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KENAI RIVER USER CONFIGURED SONAR STUDIES, 1992

Bruce E. King

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Ken Tarbox and Linda Brannian helped with the study design. Jim Cofske and Dan Huttunen assisted with collection of the data. Ken Tarbox, Linda Brannian, Steve Fried and Randall Davis counted fish traces from a selection of echograms.

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ABSTRACT

Studies were done on the Kenai River in 1992 to determine whether currently used *Bendix Corporation* single beam acoustic equipment, which has been operated since 1976 and is no longer manufactured, could be replaced by dual beam equipment. This equipment can track individual fish, estimate target strength, produce echograms, and record data onto tape. A total of about 9.5 hours of data were collected while most of the river width at the counting site was monitored. The remaining data were collected within 20 m of each bank. A random subsample of 35 pages of echograms from the nearshore areas were examined by each of five people to determine whether fish could be reliably counted at passage rates ranging from about 10-35 fish per minute (300-2,100 fish per hour). Since most fish passed the site within a relatively narrow corridor along both banks (i.e. within about 15 m of transducers), individual traces could not be reliably counted at passage rates exceeding about 10 fish per minute (600 fish per hour). This indicated that the currently manufactured dual beam data processing format was not suitable for counting sockeye salmon on the Kenai River during periods of high passage rates.

KEY WORDS: escapement enumeration, Kenai River, acoustics, sockeye salmon

INTRODUCTION

Bendix Corporation[1] acoustic equipment has historically been used to enumerate adult sockeye salmon *Oncorhynchus nerka* returning to the Kenai River, Alaska (Figure 1; King and Tarbox 1990). The current equipment has been used since 1976 and, while repairs and modifications have been done by a retired *Bendix Corp.* employee under contract to the State, new equipment is no longer manufactured. Not only is it becoming increasingly difficult to obtain replacement parts for these units, but advances in acoustic technology have made the equipment obsolete for some project objectives. New equipment is able to provide data about individual fish (including target strength), and data can be recorded for later analysis or duplication of inseason escapement estimates. We were interested in finding out if available equipment was suitable for eventual replacement of the existing *Bendix Corp.* equipment used on the Kenai River.

The *Bendix Corp.* equipment estimates the number of fish passing the counting site by summing echoes returning from fish and then dividing the total number of echoes by a preset average number of echoes per fish (Gaudet 1983; Ehrenberg 1989). In contrast, newer dual beam equipment currently used by the Alaska Department of Fish and Game (ADF&G) in other areas of the state (LaFlamme and Mesiar 1990) was designed to track the progress of individual fish through the area covered by the transducer beam according to a variety of parameters specified by the operator. The number of individual fish is summed for each unit of time to estimate total passage.

Studies on the Kenai River for the 1992 season were designed to evaluate whether currently manufactured acoustic equipment could be adopted to count sockeye salmon escaping into this system. This equipment was used to collect detected echoes to echograms and video tape. If we could reasonably define and count fish on echograms, we could then proceed to determine if existing computer programs designed to track individual fish would work in the counting conditions found in the Kenai River during the sockeye salmon migration. At the existing site, these conditions included passage rates which occasionally exceed 5000 fish per hour, and narrow (generally less than 5 m), near shore migratory corridors.

Specific objectives of the 1992 Kenai River acoustic project were to:

1) evaluate the performance of available dual beam sonar equipment at a wide range of fish passage rates by manually counting echograms generated at the counting site;
2) assess the performance of available computer software used to track individual targets and calculate escapement estimates, if manual echogram counting was possible at the range of fish passage rates encountered at the site;

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[1] Use of a company name does not constitute endorsement by ADF&G.

3) determine acoustic coverage of the river attainable with available dual beam equipment during the peak of sockeye salmon migration in July; and
4) describe sockeye salmon spatial distribution at the counting site.

METHODS

The evaluation of new acoustic equipment was done in conjunction with routine, annual escapement enumeration studies conducted with *Bendix* equipment at km 31 of the Kenai River (King et al. 1992; Figure 2). The river bottom at the km 31 counting site gradually drops from the right bank out to approximately 90 m and then more steeply climbs back to the high water mark on the left bank in a span of approximately 20 m (Figure 3). The steep change in bottom angle on the left bank limited data collection to approximately 10 m from the transducer. The more gradual change in bottom angle on the right bank allowed data collection out to approximately 80 m from the transducer. This allowed data collection well past the thalweg of the river, near the point where the bottom began to climb towards the left bank. The data collection range on the right bank was set at 12-15 m most of the time to provide maximum definition of fish traces on echograms in the area where most of the fish migrated. The range was however periodically extended to 70-80 m to look for fish in the middle of the river. In the latter configuration, approximately 80% of the river cross section was ensonified.

Evaluation studies were done from 16-25 July, so that data could be collected during the peak period of sockeye salmon migration. The Department's adult *Bendix* sonar counting project has occurred at this site since 1968. Approximately 8 hours of data were collected each night, beginning at 2000 h and ending 0400 h. Additional data were collected at various times during the remainder of the day.

Equipment was deployed on both sides of the river, with the transducer mounted on a remote aiming device attached to a metal frame. The frame was placed in the river adjacent to the bank and immediately upstream of a weir which extended approximately 2 m past the transducer. A *Biosonic's Inc.*[2] model 105 transceiver was used on the left (south) bank and a model 101 transceiver was used on the right (north) bank. Both transceivers routed data through a *Biosonic's Inc.* model 171 tape recorder interface to a *Sony*[2] model 501F1 digital audio processor. After the signal was digitized, it was sent to a *Sony* model SL-HF400 video cassette recorder. Hard copies of returning echoes were obtained simultaneously using a *Biosonic's Inc.* model 111 thermal chart recorder on the right bank and a *Hydroacoustic Technology, Inc.*[2] model 403 digital chart recorder on the left bank.

