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Estimates of Chinook Salmon Abundance in the Kenai River Using Split-Beam Sonar, 2000

by

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and

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June 2002

Alaska Department of Fish and Game

Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

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

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

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

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
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
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

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	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
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.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
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
standard length	SL
total length	TL
variance	Var

FISHERY DATA SERIES NO. 02-09

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ABSTRACT

The passage of chinook salmon *Oncorhynchus tshawytscha* in the Kenai River in 2000 was estimated using side-looking split-beam sonar technology. Early (16 May-30 June) and late (1 July-10 August) runs of Kenai River chinook salmon have been monitored acoustically since 1987. A 200 kHz split-beam sonar system has been used since 1995 to estimate numbers of migrating adult chinook salmon returning to their natal stream. From 1987 to 1994, a 420 kHz dual-beam sonar was used to generate similar estimates. In 2000, total upstream chinook salmon passage from 16 May through 10 August was an estimated 56,996 (SE = 709) fish, 12,479 (SE = 234) during the early run and 44,517 (SE = 669) during the late run. The daily peak of the early run occurred on 19 June with 50% of the run having passed by that date. The daily peak of the late run occurred on 15 July, with 50% of the late run having passed by 17 July.

Key words: split-beam sonar, dual-beam sonar, chinook salmon, *Oncorhynchus tshawytscha*, acoustic assessment, Kenai River, riverine sonar, early run, late run.

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 (Nelson et al. 1999). 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. The fishery has been politically volatile because the Upper Cook Inlet commercial sockeye fishery and subsistence and personal use fisheries also harvest chinook salmon during the months of July and August.

Chinook salmon returning to the Kenai River are managed as two distinct runs, early and late, which typically peak in mid-June and late July (Burger et al. 1985). Early-run chinook are harvested primarily by sport anglers; late-run chinook by commercial, sport, subsistence, and personal use fisheries. These fisheries may be restricted if the projected run size falls below escapement goals set by the Alaska Board of Fisheries (ADF&G 1990). From 1989 through 1998 these runs were managed for spawning escapement goals of 9,000 for early-run (16 May-30 June) and 22,300 for late-run (1 July-10 August) chinook salmon (McBride et al. 1989). In February 1999, the Alaska Board of Fisheries set new escapement goals based on the escapement of chinook salmon estimated by sonar and our best understanding of its biases (Hammarstrom and Hasbrouck 1998, 1999; Bosch and Burwen 1999). The new escapement goals define a range of escapement levels desired for the early run at 7,700 to 14,000 chinook (5AC 56.070 Kenai River Early Run Chinook Management Plan) and the late run at 23,000 to 37,000 chinook (5AAC 21.359 Kenai River Late Run Chinook Management Plan). These escapement goal ranges should provide for a more stable fishing season without compromising either run.

Sonar estimates of inriver return provide the basis for estimating spawning escapement and implementing management plans that regulate harvest in competing sport and commercial fisheries for this stock. Implementation of these management plans has been a contentious issue for the state, one that commands much public attention. Restrictions on the sport fishery were imposed in each year from 1989 through 1992 to ensure optimum escapement goals were met. Since 1993, the 1997, 1998, and 2000 early runs, and the 1998 late run required a restriction of the sport fishery to meet escapement goals.

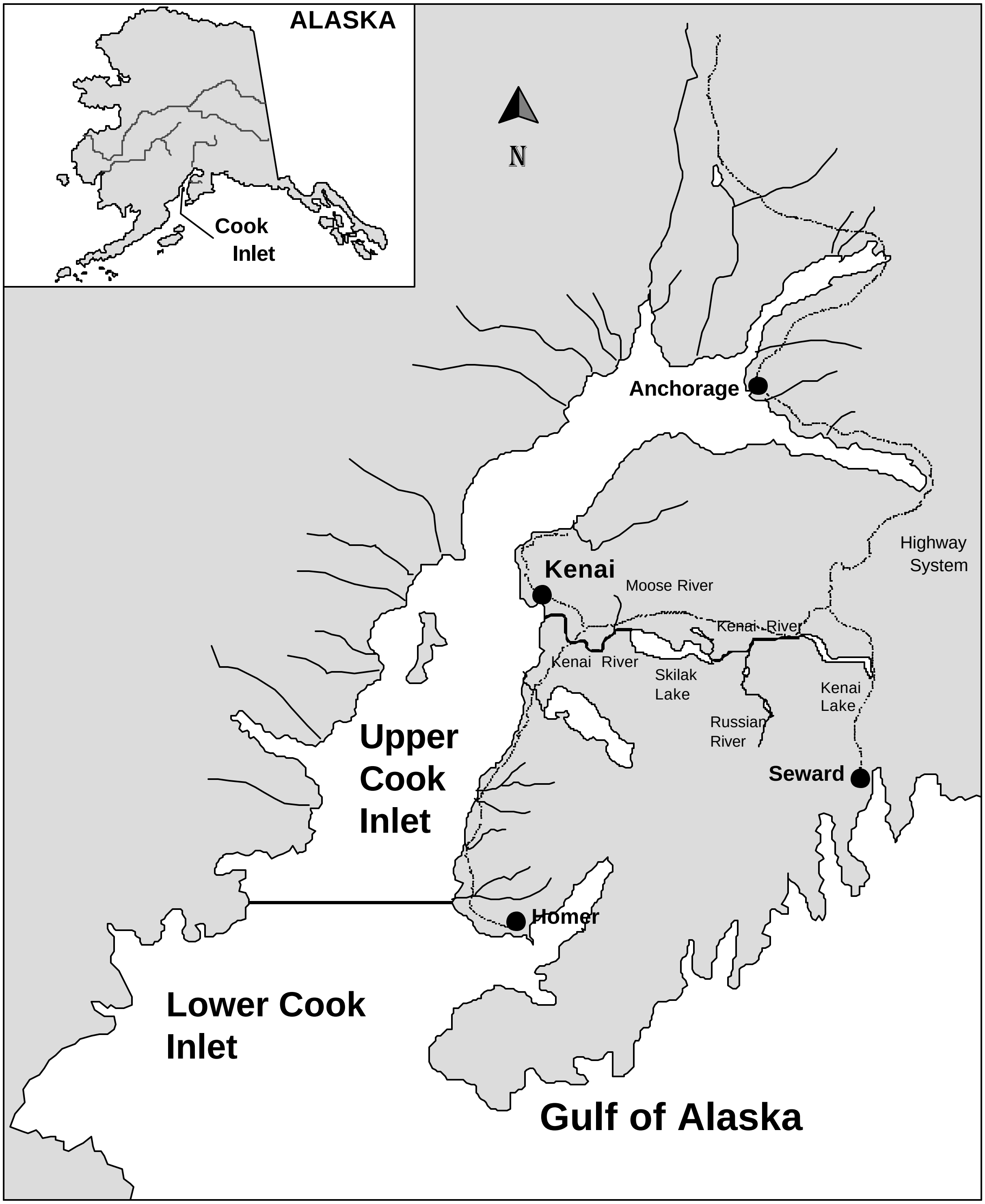


Figure 1.-Map of Cook Inlet showing location of the Kenai River.

The first estimates of chinook abundance were generated for the 1984 late run with a mark-recapture project using drift gillnets (Hammarstrom et al. 1985). The mark-recapture project produced estimates of riverine abundance through 1990 (Hammarstrom and Larson 1986; Conrad and Larson 1987; Conrad 1988; Carlon and Alexandersdottir 1989; Alexandersdottir and Marsh 1990). These estimates had low precision and were biased high (Bernard and Hansen 1992). The low precision and high bias were more apparent in the late-run estimates due to lower tagging rates and unaccounted-for tag loss. The unaccounted-for tag loss arose because some marked fish emigrated from the river back into Upper Cook Inlet and were subsequently harvested in the commercial fishery.

In order to obtain timely and accurate estimates of chinook salmon passage, the department initiated studies to determine whether an acoustic assessment program could be developed to provide daily estimates of chinook salmon into 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. Since 1987, sockeye salmon escapement estimates generated by the mile-19 sockeye sonar project have ranged from 630,000 to 1,600,000 (Davis 2000) while late-run chinook salmon escapement estimates generated by the chinook sonar project have ranged from 29,000 to 55,000. Dual-beam sonar was initially chosen for the chinook 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 large chinook salmon. Due to the considerable size difference between Kenai River chinook salmon and other species of fish present in the river, it was postulated that dual-beam sonar could be used to distinguish the larger chinook salmon from smaller fish (primarily sockeye) and estimate their numbers returning to the river.

Early studies indicated that chinook salmon could be distinguished from sockeye salmon based on target strength and spatial separation in the river. Sockeye salmon were believed to migrate near the bank and to have a smaller target strength than chinook salmon, which preferred the midchannel section of the river. A target strength threshold was established to censor "counts" based on acoustic size. A range threshold was also used when sockeye salmon were abundant, that is, targets within a designated distance from the transducer were interpreted to be sockeye salmon and not counted. These two criteria have been the basis for discriminating between species and estimating the return of chinook salmon to the Kenai River.

Daily and seasonal acoustic estimates of chinook salmon have been generated since 1987. Estimates of total passage made with sonar were consistently lower than the mark-recapture estimates for the years 1987 through 1990 (Eggers et al. 1995). The inconsistencies between sonar and mark-recapture estimates were highest during the late run, presumably due to the mark-recapture biases discussed earlier.

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 spatial distribution (three-dimensional) of fish in the acoustic beam could be determined for the first time. The split-beam system operated at a lower frequency, which resulted in an improved (higher) signal-to-noise ratio (SNR). 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 and run concurrently with the dual-beam for much of the 1994 season (Burwen et al. 1995). In a comparative study, both systems performed similarly, detecting comparable numbers of fish. The split-beam data confirmed earlier studies showing that fish were strongly oriented to the river bottom. However, experiments conducted with the split-beam system could not confirm the validity of discriminating chinook salmon from sockeye salmon based on acoustic size. These results supported modeling exercises performed by Eggers (1994) that also questioned the feasibility of discriminating between chinook and sockeye salmon using target strength. It was hypothesized that separation of the two species was primarily accomplished by range thresholds combined with spatial segregation (sockeye salmon nearshore and chinook salmon midriver) (Eggers et al. 1995; Burwen et al. 1995). In 1995, the dual-beam system was replaced with the split-beam system in order to take advantage of the additional information on direction of travel and spatial position of targets.

Two ancillary studies (Burwen et al. 1998*)* were conducted in 1995 directed at providing more definitive answers to remaining questions regarding: (1) the degree to which sockeye and chinook salmon are spatially separated at the site at river km 14 (river mile 8.5), and (2) the utility of using target strength and/or other acoustic parameters as discriminatory variables for species separation. Results of these studies showed the potential for including sockeye salmon in chinook salmon estimates using current methodology. The netting study found that sockeye salmon were present in the middle insonified portion of the river during the study period, and in a concurrent tethered, live-fish experiment, most sockeye salmon tethered in front of the split-beam sonar had mean target strengths exceeding the target strength threshold.

To address concerns raised by these studies, radiotelemetry projects were implemented in 1996 and 1997 to estimate the magnitude of bias introduced during periods of high sockeye passage. These studies were designed to provide an independent and accurate estimate of inriver chinook abundance during the late run when the potential to misclassify sockeye is greatest. Use of radio-telemetry technology also avoided certain biases introduced in previous mark-recapture estimates. In both 1996 and 1997, late-run sonar estimates were 21% higher than the telemetry estimates (Hammarstrom and Hasbrouck 1998, 1999).

An alternative site investigation conducted in 1999 (Burwen et al. 2000) attempted to identify alternative sites above tidal influence that might strengthen the bank orientation of sockeye salmon and thereby increase the effectiveness of range thresholds in filtering sockeye salmon from chinook salmon abundance estimates. The investigation concentrated on a site located at river km 21.2 (river mile 13.2) that was above tidal influence but below areas of major spawning activity. A netting program indicated that there were fewer sockeye salmon in the offshore area at the alternative site than there were 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 greater boat traffic, less acoustically favorable bottom topography, and increased background noise resulting in difficult fish tracking conditions.

We continue to pursue improved techniques for separating chinook and sockeye salmon using acoustic information. Studies with tethered and free-swimming fish indicate that there are other acoustic variables that may provide higher discriminatory power than target strength for separating sockeye and chinook salmon (Burwen and Fleischman 1998). We have also made progress in developing methods to estimate target strength more accurately (Fleischman and Burwen 2000).

METHODS

STUDY AREA

The Kenai River drains an area 2,150 square miles. It is glacially influenced with discharge rates lowest during winter, increasing throughout the summer and peaking in August (USDA 1992). The Kenai River has 10 major tributaries, many of which provide important spawning and/or rearing habitat for salmon. Some of these tributaries are 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 influences both rainfall and temperature throughout the drainage. Average annual rainfall ranges from over 101 cm in the Kenai Mountains at its source, to 46 cm in the city of Kenai at its mouth. Average summer temperatures in the drainage range from 4°C to 18°C; average winter low temperatures range from -23°C to -40°C (USDA 1992).

SITE DESCRIPTION

The 2000 sonar site was located 14 km (8.5 mi) 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 relative to the sport fishery and known spawning habitat for chinook salmon.

The river bottom in this area has remained stable for the past 16 years despite a 140-year flood during September 1995 (Joe Dorava, United States Geological Survey [USGS], Anchorage, personal communication). The slope from both banks has remained 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 rather than reflective surface. This absorptive property improves the signal-to-noise ratio 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 below the lowest suspected spawning sites of chinook salmon yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Alexandersdottir and Marsh 1990), reducing the incidence of chinook salmon loitering in the sonar beam or returning downstream. Initially, almost all sport fishing occurred some distance upstream of this site. However, fishing activity near the site has increased over the past few years, mostly during the late run.

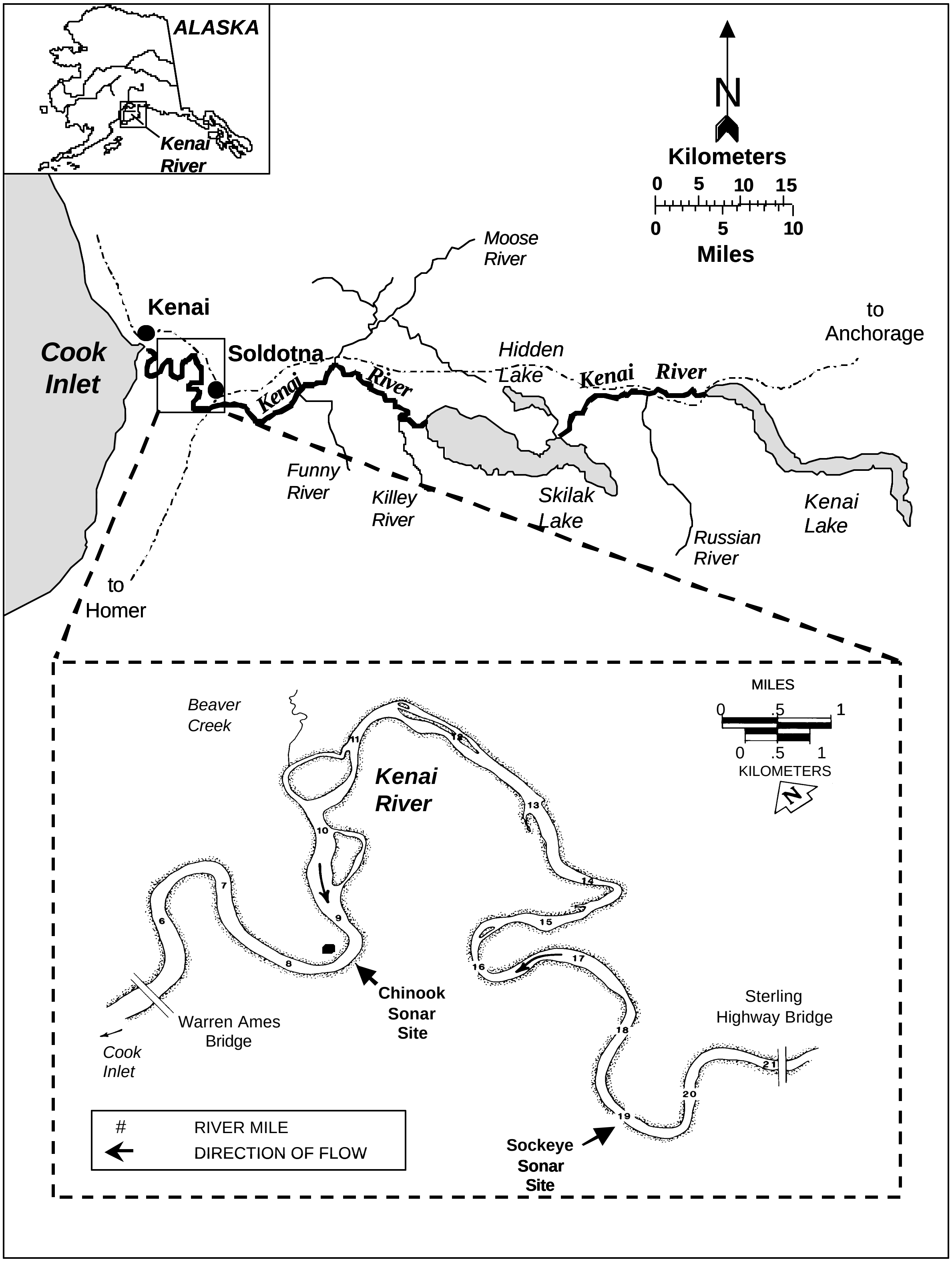


Figure 2.-Map of Kenai River showing location of chinook salmon sonar site, 2000.

Table 1.-Principal components of the split-beam sonar system used in 2000.

System Component	Description
Sounder	Hydroacoustics Technology Inc. (HTI) Model 244 Split-Beam Echo sounder operating at 200 kHz
Signal Processor	HTI Model 340 Digital Echo Processor based in a Dell XPS T450 personal computer
Transducers	(2) HTI Split-Beam transducers: Left Bank: nominal beam widths: 2.9^{o}x10.2^{o} Right Bank: nominal beam widths: 2.8^{o}x10.0^{o}
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. Uwinstru Underwater Measurement Device.

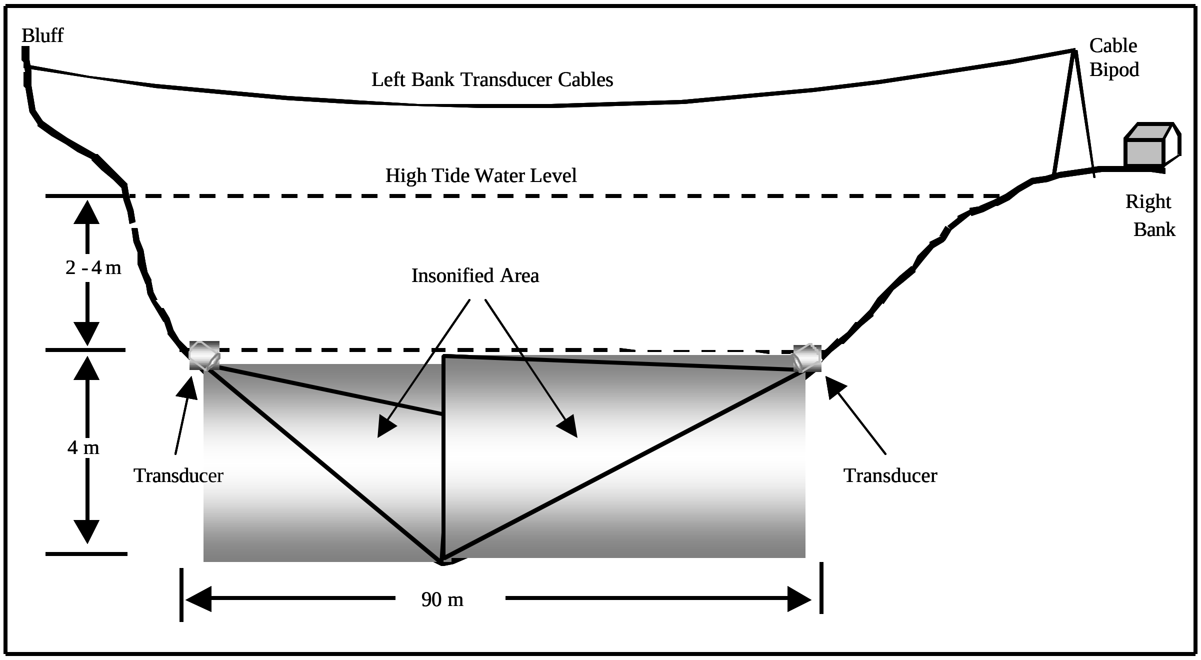
ACOUSTIC SAMPLING

A Hydroacoustic Technology Inc. (HTI)[1] split-beam sonar system operated from 16 May through 10 August 2000. Components of the system are listed in Table 1 and further described in HTI manuals (HTI 1996a, 1996b). A brief explanation of the theory of split-beam sonar and its use in estimating target strength can be found in Appendix A1. A more detailed explanation can be found in Ehrenberg (1983).

Sonar System Configuration

Sampling on both banks was controlled by electronics housed in a tent located on the right bank of the river. Communication cables led to transducers and their aiming devices 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 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. During the 16 May to 10 August time frame, water level at low tide rose approximately 1.3 m. As the water level rose, the tripods were periodically moved closer to shore so that the total range insonified by the sonar beams increased from approximately 72 m at the lowest water conditions (16 May–7 June) to 93 m at high water (17 July–18 July; Figure 4).

[1] Use of a company's name does not constitute endorsement.



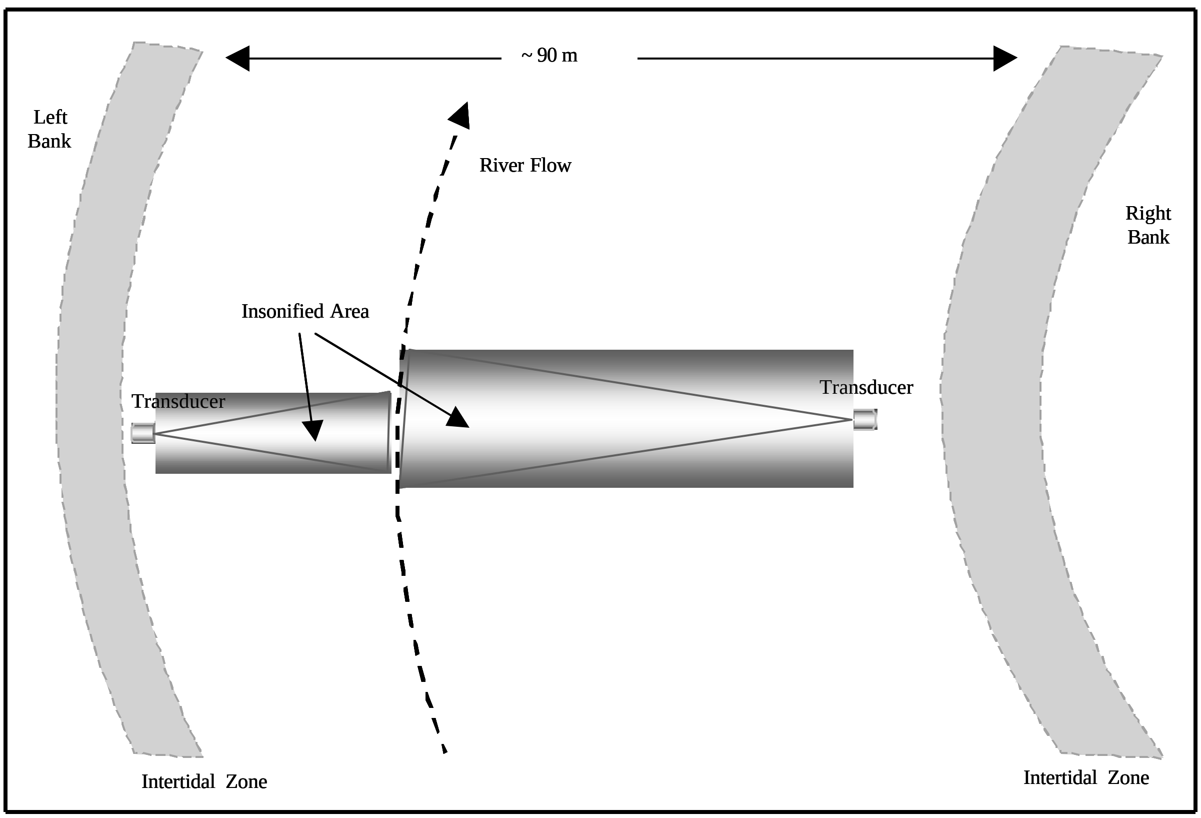


Figure 3.-Cross-sectional (top) and aerial (bottom) views of sonar site showing insonified portions of the Kenai River, 2000.

