Fishery Data Series No. 14-18

Estimates of Chinook Salmon Passage in the Kenai River Using Split-Beam and Dual-Frequency Identification Sonars, 2011

by

James D. Miller

Debby L. Burwen

and

Steve J. Fleischman

April 2014

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

Symbols and Abbreviations

The following symbols and abbreviations, and others approved for the Système International d'Unités (SI), are used without definition in the following reports by the Divisions of Sport Fish and of Commercial Fisheries: Fishery Manuscripts, Fishery Data Series Reports, Fishery Management Reports, and Special Publications. All others, including deviations from definitions listed below, are noted in the text at first mention, as well as in the titles or footnotes of tables, and in figure or figure captions.

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

FISHERY DATA SERIES NO.14-18

ESTIMATES OF CHINOOK SALMON PASSAGE IN THE KENAI RIVER USING SPLIT-BEAM AND DUAL-FREQUENCY IDENTIFICATION SONARS, 2011

by

James D. Miller
Debby L. Burwen
Division of Sport Fish, Anchorage
and
Steve J. Fleischman
Division of Sport Fish, Research and Technical Services, Anchorage

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

April 2014

This investigation was partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-26 and 27, Job No. S-2-5b.

ADF&G Fishery Data Series was established in 1987 for the publication of Division of Sport Fish technically oriented results for a single project or group of closely related projects, and in 2004 became a joint divisional series with the Division of Commercial Fisheries. Fishery Data Series reports are intended for fishery and other technical professionals and are available through the Alaska State Library and on the Internet: http://www.adfg.alaska.gov/sf/publications/. This publication has undergone editorial and peer review.

James D. Miller, Debby L. Burwen,
Alaska Department of Fish and Game, Division of Sport Fish
333 Raspberry Road, Anchorage, Alaska 99518-1599, USA
and
Steve J. Fleischman
Alaska Department of Fish and Game, Division of Sport Fish,
Research and Technical Services
333 Raspberry Road, Anchorage, Alaska 99518-1599, USA

This document should be cited as:
Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2014. Estimates of Chinook salmon passage in the Kenai River using split-beam and dual-frequency identification sonars, 2011. Alaska Department of Fish and Game, Fishery Data Series No. 14-18, Anchorage.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF APPENDICES (Continued)

Appendix **Page**

ABSTRACT

Kenai River Chinook salmon (*Oncorhynchus tshawytscha*) passage was estimated in 2011 using split-beam sonar and experimental dual-frequency identification sonar (DIDSON). Both sonar systems operated from 16 May to 10 August. Based on split-beam echo-length standard deviation measurements, total upstream passage of Chinook salmon was estimated to be 10,561 (SE 393) fish during the early run (16 May–30 June) and 37,261 (SE 2,057) fish during the late run (1 July–10 August). Based on DIDSON length measurements, estimates of Chinook salmon passage were 7,366 (SE 318) fish for the early run (16 May–30 June) and 23,713 (SE 725) fish for the late run (1 July–10 August). It is recommended that split-beam sonar estimates be discontinued in favor of DIDSON-based estimates in 2012.

Key words: split-beam sonar, DIDSON, Chinook salmon, *Oncorhynchus tshawytscha,* acoustic assessment, Kenai River, riverine sonar.

INTRODUCTION

Chinook salmon (*Oncorhynchus tshawytscha*) returning to the Kenai River (Figure 1) support one of the largest and most intensively managed recreational fisheries in Alaska (Gamblin et al. 2004). Kenai River Chinook salmon are among the largest in the world and have sustained in excess of 100,000 angler-days of fishing effort annually (Howe et al. 1995-1996, 2001a-d; Mills 1979-1980, 1981a-b,1982-1994; Walker et al. 2003; Jennings et al. 2004, 2006a-b, 2007, 2009a-b, 2010a-b, 2011a-b). The Kenai River Chinook salmon fishery has been a source of contention because of competition for a fully allocated resource among sport, commercial, subsistence, and personal use fisheries.

Chinook salmon returning to the Kenai River are managed as 2 distinct runs (Burger et al. 1985): early (16 May–30 June) and late (1 July–10 August). Early-run Chinook salmon are harvested primarily by sport anglers, and late-run Chinook salmon by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted if the projected escapement falls below goals adopted by the Alaska Board of Fisheries (BOF). These goals are defined by Alaska Administrative Codes 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) and are intended to provide a stable fishing season without compromising sustainability. Escapement goals have evolved over the years as stock assessment and our understanding of stock dynamics have improved (McBride et al. 1989; Hammarstrom and Hasbrouck 1998-1999; Bosch and Burwen 1999). During the 2011 season, goals of 5,300–9,000 early-run and 17,800–35,700 late-run Chinook salmon were in effect. Sonar estimates of inriver Chinook salmon passage provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in the competing sport and commercial fisheries for this stock. Implementation of these management plans has been contentious and attracts public scrutiny. Restrictions were imposed on the sport fishery to meet escapement goals during the early run in 1990 through 1992, 1997, 1998, 2000, 2002, 2010, and 2011, and during the late run in 1990, 1992, 1998, and 2011.

PROJECT HISTORY

Mark–recapture

The first estimates of Kenai River Chinook salmon abundance were generated in 1984 for the late run using a mark–recapture project (Hammarstrom et al. 1985). From 1985 through 1990, the mark–recapture project produced estimates for both early- and late-run riverine abundance (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and

Alexandersdottir 1989; Alexandersdottir and Marsh 1990). These estimates had low precision and appeared to be positively biased, particularly during the late run (Bernard and Hansen 1992).

Dual-beam Sonar

The Alaska Department of Fish and Game (ADF&G) initiated studies in 1984 to determine whether an acoustic assessment program could provide timely and accurate daily estimates of Chinook salmon passage in the Kenai River (Eggers et al. 1995). Acoustic assessment of Chinook salmon in the Kenai River is complicated by the presence of more abundant sockeye salmon (*O. nerka*), which migrate concurrently with Chinook salmon. From 1987 to 2009, sockeye salmon escapement estimates generated by the river mile–19 sockeye salmon sonar project ranged from 625,000 to 1,600,000 fish (Westerman and Willette 2011) while late-run Chinook salmon passage estimates generated by the Chinook salmon sonar project at river mile (RM) 8.5 ranged from 29,000 to 56,000 fish. Dual-beam sonar was initially chosen for the Chinook salmon sonar project because of its ability to estimate acoustic size (target strength), which was to serve as the discriminatory variable to systematically identify and count only Chinook salmon. Because of the considerable size difference between Chinook salmon and other fish species in the Kenai River, it was postulated that dual-beam sonar could be used to distinguish Chinook salmon from smaller fish (primarily sockeye salmon) and to estimate their numbers returning to the river.

Early Kenai River sonar and gillnetting studies indicated that Chinook salmon could be distinguished from sockeye salmon based on target strength and spatial separation in the river (Eggers et al. 1995). Target strength (TS) is a measure of the loudness of the echo returning from a fish, corrected for position of the fish in the beam. Sockeye salmon are smaller, on average, than Chinook salmon, and were assumed to have smaller target strength. A target strength threshold was established to censor small fish. Sockeye salmon also were thought to migrate primarily near the bank, therefore a range or distance threshold was also imposed. Since 1987, "TS-based estimates" based on these two criteria have been the primary basis for monitoring the number of Chinook salmon returning to the Kenai River for comparison with established escapement goals.

TS-based estimates made with dual-beam sonar were consistently lower than the 1987–1990 mark–recapture estimates (Eggers et al. 1995). The inconsistencies between sonar and mark–recapture estimates were greatest during the late run, presumably due to the mark–recapture biases mentioned above.

Split-beam Sonar

A more advanced acoustic technology, known as split-beam sonar, was used to test assumptions and design parameters of the dual-beam configuration in 1994 (Burwen et al. 1995). The split-beam system provided advantages over the dual-beam system in its ability to determine the 3-dimensional position of an acoustic target in the sonar beam. Consequently, the direction of travel for each target and the 3-dimensional spatial distribution of fish in the acoustic beam could be determined for the first time. The split-beam system also operated at a lower frequency than the dual-beam system, providing a higher (improved) signal-to-noise ratio (SNR; Simmonds and MacLennan 2005). It also interfaced with improved fish-tracking software, which reduced the interference from boat wake, and improved fish-tracking capabilities (Burwen and Bosch 1996). The split-beam system was deployed side-by-side with the dual-beam and was run concurrently for much of the 1994 season (Burwen et al. 1995). Both systems detected comparable numbers of fish. The split-beam data confirmed earlier studies (Eggers et al. 1995) showing that most fish targets were strongly oriented to the river bottom. However, experiments conducted with the split-beam system could not confirm that Chinook salmon could be discriminated from sockeye salmon based on target strength. Modeling exercises performed by Eggers (1994) also questioned the feasibility of discriminating between Chinook and sockeye salmon using target strength. It was hypothesized that discrimination between the two species was primarily accomplished using range thresholds on the acoustic data that exploited the known spatial segregation of the species (sockeye salmon migrate near shore and Chinook salmon migrate midriver; Burwen et al. 1995; Eggers et al. 1995). In 1995, the dual-beam system was replaced with the split-beam system to take advantage of the additional information on direction of travel and spatial position of targets. TS-based estimates continued to be produced with the split-beam sonar.

Ancillary drift gillnetting and sonar studies conducted in 1995 (Burwen et al. 1998) were directed at providing definitive answers to remaining questions regarding 1) the degree to which sockeye and Chinook salmon are spatially separated at the RM-8.5 Chinook salmon sonar site and 2) the utility of using target strength and other acoustic parameters for species separation. These studies confirmed the potential for misclassifying sockeye salmon as Chinook salmon. The drift gillnetting study found that sockeye salmon were present in the middle insonified portion of the river. In the concurrent sonar experiment, using live fish tethered in front of the split-beam sonar, most sockeye salmon had mean target strengths exceeding the target strength threshold.

Concurrent Studies to Verify and Improve Sonar Passage Estimates

Radiotelemetry projects were implemented in 1996 and 1997 to estimate the magnitude of bias introduced into the Chinook salmon passage estimates during periods of high sockeye salmon passage (Hammarstrom and Hasbrouck 1998-1999). The radiotelemetry studies were designed to provide an independent and accurate estimate of inriver Chinook salmon passage during the late run when the potential to misclassify sockeye salmon using sonar is greatest. Although the precision of radiotelemetry estimates and previous mark–recapture estimates was similar, the use of radiotelemetry avoided certain biases associated with the earlier mark–recapture studies. Sonar estimates of late-run Chinook salmon abundance were 26% greater in 1996 and 28% greater in 1997 than the corresponding telemetry estimates.

An investigation in 1999 (Burwen et al. 2000) attempted to identify alternative sites above tidal influence with stronger bank orientation of sockeye salmon, where range thresholds would be more effective. The investigation concentrated on a site located at RM 13.2 that was upstream of tidal influence but downstream of major spawning areas. Gillnetting data indicated that there were fewer sockeye salmon in the offshore area at the alternative site than at the current site. However, there were still relatively large numbers of sockeye salmon present in the offshore area of the alternative site during peak migration periods as well as high numbers of Chinook salmon present in the nearshore area. The alternate sonar site also had several disadvantages over the current site including more boat traffic, less acoustically favorable bottom topography, and higher background noise resulting in difficult fish tracking conditions.

The inriver drift gillnetting program, originally designed to collect age, sex, and length (ASL) samples (Marsh 2000), was modified in 1998 to produce standardized estimates of Chinook salmon catch per unit effort (CPUE) for use as an index of Chinook salmon passage (Reimer et al. 2002). A drift zone was established just downstream from the sonar site and crews fished relative to the tide cycles because gillnets could not be fished effectively during parts of the rising and high tide stages due to lack of river current. In addition, the schedule was intensified so that CPUE estimates could be generated daily. During subsequent years, inriver gillnet CPUE was used as a comparison with sonar passage estimates to detect periods when Chinook salmon passage estimates were potentially high because of inclusion of sockeye salmon or other species (Bosch and Burwen 2000; Miller and Burwen 2002; Miller et al. 2002-2005, 2007a-b, 2010-2012).

Analysis of the 1998–2000 standardized CPUE data suggested the gillnetting data were better suited for determining species apportionment of split-beam sonar counts than for passage estimates (Reimer et al. 2002). In 2002, the inriver gillnetting program was modified further. A 5-inch mesh gillnet was introduced, alternating with the existing 7.5-inch mesh to reduce size selectivity; nets were constructed of multi-monofilament (formerly cable-lay braided nylon); the color of the mesh was changed to more closely match that of the river; and drifts were shortened and constrained to more closely match the portion of the channel sampled by the sonar. These changes increased netting efficiency and decreased the effect of water clarity on gillnet catches (Reimer 2004).

In 2002, we refined the species discrimination algorithm for TS-based estimates, censoring selected hourly samples based on fish behavior. During samples when sockeye salmon were abundant, as evidenced by aggregation of migrating fish into groups, the data were censored, and Chinook salmon passage was estimated from the remaining hourly samples.

Also in 2002, two experimental methods of estimating Chinook salmon passage were initiated. The first alternative estimate, referred to as the net-apportioned estimate, used the product of Chinook salmon catch proportions from the netting program (Eskelin 2010) and sonar upstream midriver fish passage estimates (see Methods). Net-apportioned estimates have been published annually since 2002 (Miller et al. 2004-2005, 2007a-b, 2010-2012), and have proven useful for tracking short term trends in Chinook salmon abundance.

The second alternative estimate was based on split-beam measures of echo envelope length, which is a better predictor of fish length than target strength (Burwen and Fleischman 1998; Burwen et al. 2003). Statistical methods were developed that enable robust estimates of species composition even when species overlap in size (Fleischman and Burwen 2003). Echo length standard deviation (ELSD) information from the sonar was combined with fish length data from the netting program to estimate the species composition of fish passing the sonar site. The resulting estimated proportion of Chinook salmon was then multiplied by upstream fish passage estimates from the sonar. The resulting "ELSD-based" estimates, considered to be more accurate than the official TS-based estimates, were produced for the years 2002–2006. Because echo length measurements can be corrupted when 2 or more fish swim very close to one another, resulting in higher values of ELSD, only early-run estimates were published (Miller et al. 2004-2005, 2007a-b, 2010). The corresponding late-run estimates were suspected to be too high due to high sockeye salmon densities.

In 2007, the ELSD mixture model method was modified in an attempt to reduce the bias at high fish densities. Using split-beam measurements of 3-dimensional fish location, the distance between fish was calculated and fish within 1 meter of any other fish[1] were censored before fitting the mixture model. ELSD-based estimates published in the 2007 report (Miller et al. 2011) supplanted the previously published early-run estimates.

Dual-frequency Identification Sonar (DIDSON)

ADF&G began testing dual-frequency identification sonar (DIDSON[2]) in the Kenai River in 2002 (Burwen et al. 2007). DIDSON uses a lens system that provides high resolution images that approach the quality achieved with conventional optics (Simmonds and MacLennan 2005), with the advantage that images can be obtained in dark or turbid waters. Fish size was immediately evident from DIDSON footage[3] of migrating Kenai River salmon, suggesting that DIDSON had promise for improved discrimination of large Chinook salmon from smaller fish in the Kenai River. With ADF&G input, DIDSON developers designed custom software for manually measuring fish size directly from still images. Initial experiments using live tethered salmon showed that at ranges up to 12 m, precise estimates of fish length could be obtained by manually measuring fish images produced by a standard DIDSON unit (Burwen et al. 2007). Ranges to 30 m are required to adequately insonify the Kenai River at the current sonar location (RM 8.5), and subsequent advancements in DIDSON technology resulted in improved long-range image resolution. The development of a lower frequency DIDSON model (i.e., “long-range” DIDSON operating at 1.1 MHz) in 2004 extended the range of high-frequency operation to approximately 30 m, and a high resolution lens developed in 2007 improved the resolution by nearly a factor of two. Tethered-fish experiments conducted in 2007 with the new equipment established that DIDSON-estimated fish length was closely related to true length at ranges up to 22 m (Burwen et al. 2010; Miller et al. 2011). Additional experiments conducted with multiple observers on the left bank during 2009 confirmed the 2007 results at ranges up to 32 m (Miller et al. 2012).

In the years 2007–2009, the long-range high-resolution DIDSON sonar was deployed on the left bank to sample 10 m of river cross section that was simultaneously sampled by the split-beam transducer (Miller et al. 2011-2012). Methods and equipment were developed to minimize accumulation of silt in the lens, which could result in degraded image resolution. A pilot study concluded that automated tracking and measuring of free-swimming fish was feasible and potentially advantageous under some circumstances. DIDSON exhibited multiple advantages over split-beam sonar with respect to detection, tracking, and species classification of passing fish. Frequency distributions of DIDSON length measurements, along with paired netting data, lent themselves well to mixture modeling, which enabled estimation of species composition of passing fish. Such estimates agreed well with corresponding split-beam estimates from the ELSD mixture model in 2009.

A second DIDSON system was acquired in 2010, which made it possible to provide simultaneous coverage of both banks for the first time. DIDSON-based passage estimates were successfully produced for 48 of 87 days in 2010 (Miller et al. 2013). Comparisons of TS-based estimates with DIDSON estimates and other indices of Chinook salmon abundance showed that the assumptions underpinning TS-based estimates of Chinook salmon abundance were not valid, and it was recommended that TS-based estimates be discontinued. The DIDSON also detected large fish at short ranges that had been sampled by neither the split-beam sonar nor the onsite

[1] Essentially, fish swimming close to other fish were assumed not to be Chinook salmon.
[2] DIDSON was designed by the University of Washington Applied Physics Laboratory, originally for military applications.
[3] DIDSON imagery resembles somewhat pixelated video footage taken from a vantage point above the fish (see Appendix D).

netting project. Further investigation of Chinook salmon near shore was recommended (Miller et al. 2013).

In this report, we present daily and seasonal net-apportioned and ELSD-based estimates of Chinook salmon inriver abundance from the split-beam sonar and compare them with corresponding DIDSON-based estimates of abundance.

OBJECTIVES

The stated primary objective of this project was to produce weekly and seasonal ELSD-based estimates of the inriver run of Chinook salmon to the Kenai River such that the seasonal estimate was within 10% of the true value 95% of the time. This estimate was based on mixture modeling of ELSD measurements subject to censoring based on fish behavior. The precision criterion for ELSD-based estimates was intended to address sampling error and species classification, but not target tracking or detection[4].

A second objective was to continue the experimental development of DIDSON for inseason assessment of Kenai River Chinook salmon. DIDSON was deployed from the left and right banks of the river at RM 8.5; protocols were tested and refined for measuring fish and processing data in real time, and Chinook salmon abundance estimates were produced for comparison with those from split-beam sonar.

A third objective was to test for the presence of large Chinook salmon shoreward of existing transducer placements.

METHODS

STUDY AREA

The Kenai River drainage is approximately 2,150 square miles. It is glacially influenced, with discharge rates lowest during winter (<1,800 ft^3/s), increasing throughout the summer, and peaking in August (>14,000 ft^3/s; Benke and Cushing 2005). The Kenai River has 10 major tributaries, many of which provide important spawning and rearing habitat for salmon. Tributaries include the Russian River, Skilak River, Killey River, Moose River, and Funny River.

The Kenai River drainage is located in a transitional zone between a maritime climate and a continental climate (USDA 1992). The geographic position and local topography influence both rainfall and temperature throughout the drainage. Average annual (1971–2006) precipitation for the City of Kenai, located at the mouth of the Kenai River, is 48 cm (WRCC 2008). Average summer (June, July, and August) temperature for the City of Kenai is 12°C (WRCC 2008).

SITE DESCRIPTION

The sonar site was located 14 km (8.5 miles) from the mouth of the Kenai River (Figure 2). This site has been used since 1985 and was selected for its acoustic characteristics and its location downstream of the sport fishery and known Chinook salmon spawning habitat.

---

[4] In addition, daily ELSD-based estimates of Chinook salmon passage were produced inseason during 2011 based on adaptive ELSD threshold values. These estimates, described by Miller et al (2012: page 18), served as daily proxies for the weekly ELSD-based estimates. Adaptive ELSD threshold estimates are not reported here.

The river bottom in this area has remained stable for the past 25 years (Bosch and Burwen 1999). The slope from both banks is gradual and uniform, which allows a large proportion of the water column to be insonified without acoustic shadowing effects. On the right bank, the bottom is composed primarily of mud, providing an acoustically absorptive surface. This absorptive property improves the signal-to-noise ratio (SNR) when the beam is aimed along the river bottom. The left-bank bottom gradient is steeper and consists of more acoustically reflective small rounded cobble and gravel.

The sonar site is located downstream of the lowest suspected Chinook salmon spawning sites, yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Alexandersdottir and Marsh 1990). Most sport fishing activity occurs upstream of the site[5].

SPLIT-BEAM SONAR

Acoustic Sampling

A Hydroacoustic Technology Inc. (HTI[6]) split-beam sonar system was operated from 16 May to 10 August in 2011. Components of the system are listed in Table 1 and are further described in HTI manuals (HTI 1996-1997).

Sonar System Configuration

Sonar sampling on both banks was controlled by electronics housed in a tent located on the right (north) bank of the river. Communication cables were connected to the sonar equipment on both banks. Cables leading to the left-bank equipment were suspended above the river at a height that would not impede boat traffic (Figure 3). Steel tripods were used to deploy the transducers offshore. One elliptical, split-beam transducer was mounted horizontally (side-looking) on each tripod. At the start of the season, the transducer tripods were placed on each bank in a position close to shore but still submerged at low tide. Throughout the season, water levels at low tide increased approximately 1.7 m. Rising water level and heavy debris accumulation resulted in occasional relocation of transducer tripods. Total range insonified by both (right and left bank) sonar beams ranged from approximately 58.3 m to 68.0 m (Figure 4).

Vertical and horizontal aiming of each transducer was remotely controlled by a dual-axis electronic pan-and-tilt system. A digital readout from an angular measurement device (attitude sensor) attached to the transducer indicated the aiming angle in the vertical and horizontal planes. In the vertical plane, the transducer was aimed using an oscilloscope and chart recorder to verify that the sonar beam was aligned along the river bottom. In the horizontal plane, the transducer was aimed perpendicular to the river flow to maximize probability of insonifying fish from a lateral aspect. The range encompassed by each transducer was determined by the river bottom contour and the transducer placement. Transducers were placed to maximize the counting range and to fully insonify the cross section of the river between the right- and left-bank transducers.

[5] In 2005, approximately 98% of the early-run Chinook salmon sport fishing effort and 86% of the late-run effort occurred upstream of the Chinook salmon sonar site (Eskelin 2007).

[6] Product names used in this publication are included for completeness but do not constitute product endorsement.

River Profile Mapping and Coverage

A detailed profile of the river bottom and the area encompassed by the sonar beams was produced prior to acoustic sampling. Depth readings collected with a Lowrance X-16 were paired with range measurements taken from a Bushnell Laser Ranger (±1 m accuracy) aimed at a fixed target on shore. When bottom profile information is combined with information from the attitude sensor, a detailed visualization of how the acoustic beam insonifies the water column above the bottom substrate can be generated (Figure 5). Each time a transducer was moved, new measurements of the transducer height above the bottom substrate and its position relative to a fixed shore location were updated in an EXCEL worksheet so that beam coverage at the new location could be evaluated.

Before 2001, the right- and left-bank transducers were deployed directly across the river from each other, and complete beam coverage for the entire middle portion of the river was accomplished by extending the counting range for both banks to the thalweg (the line delimiting the lowest points along the length of the river bed). Under these conditions, we could be relatively certain that the entire middle portion of the river was insonified. In 2001, river bottom profiles indicated improved beam coverage (in the vertical plane) could be attained on the left bank by moving the transducer approximately 35 m downstream of its original location (Miller et al. 2003). The left-bank transducer has been deployed at this location since 2001. Because of the offset deployment of the right- and left- bank transducers (Figure 3), it is difficult to determine if there is complete beam coverage[7] (Miller et al. 2004).

Sampling Procedure

A systematic sample design (Cochran 1977) was used to estimate fish passage from each bank for 20 minutes each hour. Although the sonar system is capable of sampling both banks continuously, data collection was restricted to 20 min samples per hour to limit the data processing time and personnel required to estimate daily fish passage. The equipment was automated to sample the right bank for 20 min starting at the top of each hour followed by a 20 min left-bank sample. The system was inactive for the third 20 min period unless ancillary sonar studies were being conducted. This routine was followed 24 hours per day and 7 days per week unless a transducer on one or both banks was inoperable. A test of this sample design in 1999 found no significant difference between estimates of Chinook salmon passage obtained using 1-hour counts and estimates obtained by extrapolating 20 min counts to 1 hour (Miller et al. 2002).

Because fish passage rates are related to tides (Eggers et al. 1995), tide stage was recorded at the top of each hour and at 20 min past each hour to coincide with the start of each 20 min sample. Tide stage was determined using water level measurements taken from depth sensors attached to the sonar transducers.

Data Collection Parameters

An HTI Model 244 digital echo sounder (DES) was used for data collection. Key data collection parameters (echo-sounder settings) are listed in Table 2 with complete summaries by bank in Appendices A1 and A2. Most echo-sounder settings were identical for each bank and remained consistent throughout the sample period. High power and low gain settings were used to

---

[7] For this reason it is possible that some fish migrating near the thalweg (comprising a small fraction of the inriver run) are double-counted or missed entirely.

maximize SNR. The transmitted pulse width was set relatively low to maximize resolution of individual fish and SNR.

Data Acquisition

The DES performed the initial filtering of returned echoes based on user-selected criteria (Table 3, Appendices A1 and A2) that are input via software stored on an external data processing computer (Table 1, Figure 6). The DES recorded the start time, date, and number of pings (acoustic pulses) processed for each sample.

Echoes that originated in the transducer near field (≤2.0 m) were excluded because fluctuating sound intensity near the face of the transducer results in unreliable data (Simmonds and MacLennan 2005). Echoes that exceeded maximum vertical and horizontal angles off axis were also excluded to prevent consideration of unreliable data near the edge of the sonar beam.

Voltage thresholds were used to exclude most background noise from spurious sources such as boat wake, the river bottom, and the water surface. Collection of data from unwanted noise causes data management problems and makes it difficult to distinguish echoes originating from valid fish targets. The level of background noise is determined largely by the dimensions of the sonar beam in relation to the depth of the river. Because the water level at the sonar site is strongly influenced by tidal stage (vertical fluctuations of more than 4 m), the background noise fluctuates periodically, with the lowest noise levels during high tide and the highest levels during falling and low tides. Voltage thresholds corresponding to a –35 dB target on axis were selected for each bank as the lowest thresholds that would exclude background noise at low tide when noise was at a maximum.

For each echo passing initial filtering criteria, the DES wrote information in ASCII file format (*.RAW files). This file provided a record of all raw echo data, which could then be used by other post-processing software. A uniquely-named file was produced for each sample hour. The file stored the following statistics for each tracked echo: 1) distance from the transducer, 2) sum channel voltage produced by the echo, 3) pulse widths measured at −6 dB, −12 dB, and −18 dB down from the peak voltage, 4) up-down (vertical) angle, left-right (horizontal) angle, and 5) multiplexer port.

The sum channel voltage from the DES was also output to a printer, to a Nicolet 310 digital storage oscilloscope, and to a Harp HC2 color chart monitor. Output to the printer was filtered only by a voltage threshold, which was set equal to the DES threshold. Real-time echograms were produced for each sample. The echograms were used for data backup and transducer aiming, and to aid in manual target tracking. Voltage output to the oscilloscope and color monitor was not filtered. Monitoring the unfiltered color echogram ensured that sub-threshold targets were not being unintentionally filtered. Advanced features on the digital oscilloscope aided in performing field calibrations with a standard target and in monitoring the background noise level relative to the voltage threshold level.

Fish Tracking and Echo Counting

Using HTI proprietary software called TRAKMAN 1400 (version 1.31), echoes (from the *.RAW files) were manually grouped (tracked) into fish traces. TRAKMAN produces an electronic chart recording for all valid echoes collected during a 20 min sample. Selected segments of the chart can be enlarged and echoes viewed on a Cartesian grid. Echoes that displayed a sequential progression through the beam were selected by the user and classified into fish traces (targets). TRAKMAN then produced 3 output files. The first file contained each echo that was tracked from a valid target (*.MEC file) and included the following data for each echo: estimated *X* (left-right), *Y* (up-down), and *Z* (distance from the transducer) coordinates in meters where the transducer face is the origin of the coordinate system; pulse widths measured at –6 dB, –12 dB, and –18 dB amplitude levels; combined beam pattern factor in decibels; and target strength in decibels. The second fixed-record ASCII file (*.MFS file) summarized data from all echoes associated with an individual tracked target and output the following fields by target: total number of echoes tracked; starting *X*, *Y*, and *Z* coordinates; distance traveled (m) in the *X*, *Y*, and *Z* directions; mean velocity (m/sec); and mean target strength (dB). The third file was identical to the *.RAW file described earlier except that it contained only those echoes combined into tracked targets. Direction of travel was estimated by calculating the simple linear regression of *X*-axis position (distance up- or downriver from the beam axis) on ping number, for echoes with absolute *X*-axis angle less than 5 degrees. On the right bank, a target was classified as upstream bound if the slope of the regression was negative or downstream bound if the slope was positive. On the left bank, the criteria were reversed. Only upstream bound targets contributed to estimates of Chinook salmon passage. A diagram illustrating data flow can be found in Appendix B1.

Downstream moving targets (and occasionally upstream moving targets during a strong flood tide) were further classified as fish or debris primarily by looking at the angle of passage and degree of movement in the *Z*-axis (distance from transducer) as the target moved through the acoustic beam. For debris, the angle of passage through the beam is constant with little change in the range as it passes through the beam. Consequently, debris resembles a line drawn on the echogram with a straightedge. A fish typically leaves a meandering trace that reflects some level of active movement as it passes through the acoustic beam. Separate summary files were generated for tracked targets classified as debris (i.e., *.DEC and *.DFS files). Except for debris, only targets comprising echoes displaying fish-like behavior were tracked. Echoes from structures, boat wakes, and sport-fishing tackle were ignored.

Data Analysis

Split-beam Sonar Upstream Fish Passage Estimates

The following procedures are used to estimate the number of salmon of all species that migrate upstream past the sonar site in midriver, where midriver is defined as at least 15 m from the right-bank transducer and at least 10 m from the left-bank transducer. This estimate[8] was used as the basis for all other split-beam sonar-based estimates described herein. The remaining estimates pertain only to Chinook salmon, and differ in the manner in which species classification is carried out.

As mentioned above, the split-beam sonar operated 20 minutes per hour from each bank of the river, 24 hours per day. The number of salmon-sized fish (hydroacoustic variable *y*) passing midriver and upstream through the sonar beams during day *i* was estimated as follows:

$$\hat{y}_i = 24\hat{\bar{y}}_i \qquad (1)$$

where

[8] These were known in-house as "unfiltered" estimates in the sense that TS and time-varying range thresholds had not been applied. Technically, these counts were still filtered by time-invariant minimum range criteria to exclude fish close to the transducer. Fish close to the transducer are subject to imperfect detection due to the narrowness of the sonar beams at close range. Traditionally, they have been assumed to be composed almost entirely of sockeye salmon.

$$\hat{\bar{y}}_i = \frac{1}{n_i}\sum_{j=1}^{n_i}\hat{y}_{ij} \qquad (2)$$

and where n_i is the total number of hours (j) during which fish passage was estimated[9] for day i, and

$$\hat{y}_{ij} = \sum_{k=1}^{2}\hat{y}_{ijk} \qquad (3)$$

where $\hat{y}_{ijk}$ is the estimate of upstream midriver fish passage on bank k during hour j of day i.

When the sonar was functional on bank k during hour j of day i, then hourly upstream midriver fish passage was estimated as follows:

$$\hat{y}_{ijk} = \frac{60}{m_{ijk}}c_{ijk} \qquad (4)$$

where

m_{ijk} = number of minutes (usually 20) sampled from bank k during hour j of day i, and

c_{ijk} = number of upstream bound fish greater than 15 m from the right-bank transducer and greater than 10 m from the left-bank transducer, for bank k, hour j, and day i.

When the sonar system was functional on one bank but not the other, the passage on the non-functional bank k' was estimated from passage on the functional bank k as follows:

$$\hat{y}_{ijk'} = \hat{R}_{ikt}\hat{y}_{ijk} \qquad (5)$$

where the estimated bank-to-bank ratio R_{ikt} for day i and tide stage t is calculated by pooling counts from all hours at tide stage t (set J_t) during the previous 2 days (to ensure adequate sample size):

$$\hat{R}_{ikt} = \frac{\sum_{j\in J_t}\hat{y}_{(i-2)jk'} + \sum_{j\in J_t}\hat{y}_{(i-1)jk'}}{\sum_{j\in J_t}\hat{y}_{(i-2)jk} + \sum_{j\in J_t}\hat{y}_{(i-1)jk}}. \qquad (6)$$

The variance of the estimates of y, due to systematic sampling in time, was approximated (successive difference model, Wolter 1985) with adjustments for missing data as follows:

$$\hat{V}[\hat{y}_i] \cong 24^2(1-f)\frac{\sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}\left(\hat{y}_{ij}-\hat{y}_{i(j-1)}\right)^2}{2\sum_{j=1}^{24}\phi_{ij}\sum_{j=2}^{24}\phi_{ij}\phi_{i(j-1)}} \qquad (7)$$

where f is the sampling fraction (proportion of time sampled daily, usually 0.33), and ϕ_{ij} is 1 if $\hat{y}_{ij}$ exists for hour j of day i, or 0 if not.

---

[9] Hours for which passage is *not* estimated include hours when equipment on both banks was not functional (<1% of time).

The total estimate of upstream midriver fish passage during the period of sonar operation, and its variance, was the sum of all daily estimates:

$$\hat{Y} = \sum_i \hat{y}_i \tag{8}$$

and

$$\hat{V}\left[\hat{Y}\right] = \sum_i \hat{V}\left[\hat{y}_i\right]. \tag{9}$$

Split-beam Sonar Net-Apportioned Chinook Salmon Passage Estimates

The "net-apportioned" daily estimate of Chinook salmon passage was calculated by multiplying the upstream midriver fish passage estimate by the estimated proportion of Chinook salmon ($\hat{\pi}_{NETi}$) in 5-inch and 7.5-inch drift net catches near the sonar site (Perschbacher 2012) [10]:

$$\hat{y}_{NETi} = \hat{y}_i \hat{\pi}_{NETi}. \tag{10}$$

The variance estimate followed Goodman (1960):

$$\hat{\text{var}}\left(\hat{y}_{NETi}\right) = \hat{y}_i^2 \ \hat{\text{var}}\left(\hat{\pi}_{NETi}\right) + \hat{\pi}_{NETi}^2 \ \hat{\text{var}}\left(\hat{y}_i\right) - \hat{\text{var}}\left(\hat{\pi}_{NETi}\right)\hat{\text{var}}\left(\hat{y}_i\right). \tag{11}$$

Split-beam Sonar Echo Length Standard Deviation (ELSD)-based Chinook Salmon Passage Estimates

Alternative estimates based on echo length standard deviation were first produced in 2002, based on work initiated in the mid-1990s that showed ELSD to be a better predictor of fish size than target strength (Burwen et al. 2003). ELSD-based estimates were generated by fitting a statistical species–age mixture model to sonar and netting data. Mixture model methodology is described below.

Mixture Models[11]

Mixture models are useful for extracting information from the observed frequency distribution of a carefully selected measurement. For example, if one were able to observe the exact length, but not the species, of every fish passing the sonar, the distribution of such measurements might look like Figure 7a. With auxiliary information about sockeye and Chinook salmon size, the shape of such a distribution can reveal much about the relative abundance of sockeye and Chinook salmon. For instance, if sockeye salmon were known not to exceed 70 cm, and small Chinook salmon were known to be rare, one could conclude that the left hand mode of the distribution is almost all sockeye salmon and that the species composition is perhaps 50:50 sockeye salmon to Chinook salmon. Mixture model analysis is merely a quantitative version of this assessment in which the shape of the overall frequency distribution is modeled and "fitted" until it best approximates the data. Uncertainty is assessed by providing a range of plausible species compositions that could have resulted in the observed frequency distribution.

---

[10] In 2011, the inriver netting program was designed to sample the river corridor insonified by the split-beam sonar (Perschbacher 2012).

[11] Statistical notation in this section may overlap with the notation used in the remainder of the report. Specifically, the meaning of variables *x*, *y*, and *z* are unique to this section.

As another example, imagine that many Chinook salmon are small, and that there is error in the length measurements. The effect of the measurement error is to cause the modes of the distribution to begin to overlap, reducing the ability to detect detail in the length distribution and reducing the precision of the estimates (e.g., Figure 7b). Under this scenario, it is more difficult to interpret the data, and a mixture model approach is helpful to provide objective estimates with realistic assessments of uncertainty.