A 2° transducer was used to collect data on the right bank; 2°, 6°x15°, and 3°x7°/10°x21° transducers were used on the left bank (Table 1). Data were collected at a frequency of 420 kHz, primarily using a pulse width of 0.1 ms on the right bank and 0.2 ms on the left bank.

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The range for data collection was initially set at the maximum allowed by water depth and bottom configuration.

Echograms and corresponding tapes were marked at one hour intervals and identified in a logbook with an eight digit code:

BDDDHHHH ,

where:

B = bank (L for left and R for right);
DDD = julienne date; and
HHHH= hour in 24-hour notation.

In addition, a calibration tone was recorded at the beginning of each tape used on the left bank. After deployment of equipment and prior to data collection, target strength threshold and signal pulse rate were selected to maximize the number and clarity of returning echoes visible as traces on the echogram. The threshold was generally set at or slightly about the ambient noise level.

After the season, echograms were initially classified into three categories based on counts obtained from *Bendix* equipment: less than 20 fish per minute (low density), 20-50 fish per minute (medium density), and greater than 50 fish per minute (high density). When viewing these results, it became obvious that it would not be possible to count traces on high density echograms, since there was too much overlap among targets at this rate of fish passage (Figure 4). Therefore, classification categories were changed to reflect the range of densities at which counting might be feasible: less than 10 fish per minute (low), 10-20 fish per minute (medium), and greater than 20, but less than 35, fish per minute (high).

One criteria for determining if counting from echograms was feasible was the agreement between readers as to what constitutes a single fish trace. If readers could not reliably determine which traces were individual fish, they could not assess the suitability of various data processing parameter combinations or how changes in the parameters might affect the accuracy of fish designation by the tracking software. In order to obtain a measure of the reliability or repeatability of the trace counting technique, we chose a random sample of echograms from each density stratum. Each of these echograms was counted by 5 biologists. Each biologist counted and recorded the number of fish per echogram page. Thirty five pages of echograms were counted, each of which included approximately 3 minutes of data. Each reader was given the following set of criteria to use to count traces: 1) simultaneous echoes returning at different ranges from the same ping were counted as separate fish; 2) traces with pulse widths (per ping) similar to those observed in traces obtained at very low fish densities were counted as one fish; and, 3) loss of a single ping was interpreted as the end of a single fish trace, if it did not occur during an extreme change in the direction of travel (Figure 5).

Counts from the most experienced reader were treated as actual (expected) counts. Counts from the remaining four readers were then plotted against these expected values to examine the variability of target recognition as fish density increased. The 10% and 20% relative error bounds were also plotted to determine how many of the observations fell outside these ranges. A relative error of 10% among readers was subjectively chosen as the level at which echogram counting would be considered reliable.

All of the echograms produced at ranges exceeding 70 m were examined for fish traces and those outside of 20 m of the transducer were enumerated. Fish migrating near shore (inside 20 m) were not counted since passage rates exceeded those deemed feasible for echogram counting.

No attempt was made to assess the accuracy of fish tracking software, since accurate manual echogram counting was not possible at the very high densities which were often encountered during peak sockeye salmon passage at Kenai River counting site.

RESULTS

Most fish migrated within 15 m of the transducer during both day and night, on both sides of the river, and at all passage densities. On the left bank, most fish were detected within a 5 m corridor beginning from 1-3 m from the transducer (Table 1). On the right bank, most fish were detected within a 2-15 m corridor beginning 1-5 m from the transducer. In general, fish were more dispersed (i.e. traveled within a wider corridor) during daylight on both banks, but passage rates were generally greatest at night when fish were less dispersed.

Approximately, 9.5 h of data were collected at long range (70-80 m) from the right bank during 18-22 July. Few fish migrated more than 20 m from the transducer: maximum fish passage beyond 20 m was less than 0.4 fish per minute. Fish distribution on the right bank was typically concentrated within 10 m of shore for the season (Davis and King 1993).

Staff member counts of fish per minute ranged from 7 to 36 (400-2,000 fish per hour). Observer three's counts were consistently higher than those of the other observers, and usually fell outside the upper 10% relative error bound (Figure 6). Counts from the other three readers generally fell within the 10% error bounds only at fish densities less than 30 per 3 minutes (600 fish per hour). Increasing the acceptable relative error to 20% resulted in good agreement among these three readers at nearly all density levels measured.

DISCUSSION

The primary goal of this study was to determine whether currently manufactured acoustic equipment and associated computer software could be used to count sockeye salmon migrating up the Kenai River. To accomplish this goal, the first step was to determine whether individual fish traces could be manually counted on echograms produced during times of high fish densities. During the peak of sockeye salmon migration on the Kenai River, passage rates often exceed 2,000 fish per hour and can occasionally reach rates of 5,000 fish per hour (King and Tarbox 1989, 1991). A greater problem was the tendency of sockeye salmon to migrate within a narrow corridor of the river, close to shore. This made it impossible for investigators to reliably and consistently count individual fish traces on echograms. Without the ability to manually analyze echograms, it was not feasible to evaluate available software used to analyze video tapes and estimate fish numbers. This was because we could not reliably measure the results of varying each parameter or combination of parameters used in the tracking software.

