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KENAI RIVER SOCKEYE SALMON RESTORATION STUDY #53 - STATE/FEDERAL RESTORATION SCIENCE STUDIES PRELIMINARY STATUS REPORT

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PRELIMINARY STATUS REPORT

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INTRODUCTION

Sockeye salmon *Oncorhynchus nerka* which spawn in the Kenai River system (Figure 1) were injured by the Exxon Valdez oil spill (EVOS). Greatly reduced fishing time in the Upper Cook Inlet (UCI) area due to EVOS caused sockeye salmon spawning escapement levels in the Kenai River system to exceed the desired amount by three times. The biological impact of EVOS on Kenai River sockeye salmon stocks may be one of the most serious documented. Data collected by NRDA Fish/Shellfish Study 27, Sockeye Salmon Overescapement, indicated greatly reduced survival of juvenile sockeye salmon during the winter-spring rearing period (Schmidt et. al. 1993). The extremely high escapement may have initially produced more rearing juvenile sockeye salmon than could be supported by nursery lake productivity. In general, when rearing salmon abundance greatly exceeds lake carrying capacity, the species and size composition of prey resources are altered which affects all trophic levels. Because of such changes, juvenile sockeye growth is reduced, freshwater mortality is increased, greater proportions of fry remain in the lake for another year of rearing, and smolt condition is reduced and marine mortality is increased. Limiting sockeye salmon fry production by closely regulating the number of spawning adults may be the only way to restore the productivity of these rearing areas. However, the number of adult sockeye salmon returning from the 1989 escapement may be so low that a severe reduction, or complete elimination, of human use of this species may be necessary starting in 1994 to ensure minimum spawning escapements.

The goal of this project is to restore Kenai River sockeye salmon stocks injured by EVOS. This will be accomplished through improved stock assessment capabilities, more accurate regulation of spawning levels, and modification of human use. Restoration of Kenai River sockeye salmon stocks will be accomplished when production of sockeye salmon fry is matched with the food resources within the rearing lakes and overwinter survival of fry to smolt returns to normal levels (40 - 80%).

OBJECTIVES

The objectives of this study are to:

1) improve stock identification capabilities by combining parasite and genetic stock identification information with available scale growth data in algorithms to provide estimates of Kenai River stocks in the mixed stock fishery of UCI.

2) increase the accuracy and precision of escapement monitoring by replacing existing hydroacoustic equipment.

3) provide more accurate estimates of abundance of Kenai River sockeye salmon within UCI by increasing the sampling power of the offshore test fishing program.

METHODS

During the development of this project it was apparent that the most efficient way to handle data collection and reporting was to contract the offshore hydroacoustic work including report preparation and to report results for the escapement equipment evaluation in the Alaska Department of Fish and Game (ADF&G), Commercial Fisheries Division, Regional Report Series. Therefore, attached as Appendix A & B are the contract report and Regional Information Report prepared for these phases of the project. A brief summary of methods and results are presented in this status report for overview purposes.

Stock Identification

Sockeye salmon entering the major drainages of Upper Cook Inlet were sampled for genetic, parasite, scale and otolith characteristics in 1992. Twenty five baseline populations were sampled for genetic characteristics (Table 1). In addition, mixed stock samples were collected from four mainstem sites and from two drift net fishing periods. Sample sizes for allozyme baseline collections were set at 100 (Allendorf and Phelps 1981, Waples 1990). Mixed stock sample sizes were set at 200 (Pella and Milner 1987) and will be adjusted in 1993 based on the results of simulation studies conducted with 1992 baseline data (Restoration Science Project R59).

Muscle, liver, eye, and heart were dissected from recently killed sockeye salmon. Samples of these tissues were placed in labeled cryovials stored in liquid nitrogen until transferred to -80°C storage freezers located at ADF&G offices in Soldotna or Anchorage. Soldotna samples were shipped to the ADF&G Anchorage laboratory on dry ice or liquid nitrogen and again placed in -80°C storage until processed.

The body cavity of each sockeye salmon was examined for the presence of the nematode *Philonema oncorhynchi* (Tarbox et al. 1991). Scales were taken from the left side of each sockeye salmon sampled. These scales were removed from a location approximately two rows above the lateral line on the diagonal row that extends down from the posterior insertion of the dorsal fin (Koo 1955). Sacculus otoliths were taken using procedures of Williams and Bedford (1974).

Escapement Monitoring

An "in situ" test of *BioSonic's Inc.*[1] equipment was conducted at river km 31 of the Kenai River between 16 through 25 July, 1992. A *BioSonic's* model 105 (left bank) and model 101 (right bank) transceiver was used to record echoes onto echograms and tape for latter analysis (see Appendix A for detailed report of methods). In order to assess the reliability and repeatability of echogram counting five different readers were used to count and record the number of fish per echogram page. Single target criteria were developed and applied equally by all readers. If the results of the echogram counting indicated an error of less than 10% between readers, then echo tracking computer software would have been

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

evaluated. However, the high density (> 1500 fish/hr) and nearshore migratory pathway of Kenai sockeye salmon made this portion of the project impractical.

Offshore Test Fish Program

BioSonics, Inc. was awarded a contract by the ADF&G to conduct a feasibility study using hydroacoustic techniques for adult salmon assessment in UCI. Field work commenced on 14 July and continued until 26 July, 1992. Three modes of operation were used in the study: (1) side-looking studies, (2) paravane studies and (3) fixed-location studies. A Model 102 Dual-Beam Scientific Echosounder with 120/420 dual frequency was used to collect data to echograms and DAT tape. The 120 kHz transducer was a 10°/22° dual beam and the 420 kHz was a 6°/15° dual beam. The side looking deployment, using a *BioSonics Inc.* BioFin , was the primary data collection method. A total of 17 transects was completed during the survey. Transect speed was approximately 5.5 km/hr. In addition, fixed aspect studies were completed at three stations. A complete description of methods is presented in Appendix B.

RESULTS

Stock Identification

A total of 4,174 sockeye salmon were sampled for genetic characteristics and parasites (Table 1). Genetic samples were transferred to the Anchorage laboratory and are currently being processed. Preliminary results indicate significant differences between stocks within the Kenai and Susitna river drainages (Seeb, personal communication, ADF&G, Anchorage). A complete report detailing the results of these efforts will be prepared as part of Restoration Study 59.

The parasite *Philonema* was present in all Central District systems sampled and most Northern District systems (Table 1). Ten age classes of adult sockeye return were represented in samples (Table 2).

Escapement Monitoring

During this portion of the study it soon became obvious that presently available equipment was not suitable for replacing *Bendix Corporation* sounders. The relatively high density (> 1500 hr) of fish migrating nearshore (within 5 m) made echogram counting impossible. Without the ability to echo count from the echograms, it was not possible to evaluate computer software fish tracking and counting programs which are integral to new hydroacoustic equipment performance. These programs required a number of fish behavior criteria be established for counting. These are initially set by subjective evaluation (personal experience with fish behavior in the system and counting criteria used in other applications). These criteria are then applied to the raw echo count data set (obtained from the hardware part of the system) and the counts obtained compared with known counts from echograms. Based on the agreement between the two methods the criteria may be modified to bring the software counts into closer agreement with the echogram counts. This process is repeated through-out the season to correspond with changing fish behavior or counting conditions. Without the echogram counts the ability to set these criteria is lost.

The project could have been terminated at the conclusion of the field season. However, it was our feeling that this would result in the loss of data and the inability to assess application of echogram counting to other UCI rivers. Therefore, at no cost to the project, 35 moderate to low density echograms were randomly selected and read by five permanent staff to evaluate relative error between readers. At fish densities of 600 fish per hour the error between readers was greater than 10%. At an error of 20% acceptable agreement between 4 of the 5 readers was obtained at nearly all density levels up to 1500 fish/hr (Figure 6; Appendix A).

Offshore Test Fish

A complete report detailing results, prepared by the contractor, is attached as Appendix B. All three modes of operation detected fish within UCI. The side-looking mode of operation was the most effective because of the high sampling power, but was more susceptible to noise associated with water surface roughness. A total of 3,879 targets were detected during the side-looking transects. Most targets were individual echoes but small schools of fish were also evident. The most effective range of detection was 45 - 50m and target strengths had a mean value of -42 dB (120 kHz, n = 1398). The 420 kHz system recorded larger mean targets (-27 to -32 dB) but was probably biased against smaller targets.

Density estimates ranged as high as 1.63 fish/1000 m^2. The spatial distribution of fish was highly variable and this was reflected in the error bounds for the various population estimates. A population estimate of 2.0 million fish with a 95% confidence interval of 0.7 million fish was made by combining the density values from all transects and treating each as a random variable. An independent population estimate made from commercial fishery data indicated that approximately 2.2 million sockeye salmon were in the District during the mid-point of the study.

DISCUSSION

Stock Identification

Stock identification studies used to regulate human use of UCI sockeye salmon have, in past years, relied on scale growth. The accuracy and precision of this technique has varied considerably from year to year (Waltemyer, D., personal communication, ADF&G). Kenai stocks typically dominate the total run, and their scale growth is generally distinct enough to provide some separation from other stocks. However, when runs to other systems are more abundant (as may occur in 1993,1994) separation of Kenai stocks will be much more difficult. To be able to identify the contribution of Kenai River sockeye salmon to the total run accurately in this situation will require improvements in stock identification procedures. Recent work by the Principal Investigators, in cooperation with National Marine Fisheries Service staff, has shown that parasite occurrence can be used to improve estimates of stock contribution during the fishing season. The combination of scale growth, parasites and genetic stock identification techniques (Restoration Science Study Number 59) should greatly increase the accuracy of UCI stock assessment estimates. At present the baseline genetic samples are being processed. A preliminary evaluation of the success of this technique will not be available until June 1993.

Escapement Monitoring

Bendix Corp. side scan hydroacoustic equipment has been used to count adult sockeye salmon entering the Kenai River to spawn. This equipment has been used since 1976 and, while repairs and modifications have been done by a retired Bendix employee under contract to the State, is no longer manufactured by *Bendix Corp.* Not only has it been difficult to obtain parts for these units, but advances in hydroacoustic technology have made this equipment obsolete. New units are able to track individual fish, obtain target strength measurements, and document calibration. Court actions associated with the T/V Glacier Bay oil spill in UCI placed the hydroacoustic escapement monitoring program under intense scrutiny. Although Ehrenberg (1992) concluded that the *Bendix Corp.* counters produced reliable escapement counts under conditions found in UCI systems it is imperative that replacement alternatives be pursued. Lack of *Bendix Corp.* replacement parts and the inability to purchase new *Bendix Corp.* counters may compromise our future ability to provide escapement estimates. In addition, precision of the estimates should be enhanced through use of newer, more technically advanced equipment. However, the research and design efforts and time needed to provide a new counting system in the Kenai River will prohibit installation prior to the 1996 field season. Therefore, it is our recommendation that this phase of the project be eliminated. The inability to purchase "off the shelf" equipment will not allow us to meet project objective 2. ADF&G must develop and implement a long term plan of *Bendix Corp.* replacement. This is beyond the scope of this project, and future project costs and efforts will be reduced accordingly.

The inability of new equipment to replace the *Bendix Corp.* counters because of the lack of adequate software programs was discouraging. However, this should not be interpreted to mean that Kenai River sockeye salmon escapement counts will not be made in the near future. Presently, within UCI there are a number of *Bendix Corp.* counters available for use on the Kenai if one counter fails. It is the intent of ADF&G to maintain counting capabilities in the Kenai River. Therefore, in the event of a Kenai River salmon counter malfunction which cannot be repaired a replacement counter will be moved from a secondary system in UCI or from another section of the State to the Kenai River.

Offshore Test Fish

The feasibility study clearly indicated that hydroacoustic techniques could detect fish in UCI and provide population estimates for management of the commercial fisheries. The side-looking mode was most effective because of high sampling power but was more susceptible to noise from surface interaction. Signal to noise conditions favored the 120 kHz system with a threshold level of -49 to -57dB. The near surface distribution of targets (peak at 3m with fish detections to 13m) also favors operation in a side-looking mode with the 10° 120 kHz transducer. The effective beam width at approximately 50m should adequately sample the vertical distribution of targets.

The primary limitation identified in the study was the transect speed of the vessel. Examination of the data set indicated that a minimum of 12 random orthogonal transects within UCI would be needed to provide a useable estimate of adult abundance. Each transect is approximately 32 km so total survey line would be 384 km. At a speed of 5.5 km/hr this would require almost 70 hr to complete. Multiple vessels could reduce this time, but would increase cost significantly. Therefore, it is recommended that the 1993 study examine the issue of optimum vessel speed relative to data collection. An increase of speed to 10 km/hr would meet project objectives. In addition, a better measure of spatial variance, as opposed to temporal variance, is needed. In 1993, a survey of the inlet within 48 hours should be attempted at a vessel speed of 10 km/hr).

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Table 1. Genetic samples collected and the presence of the nematode *Philonema* in sockeye salmon of Upper Cook Inlet river systems, 1992.

Date	Location/Description	Sample Size	% Parasitized
	CENTRAL DISTRICT		
	Kasilof River drainage		
7/02-7/03	Kasilof River (sonar site)	200	99.0
7/22-7/23	Kasilof River (sonar site)	200	98.5
7/29	Nikolai Creek	100	100.0
8/10	Moose Creek	100	100.0
8/11	Glacier Flats Creek	100	99.0
8/12	Bear Creek	100	100.0
	Kenai River drainage		
7/01	Russian River (early run)	100	98.0
8/7	Russian River (late run)	100	97.0
7/13-7/14	Kenai River (sonar site)	200	99.0
8/3	Hidden Creek	100	99.0
8/13	Quartz Creek	100	100.0
8/18	between Skilak/Kenai Lakes	100	98.0
8/19	Skilak Lake outlet	100	99.0
8/31	Ptarmigan Creek	100	99.0
9/1	Tern Lake	50	88.0
7/02-7/28	Crescent River	200	97.0
7/16	Packers Creek	100	99.5
	Commercial Catch		
7/13	Drift gillnet fishery	200	95.5
7/20	Drift gillnet fishery	160	82.5

-continued-

Table 1. (p. 2 of 2)

Date	Location/Description	Sample Size	% Parasitized
	NORTHERN DISTRICT		
	Bishop Creek drainage		
9/2	Daniels Lake	100	6.0
9/1	Beluga River drainage		
	Coal Creek	100	99.0
	Chakachatna River drainage		
9/8	Chilligan River	100	100.0
7/22	Fish Creek	100	0.0
	Susitna River drainage		
	Mainstem		
7/26-7/27	Sunshine Station	200	88.5
8/4	Sunshine Station	114	93.0
8/20	Larson Creek	100	100.0
	Yentna River		
7/15	Yentna River	200	40.0
7/24	Yentna River	200	28.0
8/20	Chelatna Lake	100	33.0
8/24	Judd Lake	100	100.0
8/24	Hewitt Lake	50	94.0
8/25	Shell Lake	100	100.0
8/25	Trinity Lake	100	92.0
9/9	West Fork Yentna River	100	17.0
	TOTAL	4,174	

Table 2. Age composition of sockeye salmon sampled for genetic tissues in Upper Cook Inlet, 1992.

Date	Location	Sample Size	Age Class[a] 1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.2	3.3	Unreadable
	CENTRAL DISTRICT												
	Kasilof River drainage												
7/02	Kasilof River (sonar site)	200		15.0	32.5			22.0	30.5				
7/22	Kasilof River (sonar site)	200		35.5	4.5		1.0	57.5	1.5				
7/29	Nikolai Creek	100		13.0	37.0			20.0	30.0				
8/10	Moose Creek	100		10.0	12.0			67.0	11.0				
8/11	Glacier Flats Creek	100		17.0	23.0			49.0	10.0				1.0
8/12	Bear Creek	100		37.0	9.0		1.0	46.0	7.0				
	Kenai River drainage												
7/1	Russian River (early run)	100			5.0			7.0	88.0				
8/6	Russian River (late run)	100	1.0	1.0			4.0	87.0	2.0		5.0		
7/13	Kenai River (sonar site)	200		2.5	90.0			4.0					
8/3	Hidden Creek	100		78.0	16.0			6.0					
8/13	Quartz Creek	100			79.0			1.0	19.0				
8/18	between Skilak/Kenai Lakes	100		3.0	66.0			2.0	28.0				
8/19	Skilak Lake outlet	100		4.0	72.0				23.0				1.0
8/31	Ptarmigan Creek	100		1.0	80.0			14.0	5.0				
9/1	Tern Lake	50		22.0	40.0			8.0	28.0				2.0
7/2-7/28	Crescent River	200		3.5	25.5			12.5	56.0		0.5	1.0	
7/15	Packers Creek	100		2.0	59.0			29.0	7.0		1.0		2.0
	Commercial Fishery												
7/13	Drift gillnet fishery	200		4.0	81.5			2.5	10.5	1.0			1.0
7/20	Drift gillnet fishery	160		2.0	88.0			3.0	8.0				

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Table 2. (p. 2 of 2)

Date	Location	Sample Size	Age Class[a] 1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.2	3.3	Unreadable
	NORTHERN DISTRICT												
	Bishop Creek drainage												
9/2	Daniels Lake	100	4.0	89.0	4.0			3.0					
	Beluga River drainage												
9/01	Coal Creek	100			23.0			10.0	63.0			4.0	
	Chakachatna River drainage												
9/08	Chilligan River	100			3.0			7.0	82.0	1.0		7.0	
7/22	Fish Creek	100	10.0	77.0			1.0	11.0					1.0
	Susitna River drainage												
	Mainstem												
7/26	Sunshine Station (mile 80)	200		47.0	39.5			25.0	11.5	0.5			
8/4	Sunshine Station (mile 80)	114		32.5	24.0			32.5	12.0				
8/20	Larson Creek	100		38.0	37.0			20.0	5.0				
	Yentna River drainage												
7/15	Yentna River (sonar site)	200		38.0	26.5			13.0	22.0				
7/24	Yentna River (sonar site)	200		27.0	17.0		0.5	24.0	30.0				1.5
8/20	Chelatna Lake	100		30.0	65.0			1.0	4.0				
8/24	Judd Lake	100		3.0	24.0	1.0		11.0	59.0			2.0	
8/24	Hewitt Lake	50		8.0	18.0	2.0		12.0	60.0				
8/25	Shell Lake	100		10.0	57.0			10.0	23.0				
8/25	Trinity Lake	100		10.0	42.0	1.0		7.0	40.0				
9/9	West Fork Yentna River	100		22.0	49.0			12.0	15.0	1.0			1.0

[a] Each sample included scales and otoliths. Ages were determined by combining best results from scales and otoliths.

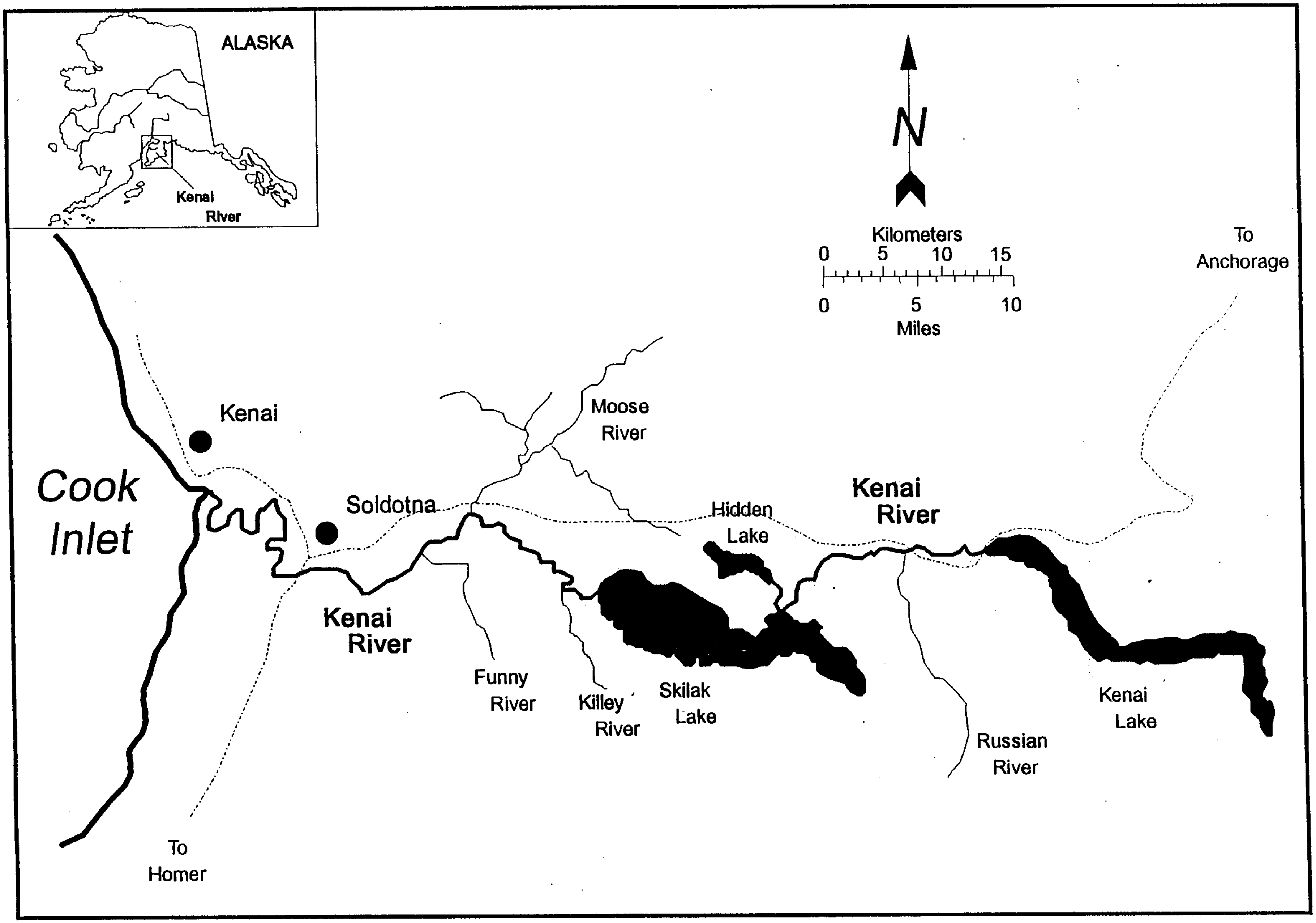

Figure 1. Map of the Kenai River drainage

APPENDIX A

KENAI RIVER USER CONFIGURED SONAR STUDIES, 1992

Bruce E. King

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

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.

LITERATURE CITED

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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	

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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 Receiver Gain (dB)	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.

