Fishery Data Series No. 00-43

Investigations of Alternate Sites for Chinook Salmon Sonar on the Kenai River

by

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December 2000

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

Hydroacoustic assessment of chinook salmon *Oncorhynchus tshawytscha* populations on the Kenai River is complicated by the presence of more abundant sockeye salmon *O. nerka* which migrate concurrently with chinook salmon. Accuracy of Kenai River chinook salmon sonar estimates relies on our ability to acoustically separate chinook salmon from sockeye salmon. Acoustic size and range thresholds are presently used to separate the two species. In general, sockeye salmon are smaller and migrate primarily near shore whereas chinook salmon are larger and tend to migrate up the middle of the river. One disadvantage of the current sonar site is that it is exposed to extreme tidal influence and experiences reversed current flow during some high tides. Although normally a bank-oriented species, there is some evidence that sockeye salmon stray further from the bank during rising tides, possibly in response to reduced current velocity. One unanswered question is whether spatial segregation of species would be more complete at another site above tidal influence.

In this study, we evaluated a second sonar site at river mile 13.2 on the Kenai River where tidal influence is minimal. We hypothesized that a sonar site above tidal influence would be subject to more consistent water velocities that may lead to a higher degree of spatial segregation between sockeye and chinook salmon. A netting program indicated that there were fewer sockeye salmon in the offshore area at the alternate site. However there were still relatively large numbers of sockeye present in the offshore area during peak migration periods and high numbers of chinook salmon were caught in the nearshore area. The alternate sonar site at river mile 13.2 also had several disadvantages over the current site at river mile 8.6. Boat traffic was considerably greater, the bottom topography was less acoustically favorable, and fish were more difficult to track on at least one bank due to increased background noise levels.

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

INTRODUCTION

Chinook salmon *Oncorhynchus tshawytscha* returning to the Kenai River support one of the largest and most intensively managed recreational fisheries in Alaska (Nelson et al. 1999). Kenai River chinook salmon are among the largest in the world and have sustained in excess of 100,000 angler-days of fishing effort annually (Nelson et al. 1999). Daily sonar estimates provide information to evaluate both run strength and run timing of early- and late-run chinook salmon. These data combined with other indices provide the information necessary to manage relevant fisheries as required by Kenai River Chinook Salmon Management Plans (5 AAC 56.070, 5 AAC 21.359).

Side-looking sonar has been used to assess chinook salmon returns to the Kenai River since 1987 (Hammarstrom and Timmons, *In prep* a, b). Sonar estimates of inriver return provide the basis to estimate spawning escapement and implement management plans that regulate harvest in sport and commercial fisheries for this stock. Implementation of these management plans has been a contentious issue for the State, one that commands much public attention. In recent years, implementing some provisions of the management plan resulted in significant fishery restrictions.

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. Accuracy of sonar estimates of chinook salmon abundance depends on our ability to acoustically separate these two species, which is accomplished using acoustic size and range thresholds (Eggers et al. 1995). In general, sockeye salmon are smaller and migrate primarily near shore whereas chinook salmon are larger and tend to migrate up the middle of the river. However, some studies have indicated that neither filter is completely effective in excluding all sockeye salmon from estimates of chinook salmon abundance (Burwen et al. 1998). A netting study found sockeye salmon present in the middle insonified portion of the river, and in a concurrent experiment most sockeye salmon tethered in front of the sonar exceeded the target strength threshold (Burwen and Fleischman 1998). To assess the accuracy of sonar estimates, a radio-telemetry study was conducted in 1996 and 1997 to provide an independent and accurate estimate of inriver chinook salmon abundance during the late run when the potential to misclassify sockeye is greatest. Late-run sonar estimates in both years were 21% greater than the telemetry estimates (Hammarstrom and Hasbrouck 1998, 1999).

One unanswered question is whether spatial segregation of species would be more complete at a site above tidal influence. The current chinook salmon sonar site at river mile (rm) 8.6 was selected for its acoustically favorable characteristics and its location downstream from the majority of the riverine sport fishery and known chinook spawning sites (Burger et al. 1985, Bendock and Alexandersdottir 1992, Eggers et al. 1995). One disadvantage of the site is that it is exposed to extreme tidal influence and experiences reversed current 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. There is some evidence that sockeye salmon stray further from the bank during rising tides, possibly in response to reduced current velocity (Burwen et al. 1998).

In this study, we evaluated a second sonar site at river mile 13.2 on the Kenai River where tidal influence is minimal. We hypothesized that a sonar site above tidal influence would be subject to more consistent water velocities that may lead to a greater degree of spatial segregation between sockeye and chinook salmon. A netting program was initiated to compare the ratio of sockeye to chinook salmon found in the midchannel section of the river at the two sites. Hydroacoustic equipment was also deployed to determine whether acoustic properties of the site were conducive to estimating fish passage.

The general goal of this project was to identify a better sonar site where sockeye salmon maintain a stronger bank orientation than at the current sonar site. Specific tasks and objectives were to:

Tasks

1. Conduct intensive depth profile surveys in the Kenai River between river miles 12.0 and 14.0.
2. Identify sites with favorable bottom topography for deploying side-looking sonar (Appendix A1).
3. Determine land availability at promising sites.
4. Select a site with the most favorable characteristics with respect to bottom topography and land availability for establishing a long-term sonar site.
5. Deploy a split-beam sonar system with a narrow (2.5 degree) beam transducer to determine whether the water column can effectively be insonified at the selected site.

Objectives

1. Test the null hypothesis that the ratio of sockeye salmon to chinook salmon caught in gill nets drifted through the midchannel insonified area of the Kenai River at the selected site is equal to this same ratio at the current sonar site.

METHODS

There were three phases to this project. Phase 1 involved selecting a suitable site above tidal influence with favorable bottom topography and legal access. Phase 2 required deploying hydroacoustic gear to evaluate potential acoustic-related problems due to boat traffic, spawning fish, and reverberative noise. Phase 3 required implementing a mid-river netting program to determine whether spatial segregation of sockeye and chinook salmon was improved at the alternate site compared with the current site.

SITE SELECTION

A detailed description of the physical requirements for a side-looking sonar site can be found in Appendix A1 and Appendix A2. At a minimum, the proposed alternate site required a single channel with laminar flow and a uniformly sloping bottom from each bank to the middle of the river to avoid sound shadows. We required a bottom substrate that was relatively smooth and unreflective so that the beam could be aimed close to the bottom where fish generally travel. Hardware limitations required a water depth sufficient to accommodate a 2^o or larger transducer beam width at midchannel.

The search for an alternate site above tidal influence extended from just below river mile 12.0 to river mile 14.0. We restricted surveys to this section of river because mile 12.0 is the approximate upper limit of tidal influence and because radiotelemetry studies indicated that a minimal amount of spawning activity occurs below river mile 14.0 (Burger et al. 1985, Bendock and Alexandersdottir 1992). Initial surveys were conducted on 4 May during low water conditions so that more of the bottom substrate was visible (Figure 1). More comprehensive surveys were conducted on 18 May and 4 August (Figure 2, Figure 3).

On 18 May (transects 1-11 on Figure 2, transects 12-16 on Figure 3) and 4 August (transects 17-22 on Figure 2), depth profile transects were taken at approximately 1/8 mile intervals in more promising areas (areas not unacceptably influenced by gravel bars and multiple channels). Profiles were recorded using a Lowrance X-16 paper depth sounder. A hardcopy of each transect was uniquely numbered and cross-referenced on a 1:1000 aerial photograph.

HYDROACOUSTIC SAMPLING

Sonar equipment was installed on each bank at the alternate site to determine signal-to-noise ratio (SNR), beam geometry relative to the bottom topography, and effects of boat wake on acoustic data. We also required baseline information on fish behavior at the site. Hydroacoustic data were collected with a Hydroacoustics Technology, Inc. (HTI) Model 240 split-beam echosounder operating at 200 kHz, and a 2.9 by 10^o elliptical-beam transducer with a near-field range of 3.1 m. Pulses were 0.2 ms long and transmitted at a rate of 11 sec^{-1} on each bank. Echoes were rejected if they did not meet minimum amplitude of 0.742 volts, equivalent to a -35 dB target on axis. Integrated HTI fish-tracking software was used to coalesce raw echoes into fish tracks. A detailed description of hydroacoustic data collection and fish-tracking methods can be found in Bosch and Burwen (1999).

NET SAMPLING

The netting study was designed to index the relative abundance of sockeye salmon and chinook salmon mid-channel at the two sites (current and alternate), not to estimate actual species composition. The objective was to test the null hypothesis that the ratio ($\hat{\theta}$) of sockeye salmon to chinook salmon catches was equal at the two sites (H_o: $\theta = 1.0$). To justify moving the sonar

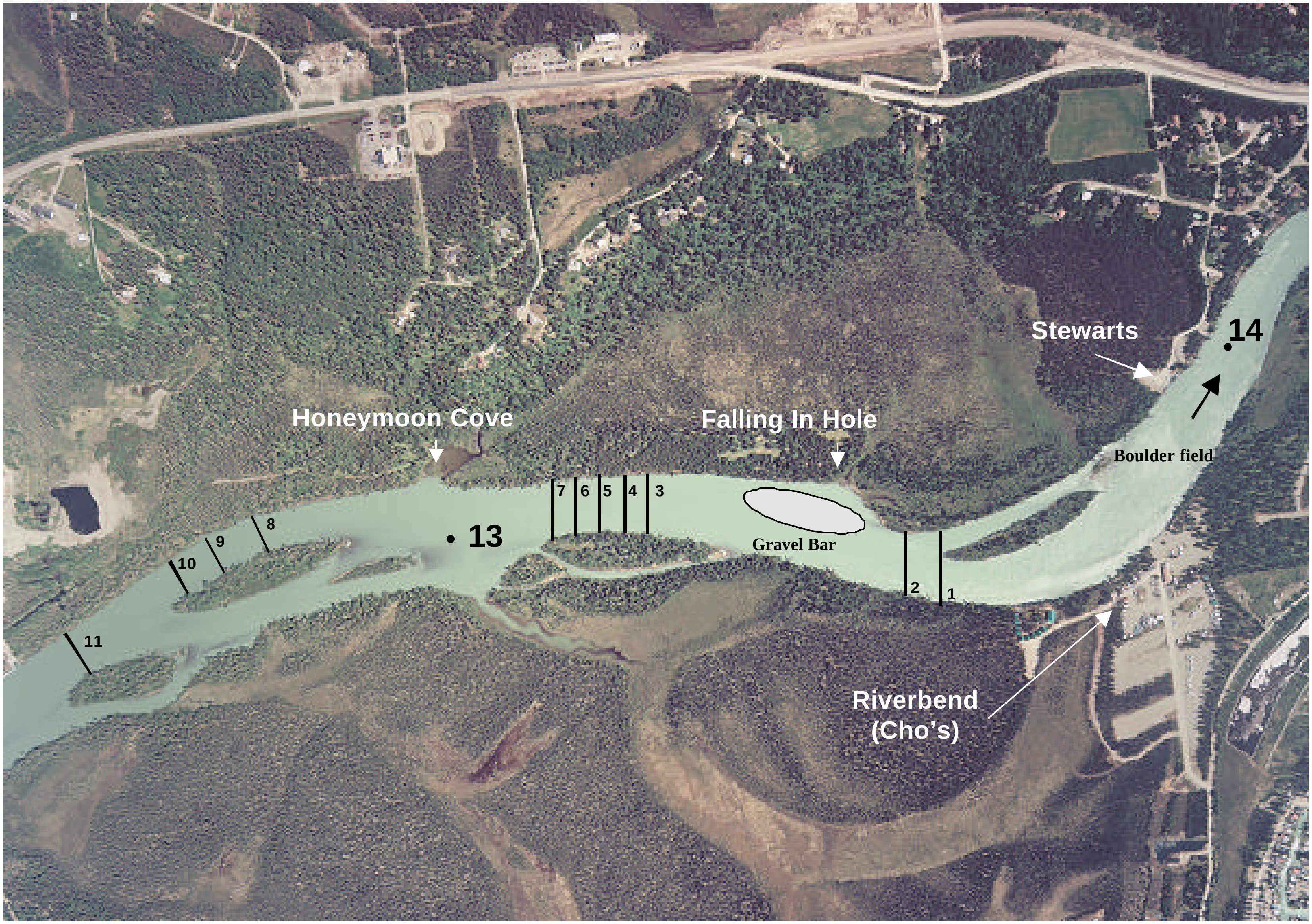


Figure 1.-Aerial (1:1000) photograph of the Kenai River showing the location of bottom transects between river miles 12 and 14 on 4 May 1999.

