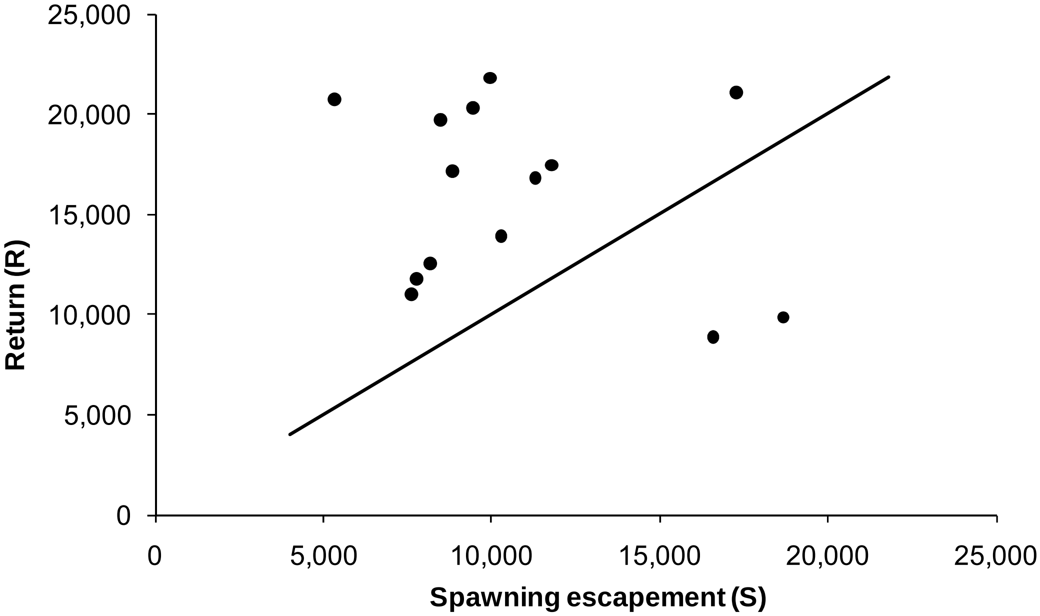
1986-2006 combined

2002 only, (lowest inriver run)

1998 only, (2nd lowest inriver run)

1992 only, (3rd lowest inriver run)

Figure 13.–Estimated age composition (ages 1.2, 1.3, 1.4, and 1.5 only) of inriver early-run Kenai River Chinook salmon by date, 1986–2006.



Note: Diagonal line is the replacement line, where *R*=*S*.

Figure 14.–Total return of early-run Kenai River Chinook salmon for a given brood year escapement, all complete brood years (1986–1999).

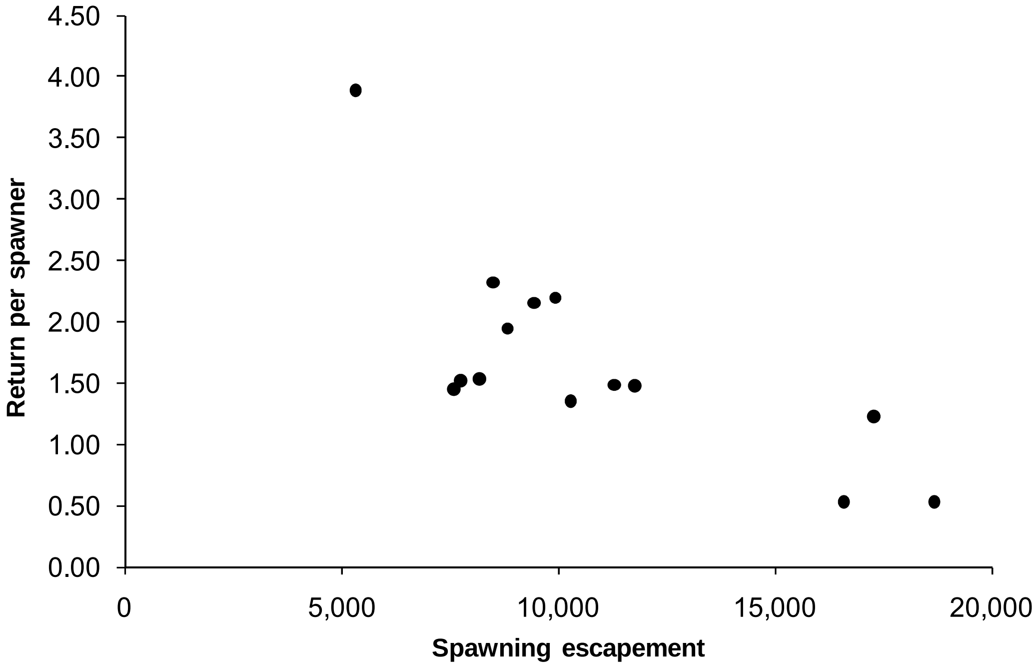
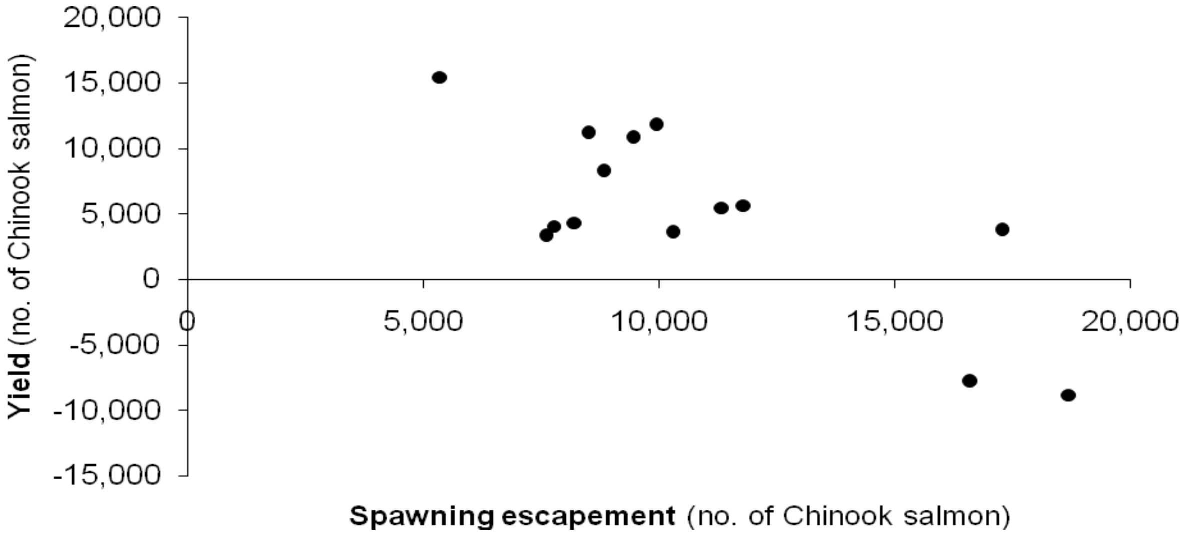


Figure 15.–Return-per-spawner estimates of early-run Kenai River Chinook salmon for a given brood year escapement, all complete brood years (1986–1999).



Note: *Yield* = the surplus production of a given escapement above the total return necessary to replace the escapement.

Figure 16.–Estimated yield of early-run Kenai River Chinook salmon for a given brood year escapement, all complete brood years (1986–1999).

SPAWNER-RECRUIT ANALYSIS

See Appendix B1 for a detailed description of the age-structured Ricker spawner-recruit model that was fit to the stock assessment data.

Estimates of annual spawning escapements were imprecise (Figure 17 because of measurement error in the sonar estimates of inriver run. Brood year return estimates *R* were also imprecise because escapement generally comprised a large fraction of the total run. Measurement error in harvest estimates, and to a smaller extent age composition, also contributed to uncertainty in *R*. Posterior medians of *S* and *R* differed from the original data-based point estimates (Figure 17) because of measurement error and because all of the data were considered simultaneously in the context of the full statistical model. Point estimates of *R* are not available for brood years 1979–1981 or 2001–2003 because documented returns from these brood years were incomplete (i.e., one or more age classes were not estimated). One of the advantages of the Bayesian MCMC analysis is that estimates are still produced for incomplete brood years at the beginning and end of the *R* time series, and the additional uncertainty is reflected in wider intervals.

Because we included *S* and *R* measurement error in the age-structured spawner-recruit model, the results automatically take the effect of such measurement error into account when estimating the Ricker parameters and reference points. Thus, the Bayesian MCMC point estimate (already mentioned previous) of the Ricker relationship, constructed from the posterior medians of ln(α) and β (Table 10) differs substantially (higher productivity, more density dependence) from the classical estimate, calculated by simple linear regression (Figure 18). The classical estimate ignores the measurement error in *S* and *R*, resulting in negative bias in classical estimates of ln(α) and β. In addition, classical analysis does not use information from incomplete brood years.

