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November 9, 2007

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STATE/FEDERAL RESTORATION SCIENCE STUDIES
PRELIMINARY STATUS REPORT

94255
DRAFT
FINAL

Project Title: KENAI RIVER SOCKEYE SALMON RESTORATION

Study ID Number: Restoration Science Study Number 94255

Lead Agency: State of Alaska, Alaska Department of Fish & Game;
Commercial Fisheries Management and Development Division

Cooperating Agency(ies): None

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Date Submitted: March 1, 1995

Revised:

Report Note: This is a report of studies that are in progress. All data and analyses provided are incomplete and preliminary. This report does not constitute publication of these data and this report may not be cited or the data used without written authorization of the principal investigators.

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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 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.

The goal of this continuing project (started as Restoration Project 53) is to restore Kenai River, Alaska 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%).

Results from the 1992 and 1993 investigations are presented in Tarbox et al. (1994a, 1994b).

OBJECTIVES

The objectives of this study were to:

- 1) improve stock identification capabilities by combining parasite and genetic stock identification information data in algorithms to provide estimates of Kenai River stocks in the mixed stock fishery of Upper Cook Inlet (UCI).
- 2) 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. Therefore, attached as Appendix A.1 is the contract report prepared for this phase of the project. A brief summary of methods and results are presented in this status report for overview purposes.

This report also details only the collection phase of the genetic stock identification program. Laboratory analysis and reporting of separation methods and results are covered under the status report prepared for Restoration Project 94504 (L. Seeb, personal communication, ADF&G, Anchorage).

Stock Identification

Sockeye salmon entering the major drainages of UCI were sampled for genetic and parasite characteristics in 1994. Ten baseline populations were sampled for genetic characteristics (Table 1). In addition, mixed stock samples were collected from one drift gill net fishing period and from the Kenai, Kasilof, and Yentna Rivers. Sample sizes for allozyme baseline collections were set at 100 (Allendorf and Phelps 1981, Waples 1990). Mixed stock sample sizes were set at 350 for the fisheries sample and 200 for the main river samples (L. Seeb,

personal communication, ADF&G, Anchorage).

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; Waltemyer et al. 1993).

Offshore Test Fish Program

In 1992 and 1993 hydroacoustic equipment and techniques were tested in UCI offshore waters. Results of this work indicated that hydroacoustic techniques could detect salmon and provide a population index for "in season " management use (Thorne and Salomone 1993). However, the primary limitation identified in the study was vessel speed relative to limitations (signal/noise ratio) of the hydroacoustic gear. 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 salmon abundance. Therefore, in 1994 an increase of vessel speed was attempted while completing 12 randomly selected transects during two 48 hour periods. These started on 13 and 19 July (see Figures 1 and 2 in Appendix A.1).

Estimates of hydroacoustic derived salmon abundance were compared to the abundance estimates generated from the commercial harvest (method detailed in Appendix A.2).

A Model 102 Dual-Beam Scientific Echosounder with 120/420 dual frequency was used to collect data to echograms and DAT tape. The 120 and 420 kHz transducer had nominal beam widths of 7 and 6 degrees respectively. The BioFin towing vehicle was towed behind the vessel at a depth of approximately 3m. The transducers were oriented in the side-looking mode. Echogram range was 100m, and the acoustic threshold was -47 dB.

RESULTS

Stock Identification

A total of 3,391 sockeye salmon were sampled for genetic characteristics and parasites (Table 1). Sockeye salmon for baseline genetic samples were successfully collected in 10 spawning sites. A total of 7 spawning populations were sampled for a second or third year and 3 new populations were sampled. Genetic samples were transferred to the Anchorage laboratory and are currently being processed. Preliminary results indicated significant differences between stocks within the Kenai and Susitna river drainages (L. Seeb, personal communication, ADF&G, Anchorage). A complete report detailing the results of these efforts will be prepared as part of Restoration Study 94504.

The parasite *Philonema* was present in all systems sampled (Table 1). Infestation rates were variable ranging from 11% to 100%. As in previous years the Central District rivers of UCI had infestation rates of greater than 95% while Northern District systems had more variable rates (Table 1).

Offshore Test Fish

A complete report detailing results, prepared by the contractor, is attached as Appendix A.1. In addition, a draft copy of a technical paper accepted for presentation at the ICES international symposium on fisheries and plankton acoustics is attached as Appendix A.2. The technical paper is a summary of the developmental history of this project and results to date. In addition, a slight modification in the calculation of variance is presented and should replace previous reported variance estimates. Also, techniques of run reconstruction estimates are presented.