Mixture models can also be fit to measurements of other quantities, like ELSD, that are related to length. Given quantitative knowledge of the relationship between length and ELSD (gleaned from tethered fish experiments, Burwen et al. 2003), it is straightforward to convert from length units to ELSD units by including the slope, intercept, and mean squared error of the relationship in the mixture model (Equation 14 below). The more closely related the surrogate measurement is to the one of interest, the more the two distributions will resemble each other and the better the resulting estimate will be. Because ELSD is a reasonably good predictor of fish length (Figure 8)[12], the observed frequency distribution of ELSD supplies valuable information about species composition, even though there is some overlap of ELSD measurements between species. An ELSD distribution with greater mass on the left-hand side indicates an abundance of sockeye salmon, whereas more mass on the right-hand side indicates more Chinook salmon (Figure 9).

The mixture model approach explicitly incorporates the expected variability in hydroacoustic measurements (known from tethered fish experiments), as well as current information about fish size distributions (from the onsite netting program).

Echo length standard deviation (ELSD) was calculated as follows:

$$ELSD = \sqrt{\sum_{j=1}^{n_E} \left(EL_j - \overline{EL}\right)^2 \Big/ \left(n_E - 1\right)} \qquad (12)$$

where n_E is the number of echoes and EL_j is the length of the j^{th} echo measured in 48 kHz sample units at –12 dB or higher, depending on peak echo amplitude. If peak amplitude was greater than 12 dB above the voltage threshold, then echo length was measured at 12 dB below peak amplitude. If peak amplitude was 6–12 dB above the threshold, echo length was measured at the threshold. If peak amplitude was less than 6 dB above threshold, EL_j was not defined.

Fish traces with fewer than 8 defined measurements of –12dB pulse width ($n_E < 8$) were excluded from the mixture model; they were assumed to be sockeye salmon because they generally occurred at close ranges, where the beam is very narrow. These fish generally comprised only 1–3% of all fish in the dataset.

The probability density function (PDF) of ELSD (denoted here as y, for convenience) was modeled as a weighted mixture of 2 component distributions arising from sockeye salmon and Chinook salmon (Figure 10):

$$f(y) = \pi_S f_S(y) + \pi_C f_C(y) \qquad (13)$$

where $f_S(y)$ and $f_C(y)$ are the PDFs of the sockeye salmon and Chinook salmon component distributions, and the weights π_S and π_C are the proportions of sockeye salmon and Chinook salmon in the population.

[12] ELSD can be a good predictor of length, though not as precise as the DIDSON length estimates.

Individual observations of y for fish i were modeled as normal random variables whose mean is a linear function of fish length x:

$$y_i = \beta_0 + \beta_1 x_i + \gamma z_i + \varepsilon_i \tag{14}$$

where β_0 is the intercept; β_1 the slope; γ is the mean difference in y between sockeye salmon and Chinook salmon after controlling for length; z_i equals 1 if fish i is a sockeye salmon, or 0 if Chinook salmon; and the error ε_i is normally distributed with mean 0 and variance σ^2.

Thus, the component distributions $f_S(y)$ and $f_C(y)$ are functions of the length distributions $f_S(x)$ and $f_C(x)$ and the linear model parameters β_0, β_1, γ, and σ^2 (Figure 10). The species proportions π_S and π_C were the parameters of interest.

Length measurements were obtained from fish captured by gillnets (Eskelin 20102) immediately downstream of the sonar site. In 2011, the netting program was designed to sample the river corridor insonified by the split-beam sonar. Length data from the nets were paired with hydroacoustic data from the same time periods.

Sockeye salmon and Chinook salmon return from the sea to spawn at several discrete ages. We modeled sockeye salmon and Chinook salmon length distributions as 3-component normal age mixtures:

$$f_S(x) = \theta_{S1} f_{S1}(x) + \theta_{S2} f_{S2}(x) + \theta_{S3} f_{S3}(x) \tag{15}$$

$$f_C(x) = \theta_{C1} f_{C1}(x) + \theta_{C2} f_{C2}(x) + \theta_{C3} f_{C3}(x) \tag{16}$$

where θ_{Ca} and θ_{Sa} are the proportions of Chinook salmon and sockeye salmon belonging to age component a and the distributions

$$f_{Sa}(x) \sim N(\mu_{Sa}, \tau^2_{Sa}), \text{ and} \tag{17}$$

$$f_{Ca}(x) \sim N(\mu_{Ca}, \tau^2_{Ca}) \tag{18}$$

where μ is mean length-at-age and τ is the standard deviation. The overall design was therefore a mixture of (transformed) mixtures. That is, the observed hydroacoustic data were modeled as a 2-component mixture (sockeye salmon and Chinook salmon) of echo length standard deviation (y), each component of which was transformed from a 3-component normal age mixture of fish length (x).

Bayesian statistical methods were employed because they provided realistic estimates of uncertainty and the ability to incorporate auxiliary information. We implemented the Bayesian mixture model in WinBUGS (Bayes Using Gibbs Sampler; Gilks et al. 1994). Bayesian methods require that prior probability distributions be formulated for all unknowns in the model (Gelman et al. 2004). Species proportions π_S and π_C were assigned an uninformative Dirichlet (1,1) prior. Age proportions $\{\theta_{Sa}\}$ and $\{\theta_{Ca}\}$ were assigned informative Dirichlet priors based on a hierarchical analysis of historical data (Appendix C1). Likewise, informative normal priors based on historical data were used for the length-at-age means μ and standard deviations τ (Appendix C1). A linear statistical model of tethered fish data (Burwen et al. 2003) was integrated into the mixture model (Appendix C1) to provide information on regression parameters β_0, β_1, γ, and σ^2.

WinBUGS uses Markov chain Monte Carlo methods to sample from the joint posterior distribution of all unknown quantities in the model. A single Markov chain[13] was initiated for each daily run of the model, samples were thinned 20 to 1, and history plots were monitored to confirm convergence and mixing. The first 4,000 or more "burn-in" samples were discarded, and at least 20,000 additional samples were drawn from the posterior distribution.

The end product of a Bayesian analysis is the joint posterior probability distribution of all unknowns in the model. For point estimates, posterior means were used. Posterior standard deviations were reported as analogues to the standard error of an estimate from a classical (non-Bayesian) statistical analysis.

Sample size limitations necessitated pooling data from the first week of operation (16–22 May). Netting length data from day d and $d-1$ were paired with ELSD data from day d. WinBUGS code for the ELSD mixture model is in Appendix C2. Figure 10 is a flow chart with major components of the ELSD mixture model. See also Fleischman and Burwen (2003).

ELSD-based Chinook Salmon Passage Estimates[14]

ELSD mixture model estimates of daily Chinook salmon passage were obtained as follows. First, the proportion p_{Mi} of sonar-sampled fish that satisfied the sample size criterion ($n_E \geq 8$) and the proportion p_{Bi} that satisfied the behavior criterion (fish could not be less than 1 m of range from another fish) for day i were calculated. Then the ELSD frequency distribution from fish meeting both criteria was analyzed with the mixture model methods described above, yielding $\hat{\pi}_{Ci}$, the posterior mean of the Chinook salmon fraction in the reduced data set for day i.

The estimated number of Chinook salmon passing during day i was then

$$\hat{y}_{ELi} = \hat{y}_i \hat{\pi}_{Ci} p_{Mi} p_{Bi} \tag{19}$$

with estimated variance

$$\hat{\text{var}}(\hat{y}_{ELi}) = \left[\hat{y}_i^2 \, \hat{\text{var}}(\hat{\pi}_{Ci}) + \hat{\pi}_{Ci}^2 \, \hat{\text{var}}(\hat{y}_i) - \hat{\text{var}}(\hat{\pi}_{Ci}) \hat{\text{var}}(\hat{y}_i)\right] \hat{p}_{Mi}^2 \hat{p}_{Bi}^2 \tag{20}$$

where $\hat{\text{var}}(\hat{\pi}_{Ci})$ is the squared posterior standard deviation from the mixture model. Uncertainty about p_{Mi} and p_{Bi} was ignored because it was negligible compared to $\hat{\text{var}}(\hat{\pi}_{Ci})$.

DUAL-FREQUENCY IDENTIFICATION SONAR (DIDSON)

Acoustic Sampling

A Sound Metrics Corporation (SMC[15]) DIDSON system was operated from 16 May to 10 August 2011. Components of the DIDSON system are listed in Table 4. Appendix D1 provides greater detail on DIDSON technology and theory.

Sonar System Configuration

As in 2010, DIDSON transducers were deployed on both banks of the river, mounted in a side-by-side configuration with the split-beam transducer on the same pan-and-tilt aiming device

---

[13] During initial development of the model, multiple chains were used to assess convergence (Gelman et al. 2004). This was not necessary during production of daily estimates.

[14] These were termed "behavior-censored ELSD-based estimates" in a previous report (Miller et al. 2012).

[15] Product names used in this publication are included for completeness but do not constitute product endorsement.

(Figure 11, panels A and B). The DIDSON was subject to the same deployment configuration and aiming protocol described above for the split-beam transducer with one exception, the DIDSON was aimed at a vertical angle approximately 1 degree lower than the split-beam sonar to achieve better image quality. Because silt deposition in the lens compartment can cause deterioration in both image quality and range capabilities, a custom fit fabric enclosure was used to limit silt infiltration (Figure 11, panels B and C).

During 20–26 July 2011, an additional DIDSON transducer was deployed to insonify 10 m of range behind (shoreward of) the existing left-bank transducer.

Sampling Procedure

Unlike the split-beam sonar, DIDSON sampled 3 separate range strata on each bank to increase resolution (3.3–13.3 m, 13.3–23.3 m, and 23.3–33.3 m, Figure 12). The DIDSON was programmed to sample each stratum systematically for 10 min per hour according the schedule outlined in Figure 13.

Data Collection Parameters

The transmit power of the DIDSON sonar was fixed, and receiver gain was maximized (40 dB) during all data collection. The autofocus feature was enabled so that the sonar automatically set the lens focus to the midrange of the selected display window (e.g., for a window length of 10 m that started at 15 m, the focus range would be 20 m). The frame rate (frame per second, or fps) varied for each range stratum: 12 fps for the 3.3–13.3 m stratum, 7 fps for the 13.3–23.3 m stratum, and 5 fps for the 23.3–33.3 m stratum.

Manual DIDSON Fish Length Measurements

Software included with the DIDSON system (Control and Display software Version 5.25) was used to count and measure fish from DIDSON images. Electronic echograms similar to those generated from split-beam data provided a system to manually count, track, and size individual fish (Figure 12). Noise from stationary structures was removed from the images using Sound Metric Corporation's algorithm for dynamic background removal. Fish traces displayed on the echogram could also be displayed in video mode through a toggle function (Figure 12). In video mode, technicians used the manual measuring tools to estimate the DIDSON-based length (DL) for each fish. Date, time, frame number, range, and direction of travel were also recorded for each free-swimming fish.

During 23–25 July, when it became impractical to measure every fish recorded by the DIDSON, a "Fast-Track" sampling protocol was adopted, and fish measuring less than 75 cm (DL) were counted but not measured.

Additional detail on procedures and software settings used to obtain manual fish length measurements can be found in Burwen et al. (2010) and in Appendices D1–D8.

Data Analysis

DIDSON-based Estimates of Fish Passage

DIDSON data were used to generate multiple estimates of fish passage, detailed below. All estimates apply to a midriver corridor greater than 3 m from both the left- and right-bank transducers. Note that this corridor was 19 m wider than that covered by split-beam sonar, which was greater than 15 m from the right-bank transducer and greater than 10 m from the left-bank transducer. Except where otherwise stated, all estimates apply to upstream migrating fish only.

DIDSON salmon passage estimates

The DIDSON sample design differed from split-beam sonar in that there were 3 spatial strata on each bank[16]. The number of salmon of all species exceeding 40 cm[17] that migrate upstream past the sonar site in midriver at least 3 m from the face of each sonar on day *i* was estimated following Equations 1–2, where upstream midriver fish passage on bank *k* during hour *j* of day *i* (in Equation 3) was estimated as follows:

$$\hat{y}_{ijk} = \sum_{s=1}^{3} \hat{y}_{ijks} \tag{21}$$

where $\hat{y}_{ijks}$ is the estimate of upstream midriver fish passage for stratum *s* of bank *k* during hour *j* of day *i*.

When the sonar was functional on bank *k* during hour *j* of day *i*, hourly upstream midriver fish passage for stratum *s* was estimated as follows:

$$\hat{y}_{ijks} = \frac{60}{m_{ijks}} c_{ijks} \tag{22}$$

where

m_{ijks} = number of minutes (usually 10) sampled from bank *k* stratum *s* during hour *j* of day *i*, and

c_{ijks} = number of upstream bound fish greater than 40 cm in stratum *s* of bank *k* during hour *j* of day *i*.

When the DIDSON was functional on one bank but not the other, the passage on the nonfunctional bank was estimated from passage on the functional bank following Equations 5 and 6.

The variance followed Equation 7, and seasonal totals followed Equations 8 and 9 as before.

DIDSON Chinook salmon passage estimates

The number of Chinook salmon passing upstream on day *i* was estimated by multiplying the DIDSON midriver upstream salmon passage estimate *y* by the estimated proportion of Chinook salmon ($\hat{\pi}_{Ci}$) derived by fitting the DIDSON length mixture model described below:

$$\hat{z}_i = \hat{y}_i \hat{\pi}_{Ci}. \tag{23}$$

Variance estimates follow Goodman (1960):

$$\hat{\text{var}}(\hat{z}_i) = \hat{y}_i^2 \,\hat{\text{var}}(\hat{\pi}_{Ci}) + \hat{\pi}_{Ci}^2 \,\hat{\text{var}}(\hat{y}_i) - \hat{\text{var}}(\hat{\pi}_{Ci})\hat{\text{var}}(\hat{y}_i). \tag{24}$$

[16] Different focus settings are required for short, medium, and long ranges in order to produce high-resolution images.

[17] As measured from the DIDSON image. This quantity is intended to separate salmon from non-salmon species. It also corresponds approximately to the smallest fish gilled in the inriver netting project (Perschbacher 2012).

Cumulative estimates were obtained by summing daily estimates and variances.

DIDSON length mixture model estimates of species composition

DIDSON-based estimates of the proportion of passing fish that were Chinook salmon were obtained by fitting a mixture model to DIDSON length data. The mixture model was identical to the ELSD mixture model (Methods, Split-beam Sonar, under Mixture Models section beginning p.12) except that DIDSON length was substituted for ELSD and there was no γ parameter in the model. Thus the following was substituted for Equation 14:

$$y_i = \beta_0 + \beta_1 x_i + \varepsilon_i . \tag{25}$$

A subset[18] of tethered fish data from 2007 DIDSON experiments (Burwen et al. 2010) provided a mildly informative prior for the β_0 and β_1 parameters. Species proportions π_C and π_S were assigned a Dirichlet (0.1,0.9) prior[19]. Prior distributions for age proportions $\{\theta_{Ca}\}$ and $\{\theta_{Sa}\}$ were constructed with nested beta (0.5,0.5) prior distributions. Netting probability of capture was assumed to be equal for all 3 age classes. Netting length data (Perschbacher 2012) from days $d-3$ through $d+3$ were paired with DIDSON length data from day d[20].

On 23–25 July, "Fast-Tracked" fish judged to be less than 75 cm, but not measured, were modeled as having come from a censored sample. A test conducted on 2010 data found extremely good agreement between Chinook proportions estimated with standard vs fast-track protocols[21].

A single Markov chain[22] was initiated for each daily run of the model, samples were thinned 10 to 1, and history plots were monitored to confirm convergence and mixing. The first 5,000 or more "burn-in" samples were discarded, and at least 10,000 additional samples were drawn from the posterior distribution.

WinBUGS code for the DIDSON length mixture model is in Appendix C3. Model statements for censored observations under fast-track protocol are in the last paragraph of Appendix C4.

As with the ELSD mixture model results, posterior means are reported herein as point estimates, and posterior standard deviations as standard errors.

Some of the methodological details used for this report differ from those used to produce preliminary 2010 and 2011 mixture model estimates that were reported elsewhere (Fleischman and McKinley 2013: Table 4; and McKinley and Fleischman 2013: Table 5). These modifications are documented in Appendix E1.

---

[18] Mixture model results were more robust to length measurement error if only a minimal number of tethered fish data points was used.

[19] This is a very mildly informative prior distribution, equivalent to a single additional observation and centered on 10% Chinook salmon rather than 50% for the noninformative beta (0.5,0.5).

[20] Netting sample-size limitations were addressed differently between the ELSD and DIDSON-length mixture models. The ELSD model employed informative priors on age composition, developed from a hierarchical analysis of historical netting data. The DIDSON length model assigned noninformative priors to age composition parameters, but pooled 7 days of netting data centered on the current day to pair with a single day of DIDSON length data.

[21] Twenty-nine days with uncensored data between 4 July and 4 August 2010 were censored and reanalyzed with fast-track protocol, yielding a 0.9994 to 1.0 relationship with a coefficient of determination of 0.998.

[22] During initial development of the model, multiple chains were used to assess convergence (Gelman et al. 2004). This was not necessary during production of daily estimates.

DIDSON-length threshold large fish midriver passage estimates

Upstream large fish passage in midriver during day *i* was calculated following Equations 1–9 after redefining c_{ijk} in Equation 4 to be the number of upstream bound fish greater than 3 m from the right- and left-bank transducers exceeding 75 cm in length as measured by the DIDSON during t_{ijk}.

DIDSON-length threshold large fish passage behind left bank transducer

Data were collected 20–26 July 2011 with an additional DIDSON transducer deployed behind (shoreward of) the existing left-bank transducer. Fish exceeding 75 cm DIDSON length were tallied by direction of travel for comparison with midriver results.

RESULTS

SPLIT-BEAM SONAR

Split-beam Sonar ELSD-based Estimates of Upstream Fish Passage

Daily split-beam estimates of upstream fish passage were generated for 16 May through 10 August. A total of 673 hours of split-beam acoustic data were processed from the right bank and 664 hours from the left bank during the 87-day season. This represented 32% of the total available sample time (2,088 hours) for each bank.

Note that all split-beam fish passage estimates apply to a corridor in midriver that is greater than 15 m from the right-bank transducer and greater than 10 m from the left-bank transducer. This differs from the wider DIDSON corridor, which consists of all ranges greater than 3 m from both transducers.

ELSD-based estimates of upstream Chinook salmon passage were 10,561 (SE 393) fish during the early run and 37,261 (SE 2,057) fish during the late run (Tables 5 and 6). Peak daily passage based on ELSD mixture-model estimates occurred on 9 June during the early run and 17 July during the late run. All historical daily ELSD-based estimates for the years 2002–2011 are compiled in Appendices F1 and F2.

Split-beam Sonar Net-apportioned Estimates of Chinook Salmon Passage

Net-apportioned estimates of upstream Chinook salmon passage were 4,041 (SE 273) fish during the early run and 18,766 (SE 1,421) fish during the late run (Tables 5 and 6). Peak daily passage based on net-apportioned estimates occurred on 30 June for the early run and 23 July for the late run.

DUAL-FREQUENCY IDENTIFICATION SONAR (DIDSON)

Long-range high-resolution DIDSON was deployed from both banks and sampled the midsection of the river for 87 days (16 May–10 August) in 2011. Fish measurement data were missing or unreliable during 1% of early-run and 3% of late-run samples, which was a large improvement over 2010 (32% and 7%, respectively), when frequent focus-related problems caused degraded image resolution. In total, 81,198 fish 40 cm or longer were measured from DIDSON images. Such fish are often referred to generically as "salmon" in this report[23].

Size Distribution and Species Composition

Small fish (presumably sockeye salmon) predominated in both early and late runs, as evidenced by large left-hand modes in the DIDSON length (DL) frequency distributions (Figure 14, top panels). The modes of the DL distributions line up well[24] with mid eye to tail fork (METF) length distributions from salmon measured by the inriver netting project (Figure 14, bottom panels). The DL distributions are broader than the corresponding METF distributions because there is greater error associated with measuring length from DIDSON images. The shapes of the frequency distributions suggest that fish measuring greater than approximately 75–80 cm are probably Chinook salmon. Of fish measuring 40 cm or longer, 4.8% were 75 cm or longer and 4.1% were 80 cm or longer. In this report, "large Chinook salmon" are defined as fish greater than 75 cm DIDSON length[25].

Spatial and Temporal Distribution

During the early run, salmon of all sizes favored the left bank of the insonified zone (Figure 15). During the late run, large Chinook salmon continued to favor the left bank, but small salmon, especially during falling and rising tides, favored the right bank (Figure 15). During both the early and late runs, most (60–72%) upstream bound large (DL $\geq$ 75 cm) Chinook salmon were observed from the left-bank transducer (Table 7).

Relatively more large Chinook salmon migrated in strata further from shore in 2011. Distribution by range stratum (3–13 m, 13–23 m, and 23–33 m) was 27%, 33%, and 40%, respectively in the early run and 26%, 32%, and 42%, respectively during the late run (derived from summed values for left and right banks in Table 7). The temporal distribution of large Chinook salmon among tide stages differed by run, from 22%, 50%, and 28% on the rising, falling, and low tides, respectively during the early run to 34%, 47%, and 19%, respectively during the late run (Table 7, last column). The natural distribution of tide stages was 28% rising, 48% falling, and 23% low; comparing this to the tidal distribution of salmon (quoted above from Table 7) indicates that large Chinook salmon displayed slight "preferences" for the low tide in the early run and for the rising tide in the late run.

The proportion of all upstream-bound salmon that were classified as large Chinook salmon (≥75 cm DL) varied by run, bank, range stratum, and tide stage (Table 8). A greater proportion of salmon were large Chinook salmon in the early run (8.3%) than in the late run (4.0%). During the early run, relatively more salmon were large Chinook salmon on the right bank (11.1%) than on the left bank (7.6%), with the highest fraction (12.2%) occurring in the offshore right-bank stratum (Table 8). During the late run, when small salmon often favored the right bank (Figure 15, as mentioned above), relatively more salmon were large Chinook salmon on the left bank

---

[23] A minimum threshold of 40 cm includes virtually all Chinook salmon and effectively excludes nonsalmon species. For example, among Chinook salmon caught in gillnets at RM 8.5 in 2010, only 1% were less than 40 cm mid eye to tail fork. The proportion of fish over 40 cm that were not salmon was not estimated because nonsalmon species were not measured; however the fraction was very small.

[24] Lengths from the netting data are not representative across species because non-Chinook salmon were sampled (measured) at only one-half the rate of Chinook salmon. Chinook salmon are therefore disproportionately represented in the netting length data.

[25] Although the species of individual fish cannot be determined with certainty from DIDSON images, probably only a very few fish longer than DL = 75 cm are not Chinook salmon.

(6.0%) than on the right bank (2.6%), with the highest fraction (7.3%) occurring in the offshore left-bank stratum.

During the early run, upstream moving salmon that passed during rising tide had the highest fraction of large Chinook salmon (12.1%), followed by the low tide (8.0%), and the falling tide (7.5%) (Table 8). During the late run, fish migrating during low tide were composed of 6.4% large Chinook salmon, followed by 4.7% during the rising tide, and 3.1% during the falling tide (Table 8).

Spatial and temporal patterns of migration of small, medium, and large salmon are displayed relative to tide stage in Appendices G1–G7. In general, Chinook salmon greater than 75 cm DL were interspersed throughout the sampled range and were only mildly clustered in space and time. Smaller salmon exhibited more clustering than did large Chinook salmon, and their migration timing was strongly influenced by the tide cycle (Appendices G1–G7).

Direction of Travel

Among fish that were greater than or equal to 75 cm DIDSON length (DL), 93.7% were upstream bound in the early run, and 93.8% were upstream bound in the late run (Appendices H1 and H2). Daily percentages of fish greater than 75 cm DL that were upstream bound ranged from 50% (20 May; 1 of 2 fish) to 100% (many days; Appendices H1 and H2).

DIDSON Estimates of Upstream Salmon Passage

Daily DIDSON estimates of upstream salmon passage (Tables 9 and 10) averaged 2.65 times the corresponding split-beam sonar estimates of upstream fish passage (Figure 16). This difference can be attributed partially to the greater ability of the DIDSON to distinguish individual fish migrating in dense schools, which was responsible for a 49% increase in daily estimates (Figure 16). In addition, the DIDSON was able to count and measure fish as close as 3 m from the DIDSON transducer, compared to 10 m (left bank) or 15 m (right bank) from the split-beam transducer, yielding an additional 19 m of insonified range and an additional 78% increase (2.65/1.49) in total salmon passage estimates (Figure 16).

DIDSON Estimates of Midriver Chinook Salmon Passage

Daily proportions of upstream bound salmon that were Chinook salmon were estimated using a DIDSON-length (DL) mixture model (Methods, DIDSON, DIDSON length mixture model estimates of species composition section, page 18; Tables 9 and 10). These proportions, which ranged from 1.5% on 20 July to 80.6% on 16 May, were multiplied by DIDSON estimates of upstream salmon passage to produce DIDSON estimates of upstream Chinook salmon passage: 7,366 (SE 318) Chinook salmon during the early run (16 May–30 June) and 23,713 (SE 725) during the late run (1 July–10 August; Tables 9 and 10). The DL mixture model also produced daily estimates of Chinook salmon age composition (Tables 11 and 12). These estimates incorporated length information from DIDSON as well from inriver gillnet catches. The DIDSON-based estimates are germane to a midriver water column located between and at least 3 m from the transducers at RM 8.5. They supplant the preliminary numbers reported by Fleischman and McKinley (2013: Table 4) and McKinley and Fleischman (2013: Table 5)[26].

[26] Several technical modifications were made to mixture model methodology since preliminary estimates were published in 2013. A list of these modifications can be found in Appendix E1.

DIDSON-length Threshold Large Fish Midriver Passage Estimates

Daily "threshold" estimates of fish equal or exceeding DIDSON lengths of 75 cm, 80 cm, and 90 cm were also produced (Appendices I1 and I2). A DIDSON length of 90 cm corresponds approximately to the boundary between age-5 and age-6 Chinook salmon[27].

DIDSON-length Threshold Large Fish Passage Behind Left Bank Transducer

During 20–26 July 2011, an additional DIDSON transducer insonified 10 m of range behind (shoreward of) the existing left-bank transducer. Relative to large fish detected midriver using the standard configuration, the extra coverage resulted in detecting 9% more fish greater than 75 cm DL for the 7-day trial period, and in 14% more fish greater than 90 cm DL. During the 7-day trial, downstream-bound fish comprised 3% of total fish greater than 75 cm, both behind the transducer and in midriver. Spatial and temporal distribution of fish during the 20–26 July trial is depicted in Figure 17.

DISCUSSION AND RECOMMENDATIONS

After 10 years of onsite experience, it has been well established that DIDSON represents a substantial improvement over split-beam technology for assessing Chinook salmon abundance in the Kenai River (Burwen et al. 2007; Miller et al. 2012; Miller et al. 2013). DIDSON provides more accurate measurements of fish size (Figure 18), and is thus better able to distinguish large from small fish (Figure 14; Miller et al. 2013: Figure 23). DIDSON is also better at tracking individual fish of all sizes, preventing misclassification of multiple small fish as single large fish (e.g., Figure 19).

Split-beam ELSD-based estimates, which had previously been demonstrated to be an improvement upon the discontinued TS-based estimates (Burwen et al. 2003; Miller et al. 2013), did not perform well in 2011. For the second year in a row, ELSD-based estimates were much higher (43% for the early run and 57% for the late run) than DIDSON-based estimates (Tables 5, 6, 9, and 10), despite being germane to a smaller spatial subset of the river cross-section[28]. Subsequent analyses (McKinley and Fleischman 2013; Fleischman and McKinley 2013) confirmed that ELSD-based estimates were anomalously high compared to reconstructed run abundance in 2010 and 2011 (Appendices J1 and J2). Possible reasons for anomalously high ELSD-based estimates were discussed by Miller et al. (2013: p. 29).

DIDSON-based estimates provide a useful standard of comparison for other measures of Chinook salmon abundance. In 2011, daily values of inriver gillnetting CPUE, net-apportioned estimates, and sport fishery CPUE tracked DIDSON with varying degrees of accuracy (Figures 20, 21, and 22). As more index data are collected concurrent with DIDSON data, it will be possible to more thoroughly evaluate their strengths and weaknesses, and to identify confounding influences.

Significant numbers of large Chinook salmon were detected migrating near shore during a 7-day trial of an additional DIDSON transducer deployed shoreward of the existing left-bank transducer. This confirms that some Chinook salmon migrate undetected by the usual sonar transducer configuration and unsampled by the inriver netting project. Therefore, the DIDSON-based estimates of inriver abundance reported herein are biased low by an unknown amount.

---

[27] Ages are total age from spawning event to spawning migration.
[28] In 2010, ELSD-based estimates were 45% (early run) to 79% higher (late run) than DIDSON-based estimates (Miller et al. 2013).

RECOMMENDATIONS

Continue to produce DIDSON-based estimates and supply these estimates to fishery managers. The 2011 season confirmed that DIDSON can assess the abundance of Kenai River Chinook salmon in the presence of more numerous sockeye salmon. New escapement goals based on these DIDSON estimates of abundance will be required.

Continue to operate the inriver netting project in the same standardized protocol as has been practiced since 2002. Consistent data produced by this project may continue to prove valuable for reconstructing historical abundance.

Discontinue split-beam sonar in 2012. ELSD-based estimates failed to detect small runs of Chinook salmon in 2010 and 2011 (Appendices J1 and J2). Given that the methodology for producing daily DIDSON estimates is now well established, and that net-apportioned estimates can also be produced with DIDSON, split-beam sonar provides no important additional information. Resources devoted to split-beam operation[29] would be better spent further refining DIDSON methodology and investigating ways to count all migrating large salmon. Sonar deployment and aim could also be optimized for DIDSON.

Conduct further investigations of Chinook salmon migrating upstream behind the usual transducer placements. Comparisons of the relative abundance of nearshore migrants between runs and between banks would be especially valuable.

Investigate the feasibility of moving the sonar to a site upstream of tidal influence where all migrating fish could be counted. Reconnaissance of potential new sites should be conducted in 2012.

ACKNOWLEDGEMENTS

We would like to thank Mark Jensen for his assistance in overseeing the day-to-day operation of the project, for providing computer programming and networking support, and for his assistance in processing and analyzing data. We would also like to thank Mike Hopp, Brandon Key, Thomas Hammelman, and Spring Sibayan for meticulously collecting the sonar data and for their high level of motivation throughout the long field season. Trevor Davis and Kara Bethune spent many hours processing DIDSON data and collecting fish image measurements. We would like to express our gratitude to Melissa Brown with Hi-Lo Charters for allowing us to use her dock for project deployment and breakdown. Finally, thanks to Division of Sport Fish staff in Soldotna who provided logistical support throughout the season.

[29] Considerable staff time is required for tracking and processing split-beam data. Also, without split-beam sonar, it would no longer be necessary to stretch a cable across the river.

REFERENCES CITED

Alexandersdottir, M., and L. Marsh. 1990. Abundance estimates of the escapement of Chinook salmon into the Kenai River, Alaska, by analysis of tagging data, 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-55, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds90-55.pdf

Benke, A. C., and C. E. Cushing. 2005. Rivers of North America. Elsevier Academic Press, Burlington, Massachusetts.

Bernard, D. R., and P. A. Hansen. 1992. Mark-recapture experiments to estimate the abundance of fish: a short course given by the Division of Sport Fish, Alaska Department of Fish and Game in 1991. Alaska Department of Fish and Game, Special Publication No. 92-4, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/sp92-04.pdf

Bosch, D., and D. Burwen. 1999. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 1997. Alaska Department of Fish and Game, Fishery Data Series No. 99-3, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds99-03.pdf

Bosch, D., and D. Burwen. 2000. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 00-12, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds00-12.pdf

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

Burwen, D., and D. Bosch. 1998. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 1996. Alaska Department of Fish and Game, Fishery Data Series No. 98-2, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds98-02.pdf

Burwen, D., J. Hasbrouck, and D. Bosch. 2000. Investigations of alternate sites for Chinook salmon sonar on the Kenai River. Alaska Department of Fish and Game, Fishery Data Series No. 00-43, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds00-43.pdf

Burwen, D. L., and D. E. Bosch. 1996. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-9, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds96-09.pdf

Burwen, D. L., D. E. Bosch, and S. J. Fleischman. 1995. Evaluation of hydroacoustic assessment techniques for Chinook salmon on the Kenai River using split- beam sonar. Alaska Department of Fish and Game, Fishery Data Series No. 95-45, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds95-45.pdf

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

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

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

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

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

Carlon, J. A., and M. Alexandersdottir. 1989. Abundance estimates of the escapement of Chinook salmon into the Kenai River, Alaska, by analysis of tagging data, 1988. Alaska Department of Fish and Game, Fishery Data Series No. 107, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fds-107.pdf

Cochran, W. G. 1977. Sampling techniques. 3rd edition. John Wiley and Sons, New York.

Conrad, R. H. 1988. Abundance estimates of the escapement of Chinook salmon into the Kenai River, Alaska, by analysis of tagging data, 1987. Alaska Department of Fish and Game, Fishery Data Series No. 67, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fds-067.pdf

Conrad, R. H., and L. L. Larson. 1987. Abundance estimates for Chinook salmon (*Oncorhynchus tshawytscha*) in the escapement into the Kenai River, Alaska, by analysis of tagging data, 1986. Alaska Department of Fish and Game, Fishery Data Series No. 34, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fds-034.pdf

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

Eggers, D. M., P. A. Skvorc, and D. L. Burwen. 1995. Abundance estimate for Chinook salmon in the Kenai River using dual-beam sonar. Alaska Department of Fish and Game. Alaska Fishery Research Bulletin 2(1):1-22.

Eskelin, A. 2007. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2005. Alaska Department of Fish and Game, Fishery Data Series No. 07-87, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds07-87.pdf

Eskelin, A. 2010. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 10-63, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS10-63.pdf

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

Fleischman, S. J., and T. R. McKinley. 2013. Run reconstruction, spawner–recruit analysis, and escapement goal recommendation for late-run Chinook salmon in the Kenai River. Alaska Department of Fish and Game, Fishery Manuscript Series No. 13-02, Anchorage. http://www/adfg/alaska.gov/FedAidpdfs/FMS13-02

Gamblin, M., L. E. Marsh, P. Berkhahn, and S. Sonnichsen. 2004. Area management report for the recreational fisheries of the Northern Kenai Peninsula, 2000 and 2001. Alaska Department of Fish and Game, Fishery Management Report No. 04-04, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fmr04-04.pdf

Gelman, A., J. B. Carlin, H. S. Stern, and D. B. Rubin. 2004. Bayesian data analysis. 3rd edition. Chapman and Hall, Boca Raton, Florida.

Gilks, W. R., A. Thomas, and D. J. Spiegelhalter. 1994. A language and program for complex Bayesian modeling. The Statistician 43:169-178. http://www.mrc-bsu.cam.ac.uk/bugs Accessed 01/2010.

Goodman, L. A. 1960. On the exact variance of products. Journal of the American Statistical Association 55:708-713.

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

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

Hammarstrom, S. L., L. Larson, M. Wenger, and J. Carlon. 1985. Kenai Peninsula Chinook and coho salmon studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration. Annual Performance Report, 1984-1985, Project F-9-17(26)G-II-L, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-17(26)G-II-L.pdf

Hammarstrom, S. L., and L. L. Larson. 1986. Kenai River salmon escapement. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1985-1986, Project F-10-1, 27 (S-32-2), Juneau. http://www.sf.adfg.state.ak.us/FedAidPDFs/FREDf-10-1(27)S-32-1,2,4,5.pdf

REFERENCES CITED (Continued)

Howe, A. L., G. Fidler, A. E. Bingham, and M. J. Mills. 1996. Harvest, catch, and participation in Alaska sport fisheries during 1995. Alaska Department of Fish and Game, Fishery Data Series No. 96-32, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds96-32.pdf

Howe, A. L., G. Fidler, and M. J. Mills. 1995. Harvest, catch, and participation in Alaska sport fisheries during 1994. Alaska Department of Fish and Game, Fishery Data Series No. 95-24, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds95-24.pdf

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001a. Revised Edition. Harvest, catch, and participation in Alaska sport fisheries during 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-29 (revised), Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds97-29(revised).pdf

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001b. Revised Edition. Harvest, catch, and participation in Alaska sport fisheries during 1997. Alaska Department of Fish and Game, Fishery Data Series No. 98-25 (revised), Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds98-25(revised).pdf

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001c. Revised Edition. Participation, catch, and harvest in Alaska sport fisheries during 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-41 (revised), Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds99-41(revised).pdf

Howe, A. L., R. J. Walker, C. Olnes, K. Sundet, and A. E. Bingham. 2001d. Participation, catch, and harvest in Alaska sport fisheries during 1999. Alaska Department of Fish and Game, Fishery Data Series No. 01-08, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds01-08.pdf

HTI (Hydroacoustic Technology Inc.). 1996. Model 340 digital echo processor (split-beam) operator's manual, version 1.6 Hydroacoustic Technology Inc., Seattle, WA.

