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Evaluation of Hydroacoustic Assessment Techniques for Chinook Salmon on the Kenai River, 1995

by

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and

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April 1998

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

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ABSTRACT

Passage of chinook salmon *Oncorhynchus tshawytscha* in the Kenai River was estimated using side-looking dual-beam sonar technology from 1987 through 1994. Sockeye salmon *O. nerka* migrate concurrently with chinook salmon and are far more numerous. To exclude as many sockeye salmon as possible from counts of chinook salmon only those targets which exceeded minimum-range criteria and target-strength thresholds were counted. In 1995, in addition to normal procedures for estimating fish passage, the dual-beam system was replaced with a split-beam system and three ancillary experiments were conducted to evaluate the accuracy of chinook salmon passage estimates. The first study used spatial location data from the split-beam sonar to determine direction of travel for each target and estimate the proportion of fish migrating downstream by day, bank, and tide stage. In the second study, live fish of known size and species were tethered in front of the transducer to evaluate the effectiveness of the target strength threshold and determine whether there were other measurable acoustic parameters that could be used instead of or in conjunction with target strength to separate chinook salmon from other species. The third study used drift gillnets to address the question of whether there is sufficient spatial separation between chinook and sockeye salmon to distinguish between the species.

Downstream-migrants comprised 12% and 5% of fish during the early and late runs respectively, with greater downstream proportions on the left bank than on the right bank. The proportion of downstream fish differed little by tide stage.

The relationship between mean target strength and length of tethered fish was imprecise ($r^2 = 0.23$, $P < 0.0001$) and distributions of mean target strength overlapped almost completely between species and between length classes. Tethered chinook salmon had a mean target strength of -24.8 dB (SD = 2.5), sockeye salmon averaged -25.5 dB (SD = 2.0) and coho salmon averaged -26.1 dB (SD = 1.1). Fish shorter than 650 mm (n = 55) averaged -25.9 dB (SD = 1.9), whereas fish longer than 650 mm (n = 38) averaged -24.2 dB (SD = 2.3). Most sockeye salmon tethered in front of the split-beam sonar had mean target strengths exceeding the target strength threshold of -28 dB. Target strength measurements were sensitive to fish movement, position, and transducer aim. Other acoustic parameters based on pulse duration showed potential as size and species discriminators.

Substantial numbers of sockeye salmon were present in mid-river during the study period, although relative proportions of sockeye and chinook salmon could not be estimated due to net selectivity biases. We conclude that chinook salmon passage estimates include some sockeye salmon, and further ground-truthing of sonar estimates with an independent abundance estimate is recommended.

Key words: Split-beam sonar, dual-beam sonar, chinook salmon, sockeye salmon, Oncorhynchus tshawytscha, Oncorhynchus nerka, hydroacoustic assessment, Kenai River, riverine sonar, target strength, pulse length, species discrimination, gill nets.

INTRODUCTION

Chinook salmon *Oncorhynchus tshawytscha* returning to the Kenai River are among the largest in the world and support one of the largest and most intensively managed recreational fisheries in the state, sustaining in excess of 100,000 angler-days of fishing effort annually (Nelson 1994). Side-looking sonar has been used to assess chinook salmon returns to the Kenai River since 1987. Sonar estimates of inriver return provide the basis for estimating spawning escapement and regulating harvest in competing sport and commercial fisheries for these fish.

Hydroacoustic 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. Dual-beam sonar was initially chosen for 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. Research with dual-beam sonar conducted in 1985 and 1986 concluded that target strength could be used to discriminate large chinook salmon from other salmon in the Kenai River (Eggers et al. 1995). 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.

Efficiency of target strength as a discriminatory variable was seriously questioned by Eggers (1994) who concluded that, theoretically, chinook and sockeye salmon could not be differentiated based on mean target strength because of high within-fish variability in target strength. To address these and other concerns, a split-beam system was deployed side-by-side and run concurrently with the dual-beam system for much of the 1994 season (Burwen et al. 1995). The split-beam system provided advantages over the dual-beam system in its ability to determine the direction of travel for each target and the spatial distribution of fish in the acoustic beam. Although results from 1994 failed to confirm the validity of discriminating species using target strength, Burwen et al. (1995) noted that estimates still appeared reasonable because they tracked fairly well with other indices. Burwen et al. (1995) and Eggers et al. (1995) hypothesized that range thresholds and spatial segregation (sockeye salmon near shore and chinook salmon mid-river) had effectively prevented substantial numbers of sockeye salmon from being counted.

The dual- and split-beam systems detected similar numbers of targets, and the split-beam data confirmed earlier studies showing that fish were strongly oriented to the bottom of the river (Burwen et al. 1995). However, the proportion of downstream-moving targets estimated by the split-beam system was substantially higher than previous estimates. In 1995, the dual-beam system was retired and the split-beam system used to generate daily estimates of passage (Burwen and Bosch 1996).

This report presents the results of three additional studies from 1995, designed to further evaluate accuracy of past and present estimates of chinook salmon passage. We estimated the proportion of fish traveling downstream relative to any spatial or temporal changes. We tethered live fish of known size and species in the acoustic beam, as an additional test of the validity of using target strength to discriminate between chinook and sockeye salmon. Finally, we used drift gillnets to assess the degree to which sockeye and chinook salmon are spatially segregated at the mile 8.6 site.

BIOLOGICAL AND PHYSICAL SETTING

The Kenai River has two stocks of chinook salmon: an early run which enters the river from mid-May through June, and a late run which enters the river from late June through early August (Burger et al. 1985). There are early and late runs of sockeye salmon which mirror the timing of early- and late-run chinook salmon. Most early-run sockeye salmon migrate to the Russian River, and have numbered from 5,460 to 215,710 since 1963 (Nelson 1994). Late-run sockeye salmon are destined for spawning locations throughout the drainage and are far more numerous. Estimated passage of late-run sockeye salmon has ranged from 285,000 to 1,598,000 since 1977 (Nelson 1994).

The current site at river mile 8.6 (Figure 1) was originally selected in 1985 for its acoustically favorable characteristics, its location relative to the riverine sport fishery, and its location downstream of known spawning grounds (Alexandersdottir and Marsh 1990). At this site, the river has a single channel with a uniformly-sloping, absorptive bottom from each bank to the

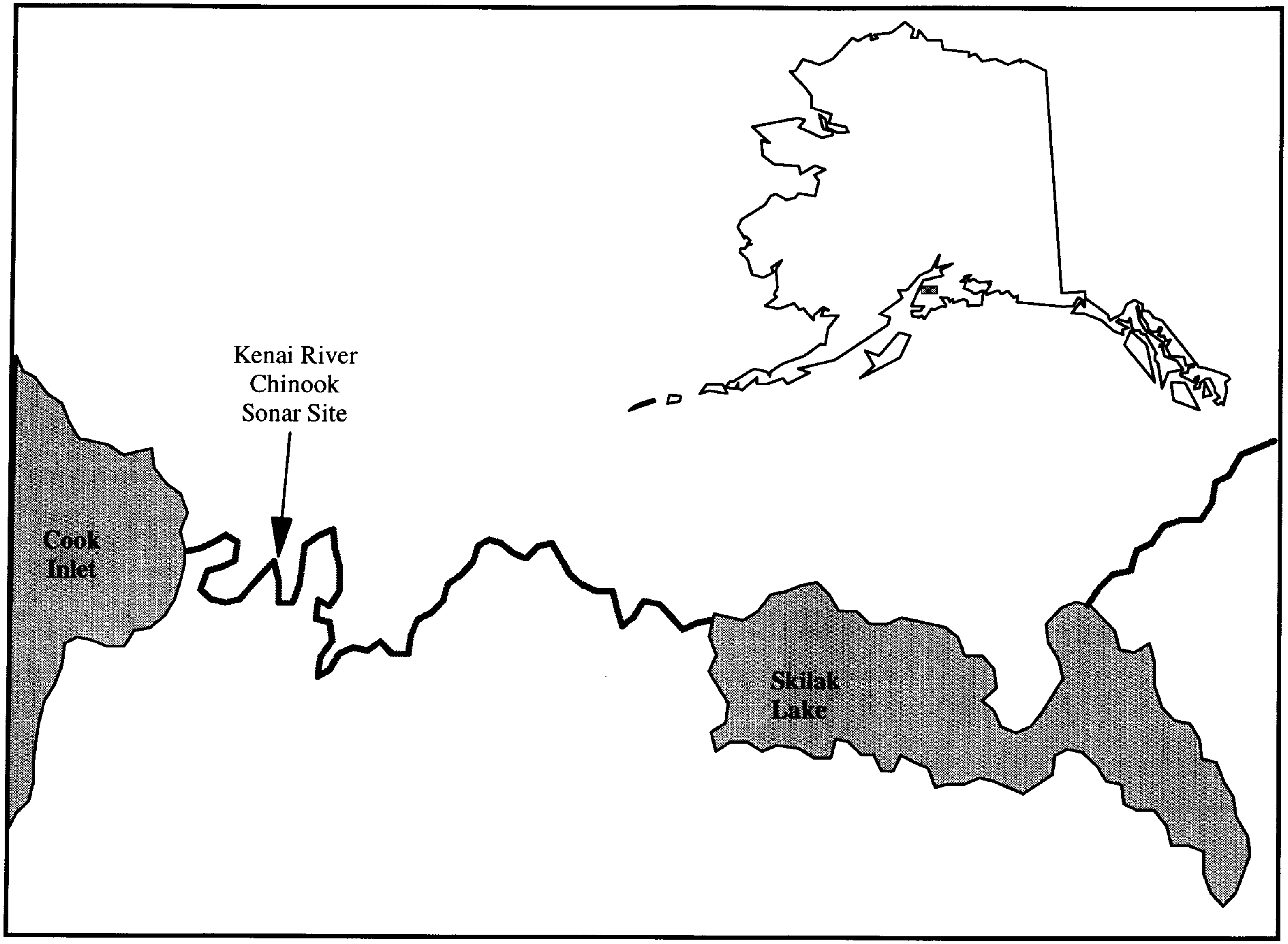

Figure 1.-Location of the Kenai River chinook salmon sonar, 1995.

center of the channel. The amount of boat traffic and associated boat wake, which interferes with sonar, is somewhat reduced because the site is downstream from the highest concentration of sport fishing effort. One disadvantage of the site is that it is located within tidal influence and experiences reversed flows during some high tides. The effect of tidal cycles on fish distribution and direction of travel has been a matter of concern since project inception.

EXPERIMENT I:
DIRECTION OF TRAVEL

Prior to the switch to split-beam sonar in 1995, direction of travel for each acoustic target could not be determined. Consequently, passage estimates have included an unknown number of fish traveling downstream. Three previous experiments have been conducted to estimate the number of downstream fish. The first in 1985 used angle of passage through the acoustic beam to determine direction of travel. This study estimated a downstream component of 3.5%, however results were inconclusive due to the large number of targets (>50%) for which direction of travel could not be determined (Eggers et al. 1995). A second study, conducted in 1990, used two transducers mounted side-by-side with overlapping beams. Although this study estimated only 3% of targets had been headed downstream, data were limited to a small subsample of targets from the late run of chinook salmon and from the right bank only. The third study utilized an auxiliary split-beam sonar system deployed for several weeks in 1994. This study estimated much higher proportions of targets moving downstream (9% to 16%), although sampling was again limited in scope (Burwen et al. 1995).

Analyses with 1995 data allowed the first complete summary of upstream and downstream-moving targets throughout both early and late runs of chinook salmon. Proportions of upstream and downstream targets were compared by run (early and late), bank (north or south, referred to as right and left hereafter), range (distance from transducer), acoustic size (target strength), and tide stage. In the future, the accuracy of estimates of chinook salmon passage may be improved by adjusting for the proportion of downstream migrants.

METHODS

Hydroacoustic Data Collection

Data were generated during normal operations with a 200 kHz split-beam sonar system manufactured by Hydroacoustics Technology, Inc.[1] (HTI) (Table 1). Two transducers were deployed, one on either side of the river. Pulse repetition rate was 8 sec^{-1} and transmitted pulse length 0.2 msec (Appendix A). The sonar system was professionally calibrated at Aliant Tech Systems[1] in Seattle before installation. Calibration was verified twice during the season for each transducer using a 38.1 mm tungsten carbide sphere (Foote and MacLennan 1984, Burwen and Bosch 1996).

Each transducer was mounted on a steel tripod and deployed at depths of 0.5-1.0 m at low tide. During high tide, water could be up to 5 m deep at the transducers. Vertical and horizontal aiming of each transducer was remotely controlled with a dual-axis electronic pan and tilt system. In the

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

Table 1.-Components of the split-beam sonar system used at mile 8.6 of the Kenai River in 1995.

System Component	Description
Sounder	Hydroacoustics Technology Inc. (HTI) Model 240 Split-Beam Echosounder operating at 200 kHz
Signal Processor	Model 340 Digital Echo Processor based in a Dell XPS Pentium 100 personal computer
Transducers	(2) HTI Split-Beam Left Bank: nominal beam widths: 2.9°x10.2° Right Bank: nominal beam widths: 2.8°X10°
Chart Recorder	HTI model 403 digital dual-channel chart recorder
Video Display	Simrad Model CF-100 color video monitor
Remote Pan and Tilt Aiming Controller	Remote Ocean Systems Model PTC-1 Pan and Tilt Controller
Remote Pan and Tilt Aiming Unit	Remote Ocean Systems Model P-25 Remote Pan and Tilt Unit

vertical plane, the transducer was aimed so that the sonar beam lightly grazed the bottom of the river (Figure 2). In the horizontal plane, the transducer was aimed perpendicular to the flow of the river to maximize probability of ensonifying fish from a lateral aspect (Figure 2). A complete description of data collection and equipment methods is given in Burwen and Bosch (1996).

Analytical Methods

Targets were manually tracked using proprietary software supplied by HTI. Tracked targets were then filtered using historical criteria intended to minimize the number of sockeye salmon counted. Target strength was calculated for individual echoes (Appendix B1) and averaged for each target. Targets with mean target strength less than -28 dB were deleted, as were targets near shore during the peak of the sockeye salmon run (0 to 10 m range, left bank; 0 to 15 or 25 m range, right bank; 7 June through 9 August; Burwen and Bosch 1995).

Direction of travel was determined using target-tracking techniques through the beam (Appendix B), Johnston et al. 1993). For each returned echo, the split-beam system estimated X (left-right), Y (up-down), and Z (distance from the transducer, referred to as range hereafter) coordinates in meters, where the center of the transducer face is the origin of the coordinate system. A target was classified as upstream if its ending (X-axis) position was located upriver from its starting position, and downstream if its ending position was downriver from its starting position.

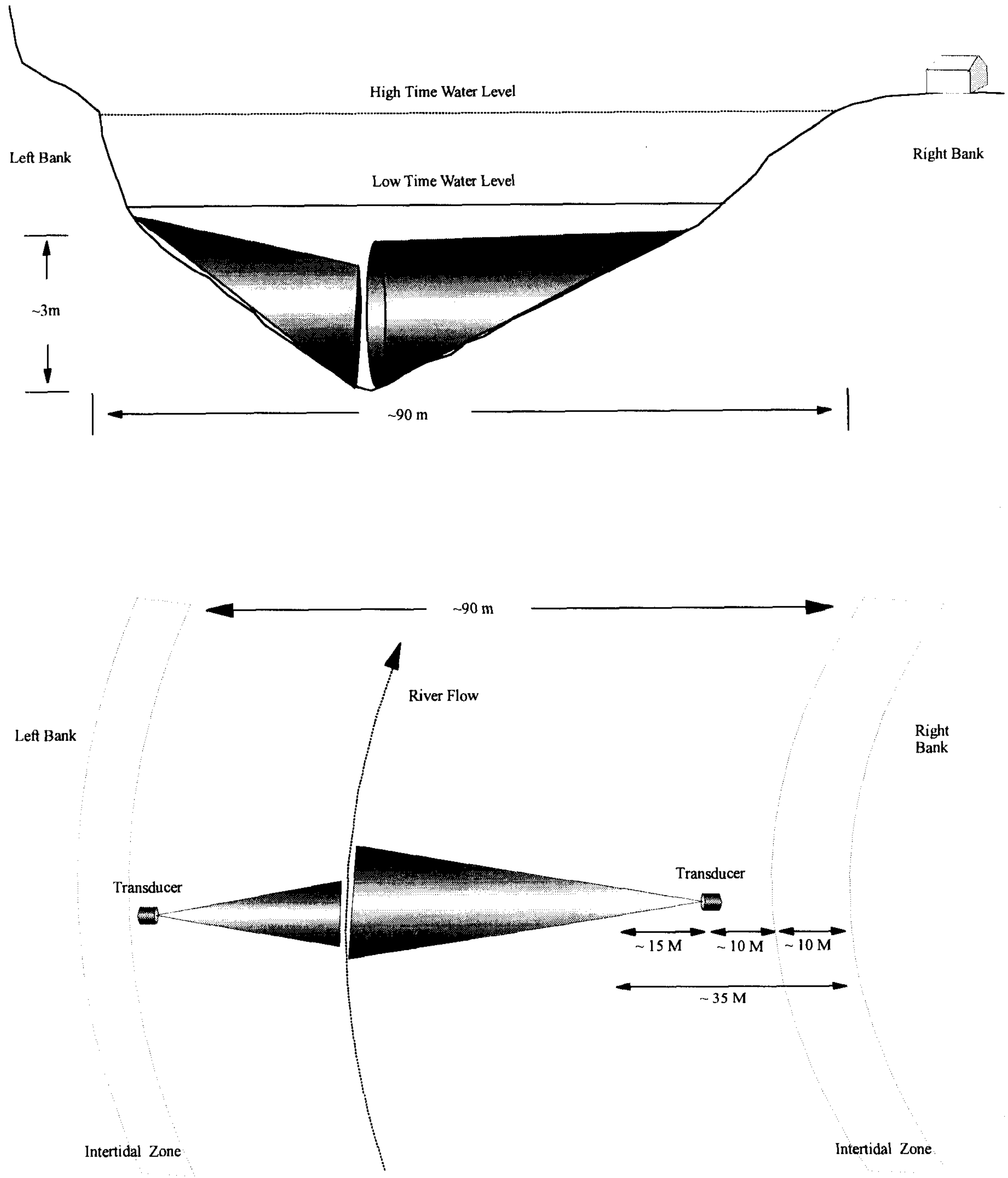

Figure 2.-Aerial and cross-sectional views of sonar site showing ensonified portions of the Kenai River, 1995.

RESULTS AND DISCUSSION

From 16 May to 9 August, 23,983 targets were tracked which met target strength and range criteria, of which 1,730 (7.2%) had been traveling downstream (Table 2). The early run (≤ 30 June) had a higher proportion of downstream targets (12.1%, SE = 0.4%) than the late run (5.0%, SE = 0.2%; Table 2). The highest proportion of downstream targets occurred during the first 2 weeks of the early run (Table 3, Table 4, Figure 3). The left bank, although it had fewer targets overall than the right bank, had consistently higher proportions of downstream targets (Table 2).

During the early run, the greatest density of targets occurred in mid-river (Table 5, Figure 4). On the right bank, the cumulative range distributions showed that upstream targets were more channel oriented than downstream targets (Anderson-Darling test, $T_{akn} = 4.88$, $P = 0.0037$). On the left bank, the range distributions of upstream and downstream-moving targets were similar ($T_{akn} = 1.02$, $P = 0.12$). During the late run the greatest density of upstream targets occurred near shore on the right bank (Table 6, Figure 4). Downstream targets were distributed differently ($T_{akn} = 102.2$, $P < 0.001$), with the greatest density near midchannel.