Since all echograms examined in the present study were from the left bank, where the tendency of sockeye salmon to migrate in a narrow corridor was most pronounced, manual trace counting may have been possible at somewhat higher densities on the right bank. However, a less rigorous examination of echograms from the right bank indicated that densities were still great enough to prevent reliable manual counting of individual fish traces.

In summary, the following conclusions were reached: 1) The method of enumerating fish using existing individual fish tracking software will not work for counting Kenai River adult sockeye salmon at all density levels; 2) investigators could only identify and count individual fish traces at densities as great as 10 fish per minute (600 fish per hour); and, 3) most fish were concentrated within 15 m of the transducer on both banks.

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Table 1. Equipment settings used for data collection on the Kenai River, 1992.

Date	Echogram/ Tape Name	Ping Rate	Range: Transceiver Blanking (m)	Range: Transceiver Total (m)	Range: Chart Recorder Start (m)	Range: Chart Recorder Total (m)	Pulse Width (ms)	Chart Recorder Threshold (mv)	Chart Recorder Threshold (dB)[a]	Receiver Gain (dB)	Transducer Nominal Beam Width (degrees)	Range of Primary Fish Distribution (m)
16 Jul	R198003	10	0.5	20	0		0.4			0	2	1-5
17 Jul	R199004	10	0.5	20	0		0.1			0	2	1-3
18 Jul	R200003	10	0.5	15	0		0.1			0	2	1-3
18 Jul	R200133	10	0.5	74	0	74	0.2			0	2	5-20[b]
18 Jul	R200154	10	0.5	74	0	74	0.2			0	2	5-20[b]
19 Jul	R201000	15	0.5	50	0	10	0.1	130	-54.9	0	2	4-6
19 Jul	R201030	15	0.5	10	0	10	0.1	130	-54.9	0	2	4-6
20 Jul	R202001	30	0.5	15	0	15	0.1	130	-54.9	0	2	2-10
20 Jul	R202024	30	0.5	15	0	15	0.1	130	-54.9	0	2	4-14
20 Jul	R202163	10	0.5	74	0	74	0.1	130	-54.9	0	2	5-15[b]
20 Jul	R202181	30	0.5	15	1	12	0.1	130	-54.9	0	2	2-12[b]
21 Jul	R203003	30	0.5	20	0	10	0.1	130	-54.9	0	2	1-4
21 Jul	R203030	30	0.5	20	0	10	0.1	130	-54.9	0	2	2-10
21 Jul	R203143	35	0.5	20	2	12	0.1	160	-53.1	0	2	2-10[b]
21 Jul	R203154	35	0.5	70	0	70	0.2	160	-53.1	0	2	2-20[b]
22 Jul	R204000	35	0.5	20	0	12	0.1	150	-53.7	0	2	2-6
22 Jul	R204030	35	0.5	20	0	12	0.1	150	-53.7	0	2	2-8
22 Jul	R204151	35	0.5	20	0	16	0.1	150	-53.7	0	2	4-10
22 Jul	R204170	35	0.5	75	0	75	0.1	150	-53.7	0	2	5-15[b]
23 Jul	R205001	35	0.5	20	0	12	0.1	150	-53.7	0	2	2-6
23 Jul	R205234	35	0.5	20	0	12	0.1	150	-53.7	0	2	
24 Jul	R206021	35	0.5	20	0	12	0.1	150	-53.7	0	2	
15 Jul	L197200	10	0	10	0	10	0.4	250	-48.9	-12	3/10X7/21	2-7[b]
15 Jul	L197210	10	0	10	0	10	0.4	250	-48.9	-12	3/10X7/21	2-7[b]
16 Jul	L198202	10	0	10	0	10	0.4	250	-48.9	-12	3/10X7/21	2-7[b]
16 Jul	L198213	10	0	10	0	10	0.4	250	-48.9	-12	3/10X7/21	2-7[b]
16 Jul	L198223	10	0	10	0	10	0.4	250	-48.9	-12	3/10X7/21	1-6
17 Jul	L199120	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199130	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199140	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199152	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199162	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199173	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199184	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199200	10	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199210	5	0	10	0	10	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
17 Jul	L199221	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
17 Jul	L199231	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
18 Jul	L200080	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
18 Jul	L200090	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
18 Jul	L200101	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
18 Jul	L200112	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
18 Jul	L200201	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
18 Jul	L200211	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
18 Jul	L200221	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
19 Jul	L201084	10	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
19 Jul	L201095	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
19 Jul	L201105	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
19 Jul	L201120	5	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
19 Jul	L201194	10	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
19 Jul	L201205	10	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
20 Jul	L202081	10	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
20 Jul	L202092	10	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	