HTI (Hydroacoustic Technology Inc.). 1997. Model 241/243/244 split-beam digital echo sounder system operator's manual, version 1.6. Hydroacoustic Technology Inc., Seattle, WA.

Jennings, G. B., K. Sundet, and A. E. Bingham. 2007. Participation, catch, and harvest in Alaska sport fisheries during 2004. Alaska Department of Fish and Game, Fishery Data Series No. 07-40, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds07-40.pdf

Jennings, G. B., K. Sundet, and A. E. Bingham. 2009a. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2005. Alaska Department of Fish and Game, Fishery Data Series No. 09-47, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS09-47.pdf

Jennings, G. B., K. Sundet, and A. E. Bingham. 2009b. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2006. Alaska Department of Fish and Game, Fishery Data Series No. 09-54, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS09-54.pdf

Jennings, G. B., K. Sundet, and A. E. Bingham. 2010a. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2007. Alaska Department of Fish and Game, Fishery Data Series No. 10-02, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/Fds10-02.pdf

Jennings, G. B., K. Sundet, and A. E. Bingham. 2010b. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2008. Alaska Department of Fish and Game, Fishery Data Series No. 10-22, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS10-22.pdf

Jennings, G. B., K. Sundet, and A. E. Bingham. 2011a. Estimates of participation, catch, and harvest in Alaska sport fisheries during 2009. Alaska Department of Fish and Game, Fishery Data Series No. 11-45, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS11-45

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

Jennings, G. B., K. Sundet, A. E. Bingham, and D. Sigurdsson. 2004. Participation, catch, and harvest in Alaska sport fisheries during 2001. Alaska Department of Fish and Game, Fishery Data Series No. 04-11, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds04-11.pdf

Jennings, G. B., K. Sundet, A. E. Bingham, and D. Sigurdsson. 2006a. Participation, catch, and harvest in Alaska sport fisheries during 2002. Alaska Department of Fish and Game, Fishery Data Series No. 06-34, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/fds06-34.pdf

Jennings, G. B., K. Sundet, A. E. Bingham, and D. Sigurdsson. 2006b. Participation, catch, and harvest in Alaska sport fisheries during 2003. Alaska Department of Fish and Game, Fishery Data Series No. 06-44, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/fds06-44.pdf

Marsh, L. E. 2000. Angler effort and harvest of Chinook salmon by the recreational fisheries in the lower Kenai River, 1998. Alaska Department of Fish and Game, Fishery Data Series No. 00-21, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds00-21.pdf

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

McKinley, T. R., and S. J. Fleischman. 2013. Run reconstruction, spawner–recruit analysis, and escapement goal recommendation for early-run Chinook salmon in the Kenai River. Alaska Department of Fish and Game, Fishery Manuscript Series No. 13-03, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FMS13-03.pdf

Miller, J. D., D. Bosch, and D. Burwen. 2002. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 1999. Alaska Department of Fish and Game, Fishery Data Series No. 02-24, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds02-24.pdf

Miller, J. D., and D. Burwen. 2002. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2000. Alaska Department of Fish and Game, Fishery Data Series No. 02-09, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds02-09.pdf

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2003. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2001. Alaska Department of Fish and Game, Fishery Data Series No. 03-03, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds03-03.pdf

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2004. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2002. Alaska Department of Fish and Game, Fishery Data Series No. 04-29, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds04-29.pdf

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

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2007a. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2004. Alaska Department of Fish and Game, Fishery Data Series No. 07-57, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds07-57.pdf

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2007b. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2005. Alaska Department of Fish and Game, Fishery Data Series No. 07-92, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/Fds07-92.pdf

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2010. Estimates of Chinook salmon passage in the Kenai River using split-beam sonar, 2006. Alaska Department of Fish and Game, Fishery Data Series No. 10-40, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS10-40.pdf

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2011. Estimates of Chinook salmon passage in the Kenai River using split-beam sonar, 2007. Alaska Department of Fish and Game, Fishery Data Series No. 11-52, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS11-52

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

REFERENCES CITED (Continued)

Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2013. Estimates of Chinook salmon passage in the Kenai River using split-beam and dual-frequency identification sonars, 2010. Alaska Department of Fish and Game, Fishery Data Series No. 13-58, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS13-58.pdf

Mills, M. J. 1979. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1978-1979, Project F-9-11(20)SW-I-A, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-11(20)SW-I-A.pdf

Mills, M. J. 1980. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game. Federal Aid in Fish Restoration, Annual Performance Report, 1979-1980, Project F-9-12(21) SW-I-A, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-12(21)SW-I-A.pdf

Mills, M. J. 1981a. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1980-1981, Project F-9-13, 22 (SW-I-A), Juneau. http://www.sf.adfg.state.ak.us/FedAidPDFs/FREDf-9-13(22b)SW-I-A.pdf

Mills, M. J. 1981b. Alaska statewide sport fish harvest studies. 1979 data. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1980-1981, Project F-9-13(22a)SW-I-A, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-13(22a)SW-I-A.pdf

Mills, M. J. 1982. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1981-1982, Project F-9-14(23)SW-I-A, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-14(23)SW-I-A.pdf

Mills, M. J. 1983. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1982-1983, Project F-9-15(24)SW-I-A, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-15(24)SW-I-A.pdf

Mills, M. J. 1984. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1983-1984, Project F-9-16(25)SW-I-A, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-16(25)SW-I-A.pdf

Mills, M. J. 1985. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1984-1985, Project F-9-17(26)SW-I-A, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-9-17(26)SW-I-A.pdf

Mills, M. J. 1986. Alaska statewide sport fish harvest studies. Alaska Department of Fish and Game, Federal Aid in Fish Restoration, Annual Performance Report 1985-1986, Project F-10-1(27)RT-2, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/FREDf-10-1(27)RT-2.pdf

Mills, M. J. 1987. Alaska statewide sport fisheries harvest report, 1986. Alaska Department of Fish and Game, Fishery Data Series No. 2, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fds-002.pdf

Mills, M. J. 1988. Alaska statewide sport fisheries harvest report, 1987. Alaska Department of Fish and Game, Fishery Data Series No. 52, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fds-052.pdf

Mills, M. J. 1989. Alaska statewide sport fisheries harvest report, 1988. Alaska Department of Fish and Game, Fishery Data Series No. 122, Juneau. http://www.adfg.alaska.gov/FedAidPDFs/fds-122.pdf

Mills, M. J. 1990. Harvest and participation in Alaska sport fisheries during 1989. Alaska Department of Fish and Game, Fishery Data Series No. 90-44, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds90-44.pdf

Mills, M. J. 1991. Harvest, catch, and participation in Alaska sport fisheries during 1990. Alaska Department of Fish and Game, Fishery Data Series No. 91-58, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds91-58.pdf

Mills, M. J. 1992. Harvest, catch, and participation in Alaska sport fisheries during 1991. Alaska Department of Fish and Game, Fishery Data Series No. 92-40, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds92-40.pdf

REFERENCES CITED (Continued)

Mills, M. J. 1993. Harvest, catch, and participation in Alaska sport fisheries during 1992. Alaska Department of Fish and Game, Fishery Data Series No. 93-42, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds93-42.pdf

Mills, M. J. 1994. Harvest, catch, and participation in Alaska sport fisheries during 1993. Alaska Department of Fish and Game, Fishery Data Series No. 94-28, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds94-28.pdf

Perschbacher, J. 2012. Chinook salmon creel survey and inriver gillnetting study, lower Kenai River, Alaska, 2011. Alaska Department of Fish and Game, Fishery Data Series No. 12-84, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/FDS12-84.pdf

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

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

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

USDA (United States Department of Agriculture). 1992. Kenai River landowner's guide. Prepared by the U. S. Department of Agriculture, Soil conservation Service (SCS) for the Kenai Soil and Water Conservation District, Kenai, Alaska.

Walker, R. J., C. Olnes, K. Sundet, A. L. Howe, and A. E. Bingham. 2003. Participation, catch, and harvest in Alaska sport fisheries during 2000. Alaska Department of Fish and Game, Fishery Data Series No. 03-05, Anchorage. http://www.adfg.alaska.gov/FedAidPDFs/fds03-05.pdf

Westerman, D. L., and T. M. Willette. 2011. Upper Cook Inlet salmon escapement studies, 2010. Alaska Department of Fish and Game, Fishery Data Series No. 11-66, Anchorage. http://www.adfg.alaska.gov/FedAidpdfs/FDS11-66

Wolter, K. M. 1985. Introduction to variance estimation. Springer-Verlag, New York.

WRCC (Western Region Climate Center). 2008. Kenai FAA Airport, Alaska. Website Western U.S. Climate Historical Summaries, Climatological Data Summaries, Alaska, accessed February 4, 2008. http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?4546

TABLES

Table 1.–Main components of the split-beam sonar system used in 2011.

System component	Description
Sounder	Hydroacoustics Technology Inc. (HTI) Model 244 Split-Beam Echo sounder operating at 200 kHz
Data processing computer	Dell Dimension 2350 personal computer
Transducers	(2) HTI Split-Beam transducers: Left Bank: nominal beam widths: 2.9°×10.2° Right Bank: nominal beam widths: 2.8°×10.0°
Chart recorder	HTI model 403 digital dual-channel chart recorder
Oscilloscope	Nicolet model 310 digital storage oscilloscope
Video display	Hydroacoustic Assessments HARP-HC
Remote pan and tilt aiming controller	Remote Ocean Systems Model PTC-1 Pan and Tilt Controller
Remote pan and tilt aiming unit	Remote Ocean Systems Model PT-25 Remote Pan and Tilt Unit
Heading and angular measurement device	JASCO Research Ltd. AIM-2000 Underwater Measurement Device

Table 2.–Hydroacoustics Technology Inc. model 244 digital echo sounder settings used in 2011.

Echo sounder parameter	Value
Transmit power	25 dB
System gain (G_r)	−18 dB
TVG	$40\log_{10}R$
Transmitted pulse width	0.20 msec
Ping rate right bank	11 pings/sec
Ping rate left bank	16 pings/sec

Table 3.–Echo acceptance criteria for digital echo processing, 2011.

Bank	Pulse width[a] (ms) at −6 dB	Vertical angle off axis (°)	Horizontal angle off axis (°)	Threshold mV (dB)	Minimum range (m)
Right	0.04 to 10.0	–2.5 to 2.0	–5.0 to 5.0	726 (–35 dB)	2
Left	0.04 to 10.0	–2.5 to 2.0	–5.0 to 5.0	448 (–35 dB)	2

Note: criteria are for 16 May–10 Aug 2011.

[a] Pulse width filters have not been used since 1996 (Burwen and Bosch 1998) in order to retain information potentially useful for species classification (Burwen et al. 2003; Fleischman and Burwen 2003).

Table 4.–Components of the DIDSON sonar system used in 2011.

System component	Description
Sounder	DIDSON-LR operating at 1.2 MHz
Orientation sensor	Honeywell Truepoint Compass (internal)
Lens	Large Lens Assembly with ~3°×15° beam pattern
Data collection computer	Dell Latitude E6500 laptop computer
Remote pan-and-tilt aiming controller	Remote Ocean Systems Model PTC-1 Pan and Tilt Controller
Remote pan-and-tilt aiming unit	Remote Ocean Systems Model P-25 Remote Pan and Tilt Unit

Table 5.–Estimated upstream fish passage based on split-beam sonar (all species), ELSD-based split-beam sonar (Chinook only), and net-apportioned split-beam sonar (Chinook only), Kenai River RM 8.5, early run, 2011.

	Upstream fish		ELSD-based		Net apportioned[a]	
Date	Passage	SE	Passage	SE	Passage	SE
16 May	54	24	26	13	54	24
17 May	48	22	23	12	48	22
18 May	45	22	22	11	–	–
19 May	21	8	10	4	0	0
20 May	81	24	39	14	0	0
21 May	111	35	54	20	39	22
22 May	138	26	67	19	54	26
23 May	243	35	123	32	19	24
24 May	365	36	145	24	43	18
25 May	505	57	195	35	138	83
26 May	446	42	91	21	66	35
27 May	545	40	127	29	18	19
28 May	709	60	131	32	74	68
29 May	970	92	233	52	68	41
30 May	1,121	109	219	53	30	19
31 May	909	95	293	69	73	28
1 Jun	666	97	111	31	39	13
2 Jun	385	48	50	19	15	12
3 Jun	580	60	104	28	108	18
4 Jun	1,034	98	254	49	35	18
5 Jun	1,073	82	364	66	138	21
6 Jun	1,487	118	556	113	79	27
7 Jun	1,577	88	530	116	63	38
8 Jun	1,341	116	539	122	275	79
9 Jun	1,562	109	626	154	134	75
10 Jun	1,472	98	518	100	163	89
11 Jun	1,215	92	299	61	30	8
12 Jun	1,121	77	322	65	106	42
13 Jun	853	59	317	57	49	13
14 Jun	1,170	110	410	91	40	13
15 Jun	883	79	366	80	93	49
16 Jun	761	57	501	74	67	9
17 Jun	610	55	262	55	43	17
18 Jun	652	53	301	60	89	47
19 Jun	611	49	293	49	97	37
20 Jun	374	26	135	37	49	32
21 Jun	417	40	204	35	95	39
22 Jun	457	66	162	40	117	61
23 Jun	4,10	48	150	28	149	21
24 Jun	286	30	131	24	109	50
25 Jun	481	32	188	27	266	60
26 Jun	309	38	137	29	82	40
27 Jun	1,59	22	66	18	44	19
28 Jun	297	26	171	28	169	60
29 Jun	487	40	263	35	253	51
30 Jun	688	80	431	63	319	50
Total	29,729	451	10,561	393	4,041	273

Note: Estimated upstream fish passage based on split-beam sonar (all species) are internally termed "unfiltered" estimates. ELSD-based split-beam sonar estimates were termed "behavior-censored ELSD-based estimates" in a previous report (Miller et al. 2012).

a No net apportioned estimate could be produced for 18 May because no fish were caught in the inriver nets on 18 May.

Table 6.–Estimated upstream fish passage based on split-beam sonar (all species), ELSD-based split-beam sonar (Chinook only), and net-apportioned split-beam sonar (Chinook only), Kenai River late run, 2011.

	Upstream fish		ELSD-based		Net apportioned	
Date	Passage	SE	Passage	SE	Passage	SE
1 Jul	1,121	62	473	93	350	40
2 Jul	1,597	138	1,147	204	200	117
3 Jul	1,051	86	603	139	315	62
4 Jul	1,173	87	338	97	183	69
5 Jul	1,518	120	88	73	238	108
6 Jul	1,687	186	1,083	224	499	71
7 Jul	2,092	152	981	213	521	117
8 Jul	2,437	180	1,272	309	222	61
9 Jul	3,280	332	2,139	322	197	87
10 Jul	1,788	158	763	179	268	96
11 Jul	1,016	95	253	59	265	84
12 Jul	1,119	92	568	81	446	111
13 Jul	2,406	197	1,169	258	763	68
14 Jul	2,834	194	1,536	286	1,060	414
15 Jul	1,169	89	650	97	814	107
16 Jul	10,720	1,912	1,383	507	729	677
17 Jul	11,439	1,452	2,437	779	1,110	307
18 Jul	8,525	628	1,364	387	938	240
19 Jul	13,049	1,410	1,475	469	744	296
20 Jul	19,544	2,344	1,935	663	1,153	467
21 Jul	9,276	830	1,670	530	1,512	181
22 Jul	9,467	762	1,742	694	492	147
23 Jul	15,782	1,089	2,352	742	1,641	764
24 Jul	12,251	861	1,433	499	502	187
25 Jul	9,339	559	1,093	342	542	81
26 Jul	6,691	499	1,071	291	388	156
27 Jul	4,912	338	634	177	359	139
28 Jul	2,374	232	342	87	142	45
29 Jul	2,080	178	476	104	470	195
30 Jul	1,899	198	503	139	156	75
31 Jul	1,834	145	407	80	165	51
1 Aug	1,954	177	406	95	238	109
2 Aug	1,561	126	332	96	98	58
3 Aug	1,522	129	420	109	62	41
4 Aug	1,571	130	264	87	151	37
5 Aug	2,751	240	715	186	179	65
6 Aug	4,030	290	661	207	169	113
7 Aug	1,595	157	359	99	212	79
8 Aug	890	100	214	47	64	31
9 Aug	2,311	198	270	86	122	79
10 Aug	1,900	159	239	78	86	13
Total	185,555	4,285	37,261	2,057	18,766	1,421

Note: Estimated upstream fish passage based on split-beam sonar (all species) are internally termed "unfiltered" estimates. ELSD-based split-beam sonar estimates were termed "behavior-censored ELSD-based estimates" in a previous report (Miller et al. 2012).

Table 7.–Percentage of upstream bound large Chinook salmon (DIDSON length ≥ 75 cm) by riverbank, range stratum (distance from transducer), and tide stage sampled by DIDSON for the 2011 early and late runs.

		Left bank				Right bank				
		Range stratum				Range stratum				
Run	Tide stage	3–13 m	13–23 m	23–33 m	All strata	3–13 m	13–23 m	23–33 m	All strata	Both banks
Early										
	Rising	5	4	5	13	2	2	5	9	22
	Falling	11	15	13	38	2	4	6	12	50
	Low	7	6	7	21	1	2	4	7	28
	All stages	23	25	24	72	5	8	15	28	100
Late										
	Rising	6	7	7	20	3	5	7	15	34
	Falling	8	9	11	28	5	5	9	19	47
	Low	4	5	5	13	1	1	4	6	19
	All stages	17	21	22	60	9	11	20	40	100

Note: Due to rounding, sums of values across individual cells may not sum to marginal totals.

Table 8.–Percentage of upstream bound salmon that were classified as large Chinook salmon (DIDSON length ≥ 75cm) by riverbank, range stratum (distance from transducer), and tide stage; for the 2011 early and late runs.

		Left bank				Right bank				
		Range stratum				Range stratum				
Run	Tide stage	3–13 m	13–23 m	23–33 m	All strata	3–13 m	13–23 m	23–33 m	All strata	Both banks
Early										
	Rising	8.9	8.8	15.7	10.5	15.2	11.0	19.2	15.6	12.1
	Falling	6.6	6.7	8.3	7.1	8.4	8.8	9.3	9.0	7.5
	Low	8.5	5.5	8.4	7.3	12.2	10.1	12.0	11.4	8.0
	All stages	7.5	6.5	9.1	7.6	10.7	9.6	12.2	11.1	8.3
Late										
	Rising	4.8	6.5	7.3	6.1	1.9	3.4	6.1	3.5	4.7
	Falling	4.1	5.0	6.2	5.1	1.2	1.4	4.9	2.0	3.1
	Low	6.7	11.2	11.6	9.5	1.7	2.6	8.0	3.8	6.4
	All stages	4.7	6.3	7.3	6.0	1.4	2.0	5.7	2.6	4.0

Table 9.–DIDSON-based estimates of upstream salmon passage, DL mixture model (DLMM) proportion of Chinook salmon, and DLMM and DSEQ (DIDSON equivalent) Chinook salmon passage, RM 8.5 Kenai River, early run, 2011.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
16 May	25	9	0.806	0.18	20	8	0.42
17 May	7	4	0.549	0.29	4	3	0.69
18 May	13	7	0.424	0.27	6	4	0.70
19 May	6	5	0.354	0.34	2	2	1.05
20 May	6	4	0.532	0.30	3	3	0.84
21 May	60	13	0.392	0.19	23	12	0.53
22 May	308	45	0.272	0.08	84	26	0.31
23 May	338	37	0.253	0.07	85	26	0.31
24 May	338	47	0.236	0.07	80	25	0.31
25 May	580	85	0.264	0.06	153	40	0.26
26 May	743	142	0.115	0.04	86	32	0.37
27 May	1,015	97	0.075	0.03	76	27	0.35
28 May	1,232	105	0.113	0.03	139	44	0.32
29 May	1,734	162	0.067	0.02	116	35	0.31
30 May	2,036	222	0.071	0.02	144	43	0.30
31 May	1,353	136	0.119	0.03	161	47	0.29
1 Jun	1,086	156	0.036	0.02	39	22	0.56
2 Jun	610	70	0.063	0.03	39	19	0.48
3 Jun	997	90	0.090	0.04	90	36	0.40
4 Jun	1,812	199	0.063	0.02	114	41	0.36
5 Jun	2,060	173	0.101	0.02	208	53	0.25
6 Jun	2,560	178	0.111	0.02	284	66	0.23
7 Jun	3,195	288	0.037	0.01	117	42	0.36
8 Jun	2,990	259	0.068	0.02	204	75	0.37
9 Jun	3,141	297	0.050	0.01	156	49	0.31
10 Jun	3,292	240	0.091	0.02	299	81	0.27
11 Jun	3,292	315	0.059	0.02	196	60	0.31
12 Jun	2,313	145	0.041	0.01	95	34	0.36
13 Jun	1,800	151	0.157	0.03	282	57	0.20
14 Jun	2,869	213	0.086	0.02	246	59	0.24
15 Jun	2,746	413	0.090	0.02	248	70	0.28
16 Jun	1,969	169	0.087	0.02	172	49	0.28
17 Jun	1,438	137	0.135	0.03	194	49	0.25
18 Jun	1,727	166	0.148	0.03	255	62	0.24
19 Jun	1,522	104	0.189	0.04	287	61	0.21
20 Jun	1,117	94	0.190	0.04	212	46	0.22
21 Jun	1,027	78	0.202	0.04	207	41	0.20
22 Jun	1,027	110	0.179	0.04	184	42	0.23
23 Jun	1,317	103	0.244	0.04	321	56	0.18
24 Jun	707	106	0.310	0.06	219	52	0.24
25 Jun	1,365	156	0.254	0.04	347	68	0.20
26 Jun	695	80	0.174	0.04	121	33	0.27
27 Jun	464	76	0.185	0.06	86	30	0.35
28 Jun	604	69	0.299	0.06	181	42	0.23
29 Jun	1,232	110	0.230	0.04	283	57	0.20
30 Jun	1,684	158	0.296	0.05	498	95	0.19
Total	62,452	1,074			7,366	318	0.04

Note: all estimates are of upstream bound fish in midriver between and at least 3 m from the transducers.

Table 10.–DIDSON-based estimates of upstream salmon passage, DL mixture model (DLMM) proportion of Chinook salmon, and DLMM and DSEQ (DIDSON equivalent) Chinook salmon passage, RM 8.5 Kenai River, late run, 2011.

	DIDSON upstream salmon		DLMM Chinook salmon		DLMM Chinook salmon		
Date	Passage	SE	Proportion	SE	Passage	SE	CV
1 Jul	2,513	188	0.180	0.03	453	80	0.18
2 Jul	3,594	286	0.155	0.02	557	99	0.18
3 Jul	2,175	149	0.179	0.03	388	78	0.20
4 Jul	2,317	130	0.149	0.03	345	71	0.20
5 Jul	3,117	277	0.132	0.02	411	77	0.19
6 Jul	3,435	382	0.131	0.02	451	94	0.21
7 Jul	4,299	335	0.224	0.03	961	145	0.15
8 Jul	5,007	512	0.110	0.02	553	108	0.19
9 Jul	6,687	845	0.066	0.01	438	102	0.23
10 Jul	3,811	325	0.149	0.02	569	102	0.18
11 Jul	2,658	253	0.112	0.02	297	63	0.21
12 Jul	2,289	230	0.254	0.04	581	100	0.17
13 Jul	4,657	359	0.224	0.03	1,044	155	0.15
14 Jul	6,911	621	0.209	0.03	1,443	222	0.15
15 Jul	2,103	150	0.379	0.05	796	113	0.14
16 Jul	27,994	5,926	0.024	0.00	669	167	0.25
17 Jul	34,230	4,549	0.048	0.01	1,650	291	0.18
18 Jul	30,242	2,388	0.032	0.00	980	136	0.14
19 Jul	32,702	2,900	0.027	0.00	869	128	0.15
20 Jul	49,852	4,187	0.015	0.00	765	117	0.15
21 Jul	20,071	1,891	0.050	0.01	998	141	0.14
22 Jul	25,229	1,879	0.029	0.00	743	103	0.14
23 Jul	46,194	4,802	0.034	0.00	811	135	0.17
24 Jul	34,868	2,571	0.030	0.00	762	115	0.15
25 Jul	23,285	1,144	0.037	0.01	810	114	0.14
26 Jul	17,485	1,085	0.033	0.01	572	97	0.17
27 Jul	10,751	856	0.056	0.01	604	137	0.23
28 Jul	5,696	527	0.045	0.01	258	64	0.25
29 Jul	4,943	439	0.068	0.01	335	68	0.20
30 Jul	4,035	449	0.093	0.02	376	77	0.21
31 Jul	4,868	621	0.136	0.02	660	130	0.20
1 Aug	3,338	373	0.114	0.02	380	86	0.23
2 Aug	3,369	308	0.046	0.01	154	44	0.29
3 Aug	3,330	272	0.050	0.01	167	46	0.27
4 Aug	3,461	257	0.028	0.01	95	28	0.29
5 Aug	6,112	554	0.059	0.01	361	65	0.18
6 Aug	7,284	514	0.059	0.01	430	67	0.16
7 Aug	2,923	382	0.081	0.02	236	59	0.25
8 Aug	1,731	172	0.122	0.03	210	53	0.25
9 Aug	4,554	379	0.083	0.01	376	72	0.19
10 Aug	4,171	334	0.037	0.01	155	43	0.27
Total	468,291	11,494			23,713	725	0.03

Note: all estimates are of upstream bound fish in midriver between and at least 3 m from the transducers.

Table 11.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from DIDSON and inriver gillnet catches, RM 8.5 Kenai River, early run, 2011.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
16 May	0.09	0.11	0.18	0.17	0.73	0.19
17 May	0.13	0.15	0.12	0.14	0.75	0.19
18 May	0.10	0.12	0.08	0.10	0.82	0.15
19 May	0.07	0.09	0.08	0.09	0.86	0.12
20 May	0.06	0.08	0.07	0.09	0.87	0.12
21 May	0.08	0.10	0.20	0.15	0.72	0.17
22 May	0.12	0.10	0.10	0.10	0.77	0.13
23 May	0.11	0.09	0.09	0.09	0.80	0.11
24 May	0.10	0.08	0.13	0.11	0.77	0.12
25 May	0.15	0.09	0.22	0.12	0.63	0.13
26 May	0.20	0.10	0.20	0.12	0.59	0.13
27 May	0.19	0.09	0.29	0.16	0.51	0.16
28 May	0.24	0.10	0.45	0.14	0.31	0.13
29 May	0.24	0.10	0.58	0.13	0.18	0.11
30 May	0.29	0.11	0.45	0.17	0.26	0.15
31 May	0.30	0.10	0.47	0.14	0.23	0.12
1 Jun	0.27	0.10	0.52	0.15	0.21	0.13
2 Jun	0.32	0.10	0.40	0.16	0.28	0.16
3 Jun	0.35	0.10	0.43	0.11	0.22	0.09
4 Jun	0.35	0.10	0.44	0.15	0.21	0.13
5 Jun	0.31	0.08	0.47	0.12	0.22	0.11
6 Jun	0.36	0.08	0.37	0.11	0.27	0.11
7 Jun	0.36	0.09	0.37	0.11	0.27	0.11
8 Jun	0.39	0.09	0.40	0.13	0.21	0.12
9 Jun	0.40	0.08	0.41	0.10	0.19	0.08
10 Jun	0.46	0.09	0.40	0.10	0.14	0.08
11 Jun	0.47	0.09	0.33	0.09	0.20	0.07
12 Jun	0.40	0.09	0.43	0.09	0.17	0.06
13 Jun	0.44	0.08	0.37	0.08	0.19	0.06
14 Jun	0.42	0.08	0.43	0.08	0.15	0.06
15 Jun	0.43	0.08	0.33	0.08	0.24	0.07
16 Jun	0.38	0.08	0.27	0.09	0.35	0.09
17 Jun	0.33	0.08	0.25	0.08	0.42	0.08
18 Jun	0.32	0.08	0.32	0.09	0.37	0.08
19 Jun	0.33	0.08	0.23	0.08	0.44	0.08
20 Jun	0.27	0.08	0.20	0.08	0.54	0.09

-continued-

Table 11.–Page 2 of 2.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
21 Jun	0.21	0.07	0.29	0.08	0.50	0.08
22 Jun	0.16	0.06	0.13	0.07	0.70	0.08
23 Jun	0.22	0.07	0.09	0.06	0.69	0.07
24 Jun	0.25	0.07	0.10	0.07	0.65	0.08
25 Jun	0.25	0.07	0.10	0.07	0.66	0.09
26 Jun	0.26	0.06	0.06	0.07	0.68	0.08
27 Jun	0.31	0.06	0.08	0.06	0.61	0.08
28 Jun	0.33	0.06	0.10	0.06	0.57	0.07
29 Jun	0.39	0.06	0.09	0.05	0.52	0.07
30 Jun	0.39	0.07	0.09	0.05	0.52	0.06
Weighted mean	0.32		0.27		0.41	

Note: Estimates apply to upstream bound fish in midriver between and at least 3 m from the transducers, although netting data were obtained from the narrower split-beam corridor in 2011. In the mixture model, ages 3 and 4 are pooled, as are ages 6 and 7. Means are weighted by daily DLMM estimates.

Table 12.–Daily estimates of Chinook salmon age composition derived from fitting a mixture model to length measurements from DIDSON and inriver gillnet catches, RM 8.5 Kenai River, late run, 2011.

	Ages 3 and 4		Age 5		Ages 6 and 7	
Date	Proportion	SE	Proportion	SE	Proportion	SE
1 Jul	0.40	0.06	0.12	0.05	0.48	0.06
2 Jul	0.37	0.06	0.12	0.05	0.51	0.06
3 Jul	0.41	0.06	0.10	0.05	0.49	0.06
4 Jul	0.43	0.06	0.12	0.06	0.45	0.06
5 Jul	0.44	0.06	0.05	0.04	0.51	0.06
6 Jul	0.43	0.06	0.05	0.04	0.52	0.06
7 Jul	0.43	0.06	0.10	0.06	0.47	0.07
8 Jul	0.39	0.06	0.04	0.04	0.57	0.07
9 Jul	0.45	0.07	0.06	0.05	0.49	0.07
10 Jul	0.41	0.06	0.03	0.03	0.56	0.06
11 Jul	0.43	0.06	0.05	0.04	0.52	0.06
12 Jul	0.39	0.06	0.05	0.05	0.56	0.06
13 Jul	0.39	0.06	0.02	0.03	0.59	0.06
14 Jul	0.37	0.05	0.02	0.03	0.61	0.05
15 Jul	0.36	0.05	0.02	0.03	0.62	0.05
16 Jul	0.33	0.06	0.08	0.06	0.59	0.06
17 Jul	0.32	0.07	0.19	0.07	0.49	0.07
18 Jul	0.24	0.05	0.09	0.06	0.67	0.07
19 Jul	0.22	0.05	0.18	0.10	0.60	0.10
20 Jul	0.20	0.05	0.17	0.08	0.63	0.08
21 Jul	0.17	0.06	0.23	0.06	0.60	0.06
22 Jul	0.19	0.05	0.29	0.10	0.52	0.11
23 Jul	0.23	0.07	0.16	0.07	0.61	0.07
24 Jul	0.22	0.06	0.08	0.07	0.70	0.07
25 Jul	0.24	0.07	0.07	0.06	0.68	0.07
26 Jul	0.30	0.08	0.16	0.09	0.53	0.09
27 Jul	0.46	0.12	0.21	0.09	0.33	0.07
28 Jul	0.44	0.08	0.04	0.04	0.52	0.08
29 Jul	0.40	0.07	0.07	0.08	0.53	0.09
30 Jul	0.38	0.07	0.12	0.10	0.50	0.11
31 Jul	0.40	0.07	0.10	0.10	0.50	0.11
1 Aug	0.36	0.08	0.13	0.12	0.51	0.12
2 Aug	0.31	0.08	0.16	0.10	0.53	0.11
3 Aug	0.24	0.09	0.20	0.12	0.57	0.12
4 Aug	0.11	0.07	0.26	0.11	0.63	0.11
5 Aug	0.08	0.07	0.14	0.09	0.78	0.09
6 Aug	0.12	0.07	0.33	0.18	0.55	0.17
7 Aug	0.24	0.09	0.06	0.07	0.70	0.09
8 Aug	0.27	0.10	0.09	0.08	0.64	0.10
9 Aug	0.25	0.09	0.17	0.10	0.58	0.10
10 Aug	0.31	0.11	0.11	0.08	0.58	0.11
Weighted mean	0.32		0.12		0.56	

Note: Estimates apply to upstream bound fish in midriver between and at least 3 m from the transducers, although netting data were obtained from the narrower split-beam corridor in 2011. In the mixture model, ages 3 and 4 are pooled, as are ages 6 and 7. Means are weighted by daily DLMM estimates.

FIGURES

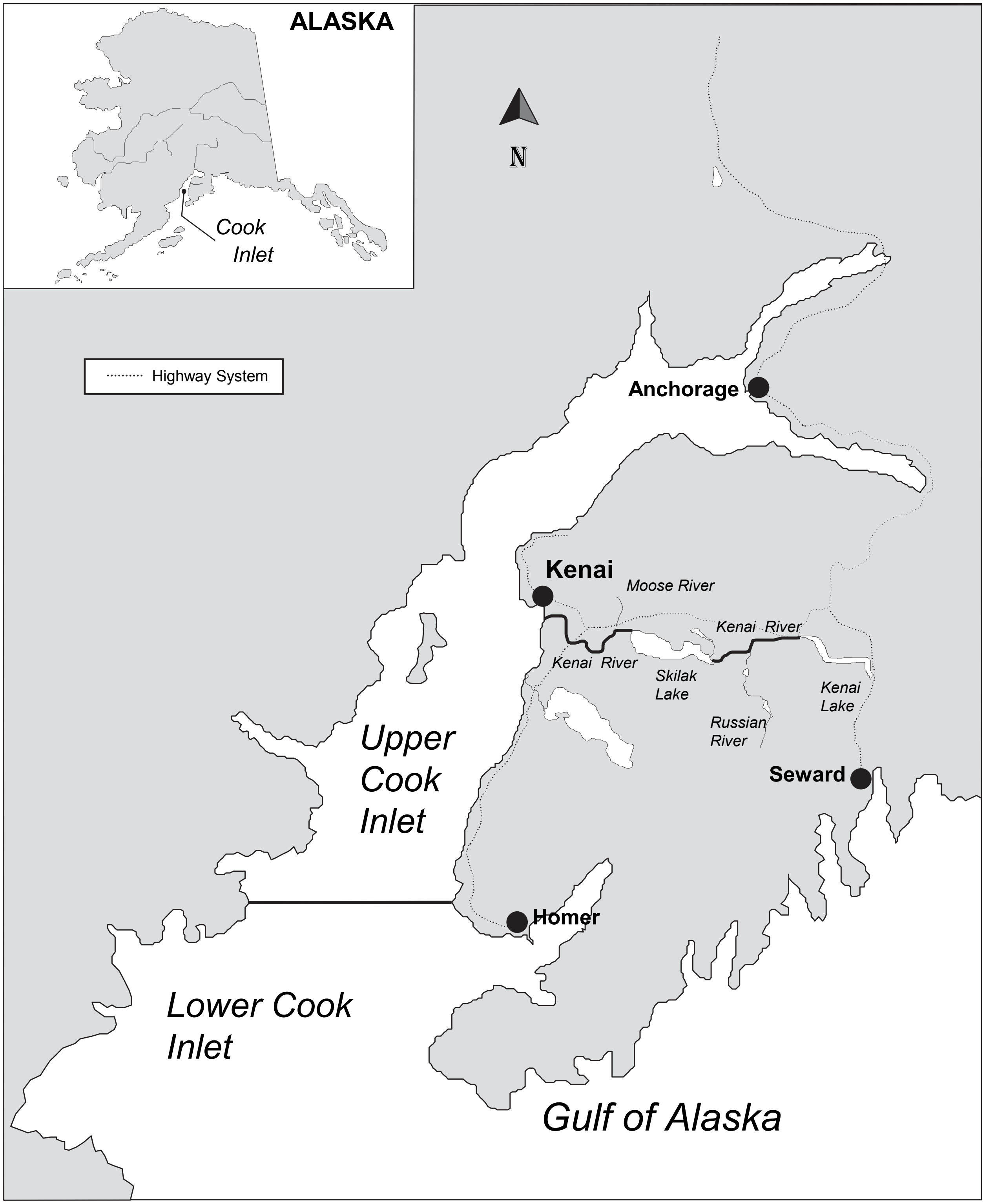


Figure 1.–Cook Inlet showing location of Kenai River.