During the early run on the right bank, downstream targets had significantly lower ($t = 7.83$, df = 5,860, $P < 0.001$) mean target strength ($\bar{x} = -24.73$ dB, SD = 2.18, n = 598) than upstream targets ($\bar{x} = -23.97$ dB, SD = 2.25, n = 5,264) although the actual difference in means was less than 1 dB (Figure 5). The variance of target strength did not differ by direction of travel ($F = 1.07$, df = 5,263; 597, $P = 0.14$). On the left bank, the difference was more pronounced (Figure 5); downstream targets had almost 3 dB lower target strength on average ($\bar{x} = -21.68$ dB, SD = 3.84, n = 296) than upstream targets ($\bar{x} = -18.73$ dB, SD = 3.46, n = 1,214). The difference was significant ($t = 12.08$, df = 419, $P < 0.001$). The variance of target strength also differed by direction of travel ($F = 1.23$, df = 1,213; 295, $P = 0.0097$).

Table 2.-Number of tracked targets, by bank and direction of travel, 16 May to 30 June (early run) and 1 July to 9 August (late run), 1995.

	Number of Targets	Downstream Component	Upstream Component	Downstream Percent	Upstream Percent
Early Run					
Left Bank	1,510	296	1,214	19.6%	80.4%
Right Bank	5,862	598	5,264	10.2%	89.8%
Total Run	7,372	894	6,478	12.1%	87.9%
Late Run					
Left Bank	1,137	144	993	12.7%	87.3%
Right Bank	15,474	692	14,782	4.5%	95.5%
Total Run	16,611	836	15,775	5.0%	95.0%
Both Runs					
Left Bank	2,647	440	2,207	16.6%	83.4%
Right Bank	21,336	1,290	20,046	6.0%	94.0%
Total Run	23,983	1,730	22,253	7.2%	92.8%

Table 3.-Daily number of upstream and downstream tracked targets, for the early run in 1995.

Date	Upstream	Downstream	Total	Daily Percent Upstream	Daily Percent Downstream
16 Mav	22	7	29	75.9%	24.1%
17 May	17	6	23	73.9%	26.1%
18 May	20	6	26	76.9%	23.1%
19 May	35	12	47	74.5%	25.5%
20 May	57	19	76	75.0%	25.1%
21 May	89	23	112	79.5%	20.5%
22 May	61	20	81	75.3%	24.7%
23 May	58	40	98	59.2%	40.8%
24 May	54	30	84	64.3%	35.7%
25 May	35	27	62	56.5%	43.5%
26 May	46	14	60	76.7%	23.3%
27 May	45	11	56	80.4%	19.6%
28 May	43	12	55	78.2%	21.8%
29 May	57	17	74	77.0%	23.0%
30 May	88	29	117	75.2%	24.8%
31 May	86	8	94	91.5%	8.5%
1 June	106	13	119	89.1%	10.95
2 June	107	16	123	87.0%	13.0%
3 June	154	29	183	84.2%	15.9%
4 June	199	32	231	86.1%	14.0%
5 June	127	10	137	92.7%	7.3%
6 June	214	55	269	79.6%	20.4%
7 June	229	52	281	81.5%	18.5%
8 June	304	28	332	91.6%	8.4%
9 June	244	19	263	92.8%	7.2%
10 June	263	29	292	90.1%	9.9%
11 June	223	35	258	86.4%	13.6%
12 June	119	20	139	85.7%	14.4%
13 June	109	14	123	88.6%	11.5%
14 June	184	24	208	88.5%	11.5%
15 June	191	21	212	90.1%	9.9%
16 June	206	10	216	95.4%	4.6%
17 June	257	28	285	90.2%	9.8%
18 June	271	24	295	91.9%	8.1%
19 June	137	8	145	94.5%	5.5%
20 June	204	6	210	97.1%	2.9%
21 June	148	13	161	91.9%	8.1%
22 June	155	10	165	93.9%	6.1%
23 June	59	7	66	89.4%	10.6%
24 June	139	19	158	88.0%	12.0%
25 June	149	3	152	98.0%	2.0%
26 June	112	11	123	91.1%	8.9%
27 June	317	18	335	94.6%	5.4%
28 June	222	21	243	91.4%	8.6%
29 June	310	24	334	92.8%	7.2%
30 June	206	14	220	93.6%	6.4%
Early Run Total	6,478	894	7,372	87.9%	12.1%

Table 4.-Daily number of upstream and downstream tracked targets, for the late run in 1995.

Date	Upstream	Downstream	Total Targets	Daily Percent Upstream	Daily Percent Downstream
1 July	107	17	124	86.3%	13.7%
2 July	131	6	137	95.6%	4.4%
3 July	104	11	115	90.4%	9.6%
4 July	134	12	146	91.8%	8.2%
5 July	211	9	220	95.9%	4.1%
6 July	236	5	241	97.9%	2.1%
7 July	285	19	304	93.8%	6.3%
8 July	126	13	139	90.6%	9.4%
9 July	159	14	173	91.9%	8.1%
10 July	137	14	151	90.7%	9.3%
11 July	94	11	105	89.5%	10.5%
12 July	80	11	91	87.9%	12.1%
13 July	181	9	190	95.3%	4.7%
14 July	224	14	238	94.1%	5.9%
15 July	236	14	250	94.4%	5.6%
16 July	846	25	871	97.1%	2.9%
17 July	226	9	235	96.2%	3.8%
18 July	1,344	55	1,399	96.1%	3.9%
19 July	1,643	62	1,705	96.4%	3.6%
20 July	1,628	74	1,702	95.7%	4.3%
21 July	1,041	45	1,086	95.9%	4.1%
22 July	1,348	54	1,402	96.1%	3.9%
23 July	999	58	1,057	94.5%	5.5%
24 July	334	36	370	90.3%	9.7%
25 July	342	17	359	95.3%	4.7%
26 July	757	7	764	99.1%	0.9%
27 July	794	19	813	97.7%	2.3%
28 July	266	14	280	95.0%	5.0%
29 July	170	21	191	89.0%	11.0%
30 July	157	21	178	88.2%	11.8%
31 July	164	23	187	87.7%	12.3%
1 August	156	26	182	85.7%	14.3%
2 August	148	10	158	93.7%	6.3%
3 August	182	11	193	94.3%	5.7%
4 August	198	22	220	90.0%	10.0%
5 August	141	10	151	93.4%	6.6%
6 August	157	7	164	95.7%	4.3%
7 August	101	10	111	91.0%	9.0%
8 August	99	6	105	94.3%	5.7%
9 August	89	15	104	85.6%	14.4%
Late Run Total	15,775	836	16,611	95.0%	5.0%

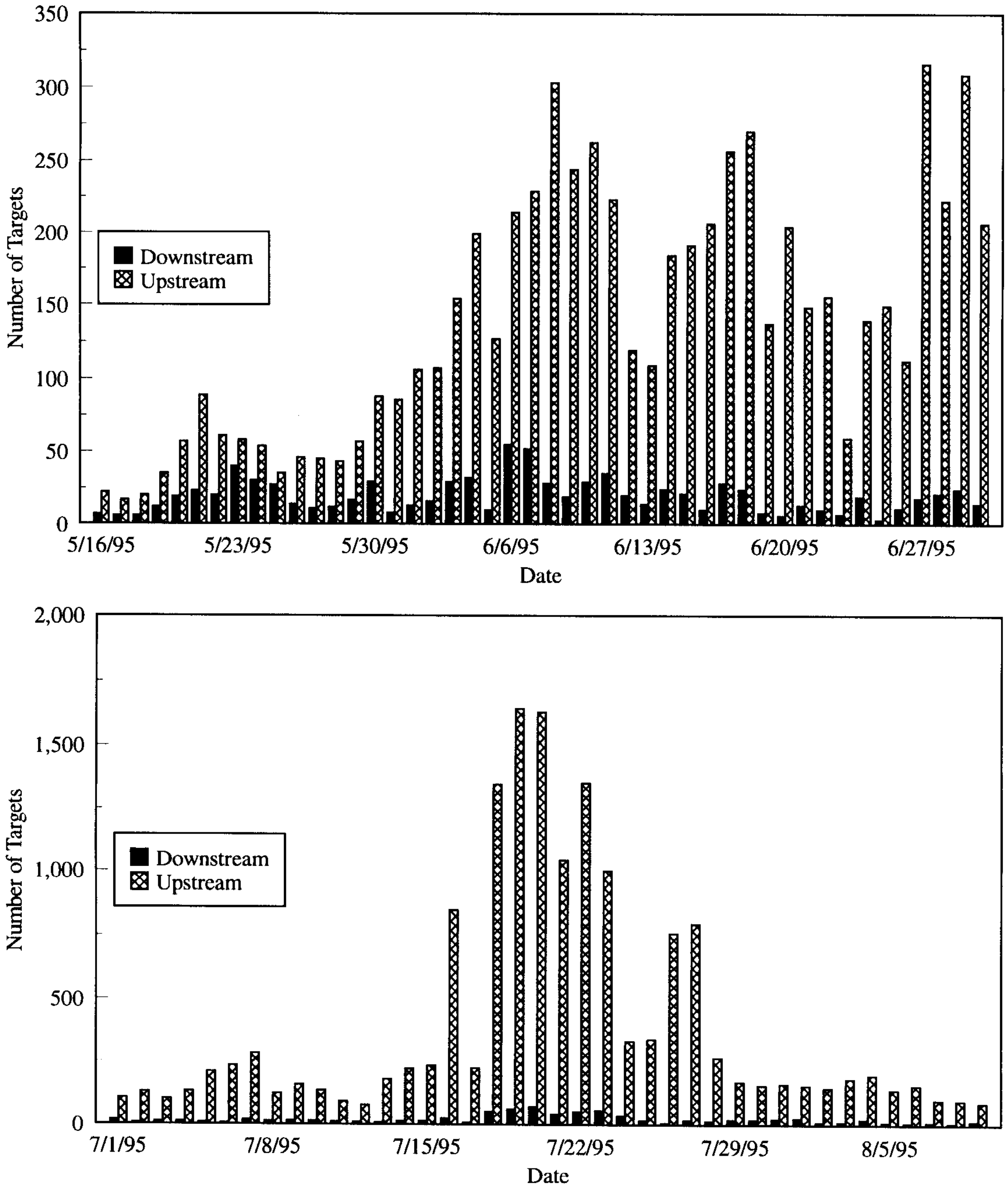

Figure 3.-Number of tracked targets, by date and direction of travel, early (Top) and late (Bottom) runs, 1995.

Table 5.-Direction of travel by range for targets, from 16 May to 30 June 1995.

Range (m)	Downstream Targets	Upstream Targets	Percent of Total Downstream	Percent of Total Upstream	Downstream Percent	Upstream Percent
Right Bank						
0 - 4.99	0	10	0.0%	0.2%	0.0%	100.0%
5 - 9.99	3	163	0.5%	3.1%	1.8%	98.2%
10 - 14.99	18	320	3.0%	6.1%	5.3%	94.7%
15 - 19.99	49	403	8.2%	7.7%	10.8%	89.2%
20 - 24.99	75	447	12.5%	8.5%	14.4%	85.6%
25 - 29.99	72	530	12.0%	10.1%	12.0%	88.0%
30 - 34.99	61	657	10.2%	12.5%	8.5%	91.5%
35 - 39.99	63	772	10.5%	14.7%	7.5%	92.5%
40 - 44.99	115	883	19.2%	16.8%	11.5%	88.5%
45 - 49.99	110	717	18.4%	13.6%	13.3%	86.7%
50 - 54.99	32	360	5.4%	6.8%	8.2%	91.8%
55 - 59.99	0	2	0.0%	0.0%	0.0%	100.0%
Total	598	5,264	100.0%	100.0%		
Left Bank						
0 - 4.99	0	31	0.0%	2.6%	0.0%	100.0%
5 - 9.99	7	42	2.4%	3.5%	14.3%	85.7%
10 - 14.99	11	61	3.7%	5.0%	15.3%	84.7%
15 - 19.99	29	96	9.8%	7.9%	23.2%	76.8%
20 - 24.99	51	146	17.2%	12.1%	25.9%	74.1%
25 - 29.99	128	526	43.2%	43.3%	19.6%	80.4%
30 - 34.99	70	312	23.6%	25.7%	18.3%	81.7%
Total	296	1,214	100.0%	100.0%		

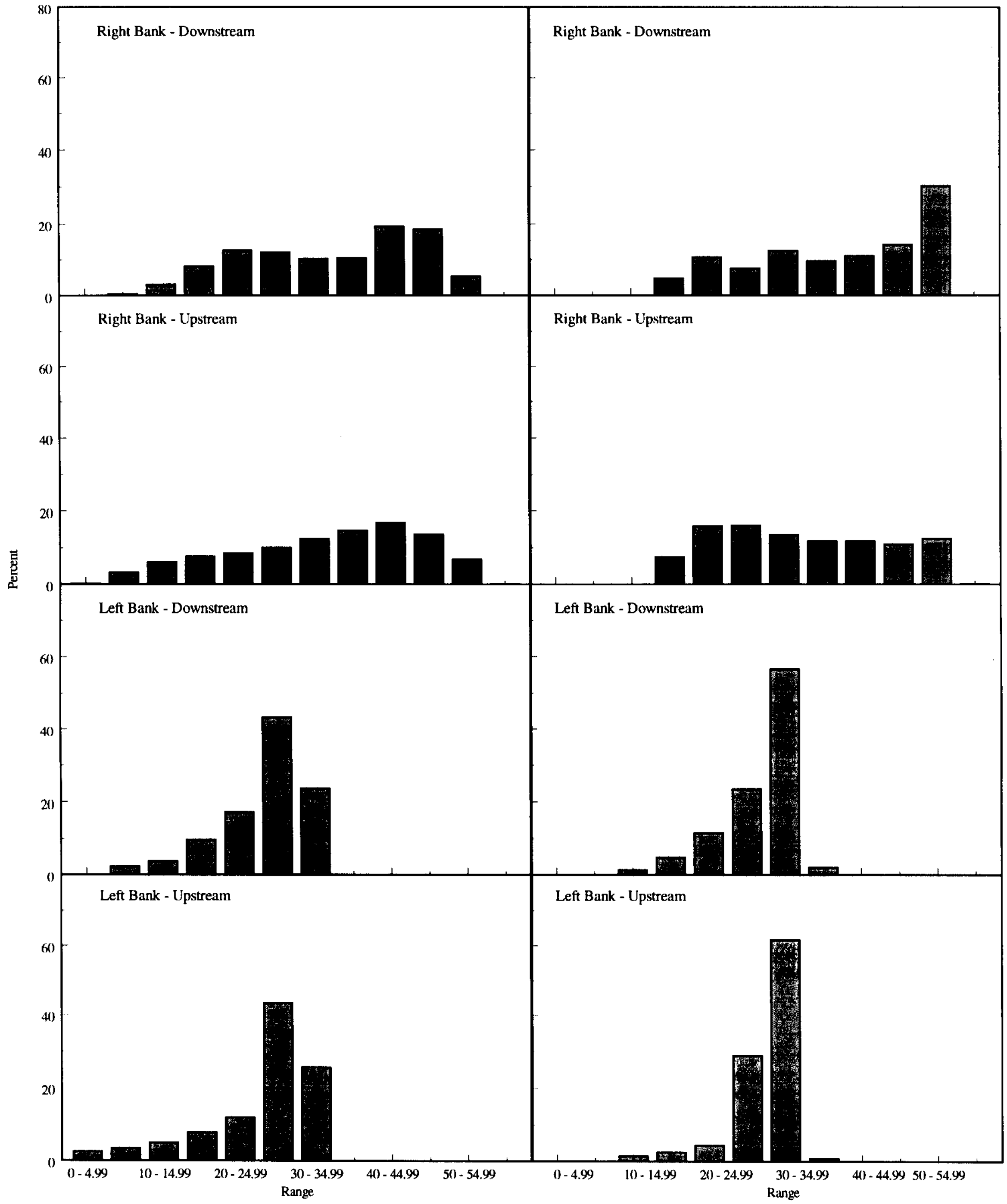

Figure 4.-Percent of targets falling within range categories (distance from transducer) during the early (16 May-30 June) and late (1 July-9 August) runs of chinook salmon to the Kenai River, 1995. Range for the left bank ends at 34.99.

Table 6.-Direction of travel by range, for targets from 1 July to 9 August 1995.

Range (m)	Downstream Targets	Upstream Targets	Percent of Total Downstream	Percent of Total Upstream	Downstream Percent	Upstream Percent
Right Bank						
15.00 - 19.99	33	1115	4.8%	7.5%	2.9%	97.1%
20.00 - 24.99	74	2,347	10.7%	15.9%	3.1%	96.9%
25.00 - 29.99	52	2,367	7.5%	16.0%	2.1%	97.9%
30.00 - 34.99	86	1,980	12.4%	13.4%	4.2%	95.8%
35.00 - 39.99	66	1,752	9.5%	11.9%	3.6%	96.4%
40.00 - 44.99	76	1,745	11.0%	11.8%	4.2%	95.8%
45.00 - 49.99	97	1,624	14.0%	11.0%	5.6%	94.4%
50.00 - 54.99	208	1,850	30.1%	12.5%	10.1%	89.9%
55.00 - 59.99	0	2	0.0%	0.0%	0.0%	100.0%
Total	692	14,782	100.00%	100.00%		
Left Bank						
10.00 - 14.99	2	15	1.4%	1.5%	11.8%	88.2%
15.00 - 19.99	7	26	4.7%	2.6%	21.2%	78.8%
20.00 - 24.99	16	44	11.1%	4.4%	26.7%	73.3%
25.00 - 29.99	34	288	23.6%	29.0%	10.6%	89.4%
30.00 - 34.99	82	613	56.9%	61.7%	11.8%	88.2%
35.00 - 39.99	3	7	2.1%	0.7%	30.0%	70.0%
Total	144	993	100.0%	100.0%		

During the late run on the right bank, downstream targets had slightly higher ($t = -3.20$, df = 15,472, $P = 0.001$) mean target strength (mean = -24.11 dB, SD = 1.89, n = 692) than upstream targets (mean = -24.35 dB, SD = 1.91, n = 14,782), although the difference was only 0.24 dB (Figure 5). Target strength variance did not differ by direction of travel ($F = 1.02$, df = 14,781; 691, $P = 0.39$). On the left bank, the difference was again more pronounced (Figure 5); downstream targets (mean = -21.32 dB, SD = 3.77, n = 144) had 3.6 dB lower target strength on average than upstream targets (mean = -17.72 dB, SD = 2.88, n = 993). The difference was significant ($t = 11.0$, df = 168, $P < 0.001$). Target strength variance also differed by direction of travel ($F = 1.70$, df = 992; 143, $P < 0.001$).