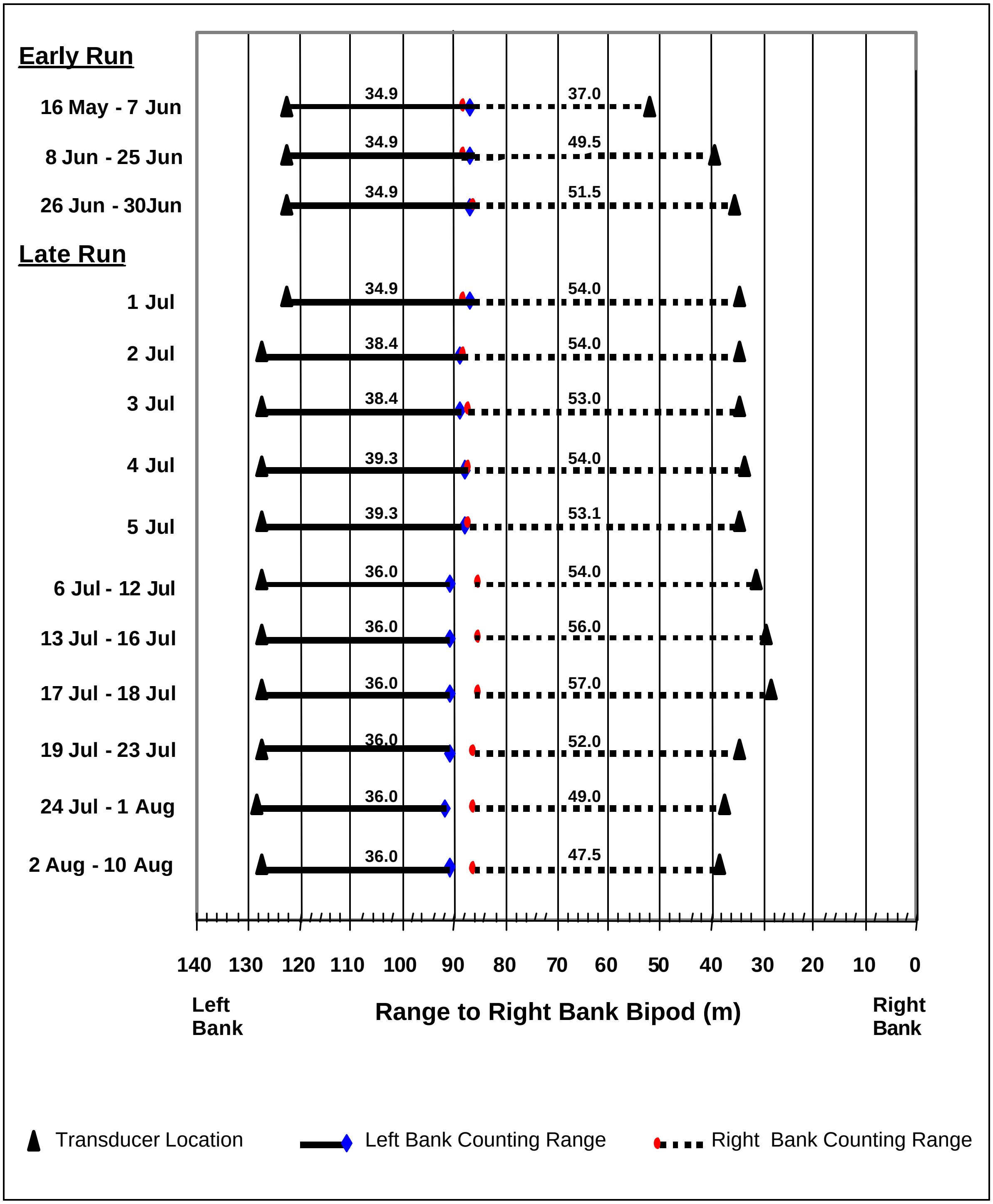


Figure 4.-Daily right and left bank transducer locations and counting ranges relative to bipod tower located on the right bank, Kenai River, 2000.

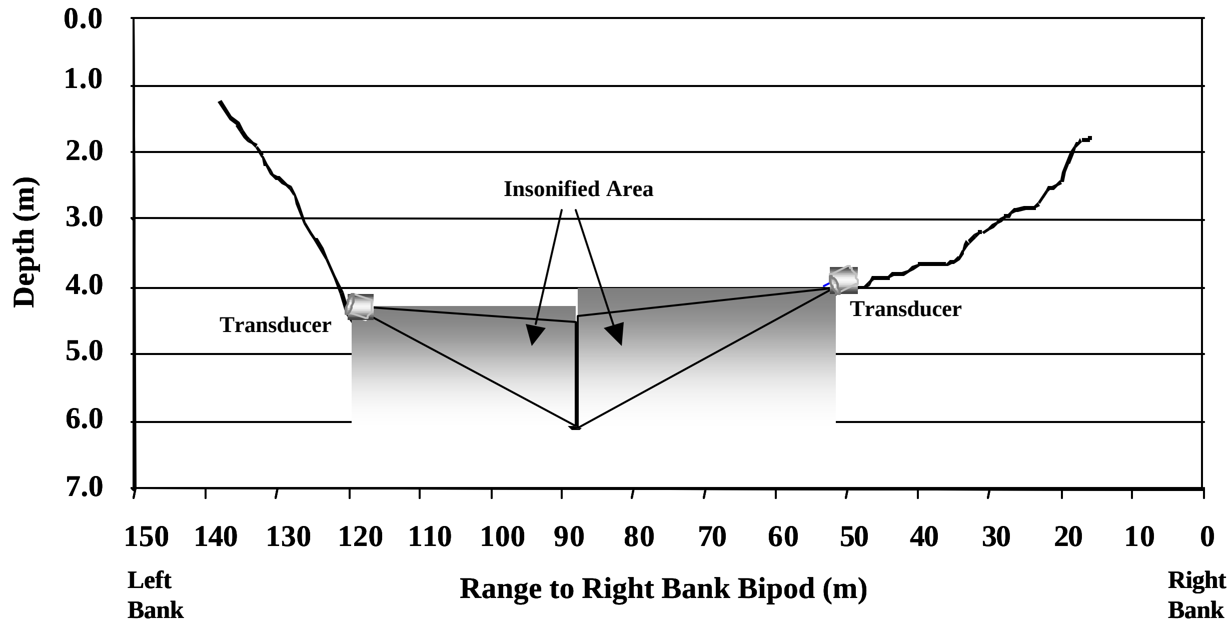


Figure 5.-Bottom profile at the Kenai River chinook sonar site with approximate transducer locations and sonar beam coverage for May 16, 2000.

Vertical and horizontal aiming of each transducer was remotely controlled by a dual-axis electronic pan and tilt system. A digital readout 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 grazing the river bottom. In the horizontal plane, the transducer was aimed perpendicular to the flow of the river to maximize probability of insonifying fish from a lateral aspect. The range encompassed by each transducer was initially determined by using a depth sounder to find the center of the river channel between the two sonar beams, deploying a large underwater target in midchannel, aiming both sonar transducers at the underwater target and recording the range from each.

Bottom Mapping and Beam Coverage

A detailed profile of the river bottom and the area encompassed by the sonar beams was produced prior to acoustic sampling. Depth readings from a Lowrance X-16 were paired with range measurements from a fixed target on shore using a Bushnell Laser Ranger (±1 m accuracy). When combined with information from the attitude sensor or the dual-axis rotator, a detailed visualization of how well the water column above the bottom substrate was insonified by the acoustic beam could be generated (Figure 5). The attitude sensor is a more reliable indicator of the transducer position than the rotator digital readout, thus information from the attitude sensor provided a more accurate representation of beam aim and coverage than did the rotator output. Because of limitations in cable transmission, only the right bank was equipped with an attitude sensor in 2000 (a 1000 ft cable is required to reach the left bank system). The left bank transducer aim was determined using the output of the dual-axis rotator system. Although only a relative position can be obtained from this instrument, a reasonable approximation of the transducer aim could be used to determine beam coverage on the left bank. Recent advances made by the manufacturer will allow an attitude sensor to be added to the left bank system in 2001.

Each time the transducer was moved throughout the season, 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. During the early run, beam coverage was complete across the middle of the river as the beams on each bank extended to the thalweg. Rising water level and transducer relocations during the late run resulted in an approximate 2-6 m gap in beam coverage in the middle of the river beginning approximately 6 July (Figure 4). As the transducer tripods were moved closer to shore with rising water, the bottom profile interfered with the ability of the sonar beam from each bank to reach the thalweg.

Increased boat activity in front of the site in late July resulted in the need for an offshore deployment of the right bank transducer on 19 July. The offshore deployment was necessary because movement of the transducer closer to shore late in the season resulted in an increase in coverage range which in turn resulted in an increase in beam dimension at far range. The increased beam dimension made the effect of boat wake more pronounced, resulting in excessive background noise at far range. The offshore deployment reduced the overall coverage range and decreased the inshore coverage by about 5-10 m, but maintained the same end range used throughout much of the late run (Figure 4). The decreased range resulted in a decreased beam dimension at far range and thus a reduction in background noise caused by boat wake. The offshore deployment was maintained through the end of the season.

System Calibration

Reciprocity calibrations with a naval standard transducer were performed by HTI in Seattle (HTI 1999). Calibration results were verified at the calibration facility with a 38.1-mm tungsten carbide sphere (Foote and MacLennan 1984). Further verification was obtained *in situ* by measuring the same standard sphere on 10 May, 5 June, 20 June, and 26 June. For each calibration verification, we recorded the maximum background noise level and voltage threshold in addition to the data collected automatically by the onboard signal-processing software (see Data Acquisition).

Sampling Procedure

A systematic sample design (Cochran 1977) was used to sample from each bank for 20 min 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 produce daily fish passage estimates. 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 quiescent or activated for ancillary studies during the third 20-min period. This routine was followed 24 hours per day and 7 days per week unless one or both banks were inoperable.

A test of this sample design conducted in 1999 found no significant difference between hourly estimates of chinook salmon passage obtained using full one-hour counts and estimates obtained using expanded 20-min counts (Bosch et al. *In prep*).

Echo Sounder Settings

Relevant echosounder settings are listed in Table 2 with a more complete summary in Appendix B1 and Appendix B2. Most echosounder settings were identical for each bank and remained consistent throughout the sample period. High power and low gain settings were used to maximize SNR. The transmitted pulse width was set relatively low to maximize resolution of individual fish, and SNR.

Data Acquisition

The digital echo sounder (DES) sent data from each returned echo to the digital echo processor (DEP; Figure 6). The DEP performed the initial filtering of returned echoes based on user-selected criteria (Table 3, Appendix B1 and Appendix B2); it also recorded the start time, date and number of pings processed for each sample.

Echoes in the transducer near field (<= 2.0 m) were excluded (MacLennan and Simmonds 1992). Minimum vertical and horizontal off-axis values were used to prevent consideration of unreliable data from transducer side lobes. Pulse width filters used prior to 1997 (Burwen and Bosch 1998) have not been used in recent years nor were they used in 2000 in order to examine the distribution of pulse widths from valid fish targets without truncation. Conventionally, pulse width filters are used to aid in excluding echoes from multiple targets. However, multiple targets are not considered an issue on this project due to the low target density within the insonified range.

Table 2.-HTI model 244 digital echo sounder settings used in 2000.

Echo Sounder Parameters	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

Voltage thresholds for data acquisition were set high enough 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 also makes it difficult to distinguish echoes originating from valid fish targets. The amount of background noise is determined largely by the dimensions of the sonar beam in relation to the depth of the river. Since the water level at the sonar site is strongly influenced by tidal stage (vertical fluctuations of more than 4 m), the amount of background noise fluctuates periodically, with 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 threshold that would exclude background noise at low tide when noise was at a maximum.

For each echo passing initial filtering criteria, the DEP wrote information to the computer hard disk in ASCII file format (*.RAW files). This file provided a permanent 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 and stored the following statistics for each echo: (1) range 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.

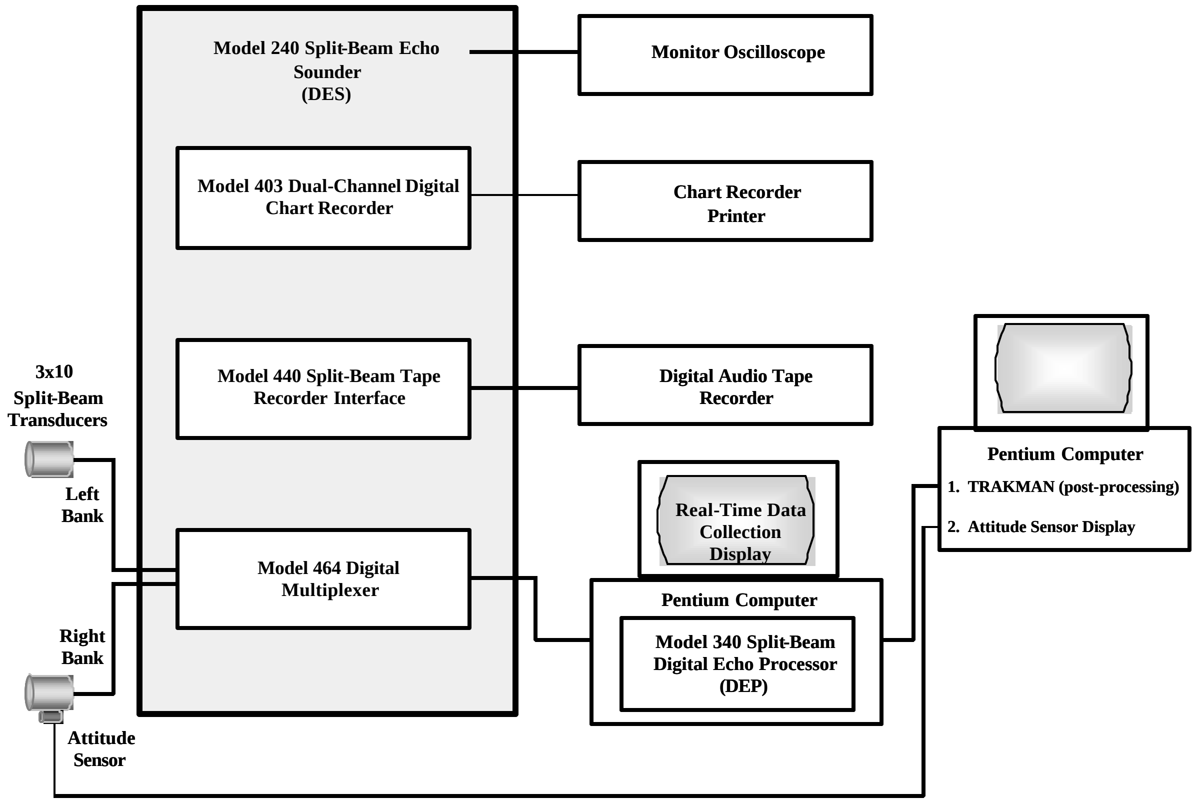


Figure 6.-Schematic diagram of 2000 split-beam sonar system configuration and data flow.

Table 3.-Echo acceptance criteria for digital echo processing, 2000.

Bank	Pulse width (ms) at -6 dB	Vertical angle off-axis (°)	Horizontal angle off-axis(°)	Threshold mV (dB)	Range (m)
Right					
16-May to 10-Aug	0.04 to 10.0	-2.5 to 2.5	-5.0 to 5.0	653 (-35 dB)	2.0
Left					
16- May to 10- Aug	0.04 to 10.0	-2.5 to 2.5	-5.0 to 5.0	419 (-35 dB)	2.0

The sum channel voltage from the Model 244 DES was also output to a dot matrix printer using a Model 403 Digital Chart Recorder. Chart recorder output was filtered only by a voltage threshold, which was set equal to the DEP threshold. The chart recorder ran concurrently with the echo sounder and produced real-time echograms for each sample. The echograms were used for data backup and transducer aiming, and to aid in manual target tracking.

FISH TRACKING AND ECHO COUNTING

A diagram illustrating inseason data flow can be found in Appendix C1. Echoes in the *.RAW files were manually grouped (tracked) into fish using HTI proprietary software called TRAKMAN. TRAKMAN produces an electronic chart recording for all valid echoes collected during a 20-min sample on the computer monitor. Selected segments of the chart can be enlarged and echoes viewed on a Cartesian grid. Echoes following a sequential progression through the beam were selected by the user and classified into fish traces. TRAKMAN then produced three output files. The first file contained each echo that was tracked in 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 dB, and target strength in dB. 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 (meters) 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 determined using information from the echo coordinates of individually tracked targets. A target was classified as upstream if its ending (X-axis) position in the acoustic beam was located upriver from its starting position and downstream if its ending position was down river from its starting position.

Downstream targets (and occasionally upstream 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 (range from transducer) as the target transited 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 straight-edge. A fish typically leaves a meandering trace that reflects some level of active movement as it passes through the acoustic beam. In 2000, obvious debris-like downstream targets were excluded from consideration as valid fish targets during the tracking procedure and the remainder of downstream targets was retained to adjust the total estimate of fish passage. 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. Erroneous echoes from structure, boat wake and sport fishing tackle were ignored. During periods of high sockeye or pink *O. gorbuscha* salmon passage, targets within a given range (15 m from 18 July through 25 July and 20 m from 26 July through 10 August) were assumed to be sockeye or pink salmon and were not tracked. This range was extended to 30 m during peak passage hours on 25 July–27 July.

DATA ANALYSES

Tidal and Temporal Distribution

Fish passage rates have been shown to be related to tidal stage (Eggers et al. 1995). Therefore tide stage was determined throughout the season using water level measurements taken at the top of each hour and at 20 minutes past each hour from a staff gauge located at the site. For the purpose of this study, falling tide was defined as the period of decreasing staff gauge readings, low tide as the period of low static readings, and high tide as the period of both increasing readings and high static readings (i.e. high slack tide). Data from both banks were combined to summarize fish passage by tide stage (falling, low, and rising) for both upstream and downstream traveling fish. Data were first filtered using target strength and range criteria (see section on species discrimination).

Spatial Distribution

Knowledge of the spatial distribution of fish is desirable for developing strategies for insonifying a specific area, for determining appropriate transducer beam dimensions, and for evaluating the probability of detecting fish near the edge of the acoustic beam (Mulligan and Kieser 1996).

Inseason range (z-axis) distributions for each bank were plotted separately for upstream and downstream fish. Range distributions were calculated using the midpoint range for each target as follows:

$$z_m = z_s + \left(\frac{d_z}{2}\right), \qquad (1)$$

where:

z_m = midpoint range (m),

z_s = starting range (m), and

d_z = distance traveled in the range z direction.

In previous years, range distribution comparisons were made using z_m, the distance from the face of the transducer to the target location. These comparisons provided information on distribution of fish targets from the face of the transducer, but because tripod/transducer locations change throughout the season the comparisons were poor descriptors of actual fish range distributions across the river. For this report, range estimates by bank were standardized to the nearest shore transducer deployment for that bank based on distances to a fixed point on the right bank (cable bipod, Figures 3 and 4):

$$z_a = z_m + \left|z_t - z_n\right|, \qquad (2)$$

where:

z_a = adjusted range (m),

z_t = distance from right bank bipod to transducer (m), and

z_n = distance from right bank bipod to nearest shore (right bank or left bank) deployment location (m).

Range distribution plots were produced postseason with the adjusted (standardized) range estimates allowing for comparisons of actual fish target locations across the river. The end range in these range distribution graphs was the maximum distance covered (generally to the thalweg) by the sonar beam on that particular bank.

Vertical distributions were plotted by direction of travel (upstream and downstream) and tide stage. Vertical distributions were calculated from the midpoint angle off-axis in the vertical plane as follows:

$$\theta_y = \arcsin \frac{y_s + \left(\frac{d_y}{2}\right)}{z_m}, \quad (3)$$

where:

θ_y = vertical angle-off-axis midpoint (degrees),

y_s = starting vertical coordinate (m), and

d_y = distance traveled in vertical direction (m).

Target Strength Distribution

Target strength was calculated for individual echoes (Appendix A1) and averaged for each tracked fish. Inseason target strength distributions were plotted separately for early- and late-run fish and for upstream and downstream fish.

Species Discrimination

Tracked fish were filtered using criteria intended to minimize the number of sockeye salmon counted. Two parameters have been used historically on this project to separate large chinook salmon from smaller species: target strength and distance from the transducer (range). Although recent studies have questioned the usefulness of these parameters for our application (Eggers 1994, Burwen et al. 1995), we continued their use in 2000 to ensure comparability of passage estimates with those of past years, while continuing to investigate other means of discriminating between fish sizes (Burwen and Fleischman 1998; Fleischman and Burwen 2000).

Tracked fish with mean target strength less than -28 dB were assumed to be species other than chinook salmon and excluded from further analysis. The majority of fish within the nearshore area were assumed to be smaller species such as sockeye, pink, and coho *O. kisutch* salmon. All left-bank traveling fish within 10 m of the transducer (16 May-10 August) were filtered out. Several range thresholds were applied on right-bank fish, all associated with moving the transducer pod closer to shore and increasing the insonified range to maintain mid-channel coverage. The following range thresholds were used on the right bank: 15 m (16 May–27 June), 25 m (28 June–14 July), 35 m (15-18 July), and 30 m (19 July–10 August).

On several days (14-16 July, 22 and 23 July, and 6 August) the high passage and offshore distribution of sockeye or pink salmon rendered the range thresholds ineffective and made it impossible to accurately track chinook salmon on either bank for several consecutive hours.

Passage Estimates

To meet fishery management needs, estimates of fish passage were generated for each day, and were generally available by noon of the following day.

An estimate of fish passage was calculated for each hour for which a sample existed. This was usually an exact 20-min count, which was multiplied by 3 for the hourly estimate on each bank. In this case, the number of fish passing bank b during hour j ($\hat{y}_{bj}$) was estimated as:

$$\hat{y}_{bj} = \frac{60}{t_{bj}} c_{bj}, \qquad (4)$$

where:

t_{bj} = number of minutes sampled on bank b during hour j, and

c_{bj} = sample count for bank b and hour j.

When the sonar system on one bank was not operating (<1% of samples), the omission was treated as a "missing datum" with substitution as a correction. If information from the other bank was available for that hour, we applied a ratio estimator $\hat{R}_b$ (Cochran 1977) between banks, using data from those hours when both banks were sampled for the same number of minutes. When the sonar system was not operating on one bank, the chinook passage for that bank was estimated as:

$$\hat{y}_{bj} = \hat{R}_b \hat{y}_{b'j}, \qquad (5)$$

where:

$$\hat{R}_b = \frac{\sum_{j=1}^{n_B} \hat{y}_{bj}}{\sum_{j=1}^{n_B} \hat{y}_{b'j}}, \qquad (6)$$

$\hat{y}_{b'j}$ = estimated passage for opposite bank b' during hour j, and

n_B = number of hours during the season in which both banks were sampled for the same number of minutes.

During the season, for purposes of daily reporting of estimated passage, $\hat{R}_b$ was calculated from the cumulative number, to date, of hours when both banks were sampled for the same number of minutes. Final estimates were generated postseason.

When the sonar system was inoperable on both banks for a full hour, estimated passage on each bank was interpolated as the mean of the estimated passage before and after the missing sample:

$$\hat{y}_{bj} = \frac{\hat{y}_{b(j-1)} + \hat{y}_{b(j+1)}}{2}. \tag{7}$$

If several consecutive hourly estimates from both banks were missing, as was the case when offshore distribution of sockeye and pink salmon hampered our ability to accurately track chinook salmon, we used a daily expansion of available tracked hours to estimate the missing hours:

$$\hat{y}_{bj} = \frac{\frac{24}{n'}\sum_{j'}\hat{y}_{bj'}}{24 - n'}, \tag{8}$$

where:

j' = tracked hour for which a passage estimate was obtained, and

n' = number of tracked hours for which a passage estimate was obtained.

