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Estimates of Chinook Salmon Abundance in the Kenai River Using Dual-beam Sonar, 1994

by

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and

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December 1995

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

Dual-beam sonar has been used since June 1987 to estimate the riverine abundance of chinook salmon *Oncorhynchus tshawytscha* in the Kenai River. During 1994 daily abundance estimates of chinook salmon were generated from 16 May through 7 August. The total seasonal estimate of 71,877 was broken into estimates of 18,403 for the early run and 53,474 for the late run.

Key words: Dual-beam sonar, chinook salmon, *Oncorhynchus tshawytscha*, hydroacoustic, Kenai River, riverine sonar.

INTRODUCTION

The Kenai River supports the largest sport fishery for chinook salmon *Oncorhynchus tshawytscha* in Alaska (Nelson 1990). Because of the consistently large size (mean weight) of Kenai chinook salmon, this river attracts fishermen from around the world, as well as a growing number of anglers from within the state. The fishery has been politically volatile because substantial numbers of chinook salmon are also intercepted by the Cook Inlet sockeye salmon *O. nerka* commercial fishery during the months of July and August.

In 1974 a creel census program was implemented to estimate angler effort, harvest and success rates in the chinook fishery (Nelson 1990). The need for biological information about Kenai River chinook salmon was identified as early as 1975 when the department proposed a tag-and-recovery project to estimate abundance of early-run and late-run fish as well as age structure, mean length-at-age, and sex ratios. A variety of methods were tested for catching chinook salmon including electrofishing, drift gillnets (Hammarstrom 1980), fish traps, and fish wheels (Hammarstrom and Larson 1982, 1983, 1984). Beginning with the late run of 1984, a tag-and-recovery project was implemented using drift gillnets (Hammarstrom et al. 1985). The tag-and-recovery project produced estimates of riverine abundance through 1990 (Hammarstrom and Larson 1986, Conrad and Larson 1987, Conrad 1988, Carlon and Alexandersdottir 1989, Alexandersdottir and Marsh 1990). Recognizing the need for in-season information on chinook salmon abundance for more effective management of the sport fishery, the department initiated a research project in 1984 to determine whether dual-beam sonar technology could be used to count chinook salmon. Due to the considerable size difference between Kenai chinook salmon and other species of fish present in the river, it was postulated that dual-beam sonar might distinguish the larger chinook salmon from smaller fish and count the number returning to the river. Feasibility studies were conducted from 1984 through 1986 (Eggers et al. 1995) and the first daily sonar abundance estimates of chinook salmon were produced in July 1987.

Chinook salmon returning to the Kenai River are managed as two distinct runs, early and late, which typically peak in mid-June and late July. Early-run fish are harvested primarily by the sport fishermen; late-run fish by both commercial and sport fishermen. In November 1988 the Alaska Board of Fisheries set the first optimum spawning escapement goals of 9,000 and 22,300 for early-run and late-run chinook salmon, respectively (McBride et al. 1989). As part of the management plan, commercial, sport, subsistence, and personal use fisheries could be restricted if the projected run size fell below set escapement goals (ADF&G 1990). The Board further defined the early run as those fish entering the river from 16 May through 30 June and the late run as those fish entering the river between 1 July and

10 August. This delimitation is somewhat arbitrary as overlap between the timing of the two runs does occur.

The primary goal of this ongoing project is to provide daily and seasonal estimates of chinook salmon passage into the lower Kenai River. These figures, used in conjunction with other run information, facilitate in-season management of the fishery. Additionally, the estimates contribute to a database used for long-term assessment of the Kenai River chinook salmon population.

METHODS

SITE DESCRIPTION

The 1994 sonar site was located 14 km from the mouth of the Kenai River (Figure 1). This site has been used since 1985 and was selected for its acoustic characteristics and its location relative to the sport fishery and known spawning habitat for chinook salmon.

The river bottom in this area has remained topographically stable for the past 8 years. The slope from both banks is gradual and uniform, which allows the maximum proportion of the water column to be ensonified without acoustic shadowing effects. The bottom is composed primarily of mud, which is an absorptive rather than reflective surface. This absorptive property improves the signal-to-noise ratio when the beam is aimed along the bottom.

The sonar site is located below the lowest suspected spawning sites of chinook salmon yet far enough from the mouth that most of the fish counted are probably committed to the Kenai River (Steve Hammarstrom, Alaska Department of Fish and Game, Soldotna, personal communication). Initially, almost all sport fishing occurred upstream of this site. In recent years, fishing at, and below the sonar site has increased dramatically.

HYDROACOUSTIC SAMPLING

The main acoustic components of the sonar system were manufactured by Biosonics, Inc. Dual-beam techniques were used to estimate fish target strengths, which are related to fish size (Figure 2). An explanation of the theory of dual-beam sonar and its use in estimating target strength can be found in Ehrenberg (1983).

Sonar System Configuration

The sonar system consisted of the following hardware:

(1) Biosonics[1] model 102 dual-beam echosounder, operating frequency 420 kHz

(2) Biosonics[1] elliptical dual-beam transducers with the dimensions: narrow beam = 3° x 10° (narrow x wide axis), wide beam = 7° x 21°

(1) Biosonics[1] model 281 Echo Signal Processor card installed in a Compaq[1] 386/20e computer

(1) Simrad[1] model CF-100 color video monitor

(1) Nicolet[1] model 310 digital storage oscilloscope

(1) Biosonics[1] model 151 transducer multiplexer

(1) Dowty[1] model 3700 dual-channel thermal chart recorder

(1) Biosonics[1] remote-aiming controller

(2) Biosonics[1] pan and tilt remote aiming axes.

Sampling was controlled by electronics housed in a tent located on the right bank of the river, from which communication cables were deployed to the transducers and their aiming devices on both banks (Figure 3). The