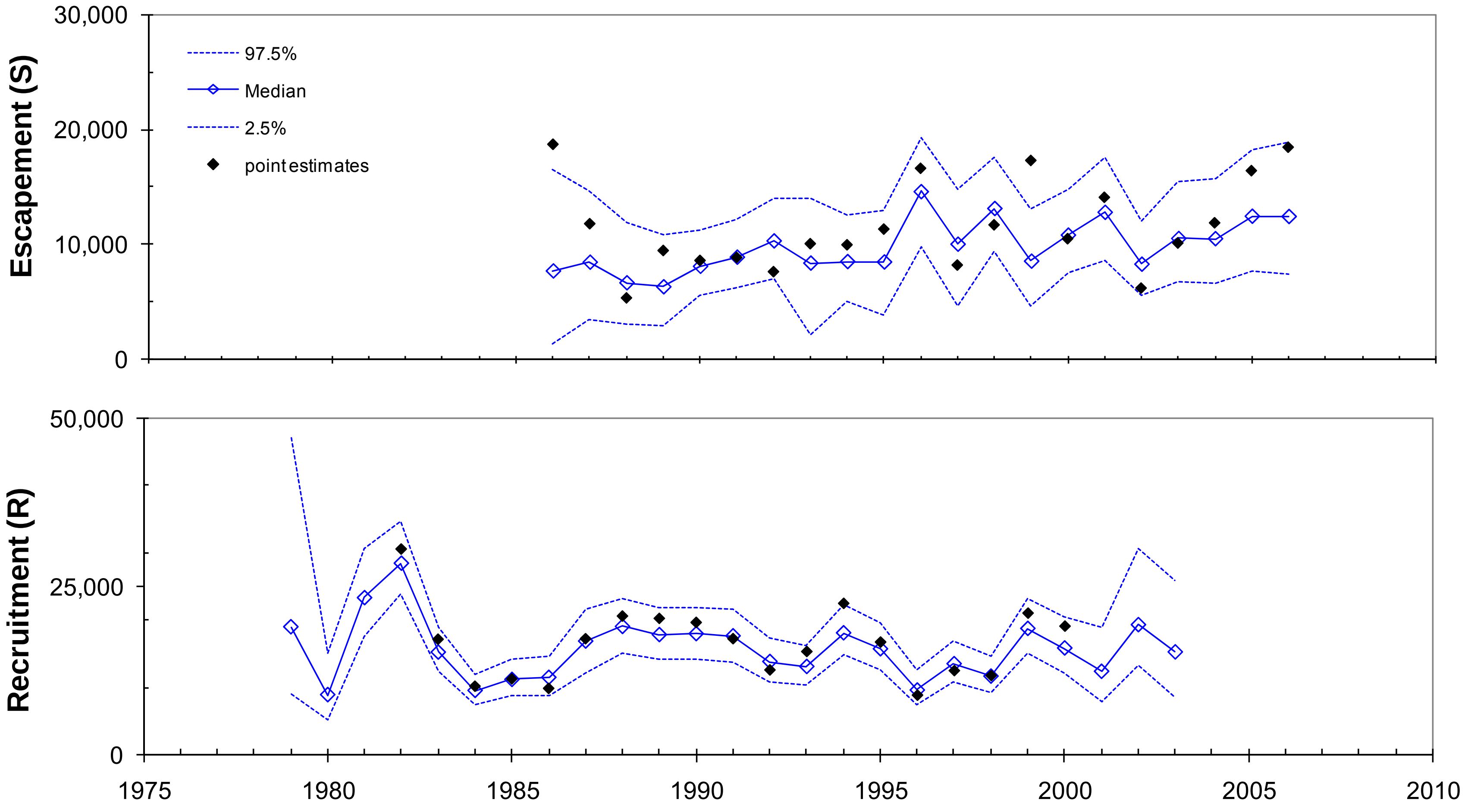
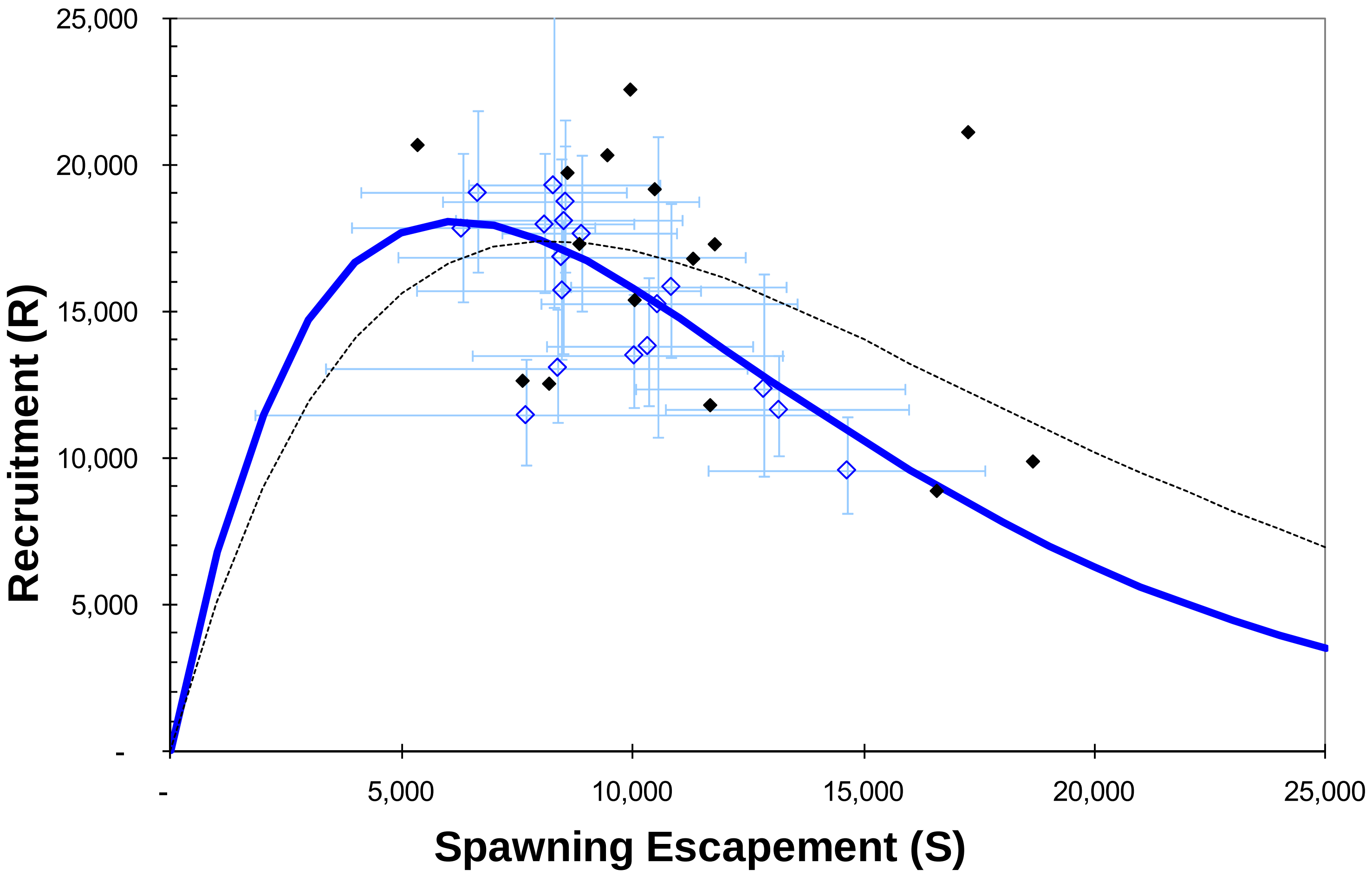


Figure 17.–Data-based point estimates (*solid symbols*) and Bayesian posterior percentiles (*open symbols and lines*) of spawning escapement and recruitment for early-run Kenai River Chinook salmon, brood years 1979–2006.



Note: Posterior medians are plotted as *open symbols*, 10th and 90th posterior percentiles are *bracketed by error bars*. Original data-based estimates of *S* and *R* are plotted as *solid symbols*. Ricker relationships are Bayesian posterior median (*solid thick line*) and classical estimate (*dashed line*).

Figure 18.–Scatter plot of recruitment versus escapement estimates for early-run Kenai River Chinook salmon, brood years 1979–2003.

Table 10.–Posterior percentiles from a Bayesian Ricker spawner-recruit analysis of early-run Kenai River Chinook salmon, 1979–2003 brood years.

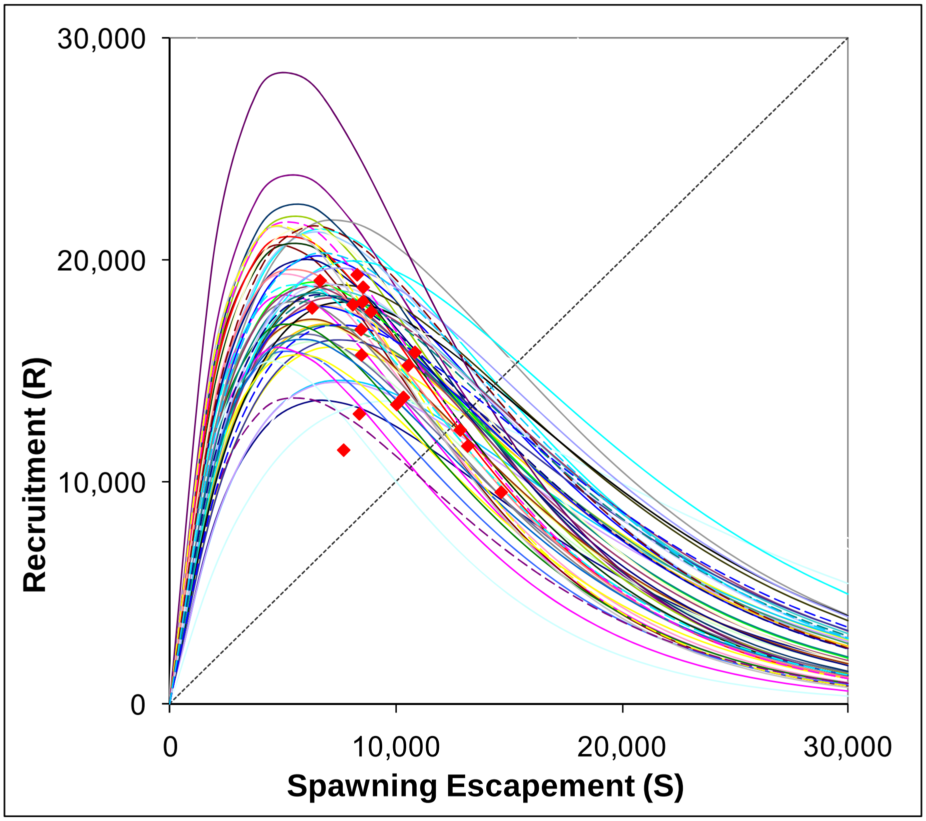
	Percentiles				
Parameters	2.5%	10%	Median	90%	97.5%
ln(a)	1.46	1.71	2.07	2.44	2.64
a	4.1	5.3	7.9	11.5	15.0
$b \times 10^5$	1.03E-04	1.25E-04	1.62E-04	2.02E-04	2.25E-04
s_{SR}	0.06	0.09	0.15	0.25	0.32
f	-0.67	-0.38	0.24	0.77	0.93
$s_{SR/(1-f^2)}$	0.07	0.10	0.18	0.33	0.53
S_{MSY}^{c}	3,592	3,917	4,579	5,412	6,073
S_{MAX}	4,443	4,953	6,189	7,996	9,755
S_{EQ}	10,750	11,550	12,970	14,690	16,260
1990 and before					
D	35	45	76	131	168
p_1	0.037	0.043	0.053	0.067	0.076
p_2	0.212	0.224	0.246	0.269	0.284
p_3	0.599	0.616	0.645	0.669	0.682
p_4	0.040	0.045	0.055	0.067	0.074
1991 and after					
D	14	18	29	47	60
p_1	0.111	0.123	0.147	0.174	0.190
p_2	0.290	0.310	0.345	0.380	0.400
p_3	0.409	0.433	0.473	0.510	0.530
p_4	0.018	0.023	0.034	0.049	0.059

Note: parameters defined in the Methods section.