Fish passage on day i was estimated as:

$$\hat{y}_i = \sum_{b=1}^{2}\sum_{j=1}^{24}\hat{y}_{bj}, \tag{9}$$

where $\hat{y}_{bj}$ was obtained from either (4), (5), (7), or (8) as appropriate. Finally, the number of chinook salmon migrating into the Kenai River during a run was estimated as:

$$\hat{Y} = \sum_{i=1}^{N_D}\hat{y}_i, \tag{10}$$

where N_D is the number of days in the run. Its variance (successive difference model, Wolter 1985) was estimated, with adjustments for missing data, as:

$$\hat{V}[\hat{Y}] = \sum_{b=1}^{2} 9N_H^2(1 - f_S)\frac{\sum_{j=2}^{N_H}\phi_{bj}\phi_{b,j-1}(c_{bj} - c_{b,j-1})^2}{2\sum_{j=1}^{N_H}\phi_{bj}\sum_{j=2}^{N_H}\phi_{bj}\phi_{b,j-1}}, \tag{11}$$

where:

N_H = total number of hours during the run, and

f_S = fraction of available periods sampled (0.33), and

ϕ_{bj} = if the sonar was operating on bank b during hour j, or 0 if not.

RESULTS

SYSTEM CALIBRATION

During system calibration at the HTI calibration facility, the target strength of a 38.1-mm tungsten carbide standard sphere was measured at -37.90 dB and –37.96 dB with the right and left bank transducers, respectively (HTI 1999; Table 4). The theoretical value for the sphere is -39.5 dB (MacLennan and Simmonds 1992). During subsequent *in situ* calibration checks using the same sphere, mean target strength varied from -38.72 dB to -39.50 dB on the right bank and from -37.65 dB to -38.81 dB on the left bank (Table 4). Target strength can vary with water temperature, depth, conductivity and other factors. Consequently small fluctuations throughout the season are expected.

Table 4.-Results of 2000 *in situ* calibration verifications using a 38.1 mm tungsten carbide standard sphere.

Location	Date	Mean Target Strength (dB)	SD	N	Range (m)	Noise (mV)	Threshold (mV)
Right Bank							
HTI[a]	10 Dec	-37.90	0.64	262	N/A[b]	N/A[b]	N/A[b]
Kenai River	5 June	-38.72	1.91	2,419	10.4	100	117
Kenai River	26 June	-39.50	1.62	2,476	14.9	145	150
Left Bank							
HTI[a]	10 Dec	-37.96	0.71	256	N/A[b]	N/A[b]	N/A[b]
Kenai River	10 May	-37.74	1.76	4,722	16.3	N/A[b]	75
Kenai River	5 June	-38.81	1.46	4,362	8.8	60	75
Kenai River	20 June	-37.65	1.19	625	8.2	60	75

[a] Measurements taken at Hydroacoustic Technology Inc. facility during system calibration.

[b] Not available.

TARGET TRACKING

A total of 43,330 targets were manually tracked, 6,491 during the early run and 36,839 during the late run. After filtering for range and target strength criteria and making temporal expansions, the proportion of upstream fish was 91.1% for the early run and 94.0% for the late run (Appendix D1 and Appendix D2).

The number of acquired echoes per fish varied by run, bank, and direction of travel. During the early run, upstream fish averaged 48 (SD = 39) and 63 (SD = 48) echoes per fish on the left and right banks, respectively. Downstream fish averaged 73 echoes (SD = 67) on the left bank and 69 echoes (SD = 66) on the right bank. Upstream fish during the late run averaged 46 (SD = 36) echoes on the left bank and 76 (SD = 45) echoes on the right bank. Downstream fish averaged 57 (SD = 43) echoes on the left bank and 73 (SD = 63) echoes per fish on the right bank.

TIDAL AND TEMPORAL DISTRIBUTION

Most upstream fish were counted during the falling tide for both early (52.5%) and late (46.0%) runs (Table 5, Table 6, Figure 7). Likewise, most downstream fish were counted during the falling tide for both the early (42.3%) and late (44.3%) runs.

Table 5.-Estimates of chinook salmon passage by tide stage and direction of travel for the 2000 early run (16 May to 30 June).

2000 Early Run	Total Number of Fish	Rising	Falling	Low
Upstream	12,479	3,842	6,551	2,086
Row %	100.0%	30.8%	52.5%	16.7%
Column %	91.1%	90.5%	92.7%	87.3%
Downstream	1,219	401	515	303
Row %	100.0%	32.9%	42.3%	24.9%
Column %	8.9%	9.5%	7.3%	12.7%

Test for Independence: Chi-square = 65.99, df = 2, P<<0.01.

Table 6.-Estimates of chinook salmon passage by tide stage and direction of travel for the 2000 late run (1 July to 10 August).

2000 Late Run	Total Number of Fish	Rising	Falling	Low
Upstream	44,517	16,417	20,461	7,639
Row %	100.0%	36.9%	46.0%	17.2%
Column %	94.0%	94.4%	94.2%	92.5%
Downstream	2,858	978	1,265	615
Row %	100.0%	34.2%	44.3%	21.5%
Column %	6.0%	5.6%	5.8%	7.5%

Test for Independence: Chi-square = 36.15, df = 2, P <<<0.01.

SPATIAL DISTRIBUTION

Fish were bottom-oriented during both runs, although vertical distribution did vary somewhat by direction of travel, tide stage, and season (Appendix E1 and Appendix E2). During the early run, 92% of the upstream fish (chinook targets) on the left bank and 76% on the right bank were below the acoustic axis (Figure 8). Downstream fish were less bottom-oriented (Appendix E1 and Appendix E2). Seventy-seven percent of downstream fish on the left bank and 61% on the right bank were below the acoustic axis (Figure 8). Upstream fish (chinook targets) on the left bank (mean = -1.29^{o}, SD = 0.70,

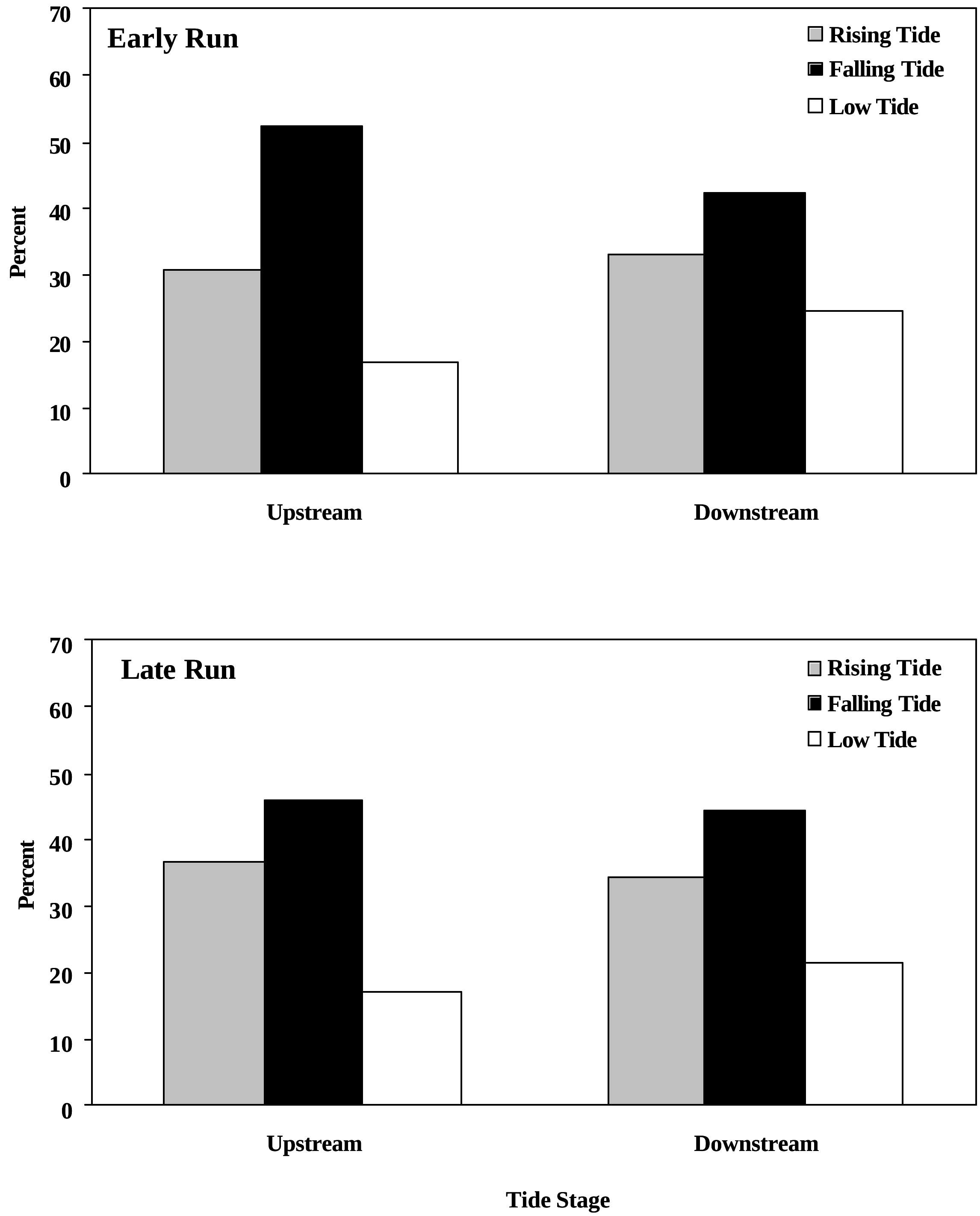


Figure 7.-Distribution of upstream and downstream fish by tide stage during the early and late run, Kenai River, 2000.

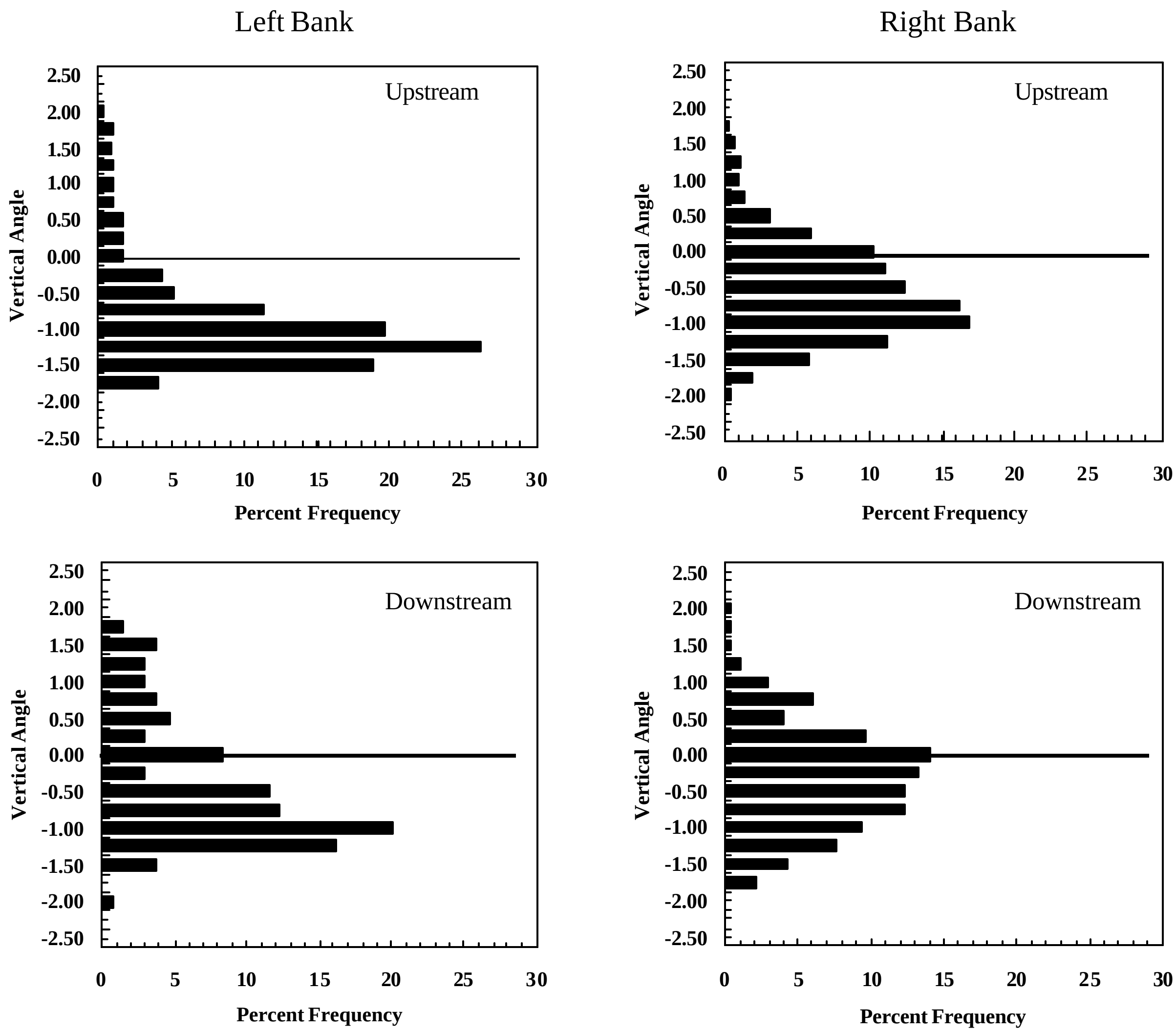


Figure 8.-Vertical distributions of early-run upstream and downstream fish on the left and right banks, Kenai River, 2000.

n = 1,690) were on average significantly lower (P << 0.001) in the water column than downstream fish (mean = -0.79 ^{o}, SD = 0.86, n = 129). On the right bank, upstream fish (mean = -0.69 ^{o}, SD = 0.65, n = 2,447) were also significantly lower in the water column (P << 0.001) than downstream fish (mean = -0.45^{o}, SD = 0.71, n = 278). Upstream traveling fish on both banks were bottom oriented during all tide phases, but were distributed slightly higher in the water column during the rising tide phase (Figure 9).

Late-run fish also showed a tendency to travel along the river bottom (Figure 10 and Appendix E2). Ninety-six percent of upstream fish on the left bank and 55% of upstream fish on the right bank were below the acoustic axis. Ninety percent of downstream fish on the left bank and 45% of downstream fish on the right bank were below the acoustic axis. The difference in vertical range distributions between the right and left banks was due in part to the reflective nature of the left bank bottom

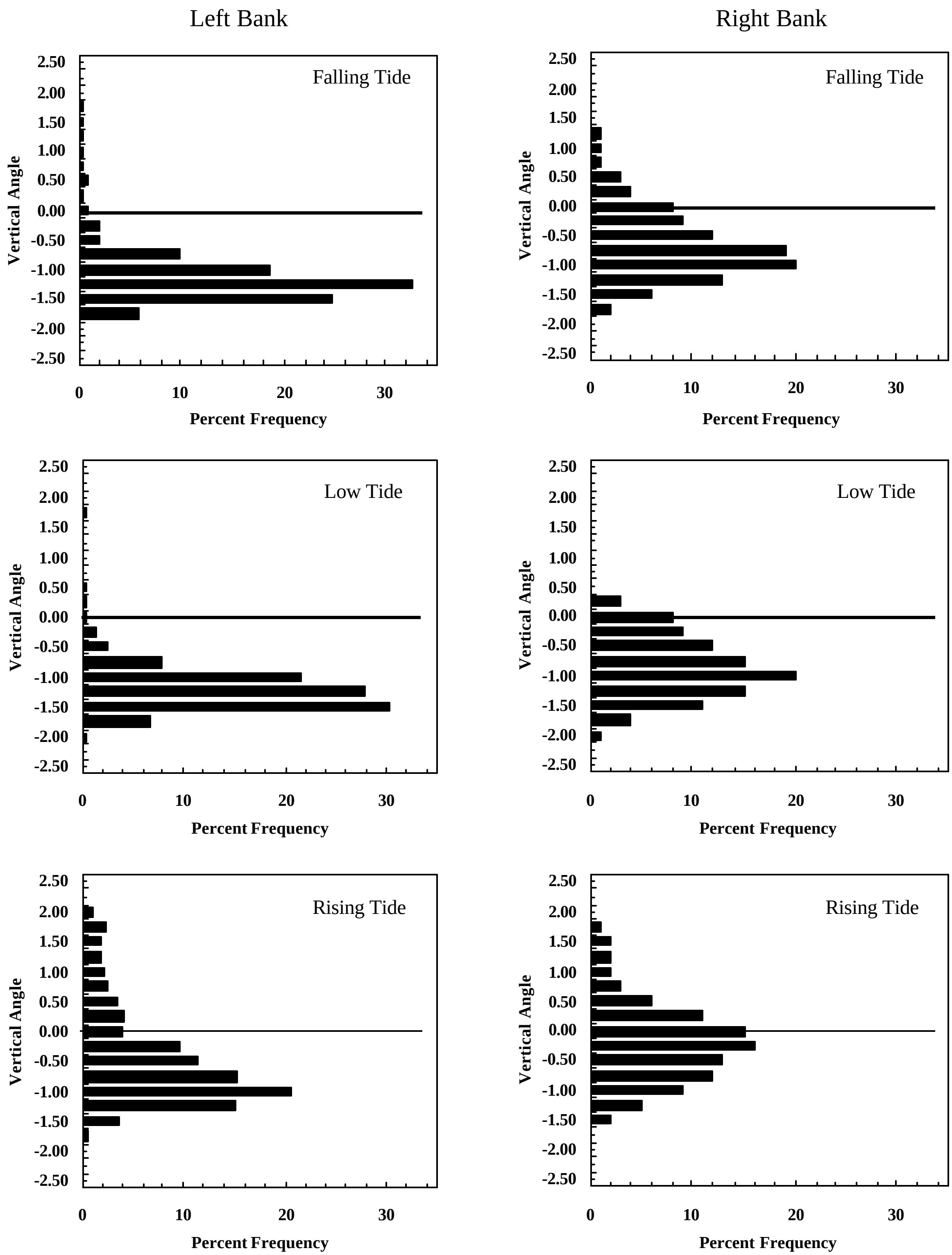


Figure 9.-Vertical distributions of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2000.

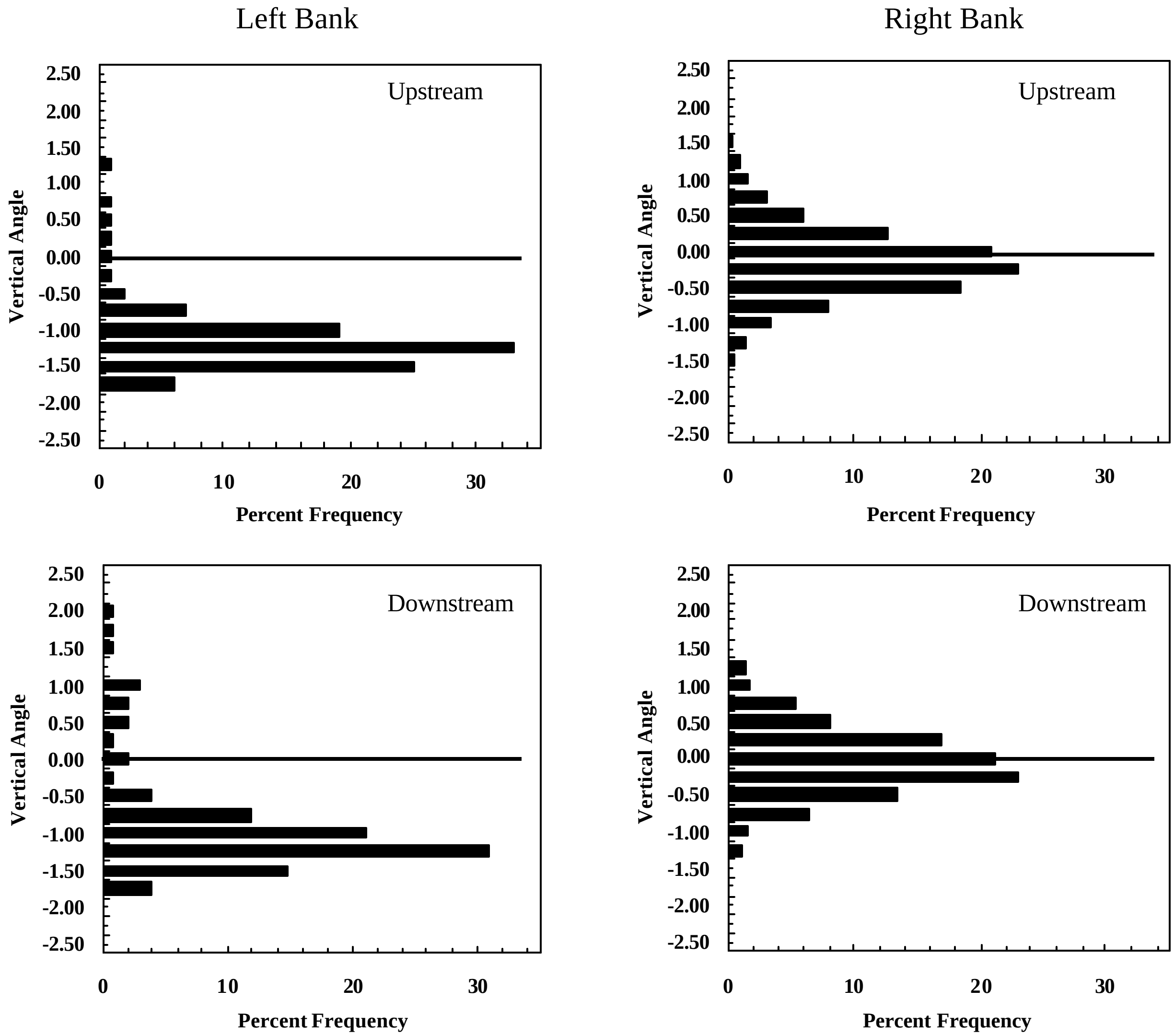


Figure 10.-Vertical distributions of late-run upstream and downstream fish on the left and right banks, Kenai River, 2000.

substrate. The more reflective left bank substrate required the acoustic axis to be aimed higher in the water column, while the more absorptive right bank substrate allowed the acoustic axis to be aimed closer to the river bottom. Upstream fish on the left bank (mean = -1.50^{o}, SD = 0.57, n = 5,925) traveled lower ($P << 0.001$) in the insonified water column than downstream fish (mean = -1.27^{o}, SD = 0.73, n = 475). Similarly, upstream fish on the right bank (mean = -0.28^{o}, SD = 0.48, n = 10,799) traveled lower ($P << 0.001$) in the insonified water column than downstream fish (mean = -0.16^{o}, SD = 0.45, n = 533). Upstream traveling fish on both banks maintained fairly similar vertical range distributions through all tide stages (Figure 11).

During the early run, fish on the left bank were more channel-oriented than fish on the right bank (Figure 12). There was no significant difference between upstream and downstream range distributions for both

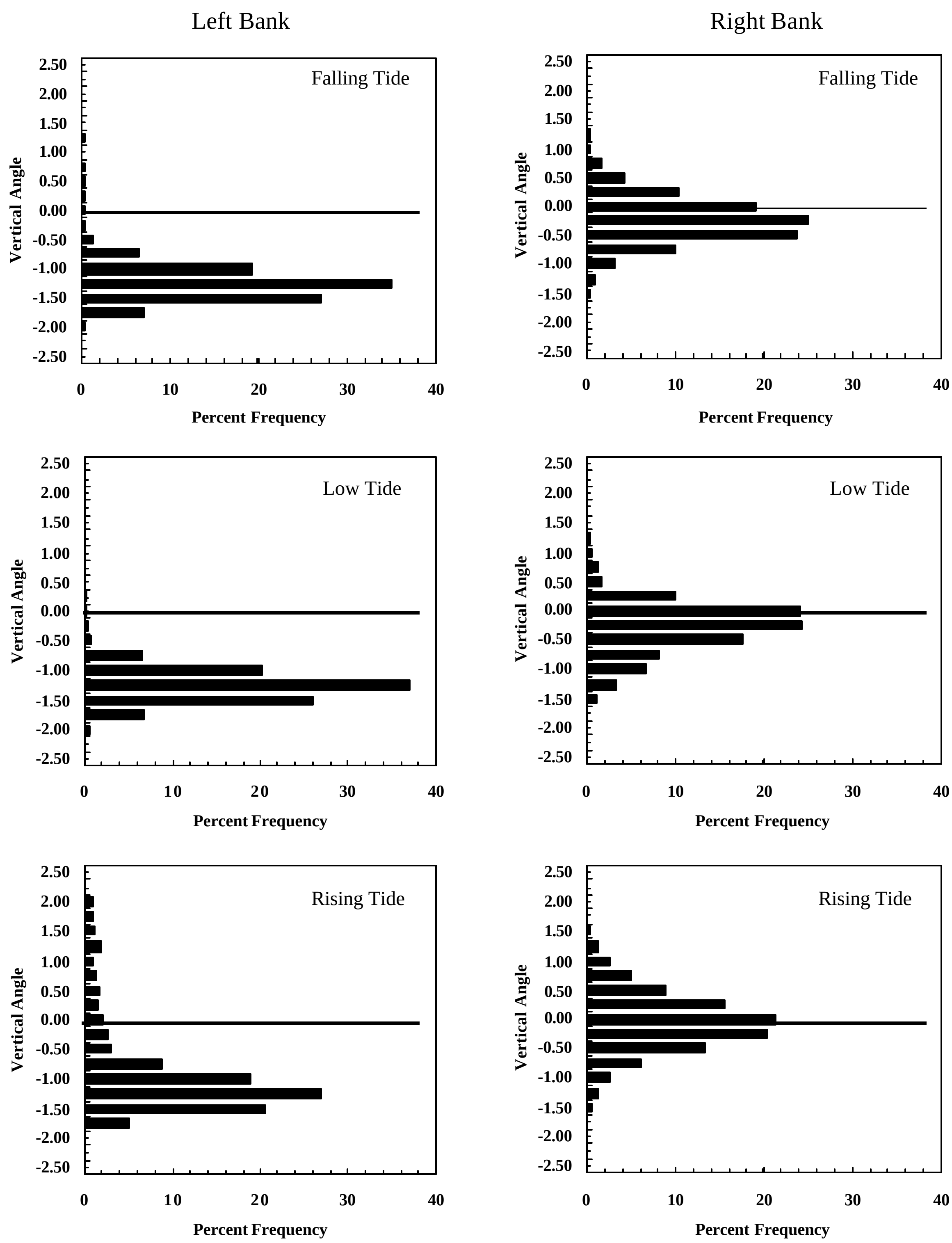


Figure 11.-Vertical distribution of late-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2000.

