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A Qualitative Evaluation of Parameters Used to Assess Kenai River King Salmon, 1986–2010

by

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and

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

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Weights and measures (metric)	
centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

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

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

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

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

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

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A QUALITATIVE EVALUATION OF PARAMETERS USED TO ASSESS KENAI RIVER KING SALMON, 1986–2010

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EXECUTIVE SUMMARY

- Two populations of king salmon return to the Kenai River to spawn. The first population, composed of king salmon bound for tributaries of the Kenai River (tributary spawners), enter the river from late April through early July. The second population, composed of king salmon that spawn in the Kenai River itself (mainstem spawners), enter the river from late June through mid August.
- Kenai River king salmon are managed as two stocks (early run and late run). A comprehensive stock assessment program using multiple assessment parameters drives the implementation of management plans for both stocks. Each of the stock assessment parameters has error associated with it.
- The assessment of inriver run size contributes considerably more error for both runs than any other parameter used for assessing Kenai River king salmon stocks. Inriver run size estimates are produced with split-beam sonar, which does not accurately differentiate king salmon from more numerous sockeye salmon. A critical concern is the inability of the split-beam sonar to consistently detect smaller than average runs.
- Two other sources of error associated with Kenai River king salmon stock assessment that are important and need to be addressed are:
    - Actual harvest of Kenai River king salmon in the Cook Inlet commercial Eastside setnet (ESSN) fishery is unknown. All reported king salmon harvest in the ESSN fishery is attributed to the Kenai River late run, while the harvest is also composed of Kasilof River king salmon and, possibly, other stocks.
    - The timing and overlap between the tributary and mainstem spawning populations are not consistent with a management cutoff date of July 1 to delineate the early and late run stocks, thereby introducing multiple sources of error in accounting for each population.
- Current studies are being conducted to address the largest sources of error associated with Kenai River king salmon assessment. These studies include: (1) the testing of DIDSON (dual frequency identification sonar) for assessing inriver run size, and (2) the use of genetic stock identification (GSI) techniques as a tool for improving assessment of stock-specific harvest estimates, and run timing and productivity of tributary and mainstem spawning fish.
    - DIDSON has been tested on the Kenai River at the current sonar location and can differentiate king salmon from other species more accurately than Split-beam sonar. Although some issues with this new technology are still being resolved, future transition from the current split-beam sonar to DIDSON should reduce the amount of error associated with inriver run-size estimates.
    - Collection of GSI information will improve understanding of the overlap in run timing and harvest of Kenai River tributary and mainstem populations, and harvest estimates in mixed-stock fisheries such as the ESSN fishery. In addition, GSI information collected inriver may provide estimates of annual abundance that are independent of sonar estimates and can be used to evaluate biases that may exist in the sonar estimates.

INTRODUCTION

Two populations of Chinook salmon *Oncorhynchus tshawytscha* (hereafter referred to as king salmon) return to the Kenai River (Figure 1) to spawn, both of which are highly prized by anglers for their size, relative to other king salmon stocks (Roni and Quinn 1995). A major inriver sport fishery occurs here and anglers expend in excess of 300,000 days annually fishing for the prized salmon (Jennings et al. 2010a). King salmon bound for tributaries of the Kenai River (tributary spawners) enter the river from late April through early July while king salmon that spawn in the Kenai River itself (mainstem spawners) enter the river from late June through mid August (Burger et al. 1985; Bendock and Alexandersdottir 1992).

Kenai River king salmon are currently managed as two stocks (early run and late run) based on a calendar date. King salmon entering the river prior to July 1 are classified as early-run fish whereas king salmon entering the river on July 1 or later are classified as late-run fish. Management of each stock is directed by management plans established by the Board of Fisheries (5 AAC 56.070, *Kenai River and Kasilof River Early-Run King Salmon Conservation Management Plan* and 5 AAC 21.359, *Kenai River Late-Run King Salmon Management Plan*).

A comprehensive stock assessment program using creel surveys, harvest sampling, inriver gillnetting, and estimation with sonar of inriver run size drives the implementation of management plans for these stocks (McKinley and Fleischman 2010a-b). Objectives of the stock assessment program are to: (1) model inriver run and fishery mortality to manage the fisheries inseason, and (2) develop brood tables for long-term stock assessment and escapement goal analyses.

Kenai River king salmon stock assessment is complex. In total, there are 24 stock parameters used to assess Kenai River king salmon, all of which are used to assess the late run and only 14 of which are used to assess the early run (Table 1). Ten parameters are estimated directly by active sampling, reported harvest, or from the Statewide Harvest Survey (SWHS). The remaining 14 parameters are estimated indirectly by using information from parameters that were estimated directly.

Inriver run size has been estimated with sonar since 1987 and has undergone several modifications as sonar technology has advanced. Currently, run size is estimated with split-beam sonar that relies on the loudness of the returning echo (target strength) and distance from the face of the transducer (range) to differentiate between king salmon and smaller, more abundant sockeye salmon.

Harvest of Kenai River king salmon occurs in several Upper Cook Inlet (UCI) fisheries including: (1) an inriver sport fishery, (2) commercial set and drift gillnet fisheries in Cook Inlet that harvest king salmon while primarily targeting sockeye salmon, (3) a marine sport fishery along the eastern shore of Cook Inlet from Anchor Point to Cape Ninilchik, (4) a shore- and boat-based personal use dip net fishery in the lowest 5 miles of the Kenai River that harvests king salmon incidentally while targeting sockeye salmon, and (5) several educational fisheries near river mouths with very small king salmon quotas.

Corresponding Kenai River king salmon harvest and age and sex compositions are estimated for each of the mentioned fisheries, and are delineated by the early and late runs. Age composition estimates are required to reconstruct the return of fish originating from individual annual spawning events (brood years). Reconstructed brood year returns are then used to create brood tables to evaluate stock productivity and develop escapement goals. For Kenai River king salmon stock assessment, age composition information is collected (sampled directly) from the most important parameters. Age compositions of parameters that are not sampled directly are estimated from those that are directly sampled.

The objective of this report is to provide an informative summary of the parameters used to assess Kenai River king salmon and to identify known or potential sources of error associated with each parameter. Sources of error for each parameter are then evaluated for relative importance in assessing run size. In addition, a brief description is given on how important sources of error associated with parameters are being addressed. This report provides a qualitative evaluation of stock assessment parameters and is not intended as a comprehensive evaluation of management precision of Kenai River king salmon.

AN EVALUATION OF STOCK ASSESSMENT PARAMETERS

COOK INLET MARINE SPORT HARVEST

The Cook Inlet marine sport fishery harvests king salmon that migrate along the eastern shore of central Cook Inlet during April through early August (Begich 2010). Most fishing occurs from boats within 3 miles of shore between Bluff Point and Deep Creek (approximately 30 miles). Three conservation zones encompassing stream mouths (Ninilchik River, Deep Creek, Anchor River, and Stariski Creek) within the fishery are closed to fishing for all species from April 1 through June 30. Commercial operators provide beach launching and take-out service at Deep Creek and Anchor Point making it possible to use large boats and launch all boats at most tide stages. Historically, angler effort has been dependent on local weather conditions. As a result, adverse weather has, on occasion, limited fishing to as little as 30% of the available fishing days in which king salmon are present (Szarzi et al. 2010).

King salmon harvest in this fishery is currently estimated postseason with the Statewide Harvest Survey. King salmon harvested prior to June 25 are classified as early run and those harvested from June 25 or later are classified as late run. The number of Kenai River king salmon harvested in this fishery is unknown.

There are many king salmon stocks in Cook Inlet (e.g. Kenai River, Anchor River, Ninilchik River, Crooked Creek, Deep Creek, Stariski Creek, Anchorage area, and Susitna River stocks) that return in May and June and are susceptible to harvest in the early-run Cook Inlet marine fishery, whereas few known stocks (i.e. Kenai River and Kasilof River) return in July and are susceptible to harvest in the late-run Cook Inlet marine fishery.

Early Run

The early-run fishery is managed for a guideline harvest level (GHL) of 8,000 king salmon (5 AAC 58.055, *Upper Cook Inlet Salt Water Early-run King Salmon Management Plan*). From 1986 through 2009, annual harvest in the Cook Inlet early-run marine sport fishery has averaged 4,602 king salmon, ranging from 1,415 fish in 2009 to 8,230 fish in 1995 (Table 2). From 1996 through 2002, approximately 40% of the harvest of early-run marine sport fishery was sampled by the Alaska Department of Fish and Game (ADF&G) to estimate contributions of coded wire tagged king salmon stocks which included tagged Kenai River king salmon (McKinley 1999; Begich 2007; Begich 2010). Efforts to estimate the number of Kenai River king salmon harvested in this fishery were unsuccessful due to insufficient numbers of recovered tags. However, sampling results confirmed the harvest is comprised of numerous Cook Inlet and non-Cook Inlet (Southeast Alaska, British Columbia, Washington, and Oregon) stocks with low levels of stock-specific exploitation, suggesting that less than 10% of the harvest is of Kenai River king salmon (Begich 2010).

At this magnitude of harvest, the Cook Inlet marine sport fishery would account for less than 3% of the Kenai River early run, on average. For this reason, none of the Cook Inlet marine sport harvest is currently attributed to the Kenai River early run, introducing a negative, but inconsequential bias, to the estimate of the total run.

Late Run

Total king salmon harvest in the Cook Inlet marine sport fishery is considerably smaller in the late run than the early run. On average (1986–2009), 1,353 fish were harvested annually in the late run, ranging from 200 fish in 2003 to 2,931 fish in 1997 (Table 3). Late-run harvest has declined overall since 1999, averaging 801 fish (1999–2009), compared to the pre-1999 average of 1,819 fish (1986–1998).

All king salmon harvested in the Cook Inlet late-run marine sport fishery are counted towards the Kenai River late-run stock assessment. Consequently, harvest estimates of late-run Kenai River king salmon in this fishery are likely to be positively biased (overestimated) because other stocks (e.g., Kasilof River) are harvested and contributory harvests by river of origin (stock) are not known. However, again, the bias is small. The fishery only accounts for an average of 2% of total Kenai River late-run estimates annually, ranging from less than 1% in 2003 to 5.4% in 1997. The percentage has not exceeded 2% since 1998.

Sampling the Cook Inlet marine sport fishery for stock-specific harvest information using genetics would be informative. However, considering that exploitation of Kenai River king salmon from this fishery is estimated to be low (less than 5%), sampling the fishery solely to address harvest of Kenai River king salmon would likely not be cost-effective at this time.

Age Composition of Early- and Late-run Cook Inlet Marine Sport Harvest

None of the harvest in the early-run Cook Inlet marine sport fishery is currently counted towards the Kenai River early run, so an age composition estimate is currently not necessary. If the early-run Cook Inlet marine sport fishery is sampled in the future for genetic stock identification, age composition data will also be collected.

Because all king salmon harvested in the late-run Cook Inlet marine sport fishery are counted towards the Kenai River late run, estimates of harvest by age are necessary. Age composition data was last collected in the Cook Inlet late-run marine sport fishery in 1986 (McKinley and Fleischman 2010a). From 1983 through 1986, age composition was not significantly different from the late-run Kenai River sport harvest (Sonnichsen and Alexandersdottir 1991). Therefore, for years after 1986, age composition of the late-run Kenai River sport harvest has been used as a surrogate for age composition of the late-run Cook Inlet marine sport harvest.

King salmon harvest in the late-run Cook Inlet marine sport fishery is small. Even large differences between estimated and actual composition by age would have negligible effects on run size estimates, the brood table, and escapement goals.

COMMERCIAL EASTSIDE SETNET (ESSN) HARVEST

The ESSN fishery occurs along the eastern shore of Cook Inlet between Ninilchik and Boulder Point (Shields 2010). The ESSN fishery is divided into 3 sections (Kenai, Kasilof and East Forelands). The Kasilof section is open from June 25 through August 15; however, if 50,000 sockeye salmon are estimated to have entered the Kasilof River before June 25, the season may begin as early as June 20. The Kenai and East Forelands Sections are open from July 8 through August 15. Regular fishing periods are Mondays and Thursdays from 7:00 a.m. to 7:00 p.m.

Commercial harvest data comes from sales receipts, referred to as fish tickets. To estimate king salmon harvest, each fish is individually counted and recorded. Because all king salmon are actually counted and not subsampled, king salmon harvest in the Cook Inlet commercial fishery is considered measured without error. Harvest estimates are reported annually by ADF&G Division of Commercial Fisheries (CF) (Shields 2010).

Stock-specific harvest of king salmon in the ESSN fishery is unknown. All king salmon are counted towards the Kenai River late-run stock assessment, although there are other stocks (e.g. Kasilof River) in the harvest. Consequently, harvest estimates of late-run Kenai River king salmon in the ESSN commercial fishery are positively biased to an unknown degree. King salmon harvest in the ESSN fishery is considered to comprise a large percentage of the overall Kenai River king salmon late run, compared to most other sources of harvest. Annual king salmon ESSN harvests have ranged from 3,684 fish in 2000 to 21,625 fish in 2004, averaging 11,225 fish since 1986 (Table 3). ESSN harvest accounts for an average of 19% of the Kenai River late run, ranging from 7% in 2000 to 30% in 2005 (Table 4; Figure 2).

Accurately estimating the number and proportion of Kenai River king salmon harvested in the ESSN commercial fishery is important in assessing run size. Sampling the harvest for genetic stock identification (GSI) is warranted for this fishery (See GSI Studies below). Other sources of error in the harvest estimate include non-reporting and dropouts. Non-reporting occurs when king salmon are harvested but are not reported to ADF&G. By regulation, all harvested salmon sold in the commercial fishery must be reported to ADF&G (5 ACC 39.130), even fish retained but not sold (5 ACC 21.355). The degree to which nonreporting of harvested king salmon occurs is unknown. The high price garnered for king salmon compared to other species is further incentive for commercial harvesters to sell the harvest and not retain king salmon for personal use. Some fish are killed, fall out of gillnets, and are not harvested, and these are termed "drop outs." The degree to which drop outs occur is also unknown. Those fish killed by the ESSN fishery and not harvested, or harvested and not reported, would count toward total run size estimates of Kenai River king salmon.