- continued -

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Date	Echogram/ Tape Name	Ping Rate	Range: Transceiver Blanking (m)	Range: Transceiver Total (m)	Range: Chart Recorder Start (m)	Range: Chart Recorder Total (m)	Pulse Width (ms)	Chart Recorder Threshold (mv)	Chart Recorder Threshold (dB)[a]	Receiver Gain (dB)	Receiver Transducer Nominal Beam Width (degrees)	Range of Primary Fish Distribution (m)
20 Jul	L202102	10	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
20 Jul	L202112	10	0	8	0	10	0.2	250	-48.9	-12	3/10X7/21	
20 Jul	L202200	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
20 Jul	L202210	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	1-6[b]
20 Jul	L202221	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	1-6
20 Jul	L202232	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	1-3
21 Jul	L203162	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
21 Jul	L203172	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
21 Jul	L203182	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
21 Jul	L203194	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
21 Jul	L203204	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
21 Jul	L203215	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
21 Jul	L203230	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6
22 Jul	L204202	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
22 Jul	L204213	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
22 Jul	L204223	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
22 Jul	L204232	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	1-3
23 Jul	L205094	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L205105	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L205115	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L205130	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L205140	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L205150	5	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L205200	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	3-6[b]
23 Jul	L205210	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L205221	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L206195	10	0	8	0	8	0.2	400	-44.8	-12	3/10X7/21	2-6[b]
23 Jul	L206210	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	2-6[b]
23 Jul	L206220	10	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-6[b]
23 Jul	L206230	5	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-3
24 Jul	L207000	10	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-3
24 Jul	L207010	10	0	8	0	8	0.2	250	-48.9	-12	3/10X7/21	1-3
24 Jul	L207080	10	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	2-6[b]
24 Jul	L207090	5	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-6[b]
24 Jul	L207101	10	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-6[b]
24 Jul	L207112	10	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-6[b]
24 Jul	L207122	5	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-6[b]
24 Jul	L207132	5	0	8	0	8	0.2	250	-42.9	-18	3/10X7/21	1-6[b]
24 Jul	L207152	10	0	8	0	8	0.2	250	-45.4	-18	6X15	3-6[b]
24 Jul	L207200	10	0	8	0	8	0.2	250	-51.4	-12	6X15	4-6[b]
24 Jul	L207210	10	0	8	0	8	0.4	250	-45.4	-18	6X15	3-6[b]
24 Jul	L207221	5	0	8	0	8	0.4	250	-45.4	-18	6X15	3-6[b]
24 Jul	L207231	5	0	8	0	8	0.2	250	-45.4	-18	6X15	2-6
25 Jul	L208001	5	0	8	0	8	0.2	250	-51.4	-12	6X15	1-3
25 Jul	L208011	10	0	8	0	8	0.2	100	-50.9	-18	3/10X7/21	1-3
25 Jul	L208094	10	0	8	0	8	0.2	250	-45.4	-18	6X15	1-6[b]
25 Jul	L208104	10	0	8	0	8	0.2	250	-51.4	-12	6X15	1-6[b]
25 Jul	L208120	5	0	8	0	8	0.2	250	-45.4	-18	6X15	2-6[b]
25 Jul	L208130	5	0	8	0	8	0.2	250	-51.4	-12	6X15	1-6[b]
25 Jul	L208141	10	0	8	0	8	0.4	250	-45.4	-18	6X15	1-6[b]
25 Jul	L208152	10	0	8	0	8	0.4	250	-51.4	-12	6X15	1-6[b]
25 Jul	L208202	20	0	8	0	8	0.2	250		-18	2	3-6[b]
25 Jul	L208213	10	0	8	0	8	0.2	250		-18	2	3-6[b]

- continued -

Table 1. (p. 3 of 3)

[a] System parameters:

Sounder Model	Transducer	Source Level	Through system gain	Transmit Power
101	2 degree	222.0 dBv	-122.9 dBv at 25 m	-6 dB
105	6X15 degree	217.4 dBv	-126.1 dBv at 10 m	
105	3/10X7/21 degree	215.4 dBv	-126.5 dBv at 10 m	

[b] Data collection during daylight hours.