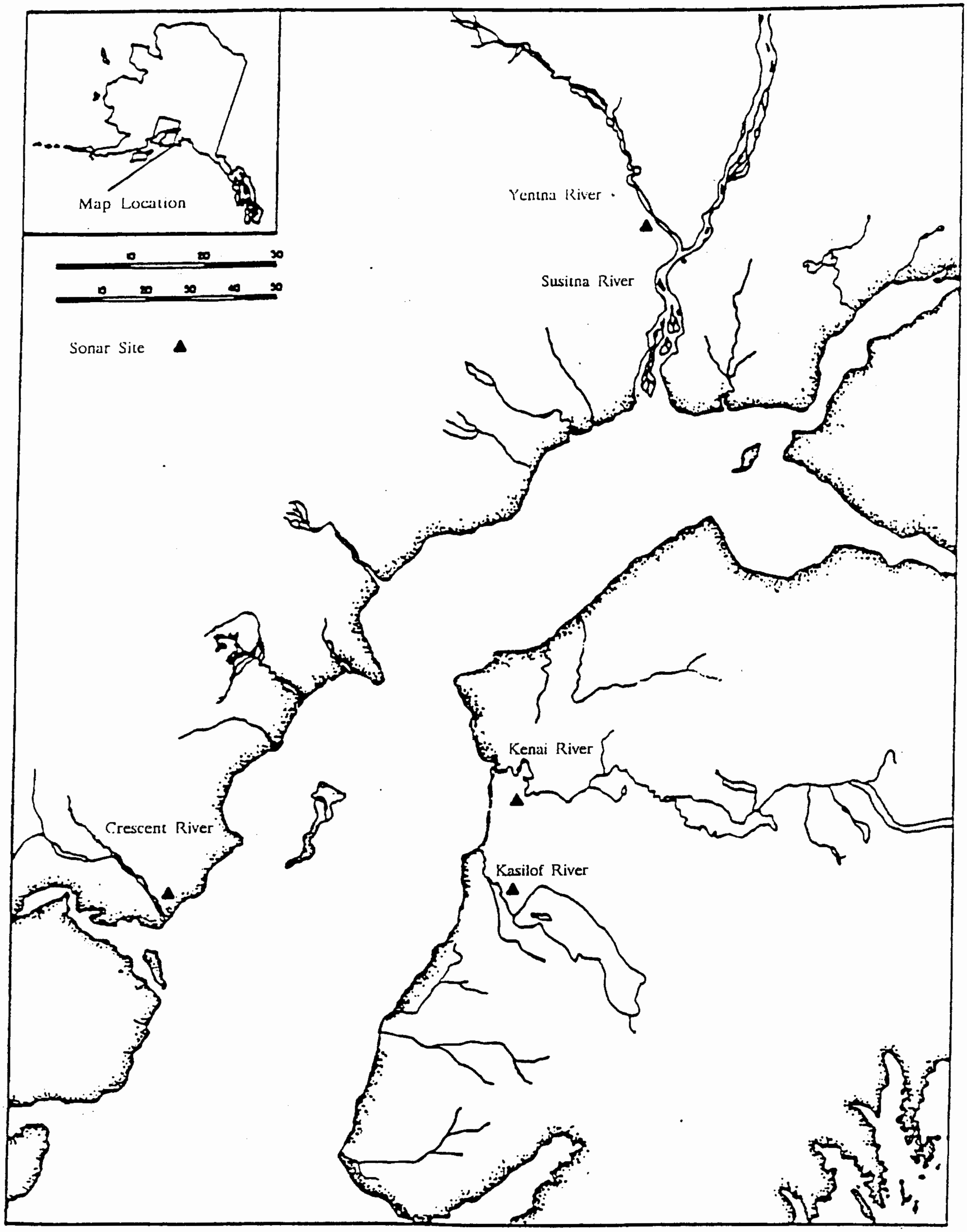

Figure 1. Upper Cook Inlet, Alaska, and sites where sockeye salmon escapement is monitored with Bendix Corp. sonar counters.

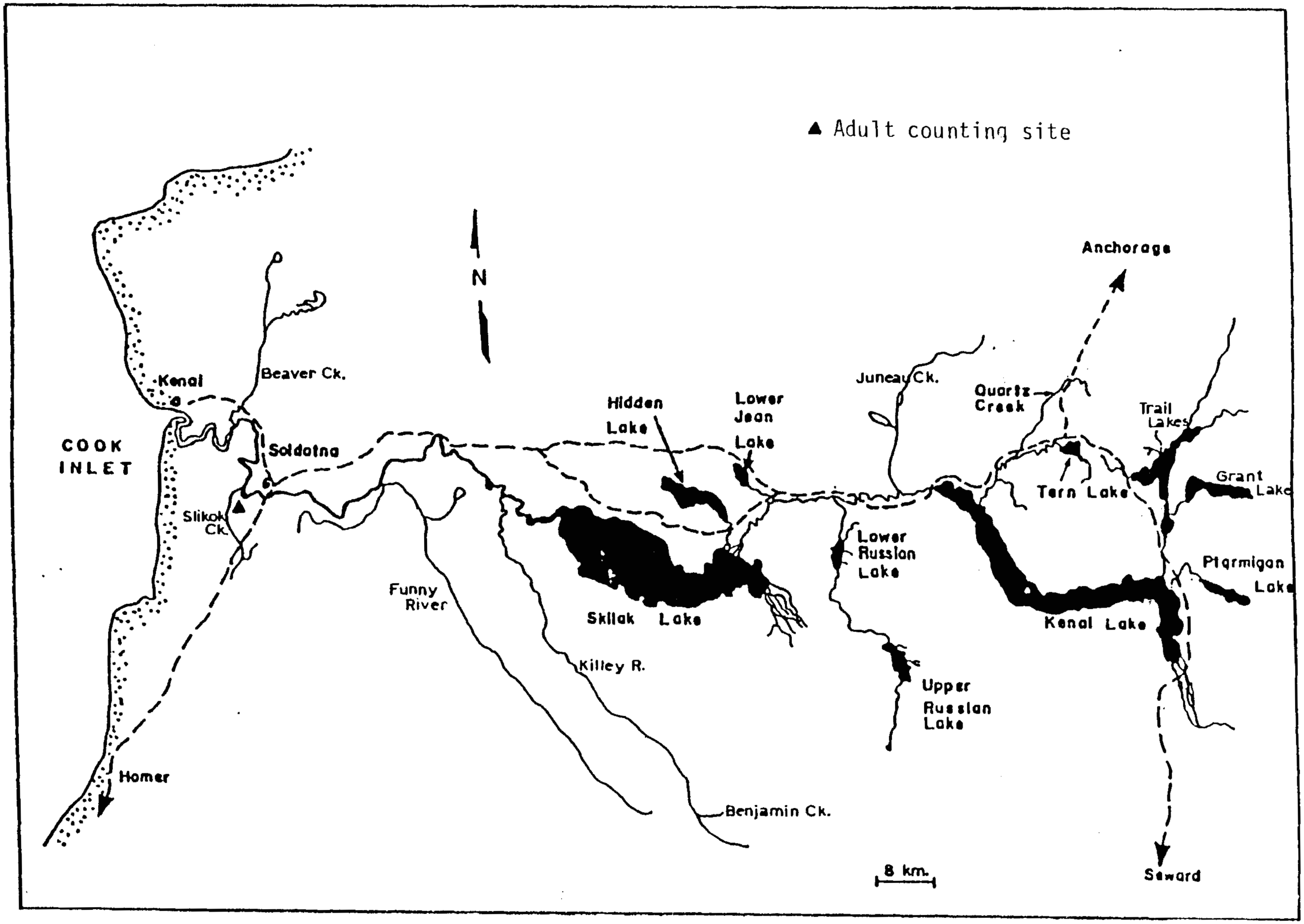

Figure 2. Kenai River drainage and major salmon rearing lakes.

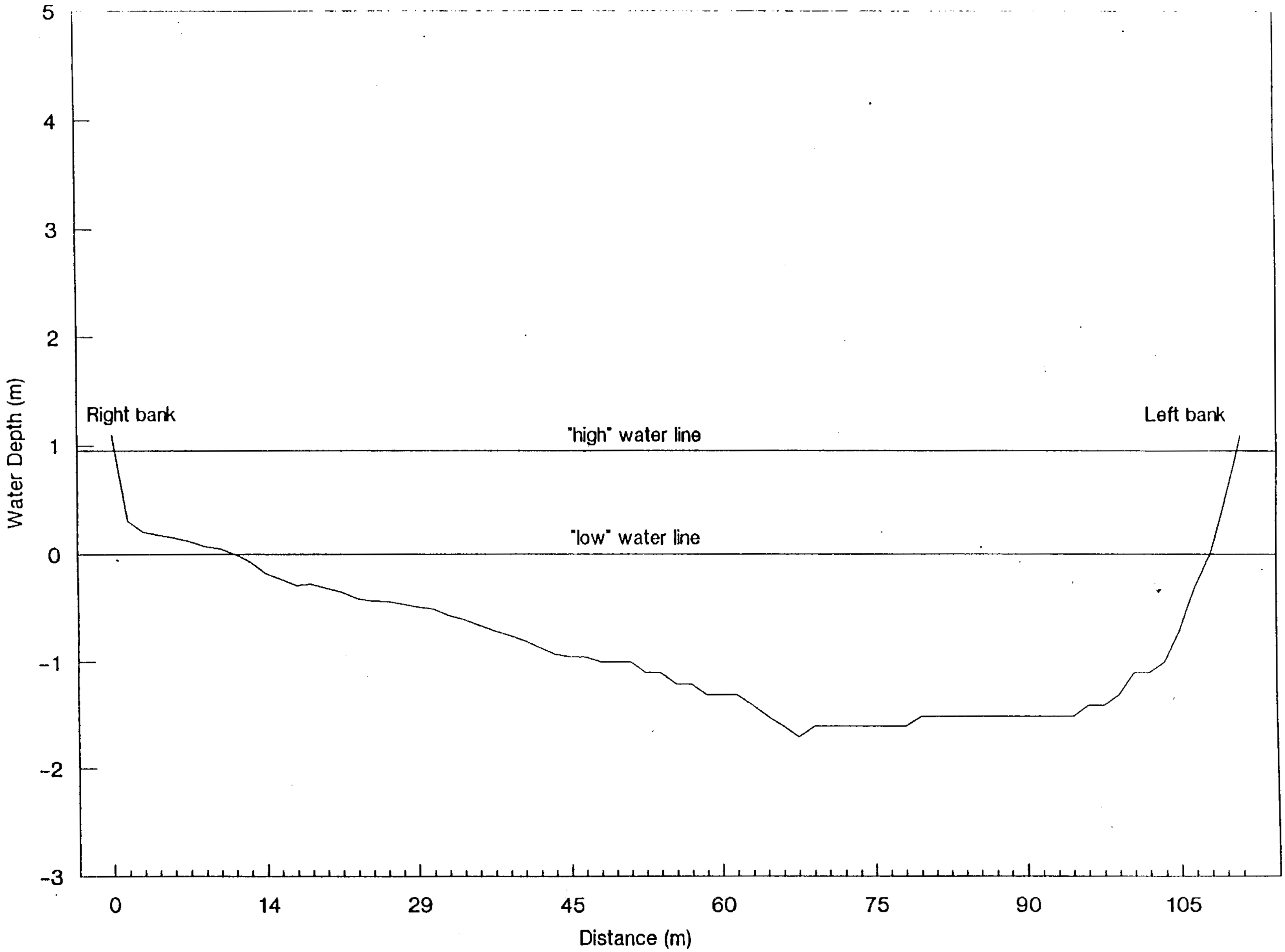

Figure 3. Kenai River bottom contour at the km 31 sockeye salmon counting site.

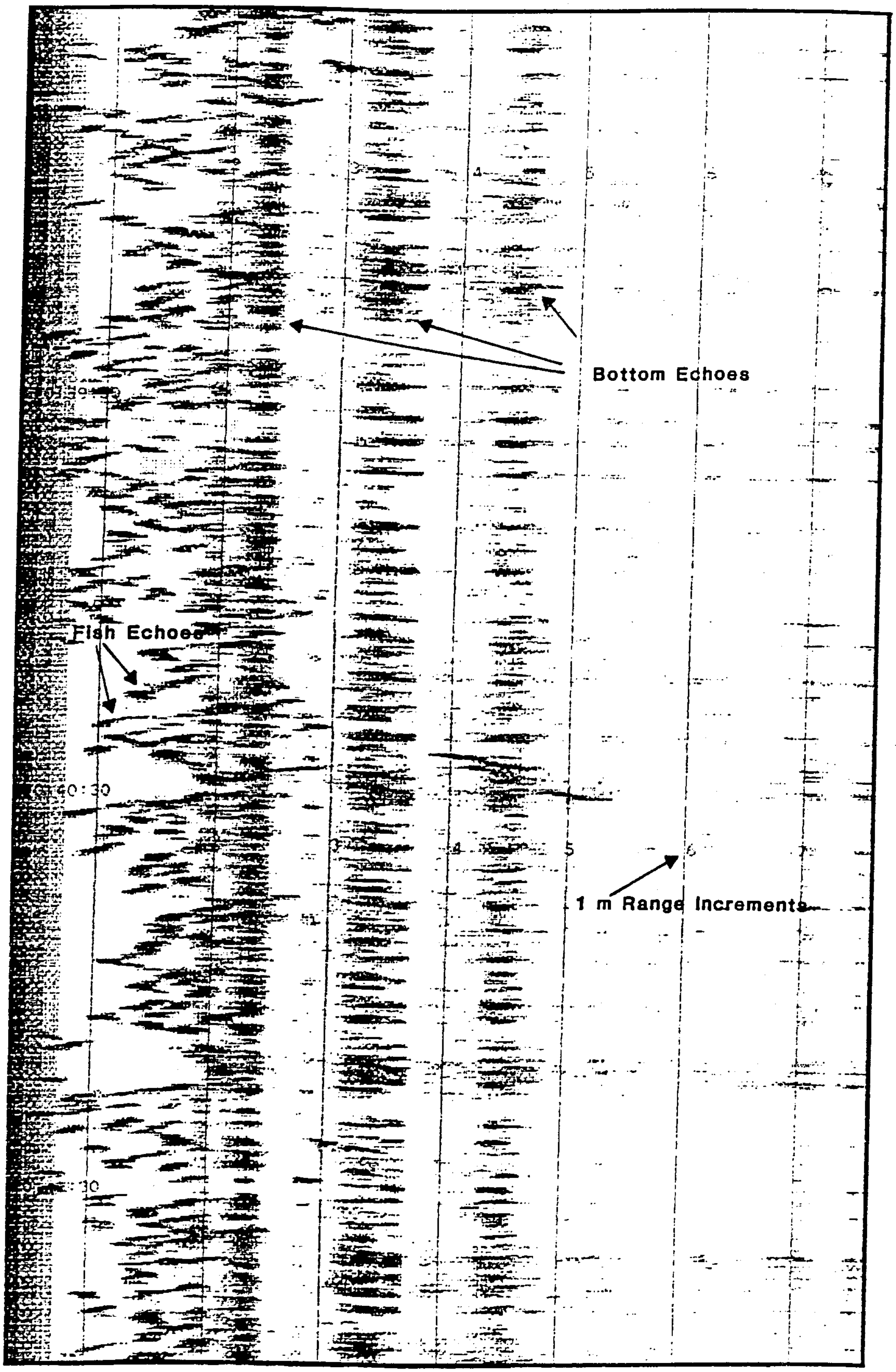

Figure 4. Echogram made during upstream migration of sockeye salmon in the Kenai River, 1992.

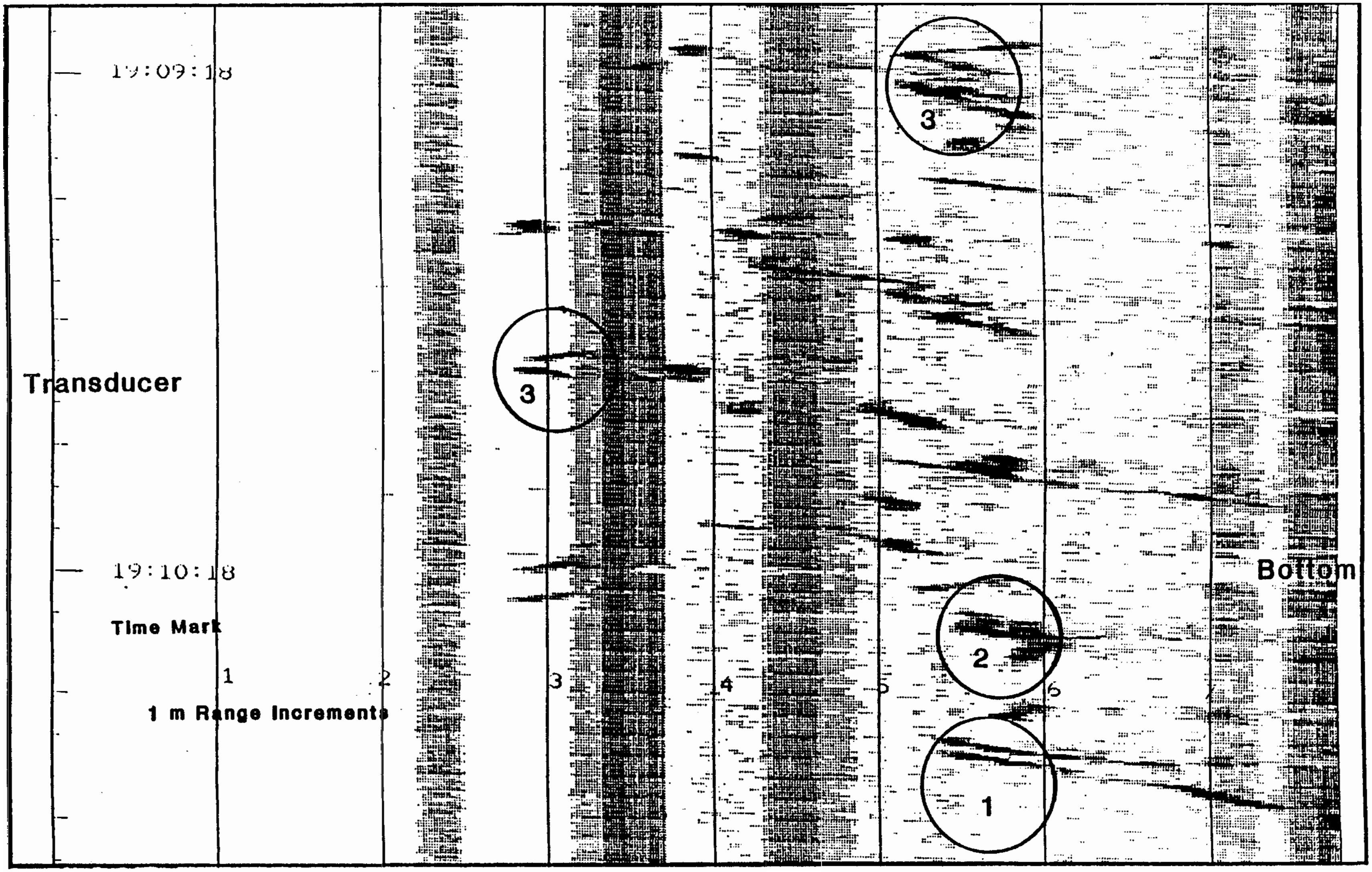

Figure 5. Examples of single target criteria: 1) simultaneous echoes returning at different ranges from the same ping represent more than one fish; 2) pulse width of each mark (per ping) in a trace should approximate that observed in traces at very low densities; and 3) the loss of one ping constitutes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

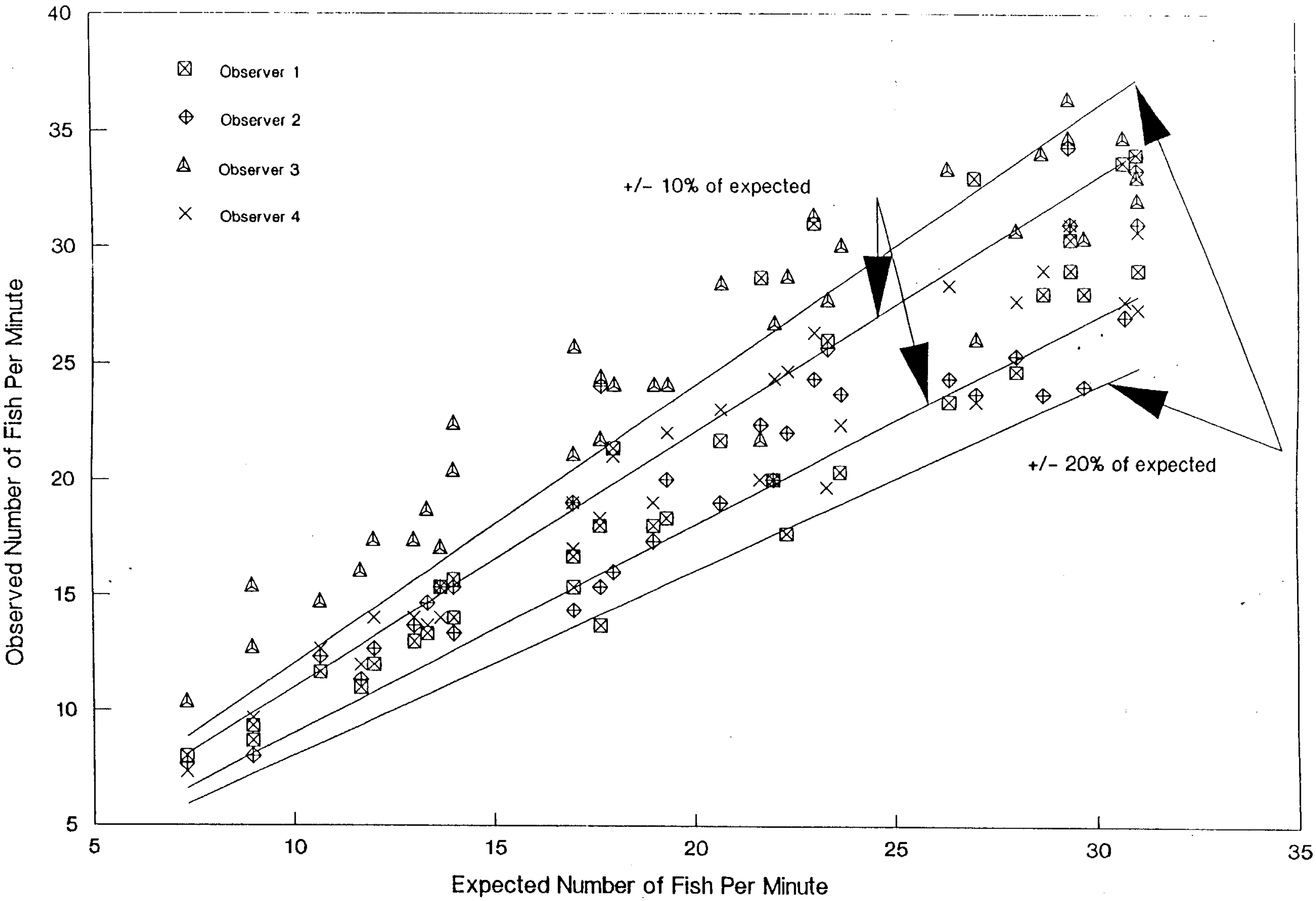

Figure 6. Relative error of counting fish from echograms between five observers.

APPENDIX B

Feasability Study of Acoustic Techniques for Adult Salmon Assessment in Upper Cook Inlet

Prepared for

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FEASIBILITY STUDY OF ACOUSTIC TECHNIQUES FOR ADULT SALMON ASSESSMENT IN UPPER COOK INLET

FINAL REPORT

INTRODUCTION

BioSonics, Inc. contracted with Alaska Department of Fish and Game to study the feasibility of acoustic assessment techniques for adult salmon in Upper Cook Inlet. Historically, ADF&G has estimated the adult salmon run from test fishery programs during the commercial fishery. Since this approach requires an open commercial fishery, it lacks timeliness and is ineffective during closed commercial periods. Acoustic techniques are seen as a potential fishery-independent technique that could replace or augment the current management approach.

The feasibility study was conducted during July 1992. There were eight specific objectives of the study:

1. Investigate the level of precision and accuracy of adult sockeye salmon estimates based on various survey designs. At least three survey designs would be completed: (1) at least six randomly placed parallel transects crossing UCI in an east-west manner; (2) at least four zigzig transects with a random start running east-west; and (3) stratify the inlet into two areas with and without the influence of a tidal rip and survey at least two systematic transects north-south along the tidal rips, placing an additional two transects randomly with the area not affected by tidal rips.