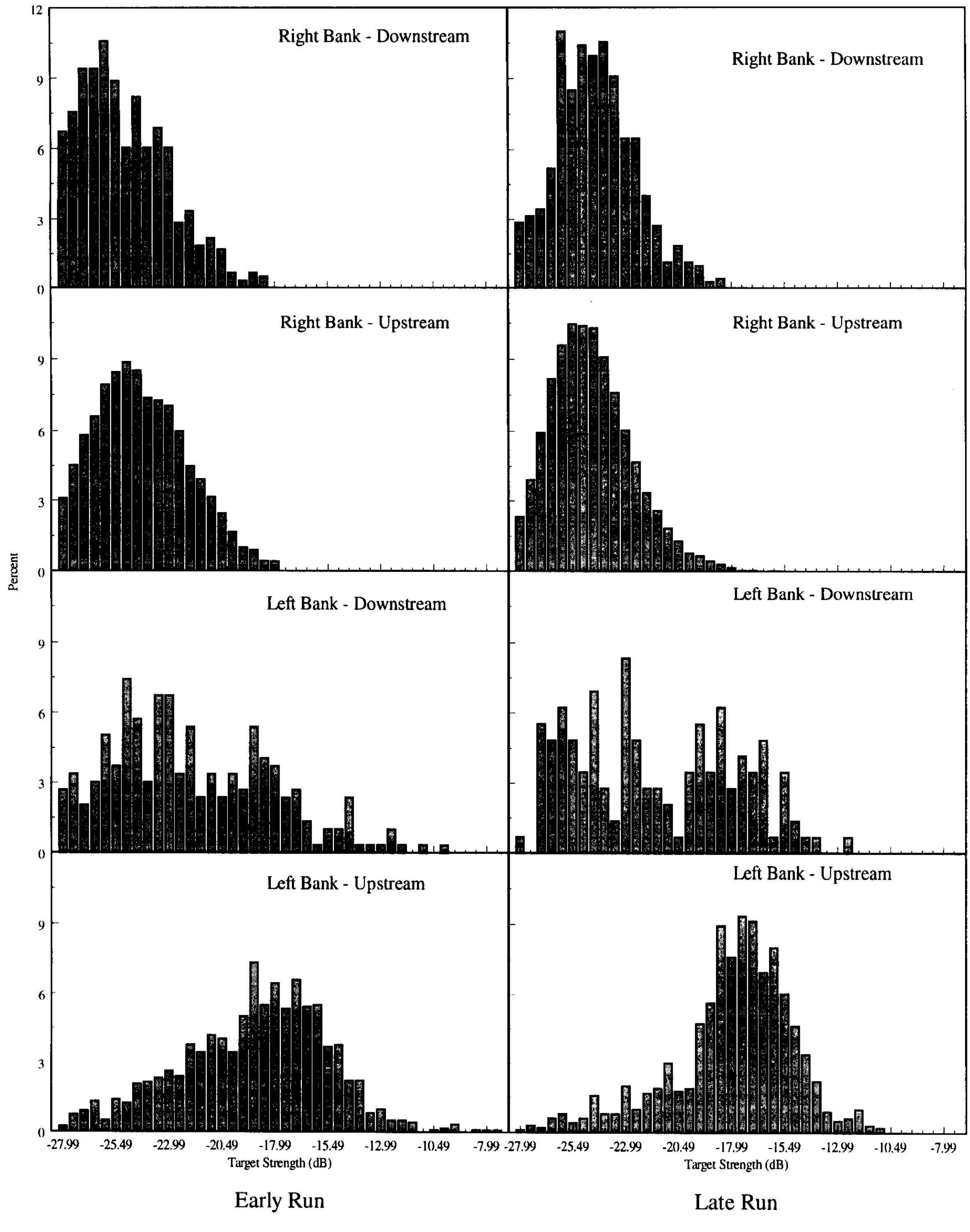

Figure 5.-Percent of targets falling within target strength categoried (dB) during the early (16 May-30 June) and late (1 July-9 August) runs of chinook salmon on the Kenai River, 1995.

Proportions of downstream targets differed only slightly between tide stages; 11% to 15% during the early run and 4% to 5% during the late run (Table 7). Thirty-eight percent of all downstream targets passed the site during falling tide during both runs, 32% and 37% were measured during rising tides, and 30% and 25% during low tide for the early and late runs, respectively (Table 7).

The primary concern with respect to both identifying and integrating downstream targets into estimates of fish passage centers around the accuracy with which we can correctly classify downstream targets as either fish or debris. A target moving actively upstream against current is easily classified as a fish. However, there is little doubt that some proportion of downstream moving targets may be debris that meet threshold criteria for valid fish targets (i.e., target strength, range and pulse width criteria). A target is 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 transits 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. Fish typically leave a meandering trace that reflects some level of active movement as it passes through the acoustic beam.

Studies from 1994 (Burwen et al. 1995) yielded the first direction of travel information using split-beam sonar. During the 1994 study, staff used new manual fish-tracking software for the first time, and minimal effort was given to visually filtering debris-like traces from consideration as fish. Target-strength distributions for downstream targets appeared to be bimodal, with the upper mode similar to the mode of the corresponding distribution of upstream targets. These data suggested that not all downstream targets were chinook salmon, but may have included smaller fish or debris. In 1995, obvious debris-like targets were excluded during the tracking procedure. Target strength distributions for upstream and downstream fish on the right bank were similar for both early and late runs (Figure 5). The downstream target strength distributions were unimodal and corresponded to the modes of the upstream target strength distributions. This suggests little contamination by debris in classifying downstream targets on the right bank. However, fish moving downstream on the left bank during both runs were, on average, considerably smaller than fish moving upstream on the left bank. The mean target strength estimates for upstream moving fish, for both runs, were 3 to 4 dB larger than the mean target strength estimates of downstream moving fish (Figure 5).

These differences in the estimates of mean target strength can most likely be explained by the effects of threshold-induced bias rather than by contamination by debris. Unlike targets on the right bank which displayed similar vertical distributions for upstream and downstream targets, downstream targets on the left bank were found to be, on average, twice as close (vertically) to the acoustic axis as upstream-moving targets, thus reducing the effects of threshold-induced bias and causing them to appear smaller. Upstream-traveling targets in the Kenai River are strongly bottom-oriented on both banks (Burwen et al. 1995). However, fish traveling upstream on the left bank may be forced closer to the bottom due to higher water velocities found on the deeper cutbank 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 a more acoustically reflective gravel compared to the acoustically lossy mud on the right bank which allows a lower grazing angle as the beam is aimed parallel to the bottom.

Table 7.-Direction of travel by tide stage for targets, 1995.

	Total # of Targets	Rising Tide	Falling Tide	Low Tide
1 May to 30 June				
Upstream number	6,478	2,158	2,847	1,473
row %	100%	33%	44%	23%
column %	88%	88%	89%	85%
Downstream number	894	291	337	266
row %	100%	32%	38%	30%
column %	12%	12%	11%	15%
Total number	7,370	2,449	3,184	1,739
Test of independence	$\chi^2 = 23.6$, df = 2, $P < 0.00001$			
1 July to 9 August				
Upstream	15,775	6,398	6,097	3,280
row %	100%	40%	39%	21%
column %	95%	96%	96%	94%
Downstream	816	300	311	205
row %	100%	37%	38%	25%
column %	5%	4%	4%	5%
Total	16,589	6,698	6,408	3,485
Test of independence	$\chi^2 = 9.7$, df = 2, $P < 0.008$			

Several approaches have been used for applying direction-of-travel information to estimates of fish passage. Many department sonar projects (e.g., side-scan Bendix as well as the Kenai River chinook sonar) do not adjust passage estimates for downstream-moving targets because this information is not or has not been available, and the downstream component is believed to be relatively small (Burwen et al. 1995). Other projects (Fleischman et al. 1995, Daum and Osborne 1995) simply do not include downstream-moving targets in passage estimates (this is the equivalent of subtracting one fish for each downstream target from the total count of targets). This method assumes that all downstream-moving targets are debris since, if a downstream target is actually a fish, two fish should be subtracted from the total count of targets. Misclassifying downstream targets as debris or fish, therefore, may have a potentially large impact on passage estimates since you subtract twice as many targets from the total count when you classify a downstream object as a fish rather than debris.

SUMMARY AND CONCLUSIONS

The number of downstream targets (both debris and fish) is relatively low and varies between runs. We have made good progress from 1994 to 1995 in our ability to classify downstream moving targets as either fish or debris. In most cases, downstream targets can easily be classified as debris or fish because their "chart signature" shows either fish-like movement (as seen on a paper chart and on the Trakman chart) or is obviously debris-like. This reduces the number of decisions technicians have to make concerning downstream targets. If a downstream target is still in question the next step is to look at an X-Y plot of the echoes of the target. Debris is often not an ordered progression of echoes (like a fish would be), but looks constellation-like. In each step of the process the technician is working to reduce the number of decisions made, thus reducing subjectivity. However, there is still some subjectivity involved in tracking and we try to reduce this to as small a sample of downstream targets as possible.

In the future, we hope to reduce the subjectivity involved in classifying downstream targets as debris or fish. Downstream targets classified as debris are currently tracked in the same manner as valid targets and stored in a separate database. Frequently, echoes from debris-like targets display a combination of features that are atypical of valid fish targets such as extreme pulse width and target strength values. Investigations continue into allowing the computer to make the final classification of downstream targets using a discrimination function algorithm based on such acoustic information.

EXPERIMENT II: ACOUSTIC MEASUREMENTS ON TETHERED LIVE FISH

Ehrenberg (1984) first suggested that target strength might be used to discriminate between different species of salmon in rivers, given large enough differences in size between species and a sufficient number of measurements on each fish. In 1985 and 1986, ADF&G deployed dual-beam sonar in the Kenai River to assess whether chinook salmon could be discriminated from smaller salmon based on target strength. These studies found that the mean target strength of fish had a bimodal distribution, with the two modes approximately 12 decibels (dB) apart and separated by a notch at approximately -28 dB. The two modes were believed to correspond to sockeye and chinook salmon (Paul Skvorc, Alaska Department of Fish and Game, Anchorage, personal communication). Beginning in June 1987 chinook salmon passage was estimated based on the number of targets with means exceeding -28 dB.

There were some early indications that the -28 dB threshold was not excluding all sockeye salmon. There were sometimes numerous nearshore targets on the echograms which differed greatly in appearance from the usual targets yet exceeded the -28 dB threshold. Range thresholds were developed in 1989 which excluded nearshore targets from counts of chinook salmon.

More recently, the theoretical validity of discriminating sockeye and chinook salmon based on target strength has been questioned. Eggers et al. (1995) noted that the observed 12 dB difference in target strength modes from the 1985 and 1986 data was inconsistent with predictions from most models of target strength versus length, given the observed length distributions of sockeye and chinook salmon in the Kenai River. These models, based on theoretical considerations as well as empirical data (MacLennan and Simmonds 1992), would have predicted approximately a 5 dB difference between modes of sockeye and chinook salmon. Eggers (1994) also used a stochastic computer model to simulate target strength distributions under different mixtures of species and different interrogation rates (number of measurements per fish). Under ideal conditions for sonar (low noise, low threshold), predictions were that the resulting target strength distributions should have been unimodal, not bimodal. Eggers concluded that, under idealized conditions, it would not be possible to completely discriminate Kenai River sockeye and chinook salmon based on mean target strength.

Split-beam sonar was deployed at the site in 1994 (Burwen et al. 1995) in part to reproduce 1985-1986 results which had showed bimodal target strength distributions. No such bimodal distributions were detected in 1994. Furthermore, as in 1989, most nearshore targets during the peak of the sockeye salmon run exceeded -28 dB. We believed these targets to be composed primarily of sockeye salmon.

Although the target strength threshold did not appear to be working as intended, direct evidence was lacking. Live fish, tethered in front of the split-beam sonar on the right bank, enabled us to obtain *in-situ* measurements of target strength and other acoustic parameters on fish of known size and species. Captured live salmon were conveniently available from a concurrent gill-netting study being conducted at the sonar site (Section III). Our primary objective was to document the relationship between mean target strength and fish size, by species. Secondarily, we wished to explore the potential for using other measured acoustic parameters for discriminating fish of different sizes.

METHODS

Fish Deployment

Live sockeye, chinook and coho salmon were obtained from the drift gillnet project conducted in front of the sonar site (Section III). Fish were sampled opportunistically, except that we attempted to obtain fish with a wide range of sizes. Fish were held in live pens or totes until they could be deployed. Length and girth of each fish were measured, then a 6-inch cable tie was inserted through a small hole in the anterior edge of the jaw and secured around the dentary. This technique could be performed without any loss of blood or other observable harm to the fish. The fish was then attached to approximately 30 feet of 180-lb test Dacron fishing line which led to two 3-lb lead downrigger weights (Figure 6). Another section of Dacron line (approximately 20 feet in length) led to a buoy on the surface. The buoy, in turn, was attached with ½ inch polypropylene line to an anchor upstream. Fish were deployed from 13 m to 41 m from the transducer. Using this technique, we were able to isolate the fish from other scattering surfaces (i.e. the lead weights, buoy, etc.).

Occasionally water-borne debris collected where the line attached to the fish. When the amount of debris was excessive, we discarded the associated data. Otherwise, we recorded its presence or absence.

Hydroacoustic Data Collection

Equipment, calibration, and transducer deployment are described in Experiment 1. Only the right-bank transducer was used to collect data on tethered fish. Usually we collected data with the same aim used for estimating fish passage, although occasionally it was necessary to use a slightly higher aim (Table 8). Data collection and processing parameters were the same as those used to estimate fish passage, except that the minimum threshold voltage was set slightly lower (equivalent to a -35 dB target on-axis compared to -33 dB; Table 9, Table 10).

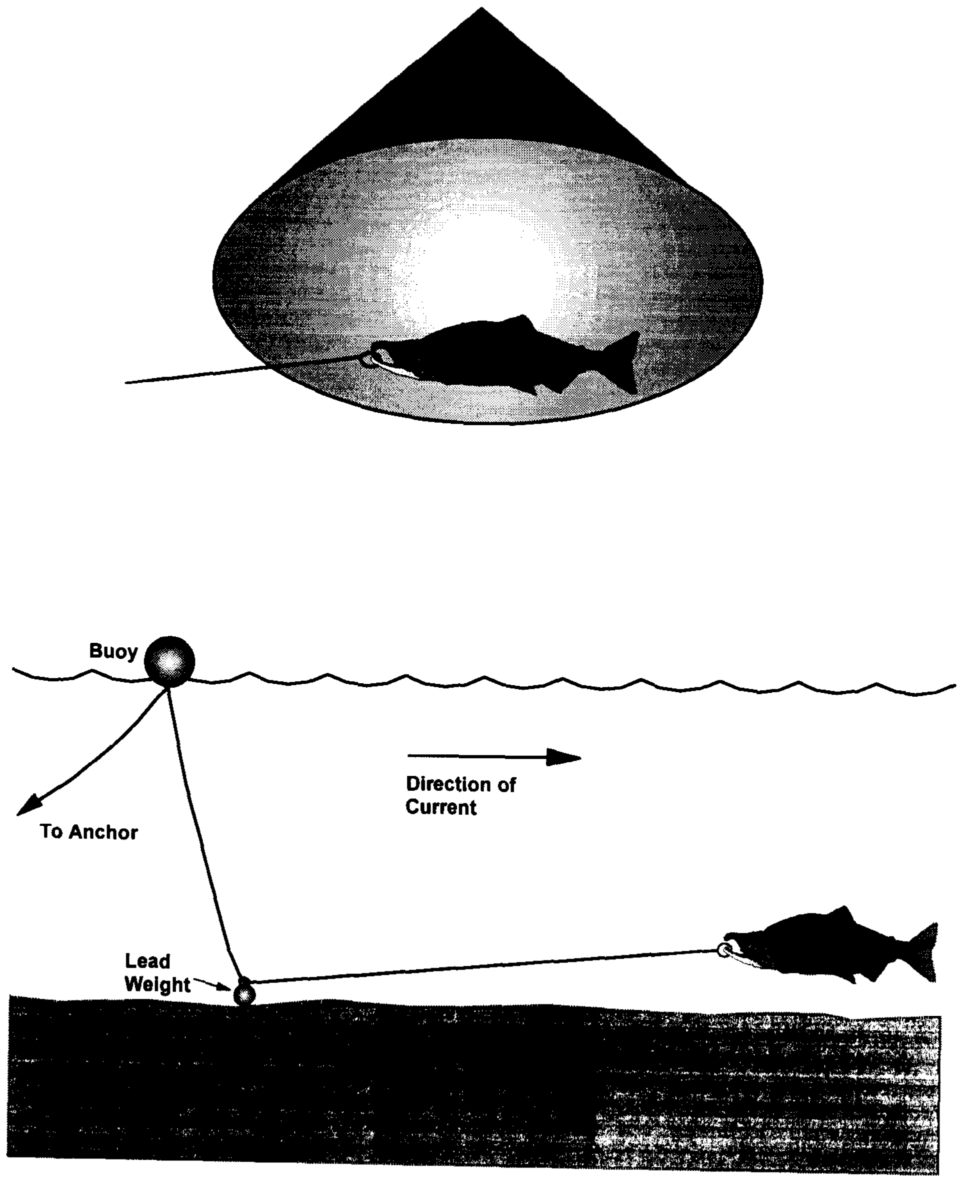

Figure 6.-Configuration used to tether live fish for acoustic data collection, 1995.

Table 8.-Fish tethered live in front of right bank transducer, 1995.

Fish Number	Date	Time	Tide Stage[a]	Species	Sex	Length (mm)	Girth (mm)	Debris[b]	Transducer Aim[c]	Activity[d]
1	6/19/95	1247	F	chinook	?	610		N	M	M
2	6/19/95	1322	F	chinook	?	990		N	M	MH
3	6/19/95	1342	F	sockeye	?	560		N	N	L
4	6/19/95	1420	L	chinook	M	520		N	N	LM
5	6/20/95	1802	F	chinook	M	1050		N	N	L
6	6/20/95	1843	L	chinook	M	880	570	N	N	M
7	6/20/95	1900	L	sockeye	M	600	360	N	N	L
8	6/20/95	2000	L	chinook	M	1030	730	N	N	H
9	6/21/95	1700	F	sockeye	M	580	320	Y	N	L
10	6/21/95	1841	L	chinook	M	1040	760	Y	N	M
11	6/26/95	1041	L	chinook	M	900	510	N	N	L
12	6/26/95	1149	L	chinook	F	1050	700	N	NM	L
13	6/26/95	1344	L	chinook	?	945	520	N	N	MH
14	6/27/95	1000	F	chinook	M	1140	750	N	N	LM
15	6/27/95	1100	L	chinook	M	990	705	N	N	M
16	6/27/95	1202	L	chinook	M	760		Y	N	L
17	6/27/95	1247	L	chinook	?	720	490	N	N	M
18	6/28/95	900	F	chinook	M	790	490	Y	N	L
19	6/28/95	948	F	chinook	F	1025	700	Y	N	LM
20	6/28/95	1056	L	chinook	M	865	635	Y	N	LM
21	6/28/95	1140	L	chinook	M	620	400	N	N	MH
22	6/28/95	1200	L	chinook	?	1070	770	N	N	M
23	6/28/95	1344	L	chinook	M	1090	740	N	N	M
24	6/28/95	1400	L	chinook	?	930	610	N	N	L
25	6/28/95	1500	L	chinook	F	960	585	N	N	H
26	6/28/95	1541	R	chinook	F	1050	715	N	N	L
27	7/3/95	1300	L	sockeye	?	590	370	N	N	L
28	7/3/95	1500	L	chinook	?	1030	700	N	N	L
29	7/3/95	1545	L	sockeye	M	590	360	N	N	L
30	7/3/95	1700	L	chinook	M	1040	760	N	N	M
31	7/3/95	1740	L	chinook	F	890	595	N	N	L
32	7/3/95	1800	R	chinook	F	700	590	N	M	M
33	7/5/95	1509	L	chinook	M	500	345	N	N	LM
34	7/5/95	1547	L	sockeye	?	565	350	N	M	L
35	7/5/95	1700	L	sockeye	?	610	425	N	N	L
36	7/5/95	1742	L	chinook	M	515	365	Y	N	L
37	7/5/95	1800	L	sockeye	?	550	350	N	N	L
38	7/5/95	1848	L	chinook	M	910	620	N	N	MH
39	7/6/95	1642	L	chinook	M	1010	715	N	N	L
40	7/6/95	1700	L	sockeye	M	620	380	N	N	L
41	7/6/95	1746	L	sockeye	M	550	355	N	N	L
42	7/6/95	1755	L	sockeye	M	490	310	Y	M	L
43	7/6/95	1815	L	chinook	M	840	390	N	N	LM
44	7/7/95	1743	F	chinook	M	775	540	N	N	M
45	7/7/95	1803	F	chinook	F	1065	700	N	N	M
46	7/7/95	1840	F	chinook	M	565	385	Y	N	L
47	7/7/95	1900	F	chinook	M	570	400	N	N	LM
48	7/7/95	2000	L	chinook	F	970	645	Y	N	LM
49	7/7/95	2051	L	chinook	M	970	700	N	N	LM

-continued-

Table 8.-Page 2 of 2.