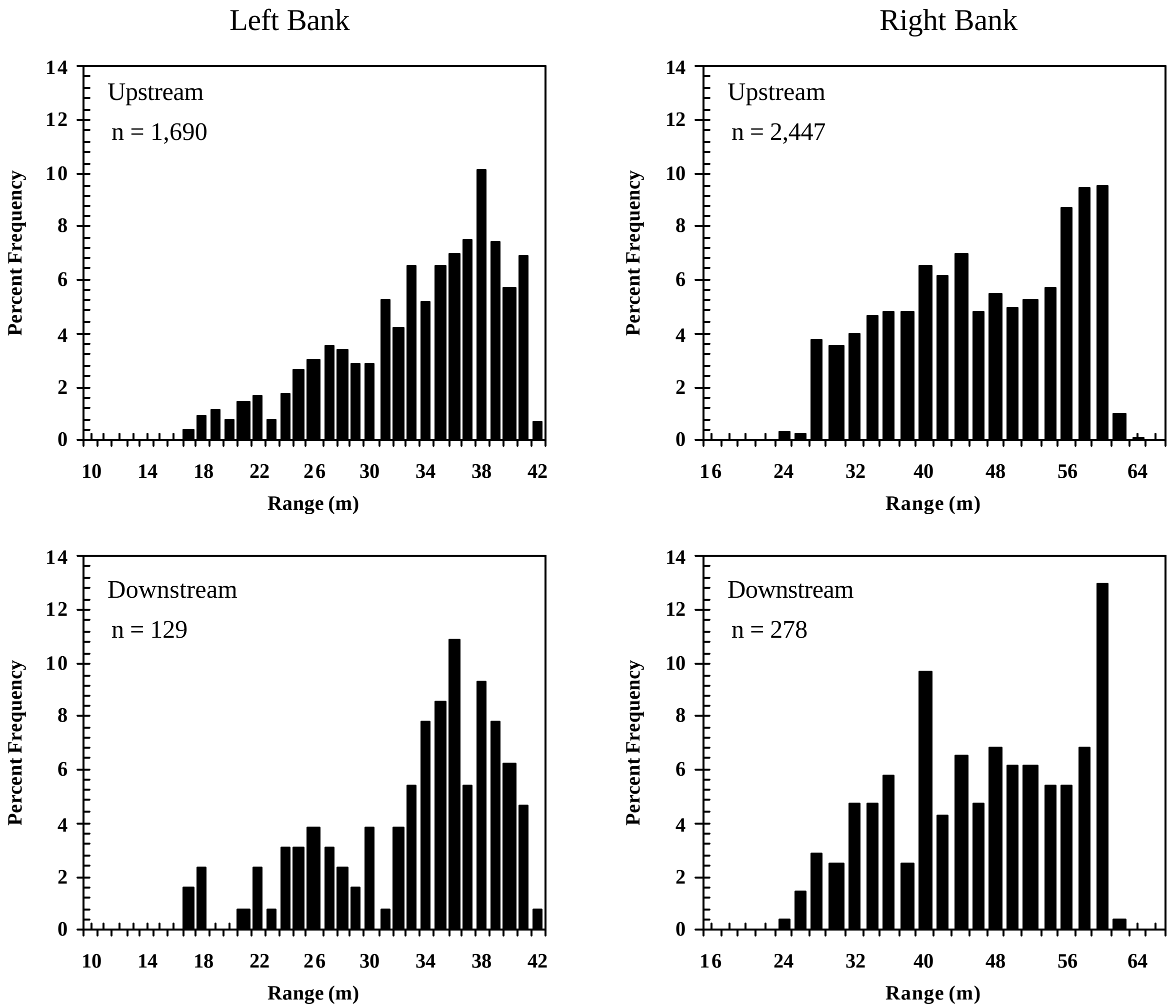


Figure 12.-Range distributions of early-run upstream and downstream fish on the left and right banks, Kenai River, 2000.

the left (Anderson-Darling, P = 0.57) and right (Anderson-Darling, P = 0.60) banks (Table 7, Figure 12). Fish on the left bank were more channel-oriented during the falling and low tide phases, and more evenly distributed during the rising tide phase (Figure 13). The right bank experienced a channel-oriented range distribution during the low tide phase, a bimodal distribution during the falling tide phase, and a more even distribution during the rising tide phase (Figure 13).

During the late run, upstream moving fish on the left bank remained channel-oriented, while upstream moving fish on the right bank maintained a bimodal range distribution (Figure 14). Range distributions for upstream and downstream moving fish were similar on the left bank (Anderson-Darling, P = 0.012, Table 8, Figure 14), while range distributions for upstream and downstream moving fish on the right bank were significantly different (Anderson-Darling, P <<< 0.001, Table 8, Figure 14). Left bank range distributions remained channel oriented and relatively unchanged throughout the falling, low and rising tide phases (Figure 15). Right-bank range distributions appeared bimodal during all three tide phases (Figure 15).

Table 7.-Range distribution (5 m increments) for upstream and downstream traveling fish (unexpanded) during the 2000 early run (16 May to 30 June).

Range[a]	Number of Fish Upstream[b]	Number of Fish Downstream[b]	Percent of Total Upstream	Percent of Total Downstream	Percent Upstream of Range	Percent Downstream of Range
Left Bank						
10 - 14.99	0	0	0.0%	0.0%	0.0%	0.0%
15 - 19.99	53	5	3.1%	3.9%	91.4%	8.6%
20 - 24.99	139	13	8.2%	10.1%	91.4%	8.6%
25 - 29.99	266	19	15.7%	14.7%	93.3%	6.7%
30 - 34.99	466	34	27.6%	26.4%	93.2%	6.8%
35 - 39.99	639	51	37.8%	39.5%	92.6%	7.4%
40 - 44.99	127	7	7.5%	5.4%	94.8%	5.2%
Bank Total	1,690	129	100.0%	100.0%	92.9%	7.1%
Right Bank						
15 - 19.99	0	0	0.0%	0.0%	0.0%	0.0%
20 - 24.99	7	3	0.3%	1.1%	70.0%	30.0%
25 - 29.99	182	17	7.4%	6.1%	91.5%	8.5%
30 - 34.99	261	32	10.7%	11.5%	89.1%	10.9%
35 - 39.99	339	44	13.9%	15.8%	88.5%	11.5%
40 - 44.99	380	34	15.5%	12.2%	91.8%	8.2%
45 - 49.99	310	45	12.7%	16.2%	87.3%	12.7%
50 - 54.99	366	39	15.0%	14.0%	90.4%	9.6%
55 - 59.99	578	63	23.6%	22.7%	90.2%	9.8%
60 - 64.99	24	1	1.0%	0.4%	96.0%	4.0%
Bank Total	2,447	278	100.0%	100.0%	89.8%	10.2%

[a] Ranges standardized by bank based on the most nearshore transducer deployment for that bank.

[b] Data have been filtered by range and target strength criteria.

Estimates of fish passage were higher for the right bank than for the left bank during both early and late runs. During the early run 59.4% of the estimated upstream inriver return passed on the right bank while 40.6% of the upstream passage estimate passed by on the left bank (Table 9). The pattern of inriver return for the late run was similar to that of the early run with 66.5% of the upstream moving fish passing on the right bank and 33.5% passing on the left bank (Table 10).

TARGET STRENGTH

Target strength distributions varied by bank, direction of travel, and run. Table 11 shows target strength statistics for fish that met minimum range and target strength criteria, whereas Figure 16 and Figure 17 show target strength distributions and statistics that include all tracked targets.

Mean target strength estimates for all upstream targets on the left bank during the early run averaged about 2 dB higher than right bank estimates (Figure 16). Mean target strength estimates for all

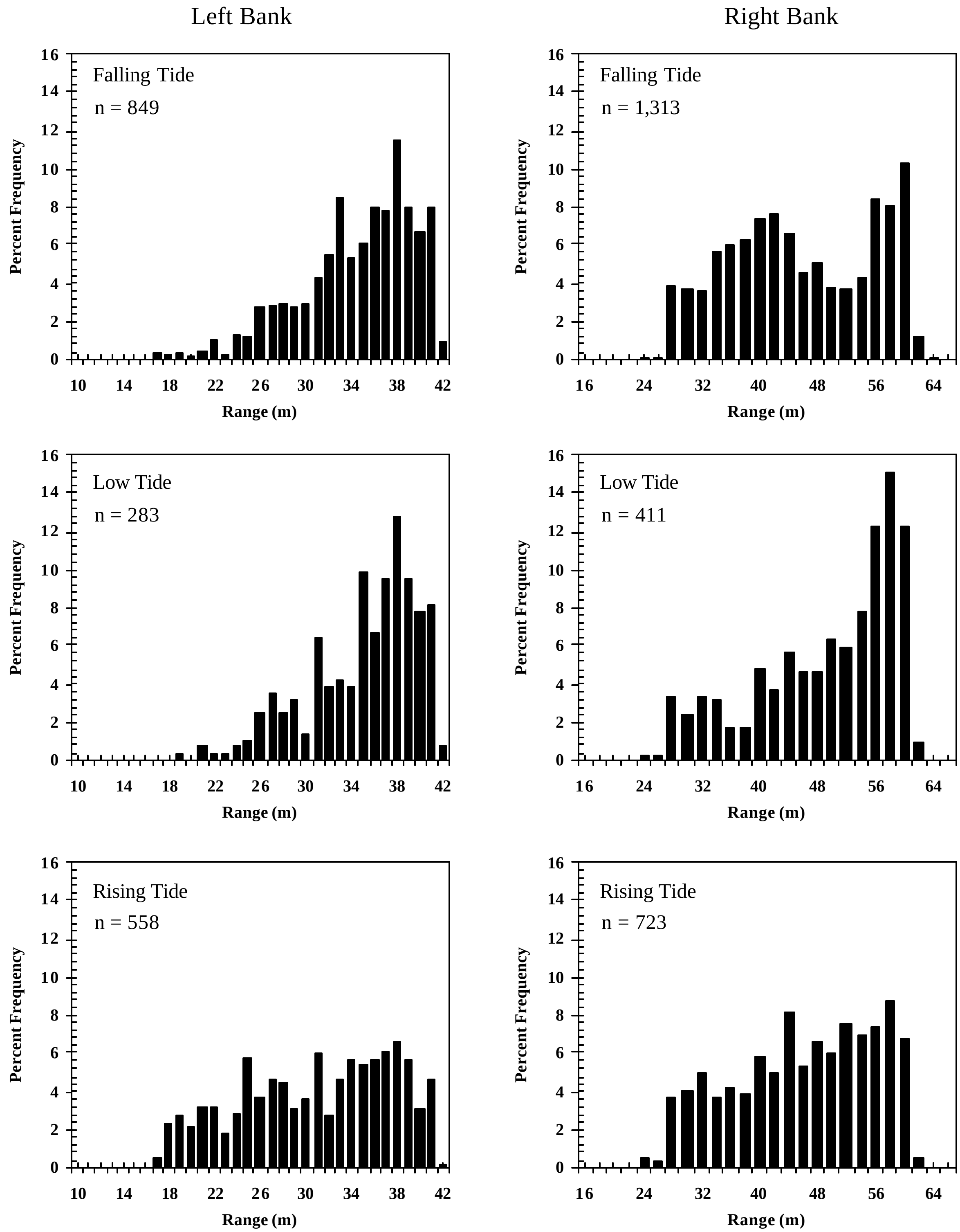


Figure 13.-Range distributions of early-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2000.

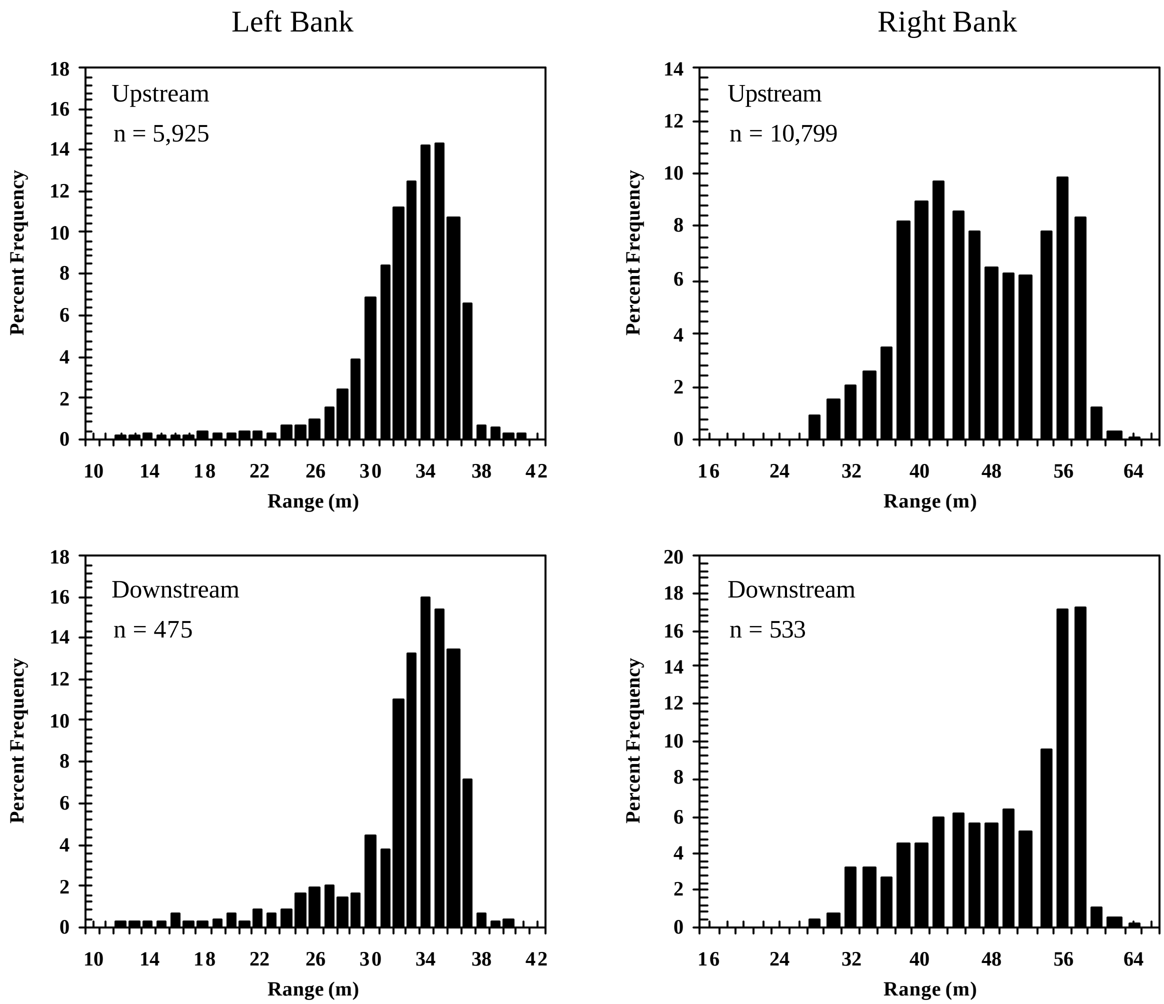


Figure 14.-Range distributions of late-run upstream and downstream fish on the left and right banks, Kenai River, 2000.

upstream targets on the left bank during the late run averaged over 3 dB higher than right bank estimates (Figure 17). Mean target strength of all upstream and downstream targets varied the most between banks during the late run (Figure 17).

During the early run on the left bank, mean target strength of chinook salmon was higher ($t = -9.06$, $P <<< 0.01$) and less variable ($F = 0.71$, $P < 0.01$) among upstream traveling fish than among downstream traveling fish (Table 11). On the right bank, mean target strength for upstream traveling fish was again higher ($t = -5.92$, $P <<< 0.01$), by less than 1 dB (Table 11), and slightly more variable ($F = 0.83$, $P = 0.02$).

During the late run on the left bank, mean target strength of chinook salmon was higher ($t = -7.15$, $P <<< 0.01$) among upstream traveling fish than among downstream traveling fish and variability in mean target strength was similar ($F = -7.15$, $P <<< 0.01$, Table 11). On the right bank during the late run, mean target strength was higher ($t = -3.25$, $P < 0.01$) among upstream traveling fish than among

Table 8.-Range distribution (5 m increments) for upstream and downstream traveling fish (unexpanded) during the 2000 late run (1 July to 10 August).

Range[a]	Number of Fish Upstream[b]	Number of Fish Downstream[b]	Percent of Total Upstream	Percent of Total Downstream	Percent Upstream of Range	Percent Downstream of Range
Left bank						
10 - 14.99	43	4	0.7%	0.8%	91.5%	8.5%
15 - 19.99	75	10	1.3%	2.1%	88.2%	11.8%
20 - 24.99	142	20	2.4%	4.2%	87.7%	12.3%
25 - 29.99	936	55	15.8%	11.6%	94.5%	5.5%
30 - 34.99	3,593	282	60.6%	59.4%	92.7%	7.3%
35 - 39.99	1,121	104	18.9%	21.9%	91.5%	8.5%
40 - 44.99	15	0	0.3%	0.0%	100.0%	0.0%
Bank Total	5,925	475	100.0%	100.0%	92.6%	7.4%
Right bank						
25 - 29.99	254	6	2.4%	1.1%	97.7%	2.3%
30 - 34.99	649	45	6.0%	8.4%	93.5%	6.5%
35 - 39.99	2,073	50	19.2%	9.4%	97.6%	2.4%
40 - 44.99	2,396	82	22.2%	15.4%	96.7%	3.3%
45 - 49.99	1,774	78	16.4%	14.6%	95.8%	4.2%
50 - 54.99	2,060	133	19.1%	25.0%	93.9%	6.1%
55 - 59.99	1,550	135	14.4%	25.3%	92.0%	8.0%
60 - 64.99	43	4	0.4%	0.8%	91.5%	8.5%
Bank Total	10,799	533	100.0%	100.0%	95.3%	4.7%

[a] Ranges standardized by bank based on the most nearshore transducer deployment for that bank.

[b] Data have been filtered by range and target strength criteria.

downstream traveling fish and there was no statistical difference (F = 0.99, P = 0.42) in variability of mean target strength among upstream and downstream traveling fish (Table 11). In both cases, the difference in mean target strength was less than 0.7 dB and the statistical significance was an artifact of sample size rather than an actual difference in mean target strength.

PASSAGE ESTIMATES

Daily estimates of chinook salmon passage were generated for 16 May-10 August. Sampling was terminated at 2200 hours on 10 August. A total of 1,332 hours (two banks) of acoustic data were processed during the 87-day season representing 32% of the total available sample time between two banks.

To maintain comparability between recent (1995-2000) estimates of fish passage derived from split-beam sonar and past (1987-1994) estimates generated by dual-beam sonar, two passage estimates were generated. The first estimate, total passage, is comparable with past estimates generated by dual-beam sonar when we were unable to determine direction of travel. It assumes all targets are upstream

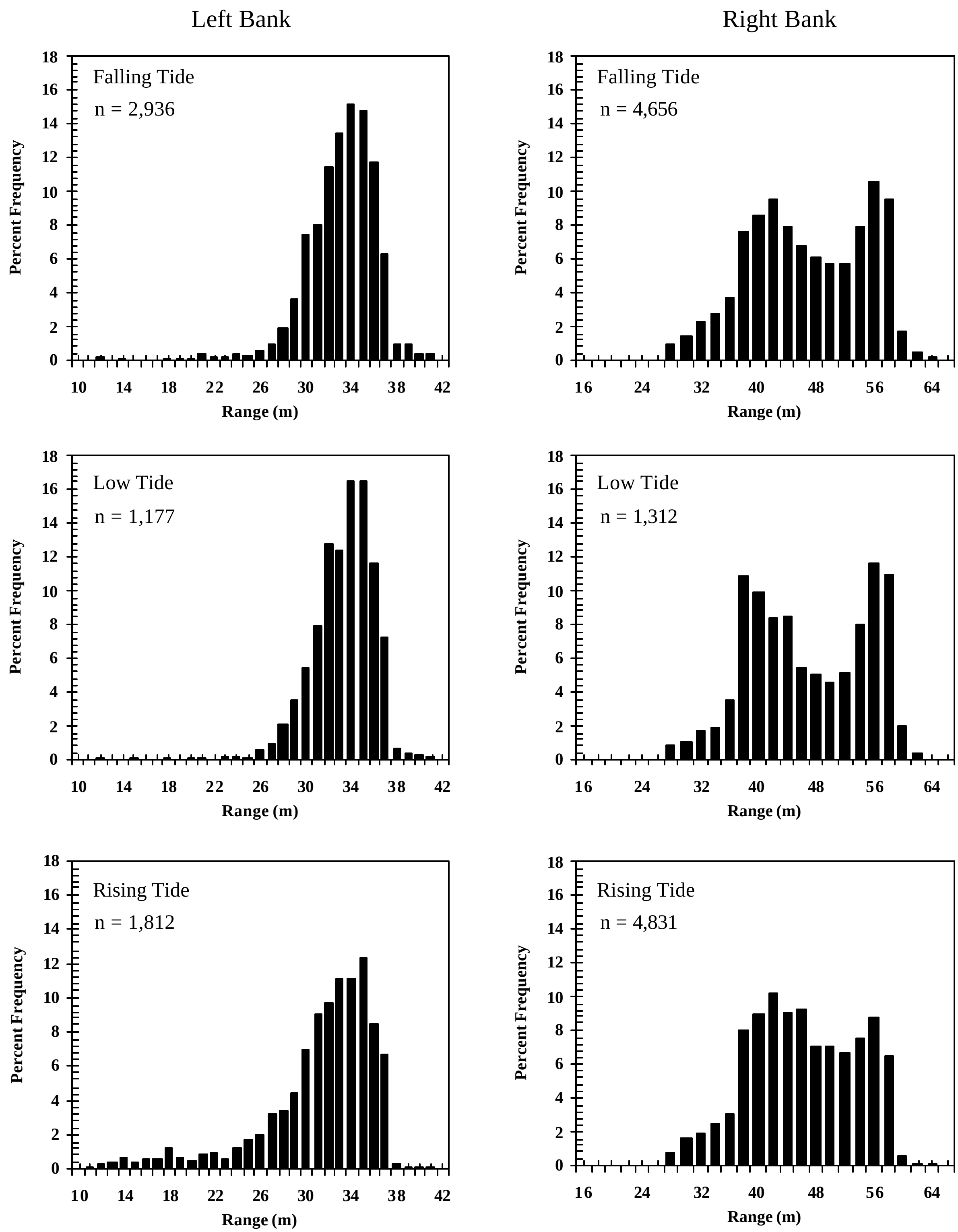


Figure 15.-Range distributions of late-run upstream fish during falling, low, and rising tide stages on the left and right banks, Kenai River, 2000.

Table 9.-Estimates of early-run fish passage by direction of travel, 2000.

Bank	Estimate of Total Fish Passage		Estimate of Downstream Component		Estimate of Upstream Component	
Right Bank	8,254	(201)	837	(44)	7,417	(191)
Left Bank	5,444	(140)	382	(28)	5,062	(135)
Both Banks	13,698	(245)	1,219	(52)	12,479	(234)

Note: Standard errors are in parenthesis.