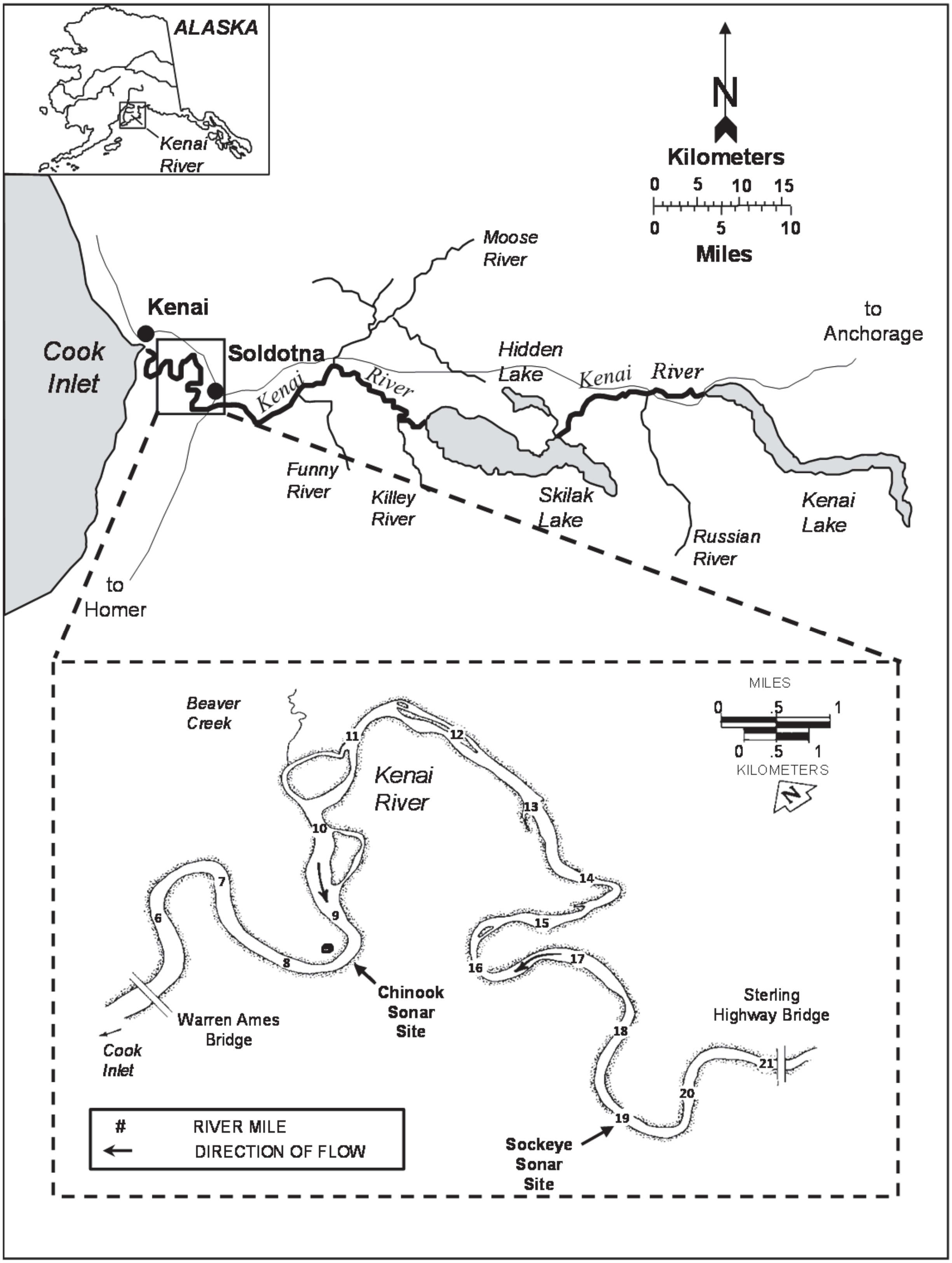
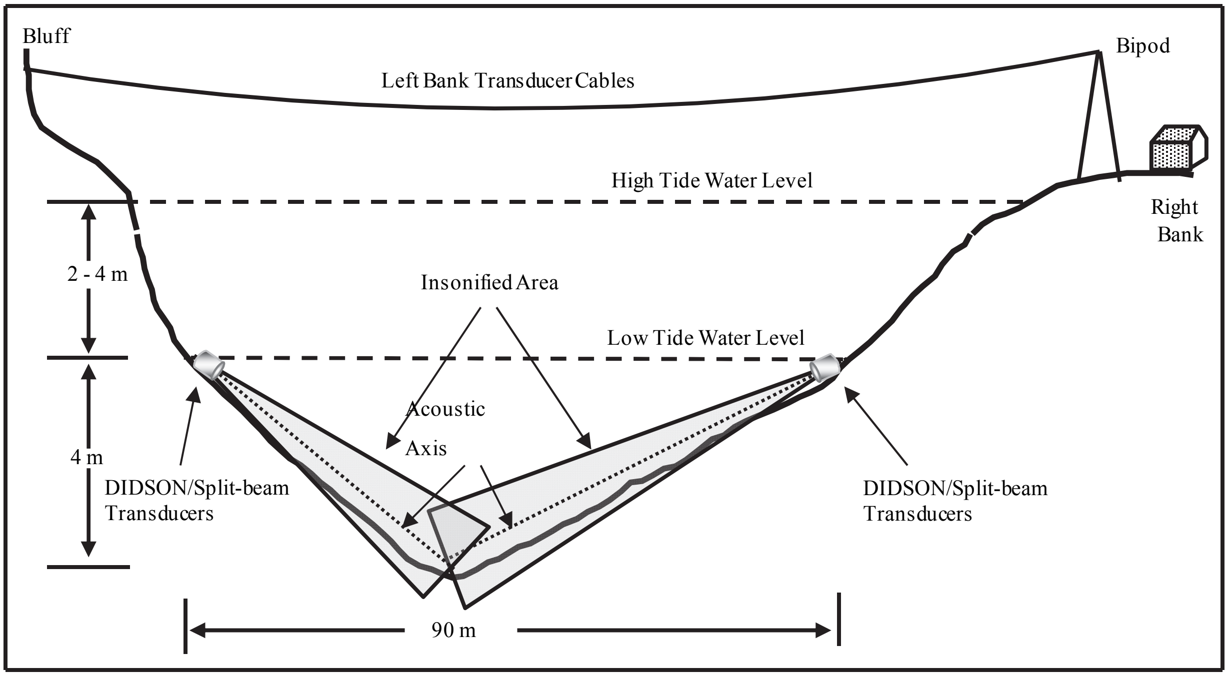
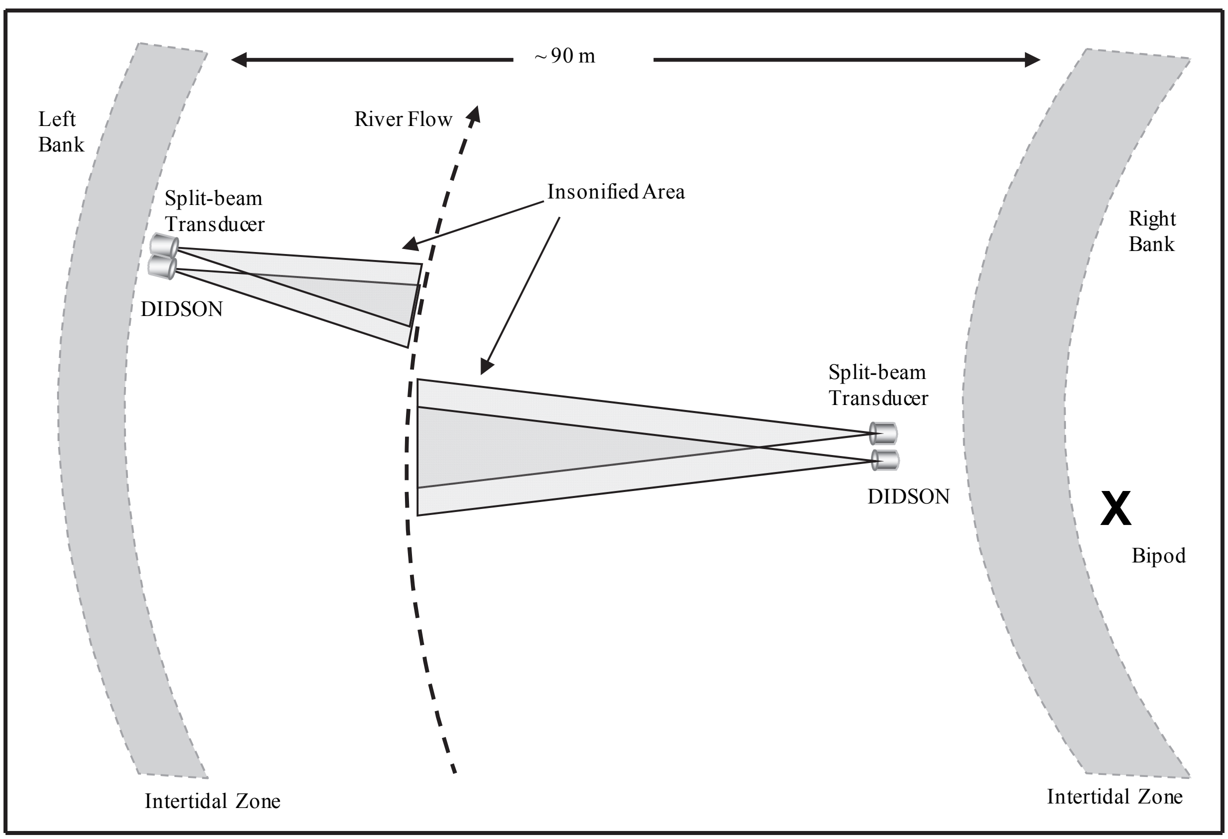


Figure 2.–Kenai River sonar site locations, 2011.





Note: Distance from bipod to thalweg (shown as dashed line depicting lowest course of the river) is approximately 88 m.

Figure 3.–Cross-sectional (top) and aerial (bottom) diagrams of sonar site illustrating insonified portions of RM 8.5 of the Kenai River, 2011.

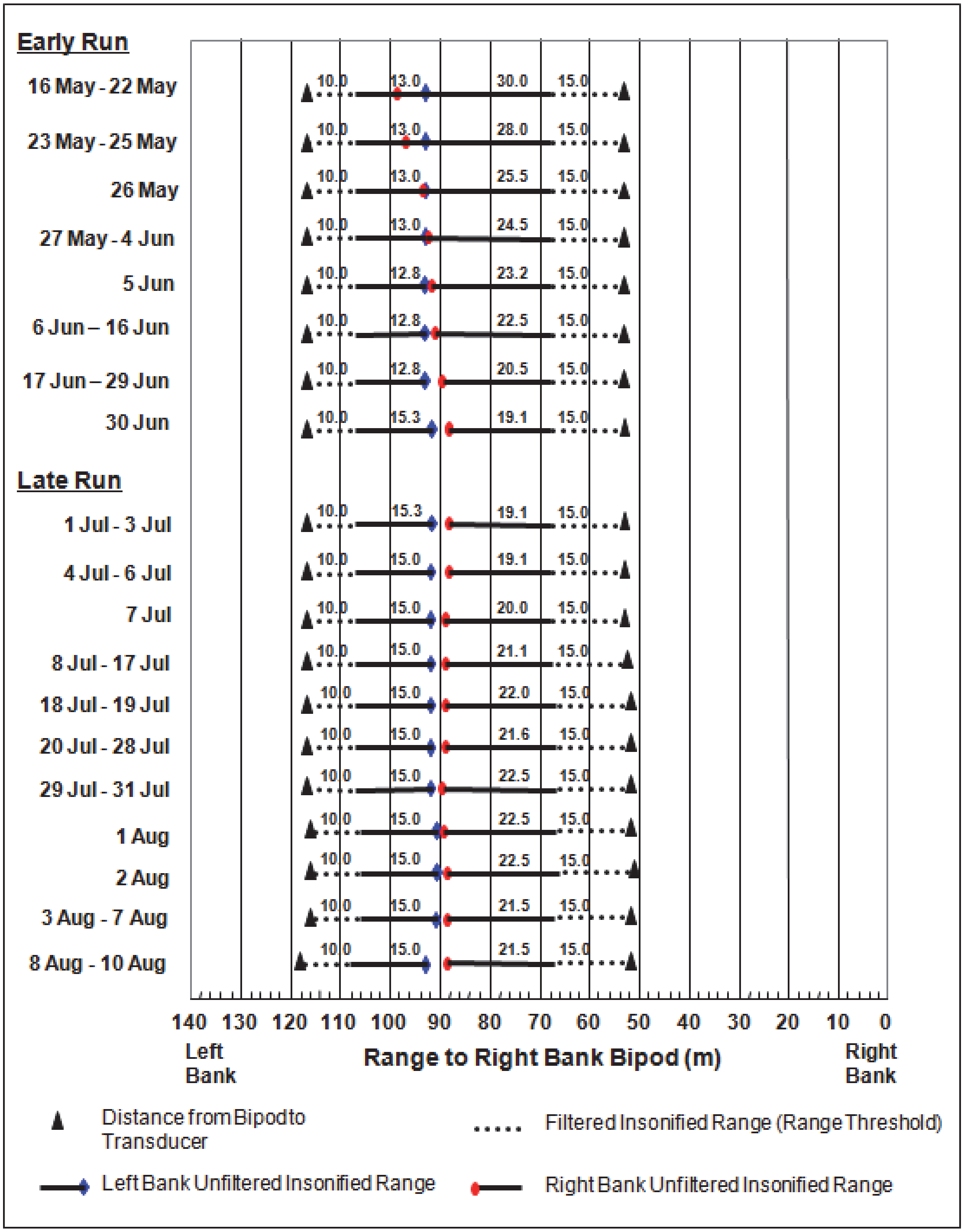


Figure 4.–Daily right- and left-bank transducer placement and insonified ranges relative to bipod tower located on the right bank, Kenai River RM 8.5, 2011.

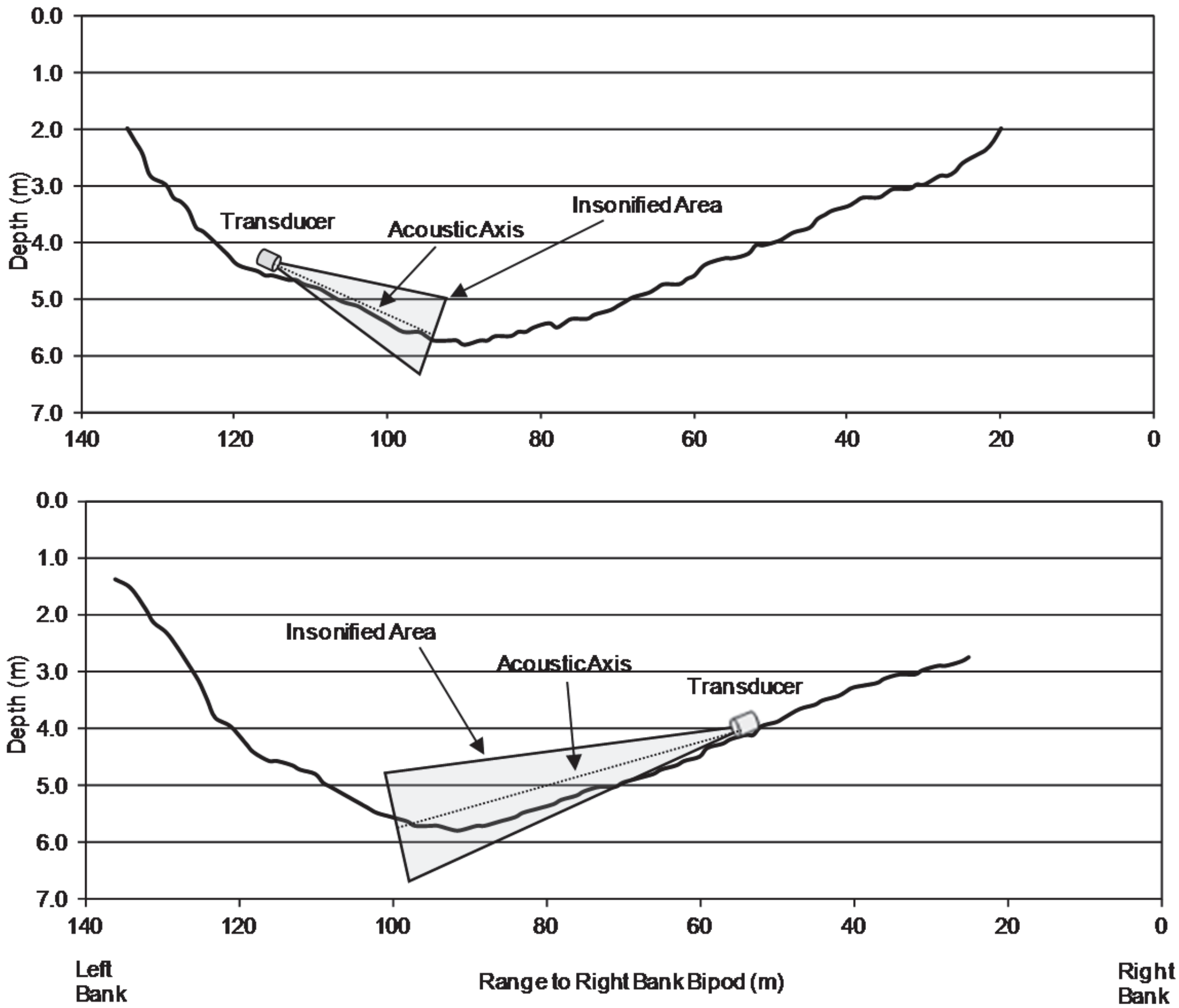


Figure 5.–Bottom profiles for the left bank transducer (top) and right bank transducer (bottom) at the Kenai River Chinook salmon sonar site with approximate transducer placement and sonar beam coverage for 16 May 2011.

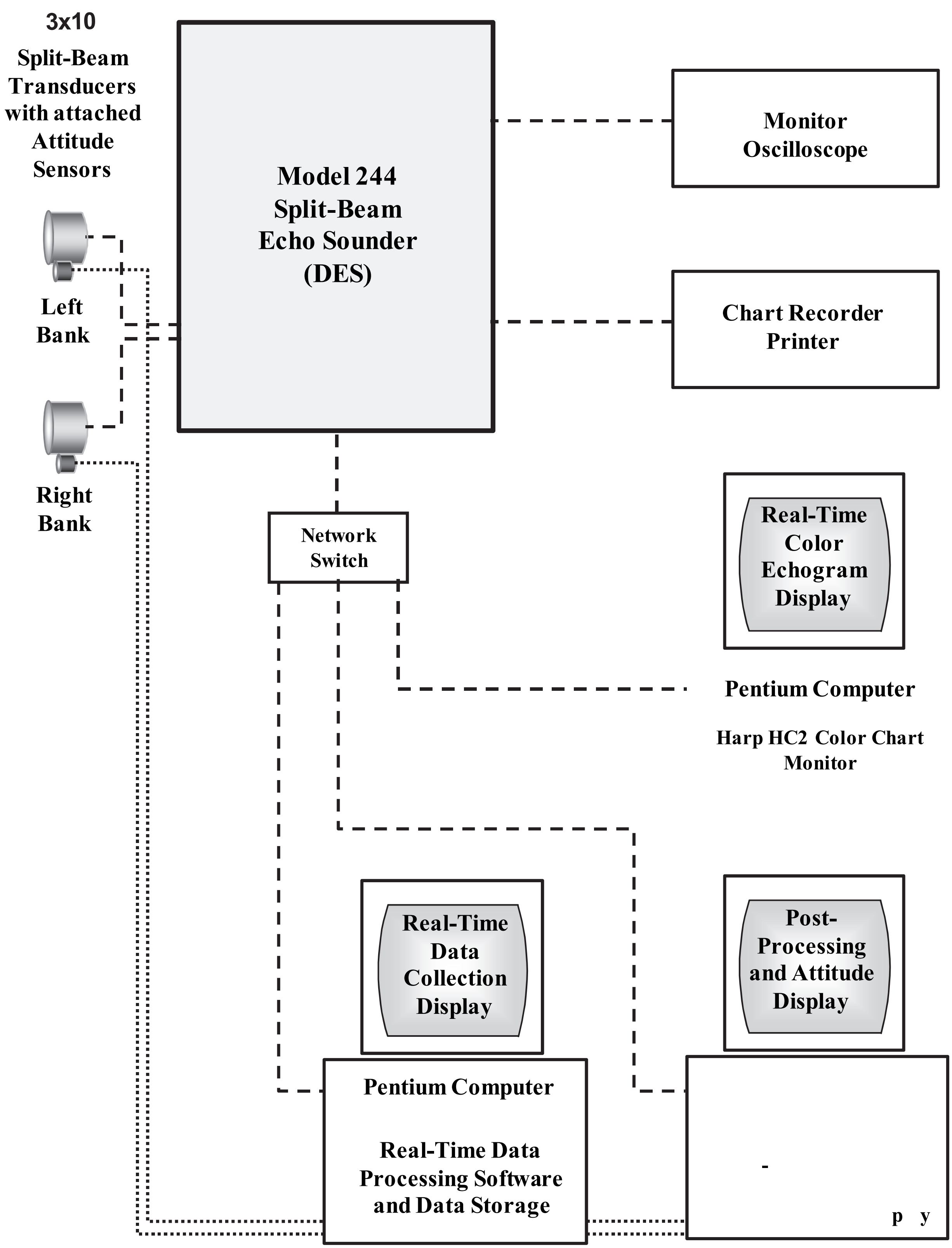
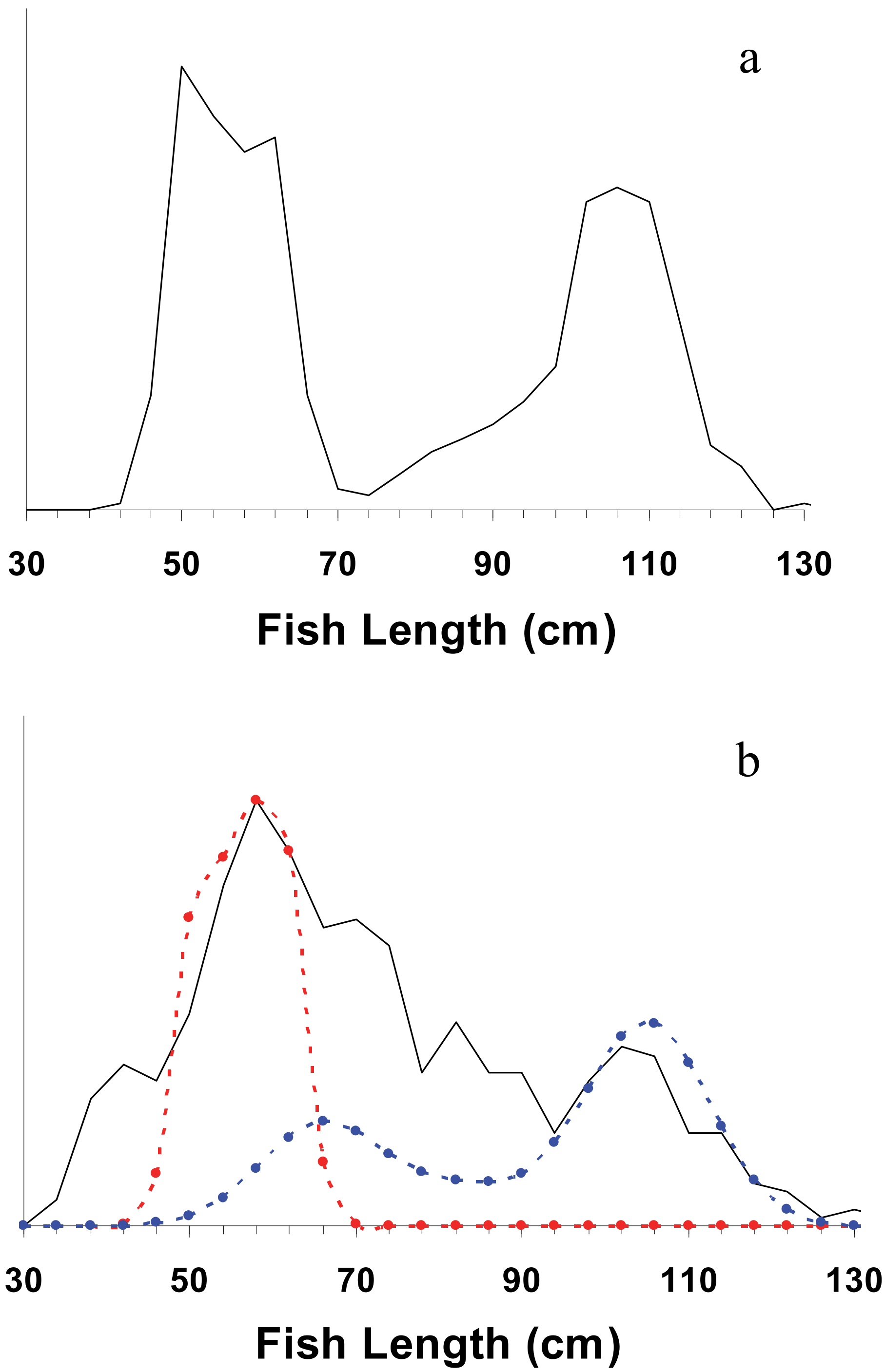


Figure 6.–Diagram of 2011 split-beam sonar system configuration and data flow.



Note: True length distributions of sockeye salmon (red dashed line) and Chinook salmon (blue dashed line) are shown.

Figure 7.–Hypothetical frequency distributions of fish length measurements (black solid lines) at the Kenai River sonar site for true species composition 50% sockeye salmon, 50% Chinook salmon. Vertical axis is relative frequency. Top graph (a) depicts hypothetical distribution when there are few small Chinook salmon and no measurement error. Bottom graph (b) depicts hypothetical distribution when 40% of Chinook salmon are small and measurement error standard deviation is 10 cm.

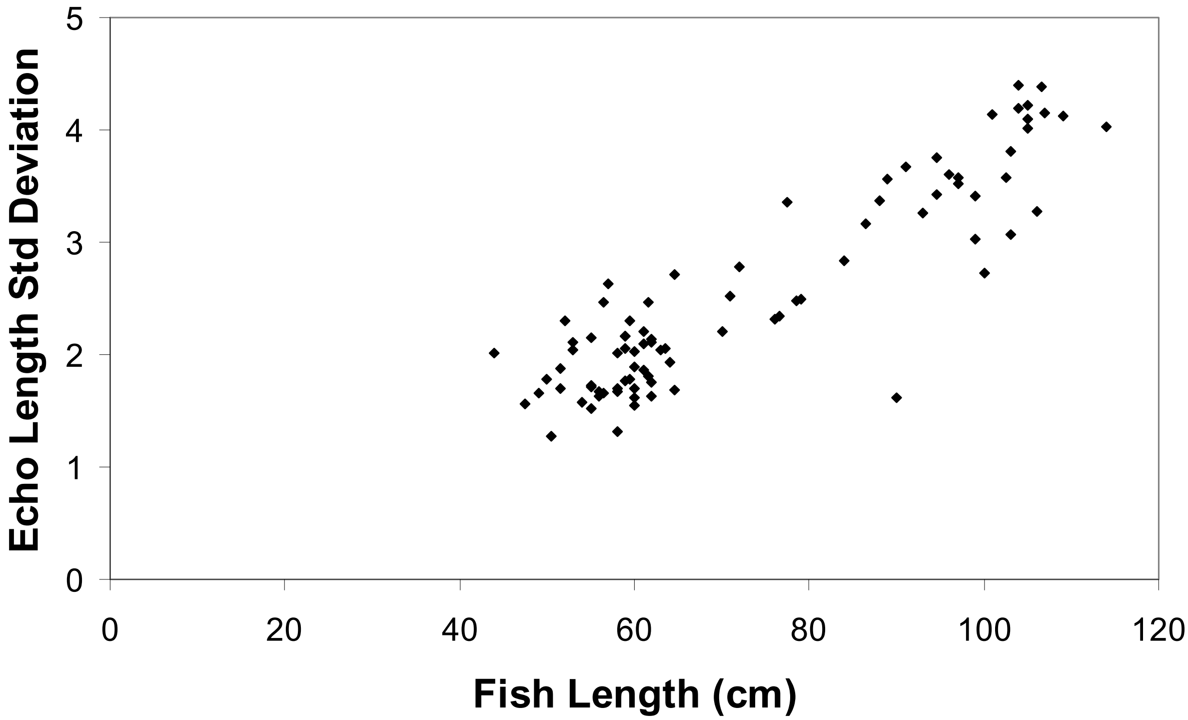
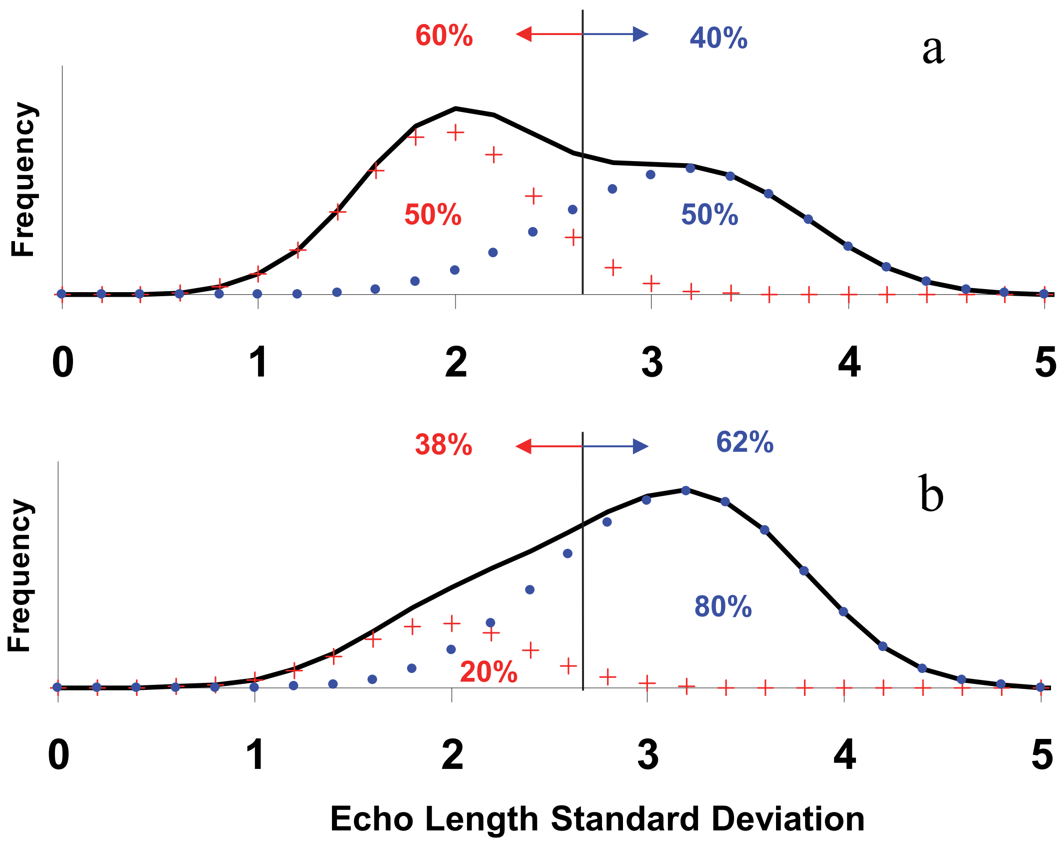
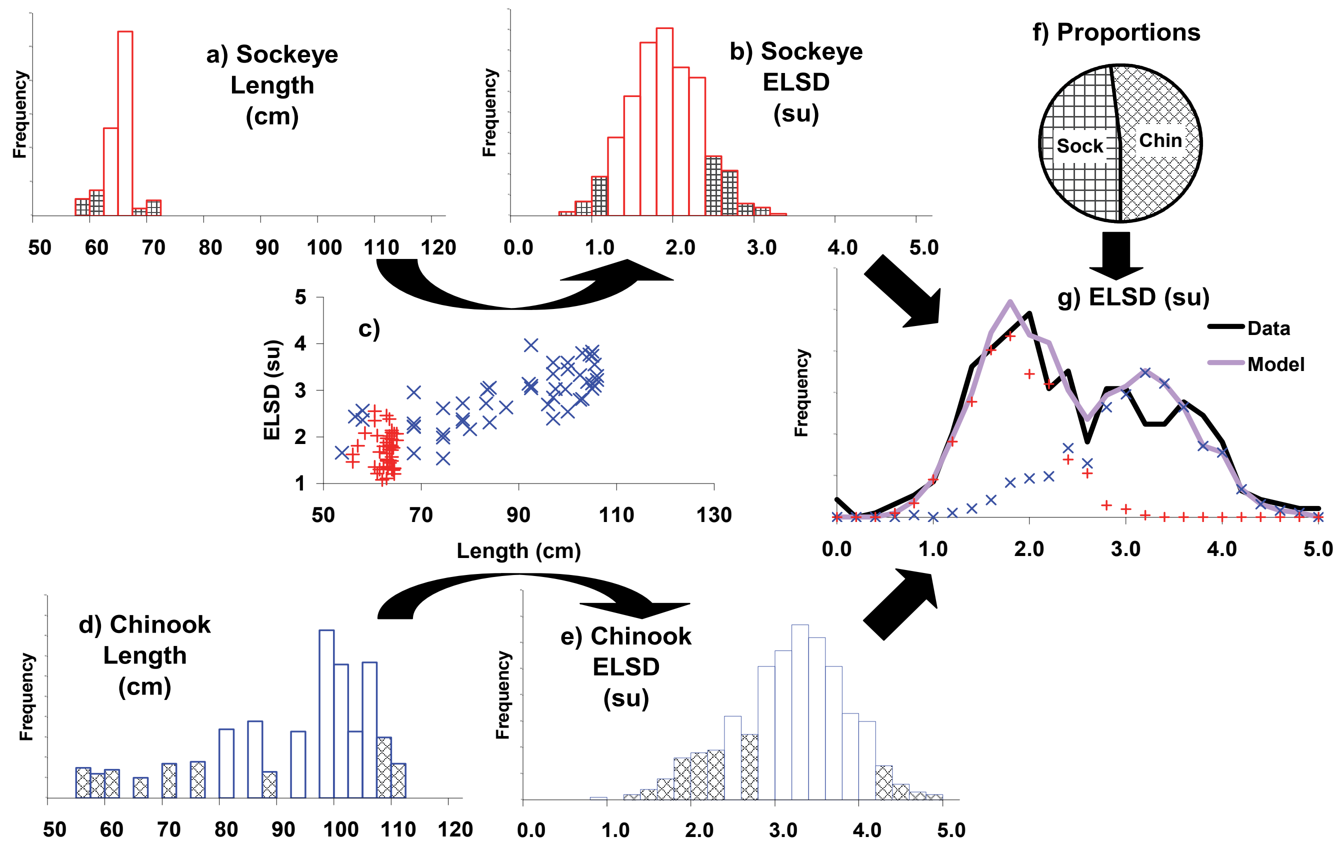


Figure 8.–Echo length standard deviation versus fish length for tethered Pacific salmon in the Kenai River, 1995. Data from Burwen and Fleischman (1998).



Note: Threshold-based discrimination is subject to bias when discriminating variables are imprecise. Solid lines are simulated frequency distributions of echo length standard deviation arising from component distributions due to sockeye salmon (plus symbols) and Chinook salmon (solid symbols).

Figure 9.–An example of threshold-based discrimination of Chinook and sockeye salmon. Top graph (a) depicts a simulated frequency distribution if the true species composition is 50% sockeye, 50% Chinook salmon, and a threshold criterion of 2.7 is used; estimated species composition will be 60:40. Bottom graph (b) depicts a simulated frequency distribution if the true species composition is 20:80, and the same threshold criterion of 2.7 is used; estimated species composition will be 38:62.