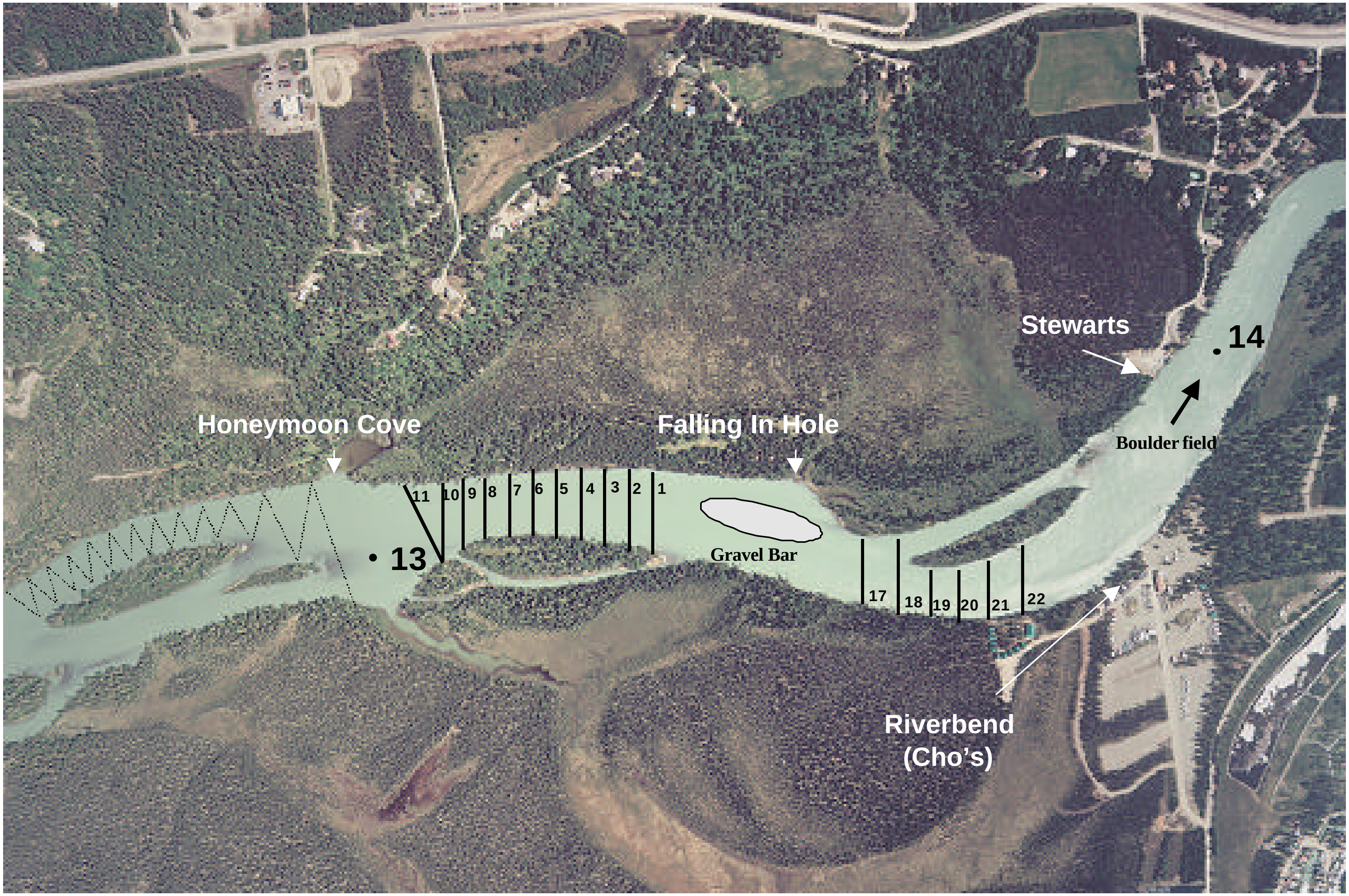


Figure 2.-Aerial (1:1000) photograph of the Kenai River showing the location of bottom transects between river miles 11.5 and 13 on 18 May and 4 August 1999.

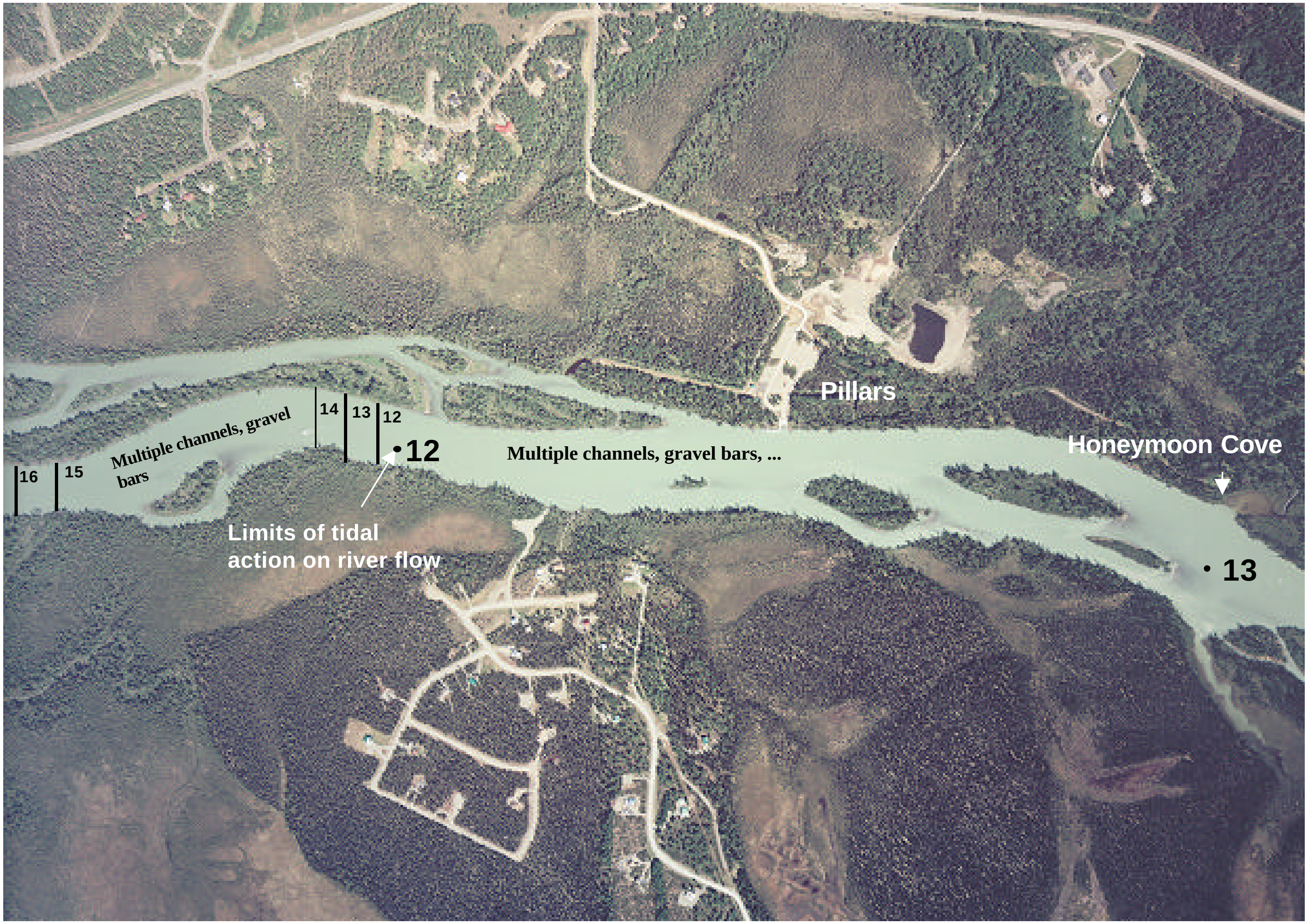


Figure 3.-Aerial (1:1000) photograph of the Kenai River showing the location of bottom transects between river miles 13 and 14 on 18 May 1999.

site, the ratio of the catch of sockeye salmon to chinook salmon at an alternate site must be much smaller than at the current site (H_a: $\theta << 1.0$).

Previous sonar data (Hammarstrom 1994) indicate that higher sonar counts occur during neap tide periods, which occur twice monthly, and in general during rising and falling tides. Both sites were sampled over 4 days during each of four neap tide periods: 20-23 June, 5-8 July, 20-23 July, and 4-7 August (Appendix B1). To avoid interference with an inriver netting program designed to assess the age structure of the inriver return, only the tide cycle prior to a morning high tide or the tide cycle after an afternoon high tide was sampled.

In planning the study it appeared that 3 hours of sampling per site each day was sufficient to achieve the objective. For all afternoon falling tides the entire 3 hours per site could be sampled. On many of the morning tides it was not possible to sample 3 hours per site due to insufficient daylight, but on nearly all of these days at least 2.5 hours could be sampled per site. In these situations, the total sample time was divided evenly between sites.

Gillnets with 13.5 cm (5.25 inch) stretched-mesh were used. The net was drifted with the current for approximately 200 m for each "set," from 100 m upstream to 100 m downstream of the respective transducers (or likely location of the transducers at the alternate site; Figure 4). The crew extended the net in mid-channel upstream of a transducer and drifted through the main channel of the river. Alternate banks were fished with each drift. Beginning 23 June, the crew also made nearshore sets at the alternate sonar site; no such sets were made at the current sonar site.

The number of sockeye and chinook salmon captured was recorded for each set. All captured fish were measured for fork length, marked with an adipose finclip, and then released downstream of the respective site.

The analyses of the netting data involved estimating the log odds ratio and its variance as (Agresti 1990):

$$\log \hat{\theta} = \log\left[\frac{(n_{11}+0.5)(n_{22}+0.5)}{(n_{12}+0.5)(n_{21}+0.5)}\right], \text{ and} \tag{1}$$

$$\mathrm{Var}(\hat{\theta}) = \left(\frac{1}{n_{11}+0.5}+\frac{1}{n_{12}+0.5}+\frac{1}{n_{21}+0.5}+\frac{1}{n_{22}+0.5}\right), \tag{2}$$

where:

n_{11} = catch of sockeye salmon at the alternate sonar site,

n_{12} = catch of chinook salmon at the alternate sonar site,

n_{21} = catch of sockeye salmon at the current sonar site, and

n_{22} = catch of chinook salmon at the current sonar site.

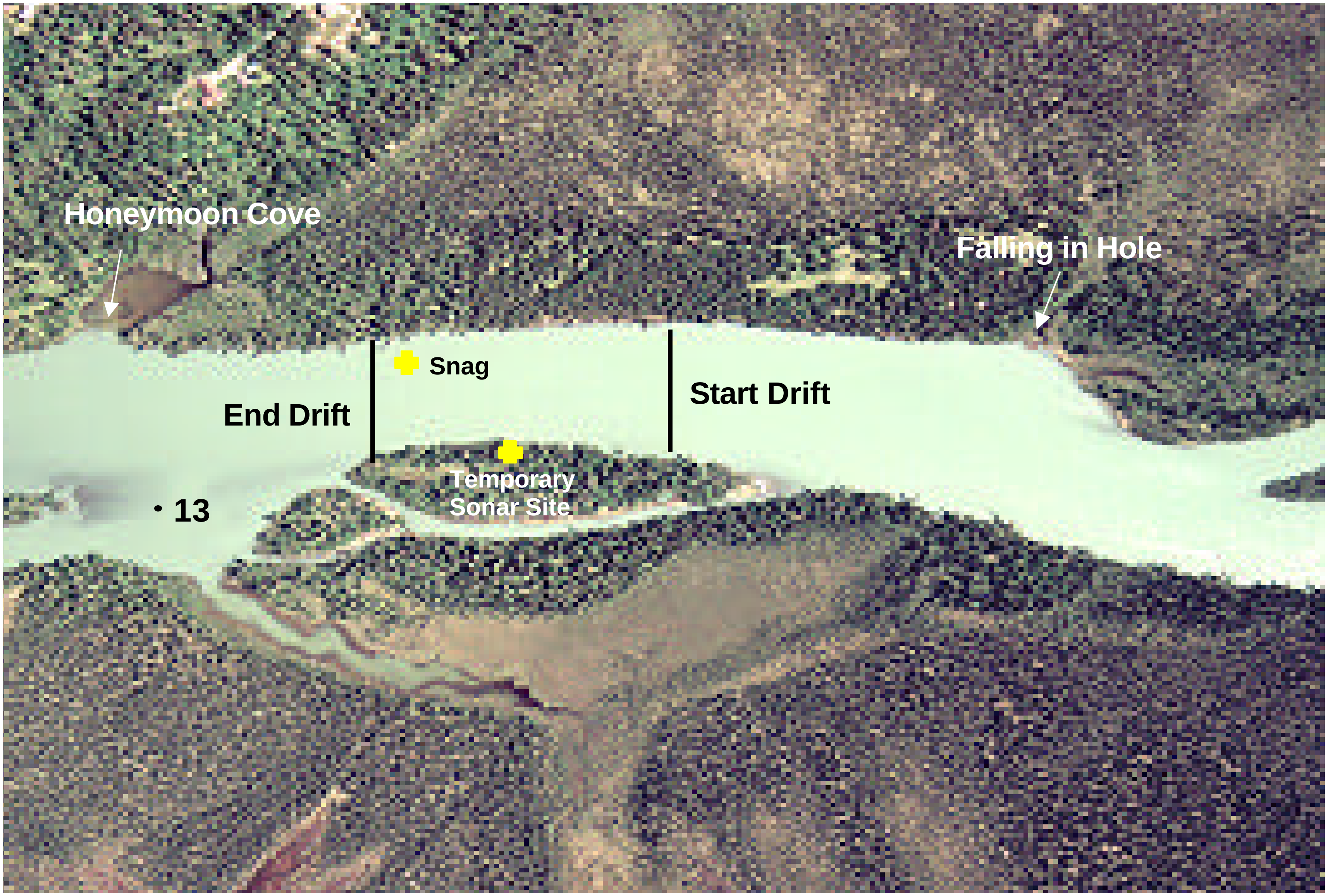


Figure 4.-Aerial (1:1000) photograph of the Kenai River showing the location of the netting study drift zone in front of the alternate sonar site at river mile 13.2.