Age and Sex Composition of the Commercial ESSN Harvest

Age and sex information are collected from harvested ESSN king salmon at processors or buying stations along the eastern shore of Cook Inlet. ADF&G personnel opportunistically rove amongst processors and buying stations to collect samples. The percentage of the harvest that was sampled ranged from 3% to 31%, averaging 13% since 1987. The proportion of harvest that is sampled each year is primarily dependent on the magnitude of ESSN king salmon harvest. Higher harvest numbers usually result in a lower proportion of the harvest sampled and vice versa. Only regularly scheduled fishing periods are sampled. Fishing periods opened by emergency order are not sampled.

Sources of error in age and sex composition estimates could include non-representative sampling, sex estimation inaccuracies, and differences between the age and sex compositions of the sampled mixed stock harvest and the true harvest of Kenai River king salmon. To collect a representative sample of the harvest, samples are collected at each location without any known selectivity. Emergency order periods are not sampled, but it is unlikely that age and sex composition during those periods differ greatly from that of regular periods. Additional sampling during emergency order openings would probably not be cost-effective. A larger source of error occurs because some king salmon are incorrectly attributed to the Kenai River late run. Additionally, estimating sex of sea-bright king salmon accurately from external characteristics is problematic with fish aged 1.1 and 1.2, so sex of fish less than 28 inches have been determined via internal visual examination in recent years. Sex estimation of fish larger than 28 inches via external examination is considered accurate. Ageing error is considered minor.

Commercial Upper Cook Inlet Central District Driftnet (CDD) Harvest

The CDD fishery occurs in Cook Inlet north of Anchor Point to Boulder Point from mid to late June through mid August (Shields 2010).

The CDD harvest is reported directly to ADF&G with fish tickets. All king salmon are individually counted so harvest is considered measured without error. The king salmon harvest is not sampled by ADF&G. All king salmon harvested in the CDD fishery are attributed to the Kenai River late run even though fish from other stocks (e.g., Kasilof River) are harvested. The CDD king salmon harvest is small relative to Kenai river run size. Annual harvests have averaged 919 fish since 1986, ranging from zero fish in 1989 (due to the Exxon Valdez oil spill) to 4,561 fish in 1987 (Table 3). Even though estimates of Kenai River king salmon harvest in the CDD fishery are positively biased because not all harvest is of Kenai River fish, CDD harvests account for on average only 2% of the Kenai River late run, with the highest estimated percentage of 6% in 1987 (Table 4; Figure 2).

To the degree that other stocks are harvested in the CDD fishery, or that the reporting is inaccurate, error is introduced into the estimate of the total run of late-run Kenai River king salmon. However, such errors are inconsequential due to the very low numbers of harvested king salmon in this fishery. It would not be cost-effective to sample the CDD king salmon harvest for GSI at this time.

Age and Sex Composition of the CDD Harvest

CDD king salmon harvest is not sampled for age and sex composition. The estimated age and sex composition of ESSN king salmon harvest is used as a surrogate for age and sex composition of CDD Kenai River king salmon harvest. Due to differences in gillnet web material, net deployment, and area fished between the fisheries, the actual age composition of the CDD harvest is likely of smaller, younger fish, but because harvest is small relative to run size, it would not be cost-effective to sample the CDD king salmon harvest directly.

Educational Harvest and Associated Age and Sex Composition

Several educational fishery permits are granted in Upper Cook Inlet. The Kenaitze Indian Tribe, Kasilof Regional Historical Association, Alaska Territorial Lodge, Ninilchik Tribal Council, and

Ninilchik Native Descendents each have permits to harvest salmon, mostly using short 10-fathom gillnets. Permittees have allowable salmon quotas and are mostly allowed to fish on eastern Cook Inlet beaches adjacent to local river mouths or in lower reaches of the rivers. All educational harvest is reported directly to ADF&G postseason. King salmon quotas are small. Annual king salmon harvests have ranged from 2 fish in 1998 to 646 fish in 1995, and have averaged 101 fish (Table 3). All king salmon harvest occurring north of Ninilchik River is attributed to Kenai River stocks. King salmon reported as harvested prior to July 1 are attributed to the early run and fish harvested on July 1 or later are attributed to the late run. Age and sex composition of the ESSN king salmon harvest is used as a surrogate for age and sex composition of the educational harvest of Kenai River king salmon. Due to the small harvest, any inaccuracies in either the harvest estimate or age and sex compositions would be inconsequential to Kenai River run size estimates and brood tables.

Kenai River Personal Use (PU) Dip Net Harvest

The Kenai River PU dip net fishery in its current form began in 1996. The fishery occurs from the markers located approximately 1 mile from the Kenai River mouth (on either beach) and inriver from the river mouth upstream to the Warren Ames Bridge (river mile [RM] 8.0). Most often, king salmon are caught incidentally while harvesters are targeting more abundant sockeye salmon. Participants in the PU dip net fishery are required to return a harvest record to ADF&G after the season closes. Total harvest is estimated by expanding the reported harvest on returned permits by the number of nonreturned permits. Since 1996, estimated annual king salmon harvests have ranged from 45 fish in 1996 to 1,509 fish in 2007, and have averaged 748 fish (Table 3). The fishery occurs during the last 22 days of July (July 10–31), so all harvest is considered to be of the Kenai River late run. The fishery has not harvested more than 3% of the Kenai River late run in any year (Table 4).

Possible sources of error in the harvest estimate include inaccurate reporting and whether or not permit holders who did not return permits harvested more or less king salmon, on average, than what is reported on returned permits. King salmon (especially small ones) could sometimes be misidentified as more abundant sockeye or coho salmon, or harvest could just be reported inaccurately. However, species misidentification and inaccurate reporting are not considered major sources of error. Approximately 86% of permits are returned each year (Dunker 2010, Dunker and Lafferty 2007, Reimer and Sigurdsson 2004) and the expansion to estimate harvest from nonreturned permits is small. Total king salmon harvest estimates are precise; relative precision of total harvest estimates are generally less than 1%. Overall, error associated with estimating king salmon harvest in this fishery is minimal and no changes are recommended to this aspect of the assessment.

Age and Sex Composition of the PU Dip Net Harvest

The PU dip net harvest is not directly sampled. The estimated age and sex composition of the ESSN harvest is used as a surrogate for the age and sex composition of the Kenai River king salmon PU dip net harvest. Although the true age and sex composition of the harvest may be different than estimated, any inaccuracies in age and sex composition estimation would not be large enough to significantly affect run size estimates, the brood table, or escapement goals. Consequently, sampling the PU dip net king salmon harvest directly would not be cost-effective.

INRIVER RUN

The inriver run of king salmon is estimated using split-beam sonar located at RM 8.6. Three estimates of inriver run are currently produced from split-beam sonar: (1) a target strength (TS-based) estimate; (2) an echo length standard deviation (ELSD-based) estimate; and (3) a net-apportioned estimate (Table 5). All three estimates are used for inseason assessment, but only the TS-based estimate is used for evaluating escapement goals.

Sources of error associated with estimating fish passage using sonar include target (fish) detection, target (fish) tracking, temporal (time) sampling and expansion, and species (king salmon vs. other) classification.

Target detection refers to the ability of the sonar to detect fish (targets) as they pass the sonar site. Errors associated with target detection include: (1) fish that swim upriver outside (behind/inshore of, offshore of, above, or below) the sonar beam; and (2) fish that swim within the sonar beam, but are not detected by the sonar. Target detection errors result in a negative bias (underestimation of fish passage).

Target tracking is the process of identifying and following (tracking) individual targets through the sonar beam. There are four potential sources of error associated with target tracking: (1) incorrectly classifying a group of fish as one fish; (2) incorrectly classifying one fish as more than one fish; (3) incorrectly determining direction of travel (upstream or downstream); and (4) incorrectly classifying non-fish targets (i.e. seals or debris) as fish. Target tracking errors can result in positive or negative bias.

Target tracking can be especially problematic when fish are not committed to upstream migration and swim multi-directionally within the sonar beam. Such milling behavior can introduce bias in either direction depending on whether the milling fish swim up or down river within or outside of the sonar beam. However, studies conducted by Eggers et al. (1995) found milling behavior at the RM 8.6 sonar site to be minimal and to have little effect on the king salmon passage estimates. Also, from 1995 through 2006, less than 6% of the total number of tracked targets were classified as moving downstream (Burwen and Bosch 1996, 1998; Bosch and Burwen 1999, 2000; Miller et al. 2002-2005, 2007a-b, 2010; Miller and Burwen 2002), indicating that most fish passing the king salmon sonar are committed to upstream migration.

Regarding *temporal sampling*, normal dates of operation for the king salmon sonar project are May 16 through August 10. The total passage estimates would be negatively biased by any king salmon passing before or after these dates. Of greatest concern is the number of king salmon missed at the end of the run after the sonar is done counting for the season. This problem can be exacerbated when the project terminates early (prior to August 10) due to tracking difficulties associated with pink salmon in even-numbered years. Early project termination has occurred 5 of the past 24 years of operation due to numerous pink salmon "holding" in the sonar beam, making it difficult to accurately track fish targets. A lesser concern is the fish that are missed early in the season, prior to when the sonar begins counting on May 16. In most years, passage estimates are low (less than 100 fish per day on average) during the first few days of sonar deployment. A study in 1998 investigating the number of fish missed prior to normal dates of operation found 1.4% of the early run in 1998 passed the sonar between May 7 and May 16 (Bosch and Burwen 2000).

Temporal expansion refers to using passage estimates during sampled times to estimate passage during unsampled periods of time to produce total passage estimates. Currently, sampling occurs for 20 consecutive minutes every hour from each bank. Error from temporal expansion would be introduced if the fish passage during sampled times was not representative of fish passage during unsampled times. Error due to temporal expansion is considered negligible based on a study conducted at the sonar site in 1999 that found no significant difference between estimates generated with full 1-hour samples and those generated with 20-minute samples (Miller et al. 2002).

S*pecies classification* refers to the process of classifying fish targets as king salmon or other species. In the Kenai River, sockeye salmon are far more abundant than king salmon and overlap with king salmon in size and migratory timing. Thus, error due to species classification has the potential to be very large. In addition, error due to species classification differs depending on the number and behavior of sockeye salmon present, whereas errors due to target detection and tracking are more likely to be consistent over time. For these reasons, species classification errors are of greater concern than are other errors associated with sonar estimation of fish passage. The direction and magnitude of bias associated with species classification depend on the type of estimator used, as discussed in the appropriate sections below.

Split-beam Target Strength (TS-based) Sonar Estimates (used inseason and for escapement goals)

The TS-based estimate was developed in the mid 1980s using dual-beam sonar technology. The first TS-based estimates were produced in 1987. Split-beam sonar replaced dual-beam sonar in 1995; TS-based estimates have been produced using split-beam sonar ever since. The TS-based estimator classifies species based on two parameters: (1) acoustic size of the fish target (i.e., loudness of returning echoes), and (2) location (distance from the transducer) of the target in the sonar beam (referred to as a range threshold). In addition, hourly samples that contain large numbers of tightly grouped targets (assumed to be sockeye salmon) are not used to estimate passage (referred to as sample censoring). Sample censoring has been used since 2002. Initial research indicated that target strength and range (distance from the sonar transducer) could be used to distinguish sockeye salmon from king salmon (Eggers et al. 1995). Further research indicated that neither of these species discriminators is effective (Eggers 1994, Burwen et al. 1998). TS-based estimates are highly sensitive to fish behavior, sonar transducer aim, and sonar equipment calibration. Range thresholds have been only partially effective at accurately eliminating sockeye salmon from passage estimates (Burwen et al. 1998) and the thresholds are subjective to implement. Sample censoring has reduced the probability of overestimating king salmon passage due to misclassifying sockeye salmon as king salmon, but is also subjective to implement. The TS-based method cannot accurately discriminate between king salmon and sockeye salmon resulting in positively biased estimates and the magnitude of bias is inconsistent. Comparison with other sonar-based indices (see the following two sections) suggests that the TS-based estimates have become less accurate in recent years, especially during the early run (Table 6; Figure 3). The biggest concern is the inability of the TS-based method to consistently detect smaller than average runs so that management actions can be appropriately implemented.

Split-beam Echo Length Standard Deviation (ELSD-based) Sonar Estimates (used inseason only)

The split-beam ELSD-based estimate was first developed in 2002, based on work initiated in the mid 1990s that revealed echo length standard deviation is a better predictor of fish size than target strength (Burwen and Fleischman 1998; Burwen et al. 2003). The ELSD-based estimate discriminates based on the variability in echo length (duration of the returning echo) between species and is considered to be more accurate than the TS-based estimate, although there is still potential for positive bias. ELSD-based estimates of inriver run are generally lower than TS-based estimates, especially during the early run (Figure 3).

With regard to species classification, ELSD-based estimates have several advantages over the TS-based estimates:

- ELSD is a better predictor of fish size than TS (Burwen et al. 2003).
- ELSD is based on echo length (duration of the sound) rather than on echo amplitude (loudness of the sound); consequently, estimates are not sensitive to equipment calibration errors. A preseason calibration error in 2005 resulted in an inseason TS-based positively biased estimate (Miller et al. 2007b).
- ELSD-based estimates are less subjective than TS-based estimates. There is no subjective selection of range thresholds nor are there samples to censor.
- ELSD-based estimates are generally less sensitive to king salmon size distribution, because a mixture model (Miller et al. 2010) is used to differentiate species rather than a threshold.

Split-beam Net-apportioned Sonar (used inseason only)

The split-beam net-apportioned estimate was first developed in 2002 in conjunction with major revisions to the inriver gillnetting program (see the following section on *age and sex composition of the inriver run* for description of the gillnetting program). The net-apportioned estimate is produced by multiplying the proportion of total fish caught in the inriver gillnetting program that are king salmon by the total (all species) upstream fish passage estimate produced from split-beam sonar.

With regard to species classification, net-apportioned estimates are independent of issues associated with classifying species based on sonar alone and are subject to a different set of concerns and potential sources of error. Accurate species apportionment from inriver gillnetting rests on assumptions related to spatial and temporal sampling, as well as capture efficiency with respect to fish size (size selectivity). These sources of error are discussed in more detail in the following section (*age and sex composition of the inriver run*). Error resulting from spatial sampling, temporal sampling, and size selectivity could result in both positive and negative biases in estimating king salmon passage. Size selectivity has likely been adequately addressed by careful selection of mesh sizes (see following section). Net-apportioned estimates are also sensitive to other factors that affect the probability of capture in gillnets. These include tide cycle (neap versus spring tide sequences), river discharge, and turbidity. The amount of error associated with these factors is unknown and is a topic of current and future research.