Fish Number	Date	Time	Tide Stage[a]	Species	Sex	Length (mm)	Girth (mm)	Debris[b]	Transducer Aim[c]	Activity[d]
50	7/10/95	840	L	chinook	M	710	490	N	N	L
51	7/10/95	900	L	chinook	?	615	380	N	N	L
52	7/10/95	941	L	chinook	F	1060	615	N	N	L
53	7/10/95	1000	L	chinook	?	645	450	Y	N	L
54	7/10/95	1041	L	chinook	?	630	425	N	N	M
55	7/10/95	1141	L	chinook	M	1000	665	N	N	L
56	7/17/95	1355	L	sockeye	?	475	305	N	N	L
57	7/17/95	1407	L	sockeye	?	600	400	Y	N	L
58	7/24/95	1348	R	sockeye	M	645	400	N	N	L
59	7/24/95	1441	R	sockeye	F	550	345	N	N	L
60	7/24/95	1553	R	sockeye	F	590	375	N	N	L
61	7/24/95	1700	F	chinook	?	945	655	N	N	MH
62	7/24/95	1741	F	sockeye	?	530	360	N	N	L
63	7/24/95	1840	F	sockeye	?	620	365	N	N	L
64	7/24/95	1849	F	sockeye	F	560	350	N	N	L
65	7/24/95	1900	F	sockeye	F	580	330	N	M	L
66	7/24/95	1940	F	sockeye	F	550	340	N	N	L
67	7/24/95	1949	F	sockeye	M	610	405	N	N	L
68	7/24/95	2000	F	sockeye	F	590	365	N	N	LM
69	7/24/95	2012	F	sockeye	F	595	365	N	N	M
70	7/24/95	2040	F	chinook	?	765	465	N	N	MH
71	7/24/95	2100	F	chinook	M	580	350	N	N	L
72	8/2/95	1100	F	sockeye	?	505	270	Y	N	L
73	8/2/95	1200	F	sockeye	?	515	310	Y	N	L
74	8/2/95	1240	F	sockeye	?	440	275	Y	N	L
75	8/2/95	1400	L	sockeye	F	595	360	N	N	M
76	8/2/95	1440	L	sockeye	M	600	380	N	N	L
77	8/2/95	1545	L	sockeye	M	600	375	N	N	L
78	8/7/95	743	L	coho	M	555	360	N	N	L
79	8/9/95	1043	L	coho	?	545	380	Y	N	L
80	8/9/95	1100	L	coho	?	570	385	Y	N	L
81	8/9/95	1152	L	coho	?	565	350	N	N	L
82	8/9/95	1232	L	chinook	?	785	555	N	N	L
83	8/9/95	1256	L	coho	?	570	360	N	N	L
84	8/9/95	1310	L	coho	?	635	400	N	N	L
85	8/9/95	1321	L	sockeye	M	615	410	N	N	L
86	8/9/95	1334	L	sockeye	M	600	360	N	N	L
87	8/9/95	1352	R	sockeye	?	530	290	N	N	?
88	8/10/95	900	F	coho	M	690	450	N	N	L
89	8/10/95	912	F	sockeye	M	620	400	N	N	L
90	8/10/95	1000	F	sockeye	M	640	420	N	M	L
91	8/10/95	1010	F	sockeye	M	635	400	Y	N	M
92	8/10/95	1117	L	sockeye	M	580	395	N	N	M
93	8/10/95	1200	L	sockeye	?	540	290	?	N	L

[a] F = Falling tide; L = Low tide; R = Rising tide

[b] Y = Yes, a small amount of debris present (generally a clump of weeds that was golf ball sized or less); N = No debris present

[c] N = Normal aim used for estimating fish passage (grazing river bottom); M = aimed up toward middle of water column to keep fish in beam;

[d] L = Low activity level, very little movement in x, y, and z axes; LM = Low to Medium activity, generally low activity level interrupted by periods of gradual movement in x, y, z axes; M = Medium activity, sample period dominated by gradual but distinct movement in x, y, z axes; MH = Medium to high activity level, generally medium activity level with some periods of frequent and abrupt movement in x, y, z axes.

Table 9.-Summary of echo sounder collection parameters for the HTI Model 240 Split-beam Echosounder and Model 250 Digital Echo Processor during data collection on 93 tethered live fish, 1995.

Echo Sounder Parameters	Value
Transmit Power	25 dB_w
Receiver Gain	-18 dB_v
TVG	40LogR
Transmitted Pulse Length	0.2 msec
Ping Rate	8 pings/sec

Table 10.-Summary of processing parameters and filters for the Model 250 Digital Echo Processor during data collection on 93 tethered live fish, 1995.

Digital Echo Processor Parameters	Value
Target strength (voltage) threshold	-35 dB (600 mV)
Maximum vertical off-axis angle	2.0^o
Maximum horizontal off-axis angle	5.0^o
-6 dB min. pulse filter	0.15 msec
-6 dB max. pulse filter	0.3 msec
-12 dB min. pulse filter	0 msec
-12 dB max. pulse filter	2 msec
-18 dB min. pulse filter	0 msec
-18 dB max. pulse filter	2 msec

We recorded acoustic parameters for 440 to 9,300 echoes per fish, including sum channel voltage, x-axis angle, y-axis angle, range, and pulse width at 6, 12, and 18 dB below peak voltage. Beam pattern factor was determined from x-axis angle and y-axis angle. Target strength was calculated following methods in Appendix B. For each fish, we recorded tide stage and maximum background noise level in millivolts, as well as a subjective index of fish movement with values ranging from 1 (fish stationary in beam) to 5 (fish very active).

Fish traces were manually tracked using proprietary software supplied by HTI[2]. Only echoes that could be reliably attributed to tethered fish were included.

Analytical Methods

Target strength was regressed against log-transformed fish length (MacLennan and Simmonds 1992:189). We tested for effects of range, transducer aim, position in the beam, fish movement, and background noise on target strength using regression analysis. We tested for effects of tide stage and debris on target strength measurements using analysis of covariance. To reduce the effects of fish movement on measured target strength, we filtered data to remove echoes collected during high rates of side-to-side movement. To quantify this movement, we calculated the change in range (distance from transducer) between adjacent pings, and averaged the absolute changes in range before and after each echo:

$$\bar{d}_{ij} = \frac{\left|r_{ij} - r_{i,j-1}\right| + \left|r_{i,j+1} - r_{ij}\right|}{2}, \tag{2.1}$$

where $\bar{d}_{ij}$ is the mean absolute change in range before and after echo i from fish j, and r_{ij} is the range of fish i during echo j. Echoes with mean absolute range change greater than the median absolute range change for all echoes for all fish were censored. We performed a second filtering procedure on the remaining echoes to reduce the effects of fish vertical position in the beam on measured target strength. We calculated the median absolute y-axis angle over all echoes for all fish, and censored all echoes exceeding it.

Echoes in this study (up to several thousand echoes per fish) far exceeded those recorded for free-swimming fish ($\bar{x}$=45 echoes per fish), which generally remain in the beam for only a few seconds. We used resampling methods to assess the degree to which the discriminatory power of target strength would decline if mean target strength were estimated less precisely (with fewer echoes) on each fish. Specifically, we simulated how target strength distributions for tethered fish might change under conditions present for sampling free-swimming fish on the right bank of the Kenai in 1995 (23,694 fish @ $\bar{x}$=45 echoes each). We resampled, at random and with replacement, 20,000 fish from the 93 tethered fish in this study. We then resampled, at random and with replacement, 45 echoes from each resampled fish and calculated mean target strength.

RESULTS AND DISCUSSION

We deployed and took measurements on 93 fish from 19 June to 10 August (Table 11), including 48 chinook salmon, 38 sockeye salmon, and 7 coho salmon. Neither range (t=1.24, df=90, P=0.22), horizontal position in the beam (t=1.69, df=90, P=0.09), tide stage (F=0.72, df=289, P=0.49), presence or absence of debris (F=0.34, df=1,89, P=0.71), nor background noise (t=0.24, df=86, P=0.81) had a detectable effect on the relationship between fish length and measured target strength. However fish movement, vertical position in the beam, and transducer aim did have significant effects. Controlling for fish length, more active fish had lower target strength readings (t=-4.76, df=89, P<0.0001), and fish ensonified greater vertical distances from the center of the beam had higher target strength readings (t=4.88, df=90, P<0.0001). Higher

[2] Mention of a company's name does not constitute endorsement.

Table 11.-Acoustic measurements of fish tethered live in front of right bank transducer, 1995.

Fish No.	Species	Length mm	Pings	X-axis angle	Y-axis angle	Range m	Background Noise mV	-6 dB Pulse Width Mean	-6 dB Pulse Width SD	-12 dB Pulse Width Mean	-12 dB Pulse Width SD	-18 dB Pulse Width Mean	-18 dB Pulse Width SD	Volts Mean	Volts SD	Beam Pattern Factor (dB) Mean	Beam Pattern Factor (dB) SD	Target Strength (dB) Mean	Target Strength (dB) SD
1	Chinook	610	930	-0.12	-0.03	21.7		9.2	1.42	12.0	1.87	14.1	1.96	1.15	0.43	-0.63	0.95	-29.2	2.93
2	Chinook	990	1,485	0.13	0.00	12.9		9.6	1.73	13.3	3.03	16.4	3.58	1.37	0.60	-2.45	2.31	-26.1	3.47
3	Sockeye	560	2,025	0.13	-0.14	17.2		9.2	1.17	12.4	1.63	14.6	1.89	1.93	0.96	-0.91	1.00	-25.0	4.15
4	Chinook	520	3,460	-0.09	-0.13	17.5		9.5	1.45	13.0	2.30	15.5	2.68	1.93	1.18	-1.18	1.30	-24.9	4.53
5	Chinook	1,050	3,838	0.35	-0.29	33.6	550	9.7	1.75	14.3	4.24	18.4	5.02	2.09	1.23	-1.04	0.84	-24.2	4.23
6	Chinook	880	3,234	-0.14	-0.20	25.0	550	9.4	1.69	13.2	3.37	16.5	3.90	1.28	0.71	-1.33	1.42	-28.0	3.94
7	Sockeye	600	3,936	-0.11	-0.21	22.4	600	9.4	1.31	12.8	1.89	15.1	2.02	2.33	1.44	-1.48	1.70	-23.2	4.89
8	Chinook	1,030	2,781	0.36	-0.08	28.9	550	9.6	1.67	14.1	3.80	17.9	4.70	2.27	1.36	-2.02	2.03	-22.6	4.66
9	Sockeye	580	1,006	0.39	-0.21	19.7	550	8.7	0.99	11.4	1.32	13.1	1.51	1.08	0.37	-3.19	2.05	-27.1	3.19
10	Chinook	1,040	9,319	0.67	-0.20	25.2	550	9.8	1.66	15.1	4.39	19.7	5.29	2.84	1.72	-2.60	1.90	-20.4	5.18
11	Chinook	900	3,998	0.17	-0.14	16.2	400	9.0	1.07	12.0	1.61	14.1	1.92	1.71	0.85	-2.24	1.71	-24.7	4.27
12	Chinook	1,050	5,608	0.52	-0.04	16.1	400	9.8	1.73	14.5	4.09	18.5	4.87	1.62	0.90	-2.70	2.13	-24.7	4.17
13	Chinook	945	3,828	0.23	-0.27	24.2	400	9.4	1.62	13.6	3.75	17.0	4.39	1.48	0.84	-1.58	1.33	-26.6	4.31
14	Chinook	1,140	7,039	-0.02	-0.10	20.6	400	9.8	1.68	14.6	4.05	18.9	4.87	2.33	1.48	-2.82	2.58	-21.9	5.26
15	Chinook	990	3,095	0.12	0.08	23.1	400	9.7	1.62	14.0	3.41	17.1	3.93	1.80	1.04	-2.11	2.22	-24.5	4.81
16	Chinook	760	4,843	-0.16	-0.30	23.5	250	9.5	1.57	12.7	2.31	15.0	2.48	1.31	0.57	-2.51	1.79	-26.3	3.66
17	Chinook	720	2,894	0.09	-0.29	20.0	350	9.3	1.58	12.7	2.77	15.4	3.15	1.29	0.66	-2.83	2.22	-26.4	4.27
18	Chinook	790	6,222	-0.03	-0.25	19.9	600	9.5	1.42	13.1	2.49	15.7	3.02	1.83	1.04	-2.31	1.97	-24.2	4.61
19	Chinook	1,025	7,222	-0.18	-0.09	15.0	500	9.7	1.70	14.1	3.57	17.7	4.10	1.68	0.88	-2.13	2.26	-24.9	4.22
20	Chinook	865	1,606	-0.02	0.06	15.8	300	9.8	1.77	13.9	3.19	17.2	3.43	1.49	0.78	-2.07	2.18	-26.0	4.09
21	Chinook	620	468	-0.21	-0.19	23.1	500	9.0	1.38	12.0	2.11	14.0	2.52	1.05	0.40	-1.41	1.47	-29.2	3.08
22	Chinook	1,070	2,358	0.17	-0.05	22.2	400	9.9	1.77	15.1	4.15	19.4	5.02	2.14	1.29	-1.97	1.97	-23.3	4.85
23	Chinook	1,090	1,751	-0.34	0.21	34.4	500	9.6	1.66	14.3	4.12	18.4	5.01	1.64	1.01	-1.17	1.53	-26.3	4.41
24	Chinook	930	2,358	0.06	-0.10	18.0	600	9.7	1.76	14.0	3.26	17.0	3.45	1.47	0.73	-2.02	2.05	-26.0	3.91
25	Chinook	960	3,482	0.33	-0.25	19.3	600	9.4	1.78	13.1	3.57	16.4	4.07	1.06	0.44	-2.45	1.84	-28.2	3.42
26	Chinook	1,050	1,291	-0.23	-0.27	13.7	250	9.7	1.69	15.0	4.02	19.1	4.47	2.27	0.91	-4.35	2.83	-19.7	4.61
27	Sockeye	590	1,563	0.07	-0.45	24.4	500	9.2	1.49	12.1	2.05	14.1	2.11	1.12	0.43	-4.34	2.66	-25.8	3.78
28	Chinook	1,030	2,970	0.00	-0.66	40.7	500	9.4	1.61	13.1	3.07	16.0	3.72	1.79	0.88	-2.78	1.79	-23.5	3.94
29	Sockeye	590	1,000	0.47	-0.42	32.1	400	8.9	1.25	11.6	1.76	13.6	1.92	1.02	0.35	-2.10	1.70	-28.7	3.00
30	Chinook	1,040	2,414	-0.80	0.06	35.7	450	9.8	1.77	14.7	4.19	19.0	5.00	1.81	1.15	-2.86	2.73	-23.9	4.97
31	Chinook	890	4,515	0.11	-0.36	37.8	450	9.7	1.68	14.4	3.56	18.0	3.81	2.25	1.32	-1.19	1.10	-23.6	4.71

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Table 11.-Page 2 of 3.

Fish No.	Species	Length mm	Pings	X-axis angle	Y-axis angle	Range m	Background Noise mV	-6 dB Pulse Width Mean	-6 dB Pulse Width SD	-12 dB Pulse Width Mean	-12 dB Pulse Width SD	-18 dB Pulse Width Mean	-18 dB Pulse Width SD	Volts Mean	Volts SD	Beam Pattern Factor (dB) Mean	Beam Pattern Factor (dB) SD	Target Strength (dB) Mean	Target Strength (dB) SD
32	Chinook	700	1,373	0.13	0.49	33.3	300	9.2	1.53	12.0	2.20	14.1	2.46	1.00	0.36	-3.85	3.50	-27.1	4.22
33	Chinook	500	878	0.06	-0.07	27.4	500	8.9	1.32	11.5	1.77	13.4	1.75	1.02	0.34	-1.53	2.01	-29.3	2.96
34	Sockeye	565	696	-0.12	0.19	25.7	350	8.6	1.10	10.9	1.66	12.3	0.95	0.88	0.20	-2.10	2.25	-29.7	2.43
35	Sockeye	610	6,398	-0.89	-0.47	28.3	580	9.4	1.37	12.9	2.10	15.5	2.38	2.05	1.07	-3.51	2.12	-21.9	4.75
36	Chinook	515	897	0.12	-0.36	27.7	400	9.4	1.32	12.5	1.87	14.7	2.02	1.56	0.67	-1.54	1.03	-25.9	3.63
37	Sockeye	550	3,154	0.27	-0.42	27.9	400	9.5	1.44	12.8	2.15	15.1	2.25	1.55	0.77	-2.19	1.47	-25.5	4.05
38	Chinook	910	3,374	0.14	-0.25	26.1	400	9.5	1.70	13.7	3.65	17.2	4.39	1.38	0.74	-2.43	2.17	-26.2	4.45
39	Chinook	1,010	1,349	-0.95	-0.56	32.3	500	9.8	1.72	15.2	4.14	19.7	4.44	2.29	1.29	-3.93	2.67	-20.6	4.95
40	Sockeye	620	2,149	0.25	-0.36	25.2	500	9.4	1.47	12.6	2.14	15.0	2.40	1.47	0.79	-2.49	1.70	-25.7	4.32
41	Sockeye	550	1,004	0.01	-0.57	24.5	500	8.9	1.15	11.7	1.52	13.6	1.67	1.34	0.65	-4.76	2.04	-24.0	4.20
42	Sockeye	490	1,766	0.21	0.07	22.0	400	9.0	1.20	11.7	1.65	13.6	1.86	1.15	0.46	-2.98	2.56	-26.9	3.66
43	Chinook	840	2,041	0.10	-0.49	25.5	600	9.6	1.65	13.2	2.84	15.8	3.22	1.39	0.62	-3.59	2.20	-24.9	4.14
44	Chinook	775	1,280	-0.35	-0.28	24.5	500	9.6	1.60	13.6	3.35	16.7	3.76	1.46	0.75	-1.70	1.40	-26.5	3.83
45	Chinook	1,065	607	0.21	-0.35	31.5	500	9.8	1.72	15.6	4.37	20.7	5.12	2.35	1.19	-1.62	1.32	-22.5	4.53
46	Chinook	565	1,145	0.18	-0.39	25.8	500	9.8	1.58	13.5	2.47	16.1	2.77	1.62	0.75	-2.18	1.27	-25.0	3.96
47	Chinook	570	3,339	0.65	-0.28	26.7	500	9.5	1.62	12.8	2.64	15.5	3.05	1.26	0.61	-1.87	1.43	-27.5	3.86
48	Chinook	970	2,664	-1.54	-0.68	36.4	500	9.6	1.57	13.8	3.50	17.3	4.49	1.75	0.98	-4.84	3.09	-22.0	5.13
49	Chinook	970	1,208	-0.58	-0.39	30.3	450	9.8	1.65	14.5	3.58	18.9	4.50	2.75	1.77	-2.61	2.52	-20.9	5.51
50	Chinook	710	2,694	0.12	-0.55	26.8	400	9.6	1.53	13.3	2.52	15.9	2.83	1.68	0.80	-3.99	2.15	-23.0	4.27
51	Chinook	615	3,858	0.34	-0.26	28.6	400	9.4	1.53	12.6	2.54	15.2	3.18	1.24	0.55	-2.79	2.01	-26.6	3.91
52	Chinook	1,060	2,669	-0.02	-0.56	28.5	450	9.8	1.70	14.3	3.27	17.5	3.47	1.97	0.96	-3.70	2.05	-21.9	4.42
53	Chinook	645	3,458	0.39	-0.53	28.2	400	9.4	1.57	12.8	2.71	15.8	3.21	1.43	0.86	-3.48	1.89	-25.1	4.58
54	Chinook	630	350	0.26	0.26	27.2	400	9.0	1.43	11.7	2.02	13.8	1.88	0.99	0.33	-2.36	2.36	-28.7	2.96
55	Chinook	1,000	4,344	-0.11	-0.44	28.0	400	9.6	1.46	13.9	2.72	17.1	3.09	2.96	1.40	-2.20	1.37	-19.9	4.24
56	Sockeye	475	1,244	-0.12	-0.47	23.8	400	9.0	1.16	11.9	1.56	13.8	1.71	1.34	0.57	-3.46	1.75	-25.2	3.75
57	Sockeye	600	4,501	0.12	-0.38	20.9	400	9.3	1.20	12.5	1.62	14.8	1.76	2.15	1.12	-3.21	1.88	-21.8	4.84
58	Sockeye	645	1,750	0.11	-0.15	22.7	350	9.2	1.20	12.5	1.69	14.8	1.91	2.20	1.23	-1.19	1.52	-23.8	5.05
59	Sockeye	550	841	0.20	-0.28	26.8	275	9.3	1.23	12.3	1.71	14.5	1.69	1.62	0.81	-1.28	1.32	-26.0	4.27
60	Sockeye	590	732	-0.09	0.04	23.6	275	9.5	1.37	12.9	2.17	15.2	2.31	1.49	0.64	-0.73	1.19	-27.0	3.44
61	Chinook	945	505	-0.08	-0.30	36.0	275	9.7	1.62	14.2	3.42	17.8	3.78	2.02	1.16	-2.52	1.99	-23.2	4.73
62	Sockeye	530	3,129	0.22	-0.34	22.2	300	9.4	1.40	12.6	2.04	14.9	2.37	1.47	0.71	-2.19	1.06	-25.9	3.84

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Table 11.-Page 3 of 3.