RESULTS

SITE SELECTION

We could find no acoustically ideal sites in this restricted area of the Kenai River (rm 12.0–14.0). Much of the river had multiple channels caused by islands or irregular bottom topographies caused by submerged gravel bars and boulders. However, a site at river mile 13.2 offered the most favorable attributes for effectively insonifying most of the water column. At this site the right bank (referenced to looking downstream) sloped steeply (4^o slope) to the middle of the channel 35 m from the shoreline (Figure 5, Appendix C1). The left bank had a more complicated profile where the bottom first sloped gently out to 35 m ($\approx 1.5^o$ slope) then sloped more steeply for another 40 m ($\approx 2.5^o$ slope) out to the middle of the river channel.

For comparative purposes, the right bank of the alternate site (rm 13.2) is most similar to the left bank at the current site (rm 8.6). This is essentially the cutbank side of the river where the current velocity is swifter, the slope steeper, and the distance to the thalweg is shorter than on the opposite bank. Conversely, the left bank of the alternate site is most comparable to the right bank of the current site. This is the depositional side of the river where the current velocity is slower, the slope is gentler and the distance from the shoreline to the thalweg is further.

HYDROACOUSTIC SAMPLING

Left Bank

A summary of the hours and dates that acoustic data were collected on the left bank can be found in Table 1. Data were collected on the left bank at low water conditions in late May and during higher water conditions in late July.

Water level observed in late May was typical of Kenai River water levels found in late spring and early summer (USGS 1999). On 26 May, we set up a temporary site on the left bank for an initial assessment of whether this site could be effectively insonified given the bottom substrate and topography. The transducer was placed 45 m from shore at the edge of the gradually-sloping shelf and at the start of the incline that continues to the middle of the river channel (Figure 6). Due to the shallow water, no effort was made to insonify the nearshore area. Fish passage was low, and during 5 hours of data collection only 22 targets were tracked. Fish distribution in both the horizontal (range) and vertical (depth) planes were similar to those observed at the current site on the right bank (Bosch and Burwen 1999). Fish were located primarily offshore and near the bottom (Figure 7). Signal-to-noise ratio (SNR) was lower than at the current site, most likely due to reverberative noise from the faster current, rockier bottom, and increased boat traffic. Positional estimates from fish echoes were consequently more variable than typically observed at the current site (Figure 8).

Much of the hydroacoustic sampling effort was focused on the left bank during late July, a period of peak passage for chinook and sockeye salmon runs. It was during this period and on this bank that we anticipated having the most problems with high boat traffic, spawning fish, and offshore transducer deployment. Water levels were approximately 1.5 m to 2 m higher in late July. Increased water velocities made it impossible to deploy an offshore transducer. Consequently, only the nearshore area (from 1 m to 35 m) could be insonified from 20-22 July (Figure 9). A total of 526 targets was tracked during this time period. Interference from boat wake was so severe during the day that most of these targets were tracked during hours when boat travel was minimal (e.g., 2200–2400 hours and 0000-00600 hours). Fish were again

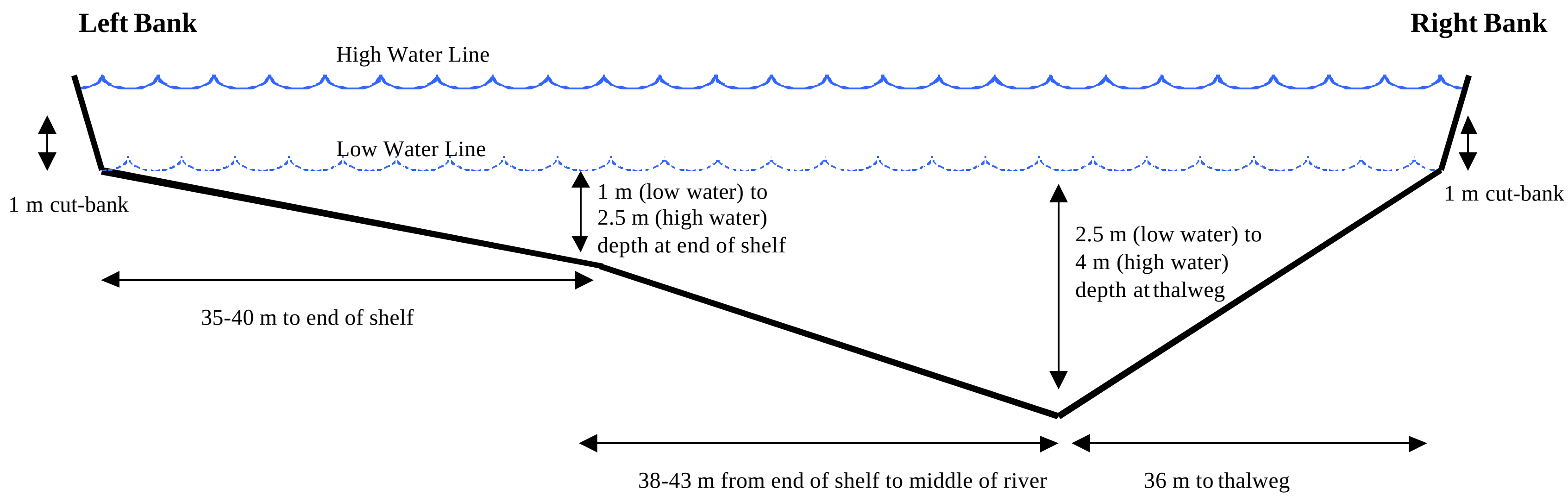


Figure 5.-Depth profile of alternate sonar site evaluated in 1999 at Kenai river mile 13.2.

Table 1.-Hours and dates of acoustic data collection at the Kenai River alternate sonar site at river mile 13.2.

Date	Bank	Hours of data collection	Targeted species
26 May	Left - offshore	0700 - 1200	chinook
20 July	Left - nearshore	0430-1600	chinook
21 July[a]	Left - nearshore	0400-0859	chinook
		0900-2159	sockeye
		2200-2359	chinook
22 July	Left - nearshore	0000-0900	chinook
3 August	Right	1600-2359	chinook
4 August	Right	0000-1800	chinook

[a] On 21 July, the aim was optimized to insonify nearshore sockeye salmon for certain periods during the day, when boat wake was so severe, that it was impractical to insonify long-range targets.

located primarily offshore and near the bottom (Figure 10). Tracking of fish was extremely difficult due to reduced SNR and the presence of spawning fish (Figure 11).

Right Bank

The right bank was sampled in early August under water level conditions similar to those encountered in late July on the left bank. The right bank bottom profile allowed the entire bank to be adequately insonified with one nearshore transducer (Figure 12). Finding a suitable site on the right bank was difficult because of irregular bottom topography.

Fish were located further offshore and closer to the bottom than on the left bank (Figure 13), most likely because of the faster current and deeper water.

The right bank was generally less impacted by boat wake and spawning fish, and overall SNR appeared higher, which resulted in “cleaner” fish traces which were easier to track (Figure 14).

NET SAMPLING

Both sonar sites were sampled on all days that sampling occurred (Appendix B1). Nearly the same number of sets was made daily at each site except during the August neap-tide period. In general, fewer sets were made during the first 2 days than during the second 2 days of each neap tide period. This likely occurred because morning tides were sampled during the first 2 days and there was less time available to sample morning tides as previously mentioned. The number of sets made was not recorded on 20 June, the first day of the study. Sampling was cancelled on 7 July to reduce conflicts with a local fishing derby.

There was no significant difference ($\chi^2 = 0.03$, df = 1, P = 0.86) in the catch of sockeye and chinook salmon between nearshore and mid-channel sets at the alternate sonar site. Therefore we combined all of the netting data from the alternate site for comparison with the current site. A nearly equal number of chinook salmon were captured in nearshore and mid-channel sets during the late July and August neap tide periods (Table 2). Over three times the number of

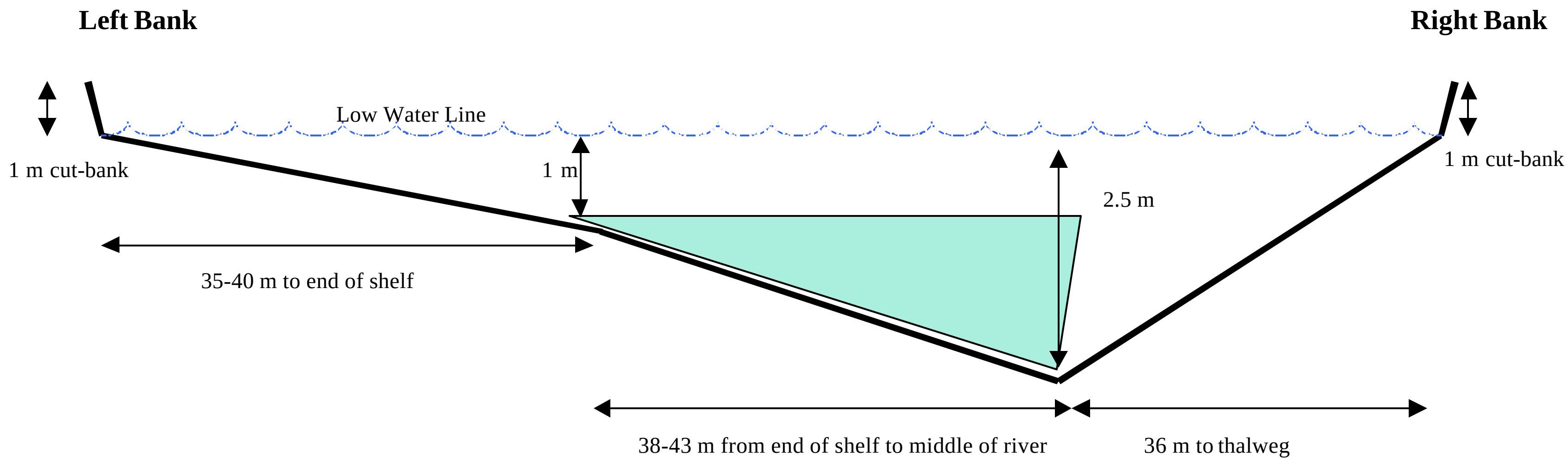


Figure 6.-Profile of alternate sonar site at Kenai river mile 13.2 showing the insonified area on the left bank during low water conditions.

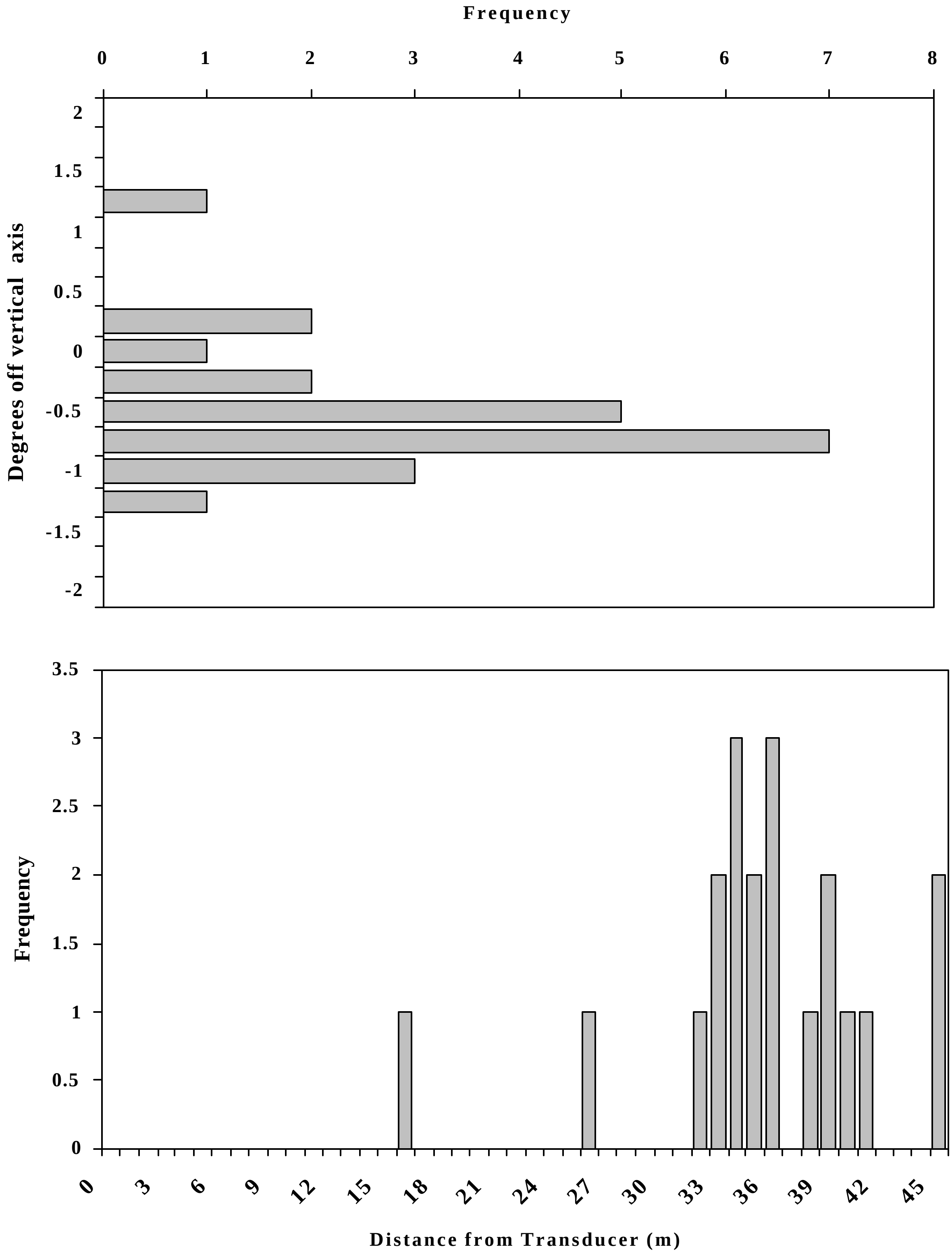


Figure 7.-Vertical (top) and horizontal (bottom) distribution of targets on the left bank at river mile 13.2 on 16 May 1999. The horizontal distribution covers the distance from the transducer placed approximately 40 m from shore to mid channel.