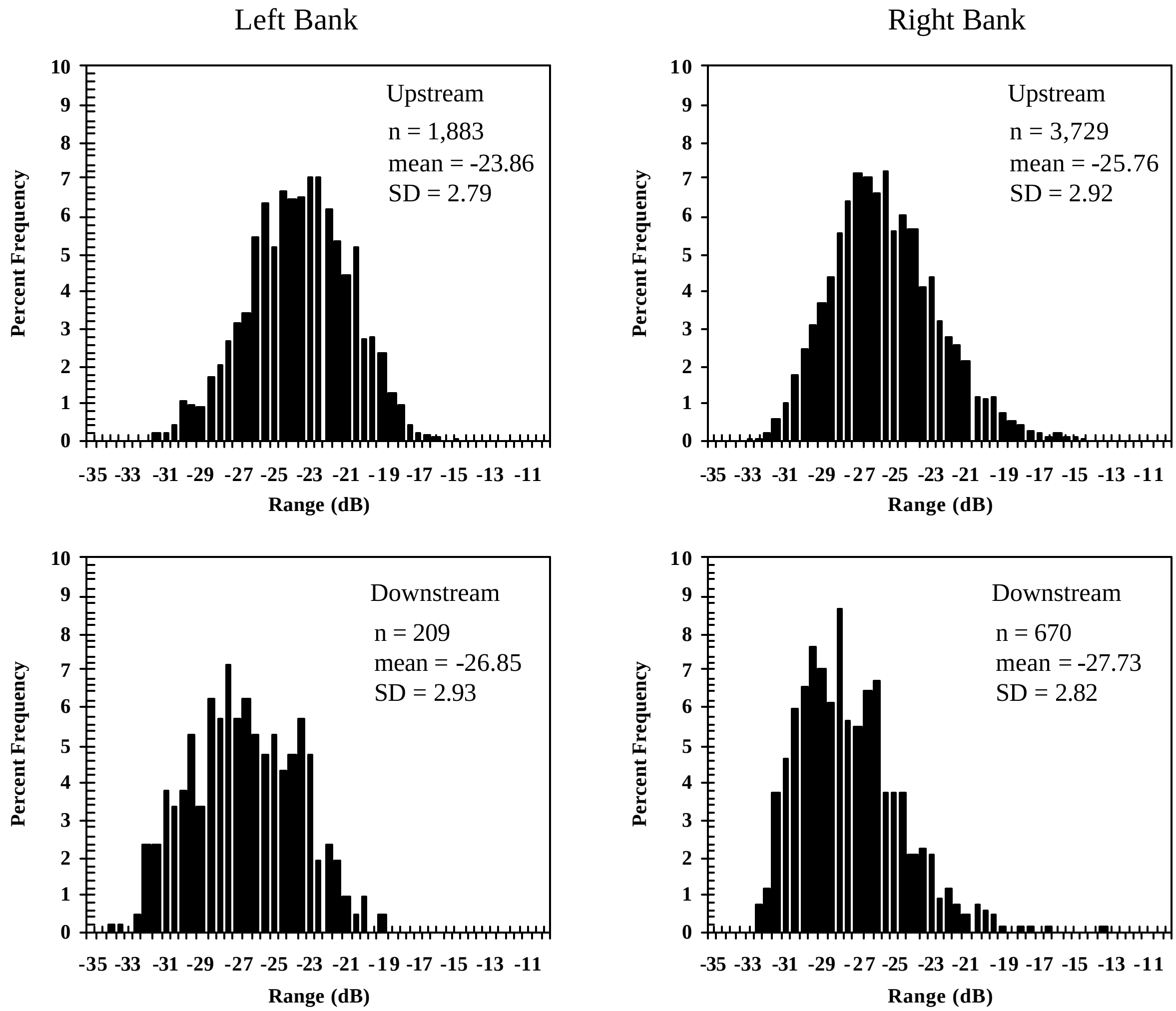
Table 10.-Estimates of late-run fish passage by direction of travel, 2000.

Bank	Estimate of Total Fish Passage		Estimate of Downstream Component		Estimate of Upstream Component	
Right Bank	31,096	(635)	1,510	(64)	29,586	(625)
Left Bank	16,279	(250)	1,348	(65)	14,931	(240)
Both Banks	47,375	(682)	2,858	(91)	44,517	(669)

Note: Standard errors are in parenthesis.

Table 11.-Mean target strength (dB) for upstream and downstream targets by bank (chinook only) during the early (16 May-30 June) and late (1 July-10 August) runs, 2000.

	Upstream			Downstream		
Location	mean	SD	n	mean	SD	N
Early Run						
Left Bank	-23.36	2.38	1,690	-25.05	2.00	129
Right Bank	-24.59	2.43	2,447	-25.43	2.21	278
Late Run						
Left Bank	-23.13	2.01	5,925	-23.82	2.10	475
Right Bank	-25.53	1.84	10,799	-25.80	1.83	533



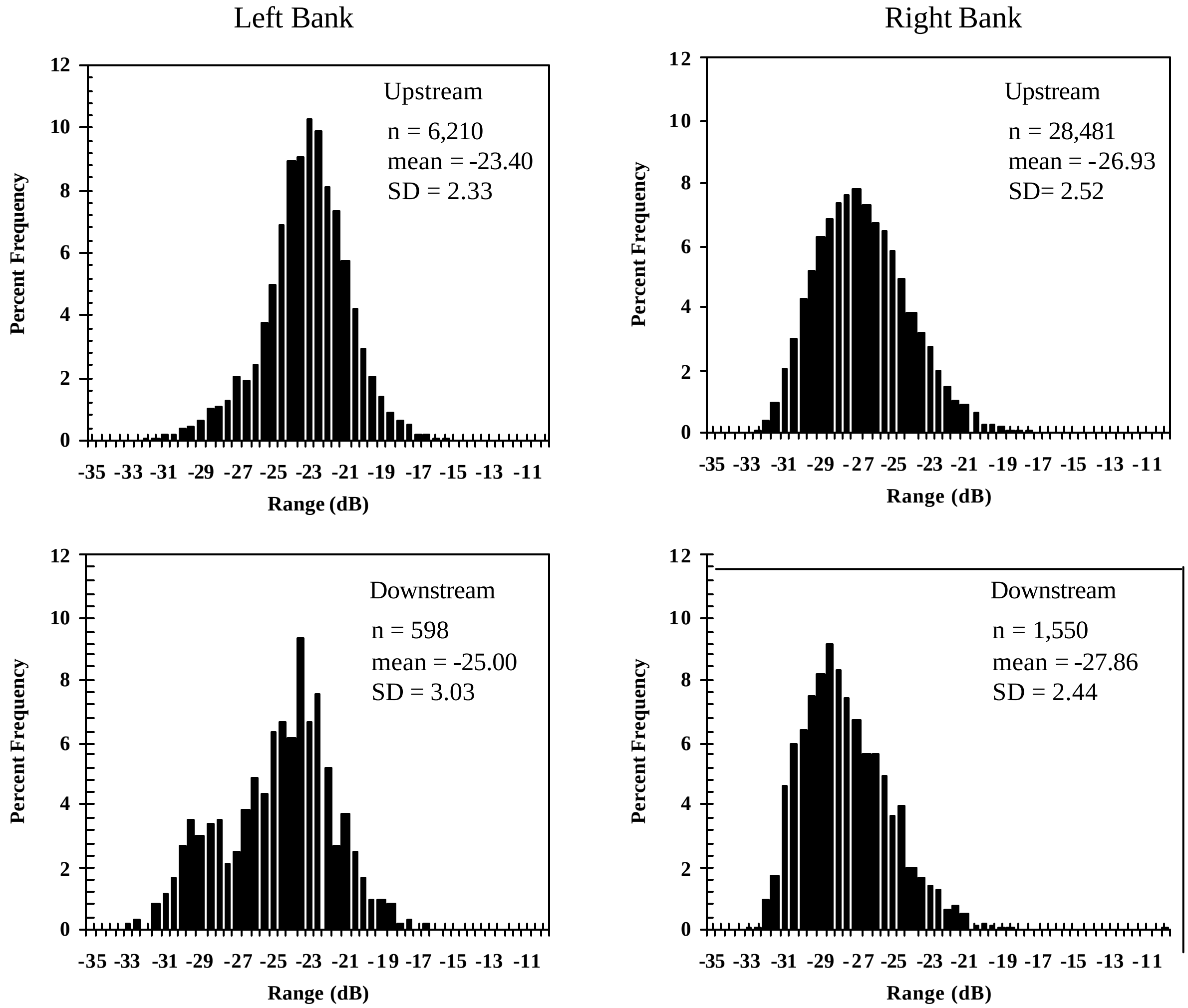
Note: Data have not been filtered by range or target strength criteria.

Figure 16.-Early run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 2000.

migrants. The second estimate, upstream passage, includes only those chinook (after size and range filters) that were determined to be traveling upstream.

Total chinook salmon passage from 16 May through 10 August was an estimated 61,073 (SE = 725) fish; 13,698 (SE = 245) during the early run and 47,375 (SE = 682) during the late run (Table 9, Table 10).

Upstream chinook salmon passage from 16 May through 10 August was estimated at 56,996 (SE = 709) fish; 12,479 (SE = 234) during the early run and 44,517 (SE = 669) during the late run (Table 9, Table 10, Table 12, Table 13). The daily peak of the early run occurred on 17 June with 50% of the run having passed by that same date (Figure 18). Migratory timing for the early run was late compared to historic mean run timing (Figure 19 and Appendix F1). The daily peak



Note: Data have not been filtered by range or target strength criteria.

Figure 17.-Late run target strength distributions for all upstream and downstream targets on the left and right banks, Kenai River, 2000.

of the late run occurred on 15 July, with 50% of the late run having passed by 17 July (Figure 20). Migratory timing for the late run was early compared to historic mean run timing (Figure 19 and Appendix F2).

DISCUSSION

SPATIAL DISTRIBUTION

Bank Preference

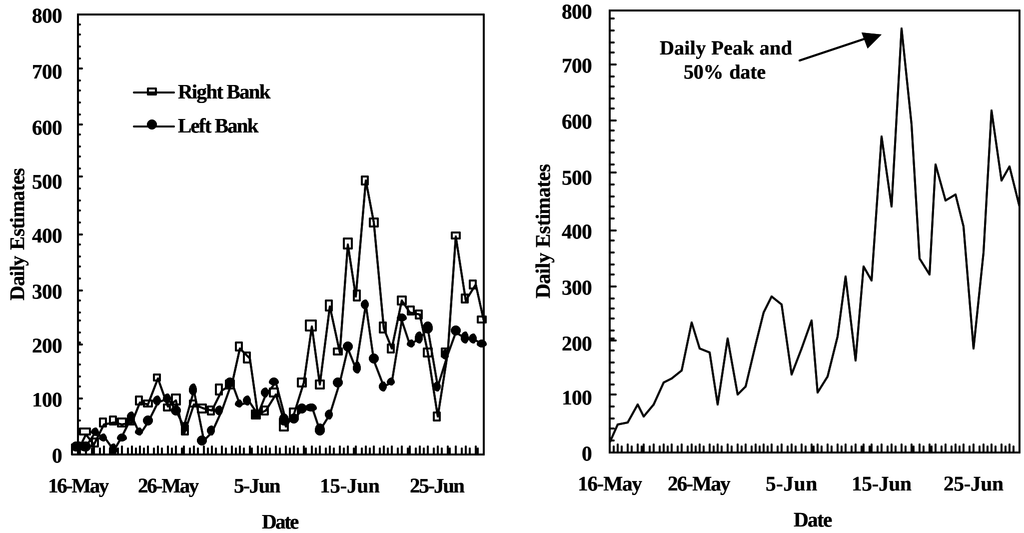
Historically, the right bank has been heavily favored by migrating fish during both the early and late runs. At the start of the season, there are roughly equal proportions of fish on each bank. However, the proportion of fish traveling up the right bank typically increases as the season progresses

Table 12.-Estimated daily upstream passage of chinook salmon, Kenai River sonar, early run, 2000.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	12	6	18	18
17-May	12	37	49	67
18-May	36	18	54	121
19-May	30	54	84	205
20-May	6	58	64	269
21-May	30	54	84	353
22-May	66	57	123	476
23-May	36	96	132	608
24-May	57	90	147	755
25-May	96	138	234	989
26-May	102	84	186	1,175
27-May	78	99	177	1,352
28-May	48	36	84	1,436
29-May	114	90	204	1,640
30-May	24	81	105	1,745
31-May	39	78	117	1,862
1-Jun	78	114	192	2,054
2-Jun	126	124	250	2,303
3-Jun	89	193	282	2,585
4-Jun	94	172	266	2,851
5-Jun	70	69	139	2,990
6-Jun	108	78	186	3,176
7-Jun	129	108	237	3,413
8-Jun	60	48	108	3,521
9-Jun	63	72	135	3,656
10-Jun	81	126	207	3,863
11-Jun	84	231	315	4,178
12-Jun	42	123	165	4,343
13-Jun	69	268	337	4,680
14-Jun	126	183	309	4,989
15-Jun	192	379	571	5,560
16-Jun	156	285	441	6,001
17-Jun	270	495	765	6,766
18-Jun	171	420	591	7,357
19-Jun	120	228	348	7,705
20-Jun	129	190	319	8,024
21-Jun	246	276	522	8,546
22-Jun	198	258	456	9,002
23-Jun	210	252	462	9,464
24-Jun	228	180	408	9,872
25-Jun	120	66	186	10,058
26-Jun	179	180	359	10,418
27-Jun	222	393	615	11,033
28-Jun	210	279	489	11,522
29-Jun	207	309	516	12,038
30-Jun	199	242	441	12,479
Total	5,062	7,417	12,479	

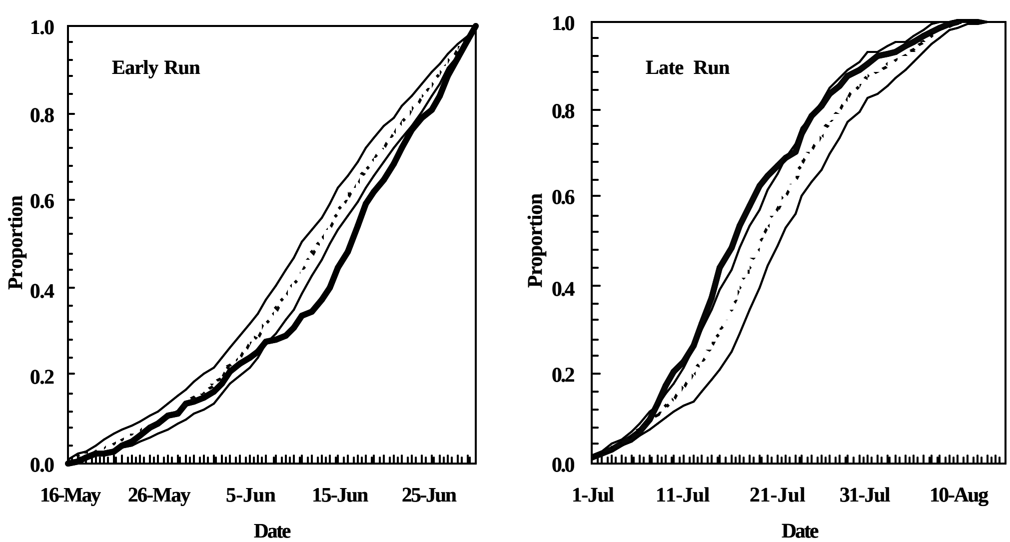
Table 13.-Estimated daily upstream passage of chinook salmon, Kenai River sonar, late run, 2000.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	190	271	461	461
2-Jul	99	274	373	834
3-Jul	95	275	370	1,204
4-Jul	131	357	488	1,692
5-Jul	134	653	787	2,480
6-Jul	98	680	778	3,258
7-Jul	219	801	1,020	4,278
8-Jul	351	1,362	1,713	5,991
9-Jul	417	1,215	1,632	7,623
10-Jul	321	1,140	1,461	9,084
11-Jul	216	822	1,038	10,122
12-Jul	339	1,167	1,506	11,628
13-Jul	563	1,763	2,327	13,955
14-Jul	630	2,079	2,709	16,664
15-Jul	540	2,268	2,808	19,472
16-Jul	567	1,697	2,264	21,735
17-Jul	573	1,341	1,915	23,650
18-Jul	708	1,446	2,154	25,804
19-Jul	507	1,412	1,919	27,722
20-Jul	405	750	1,155	28,877
21-Jul	387	546	933	29,810
22-Jul	468	234	702	30,512
23-Jul	576	184	760	31,272
24-Jul	545	1,322	1,868	33,140
25-Jul	537	1,224	1,761	34,901
26-Jul	297	737	1,034	35,935
27-Jul	315	677	992	36,927
28-Jul	450	549	999	37,926
29-Jul	480	549	1,029	38,955
30-Jul	360	217	577	39,533
31-Jul	387	162	549	40,082
1-Aug	373	322	695	40,777
2-Aug	148	273	421	41,198
3-Aug	160	134	294	41,492
4-Aug	294	159	453	41,945
5-Aug	360	129	489	42,434
6-Aug	441	63	504	42,938
7-Aug	264	102	366	43,304
8-Aug	315	102	417	43,721
9-Aug	354	45	399	44,120
10-Aug	315	82	397	44,517
Total	14,931	29,586	44,517	



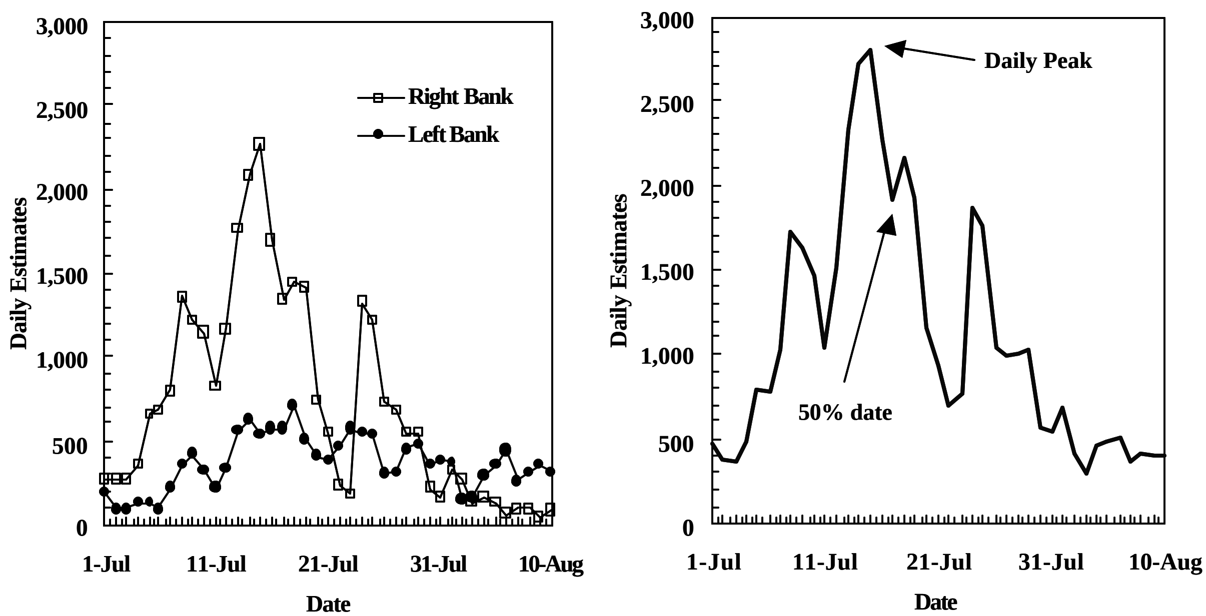
Note: Estimates by bank (left) and total run (right).

Figure 18.-Daily sonar estimates of passage for the early run of chinook salmon returning to the Kenai River, 2000.



Note: Mean migratory timing curves for the years 1987-1999 (dashed lines), and 95% confidence intervals (thin solid lines) are presented for comparison and are based on estimates of total passage through 1997 and upstream passage after 1997.

Figure 19.-Migratory timing curves for early and late runs of chinook salmon to the Kenai River, 2000 (thick solid lines).



Note: Estimates by bank (left) and total run (right).

Figure 20.-Daily sonar estimates of passage for the late run of chinook salmon returning to the Kenai River, 2000.

(Burwen and Bosch 1995a, 1995b, 1996, 1998; Eggers et al. 1995; Bosch and Burwen 1999). The right bank is the depositional bank, with a more gradual slope and slower water velocities than the left bank. Since the channel is offset to the left bank, the right-bank transducer also covers a greater proportion of the river cross-section (Figure 3). The increase in the proportion of right-bank oriented fish during June and July may be a response to increasing discharge that occurs over the same period. The proportion of the river cross-section covered by the right bank also increases with increasing water levels as the transducers are moved closer to shore. Exceptions to this entry pattern occurred during the early runs in 1996 and 1997 when more fish were consistently detected on the left bank. However, discharge was also far below average during each of these runs (Burwen and Bosch 1998, Bosch and Burwen 1999). In 2000, fish passage was higher on the right bank during both runs and average monthly discharge was near average for May and July, and below average for June and August (USGS 2001)

Vertical Distribution

The spatial distribution of fish is particularly important at the present site, where tide-induced changes in water level have been shown to affect fish distribution. A primary concern is that fish may swim over the beam during rising and falling tide stages. Because the site experiences extreme semidiurnal tidal fluctuations that average 4 m and are as high as 7 m (Figure 3), it is not possible to insonify the entire cross-sectional area of the river that can potentially be used by migrating chinook salmon. Fish position data suggest that most upstream fish are within the insonified zone. When sockeye are not present in large numbers, most fish prefer the offshore, bottom section of the river where beam coverage is maximized. Although there was a slight tendency for upstream fish to rise off the bottom during the rising tide stage on both banks during the 2000 early run (Figure 9), very few fish occupied the upper half of the beam overall. The tendency to rise off the bottom on rising tides during the early run may be related to the relatively low discharge occurring in the spring. Data collected in previous years showed that fish have maintained a strong bottom orientation during all three tide stages during both the early and late runs (Eggers et al. 1995; Burwen et al. 1995; Bosch and Burwen 1999; Bosch and Burwen 2000; Bosch et al. *In prep*).

Because the vast majority of fish travel close to the river bottom (Figure 8, Figure 10), our greatest concern is missing fish passing under the sonar beam. Relatively few fish were detected below the -2.0^{o} beam angle (Figure 8, Figure 10). Even with the decreased ability to detect targets on the edge of the beam, we believe there would be larger numbers of targets detected in this region if substantial numbers of fish were traveling below the effective beam, given the large acoustic size of chinook salmon.

It should be noted that fish on the right bank only appear to be traveling higher in the water column than fish traveling on the left bank (Figure 8, Figure 10). The less reflective sediments on the right bank allows for aiming of the sonar beam closer to the river bottom. This likely increases our ability to detect bottom-oriented fish on the right bank, but it also shifts the distribution of bottom-oriented fish upward, making fish on this bank appear higher in the water column.

Range Distribution

Note that transducer deployment locations varied throughout the season due to changing water levels and that fish range distributions by bank and run were standardized based on the most nearshore deployment locations within that run. Hence, fish range distributions for a given bank reflect distance from the most nearshore deployment location for that bank.

The range distribution of upstream-moving fish on the left bank was similar between runs, with a majority of the fish passing between 30 m and 41 m. Although both runs were channel-oriented, the early run appeared more dispersed while the late run passage was mostly confined to a < 10 m band. The decline in the left bank distribution at the far ranges during the late run is likely an artifact of aiming and of having to shorten the range by a few meters after the tripod was moved on 5 July. In order to maintain an aim close to the bottom we were forced to shorten the insonified range to reduce the bottom backscatter at far range. Finding an optimal aim on the left bank is more difficult than on the right bank due to the reflective and less uniform bottom topography on the left bank.

The range distribution on the right bank was bimodal for both the early and late runs, with peaks occurring at approximately 39-43 m and 55-60 m. It should be noted that the nearshore truncation of the right bank early-run range distribution is the result of the range threshold used for eliminating nearshore sockeye salmon from chinook salmon counts. The nearshore range distribution during the late run was partially influenced by varying range thresholds and by tripod relocations closer to shore as the water level rose.