The 1994 estimates of abundance of salmon in the fishing district was $630,000 \pm 187,000$ and $300,000 \pm 100,000$ fish on 13 and 19 July, respectively. Run reconstruction estimates were greater than the acoustic survey in both cases. Run reconstruction estimates were 1,220,000 and 733,000. The acoustic estimates were 52% and 41% of the run reconstruction estimates.

DISCUSSION

Stock Identification

The number of systems sampled in 1994 exceeded the original plan and was the result of favorable weather conditions which minimized transportation delays and increased efficiency from having experienced sampling crews. All program objectives were met with the exception of sampling the commercial fishery..

Our original plan was to sample the drift gill net fleet more frequently. However, because of uncertainty in the stock separation results in the 1993 proof test we took a calculated approach in 1994. Our intent was to sample the Kenai and Kasilof rivers early in the season, run the GSI models, evaluate the results, and proceed if everything looked reasonable. What we found in the first sample was relatively poor classification of Kenai river stocks. Therefore, the drift gill net fishery samples were not collected. Instead, our efforts concentrated on improving the GSI model by collecting additional baseline samples. Results to date (reported under project 94504) indicate that this approach was successful and the GSI model will be available for the 1995 field season.

No major technical issues were evident in the sampling phase of this project. Evaluation and use of this program for management in 1995-1996 should proceed.

Offshore Test Fish

Useful management information could be obtained from acoustic estimates without 100% detection or absolute population estimates. At issue is the need for an index to substitute for commercial catch data. At detection rates of about 50% the acoustic estimate could replace the drift gill net fleet harvest in the run reconstruction models (assumes average exploitation rate of 40%). However, the factors which affect acoustic detectability need to be understood. These factors are discussed in detail in Appendix A.2.

This component of the study has met its' project objectives and ADF&G has assumed responsibility for implementation during the 1995 season. In addition, the reporting of these results at the ICES conference will aid other researchers in identifying acoustic detectability parameters.

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Table 1. Daily summary of tissue sample collection by day by site and results of examination of sockeye salmon for the presence of the nematode PHILONEMA in Upper Cook Inlet, 1994.

Date	Location	Loc. code	Daily sample size	Total sample size	Parasite present	Parasite absent	Percent infested	Percent absent
7/08	Kenai R. RM 19.5	244-40-200-902	46					
7/09	Kenai R. RM 19.5	244-40-200-902	24					
7/10	Kenai R. RM 19.5	244-40-200-902	18					
7/11	Kenai R. RM 19.5	244-40-200-902	12					
7/12	Kenai R. RM 19.5	244-40-200-902	12					
7/13	Kenai R. RM 19.5	244-40-200-902	4					
7/15	Kenai R. RM 19.5	244-40-200-902	27					
Total				143	142	1	99.3%	0.7%
7/08	Kasilof R. RM 12.0	244-30-300-903	100					
7/09	Kasilof R. RM 12.0	244-30-300-903	60					
7/10	Kasilof R. RM 12.0	244-30-300-903	40					
Total				200	200	0	100.0%	0.0%
7/15	Cent. Dist. Drift	244-00-000-932	350	350	336	14	96.0%	4.0%
7/17	Kasilof R. RM 12.0	244-30-300-903	200	200	200	0	100.0%	0.0%
7/17	Kenai R. RM 19.5	244-40-200-902	41					
7/18	Kenai R. RM 19.5	244-40-200-902	159					
Total				200	200	0	100.0%	0.0%
7/25	Yentna R.	247-41-101-802	106					
7/26	Yentna R.	247-41-101-802	94					
Total				200	163	37	81.5%	18.5%
7/31	Kenai R. RM 19.5	244-40-200-902	53					
8/01	Kenai R. RM 19.5	244-40-200-902	147					
Total				200	199	1	99.5%	0.5%
8/01	Kasilof R. RM 12.0	244-30-300-903	55					
8/02	Kasilof R. RM 12.0	244-30-300-903	25					
8/03	Kasilof R. RM 12.0	244-30-300-903	18					
Total				98	98	0	100.0%	0.0%
8/04	Glacier Flat Cr.	244-30-300-605	100	100	100	0	100.0%	0.0%
8/04	Seepage Cr.	244-30-300-608	0					
8/09	Kenai R. RM 19.5	244-40-200-902	90					
8/10	Kenai R. RM 19.5	244-40-200-902	72					
8/11	Kenai R. RM 19.5	244-40-200-902	38					
Total				200	200	0	100.0%	0.0%
8/11	Ken/Ski (site 1)	244-40-200-604	50					
8/12	Ken/Ski (site 2)	244-40-200-604	50					
8/12	Ken/Ski (site 3)	244-40-200-604	100					
Total				200	200	0	100.0%	0.0%
8/13	Moose Cr.	244-40-200-607	100	100	100	0	100.0%	0.0%
8/14	Crescent L. (site 1)	245-30-400-905	50					
8/14	Crescent L. (site 2)	245-30-400-905	50					
Total				100	100	0	100.0%	0.0%
8/15	Fish Cr. (Knik arm)	247-50-000-801	99	99	11	88	11.1%	88.9%
8/19	Stephan Lk. (lake)	247-41-105-702	25					
8/19	Stephan Lk. (outlet)	247-41-105-702	25					
Total				50	48	2	96.0%	4.0%
8/20	Out. Skilak (site 1)	244-40-200-605	200	200	200	0	100.0%	0.0%
8/22	Ken/Ski Lks. (site 1)	244-40-200-604	50					
8/23	Ken/Ski Lks. (site 2)	244-40-200-604	50					
8/23	Ken/Ski Lks. (site 3)	244-40-200-604	50					
8/23	Ken/Ski Lks. (site 4)	244-40-200-604	50					
Total				200	200	0	100.0%	0.0%
8/25	Seepage Cr.	244-30-300-608	100	100	100	0	100.0%	0.0%
8/30	Out. Skilak (site 2)	244-40-200-605	200	200	200	0	100.0%	0.0%
8/31	Tustu. Lk.*	244-30-300-808	50					
9/01	Tustu. Lk.**	244-30-300-808	50					
Total				100	100	0	100.0%	0.0%
9/09	Ken/Ski (site 5)	244-40-200-604	100	100	100	0	100.0%	0.0%
9/13	Chilligan R.	247-10-000-704	50	50	50	0	100.0%	0.0%
Total				3390				