2. Define the depth distribution of salmon in the survey areas using up and downlooking techniques.

3. Identify the signal to noise ratio in the environment relative to adult salmon.

4. Define the average target strength of fish by depth strata.

5. Estimate the spatial distribution of salmon in the Central District of UCI as measured by hydroacoustic techniques.

6. Define the hydroacoustic system that will meet the above objectives.

7. Identify the diel migrational pattern of salmon in UCI during the survey period.

8. Define the physical and chemical environment (temperature, salinity, wind velocity, tidal stage and wave height) along the survey.

METHODS AND MATERIALS

EQUIPMENT AND SURVEY PROCEDURES

Locations and times of all transects and stations are given in Table 1. The study comprised three distinct components: (1) side-looking studies, (2) paravane studies and (3) fixed-location studies. Because the geographical extent of Upper Cook Inlet is relatively large, and detailed information on distributional characteristics of the adult salmon were generally lacking, we felt that a primary assessment mode with high sampling power was essential in a feasibility study. Thus we chose side-looking deployment as the primary survey tool. We developed a dual-frequency approach that would allow us to scan perpendicular to the transect on both sides. This approach maximized the amount of coverage that we could obtain. We completed 17 transects with this approach (Figs 1 - 3). Seven of the transects were orthogonal, five were zigzag and five were associated with rip and non-rip areas.

Weaknesses of the side-looking deployment included susceptibility to surface conditions (roughness), uncertain vertical coverage, and highly variable target strengths. An alternate approach is paravaning. In this case, the transducer is mounted in a surface-looking orientation on a vehicle which is towed at depth and paravanes out from the boat. The theoretical advantages are better vertical coverage, less sensitivity to surface water conditions and less variable target strengths. The disadvantages are more unstable vehicle performance and smaller sampling coverage. We conducted 4 transects (# 18-21) in this mode (Fig 4). One was orthogonal, the other three were north-south in association with rip and non-rip areas.

The most complete vertical (depth) coverage can be obtained in a fixed-location mode where the transducers are either located on the bottom and looking toward the surface, or vice-versa. The disadvantage of fixed-location deployment is the limited geographical coverage. In addition, deployment can be logistically difficult. We allocated three 24-hr periods to fixed-location data collection and covered three locations (Fig. 5).

The equipment for the side-looking study included a BioSonics Model 102 Dual-Beam Scientific Echosounder with 120/420 dual frequency. This system allowed experimentation with two frequencies and simultaneous coverage on both sides of the vessel track. The two transducers were mounted in a BioSonics BioFin, a large, highly stable towing platform, and oriented horizontally, one on each side. The fin was towed behind the vessel, just below the turbulence from the boat wake. The 120 kHz transducer was a 10°/22° dual-beam. The 420 kHz was a 6°/15° dual-beam. The data were recorded in digital format on a DAT recorder for post processing, and were graphically output on a BioSonics Model 111 Thermal Chart Recorder in real time.

In addition to the primary side-looking system, some data were collected using a small, commercial side-looking system which could be used from a towing vehicle but orientation could be remotely controlled.

The equipment used in the paravane study was essentially the same as for the side-looking except that only the 420 kHz frequency was used, and the 420 kHz dual-beam transducer was mounted on the top of a BioFin which was modified to paravane away from the boat. Various depths and paravane settings were investigated during the transects.

A second acoustic system was used for the fixed-location study. All data were collected at anchor stations. The echosounder was a 420 kHz BioSonics Model 101 Scientific Echosounder. The 101 was used in conjunction with a BioSonics Model 151 Multiplexor/Equalizer. This allowed synoptic use of multiple transducers. Three transducers were used during the fixed-location studies. One was a 6°/15° dual-beam; the others were 15° single-beam transducers. All were lowered to the bottom, oriented toward the surface. The acoustic signals were analyzed in real time with a BioSonics Model 281 ESP signal processor. Data were stored on computer files for later post processing.

DATA ANALYSIS

Primary analysis was conducted using a BioSonics Model 281 echo signal processor (ESP). The ESP measures the location and target strength of every target and writes the information to a data base file. The ESP performance was checked against the echogram records. In some circumstances with high reverberation levels, the ESP did not detect targets as well as the echograms. In those cases, the information on target abundance and location was extracted from the echograms.

For the side-looking data, the numbers of fish detected in each 5-m range interval were summed for each transect. The area swept by the sonar along each transect was calculated by multiplying each 5-m range interval by the length of the transect. Then densities of fish per unit surface area were calculated for each 5-m range and for both frequencies from the number of detected fish.

Analysis of the paravane data used similar procedures. In this case, numbers of fish were summed in 1-m range intervals. Densities for each 1-m interval were determined by dividing the detections by the effective sweep of the beam at the range interval. Then the 1-m range intervals were summed through the water column to obtain an estimate of density per unit surface area.

Population estimates and variances were determined from the mean densities along each transect according to standard procedures (Scheaffer, Mendenhall and Ott, 1979). The formulas were:

(1) Estimator of the mean population density:

$$\hat{\mu} = \sum_{i=1}^{n} y_i/n$$

where y_i is the observed density (#/m^2) for the i^{th} transect.

(2) Estimated variance of y:

$$\hat{V}(\bar{y}) = s^2/n$$

(3) Estimator of the population total:

$$\hat{\tau} = A\bar{y}$$

where A equals area

(4) Estimated variance of τ

$$\hat{V}(\hat{\tau}) = A^2 \hat{V}(\bar{y})$$

and

(5) Confidence bound on population estimate:

$$CB = 2\sqrt{\hat{V}(\hat{\tau})}$$

RESULTS AND DISCUSSION

SIDE-LOOK STUDY

Target Detections and Densities

A total of 3,879 targets were detected during the 17 side-looking transects. In general, fish were resolved as individual echoes, but there were some instances of small schools, especially later in the study (Figs 6-9).

Numbers of fish detected by 5-m range interval for each frequency and the 17 side-looking transects are given in Table 2. In general, the numbers of fish detected increased with range as both the amount of vertical coverage and the beam overlap increased, then fell off at greater ranges because of increasing noise from surface (and sometimes bottom) reverberation as the beam width increased. The 120 kHz frequency detected more targets during 12 of the transects, and overall detected nearly 4 times as many targets as the 420 kHz. This greater effectiveness was the result of a combination of the wider beam angle, greater range and better aiming angle. The 120 kHz transducer, by design, was oriented with a lower surface grazing angle, so it was less susceptible to noise caused by surface reverberation. During the initial seven transects, the 420 kHz transducer had too high a grazing angle and was not very effective. Its performance was improved considerably after lowering its orientation after transect #7. The 120 kHz frequency was more susceptible to noise from bottom reflections because of its wider angle. This limited its range in areas with relatively shallow water. Surprisingly, the most effective range for the 420 kHz system was 45-50 m, and ranges between 25 and 50 m were similar in overall performance. The data are strongly influenced by a few transects with exceptionally good propagation conditions (flat calm). The 420 kHz system did detect more fish than the 120 kHz in shallower depths, where the wider beam and slightly lower orientation of the 120 kHz transducer limited its range. Overall, the results clearly show that the number of detections increase with widening vertical extent of the beam, at least out to 50 m range, and that detections are limited when noise conditions (surface or bottom reverberation) do not allow these ranges to be obtained. Most of the differences between the frequencies were the result of beam angle and aiming angle, rather than of the frequency itself, even though the 120 kHz system theoretically has greater range.

Densities of fish per unit surface area for each 5-m range and for both frequencies are given in Table 3. Values range to a high of 1.63 fish per 1000 sq. m. The total study area, Anchor Point to Boulder Point excluding the unsampled area West of Kalgin Island, encompassed 3295 million square meters. Extrapolation of these densities to the total study area would produce total population estimates ranging up to 5.38 million fish.

Target Strengths

Target strength measurements were made on 10 of the transects with relatively good signal to noise characteristics (Table 4). A total of 1398 measurements were made with the 120 kHz system. Unfortunately, the wide-beam cable suffered a partial break sometime after transect 5, so reliable target strength measurements were limited to the first few transects. Fig. 10 shows the distribution of all the 120 kHz observations. Values ranged from -16 to -57 dB, with the peak about -42. Transect 1, which detected the most fish, had the broadest distribution (Fig. 11). Transect 5 had the sharpest mode, but the mean was similar to transect 1 (Fig. 12). Transects 2-4 had much smaller samples sizes, wide distributions and slightly higher modes (Fig. 13).

A total of 256 target strength measurements were made with the 420 kHz system (Fig 14). Most of these were from later transects when orientation and propagation conditions were improved. All transects showed similar results, ranging from -14 to -43 with mean values between -27 and -32 dB. The higher mean values for the 420 kHz system most likely result from the more limited range of this system. The results are undoubtedly biased against smaller targets because of signal to noise ratio deterioration with range for this frequency. The results are in agreement with the generally smaller numbers of targets detected with 420 kHz. Apparently, many of the smaller targets are not detected, resulting in smaller numbers detected and bias toward large targets in the target strength distribution.

Side-aspect target strengths from salmonids in size range of the Cook Inlet run are expected to be primarily between -18 and -34 dB (Dahl and Mathisen 1981). The greater size range and lower mean values in the 120 kHz observations result from the much greater aspect variability in the side-looking deployment, and are in very reasonable agreement with theoretical expectations. There is no indication that the side-look data include targets from nonsalmonids. The 420 kHz detections probably represent primarily side aspect reflections, while the smaller returns from head or tail aspects are probably below detection thresholds for this frequency.

Sweeping Sonar

Experiments with a small, commercial side-looking system showed that remote controlled orientation could be used to optimize aiming angles and reduce surface reverberation. However, the system's output was limited to an LED display and was impossible to quantify. Remote aiming capability could be added to the scientific system used in this study, but it would be very costly. The towing system used with the scientific system was very stable, so it would be much more practical to minimize reverberation by altering the towing depth.

PARAVANE STUDY

Four transects were completed in the paravane mode of operation (Fig. 15). Paravane angles and towing depths and speeds were investigated during the first transect (#18). A total of 170 fish were detected along the subsequent three transects (Table 5). Peak densities were observed near surface (Fig. 16). The target strengths were generally lower than expected (Fig. 17). There were no obvious effects of depth. Since this portion was done near end of the study, the data may be more representative of pink salmon targets than of sockeye.

We were unable to achieve the degree of paravane that we had hoped. Attempts to achieve greater paravane angle resulted in vehicle instability. Observations probably represent fish detected about 5 m outside the track of the boat. It was encouraging that the paravane values were similar in magnitude to the side-looking values at the optimal ranges.

FIXED-LOCATION STUDIES

Fixed location data were collected at three sites. The sites required a location with suitable depth to deploy both anchors and bottom mounted transducers, as well as fish concentrations. The first, near the navigation buoy east of Snug Harbor, was a site where fish had been observed during the side-looking transects. The anchor station was more difficult to establish than expected because of the strong tides. After a 6-hr, two boat effort, a suitable three point anchor station was achieved, and three transducers were deployed, including a dual-beam (Figs 18-21). After 12 hrs of successful data collection, all three anchors began to drag and the station was abandoned. Although all three transducers were recovered, every transducer cable was broken. The other two sites were along the east shore just south of the Kasiloff River. A total of 24 hrs of data were collected at these two sites, 21 hrs at the second site and 3 hrs at the third (Figs 22-23). Only one single beam transducer was used at these sites because of the damaged cables.

Unlike the paravane observations, there was no apparent surface orientation of the fish at either site (Figs. 19, 22) The target strength distribution was also much smaller than expected for ventral aspect (Fig. 20). The location of the target strength measurements at the end of the sand bar by the navigation buoy may not have been representative of salmonids. Diel patterns show a maximum at night, which may represent non-salmonid activity (Figs. 21, 23).

ENVIRONMENTAL OBSERVATIONS

Temperature and salinity profiles were made at 6 locations (Table 6; Fig. 24). In general the water column was well mixed (Figs 25-26). The exception was location 4, just off the Kenai River and within the freshwater plume from the river. Weather conditions during the study were generally favorable, with light winds or calm conditions (Table 7). Exceptions were transects 2 and 3.

POPULATION ESTIMATES

Orthogonal Transects

Three aspects of this side-looking data must be considered in order to investigate of the level of precision and accuracy of the estimates (objective #1). First is selection of the range and frequency information that best characterizes the true fish density, second is the area over which to extrapolate the density estimates, and third is evaluation of the variances in order to estimate precision.

One alternative for the density value is simply to chose the highest 5-m range value for each transect. The arguments for this approach are twofold. First, there is little chance of a correlation between range and real abundance. Even in cases where the transects were parallel to rips, there was insufficient control of transect spacing in relation to the rips for a correlation between range and true density. Consequently, the variability among 5-m range intervals should be independent of fish density, but dependent upon propagation conditions. Second, detectability is clearly limited by both propagation conditions and vertical extent of the beam. Thus the highest detectability is most likely the best estimate, and even the best is probably an underestimate. The only argument against choice of the highest value would be simple random variability. If several 5-m range increments are equally good estimates because of similar propagation conditions, then choice of the largest would violate statistical principles of randomness. Thus the choice of 5-meter intervals to represent the density estimate for the transect becomes a tradeoff between an expected bias toward underestimation and principles of random selection.

We have no definitive answer to this dilemma in this feasibility study. In order to proceed with an analysis, we chose an arbitrary compromise and pooled all 5-m range observations for each transect that were within 75% of the peak density observation for that transect. Our argument in taking this approach is that the potential bias toward underestimation is most critical, but we compromise to randomness by accepting similar values. Support for this approach can be found in examination of the range trends. Many show a smooth trend (increase consistently to a peak, then decrease consistently) which argues that bias, not randomness, is the major factor.

Table 8 gives the resulting estimated densities for each transect. The next step is to decide on the areas for extrapolation. For the orthogonal transects, the random selection tended to clump in two general locations (see Fig. 1). A stratified random block approach appears suitable. The total area was divided equally into two sections. Mean and variances were calculated from the four transects in the southern area and the three transects in the northern area. The resulting population estimate is 1.25 million fish with error bounds of +/- 0.91 million fish (Table 8). The low precision results primarily from the large densities observed along transect #1. The remaining southern transects (8-10) are similar. The results show that time is an important source of variation, which is not surprising in a migratory environment. The 5-day interval between transect 1 and transects 8-10 added considerable variability. For comparison purposes, the analysis was rerun excluding transect 1. The resulting population estimate was 0.79 million fish with error bounds of +/- 0.22 million (Table 8).

ZigZag Transects

The zigzag transects covered much of the entire survey area. A population estimate can be readily calculated from the mean of the transect observations extrapolated over the entire study area. The resulting population estimate is 1.7 million fish. The error bound calculates out to +/- 1.8 million, a very low precision (Table 9). Examination of the data clearly shows considerable spatial variability. For example, transect 6 was located in an area with low tidal currents and huge kelp beds, with no fish. It is clear that improved precision with the zig-zag survey design would require both a more elaborate design and a more sophisticated variance formulation that would minimize the impact of spatial variability.

Rip Area Transects

The transects in and around the rips were by far the most difficult to evaluate. Extrapolation requires information on the relative extent of rip versus non-rip areas. We observed that the rip structure was much more complicated than expected, with many secondary rip features along with primary rips. We found it very difficult to stay on rips when we wanted to, and nearly impossible to avoid rips when we wanted non-rip transects. Further, correlation between fish abundance and rips was weak. We investigated the relationship by plotting the number of fish detected in 10-min blocks with the # of rips observed for all orthogonal transects. The correlation coefficient, r, was only 0.16. The general concept is that there are three major horizontal rips in Upper Cook Inlet. This simple structure was occasionally observed (Fig 27), and there was some relationship between the rips and fish, although the fish tended to be along the edges of the rips rather than in the rips themselves. However, there were other occasions where the rip structure was very complex (Fig. 28), and several other situations between these extremes (Figs. 29-32). The mere presence of a rip did not ensure concentrations of fish, and fish were often detected in areas without rips.

With this complexity, there did not seem to be any obvious way to stratify rip versus non-rip areas and transects. For purposes of population estimation, all the transects were pooled and treated as random samples. Analysis was made with and without the paravane transects, which were generally located along the edges of rips. The population estimate from the five side-looking transects was 2.10 million fish +/- 1.03 million (Table 10). The estimate from the paravane transects was 3.8 million fish +/- 1.5 million. These relatively higher numbers, especially for the paravane transects which were along the edges of the rips, suggest that there is greater abundance of fish associated with the rips, even though stratification and allocation of areas does seem to be an extremely difficult task. The population estimate from the pooled rip and paravane transects was 2.7 million fish +/- 1.0 million (Table 10).

A final population estimation was made by combining the density values from all the transects and treating each as a random variable. The resulting population estimate was 2.0 million fish with error bounds of 0.7 million fish (Table 11). The precision is relatively low for a 20 transect sample size, but it does reflect considerable variability in space, time and mode of operation. The population estimate of around two million fish appears reasonable for a snapshot estimate of the Upper Cook Inlet population. An estimate derived from the commercial catches would place the population in the district at about 2.2 million fish at the midpoint of the study period (Ken Tarbox, personal communication).

Upper Cook Inlet is a very dynamic area. The salmon population at any given time is a function of several factors including the size and run timing of several stocks and the operation of the commercial fishery. Because of the variety of objectives and operations, complicated by working around commercial fishery openings, this study extended over a 15-day period. Population estimates from various survey modes varied from 0.8 to 3.8 million fish. This variation reflects the variability in space and time combined with the dynamic environment. Both higher precision and a more accurate snapshot estimate of the population in the entire district would require complete coverage in a short time. It is clear that useful data for fisheries management would require more rapid and complete coverages than were accomplished during most of this study.

SUMMARY AND CONCLUSIONS

All three modes effectively detected fish. The side-looking mode appeared to be the most effective because of its high sampling power, but was the most variable in its performance because of variable propagation conditions, especially surface roughness. The paravane method looked very promising. Although the degree of paravane was less than desired, the density observations look very reasonable, and this mode was much less susceptible to surface conditions. The anchor stations were the least effective because of the greatly reduced sampling power, questions of representativeness, and logistic difficulties associated with anchor stations in strong tidal currents.

Both the magnitudes appear and target strength values were generally reasonable for the mobile modes. Dahl and Mathisen (1981) showed side aspect target strengths between -16 and -42 dB for similar salmonids. Signal to noise conditions during most transects allowed a threshold level for the 120 kHz system between -49 and -57 dB, which would readily detect all side-aspect echoes and should detect over 90% of all aspect echoes for these fish sizes. The 420 kHz frequency was clearly more limiting. The best threshold level was only -43 dB at 30 m range, and this detection capability deteriorated an additional 10 dB by 45 m range.

An additional consideration for the side-looking mode was the depth distribution of the fish. The paravane observations indicated a peak distribution at 3 meters below the surface with fish extending down to 13 m. The anchor stations also showed fish at least down to 13 m. The nominal 6° 420 kHz beam would require over 100 m range to fully encompass this vertical extent. The nominal 10° 120 kHz beam would require 74 m. Since the effective beams are usually larger than the nominal, the 120 kHz system had sufficient range in most cases to effectively sample the vertical distribution, but the 420 was clearly limited in this regard.

On the basis of these observations, we recommend the side-looking mode for 1993 studies, along with further investigation of improved paravane techniques. The paravane mode has the greatest potential to provide consistent and accurate data. However, the very high sampling capability of the side-look mode was attractive. It was clear that the size and dynamic nature of Upper Cook Inlet requires a technique that can obtain an estimate in a very short time. The side-looking technique can accomplish that objective. Further, the transecting speed of the side-look can be increased appreciably above that used in this study, while the paravane mode requires a slower towing speed. The two-transducer orientation virtually doubles the sampling power. Either two 120 kHz transducers or the same arrangement as in 1992 would be suitable.

Of the various survey designs, the random orthogonal appeared to have the best statistical promise. Repeatability during similar times and locations was good, but there were clear sources of variability over space and time. A randomized block design completed in under 48 hrs should produce a precision on the order of +/- 30%. A potential disadvantage of the orthogonal transects is that they are run perpendicular to wind and waves. We experienced unusually good weather conditions during this study. Orthogonal transects would be difficult to run in rough water conditions. On the other hand, the orthogonal transects are less impacted by tidal conditions.

The zigzag transects provided the most efficient geographical coverage. At towing speed of 8 knots, the side-look could cover the entire inlet in about 12 hrs at a closer spacing than that used in this study. The low precision in this study caused by the large spatial variability in fish abundance could be overcome by a more elaborate design and statistical treatment, such as bootstrap or cluster analysis.

Surveys associated with the rips produced the least satisfactory result because the rip structure was complex and variable, and the fish were usually associated with the edge areas rather than the rip areas themselves. The north/south transects were the least weather dependent, but the most influenced by tidal currents. For example, transect # 3 covered very little distance over ground, but detected many fish because strong tidal currents were sweeping fish concentrations by the boat.

The primary contribution of this study was to document that Upper Cook Inlet adult salmon are detectable by acoustic techniques. Vertical distributions, target strengths and general magnitudes all verify that the framework exists for a fishery-independent technique that can provide much-needed information on stock abundance. Further refinements on the survey designs and deployment modes are needed to improve the application, and multi-annual correlations between acoustic observations and conventional catch-related assessment techniques need to be made before full confidence can be placed in acoustic techniques as the primary assessment methodology. However, the results of this study confirm the potential of acoustic techniques as an alternate, fishery-independent assessment technique.

LITERATURE CITED

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Scheaffer, R.L., W. Mendenhall and L. Ott 1979. Elementary survey sampling. Duxbury Press, Belmont, CA 278p.

Table 1. Locations and times of various transects and stations

Transect	Date	Start N	Start W	End N	End W	Start time	End time	Length (meters)
1	7/14/92	59:54:16	151:54:55	59:54:33	152:24:82	1952	2304	19461
2	7/16/92	60:28:91	151:43:97	60:27:47	151:27:87	710	~900	15684
3	7/16/92	60:19:99	151:42:47	60:19:79	151:43:70	1036	1200	1238
4	7/18/92	60:21:83	151:31:29	60:12:34	152:01:71	1115	1335	36505
5		60:12:11	152:02:01	60:02:08	151:49:85	1350	1700	20402
6		60:02:77	151:49:25	59:57:01	152:03:87	1718	2000	14633
7		59:56:91	152:08:90	60:00:14	152:18:88	2045	2226	11297
8	7/19/92	59:58:95	152:20:92	59:56:07	152:10:61	923	1028	11245
9		60:00:07	152:02:59	60:01:20	152:19:00	1105	1250	15918
10		60:06:65	152:14:04	60:03:77	151:58:31	1335	1530	16016
11	7/21/92	60:24:10	151:24:78	60:30:05	151:43:86	1132	1438	21379
12		60:34:68	151:44:40	60:34:56	151:22:07	1526	1800	21438
13	7/25/92	60:19:36	151:31:34	60:21:84	151:55:09	1750	2033	23258
14		60:11:18	151:51:20	60:20:00	151:41:77	2147	005hrs 7/26	17560
15	7/26/92	60:21:29	151:41:84	60:23:91	151:36:18	011	045	6495
16		60:23:91	151:36:18	60:21:25	151:38:63	046	148	5461
17		60:20:96	151:29:96	60:23:42	151:26:42		312	5686
18	7/28/92	60:28:00	151:37:00	60:23:32	151:39:48	1805	1915	8993
19		60:21:71	151:39:44	60:06:33	151:54:81	1926	2134	32092
20	7/29/92	59:58:08	152:27:71	59:50:90	152:11:40	953	1157	20547
21		59:50:90	152:11:06	60:12:75	151:48:47	1159	1559	45930
Fixed Location								
1	7/23-7/24	~60:17:00	~152:03:00					
2	7/25	60:21:23	151:25:79					
3	7/26	60:21:33	151:26:71					

Table 2. Numbers of fish detected in 5-m range intervals from side-looking transects.