Age and Sex Composition of the Inriver Run

Age and sex composition of each run is estimated directly with the inriver gillnetting program by collecting and ageing scale samples and estimating sex from captured king salmon. Gillnets are drifted downstream with the river current beginning directly downstream of the sonar and for approximately 0.3 RM. The project runs annually from May 16 through August 10 to encompass the operating dates of the king salmon sonar program. Sampling goals are consistently met for each run to estimate age and sex composition.

The inriver gillnetting project is highly standardized. The project was initially standardized in 1998. Most modifications to further standardize the project and capture a representative sample of passing fish occurred in 2002. Gillnets of 2 mesh sizes (5.0 and 7.5 inch stretched mesh) are currently used to reduce capture selectivity due to fish size (prior to 2002, only 7.5 inch stretched mesh was used). Overall, capture selectivity due to fish size is not considered a major source of error, but gillnets are likely less efficient at capturing very small and very large fish compared to other sizes. The degree to which reduced capture efficiency occurs for very large or very small fish is unknown. In order to spread effort evenly within the sampling area, gillnets are alternately deployed from the north and south river banks on successive drifts. Gillnetting is only conducted within the cross-sectional area of the river insonified by the king salmon sonar (middle 40 m of the river). King salmon do migrate upstream near each bank and some fish do not enter the sampling area. The relative size and age composition of those fish that migrate near the bank compared to those within the sampling area is unknown. Due to tidal constraints, sampling occurs during a fixed portion of the tide cycle from 1 hour after a high tide to approximately 1 hour after the following low tide (Eskelin 2010). This portion of the tide is sampled in an attempt to maximize interception of all fish species passing the sonar yet ensuring downstream current, thereby allowing the net to be fished effectively. It is assumed the age and sex composition of fish sampled during the netting period is representative of the remainder of the day. Testing this assumption is likely not necessary because the assumption is probably not grossly violated. There are king salmon that enter the river and pass the sonar location prior to May 16 and after August 10; however, as previously stated, probably in very low numbers. Ageing and sex estimation inaccuracies are both considered to be minor.

Accurately estimating the age and sex composition of the inriver run is an important aspect of Kenai River king salmon stock assessment. As mentioned, there are many potential sources of error in age and sex composition estimates; however, the magnitude of error is considered to be small.

SPORT CATCH, HARVEST, AND ANGLER EFFORT BELOW THE SOLDOTNA BRIDGE

The inriver sport fishery below the Soldotna Bridge is sampled to provide catch and harvest estimates from the Warren Ames Bridge to the sonar and from the sonar to the Soldotna Bridge. The sport fishery below the Soldotna Bridge is the predominate source of harvest in the early run. Since 1986, harvests have ranged from 376 fish in 2002 to 11,949 fish in 1988, averaging 3,769 fish (Table 7). The sport fishery below the Soldotna Bridge has harvested an average of 20% of the early run since 1986, ranging from 5% in 1998 and 2002 to 57% in 1988 (Table 8; Figure 4).

The inriver sport fishery below the Soldotna Bridge (below sonar and sonar to bridge) also harvests a large component of the late run. Since 1986, annual harvest has averaged 10,443 fish, ranging from 5,375 fish in 2010 to 16,435 fish in 1988 (calculated from Table 3). On average, 19% of the total late run is harvested by the sport fishery below the Soldotna Bridge, ranging from 10% in 1986 to 32% in 2001 (calculated from Table 4; Figure 2).

Sport catch, harvest, and effort are estimated with an onsite creel survey. Angler effort, measured in hours fished, is estimated by conducting regular, periodic angler counts, and averaging counts by day. Only anglers observed actively fishing are counted. The catch rate (catch per hour) and harvest rate (harvest per hour) are estimated from interviewing anglers as they exit the fishery at several public boat launches. Catch rates and harvest rates are then multiplied by angler effort to estimate catch and harvest. All estimates are stratified by guided and unguided anglers, and upstream and downstream of the king salmon sonar. Sampling is conducted 4 days out of every week and estimates are expanded for days not sampled. Sufficient samples are usually collected for each run to satisfy predetermined sampling goals. During the early run, approximately 1,110 angler interviews are conducted and about 100 valid age samples are collected. During the late run, approximately 1,800 angler interviews are conducted and about 275 valid age samples are collected.

Unguided anglers have been allowed to fish from drift boats on Mondays during the late run since 1999 and during the early run since 2003. The Monday drift boat fishery has continued to expand since its inception. Mid-day angler counts have been as high as 551 but there are usually less than 300 anglers in the late run and less than 100 anglers in the early run. Mondays during the early run have not been sampled. Mondays during the late run have been sampled periodically and an index estimation method has been developed to track this portion of the fishery during years that Mondays are not directly sampled.

Onsite Creel Survey, Statewide Harvest Survey (SWHS), and Guide Logbook Comparison

Actual catch and harvest that occurs in the sport fishery below the Soldotna Bridge is unknown; however, creel survey estimates can be compared to SWHS estimates. Guide logbook data, collected since 2006, allow for additional comparisons.

Estimates of early-run harvest from guided anglers were similar for the creel survey and SWHS, and guide logbook data was similar to both estimates for 2 of 4 years that logbook data are available (Figure 5). In the late run, creel survey harvest estimates were consistently larger than SWHS estimates and logbook data, which were similar for 3 of 4 years (Figure 6). For early-run unguided harvest, creel survey estimates were consistently smaller than SWHS estimates (Figure 7). For late-run unguided harvest, creel survey estimates were similar to SWHS estimates through 2006 (Figure 8). Since 2006, SWHS estimates have been consistently larger than creel survey estimates.

For guided catch, creel survey estimates and logbook data were similar during both runs for all 4 years (2006–2009) (Figures 9 and 10). For unguided catch, creel survey estimates have been consistently smaller than SWHS estimates for both runs (Figures 11 and 12).

The largest discrepancies between the three estimators were for early-run unguided harvest, late-run guided harvest, and unguided catch for both runs. For early-run unguided harvest and unguided catch (both runs), creel survey estimates were consistently lower than SWHS estimates. For late-run guided harvest, creel survey estimates were consistently higher than both SWHS estimates and logbook data.

Sources of Error

There are several potential sources of error with the onsite creel survey. To be accurate, anglers who are interviewed must be representative of the fishery as a whole. Sufficient numbers of angler interviews are usually collected to satisfy predetermined sampling goals; however, only public boat launches and a couple of privately-owned locations are used as interview locations. Anglers that use private launches or moorings, such as landowners along the river or those who moor their boats at private locations, are rarely interviewed. If interviewed anglers are less successful on average than those who are not interviewed, creel survey estimates could be negatively biased (underestimated) which could partially explain why SWHS estimates were consistently larger than creel survey estimates for unguided anglers. Inaccurate reporting could influence estimates of catch but likely does not influence harvest estimates because boats are visually inspected for fish at interview sites and all harvested fish observed are sampled.

In the creel survey, the unguided angler-day is defined as a 20 hour period from 4:00 AM until midnight. Sampling does not occur between midnight and 4:00 AM (or later depending on when the first boat count is conducted for the day). Any fishing that occurs during that time is not part of the sample and negatively biases the creel survey estimates. Some fishing does occur during this time, although usually in low numbers. Also, any anglers that exit the fishery prior to the time when interviews begin are not counted towards catch and harvest rates. Anglers are interviewed beginning sometime between about 5:00 a.m. and 9:00 a.m. depending on when the first angler count is conducted for that day. The number of interviews conducted is usually low during the first portion of a sampling shift. In addition, the expansion that occurs to account for unsampled days could introduce error into catch and harvest estimates, although any biases would not be systematically positive or negative. Sampling additional days would likely not be cost-effective.

At times, ADF&G personnel have had difficulties interviewing all anglers exiting the fishery at a sampling location. It takes more time to interview anglers with harvested fish, so if any selectivity in interviewing occurs, it would likely be towards successful anglers. This would only occur when boat launches are very busy. Selectivity toward successful anglers would positively bias catch and harvest estimates and could partly explain why late-run guided harvest estimates from the creel survey are consistently larger than SWHS estimates and logbook data.

Another source of error is the portion of the sport fishery occurring on Mondays. Estimates on Mondays are not included in seasonal totals during years that Mondays are not directly sampled. About 100-200 fish are estimated to be harvested in the early run and about 200-500 fish are estimated to be harvested in the late run. Harvest estimates on Mondays below the Soldotna Bridge have never exceeded about 5% of total early- or late-run harvest estimates below the Soldotna Bridge. Periodic recalibration of the index estimation method will be necessary to track this portion of the fishery. A recalibration was done in 2009 and 2010. Although this is still a growing fishery, it does not account for a large portion of the inriver sport harvest of either run.

The factors discussed above can cause both positive and negative biases to catch and harvest estimates and to some degree are compensatory. To account for escapement, harvest estimates are most important, so any biases in estimating catch are negligible compared to biases in estimating harvest. Differences from creel survey estimates with SWHS and guide logbook data do indicate that the creel survey harvest estimates could be negatively biased, especially for unguided anglers, and may underestimate harvest. However, the magnitude of the bias is probably not enough to significantly affect escapement estimates, the brood table, or escapement goals. Major modifications to the onsite creel survey are not necessary at this time.

Age and Sex Composition of the Sport Fishery Harvest Below the Soldotna Bridge

Age samples from the harvest in this section of river are collected directly from the onsite creel survey. Potential sources of error in age composition estimation include collection of a representative sample of the harvest, collection of sufficient numbers of samples to produce statistically valid estimates, and scale reading (ageing) error. Scale samples are collected from every harvested king salmon during the course of interviewing anglers, so there is no selectivity from sampling harvested fish in that regard. However, if interviews are not collected representatively, age and sex composition estimates could be biased. Since 2002, an average of 114 and 279 age samples were collected in the early and late runs, more than adequate to satisfy predetermined sampling goals. Scale ageing and sex determination error is considered minor. Overall, age and sex compositions of harvested fish below the Soldotna Bridge are considered to be relatively accurate and do not warrant further investigation.

Inriver Sport Fishery Harvest Below the King Salmon Sonar

Inriver sport fishery harvest below the king salmon sonar is a component of the below Soldotna Bridge harvest and is estimated with the onsite creel survey. Nearly all harvest below the king salmon sonar occurs during the late run. Very few anglers are observed fishing below the king salmon sonar during the early run. Records of sport fishery harvest below the sonar have been compiled since 1999. Harvest in this area steadily increased to a high of 3,332 fish in 2006 but has averaged approximately 1,100 fish from 2007 to 2010 (Table 3). In 2006, estimated sport harvest below the sonar accounted for about 6% of the total Kenai River late run; however, the average for all years is between 1% and 2% (Table 4; Figure 2).

Sources of error include all previously mentioned sources of error in estimating the harvest below the Soldotna Bridge. In addition, the harvest rate above the king salmon sonar is assumed to be equal to the harvest rate below the sonar. Although the catch rate is observed, anecdotally, to be higher at times downstream of the king salmon sonar, harvest rates for each area likely balance out throughout the season as the catch rate in this tidal area can be sporadic. Past attempts at estimating fishing catch and harvest rates above and below the sonar from interviewing anglers as they exited the fishery were unsuccessful (Marsh 2000). Most anglers that fished below the sonar also fished above the sonar during the course of the fishing day. Recalling the time spent in each location was difficult for anglers and some anglers were unaware of the king salmon sonar location.

Although estimates of harvest in the sport fishery below the king salmon sonar could be biased, resulting errors from any bias are likely small because of the limited amount of harvest occurring in this area. Further attempts to improve accuracy of the estimate are not warranted, considering harvest downstream of the king salmon sonar is small compared to run size. The sport fishery below the sonar will continue to be monitored with the onsite creel survey using the current study design.

Age and Sex Composition of the Sport Fishery Harvest Below the King Salmon Sonar

Age and sex composition of sport fishery harvest below the king salmon sonar is assumed to be the same as the age and sex composition of sport fishery harvest below the Soldotna Bridge. This assumption has not been tested; however, any differences between estimated age and sex compositions and the true age and sex compositions would be inconsequential to total run size estimates and brood tables.

SPORT CATCH AND HARVEST ABOVE THE SOLDOTNA BRIDGE

Sport catch and harvest above the Soldotna Bridge has been estimated with the SWHS since 1996, whereas data from onsite creel surveys were used to estimate catch and harvest prior to 1996. Estimates are stratified into early and late runs. Most harvest above the Soldotna Bridge (RM 21.1) occurs downstream of the Moose River confluence (RM 36.3). A minimal amount of harvest occurs between the Moose River confluence and the outlet of Skilak Lake. Sport fishing for king salmon is not allowed above the outlet of Skilak Lake (RM 50.0).

Historically, catch and harvest above the Soldotna Bridge has been small compared to that below the Soldotna Bridge. In addition, since 2003, the slot limit has been in effect above the Soldotna Bridge until July 15 whereas the slot limit is rescinded July 1 downstream of the Soldotna Bridge. On average (1986–2010), early-run harvest above the Soldotna Bridge has accounted for 34% of total inriver early-run sport harvest (calculated from data in Table 7), ranging from 17% in 1987 to 60% in 1990. Late-run harvest above the Soldotna Bridge accounts for an average of 17% of total inriver late-run sport harvest (calculated from data in Table 3), ranging from 9% in 2000 to 27% in 1996.

Harvest above the Soldotna Bridge during the late run is larger than the early run. However, early-run harvest above the Soldotna Bridge is generally a larger proportion of the total early run than late-run harvest is of the total late run. Early-run harvest above the Soldotna Bridge has averaged 1,512 fish since 1986, ranging from 522 fish in 1998 to 3,449 fish in 1994 (Table 7);, whereas in the late run, the average harvest is 2,184 fish, ranging from 876 fish in 1992 to 3,449 fish in 1994 (Table 3). The early-run sport fishery above the Soldotna Bridge has, on average, harvested 9% of the total early run, ranging from 4% in 1998 to 19% in 1994 (Table 8; Figure 4). Whereas, in the late run, the average is 4% of the total late run, ranging from 2% in 1986, 1992 and 2002 to 6% in 2000 and 2001 (Table 4; Figure 2).