The first sample of the outlet of Skilak Lk. was taken from the upper area close to the lake (site 1), same area as sampled in 1993.

The second sample of the outlet of Skilak Lk. was taken from the area surrounding the outlet of Lower Olsen Cr. (site 2).

* Samples taken from the lake in the area surrounding the outlet of the stream that drains the glacier (south of Seepage Cr.).

** Samples taken from lake shore on both sides of the outlet of Crystal Cr.

Stephan Lk. (outlet) samples are from Prairie Cr. near its confluence with Murder Lk.

Site locations for the area between Skilak and Kenai Lks: site 1 is approximately 1 mi. upstream from Cooper Cr. campground; site 2 is

appx. 1/2 mi. upstream of the river bridge at Resurrection Pass trailhead; site 3 is appx. 3/4 mi. upstream of the outlet of Jean Cr.

on the south bank and appx. 1/2 mi. upstream of site where fish were taken in 1992-93; site 4 is appx. 2 mi. downstream of Russian

River campground; and site 5 is appx. 1/2 mi. from the outlet of the Kenai River with Skilak Lk.

Crescent Lk. site 1 is the lake area near the outlet of an unnamed stream on the south shore located appx. 1 3/4 mi. west of the outlet of the lake.

Site 2 at Crescent Lk. is the area near the outlet of the lake.