Transect	Frequency	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	60 - 65	65 - 70	70 - 75	Total	Length (m)
1	120	7	28	57	82	104	129	159	138	116	72	9			901	19461
	420	1	1	1	0	1	1	3	3	3	4	1			19	19461
2	120	4	1	7	3	3	5	0	1	2					26	15684
	420	not useable - too much surface reverberation													0	15684
3	120	2	3	8	1	5	3								22	1238
	420	not useable - too much surface reverberation													0	1238
4	120	1	3	2	7	8	4	3	3	3	4				38	36505
	420	not useable - too much surface reverberation													0	36505
5	120	9	21	36	50	97	117	96	27	6	3				462	20402
	420	not useable - too much surface reverberation													0	20402
6	120	0	0	0	0	0	0	0	0	0	0				0	14633
	420	0	0	0	0	0	0	0	0	0	0				0	14633
7	120	24	32	32	42	69	79	72	59	62	45				516	11297
	420	27	12	15	9	7	3	4	8	0	0				85	11297
8	120	1	0	2	4	3	9	8	20	16	17	12	16	13	121	11245
	420	0	0	0	1	0	0	0	0	0	0	1	0	0	2	11245
9	120	11	19	18	34	39	44	43	34	40	38	19	8	2	349	15918
	420	7	10	16	16	22	15	24	18	12	9	8	6	0	163	15918
10	120	10	6	16	14	25	23	13	19	14	12	5	2		159	16016
	420	4	5	9	11	9	2	6	7	6	4	0	0		63	16016
11	120	11	30	26	25	9	8	5	5	4					123	21379
	420	1	5	3	1	1	1	1	0	1					14	21379
12	120	4	2	0	1	0	1	1							9	21438
	420	10	2	2	1	1	1	1							18	21438
13	120	2	7	11	18	6	2	2	4	3					55	23258
	420	2	3	7	16	10	22	19	24	4	20				127	23258
14	120	6	9	6	20	38	3								82	17560
	420	0	4	9	14	15	17	18	24	11	5				117	17560
15	120	1	6	10	15	18	13	5	1						69	6495
	420	1	3	3	5	14	15	14	8	2	3				68	6495
16	120	11	23	25	30	22	19								130	5461
	420	0	0	2	12	14	10	12	20	13	10				93	5461
17	120	4	4												8	5686
	420	2	2	2	6	10	4	4	4	2	4				40	5686
Average	120	6.75	12.13	16.00	21.63	27.88	28.69	25.44	19.44	16.63	11.94	2.81	1.63	0.94		
	420	4.58	3.92	5.75	7.67	8.67	7.58	8.83	9.67	4.50	4.92	0.83	0.50	0.00		

Table 3. Fish densities (#/1000 sq.m.) by 5-m range interval for side-looking transects

Transect	Frequency	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 - 45	45 - 50	50 - 55	55 - 60	60 - 65	65 - 70	70 - 75
1	120	0.07	0.29	0.59	0.84	1.07	1.33	1.63	1.42	1.19	0.74	0.09	0.00	0.00
	420	0.01	0.01	0.01	0.00	0.01	0.01	0.03	0.03	0.03	0.04	0.01	0.00	0.00
2	120	0.05	0.01	0.09	0.04	0.04	0.06	0.00	0.01	0.03	0.00	0.00	0.00	0.00
	420	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
3	120	0.32	0.48	1.29	0.16	0.81	0.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	420	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
4	120	0.01	0.02	0.01	0.04	0.04	0.02	0.02	0.02	0.02	0.02	0.00	0.00	0.00
	420	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5	120	0.09	0.21	0.35	0.49	0.95	1.15	0.94	0.26	0.08	0.03	0.00	0.00	0.00
	420	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
6	120	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	420	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	120	0.42	0.57	0.57	0.74	1.22	1.40	1.27	1.04	1.10	0.80	0.00	0.00	0.00
	420	0.48	0.21	0.27	0.16	0.12	0.05	0.07	0.14	0.00	0.00	0.00	0.00	0.00
8	120	0.02	0.00	0.04	0.07	0.05	0.16	0.14	0.36	0.28	0.30	0.21	0.28	0.23
	420	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
9	120	0.14	0.24	0.23	0.43	0.49	0.55	0.54	0.43	0.50	0.48	0.24	0.10	0.03
	420	0.09	0.13	0.20	0.20	0.28	0.19	0.30	0.23	0.15	0.11	0.10	0.08	0.00
10	120	0.12	0.07	0.20	0.17	0.31	0.29	0.16	0.24	0.17	0.15	0.08	0.02	0.00
	420	0.05	0.08	0.11	0.14	0.11	0.02	0.07	0.09	0.07	0.05	0.00	0.00	0.00
11	120	0.10	0.28	0.24	0.23	0.08	0.07	0.05	0.05	0.04	0.00	0.00	0.00	0.00
	420	0.01	0.05	0.03	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00
12	120	0.04	0.02	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	420	0.09	0.02	0.02	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
13	120	0.02	0.06	0.09	0.15	0.05	0.02	0.02	0.03	0.03	0.00	0.00	0.00	0.00
	420	0.02	0.03	0.06	0.14	0.09	0.19	0.16	0.21	0.03	0.17	0.00	0.00	0.00
14	120	0.07	0.10	0.07	0.23	0.43	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	420	0.00	0.05	0.10	0.16	0.17	0.19	0.21	0.27	0.13	0.06	0.00	0.00	0.00
15	120	0.03	0.18	0.31	0.46	0.55	0.40	0.15	0.03	0.00	0.00	0.00	0.00	0.00
	420	0.03	0.09	0.09	0.15	0.43	0.46	0.43	0.25	0.06	0.09	0.00	0.00	0.00
16	120	0.40	0.84	0.92	1.10	0.81	0.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	420	0.00	0.00	0.07	0.44	0.51	0.37	0.44	0.73	0.48	0.37	0.00	0.00	0.00
17	120	0.14	0.14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	420	0.07	0.07	0.07	0.21	0.35	0.14	0.14	0.14	0.07	0.14	0.00	0.00	0.00

Table 4. Samples sizes and ranges for target strength measurements

transect	freq	N	Comments
1	120	901	all fish sampled
	420	19	all fish sampled
2	120	26	<45m range
3	120	22	<45m range
4	120	24	<45m range
5	120	425	<45m range
13	420	66	<45m range
14	420	67	<45m range
15	420	51	<45m range
16	420	31	<45m range
17	420	22	<45m range

Table 5. Detections and fish densities by 5-m range interval for paravane transects.

			# of Detections				
Transect	Mode	Length	0-5 m	5-10 m	10 - 15m	15 - 20m	sum
18	Paravane	8993	Performance test - no counts made				
19	Paravane	32092	0	15	25	1	41
20	Paravane	20547	1	19	23	6	49
21	Paravane	45930	5	13	37	25	80
							170
			0.4	1.19	1.98	2.77	
			Density (#/1000sq.m.)				
Transect	Mode	Length					Sum
18	Paravane	8993	nd	nd	nd	nd	
19	Paravane	32092	0.00	0.39	0.39	0.01	0.80
20	Paravane	20547	0.12	0.78	0.57	0.11	1.57
21	Paravane	45930	0.27	0.24	0.41	0.20	1.11

Table 6. Temperature and salinity measurements by depth and location.

		Temperature			
depth (ft)	location 1	location 2	location 3	location 4	location 5
0	12.5	10.1	12.5	14	14
5	11.9	9.9	12.2	13.8	13.5
10	11.9	9.8	12.1	13.5	13
15	11.8	9.8	12	13.5	12.5
20	11.8	9.7	12	13.5	12
25	11.8	9.7	11.9	13.5	12
30	11.8	9.7	11.9	13.5	11.5
35	11.8	9.7	11.9	13.5	11.5
			11.8		
		Salinity			
depth (ft)	location 1	location 2	location 3	location 4	location 5
0	27.2	27.3	29.2	19.1	25.4
5	27.2	28.0	29.3	23.3	26.1
10	27.2	28.2	29.2	23.9	26.8
15	27.3	28.3	29.2	24.4	27.5
20	27.2	28.3	29.2	26.7	27.9
25	27.2	28.5	29.2	26.7	27.9
30	27.2	28.6	29.2	26.7	28.6
35	27.2	28.6	29.2	26.7	28.6
	Northing	Westing	Date	Time	
location 1	60 12 65	152 01 71	18-Jul	1335	
location 2	59 57 01	152 03 87	18-Jul	2005	
location 3	60 06 65	152 15 04	19-Jul	1345	
location 4	60 34 52	151 22 07	19-Jul	1800	
location 5	60 10 96	151 51 12	25-Jul	2100	

Table 7. Weather conditions along various transects

Transect	
1	Incoming tide (slack tide @2150) surface near glossy
2	3ft swell choppy wind SE
3	Swell increasing from t-2 (outgoing tide?)
4	Outgoing tide, swell 1-2 ft wind 3-5 knots. swell increasing to 3-5 ft late in transect.
5	Outgoing, 1-2 ft swell at end of transect
6	Incoming tide
7	Incoming tide slight chop.
8	Outgoing tide, flat calm.
9	Outgoing tide slight wind chop.
10	Outgoing tide turning to incoming, flat calm at the begining , slight chop at the end.
11	Calm
12	Water smooth
13	1 ft swell at begining to 3 ft at end.
14	2 ft swell from the south.
15	2 ft swell from the south.
16	Calm
17	Calm
18	Calm
19	1 ft swell from the north.
20	Calm, outgoing tide.
21	Calm

Table 8. Population estimation parameters for orthogonal transects.

Transect	Mode	Density	Variance	Area	Population	Variance	Error Bounds
		(#/million sq.m.)		(million sq.m.)	(# of fish)		
1	Orth., So.	1460					
8	Orth., So.	310					
9	Orth., So.	490					
10	Orth., So	300					
Mean		640	76617	1647.5	1054400	2.08E+11	912049
2	Orth., No.	90					
12	Orth., No.	90					
13	Orth., No.	170					
Mean		117	711	1647.5	192758	1.93E+09	87860
Total					1247158	2.0993E+11	916362
Excluding T1		367	3811	1647.5	604633	1.03E+10	203411
Total Exc. T1					790391	1.22E+10	221179

Table 9. Population estimation parameters for zigzag transects.

Transect	Mode	Density	Variance	Area	Population	Variance	Error Bounds
		(#/million sq.m.)		(million sq.m.)	(# of fish)		
4	zig-zag	40					
5	zig-zag	1013					
6	zig-zag	0					
7	zig-zag	1297					
11	zig-zag	223					
Mean		515	71782	3295	1695607	7.79339E+11	1765604

Table 10. Population estimation parameters for rip and paravane transects.

Transect	Mode	Density	Variance	Area	Population	Variance	Error Bounds
	(#/million sq.m.)			(million sq.m.)	(# of fish)		
3	Rip	1210					
14	Rip	430					
15	Rip	466					
16	Rip	730					
17	Rip	350					
	Rip Mean	637	24572	3295	209900	2.67E+11	1033000
19	Para	797					
20	Para	1570					
21	Para	1113					
	Para Mean	1160	50346	3295	3822200	5.47E+11	1478659
Mean	Overall Mean	833	23321	3295	2744735	2.53E+11	1006373

Table 11. Population estimation parameters for all transects combined.

Transect	Mode	Density	Variance	Area	Population	Variance	Error Bounds
		(#/million sq.m.)		(million sq. m.)	(# of fish)		
1	Orth., So.	1460					
2	Orth., No.	90					
3	Rip	1210					
4	zig-zag	40					
5	zig-zag	1013					
6	zig-zag	0					
7	zig-zag	1297					
8	Orth., So.	310					
9	Orth., So.	490					
10	Orth., So	300					
11	zig-zag	223					
12	Orth., No.	90					
13	Orth., No.	170					
14	Rip	430					
15	Rip	466					
16	Rip	730					
17	Rip	350					
18	Para. Rip	nd					
19	Para. Rip	797					
20	Para. Orth.	1570					
21	Para. Rip	1113					
Mean		607	12745	3295	2001548	1.38373E+11	743970