The Ricker relationships that could have generated the observed escapement and production data are displayed in Figure 19. The degree to which these Ricker curves differ from one another reflects the amount of uncertainty about the true Ricker relationship. For this stock, the prospective Ricker relationships are all relatively similar, indicating that both productivity and density dependence are well-estimated for early-run Kenai Chinook salmon. The slope at the origin (α) does not vary greatly among the individual curves; and neither does the point of maximum recruitment S_{MAX}, which is the inverse of the density-dependent parameter β. Finally, most of the possible curves pass through the replacement line within a fairly narrow window, indicating that carrying capacity S_{EQ} is also well estimated.

The graphical evidence is confirmed by narrow 80% interval estimates for ln(α) (1.70–2.44), β (1.25–2.02 x 10^{-4}), S_{MAX} (4,953–7,996) and S_{EQ} (11,550–14,690; Table 10). Similarly, S_{MSY} is also well estimated (80% interval 3,917–5,412; Table 10). S_{MSY} is equally likely to be above or below 4,579. The width of the 80% interval divided by the posterior median of S_{MSY} is an index of the relative uncertainty (RU) of our knowledge about S_{MSY}. For early run Kenai River Chinook salmon this ratio was RU_{80} = 0.32, which is the lowest among similarly analyzed salmon stocks (Table 11).

The sustained yield (SY) probability profile in Figure 20 displays the probability of achieving near maximal SY (>90% of MSY) for specified levels of escapement. For this stock, the limbs of the profile are very steep, indicating that we have very good information about the range of escapements that would produce near-maximal yield. For example, there is nearly 100% certainty that spawning escapements between approximately 4,000 and 5,200 fish would result in expected sustained yield exceeding 90% of MSY.



Note: Symbols are posterior medians of *R* and *S*. Curves can be interpreted as a sampling of Ricker relationships that could have resulted in the observed data.

Figure 19.–Ricker relationships represented by ~50 paired values of ln(α) and β sampled from the posterior probability distribution of stock-recruitment statistics, early-run Kenai River Chinook salmon.

Table 11.–Relative uncertainty (RU80) of Ricker spawner-recruit parameter estimates for Pacific salmon populations analyzed with Bayesian age-structured spawner-recruit methods.

								RU_{80} [a]	
Salmon species	River	Years [b]	*S* uncertainty	Harvest rate	$\hat{\phi}$	$\hat{\sigma}_{SR}$	ln(α)	β	S_{MSY}
Coho	Chilkat	7/9	high	low	0.69	0.31	0.67	0.60	0.51
Chinook	Anchor	5/31	high	low	0.23	0.17	0.85	0.98	0.42
Chinook	Karluk	12/29	low	low	0.16	0.49	1.46	1.63	1.39
Chinook	Ayakulik	12/28	low	low	0.17	0.51	1.44	0.59	0.38
Chinook	Kenai, early run	21/21	mod-high	mixed	0.24	0.16	0.35	0.48	0.32
Chinook	Kenai, late run	21/21	mod-high	moderate	*0.22*	*0.24*	*0.73*	*1.34*	*1.16*
Chinook	Deshka	10/31	low	mixed	0.67	0.44	0.77	0.69	0.57
Sockeye	Buskin	8/8	low	high	0.43	0.57	1.21	1.63	2.11

[a] RU80 is defined as the width of 80% credibility intervals (90th posterior percentile – 10th posterior percentile) divided by the posterior median.

[b] Numbers before slash represent years of complete data; numbers after dash represent years with partial data.

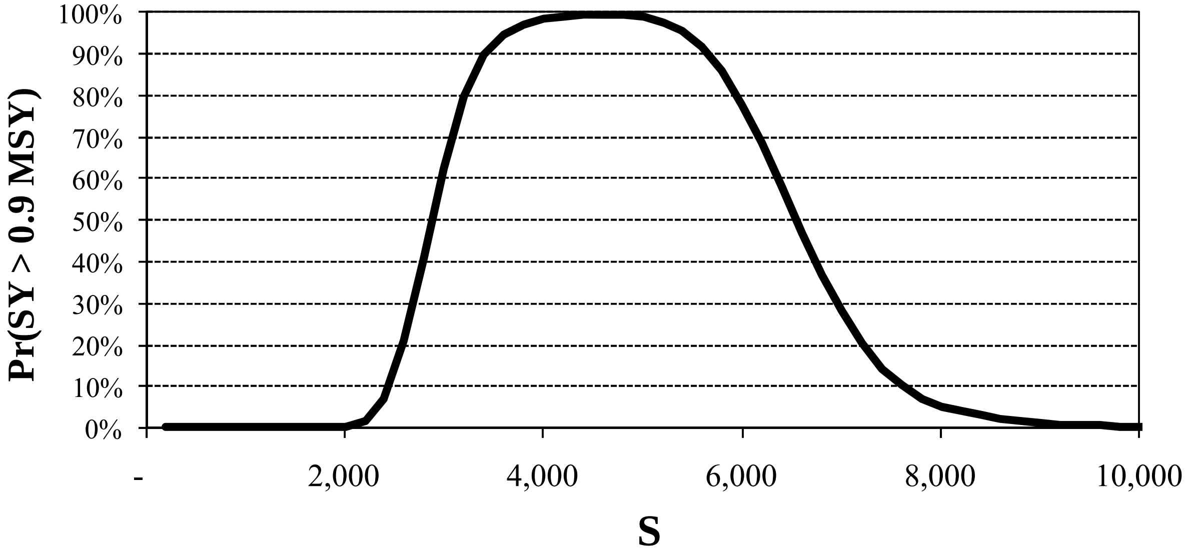


Figure 20.–Probability that a specified spawning abundance will result in sustained yield exceeding 90% of maximum sustained yield, early-run Kenai River Chinook salmon.

DISCUSSION

ASSESSMENT UNCERTAINTIES

All assessments are subject to some level of uncertainty. Uncertainties in the early-run Kenai River Chinook salmon assessment are related to the use of sonar to estimate fish numbers, difficulties in distinguishing early-run and late-run fish, and incomplete accounting for marine harvest.

Sonar Imprecision

Potential measurement error in sonar counts contribute substantial uncertainty to estimates of inriver run size and by extension total run size, escapement, and spawner-recruit analysis. Split-beam sonar attempts to distinguish Chinook salmon based on target strength and range (Eggers et al. 1995; Miller et al. 2007), and based on the premise that sockeye salmon are smaller and migrate closer to shore than Chinook salmon which are larger and tend to migrate more toward the middle of the river (Burwen et al. 2007). Measurement error can be in either direction, leading to over- or under-estimates. Burwen and Fleischman (1998) concluded that sockeye salmon can be erroneously classified as Chinook salmon, inflating Chinook salmon abundance to some degree. Underestimation errors can result when fish enter the river before the sonar program begins in mid-May, when fish migrate behind the sonar, or they migrate too close in front of the sonar where they cannot be detected (McKinley et al. 2002).

A series of tagging studies were conducted during the 1980s to estimate fish abundance (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Alexandersdottir and Marsh 1990). These abundance estimates had low precision and appeared to be biased high (Bernard and Hansen 1992). However, comparable mark-recapture and sonar estimates have been taken to suggest that sonar estimates are an approximate albeit imprecise index of the relative abundance of the early run. Any directional bias in sonar estimates relative to true abundance is implicitly assumed to be consistent among years. Imprecision in sonar estimates was explicitly incorporated into our spawner-recruit analysis.

The Alaska Department of Fish and Game is actively engaged in the development of improved sonar methodology for estimating the inriver return of Kenai River Chinook salmon. These efforts include development of statistical mixture models for analysis of echo-length data measured by the split-beam sonar (Burwen et al. 2003; Fleischman and Burwen 2003). Ultimately, these efforts will culminate in revised historical (after 2001) abundance estimates for the early and late runs. Such estimates are not yet finalized, but we have preliminary quantities that we can compare with the published estimates of Chinook salmon abundance. Ongoing efforts also involve evaluation of the accuracy and precision of dual-frequency imaging sonar (DIDSON) and an updated mark-recapture evaluation of the relative accuracy of split-beam and DIDSON sonar systems.

Distinguishing Early- from Late-Run Fish

By definition, and for management purposes, the early run ends on 30 June and the late run begins on 1 July. Yet, some fish from the early-run stock probably enter the river in July and some late-run fish enter in June. Furthermore, some early-run fish are probably harvested in July, both upstream and downstream of the Soldotna Bridge. The degree to which the two stocks overlap in time and space is unknown. Following cessation of the onsite creel project upstream of the Soldotna Bridge in 1989, 50% of the harvest estimate from SWHS was used as the harvest and catch estimates upstream of the bridge (Hammarstrom and Timmons 2001). Beginning in 1996, SWHS generated two estimates: one before 1 July and one after 30 June. The estimates before 1 July have been used as early-run harvest estimates. The degree of overlap between the tail end of the early run and the beginning of the late run in June and July (i.e., what fraction of fish entering the river during June and currently counted as early run are in fact genetically late run fish remains unanswered) is unknown. Conversely, there are probably some early-run fish that enter in July and are counted as late-run fish. Prior to the sonar program, a shift in the daily estimate of catch per unit effort for Chinook salmon as measured in the lower Kenai River creel project was used to estimate the end of the early run and the beginning of the late run (Conrad and Hammarstrom 1987). However, there is typically no obvious pause in passage rate between early and late runs of Chinook salmon in the Kenai River. Therefore, beginning in 1986, 1 July was set as the arbitrary demarcation point between the two runs.