Incorrectly apportioning harvest by run is likely the largest source of error with these estimates. This is especially true with the sport fishery harvest above the Soldotna Bridge. It is likely that some king salmon that enter the river prior to July 1, and therefore considered early-run fish, are harvested in July above the Soldotna Bridge and are subtracted from the late-run escapement estimates. Correcting harvest apportionment by run is important and should be mostly resolved with genetic sampling (see GSI Studies below). Another source of error could be from inaccuracies in the SWHS estimates. The direction and magnitude of bias resulting from SWHS inaccuracies are unknown but not considered to be a large source of error. Further investigation into the accuracy of SWHS estimates of harvest in this section of river is currently not warranted.

Age Composition of Harvested Fish Above the Soldotna Bridge

The estimated age composition of harvested fish below the Soldotna Bridge (with the onsite creel survey) is used as a surrogate for the age composition of harvested fish above the Soldotna Bridge. Sport harvest upstream of the Soldotna Bridge has been sampled for age composition since 2007. Although there were slight differences between the above Soldotna Bridge and below Soldotna Bridge age composition estimates for the 4 years that sampling occurred above the Soldotna Bridge (2007–2010), only one year (2007) had a statistically significant difference in age composition. That is despite the slot limit in effect until July 15 above the Soldotna Bridge and the slot limit rescinded below the Soldotna Bridge on July 1. Any differences between the age composition estimate below Soldotna Bridge and actual age composition above the Soldotna Bridge are likely small and negligible to the brood table and escapement by age estimates.

CATCH-AND-RELEASE MORTALITY IN THE INRIVER SPORT FISHERY

The catch-and-release mortality rate for Kenai River king salmon was estimated in 1990 and 1991 (Bendock and Alexandersdottir 1992). The mean of the two annual estimates was 6.4% for the early run and 8.25% for the late run. To estimate catch-and-release mortality, those percentages are multiplied by the estimated number of king salmon caught and released for each run.

Regulations and angler fishing techniques and preferences have changed since the catch-and-release mortality study. The fishery in recent years has concentrated more in the intertidal area of the river which could increase the catch-and-release mortality rate if king salmon are more susceptible to handling-induced stress in tidally influenced areas than non-tidally influenced areas. Since 1999, multiple hooks have not been allowed in the fishery. Single hooks are often easier to remove from fish than are multiple hooks, so regulations that don't allow multiple hooks might lower the catch-and-release mortality rate. Also, in recent years, more anglers backtroll while fishing whereas drifting was a more common fishing technique when the catch-and-release study was conducted in the early 1990s. The effect that fishing techniques have on the catch-and-release mortality rate is unknown. However, catch-and-release mortality rates for fish that have been caught multiple times are likely higher than for fish that were caught and released only once and smaller fish that are caught and released are likely to have a higher mortality rate than larger fish that are caught and released (Bendock and Alexandersdottir 1992).

Potential effects on the catch-and-release mortality rate between the 1990s (when the catch-and-release mortality study was conducted) and present are both positive and negative (i.e., compensatory), so despite differences in the fishery between the early 1990s and now, the catch-and-release mortality rate is likely low and similar to what was previously estimated. Estimates of catch-and-release mortality have averaged 246 fish annually during the early run (Table 7). In the late run, catch-and-release mortality estimates have been as high as 1,803 fish in 2003, but have averaged 554 fish annually since 1986 (Table 3). Inriver catch-and-release mortality estimates only account for, on average, 2% of the early run and 1% of the late run (Tables 4 and 8). Further investigation into catch-and-release mortality estimates are not warranted because they are low compared to total run size.

Age Composition of Catch-and-release Mortality in the Inriver Sport Fishery

Catch-and-release mortality by age is estimated by applying age composition estimates of the inriver run (at the king salmon sonar) to estimates of catch-and-release mortality rates by run. The age composition of fish that were caught and released likely does not match the age composition of the inriver run, especially in the early run due to the slot limit regulation. For instance, since 2005, 26% of fish caught in the early-run sport fishery below the Soldotna Bridge (based on angler interviews) were reported as being within the slot limit, whereas 17% of the run (based on inriver gillnetting) was estimated to be within the slot limit. However, because catch-and-release mortality estimates account for such a small proportion (<2%) of each run, biases in estimating the associated age composition of catch-and-release mortality are inconsequential to total run size estimates, escapement by age estimates, and the brood table.

ESCAPEMENT

Escapement is estimated by subtracting all known inriver mortality estimates above the king salmon sonar from the estimated inriver run size at the king salmon sonar. Inriver mortality estimates come from the sport fishery harvest above the sonar and catch-and-release mortality estimates above the sonar.

Possible sources of error in escapement estimates include those previously mentioned in estimating inriver run size (at the king salmon sonar), the sport fishery harvest above the sonar, and catch-and-release mortality above the sonar. Error in estimating inriver run size contributes much more error to escapement estimates than all other sources.

Age Composition of the Escapement

Age composition of the escapement is estimated by subtracting inriver mortality estimates by age above the king salmon sonar from the estimated inriver run (at the king salmon sonar) by age. Sources of error include those previously mentioned in estimating escapement and age composition of the escapement. The inriver run is the most important aspect of estimating age composition of the escapement, followed by the sport harvest between the king salmon sonar and the Soldotna Bridge, then the sport harvest above the Soldotna Bridge, and lastly catch-and-release mortality by age.

TOTAL RUN SIZE

Total run size is estimated by adding estimates of mortality below the king salmon sonar (including estimated harvest in Cook Inlet) to the inriver run size estimate. Multiple sources of error arise from estimating total run size and include any previously mentioned sources of error from estimating inriver run size at the sonar and from estimating harvests in Cook Inlet (commercial and sport), personal use, educational, and the sport fishery below the sonar. Inriver run size estimates and late-run harvest estimates in Cook Inlet contribute the largest sources of error in estimating total run size.

Age Composition of Total Run

Age composition of the total run is estimated by adding estimates of mortality by age below the king salmon sonar (including estimated harvest in Cook Inlet) to the inriver run size estimate by age. Multiple sources of error arise from estimating total run size by age and include any previously mentioned sources of error from estimating inriver run size by age at the sonar and from estimating harvests by age in Cook Inlet (commercial and sport), personal use, educational, and the sport fishery below the sonar.

DISCUSSION

There are many parameters used to assess Kenai River king salmon stocks, all of which have an associated level of error. Most sources of error are relatively minor; however, some sources of error can have a large impact on stock assessment. Overall, assessment of age composition is more than adequate and age composition errors are minor. Escapement goal analyses are generally insensitive to minor age composition errors, therefore no improvements to age composition assessments are recommended at this time. Sources of error that have the greatest impact on the accuracy of Kenai River king salmon stock assessment are: (1) estimates of inriver run size produced with split-beam sonar using target strength (TS) and range thresholds for species discrimination, (2) that the timing and overlap between tributary and mainstem spawning populations do not align with a management cut-off date of July 1 to delineate the early and late runs, which creates inconsistencies in estimates of inriver run size and harvest by run, and (3) estimates of the number and proportion of Kenai River king salmon harvested in the commercial eastside setnet (ESSN) fishery.

ADDRESSING THE LARGEST SOURCE OF ERROR IN PARAMETER ESTIMATES

Split-beam sonar estimates of inriver run, and late-run harvest estimates in the ESSN fishery, contribute the greatest amount of error to the assessments of Kenai River king salmon. The inriver run comprises a large fraction of the total run. For this reason, error in inriver run estimates has a large effect on estimates of the proportion of total run harvested by each fishery and the overall assessment of stock abundance, productivity, and exploitation. Current research involving relatively new dual-frequency identification sonar (DIDSON) technology and genetic stock identification (GSI) techniques should help address the major sources of error associated with assessment of Kenai River king salmon.

Dual Frequency Identification Sonar (DIDSON) Studies

DIDSON is a high definition imaging sonar that provides video-like images of passing fish, first tested at the Kenai River king salmon sonar site in 2002. DIDSON discriminates between species based on size measurements from fish images. Studies using live tethered king and sockeye salmon confirmed a high correlation between DIDSON fish image length and true fish length (Burwen et al. 2007; Burwen et al. 2010), thereby providing improved species discrimination over split-beam sonar. DIDSON also provides improved target detection and tracking capabilities. The wider field of view and improved image quality provided by the DIDSON allows for improved ability to identify individual fish targets both near the face of the transducer and at far range, even during periods of high fish passage.

Although DIDSON appears promising as a key assessment tool for Kenai River king salmon, the following issues require further attention: (1) reduced image quality from silt load can occur in May; (2) the time required to manually measure fish images is excessive; (3) the sonar equipment is vulnerable to extreme tidal fluctuations and to large debris floating downriver; and (4) there may be between-measurer variability and data quality control issues. In 2010, degraded image quality was experienced resulting from heavy silt load caused by the first spring tides following ice-out. Additional data collection during the first few weeks of the season over the next few years should help determine what effect heavy silt load has on image quality and resulting fish measurements. Continued refinement of the image measurement process and a possible shift to an automated measurement program may reduce DIDSON data processing time, and thus allow for the production of daily passage estimates inseason. Moving the sonar upriver, out of tidal influence, and to a location allowing deployment of sonar transducers closer to the river bank to avoid the heavy currents and debris that occur offshore would be preferred. However, a good alternative location has not been found. Development of data quality control measures and investigation of between-measurer variability will continue in an attempt to reduce error associated with the image measurement process. Successful development of an automated measurement system may address some of this error.

Currently, DIDSON appears to be a better long-term solution to accurate monitoring of Kenai River king salmon inriver run size than pursuing other approaches using split-beam technology. Many technical and logistical challenges using DIDSON have been resolved, and those requiring further attention will continue to be addressed in the future. ADF&G will continue using the various split-beam estimators, in conjunction with and in comparison to DIDSON estimates, over the next few years. ADF&G also plans to conduct a marking study during the next few years to better understand the accuracy and consistency of DIDSON in estimating inriver run size.

Genetic Stock Identification (GSI) Studies

With GSI techniques, genetic material is extracted from collected tissue samples and used to estimate the stock composition of migrating or harvested salmon. The development of a genetic baseline database for Kenai River king salmon stocks (Begich et al. 2010; McKinley *Unpublished*[1]) has created new opportunities for potential improvements to Kenai River king salmon stock assessment.

For instance, the number and proportion of Kenai River king salmon harvested in the ESSN fishery can be estimated using GSI techniques. Tissue samples were collected from the ESSN fishery for the first time during the 2010 season and will likely be collected in the future. Tissue sampling of other mixed-stock fisheries such as the Cook Inlet marine sport fishery might be collected in the future as well, although the reason for such sampling would likely be to address mixed-stock harvest (i.e. harvest of many Cook Inlet stocks), not solely to address harvest of Kenai River king salmon.

GSI methodology has also created new opportunities to test assumptions regarding run timing and harvest of tributary-bound and mainstem-bound fish and to evaluate management strategies with respect to their effect on individual sub-stocks. For instance, a GSI study was initiated in 2007 to estimate the annual stock composition of mainstem-bound and tributary-bound king salmon harvested in the sport fishery above the Soldotna Bridge. Preliminary results indicate that: (1) most of the harvest in June is of tributary-bound fish, (2) the harvest in the first 2 weeks of July is nearly an equal mix of tributary- and mainstem-bound fish, and (3) nearly all of the harvest in the last 2 weeks in July is of mainstem-bound fish (McKinley *Unpublished*[1]).

Recently, it has also become possible to incorporate GSI data into comprehensive abundance and run-timing models (Bromaghin et al. 2010) and obtain stock-specific estimates of annual abundance. Even though individual annual estimates are imprecise using this methodology, the potential value of the genetic-based abundance estimates is that they are independent of the sonar

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[1] McKinley, T. *Unpublished*. Kenai River Chinook genetics baseline. Alaska Sustainable Salmon Fund project completion report, June 2010. Available from Alaska Department of Fish and Game, Soldotna.

and might provide a way to evaluate any bias that may exist in the sonar estimates. All of the data required to generate such abundance estimates have been collected annually since 2006 by existing research projects. Model development and analyses are ongoing.

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TABLES

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

Stock Parameter	Estimated for early (E) and/or late (L) runs	Estimated directly (D) or indirectly (I)[a]	How Estimated
Cook Inlet marine sport harvest	L	D	SWHS: Harvest after June 24 assumed Kenai River late run
Age/sex composition of Cook Inlet marine sport harvest	L	I	Age/sex composition of late run sport harvest below the Soldotna Bridge used as a surrogate
Commercial eastside setnet (ESSN) harvest	L	D	Commerical Fisheries Division fish ticket system - all harvest assumed Kenai River late run
Age/sex composition of commercial ESSN harvest	L	D	Collection of age/sex samples at processors and buying stations
Commercial Upper Cook Inlet central district drift net harvest (CDD)	L	D	Commerical Fisheries Division fish ticket system - all harvest assumed Kenai River late run
Age/sex composition of commercial CDD harvest	L	I	Age composition of ESSN harvest used as a surrogate
Educational and subsistence harvest	E and L	D	Reported directly to ADF&G
Age/sex composition of educational and subsistence harvest	E and L	I	Age compostion of inriver run used as a surrogate
Personal use dip net harvest in Kenai River	L	D	Expansion of harvest from harvest reported on returned PU permits
Age/sex composition of personal use (PU) dip net harvest	L	I	Age composition of ESSN harvest used as a surrogate
Sport harvest below sonar	L	D	Onsite creel survey
Age/sex composition of sport harvest below sonar	L	D	Collection of age samples in onsite creel survey
Inriver run	E and L	D	Sonar at river mile (RM) 8.6
Age composition of inriver run	E and L	D	Netting project near sonar site (RM 8.6)
Total run	E and L	I	Inriver run plus harvests before the sonar
Age composition of total run	E and L	I	Age composition of inriver run plus age composition of harvests before the sonar
Sport catch, harvest, and effort from sonar to the Soldotna Bridge	E and L	D	Onsite creel survey
Age composition of sport harvest sonar to the Soldotna Bridge	E and L	D	Age samples collected in onsite creel survey
Sport catch and harvest above the Soldotna Bridge	E and L	D	SWHS: Harvest prior to July 1 is early run; harvest on July 1 or later is late run
Age composition of sport harvest above the Soldotna Bridge	E and L	I	Age composition of sport harvest below the Soldotna Bridge used as a surrogate
Catch-and-release mortalities	E and L	I	Catch-and-release mortality rates from 1990 and 1991 ADF&G studies multiplied by the number of released fish
Age composition of catch-and-release mortalities	E and L	I	Age composition of inriver run used as a surrogate
Escapement	E and L	I	Subtraction of all known inriver mortalities above the sonar from the inriver run
Age composition of the escapement	E and L	I	Subtraction of all known inriver mortalities (by age) from the inriver run (by age)

[a] "Directly" is from active sampling, or reported harvest; "Indirectly" is with assumptions from directly estimated parameters.