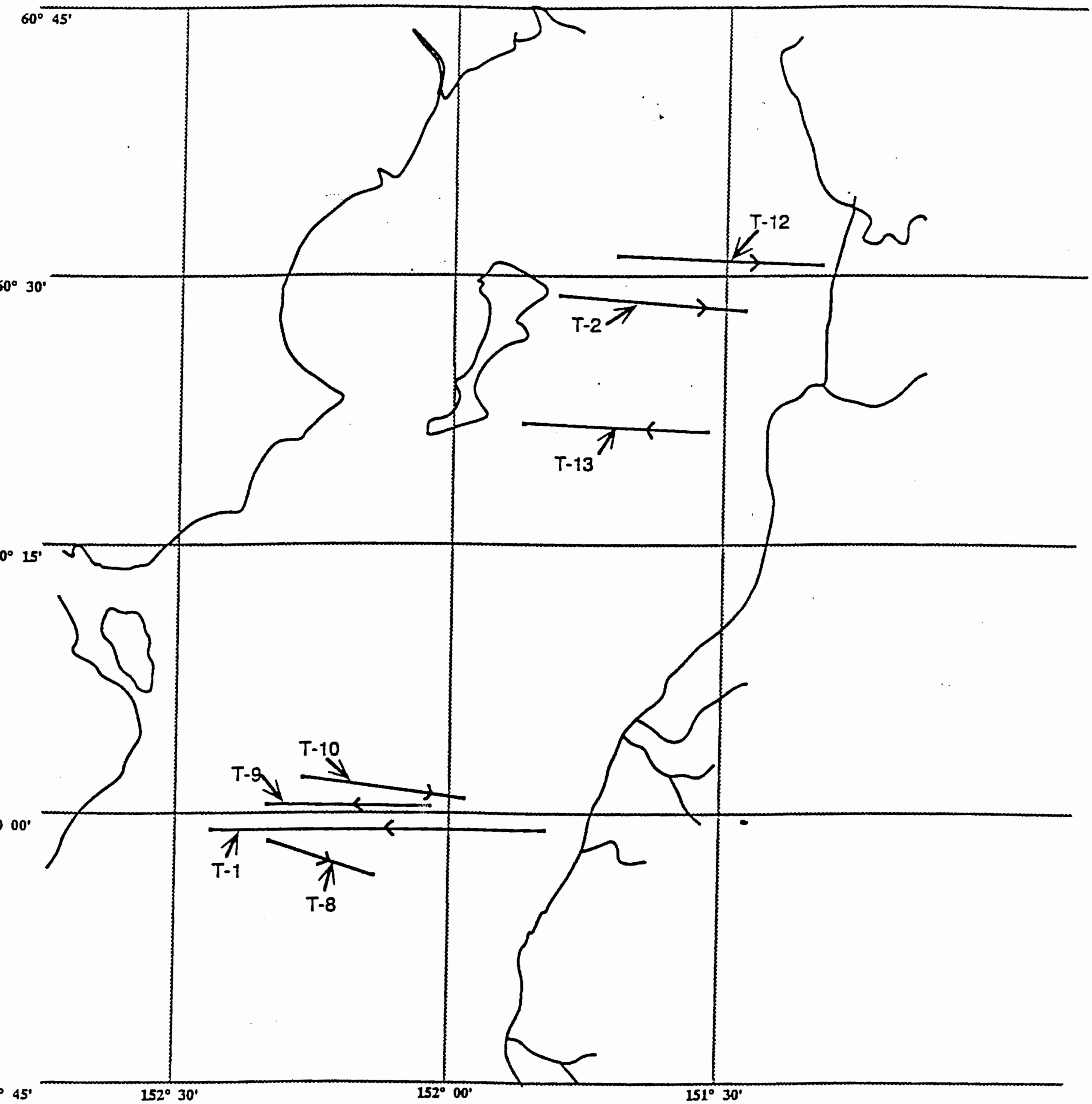

Figure 1. Locations of orthogonal side-looking transects

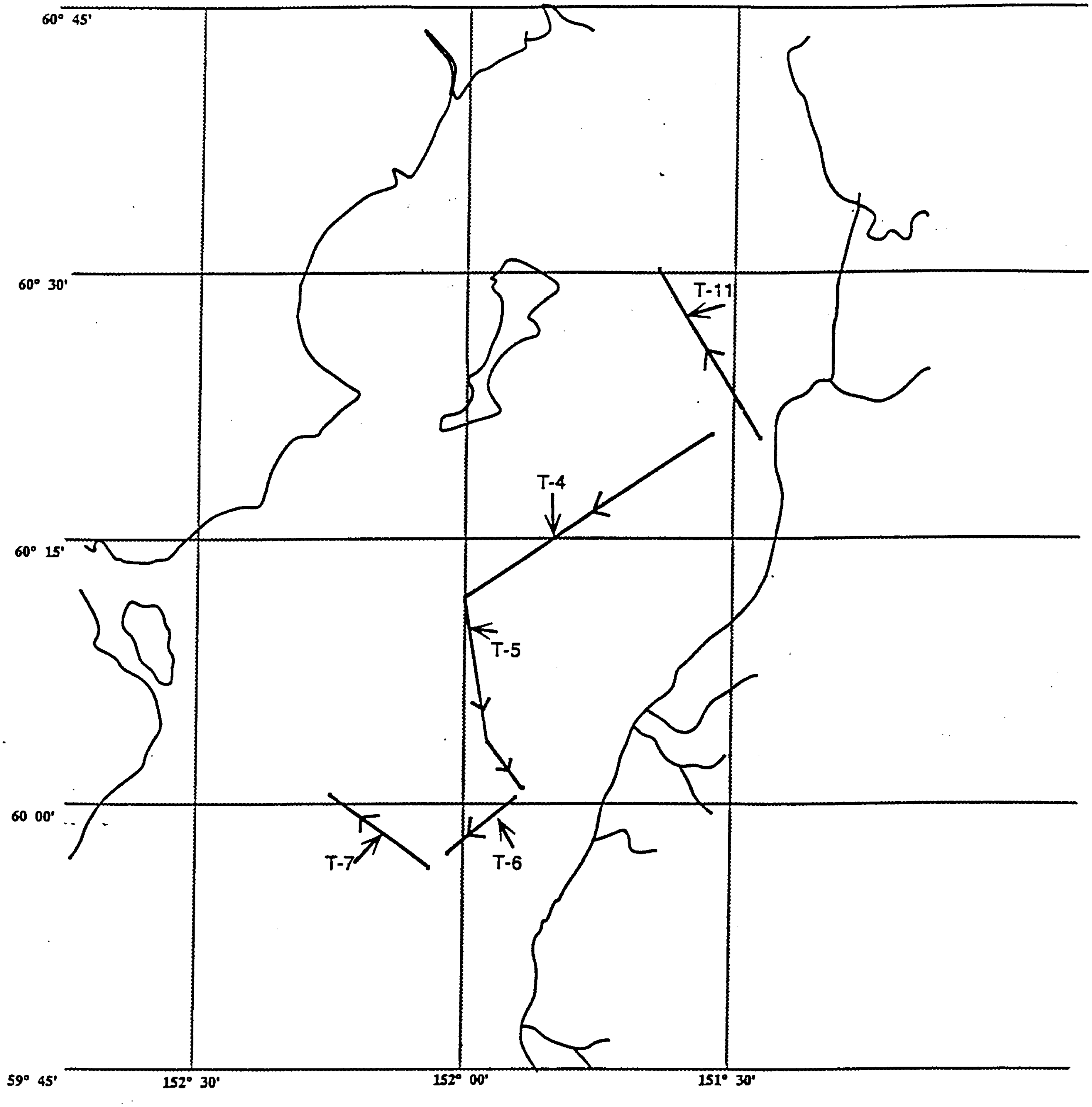

Figure 2. Locations of zig-zag side-looking transects

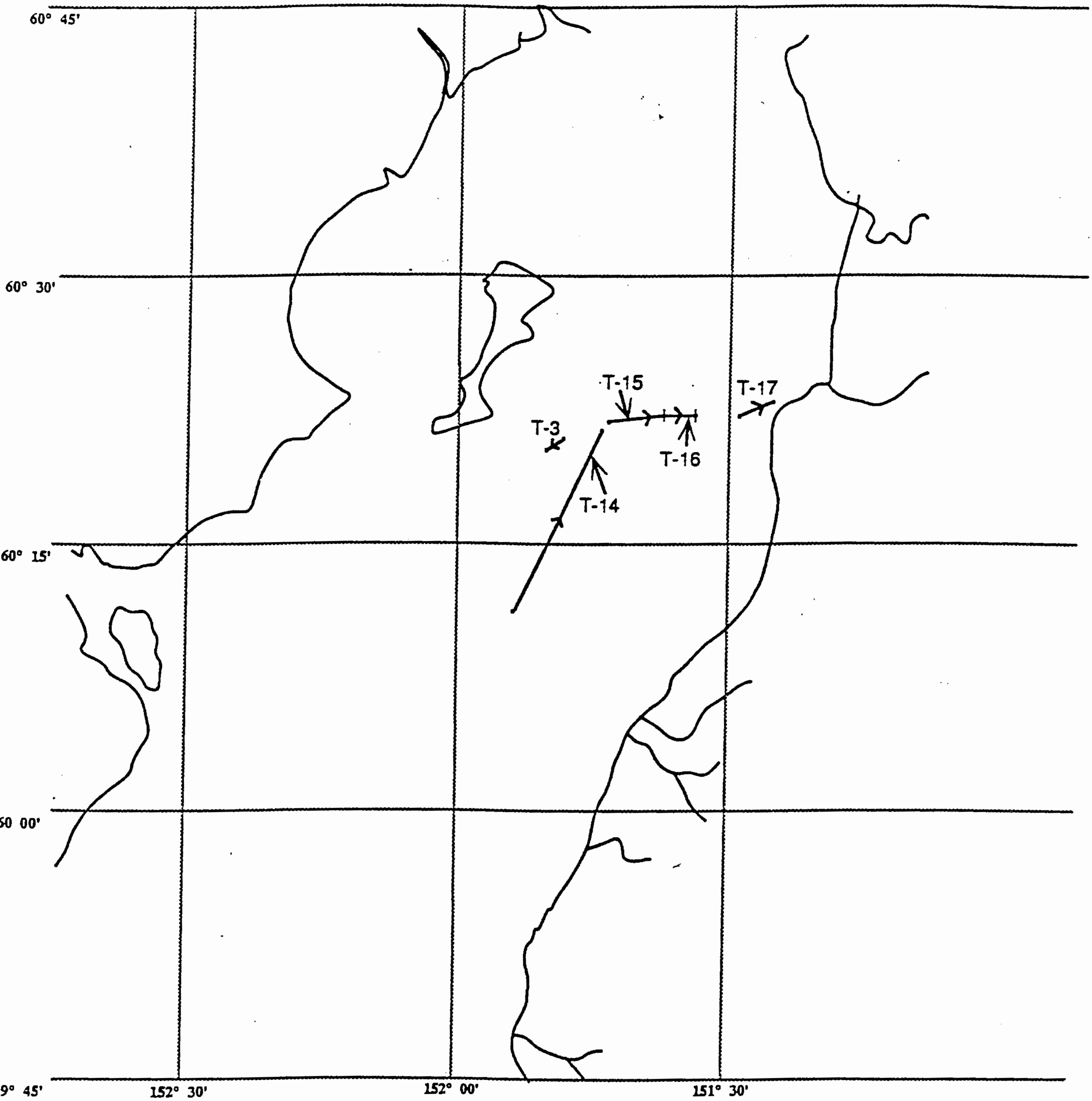

Figure 3. Locations of side-looking transects around rips

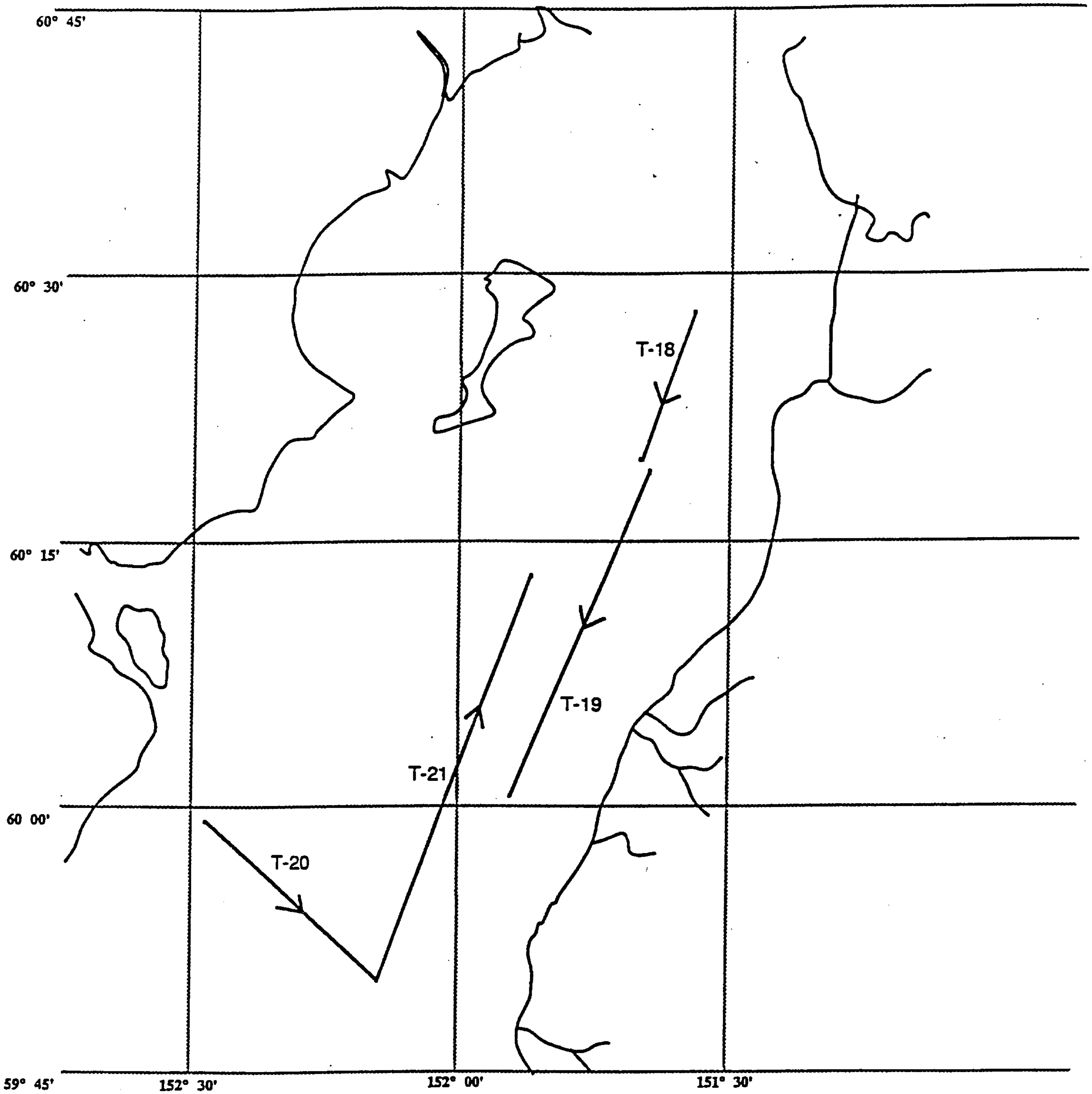

Figure 4. Location of paravane transects (#18-21)

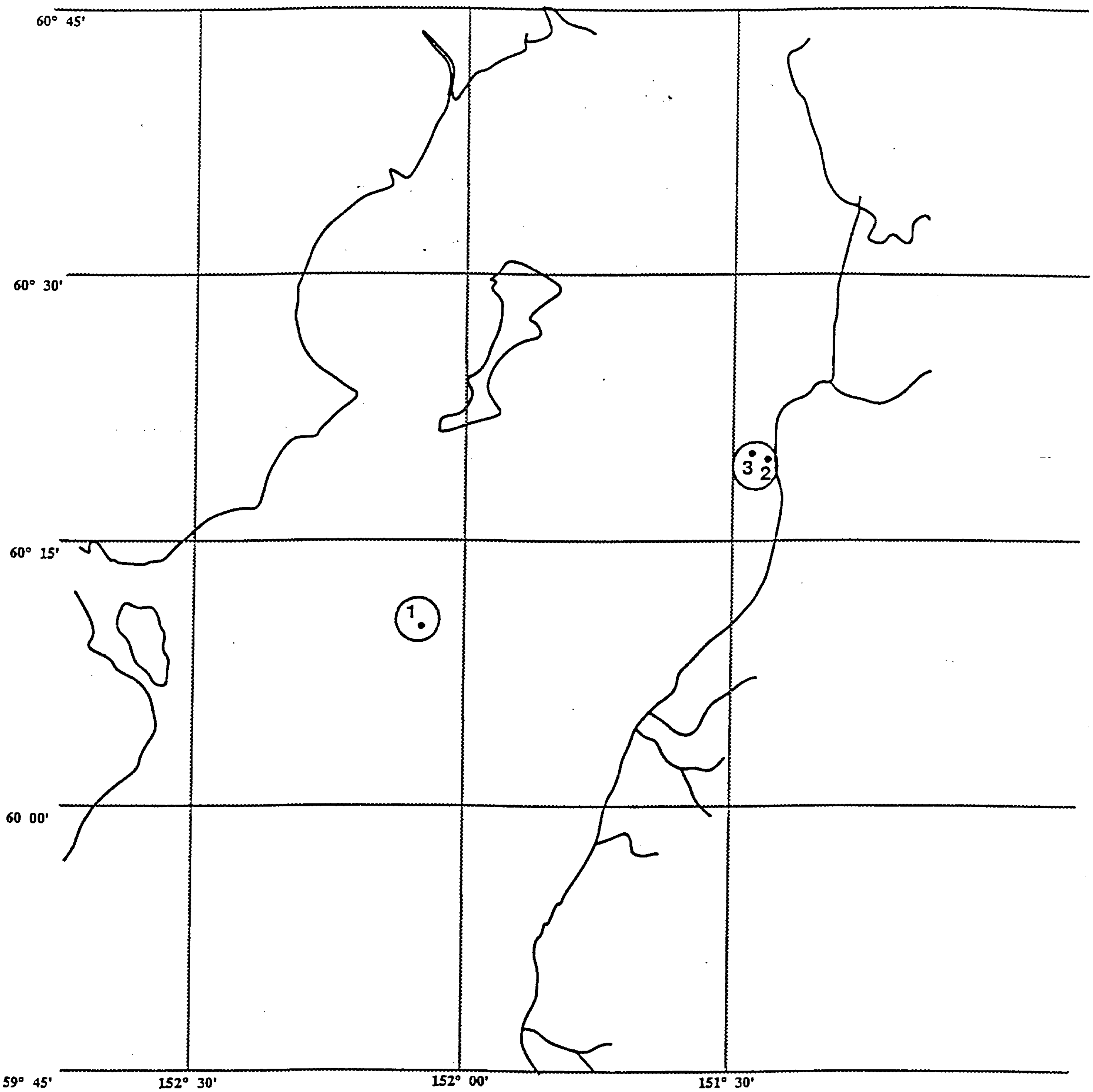

Figure 5. Location of anchor stations

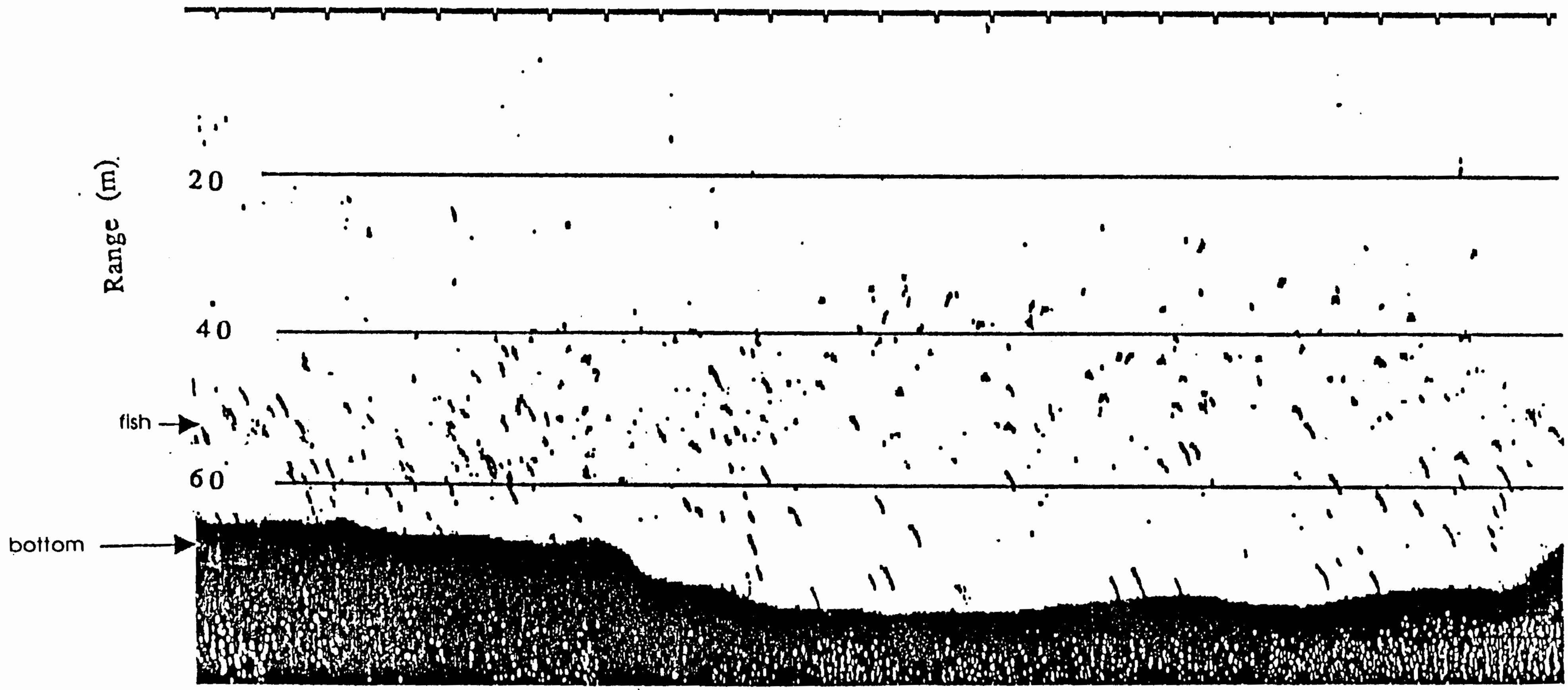

Figure 6. Echogram from transect #1, 120 kHz transducer, showing large number of targets. Range in this relatively shallow water location is ultimately limited by side-lobe reflection off the bottom.

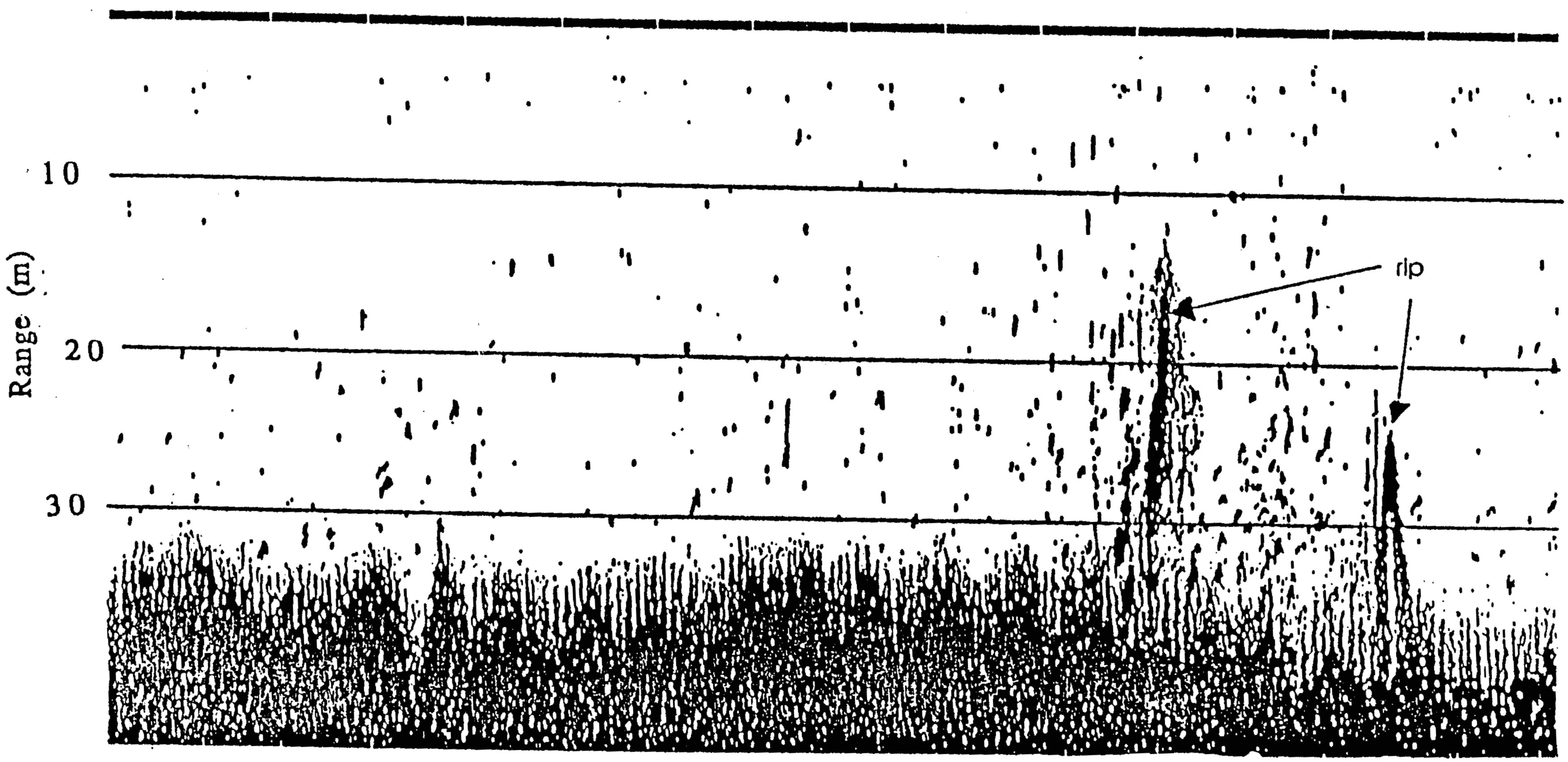

Figure 7. Echogram from 420 kHz transducer, transect 13, showing large numbers of targets and echo off riptide.

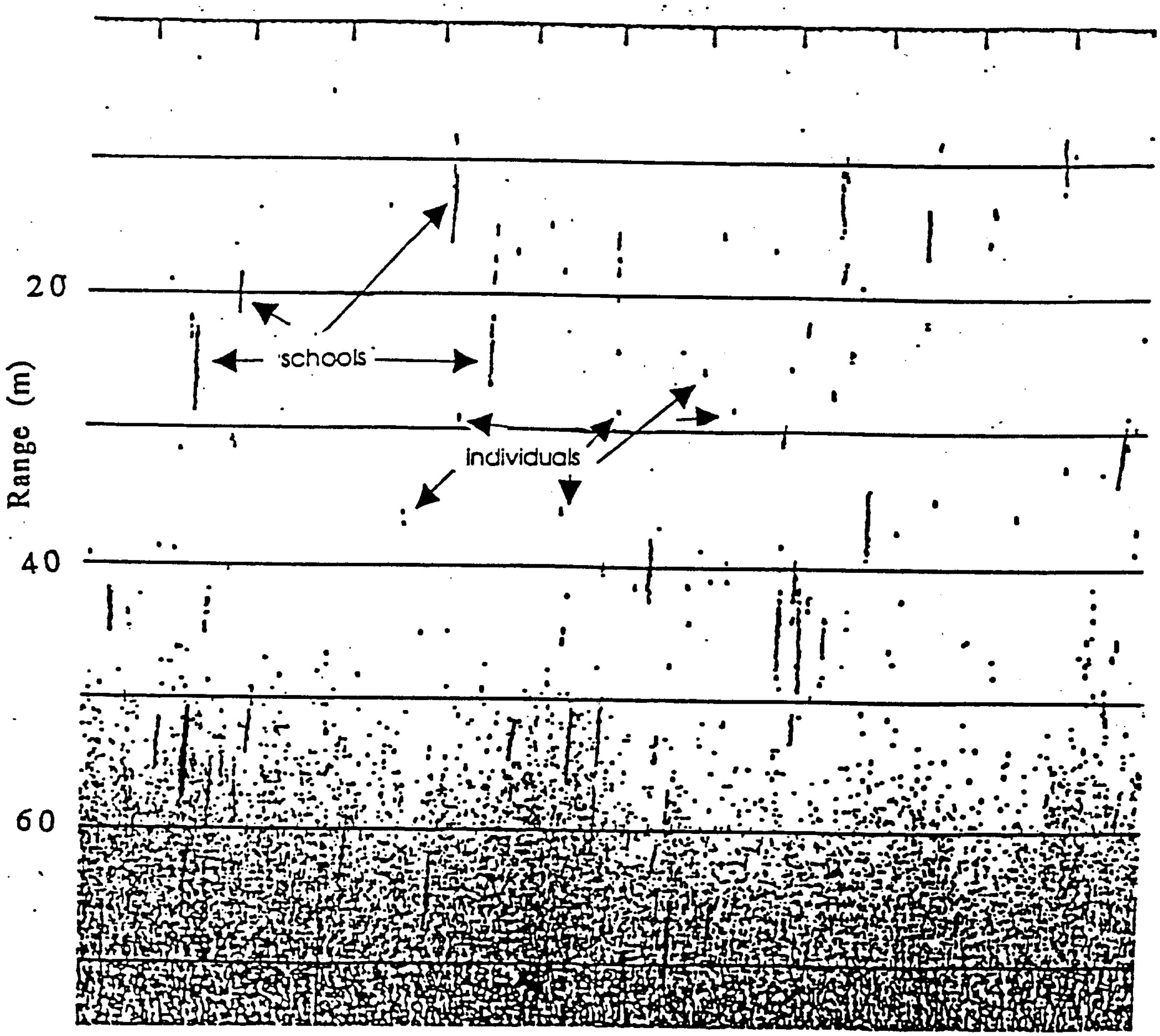

Figure 8. Echogram from 420 kHz transducer, transect 9, showing mixture of individual and school echoes. This was an area where many jumpers were observed.

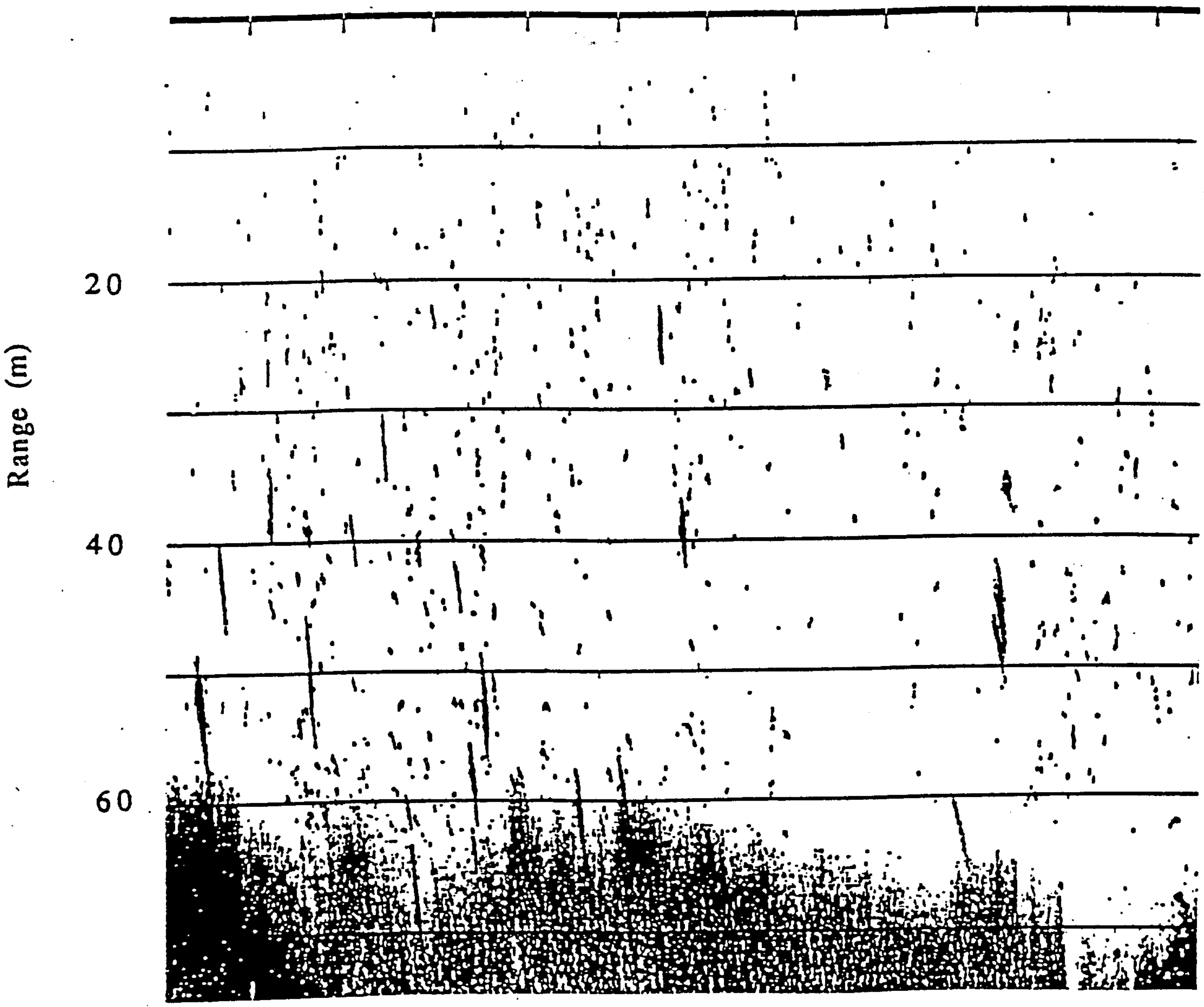

Figure 9. Echogram from 120 kHz transducer, transect 9, showing mixture of individual and school targets.