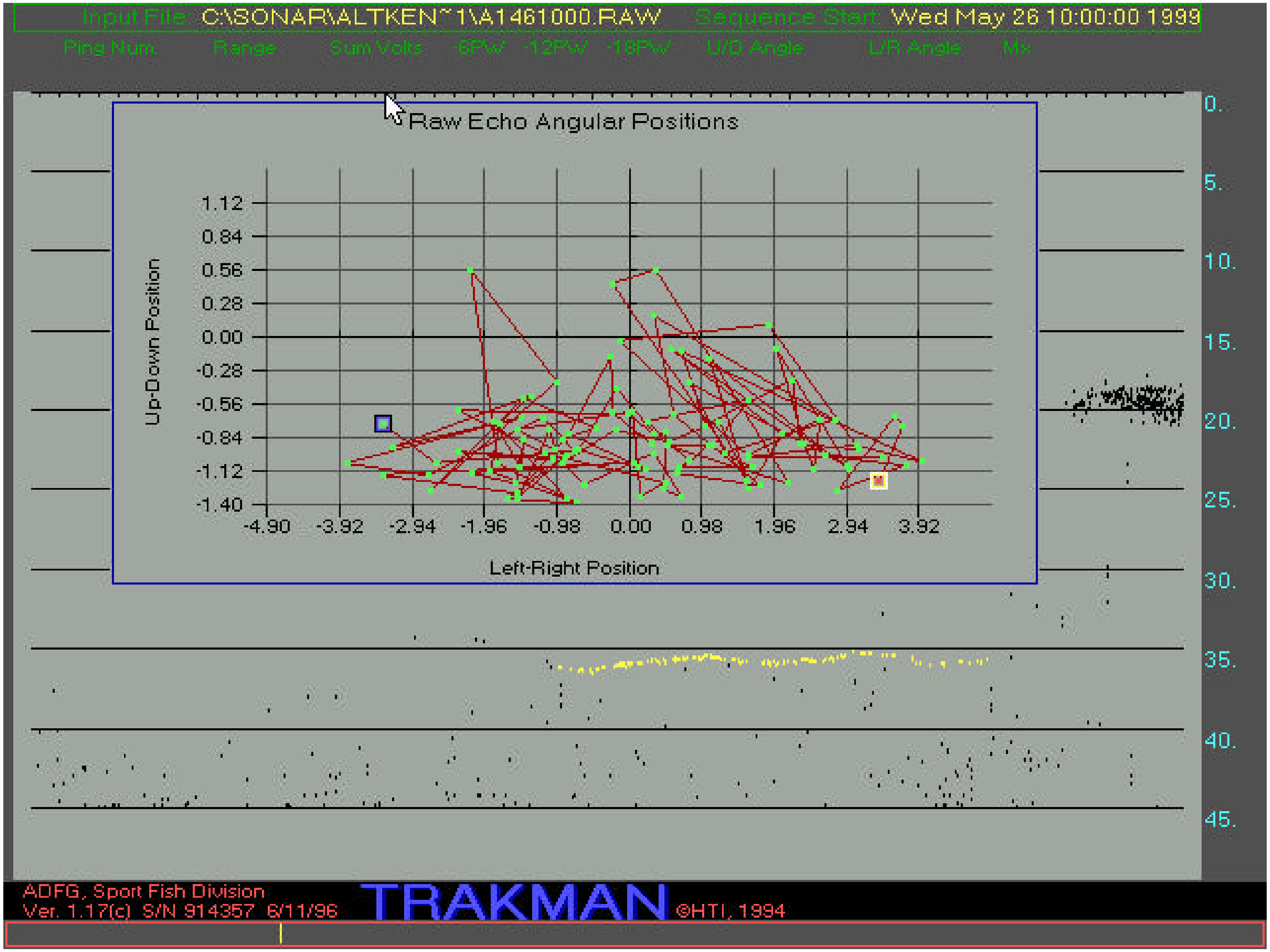


Figure 8.-Electronic chart (with x-y dimension graph insert) from left bank offshore transducer on 26 May 1999 showing a typical fish trace. Poor SNR leads to high errors in positional estimates.

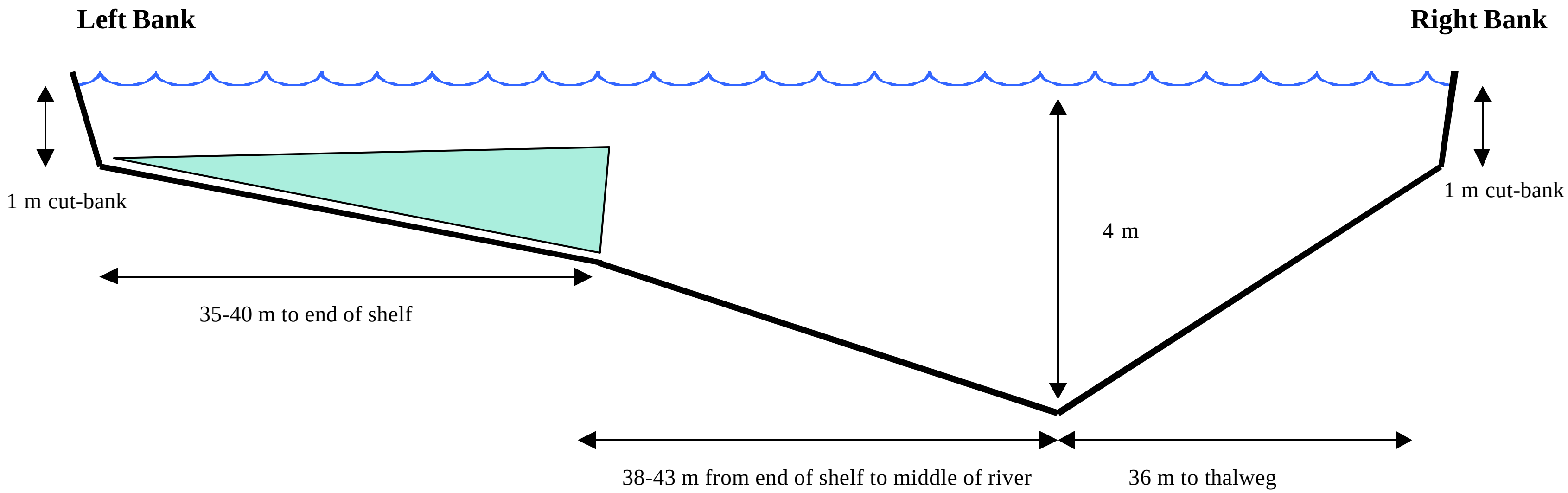


Figure 9.-Profile of alternate sonar site at Kenai river mile 13.2 showing the insonified area on the left bank during high water conditions.

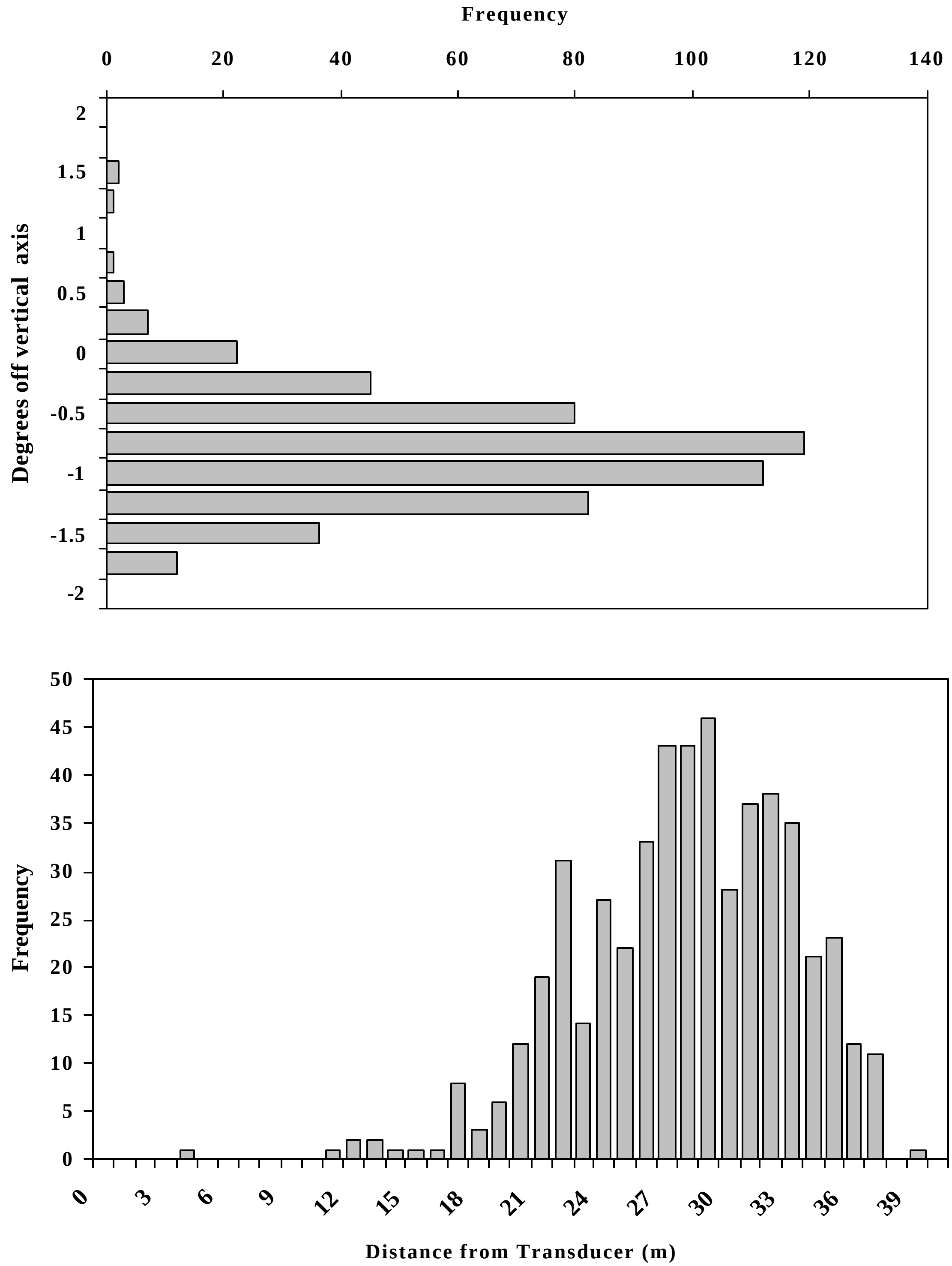


Figure 10.-Vertical (top) and horizontal (bottom) distribution of targets on the left bank at river mile 13.2 from 20-22 July 1999. The horizontal distribution covers the distance from the transducer placed approximately 1 m from shore to the end of the shelf approximately 40 m from shore.

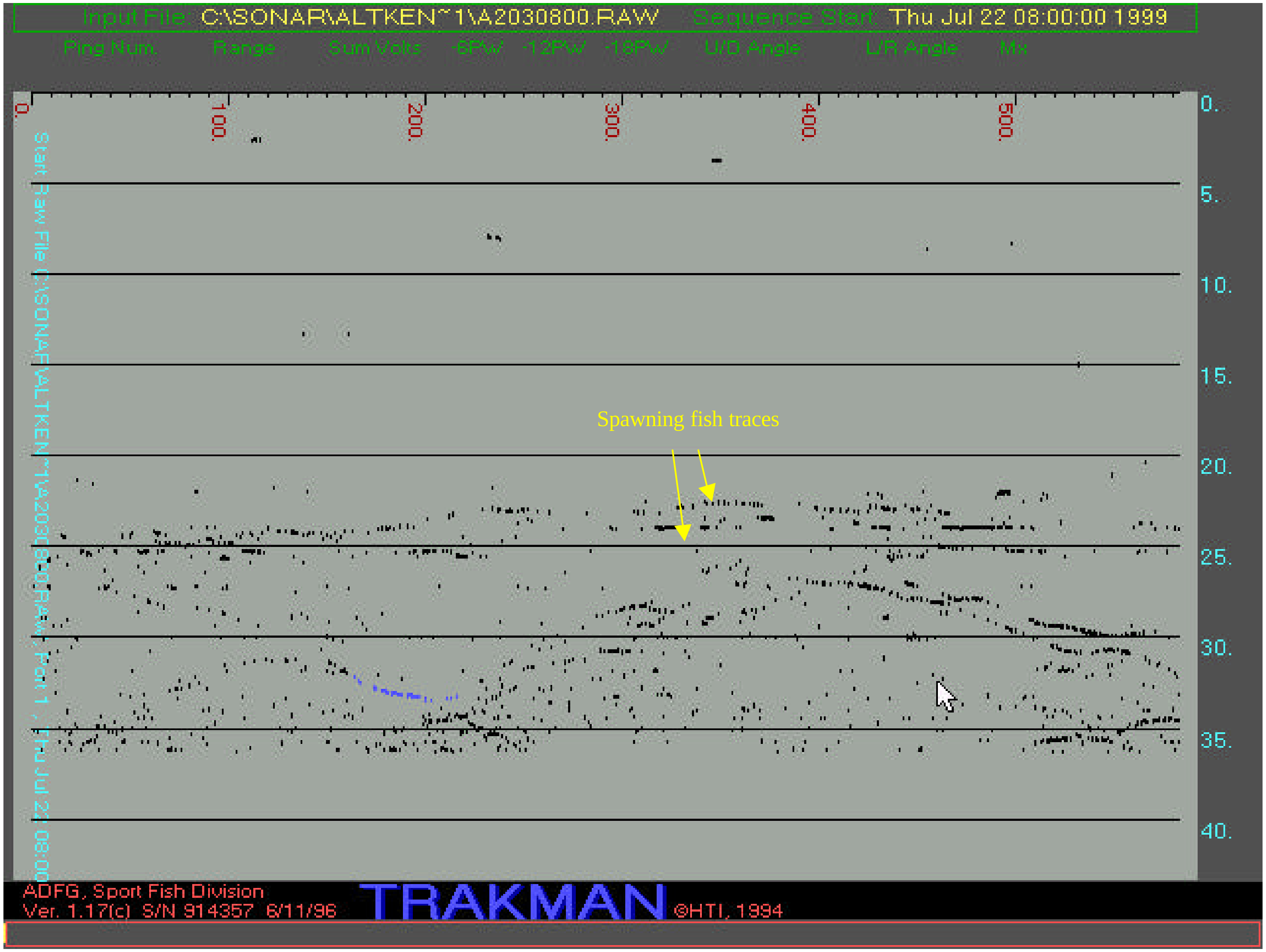


Figure 11.-Electronic chart from left bank nearshore transducer on 22 July 1999 showing typical faint, overlapping, sinuous traces mixed in with spawning fish traces. Tracking fish is difficult and subject to inaccuracies under these conditions.