Table 2.–Early-run Central Cook Inlet king salmon sport fishery harvest by boat anglers, 1986–2009.

Year	Early-run harvest
1986	2,888
1987	3,613
1988	4,243
1989	3,863
1990	4,694
1991	4,824
1992	5,996
1993	8,136
1994	6,850
1995	8,230
1996	4,702
1997	5,646
1998	5,783
1999	4,907
2000	4,773
2001	3,671
2002	3,368
2003	4,042
2004	3,880
2005	3,746
2006	5,035
2007	4,015
2008	2,137
2009	1,415
Average	4,602
Minimum	1,415
Maximum	8,230

Source: Szarzi et al. 2010, Table 9.

Table 3.–Summary of late-run Kenai River king salmon population data, 1986–2010.

Year	Cook Inlet marine sport harvest	Commercial East-side setnet harvest	Commercial drift gillnet harvest	Subsis./ educ. harvest	Kenai River personal use harvest	Sport harvest below sonar	Inriver run[a]	Total run	Sport harvest sonar to Sold. Bridge	Sport harvest above Sold. Bridge	Catch-and-release mortality	Spawning escapement
1986	630	19,824	1,834	ND	ND	ND	57,563	79,851	8,053	1,819	316	47,375
1987	1,218	21,159	4,561	ND	ND	ND	48,123	75,061	10,767	2,333	123	34,900
1988	1,487	12,859	2,237	ND	ND	ND	52,008	68,591	16,435	3,260	176	32,137
1989	1,368	10,914	0	22	ND	ND	29,035	41,339	8,008	1,683	88	19,256
1990	1,605	4,139	621	13	91	ND	33,474	39,943	5,813	1,084	69	26,508
1991	1,705	4,893	246	288	130	ND	34,614	41,876	6,849	1,054	16	26,695
1992	2,115	10,718	615	402	50	ND	30,314	44,214	6,680	876	234	22,524
1993	2,834	14,079	765	27	129	ND	51,991	69,825	15,279	2,496	478	33,738
1994	1,869	15,575	464	392	13	ND	53,474	71,787	14,388	3,449	572	35,065
1995	2,069	12,068	594	646	36	ND	44,336	59,749	10,125	2,484	472	31,255
1996	2,038	11,564	389	294	45	ND	39,356	53,686	5,680	2,128	337	31,211
1997	2,931	11,325	627	26	339	ND	39,622	54,870	9,863	2,419	570	26,770
1998	1,784	5,087	335	2	271	ND	34,878	42,357	5,713	1,534	595	27,036
1999	1,004	9,463	575	4	488	1,170	48,069	60,773	10,857	1,568	682	34,962
2000	1,052	3,684	270	6	410	831	44,517	50,770	11,234	3,157	499	29,627
2001	920	6,009	619	8	638	1,336	33,916	43,446	12,400	2,744	825	17,947
2002	427	9,478	415	6	606	1,929	41,807	54,668	9,554	1,124	665	30,464
2003	200	14,810	1,240	11	1,016	823	41,659	59,759	13,014	3,106	1,803	23,736
2004	1,660	21,625	1,095	10	792	2,386	56,205	83,773	12,108	2,881	1,019	40,197
2005	1,040	21,472	1,839	11	775	2,287	43,240	70,664	13,026	2,901	1,267	26,046
2006	938	8,691	1,051	11	1,034	3,322	37,743	52,790	9,868	2,621	830	24,424
2007	797	12,128	896	6	1,509	1,750	42,979	60,065	7,507	2,183	670	32,619
2008	517	6,409	295	15	1,362	1,011	34,641	44,250	8,262	1,866	370	24,143
2009	256	5,588	859	4	1,189	1,132	25,688	34,716	6,246	1,658	626	17,158
2010	[b]	7,059	539	21	[b]	445	52,934	[b]	4,930	[b]	[b]	[b]
Average	1,353	11,225	919	101	546	1,535	42,087	56,618	9,706	2,184	554	28,991
Minimum	200	3,684	0	2	13	445	25,688	34,716	4,930	876	16	17,158
Maximum	2,931	21,625	4,561	646	1,509	3,322	57,563	83,773	16,435	3,449	1,803	47,375

Note: ND = no data available

Sources: From 1986–2006, see McKinley and Fleischman 2010a. For 2007–2010 data see the following sources: Cook Inlet marine sport harvest, Szarzi et al. 2007, 2010; Commercial Eastside setnet and drift gillnet harvest, Shields 2010, personal communication; Subsistence and educational harvest, Jason Pawluk ADF&G Sport Fish biologist, personal communication; Personal use harvest, Dunker 2010, personal communication; Inriver run, Miller et. al. *In prep* a-c; Sport harvest sonar to Soldotna Bridge and sport harvest below sonar, Eskelin 2010, Perschbacher *In prep*, a-c; sport harvest above Soldotna bridge, Jennings et al. 2010 a-b, *In prep*.

[a] Inriver run was estimated using TS-based sonar methodology for all years except 1986 when mark-recapture methods were used (Conrad and Larson 1987; Conrad 1988) and 1996–1997 when radiotelemetry methods were used (Hammarstrom and Hasbrouck 1998-1999). The sonar project terminated early in 1994, 1996, 2002, 2004, 2005, 2006, 2008, and 2010. Estimates for these years were expanded through August 10 based on historic passage.

[b] Estimates are not yet available for 2010.

Table 4.–Estimated stock parameter proportions of late-run Kenai River king salmon, 1986–2009.

Year	Cook Inlet marine sport harvest	Commercial East-side setnet harvest	Commercial drift gillnet harvest	Subsistence/ educational harvest	Kenai River personal use harvest	Sport harvest below sonar	Inriver run	Sport harvest sonar to Sold. Bridge	Sport harvest above Sold. Bridge	Catch-and-release mortality	Spawning escapement
1986	0.01	0.25	0.02	ND	ND	ND	0.72	0.10	0.02	0.00	0.59
1987	0.02	0.28	0.06	ND	ND	ND	0.65	0.14	0.03	0.00	0.47
1988	0.02	0.19	0.03	ND	0.00	ND	0.76	0.24	0.05	0.00	0.47
1989	0.03	0.26	0.00	0.00	0.00	ND	0.70	0.19	0.04	0.00	0.47
1990	0.04	0.10	0.02	0.00	0.00	ND	0.84	0.15	0.03	0.00	0.66
1991	0.04	0.12	0.01	0.01	0.00	ND	0.83	0.16	0.03	0.00	0.64
1992	0.05	0.24	0.01	0.01	0.00	ND	0.69	0.15	0.02	0.01	0.51
1993	0.04	0.20	0.01	0.00	0.00	ND	0.75	0.22	0.04	0.01	0.48
1994	0.03	0.22	0.01	0.01	0.00	ND	0.74	0.20	0.05	0.01	0.49
1995	0.03	0.20	0.01	0.01	0.00	ND	0.74	0.17	0.04	0.01	0.52
1996	0.04	0.21	0.01	0.01	0.00	0.01	0.73	0.11	0.04	0.01	0.57
1997	0.05	0.20	0.01	0.00	0.01	0.01	0.72	0.18	0.04	0.01	0.48
1998	0.04	0.12	0.01	0.00	0.01	0.01	0.82	0.13	0.04	0.01	0.63
1999	0.02	0.16	0.01	0.00	0.01	0.02	0.79	0.18	0.03	0.01	0.57
2000	0.02	0.07	0.01	0.00	0.01	0.02	0.88	0.22	0.06	0.01	0.58
2001	0.02	0.14	0.01	0.00	0.01	0.03	0.78	0.29	0.06	0.02	0.41
2002	0.01	0.17	0.01	0.00	0.01	0.04	0.76	0.17	0.02	0.01	0.56
2003	0.00	0.25	0.02	0.00	0.02	0.01	0.70	0.22	0.05	0.03	0.40
2004	0.02	0.26	0.02	0.00	0.01	0.03	0.67	0.14	0.03	0.01	0.48
2005	0.01	0.30	0.03	0.00	0.01	0.03	0.61	0.18	0.04	0.02	0.37
2006	0.02	0.16	0.02	0.00	0.02	0.06	0.71	0.19	0.05	0.02	0.46
2007	0.01	0.20	0.02	0.00	0.03	0.03	0.71	0.12	0.04	0.01	0.54
2008	0.01	0.17	0.01	0.00	0.03	0.02	0.76	0.18	0.04	0.01	0.53
2009	0.01	0.16	0.02	0.00	0.03	0.03	0.74	0.18	0.05	0.02	0.49
Average	0.02	0.19	0.02	0.00	0.01	0.02	0.74	0.18	0.04	0.01	0.52
Minimum	0.00	0.07	0.00	0.00	0.00	0.01	0.61	0.11	0.02	0.00	0.37
Maximum	0.05	0.30	0.06	0.01	0.03	0.06	0.88	0.29	0.06	0.03	0.66

Note: Proportions in this table are relative to total run.

Note: ND = no data available.

Table 5.–Current methods of estimating Kenai River king salmon inriver run size.

	Published	Years Produced	Strengths	Weaknesses
Split-beam Sonar TS-based	Daily on internet, Annually in sonar report	1986–2010	Long historical record	Positive bias due to unreliable species classification; unable to always detect small runs; negative bias due to missed detection; negative bias due to imperfect tracking when fish densities high; subjectivity involved with censoring samples and setting range thresholds
Split-beam Sonar ELSD-based	Annually in sonar report	2002–2010	Much better ability to exclude sockeye salmon; not sensitive to equipment calibration errors; less subjective; less sensitive to king salmon size distribution	Subject to positive bias when fish passage high and/or older king salmon age classes missing; negative bias due to missed detection; negative bias due to imperfect tracking when fish densities high
Net-Apportioned Split-beam Sonar	Annually in sonar report	2002–2010	Combines strengths of sonar and inriver gillnetting projects	Potential for bias not well understood; possible sensitivity to fish behavior, tide cycle, and other river conditions; negative bias due to missed detection; negative bias due to imperfect tracking when fish densities high

Table 6.–Comparison of annual split-beam sonar estimates of Kenai River king salmon inriver run, early and late, 2002–2010.

		TS-based	SE[a]	ELSD-based	SE[a]	Net-apportioned	SE[a]
Early Run							
	2002	7,162	169	5,210	239	6,132	355
	2003	13,325	199	13,147	327	12,657	407
	2004	15,498	261	13,633	475	17,998	710
	2005	20,450	295	13,686	482	12,334	730
	2006	23,326	394	13,071	518	7,449	505
	2007	15,904 [b]	285	8,716 [b]	350	4,516 [b]	299
	2008	15,355	296	6,560	252	4,822	349
	2009	11,334	263	4,428	201	2,834	73
	2010	13,248	235	*8,497* [c]		2,644	297
Late Run							
	2002	38,948 [d]	508	34,112 [d]	1,142	41,813 [d]	1,639
	2003	41,659	435	57,102	1,982	62,638	2,012
	2004	52,375 [d]	585	43,539 [d]	1,296	75,049 [d]	2,679
	2005	40,294 [d]	445	48,276 [d]	1,445	85,593 [d]	3,456
	2006	36,992 [d]	526	34,198 [d]	931	48,824 [d]	1,573
	2007	42,979	684	28,915	1,168	29,455	1,516
	2008	30,939 [e]	438	24,557 [e]	933	36,012 [e]	1,426
	2009	25,688	440	15,656	893	17,725	297
	2010	48,343 [f]	726	*33,934* [c]		12,501 [f]	768

[a] SE estimates represent error due to temporal expansion and, in the case of net apportioned and ELSD-based estimates, species apportionment.

[b] Sonar sampling began May 20. Estimate does not include expansion for May 16-19.

[c] ELSD-based estimates for 2010 are preliminary and will change.

[d] Sonar sampling ended August 5 due to budget constraints. Estimate does not include expansion through August 10.

[e] Sonar sampling ended August 8 due to fish holding in the sonar beam. Estimate does not include expansion through August 10.

[f] Sonar sampling ended August 4 due to fish holding in the sonar beam. Estimate does not include expansion through August 10.

Table 7.–Summary of early-run Kenai River king salmon population data, 1986–2010.

Year	Cook Inlet marine sport harvest	Subsis., P.U., and educ. harvest	Inriver run[a]	Total run	Below Sold. Bridge sport harvest[b]	Above Sold. Bridge sport harvest	Catch-and-release mortality	Spawning escapement
1986	Unknown	ND	27,080	27,080	6,337	1,819	242	18,682
1987	Unknown	ND	25,643	25,643	11,224	2,333	306	11,780
1988	Unknown	ND	20,880	20,880	11,949	3,260	340	5,331
1989	Unknown	73	17,992	18,065	6,711	1,683	149	9,449
1990	Unknown	40	10,768	10,808	723	1,084	378	8,583
1991	Unknown	2	10,939	10,941	891	1,054	152	8,842
1992	Unknown	73	10,087	10,160	1,365	876	236	7,610
1993	Unknown	118	19,669	19,787	6,846	2,496	286	10,041
1994	Unknown	56	18,403	18,459	4,722	3,449	285	9,947
1995	Unknown	37	21,884	21,921	7,733	2,484	357	11,310
1996	Unknown	14	23,505	23,519	4,166	2,457	287	16,595
1997	Unknown	141	14,963	15,104	4,942	1,487	349	8,185
1998	Unknown	122	13,103	13,225	648	522	254	11,679
1999	Unknown	114	25,666	25,780	5,534	2,595	261	17,276
2000	Unknown	124	12,479	12,603	1,149	669	185	10,476
2001	Unknown	198	16,676	16,874	1,428	971	204	14,073
2002	Unknown	64	7,162	7,226	376	523	78	6,185
2003	Unknown	46	13,325	13,371	1,948	891	389	10,097
2004	Unknown	89	15,498	15,587	2,285	1,101	257	11,855
2005	Unknown	76	20,450	20,526	2,876	934	253	16,387
2006	Unknown	75	23,326	23,401	3,397	1,296	205	18,428
2007	Unknown	16	16,217	16,233	2,645f	848	220	12,504
2008	Unknown	40	15,355	15,395	2,602f	898	123	11,732
2009	Unknown	49	11,334	11,383	898f	568	97	9,771
2010	Unknown	32	13,248	13,280	837	[c]	[c]	[c]
Average		75	17,184	17,249	4,004	1,512	246	11,534
Minimum		2	7,162	7,162	376	522	78	5,331
Maximum		198	27,080	27,080	11,949	3,449	389	18,682

Note: ND = no data available.