To address questions about the entry and harvest timing of Kenai River Chinook salmon by run, an ongoing genetic stock identification program was initiated in 2005. A previous study found genetic differences between the two Kenai River Chinook salmon runs (Adams et al. 1994). To establish a genetic baseline, tissue sampling of Chinook salmon in seven tributaries of the Kenai River and two mainstem locations is being conducted and samples are analyzed using single nucleotide polymorphisms (SNPs). The genetic baseline will allow for estimates of stock composition, overlap in the early and late runs, and harvest timing. Tissue samples will be collected from: 1) Chinook salmon in the lower Kenai River gillnetting project as fish enter the river; 2) the lower river creel survey; and 3) a sport harvest sampling program upstream of the Soldotna Bridge. This information will improve assessment of Kenai River Chinook salmon stock productivity, genetic diversity, escapement estimates, and accuracy in estimating yield and biological escapement goals.

Incomplete Accounting for Marine Harvest

Our current stock assessment program accounts for most sources of harvest, except for the marine recreational fishery in Cook Inlet. From 2002 through 2006, there were 2,137–5,035 Chinook salmon harvested annually in this fishery (SWHS estimates). An unknown fraction of these fish originate from the early-run Kenai River Chinook salmon stock. The current estimate of stock productivity is therefore biased slightly low. The effect of this bias on the estimate of S_{MSY} and the escapement goal recommendation is probably small.

AGE COMPOSITION AND THE SLOT LIMIT

It is difficult to explain why over the last two decades the relative abundance of ocean-age-5 fish has declined and ocean-age-2 fish has increased. Similar changes have occurred in the Yukon and Kuskokwim drainages (Karen Hyer, USFWS, Anchorage; personal communication). Ricker (1981) listed eight possible causes for a decline in age and size by Chinook salmon experienced in British Columbia. Four of these are plausible for early-run Kenai River Chinook salmon: 1) marine fisheries harvest some immature fish, therefore older-maturing fish are subject to harvest for longer periods of time, leading to greater fishing mortality; 2) a change in the ocean environment may have reduced age at maturity; 3) the fisheries harvesting the stock may have changed; and 4) artificial selection may be occurring because of a tendency to harvest older fish.

Conover and Munch (2002) demonstrated evolutionary effects of size-selective mortality on growth, yield, and population biomass on captive populations of a small marine species. In addition, age at maturity has been shown to be partly heritable in Chinook salmon (Hard et al. 1985; Ricker 1972; Withler et al. 1987; Hankin et al. 1993). The last two decades may be too short a timeframe for substantial genetics changes to occur, yet there is no guarantee that size-selective mortality will not cause future genetic selection.

The 2003 slot limit has been successful in eliminating the harvest of ocean-age-5 fish. In addition to allowing all early-run ocean-age-5 fish that enter the Kenai River to spawn (except for a very small number of hook-and-release mortalities), selectivity for ocean-age-4 fish has been reduced. However, selectivity for ocean-age-3 fish has increased because most fish of this age class are less than 44 inches TL, legal to harvest, and of a size acceptable for retention by anglers.

It is unknown exactly how much harvest has been reduced because of the slot limit, though analyses conducted before its implementation in 2003 concluded that the harvest would be reduced by approximately 34%. Despite the foregone harvest of large fish, the fishery has remained viable and popular. In fact, the average annual early-run harvests during the first 4 years of the slot limit (2003–2006) were higher than the annual harvests in 3 of the 4 years prior to the slot limit (1999–2002).

Although the runs in the last three years of this study showed some increase in the number of ocean-age-5 fish, we do not recommend rescinding the slot limit at this time. The first ocean-age-5 returns from these escapements will be in 2010.

ESCAPEMENT GOAL RECOMMENDATION

During 1989–2004, when a Biological Escapement Goal (BEG) of 7,200–14,400 fish was in effect for early-run Kenai River Chinook salmon, ADF&G took inseason management action in 14 of 16 years. Many of these actions restricted harvest. In 2004, the first spawner-recruit analysis (unpublished, not reported here) of early-run Kenai River Chinook salmon was conducted with data through 2003. This resulted in a recommended BEG of 4,000–9,000 fish. At the Upper Cook Inlet meeting in January 2005, the BOF adopted a modified version of that recommended goal, creating an optimal escapement goal (OEG) of 5,300–9,000 fish instead. The reasons for the modification were (1) there was public concern that a low end of 4,000 fish was too low; (2) measurement and management error have potentially more serious consequences at low escapements, and (3) escapements below 5,300 fish had never been measured. The lower end of the range was therefore increased to the lowest measured escapement (5,300 fish).

Compared to the previous BEG of 7,200–14,000 fish, the new OEG range of 5,300–9,000 fish more closely fits the Department's management abilities, as well as the stock's production and yield potential. Since instituting the new OEG range, there have been no restrictions or closures and the fishery has been liberalized each year (i.e., 2005–2007) to allow the use of bait. Given the results from recent spawner-recruit analyses, it appears the previous escapement goal was too high, resulting in closures of the early-run fishery, diminished fishing opportunity, and had adverse economic effects. Additionally, the public perception was that the early run was an "injured" stock because of the frequency of these closures. These effects were unfortunate, but perhaps unavoidable given the considerable time it takes to assemble sufficient information to conduct a viable spawner-recruit analysis. The conservative interim management strategy was ultimately successful in protecting the stock.

The spawner-recruit analysis presented here, which incorporates data from 1986 to 2006, supports the conclusion that sustained yield is maximized at relatively low levels of escapement. In fact, if yield maximization were the only consideration, escapements as low as 3,000 spawning Chinook salmon could be justified (Figure 20). However, we are not recommending that the escapement goal be modified at this time, because of the following considerations:

1. The original concern about the potentially serious consequences of measurement error during years with small escapements remains valid, especially considering that we are now better able to quantify sonar measurement error (Appendices B2–B3) and it appears to be moderately high[4].
2. The potential gain in expected sustained yield that could be realized by reducing the escapement from 5,300 to 4,761 fish (posterior median of S_{MSY} where yield is maximized) is very small (posterior median of gain in SY = 140 fish; Figure 21) and very uncertain (95% interval -399 to 1,165 fish).
3. This is primarily a sport fishery, and maximum yield is not the same as maximum abundance or maximum CPUE. With productive stocks such as Kenai River Chinook salmon ($\ln(\alpha) = 2.1$), maximum recruitment occurs at escapements greater than S_{MSY}, in this case near $S_{MAX} = 6{,}189$ fish[5] (Figure 18, Table 10).

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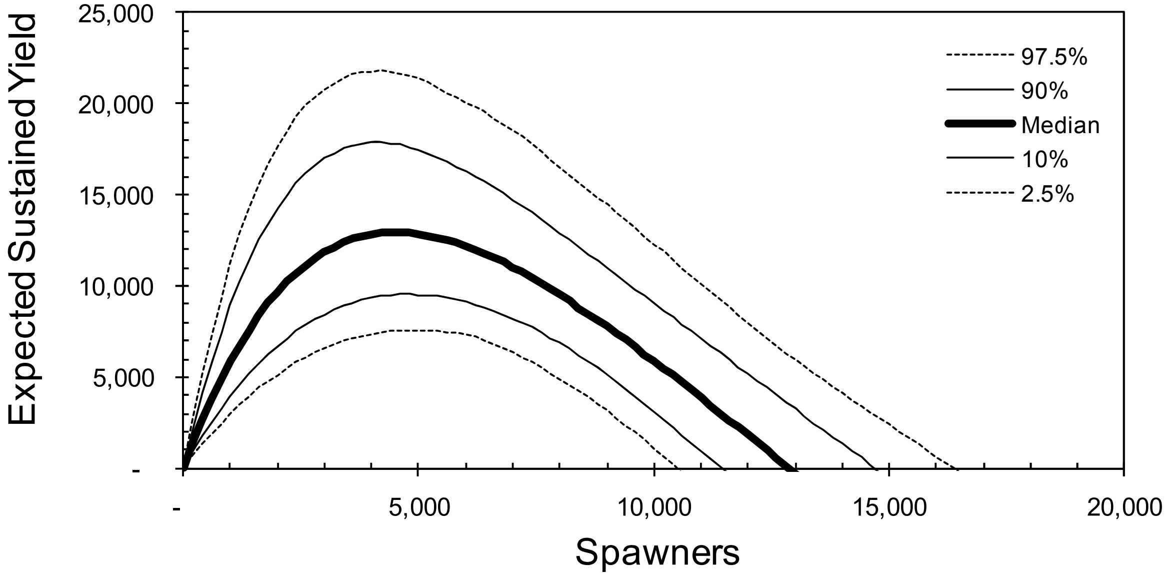
[4] ADF&G is currently developing improved sonar methodology for Kenai River Chinook salmon that will reduce the measurement error. In the near future, we anticipate switching to the new methodology and publishing revised historical estimates of inriver abundance.

[5] This is the posterior median; there is 95% certainty that S_{MAX} is between 4,443 and 9,755 (Table 10).



Note: Expected sustained yield units = number of fish.

Figure 21.–Bayesian posterior percentiles of expected sustained yield at specified spawning abundances, early-run Kenai River Chinook salmon.

CONCLUSIONS

We conclude that the early run of Kenai River Chinook salmon remains a productive and healthy stock. Since estimates of abundance and composition were initiated in the late 1980s, returns have been fairly consistent and escapements have been within or above the current OEG range. As a result of recent spawner-recruit analyses, the escapement goal has been reduced and harvest opportunities liberalized. Sex and age composition has been generally favorable, though there are some concerns about a trend toward low numbers of ocean-age-5 fish and an increasing trend in ocean-age-2 fish. There are also concerns about moderately high measurement error in the sonar abundance estimates, and we are actively engaged in efforts to develop improved methodology in that regard.