TARGET STRENGTH

The effects of threshold-induced bias rather than actual differences in fish size can most likely explain differences in mean target strength between banks. Fish traveling upstream on the left bank may be forced closer to the bottom due to higher water velocities found on this side of the river. Additionally, the sonar beam cannot be aimed as close to the bottom on the left bank because the substrate is composed of more acoustically reflective gravel compared to the acoustically absorptive mud on the right bank. Since left-bank fish are, on average, farther from the acoustic axis than right-bank fish, a greater proportion of small echoes from left bank fish do not meet the voltage threshold biasing target strength estimates upward. Recent research (Fleischman and Burwen 2000) has also identified a positive bias in target strength associated with measurement error in the echo position estimates. Since higher background noise levels lead to higher variability in positional estimates, this bias is also greater on the left bank.

Downstream unfiltered targets were considerably smaller (2 dB on the right bank, 3 dB on the left bank) than upstream unfiltered targets during the early run (Figure 16). The distribution of unfiltered data was considerably more skewed to the right for downstream fish than for upstream fish. The proportion of downstream targets was also substantially larger in the unfiltered data set than in the filtered data set during the early run (9% vs. 15%, Table 11, Figure 16). This indicates that the target strength threshold is most likely filtering out downstream traveling debris that were incorrectly classified as downstream swimming fish, or that smaller fish were more likely to travel downstream. During the late run, downstream targets were only slightly smaller (less than 1 dB on right bank, less than 2 dB on left bank) than upstream targets and the proportion of downstream targets was the same (6%) for filtered and unfiltered data (Table 11, Figure 17). The reason for relatively high numbers of small downstream targets during the early part of the season is not understood. The most likely explanation is that crewmembers become more adept at discriminating debris from downstream traveling fish as the season progresses. Another explanation is that there may be a smaller species of fish (e.g., Dolly Varden *Salvelinus malma*) migrating downstream during the early run. The tendency for downstream traveling targets to have smaller average target strengths than upstream-traveling targets has been documented in prior years (Bosch and Burwen 1999, 2000; Bosch et al. *In prep*). Discerning between debris-like traces and a fish traveling downstream can be difficult, and crewmembers are instructed to include downstream targets as valid fish traces when in doubt. Some contamination of fish estimates with downstream-traveling debris is inevitable. This is the reason that this project and many others choose to ignore downstream targets rather than subtract them from upstream estimates even when direction of travel is known. Typically, the proportion of downstream targets is small, and the potential error that would be introduced by misclassifying debris as downstream traveling fish is of greater concern.

After applying range and target strength filters, average target strength of upstream and downstream traveling chinook salmon on the left bank during the early run differed by less than 2 dB (Table 11). Average target strength of upstream and downstream chinook salmon on the left bank during the late run and on the right bank during both the early and late runs differed by less than 1 dB (Table 11). This suggests that at least in the data set used to generate chinook salmon estimates, most downstream targets were correctly classified as fish rather than debris.

DIRECTION OF TRAVEL

All tracked targets have been classified by direction of travel since 1995, when split-beam technology was first implemented. Since then, the downstream component of the early run has varied from 6% to 12% and averaged 8%, while the downstream component of the late run has ranged from 4% to 14%

and has averaged 6% (Burwen and Bosch 1996, 1998; Bosch and Burwen 1999, 2000; Bosch et al. *In prep*). The downstream component of the late run during 4 of the past 5 years has equaled 5% or less with the exception of the 14% anomaly estimated in 1998 (Bosch and Burwen 2000). Downstream passage in 2000 averaged 9% during the early run and 6% during the late run (Table 5, Table 6).

The proportion of downstream targets in 2000 varied during the early run, but showed a definite increasing trend at the tail end of the late run (Appendix D). Large proportions (>10%) of downstream traveling fish were observed from 30 July through 10 August. This trend was also documented during the 1998 season (Bosch and Burwen 2000). Late in the season, tracking fish becomes very difficult due to dramatic changes in fish behavior. Starting in early August, we typically observe numerous wallowing fish traces where fish linger in the beam for many minutes at a time. These fish often travel in pairs, as well. It appears that these fish may be late run main stem chinook spawners that may be near enough to their ultimate spawning destination that there is little incentive to swim directly upstream. Many of these traces appear to slowly swim upstream and then back downstream through the beam, thus increasing the downstream count.

PASSAGE ESTIMATES

Based on many years of research, we no longer assume that sonar estimates of chinook abundance are equally reliable under all circumstances. Recent research efforts have focused on identifying conditions when sonar estimates may not be reliable. Our foremost concern is that the sonar may mistake substantial numbers of sockeye as chinook during periods of high sockeye passage.

Early Run

Although the range distribution of early-run chinook salmon was slightly bimodal (Figure 12), there is little evidence to suggest significant inflation of chinook salmon counts by sockeye salmon during the early run. Fish passage was low and chinook salmon escapement timing was late throughout much of the early run (Figure 18, Figure 19). A decline in the daily mean –12 dB pulse width in mid-June (Figure 21) might suggest possible sockeye contamination, but chinook salmon age data from the netting program indicate that the proportion of older (larger) chinook passing the site declined during this time (Figure 22). Chinook salmon age data are highly variable and noisy due to small daily sample sizes, but an obvious trend towards younger (smaller) chinook in mid-June is apparent. A decline in chinook size during this time period would explain the decline in daily mean –12 dB pulse width.

Chinook salmon net CPUE suggests that overestimation by the sonar may have occurred in late June when sonar counts increased and net CPUE in general remained relatively low and stable (Figure 23). However, the increase in water clarity in late June may have contributed to the low CPUE estimates (Figure 24). Sockeye net CPUE estimates in late June confirm the presence of sockeye (Figure 25), and chart recordings produced by the sonar in late June showed obvious signs of sockeye (i.e. fish traveling in pairs or groups) beyond the threshold range. Most of these fish, however, were removed using the target strength filter, and we feel that inflation of the early-run chinook estimate was minimal.

Late Run

Several lines of evidence suggest large numbers of sockeye salmon passed the sonar site between 13 July and 20 July, possibly influencing chinook salmon sonar estimates. Sockeye salmon inriver netting CPUE increased dramatically on 13 July and remained elevated through 20 July (Figure 25). Fish

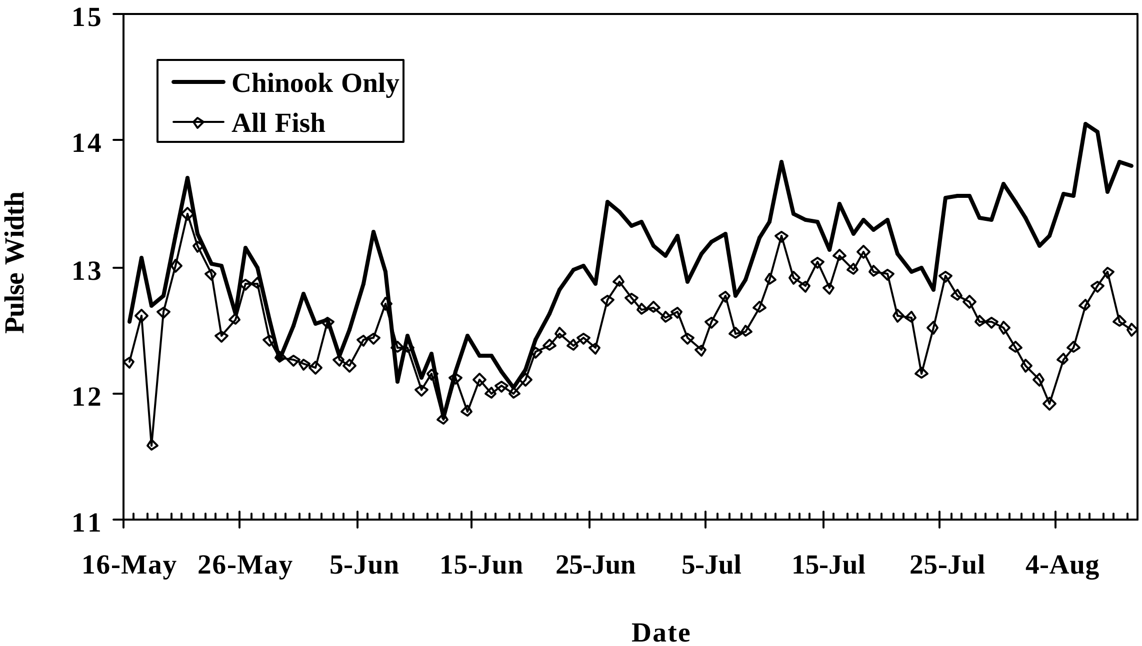
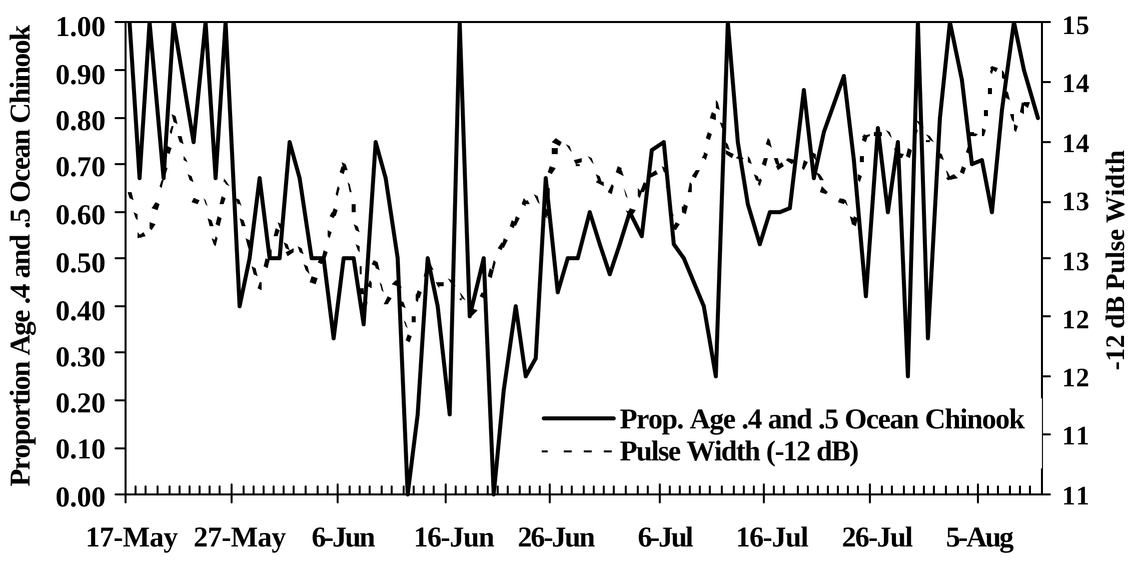


Figure 21.-Daily right bank mean pulse width (measured at -12 dB down from peak amplitude), 16 May to 10 August, 2000.



Note: Chinook salmon age data taken from Reimer et al. (*In prep*).

Figure 22.-Daily proportion of age .4 and .5 ocean chinook salmon and mean -12 dB pulse width.

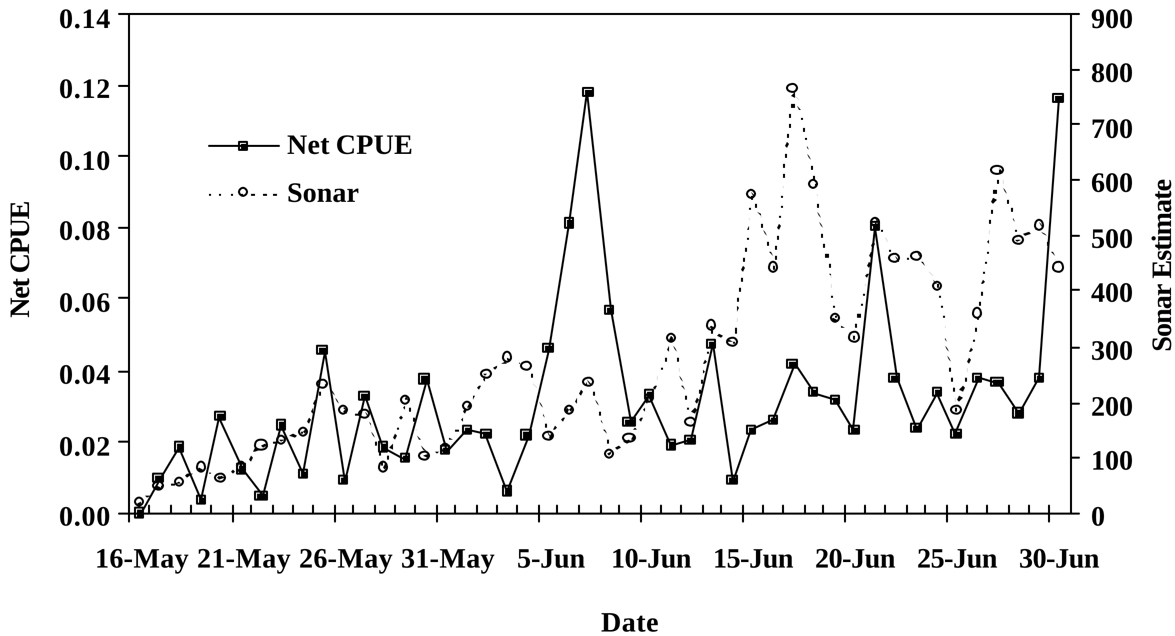


Figure 23.-Daily sonar estimates and inriver net CPUE of chinook salmon during the early run (16 May–30 June), Kenai River, 2000.

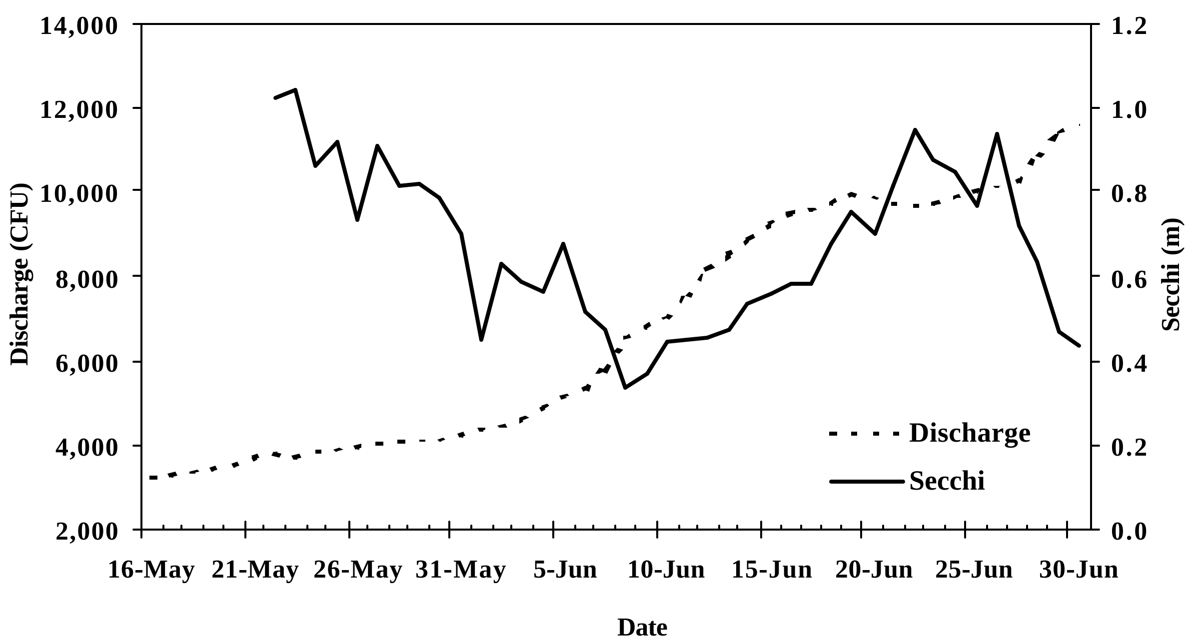


Figure 24.-Daily discharge rates at the Soldotna Bridge and secchi depth readings in front of the sonar site, Kenai River, early run (16 May–30 June), 2000.

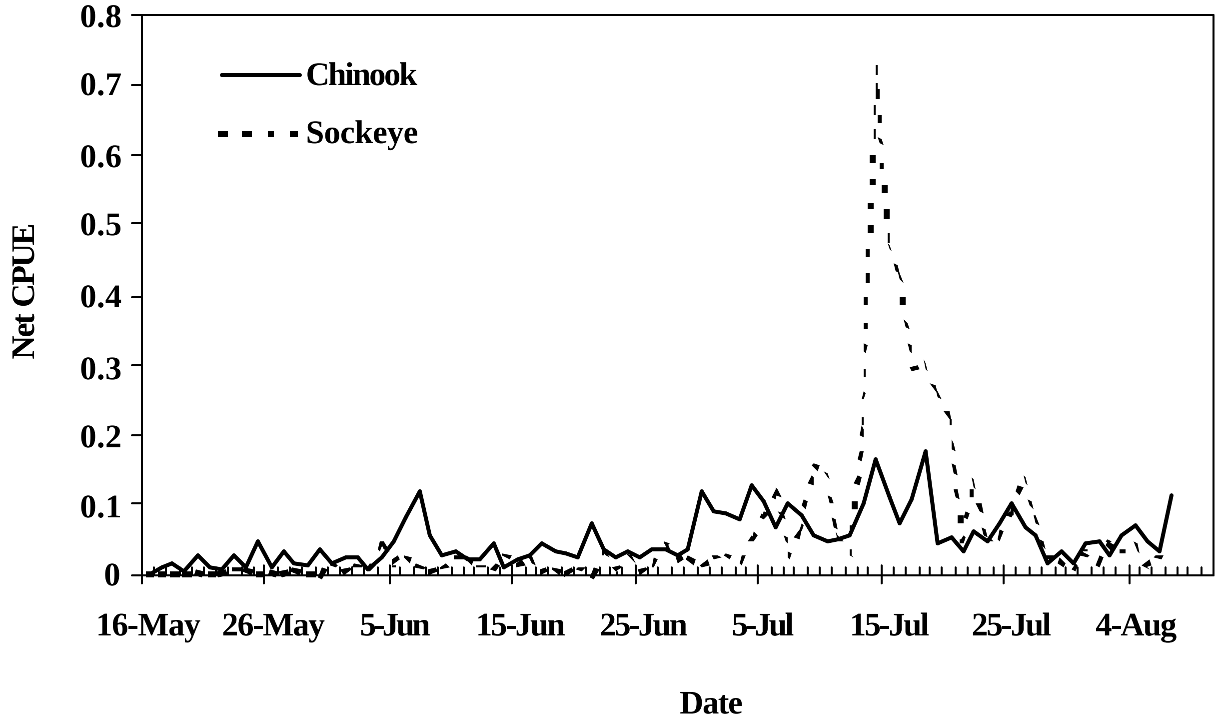


Figure 25.-Daily CPUE of chinook and sockeye salmon from inriver netting, 16 May-10 August, 2000.

density recorded by the sonar equipment and displayed on a chart recorder also increased drastically beginning 13 July, and was severe enough to hamper our ability to accurately track fish on 14-16 July and again on 22-23 July. Unlike past seasons, the charts showed no clear delineation between what appeared to be nearshore traveling sockeye salmon and offshore traveling chinook salmon. Obvious signs of sockeye (i.e. fish traveling in pairs or groups) were observed at far range during periods of high sockeye passage, but were not removed by size and range filters. Several hourly samples were considered unreliable or untrackable on 14-16 July, 22-23 July, and 6 August due to high fish densities and were not used in producing daily chinook salmon passage estimates (Table 14). Expansions of trackable hours were used for producing daily estimates on these days. Although using only a few trackable hours to estimate a full 24-hour period was a drastic measure, we felt it produced the most conservative chinook estimates possible.

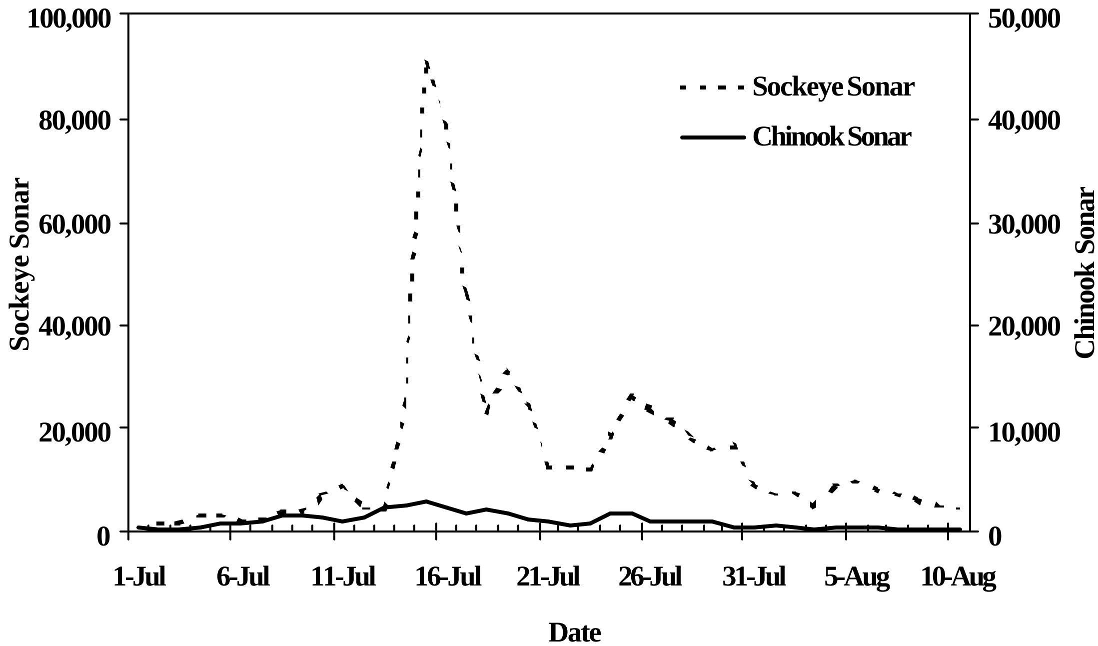
The degree to which the presence of sockeye salmon may have influenced the final chinook salmon estimate and our success at attempting to remove sockeye from chinook counts is difficult to ascertain. Some indicators suggest possible sockeye contamination while others suggest that range and size thresholds and the use of daily expansions were successful at filtering sockeye salmon from chinook salmon estimates. Beginning in late June, filtered (chinook only) targets exhibited a larger daily mean –12 dB pulse width than did unfiltered targets, indicating that filters were successful at removing smaller fish from chinook estimates (Figure 21). This became even more pronounced at the end of the late run. Also, a comparison of daily chinook sonar estimates with mile-19 sockeye sonar estimates

Table 14.-Hourly samples either not tracked or not used in producing chinook salmon daily passage estimates, Kenai River chinook sonar, 2000.

Date	Sample Hours Not Used
14-Jul	0800-2300
15-Jul	0000-0300, 0600-1700, 2000-2300
16-Jul	0000, 0800-1200, 2200-2300
22-Jul	0700-0800, 1900-2000
23-Jul	0800-0900, 2000-2100
6-Aug	0800-1100, 2000-2300

suggests that daily chinook estimates in mid-July were not significantly influenced by sockeye salmon passage. From 12 July to 14 July the mile-19 sonar project recorded a 20-fold increase in sockeye passage, while estimated chinook passage at the chinook sonar project during the same period experienced less than a 2-fold increase (Figure 26). The increase in sockeye passage at the mile-19 site was an order of magnitude higher than the corresponding increase in chinook passage at the downriver site. In addition, sockeye salmon net CPUE at the chinook sonar site experienced a dramatic increase in mid-July relative to the chinook net CPUE, with no corresponding dramatic increase in the chinook sonar estimate (Figure 25). The inriver daily net CPUE estimates for chinook salmon also appeared to track fairly well with the daily sonar estimates in mid to late July (Figure 27), despite a small increase in water clarity between July 17 and 21 (Figure 28). Thus it appears the conservative measures taken in mid to late July were effective at minimizing the influence of sockeye on the chinook estimate.

Other indicators suggest that although we were successful at filtering most sockeye from the chinook estimates, some inflation may still have occurred. In early July before large numbers of sockeye salmon were present at the sonar site, estimated distribution of chinook salmon passage on the right bank was dispersed throughout the counting range with a broad mode between 32 and 46 m and a second larger peak around 57 m (Figure 29). In late July when large numbers of sockeye salmon were present, the bimodal distribution on the right bank became more pronounced with the peak of the first mode occurring at 40 m and the peak of the second mode occurring at 55 m. The increase in size of the inshore mode may have resulted from misclassifying sockeye salmon as chinook salmon, or it may be that variations in bottom topography or differing flow regimes across the river resulted in a bimodal chinook distribution. Review of the bottom profile at the site (Figure 5) fails to explain the bimodal distribution, and a detailed current profile of the site is not available. A comparison of the cumulative sonar estimate with cumulative net CPUE (Figure 30) indicates that according to the netting data, the sonar underestimated chinook passage in early July and overestimated chinook passage throughout the remainder of the late run. Estimates of sport fish CPUE also suggest that the sonar underestimated chinook passage in early July, and overestimated chinook passage between 15-17 July when large numbers of sockeye salmon were present (Figure 31). However, sport fish CPUE is very sensitive to other factors and may not make a reliable comparison.