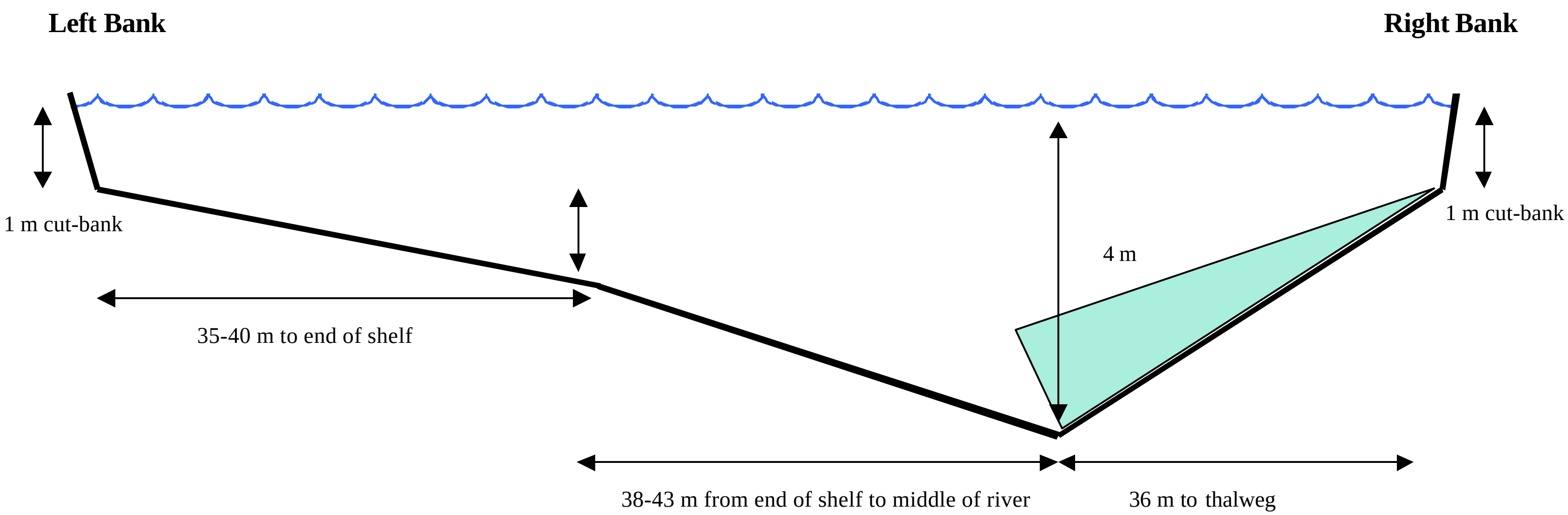
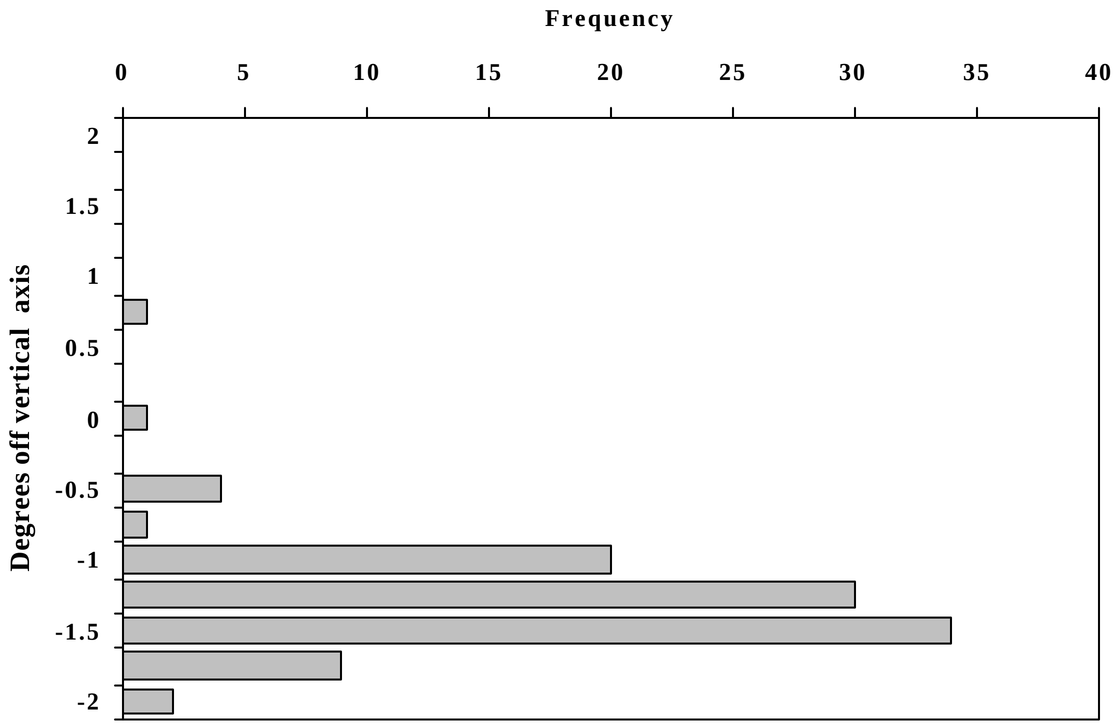


Figure 12.-Profile of alternate sonar site at Kenai river mile 13.2 showing the insonified area on the right bank during high water conditions.



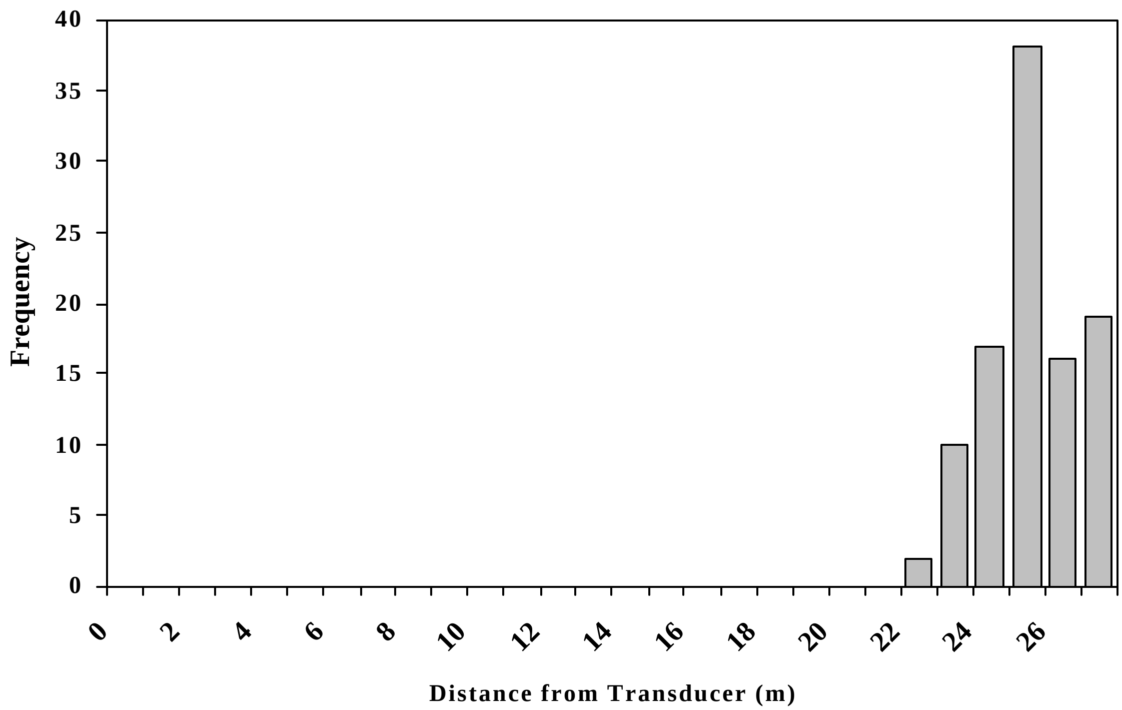


Figure 13.-Vertical (top) and horizontal (bottom) distribution of targets on the right bank at river mile 13.2 from 3-4 August 1999.

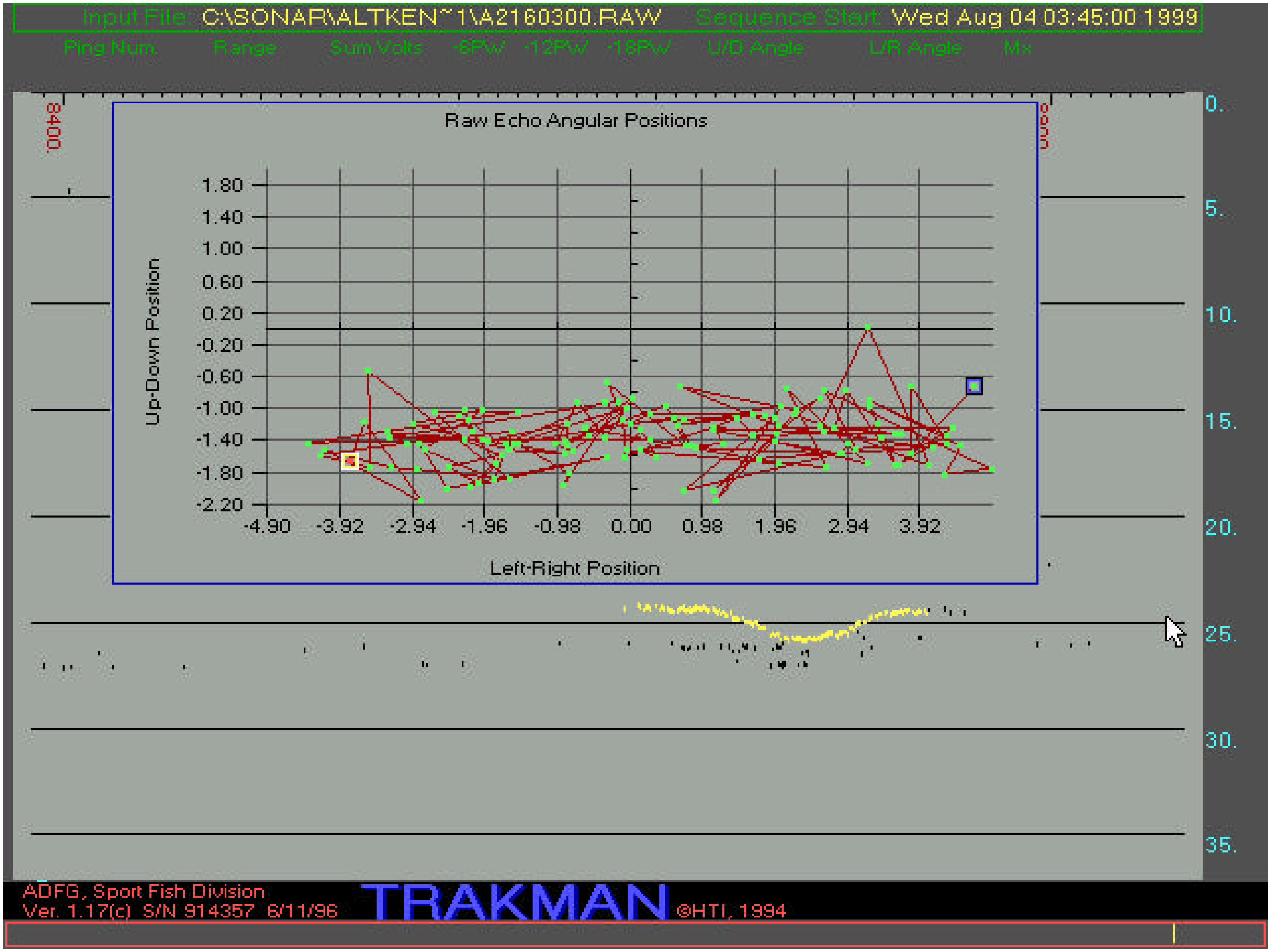


Figure 14.-Electronic chart recording (with 2-d positional graph insert) showing typical tracked fish at the right-bank site on 3 August 1999.