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

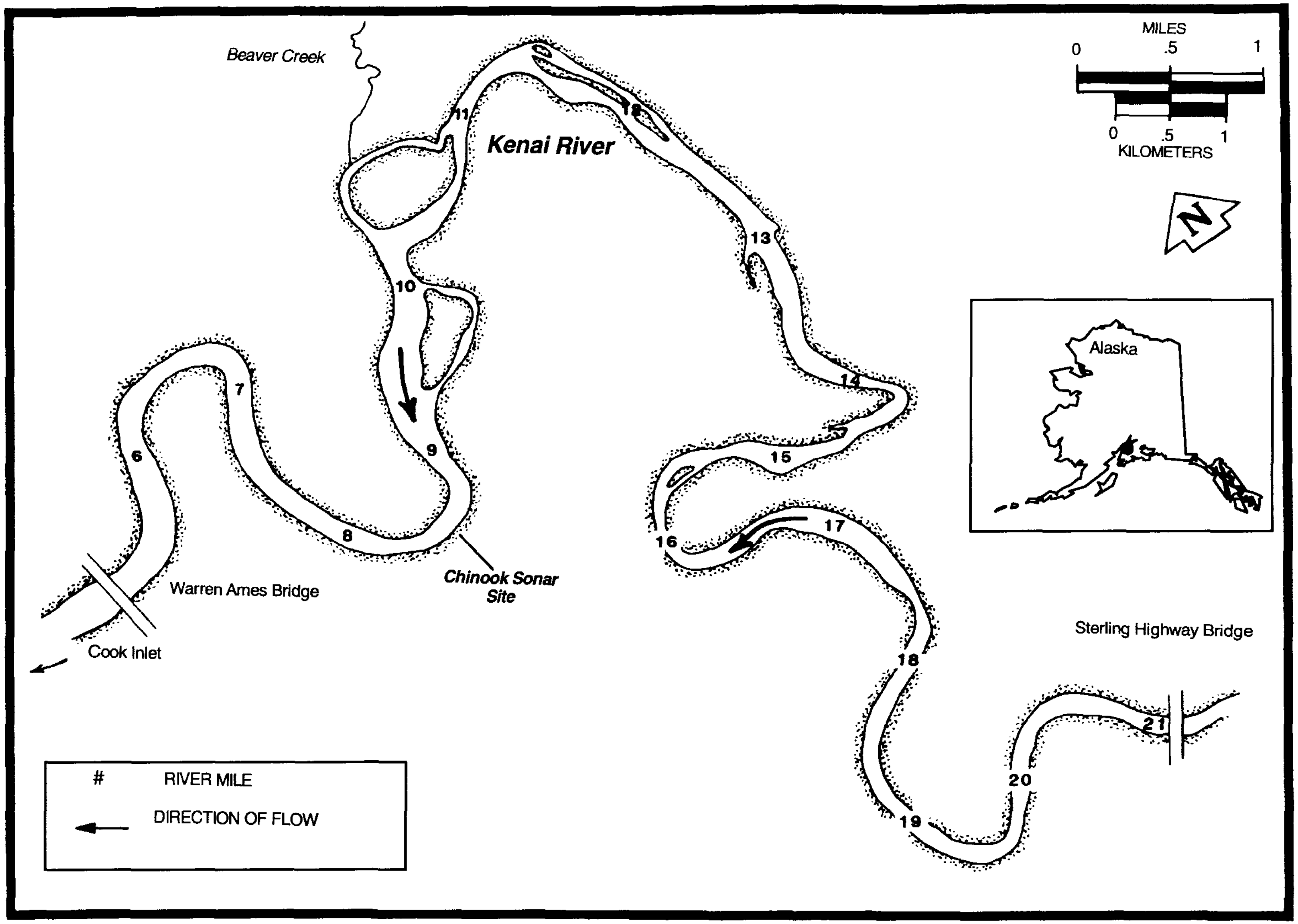

Figure 1.-Map of lower Kenai River showing location of 1994 sonar site.

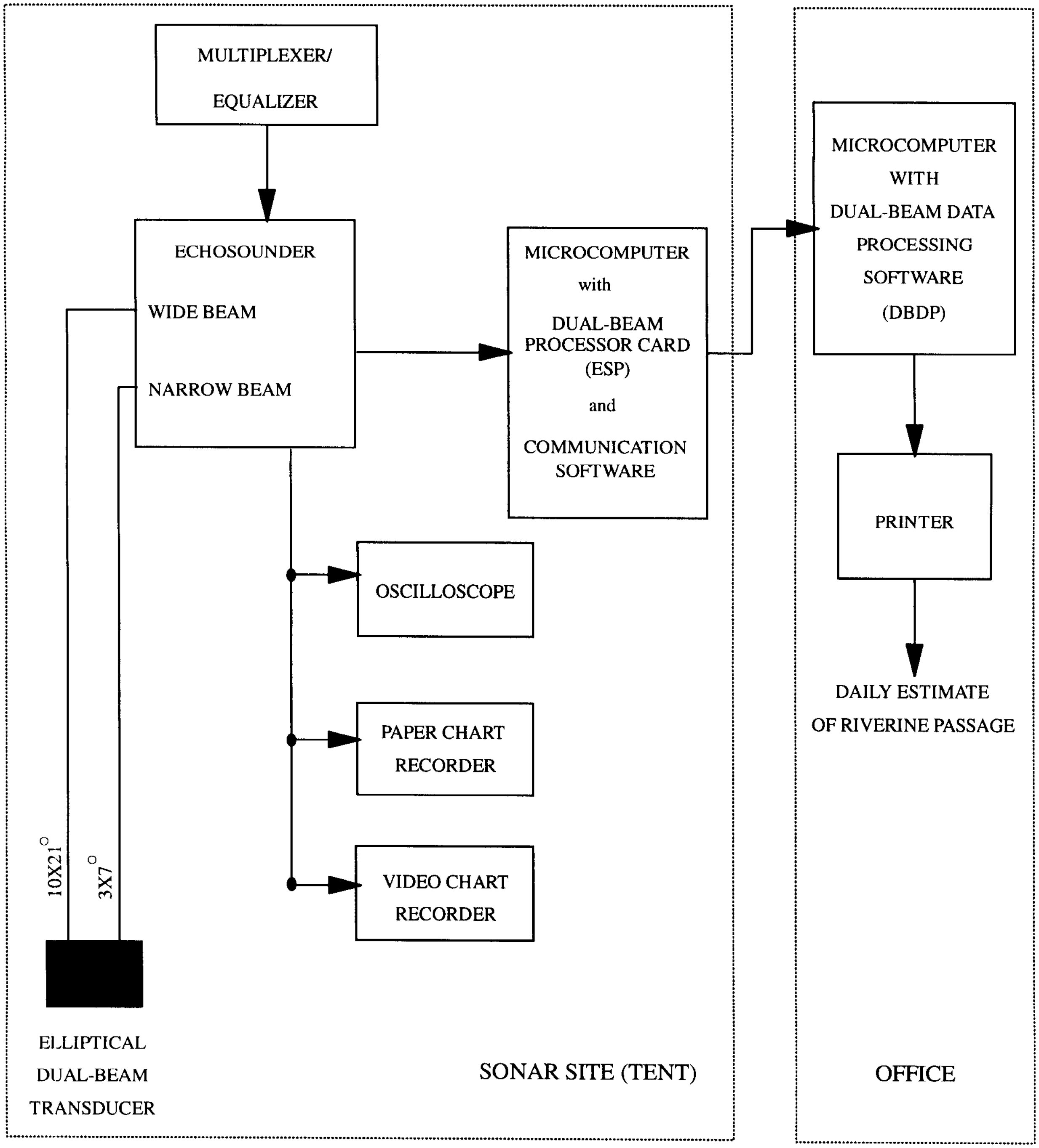

Figure 2.-Schematic diagram of sonar system and data flow.