Sources: From 1986-2006, see McKinley and Fleischman 2010*b*. For 2007–2010 data see the following sources: Subsistence, PU, and educational harvest, Jason Pawluk ADF&G Sport Fish biologist, personal communication, Inriver run, Miller *In prep* a-c; below Soldotna Bridge sport harvest, Eskelin 2010, Perschbacher *In prep* a-c; above Soldotna Bridge sport harvest, Jennings et al. 2010a-b, *In prep*.

[a] Inriver run was estimated using TS-based sonar methodology for all years except 1986 and 1987 when mark-recapture methods were used (Conrad and Larson 1987; Conrad 1988).

[b] Sport fishery harvest below the sonar is negligible in the early run.

[c] Estimates are not yet available for 2010.

Table 8.–Estimated stock parameter proportions of early-run Kenai River king salmon, 1986–2009.

Year	Cook Inlet marine sport harvest	Subsistence, PU & educ. harvest	Inriver run	Below Sold. Bridge sport harvest	Above Sold. Bridge sport harvest	Catch-and-release mortality	Spawning escapement
1986	unknown	0.00	1.00	0.23	0.07	0.01	0.69
1987	unknown	0.00	1.00	0.44	0.09	0.01	0.46
1988	unknown	0.00	1.00	0.57	0.16	0.02	0.26
1989	unknown	0.00	1.00	0.37	0.09	0.01	0.52
1990	unknown	0.00	1.00	0.07	0.10	0.03	0.79
1991	unknown	0.00	1.00	0.08	0.10	0.01	0.81
1992	unknown	0.01	0.99	0.13	0.09	0.02	0.75
1993	unknown	0.01	0.99	0.35	0.13	0.01	0.51
1994	unknown	0.00	1.00	0.26	0.19	0.02	0.54
1995	unknown	0.00	1.00	0.35	0.11	0.02	0.52
1996	unknown	0.00	1.00	0.18	0.10	0.01	0.71
1997	unknown	0.01	0.99	0.33	0.10	0.02	0.54
1998	unknown	0.01	0.99	0.05	0.04	0.02	0.88
1999	unknown	0.00	1.00	0.21	0.10	0.01	0.67
2000	unknown	0.01	0.99	0.09	0.05	0.01	0.83
2001	unknown	0.01	0.99	0.08	0.06	0.01	0.83
2002	unknown	0.01	0.99	0.05	0.07	0.01	0.86
2003	unknown	0.00	1.00	0.15	0.07	0.03	0.76
2004	unknown	0.01	0.99	0.15	0.07	0.02	0.76
2005	unknown	0.00	1.00	0.14	0.05	0.01	0.80
2006	unknown	0.00	1.00	0.15	0.06	0.01	0.79
2007	unknown	0.00	1.00	0.16	0.05	0.01	0.77
2008	unknown	0.00	1.00	0.17	0.06	0.01	0.76
2009	unknown	0.00	1.00	0.08	0.05	0.01	0.86
Average		0.00	1.00	0.20	0.09	0.02	0.69
Minimum		0.00	0.99	0.05	0.04	0.01	0.26
Maximum		0.01	1.00	0.57	0.19	0.03	0.88

Note: Proportions in this table are relative to total run.

FIGURES

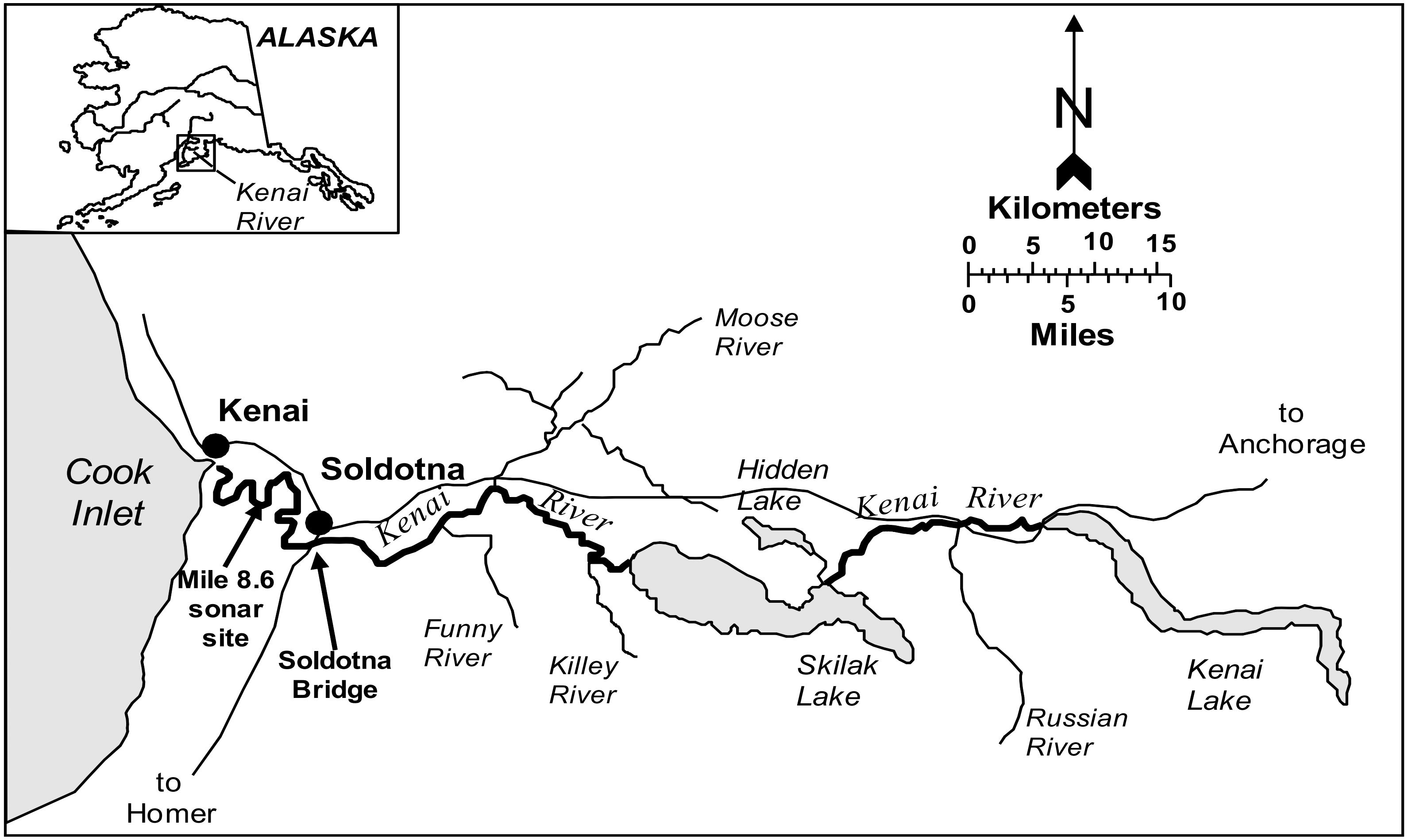


Figure 1.–Kenai River drainage showing location of the RM 8.6 sonar site, the Soldotna Bridge, and major tributaries.

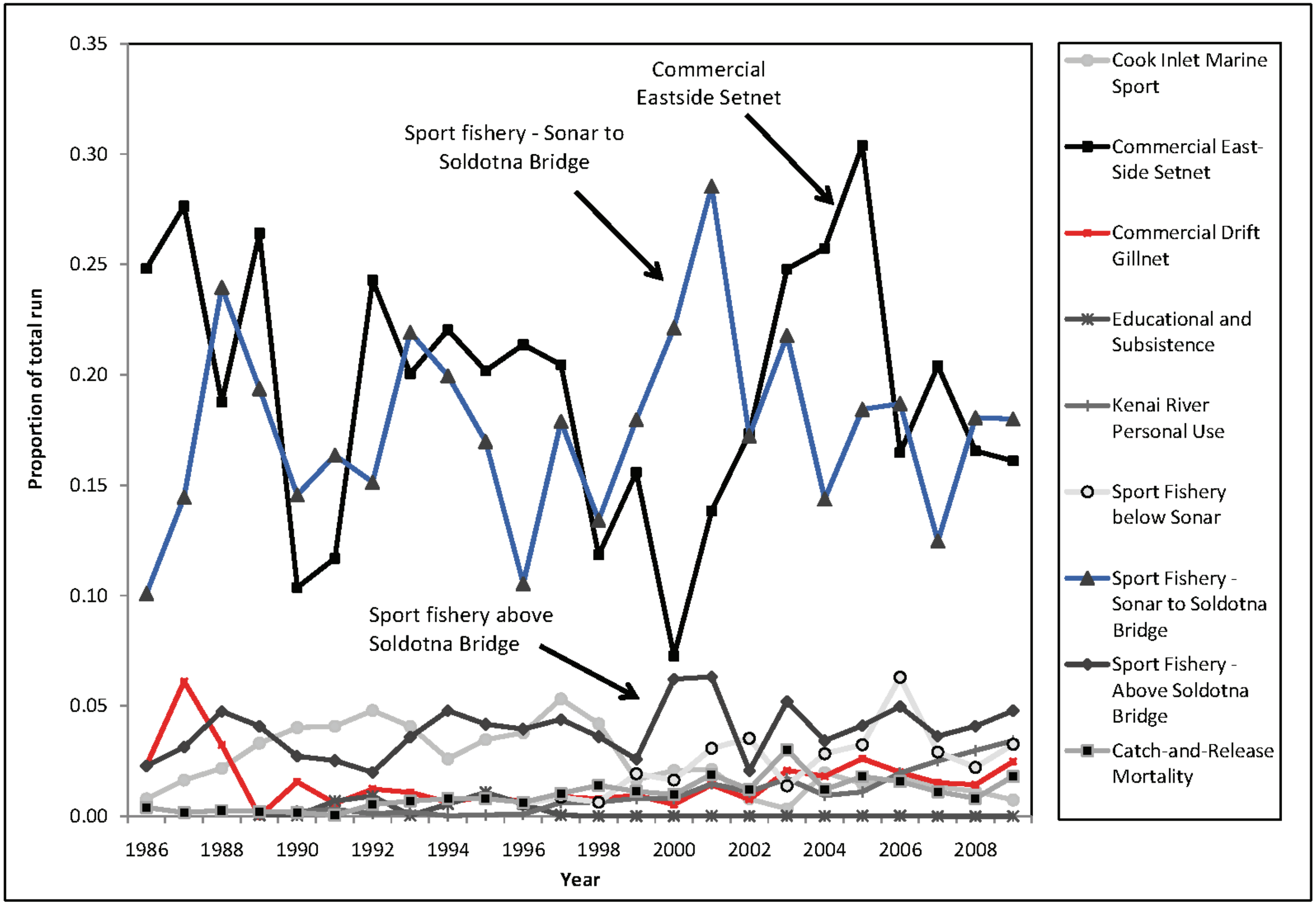
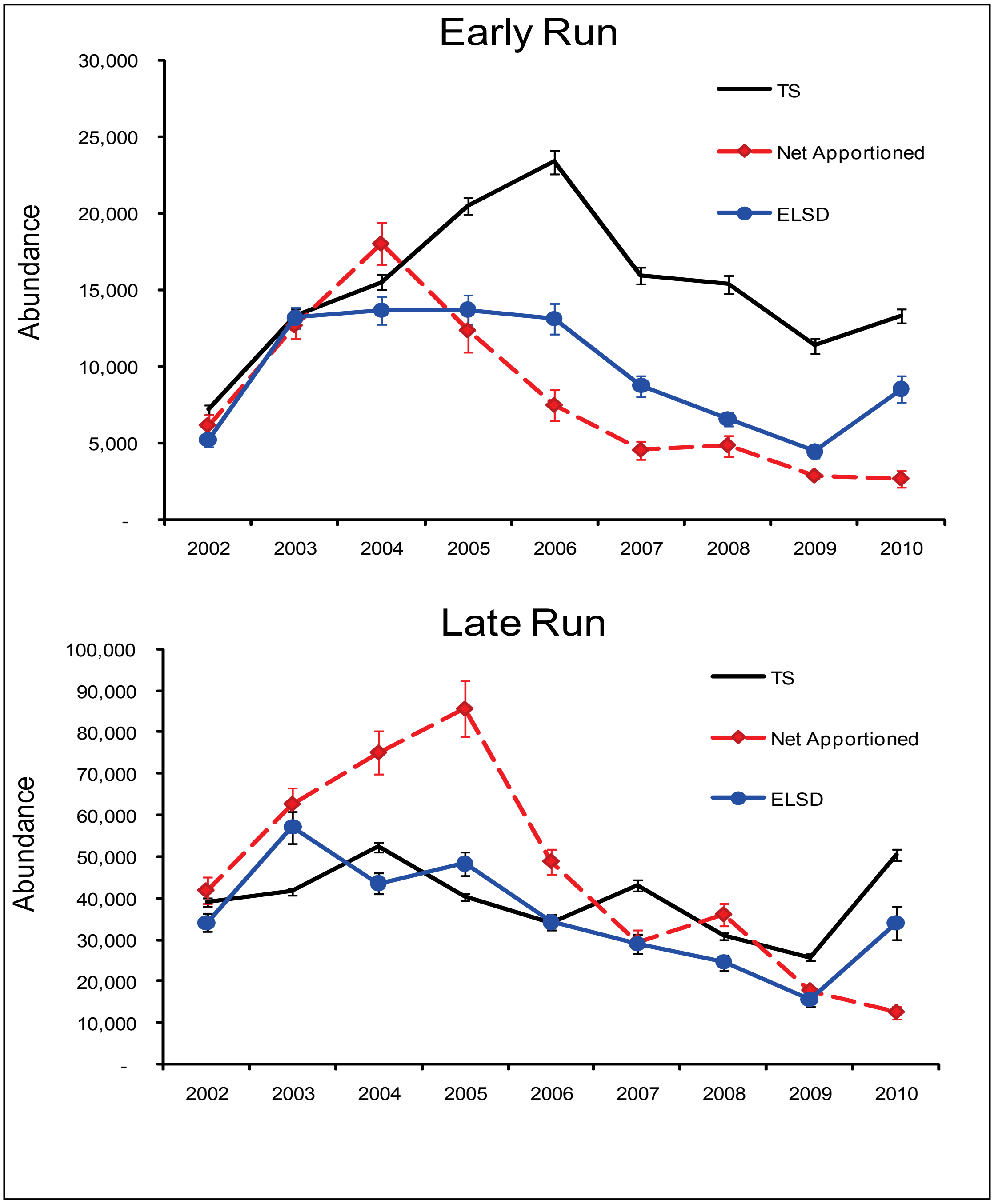


Figure 2.–Estimated stock parameter proportions of late-run Kenai River king salmon, 1986–2009.