Table 2.-Number of sets and catches of chinook and sockeye salmon in 13.5 cm mesh gillnets drifted through the alternate and current chinook salmon sonar sites on the Kenai River, 1999.

	Current Site[a]				**Alternate Site**											
	Mid-channel				Mid-channel				Near shore				Total			
Date	Sets	Percent Chinook	Percent Sockeye	Total Captured	Sets	Percent Chinook	Percent Sockeye	Total Captured	Sets	Percent Chinook	Percent Sockeye	Total Captured	Sets	Percent Chinook	Percent Sockeye	Total Captured
20-Jun	[b]	100	0	2	[b]			0					[b]			
21-Jun	11	7	93	28	16	100	0	3					16	100	0	3
22-Jun	21	14	86	28	21	60	40	5					21	60	40	5
23-Jun	21	14	86	14	16	60	40	5	9	0	100	3	25	38	63	8
Subtotal	53	14	86	72	53	69	31	13	9	0	100	3	62	56	44	16
5-Jul	12	0	100	6	5	100	0	2	5	42	58	12	10	50	50	14
6-Jul	13	7	93	14	4				4	60	40	15	8	60	40	15
7-Jul	Sampling cancelled															
8-Jul	22	6	94	17	17	100	0	3	10	33	67	12	27	47	53	15
Subtotal	47	5	95	37	26	100	0	5	19	46	54	39	45	52	48	44
20-Jul	8	19	81	32	9	73	27	11	4	36	64	28	13	46	54	39
21-Jul	14	27	73	26	11	21	79	34	4	17	83	24	15	19	81	58
22-Jul	11	7	93	57	10	14	86	21	2	0	100	18	12	8	92	39
23-Jul	15	15	85	26	9	9	91	23	2	45	55	11	11	21	79	34
Subtotal	48	15	85	141	39	22	78	89	12	23	77	81	51	23	77	170
4-Aug	10	0	100	3	4	100	0	13	2	100	0	4	6	100	0	17
5-Aug	15	67	33	3	0				1	67	33	9	1	67	33	9
6-Aug	21	0	100	6	6	100	0	2	5	86	14	7	11	89	11	9
7-Aug	18	100	0	1	10	100	0	4	1	100	0	4	11	100	0	8
Subtotal	64	23	77	13	20	100	0	19	9	83	17	24	29	91	9	43
Total	212	14	86	263	138	42	58	126	49	39	61	147	187	40	60	273

[a] Only mid-channel sets were made at the current sonar site. Sampling near shore at the alternate site began 23 June.

[b] Not recorded.

chinook salmon was captured in nearshore sets than in mid-channel sets during early July. Sockeye salmon were captured in nearshore sets during all sample periods but were caught in mid-channel sets only in late June and late July.

Nearly the same number of fish was caught in total at each site (263 fish at the current site and 273 fish at the alternate site); however, sockeye salmon comprised 86% of the catch at the current sonar site and 60% of the catch at the alternate site (Table 2). The ratio of sockeye salmon to chinook salmon caught at the alternate site (1.5) was significantly ($P < 0.01$) less than this ratio (6.3) at the current site.

The odds ratio estimates were almost identical between using all of the catch data and using only data of mid-channel sets from the alternate site (Table 3). The estimated odds ratio and its upper 99% confidence interval estimate were both were less than 0.50.

Table 3.-Log odds and odds ratio statistics comparing catches of chinook and sockeye salmon at the alternate and current chinook salmon sonar sites on the Kenai River, 1999.

	All[a]	Mid-channel
log odds	-1.44	-1.51
var(log odds)	0.05	0.06
upper 95% CI	-1.08	-1.10
upper 99% CI	-0.88	-0.86
odds ratio	0.24	0.22
upper 95% CI	0.34	0.33
upper 99% CI	0.41	0.42

[a] First comparison includes all catch data from the alternate sonar site, and second comparison includes only catch data from mid-channel sets.

DISCUSSION

HYDROACOUSTICS

The alternate sonar site at river mile 13.2 has several disadvantages over the current site at river mile 8.6. Boat traffic is considerably greater, the bottom topography is less favorable, and fish were more difficult to track on at least one bank. Table 4 outlines the pros and cons of the current site with respect to acoustic data collection and other project-related logistics. Table 5 is the corresponding table for the alternate site at river mile 13.2. Finally, Table 6 contrasts the two sites with respect to both favorable and unfavorable characteristics. The most serious difficulties encountered at the alternate site were boat traffic, bottom topography, and spawning fish.

Table 4.-Summary of pros and cons for current chinook sonar site at river mile 8.6.

Pros	Cons
Long-term history of fish behavior	Sockeye in midchannel.
Good (relatively speaking) signal-to-noise ratio which translates to: 1. More accurate/precise positional information, 2. More reliable direction of travel, 3. More accurate/precise target strength estimates, 4. Better fish detection (less chance of missing fish close to bottom of river).	Tidal influence impacts fish behavior.
Good bottom topography – sound shadows nonexistent on right bank, and minor on left bank (which translates to better fish detection capabilities).	
Good bottom substrate on both banks. Small gravel/mud allows beam to be aimed closer to bottom where fish generally migrate (good detection).	
No mainstem spawning issues except for pink salmon in August.	
Both banks can be monitored and sampled from one side of river (due to narrowness of river and bluff on left bank).	
No issues with land availability (yet).	
Increased water level from tidal influx provides a buffer zone from entrained air created by outboard motors.	
Conflicts with sport anglers are minimized: 1. This section of river not generally used early in season when water levels are low, due to poor access, 2. This section of river not generally used for backtrolling which has the most severe impact (entrained air from propellers), 3. Long history of educating guides/anglers about presence of sonar in this area.	

Boat Traffic

The alternate site is within 0.5 mile of three high-use access points: Stuarts, the Pillars, and Riverbend (Cho's). Low water conditions often limit the level of boat traffic in the lower river early in the season. Consequently, the current site does not receive boat traffic of any consequence until the end of June or even early to mid-July. Conversely, boat traffic at the alternate site is consistently greater especially early in the season due to easy access at low water levels. Boat traffic at the alternate site has several negative consequences for acoustic data collection. First, the entrained air generated by boat traffic appears to have a greater impact on the acoustic data at the alternate site. At the lower site, boat wake tends to mask fish traces where the wake is most intense. However, fish beyond the boat wake can still be detected. At the new site, the wake masks fish traces but also appears to completely block sound travel beyond the wake (Figure 15). Figure 15 also illustrates how the software program used to track fish can become overwhelmed by backscatter from the entrained air, causing truncation of the electronic projection of the chart.

Table 5.-Summary of pros and cons for alternate chinook sonar site at river mile 13.2

Pros	Cons
Fewer sockeye in mid channel.	Mainstem spawning occurring during the peak of the late run in July creates problem with tracking fish accurately.
Low tidal influence means: 1. Fish behavior should be more consistent, 2. Problems with debris impacting underwater equipment are minimized.	Poor signal-to-noise characteristics (acoustically noisy) on the left bank which leads to: 1. Lower fish detectibility, 2. Less reliable direction of travel estimates, 3. Less accurate/precise target strength estimates.
Nearshore transducers better protected and less susceptible to damage/disturbance by boats and debris than at lower site.	Will require a minimum of three transducers to cover river. Deploying an offshore transducer 45 m from shore will be problematic at best due to extremely swift current (higher project costs).
	Can not run two banks from one system. Consequently, two systems (one on each bank) will be required meaning higher project costs.
	Boat traffic is much greater than at lower site. Conflicts with fisherman will be high.
	Acoustic effect (shadowing) of boat wake is more severe.
	During peak passage periods (late July), sockeye were still present mid-channel.
	Chinook salmon were present near shore.
	The offshore transducer will be highly susceptible to damage/disturbance by boats and debris because it would be located so far offshore (40 m).
	Spawning fish and spawning behavior may be a problem during late run.

Bottom Topography

To provide full coverage on the left bank, an offshore transducer would have to be deployed approximately 40 m from shore on the left bank during higher water levels. Due to high water velocities, deploying this transducer would not be trivial and may not be possible without designing a permanent mount fixed to the bottom of the river. This offshore transducer would be extremely susceptible to displacement or damage by debris or boats, and the further offshore the more vulnerable it would be. At a minimum, a boat equipped with a davit and quick-release would be required to safely deploy the transducer offshore. Redeploying the transducer would require three people, whereas at the current site, one person can usually redeploy a transducer.

Of additional concern is that the offshore transducer would be placed in the heaviest boat traffic corridor. Boats would need to be diverted from this area to avoid damage to underwater sonar gear and the boats. Additionally, there is considerable boat traffic during the dark in this area that would necessitate some form of lighted warning.

Table 6.-Chart contrasting current sonar site at river mile 8.6 with alternate sonar site at river mile 13.2.

River Mile 8.6 (current site)	River Mile 13.2 (alternate site)
More sockeye in the middle section of the river.	Fewer sockeye in the middle section of the river.
Less conflicts with sport fisherman. This site is used infrequently during the early run (difficult to get there due to low water levels and poor boat launch access). Becomes more popular in late run but still not as intensively used as the upriver site.	More conflicts with sport anglers. Site is intensively used by anglers backtrolling during both early and late runs due to its proximity to several boat launches and fish catchability. The required offshore transducer on the left bank will prevent boat travel and fishing within 40 m from shore on the left bank.
Lower boat traffic. The effects of boat traffic are minimized by tidal influence that provides a buffer zone from entrained air caused by outboard motors.	Higher boat traffic. This site has more severe acoustic affects from boat wake on the left bank (boat wake is denser and shuts off sound beyond wake at times). Boat wake not as big an issue on the right bank. It appears to dissipate quickly.
Better bottom topography. Few sound shadows present and the water column can be covered by one transducer on each bank	More complex bottom topography. Site requires at least two transducers (near and far shore) on the left bank and one on the right bank. The offshore transducer could probably not be deployed without some aid of a specially engineered mount that is semi-permanently deployed.
Can operate both banks from one bank. High bluff on left bank and narrower river allows cable to be deployed over the river. One technician can then monitor both sites concurrently.	Both banks cannot be insonified from one bank. Without some engineering to get cable across river, will require two sonar systems plus two sites/tent.
Slower current - easy to deploy transducer with one person in waders.	Swift current - not sure how to deploy an offshore transducer. It will require a better/bigger/more highly powered boat than the one we currently have, equipped with a davit for deploying the pod. Even then, we are not sure we could get the transducer mount to hold in this high current.
Few issues with mainstem spawning. No issues with spawners in beam until August, when pink salmon can cause problems.	Mainstem spawning behavior by chinook. Spawning behavior affected our ability to track fish accurately on the left bank during sampling from 20-22 May.
No offshore transducers required. Transducers less susceptible to disturbance/damage by boats debris because they are relatively nearshore.	Offshore transducer required. Nearshore transducers will be even less susceptible to disturbance/damage by debris but offshore transducer will be highly susceptible to damage/disturbance by boats and debris.
Minor impact on sport anglers.	High impact on sport anglers.

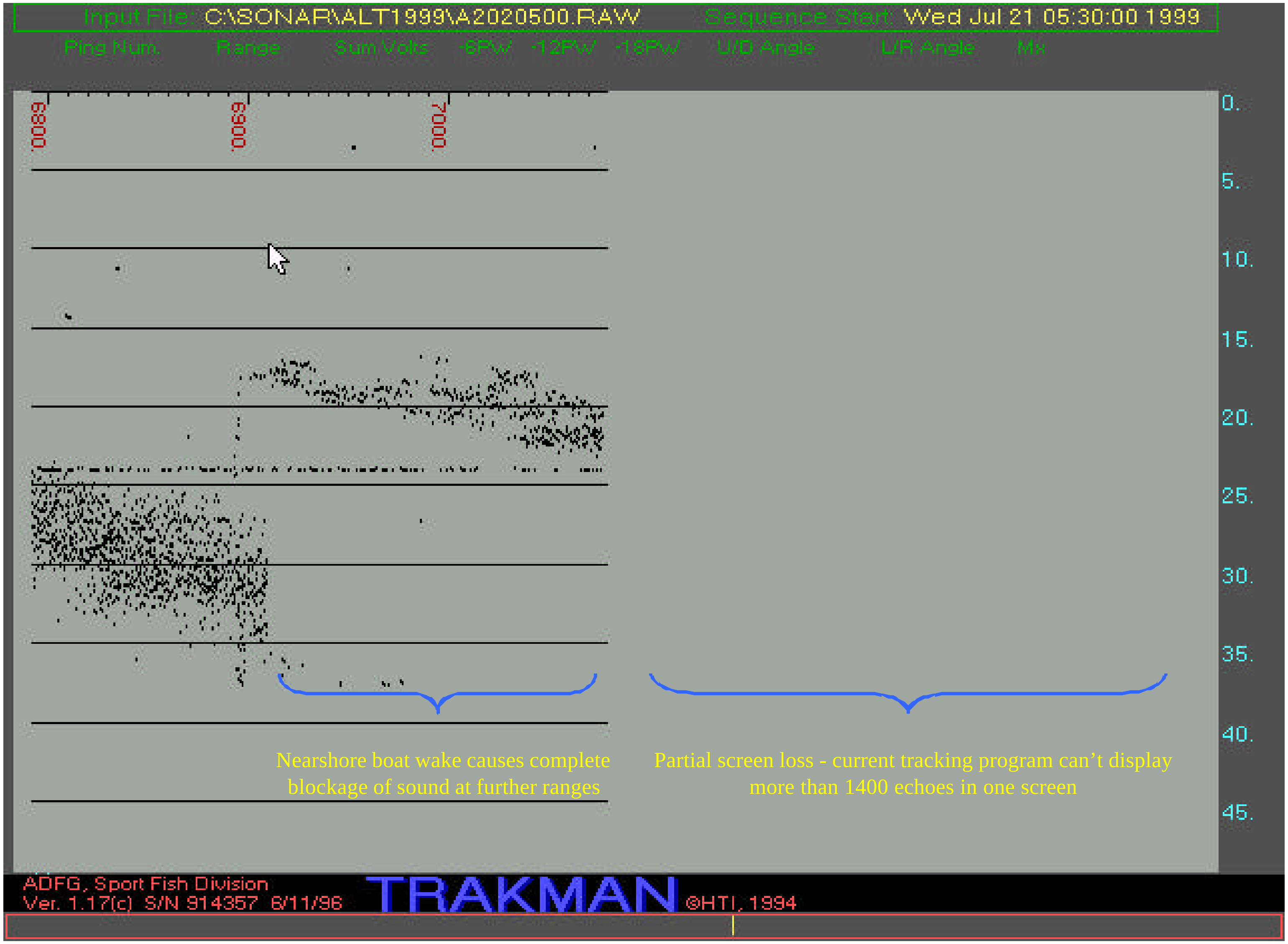


Figure 15.-Electronic chart from left bank nearshore transducer on 21 July 1999 showing how entrained air from a boat propeller blocks most of the acoustic signal beyond 25 m.