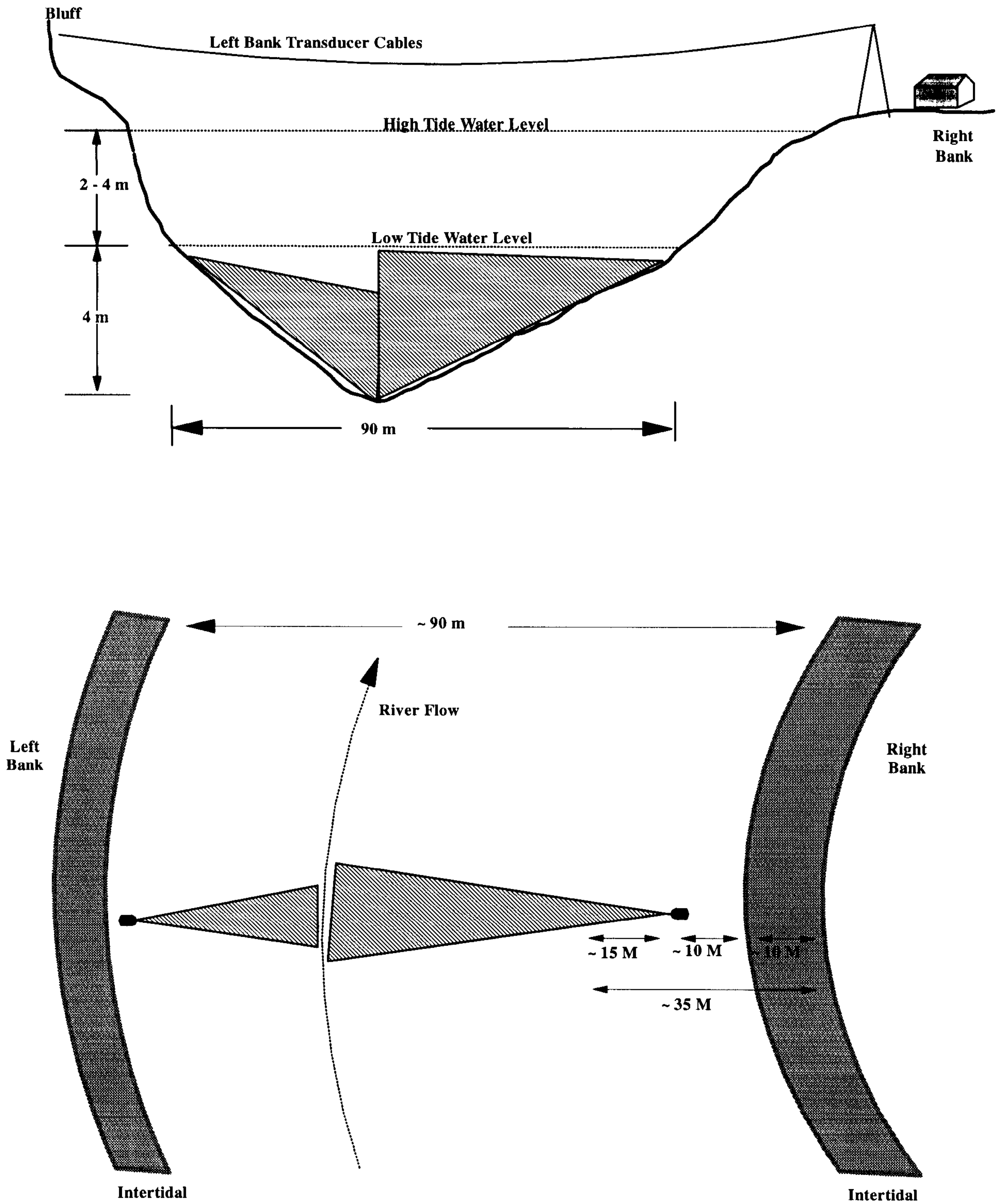

Figure 3.-Aerial and cross-sectional views of sonar site showing ensonified portions of the Kenai River.

cables leading to the left bank equipment were suspended above the river. Steel tripods were used to deploy the transducers offshore. One elliptical, dual-beam transducer was mounted on each tripod. At the start of the season the transducer tripods were placed on each bank in a position close to shore but still submerged at low tide. The Kenai River is glacially influenced and peak flows occur during August. As the water level rose throughout the season the tripods were periodically moved closer to shore so that the total range ensonified by the sonar beams increased from approximately 75 m at the lowest water conditions to 100 m at high water.

The vertical and horizontal aiming angles of each transducer were remotely controlled by a dual-axis electronic pan and tilt system. A digital readout indicated the aiming angle in the vertical and horizontal planes. In the vertical plane, the transducer was aimed using an oscilloscope and chart recorder to verify that the sonar beam was grazing the bottom of the river while maintaining at least a 10 dB signal-to-noise ratio (the mean background noise level is at least 10 times smaller than the minimum target). In the horizontal plane, the transducer was aimed perpendicular to the flow of the river current in order to maximize the probability of ensonifying fish from a lateral aspect. The range encompassed by each transducer was determined by using a depth sounder to find the center of the river channel between the two sonar beams, deploying a large underwater target in midchannel, aiming both sonar transducers at the underwater target and recording the range from each, and subtracting one half meter from each range.

Sampling Procedure

A systematic sample design (Cochran 1977) was used to sample from each bank for 20 min per hour. Although the sonar system is capable of sampling both banks continuously, data collection was restricted to 20-min samples per hour to limit the data processing time and personnel required to produce the daily count. Acoustic sampling was initiated by the model 151 multiplexer, which was programmed to cycle according to an internal clock. At the top of each hour the system started automatically sampling the right bank for 20 min. After a 5-min break, the system sampled the left bank for 20 min followed by a 15-min quiescent period. This routine was followed 24 hours per day and 7 days per week unless one or both banks were inoperable.

If one bank was inoperable, the opposite bank was operated continuously. Circumstances which necessitated this were (1) equipment failure or maintenance on one bank, or (2) high boat activity during low tide resulting in high background noise.

Continuous sampling of the left bank during some low tide stages was a function of beam configuration and bottom topography at the site. Because the deepest part of the channel is offset toward the left bank, the bottom on the right bank has a more gradual slope and almost twice the effective sampling range as the left bank (Figure 3). As a result, the cross-sectional area of the beam encompasses the entire water column of the right bank at low tide. Disturbance caused by boat wakes reflects sound when the acoustic beam lies close to the surface. Because the number of targets masked by boat noise cannot be easily quantified, we preferred to sample continuously on the left bank and use the relationship between right-bank and left-bank passage to estimate the missing right-bank data. The left bank beam was unaffected by boat traffic due to the steeper grade of the bottom and shorter sampling range. Because low tide stages represent the times at which the sonar counts are at a minimum (Eggers et al. 1995), the contribution of these extrapolations to the total variance estimate is typically small.

During the late run, at times of extremely high fishing effort, we did not always switch to sampling the left bank continuously as we had in previous years. Instead we continued to follow the normal sampling regime and collect on the right bank with the manual bottom set in to approximately 15 meters. This allowed us to eliminate the collection of files with excessive boat wake, while still collecting chart samples containing fish traces. Files of too large a size, regardless of what they contain, can not be processed by Dual-Beam Data-Processing software (DBDP). We collected right bank data in this manner for several reasons: (1) we did not want to miss valid right bank samples when few boats were present, (2) we could still estimate passage of fish on the right bank using the bank-to-bank ratio estimator, and (3) we were concerned that during extremely high fishing effort, boat traffic appeared to move fish over to the left bank and into the deeper water found there. This is not consistent with the normal travel pattern of chinook salmon that we have observed in past years. Only distinguishable fish traces which met range criterion (see Range Separation) were counted as fish.

The 20-min "chart count" samples were expanded to the full hour in the same manner as a normal sample (See Passage Estimates) and compared with estimates derived using the ratio estimator. We chose the conservative estimate of daily passage between these two methods for missing data.

Echo Signal Processor

The echo signal processor digitized incoming data and rejected echoes based on (1) minimum narrow-beam and wide-beam voltage thresholds, (2) minimum and maximum pulse widths, and (3) the minimum range (distance from the transducer face). Minimum threshold voltages exclude echoes from the bottom, smaller fish, and other spurious sources. A voltage threshold corresponding to a -34 dB target on-axis was selected for each channel of the echo signal processor based on data collected in 1985 and 1986 (Eggers et al. 1995). Voltage threshold for selected transmit-power and receiver-gain settings was calculated using calibration data provided by the manufacturer. The calibration data were field-tested for accuracy using a tungsten-carbide standard target.

The minimum pulse width criterion prevents narrow band noise from being mistaken for valid echoes. The maximum pulse width criterion excludes multiple targets when estimating target strength. Minimum and maximum pulse width parameters were set at 0.200 ms and 0.800 ms for a transmitted 0.400 ms pulse.

Echoes less than 2.5 m range from the transducer were excluded due to near-field effect (MacLennan and Simmonds 1992).

If an echo met the above criteria, data associated with the echo were passed from the echo signal processor to the microcomputer where the data were stored on hard disk in binary file format. The data file contained the following data for each echo: (1) sequential number of the ping which produced the echo, (2) echo number, (3) wide-beam voltage, (4) narrow-beam voltage, (5) range from transducer, (6) wide-beam pulse width, and (7) narrow-beam pulse width.

Data Analysis

Estimates of fish passage were made daily from 16 May to 8 August and were available to fishery managers by noon the following day. Final passage estimates were recomputed, and variance estimates calculated postseason.

Fish Tracking and Counting

The number of fish per sample were counted by using both the electronic, partially filtered data output by the echo signal processor (ESP), and paper chart recordings output by the thermal chart recorder. We developed Dual-Beam Data-Processing software which uses 26 input parameters to annotate and process data from the ESP (Figure 4, Appendix A1). In addition to performing additional filtering of individual echoes, DBDP groups surviving echoes into fish and calculates average target strength.