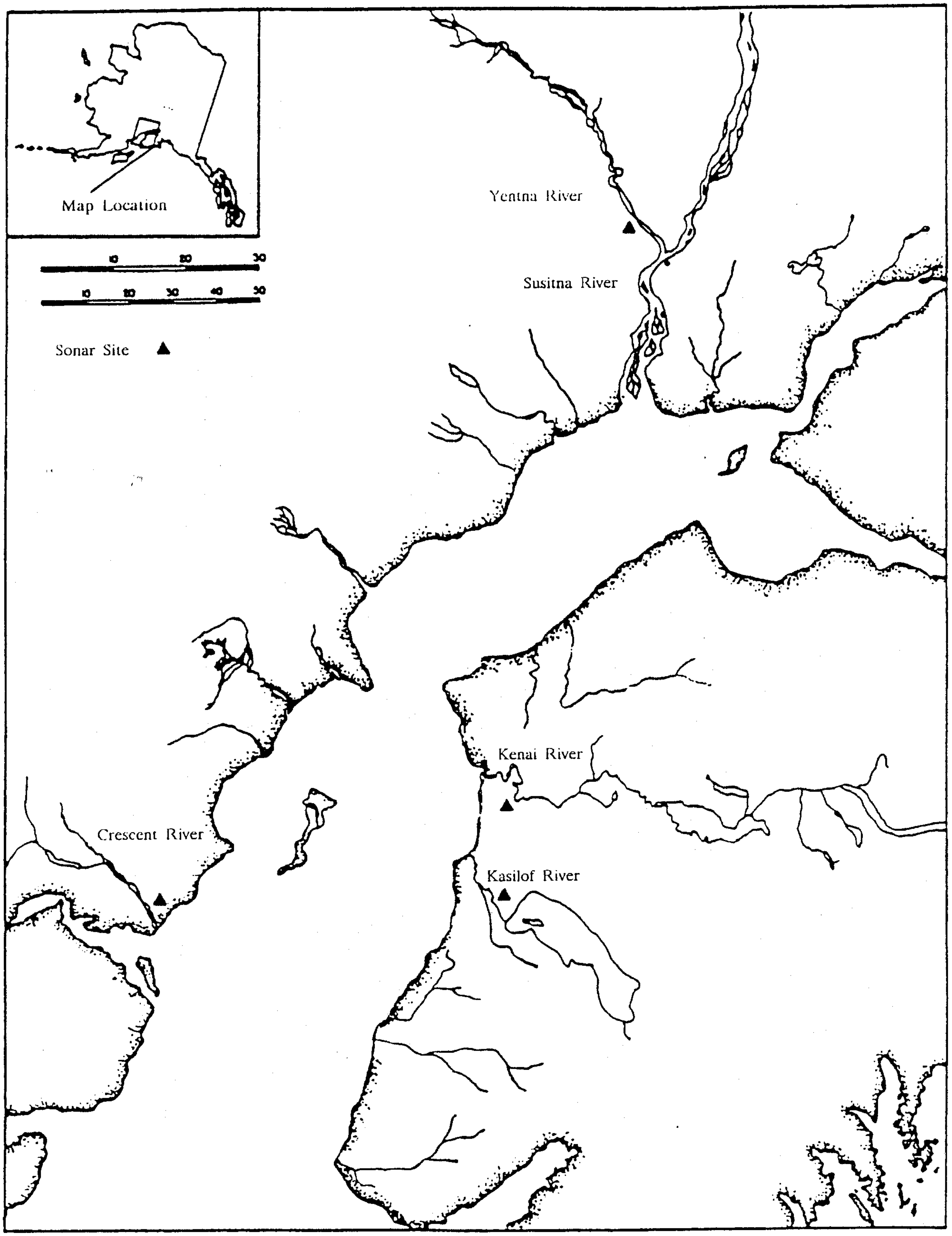

Figure 1. Upper Cook Inlet, Alaska, and sites where sockeye salmon escapement is monitored with Bendix Corp. sonar counters.

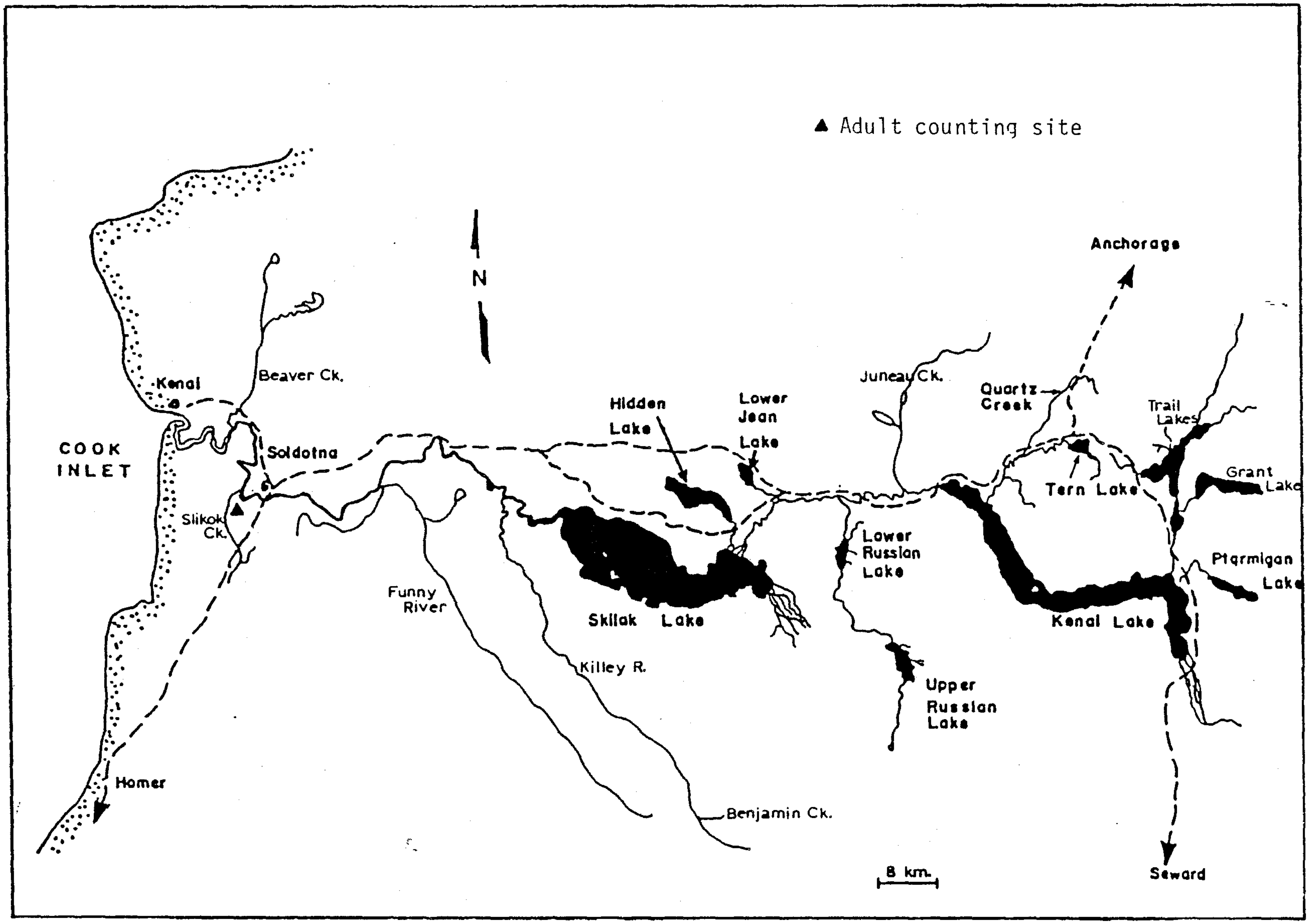

Figure 2. Kenai River drainage and major salmon rearing lakes.