Note: ELSD-based estimates for 2010 are preliminary and will change. Error bars (+/- 1 SD) represent sampling error due to temporal expansion and, in the case of net apportioned and ELSD-based estimates, species apportionment.

Figure 3.–Early- and late-run king salmon sonar passage estimates based on three different estimation methods (split-beam TS-based, split-beam net-apportioned, and split-beam ELSD-based), Kenai River, 2002–2010.

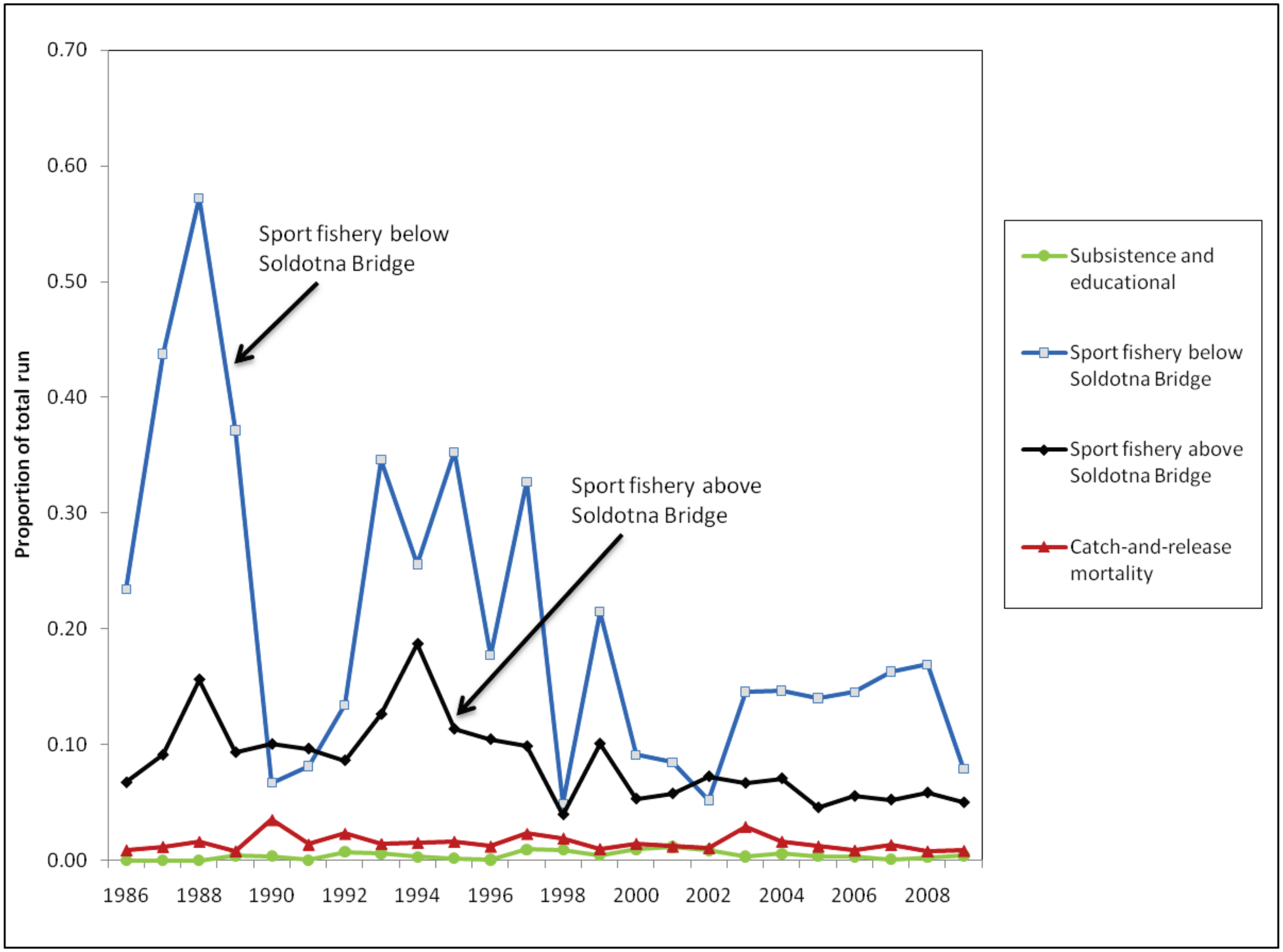
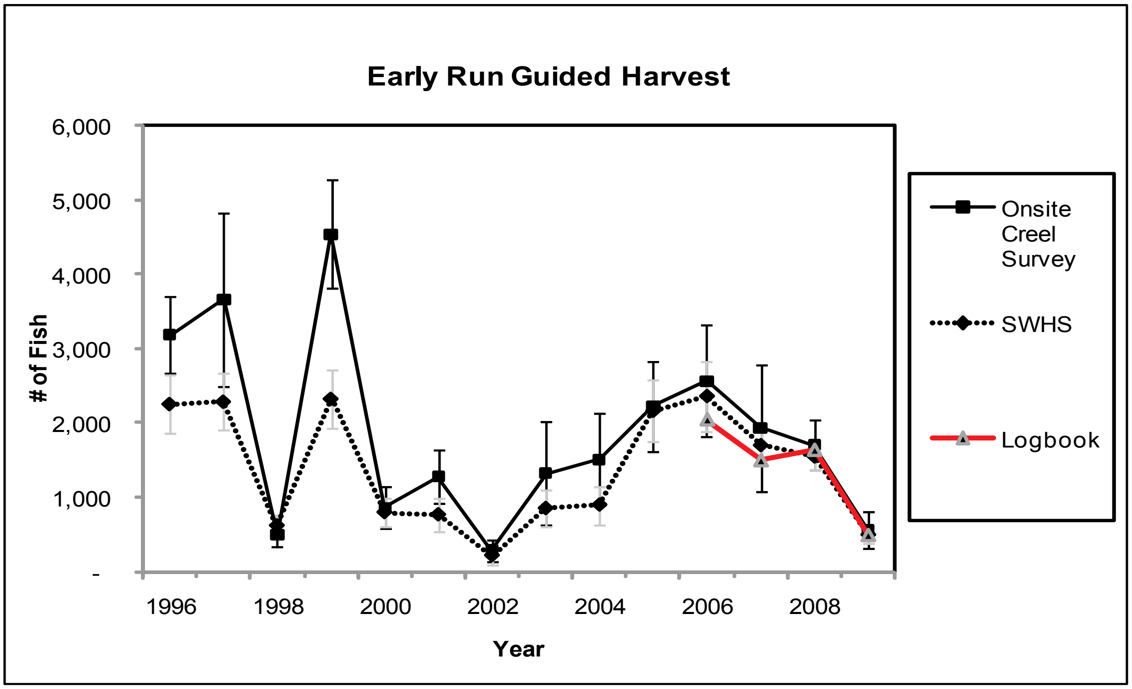


Figure 4.–Estimated stock parameter proportions of early-run Kenai River king salmon, 1986–2009.

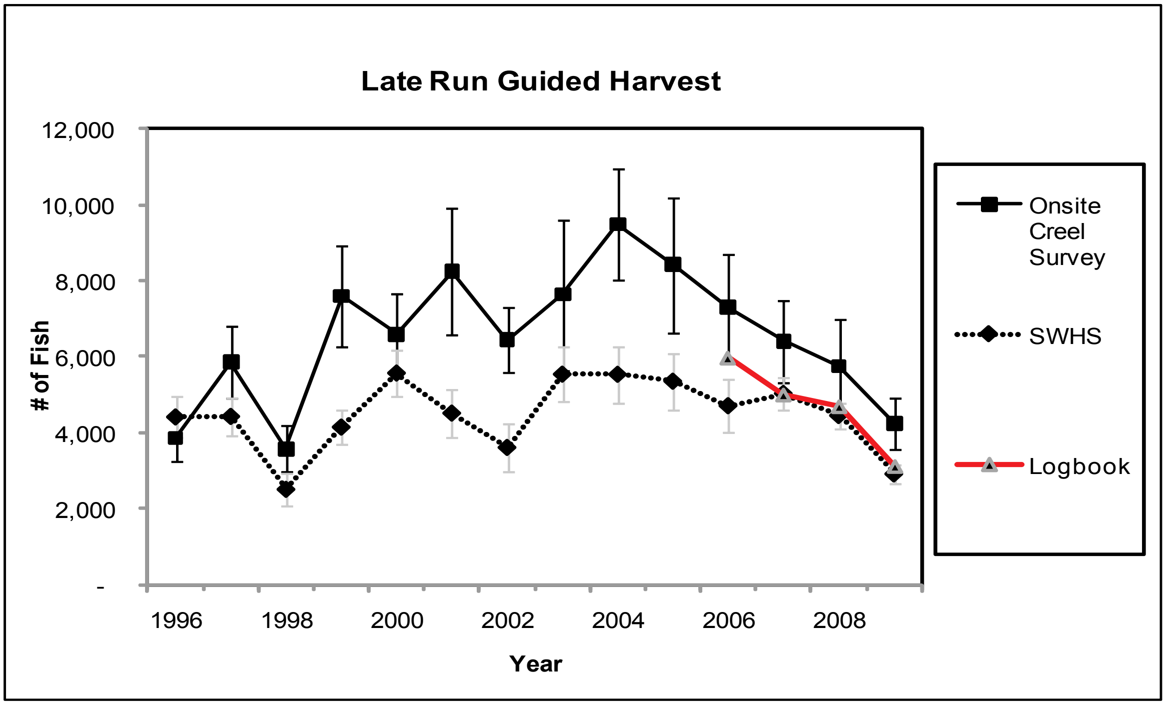


Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001a-d, Walker 2003, Jennings et al 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

Logbook: Sigurdsson and Powers 2009, 2010

Figure 5.–Estimates of Kenai River king salmon harvest downstream of the Soldotna Bridge by guided anglers in the early run from the onsite creel survey, SWHS, and logbook data, 1996–2009.

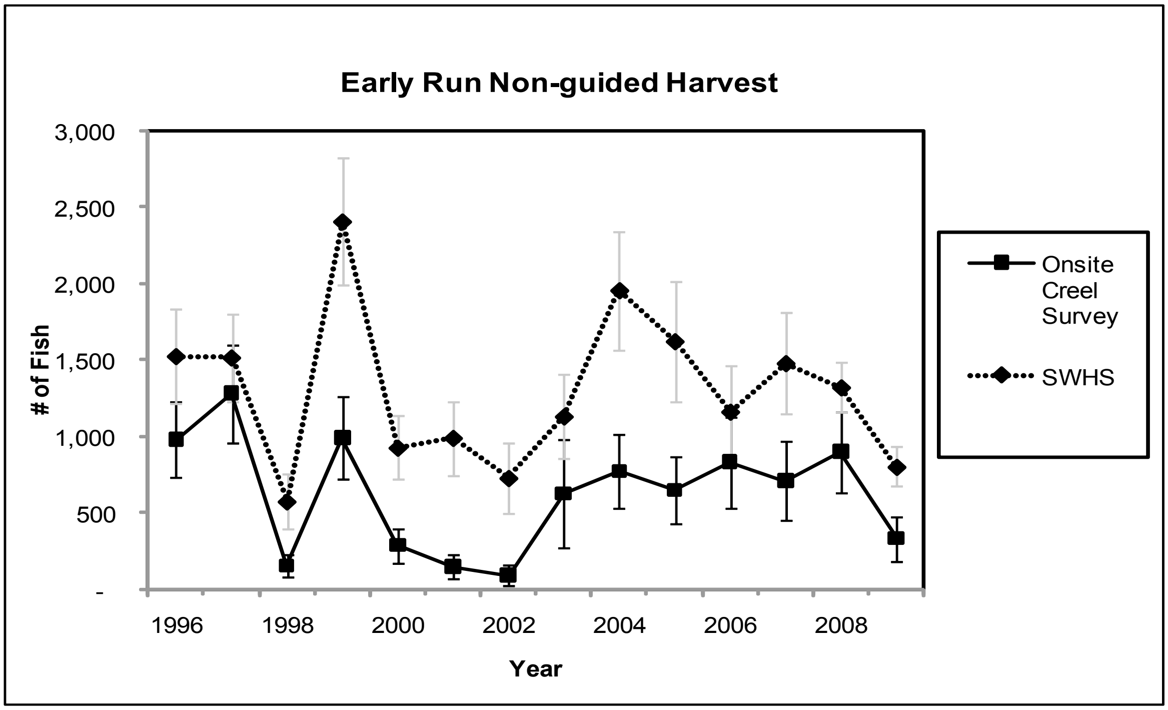


Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001a-d, Walker 2003, Jennings et al 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

Logbook: Sigurdsson and Powers 2009, 2010

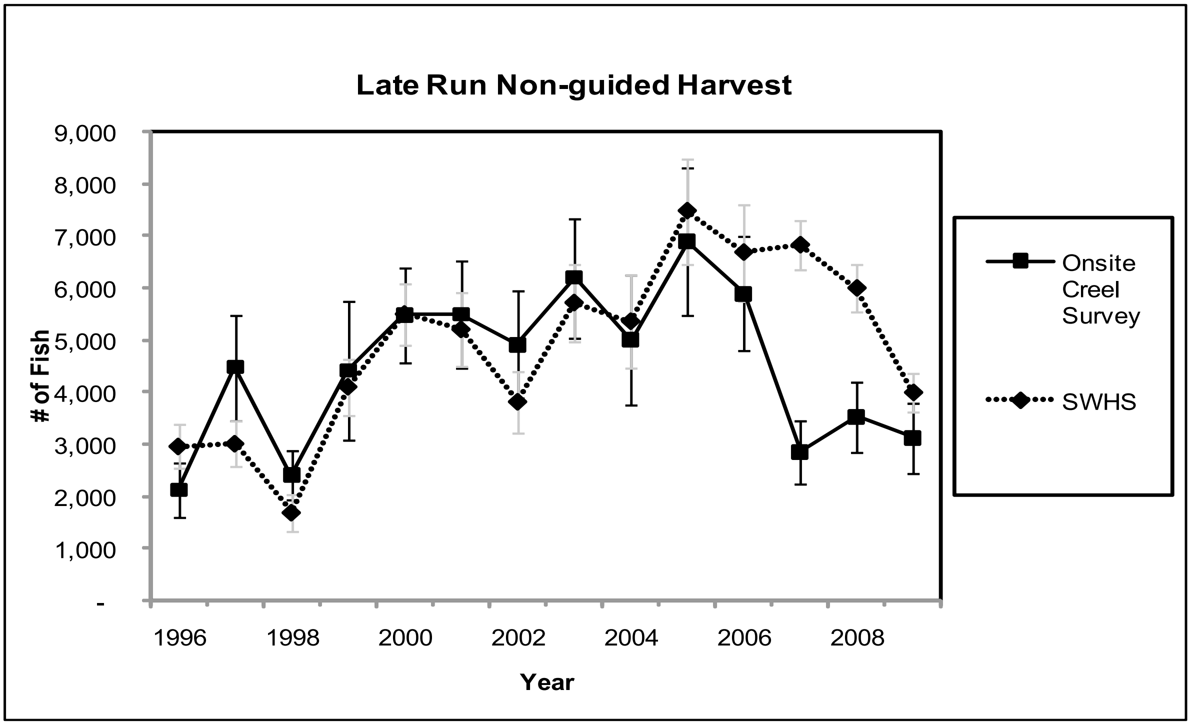
Figure 6.–Estimates of Kenai River king salmon harvest downstream of the Soldotna Bridge by guided anglers in the late run from the onsite creel survey, SWHS, and logbook data, 1996–2009.



Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001a-d, Walker 2003, Jennings et al 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

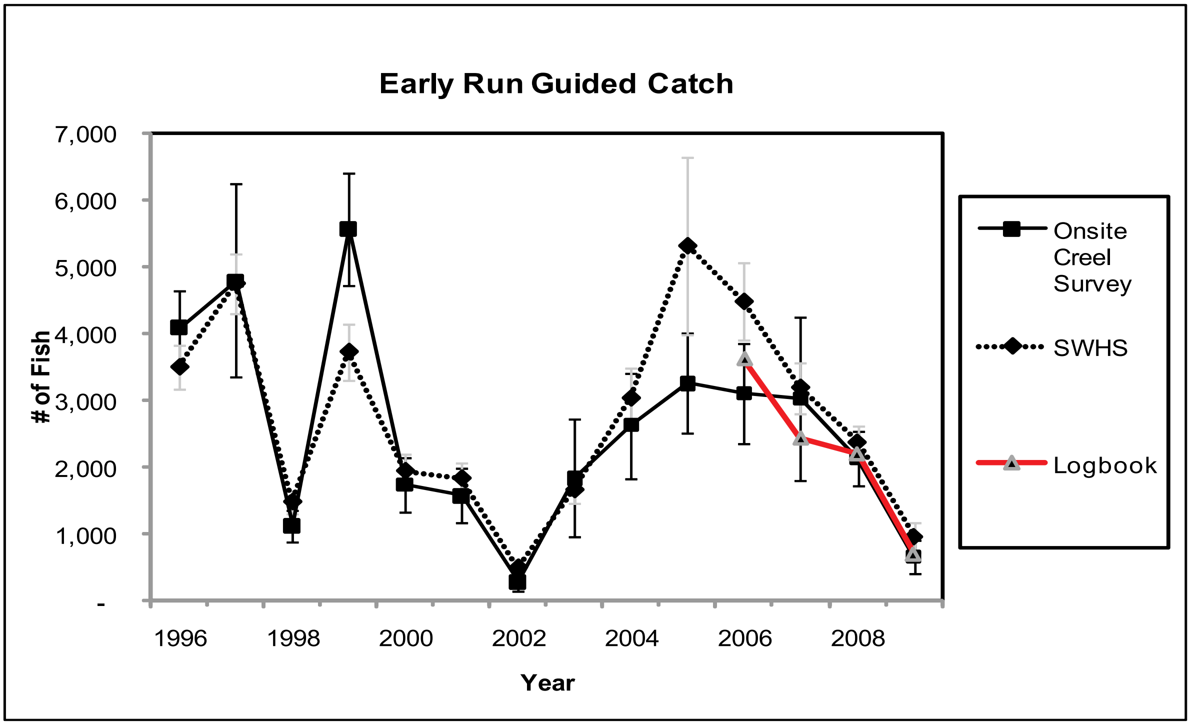
Figure 7.–Estimates of Kenai River king salmon harvest downstream of the Soldotna Bridge by unguided anglers in the early run from the onsite creel survey and SWHS, 1996–2009.



Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001 a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

Figure 8.–Estimates of Kenai River king salmon harvest downstream of the Soldotna Bridge by unguided anglers in the late run from the onsite creel survey and SWHS, 1996–2009.

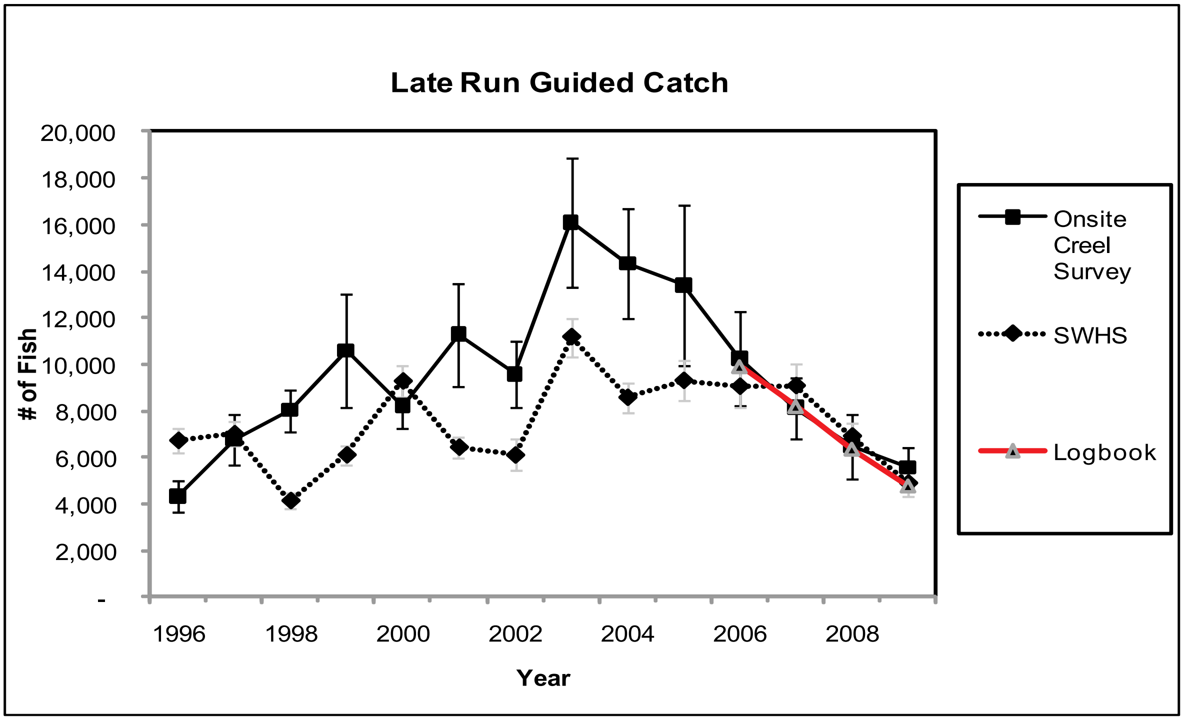


Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001 a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

Logbook: Sigurdsson and Powers 2009, 2010

Figure 9.–Estimates of Kenai River king salmon catch downstream of the Soldotna Bridge by guided anglers in the early run from the onsite creel survey, SWHS, and logbook data, 1996–2009.

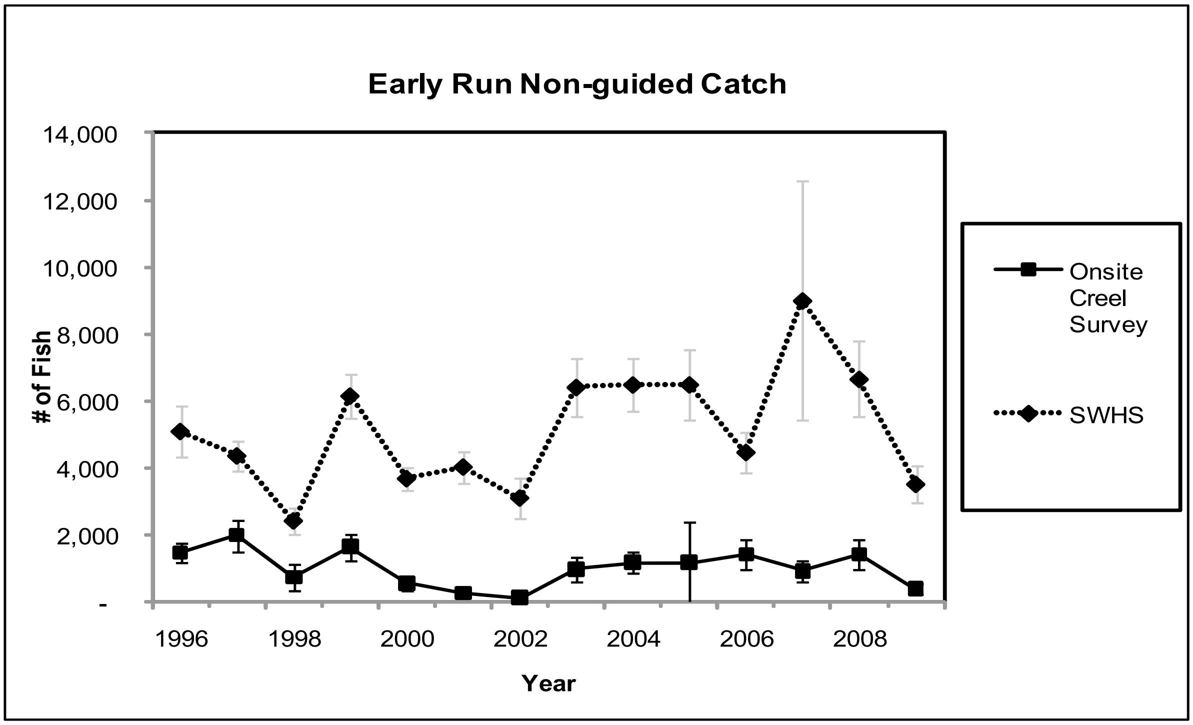


Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001 a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

Logbook: Sigurdsson and Powers 2009, 2010

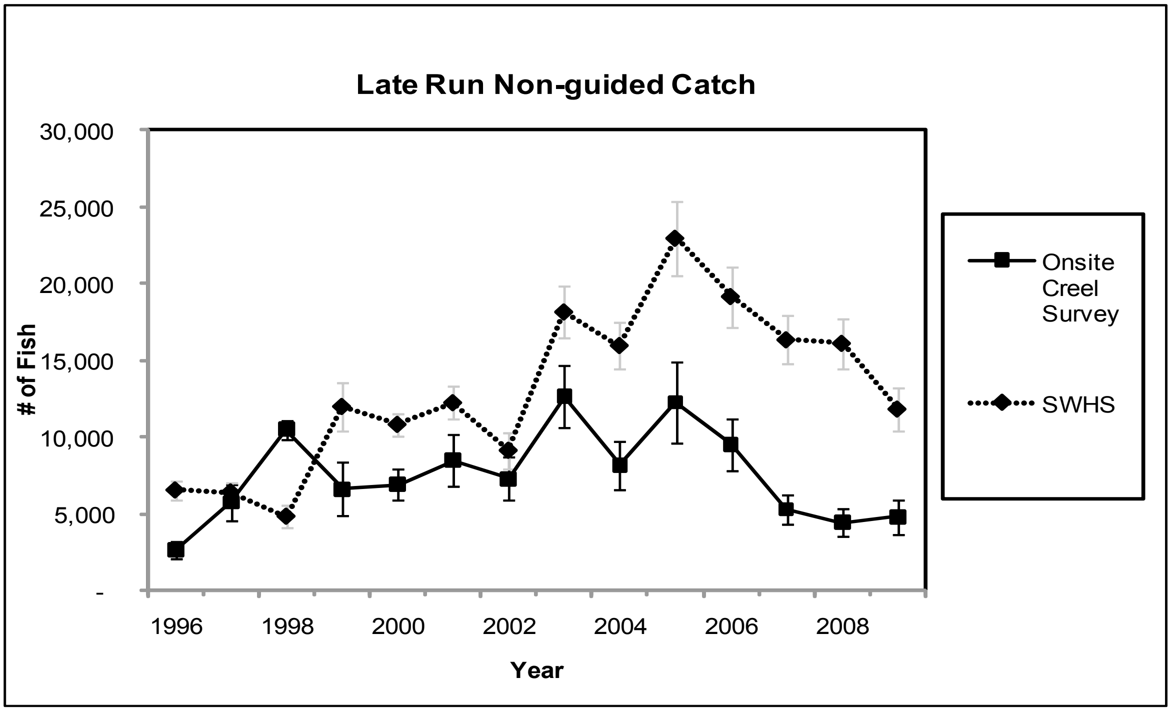
Figure 10.–Estimates of Kenai River king salmon catch downstream of the Soldotna Bridge by guided anglers in the late run from the onsite creel survey, SWHS, and logbook data, 1996–2009.



Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001 a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

Figure 11.–Estimates of Kenai River king salmon catch downstream of the Soldotna Bridge by unguided anglers in the early run from the onsite creel survey and SWHS, 1996–2009.



Note: Error bars represent 95% CIs

SWHS: Howe et al. 2001 a-d; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b, 2010a-b, *In prep*.

Figure 12.–Estimates of Kenai River king salmon harvest downstream of the Soldotna Bridge by unguided anglers in the late run from the onsite creel survey and SWHS, 1996–2009.