Grouping Echoes into Fish

Three parameters determined how echoes were grouped into individual targets: (1) minimum number of pings per fish, (2) maximum change in range between consecutive echoes (in meters/second) and (3) maximum time allowed between two consecutive echoes (in seconds). The optimum value for the minimum number of pings per fish is related to the ping rate (pings per second), fish swimming speed and transducer beam width. Appropriate values for the range and time parameters are related to fish behavior such as swimming speed and angle of passage through the beam, as well as relative abundance. If these parameters are set too small, DBDP may divide a single target into multiple targets. Conversely, if they are set too large, multiple targets may be combined into a single target. All parameters were selected by comparing the output of DBDP with a high resolution chart recording of fish traces while varying each parameter independently. At a sounder ping rate of 8 pings/sec, five was selected for the minimum number of echoes per fish, a value of 0.9 m/sec allowed a maximum range change of 0.1 m between consecutive echoes and 0.625 ms allowed four pings to drop out between consecutive echoes.

DBDP generated two ASCII output files. The first file contained the measured target strength, range, beam pattern factor and other data for each individual echo (EKO files). The second file provided the average values for each fish (FSH files) and was imported into a database for looking at the distribution of target strengths over more than a single day. The files were edited to eliminate erroneous data the program was not able to detect, primarily bottom echoes retained as valid pings. These echoes are identified by their constant range over time, large target strength values and wide pulse widths. Each electronically generated fish was compared with its corresponding trace on the chart recording to ensure that there were no echoes attributable to the bottom, or boat wakes. The chart recorder displays all echoes above a minimum threshold voltage which is set at 3 dBv less than the ESP voltage threshold. The chart recorder was not used to count chinook salmon because it cannot provide acoustic size information. However, because of the reduced voltage threshold, all valid targets in the EKO file showed up on the chart recording, as well as bottom echoes, boat wakes, and fish that remain in the beam for minutes at a time. Fish that showed up on the chart recording but did not exist in the EKO file did not meet the minimum voltage threshold or pulse width criteria and were not counted. When disagreement between the program and chart recording existed (e.g. one fish on chart recorder is separated into two fish by the software), the more conservative assessment of number of targets was used.

Species Discrimination

Two methods, target strength and range separation, were used to discriminate sockeye from chinook.

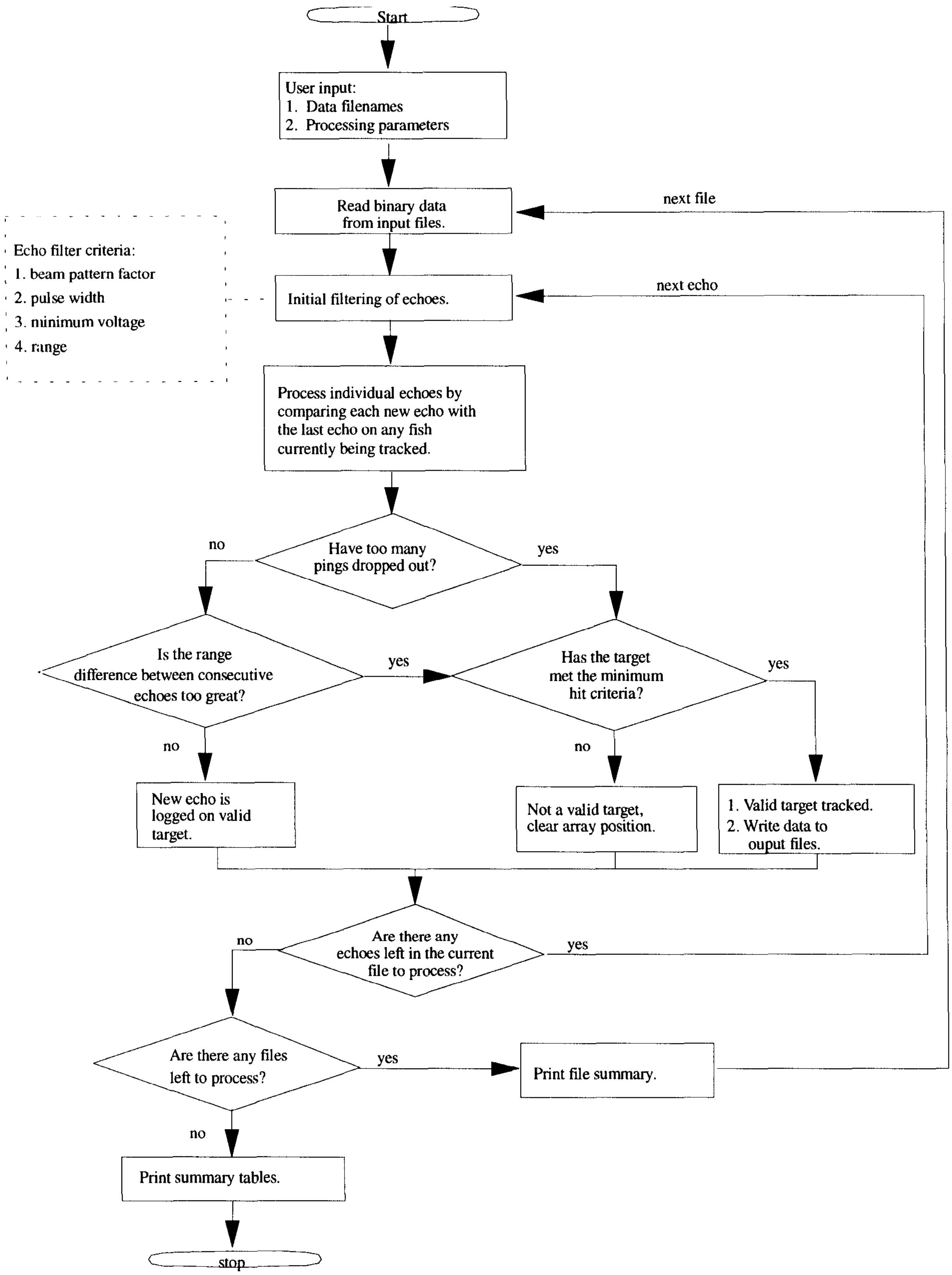

Figure 4.-Flow chart of Dual-Beam-Data-Processing software.

Target Strength

Target strength was calculated (Ehrenberg 1983) for individual echoes and averaged for each fish. Fish with less than -28 dB were assumed not to be chinook salmon (Paul Skvorc, Alaska Department of Fish & Game, Anchorage, personal communication) and were excluded from further analysis.

Range Separation

During peak sockeye passage numerous nearshore targets were seen on both the chart recordings and in the electronic data collected. It is believed that a great majority of these are sockeye salmon as they exhibit a different behavior pattern than is seen when only chinook are present in the river. These sockeye are typically nearshore (within 20 m) and travel in large groups. Both of these behavior patterns are not typically seen when only chinook salmon are present in the river. To minimize the chance of mistakenly counting sockeye salmon as chinook salmon, a range separation criterion was used. During times of peak sockeye passage, fish in the 15 to 25 m range were not enumerated as chinook salmon. The range, 15 to 25 m, was adjusted daily based on the density and distribution of these nearshore targets.

Passage Estimates

Using only those fish targets which met the target-strength and range criteria above, an expanded count was calculated for each hour for which a sample existed. This was usually an exact 20-min count which was multiplied by 3 for the hourly estimate on each bank. In this case, the number of chinook salmon passing bank b during hour j was estimated as:

$$y_{bj} = \frac{60}{t_{bj}} c_{bj} \qquad (1)$$

where:

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

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

When the sonar system on one bank was not operating, the other bank was operated for 60 minutes to obtain an actual count for the hour rather than a 20-min sample. We then applied a ratio estimator (Cochran 1977) between banks, using data from those hours when both banks were sampled for the same number of minutes. For a bank that was not operating, chinook passage was estimated as:

$$y_{bj} = R_b y_{b'j} \qquad (2)$$

where:

$$R_b = \frac{\sum_{j=1}^{n_B} y_{bj}}{\sum_{j=1}^{n_B} y_{b'j}}, \qquad (3)$$

$y_{b'j}$ = expanded count for opposite bank b' during hour j, and

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

During the season, for purposes of daily reporting of estimated passage, R_b was calculated from the cumulative number, to date, of hours when both banks were sampled for the same number of minutes. Final estimates were generated postseason.