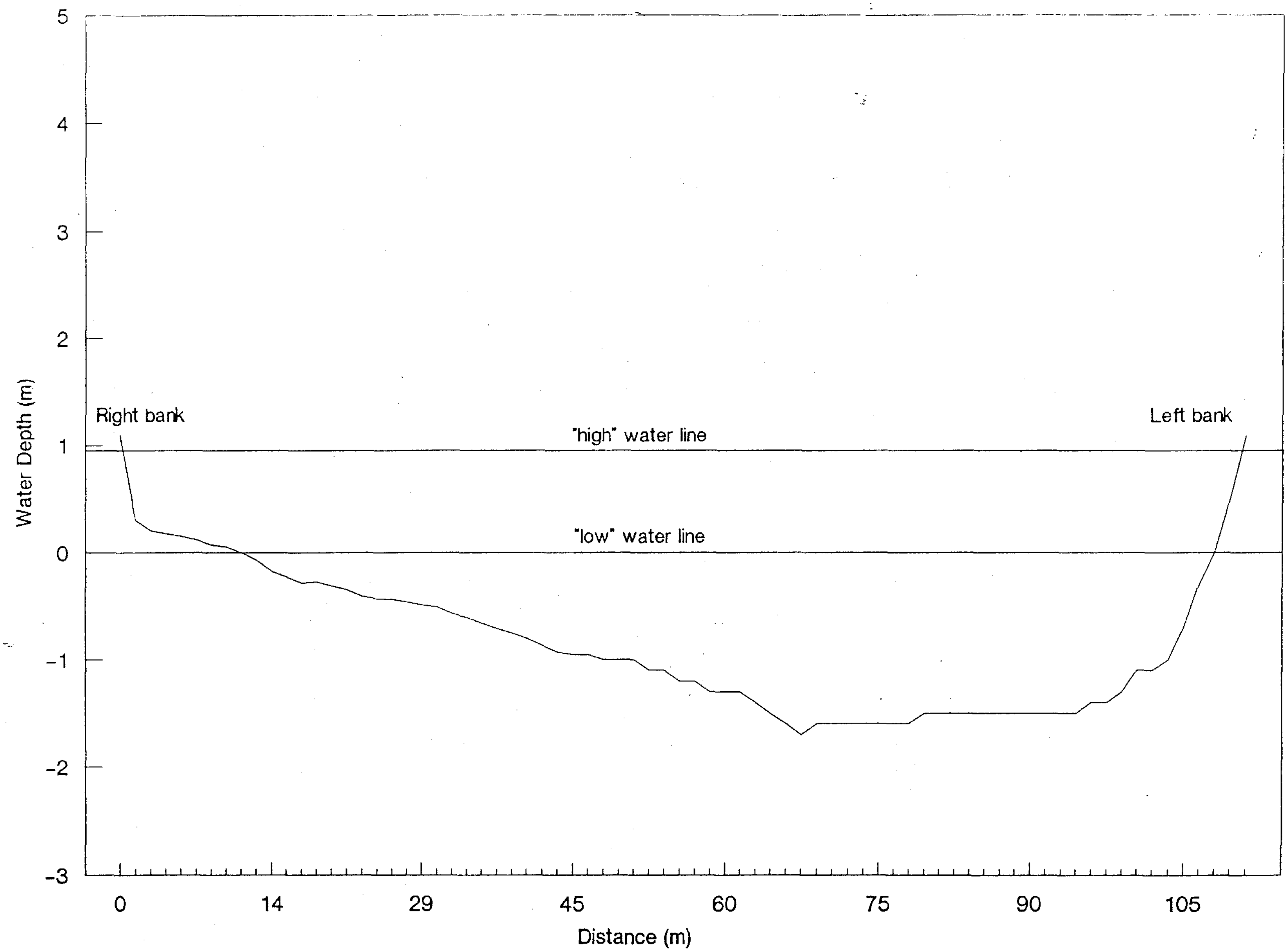

Figure 3. Kenai River bottom contour at the km 31 sockeye salmon counting site.