Fish No.	Species	Length mm	Pings	X-axis angle	Y-axis angle	Range m	Background Noise mV	-6 dB Pulse Width Mean	-6 dB Pulse Width SD	-12 dB Pulse Width Mean	-12 dB Pulse Width SD	-18 dB Pulse Width Mean	-18 dB Pulse Width SD	Volts Mean	Volts SD	Beam Pattern Factor (dB) Mean	Beam Pattern Factor (dB) SD	Target Strength (dB) Mean	Target Strength (dB) SD
63	Sockeye	620	858	0.09	-0.45	27.6	400	9.2	1.25	12.1	1.64	14.3	1.79	1.51	0.74	-2.18	1.02	-25.7	3.99
64	Sockeye	560	798	0.18	-0.39	26.4	450	9.0	1.29	11.9	1.67	14.0	1.77	1.21	0.53	-1.85	1.00	-27.7	3.37
65	Sockeye	580	762	0.19	0.05	23.1	200	9.2	1.29	12.1	1.69	14.0	1.87	1.15	0.42	-0.89	1.33	-28.9	2.95
66	Sockeye	550	1,067	0.04	-0.38	26.5	450	9.1	1.30	12.1	1.73	14.2	1.94	1.29	0.62	-2.18	1.41	-27.0	3.79
67	Sockeye	610	2,203	-0.01	-0.46	23.7	600	9.5	1.49	13.0	2.20	15.6	2.63	1.73	0.88	-3.63	2.06	-23.2	4.74
68	Sockeye	590	1,861	0.05	-0.34	26.0	450	9.3	1.49	12.4	2.16	14.5	2.35	1.19	0.48	-2.78	2.25	-26.8	3.68
69	Sockeye	595	859	0.28	-0.41	23.4	500	9.5	1.62	12.6	2.30	15.1	2.32	1.18	0.53	-3.24	2.23	-26.6	3.73
70	Chinook	765	3,064	-0.02	-0.16	21.9	450	9.4	1.58	12.6	2.35	14.9	2.46	1.24	0.57	-2.22	2.41	-27.2	3.91
71	Chinook	580	2,698	0.50	-0.40	25.5	450	9.3	1.46	12.4	2.01	14.6	2.17	1.24	0.53	-3.53	1.82	-25.8	3.81
72	Sockeye	505	1,793	-0.41	-0.19	24.1	550	9.0	1.04	11.8	1.27	13.6	1.51	1.37	0.58	-2.15	2.17	-26.3	3.81
73	Sockeye	515	2,284	0.13	-0.44	24.8	500	9.1	1.28	12.1	1.70	14.1	1.83	1.30	0.60	-2.86	1.57	-26.1	3.87
74	Sockeye	440	1,871	0.39	-0.36	22.3	500	8.9	1.32	11.7	2.01	13.6	2.08	1.01	0.34	-3.14	1.97	-27.7	3.06
75	Sockeye	595	1,836	-0.26	-0.46	24.9	500	9.1	1.31	11.9	1.78	14.0	2.02	1.19	0.51	-3.52	2.47	-26.1	4.05
76	Sockeye	600	1,252	-0.15	-0.51	25.4	400	9.4	1.30	12.5	1.70	14.7	1.87	1.64	0.78	-3.47	1.59	-23.7	4.18
77	Sockeye	600	3,254	-0.08	-0.35	25.3	400	9.3	1.32	12.6	2.03	15.0	2.18	2.13	1.31	-1.79	1.41	-23.6	5.02
78	Coho	555	4,528	0.07	-0.33	25.7	500	9.3	1.36	12.2	1.88	14.5	2.02	1.33	0.62	-2.38	1.98	-26.4	3.96
79	Coho	545	1,559	0.14	-0.54	30.5	350	9.1	1.22	11.9	1.61	13.9	1.77	1.27	0.49	-2.83	1.73	-26.2	3.35
80	Coho	570	1,850	0.23	-0.43	27.7	300	9.3	1.34	12.2	1.75	14.5	2.09	1.32	0.54	-2.93	2.02	-25.8	3.76
81	Coho	565	1,385	0.11	-0.39	23.6	350	9.1	1.35	11.9	1.84	14.1	1.94	1.17	0.46	-2.98	2.31	-26.7	3.72
82	Chinook	785	2,808	0.07	-0.58	28.2	350	9.5	1.55	13.3	2.48	15.9	2.66	1.76	0.94	-3.77	2.04	-22.9	4.79
83	Coho	570	1,128	-0.05	-0.36	28.8	350	9.0	1.09	11.8	1.38	13.7	1.57	1.37	0.57	-1.64	1.60	-26.8	3.52
84	Coho	635	1,654	0.10	-0.60	28.6	350	8.8	1.24	11.4	1.75	13.2	1.69	1.00	0.33	-4.09	2.27	-26.9	3.23
85	Sockeye	615	1,322	-0.05	-0.47	30.3	350	9.3	1.31	12.4	1.80	14.5	2.04	1.47	0.65	-2.84	2.28	-25.1	4.42
86	Sockeye	600	1,394	0.49	-0.38	28.5	550	9.2	1.17	12.1	1.55	14.3	1.66	1.74	0.90	-2.28	1.71	-24.5	4.58
87	Sockeye	530	503	0.77	-0.49	28.7	400	9.3	1.41	12.4	2.11	14.9	2.23	1.55	0.89	-3.76	1.56	-24.0	4.28
88	Coho	690	1,752	-0.10	-0.45	24.6	400	9.4	1.49	12.7	2.08	15.0	2.20	1.67	0.79	-3.10	1.81	-23.9	4.15
89	Sockeye	620	4,897	-0.20	-0.58	28.5	400	9.3	1.28	12.6	1.75	14.9	1.90	2.39	1.40	-3.60	1.74	-20.8	5.28
90	Sockeye	640	536	-0.05	0.17	26.4	300	9.5	1.40	12.6	1.93	15.0	2.37	1.48	0.81	-1.94	2.38	-26.2	4.13
91	Sockeye	635	1,016	0.02	-0.43	27.4	300	9.2	1.43	12.3	2.06	14.4	2.01	1.33	0.73	-3.44	2.95	-25.6	4.99
92	Sockeye	580	1,772	0.01	-0.47	26.5	300	9.2	1.30	12.2	1.68	14.2	1.78	1.65	0.97	-3.04	1.98	-24.4	5.02
93	Sockeye	540	440	0.20	-0.55	25.8	325	8.5	1.03	11.0	1.58	12.8	1.35	1.02	0.37	-4.08	2.03	-26.8	3.23

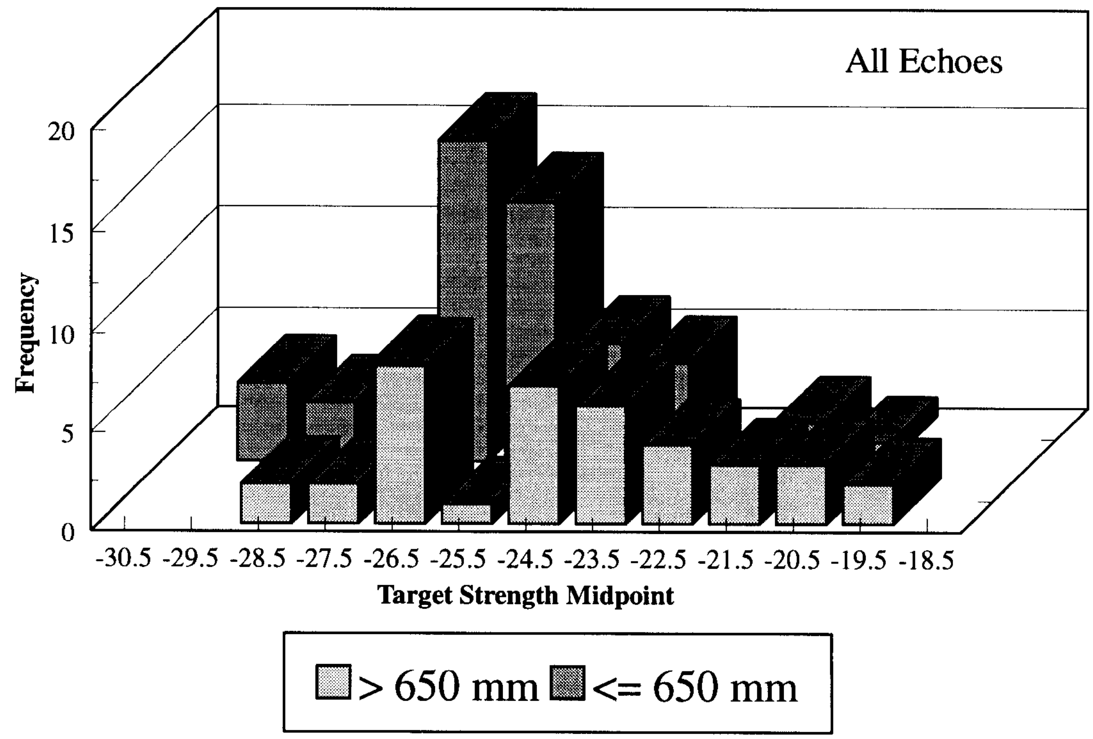
transducer aims produced lower target strength readings for fish of a given length ($t=-3.27$, $df=90$, $P=0.0015$).

The effects of movement, position, and aim on TS measurements were removed by filtering the data set. We assumed that the effect of movement was probably due to changes in fish aspect with respect to the transducer, which has a profound effect on acoustic size (Dahl and Mathisen 1982). Chinook salmon were more active than sockeye or coho salmon when tethered, which may have caused relatively low target strength measurements. After censoring echoes collected when fish were changing range (moving side to side) rapidly, and echoes collected when fish were relatively far (vertically) from the acoustic axis, effects of fish movement, vertical position, and transducer aim were no longer significant ($P>0.05$).

Target strength had virtually no power to discriminate between sizes of tethered fish when all echoes were used (Figure 7). Using all echoes, mean target strength was poorly related to (log-transformed) fish length ($r^2=0.23$, $P<0.0001$). Distributions of mean target strength overlapped almost completely between species and between length classes. Tethered chinook salmon had a mean target strength of -24.8 dB (SD=2.5), sockeye salmon averaged -25.5 dB (SD=2.0) and coho salmon averaged -26.1 dB (SD=1.1). Fish shorter than 650 mm (n=55) averaged -25.9 dB (SD=1.9), whereas fish longer than 650 mm (n=38) averaged -24.2 dB (SD=2.3).

When echoes were filtered for movement and vertical position as described above, target strength acquired a bimodal distribution and discriminatory power improved substantially. Filtering improved the relationship between target strength and (log-transformed) length ($r^2=0.37$, $P<0.0001$, Figure 8). Estimated slopes were less than 20 (Table 12), within the range of values found in other studies (MacLennan and Simmonds 1992) and are consistent with conclusions in Eggers et al. (1995), that the two modes present in 1985 and 1986 sonar data were too far apart (12 dB) to be attributed to sockeye and chinook salmon. Given that chinook salmon average less than twice as long as sockeye salmon, the slope of the (target strength)/log(length) relationship would have to exceed 40 to achieve 12 dB of separation between the two species. Even so, by applying a -26 dB cutoff to the filtered data, one would exclude 82% (45 of 55) "small" tethered fish ($\leq$650 mm) while including 63% (24 of 38) "large" tethered fish (>650 mm; Figure 7). Tethered fish shorter than 650 mm averaged -27.3 dB (SD = 2.0), whereas fish longer than 650 mm averaged -24.7 dB (SD = 2.6).

Unfortunately, we have been unable to detect any bimodality in the target strength distributions of free-swimming fish, even after applying the same range-change and vertical position filters used on tethered fish (Figure 9, see also Burwen et al. 1995). There are several possible explanations for this. First, target strength measurements are obviously sensitive to differences in behavior and position in the beam. The tendency for chinook salmon to swim at greater angles to the current (presenting less than full side-aspect to the transducer) than sockeye salmon may also extend to unrestrained fish, resulting in lower target strength measurements and poorer separation between species. Or sockeye salmon may swim closer to the bottom of the river, yielding higher target strength readings and again blurring any separation. Although applying movement and position filters to the free-swimming fish data did not reveal any modes (Figure 9), this may be partly due to the severe reduction in sample size associated with the filtering. Second, even after filtering, tethered fish averaged 539 echoes per fish compared to a mean of 45 echoes per fish in fish sampled for passage estimation in 1995. When we resampled the tethered fish data at 45 echoes per fish, the increased variability between fish smoothed the target strength



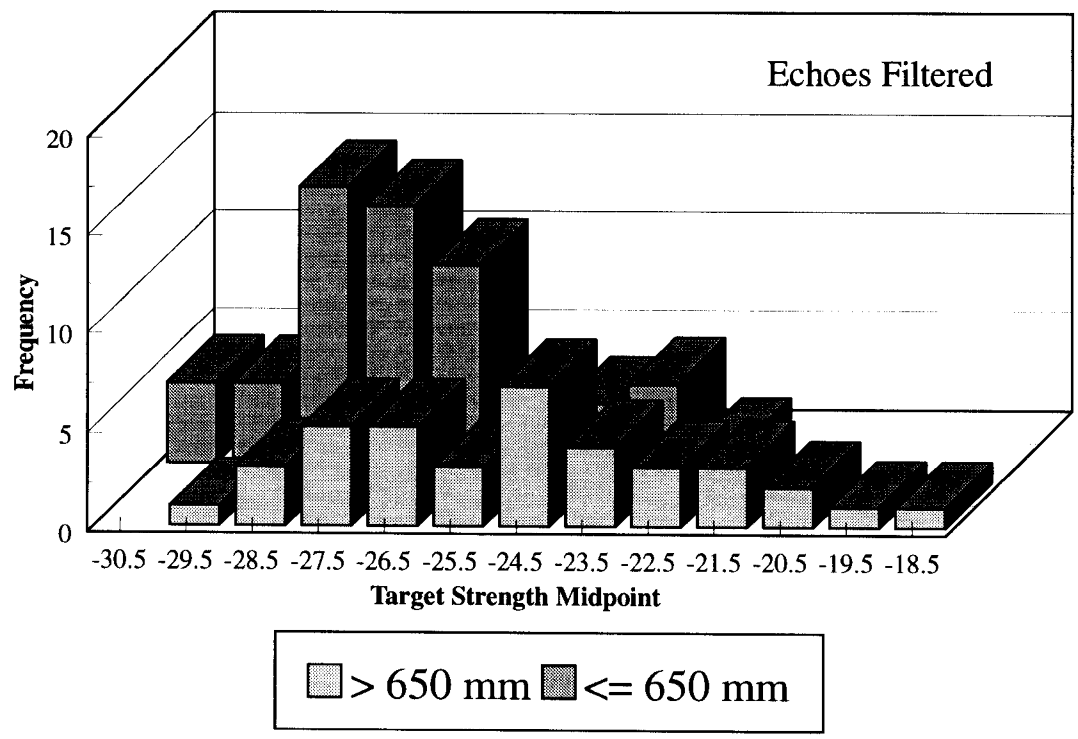


Figure 7.-Frequency distribution, by fish size, of mean target strength of 93 live tethered fish, before and after filtering echoes for movement and position criteria.

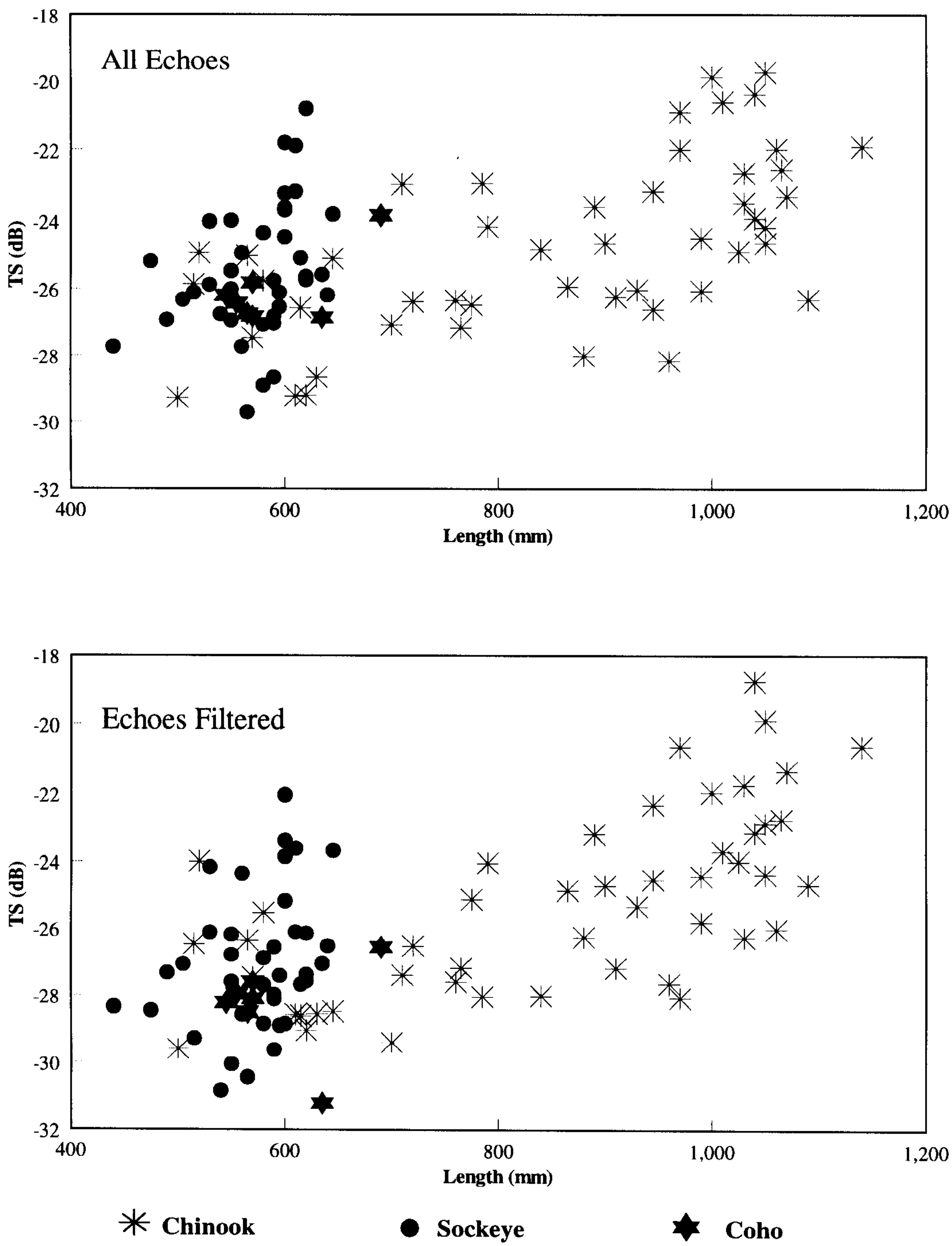
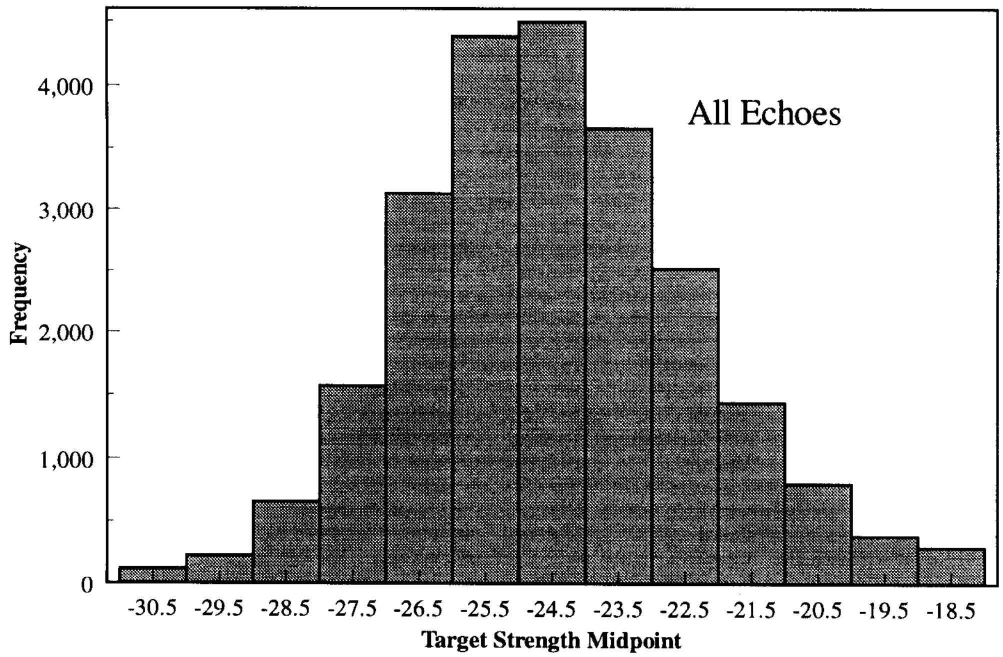


Figure 8.-Mean target strength versus length of 93 live tethered fish, before and after filtering echoes for movement and position criteria.