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APPENDIX A. CLASSICAL STATISTICAL METHODS

Appendix A1.-Statistical notation used in Appendices A and B.

Notation	Definition
a	Age or sex
h	Temporal stratum
t	Calendar year
y	Brood year
p	Proportion
n	Sample size for estimating proportions
N	Total run
N_I	Inriver run
H_A	Harvest above sonar (sport fishery)
C	Catch above sonar (sport fishery)
H_B	Harvest below sonar (subsistence, personal use, educational fisheries)
M	Hook-and-release mortality
q	Hook-and-release mortality rate
S	Spawning escapement
R	Total return
RPS	Return per spawner
r	Sibling ratio

Appendix A2.-Total run, harvest, hook and release mortality, and escapement.

Total run was estimated as the sum of inriver run and all harvest downstream of the sonar, including that from subsistence, personal use, and educational fisheries:

$$\hat{N} = N_I + H_B, \qquad \text{(A2.1)}$$

with approximate variance:

$$\hat{V}\left(\hat{N}\right) \doteq \hat{V}\left(\hat{N}_I\right), \qquad \text{(A2.2)}$$

because subsistence, personal use, and educational harvests were small and no estimates of variance were available.

Spawning escapement was estimated by subtracting harvest above the sonar and associated hook-and-release mortality from the inriver run:

$$\hat{S} = \hat{N}_I - \hat{H}_A - \hat{M}, \qquad \text{(A2.3)}$$

with variance:

$$\hat{V}\left(\hat{S}\right) = \hat{V}\left(\hat{N}_I\right) + \hat{V}\left(\hat{H}_A\right) + V\left(\hat{M}\right). \qquad \text{(A2.4)}$$

Estimated harvest above the sonar and its variance were obtained by summing sport harvest estimates from the creel survey (below the Soldotna Bridge) with estimates from the Statewide Harvest Survey (upstream of the bridge).

Hook-and-release mortality was estimated by:

$$\hat{M} = \hat{q}\left(\hat{C} - \hat{H}_A\right), \qquad \text{(A2.5)}$$

with variance:

$$\hat{V}\left(\hat{M}\right) = \hat{q}^2\left[\hat{V}\left(\hat{C}\right) + \hat{V}\left(\hat{H}_A\right)\right] + \left[\hat{C} - \hat{H}_A\right]^2 \hat{V}\left(\hat{q}^2\right) - \left[\hat{V}\left(\hat{C}\right) + \hat{V}\left(\hat{H}_A\right)\right]\hat{V}\left(\hat{q}^2\right). \qquad \text{(A2.6)}$$

where $\hat{q} = 0.088$ and $\hat{V}(\hat{q}) = 0.000625$ for 1990 (Bendock and Alexandersdottir 1991), and $\hat{q} = 0.040$ and $\hat{V}(\hat{q}) = 0.000400$ for 1991 (Bendock and Alexandersdottir 1992). For other years, we used the mean of the 1990 and 1991 estimates, $\hat{q} = 0.064$, with interannual variance

$$\boxed{\hat{V}\left(\hat{q}\right) = \frac{\sum_{i=1}^{2}\left(\hat{q}_i - \hat{q}\right)^2}{2-1} + \frac{\sum_{i=1}^{2}\hat{V}\left(\hat{q}_i\right)}{2} = 0.00167}.$$

Appendix A3.-Abundance by age and sex.

Quantities total run, inriver run, harvest above the sonar, and hook and release mortality were all apportioned by age/sex. Abundance of generic quantity X by age/sex *a* in stratum *h* was[6]:

$$\hat{X}_{ah} = \hat{X}_h \hat{p}_{ah}, \tag{A3.1}$$

with variance (Goodman 1960):

$$\hat{V}\left(\hat{X}_{ah}\right) = \hat{X}_h^2 \hat{V}\left(\hat{p}_{ah}\right) + \hat{p}_{ah}^2 \hat{V}\left(\hat{X}_h\right) - \hat{V}\left(\hat{p}_{ah}\right)\hat{V}\left(\hat{X}_h\right). \tag{A3.2}$$

where X_h is abundance in stratum *h*, and the proportion *p* of age/sex a was estimated as:

$$\hat{p}_{ah} = \frac{n_{ah}}{n_h}, \tag{A3.3}$$

with variance (Cochran 1977):

$$\hat{V}(\hat{p}_{ah}) = \frac{\hat{p}_{ah}(1-\hat{p}_{ah})}{(n_h - 1)}, \tag{A3.4}$$

where n is the number of scales for which age was determined and sex recorded.

For time-stratified estimates with two time strata (*h* = 1,2); overall age composition was estimated by weighting by X_h:

$$\hat{p}_a = \frac{\sum_h \hat{X}_h \hat{p}_{ah}}{\sum_h \hat{X}_h}, \tag{A3.5}$$

$$\hat{V}(\hat{p}_a) = \frac{1}{\hat{X}^2}\left[\frac{\hat{v}(\hat{X}_1)\left[\hat{p}_{a1}\hat{X}_2 - \hat{X}_{a2}\right]^2}{\hat{X}^2} + \frac{v(\hat{X}_2)\left[\hat{p}_{a2}\hat{X}_1 - \hat{X}_{a1}\right]^2}{\hat{X}^2} + \hat{v}(\hat{p}_{a1})\hat{X}_1^2 + \hat{v}(\hat{p}_{a2})\hat{X}_2^2\right]. \tag{A3.6}$$

Escapement by age / sex was estimated by subtraction:

$$\hat{S}_a = \hat{N}_{Ia} - \hat{H}_{Aa} - \hat{M}_a, \tag{A3.7}$$

with variance:

$$\hat{V}\left(\hat{S}_a\right) = \hat{V}\left(\hat{N}_{Ia}\right) + \hat{V}\left(\hat{H}_{Aa}\right) + \hat{V}\left(\hat{M}_a\right). \tag{A3.8}$$

Occasionally, for minor age classes, estimated harvest in the sport fishery was greater than estimated inriver run. For those age classes, spawning escapement was set to zero, causing spawning escapement by age class not to sum to total escapement.

Age composition estimates of fish sampled from the inriver return were used to apportion hook-and-release mortality. [7]

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[6] Not all estimates of age/sex composition were stratified. For unstratified estimates the subscript h was ignored.

[7] Technically this ignores the finding that mortality differed by sex and size in 1991, with higher mortality for small males (Bendock and Alexandersdottir 1992). However, given the low rate of mortality, the effect of this discrepancy is negligible. On the other hand, estimates of total hook-and-release may be biased slightly low because of the tendency of anglers to release smaller fish.

Appendix A4.-Estimation of return by brood year and return per spawner.

Brood year returns were estimated by summing total run at age for those ages comprising the same brood year *y*:

$$\hat{R}_y = \sum_a \hat{N}_{ya} , \tag{A4.1}$$

with variance:

$$\hat{V}\left(\hat{R}_y\right) = \sum_a \hat{V}\left(\hat{N}_{ya}\right). \tag{A4.2}$$

Return per spawner was then estimated for brood year y as:

$$R\hat{P}S_y = \frac{\hat{R}_y}{\hat{S}_y} , \tag{A4.3}$$

with variance (Lindgren 1976):

$$\hat{V}\left(R\hat{P}S_y\right) = R\hat{P}S_y^2 \left\{ \frac{\hat{V}\left(\hat{R}_y\right)}{\hat{R}_y^2} + \frac{\hat{V}\left(\hat{S}_y\right)}{\hat{S}_y^2} \right\}. \tag{A4.4}$$

Sibling ratios were estimated by:

$$\hat{r}_{ya} = \frac{\hat{N}_{ya}}{\hat{N}_{y(a-1)}} \mathit{or} \ \frac{\hat{N}_{ya}}{\sum_{j=4}^{a-1} \hat{N}_{yj}} , \tag{A4.5}$$

with variance (Lindgren 1976):

$$\hat{V}\left(\hat{r}_{ya}\right) = \hat{r}_{ya}^2 \left\{ \frac{\hat{V}\left(\hat{N}_{ya}\right)}{\hat{N}_{ya}^2} + \frac{\hat{V}\left(\hat{N}_{y(a-1)}\right)}{\hat{N}_{y(a-1)}^2} \right\} \text{ or } \hat{r}_{ya}^2 \left\{ \frac{\hat{V}\left(\hat{N}_{ya}\right)}{\hat{N}_{ya}^2} + \frac{\sum_{j=4}^{a-1} \hat{V}\left(\hat{N}_{yj}\right)}{\left[\sum_{j=4}^{a-1} \hat{N}_{yj}\right]^2} \right\}. \tag{A4.6}$$

For example, the sibling ratio of 6-year-old fish in the 1993 brood year could be expressed in terms of the abundance of 6-year-old fish relative to 5-year-old fish in the same brood year or in terms of the abundance of 6-year-old fish relative to 4- and 5-year old fish in the same brood year:

$$\hat{r}_{1993,6} = \frac{\hat{N}_{1993,6}}{\hat{N}_{1993,5}} \mathit{or} \frac{\hat{N}_{1993,6}}{\hat{N}_{1993,4} + \hat{N}_{1993,5}} .$$

APPENDIX B. BAYESIAN STATISTICAL METHODS

A Ricker spawner-recruit function (Ricker 1975) was chosen to model the relationship between escapement and recruitment. Under the Ricker model, the total recruitment R from brood year *y* is:

$$R = S\,\alpha\,e^{-\beta S}\,e^{\varepsilon} \tag{B1.1}$$

where *S* is the number of spawners, α and β are parameters, and the $\{\varepsilon_y\}$ are normally distributed process errors with variance σ^2_{SR}. Parameter α is the number of recruits per spawner in the absence of density dependence and is a measure of the productivity of a stock. Parameter β is a measure of density dependence; the inverse of β is the number of spawners that produces the theoretical maximum return (S_{MAX}).