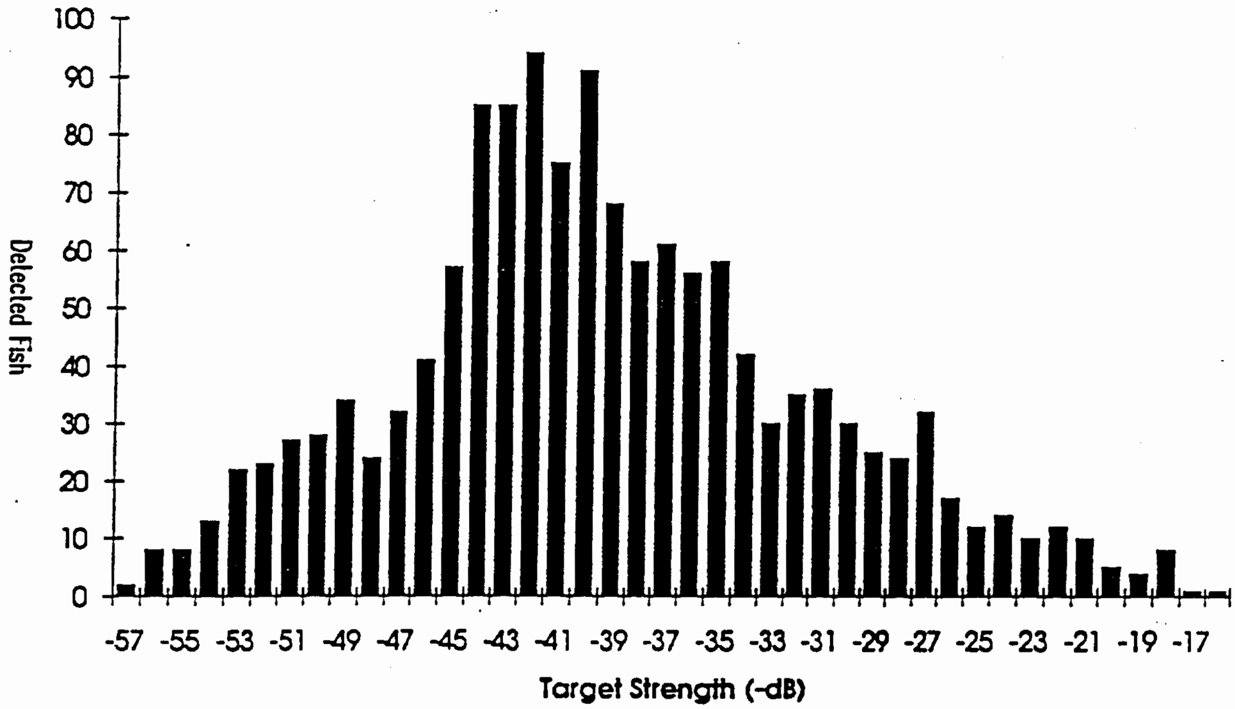

Figure 10. Target strength distribution for 120 kHz transducer, all transects combined.

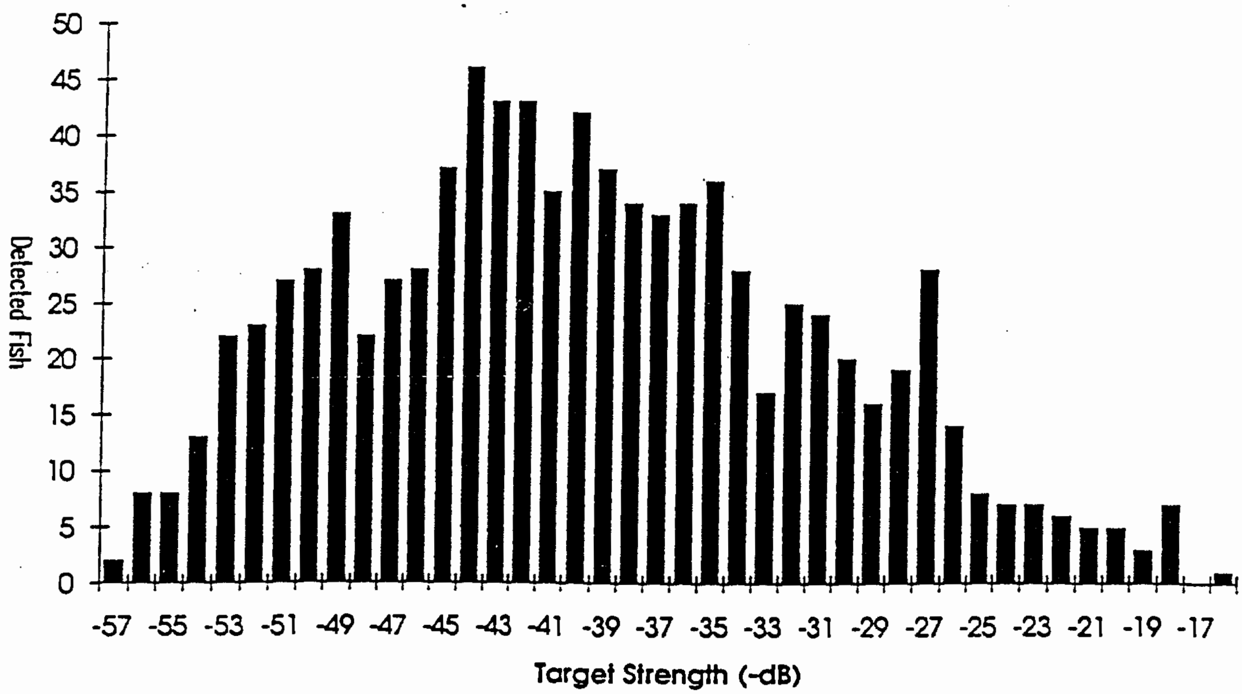

Figure 11. Target strength distribution for 120 kHz transducer, transect #1.

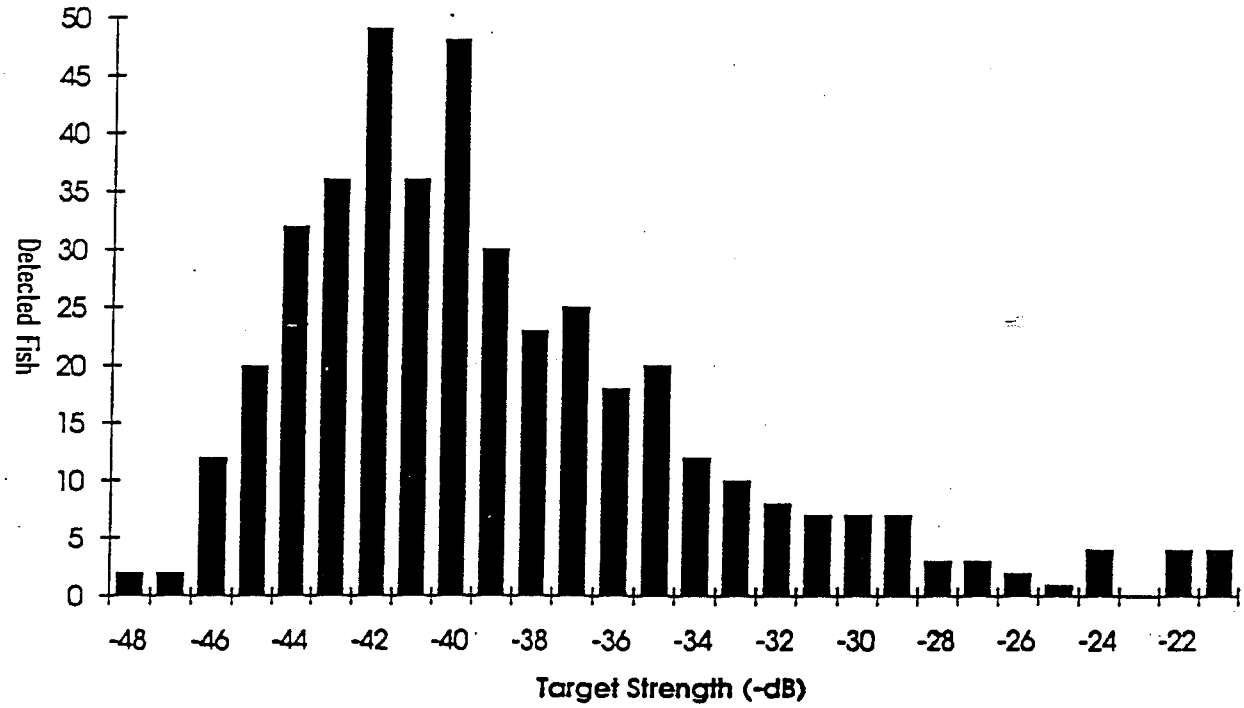

Figure 12. Target strength distribution for 120 kHz transducer, Transect #5.

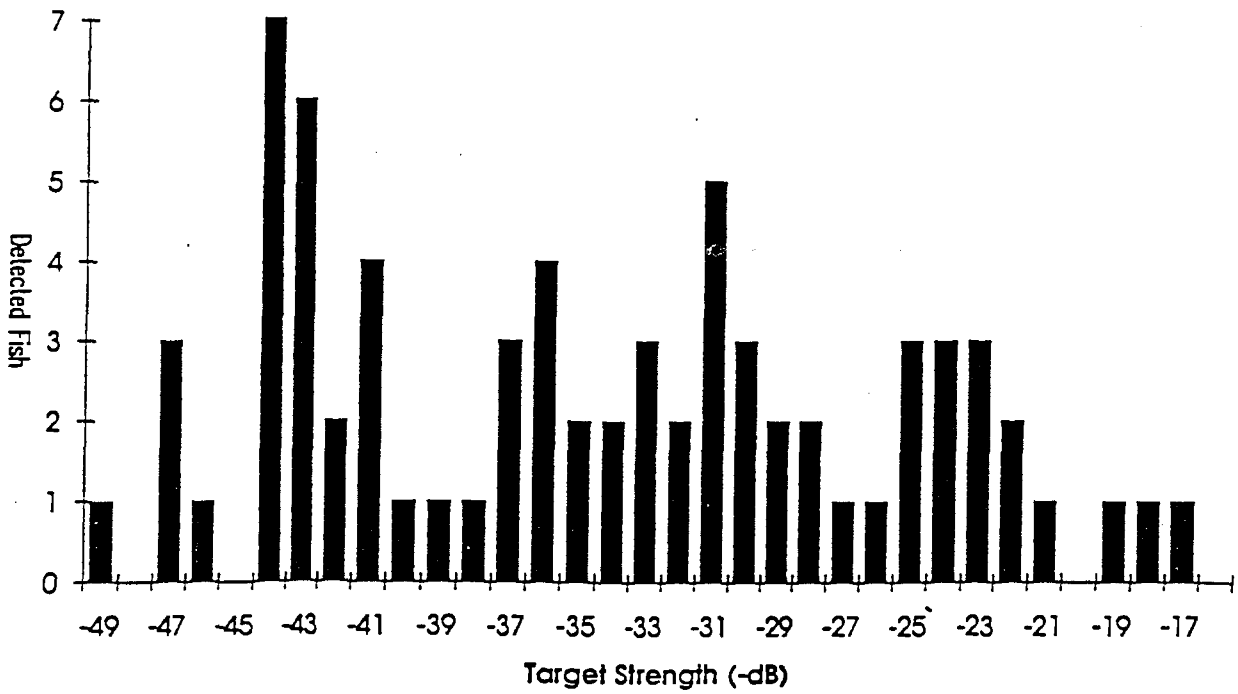

Figure 13. Target strength distribution for 120 kHz transducer, transects 2,3 and 4 combined.

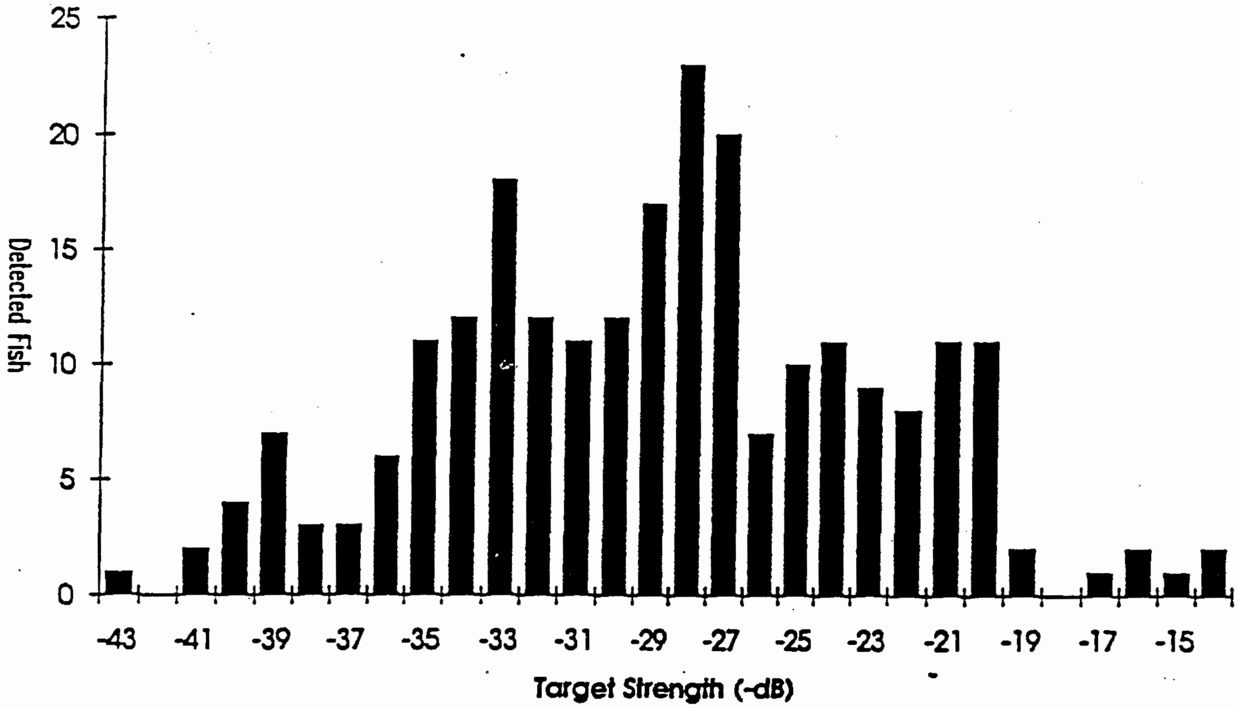

Figure 14. Target strength distribution for 420 kHz transducer, all transects combined.

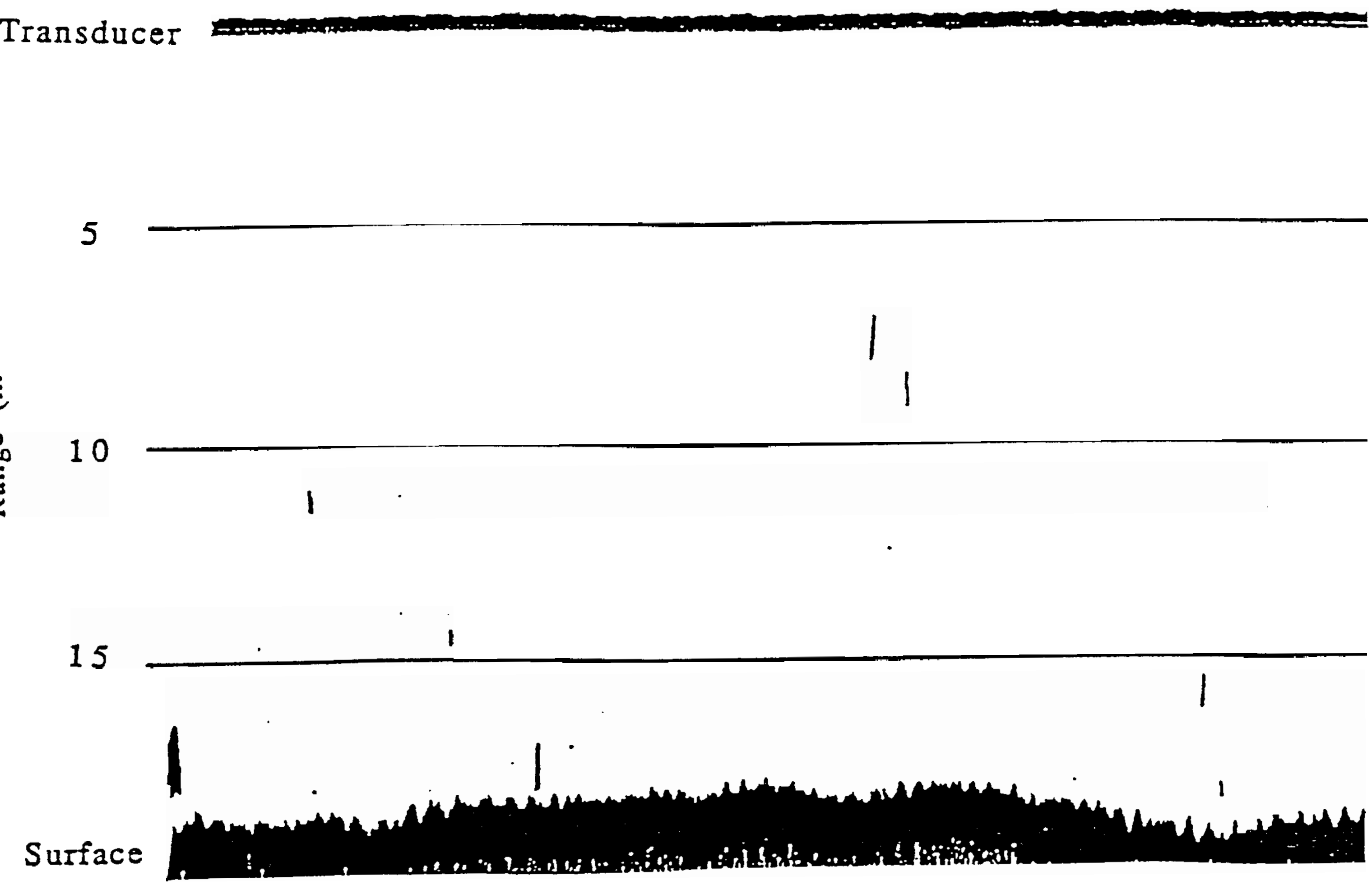

Figure 15. Echogram from section of paravane transects

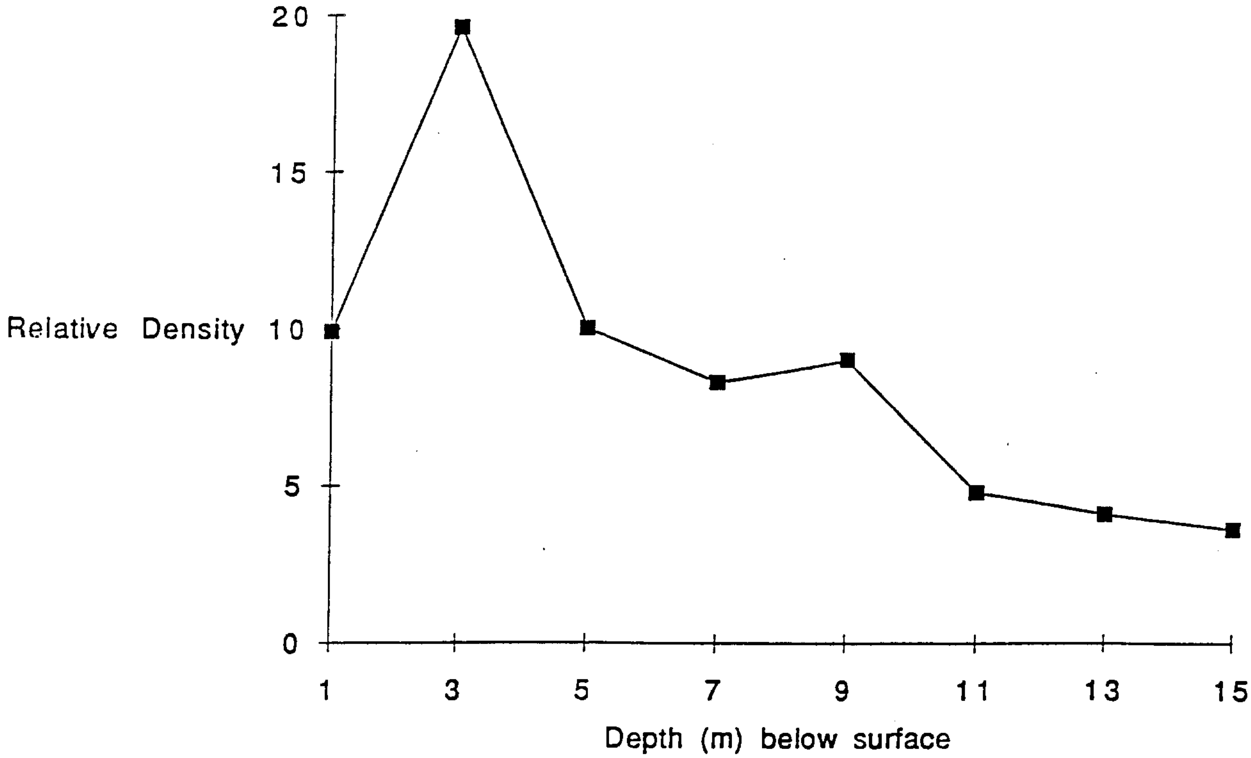

Figure 16. Vertical distribution of targets detected by the paravane transducer, all transects combined.