Note: Mile-19 sockeye salmon sonar estimates taken from Davis (*In prep*).

Figure 26.-Daily chinook sonar estimates and mile-19 sockeye sonar estimates lagged one day, late run (1 July–10 August), 2000.

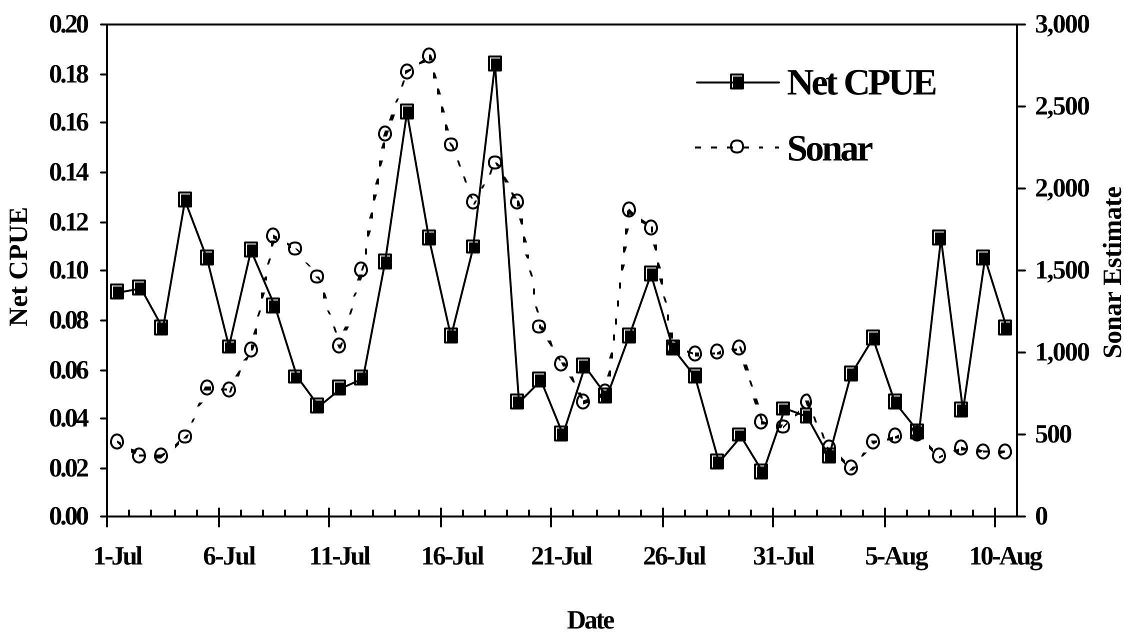


Figure 27.-Daily sonar estimates and inriver net CPUE for chinook salmon during the late run (1 July–10 August), 2000.

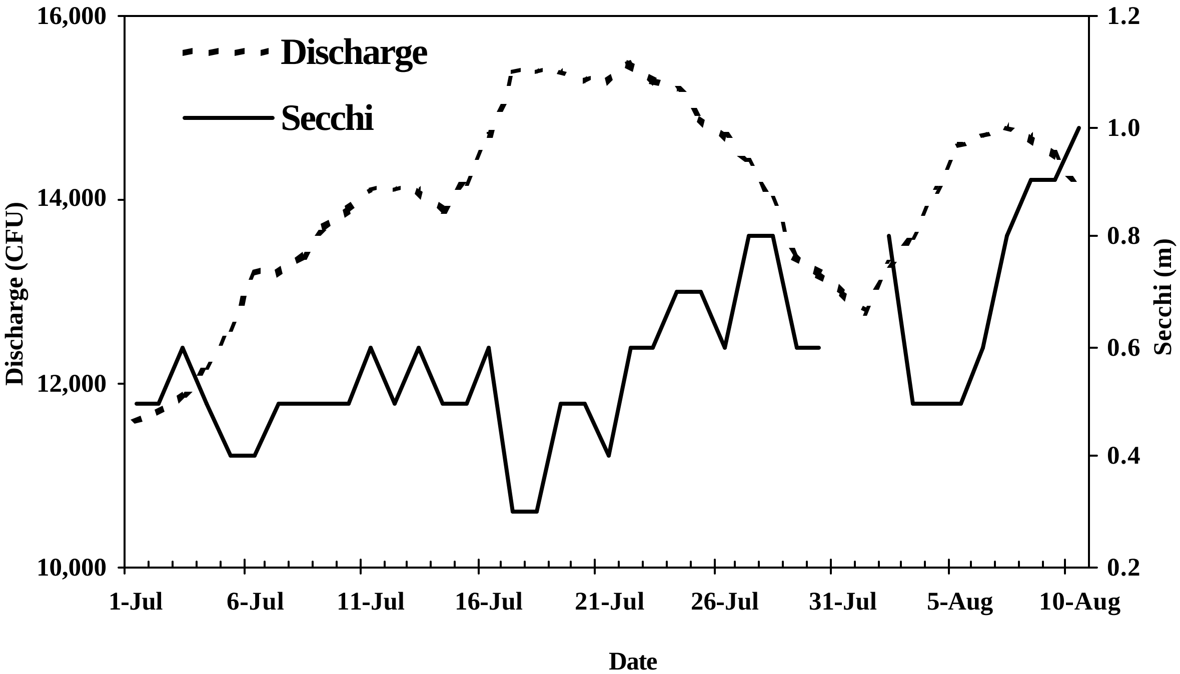


Figure 28.-Daily discharge rates at the Soldotna Bridge and secchi depth readings in front of sonar site, Kenai River, late run (1 July–10 August), 2000.

Conflicting indicators in early August raise some question as to the accuracy of the August counts. Relatively high fish numbers were observed at the sonar site through early August, most of which were removed from final chinook passage estimates using range and size filters. A comparison of the mean –12 dB pulse width between all fish and filtered (chinook only) fish in late July and early August (Figure 21) indicates that filtered fish had a much higher pulse width than did all fish combined, suggesting that fish removed from the estimate were much smaller than those that remained. In contrast, daily net CPUE showed an increase in chinook passage from late July to early August (Figure 27) while the daily sonar estimates remained relatively stable. The presence of pink salmon and of late-run fish holding in the beam in August adds to the uncertainty of the sonar estimate during this time.

In general, we feel that we produced the most conservative late-run chinook sonar estimate possible, but that some inflation due to presence of sockeye is likely.

OUTLOOK FOR FUTURE IMPROVEMENTS IN SONAR ACCURACY

Exclusive use of acoustics to precisely discriminate fish species is not possible at this time (Horne *In press*). However, we are pursuing several options to increase the accuracy of chinook abundance estimates. Some of these options strive to improve chinook estimates by improving our ability to discriminate larger chinook salmon from other smaller species. Additional options involve developing other indices of chinook abundance that may be used to either produce adjusted chinook estimates during periods of high sockeye abundance or at least indicate when sonar estimates may be significantly inflated with sockeye salmon.

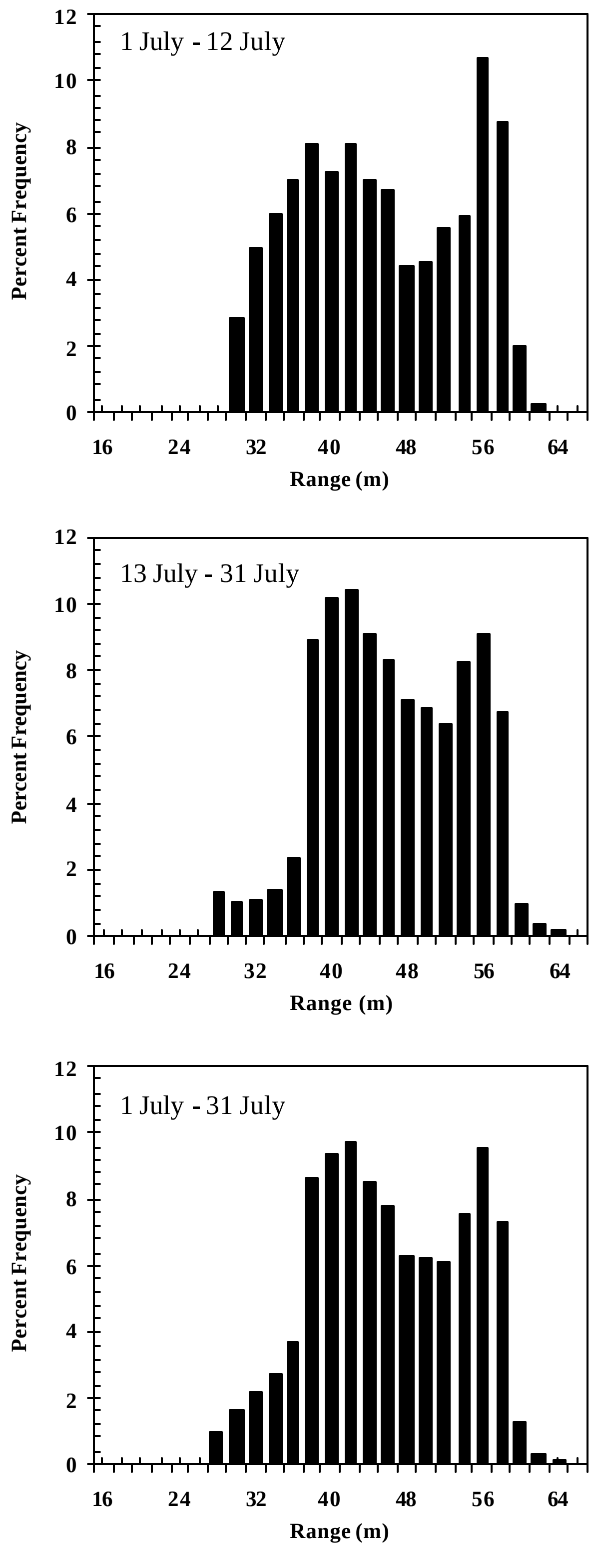


Figure 29.-Right bank range distribution of late-run upstream traveling fish during 1-14 July, 13-31 July, and 1-31 July, Kenai River, 2000.

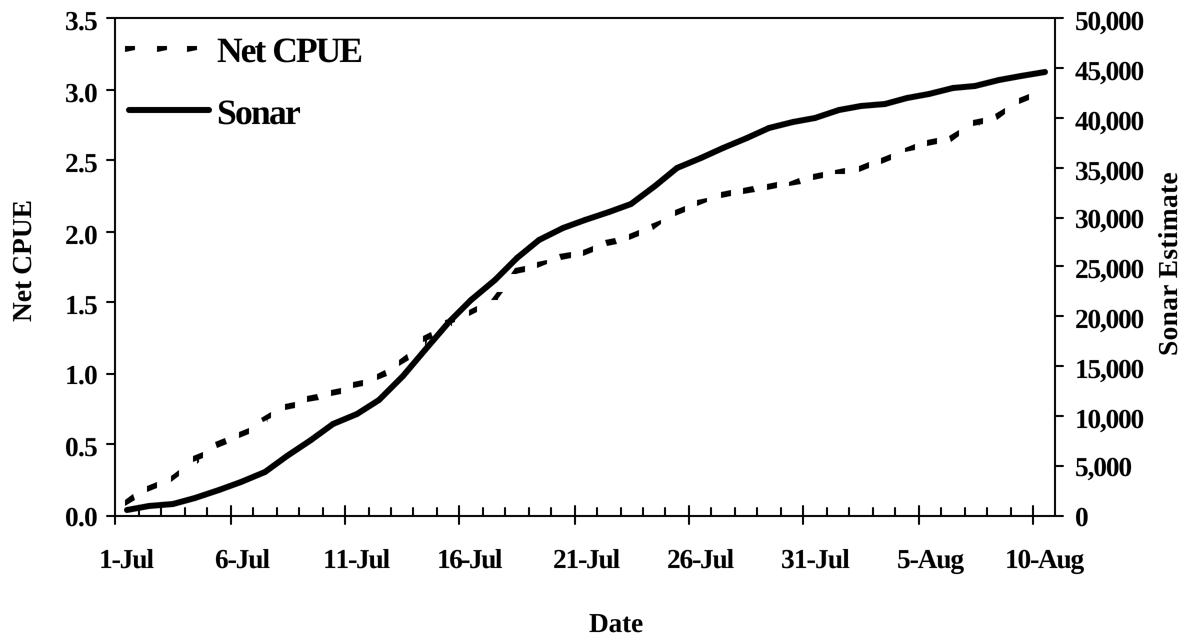
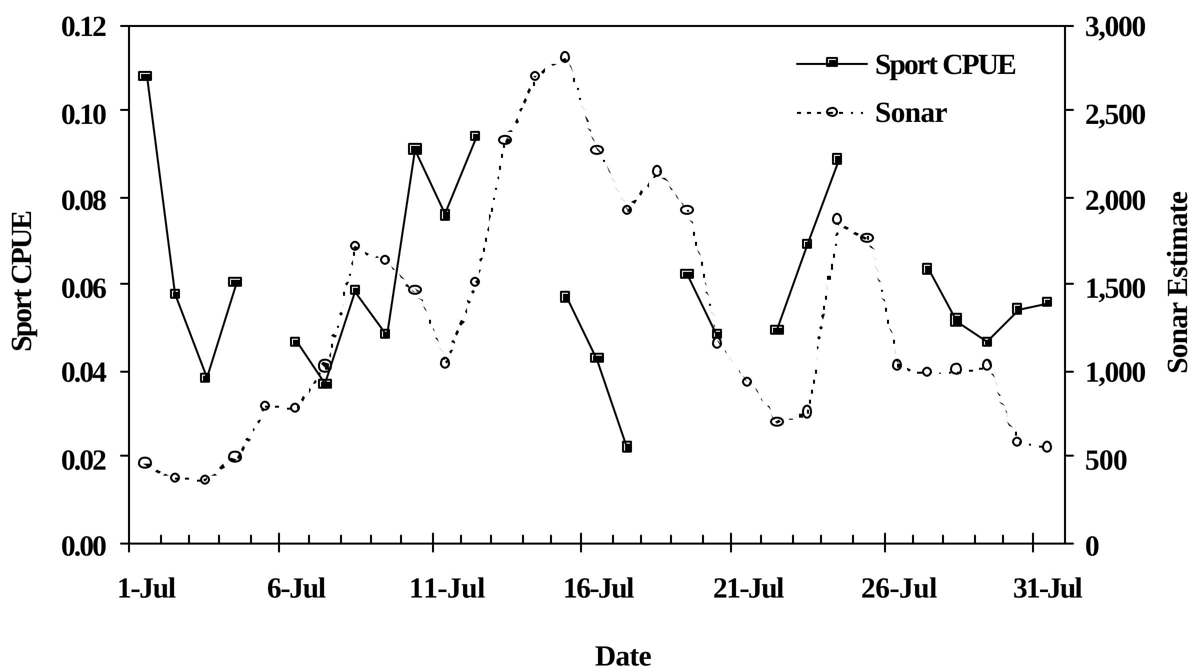


Figure 30.-Cumulative sonar estimates with cumulative inriver net CPUE, late run (1 July–10 August), 2000.



Note: Sport fish CPUE data taken from Reimer et al. (*In prep*).

Figure 31.-Daily sonar estimates and sport fish CPUE, late run (1 July-31 July), 2000.

Inriver Netting Program

In 1998, we modified the inriver chinook salmon AWL (average weight and length) netting program to provide catch per unit effort (CPUE) data as an independent index of chinook salmon abundance (Bosch and Burwen 2000). A standardized drift zone was defined just downstream from the sonar site and crews fished a standard drift period relative to the tide cycles. Our objective was to use the netting CPUE to ascertain periods when sockeye salmon (or other species) generate a bias in chinook sonar estimates. It was anticipated that in the absence of high levels of sockeye passage (or other species), sonar estimates and CPUE would track reasonably well. Conversely, during periods of high sockeye passage, we expected the two to diverge.

With 3 years of data available, analysis is in progress to determine how well and under what conditions (e.g., water clarity and discharge) netting CPUE correlates with sonar estimates of chinook salmon. If a sufficient number of paired CPUE and sonar data were collected where the two estimates tracked closely under periods of low sockeye abundance, then the relationship between the two estimates could be exploited to generate adjusted estimates of chinook passage when sockeye abundance is high.

Past research using drift gillnet CPUE has revealed that net efficiency may vary with environmental conditions such as water clarity and discharge (Burwen et al. 1998). A critical aspect of analyzing these data will be determining whether confounding effects from these and other variables can be removed. Results of these efforts will be published either in the annual sonar report for 2001 or as a separate Fishery Data Series report.

Large Fish Index

We continue to pursue improved techniques for separating chinook and sockeye salmon using acoustic information. Results of a tethered fish study conducted in 1995 indicated that echo pulse width may provide higher discriminatory power than target strength for separating sockeye and chinook salmon (Burwen and Fleischman 1998). This relationship was supported again during a study in 1998 using multifrequency sonar (Burwen and Fleischman *In prep*).

The feasibility of using pulse width as a species discriminator is still being investigated. One difficulty with this method is that many smaller chinook salmon are excluded when a pulse width filter sufficient to exclude all sockeye is implemented. Since the methodology does not exist to separate all chinook from all sockeye, we are now focusing on using pulse width data to estimate the abundance of chinook greater than a specified size (e.g. 800 mm fork length). This would provide a conservative approximation of larger chinook salmon that could be relied upon to be uninfluenced by sockeye salmon abundance. A minimum estimate of larger chinook salmon would be useful on days when we believe large numbers of chinook and sockeye are concurrently passing the site and range and target strength filters appear inadequate.

It is also likely that current pulse width measurements can be improved. Pulse width measurements are subject to biases related to poor SNR (Ehrenberg and Johnston 1996) and more work is required to fully understand the behavior of these measurements as a function of SNR.

Multifrequency Sonar

Most researchers involved in fish species discrimination acknowledge that broadband sonar holds the most promise for discriminating among similar-sized organisms (Simmonds et al. 1996, Zakharia et al. 1996, Lebourges 1990). However, broadband systems are not commercially available and are primarily used by researchers at universities and research institutes that build their own prototypes. Other acousticians have shown that more readily implemented multifrequency sonar may be a more realistic method to use for classifying targets (McKelvey 1998, Simard 1998, Demer et al. 1999, Cochrane et al. 1991). Both these techniques increase the amount of information available to classify species by increasing the frequency range. The theory is that some acoustic parameter (such as target strength) of each species may change with frequency in a characteristic way.

In 1998, we investigated the use of multifrequency sonar data to assist in discriminating between fish species (Burwen and Fleischman *In prep*). Target strength and other acoustic parameters were measured on tethered chinook and sockeye salmon at 120 kHz, 200 kHz, and 420 kHz; with and without FM slide-encoded pulses. Information from multiple frequencies substantially improved our model for predicting fish length. However, additional studies need to be conducted to identify which frequencies hold the most promise for differentiating the size classes of fish of interest. We also need to ensure that these results are repeatable because some of the results were inconsistent with what theoretical models would predict (Horne and Clay 1998).

Because continued research with multifrequency sonar requires more funding, time, and expertise than is available within the department, we hope to continue this research in cooperation with Dr. John Horne at the University of Washington using funding available through the Alaska Sea Grant Program. Application for Sea Grant funding will be made in March 2001. If this funding is granted, research will begin in 2002.

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APPENDIX A. TARGET STRENGTH ESTIMATION

Appendix A1.-Using the sonar equation to estimate target strength with dual- and split-beam applications.

Target strength (TS), in decibels (dB), of an acoustic target located at range R (in meters), θ degrees from the maximum response axis (MRA) in one plane and ϕ degrees from the MRA in the other plane is estimated as:

$$TS = 20 \log_{10}(V_o) - SL - G_r + 40 \log_{10}(R) + 2\alpha R - G_{TVG} - 2B(\theta,\phi),$$

where:

V_o	= voltage of the returned echo, output by the echo sounder;
SL	= source level of transmitted signal in dB;
G_r	= receiver gain in dB;
$40\log_{10}(R)$	= two-way spherical spreading loss in dB;
$2\alpha R$	= two-way absorption loss in dB;
G_{TVG}	= time-varied-gain correction of the echo sounder; and
$2B(\theta,\phi)$	= two-way loss due to position of the target off of the MRA.

The source level and gain are measured during calibration and confirmed using *in situ* standard sphere measurements. The time-varied-gain correction compensates for spherical spreading loss. Absorption loss ($2\alpha R$) was ignored in this study.

In practice, the location of the target in the beam (θ and ϕ) is not known, so $B(\theta,\phi)$ must be estimated in order to estimate target strength. Dual-beam and split-beam sonar differ in how they estimate $B(\theta,\phi)$, also called the beam pattern factor.

Dual-beam sonar (Ehrenberg 1983) uses one wide and one narrow beam. The system transmits on the narrow beam only and receives on both. The ratio between the voltages of the received signals is used to estimate beam pattern factor:

$$B(\theta,\phi) = 20 \log(V_N/V_W) \bullet WBDO,$$

where V_N is the voltage of the returned echo on the narrow beam, V_W is the voltage of the echo on the wide beam, WBDO is the wide beam drop-off correction, specific to each transducer, and estimated at calibration.

Split-beam sonar (MacLennan and Simmonds 1992) estimates target location (angles θ and ϕ of the target from the MRA) directly, not just the beam pattern factor ($B(\theta,\phi)$). Split-beam transducers are divided into four quadrants, and θ and ϕ are estimated by comparing the phases of signals received by opposing pairs of adjacent quadrants. The beam pattern factor is a function of θ and ϕ, determined during laboratory calibration.

APPENDIX B. SYSTEM PARAMETERS

Appendix B1.-Example of system parameters used for data collection on the right bank (transducer 733).

* Start Processing at Port 1 -FILE_PARAMETERS- Sat July 1 06:00:05 2000

* Data processing parameters used in collecting this file for Port 1

100	-1	1	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	13200	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-
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	220.1	sl - transducer source level
202	-1	-170.8	gn - transducer through system gain at one meter
203	-1	-18	rg - receiver gain used to collect data
204	-1	5.5	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	ping_rate - pulses per second
209	-1	0	echogram start range in meters
210	-1	55	echogram stop range in meters
211	-1	653	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-

220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-15.5924	ux - horizontal electrical to mechanical angle ratio
223	-1	-33.3415	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0035	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.5624	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	0.0547	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.159	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	-0.2015	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.0004	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	53.1	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)
268	-1	0	aim_tilt - transducer aiming angle in tilt (y, u/d)
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 forth threshold layer (m)

-continued-

Appendix B1.-Page 3 of 3.

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	653	th_val[0] - thr. for 1st layer (mV)
402	1	653	th_val[1] - thr. for 2nd layer (mV)
402	2	653	th_val[2] - thr. for 3rd layer (mV)
402	3	653	th_val[3] - thr. for 4th layer (mV)
402	4	653	th_val[4] - thr. for 5th layer (mV)
402	5	653	th_val[5] - thr. for 6th layer (mV)
402	6	653	th_val[6] - thr. for 7th layer (mV)
402	7	653	th_val[7] - thr. for 8th layer (mV)
402	8	653	th_val[8] - thr. for 9th layer (mV)
402	9	653	th_val[9] - thr. for 10th layer (mV)
402	10	653	th_val[10] - thr. for 11th layer (mV)
402	11	653	th_val[11] - thr. for 12th layer (mV)
402	12	9999	th_val[12] - thr. for 13th layer (mV)
405	0	100	Integration threshold layer 1 value (mV)
405	1	100	Integration threshold layer 2 value (mV)
405	2	100	Integration threshold layer 3 value (mV)
405	3	100	Integration threshold layer 4 value (mV)
405	4	100	Integration threshold layer 5 value (mV)
405	5	100	Integration threshold layer 6 value (mV)
405	6	100	Integration threshold layer 7 value (mV)
405	7	100	Integration threshold layer 8 value (mV)
405	8	100	Integration threshold layer 9 value (mV)
405	9	100	Integration threshold layer 10 value (mV)
405	10	100	Integration threshold layer 11 value (mV)
405	11	100	Integration threshold layer 12 value (mV)
405	12	9999	Integration threshold layer 13 value (mV)
602	-1	1017536	Echo sounder serial number
604	-1	306733	Transducer serial number
605	-1	Spd-3	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_External	Trigger option
608	-1	LeftToRight	River flow direction

Appendix B2.-Example of system parameters used for data collection on the left bank (transducer 738).