Occasionally both banks were down for a full hour. In this case the expanded count for that hour on each bank was interpolated as the mean of the expanded counts on either side of the missing count:

$$y_{bj} = \frac{y_{b(j-1)} + y_{b(j+1)}}{2}. \qquad (4)$$

Fish passage on day i was estimated as:

$$y_i = \sum_{j=1}^{24}\left[y_{bj} + y_{b'j}\right] \quad (5)$$

where y_{bj} and $y_{b'j}$ were obtained from either (1), (2), or (4) as appropriate.

Finally, the number of chinook salmon migrating into the Kenai River during a run was estimated as:

$$\hat{Y} = \sum_{i=1}^{N_D} y_i \quad (6)$$

where N_D is the number of days in the run. Its variance was estimated as:

$$\hat{V}(\hat{Y}) = \hat{V}_S + \hat{V}_R, \quad (7)$$

where $\hat{V}_S$ is the variance due to systematic sampling (successive difference model, Wolter 1985):

$$\hat{V}_S = \left(N_H - n_b - n_{b'}\right)^2\left[\frac{1-f_S}{N_H}\right]\sum_{j=2}^{N_H}\frac{\left(y_j - y_{j-1}\right)^2}{2(N_H - 1)} \quad (8)$$

where:

y_j = $y_{bj} + y_{b'j}$,

N_H = total number of 1-hour sampling periods during the run,

f_s = sampling fraction for systematic sampling (~0.33),

n_b = number of hours bank b not operating,

and where $\hat{V}_R$ is the variance due to ratio estimation (Cochran 1977:155):

$$\hat{V}_R = \left(n_b\right)^2\left(1-f_b\right)\frac{\sum_{j=1}^{N_B}\left(y_{bj} - R_b y_{b'j}\right)^2}{n_B\left(n_B - 1\right)} + \left(n_{b'}\right)^2\left(1-f_{b'}\right)\frac{\sum_{j=1}^{n_B}\left(y_{b'j} - R_{b'} y_{bj}\right)^2}{n_B\left(n_B - 1\right)} \quad (9)$$

where:

f_b = the bank b sampling fraction for ratio estimation: $f_b = n_B/(n_B+n_b)$, and

$f_{b'}$ = the bank b' sampling fraction for ratio estimation: $f_{b'} = n_B/(n_B+n_{b'})$.

RESULTS AND DISCUSSION

During the early run, both banks were down simultaneously for a total of 21 hours from 23 May to 28 May. The loss of sample time appears to be related to the extreme tidal fluctuations associated with spring tides in May. During this time period, there was an almost complete attenuation of sound during part of the falling and rising tide stages. This same phenomenon was also documented during the same spring tides during the 1990, 1991 and 1992 early runs. This sound attenuation may be related to high concentrations of flocculent matter introduced by the first spring tides following ice out. Conductivity changes related to a saltwater intrusion during extremely high spring tides and seasonal low water levels is another possible explanation. The observed attenuation was confined to this 6-d period and was not experienced again during the 1994 season. The daily estimates for this 6-d period should be considered conservative, since the sound attenuation was in effect during the rising and falling tide stages when fish passage rates are highest (Eggers et al. 1995). During the late run both banks were down simultaneously for 1 hour on 28 July due to a power cord failure.

Daily and cumulative sonar counts for the early (16 May-30 June) and late (1 July-7 August) runs are given in Tables 1 and 2. The total chinook salmon counted for this period was 71,877 of which 18,403 were early

Table 1.-Estimated daily chinook salmon passage, Kenai River sonar, early run, 1994.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
16-May	88	150	238	238
17-May	108	234	342	580
18-May	72	188	260	840
19-May	100	202	302	1,142
20-May	116	253	369	1,511
21-May	84	243	327	1,838
22-May	99	147	246	2,084
23-May	63	149	212	2,296
24-May	85	218	303	2,599
25-May	66	104	170	2,769
26-May	51	99	150	2,919
27-May	126	141	267	3,186
28-May	99	159	258	3,444
29-May	156	191	347	3,791
30-May	135	186	321	4,112
31-May	186	183	369	4,481
1-Jun	120	201	321	4,802
2-Jun	110	156	266	5,068
3-Jun	119	179	298	5,366
4-Jun	133	171	304	5,670
5-Jun	108	243	351	6,021
6-Jun	60	138	198	6,219
7-Jun	117	267	384	6,603
8-Jun	72	234	306	6,909
9-Jun	144	318	462	7,371
10-Jun	138	294	432	7,803
11-Jun	111	312	423	8,226
12-Jun	86	243	329	8,555
13-Jun	118	258	376	8,931
14-Jun	138	376	514	9,445
15-Jun	84	222	306	9,751
16-Jun	105	348	453	10,204
17-Jun	57	258	315	10,519
18-Jun	120	315	435	10,954
19-Jun	162	474	636	11,590
20-Jun	84	318	402	11,992
21-Jun	126	444	570	12,562
22-Jun	96	270	366	12,928
23-Jun	94	456	550	13,478
24-Jun	120	576	696	14,174
25-Jun	153	581	734	14,908
26-Jun	129	468	597	15,505
27-Jun	132	507	639	16,144
28-Jun	195	486	681	16,825
29-Jun	162	767	929	17,754
30-Jun	111	538	649	18,403

Table 2.-Estimated daily chinook salmon passage, Kenai River sonar, late run, 1994.

Date	Left Bank	Right Bank	Daily Total	Cumulative Total
1-Jul	87	576	663	663
2-Jul	60	282	342	1,005
3-Jul	70	555	625	1,630
4-Jul	159	699	858	2,488
5-Jul	141	564	705	3,193
6-Jul	147	828	975	4,168
7-Jul	162	888	1,050	5,218
8-Jul	106	549	655	5,873
9-Jul	147	597	744	6,617
10-Jul	210	1,079	1,289	7,906
11-Jul	59	450	509	8,415
12-Jul	183	645	828	9,243
13-Jul	152	920	1,072	10,315
14-Jul	240	1,092	1,332	11,647
15-Jul	285	1,936	2,221	13,868
16-Jul	555	3,247	3,802	17,670
17-Jul	768	3,924	4,692	22,362
18-Jul	729	1,428	2,157	24,519
19-Jul	579	2,925	3,504	28,023
20-Jul	327	2,001	2,328	30,351
21-Jul	246	1,449	1,695	32,046
22-Jul	231	1,155	1,386	33,432
23-Jul	225	825	1,050	34,482
24-Jul	183	1,137	1,320	35,802
25-Jul	171	1,273	1,444	37,246
26-Jul	219	1,213	1,432	38,678
27-Jul	180	1,109	1,289	39,967
28-Jul	225	2,001	2,226	42,193
29-Jul	165	1,168	1,333	43,526
30-Jul	281	1,488	1,769	45,295
31-Jul	578	1,230	1,808	47,103
1-Aug	321	716	1,037	48,140
2-Aug	204	1,019	1,223	49,363
3-Aug	171	907	1,078	50,441
4-Aug	165	493	658	51,099
5-Aug	159	377	536	51,635
6-Aug	166	876	1,042	52,677
7-Aug	127	670	797	53,474

run and 53,474 were late run. The peak of the early run occurred on 29 June while the mean (Mundy 1982) and median occurred on 11 June and 14 June, respectively (Figure 5). The peak of the late run occurred on 17 July while the mean and median occurred on 20 July and 19 July, respectively (Figure 5). More early-run fish returned early in the season (Figure 6) in 1994 than in any other year (1988-1993). However, returns slowed down, and towards the end of June, run timing was later than every year but 1993. The migratory run timing of the late run (Figure 7) appears average compared to run timing data from other years (1987-1993).