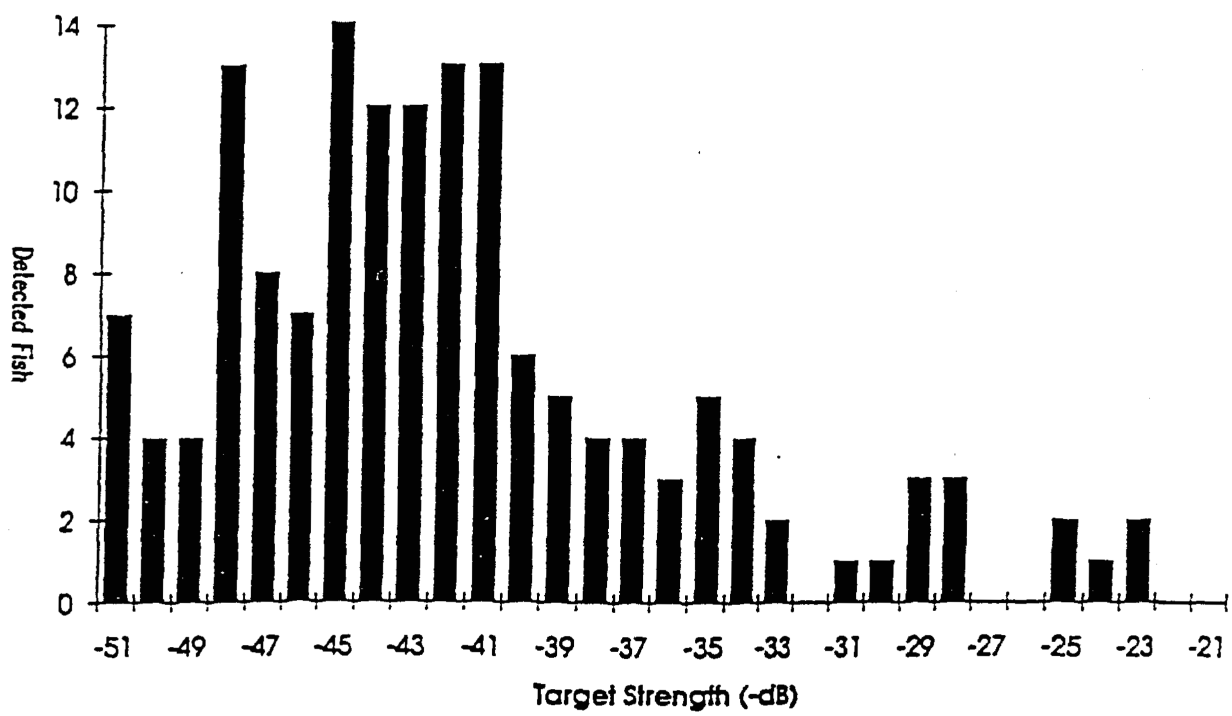

Figure 17. Target strength distribution from paravane transects

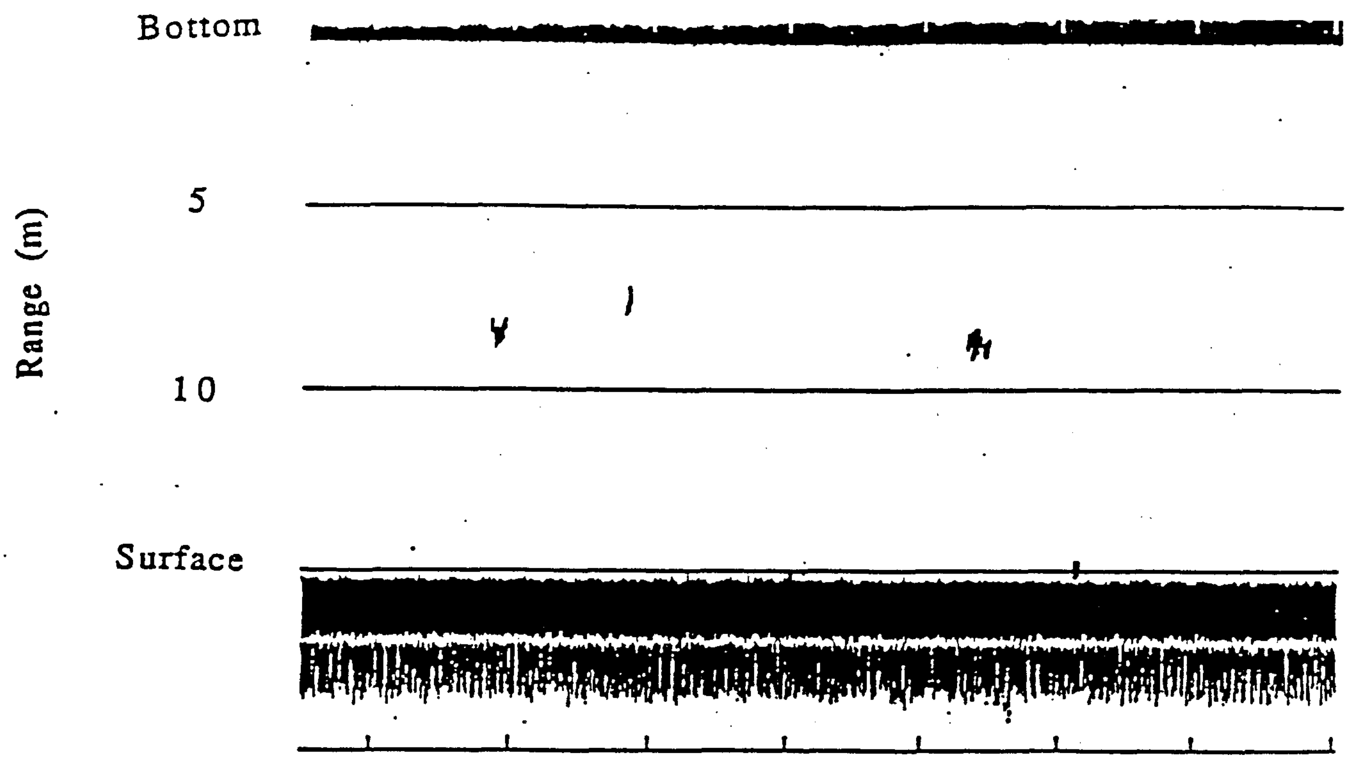

Figure 18. Echogram from first anchor station

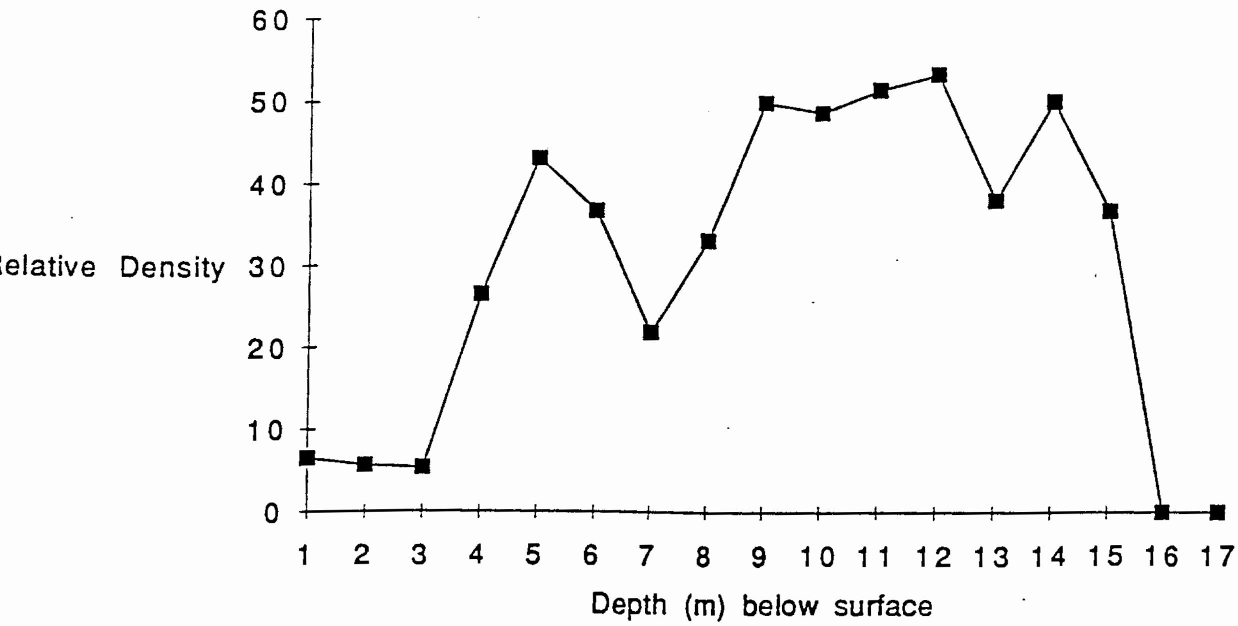

Figure 19. Vertical distribution (0 equals surface) of targets observed during first anchor station.

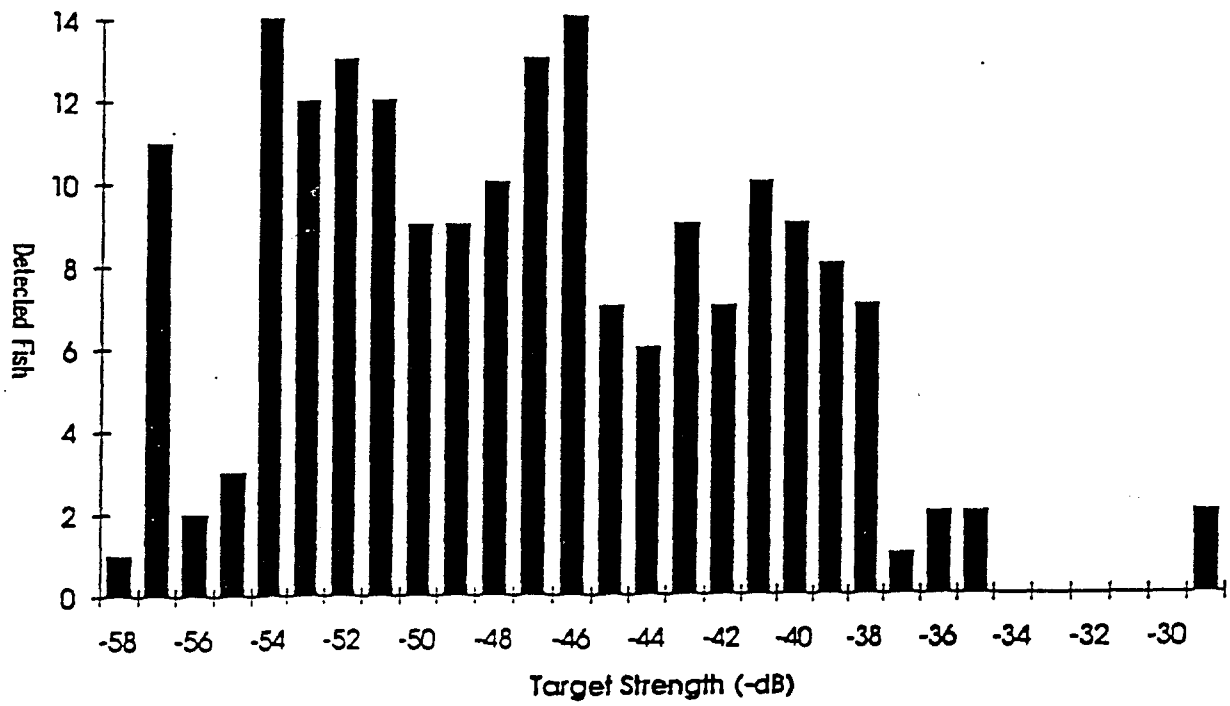

Figure 20. Target strength distribution of fish observed at first anchor station.

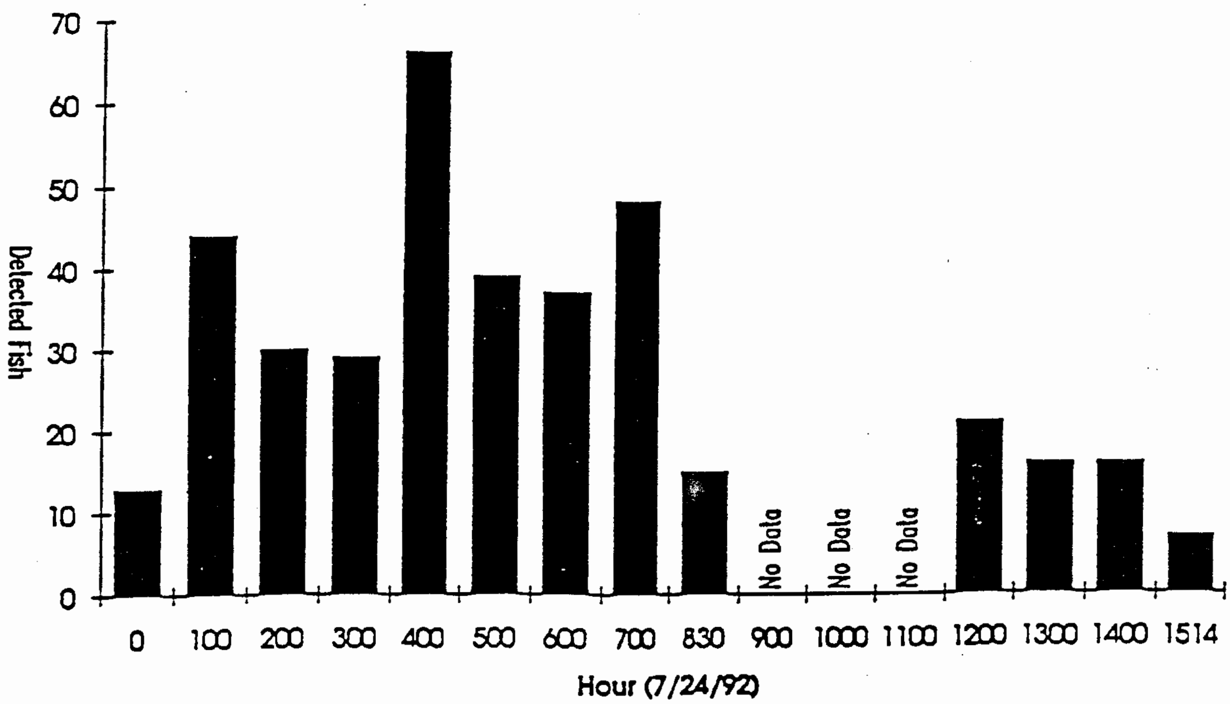

Figure 21. Diel variation of detected fish at first anchor station.

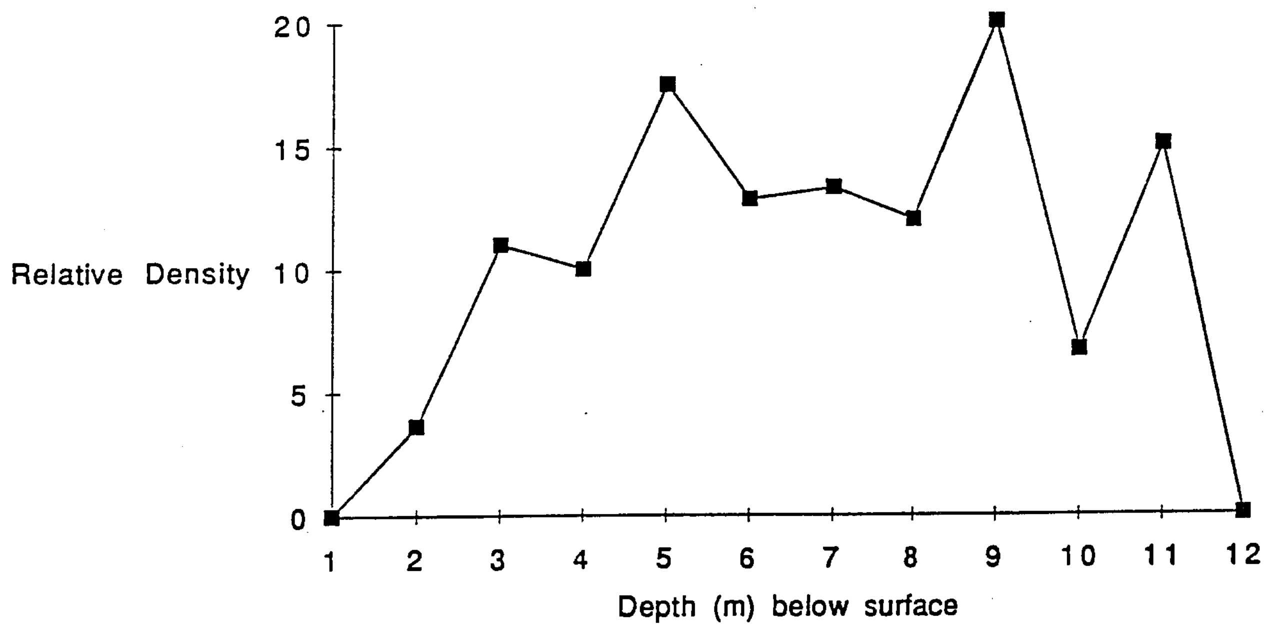

Figure 22. Vertical distribution of targets detected at second and third anchor stations.

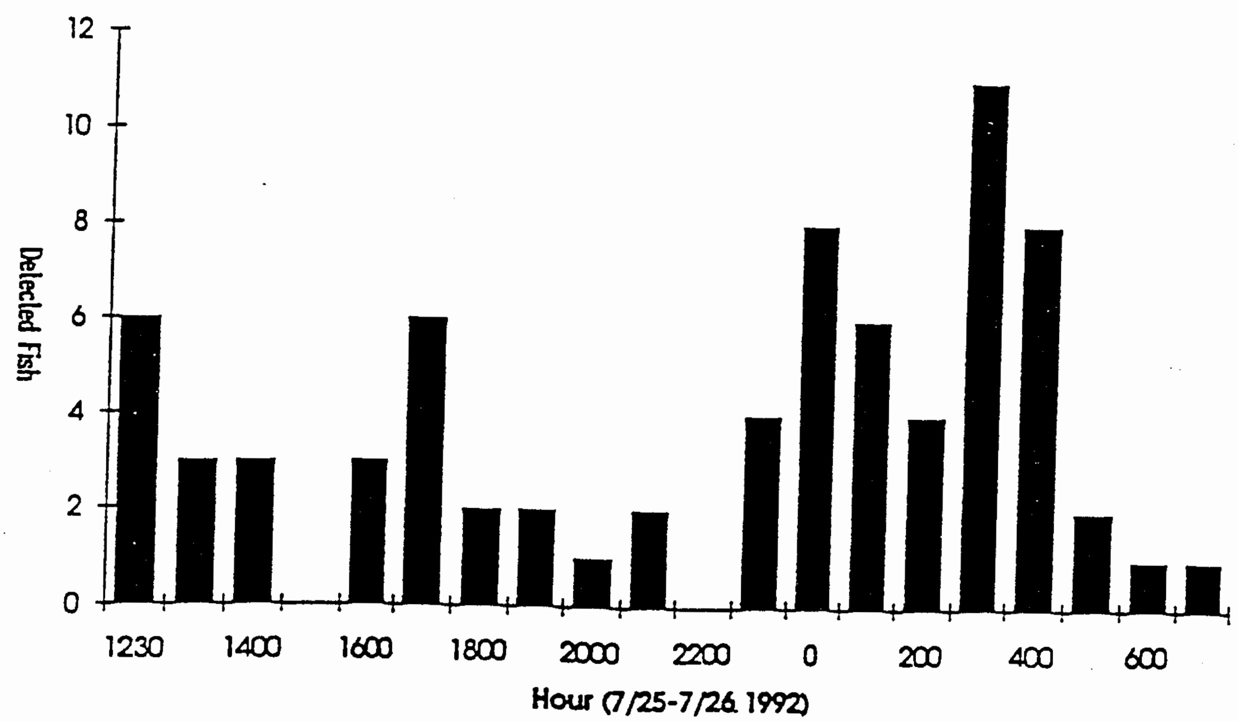

Figure 23. Diel variation in detected fish at second anchor station.