Less importantly, monitoring three transducers rather than two as at the current site would add a new level of complication to both data collection and analysis.

Spawning Fish

Acoustic sampling on the left bank was complicated by the presence of spawning fish from 20-22 July, a period of peak sockeye and chinook passage (Figure 16). Fish spawning in the beam may look like a rock, or some other structure which can cause problems in aiming the transducer. Spawning behavior can also make tracking difficult if not impossible. It is not known to what extent spawning fish would be a problem since we could not deploy an offshore transducer and sampling was limited in duration.

Other Issues

There are several other issues that would have to be resolved at the alternate site. First, the alternate site is located in an area of high angler use and passage. To protect sonar gear, much of this area would be lost to anglers. Second, lures tend to emulate fish. There is almost a continuous stream of backtrollers at the alternate site during all daylight hours and beyond. Tackle, such as jet planers and quickfish, used by many backtrollers tends to emulate fish traces in the acoustic data, causing some confusion when trying to track fish (Figure 17). This has not been an issue at the current site as it is primarily a drift fishery area and tackle associated with drift fishing does not present targets that create fish-like traces. The last issue is that project costs at the alternate site would increase due to the necessity of two sonar systems. A sonar system would be required on each bank, as opposed to one which is used now. In addition to a second sonar unit, a second system would entail two generators; increased maintenance; and crew size would either increase, or one technician would have to frequently move from bank to bank to maintain and monitor equipment.

NETTING

The netting data indicate the alternate sonar site has fewer sockeye salmon migrating mid-channel than does the current site. However, segregation of species is far from ideal at river mile 13.2. First, when sockeye salmon are relatively abundant (mid to late July), they migrate mid-channel at this site. Even though the distribution of sockeye salmon mid-channel is less severe at this site than at the current site, the problem is not eliminated. The daily inriver return of sockeye salmon estimated at the river mile 19 sockeye salmon sonar site averaged nearly 34,150 fish during 20-23 July. Second, a fairly large proportion of chinook salmon appear to migrate near shore at this site throughout the entire return.

CONCLUSIONS

In summary, the evidence indicates that moving to the alternate site evaluated in 1999 would not sufficiently resolve the main concerns regarding species discrimination at the current sonar site for Kenai River chinook salmon. The netting data suggest that a sonar project at river mile 13.2 would probably not result in substantially better estimates of chinook salmon abundance. The new site also presents a suite of new problems and issues that may prove insurmountable. Data from acoustic sampling indicate that the river mile 13.2 site would at best be a complicated site to insonify and would require several years of research to address the issues discussed above. Furthermore, after investing several years in research and development, we may discover that we cannot adequately insonify the area, keep an offshore transducer operational, and successfully divert boat traffic such that the sonar is not severely impacted by boat wake. Although there were fewer sockeye salmon in the offshore area at the alternate site, there were still relatively

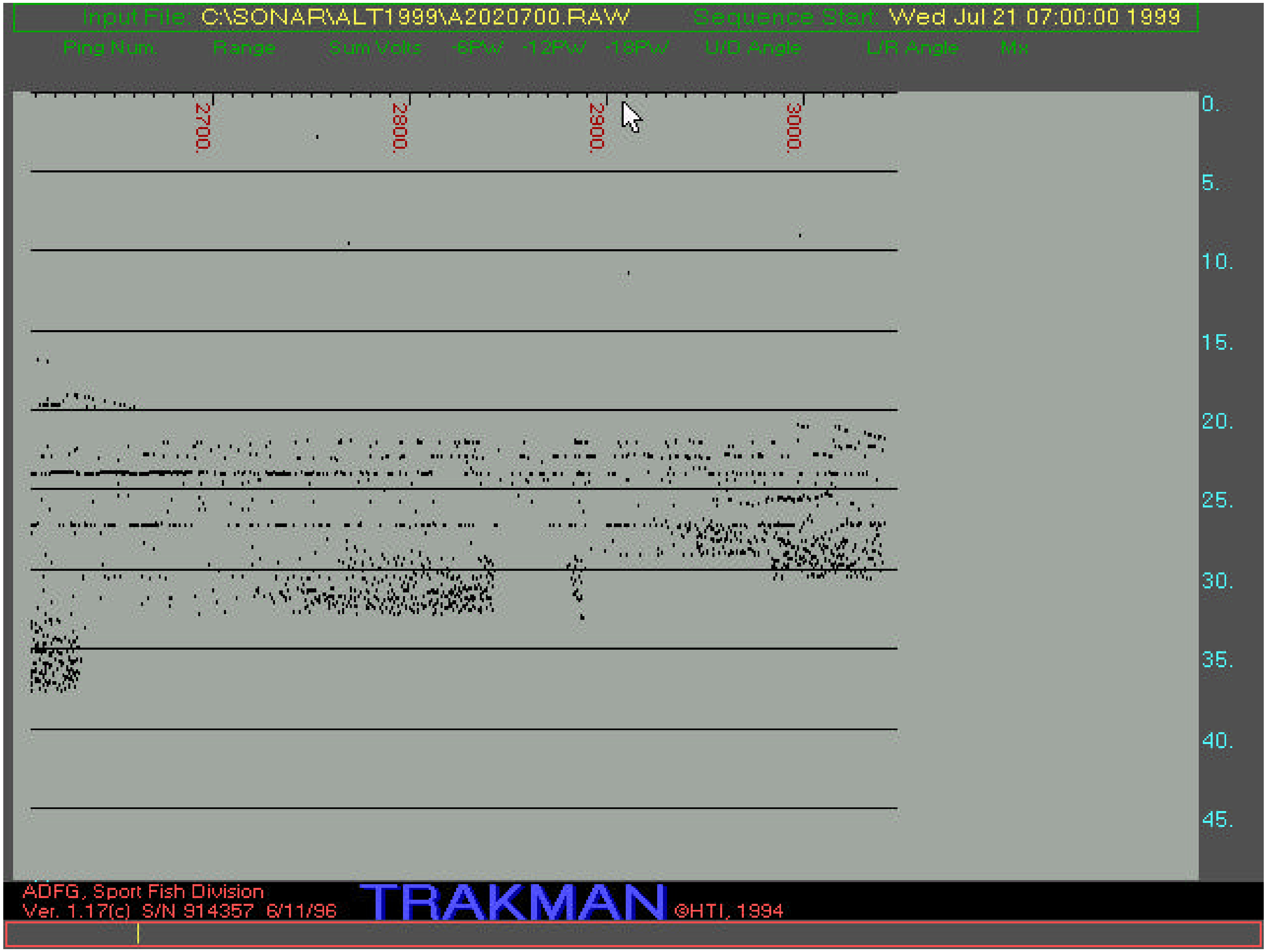


Figure 16.-Electronic chart recording showing spawning fish behavior at the left-bank site on 21 July. Spawning fish resemble stationary targets such as bottom structure.

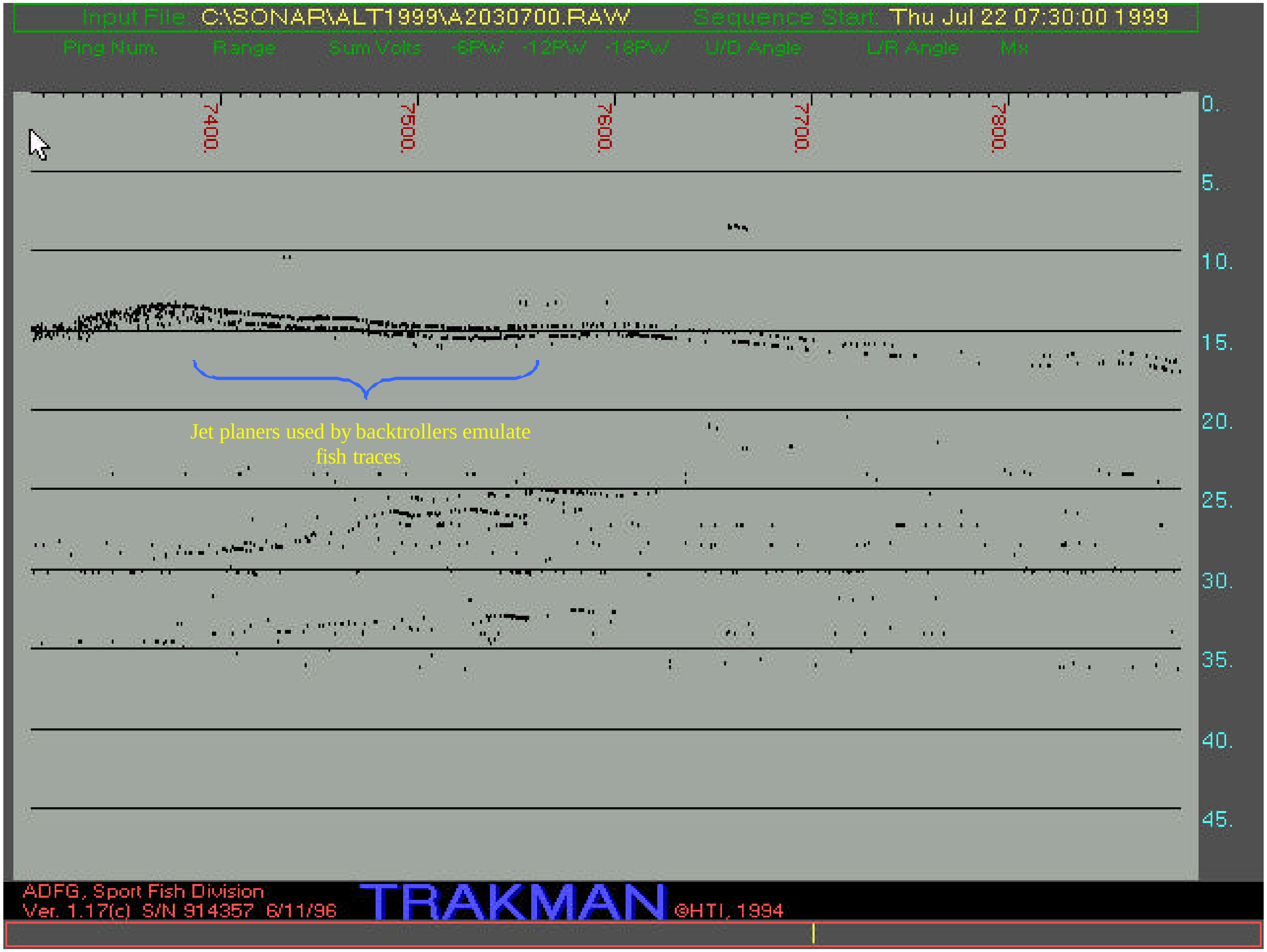


Figure 17.-Electronic chart recording from left bank nearshore transducer on 22 July 1999 showing how two lures or jet planes from a backtroller may emulate fish traces.

large numbers of sockeye salmon present in the offshore area during peak migration periods. Additionally, there were high numbers of chinook salmon caught in the nearshore area.

RECOMMENDATIONS

We do not recommend moving the current chinook salmon sonar site at this time. Although moving above tidal influence may improve spatial segregation of species, we do not currently have methods to contend with the high levels of entrained air generated by outboard motors. The effect of high boat traffic remains the biggest obstacle to moving the current sonar site upriver. Echoes from entrained air mask fish targets and overload our data processing software.

It may be feasible to investigate using a site further upriver to estimate early-run chinook salmon where the potential for missing a large proportion of late-run mainstem spawners in the lower river is not an issue. If we move far enough upriver where boat traffic is less intense (e.g., the sockeye salmon sonar counter at river mile 19) then it may be possible to find a site that offers better spatial separation without increased boat traffic. We would like to work with the Commercial Fisheries Division in evaluating whether the sockeye salmon sonar site at river mile 19 is suitable for detecting and counting early-run chinook salmon.

With respect to late-run chinook salmon estimates, we believe our efforts are better spent in two areas. First, efforts are in progress to develop a method to model chinook salmon abundance estimates from our standardized netting program that is conducted immediately downstream of the sonar site. Changes in both the location and methodology of the chinook salmon netting program were made starting in 1998 with the hopes that more standardized netting catch per unit effort (CPUE) data would be able to provide some level of ground truthing for the acoustic estimates. We also wanted to determine whether there is some basis for estimating chinook salmon abundance from the CPUE data during periods of high sockeye salmon abundance when we know that accuracy of the sonar estimates are most questionable. If the CPUE estimates can be calibrated to sonar estimates during periods of low sockeye salmon abundance, then perhaps a CPUE model will provide better estimates of chinook salmon abundance during periods of high sockeye salmon abundance. A preliminary evaluation on the feasibility of using net CPUE to model chinook salmon estimates should be completed in 2001.