A total variance of 82,926 (SE = 288) and 1,212,226 (SE = 1,101) was calculated for the early and late runs, respectively. Table 3 shows the total variance estimates broken down into their individual components due to (1) systematic sampling (temporal expansion of the hourly samples), and (2) spatial extrapolation from the opposite bank. The largest variance component for both runs was due to sampling error incurred by systematic sampling. The width of the 95% confidence interval relative to the estimate yielded a relative precision of 3.1% for the early run and 4.0% for the late run.

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We would like to thank Linda Lowder, Bruce Whelan, Mark Jensen, and Diane Campbell for meticulously collecting the sonar data and for their high motivation throughout a long field season. Steve Fleischman provided expertise in simplifying the notation for the abundance and variance estimates. Special thanks, also, to the members of the Sport Fish staff in Soldotna who provided logistical support whenever needed.

Table 3.-Variance components of the seasonal estimates of fish passage for early and late runs of chinook salmon on the Kenai River, 1994.

	Estimates of Fish Passage	Variance Due to Systematic Sampling[a]	Variance Due to Bank-to-Bank Estimation[b]	Total Variance
Early Run	18,403	82,314	612	82,926
Late Run	51,801	1,136,663	75,563	1,212,226

[a] Variance due to systematic sampling estimated using the successive difference model from equation 9.

[b] Variance due to estimating a missing hourly count using the ratio estimator from equation 5.

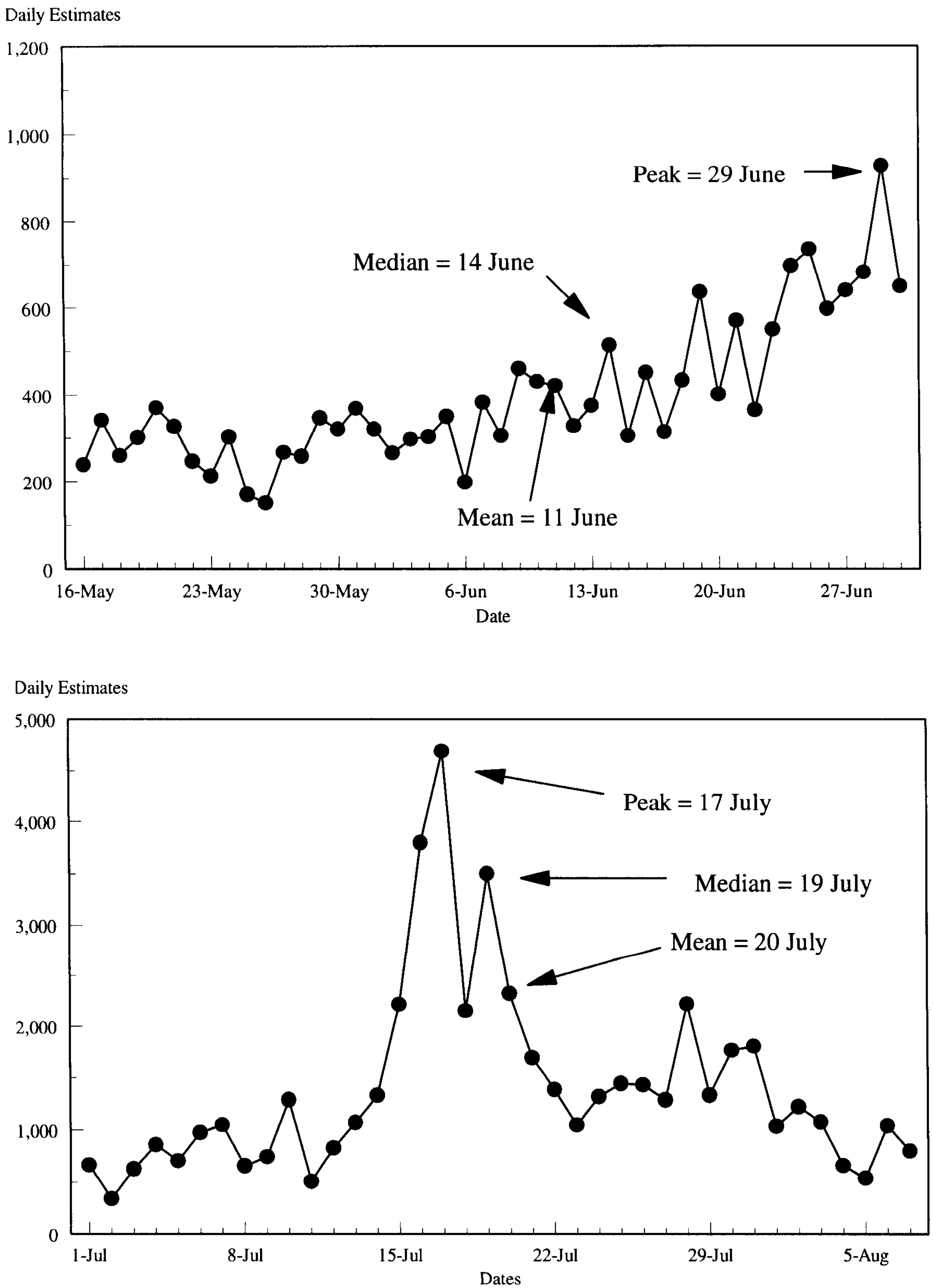

Figure 5.-Daily sonar estimates of passage for chinook salmon during the early (top) and late (bottom) runs, 1994.

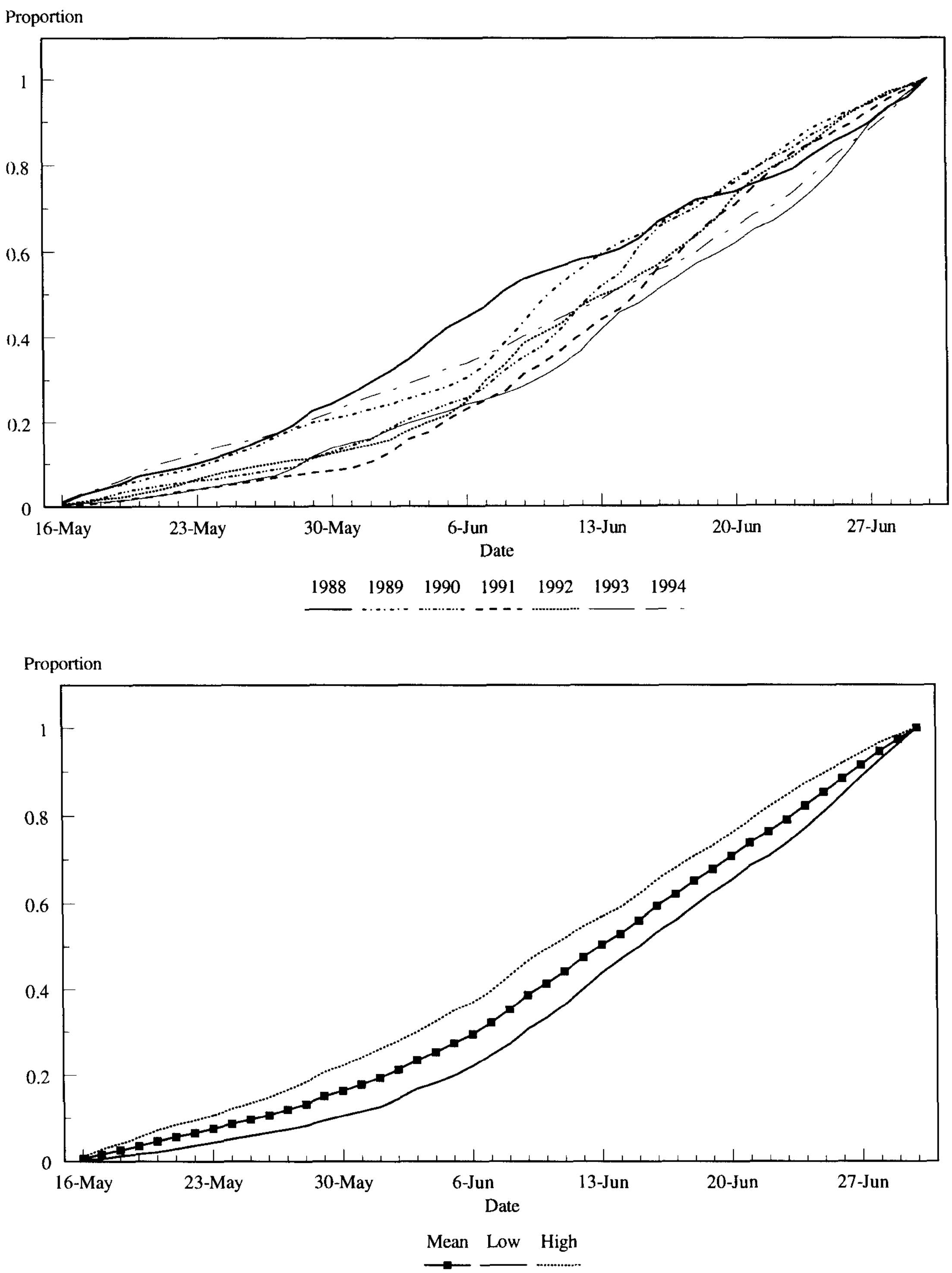

Figure 6.-Yearly (top) and mean (with 95% confidence intervals) migratory-timing curves for the early run, 1988-1994.