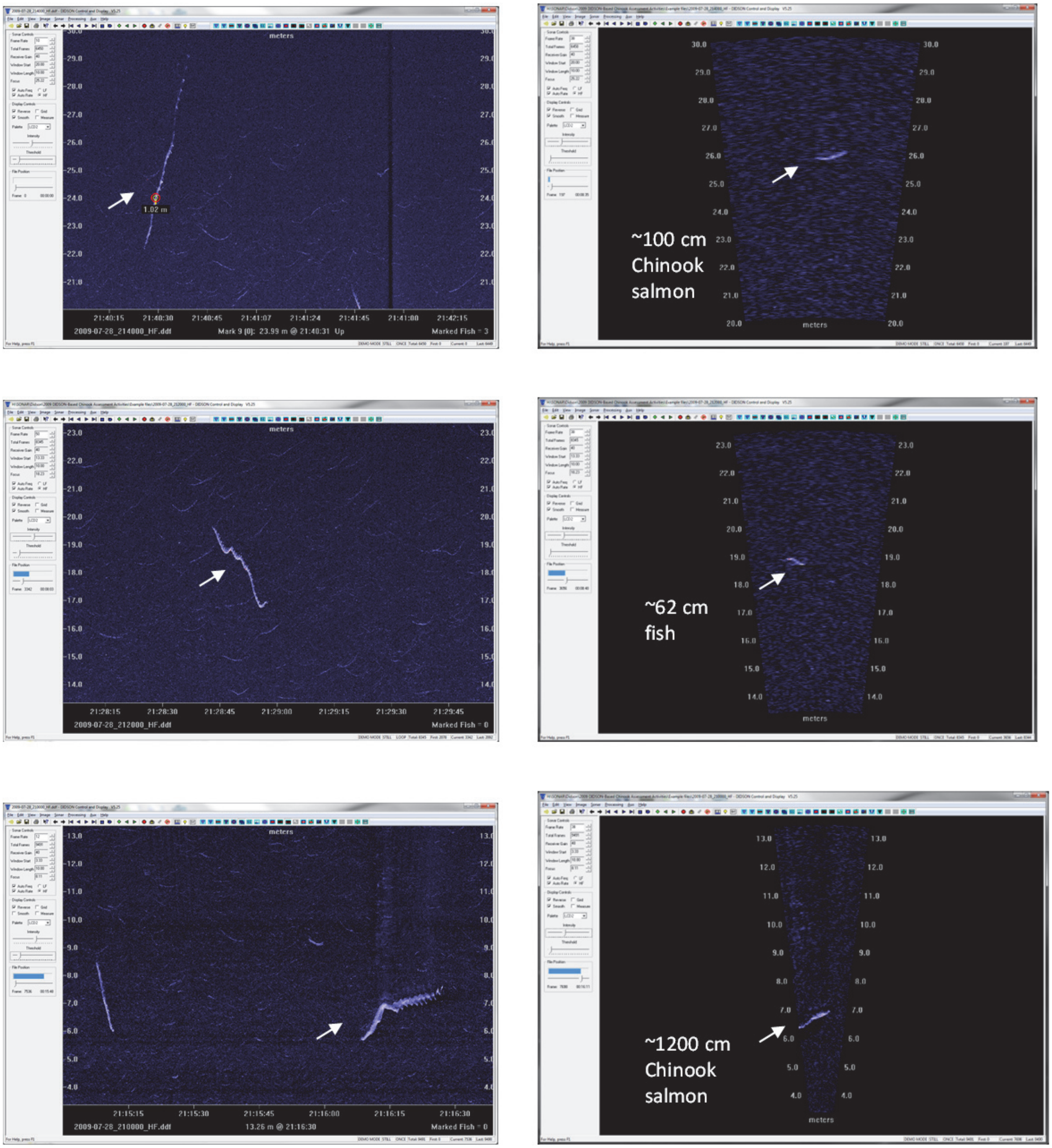


Note: Plus symbol = sockeye salmon, x = Chinook salmon. Checkered pattern = sockeye salmon, cross-hatched = Chinook salmon. Units for ELSD are 48 kHz digital sampling units.

Figure 10.–Flow chart of a mixture model. The frequency distribution of echo length standard deviation (ELSD, panel g) is modeled as a weighted mixture of species-specific ELSD distributions (panels b and e), which in turn are the products of species-specific size distributions (panels a and d) and the relationship between ELSD and fish length (panel c). The weights (species proportions, panel f) are the parameters of interest.

.

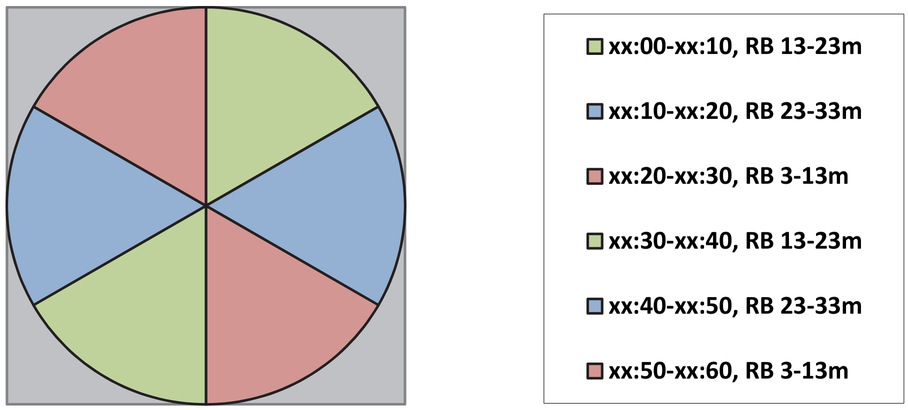
Figure 11.–DIDSON-LR with a high-resolution lens (on left in photos A and B) mounted next to a split-beam transducer (on right in photos A and B). A custom fit fabric enclosure shown in photo B protects against silt buildup in front of the lens as shown in photo C.



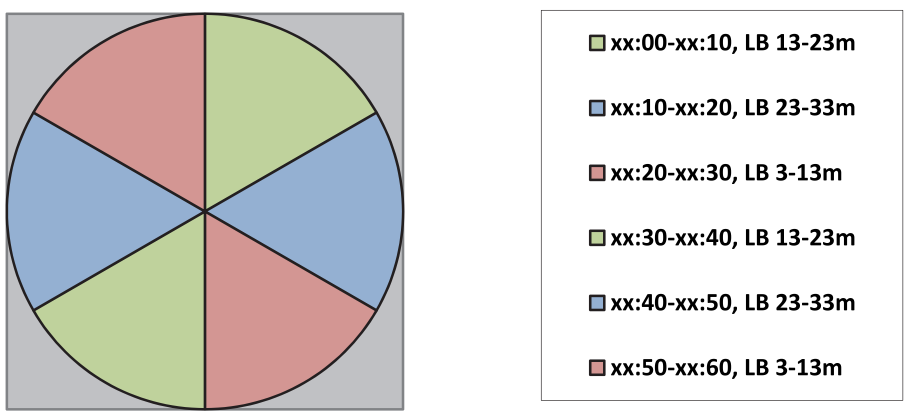
Note: the echograms display approximately 800 frames, whereas the video displays the single frame on which the measurement was taken.

Figure 12.–Example fish traces with their measured sizes are shown on DIDSON echogram (at left) and video (at right) displays for each of the 3 range strata: 3.3–13.3 m (bottom), 13.3–23.3 m (middle), and 23.3–33.3 (top).

Right Bank sample scheme



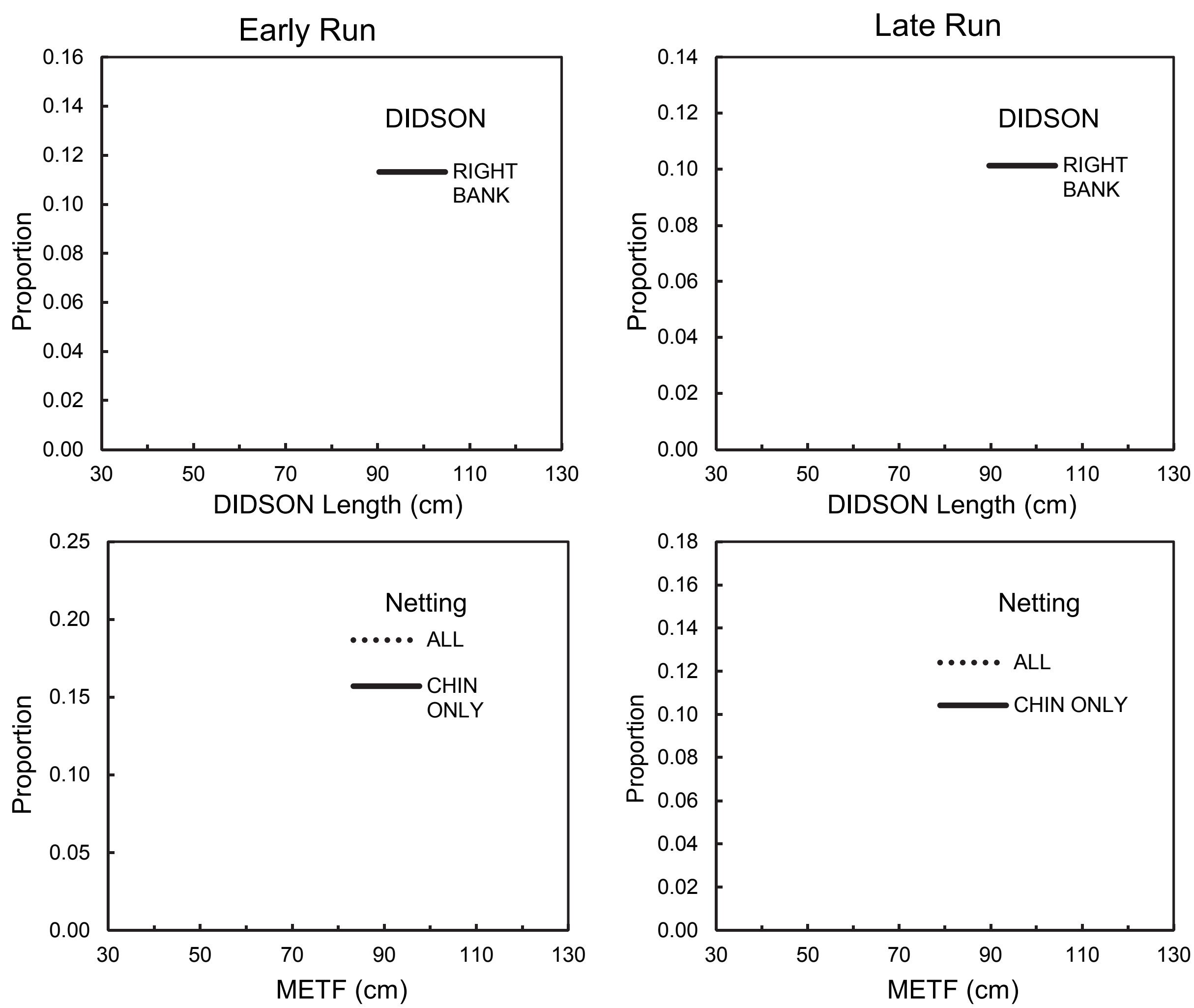
Left Bank sample scheme



Note: Time presented in hours and minutes (hh:mm) format.

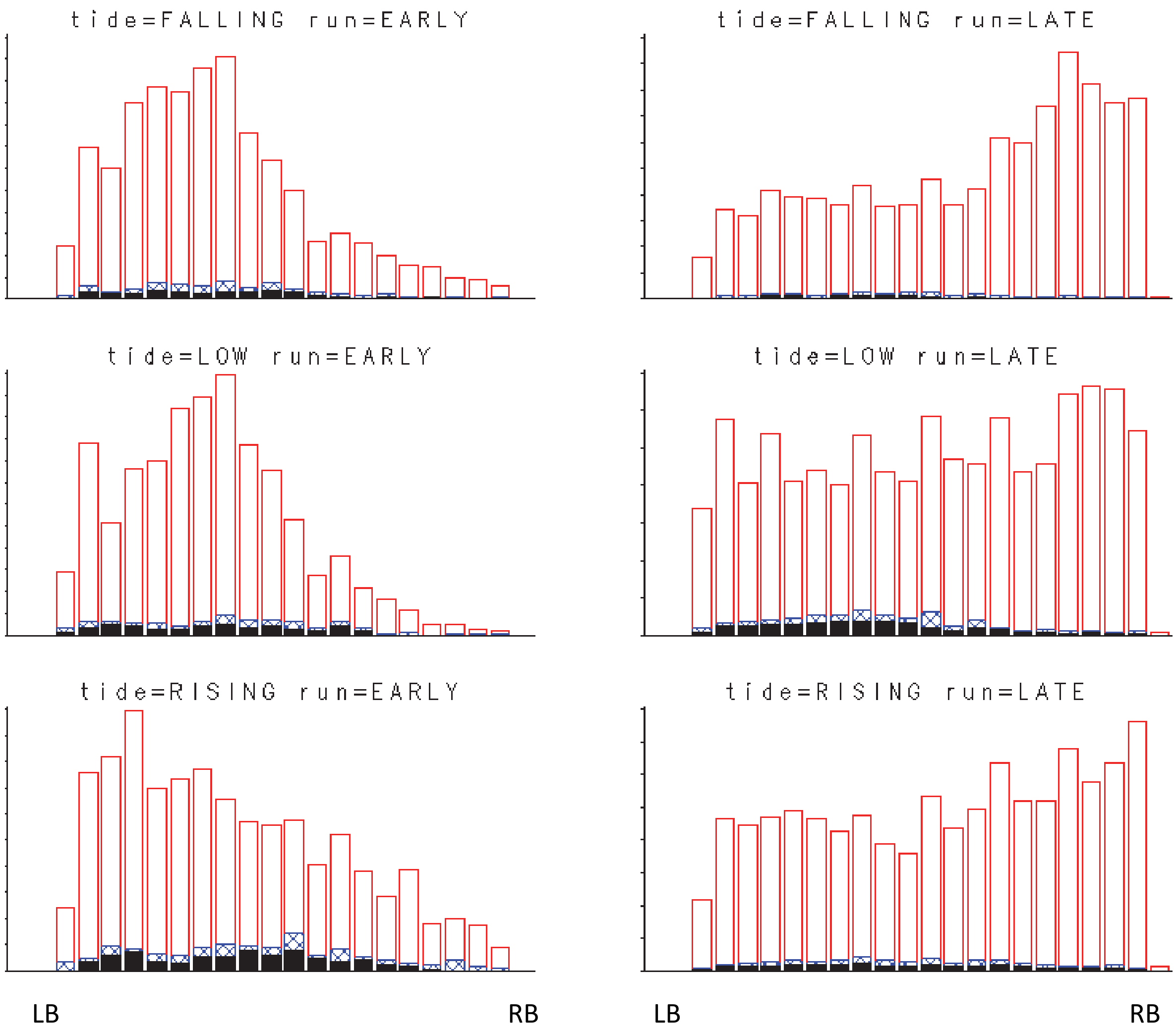
Figure 13.–Right (top) and left (bottom) bank range strata sampling schedules for 2011[30].

[30] The DIDSON caused “cross talk” (interference) for the split-beam sonar. Because the cross talk was most prevalent when sampling the 23–33 m stratum, sampling of this stratum was scheduled during the time period xx:40:00–xx:00:00 (last 20 minutes of the hour) when the split-beam sonar was least likely to be used.



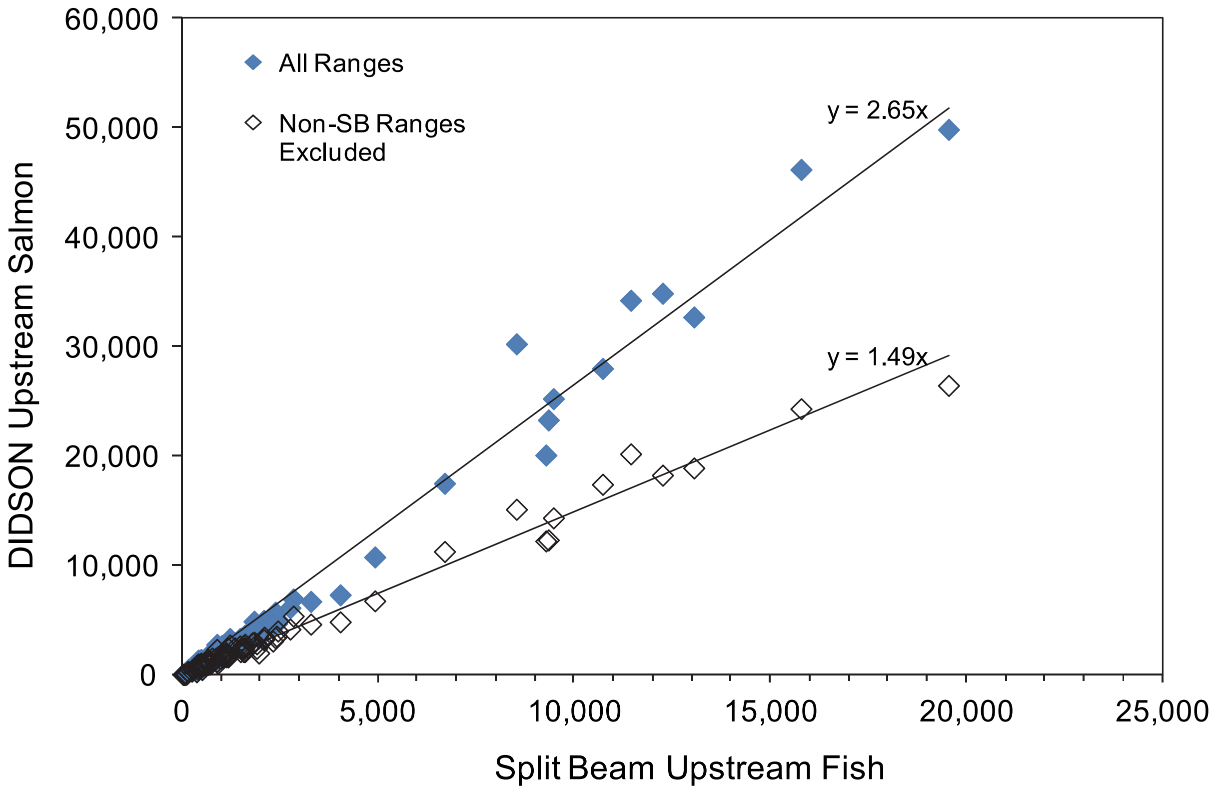
Note: data were not filtered by direction of travel.

Figure 14.–Frequency distributions of fish length as measured by the DIDSON (top, by bank) and mid eye to tail fork (METF) measurements from an onsite netting project (bottom, all species vs. Chinook salmon only), Kenai River RM 8.5, early and late runs, 2011.



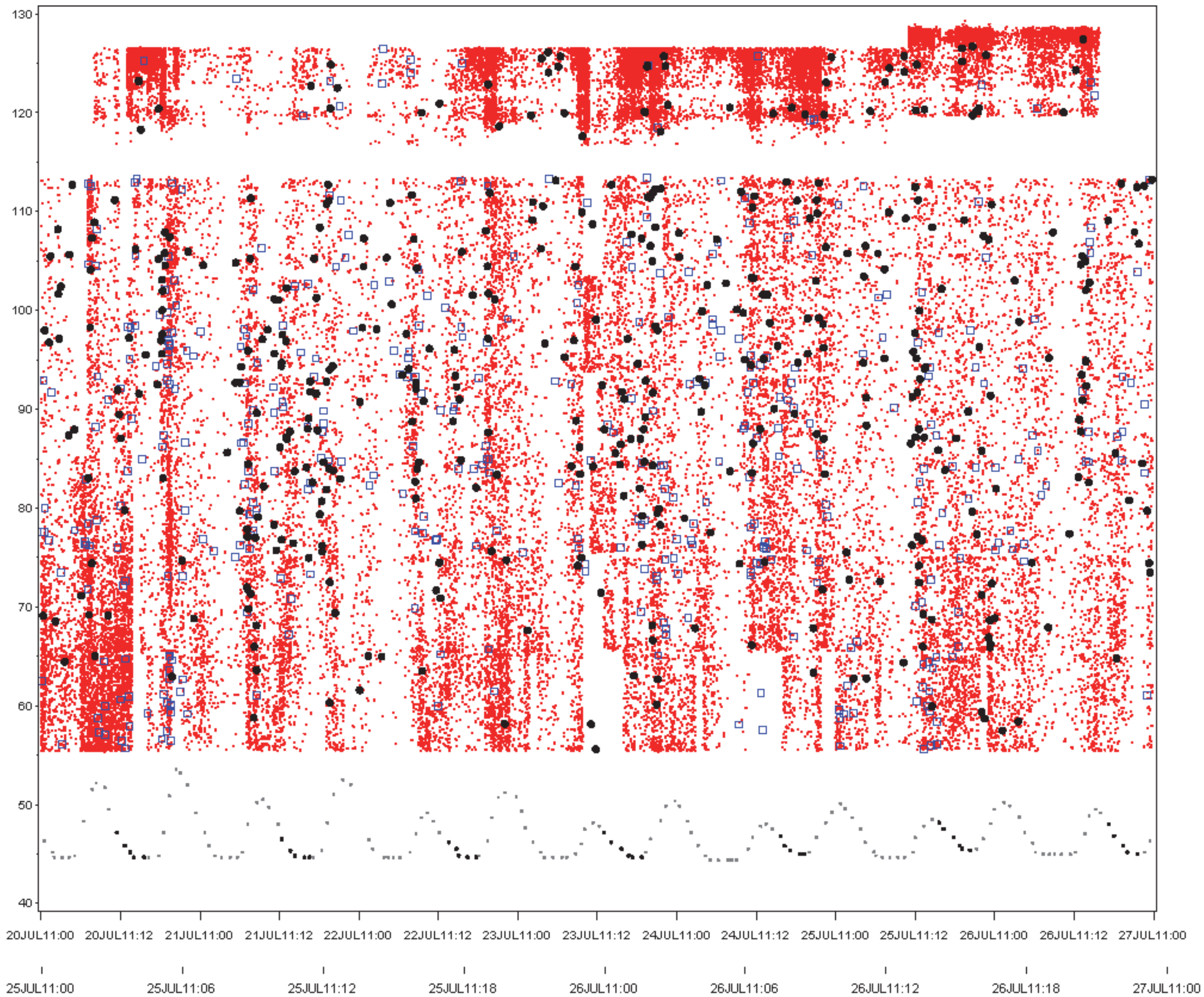
Note: Vertical axis shows percent relative frequency by run and tide stage.
Note: Approximately 60 meters separates the left-bank (LB) and right-bank (RB) transducers.

Figure 15.–Relative frequency distribution of horizontal (cross-river) position of upstream bound fish by tide stage and DIDSON length class (black solid = ≥90 cm, blue hatched = 75–90 cm, red open = <75 cm), Kenai River RM 8.5, early and late runs, 2011.



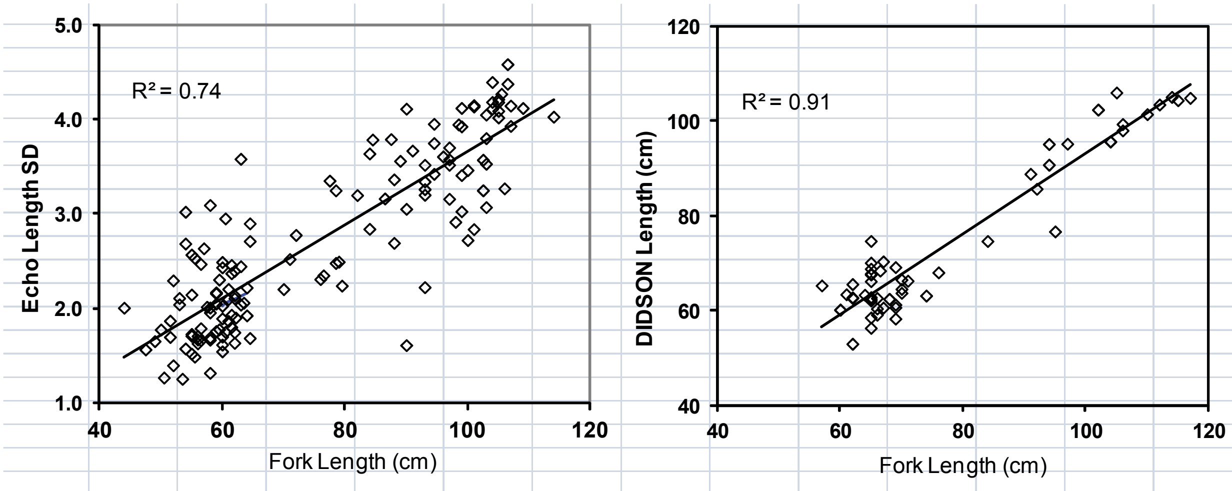
Note: Two versions of DIDSON estimates are shown: estimates with fish at all ranges included (solid symbols), and estimates with fish outside of split-beam ranges excluded (open symbols).

Figure 16.–Daily midriver upstream salmon passage at RM 8.5 Kenai River as determined by DIDSON versus split-beam sonar, 2011.



Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Figure 17.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 20–26 July 2011. This is the same representation as in Appendix E, with additional data behind the left bank transducer included.



Source: Burwen et al. (2003), Burwen et al. (2010), and Miller et al. (2012).

Figure 18.–Split-beam sonar echo length standard deviation (left) and fish length measured from DIDSON images (right) versus measured lengths of tethered fish.

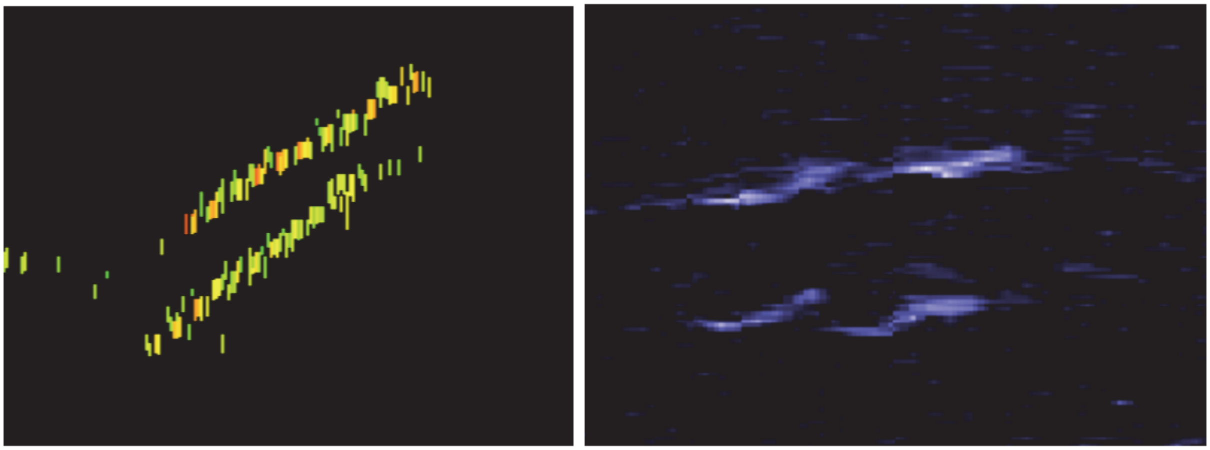


Figure 19.–Two pairs of small salmon swimming head-to-tail, as viewed on a split-beam echogram (left) and a DIDSON video frame (right).

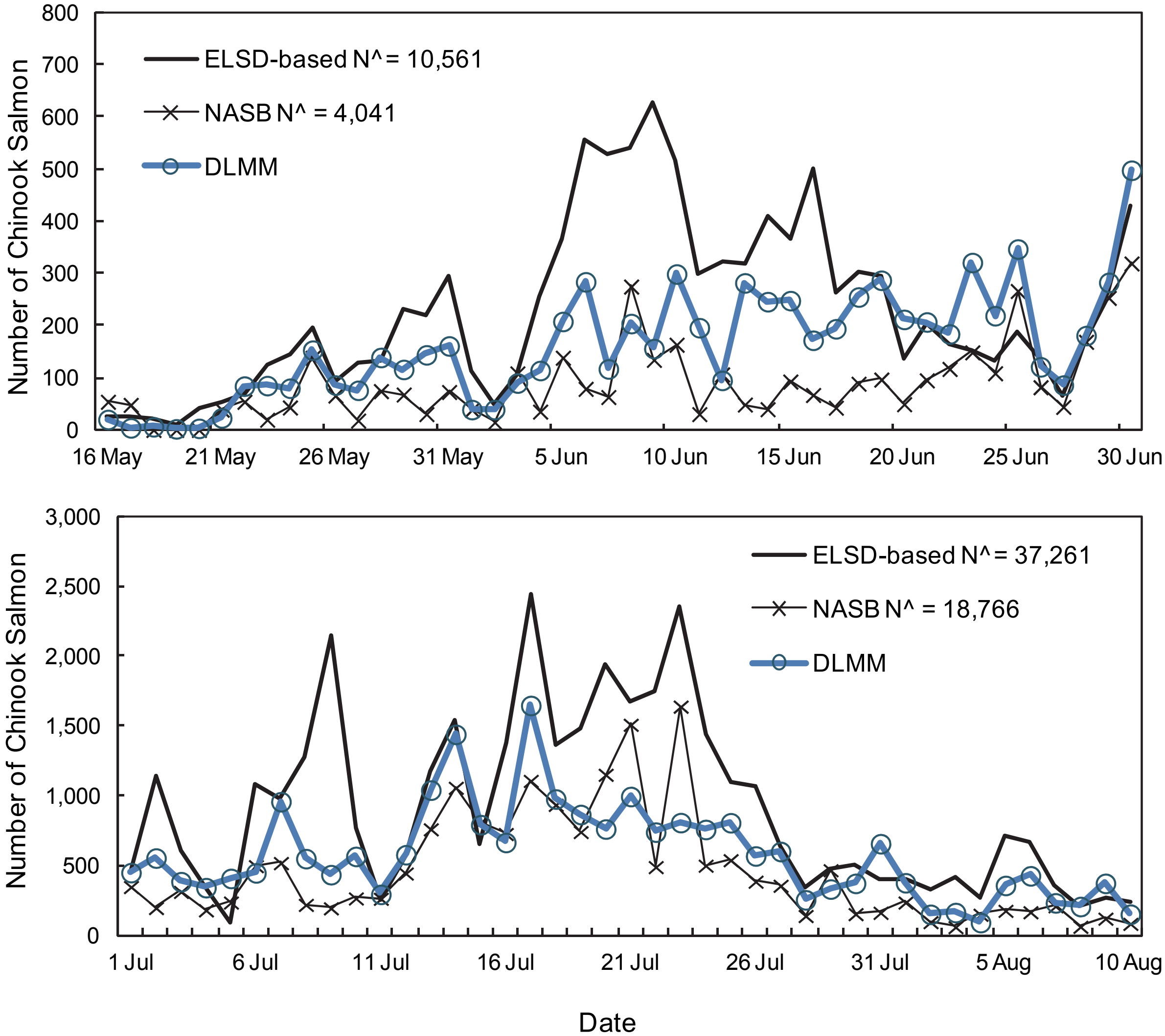
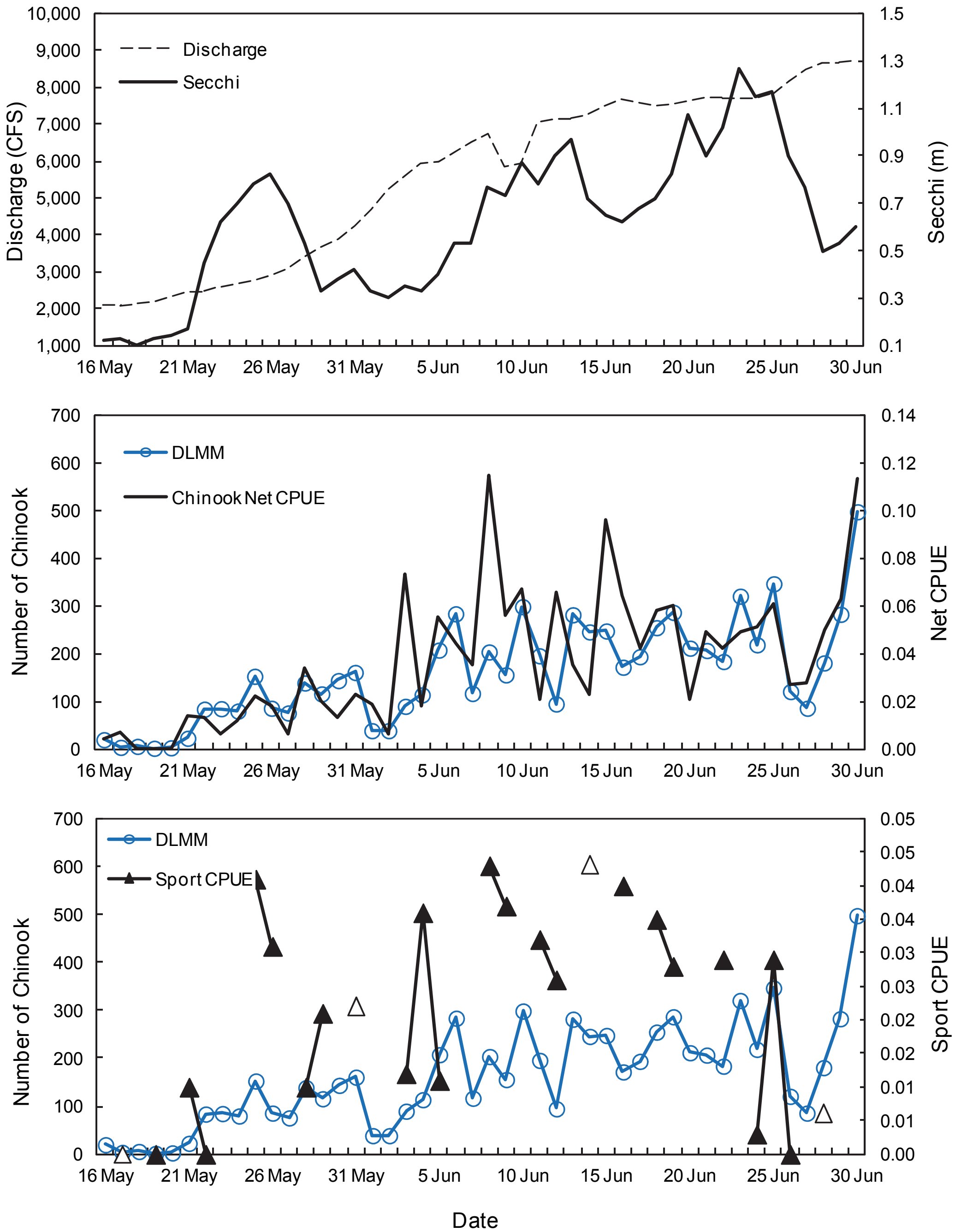


Figure 20.–Estimated upstream bound fish passage based on ELSD-based split-beam sonar, net-apportioned split-beam sonar (NASB), and DIDSON-length mixture model (DLMM), for early- (top) and late-run (bottom) Kenai River Chinook salmon, 2011.

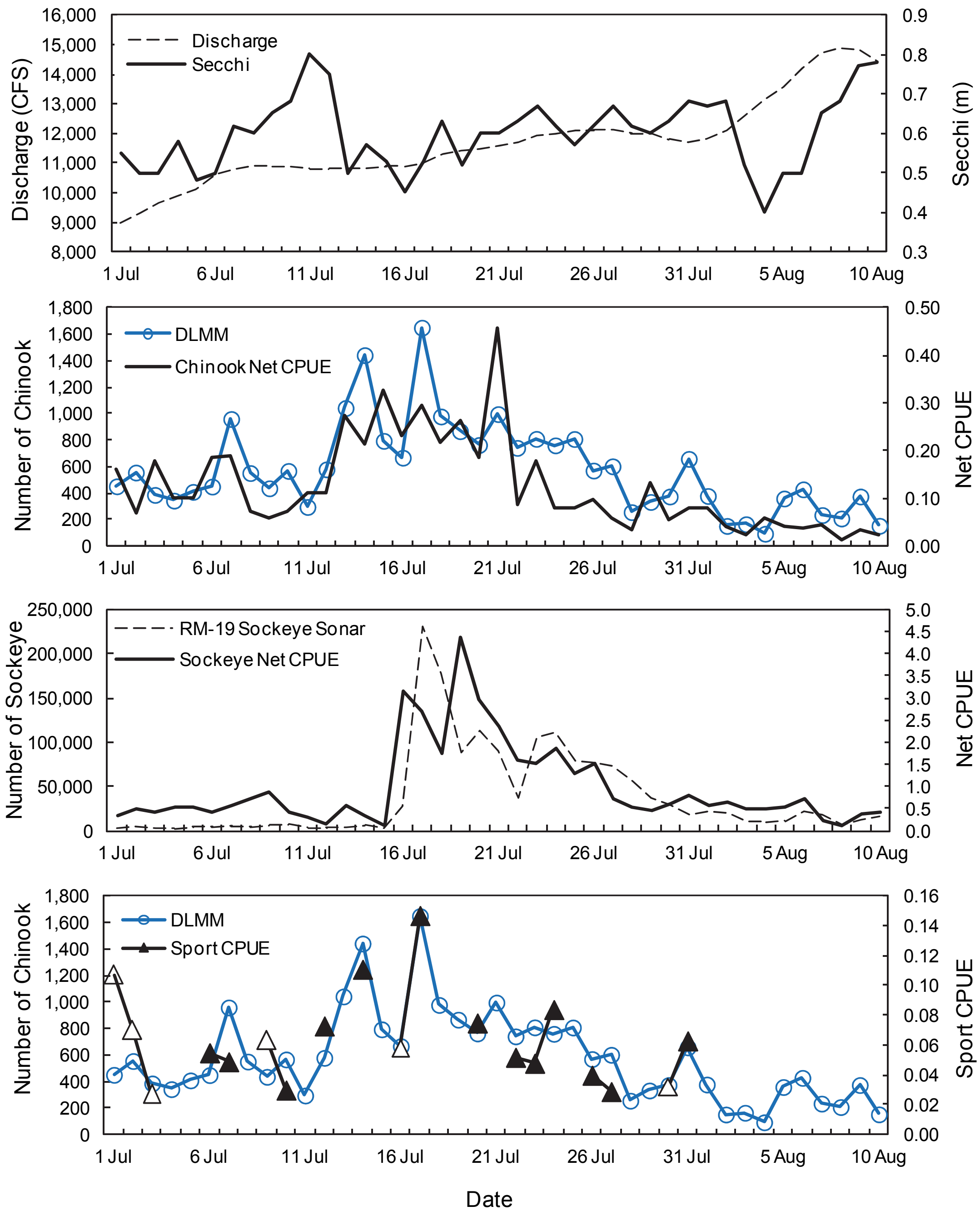


Note: river discharge taken from USGS[31]. Net CPUE and sport fish CPUE taken from Perschbacher (2012). Open triangles represent days on which only unguided anglers were allowed to fish.