* Start Processing at Port 2 -FILE_PARAMETERS- Sat Jul 1 06:20:00 2000

* Data processing parameters used in collecting this file for Port 2

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	9	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-
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	9	N_int_layers-number of integration strata
123	-1	9	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	217.51	sl - transducer source level
202	-1	-172.05	gn - transducer through system gain at one meter
203	-1	-18	rg - receiver gain used to collect data
204	-1	5.5	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	38	echogram stop range in meters
211	-1	419	echogram threshold in millivolts
212	-1	13.2	print width in inches
213	-1	0	Chirp Bandwith (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-

220	-1	5	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24	max_dB_off - maximum angle off in dB
222	-1	-15.6345	ux - horizontal electrical to mechanical angle ratio
223	-1	-54.6396	uy - vertical electrical to mechanical angle ratio
224	-1	0	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0007	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.4162	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.0015	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1679	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	-0.2109	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	0.0001	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0001	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	34.9	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	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)
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)

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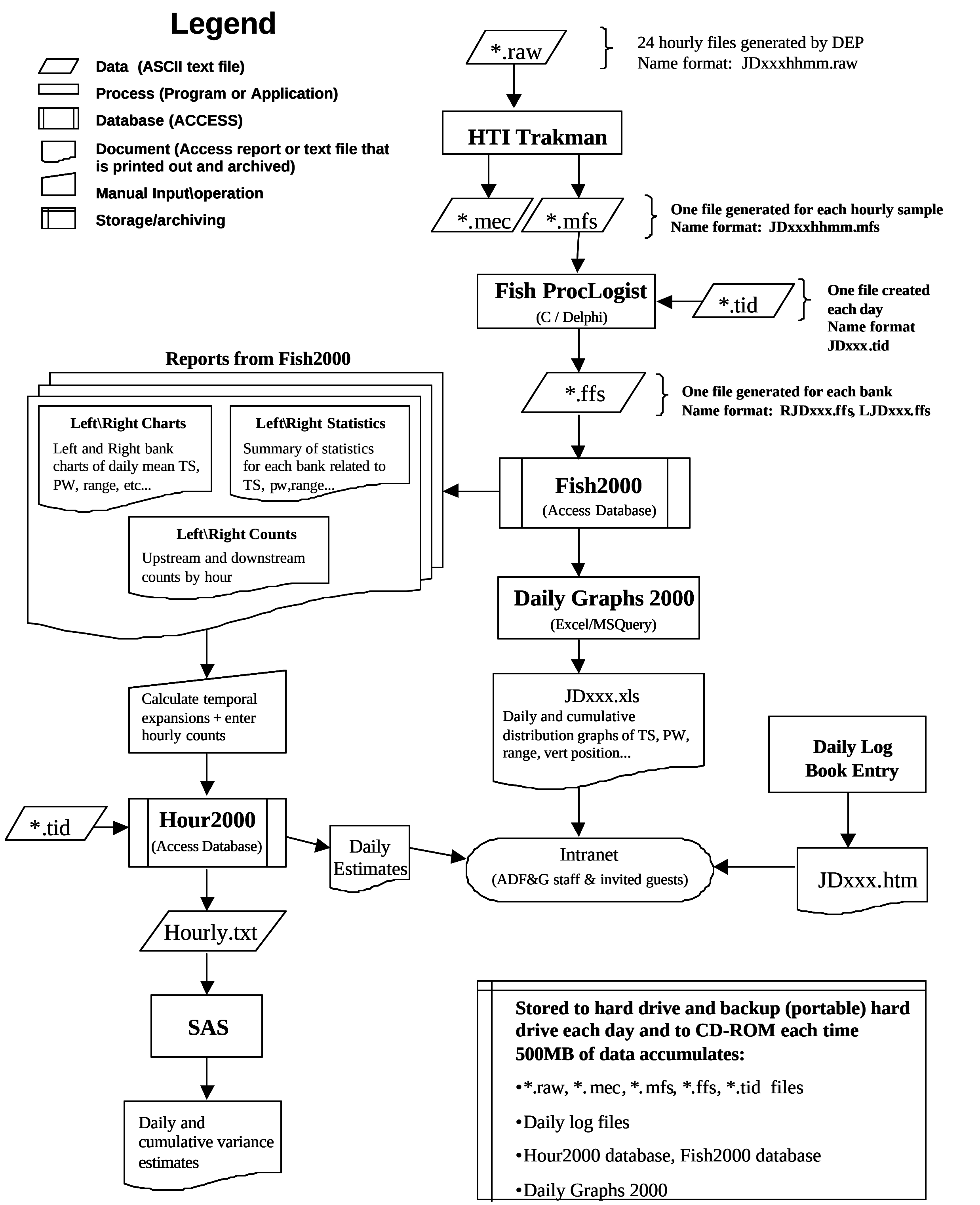
401	5	25	th_layer[5] - bottom of sixth threshold layer (m)
401	6	30	th_layer[6] - bottom of seventh threshold layer (m)
401	7	35	th_layer[7] - bottom of eighth threshold layer (m)
401	8	40	th_layer[8] - bottom of ninth threshold layer (m)
402	0	419	th_val[0] - thr. for 1st layer (mV)
402	1	419	th_val[1] - thr. for 2nd layer (mV)
402	2	419	th_val[2] - thr. for 3rd layer (mV)
402	3	419	th_val[3] - thr. for 4th layer (mV)
402	4	419	th_val[4] - thr. for 5th layer (mV)
402	5	419	th_val[5] - thr. for 6th layer (mV)
402	6	419	th_val[6] - thr. for 7th layer (mV)
402	7	419	th_val[7] - thr. for 8th layer (mV)
402	8	9999	th_val[8] - thr. for 9th layer (mV)
405	0	100	Integration threshold layer 1 value (mV)
405	1	100	Integration threshold layer 2 value (mV)
405	2	100	Integration threshold layer 3 value (mV)
405	3	100	Integration threshold layer 4 value (mV)
405	4	100	Integration threshold layer 5 value (mV)
405	5	100	Integration threshold layer 6 value (mV)
405	6	100	Integration threshold layer 7 value (mV)
405	7	100	Integration threshold layer 8 value (mV)
405	8	9999	Integration threshold layer 9 value (mV)
602	-1	1017536	Echo sounder serial number
604	-1	306738	Transducer serial number
605	-1	Spd-5	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_External	Trigger option
608	-1	LeftToRight	River flow direction

APPENDIX C. DATA FLOW

Appendix C1.-Inseason data flow diagram for the Kenai River chinook salmon sonar project, 2000.



APPENDIX D. DAILY PROPORTIONS OF UPSTREAM AND DOWNSTREAM FISH FOR THE 2000 EARLY AND LATE KENAI RIVER CHINOOK SALMON RUNS

Appendix D1.-Daily proportions of upstream and downstream fish for the 2000 Kenai River early chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
16 May	0	18	18	0.0%	100.0%
17 May	9	49	58	15.5%	84.5%
18 May	6	54	60	10.0%	90.0%
19 May	12	84	96	12.5%	87.5%
20 May	0	64	64	0.0%	100.0%
21 May	21	84	105	20.0%	80.0%
22 May	3	123	126	2.4%	97.6%
23 May	21	132	153	13.7%	86.3%
24 May	12	147	159	7.5%	92.5%
25 May	39	234	273	14.3%	85.7%
26 May	6	186	192	3.1%	96.9%
27 May	27	177	204	13.2%	86.8%
28 May	18	84	102	17.6%	82.4%
29 May	18	204	222	8.1%	91.9%
30 May	12	105	117	10.3%	89.7%
31 May	18	117	135	13.3%	86.7%
1 June	23	192	215	10.5%	89.5%
2 June	30	250	280	10.8%	89.2%
3 June	44	282	326	13.5%	86.5%
4 June	21	266	287	7.3%	92.7%
5 June	12	139	151	7.9%	92.1%
6 June	9	186	195	4.6%	95.4%
7 June	9	237	246	3.7%	96.3%
8 June	30	108	138	21.9%	78.1%
9 June	48	135	183	26.2%	73.8%
10 June	18	207	225	8.0%	92.0%
11 June	57	315	372	15.3%	84.7%
12 June	24	165	189	12.7%	87.3%
13 June	21	337	358	5.9%	94.1%
14 June	39	309	348	11.2%	88.8%
15 June	12	571	583	2.1%	97.9%
16 June	15	441	456	3.3%	96.7%
17 June	30	765	795	3.8%	96.2%
18 June	27	591	618	4.4%	95.6%
19 June	30	348	378	7.9%	92.1%
20 June	54	319	373	14.5%	85.5%
21 June	57	522	579	9.8%	90.2%
22 June	30	456	486	6.2%	93.8%
23 June	30	462	492	6.1%	93.9%
24 June	48	408	456	10.5%	89.5%
25 June	24	186	210	11.4%	88.6%
26 June	54	359	413	13.1%	86.9%
27 June	78	615	693	11.3%	88.7%
28 June	57	489	546	10.4%	89.6%
29 June	51	516	567	9.0%	91.0%
30 June	15	441	456	3.4%	96.6%
Total	1,219	12,479	13,698	8.9%	91.1%

Appendix D2.-Daily proportions of upstream and downstream fish for the 2000 Kenai River late chinook run.

Date	Downstream Count	Upstream Count	Daily Total	% Downstream	% Upstream
1 July	48	461	509	9.5%	90.5%
2 July	50	373	423	11.8%	88.2%
3 July	25	370	395	6.4%	93.6%
4 July	43	488	531	8.1%	91.9%
5 July	85	787	872	9.7%	90.3%
6 July	34	778	812	4.2%	95.8%
7 July	31	1,020	1,051	2.9%	97.1%
8 July	78	1,713	1,791	4.4%	95.6%
9 July	51	1,632	1,683	3.0%	97.0%
10 July	33	1,461	1,494	2.2%	97.8%
11 July	27	1,038	1,065	2.5%	97.5%
12 July	54	1,506	1,560	3.5%	96.5%
13 July	115	2,327	2,442	4.7%	95.3%
14 July	81	2,709	2,790	2.9%	97.1%
15 July	126	2,808	2,934	4.3%	95.7%
16 July	50	2,264	2,314	2.1%	97.9%
17 July	82	1,915	1,997	4.1%	95.9%
18 July	126	2,154	2,280	5.5%	94.5%
19 July	97	1,919	2,016	4.8%	95.2%
20 July	42	1,155	1,197	3.5%	96.5%
21 July	42	933	975	4.3%	95.7%
22 July	54	702	756	7.1%	92.9%
23 July	47	760	807	5.8%	94.2%
24 July	40	1,868	1,908	2.1%	97.9%
25 July	148	1,761	1,909	7.8%	92.2%
26 July	56	1,034	1,090	5.2%	94.8%
27 July	47	992	1,039	4.5%	95.5%
28 July	81	999	1,080	7.5%	92.5%
29 July	54	1,029	1,083	5.0%	95.0%
30 July	80	577	657	12.2%	87.8%
31 July	84	549	633	13.3%	86.7%
1 August	94	695	789	11.9%	88.1%
2 August	90	421	511	17.6%	82.4%
3 August	63	294	357	17.7%	82.3%
4 August	51	453	504	10.1%	89.9%
5 August	78	489	567	13.8%	86.2%
6 August	57	504	561	10.1%	89.9%
7 August	114	366	480	23.8%	76.3%
8 August	102	417	519	19.7%	80.3%
9 August	72	399	471	15.3%	84.7%
10 August	126	397	523	24.1%	75.9%
Total	2,858	44,517	47,375	6.0%	94.0%

APPENDIX E. AVERAGE VERTICAL ANGLE BY TIDE STAGE, RUN, BANK, AND FISH ORIENTATION (UPSTREAM OR DOWNSTREAM) FOR THE 2000 KENAI RIVER CHINOOK SALMON RUNS

Appendix E1.-Average vertical angle by tide stage and orientation for the 2000 Kenai River early chinook salmon run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Left Bank			
Falling			
Downstream	-0.71	0.89	54
Upstream	-1.49	0.51	849
Tide Stage Total	-1.10	1.03	903
Low			
Downstream	-1.21	0.61	26
Upstream	-1.58	0.38	283
Tide Stage Total	-1.39	0.72	309
Rising			
Downstream	-0.66	0.88	66
Upstream	-0.89	0.73	623
Tide Stage Total	-0.75	1.21	607
Left Bank Total	-1.08	1.75	1,819
Right Bank			
Falling			
Downstream	-0.44	0.73	120
Upstream	-0.80	0.59	1,313
Tide Stage Total	-0.62	0.94	1,433
Low			
Downstream	-0.64	0.63	75
Upstream	-0.97	0.52	411
Tide Stage Total	-0.80	0.82	486
Rising			
Downstream	-0.30	0.72	83
Upstream	-0.34	0.68	723
Tide Stage Total	-0.32	1.00	806
Right Bank Total	-0.58	1.59	2,725

Appendix E2.-Average vertical angle by tide stage and orientation for the 2000 Kenai River late chinook salmon run.

Tide Stage / Fish Orientation	Average Vertical Angle	Standard Deviation	Sample Size
Left Bank			
Falling			
Downstream	-1.17	0.85	229
Upstream	-1.58	0.44	2,936
Tide Stage Total	-1.38	0.95	3,165
Low			
Downstream	-1.48	0.50	102
Upstream	-1.62	0.32	1,177
Tide Stage Total	-1.55	0.59	1,279
Rising			
Downstream	-1.29	0.64	144
Upstream	-1.28	0.80	1,812
Tide Stage Total	-1.29	1.02	1,956
Left Bank Total	-1.41	1.52	6,400
Right Bank			
Falling			
Downstream	-0.14	0.44	231
Upstream	-0.36	0.42	4,656
Tide Stage Total	-0.25	0.61	4,887
Low			
Downstream	-0.21	0.46	96
Upstream	-0.40	0.46	1,312
Tide Stage Total	-0.36	0.71	1,408
Rising			
Downstream	-0.17	0.46	206
Upstream	-0.17	0.51	4,831
Tide Stage Total	-0.17	0.68	5,037
Right Bank Total	-0.24	1.13	11,332

APPENDIX F. HISTORIC ESTIMATES OF INRIVER RETURN BY YEAR AND DATE (1987–2000).

Appendix F1.-Kenai River early-run chinook salmon sonar estimates of inriver return, 1987-2000.

Date/Year	1987	1988	1989	**1990**	**1991**	**1992**	1993	1994	1995	1996	**1997**	**1998[a]**	1999[a]	**2000[a]**
7 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	6	NA	NA
8 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	18	NA	NA
9 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3	NA	NA
10 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3	NA	NA
11 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12	NA	NA
12 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	12	NA	NA
13 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	27	NA	NA
14 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	43	NA	NA
15 May	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	63	NA	NA
16 May	NA	188	180	78	30	54	64	238	98	60	114	48	33	18
17 May	NA	415	319	57	12	48	85	342	99	91	99	45	63	49
18 May	NA	259	264	93	65	88	91	260	78	63	93	57	66	54
19 May	NA	260	180	136	55	40	66	302	149	96	165	36	39	84
20 May	NA	406	147	93	68	78	69	369	228	177	84	54	116	64
21 May	NA	184	245	69	51	90	165	327	465	165	129	33	186	84
22 May	NA	182	164	75	111	108	117	246	265	156	114	15	192	123
23 May	NA	231	186	63	66	150	160	212	286	159	162	12	243	132
24 May	NA	288	279	51	66	126	141	303	265	159	138	33	159	147
25 May	NA	351	300	76	57	79	150	170	198	153	165	81	141	234
26 May	NA	393	270	70	81	93	168	150	189	240	220	43	330	186
27 May	NA	387	419	87	81	66	150	267	165	204	325	60	342	177
28 May	NA	483	357	61	78	78	361	258	159	330	317	63	402	84
29 May	NA	713	269	221	51	45	538	347	222	512	288	63	378	204
30 May	NA	333	164	154	51	111	388	321	351	348	350	129	273	105
31 May	NA	501	157	175	69	114	266	369	282	474	318	93	459	117
1 June	NA	556	258	153	150	106	187	321	357	603	213	111	633	192
2 June	NA	545	194	294	240	107	412	266	369	741	241	189	444	250
3 June	NA	598	233	225	362	232	324	298	549	873	376	192	540	282
4 June	NA	755	246	178	177	190	255	304	693	1,051	324	186	924	266
5 June	NA	782	280	192	316	166	276	351	429	943	427	**162**	876	139
6 June	NA	493	384	156	**296**	319	327	198	807	741	327	**150**	807	186
7 June	NA	506	545	**304**	**215**	515	198	384	843	773	591	**283**	672	237
8 June	NA	771	890	**414**	**243**	375	297	306	999	918	441	**300**	609	108
9 June	NA	569	912	**339**	**444**	**486**	378	462	789	1,140	391	**234**	504	135
10 June	NA	333	913	**272**	**275**	**264**	453	432	876	684	527	**327**	439	207
11 June	NA	320	710	**453**	**334**	**234**	549	423	774	882	512	**600**	596	315
12 June	NA	302	577	**568**	**400**	**394**	600	329	417	864	537	**1,168**	723	165
13 June	NA	188	599	**445**	**369**	**236**	951	376	492	1,071	681	**719**	393	**337**
14 June	NA	289	458	**330**	**268**	**174**	811	514	691	1,111	424	**912**	610	**309**
15 June	NA	510	335	**658**	**441**	**312**	407	306	636	1,116	318	**951**	436	**571**
16 June	NA	808	397	**485**	**615**	**239**	616	453	648	420	348	**770**	696	**441**
17 June	NA	535	514	**267**	**330**	**339**	567	315	750	495	**405**	**675**	807	**765**
18 June	NA	533	464	**238**	**493**	**320**	606	435	808	697	**315**	**498**	742	**591**
19 June	NA	200	295	**331**	**437**	**390**	422	636	419	657	**399**	**510**	771	**348**
20 June	NA	175	498	**369**	**314**	**548**	504	402	594	315	**408**	**351**	1,247	**319**
21 June	NA	373	520	**257**	**457**	**372**	621	570	438	351	**252**	**309**	1,192	**522**
22 June	NA	312	614	**267**	**433**	**297**	399	366	375	396	**390**	**273**	819	**456**
23 June	NA	375	547	**240**	**396**	**213**	607	550	178	401	**225**	**294**	935	**462**
24 June	NA	674	564	**322**	**251**	**337**	720	696	450	573	**285**	**288**	1,151	**408**
25 June	NA	582	374	**258**	**235**	**362**	808	734	429	684	**332**	**228**	1,292	**186**
26 June	NA	436	369	**322**	**261**	**330**	1,051	597	334	504	**381**	**219**	731	**359**
27 June	NA	549	309	**231**	**340**	**291**	1,158	639	946	228	**363**	**207**	678	615
28 June	NA	827	425	**240**	**327**	**253**	798	681	696	303	**297**	**308**	537	489
29 June	NA	495	376	**208**	**258**	**121**	728	929	984	234	**570**	**363**	753	516
30 June	NA	915	292	**193**	**270**	**197**	660	649	615	351	**582**	**276**	687	441
Total		20,880	17,992	**10,768**	**10,939**	**10,087**	19,669	18,403	21,884	23,505	**14,963**	**13,103**	25,666	**12,479**

[a] Upstream moving fish only reported.

Note: Bold and shaded numbers represent the dates that the chinook fishery was restricted to catch and release due to low inriver return.

Appendix F2.-Kenai River late-run chinook salmon sonar estimates of inriver return, 1987-2000.

Date/Year	1987	1988	1989	**1990**	1991	**1992**	1993	1994	1995	1996	1997	**1998[a]**	1999 [a]	2000 [a]
1 Julv	507	526	769	578	267	364	539	663	350	341	486	491	453	461
2 July	429	404	489	305	300	297	432	342	398	240	642	597	612	373
3 July	405	398	353	486	333	320	325	625	353	303	600	480	486	370
4 July	628	292	566	436	519	198	397	858	439	393	633	450	396	488
5 July	596	482	1,106	853	316	225	429	705	667	1,067	657	606	369	787
6 July	523	654	879	795	242	331	884	1,069	720	879	627	612	683	778
7 July	769	379	680	929	186	247	1,572	1,050	931	780	1,158	660	936	1,020
8 July	483	725	776	432	139	170	1,855	655	417	867	1,221	462	1,030	1,713
9 July	384	471	1,404	309	393	205	1,876	744	519	768	1,618	480	1,047	1,632
10 July	314	1,732	560	359	481	221	820	1,275	450	1,023	3,486	450	717	1,461
11 July	340	1,507	2,010	778	403	143	1,238	509	325	1,146	5,649	171	1,059	1,038
12 July	751	1,087	2,763	557	330	1,027	676	828	276	714	4,497	192	560	1,506
13 July	747	2,251	910	1,175	308	605	3,345	1,066	570	1,128	5,373	262	401	2,327
14 July	761	2,370	2,284	1,481	572	689	3,177	1,332	714	4,437	2,031	368	969	2,709
15 July	913	2,405	1,111	1,149	542	745	2,233	2,211	750	3,222	4,042	1,118	636	2,808
16 July	1,466	1,259	1,344	1,011	1,029	703	2,329	3,825	1,962	3,494	3,420	1,416	927	2,264
17 July	1,353	1,520	963	2,395	2,052	570	2,037	4,692	1,128	2,253	4,584	1,424	3,558	1,915
18 July	841	2,180	1,382	2,113	3,114	853	1,438	2,157	3,942	2,820	2,334	1,638	2,784	2,154
19 July	2,071	1,724	425	1,363	1,999	1,128	715	3,493	4,692	2,236	1,146	1,146	1,869	1,919
20 July	3,709	2,670	820	1,499	1,422	1,144	1,348	2,317	4,779	2,609	1,578	741	3,471	1,155
21 July	3,737	3,170	916	787	1,030	799	981	1,695	3,132	3,435	894	1,608	3,354	933
22 July	1,835	1,302	583	573	1,050	619	1,166	1,386	3,465	2,250	1,840	1,411	1,998	702
23 July	1,700	1,502	756	642	2,632	1,449	1,163	1,050	2,421	3,050	1,441	808	1,875	760
24 July	2,998	1,386	783	1,106	2,204	**711**	1,344	1,232	831	3,634	1,080	933	1,748	1,868
25 July	1,915	999	495	810	1,306	**1,713**	2,245	1,412	840	3,240	532	542	1,937	1,761
26 July	1,968	924	432	671	1,216	**1,296**	1,421	1,378	1,683	2,319	519	723	1,098	1,034
27 July	1,523	960	618	755	1,195	**1,561**	1,952	1,244	1,806	1,782	438	807	3,066	992
28 July	2,101	1,398	538	**603**	1,901	**1,957**	1,915	2,180	789	861	333	**954**	1,358	999
29 July	1,923	1,400	441	**546**	1,146	**1,533**	1,363	1,327	558	474	401	**1,255**	1,185	1,029
30 July	2,595	1,158	391	**382**	791	**1,198**	1,628	1,776	510	621	450	**1,556**	969	577
31 July	2,372	910	383	**316**	974	**951**	862	1,808	480	1,548	420	**1,344**	1,308	549
1 August	470	925	351	**393**	897	**921**	767	1,037	474		247	**909**	591	695
2 August	314	781	201	**388**	867	**1,018**	613	1,226	369		291	**1,512**	468	421
3 August	263	989	132	**533**	392	**837**	337	1,081	447		213	**1,006**	642	294
4 August	835	1,524	142	**717**	331	**862**	463	658	519			**1,131**	444	453
5 August	904	1,091	107	**723**	174	**861**	711	536	404			**1,094**	436	489
6 August	648	1,333	107	**552**	343	**654**	1,079	1,042	408			**864**	654	504
7 August	694	1,186	65	**516**	618	**558**	656	797	279			**843**	678	366
8 August	658	1,449		**682**	600	**217**	669		267			**750**	804	417
9 August	368	1,132		**679**		**165**	422		272			**570**	328	399
10 August	312	755		**678**		**249**	252					**496**	165	397
11 August		698		**547**										
12 August				**362**										
13 August				**221**										
14 August				**139**										
15 August				**150**										
Total	48,123	52,008	29,035	**33,474**	34,614	**30,314**	49,674	53,281	44,336	53,934	54,881	**34,878**	48,069	44,517

[a] Upstream fish only reported.

Note: Shaded numbers represent dates when the chinook fishery was restricted to catch and release due to low inriver return.