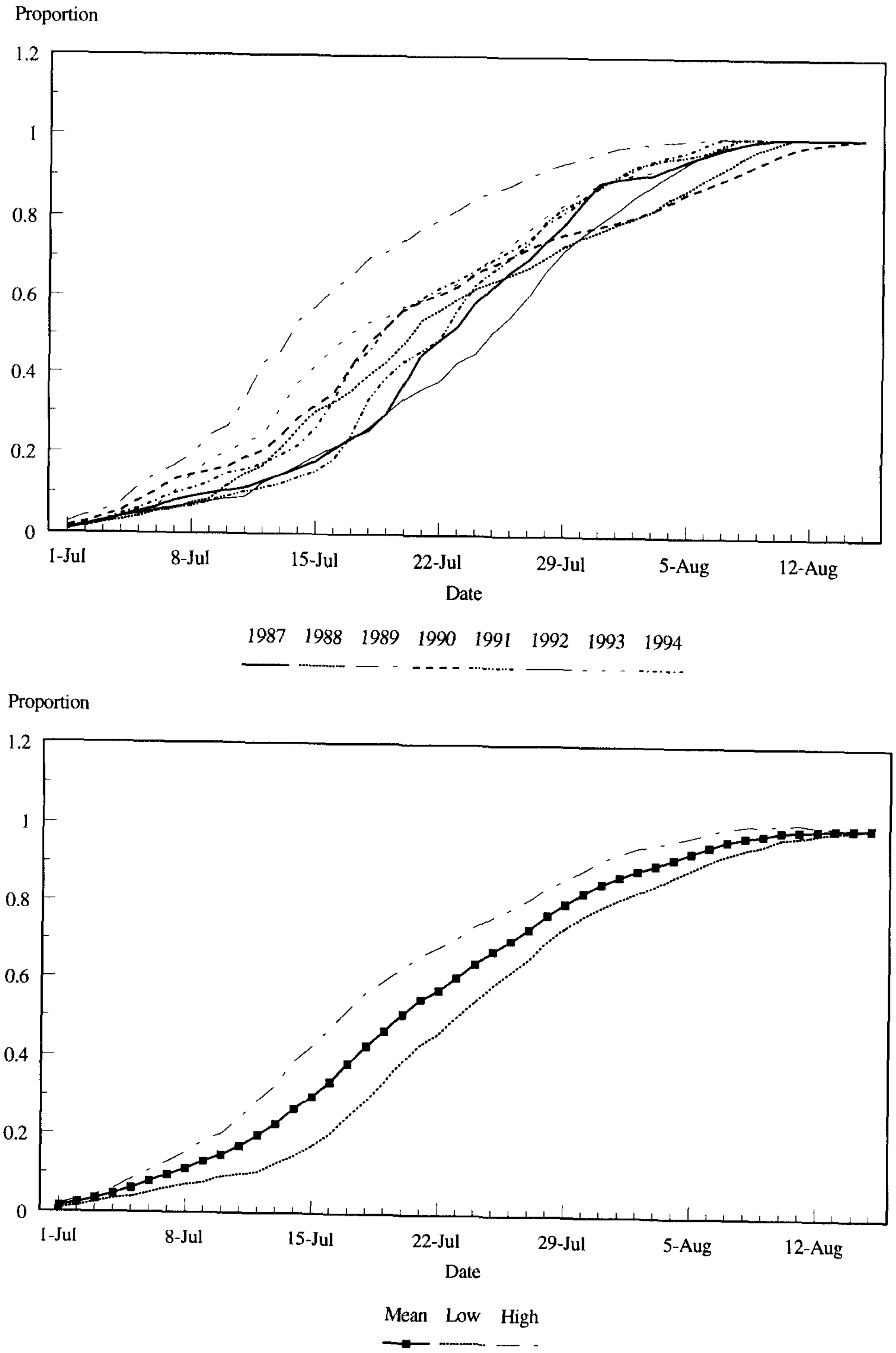

Figure 7.-Yearly (top) and mean (with 95% confidence intervals) migratory-timing curves for the late run, 1987-1994.

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APPENDIX A.

Appendix A1.-Example of interactive user session with the Dual-Beam-Data-Processing Software (DBDP).

All files will be processed using the same parameters	
How many input files to process (1 to 100) ?	2
Were these filenames computer generated? (Y or N)	y
Enter filename for input file number 1	n2101400.001
Enter filename for input file number 2	n2101500.001
Create an individual echo output file ? (Y or N)	y
Enter individual echo output filename	n210hrs.eko
Create a tracked fish summary file ? (Y or N)	y
Enter tracked fish summary filename	n210hrs.fsh
Create a file of fish <= a given TS? (Y or N)	n
Enter the minimum beam pattern factor for TS estimates :	-6.0
Was the data collected at 20 Log R (Y or N) ?	n
Will a command file be used to enter the parameters ? (Y or N) :	y
Enter command file name (e.g. a:filename.ext)	nstdcal.94

(1)	FREQUENCY	420.000	(2)	BEAM WIDTH	3.000
(3)	TVG START-UP	2.500	(4)	SOURCE LEVEL	212.668
(5)	Gx AT 1 METER	-172.597	(6)	NARROW CORR. FACTOR	1.000
(7)	WIDE CORR. FACTOR	1.000	(8)	NARROW CHANNEL	1
(9)	N THRESHOLD mV	900.000	(10)	W THRESHOLD mV	900.000
(11)	MINIMUM DEPTH	2.500	(12)	MAXIMUM DEPTH	60.000
(13)	BOT THRESH mV	9999.000	(14)	USE -18 dB PW	N
(15)	MINIMUM -6 dB PW	0.200	(16)	MAXIMUM -6 dB PW	0.734
(17)	CHECK W -6 dB PW	Y	(18)	RECEIVER GAIN	0.000
(19)	MIN B. P. FACTOR	-12.000	(20)	MEDIAN TS	-20.000
(21)	PING RATE	8.000	(22)	MIN. PINGS/FISH	5
(23)	MAX CHG. IN RANGE	1.900	(24)	MAX TIME BET. PINGS	1.000
(25)	AIMING ANGLE	0.000	(26)	WIDE-BEAM DROP OFF	1.34

TRANSDUCER TYPES ARE AS FOLLOWS :	
CIRCULAR SIDE BY SIDE ELEMENTS	1
CIRCULAR CONCENTRIC ELEMENTS	2
ELLIPTICAL ELEMENTS	3

Enter number of parameter to change (return for none) :

OPTIONS FOR PRINTER OUTPUT

(1) NO PRINT OUT AT ALL!!!!
(2) PRINT FILE HEADER INFORMATION
(3) PRINT DUAL BEAM PROCESSOR SET-UP PARAMETERS
(4) PRINT TARGET STRENGTH vs. RANGE TABLE
(5) PRINT FREQUENCY HISTOGRAM OF TARGET STRENGTHS
(6) PRINT TABLE OF BEAM PATTERN FACTORS GREATER THAN ZERO