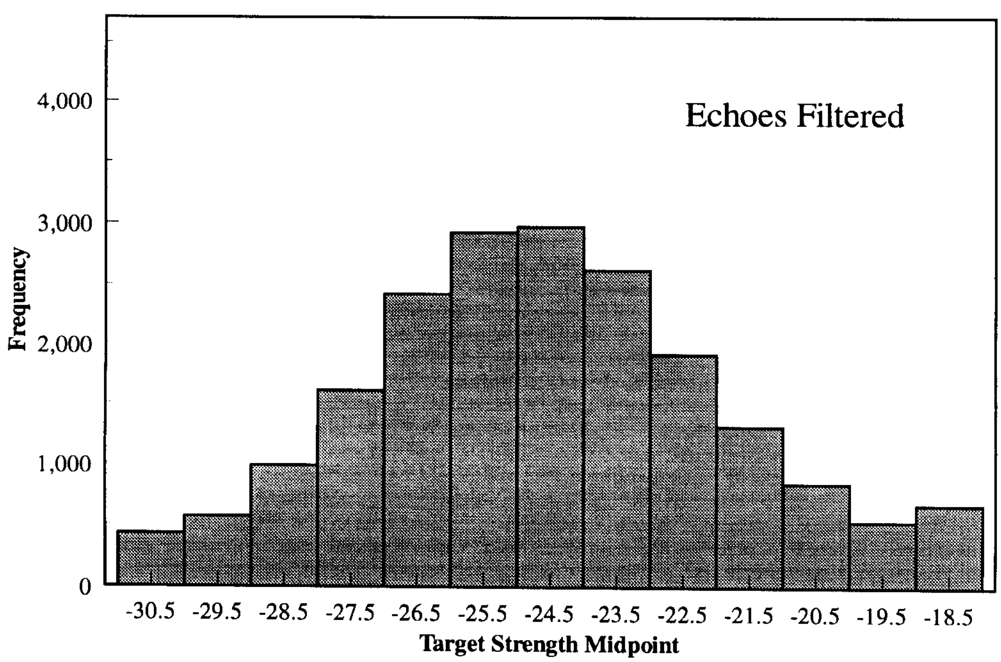


Figure 9.-Frequency distribution of mean target strength of fish sampled for abundance estimation, before and after filtering echoes for movement and position criteria.

Table 12.-Estimated linear regression parameters for the relationship between target strength and fish length (log-transformed) for live tethered fish, 1995.

Species	n	Intercept (SE)	Slope (SE)	F	P	r^2
Chinook	48	-66.1 (8.4)	14.1 (2.9)	24.03	0.0001	0.34
Coho	7	-79.2 (26.2)	19.2 (9.4)	4.12	0.098	0.45
Sockeye	38	-75.2 (23.0)	18.0 (8.3)	4.68	0.037	0.12
All	93	-52.1 (5.2)	9.5 (1.8)	27.15	0.0001	0.23

frequency distribution, completely obscuring the bimodality (Figure 10). Apparently, we should not expect to see bimodal target strength distributions at the lower sample rates. This agrees with Eggers' (1994) findings.

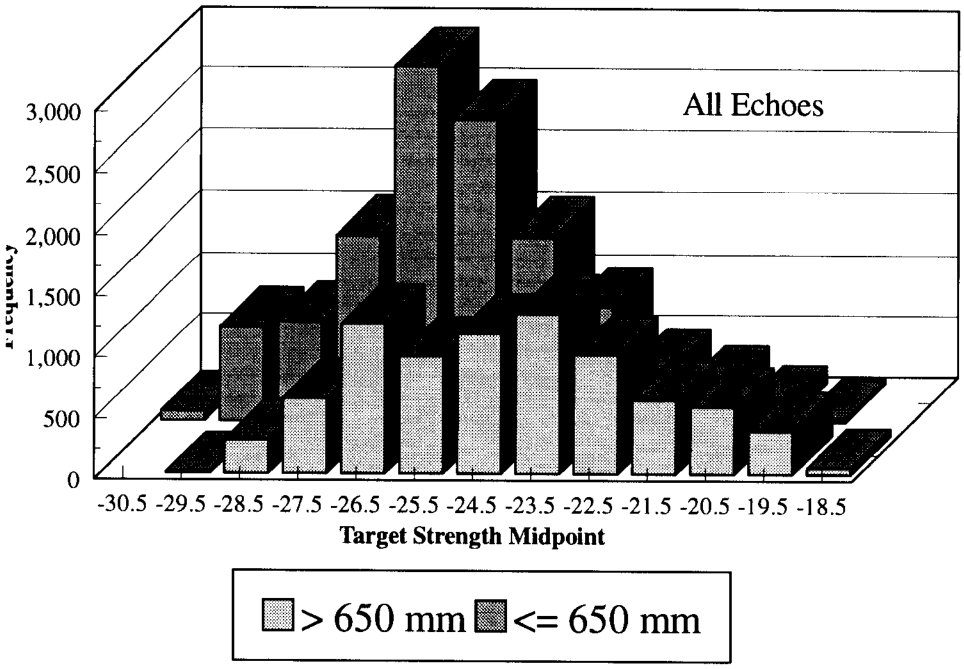
Other acoustic measurements showed promise as potential discriminatory variables for size and species classification. Duration of the returning echo ("pulse width") was measured at 6, 12, and 18 dB below the peak amplitude, and all were more highly correlated with fish length than was target strength (Table 13). Indices of pulse width variability (standard deviation) were also strongly correlated with fish length. Additional analyses of pulse-width data are reported separately (Ehrenberg and Johnston 1996, Burwen and Fleischman *In prep*).

SUMMARY AND CONCLUSIONS

Target strength measurements were sensitive to fish side-to-side movement and to their spatial position in the beam. After filtering echoes to control for these effects, two modes could be distinguished in the target strength distribution, and some discrimination of size classes of tethered fish was possible. However mean target strength differed by only a few decibels between species and size classes, and modes disappeared when sampling rates were reduced to those possible with unrestrained migrating fish.

Table 13.-Correlation matrix of fish length, target strength (TS) and pulse width duration measured 6, 12, and 18 dB below the peak amplitude (i.e., at 1/2, 1/4 and 1/8 power levels), for 93 tethered live fish, 1995.

	Length	TS	-6 dB pulse width	-12 dB pulse width	-18 dB pulse width
Length	1.000	0.486	0.718	0.859	0.879
TS	0.486	1.000	0.575	0.638	0.613
-6 dB pulse width	0.718	0.575	1.000	0.923	0.888
-12 dB pulse width	0.859	0.638	0.923	1.000	0.992
-18 dB pulse width	0.879	0.613	0.888	0.992	1.000



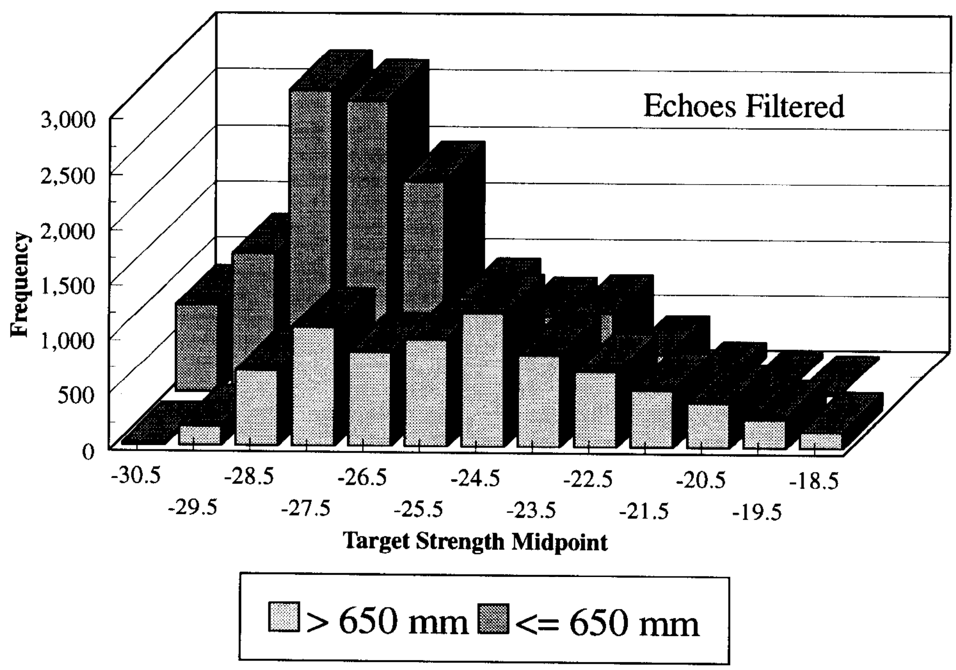


Figure 10.-Frequency distribution of mean target strength of 93 live tethered fish, resampled 20,000 times at 45 echoes per fish, before and after filtering echoes for movement and position criteria.

We conclude that the relationship between target strength and length is neither steep enough nor precise enough to provide good species or size discrimination under normal operations. To exclude a substantial fraction of small fish would require a fairly high threshold, which would also exclude many large fish (e.g., Figure 10). It appears that any species classification based on target strength alone would not be very effective, and to achieve optimal discrimination would require a target strength threshold somewhat higher than -28 dB. For example, 35 of the 38 sockeye salmon measured had mean target strength exceeding -28 dB. At present, sockeye salmon passing the sonar site more than 15 m from the transducer would appear to have a large chance of being mistaken for a chinook salmon.

To address concerns raised by these studies, a new mark-recapture study based on radio-tagged fish was initiated during the late run in 1996 (Hammarstrom and Hasbrouck *In prep*) and will continue through the late run of 1997. This study is designed to provide an independent and accurate estimate of inriver chinook salmon abundance during the late run when the potential for misclassifying sockeye salmon is greatest. Use of radio-tag technology will avoid certain biases introduced in previous mark-recapture estimates. Additionally, we continue efforts to improve current methods of species separation through research using tethered and free-swimming fish of known size and/or species (Burwen and Fleischman *In prep*).

EXPERIMENT III: SPATIAL DISTRIBUTION OF FISH AT THE SONAR SITE AS DETERMINED BY DRIFTED GILLNETS

Range thresholds to exclude sockeye salmon were first implemented in July 1989 when a large number of nearshore targets appeared up to 10-15 m from the transducer. These targets were unusual in that they occurred in dense concentrations and moved quickly through the beam. They were suspected to be sockeye salmon even though many exceeded the -28 dB target strength threshold. It was hypothesized at the time that the high target strength readings were the result of multiple targets in beam at once. In response, all late-run targets less than 10 m from the transducer on the left bank and less than 15 m on the right bank were excluded from counts. In subsequent years, range thresholds were extended to 20 or 25 m when "unusual" targets appeared even greater distances from the transducer.

Given recent questions about the effectiveness of the target strength threshold (see Experiment II), range thresholds have assumed greater importance as perhaps the primary means of discriminating chinook from sockeye salmon. Without the ability to discriminate based on target strength, and given that sockeye salmon may outnumber chinook salmon by 10- or even 100-fold, there is potential for substantial error in estimating chinook salmon abundance should only a small fraction of sockeye salmon pass the site more than 10-15 m from the transducer. Therefore in 1995 we implemented a small-scale netting program at the sonar site to test the effectiveness of range thresholds, specifically, to test the validity of our assumption that insignificant numbers of sockeye salmon migrate past the sonar site in midriver. Past data indicated that counts were cyclical, peaking during neap-tide periods. Because the greatest potential for misclassifying targets existed during these periods, netting was scheduled for beyond the range thresholds during four neap-tide periods from mid-June through early August.

METHODS

Data Collection

Sampling consisted of making paired drifts with two 18.3 m (10 fathom) gillnets of different mesh sizes through the main channel at the sonar site (Figure 11). One crew fished with a 19 cm (7.5 in) mesh net used for the inriver biological sampling of chinook salmon (Hammarstrom and Larson 1986) and a second crew fished with a 13.5 cm (5.25 in) mesh net typical of the mesh used to commercially harvest sockeye salmon in Cook Inlet. Crews fished a standardized drift area (Figure 11 and Figure 12) that started 100 m upstream of the transducer and ended 100 m downstream of the transducer. Nets were occasionally deployed from shore, but otherwise were controlled so that no part of the net strayed closer to shore than the distance equivalent to 15 m from the right-bank transducer or 10 m from the left bank transducer. Buoys were deployed to demarcate the upper and lower ends of these nearshore zones. When a net was deployed from shore, careful attention was paid to whether any fish were encountered by the net before it was entirely out of the nearshore zone. Each net was divided into quadrants which were assigned numeric labels (Figure 13) to ascertain the general position in the net where the fish was caught. Crews fished opposite banks and alternated the bank fished with each successive drift. The bank and the net used to conduct the first drift each day was selected at random. The following data specific to each drift were recorded:

1. starting and ending time of drift,
2. number of fish caught by species,
3. quadrant location for each fish caught,
4. mid-eye to fork-of-tail length (millimeters) for each fish caught,
5. which transducer (right or left bank) was sampling during the drift, and
6. whether any fish were captured before the net was fully out of the nearshore zone.

The start and end of each drift was also marked directly on the echograms used in generating fish passage estimates. Secchi-disc visibility was measured in mid-channel at the beginning of each crew shift. Relative tide stage was measured at each whole hour from a calibrated staff gauge located just offshore at the sonar site. Captured chinook salmon were classified as small (< 750 mm MEF), or large ($\geq$ 750 mm MEF). Data were not used from drifts with the 5.25 inch gear during which fish were captured when the net was near shore (inside the 15 m "sockeye" zone).

Analytical Methods

Mean catch per drift of species i and length category j in mesh m during day k was calculated as:

$$\bar{c}_{mijk} = \frac{\sum_{l}^{n_{mk}} c_{mijkl}}{n_{mk}}, \tag{3.1}$$

where c_{mijkl} is the catch during drift l, and n_{mk} is the number of drifts with mesh m on day k. Mean hourly sonar passage for day k was calculated only for those hours h when drifts were conducted:

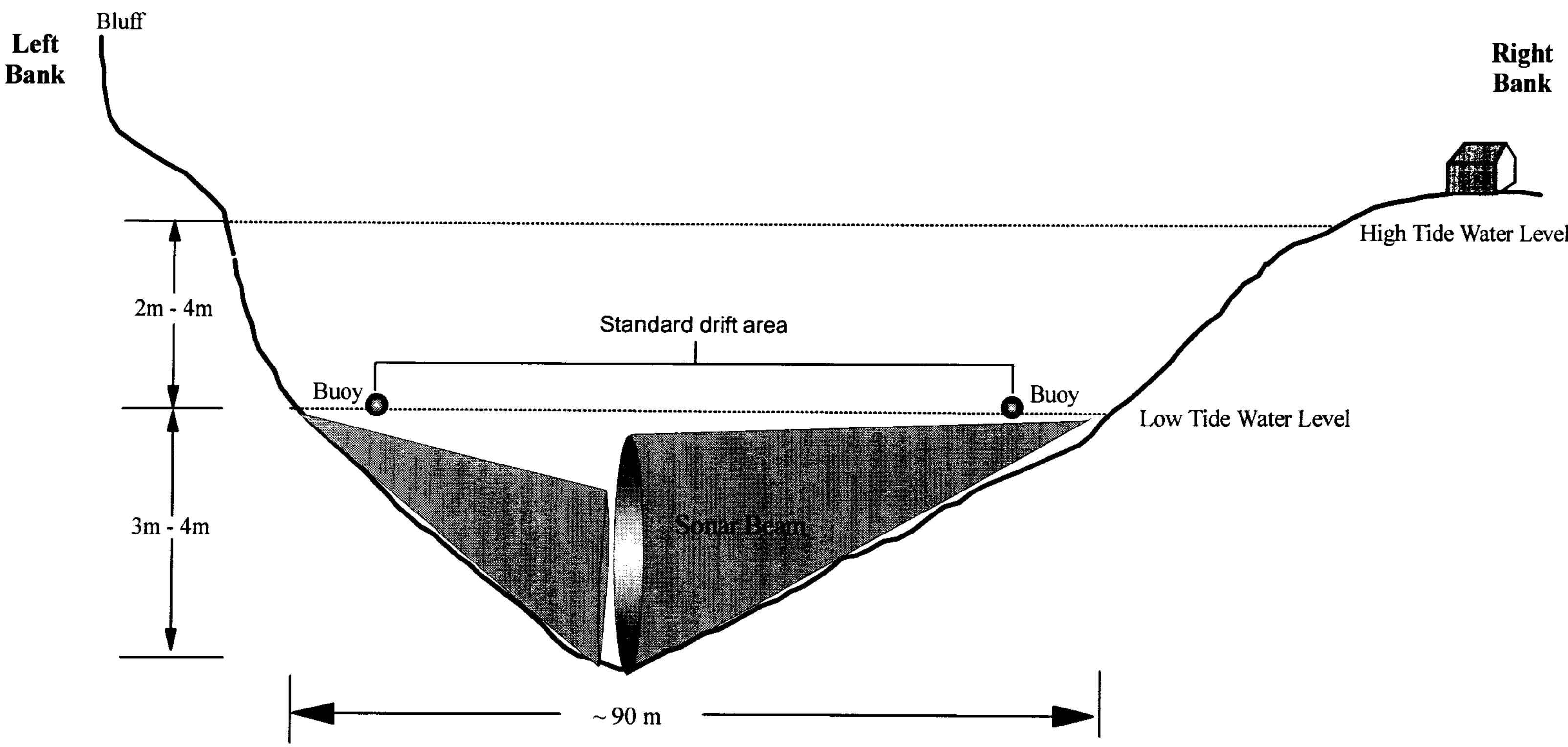


Figure 11.-Cross-section of the Kenai River in front of sonar site showing drift zone.