Second, we should continue to pursue improved techniques for separating chinook and sockeye salmon using acoustic information. Research efforts into several different aspects of acoustic species discrimination remain in progress. Results of a tethered fish study indicated that pulse width may provide higher discriminatory power than target strength for separating sockeye and chinook salmon (Burwen and Fleischman 1998). The feasibility of using pulse width as an additional species discriminator at the Kenai River site is still being investigated. We are also making significant progress in our ability to correct for threshold and noise-related bias in target strength estimates (Fleischman and Burwen 2001) which will improve the utility of target strength for classifying acoustic targets. Additional experiments with multifrequency sonar in 1998 showed that information from multiple frequencies substantially improved our model for predicting fish length (Burwen and Fleischman *In prep)*. Continued research using multiple frequency sonar is being pursued through a proposal to the Alaska Sea Grant College Program in cooperation with the University of Alaska and the University of Washington.

Finally, the department is involved in a joint project with the Department of Fisheries and Oceans, Canada to develop new target-tracking and data-editing software. This new approach to target tracking may offer some hope for tracking fish through dense boat wake and managing the large files that result from the increased data load. Though significant progress has already been made, completion of this software is not anticipated until 2002. If the tracking software is able to track fish through boat wake, we may want to revisit the idea of moving the sonar site to an alternate location.

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APPENDIX A.-CHARACTERISTICS OF SITES FOR SIDE-LOOKING SONAR

Appendix A1.-Characteristics of side-looking fisheries sonar sites.

Characteristics of a site that allow for maximum insonification of the water column are as follows:

1. A gradual and uniform slope from both banks (no shelves) is required to insonify a large proportion of the water column without acoustic shadowing effects (Appendix A2). Uneven bottom profiles with multiple slopes can be compensated for to a limited extent by use of multiple transducers and/or multiple aims.

2. The water level (depth) must be sufficient to allow use of a 2 degree (or greater) sonar beam. Two degrees is generally the narrowest transducer beam width that is commercially available.

   The appropriate transducer beam width is a function of the slope of the river bottom, water depth, and maximum range covered by the sonar beam. The beam can be thought of as a triangle (with nominal beam angle θ) that grows by the formula 2*Range*tan(θ/2) (Appendix A3). For example, to insonify 30 m from the transducer, the river must be at least 1 meter deep at 30 m to use a 2^o transducer. In practice, for a given bottom slope, a transducer with a nominal beam-width about 1^o to 1.5^o less than that slope will generally "fit" without excessive noise from the bottom and surface. In this case we would actually need 1.3 m to 1.5 m of water depth. A choppy surface and rocky bottom act as reflective surfaces and can greatly influence the ability to fit a beam. Even if the beam fits, significant echoes from reflective surfaces may effectively reduce the depth of the water column. Also, if the site has an acoustically absorptive bottom of fine silt/sand, it may be possible to aim a portion of the beam into the bottom allowing the use of a beam width that might otherwise be too large (Daum and Osborne 1996).

   If the section of river to be insonified is very deep, the best strategy for insonifying the entire water column may be to divide the water column into individual strata and use several narrow beams (or several aims with a narrow beam) rather than one very wide beam. The narrow beam may return less unwanted reverberative noise yielding a higher SNR in a noise-limited application (Enzenhofer and Cronkite 2000).

3. Laminar flow (no riffles) with minimal entrained air is required. Entrained air from riffles is detected by the sonar and usually creates unacceptable levels of background noise.

4. Optimally, the bottom on both banks should be composed primarily of one of the following:

   a. Fine sand, silt, or mud: This is the best substrate, providing an absorptive rather than reflective surface. This absorptive property improves the signal-to-noise ratio when the beam is aimed along the bottom. The right (north) bank of the current Kenai River chinook salmon sonar site has this substrate.

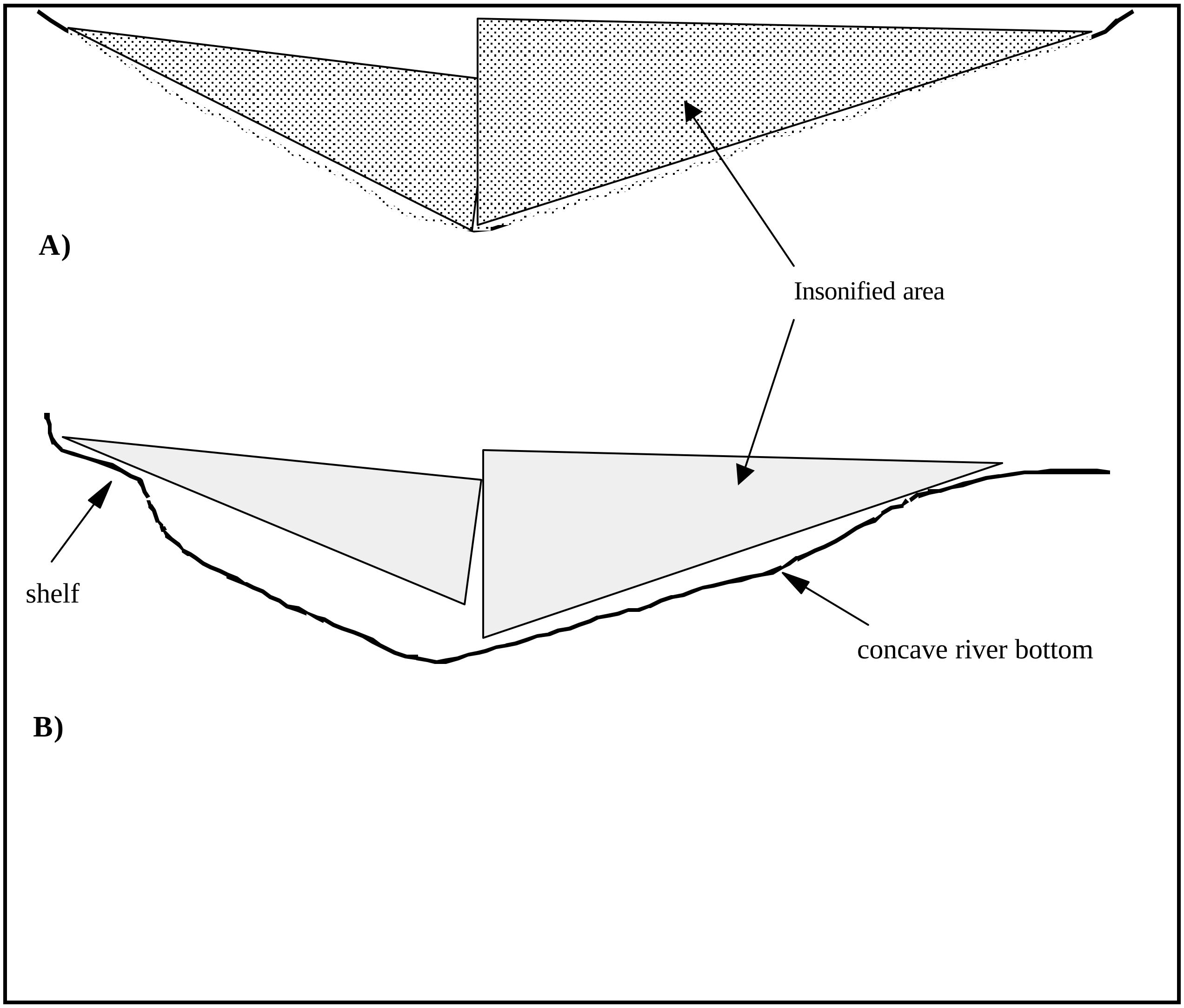
   b. Fine gravel (5 cm or less): This is less advantageous for aiming the beam close to the bottom, but is still often acceptable if other reverberative noise is minimal. The left (south) bank of the current Kenai River chinook salmon sonar site has this substrate.

   c. Large gravel (10 cm or less): This substrate is marginal, but may work in some instances especially if fish are not oriented closely to the bottom.

5. Large cobble is generally unacceptable substrate for insonifying bottom-oriented fish without an artificial substrate, or some site/substrate modification or enhancement.

6. Minimal boat travel is essential unless water depth is sufficient to provide a buffer zone for entrained air (such as the current Kenai River chinook salmon sonar site at higher tide levels) generated by boat propellers. This also assumes the fish are bottom oriented and insonification of the upper water column is not required.
7. There are several fish behavior considerations that need to be evaluated for any potential site:
   a. Milling: Because milling behavior can be difficult for any fish-tracking algorithm (depending on fish behavior while swimming through the beam), excessive milling may introduce too much uncertainty in estimates.
   b. Spawning: Fish spawning in the acoustic beam makes fish-tracking difficult or impossible.
   c. Aspect: Ideally, fish should present a consistent aspect relative to the bank as they swim through the sonar beam. Maximum echo strength (and consequently detection probability) occurs when the fish travels perpendicular to the sonar beam axis (full lateral aspect). Fish that change aspect in the beam may present problems to an automatic tracking algorithm because echoes from the fish may not be detected with extreme departures from lateral aspect.

Appendix A2.-Example of good (A) and poor (B) sites for insonifying fish in the side-looking configuration. A good site has a smooth, gradually sloping bottom with no sound shadows and allows the acoustic beam to lie close to the river bottom where fish typically migrate. A poor site has an uneven bottom which results in sound shadows that cannot be insonified by the acoustic beam, allowing some fish to escape detection.



Appendix A3.-Width of a beam (in meters) calculated for a specified range from the transducer at several nominal transducer (Tx) beam widths. For example, at 30 m, a transducer with a nominal beam width of 2^{o} is 1.05 m wide.

Distance from Tx (m)	Nominal Beam Width (degrees)								
	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
5	0.17	0.22	0.26	0.31	0.35	0.39	0.44	0.48	0.52
10	0.35	0.44	0.52	0.61	0.70	0.79	0.87	0.96	1.05
15	0.52	0.65	0.79	0.92	1.05	1.18	1.31	1.44	1.57
20	0.70	0.87	1.05	1.22	1.40	1.57	1.75	1.92	2.10
25	0.87	1.09	1.31	1.53	1.75	1.96	2.18	2.40	2.62
30	1.05	1.31	1.57	1.83	2.10	2.36	2.62	2.88	3.14
35	1.22	1.53	1.83	2.14	2.44	2.75	3.06	3.36	3.67
40	1.40	1.75	2.09	2.44	2.79	3.14	3.49	3.84	4.19
45	1.57	1.96	2.36	2.75	3.14	3.54	3.93	4.32	4.72
50	1.75	2.18	2.62	3.06	3.49	3.93	4.37	4.80	5.24
55	1.92	2.40	2.88	3.36	3.84	4.32	4.80	5.28	5.76
60	2.09	2.62	3.14	3.67	4.19	4.71	5.24	5.76	6.29
65	2.27	2.84	3.40	3.97	4.54	5.11	5.68	6.24	6.81
70	2.44	3.05	3.67	4.28	4.89	5.50	6.11	6.72	7.34
75	2.62	3.27	3.93	4.58	5.24	5.89	6.55	7.21	7.86
80	2.79	3.49	4.19	4.89	5.59	6.29	6.99	7.69	8.39
85	2.97	3.71	4.45	5.19	5.94	6.68	7.42	8.17	8.91
90	3.14	3.93	4.71	5.50	6.29	7.07	7.86	8.65	9.43
95	3.32	4.15	4.98	5.81	6.63	7.47	8.30	9.13	9.96
100	3.49	4.36	5.24	6.11	6.98	7.86	8.73	9.61	10.48

APPENDIX B.-SAMPLING SCHEDULE FOR INRIVER NETTING

Appendix B1.-Sampling schedule for inriver netting at the current (rm 8.6) and alternate (rm 13.2) Kenai River chinook sonar sites, 1999.

		First Sample Period			Second Sample Period		
Date	Crew #	Site	Begin	End	Site	Begin	End
20-Jun	1	Alternate	0400	0630	Current	0700	0930
21-Jun	1	Current	0400	0700	Alternate	0730	1030
22-Jun	2	Alternate	1330	1630	Current	1730	2030
23-Jun	2	Current	1500	1800	Alternate	1900	2200
5-Jul	2	Current	0330	0545	Alternate	0615	0830
6-Jul	2	Alternate	0400	0630	Current	0700	0930
7-Jul	1	Alternate	1230	1530	Current	1630	1930
8-Jul	1	Current	1400	1700	Alternate	1800	2100
20-Jul	1	Alternate	0400	0630	Current	0700	0930
21-Jul	1	Current	0400	0700	Alternate	0800	1100
22-Jul	2	Alternate	1400	1700	Current	1800	2100
23-Jul	2	Current	1530	1830	Alternate	1930	2230
4-Aug	2	Current	0400	0615	Alternate	0645	0900
5-Aug	2	Alternate	0400	0700	Current	0730	1030
6-Aug	1	Current	1330	1630	Alternate	1730	2030
7-Aug	1	Alternate	1500	1800	Current	1900	2200

APPENDIX C

Appendix C1.-Original chart recording from a Lowrance X-16 (top) showing the bottom profile at Kenai river mile 13.2 taken on 18 May 1999 at low water conditions. The bottom chart has been edited and enhanced to reflect the shallower nearshore bench on the left bank. The Lowrance cannot measure bottom depth within 1.5 feet of the transducer face.