Equilibrium spawning abundance, in which the expected return $R = S$, is

$$S_{EQ} = \frac{\ln(\alpha')}{\beta} \tag{B1.2}$$

where $\ln(\alpha)$ is corrected for asymmetric lognormal process error (Hilborn and Walters 1992) as follows:

$$\ln(\alpha') = \ln(\alpha) + \frac{\sigma^2_{SR}}{2} \tag{B1.3}$$

Number of spawners leading to maximum sustained yield S_{MSY} is approximately (Hilborn 1985)

$$S_{MSY} \approx S_{EQ}\left(0.5 - 0.07\ln(\alpha')\right). \tag{B1.4}$$

The classical way to estimate the Ricker parameters is to linearize the Ricker relationship by dividing both sides of equation 1 by *S* and taking the natural logarithm, yielding:

$$\ln\frac{\mathrm{R}}{\mathrm{S}} = \ln(\alpha) - \beta\mathrm{S} + \varepsilon \tag{B1.5}$$

This streamlines parameter estimation, because the relationship can now be viewed as a simple linear regression (SLR) of ln(R/S) on S, in which the intercept is an estimate of $\ln(\alpha)$, the negative slope an estimate of β, and the mean squared error an estimate of the process error variance σ^2_{SR}.

The SLR approach requires that the usual assumptions of linear regression analysis be met, including that the independent variable (S) be measured without error. Small amounts of measurement error in S have little effect; however measurement error with coefficients of variation exceeding 20% can cause substantial bias in SLR estimates of S_{MSY}, as well as increased uncertainty which is not reflected in the classical estimates. We estimate that the measurement error (expressed as CV%) associated with annual Kenai River Chinook sonar estimates ranges from 22% to 52% (Appendix B2). Other shortcomings of the SLR approach are that it cannot account for serially correlated process error or incomplete brood years.

For these reasons we employed Markov Chain Monte Carlo (MCMC) methods, which are especially well-suited for modeling complex population and sampling processes. This enabled us to analyze the escapement and return data in the context of an age-structured Ricker spawner-recruit model in which measurement error, serially correlated process errors, and incomplete brood years are explicitly considered. We implemented the MCMC algorithms in WinBUGS (Gilks et al. 1994), which is a Bayesian software program. This methodology provides a more realistic assessment of uncertainty than is possible with classical statistical methods.

Bayesian statistical methods employ probability as a language to quantify uncertainty about model parameters. Knowledge existing about the parameters outside the framework of the experimental design 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 in the data. For similar analyses see Szarzi et al. (2007).

The Bayesian MCMC analysis considers all the data simultaneously in the context of the following "full-probability" statistical model. Returns of Chinook salmon originating from spawning escapement in brood years y = 1986 - 2002 are modeled as a Ricker stock-recruit function with autoregressive lognormal errors

$$\ln(\mathrm{R}_{\mathrm{y}}) = \ln(\mathrm{S}_{\mathrm{y}}) + \ln(\alpha) - \beta \mathrm{S}_{\mathrm{y}} + \phi \nu_{\mathrm{y}-1} + \varepsilon_{\mathrm{y}} \tag{B1.6}$$

where α and β are Ricker parameters, ϕ is the autoregressive coefficient, $\{\nu_{\mathrm{y}}\}$ are the model residuals

$$\nu_y = \ln(R_y) - \ln(S_y) - \ln(\alpha) + \beta S_y , \tag{B1.7}$$

and the $\{\varepsilon_{\mathrm{y}}\}$ are independently and normally distributed process errors with variance σ^2_{SR}.

Age proportion vectors $\underline{\boldsymbol{p}}_y = (p_{y4}, p_{y5}, p_{y6}, p_{y7})$ from brood year y returning at ages 4-7 are drawn from a common Dirichlet distribution (multivariate analogue of the beta). The Dirichlet is re-parameterized such that the usual parameters:

$$D_a = \pi_a D \tag{B1.8}$$

are written in terms of location (overall age proportions π_a) and inverse scale (D, which governs the inverse dispersion of the $\underline{\boldsymbol{p}}_y$ age proportion vectors among brood years). The maturity schedule was allowed to change once, between the 1990 and 1991 brood years.

The abundance N of age-a Chinook salmon in calendar year t (t = 1977-2006) is the product of the age proportion scalar p and the total return R from brood year $y = t\text{-}a$:

$$N_{ta} = R_{t-a}\, p_{t-a,a} \tag{B1.9}$$

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

$$N_{t\cdot} = \sum_a N_{ta} \tag{B1.10}$$

Inriver run at the sonar site is total abundance minus harvest below the sonar,

$$N_{It} = N_{t\cdot} - H_{Bt} \tag{B1.11}$$

where H_{Bt} is very small and considered known without error.

Spawning abundance during year *t* is:

$$S_t = N_{It} - H_{At} \tag{B1.12}$$

where H_{At} is the sport harvest above the sonar, which in turn is the product of the annual exploitation rate and inriver return:

$$H_{At} = \mu_{At} N_{It} . \tag{B1.13}$$

Spawning abundance yielding peak return S_{MAX} is calculated as the inverse of the Ricker β parameter. Equilibrium spawning abundance S_{EQ} and spawning abundance leading to maximum sustained yield S_{MSY} are obtained using equations B1.2 – B1.4, except that ln(α) is corrected for autoregression lag-1 (AR1) serial correlation as well as lognormal process error:

$$\ln(\alpha') = \ln(\alpha) + \frac{\sigma_{SR}^2}{2(1-\phi^2)} . \tag{B1.14}$$

Expected sustained yield at a specified escapement *S* is calculated by subtracting spawning escapement from the expected return, again incorporating corrections for lognormal process error and AR1 serial correlation:

$$SY = E[R] - S = Se^{\ln(\alpha') - \beta S} - S . \tag{B1.15}$$

Probability that a given level of escapement would produce average yields exceeding 90% of MSY was obtained by calculating the expected sustained yield (SY; Equation B1.15) at multiple incremental values of *S* (0 to 10,000) for each Monte Carlo sample, then comparing SY with 90% of the value of MSY for that sample. The proportion of samples in which SY exceeded 0.9 MSY is the desired probability.

Observed data include estimates of inriver abundance, estimates of harvest, and scale age counts. Likelihood functions for the data follow.

Estimated inriver abundance is modeled as:

$$N_{It} = N_{It} e^{\varepsilon_{Nt}} \tag{ B1.16}$$

where the $\{\varepsilon_{Nt}\}$ are normal $(0,\sigma^2_{Nt})$ with measurement error variance σ^2_{Nt}[8]. Estimates were obtained from mark-recapture methods in 1986 and 1987, and sonar thereafter.

Estimated sport harvest (1986–2006) is modeled as

$$\hat{H}_t = H_t e^{\varepsilon_{Ht}} \tag{B1.17}$$

where ε_{Ht} are normal $(0,\sigma^2_{Ht})$ with individual variances σ^2_{Ht} assumed known from creel survey and SWHS coefficients of variation.

---

[8] Annual estimates of variance were available for 1986 and 1987 mark recapture estimates. Sonar measurement errors in 1988-2006 were drawn from a common variance.

Numbers of fish sampled for scales (n) that were classified as age-*a* in calendar year *t* (x_{ta}) are multinomially (r_{ta},n) distributed, with proportion parameters as follows:

$$r_{ta} = \frac{N_{ta}}{N_{t\cdot}} \qquad \text{(B1.18)}$$

Bayesian analyses require that prior probability distributions be specified for all unknowns in the model. Non-informative priors (chosen to have a minimal effect on the posterior) were used almost exclusively. Initial returns R_{1979}-R_{1985} (those with no linked spawner abundance) were modeled as drawn from a common lognormal distribution with median μ_{LOGR} and variance σ^2_{LOGR}. Normal priors with mean zero, very large variances, and constrained to be positive, were used for ln(α) and β (Millar 2002), as well as for μ_{LOGR}. The initial model residual ν_0 was given a normal prior with mean zero and variance $\sigma^2_{SR}/(1-\phi^2)$. Diffuse conjugate inverse gamma priors were used for σ^2_{SR}, and σ^2_{LOGR}. The common measurement error variance for sonar estimates of inriver abundance (σ^2_N for 1988-2006) was given an informative inverse gamma(10.5,0.5) prior distribution, based on fitting a linear relationship between 12 published annual sonar estimates and experimental mixture model estimates based on echo length measurements (Appendix B2, Fleischman and Burwen 2003, Miller et al. 2007). Sport fishery exploitation rates $\{\mu_{At}\}$ were given a beta (1,1) prior distribution.

Markov-chain Monte Carlo samples were drawn from the joint posterior probability distribution of all unknowns in the model. For each of two Markov chains initialized, a 4,000-sample burn-in period was discarded, thinning by a factor of 10 was initiated, and 25,000 additional updates were generated. The resulting total of 50,000 samples was used to estimate the marginal posterior means, standard deviations, and percentiles. The diagnostic tools of WinBUGS assessed mixing and convergence, and no major problems were encountered. Interval estimates were obtained from the percentiles of the posterior distribution.

Appendix B2.–Quantification of sonar measurement error.

The Alaska Department of Fish and Game is actively engaged in development of improved sonar methodology for estimating the inriver return of Kenai River Chinook salmon. These efforts include development of statistical mixture models for analysis of echo length data measured by the split-beam sonar (Burwen et al. 2003; Fleischman and Burwen 2003). Ultimately, these efforts will culminate in revised historical (after 2001) abundance estimates for the early and late runs. Such estimates are not yet finalized, but we have preliminary versions of these quantities that we can compare with the published estimates of Chinook salmon abundance.

These preliminary mixture-model estimates of historical abundance are likely to change, perhaps substantially, upon further analysis[9]. However these quantities, having come from a consistent and superior methodology, are useful for modeling the degree to which the published estimates may have deviated from true abundance. Published estimates for the early and late run from 2002 to 2007 are plotted versus preliminary mixture model estimates in Appendix Figure B2.1.

We modeled the mixture model estimates as being equal to true abundance N but corrupted by known multiplicative lognormal error with standard deviation equal to the estimated coefficient of variation of the estimates (standard error divided by the point estimate).

The published estimates were modeled as a multiple of the true abundance (qN), where q is equal to the slope of the relationship between Y and X in Appendix Figure B2.1. Published estimates are also subject to multiplicative lognormal error, but with a common standard deviation σ.