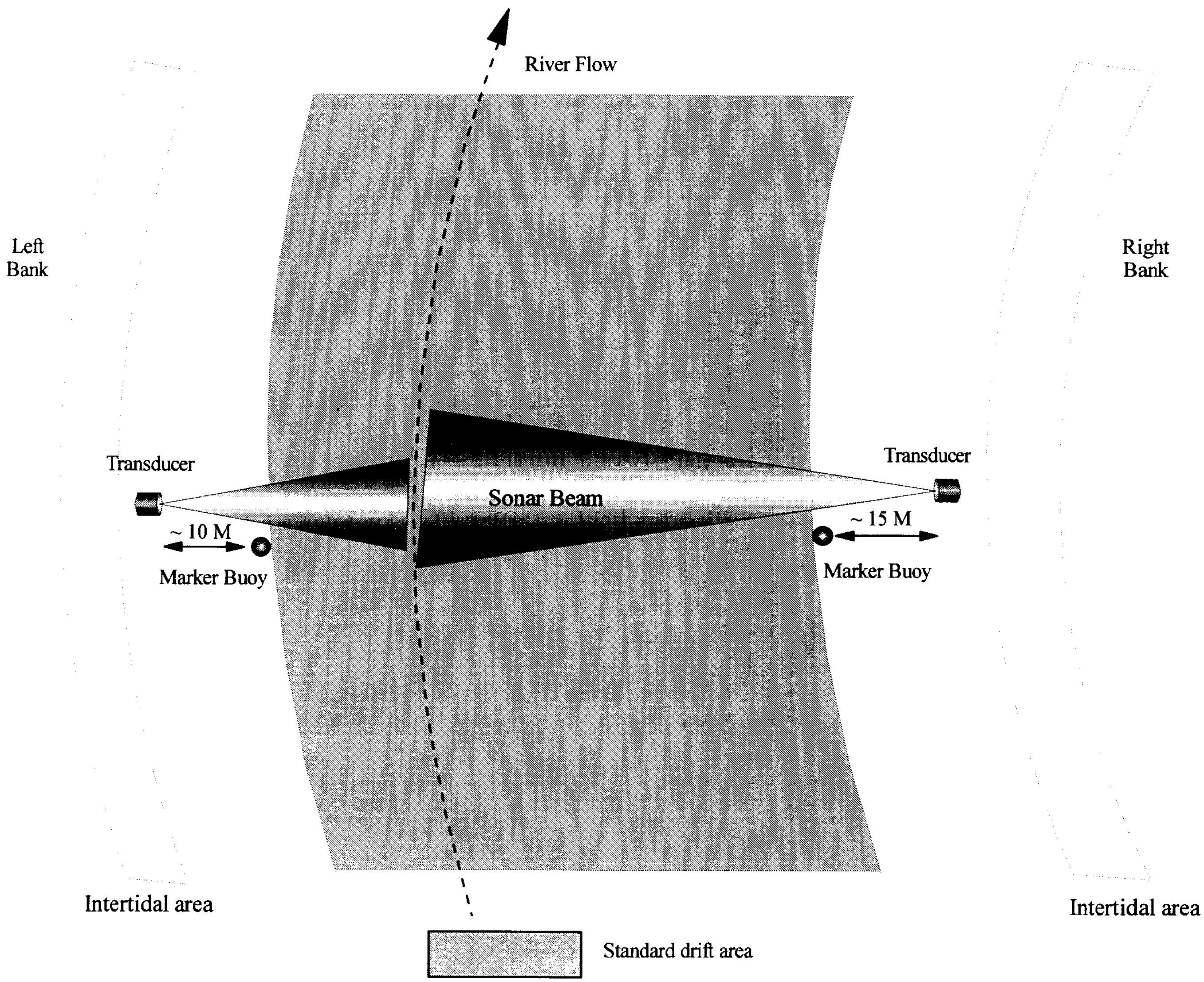


Figure 12.-Aerial view of standardized drift area.

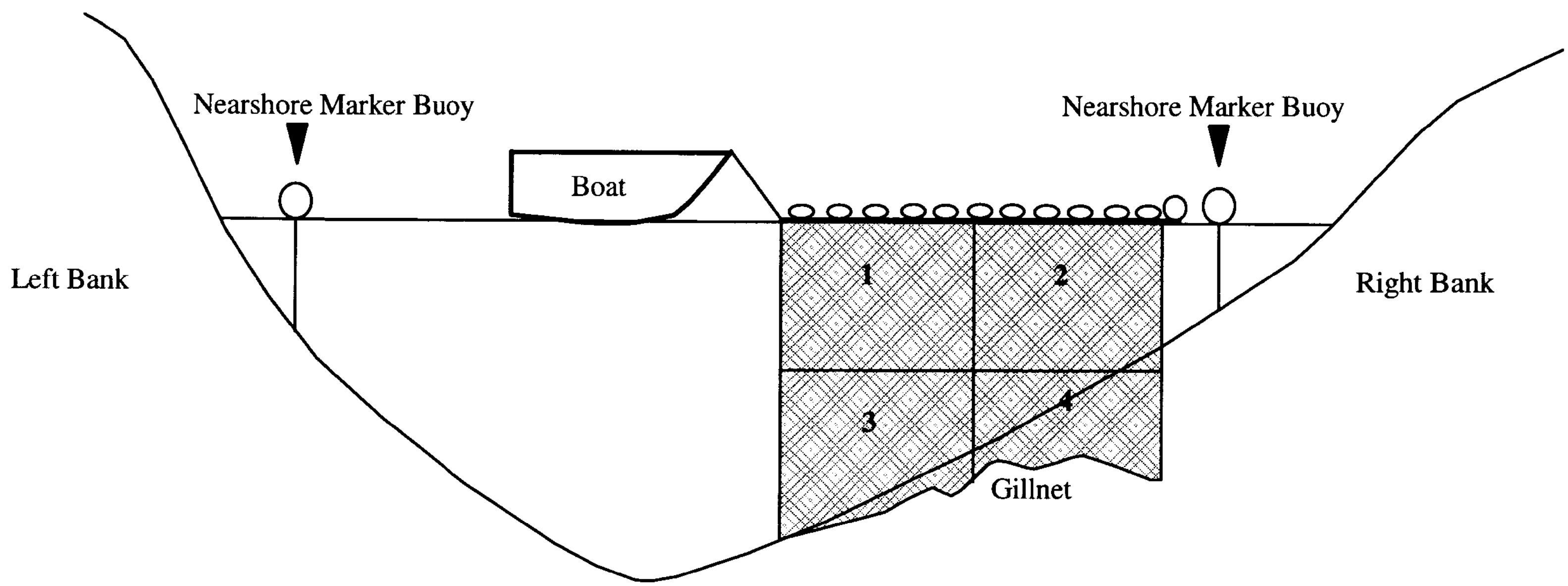


Figure 13.-Cross section of Kenai River at sonar site showing location of drifted gillnets, 1995.

$$p_k = \frac{\sum_h f_{kh}}{H_k}, \tag{3.2}$$

where f_{kh} is the estimated number of fish during hour h meeting the same criteria as were used to produce counts for fishery management: those with upstream direction of travel, located greater than 15 m from the transducer before 21 July (or >20 m on 21 July, or >25 m on 22 July and after), and having mean target strength greater than -28 dB. H_k is the number of hours in day k during which at least one drift was conducted.

Counts were regressed on CPUE and secchi disk readings from the early seasons 1987-1995, with all variables log-transformed, to test the effect of water clarity on chinook salmon catchability. Catch-per-unit-effort in gillnets from the Kenai River chinook (1987-1995) and the chinook salmon age composition sampling project were compared with counts by calculating Pearson correlation coefficients of daily values (Eggers et al. 1995). Marked to unmarked ratios were compared to mean secchi disk readings for the early and late seasons 1986 through 1989 to further assess the possible influence of water clarity on catches in gillnets.

RESULTS AND DISCUSSION

Sockeye salmon were present in the ensonified portion of the river during the study period. Three hundred fourteen sockeye salmon and 117 chinook salmon were captured in 1,002 drifts with gillnets past the sonar site (Table 14). Approximately 71% of the fish were caught in the nearshore half of the net, and 29% in the offshore (channel) half of the net; these proportions did not differ between species (χ^2=1.436, df=1, P=0.231; Table 15). The vast majority of chinook salmon (99%) and sockeye salmon (95%) were caught in the bottom half of the net. In both nets, approximately one-fourth of the chinook salmon were less than 750 mm FL (Table 14).

Relative catches of sockeye and chinook salmon differed by mesh size (Table 14). In 495 drifts with the 5.25 inch stretched-mesh gillnet, sockeye salmon outnumbered chinook salmon approximately four to one (295 to 76). In 507 drifts with the 7.25 inch stretched-mesh gillnet, chinook salmon outnumbered sockeye salmon more than two to one (41 to 19).

The manner by which fish were captured in the nets differed by species (Table 16). In the 5.25 inch net most captured sockeye salmon (61%, SE = 3%) were gilled compared to only 14% (SE = 4%) gilled for chinook salmon. Even in the 7.25 inch net the proportion of chinook salmon gilled remained relatively low (29%, SE = 7%). Overall, 58% of sockeye salmon were gilled, whereas 81% of chinook salmon were entangled. Apparently neither mesh size was large enough to capture chinook salmon optimally.

During the 1995 experiment, mean fish passage rate as estimated by the sonar was positively correlated with mean CPUE for sockeye salmon catch per drift (CPUE), but not daily mean chinook salmon CPUE (Table 17, Table 18, Figure 14). This contrasts with results from historical data. From 1987 to 1990, chinook salmon were captured almost daily with gillnets for mark-recapture experiments. Daily counts were consistently positively correlated (P < 0.05) with CPUE (Table 19). From 1991 to 1995, counts were correlated with daily gillnet CPUE during 3 of 5 years for the early run and 2 of 5 years for the late run (Table 19).

During the 1995 experiment, CPUE for chinook salmon was negatively correlated with water clarity as measured by secchi disk visibility (Table 17, Table 18), suggesting that chinook salmon

Table 14.-Number of sockeye and chinook salmon captured during drifts with two sizes of gillnets near river mile 8, June-August 1995.

	Drifts with 5.25 inch mesh gillnet					Drifts with 7.25 inch mesh gillnet				
Date	Number of Drifts[a]	Sockeye & Other[b]	Small[c] Chinook	Large[d] Chinook	All Chinook[e]	Number of Drifts	Sockeye & Other[b]	Small[c] Chinook	Large[d] Chinook	All Chinook[e]
19 June	19	10	3	3	6	22	1	0	1	1
20 June	23	13	1	7	8	24	4	1	3	4
21 June	30	13	0	3	3	32	0	1	3	4
Subtotal	72	36	4	13	17	78	5	2	7	9
Percent (SE)		67.9 (6.5)	7.5 (3.7)	24.5 (6.0)	32.1 (6.5)		35.7(13.3)	14.3(9.7)	50.0(13.9)	64.3(13.3)
4 July	46	4	3	10	13	47	0	0	2	2
5 July	37	13	5	7	12	38	0	0	7	7
6 July	22	12	2	5	7	25	0	4	5	9
Subtotal	105	29	10	22	32	110	0	4	14	18
Percent (SE)		47.5 (6.5)	16.4 (4.8)	36.1 (6.2)	52.5 (6.5)		0.0 (0.0)	22.2(10.1)	77.8(89.9)	100.0(0.0)
21 July	47	68	5	6	11	47	5	1	5	6
22 July	38	112	0	6	6	38	8	1	0	1
24 July	44	32	1	4	6	44	2	2	2	4
Subtotal	129	212	6	16	23	129	15	4	7	11
Percent (SE)		90.2 (1.9)	2.6 (1.0)	6.8 (1.6)	9.8 (1.9)		57.7(54.4)	15.4(7.2)	26.9(26.9)	42.3(45.6)
2 August	50	5	0	1	1	50	0	0	0	1
3 August	42	7	0	0	0	42	0	0	1	1
4 August	50	3	0	3	3	51	0	0	1	1
5 August	47	6	0	0	0	47	0	0	0	0
Subtotal	189	21	0	4	4	190	0	0	2	3
Percent (SE)		84.0 (7.5)	0.0 (0.0)	16.0 (7.5)	16.0 (7.5)		0.0(0.0)	0.0(0.0)	66.7(33.3)	100.0(0.0)
Total	495	298	20	55	76	507	20	10	30	41
Percent (SE)		79.7 (2.1)	5.3 (1.1)	14.7 (1.8)	20.3 (2.1)		32.8 (6.1)	16.4 (4.8)	49.2 (6.5)	67.2 (6.1)

[a] Drifts with 5.25 inch mesh during which fish were caught near shore are not included here.

[b] Fish of other species included 1 coho salmon in the 7.25 inch net on 21 July, 1 Dolly Varden in the 5.25 inch net on 3 August, 1 coho salmon in the 5.25 inch net on 3 August, and 1 coho salmon in the 5.25 inch net on 4 August.

[c] Less than 750 mm fork length.

[d] Greater than or equal to 750 mm fork length.

[e] Not all chinook salmon were measured for length, so this column may not equal the sum of small and large chinook.

Table 15.-The number of chinook and sockeye salmon captured in the shore side versus the channel side of gillnets drifted near river mile 8, 1995.

Species	Channel	Shore
Chinook Salmon	38	76
Sockeye Salmon	86	228

catch rates may have been depressed by net avoidance under clearwater conditions that year. Water clarity explained a significant amount of additional variation in early-season counts over and above that explained by gillnet CPUE in 1987-1995 (all variables log transformed; F=7.3; df=1,238; P=0.007). The effect of water clarity did not vary among years (F=1.64; df=8,238; P=0.114). The lowest marked-to-unmarked ratios for the tagging project occurred during years with the highest average water clarity for both the early and the late run (Table 20).

SUMMARY AND CONCLUSIONS

This study was designed to test for the presence or absence of substantial numbers of sockeye salmon in midriver at the sonar site. Clearly, substantial numbers of sockeye salmon were present, enough to raise serious concern regarding the effectiveness of range thresholds alone for excluding all sockeye salmon from chinook salmon passage estimates. However the relative abundance of chinook and sockeye salmon and the potential magnitude of the bias in counts are unknown. Chinook salmon comprised only 26% of the gillnet catch, but this is certainly an underestimate of their relative abundance. Neither mesh size used was large enough to capture chinook salmon efficiently. Most chinook salmon were entangled, whereas most sockeye salmon were gilled. For salmon, entanglement is usually a far less efficient method of capture than gilling (Hamley 1975). Finally, chinook salmon may also have exhibited greater net avoidance than sockeye salmon, especially during the last two netting periods when water clarity was high.

Table 16.-Method of capture, by mesh size and species, in gillnets drifted near river mile 8, 1995.

	Species	Gilled	Entangled
5.25 in mesh			
	Chinook Salmon	10	64
	Sockeye Salmon	179	113
<u>7.25 in mesh</u>			
	Chinook Salmon	12	30
	Sockeye Salmon	1	18
<u>Both meshes</u>			
	Chinook Salmon	22	94
	Sockeye Salmon	180	131

Table 17.-Daily mean catch of sockeye and chinook salmon per drift, compared to sonar counts and water clarity, 1995.

Date	Secchi Reading	Sonar estimate of hourly fish passage during hours fished	Sockeye and other species[a] per drift with 5.25 inch mesh	Large Chinook per drift with 5.25 inch mesh	Chinook per drift with 5.25 inch mesh	Large Chinook per drift with 7.25 inch mesh	Chinook per drift with 7.25 inch mesh
19 June	0.50	13.8	0.53	0.16	0.32	0.05	0.05
20 June	0.55	16.5	0.57	0.30	0.35	0.13	0.17
21 June	0.50	12.5	0.43	0.10	0.10	0.09	0.13
4 July	0.45	16.2	0.09	0.22	0.28	0.04	0.04
5 July	0.45	16.9	0.35	0.19	0.32	0.18	0.18
6 July	0.40	36.0	0.55	0.23	0.32	0.20	0.36
21 July	0.80	78.7	1.45	0.13	0.23	0.11	0.13
22 July	0.70	162.4	2.95	0.16	0.16	0.00	0.03
24 July	0.81	33.4	0.73	0.09	0.14	0.05	0.09
2 August	1.27	7.3	0.10	0.02	0.02	0.00	0.02
3 August	1.00	8.6	0.17	0.00	0.00	0.02	0.02
4 August	1.05	14.6	0.06	0.06	0.06	0.02	0.02
5 August	1.20	13.9	0.13	0.00	0.00	0.00	0.00

[a] Includes 2 coho salmon and 1 Dolly Varden.

Table 18.-Correlation matrix of sonar, catch-per-drift, and water clarity in Table 17. Correlation coefficients significantly different from zero at α=0.05 are in bold.

	Secchi Reading	Sonar estimate of hourly fish passage during hours fished	Sockeye and other species per drift with 5.25 inch mesh	Large Chinook per drift with 5.25 inch mesh	Chinook per drift with 5.25 inch mesh	Large Chinook per drift with 7.25 inch mesh
Sonar estimate of hourly fish passage during hours fished	-0.100					
Sockeye and other species per drift with 5.25 inch mesh	-0.172	**0.979**				
Large Chinook per drift with 5.25 inch mesh	**-0.842**	0.179	0.233			
Chinook per drift with 5.25 inch mesh	**-0.855**	0.094	0.160	**0.937**		
Large Chinook per drift with 7.25 inch mesh	**-0.696**	-0.109	-0.060	**0.668**	**0.726**	
Chinook per drift with 7.25 inch mesh	**-0.638**	-0.012	0.021	**0.628**	**0.636**	**0.937**

It is not possible to correct for net selectivity with data at hand. A more comprehensive netting program using more and larger mesh sizes would be required. Unfortunately, larger mesh sizes would kill or injure many chinook salmon. Also, given the observed influence of water clarity on the catchability of chinook salmon, even a comprehensive species apportionment program would yield biased results if net avoidance differs between chinook and sockeye salmon. We don't believe that gillnets are a viable tool for quantifying the relative proportions of sockeye and chinook salmon in the Kenai River.

We conclude that, although range thresholds exclude the vast majority of sockeye salmon (otherwise counts would be far greater), they are not completely effective. Furthermore, given the findings of Experiment II, that target strength in general is an inefficient discriminator of salmon species in the Kenai River, and that the -28 dB threshold in particular probably censors very few sockeye salmon, it seems an inescapable conclusion that mile-8 sonar counts include some sockeye salmon.