ENTER OPTION(S) FOR PRINTER OUTPUT (RETURN FOR NONE) 23456

First page of output from DBDP.

```
*********************DBDP version 1.0********************

                Dual Beam Data Processing program
     For use with files collected using the dual beam processor
     and the PCACQ (Personal Computer ACQuire) software.

     Authors:        Debby Burwen, Paul Skvorc, Susan Ellis
                       Alaska Department of Fish & Game
                               Juneau, Alaska
                                 March 1988
                   Modified: August 17, 1993 - M. Jensen
*******************************************************
```

Enter staff gauge reading for file # 1	-5
INPUT FILE NUMBER 1	n2101400.001
START TIME = 14 : 0 : 2	END TIME = 14: 20 : 0
TOTAL SAMPLE TIME IN MINUTES FOR THIS FILE IS :	19.967
THRESHOLD, mV =	600.24
BOTTOM THRESHOLD, mV =	1000.40
MAX -18 dB PULSE WIDTH, msec =	0.8004
MIN - 6 dB PULSE WIDTH, msec =	0.4002
MAX - 6 dB PULSE WIDTH, msec =	0.6003
BOTTOM WINDOW SIZE IN METERS =	0.3000
START DEPTH IN METERS =	2.00000
Enter staff gauge reading for file # 2 :	-7
INPUT FILE NUMBER 2	n2101500.001
START TIME = 15 : 0 : 3	END TIME = 15: 20 : 0
TOTAL SAMPLE TIME IN MINUTES FOR THIS FILE IS :	19.950
THRESHOLD, mV =	600.24
BOTTOM THRESHOLD, mV =	1000.40
MAX -18 dB PULSE WIDTH, msec =	0.8004
MIN - 6 dB PULSE WIDTH, msec =	0.4002
MAX - 6 dB PULSE WIDTH, msec =	0.6003
BOTTOM WINDOW SIZE IN METERS =	0.3000
START DEPTH IN METERS =	2.00000
NUMBER OF FISH WITH ALPHA > 0 DEGREES = 64	
NUMBER OF FISH WITH ALPHA < 0 DEGREES = 69	
NUMBER OF FISH WITH ALPHA = 0 DEGREES = 10	

Appendix A1.-Page 3 of 5.

Second page of output from DBDP.

Range in meters (x) vs. Target Strength in dB (y)

From		15.0	19.5	24.0	28.5	33.0	37.5	42.0	46.5	51.0	55.5	
To	TS	19.5	24.0	28.5	33.0	37.5	42.0	46.5	51.0	55.5	60.0	Sum
	-48	0	0	0	0	0	0	0	0	0	0	0
	-46	0	0	0	0	0	0	0	0	0	0	0
	-44	0	0	0	0	0	0	0	0	0	0	0
	-42	0	0	0	0	0	0	0	0	0	0	0
	-40	0	0	0	0	0	0	0	0	0	0	0
	-38	0	0	0	0	0	0	0	0	0	0	0
	-36	0	0	0	0	0	0	0	0	0	0	0
	-34	0	0	0	0	0	0	0	0	0	0	0
	-32	0	0	0	0	0	0	0	0	0	0	0
	-30	1	0	0	1	1	1	1	0	0	0	5
	-28	3	0	0	11	1	3	3	5	5	0	31
	-26	1	7	3	9	3	9	9	17	1	0	59
	-24	4	1	2	10	0	4	5	6	1	0	33
	-22	0	0	0	7	0	5	2	0	0	0	14
	-20	0	0	0	1	0	0	0	0	0	0	1
	-18	0	0	0	0	0	0	0	0	0	0	0
	-16	0	0	0	0	0	0	0	0	0	0	0
	-14	0	0	0	0	0	0	0	0	0	0	0
	-12	0	0	0	0	0	0	0	0	0	0	0
	-10	0	0	0	0	0	0	0	0	0	0	0
	-8	0	0	0	0	0	0	0	0	0	0	0
	-6	0	0	0	0	0	0	0	0	0	0	0
	-4	0	0	0	0	0	0	0	0	0	0	0
	-2	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0
	2	0	0	0	0	0	0	0	0	0	0	0
	4	0	0	0	0	0	0	0	0	0	0	0
	6	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0
	10	0	0	0	0	0	0	0	0	0	0	0

Appendix A1.-Page 4 of 5.

Third page of output from DBDP.

```
                Frequency Histogram of Target Strengths
30 |           * * *
29 |           * * *
28 |           * * *
27 |           * * *
26 |           * * *
25 |           * * *
24 |           * * *
23 |           * * *
22 |           * * *
21 |           * * *
20 |           * * *
19 |           * * *
18 |           * * *
17 |           * * *
16 |           * * *
15 |           * * *
14 |           * * * *
13 |           * * * *
12 |           * * * *
11 |           * * * *
10 |           * * * *
 9 |           * * * *
 8 |           * * * *
 7 |           * * * *
 6 |           * * * *
 5 |          * * * * *
 4 |          * * * * *
 3 |          * * * * *
 2 |          * * * * *
 1 |          * * * * * *
   -------------------------------------------------------------
   |     |     |     |     |     |     |
  -50   -40   -30   -20   -10    0    10

               Target Strength in dB
```

Appendix A1.-Page 5 of 5.

Fourth page of output from DBDP.

HISTOGRAM OF BEAM PATTERN FACTORS > 0 dB

B = 0 dB	TO	B = 1 dB	NUMBER OF ECHOES = 221
B = 1 dB	TO	B = 2 dB	NUMBER OF ECHOES = 124
B = 2 dB	TO	B = 3 dB	NUMBER OF ECHOES = 55
B = 3 dB	TO	B = 4 dB	NUMBER OF ECHOES = 14
B = 4 dB	TO	B = 5 dB	NUMBER OF ECHOES = 8
B = 5 dB	TO	B = 6 dB	NUMBER OF ECHOES = 6
B = 6 dB	TO	B = 7 dB	NUMBER OF ECHOES = 0
B = 7 dB	TO	B = 8 dB	NUMBER OF ECHOES = 0
B = 8 dB	TO	B = 9 dB	NUMBER OF ECHOES = 0
B = 9 dB	TO	B = 10 dB	NUMBER OF ECHOES = 0
B = 10 dB	TO	B = 11 dB	NUMBER OF ECHOES = 0
B = 11 dB	TO	B = 12 dB	NUMBER OF ECHOES = 0
B = 12 dB	TO	B = 13 dB	NUMBER OF ECHOES = 0
B = 13 dB	TO	B = 14 dB	NUMBER OF ECHOES = 0
B = 14 dB	TO	B = 15 dB	NUMBER OF ECHOES = 0
B = 15 dB	TO	B = 16 dB	NUMBER OF ECHOES = 0
B = 16 dB	TO	B = 17 dB	NUMBER OF ECHOES = 0
B = 17 dB	TO	B = 18 dB	NUMBER OF ECHOES = 0
B = 18 dB	TO	B = 19 dB	NUMBER OF ECHOES = 0
B = 19 dB	TO	B = 20 dB	NUMBER OF ECHOES = 0

TOTAL SAMPLE TIME (IN MINUTES)	=	39.916668
TOTAL NUMBER OF RECORDED ECHOES	=	5840
TOTAL ECHOES IN ALL FISH COMBINED	=	2202
TOTAL NUMBER OF FISH TRACKED	=	143
AVERAGE OF ALL BACKSCATTERING CROSS		
SECTIONS FROM EACH FISH	=	0.005276
IN dB	=	-22.777218
BACKSCATTERING CROSS-SECTION STD DEV	=	.610054
AVERAGE OF ALL TARGET STRENGTHS		
TARGET STRENGTH STD DEV IN dB	=	1.993592
NUMBER OF ECHOES WITH BEAM PATTERN		
FACTORS > 0 dB	=	428