A Bayesian MCMC approach was used to quantify uncertainty about the model parameters. Non-informative priors were specified. WinBUGS code, as well as selected percentiles of the posterior distribution for q and σ (Appendix Table B2.1), are shown below.

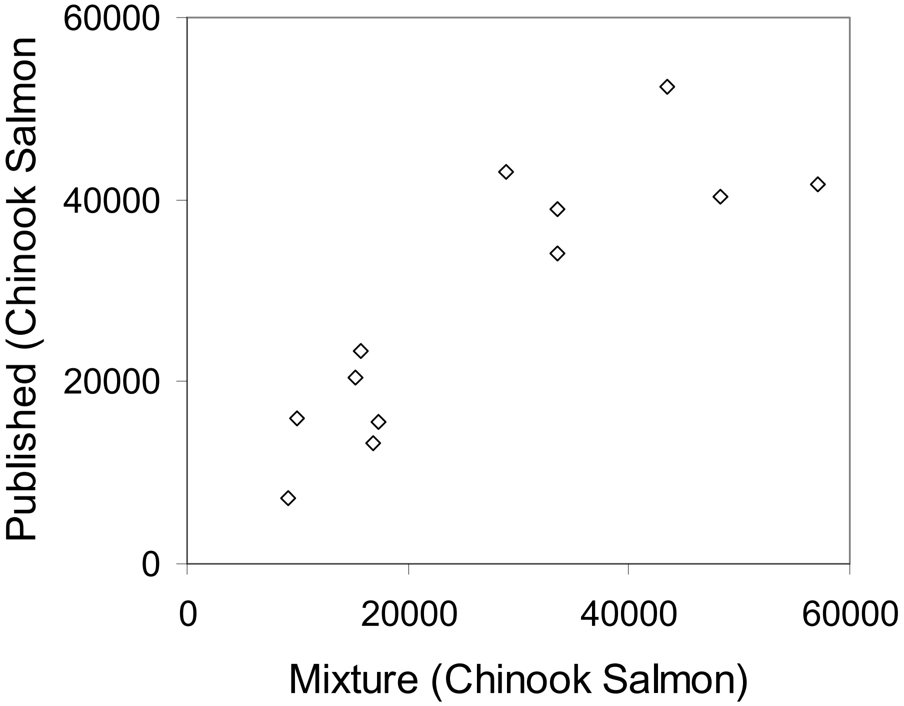
```
model {
 log.q ~ dnorm(0,1.0E-4)
 tau ~ dgamma(0.1,0.1)
 sigma <- sqrt(1/tau)
 q <- exp(log.q)
 for(y in 1:12) {
   N[y] ~ dnorm(0,1.0E-12)I(0,)
   Mixture.Model[y] ~ dlnorm(log.N[y],tau.MM[y])
   Published.Sonar[y] ~ dlnorm(log.qN[y],tau)
   log.qN[y] <- log.q + log.N[y]
   log.N[y] <- log(N[y])
   tau.MM[y] <- 1 / MM.cv[y] / MM.cv[y]
  }
 }
```

---

[9] For this reason we do not reproduce the actual numbers here.

Appendix Table B2.1.–Posterior means, standard deviations, and percentiles from Bayesian model of sonar measurement error.

	Mean	Standard deviation	2.5 percentile	Median	97.5 percentile
q (ratio of published to mixture estimates)	1.08	0.11	0.88	1.07	1.31
sigma (measurement error coefficient of variation for published estimates)	0.332	0.079	0.217	0.318	0.523



Appendix Figure B2.1.–Published estimates of early and late inriver runs of Kenai River Chinook salmon plotted against preliminary echo length mixture model estimates, 2002-2007.

Appendix B3.–WinBUGS code for Bayesian age-structured spawner-recruit analysis. Prior distributions are italicized; sampling distributions of the data are underlined.

```
model {
#  RICKER STOCK-RECRUIT RELATIONSHIP WITH AR1 ERRORS;
#  R[y] IS THE TOTAL RETURN FROM BROOD YEAR y
#  THERE ARE A TOTAL OF Y+A-1 = 22 + 4 - 1 = 25 BROOD YRS REPRESENTED IN
DATA+FORECAST
#  THE FIRST A+a.min-1 = 7 DO NOT HAVE CORRESPONDING SPAWNING ABUNDANCES
#  THE REMAINING Y-a.min = 18 DO (BROOD YEARS A+a.min=8 - 25)

  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]
    }
  log.R.mean2[A+a.min] <- log.R.mean1[A+a.min] + phi * log.resid.0
  for (y in A+a.min+1:Y+A-1) {
    log.R.mean2[y] <- log.R.mean1[y] + phi * log.resid[y-1]
    }
  lnalpha ~ dnorm(0,1.0E-6)I(0,)
  beta ~ dnorm(0,1.0E-1)I(0,)
  phi ~ dnorm(0,1.0E-4)I(-1,1)
  tau.white ~ dgamma(0.01,0.01)
  log.resid.0 ~ dnorm(0,tau.red)I(-3,3)
  alpha <- exp(lnalpha)
  tau.red <- tau.white * (1-phi*phi)
  sigma.white <- 1 / sqrt(tau.white)
  sigma.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)

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

#  DIRICHLET GENERATION OF RETURNS AT AGE CHANGING BETWEEN BY 12 AND 13
#  GENERATE ALL Y+A-1 = 25 MATURITY SCHEDULES, USE ONLY THOSE NECESSARY
  D1.scale ~ dunif(0,1)
  D2.scale ~ dunif(0,1)
  D1.sum <- 1 / (D1.scale * D1.scale)
  D2.sum <- 1 / (D2.scale * D2.scale)
  pi[1,1] ~ dbeta(1,1)
  pi[2,1] ~ dbeta(1,1)
  pi1.2p ~ dbeta(1,1)
  pi2.2p ~ dbeta(1,1)
  pi1.3p ~ dbeta(1,1)
  pi2.3p ~ dbeta(1,1)
  pi[1,2] <- pi1.2p * (1 - pi[1,1])
```

```
  pi[2,2] <- pi2.2p * (1 - pi[2,1])
  pi[1,3] <- pi1.3p * (1 - pi[1,1] - pi[1,2])
  pi[2,3] <- pi2.3p * (1 - pi[2,1] - pi[2,2])
  pi[1,4] <- 1 - pi[1,1] - pi[1,2] - pi[1,3]
  pi[2,4] <- 1 - pi[2,1] - pi[2,2] - pi[2,3]
for (a in 1:A) {
  gamma1[a] <- D1.sum * pi[1,a]
  gamma2[a] <- D2.sum * pi[2,a]
  for (y in 1:12) {
     g1[y,a] ~ dgamma(gamma1[a],1)
     p[y,a] <- g1[y,a]/sum(g1[y,])
    }
  for (y in 13:Y+A-1) {
     g2[y,a] ~ dgamma(gamma2[a],1)
     p[y,a] <- g2[y,a]/sum(g2[y,])
    }
  }
for (a in 2:A) {
  sibratio[1,a] <- pi[1,a] / pi[1,a-1]
  sibratio[2,a] <- pi[2,a] / pi[2,a-1]
  }

# ASSIGN PRODUCT OF P AND R TO ALL CELLS IN N MATRIX
# y SUBSCRIPT INDEXES BROOD YEAR
# y=1 IS THE BROOD YEAR OF THE OLDEST FISH IN YEAR 1 (upper right cell)
# y=25 IS THE BROOD YEAR OF THE YOUNGEST FISH IN YEAR Y (lower left cell)
# FIRST DO INITIAL CELLS WITHOUT SR LINK (x's IN MATRIX ABOVE)
# THEN DO CELLS DESCENDING WITH SR LINK (y's IN MATRIX)

for (y in 4:a.max)  {  N.ta[y-3,1] <- p[y,1] * R.lag[y]  }    # COLUMN 1
for (y in 3:a.max)  {  N.ta[y-2,2] <- p[y,2] * R.lag[y]  }    # COLUMN 2
for (y in 2:a.max)  {  N.ta[y-1,3] <- p[y,3] * R.lag[y]  }    # COLUMN 3
for (y in 1:a.max)  {  N.ta[y   ,4] <- p[y,4] * R.lag[y]  }    # COLUMN A=4

for (y in a.max+1:Y+3)   {  N.ta[y-3,1] <- p[y,1] * R[y]  }
for (y in a.max+1:Y+2)   {  N.ta[y-2,2] <- p[y,2] * R[y]  }
for (y in a.max+1:Y+1)   {  N.ta[y-1,3] <- p[y,3] * R[y]  }
for (y in a.max+1:Y)     {  N.ta[y  ,4] <- p[y,4] * R[y]  }

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

# APPLY (SMALL, KNOWN) HARVEST BELOW SONAR TO GET INRIVER RETURN
# HARVEST ABOVE SONAR IS ESTIMATED, AND CAN BE LARGE
for (y in 1:Y) {
  Inriver.Return[y] <- max(N[y] - Hhat.below[y],1)
  log.IR[y] <- log(Inriver.Return[y])
  IR.hat[y] ~ dlnorm(log.IR[y],tau.log.IR[y])
```

```
  S[y] <- max(Inriver.Return[y] - H.above[y],1)
  mu.Habove[y] ~ dbeta(1,1)
  H.above[y] <- mu.Habove[y] * Inriver.Return[y]
  log.Ha[y] <- log(H.above[y])
  tau.log.Ha[y] <- 1 / Harvest.cv[y] / Harvest.cv[y]
  Hhat.above[y] ~ dlnorm(log.Ha[y],tau.log.Ha[y])
  }

# 1986-1987: ESTIMATE INRIVER RETURN WITH MARK RECAP
# 1988-PRESENT:  ESTIMATE INRIVER RETURN WITH SONAR
# CV OF SONAR-ESTIMATED INRIVER RETURN HAS PRIOR BASED ON ELSD
# MIXTURE ESTIMATES (Measurement Error in IR thru 2007.ODC)
for (y in 1:2) { tau.log.IR[y] <- 1 / MarkRecap.cv[y] / MarkRecap.cv[y]  }
for (y in 3:Y) { tau.log.IR[y] ~ dgamma(10.5,0.5)}

# GENERATE FITTED VALUES OF R EVERY 1000 SPAWNING FISH FOR GRAPHICS;
for (i in 1:25) {
  S.star.1[i] <- 1000*i
  R.fit[i] <- S.star.1[i] * exp(lnalpha - beta * S.star.1[i])
  }
# CALCULATE SUSTAINED YIELD AT REGULAR INTERVALS OF S;
# FIND THE PROBABILITY THAT EACH VALUE OF S WILL RESULT IN YIELDS WITHIN 10% OF
MSC;
R.msy <- S.msy * exp(lnalpha - beta * S.msy)*exp(sigma.red*sigma.red/2)
MSY <- R.msy - S.msy
for (i in 1:100) {
  S.star.2[i] <- 200*i
  R.fit2[i] <- S.star.2[i] * exp(lnalpha - beta * S.star.2[i])*exp(sigma.red*sigma.red/2)
  SY[i] <- R.fit2[i] - S.star.2[i]
  I90[i] <- step(SY[i] - 0.9 * MSY)
  }
 SY.5300 <- 5300 * exp(lnalpha - beta * 5300)*exp(sigma.red*sigma.red/2) - 5300
 SY.4579 <- 4579 * exp(lnalpha - beta * 4579)*exp(sigma.red*sigma.red/2) - 4579
 SY.gain <- SY.4579 - SY.5300
}
```