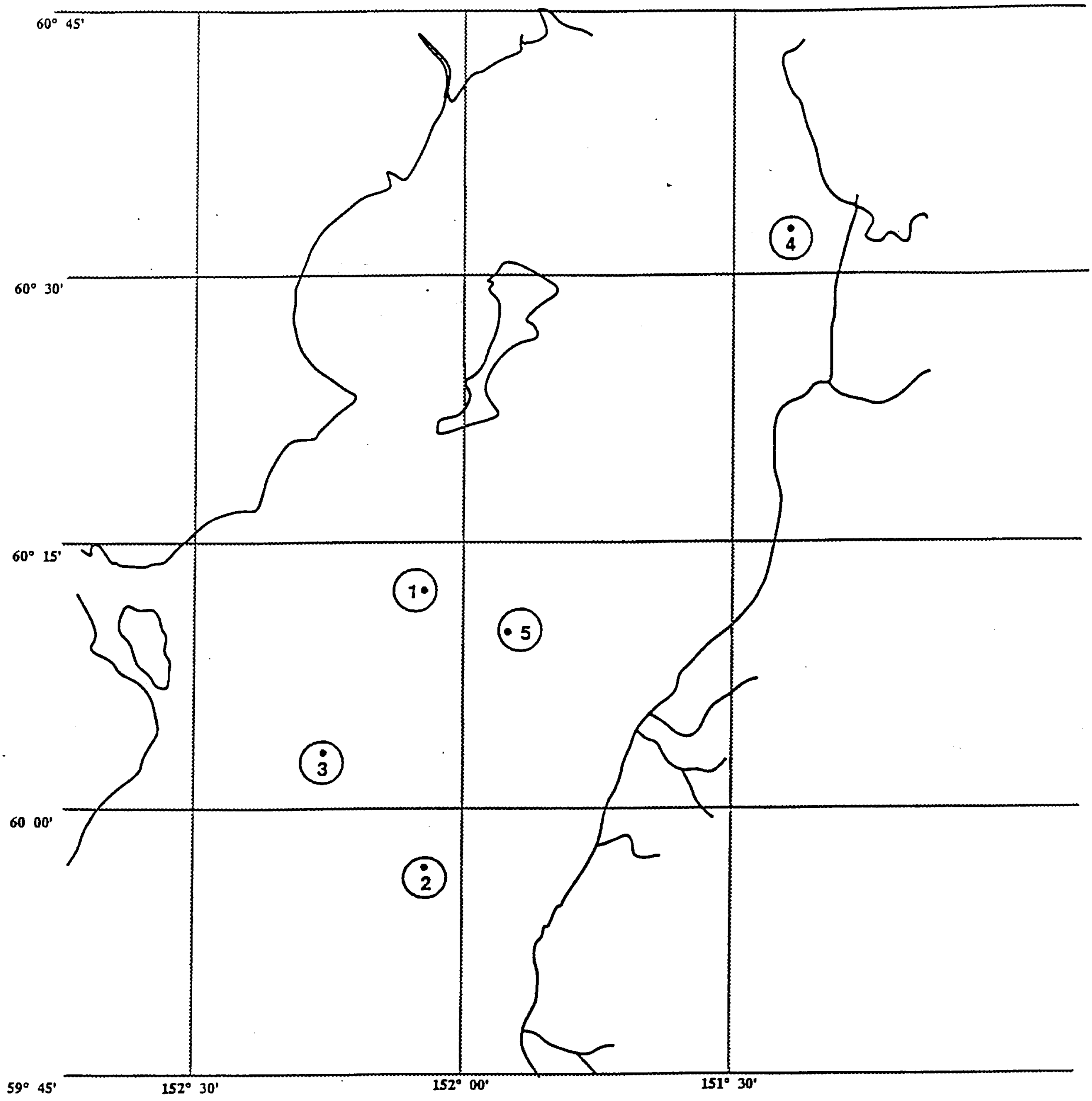

Figure 24. Locations of salinity and temperature stations

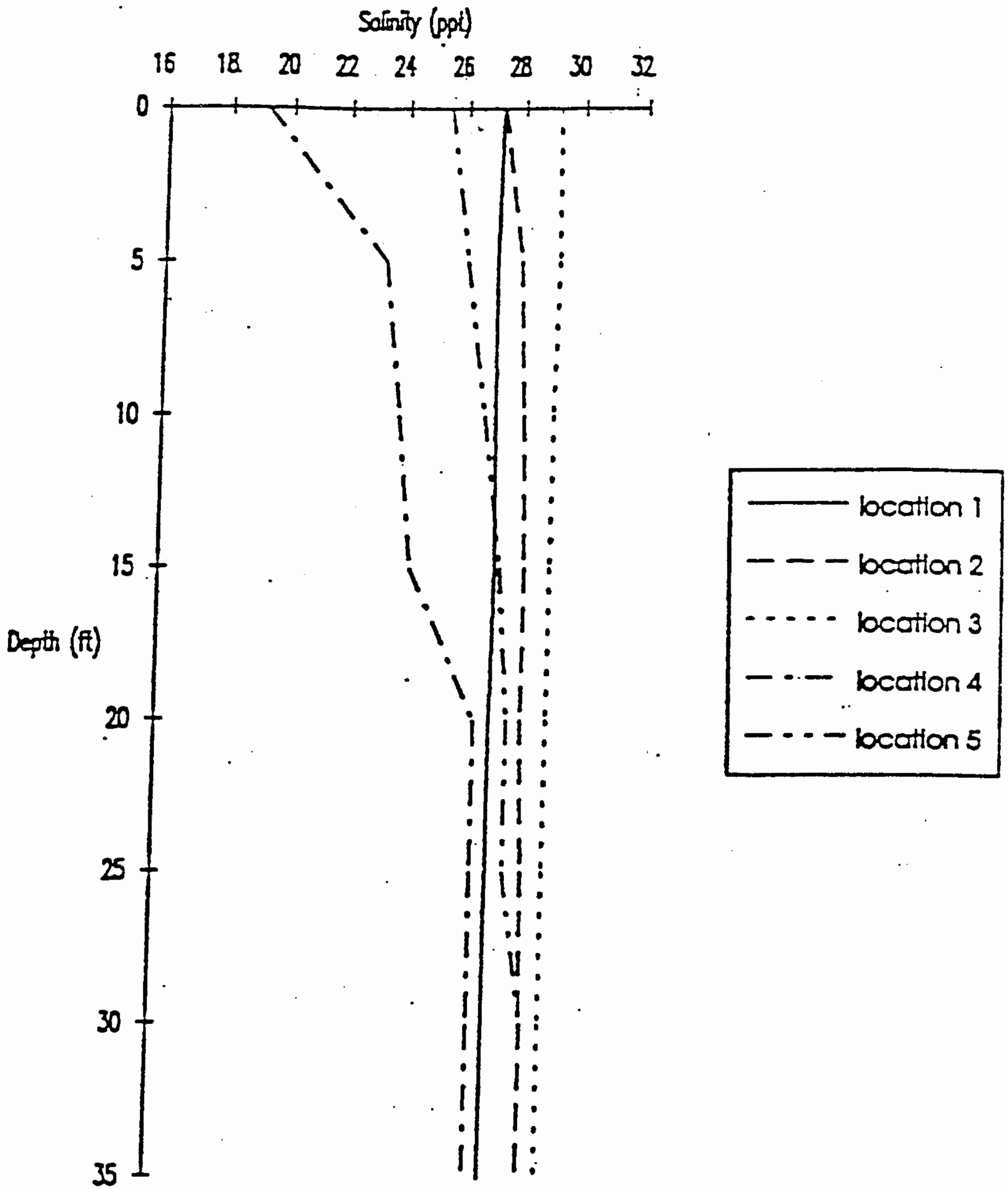

Figure 25. Salinity vertical profiles for various locations

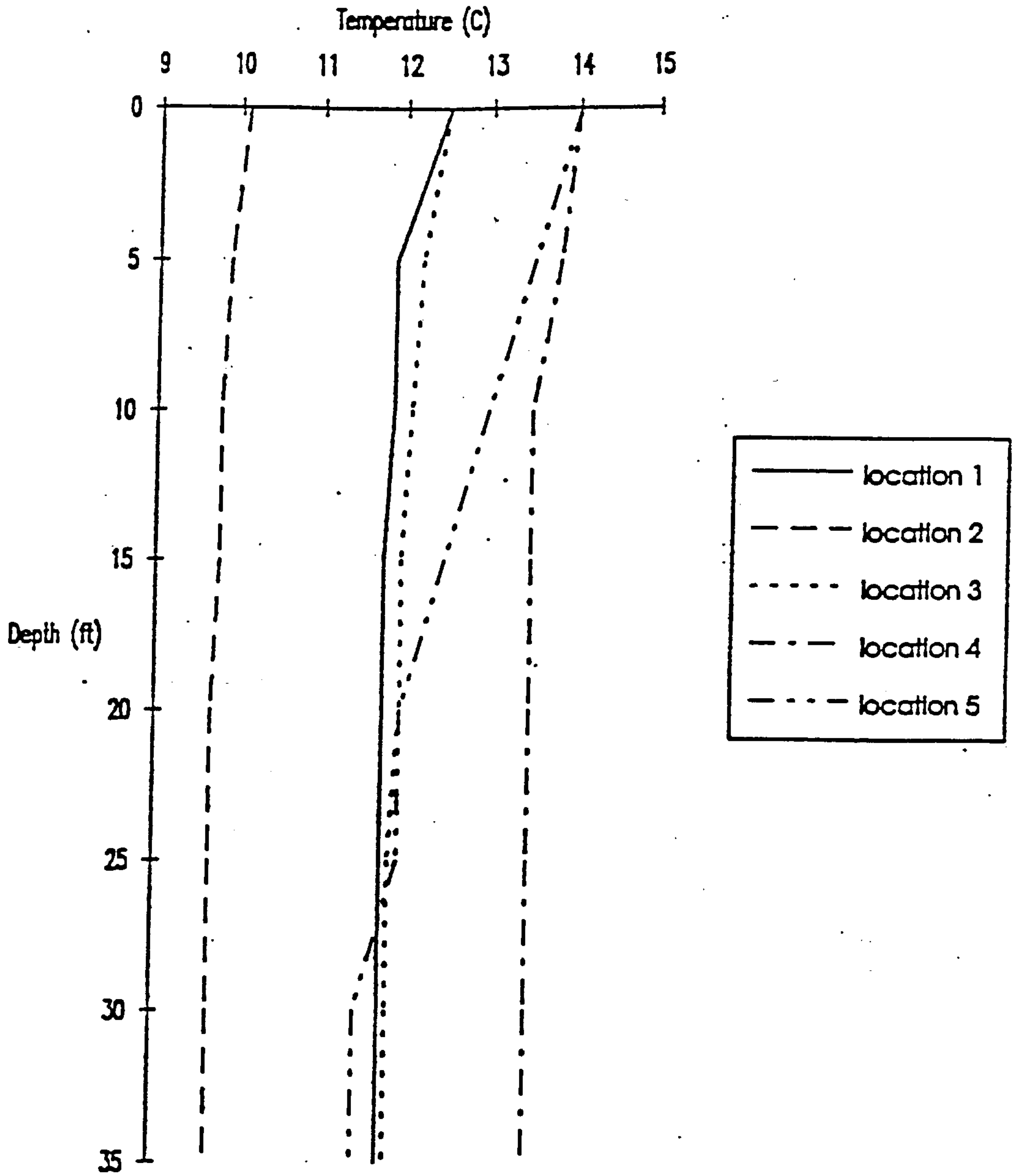

Figure 26. Temperature vertical profiles for various locations

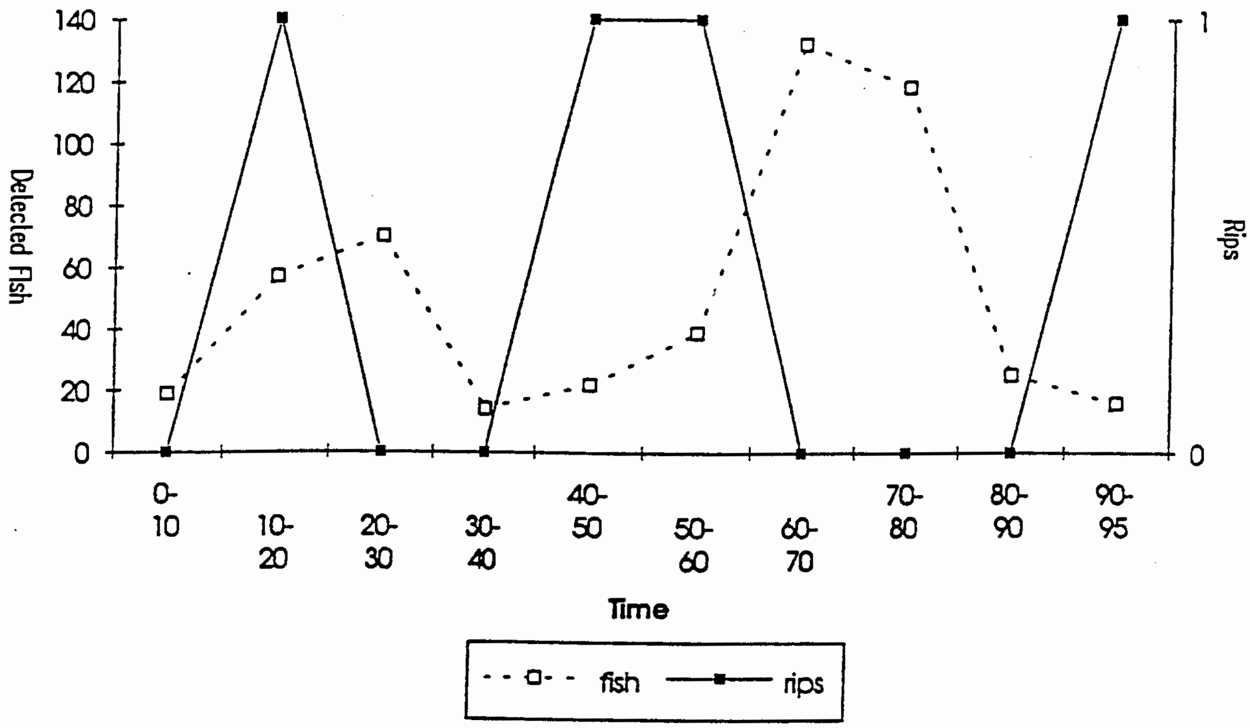

Figure 27. Relationship between detected fish and observed rips along transect # 9.

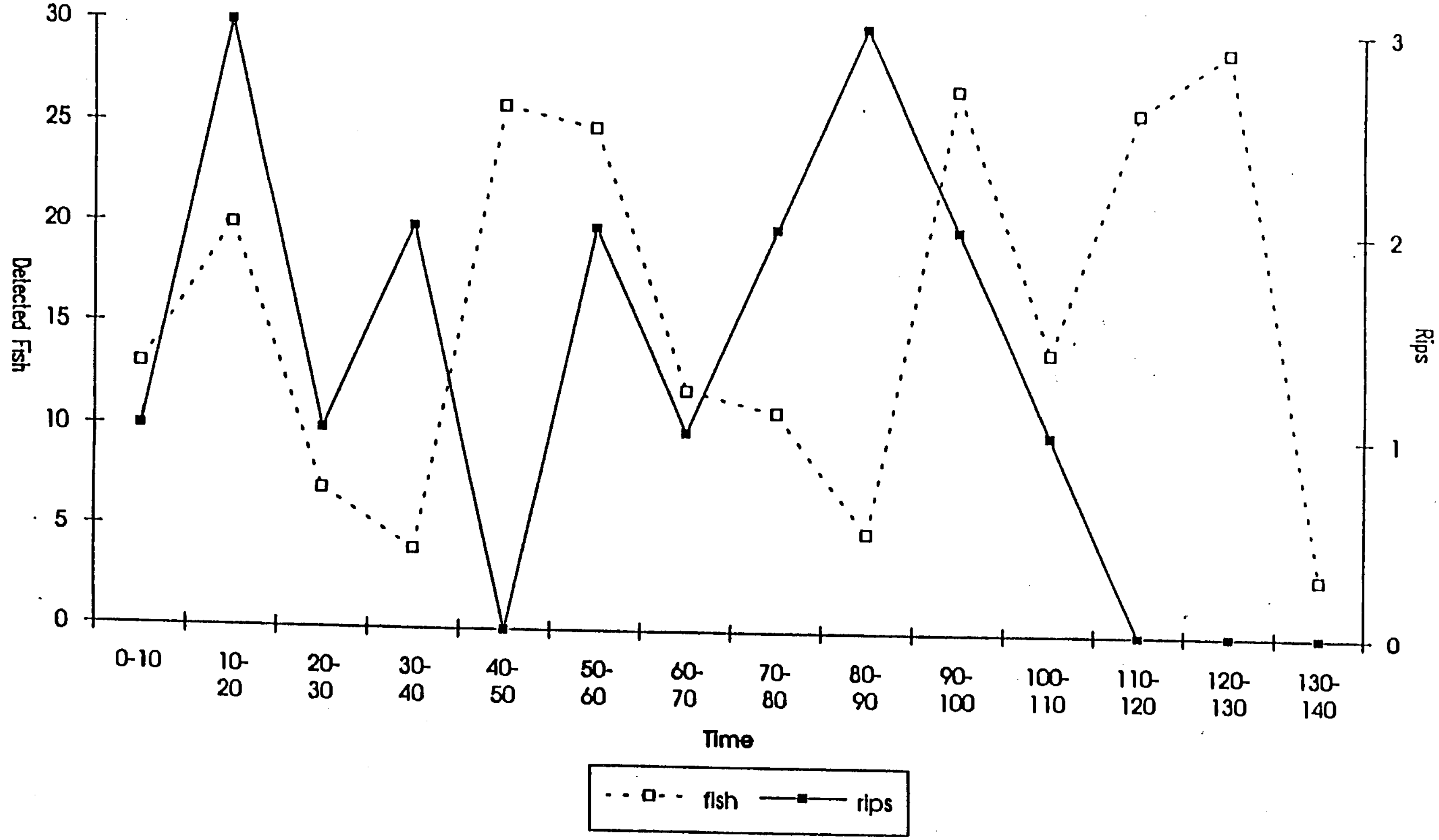

Figure 28. Relationship between detected fish and observed rips along transect # 10.

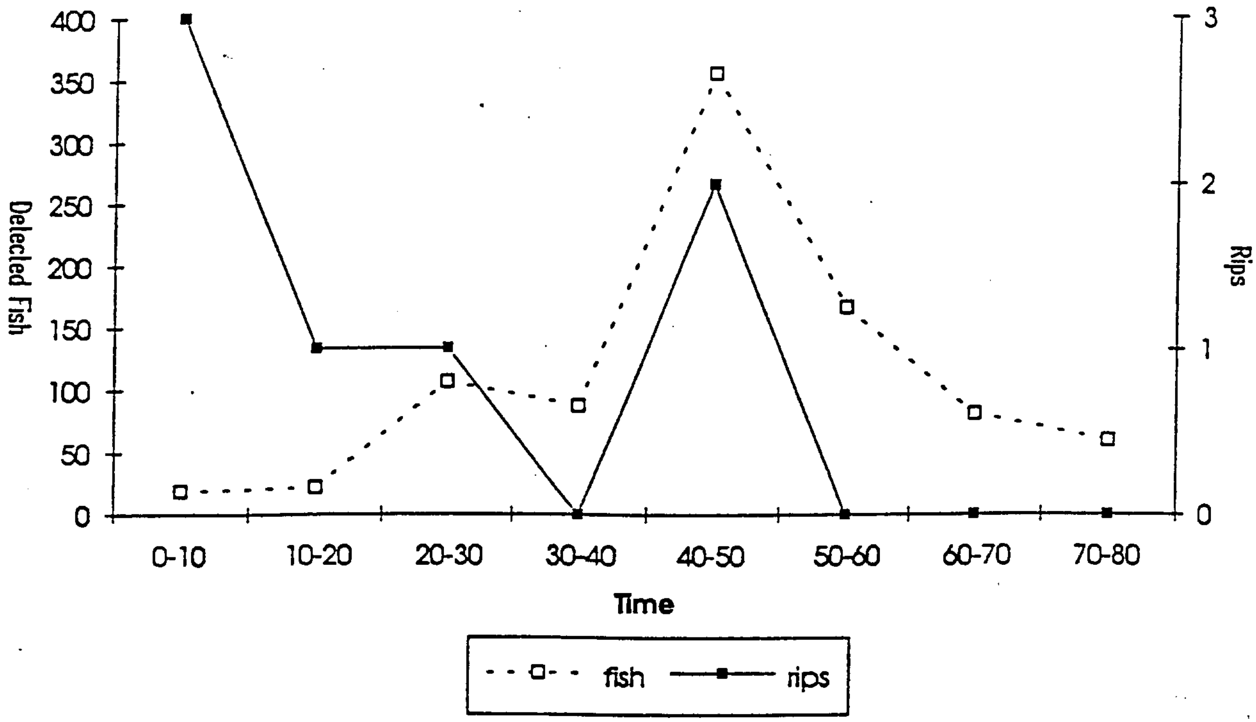

Figure 29. Relationship between detected fish and observed rips along transect # 1.

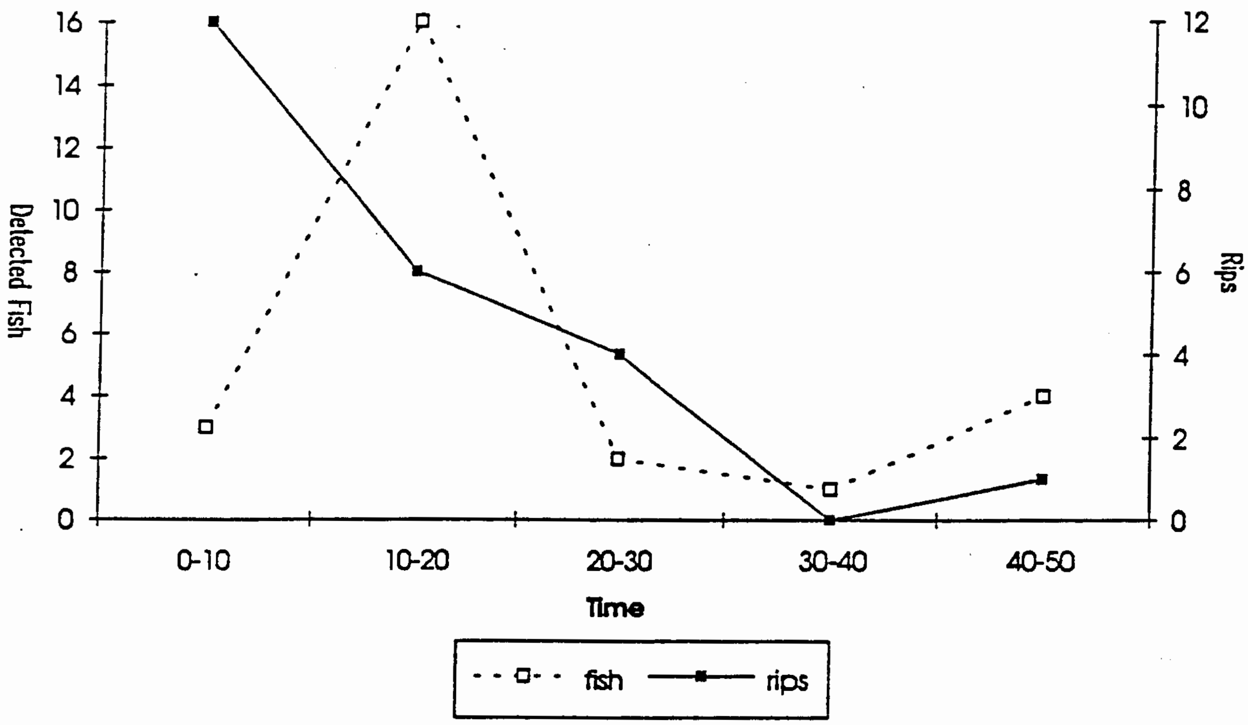

Figure 30. Relationship between detected fish and observed rips along transect # 2.

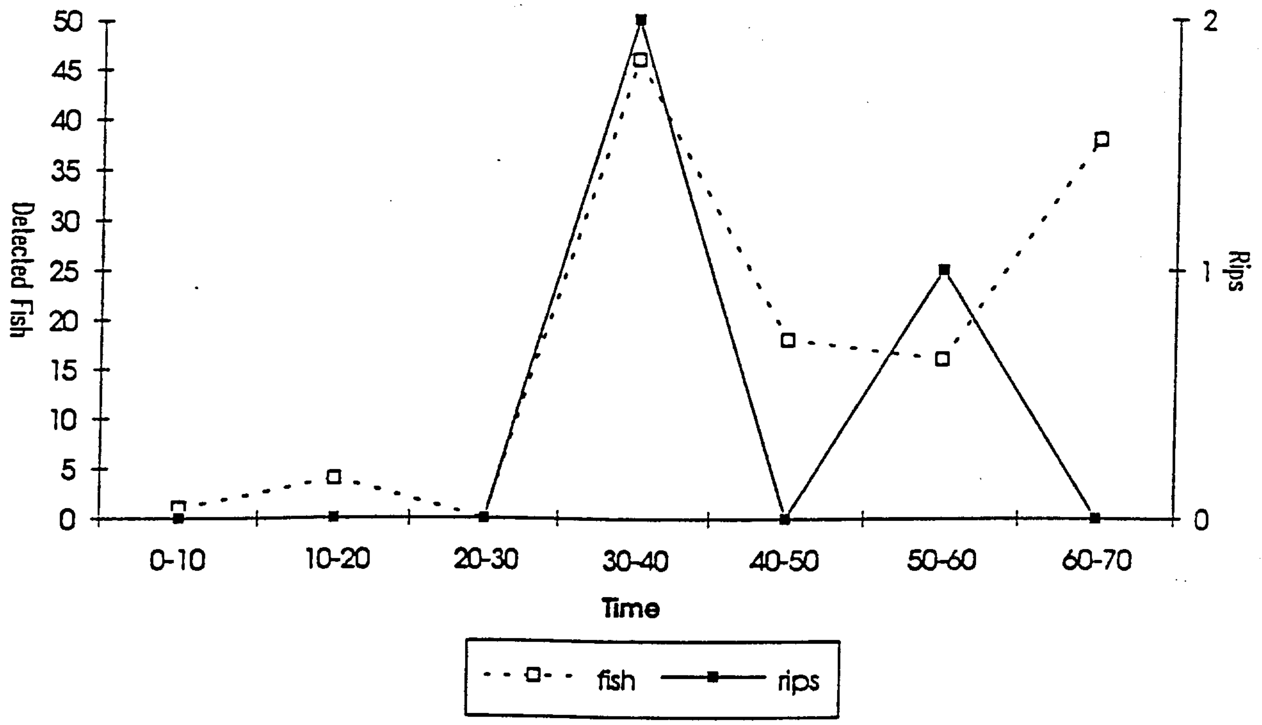

Figure 31. Relationship between detected fish and observed rips along transect # 8

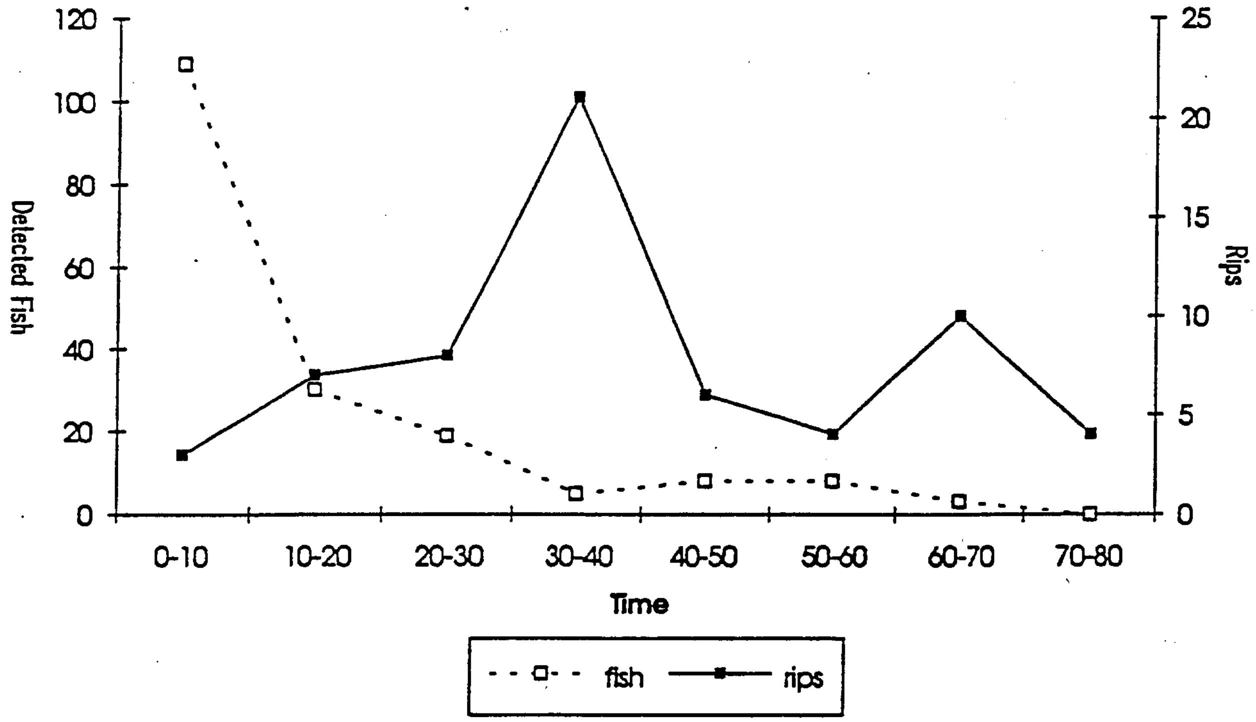

Figure 32. Relationship between detected fish and observed rips along transect # 13.