Figure 21.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken from the sonar site (A), DIDSON-length mixture model (DLMM) estimates of Chinook salmon passage and inriver gillnet Chinook salmon CPUE (B), and DLMM estimates compared to Chinook salmon sport fishery CPUE (C), Kenai River, early run 2011.

---

[31] USGS Water resource data, Alaska, water year 2011. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed December 11, 2013. http://water.usgs.gov/ak/nwis/discharge.



Note: river discharge taken from USGS[32]. Net CPUE and sport fish CPUE taken from Perschbacher (2012). Open triangles represent days on which only unguided anglers were allowed to fish. RM 19 sonar from Westerman and Willette (2012).

Figure 22.–Daily discharge rates collected at the Soldotna Bridge and Secchi disk readings taken at the RM 8.5 sonar site (A), DIDSON-length mixture model (DLMM) estimates of Chinook salmon passage and inriver gillnet Chinook salmon CPUE (B), RM 19 sockeye salmon sonar passage and inriver gillnet sockeye salmon CPUE (C), and DLMM estimates compared to Chinook salmon sport fishery CPUE (D), Kenai River, late run, 2011.

---

[32] .USGS Water resource data, Alaska, water year 2011. Website Daily Streamflow for Alaska, Soldotna gauging station, site #15266300, accessed December 11, 2013. http://water.usgs.gov/ak/nwis/discharge.

This page intentionally left blank.

APPENDIX A: SPLIT-BEAM SONAR SYSTEM PARAMETERS

Appendix A1.–Example of system parameters used for data collection on the right bank (transducer 733).

Parameter number	Subfield number[a]	Parameter value	Parameter description
100	-1	1	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	13201	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	13	N_th_layer - number of threshold layers
105	-1	5	max_tbp - maximum time between pings in pings
106	-1	5	min_pings - minimum number of pings per fish
507	-1	FED5	timval - 0xFED5 corresponds to about 20 kHz NUS
108	-1	1	mux_on - means multiplexing enabled on board NUS
109	-1	200	mux_delay - samples delay between sync and switching NUS
110	-1	0	decimate_mask - decimate input samples flag NUS
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	Hourly Sampling flag 1=On 0=Off
118	-1	5	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom- 0=fix,1=man,2=scope,3=acq_chan1,4=acq_chan2,5=auto_1,6=auto_chan2
120	-1	0	sb_int_code - sb only=0, sb-int: 40log a bot=1, 20log=2
121	-1	0	sb_int_code2 - sb only=0, sb-int 40log eg=0, 20log=2
122	-1	13	N_int_layers-number of integration strata
123	-1	13	N_int_th_layers - number of integration threshold strata
124	-1	0	int_print - print integrator interval results to printer
125	-1	0	circular element transducer flag for bpf calculation
126	-1	80	grid spacing for Model 404 DCR (in samples, 16 s/m)
127	-1	1	TRIG argument #1 - trigger source
128	-1	0	TRIG argument #2 - digital data routing
130	-1	0	TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None)
200	-1	20	sigma flag 0.0 = no sigma, else sigma is output
201	-1	220.46	sl - transducer source level
202	-1	-171.64	gn - transducer through system gain at one meter
203	-1	-18	rg - receiver gain used to collect data
204	-1	2.8	narr_ax_bw - vertical nominal beam width
205	-1	10	wide_ax_bw - horizontal axis nominal beam width
206	-1	0	narr_ ax_corr - vertical axis phase correction
207	-1	0	wide_ax_corr - horizontal axis phase correction
208	-1	11.0011	ping_rate - pulses per second
209	-1	0	echogram start range in meters
210	-1	34.8	echogram stop range in meters
211	-1	726	echogram threshold in millivolts
212	-1	13.2	print width in inches
213	-1	0	chirp bandwidth (0.0 = CHIRP OFF)
214	-1	20	sampling within hour ending time (in decimal minutes)
215	-1	1500	speed of sound (m/s)
216	-1	200	the transducer's frequency (kHz)
217	-1	-2.5	min_angoff_v - minimum angle off axis vertical
218	-1	2	max_angoff_v - maximum angle off axis vertical
219	-1	-5	min_angoff_h - minimum angle off axis horiz.

-continued-

Parameter number	Subfield number[a]	Parameter value	Parameter description
220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-16.2825	ux - horizontal electrical to mechanical angle ratio
223	-1	-33.0573	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	0.005	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.5634	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.0853	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1104	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	0	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2144	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	echo scope bottom location
236	-1	0.4	maxpw - pulse width search window size
238	-1	34.1	bottom - bottom depth in meters
239	-1	0	init_slope - initial slope for tracking in m/ping
240	-1	0.2	exp_cont - exponent for expanding tracking window
241	-1	0.2	max_ch_rng - maximum change in range in m/ping
242	-1	0.04	pw_criteia->min_pw_6-min -6 dB pulse width
243	-1	10	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.04	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	10	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.04	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	10	pw_criteria->max_pw_18 - max -18 dB pulse width
249	-1	10	maximum voltage to allow in .RAW file
250	-1	0.2	TX argument #1 - pulse width in milliseconds
251	-1	25	TX argument #2 - transmit power in dB-watts
252	-1	-12	RX argument #1 - receiver gain
253	-1	90.9	REP argument #1 - ping rate in ms per ping
254	-1	10	REP argument #2 - pulsed cal tone separation
255	-1	1	TVG argument #1 - TVG start range in meters
256	-1	100	TVG argument #2 - TVG end range in meters
257	-1	40	TVG argument #3 - TVG function (XX Log Range)
258	-1	-6	TVG argument #4 - TVG gain
259	-1	0	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.2	minimum absolute distance fish must travel in x plane
261	-1	0.2	minimum absolute distance fish must travel in y plane
262	-1	0.2	minimum absolute distance fish must travel in z plane
263	-1	2	bottom_window - auto tracking bottom window (m)
264	-1	3	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2	TVG argument #7 - 20/40 log crossover (meters)
266	-1	0	rotator - which rotator to aim
267	-1	0	aim_pan - transducer aiming angle in pan (x, lf/rt)
268	-1	0	aim_tilt - transducer aiming angle in tilt (y, u/d)

-continued-

Parameter number	Subfield number[a]	Parameter value	Parameter description
401	0	1	th_layer[0] – bottom of first threshold layer (m)
401	1	5	th_layer[1] – bottom of second threshold layer (m)
401	2	10	th_layer[2] – bottom of third threshold layer (m)
401	3	15	th_layer[3] – bottom of fourth threshold layer (m)
401	4	20	th_layer[4] – bottom of fifth threshold layer (m)
401	5	25	th_layer[5] – bottom of sixth threshold layer (m)
401	6	30	th_layer[6] – bottom of seventh threshold layer (m)
401	7	35	th_layer[7] – bottom of eighth threshold layer (m)
401	8	40	th_layer[8] – bottom of ninth threshold layer (m)
401	9	45	th_layer[9] – bottom of tenth threshold layer (m)
401	10	50	th_layer[10] – bottom of eleventh threshold layer (m)
401	11	55	th_layer[11] – bottom of twelfth threshold layer (m)
401	12	60	th_layer[12] – bottom of thirteenth threshold layer (m)
402	0	726	th_val[0], threshold for 1st layer in millivolts
402	1	726	th_val[1], threshold for 2nd layer in millivolts
402	2	726	th_val[2], threshold for 3rd layer in millivolts
402	3	726	th_val[3], threshold for 4th layer in millivolts
402	4	726	th_val[4], threshold for 5th layer in millivolts
402	5	726	th_val[5], threshold for 6th layer in millivolts
402	6	726	th_val[6], threshold for 7th layer in millivolts
402	7	726	th_val[7], threshold for 8th layer in millivolts
402	8	726	th_val[8], threshold for 9th layer in millivolts
402	9	726	th_val[9], threshold for 10th layer in millivolts
402	10	726	th_val[10], threshold for 11th layer in millivolts
402	11	726	th_val[11], threshold for 12th layer in millivolts
402	12	9999	th_val[12], threshold for 13th layer in millivolts
405	0	100	integration threshold value for layer 1 (mV)
405	1	100	integration threshold value for layer 2 (mV)
405	2	100	integration threshold value for layer 3 (mV)
405	3	100	integration threshold value for layer 4 (mV)
405	4	100	integration threshold value for layer 5 (mV)
405	5	100	integration threshold value for layer 6 (mV)
405	6	100	integration threshold value for layer 7 (mV)
405	7	100	integration threshold value for layer 8 (mV)
405	8	100	integration threshold value for layer 9 (mV)
405	9	100	integration threshold value for layer 10 (mV)
405	10	100	integration threshold value for layer 11 (mV)
405	11	100	integration threshold value for layer 12 (mV)
405	12	9999	integration threshold value for layer 13 (mV)
602	-1	1017536	echo sounder serial number
604	-1	306733	transducer serial number
605	-1	Spd-4	echogram paper speed
606	-1	9_pin	echogram resolution
607	-1	Board_Extern	trigger option
608	-1	LeftToRight	river flow direction

Note: Start processing at Port 1 –FILE_PARAMETERS- Fri. 1 July 01:00:05 2011.

Note: Data processing parameters used in collecting this file for Port 1.

[a] -1 = unique record or field; other values represent the threshold layer number.

Appendix A2.–Example of system parameters used for data collection on the left bank (transducer 738).

Parameter number	Subfield number[a]	Parameter value	Parameter description
100	-1	2	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	19200	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	293	N_th_layer - number of threshold layers
105	-1	5	max_tbp - maximum time between pings in pings
106	-1	5	min_pings - minimum number of pings per fish
507	-1	FED5	timval - 0xFED5 corresponds to about 20 kHz NUS
108	-1	1	mux_on - means multiplexing enabled on board NUS
109	-1	200	mux_delay - samples delay between sync and switching NUS
110	-1	0	decimate_mask - decimate input samples flag NUS
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	hourly sampling flag 1=On 0=Off
118	-1	5	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom- 0=fix,1=man,2=scope,3=acq_chan1,4=acq_chan2,5=auto_1,6=auto_chan2
120	-1	0	sb_int_code - sb only=0, sb-int: 40log a bot=1, 20log=2
121	-1	0	sb_int_code2 - sb only=0, sb-int 40log eg=0, 20log=2
122	-1	293	N_int_layers-number of integration strata
123	-1	293	N_int_th_layers - number of integration threshold strata
124	-1	0	int_print - print integrator interval results to printer
125	-1	0	circular element transducer flag for bpf calculation
126	-1	80	grid spacing for Model 404 DCR (in samples, 16 s/m)
127	-1	1	TRIG argument #1 - trigger source
128	-1	0	TRIG argument #2 - digital data routing
130	-1	0	TVG Blank (0=Both Start/End,1=Stop Only,2=Start Only,3=None)
200	-1	20	sigma flag 0.0 = no sigma, else sigma is output
201	-1	219.13	sl - transducer source level
202	-1	-173.33	gn - transducer through system gain at one meter
203	-1	-18	rg - receiver gain used to collect data
204	-1	2.8	narr_ax_bw - vertical nominal beam width
205	-1	10	wide_ax_bw - horizontal axis nominal beam width
206	-1	0	narr_ ax_corr - vertical axis phase correction
207	-1	0	wide_ax_corr - horizontal axis phase correction
208	-1	16	ping_rate - pulses per second
209	-1	0	echogram start range in meters
210	-1	26	echogram stop range in meters
211	-1	431	echogram threshold in millivolts
212	-1	13.2	print width in inches
213	-1	0	chirp bandwidth (0.0 = CHIRP OFF)
214	-1	40	sampling within hour ending time (in decimal minutes)
215	-1	1500	speed of sound (m/s)
216	-1	200	the transducer's frequency (kHz)
217	-1	-2.5	min_angoff_v - minimum angle off axis vertical
218	-1	2	max_angoff_v - maximum angle off axis vertical
219	-1	-5	min_angoff_h - minimum angle off axis horiz.

-continued-

Appendix A2.–Page 2 of 3.

Parameter number	Subfield number[a]	Parameter value	Parameter description
220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-16.3568	ux - horizontal electrical to mechanical angle ratio
223	-1	-55.2949	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0173	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.5994	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.285	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.2397	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	0.0001	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2225	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	-0.0005	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0002	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	4	maximum fish velocity in meters per second
235	-1	1	echo scope bottom location
236	-1	0.4	maxpw - pulse width search window size
238	-1	25.3	bottom - bottom depth in meters
239	-1	0	init_slope - initial slope for tracking in m/ping
240	-1	0.2	exp_cont - exponent for expanding tracking window
241	-1	0.2	max_ch_rng - maximum change in range in m/ping
242	-1	0.04	pw_criteria->min_pw_6-min -6 dB pulse width
243	-1	10	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.04	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	10	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.04	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	10	pw_criteria->max_pw_18 - max -18 dB pulse width
249	-1	10	maximum voltage to allow in .RAW file
250	-1	0.2	TX argument #1 - pulse width in milliseconds
251	-1	25	TX argument #2 - transmit power in dB-watts
252	-1	-12	RX argument #1 - receiver gain
253	-1	62.5	REP argument #1 - ping rate in ms per ping
254	-1	10	REP argument #2 - pulsed cal tone separation
255	-1	2	TVG argument #1 - TVG start range in meters
256	-1	100	TVG argument #2 - TVG end range in meters
257	-1	40	TVG argument #3 - TVG function (XX Log Range)
258	-1	-6	TVG argument #4 - TVG gain
259	-1	0	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.2	minimum absolute distance fish must travel in x plane
261	-1	0.2	minimum absolute distance fish must travel in y plane
262	-1	0.2	minimum absolute distance fish must travel in z plane
263	-1	2	bottom_window - auto tracking bottom window (m)
264	-1	3	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2	TVG argument #7 - 20/40 log crossover (meters)
266	-1	0	rotator - which rotator to aim
267	-1	0	aim_pan - transducer aiming angle in pan (x, lf/rt)
268	-1	0	aim_tilt - transducer aiming angle in tilt (y, u/d)

-continued-

Parameter number	Subfield number[a]	Parameter value	Parameter description
401	0-292	1-30.2	th_layer[0-292], bottom of 1st threshold layer – bottom of 293rd theshold layer (i.e. 293 threshold layers in 0.1 m increments and numbered 0 through 292)
402	0-291	448	th_val[0-291], threshold for 1st through 292nd layer in millivolts
402	292	9999	th_val[292], threshold for 293rd layer in millivolts
405	0-291	100	integration threshold value for layer 1-292 (mV)
405	292	9999	integration threshold value for layer 293 (mV)
602	-1	1017536	echo sounder serial number
604	-1	306738	transducer serial number
605	-1	Spd-4	echogram paper speed
606	-1	9_pin	echogram resolution
607	-1	Board_Ext	trigger option
608	-1	LeftToRight	river flow direction

Note: Start processing at Port 2 –FILE_PARAMETERS- Fri. 1 July 01:20:03 2011.

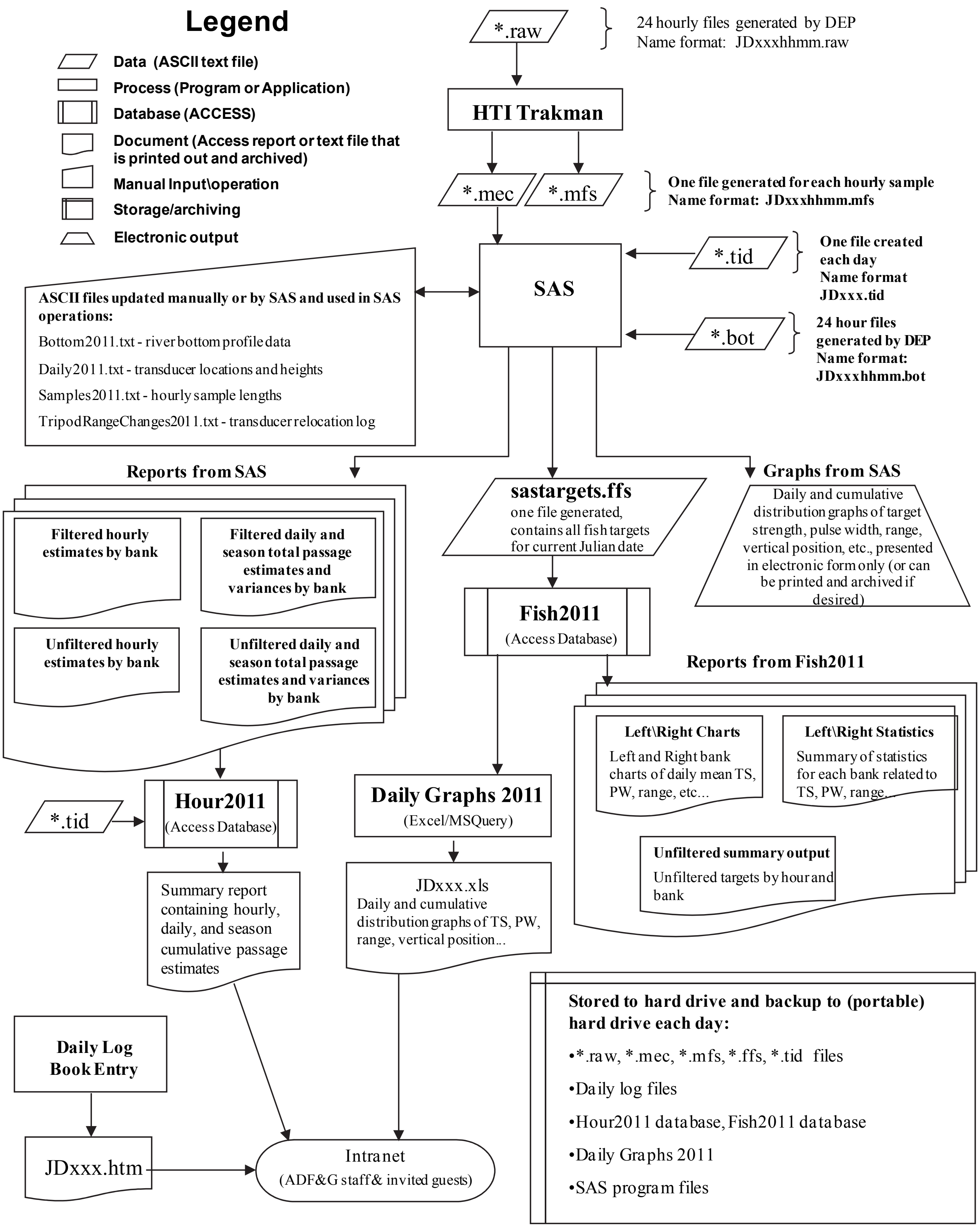
Note: Data processing parameters used in collecting this file for Port 2.

[a] -1 = unique record or field; other values represent the threshold layer number.

This page intentionally left blank.

APPENDIX B: SPLIT-BEAM SONAR DATA FLOW

Appendix B1.–Data flow diagram for the Kenai River Chinook salmon sonar project, 2011.



APPENDIX C: WINBUGS CODE

Appendix C1.–WinBUGS code for hierarchical age-composition model for development of prior distributions for ELSD mixture model.

```
# Age Mixture.odc  version 6a:

model  {
  #Overall means and std deviations
  for  ( a in 1:A)    {
    sigma[a] ~ dnorm  ( 0,1.0E-4)  I ( 0,)
    tau[a] <- 1 / sigma[a] / sigma[a]
    mu[a] ~ dnorm  ( 0,1.0E-12)  I ( 0,)
  }
  #Dirichlet distributed age proportions across years within weeks
  D.scale ~ dunif  ( 0,1)
  D.sum <- 1 /  ( D.scale * D.scale)
  for  ( w in 1:W)    {
    pi[w,1] ~ dbeta  ( 0.2,0.4)
    pi.2p[w] ~ dbeta  ( 0.2,0.2)
    pi[w,2] <- pi.2p[w] *  ( 1 - pi[w,1])
    pi[w,3] <- 1 - pi[w,1] - pi[w,2]
    for  ( y in 1:Y)    {
      for  ( a in 1:A)    {
        D[w,y,a] <- D.sum * pi[w,a]
        g[w,y,a] ~ dgamma  ( D[w,y,a],1)
        pi.wy[w,y,a] <- g[w,y,a]/sum  ( g[w,y,])
      }
    }
  }
  for  ( i in 1:nfish)    {
    age[i] ~ dcat  ( pi.wy[week[i],year[i],1:A])
    length[i] ~ dnorm  ( mu[age[i]],tau[age[i]])
  }
}
```

Appendix C2.–WinBUGS code for ELSD mixture model fit to 2011 Kenai River Chinook salmon sonar, gillnetting, and tethered fish data. Prior distributions in green font, likelihoods in blue.

```
# ELSD 07 version 4:
# fish with neighbors < 1m in range excluded,
model{
 beta0 ~ dnorm(0,1.0E-4)
 beta1 ~ dnorm(0,1.0E-4)
 gamma ~ dnorm(0,1.0E-4)
 sigma.elsd ~ dunif(0,2)
 sigma.beta0 ~ dunif(0,2)
 tau.elsd  <- 1 / sigma.elsd / sigma.elsd
 tau.beta0 <- 1 / sigma.beta0 / sigma.beta0
 ps[1:2] ~ ddirch(D.species[])
 pa[1,1] ~ dbeta(B1,B2)
 theta1 ~ dbeta(B3,B4)
 pa[1,2] <- theta1 * (1 - pa[1,1])
 pa[1,3] <- 1 - pa[1,1] - pa[1,2]
 pa[2,1] ~ dbeta(0.5,0.5)
 theta2 ~ dbeta(0.5,0.5)
 pa[2,2] <- theta2 * (1 - pa[2,1])
 pa[2,3] <- 1 - pa[2,1] - pa[2,2]

 p.chin <- ps[1] * p_n * p_i
 Lsig[1] <- 75
 Lsig[2] <- 25   #CHANGED FROM 34 in 2006, BASED ON AGE MIXTURE.ODC V5D SOCKEYE
 Ltau[1] <- 1 / Lsig[1] / Lsig[1]
 Ltau[2] <- 1 / Lsig[2] / Lsig[2]
 mu[1,1] ~ dnorm(636,0.0006)
 mu[1,2] ~ dnorm(816,0.0070)
 mu[1,3] ~ dnorm(1032,0.0006)
 mu[2,1] ~ dnorm(380,0.003)
 mu[2,2] ~ dnorm(500,0.006)
 mu[2,3] ~ dnorm(580,0.006)
 D.age.sockeye[1] <- 0.01
 D.age.sockeye[2] <- 0.5
 D.age.sockeye[3] <- 3.5
 for (a in 1:3)  {
  pa.effective[1,a] <- pa[1,a] * q1.a[a] /  inprod(pa[1,],q1.a[])
  pa.effective[2,a] <- pa[2,a]
  }

 for (y in 1:3) {
  beta0.y[y] ~ dnorm(beta0,tau.beta0)
  }
 beta0.predict ~ dnorm(beta0,tau.beta0)
 for (k in 1:141) {
  elsd1[k] ~ dnorm(mu.elsd1[k],tau.elsd)
  mu.elsd1[k] <- beta0.y[year[k]] + beta1 * cm75[k] + gamma * sock.indic[k]
  }
```

-continued-

```
for (i in 1:nfish) {
  age[i] ~ dcat(pa.effective[species[i],1:3])
  mefl[i] ~ dnorm(mu[species[i],age[i]],Ltau[species[i]])
  }
for (j in 1:ntgts) {
  species2[j] ~ dcat(ps[])
  age2[j] ~ dcat(pa[species2[j],1:3])
  mefl2[j] ~ dnorm(mu[species2[j],age2[j]],Ltau[species2[j]])
  elsd2[j] ~ dt(mu.elsd2[j],tau.elsd,8)
  cm75t[j] <- (mefl2[j] / 10) - 75;
  sock.indic2[j] <- species2[j] - 1;
  mu.elsd2[j] <- beta0.predict + gamma*sock.indic2[j] + beta1 * cm75t[j]
  } }
```

Appendix C3.–WinBUGS code for DIDSON-length mixture model, standard protocol. Prior distributions in green font, likelihoods in blue.

```
model{
 beta0 ~ dnorm(75,0.0025)
 beta1 ~ dnorm(0.8,25)
 sigma.DL ~ dunif(0,20)
 tau.DL  <- 1 / sigma.DL / sigma.DL
 ps[1:2] ~ ddirch(D.species[])
 pa[1,1] ~ dbeta(0.5,0.5)
 theta1 ~ dbeta(0.5,0.5)
 pa[1,2] <- theta1 * (1 - pa[1,1])
 pa[1,3] <- 1 - pa[1,1] - pa[1,2]
 pa[2,1] ~ dbeta(0.5,0.5)
 theta2 ~ dbeta(0.5,0.5)
 pa[2,2] <- theta2 * (1 - pa[2,1])
 pa[2,3] <- 1 - pa[2,1] - pa[2,2]
 n.chin <- ps[1] * ntgts
 p.large <- ps[1] * (1 - pa[1,1])
 n.large <- p.large * ntgts
  Lsig[1,1] <- 78
 Lsig[1,2] <- 70
 Lsig[1,3] <- 74
 Lsig[2,1] <- 25
 Lsig[2,2] <- 25
 Lsig[2,3] <- 25
 for (s in 1:2)  {for (a in 1:3)  {Ltau[s,a] <- 1 / Lsig[s,a] / Lsig[s,a] } }
 mu[1,1] ~ dnorm(621,0.0076)
 mu[1,2] ~ dnorm(825,0.0021)
 mu[1,3] ~ dnorm(1020,0.0047)
 mu[2,1] ~ dnorm(380,0.0004)
 mu[2,2] ~ dnorm(500,0.0004)
 mu[2,3] ~ dnorm(580,0.0004)
 for (a in 1:3)  {
   pa.effective[1,a] <- pa[1,a] * q1.a[a] /  inprod(pa[1,],q1.a[])
   pa.effective[2,a] <- pa[2,a]
   }
 for (k in 1:5) {
   TL.cm.75[k] <- TL.cm[k] - 75
   mu.DL1[k] <- beta0 + beta1 * TL.cm.75[k]
   DL1[k] ~ dnorm(mu.DL1[k],tau.DL)
   }
 for (i in 1:nfish) {
   age[i] ~ dcat(pa.effective[species[i],1:3])
   mefl.mm[i] ~ dnorm(mu[species[i],age[i]],Ltau[species[i],age[i]])
   }
 for (j in 1:ntgts) {
   species2[j] ~ dcat(ps[])
   age2[j] ~ dcat(pa[species2[j],1:3])
   mefl.mm.2[j] ~ dnorm(mu[species2[j],age2[j]],Ltau[species2[j],age2[j]])
   TL2.cm.75[j] <- (1.1*mefl.mm.2[j] + 2) / 10 - 75    # CONVERT TO TL -NUSHAGAK 2001 DATA
   mu.DL2[j] <- beta0 + beta1 * TL2.cm.75[j]
   DL2[j] ~ dnorm(mu.DL2[j],tau.DL)
   }
 }
```

Appendix C4.–Substitute WinBUGS code for DIDSON-length mixture model, fast-track protocol. Statements replace last paragraph of Appendix C3. Likelihoods in blue. Data DL3 are unmeasured fish judged to be less than 75 cm.

```
for (j in 1:n_meas) {
  species2[j] ~ dcat(ps[])
  age2[j] ~ dcat(pa[species2[j],1:3])
  mefl.mm.2[j] ~ dnorm(mu[species2[j],age2[j]],Ltau[species2[j],age2[j]])
  TL2.cm.75[j] <- (1.1*mefl.mm.2[j] + 2) / 10 –
  mu.DL2[j] <- beta0 + beta1 * TL2.cm.75[j]
  DL2[j] ~ dnorm(mu.DL2[j],tau.DL)
  }
for (k in 1:n_small) {
  species3[k] ~ dcat(ps[])
  age3[k] ~ dcat(pa[species3[k],1:3])
  mefl.mm.3[k] ~ dnorm(mu[species3[k],age3[k]],Ltau[species3[k],age3[k]])
  TL3.cm.75[k] <- (1.1*mefl.mm.3[k] + 2) / 10 - 75
  mu.DL3[k] <- beta0 + beta1 * TL3.cm.75[k]
  DL3[k] ~ dnorm(mu.DL3[k],tau.DL)I(,75)
  }
}
```

APPENDIX D: DIDSON CONFIGURATION FOR KENAI RIVER CHINOOK SONAR STUDY, 2011

Selection of the appropriate DIDSON hardware configuration and operating parameters is primarily determined by the range and resolution needs of a specific application. Because resolution generally decreases as the insonified range increases, the need to balance and optimize these parameters determined the configuration used at the Kenai River RM 8.5 site.

Frequency

DIDSON sonars operate at 2 frequencies: a higher frequency that produces higher resolution images and a lower frequency that can detect targets at farther ranges but at a reduced image resolution. Two DIDSON models are currently available based on different operating frequencies (Appendix D2). The short-range or standard model (DIDSON-S) operates at 1.8 MHz to approximately 15 m and 1.1 MHz to approximately 30 m and produces higher resolution images than the long-range model. The long-range model (DIDSON-LR) operates at 1.2 MHz to approximately 30 m and 0.7 MHz to ranges exceeding 100 m, but produces images with approximately half the resolution of the DIDSON-S (see explanation below). A long-range model (DIDSON-LR) was used in this study to insonify the required range and was operated in high frequency mode (1.2 MHz) to achieve maximum image resolution.

Beam Dimensions and Lens Selection

The DIDSON-LR used in this study was fitted with a high-resolution lens to further enhance the image resolution of the DIDSON-LR system (DIDSON-LR+HRL).The high-resolution lens has a larger aperture that increases the image resolution by approximately a factor of 2 over the standard lens by reducing the width of the individual beams and spreading them across a narrower field of view (Appendices D2 and D3). Overall nominal beam dimensions for a DIDSON-LR with a standard lens are approximately 29° in the horizontal axis and 14° in the vertical axis. Operating at 1.2 MHz, the 29° horizontal axis is a radial array of 48 beams that are nominally 0.54° wide and spaced across the array at approximately 0.60° intervals. With the addition of the high-resolution lens, the overall nominal beam dimensions of the DIDSON-LR are reduced to approximately 15° in the horizontal axis and 3° in the vertical axis and the 48 individual beams are reduced to approximately 0.3° wide and spaced across the array at approximately 0.3° intervals. The combined concentration of horizontal and vertical beam widths also increases the returned signal from a given target by 10 dB, which increases the range capability of the DIDSON-LR from 25 m to at least 30 m (Appendix D2). After adding the high resolution lens, the DIDSON-LR has equivalent resolution and twice the range capabilities as the DIDSON-S. However, the reduction in beam dimensions could potentially reduce detection capabilities, particularly at very close range (e.g., at ranges less than 5 m).

-continued-

Resolution

The resolution of a DIDSON image is defined in terms of down-range and cross-range resolution where cross-range resolution refers to the width and down-range resolution refers to the height of the individual pixels that make up the DIDSON image (Appendix D4). Each image pixel in a DIDSON frame has (x, y) rectangular coordinates that are mapped back to a beam and sample number defined by polar coordinates. The pixel height defines the down-range resolution and the pixel width defines the cross-range resolution of the image. Appendix D4 shows that image pixels are sometimes broken down into smaller screen pixels (e.g., pixels immediately to the right of the enlarged pixels), which are an artifact of conversions between rectangular and polar coordinates.

"Window length" is the range interval sampled by the sonar, and it controls the down-range resolution of the DIDSON image. Because the DIDSON image is composed of 512 samples (pixels) in range, images with shorter window lengths are better resolved (i.e., down-range resolution = window length/512). Window length can be set to 2.5, 5.0, 10.0, or 20.0 m for the DIDSON-LR+HRL at 1.2 MHz. Shorter window lengths have higher resolution, but require more individual strata to cover the desired range. However, dividing the total range covered into too many discrete strata increases the data-processing time. For this study, a window length of 10 m was used for each of 3 range strata sampled, a compromise which allowed a relatively high resolution while allowing a reasonable distance to be covered by each stratum. The down-range resolution (or pixel height) for a 10 m window length is 2 cm (1,000 cm/512).

The cross-range resolution is primarily determined by the individual beam spacing and beam width, both of which are approximately 0.3° for the DIDSON LR+HRL at 1.2 MHz (Appendix D2). Targets at closer range are better resolved because the individual beam widths and corresponding image pixels increase with range following the formula below:

$$X = 2R\tan\left(\theta/2\right) \qquad \text{(F1)}$$

where

X = width of the individual beam or "image pixel" in meters,

R = range of interest in meters, and

θ = individual beam angle in degrees (approximately 0.3°).

Other Settings

The transmit power of the DIDSON sonar is fixed but the receiver gain is user-configurable. The maximum receiver gain (−40 dB) was used during all data collection. The autofocus feature was enabled so that the sonar automatically set the lens focus to the midrange of the selected display window (e.g., for a window length of 10 m that started at 5 m, the focus range would be 15 m – (5 m/2).

Appendix D2.–Summary of manufacturer specifications for maximum range, individual beam dimensions, and spacing for a DIDSON-S and a DIDSON-LR with and without the addition of a high resolution lens (specifications from Sound Metrics Corporation).

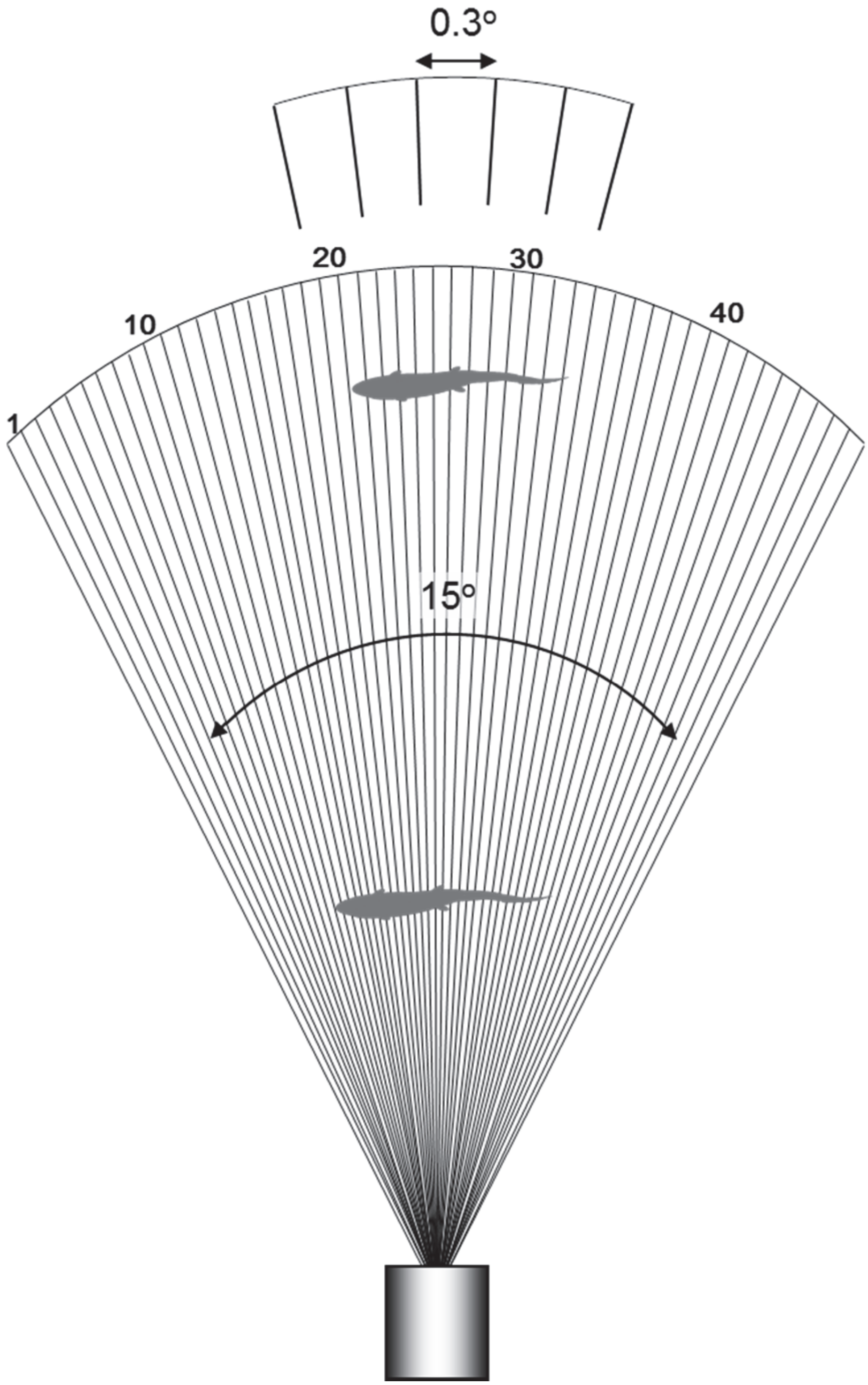
System	Maximum range (m)[a]	Horizontal beam width	Vertical beam width	Number of beams	Individual beam width[b,c]	Individual beam spacing[b,c]
DIDSON-S (1.8 MHz)	15	29°	14°	96	0.30°	0.30°
DIDSON-S (1.1 MHz)	30	29°	14°	48	0.40°	0.60°
DIDSON-S (1.8 MHz) +HRL	20	15°	3°	96	0.17°	0.15°
DIDSON-S (1.1 MHz) +HRL	40	15°	3°	48	0.22°	0.30°
DIDSON-LR (1.2 MHz)	25	29°	14°	48	0.40°	0.30°
DIDSON-LR (0.7 MHz)	80	29°	14°	48	0.60°	0.60°
DIDSON-LR (1.2 MHz) +HRL	30	15°	3°	48	0.27°	0.30°
DIDSON-LR (0.7 MHz) +HRL	100	15°	3°	48	0.33°	0.60°

[a] Actual range will vary depending on site and water characteristics.