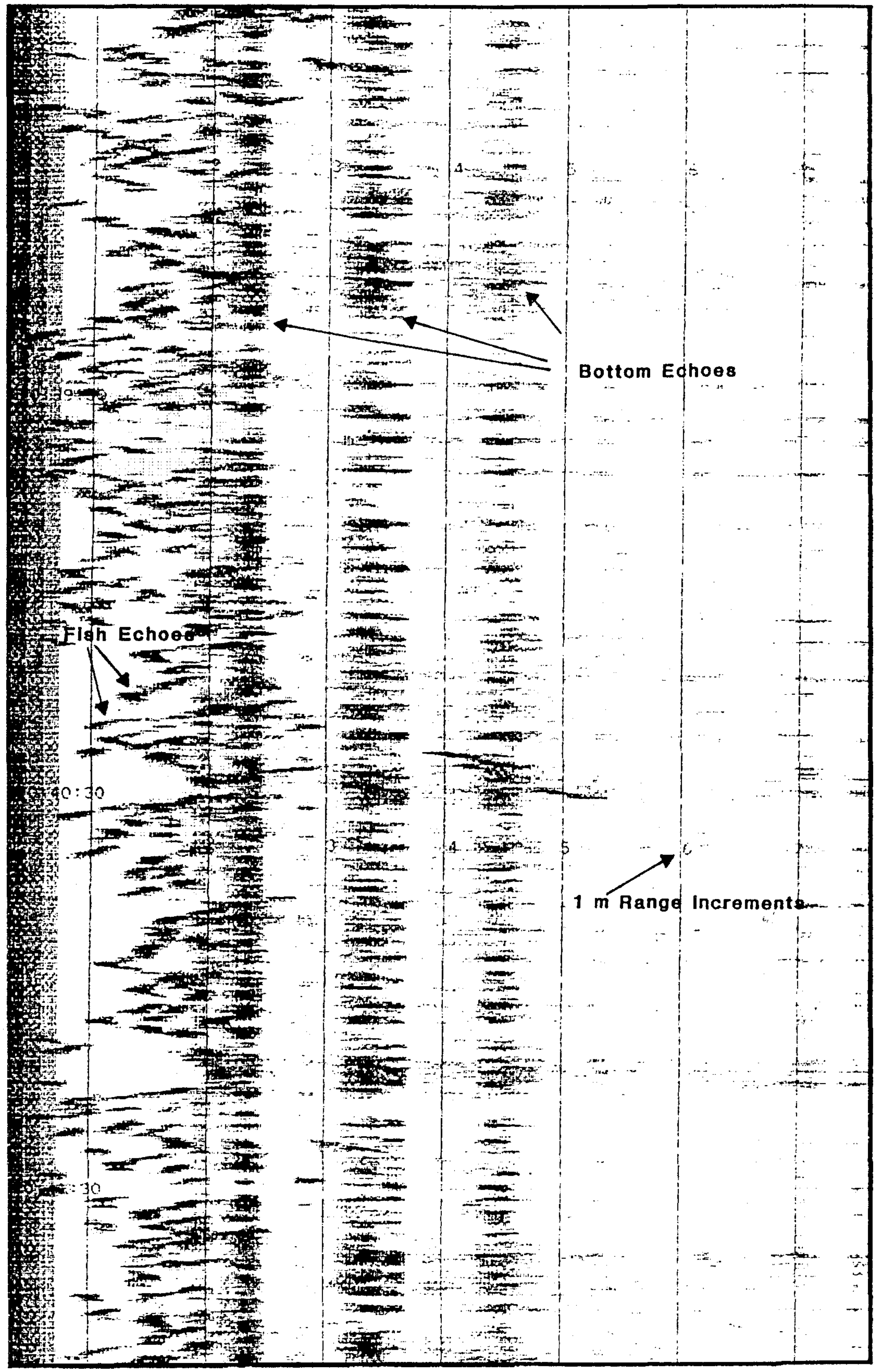

Figure 4. Echogram made during upstream migration of sockeye salmon in the Kenai River, 1992.