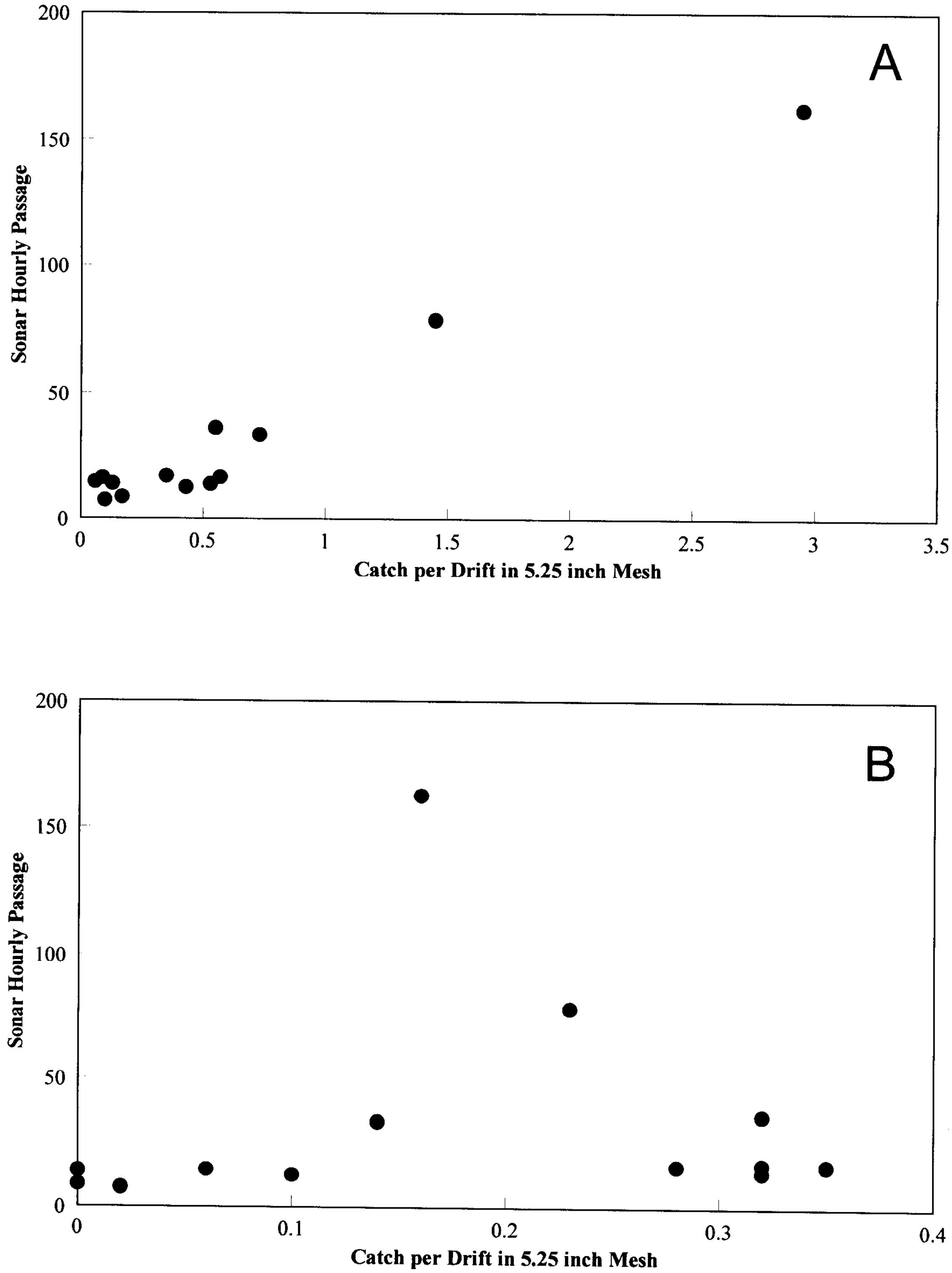


Figure 14.-Relationship between daily mean catch of sockeye (A) and chinook salmon (B) per drift with a 5.25 inch stretched-mesh gillnet and the mean hourly passage of fish as estimated by the Kenai River chinook sonar, 1995.

Table 19.-Pearson correlation coefficients between daily passage estimates and gillnet CPUE of chinook salmon (1987-1995). Correlation coefficients with one asterisk are significantly different from zero at P=0.05; those with two asterisks are different from zero at P=0.01.

	Early Run			Late run		
Year	n	r		n	r	
1987	27	0.40	*	41	0.57	**
1988	41	0.42	**	39	0.54	**
1989	46	0.48	**	36	0.63	**
1990	41	0.55	**	41	0.32	*
1991	19	0.69	**	20	0.85	**
1992	22	0.79	**	17	0.01	
1993	22	0.44	*	19	0.52	*
1994	21	0.11		20	0.40	
1995	21	0.34		11	-0.02	

Table 20.-Marked-to-unmarked ratios of chinook salmon examined during tagging experiments on the Kenai River, and mean water clarity (secchi disk visibility in meters), during early and late runs 1986-1989.

	Early Run ($\leq$30 June)				Late Run ($\geq$ 1 July)			
Year	Number Examined	Number with marks	Marked to unmarked ratio	Water Clarity	Number Examined	Number with marks	Marked to unmarked ratio	Water Clarity
1986	952	46	0.051	0.99	913	34	0.039	0.79
1987	1,161	63	0.057	1.03	1,139	51	0.047	0.78
1988	940	46	0.051	1.12	918	16	0.018	0.99
1989	689	31	0.047	1.33	1,371	35	0.027	0.80

RECOMMENDATIONS

In addition to documenting the relative number and distribution of downstream targets, these studies found that the combination of target strength and range thresholds have not been completely effective at excluding sockeye salmon from sonar passage estimates. The relative contributions of chinook and sockeye salmon to the sonar passage estimates are unknown, but the sockeye salmon contribution is likely to be greater during the late run, when sockeye salmon are far more abundant. We recommend the following courses of action in relation to these findings.

1. Discontinue strict interpretation of passage estimates as counts of chinook salmon. They are probably biased, to some extent, by the presence of sockeye salmon in the ensonified zone. Consider that there may be negative biases operating also, including chinook salmon escaping detection by swimming too close to shore. Treat the numbers as an index, to be weighed against other indices of chinook salmon abundance when developing management strategies.
2. Continue to implement target-strength and range thresholds as currently configured, while exploring other means of species discrimination such as returning echo pulse width.
3. Incorporate direction of travel information into passage estimates. Subtract the downstream from the upstream counts to estimate net passage upstream (same as subtracting two fish for each downstream fish from the total number of fish).
4. Conduct a mark-recapture experiment with radio-tags for marks to provide an independent estimate of chinook salmon abundance during the late run, when the potential for misclassification of sockeye salmon is greatest. A fringe benefit of this project would be continuous, improved gillnet CPUE data for use in management of the fishery and for daily comparison with the passage estimates.
5. Obtain acoustic measurements on free-swimming fish of known species and size if the opportunity arises. It is possible that free-swimming chinook and sockeye salmon yield different acoustic measurements than tethered fish of the same species.

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APPENDIX A. EQUIPMENT AND SOFTWARE SETTINGS

Appendix A1.-Criteria used for the collection of echoes for the right bank transducer.

* Start Processing at Port 1 -FILE_PARAMETERS- Wed Aug 09 06:00:00 1995

* 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	32767	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	5	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
111	-1	3	plot_up_fish - number of fish between stbar updates
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	f_inst->o_raw - write raw file flag 1 = on, -1 or 0=off
114	-1	1	f_inst->o_ech - write echo file flag 1 = on, -1 or 0=off
115	-1	1	f_inst->o_fsh - write fish file flag 1 = on, -1 or 0=off
116	-1	0	f_inst->o_sum - write summary table file flag 1 or 0=on
117	-1	0	print summary table on printer, 1 = on, -1 or 0=off
118	-1	25	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom_code - bottom tracking, 0=fix, 1=man, 2=auto
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	1	N_int_layers-number of integration strata
123	-1	1	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
129	-1	1	FILTER argument #1 - filter number
200	-1	0.0000	sigma_flag - if!=0.0000, sigma is output, not ts
201	-1	220.0200	sl - transducer source level
202	-1	-171.4900	gn - transducer through system gain at one meter
203	-1	-18.0000	rg - receiver gain used to collect data
204	-1	2.8000	narr_ax_bw - vertical nominal beam width
205	-1	10.0000	wide_ax_bw - horizontal axis nominal beam width
206	-1	0.0000	narr_ ax_corr - vertical axis phase correction
207	-1	0.0000	wide_ax_corr - horizontal axis phase correction
208	-1	8.0000	ping_rate - pulses per second
209	-1	0.0000	echogram start range in meters
210	-1	60.0000	echogram stop range in meters
211	-1	844.0000	echogram threshold in millivolts
212	-1	13.2000	print width in inches
213	-1	-40.0000	ts plot minimum target strength in dB
214	-1	-10.0000	ts plot maximum target strength in dB

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215	-1	0.0000	range plot minimum in meters
216	-1	60.0000	range plot maximum in meters
217	-1	-2.0000	min_angoff_v - minimum angle off axis vertical
218	-1	2.0000	max_angoff_v - maximum angle off axis vertical
219	-1	-5.0000	min_angoff_h - minimum angle off axis horiz.
220	-1	5.0000	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24.0000	max_dB_off - maximum angle off in dB
222	-1	-7.7867	ux - horizontal electrical to mechanical angle ratio
223	-1	-17.4163	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0021	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.1669	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.0562	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.2042	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0.0000	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	0.0005	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2090	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	-0.0010	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	5.0000	maximum fish velocity in meters per second
235	-1	10.0000	thd_up_time - minutes between 3d plot updates
236	-1	0.5000	maxpw - pulse width search window size
237	-1	2.0000	cltop - start of processing in meters
238	-1	54.8000	bottom - bottom depth in meters
239	-1	0.0000	init_slope - initial slope for tracking in m/ping
240	-1	0.0000	exp_cont - exponent for expanding tracking window
241	-1	0.3500	max_ch_rng - maximum change in range in m/ping
242	-1	0.1000	pw_criteia->min_pw_6-min -6 dB pulse width
243	-1	0.4000	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.0000	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	2.0000	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.0000	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	2.0000	pw_criteria->max_pw_18 - max -18 dB pulse width
248	-1	1.0000	Intake width to weight fish to (in meters)
249	-1	10.0000	maximum echo voltage to accept (Volts - peak)
250	-1	0.2000	TX argument #1 - pulse width in milliseconds
251	-1	25.0000	TX argument #2 - transmit power in dB-watts
252	-1	-6.0000	RX argument #1 - receiver gain
253	-1	125.0000	REP argument #1 - ping rate in ms per ping
254	-1	10.0000	REP argument #2 - pulsed cal tone separation
255	-1	1.0000	TVG argument #1 - TVG start range in meters
256	-1	100.0000	TVG argument #2 - TVG end range in meters
257	-1	40.0000	TVG argument #3 - TVG function (XX Log Range)
258	-1	-12.0000	TVG argument #4 - TVG gain
259	-1	0.0000	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.0000	minimum absolute distance fish must travel in x plane
261	-1	0.0000	minimum absolute distance fish must travel in y plane
262	-1	0.0000	minimum absolute distance fish must travel in z plane
263	-1	2.0000	bottom_window - auto tracking bottom window (m)

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264	-1	3.0000	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2200	TVG argument #7 - 20/40 log crossover (meters)
300	0	0	
300	1	16256	
300	2	0	
300	3	16544	
300	4	0	
300	5	16800	
401	0	5.0000	th_layer[0] - bottom of first threshold layer (m)
401	1	25.0000	th_layer[1] - bottom of second threshold layer (m)
401	2	50.0000	th_layer[2] - bottom of third threshold layer (m)
401	3	60.0000	th_layer[3] - bottom of forth threshold layer (m)
401	4	100.0000	th_layer[4] - bottom of fifth threshold layer (m)
402	0	844.0000	th_val[0] - thr. for 1st layer (mV)
402	1	844.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	844.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	844.0000	th_val[3] - thr. for 4th layer (mV)
402	4	9999.0000	th_val[4] - thr. for 5th layer (mV)
403	0	1.0000	Integration layer 1 top (m)
403	1	50.0000	Integration layer 1 bottom (m)
404	0	50.0000	Integration threshold layer 1 bottom (m)
405	0	50.0000	Integration threshold layer 1 value (mV)
601	-1	HTI-SB-200kHz	Echo sounder type
602	-1	305785	Echo sounder serial number
603	-1	HTISB-2.8X10	Transducer type
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	Left_to_Right-->	River flow direction
609	-1	All_Fish	Fish included in 3d plot
610	-1	OFF	Echogram enable flag
611	-1	C:\SBDATA\K	Drive and first letter to send files

Appendix A2.-Criteria used for the collection of echoes for the left bank transducer.

* Start Processing at Port 2 -FILE_PARAMETERS- Wed Aug 09 06:00:00 1995

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

100	-1	1	MUX argument #1 - multiplexer port to activate
101	-1	0	percent - sync pulse switch, ping rate determiner NUS
102	-1	32767	maxp - maximum number of pings in a block NUS
103	-1	32767	maxbott - maximum bottom range in samples NUS
104	-1	5	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
111	-1	3	plot_up_fish - number of fish between stbar updates
112	-1	1	echogram_on - flag for DEP echogram enable 0=off, 1=on
113	-1	1	f_inst->o_raw - write raw file flag 1 = on, -1 or 0=off
114	-1	1	f_inst->o_ech - write echo file flag 1 = on, -1 or 0=off
115	-1	1	f_inst->o_fsh - write fish file flag 1 = on, -1 or 0=off
116	-1	0	f_inst->o_sum - write summary table file flag 1 or 0=on
117	-1	0	print summary table on printer, 1 = on, -1 or 0=off
118	-1	25	maxmiss - maximum number of missed pings in auto bottom
119	-1	0	bottom_code - bottom tracking, 0=fix, 1=man, 2=auto
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	1	N_int_layers-number of integration strata
123	-1	1	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
129	-1	1	FILTER argument #1 - filter number
200	-1	0.0000	sigma_flag - if!=0.0000, sigma is output, not ts
201	-1	215.6400	sl - transducer source level
202	-1	-170.4400	gn - transducer through system gain at one meter
203	-1	-18.0000	rg - receiver gain used to collect data
204	-1	2.8000	narr_ax_bw - vertical nominal beam width
205	-1	10.0000	wide_ax_bw - horizontal axis nominal beam width
206	-1	0.0000	narr_ ax_corr - vertical axis phase correction
207	-1	0.0000	wide_ax_corr - horizontal axis phase correction
208	-1	8.0000	ping_rate - pulses per second
209	-1	0.0000	echogram start range in meters
210	-1	37.0000	echogram stop range in meters
211	-1	569.0000	echogram threshold in millivolts
212	-1	13.2000	print width in inches
213	-1	-60.0000	ts plot minimum target strength in dB
214	-1	-30.0000	ts plot maximum target strength in dB

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215	-1	0.0000	range plot minimum in meters
216	-1	60.0000	range plot maximum in meters
217	-1	-2.5000	min_angoff_v - minimum angle off axis vertical
218	-1	2.0000	max_angoff_v - maximum angle off axis vertical
219	-1	-5.0000	min_angoff_h - minimum angle off axis horiz.
220	-1	5.0000	max_angoff_ h - maximum angle off axis horiz.
221	-1	-24.0000	max_dB_off - maximum angle off in dB
222	-1	-7.7307	ux - horizontal electrical to mechanical angle ratio
223	-1	-28.0668	uy - vertical electrical to mechanical angle ratio
224	-1	0.0000	ud_coef_a - a coeff. for up-down beam pattern eq.
225	-1	-0.0030	ud_coef_b - b coeff. for up-down beam pattern eq.
226	-1	-2.6258	ud_coef_c - c coeff. for up-down beam pattern eq.
227	-1	-0.0563	ud_coef_d - d coeff. for up-down beam pattern eq.
228	-1	-0.1323	ud_coef_e - e coeff. for up-down beam pattern eq.
229	-1	0.0000	lr_coef_a - a coeff. for left-rt beam pattern eq.
230	-1	-0.0000	lr_coef_b - b coeff. for left-rt beam pattern eq.
231	-1	-0.2155	lr_coef_c - c coeff . for left-rt beam pattern eq.
232	-1	-0.0005	lr_coef_d - d coeff. for left-rt beam pattern eq.
233	-1	-0.0001	lr_coef_e - ecoeff. for left-rt beam pattern eq.
234	-1	5.0000	maximum fish velocity in meters per second
235	-1	10.0000	thd_up_time - minutes between 3d plot updates
236	-1	0.5000	maxpw - pulse width search window size
237	-1	2.0000	cltop - start of processing in meters
238	-1	35.5000	bottom - bottom depth in meters
239	-1	0.0000	init_slope - initial slope for tracking in m/ping
240	-1	0.0000	exp_cont - exponent for expanding tracking window
241	-1	0.3500	max_ch_rng - maximum change in range in m/ping
242	-1	0.1500	pw_criteia->min_pw_6-min -6 dB pulse width
243	-1	0.3000	pw_criteria->max_pw_6-max -6 dB pulse width
244	-1	0.0000	pw_criteria->min_pw_12 - min -12 dB pulse width
245	-1	2.0000	pw_criteria->max_pw_12 - max -12 dB pulse width
246	-1	0.0000	pw_criteria->min_pw_18 - min -18 dB pulse width
247	-1	2.0000	pw_criteria->max_pw_18 - max -18 dB pulse width
248	-1	1.0000	Intake width to weight fish to (in meters)
249	-1	10.0000	maximum echo voltage to accept (Volts - peak)
250	-1	0.2000	TX argument #1 - pulse width in milliseconds
251	-1	25.0000	TX argument #2 - transmit power in dB-watts
252	-1	0.0000	RX argument #1 - receiver gain
253	-1	125.0000	REP argument #1 - ping rate in ms per ping
254	-1	10.0000	REP argument #2 - pulsed cal tone separation
255	-1	1.0000	TVG argument #1 - TVG start range in meters
256	-1	100.0000	TVG argument #2 - TVG end range in meters
257	-1	40.0000	TVG argument #3 - TVG function (XX Log Range)
258	-1	-12.0000	TVG argument #4 - TVG gain
259	-1	0.0000	TVG argument #5 - alpha (spreading loss) in dB/Km
260	-1	0.0000	minimum absolute distance fish must travel in x plane
261	-1	0.0000	minimum absolute distance fish must travel in y plane
262	-1	0.0000	minimum absolute distance fish must travel in z plane
263	-1	2.0000	bottom_window - auto tracking bottom window (m)

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264	-1	3.0000	bottom_threshold - auto tracking bottom threshold (V)
265	-1	11.2200	TVG argument #7 - 20/40 log crossover (meters)
266	-1	1.0000	
267	-1	5.0000	
268	-1	20.0000	
401	0	5.0000	th_layer[0] - bottom of first threshold layer (m)
401	1	15.0000	th_layer[1] - bottom of second threshold layer (m)
401	2	50.0000	th_layer[2] - bottom of third threshold layer (m)
401	3	100.0000	th_layer[3] - bottom of forth threshold layer (m)
402	0	569.0000	th_val[0] - thr. for 1st layer (mV)
402	1	569.0000	th_val[1] - thr. for 2nd layer (mV)
402	2	569.0000	th_val[2] - thr. for 3rd layer (mV)
402	3	569.0000	th_val[3] - thr. for 4th layer (mV)
402	4	569.0000	th_val[4] - thr. for 5th layer (mV)
403	0	1.0000	Integration layer 1 top (m)
403	1	50.0000	Integration layer 1 bottom (m)
404	0	50.0000	Integration threshold layer 1 bottom (m)
405	0	50.0000	Integration threshold layer 1 value (mV)
601	-1	HTI-SB-200kHz	Echo sounder type
602	-1	305785	Echo sounder serial number
603	-1	HTISB-2.8X10	Transducer type
604	-1	306738	Transducer serial number
605	-1	Spd-3	Echogram paper speed
606	-1	9_pin	Echogram resolution
607	-1	Board_External	Trigger option
608	-1	Right_to_Left-->	River flow direction
609	-1	All_Fish	Fish included in 3d plot
610	-1	OFF	Echogram enable flag
611	-1	C:\SBDATA\K	Drive and first letter to send files

APPENDIX B. TARGET STRENGTH CALCULATION

Appendix B1.-Target strength calculation.

Target strength (TS) in decibels (dB) of a fish located at angular coordinates (θ, ϕ) was calculated for an individual echo as

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

where:

V_o	=	the echo sounder output level in dB,
SL	=	source level of transmitted signal in dB (measured during system calibration),
G_r	=	fixed receiving gain in dB from transducer input to sounder output (receiver gain setting on the sounder plus through-system gain level measured during calibration),
$40\log_{10}(R)$	=	spreading loss in dB, compensated for by the next term,
G_{TVG}	=	time-varied-gain of the sounder in dB,
$B(\theta, \phi)$	=	loss of signal intensity in dB due to less than maximal transducer sensitivity at angular coordinates θ and ϕ (multiplied by 2 to account for the effect in both directions) .

To calculate $B(\theta, \phi)$, one must know θ and ϕ, i.e., the position of the target in the acoustic beam. The split-beam transducer is divided into four quadrants (Appendix B2). Target direction is determined by comparing the signals received by each quadrant. The angle θ of the target in one plane is determined by the phase differences (a-b) and (c-d), which should be the same. In practice, the summed signal (a+c) is compared with (b+d). The angle ϕ in the plane perpendicular to the first is similarly determined by the phase difference between (a+b) and (c+d). The two angles allow the target position to be defined uniquely. Given θ and ϕ, $B(\theta, \phi)$ is determined directly during calibration by measuring transducer sensitivity in the relevant direction.

Appendix B2.-Principles of the split-beam echosounder. Signals from the four transducer quadrants a-d have phase differences which determine the angles of the target direction (MacLennan and Simmonds 1992).