[b] Beam width values are for 2-way transmission at the −3 dB points.

[c] Values for beam spacing and beam width are approximate. Beam widths are slightly wider near the edges of the beam and the beam spacing is slightly narrower. Conversely, beams are slightly narrower near the center of the beam, and the beam spacing is slightly wider (e.g., the center beam spacing is closer to 0.34°, and the beam width is 0.27° for a DIDSON-S at 1.8 MHz (Bill Hanot, Sound Metrics Corporation, personal communication). Nonlinear corrections are applied by the manufacturer in software to correct for these effects in the standard (but not large) lens.

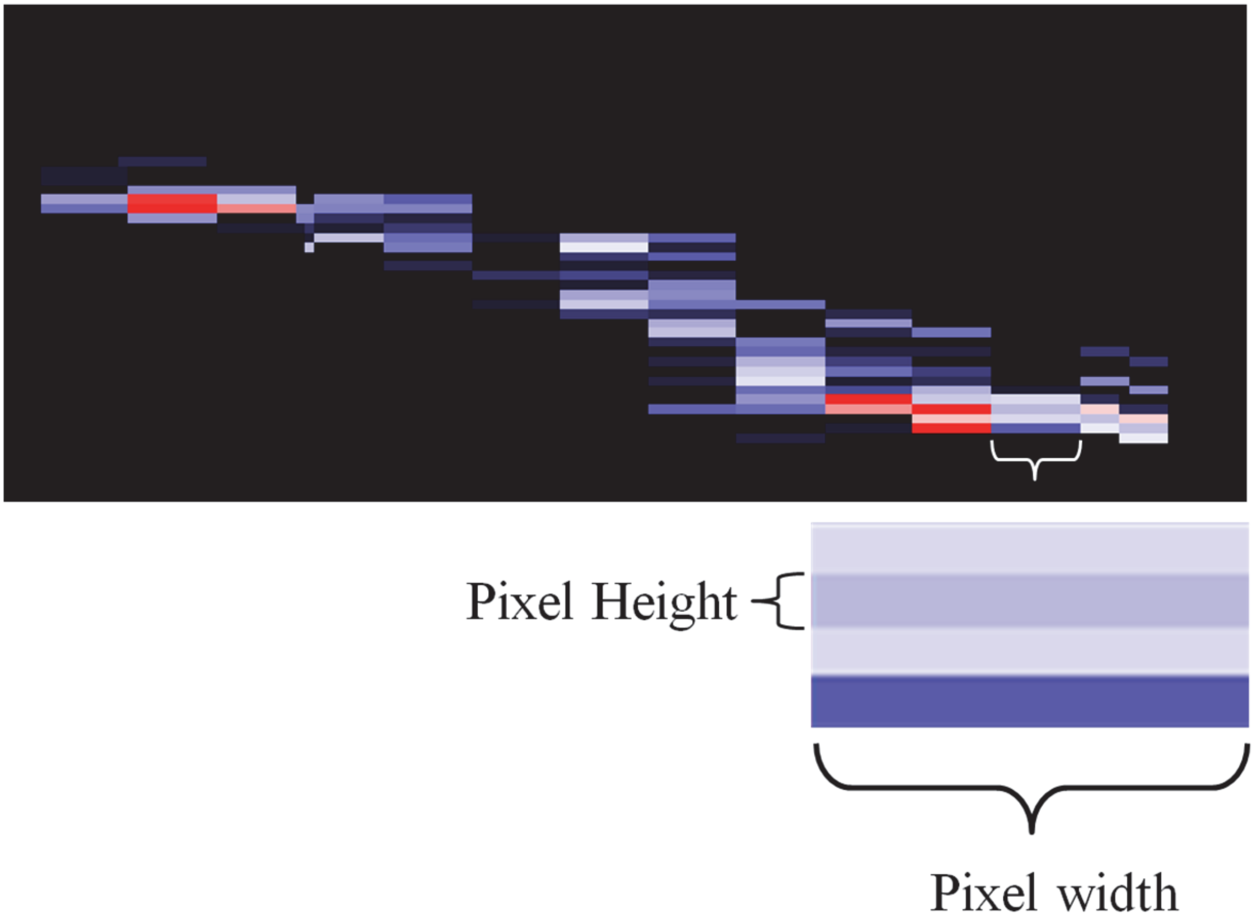
Appendix D3.–Diagram showing the horizontal plane of a DIDSON-LR sonar with a high resolution lens (DIDSON-LR+HRL). The overall horizontal beam width of 15° is comprised of 48 sub-beams with approximately 0.3° beam widths.



Note: because the beam widths grow wider with range, fish at close range are better resolved than fish at far range.

Note: adapted from Burwen et al. 2007.

Appendix D4.–An enlargement of a tethered Chinook salmon showing the individual pixels that comprise the image. Each image pixel in a DIDSON frame has (x, y) rectangular coordinates that are mapped back to a beam and sample number defined by polar coordinates range.



Note: adapted from Burwen et al. 2010.

Appendix D5.–Instructions and settings used for manual length measurements from DIDSON images in 2011 using Sound Metrics Software Version 5.25.28.

Parameter setup prior to beginning measurements

Step 1. Set the number of frames displayed (i.e., when right-clicking on a fish in echogram mode to display in movie mode) from the default of plus-minus one second to plus-minus any number of frames:

1) Select **<image><playback><set endpoints>**.
2) [√] Loop on still for +/- N frames.
3) Enter the number of frames (I suggest 20–30).

Step 2. Select **<Processing><Echogram><Use Cluster Data>** to use ALL the beams when creating the echogram (we generally do). Use fewer beams by unchecking this option and selecting the number of beams.

Step 3. Set up **processing parameters** (last Icon on right) for **<u>File Creation</u>** as follows:

1) Auto Countfile Name
2) Binary CountFile (.dat)
3) New Countfile on Open
4) Echogram File (.ech)

Step 4. Echogram counts can be reloaded to finish or review at a later time if the Echogram file has been checked as follows:

1) Select **<File><Open> then Files of type .ech** from drop-down menu.
2) Open desired file.
3) The Echogram file should reload showing previous measurements.

Or this option will work as long as the .dat file has been saved (as shown above):

1) Open the file and bring up the echogram (follow instructions below).
2) Select **<Processing><Echogram><Import Echogram Counts>**.
3) Select the **.dat** file with saved counts. The file should reload, showing previous measurements (the filename for the .dat file will begin with **FC_**).

Step 5. Make sure **<Image><Configure><Auto Threshold/Intensity>** is UNCHECKED. This will keep the threshold and intensity settings from changing when switching between Echogram and Movie mode.

Step 6. Uncheck the 'Display Raw Data' toolbar icon (first button on left in Combined toolbar). (If you are in Movie mode and it is displaying the raw image data, it is because 'Display Raw Data' is enabled by default).

Instructions for manual echogram-based length measurements

***Note that these settings may already be active because some of them have "memory" and are saved until changed.**

1) Select **<BS>** (background subtraction) from toolbar or under **<Processing><Background><Background Subtraction>**.
2) Select **<Processing><Background><Fixed Background>**.
3) Select threshold and range settings given in Table 1. To adjust these settings, use the slider bars under Display Controls to the left of the echogram.
4) Select the threshold and intensity settings for each range stratum as indicated below. To adjust these settings, use slider bars under the Display Controls to the left side of the Echogram or Movie window.

	3–13 m	13–23 m	23–33 m
Threshold	11	10	9
Intensity	50	45	40

-continued-

5) Select **<EG>** (for view echogram) from toolbar or under **<Processing><Echogram><View echogram**>.
6) **<left click>** on the echogram near or on the fish trace of interest to "mark it." A white circle should be visible.
7) **<right click>** INSIDE the white circle to switch to Movie mode (Movie mode will play the 16 frames encompassing this circle continuously).
8) Press **<space bar>** to pause the movie.
9) Step through the movie frames using the right or left arrows until finding a frame that displays the entire length of the fish well (see section below for selecting optimal images).
10) **<right mouse click drag>** will magnify the area in the rectangle.
11) **<left click>** on the FISH SNOUT and continue to <left click> along the body to create a "segmented measurement." ***The segments should follow the midline of the body of the fish*** ending with the tail. Try not to use more than 3 or 4 segments to define the fish (see section below for selecting optimal images).
12) **<double left click>** or select **<f>** key to add measurement to file.
13) **<right click>** to unzoom.
14) **<right click>** to return to the echogram.

Hot keys

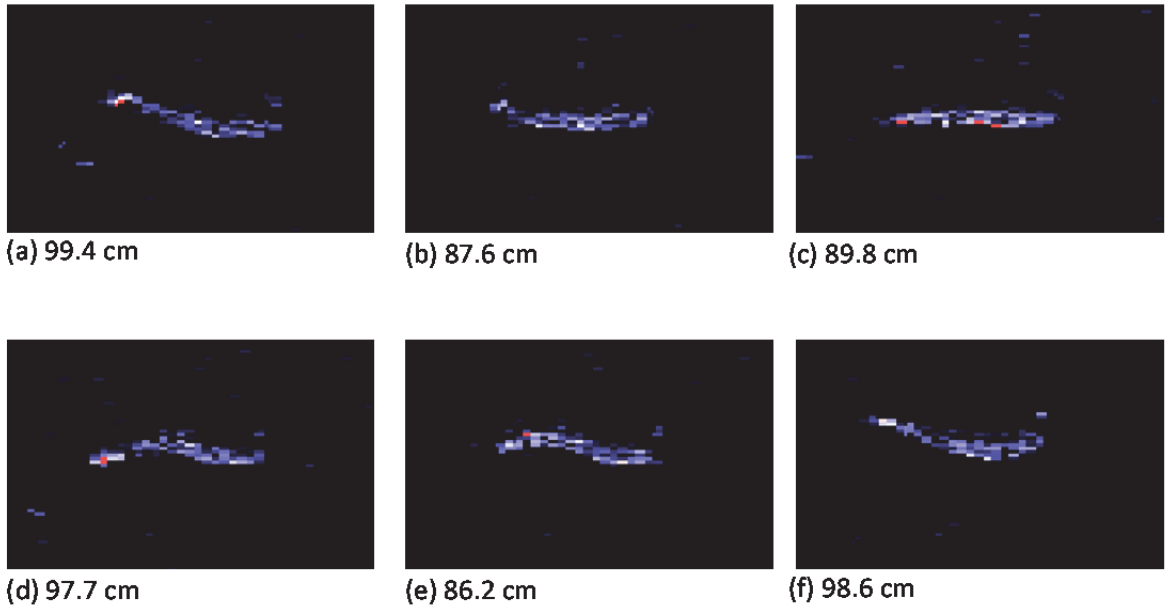
1) **<e>** to "save" all echogram measurements to file
2) **<f>** to "fish it" (to accept the measurement and display it on the echogram)
3) **<u>** to "undo" the last segment
4) **<d>** to "delete" the all segments
5) **<space bar>** to pause in Movie mode (if this doesn't work, click in the black area of the display)
6) **<right arrow>** forward direction when selecting play or advances frame one at a time if the pause button is on (pause button = blue square on the toolbar)
7) **<left arrow>** opposite of above
8) **Left Click Drag** to show movie over the selected time
9) **Right Click Drag** zooms the selected area

Selecting optimal images to measure

Measurements should be taken from frames where contrast between the fish image and background are high and where the fish displays its full length (e.g., panels a, d, and f in Appendix D6). In general, the best images are obtained when the fish is sinusoidal in shape, rather than linear (e.g., panel c in Appendix D6), because it is easier to identify the snout and tail and to assess whether the entire length of the fish is visible when there is some curvature to the fish body (e.g., Appendices D6 and D7). Images that appear distorted or truncated should not be measured. For example, under some conditions where a fish is highly reflective or near range, the image will appear "smeared" out into adjacent beams. This condition, also referred to as "arcing," most often occurs when the target is both linear and perpendicular relative to the sonar beams as in shown in Appendix D8.

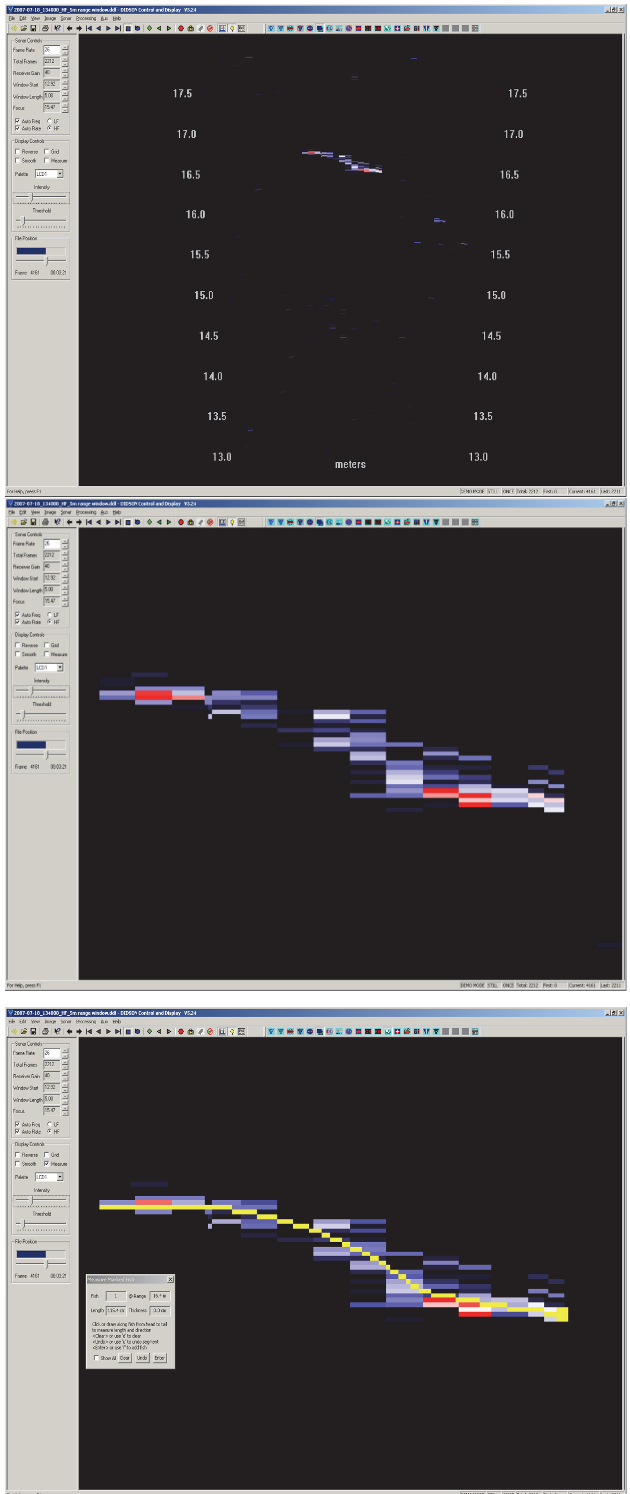
Appendix D7 demonstrates the process of measuring a fish using the manual measuring tool. The user pauses the DIDSON movie (top), zooms in on the fish of interest (middle), and measures the fish length with a segmented line created by mouse clicks along the center axis of the fish (bottom). The user selects the leading pixel edge of the snout to start the measurement (yellow start pixel extends beyond snout), and clicks just before the trailing edge of the pixel(s) defining the tail such that the "yellow measurement line" is flush with the trailing pixel edge.

Appendix D6.–Panels a–f show the variability in length measurements from DIDSON images of a tethered Chinook salmon during one full tail-beat cycle.



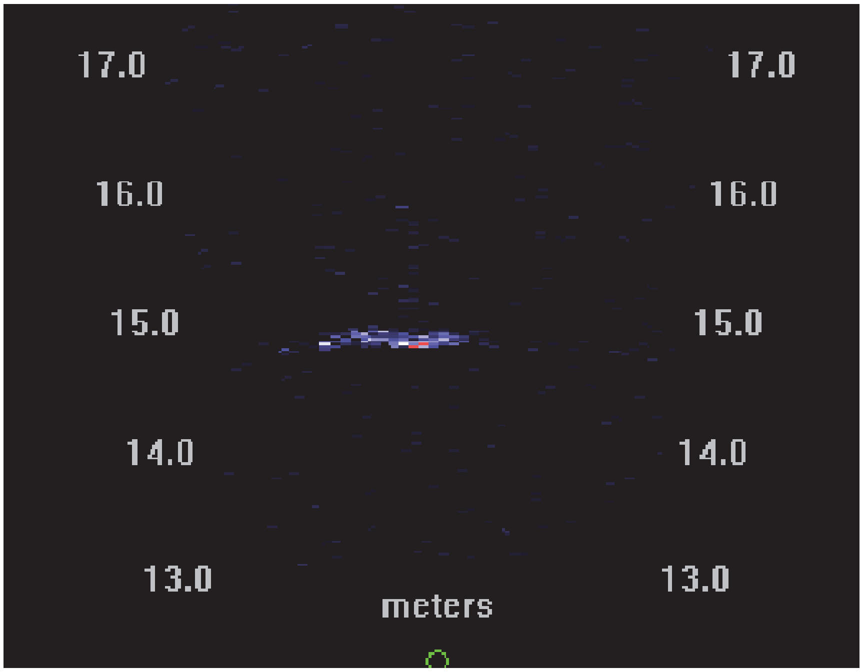
Note: adapted from Burwen et al. 2010.

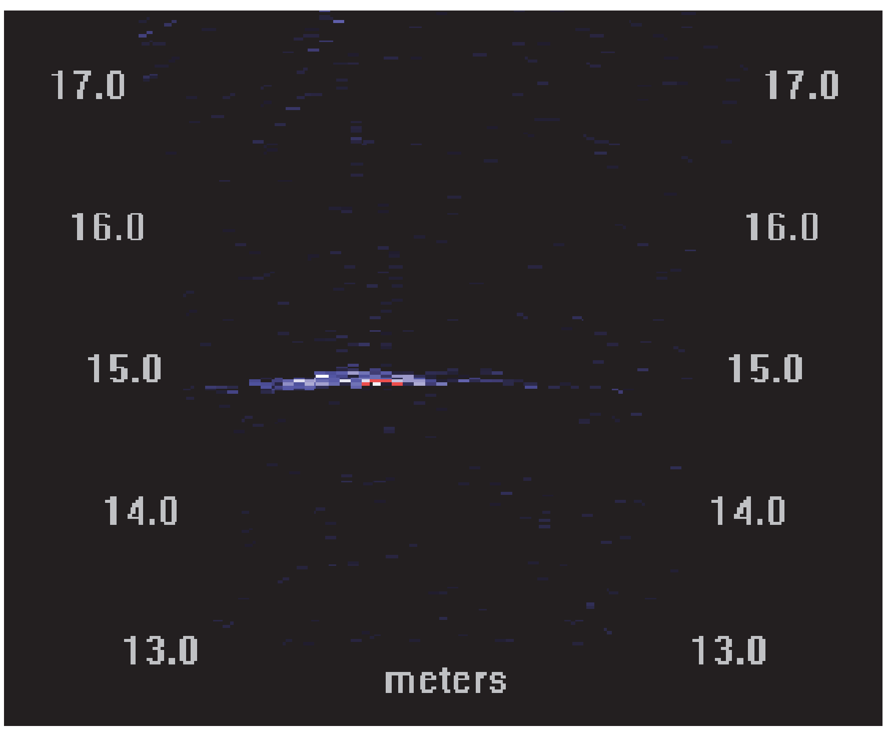
Appendix D7.–DIDSON images from a tethered Chinook salmon showing the original DIDSON image (top), the zoomed image (middle), and the segmented lines that result when the observer clicks along the length of the fish to mark its length (bottom).



Note: adapted from Burwen et al. 2010.

Appendix D8.–DIDSON images from a Chinook salmon showing a well-defined image of the fish swimming through the beam (top) and a "smeared" image of the same fish (bottom).





This page intentionally left blank.

APPENDIX E: TECHNICAL MODIFICATIONS TO DIDSON-BASED ESTIMATORS OF ABUNDANCE, 2010–2011

Appendix E1.–Technical modifications to DIDSON-based estimators of abundance.

Preliminary values of some of the estimates in this report were published by Fleischman and McKinley (2013: Table 4, for late-run Chinook salmon) and McKinley and Fleischman (2013: Table 5, for early-run Chinook salmon). Technical methodological details that differed between preliminary and final estimates for 2010 and 2011 are summarized here.

	Preliminary[a]		Final[b]
Modification	2010	2011	2010–2011
Age composition prior	informative[c]	informative[c]	noninformative[d]
Species composition prior	Dirichlet(0.5,0.5)	Dirichlet(0.5,0.5)	Dirichlet(0.1,0.9)
Days of netting data pooled and paired with day *d* of sonar data	*d-1 to d*	*d-6 to d*	*d-3 to d+3*
Chinook salmon size selectivity by age class	0.61, 0.57, 0.41	0.61, 0.57, 0.41	1, 1, 1

[a] Used to produce results reported in McKinley and Fleischman (2013: Table 5) and Fleischman and McKinley (2013: Table 4).
[b] Used to produce results reported herein and in Miller et al. (2013)
[c] Informative priors differed by week, as developed from the hierarchical age composition model in Appendix C1
[d] Non informative nested beta priors

APPENDIX F. DAILY ELSD-BASED ESTIMATES OF CHINOOK SALMON ABUNDANCE, 2002–2011

Appendix F1.–ELSD-based split-beam sonar passage estimates for RM 8.5, Kenai River early-run Chinook salmon, 2002–2011.

Date	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
16 May	13	41	18	47	28	[a]	32	44	22	26
17 May	7	38	20	44	23	[a]	36	10	31	23
18 May	16	58	21	25	20	[a]	38	24	32	22
19 May	54	68	47	9	42	[a]	27	29	55	10
20 May	33	105	34	39	32	11	37	43	29	39
21 May	17	133	87	69	16	49	39	34	21	54
22 May	30	147	60	36	30	65	89	12	52	67
23 May	31	188	117	44	25	26	73	27	15	123
24 May	13	96	79	26	29	43	74	25	21	145
25 May	23	82	90	26	26	43	44	29	32	195
26 May	16	107	110	31	27	38	77	44	27	91
27 May	51	119	258	24	27	43	94	49	27	127
28 May	39	161	167	80	39	35	108	128	13	131
29 May	11	138	68	88	36	55	95	164	13	233
30 May	11	104	57	77	88	89	113	108	15	219
31 May	33	226	91	116	185	111	82	67	7	293
1 Jun	60	232	122	186	276	131	52	69	13	111
2 Jun	88	171	91	215	191	123	48	71	3	50
3 Jun	77	280	73	169	112	156	59	63	12	104
4 Jun	73	331	88	364	171	121	68	32	43	254
5 Jun	113	267	99	398	107	153	90	120	91	364
6 Jun	175	357	78	569	174	116	157	195	73	556
7 Jun	175	303	317	579	205	282	121	99	82	530
8 Jun	283	453	628	717	204	506	173	105	282	539
9 Jun	382	403	712	678	229	453	164	134	281	626
10 Jun	145	277	758	574	270	281	234	189	234	518
11 Jun	107	305	659	698	328	307	421	246	297	299
12 Jun	122	383	525	564	338	451	335	176	161	322
13 Jun	116	358	312	334	495	304	345	136	277	317
14 Jun	69	226	274	477	434	320	397	166	320	410
15 Jun	61	317	427	292	478	352	282	47	356	366
16 Jun	57	279	370	411	389	261	137	84	489	501
17 Jun	164	319	291	316	597	227	153	101	144	262
18 Jun	118	292	218	410	621	225	110	49	167	301
19 Jun	132	417	313	271	444	287	207	14	236	293
20 Jun	195	445	187	294	506	216	176	97	133	135
21 Jun	171	477	425	271	488	176	138	84	106	204
22 Jun	172	519	369	223	815	314	135	139	333	162
23 Jun	200	487	615	307	590	366	85	88	273	150
24 Jun	165	696	791	279	508	213	161	219	363	131
25 Jun	261	503	616	541	440	181	165	148	304	188
26 Jun	261	448	425	375	443	162	177	155	313	137
27 Jun	257	278	431	324	541	202	193	133	619	66
28 Jun	193	321	768	373	552	447	257	172	577	171
29 Jun	173	477	614	511	758	393	236	146	486	263
30 Jun	247	715	713	1,185	694	382	226	114	1,015	431
Total	5,210	13,147	13,633	13,686	13,071	8,716	6,560	4,428	8,497	10,561

[a] Extreme tides and debris prevented sampling 16–19 May 2007. Values for 16–19 May were inferred from previous years.

Appendix F2.–ELSD-based split-beam sonar passage estimates for RM 8.5, Kenai River late-run Chinook salmon, 2002–2011.

Date	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
1 Jul	519	1129	1,428	1,473	553	318	237	401	546	473
2 Jul	1,030	1,016	1,605	1,393	447	243	399	432	913	1,147
3 Jul	1,351	998	1,020	1,309	352	437	335	292	568	603
4 Jul	1,233	1,800	796	870	902	359	176	426	1,560	338
5 Jul	1,127	2,080	1,076	1,443	1,069	432	95	343	1,182	88
6 Jul	1,861	1,866	1,309	1,308	823	297	169	408	1,084	1,083
7 Jul	1,446	2,293	1,691	1,040	894	446	232	369	1,665	981
8 Jul	863	2,056	1,625	1,368	1,177	831	213	482	1,929	1,272
9 Jul	1,104	1,965	709	2,012	1,002	524	450	477	261	2,139
10 Jul	1,083	3,083	627	2,273	579	537	615	448	215	763
11 Jul	635	3,094	1,062	2,313	360	971	495	544	237	253
12 Jul	821	3,022	1,125	3,080	435	578	693	463	360	568
13 Jul	1,175	2,101	2,103	2,444	436	477	762	596	301	1,169
14 Jul	1,180	1,302	1,966	1,385	726	1,006	456	954	263	1,536
15 Jul	655	2,481	1,576	1,899	1,320	1,030	1,078	785	429	650
16 Jul	1,145	2,277	1,883	2,413	1,652	607	1,033	625	634	1,383
17 Jul	1,262	2,383	1,588	1,643	985	871	677	1,612	1,177	2,437
18 Jul	1,435	1,951	1,181	1,481	1,219	1,539	648	496	1,019	1,364
19 Jul	1,388	2,334	1,264	1,925	1,381	1,035	485	757	364	1,475
20 Jul	901	1,565	1,532	1,183	1,298	1,826	821	442	1,671	1,935
21 Jul	943	1,183	1,415	894	1,311	1,923	944	299	564	1,670
22 Jul	1,021	2,639	1,168	921	1,325	1,848	990	234	2,386	1,742
23 Jul	1,359	2,035	1,489	917	1,142	1,344	827	117	2,879	2,352
24 Jul	952	1,949	1,392	625	797	1,694	577	146	2,050	1,433
25 Jul	1,332	1,073	1,061	774	1,061	825	752	138	1,010	1,093
26 Jul	1,063	1,009	991	1,075	1,057	1,507	1,210	284	710	1,071
27 Jul	573	1,093	1,601	1,043	1,026	1,355	1,331	288	402	634
28 Jul	595	632	976	781	1,297	697	847	551	712	342
29 Jul	415	869	1,135	870	1,462	451	854	405	1,164	476
30 Jul	602	749	1,144	1,004	1,148	751	1,055	394	627	503
31 Jul	477	702	681	941	612	697	1,418	287	1,344	407
1 Aug	439	468	724	793	597	520	1,252	267	812	406
2 Aug	378	519	569	1,053	574	293	1,269	309	647	332
3 Aug	637	404	522	945	564	301	1,162	196	590	420
4 Aug	654	504	727	788	850	343		389	666	264
5 Aug	458	478	778	597	1,765					715
6 Aug					992					661
7 Aug					984					359
8 Aug					1,517					214
9 Aug										270
10 Aug										239
Total	34,112[a]	57,102[a]	43,539[a]	48,276[a]	37,692[b]	28,915[c]	24,557[d]	15,656[c]	32,941[e]	37,261

[a] Sampling was terminated on 5 August in 2002-2005 due to budget constraints.

[b] Sampling was terminated on 8 August 2006 due to fish holding in the sonar beam.

[c] Sampling was terminated on 4 August 2007 and 2009 following 3 consecutive days of target-strength-based passage less than 1% of the cumulative passage.

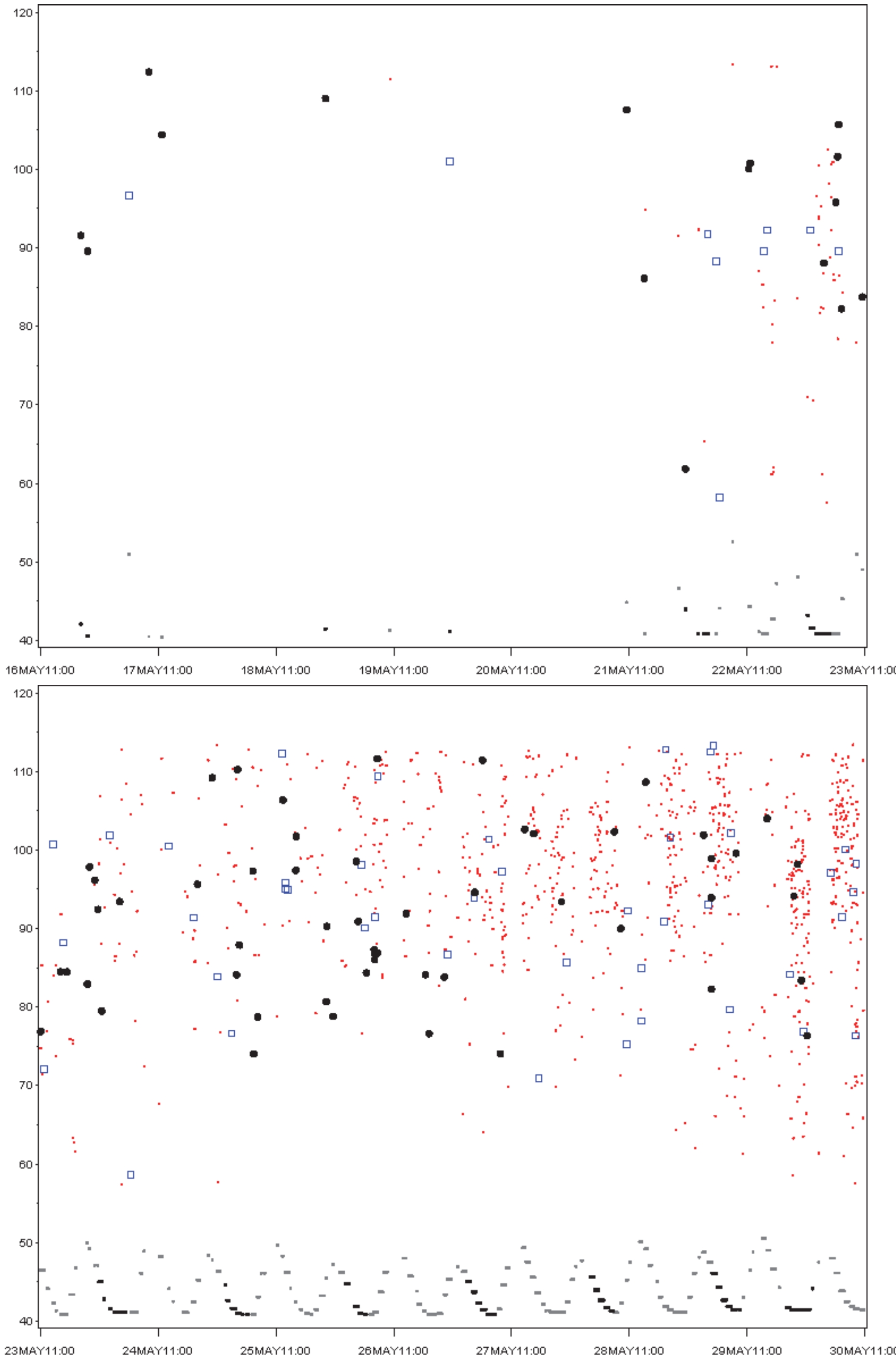
[d] Sampling was terminated on 3 August 2008 due to fish holding in the sonar beam.

[e] Sampling was terminated on 4 August 2010 due to fish holding in the sonar beam.

This page intentionally left blank.

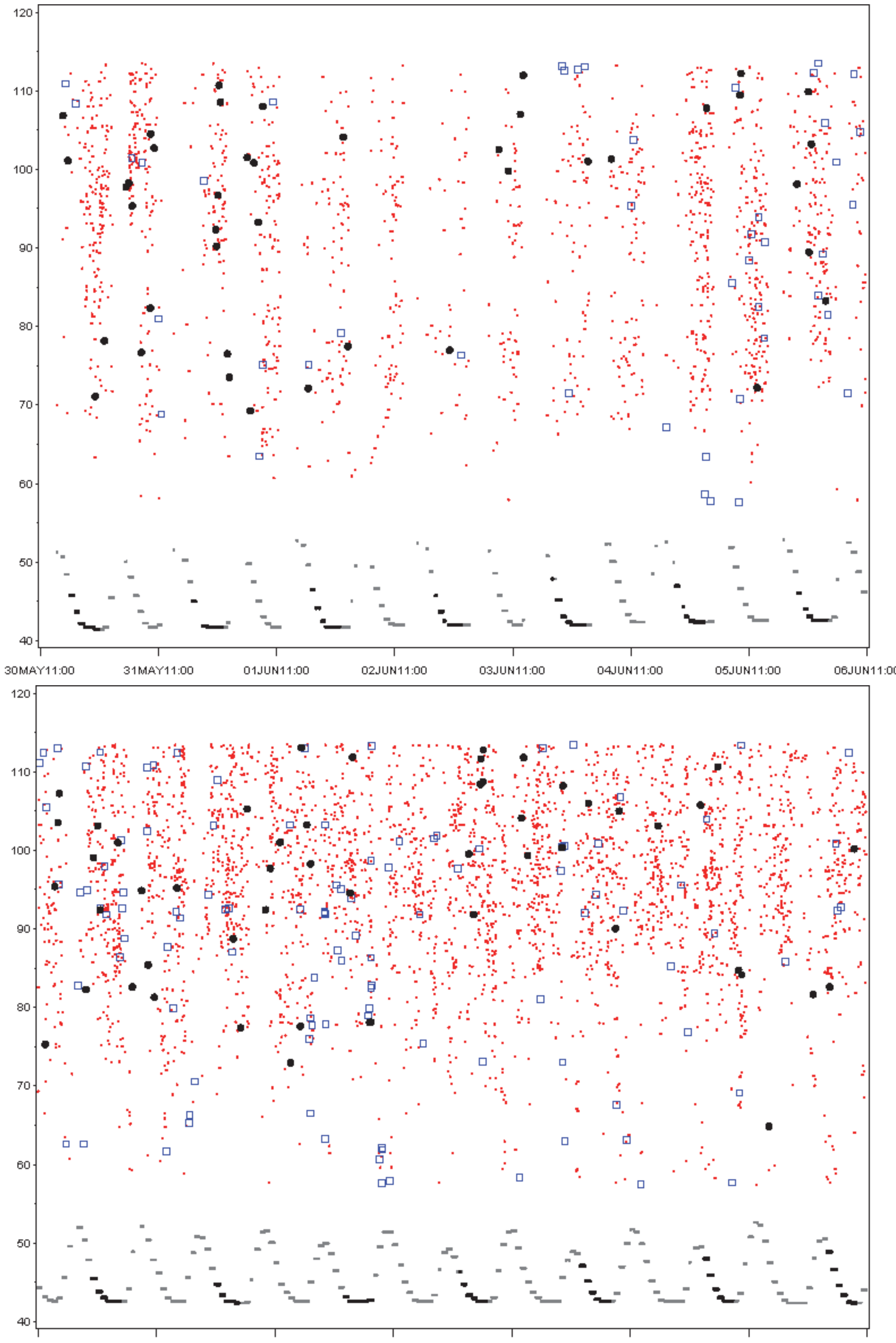
APPENDIX G: SPATIAL AND TEMPORAL DISTRIBUTION OF FISH BY SIZE AS MEASURED BY DIDSON, RM 8.5 KENAI RIVER, 2011

Appendix G1.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 16–29 May 2011.