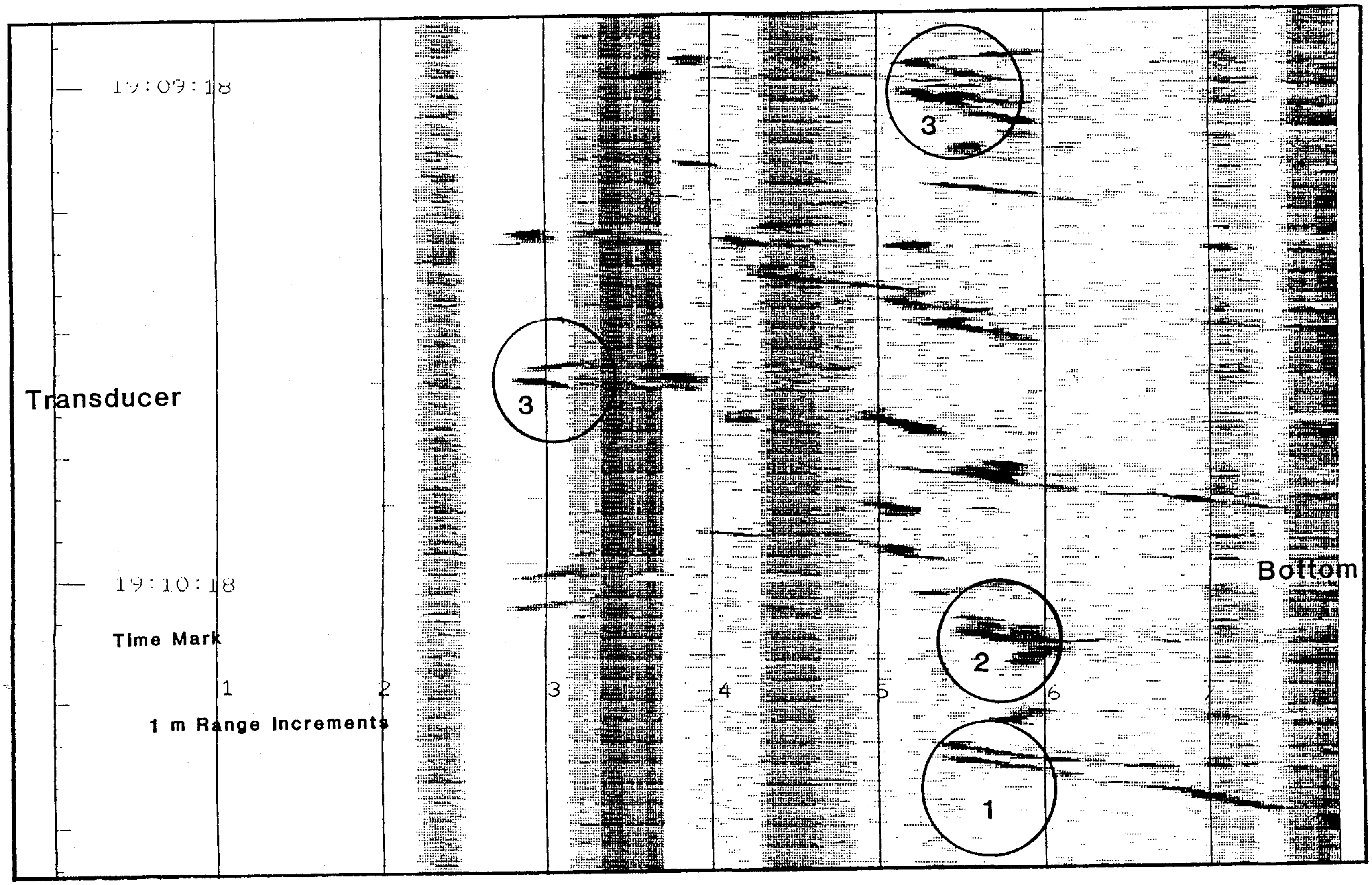

Figure 5. Examples of single target criteria: 1) simultaneous echoes returning at different ranges from the same ping represent more than one fish; 2) pulse width of each mark (per ping) in a trace should approximate that observed in traces at very low densities; and 3) the loss of one ping constitutes the end of a fish trace if it does not occur during an extreme change in direction of travel.

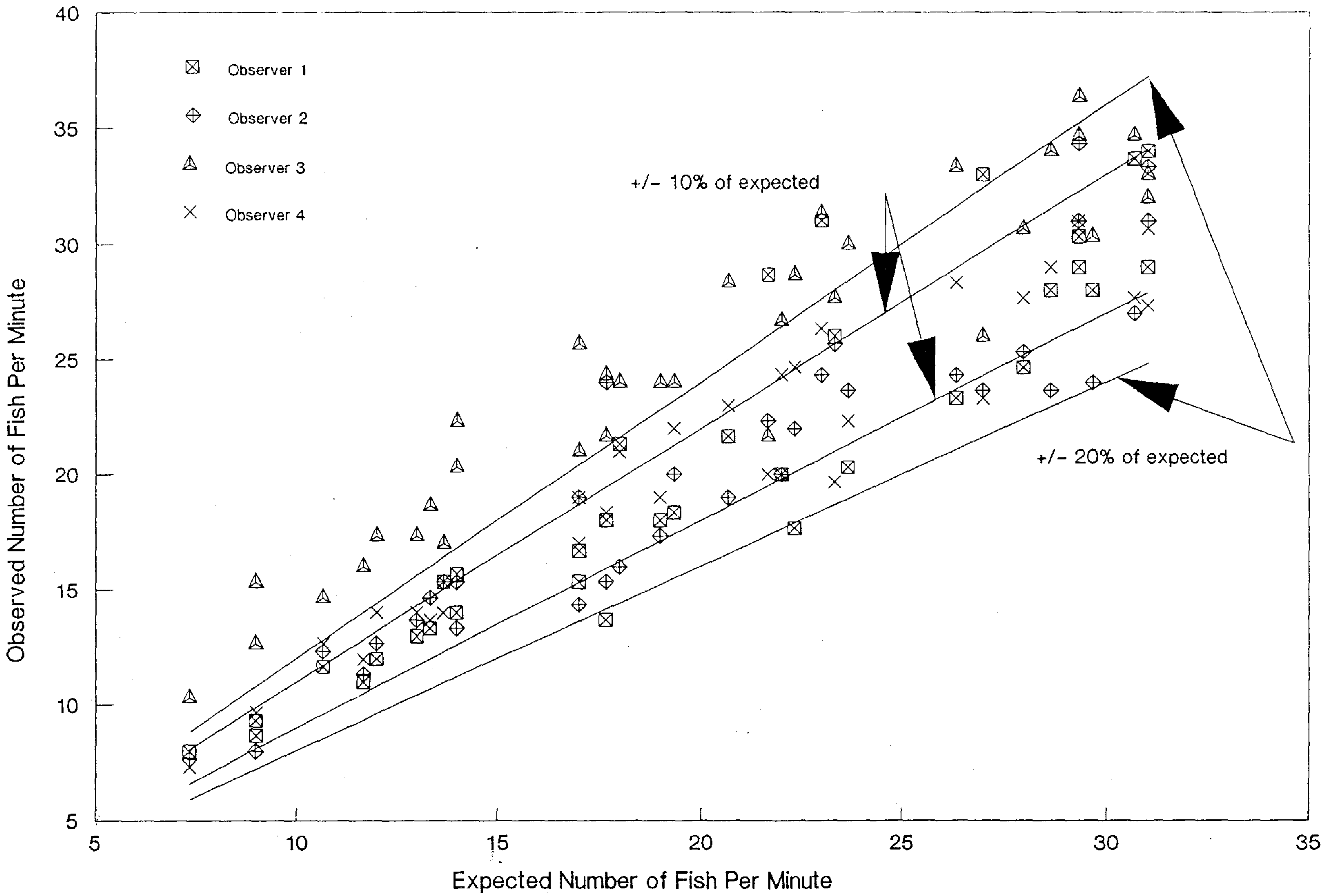

Figure 6. Relative error of counting fish from echograms between five observers.