Appendix B4.–Data for Bayesian age-structured spawner-recruit analysis.

```
list( Y=22, A=4, a.min=4, a.max=7,
x = structure(.Data =c(
208     ,       565     ,       464     ,       107     ,
15      ,       376     ,       561     ,       26      ,
14      ,       124     ,       561     ,       84      ,
29      ,       108     ,       496     ,       66      ,
34      ,       125     ,       281     ,       30      ,
17      ,       52      ,       151     ,       12      ,
20      ,       70      ,       143     ,       13      ,
13      ,       93      ,       211     ,       12      ,
16      ,       92      ,       324     ,       22      ,
11      ,       46      ,       157     ,       11      ,
26      ,       95      ,       203     ,       7       ,
16      ,       132     ,       227     ,       4       ,
54      ,       105     ,       117     ,       9       ,
26      ,       174     ,       123     ,       1       ,
21      ,       99      ,       106     ,       1       ,
34      ,       55      ,       105     ,       4       ,
50      ,       118     ,       127     ,       11      ,
230     ,       144     ,       342     ,       7       ,
52      ,       118     ,       165     ,       15      ,
45      ,       111     ,       193     ,       13      ,
77      ,       49      ,       115     ,       9       ,
0,0,0,0
),.Dim = c(22, 4)),
IR.hat=c(27080,25643,20880,17992,10768,10939,10087,19669,18403,21884,
23505,14963,13103,25666,12479,16676,7162,13325,15498,20450,23326,NA),
MarkRecap.cv=c(0.36,0.23),
Hhat.below=c(0,0,0,73,40,2,73,118,56,37,14,141,122,114,124,198,64,46,89,76,75,0),
Hhat.above=c(
8398,13863,15549,8543,2185,2097,2477,9628,8456,10574,
6910,6778,1424,8390,2003,2603,977,3228,3643,4063,4898,1),
Harvest.cv=c(
0.06,0.07,0.05,0.06,0.12,0.11,0.09,0.05,0.05,0.05,
0.06,0.10,0.14,0.06,0.12,0.09,0.15,0.09,0.11,0.10,0.03,0.08)
)
```

APPENDIX C. TOTAL RETURN BY AGE CLASS

Appendix C1.–Estimates of the early-run Kenai River Chinook salmon total return by age class, 1986–2006.

	Age class																
Year	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
1986																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	15.5	42.0	34.5	7.8	0.0	0.0	0.0	0.0	0.1	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	1.0	1.3	1.3	0.7	0.0	0.0	0.0	0.0	0.1	0.0	0.0	
Total return	0	0	0	0	0	4,191	11,384	9,349	2,116	0	0	0	0	40	0	0	27,080
SE total return	0	0	0	0	0	1,537	4,133	3,399	788	0	0	0	0	30	0	0	9,799
1987																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	1.5	38.4	57.3	2.2	0.0	0.0	0.0	0.1	0.4	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	0.4	1.6	1.6	0.5	0.0	0.0	0.0	0.1	0.2	0.0	0.0	
Total return	0	0	0	0	0	393	9,859	14,683	577	0	0	0	26	105	0	0	25,643
SE total return	0	0	0	0	0	134	2,312	3,417	178	0	0	0	26	56	0	0	5,928
1988																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	1.8	15.8	71.3	10.7	0.3	0.0	0.0	0.1	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	0.5	1.3	1.6	1.1	0.2	0.0	0.0	0.1	0.0	0.0	0.0	
Total return	0	0	0	0	0	373	3,302	14,888	2,237	53	0	0	27	0	0	0	20,880
SE total return	0	0	0	0	0	99	281	465	236	38	0	0	27	0	0	0	449
1989																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	4.1	15.5	71.0	9.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	0.8	1.4	1.7	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	0	0	0	0	749	2,791	12,819	1,706	0	0	0	0	0	0	0	18,065
SE total return	0	0	0	0	0	137	254	415	203	0	0	0	0	0	0	0	389
1990																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	7.2	26.6	59.8	6.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	1.2	2.0	2.3	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	0	0	0	0	782	2,874	6,462	690	0	0	0	0	0	0	0	10,808
SE total return	0	0	0	0	0	130	230	284	123	0	0	0	0	0	0	0	242
1991																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	7.3	22.4	65.1	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	1.7	2.7	3.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	0	0	0	0	802	2,452	7,121	566	0	0	0	0	0	0	0	10,941
SE total return	0	0	0	0	0	189	306	385	160	0	0	0	0	0	0	0	269
1992																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	8.1	28.5	58.1	5.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	1.7	2.9	3.2	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	0	0	0	0	826	2,891	5,906	537	0	0	0	0	0	0	0	10,160
SE total return	0	0	0	0	0	179	302	353	146	0	0	0	0	0	0	0	255
1993																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	4.0	28.0	63.2	3.6	0.0	0.0	0.3	0.9	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	1.1	2.5	2.7	1.0	0.0	0.0	0.3	0.5	0.0	0.0	0.0	
Total return	0	0	0	0	0	782	5,533	12,510	722	0	0	60	180	0	0	0	19,787

-continued-

Appendix C1.–Page 2 of 2.

	Age class															
Year	0.2	0.3	0.4	0.5	1.1	1.2	1.3	1.4	1.5	1.6	2.1	2.2	2.3	2.4	2.5	2.6	All
1998																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	18.9	36.8	41.1	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	2.3	2.9	2.9	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	0	0	0	0	2,506	4,872	5,429	418	0	0	0	0	0	0	0	13,225
SE total return	0	0	0	0	0	311	388	397	137	0	0	0	0	0	0	0	230
1999																	
Inriver return %	0.0	0.0	0.0	0.0	0.0	8.0	53.7	37.7	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.0	1.5	2.8	2.7	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	
Total return	0	0	0	0	0	2,069	13,845	9,707	80	0	0	0	80	0	0	0	25,780
SE total return	0	0	0	0	0	391	742	709	80	0	0	0	80	0	0	0	370
2000																	
Inriver return %	0.0	0.8	0.3	0.0	0.0	8.4	43.4	46.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.5	0.3	0.0	0.0	2.1	3.5	3.5	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	104	35	0	0	1,056	5,471	5,865	73	0	0	0	0	0	0	0	12,603
SE total return	0	59	35	0	0	261	452	452	73	0	0	0	0	0	0	0	234
2001																	
Inriver return %	0.0	1.0	0.0	0.0	0.0	16.2	27.8	53.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.7	0.0	0.0	0.0	2.6	3.2	3.6	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	170	0	0	0	2,727	4,687	8,948	341	0	0	0	0	0	0	0	16,874
SE total return	0	120	0	0	0	445	544	619	169	0	0	0	0	0	0	0	285
2002																	
Inriver return %	0.7	0.0	0.0	0.0	2.9	15.7	37.3	39.5	3.6	0.0	0.0	0.0	0.3	0.0	0.0	0.0	100.0
SE %	0.5	0.0	0.0	0.0	1.0	2.1	2.8	2.8	1.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	
Total return	47	0	0	0	213	1,133	2,692	2,857	260	0	0	0	24	0	0	0	7,226
SE total return	33	0	0	0	70	153	210	213	77	0	0	0	24	0	0	0	169
2003																	
Inriver return %	0.0	0.1	0.0	0.0	1.0	31.4	19.8	46.8	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.1	0.0	0.0	0.4	1.7	1.5	1.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	18	0	0	129	4,192	2,641	6,261	129	0	0	0	0	0	0	0	13,371
SE total return	0	18	0	0	49	239	202	265	49	0	0	0	0	0	0	0	199
2004																	
Inriver return %	0.0	0.0	0.0	0.0	0.9	14.8	33.3	46.4	4.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.5	1.9	2.5	2.7	1.1	0.0	0.0	0.0	0.3	0.0	0.0	0.0	
Total return	0	0	0	0	133	2,309	5,196	7,238	666	0	0	0	44	0	0	0	15,587
SE total return	0	0	0	0	77	298	402	433	169	0	0	0	44	0	0	0	261
2005																	
Inriver return %	0.0	0.0	0.0	0.0	1.1	12.4	30.2	52.8	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.7	2.0	2.7	2.9	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Total return	0	0	0	0	233	2,541	6,196	10,829	726	0	0	0	0	0	0	0	20,526
SE total return	0	0	0	0	134	404	557	610	223	0	0	0	0	0	0	0	295
2006																	
Inriver return %	0.0	0.0	0.0	0.0	0.8	30.6	19.4	45.1	3.7	0.0	0.0	0.0	0.4	0.0	0.0	0.0	100.0
SE %	0.0	0.0	0.0	0.0	0.6	2.9	2.5	3.1	1.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	
Total return	0	0	0	0	196	7,150	4,540	10,552	865	0	0	0	98	0	0	0	23,401
SE total return	0	0	0	0	138	690	591	750	284	0	0	0	98	0	0	0	394