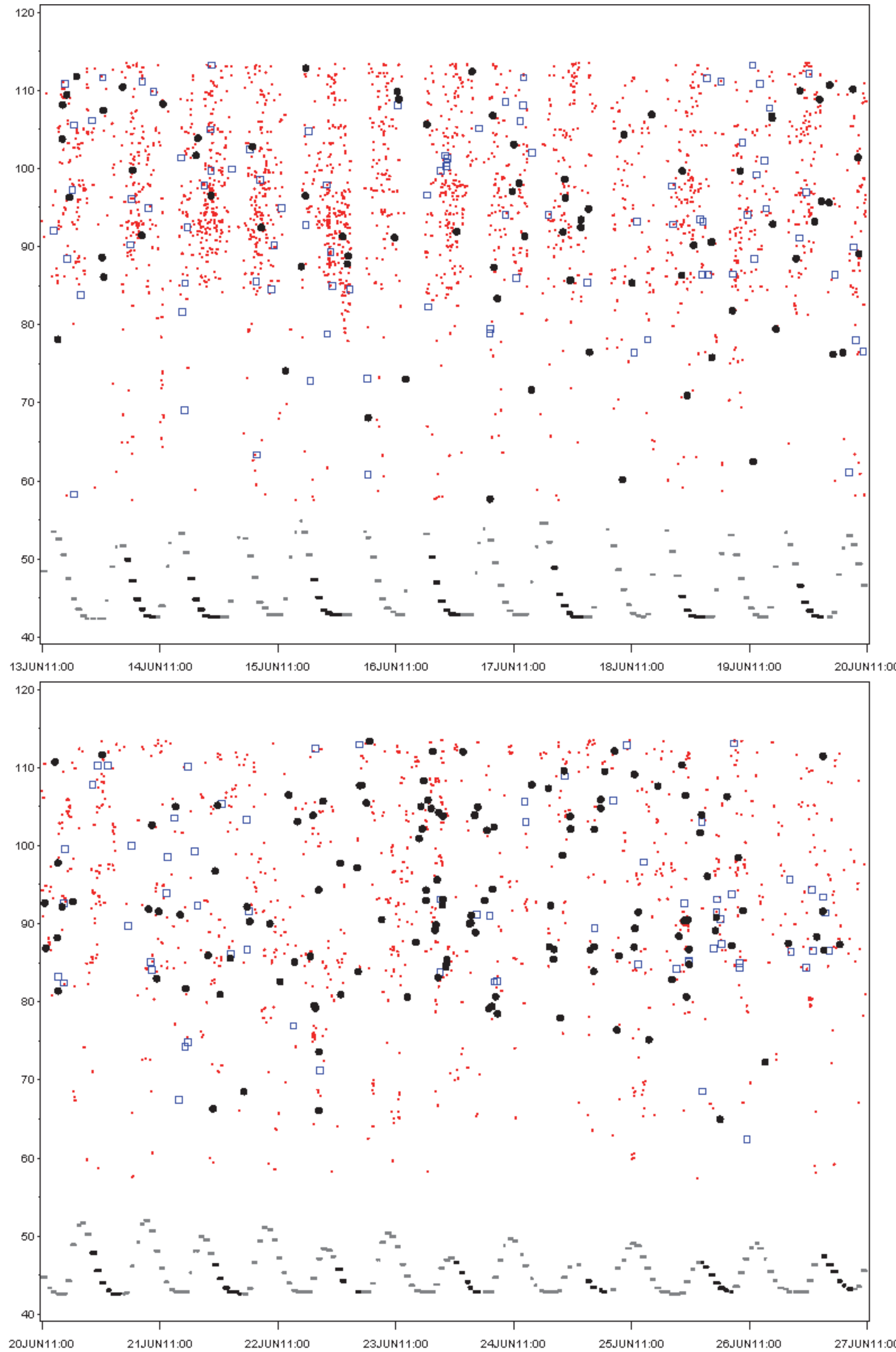
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix G2.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 30 May–12 June 2011.



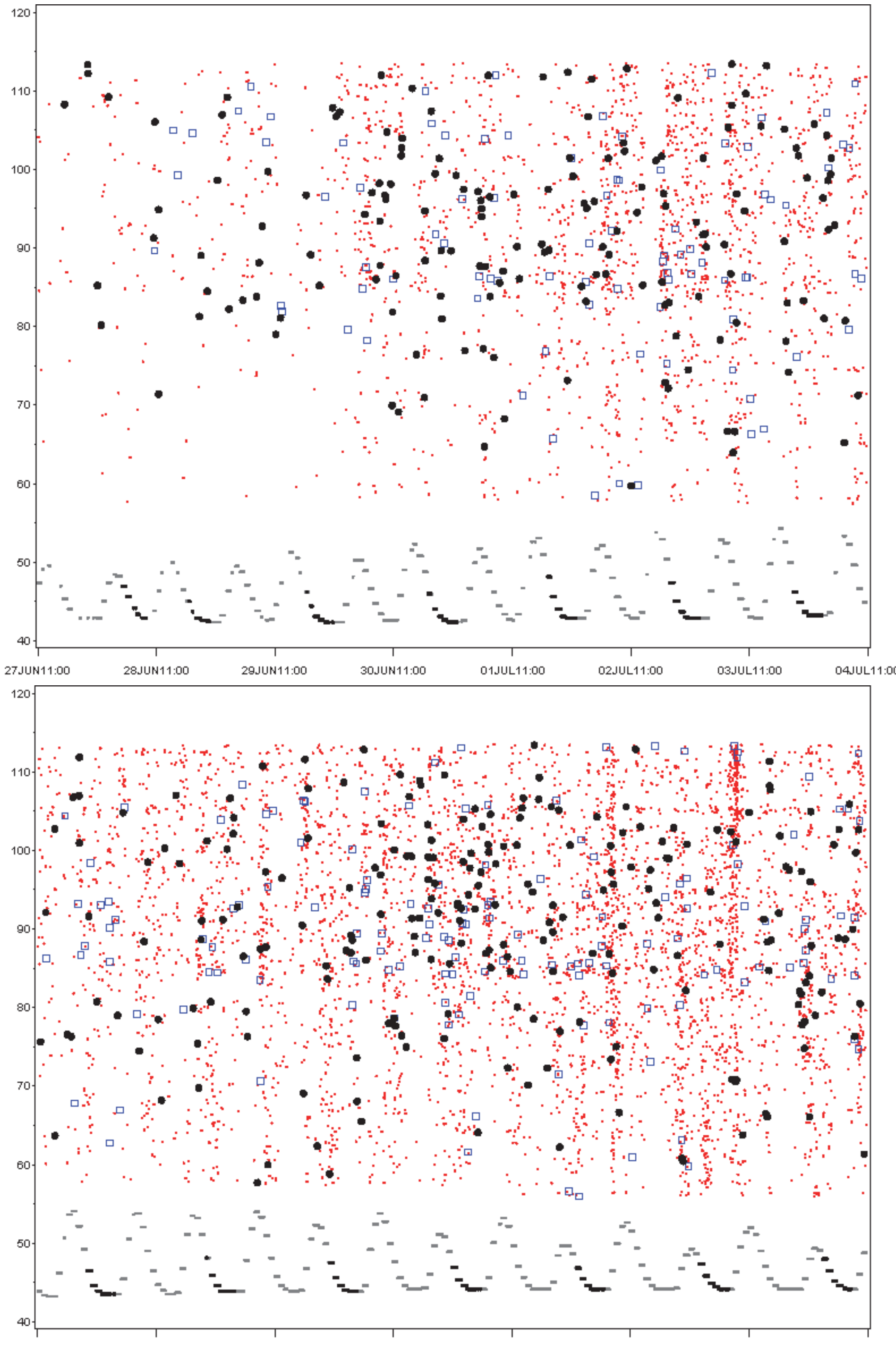
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix G3.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 13–26 June 2011.



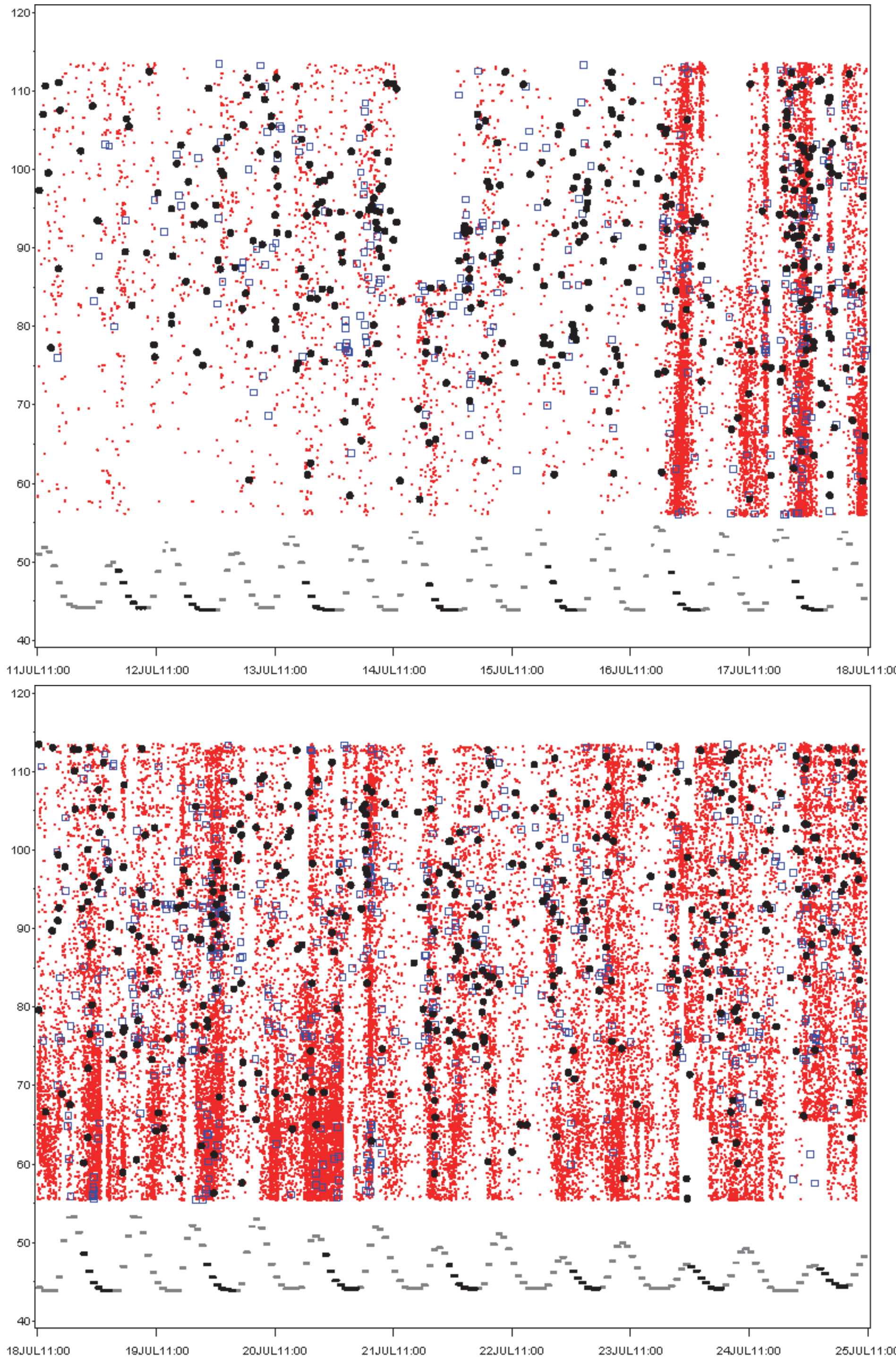
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix G4.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 27 June–10 July 2011.



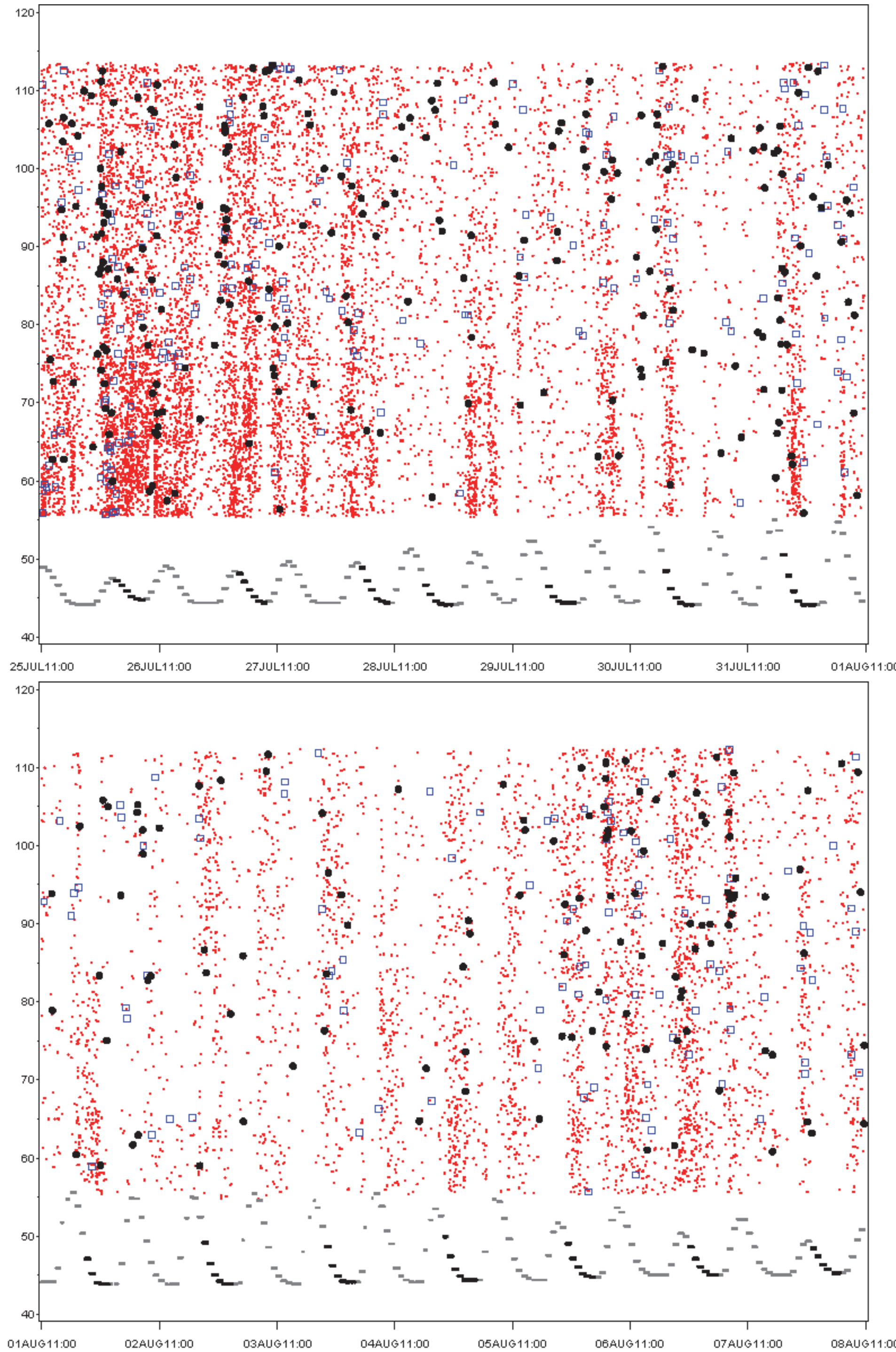
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix G5.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 11–24 July 2011.



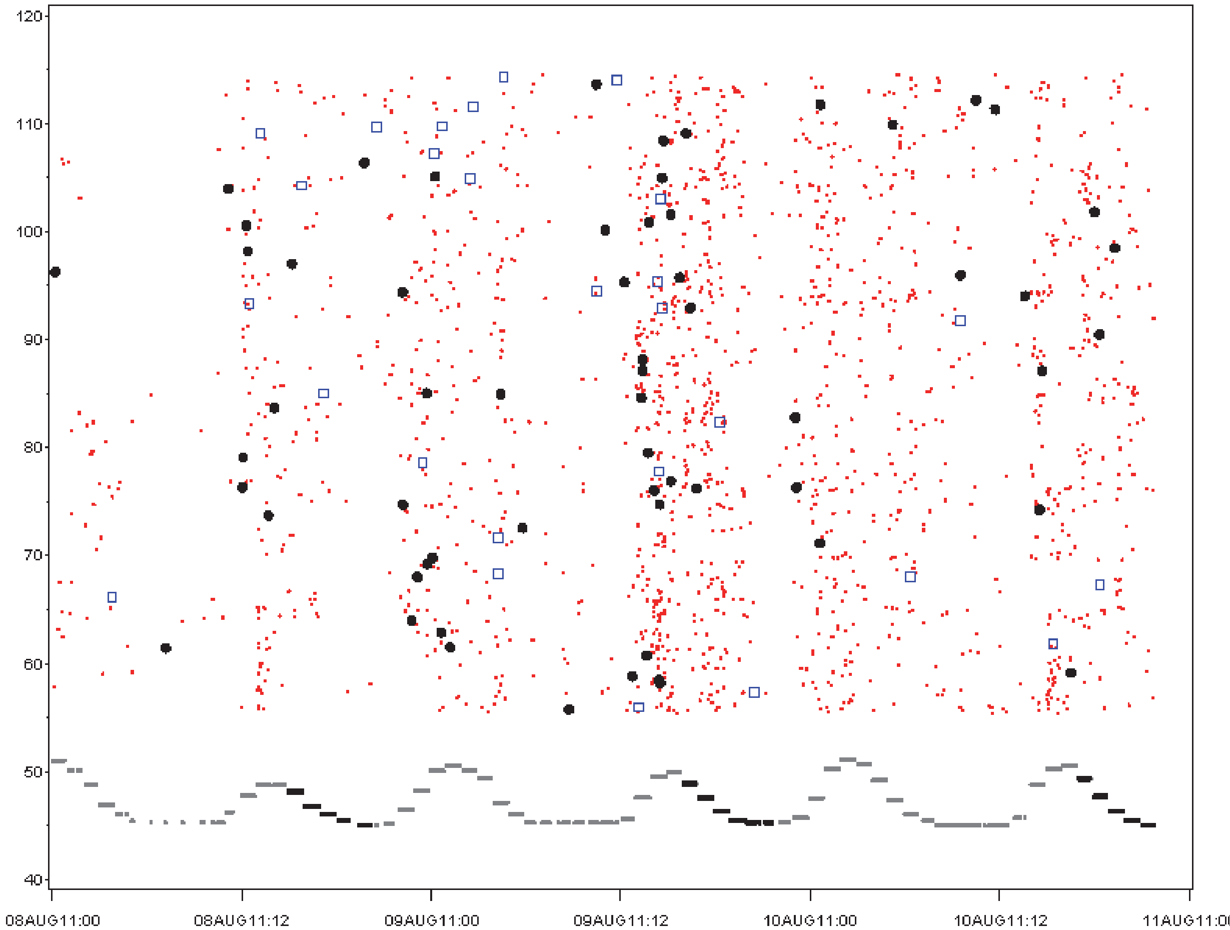
Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix G6.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 25 July–7 August 2011.



Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black.

Appendix G7.–Spatial and temporal distribution of small (DIDSON length DL < 75 cm; small red symbols), medium (75 cm ≤ DL < 90 cm; larger blue squares), and large fish (DL ≥ 90 cm; large black symbols), RM 8.5 Kenai River, 8–10 August 2011.



Note: Vertical axis is distance (m) from benchmark on right bank shore, except that relative water level is plotted at bottom (small grey symbols), with netting periods in black. Beginning on 5 August, only medium and large fish were measured in some samples.

APPENDIX H: DIRECTION OF TRAVEL OF LARGE FISH DETECTED BY DIDSON, RM 8.5 KENAI RIVER, 2011.

Appendix H1.–Daily proportion of upstream and downstream moving fish greater than or equal to 75 cm DIDSON length for the early run, RM 8.5 Kenai River, 2011.

Date	Number downstream	Number upstream	Total fish sampled	Percent downstream	Percent upstream
16 May	0	4	4	0%	100%
17 May	0	1	1	0%	100%
18 May	0	1	1	0%	100%
19 May	0	1	1	0%	100%
20 May	1	1	2	50%	50%
21 May	1	5	6	17%	83%
22 May	4	12	16	25%	75%
23 May	2	14	16	13%	88%
24 May	3	12	15	20%	80%
25 May	1	22	23	4%	96%
26 May	0	11	11	0%	100%
27 May	2	9	11	18%	82%
28 May	1	16	17	6%	94%
29 May	0	13	13	0%	100%
30 May	2	15	17	12%	88%
31 May	5	13	18	28%	72%
1 Jun	0	5	5	0%	100%
2 Jun	0	4	4	0%	100%
3 Jun	0	9	9	0%	100%
4 Jun	0	13	13	0%	100%
5 Jun	1	23	24	4%	96%
6 Jun	1	36	37	3%	97%
7 Jun	0	21	21	0%	100%
8 Jun	0	43	43	0%	100%
9 Jun	0	14	14	0%	100%
10 Jun	0	24	24	0%	100%
11 Jun	1	14	15	7%	93%
12 Jun	1	9	10	10%	90%
13 Jun	0	26	26	0%	100%
14 Jun	0	22	22	0%	100%
15 Jun	1	20	21	5%	95%
16 Jun	2	24	26	8%	92%
17 Jun	0	22	22	0%	100%
18 Jun	2	25	27	7%	93%
19 Jun	0	32	32	0%	100%
20 Jun	1	24	25	4%	96%
21 Jun	0	27	27	0%	100%
22 Jun	4	25	29	14%	86%
23 Jun	1	43	44	2%	98%
24 Jun	2	27	29	7%	93%
25 Jun	6	43	49	12%	88%
26 Jun	5	15	20	25%	75%
27 Jun	0	9	9	0%	100%
28 Jun	0	21	21	0%	100%
29 Jun	2	30	32	6%	94%
30 Jun	5	50	55	9%	91%
Total	57	850	907	6.3%	93.7%

Appendix H2.–Daily proportion of upstream and downstream moving fish greater than or equal to 75 cm DIDSON length for the late run, RM 8.5 Kenai River, 2011.

Date	Number downstream	Number upstream	Total fish sampled	Percent downstream	Percent upstream
1 Jul	6	45	51	12%	88%
2 Jul	4	57	61	7%	93%
3 Jul	6	39	45	13%	87%
4 Jul	2	33	35	6%	94%
5 Jul	2	42	44	5%	96%
6 Jul	1	42	43	2%	98%
7 Jul	7	90	97	7%	93%
8 Jul	0	61	61	0%	100%
9 Jul	4	49	53	8%	93%
10 Jul	5	59	64	8%	92%
11 Jul	0	29	29	0%	100%
12 Jul	6	63	69	9%	91%
13 Jul	7	109	116	6%	94%
14 Jul	9	92	101	9%	91%
15 Jul	10	82	92	11%	89%
16 Jul	9	77	86	11%	90%
17 Jul	13	203	216	6%	94%
18 Jul	18	133	151	12%	88%
19 Jul	5	157	162	3%	97%
20 Jul	5	147	152	3%	97%
21 Jul	7	134	141	5%	95%
22 Jul	5	97	102	5%	95%
23 Jul	3	109	112	3%	97%
24 Jul	2	120	122	2%	98%
25 Jul	5	120	125	4%	96%
26 Jul	0	70	70	0%	100%
27 Jul	2	47	49	4%	96%
28 Jul	3	26	29	10%	90%
29 Jul	4	36	40	10%	90%
30 Jul	3	41	44	7%	93%
31 Jul	5	67	72	7%	93%
1 Aug	10	32	42	24%	76%
2 Aug	6	15	21	29%	71%
3 Aug	3	17	20	15%	85%
4 Aug	1	13	14	7%	93%
5 Aug	0	50	50	0%	100%
6 Aug	1	62	63	2%	98%
7 Aug	0	29	29	0%	100%
8 Aug	1	24	25	4%	96%
9 Aug	2	48	50	4%	96%
10 Aug	0	17	17	0%	100%
Total	179	2694	2873	6.2%	93.8%

This page intentionally left blank.

APPENDIX I: DIDSON-LENGTH THRESHOLD ESTIMATES OF LARGE CHINOOK SALMON, RM 8.5 KENAI RIVER, 2011

Appendix I1.–Daily DIDSON length (DL) threshold estimates of large Chinook salmon passage (DL ≥ X cm) at RM 8.5 in the Kenai River, early run 2011.

	DL > 75 cm		DL > 80 cm		DL > 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
16 May	25	9	19	8	19	8
17 May	7	4	7	4	7	4
18 May	7	6	7	6	7	6
19 May	6	5	6	5	0	0
20 May	6	4	6	4	6	4
21 May	30	9	18	9	12	7
22 May	73	22	73	22	48	16
23 May	85	17	72	14	54	11
24 May	72	18	66	18	48	19
25 May	133	42	121	40	85	31
26 May	66	15	60	15	42	12
27 May	54	10	54	10	30	10
28 May	97	26	66	17	36	15
29 May	79	13	72	11	30	7
30 May	91	22	85	22	66	16
31 May	109	22	97	21	72	19
1 Jun	30	13	18	7	18	7
2 Jun	24	9	24	9	18	8
3 Jun	54	12	42	10	24	9
4 Jun	79	24	60	20	18	11
5 Jun	139	20	115	22	36	17
6 Jun	217	33	139	22	79	16
7 Jun	127	25	66	14	36	9
8 Jun	260	65	103	25	60	18
9 Jun	85	19	79	17	36	9
10 Jun	145	40	127	36	48	17
11 Jun	85	26	72	25	30	13
12 Jun	54	13	30	11	24	10
13 Jun	157	30	127	29	72	20
14 Jun	133	28	121	27	36	14
15 Jun	196	81	217	108	139	77
16 Jun	145	34	91	19	66	16
17 Jun	133	27	115	27	91	22
18 Jun	151	26	151	26	66	20
19 Jun	193	22	175	21	103	22
20 Jun	145	23	127	20	79	16
21 Jun	163	35	151	33	79	14
22 Jun	151	29	151	29	127	23
23 Jun	260	34	248	32	223	28
24 Jun	163	25	157	25	127	20
25 Jun	260	39	242	40	151	27
26 Jun	91	30	91	30	42	18
27 Jun	54	19	54	19	48	17
28 Jun	127	16	121	16	85	16
29 Jun	181	22	175	21	127	15
30 Jun	306	41	289	42	211	38

Note: all estimates are of upstream bound fish in midriver between and greater than 3 m from the transducers.

Appendix I2.–Daily DIDSON length (DL) threshold estimates of large Chinook salmon passage (DL ≥ X cm) at RM 8.5 in the Kenai River, late run 2011.

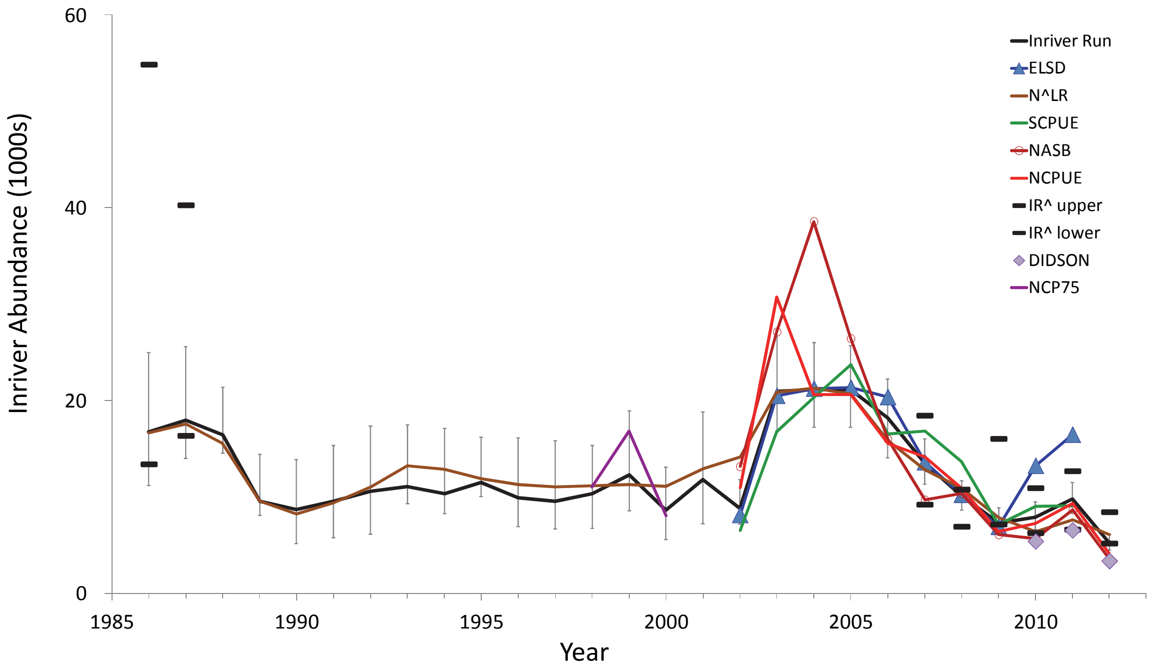
	DL > 75 cm		DL > 80 cm		DL > 90 cm	
Date	Passage	SE	Passage	SE	Passage	SE
1 Jul	272	37	254	36	169	27
2 Jul	344	49	332	47	211	31
3 Jul	236	38	217	36	139	28
4 Jul	196	32	160	26	103	21
5 Jul	254	29	236	25	163	23
6 Jul	271	65	256	59	159	31
7 Jul	581	68	531	59	367	49
8 Jul	368	32	326	29	236	26
9 Jul	296	41	230	27	157	16
10 Jul	356	44	338	40	242	37
11 Jul	178	32	171	32	127	24
12 Jul	381	40	338	35	242	31
13 Jul	658	57	622	52	411	47
14 Jul	915	136	883	130	540	96
15 Jul	494	40	488	40	354	49
16 Jul	566	74	477	68	288	39
17 Jul	1,226	124	991	100	634	63
18 Jul	824	73	657	65	406	48
19 Jul	959	97	644	64	383	42
20 Jul	969	131	506	60	309	53
21 Jul	809	84	683	75	453	51
22 Jul	586	79	532	65	302	51
23 Jul	658	50	568	53	393	49
24 Jul	725	77	556	81	332	45
25 Jul	725	72	574	62	387	54
26 Jul	423	54	356	54	236	49
27 Jul	284	24	211	24	145	23
28 Jul	157	22	139	19	115	20
29 Jul	211	38	211	38	115	26
30 Jul	236	43	230	43	145	30
31 Jul	405	47	381	45	236	32
1 Aug	209	23	199	22	114	21
2 Aug	100	25	99	24	77	22
3 Aug	103	22	97	21	42	12
4 Aug	79	19	79	19	54	16
5 Aug	301	59	301	59	168	36
6 Aug	374	58	368	58	217	32
7 Aug	175	25	169	24	85	19
8 Aug	155	28	148	28	103	21
9 Aug	290	45	266	38	193	26
10 Aug	112	22	112	22	86	19

Note: all estimates are of upstream bound fish in midriver between and greater than 3 m from the transducers.

This page intentionally left blank.

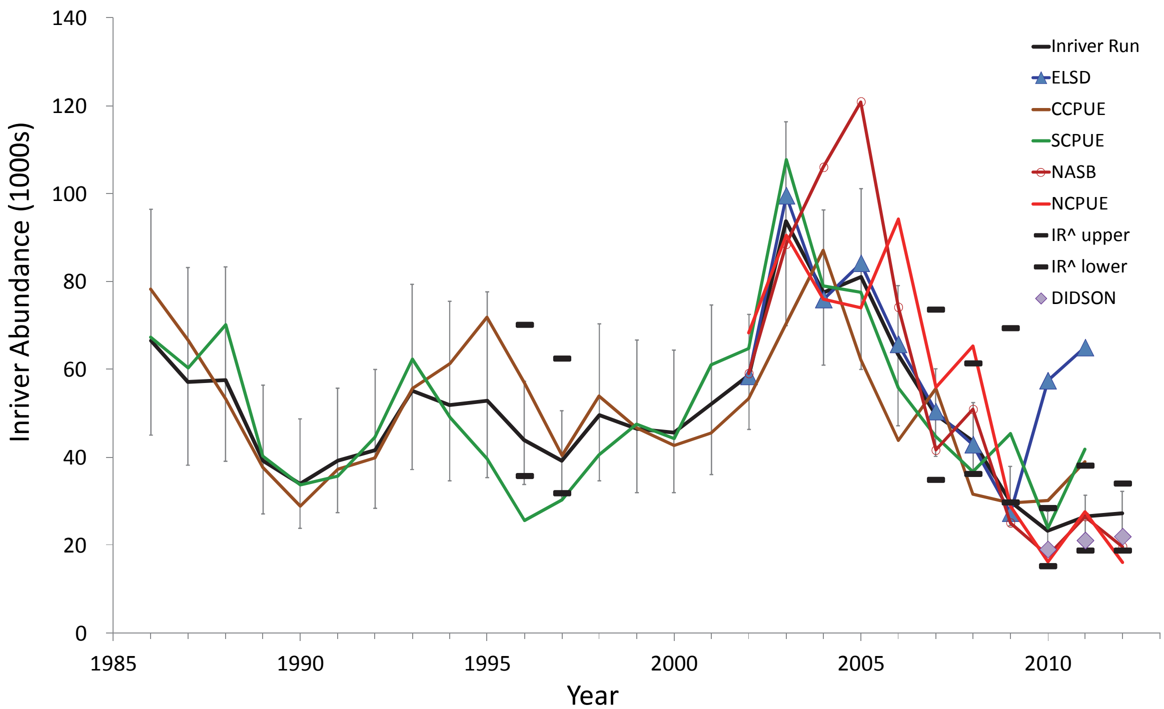
APPENDIX J: COMPARISON OF KENAI RIVER CHINOOK SALMON ANNUAL ABUNDANCE MEASURES, 1986–2012

Appendix J1.–Comparison of 2010–2011 ELSD-based estimates with other measures of relative abundance employed by McKinley and Fleischman (2013) in an inriver run reconstruction of Kenai River early-run Chinook salmon.



Note: The run reconstruction employed inriver gillnet catch rate (NCPUE, NCP75), split-beam sonar salmon abundance apportioned by Chinook salmon fraction in test gillnets (NASB), catch rate in the lower-river sport fishery (SCPUE), late-run Chinook salmon abundance (N^LR), and split-beam sonar estimates of Chinook salmon passage based on echo-length standard deviation (ELSD; 2002–2009 only), plus estimates (IR^) of inriver abundance and estimates of midriver run from imaging sonar (preliminary DIDSON point estimates, 2010–2012). ELSD-based estimates for 2010 and 2011 were discordant with other data.

Appendix J2.–Comparison of 2010–2011 ELSD-based estimates with other measures of relative abundance employed by Fleischman and McKinley (2013) in an inriver run reconstruction of Kenai River late-run Chinook salmon.



Note: The run reconstruction employed inriver gillnet catch rate (NCPUE, NCP75), split-beam sonar salmon abundance apportioned by Chinook salmon fraction in test gillnets (NASB), catch rate in the lower-river sport fishery (SCPUE), catch rate in a commercial set-net fishery near the river mouth (CCPUE), and split-beam sonar estimates of Chinook salmon passage based on echo-length standard deviation (ELSD; 2002-2009 only), plus estimates (IR^) of inriver abundance and estimates of midriver run from imaging sonar (preliminary DIDSON point estimates, 2010–2012). ELSD-based estimates for 2010 and 2011 were discordant with other data.