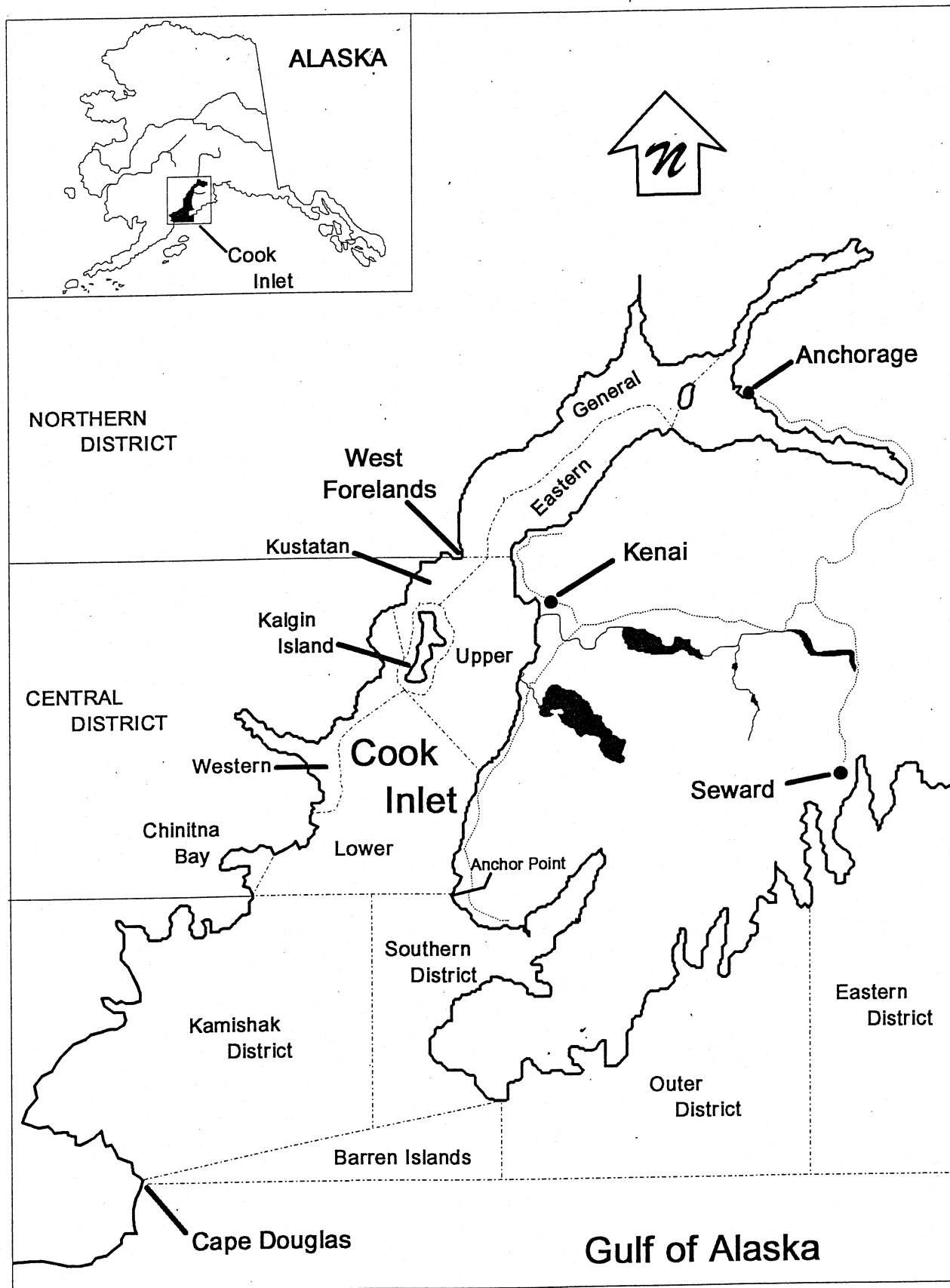


Figure 1. Map of the Kenai River drainage.

Appendix A.1

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

PRELIMINARY REPORT -1994-

Prepared by

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October 3, 1994

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

PRELIMINARY REPORT

-1994-

INTRODUCTION

BioSonics, Inc. contracted with Alaska Department of Fish and Game (ADF&G) for the third year of study on the feasibility of acoustic assessment techniques for adult salmon in Upper Cook Inlet. During the first year, 1992, various deployment modes and survey designs were explored. It was concluded that adult salmon could be detected with mobile side-looking acoustic techniques and that a randomized block design with orthogonal transects should produce an estimate with reasonable precision (Thorne and Salomone 1993). During the second year, 1993, the first 48-hr district-wide survey and real-time population estimate was conducted, as well as many transects along the Anchor Point line for correlation with the test fishing program (Thorne 1994). The purpose of the 48-hr survey was to develop an approach that could obtain an estimate of the numbers of fish in the district that could serve as an alternative to fisheries catch data in the future years when stocks were too low to allow an open fishery. The purpose of the Anchor Point transects was to compare acoustic counts with test fishing catches and explore the potential of improving index precision with acoustic observations.

The 1993 study indicated that the 48-hr surveys could provide much needed management information. Detection efficiency was not 100 per cent; the acoustic survey seemed to underestimate the total population. However, it appeared capable of providing a usable index. Consequently, the third year of study, 1994, focused on the 48-hr district-wide survey and real-time population estimates. The major objective was to determine the relationship between the acoustic estimates and the actual adult salmon population. Secondary objectives included further investigation of the signal to noise environment for acoustic detection of adult

salmon and measurement of the target strength characteristics of the adult salmon. These factors clearly affected the detection efficiency of the acoustic surveys.

This report provides preliminary results of the 1994 surveys. Specifically, it details the results of the two 48-hr surveys that were conducted and the relationship of the results of these surveys to other information about the populations of salmon that were present at the time of the surveys. It also examines the detection efficiency as a function of range and its relationship to population estimation. This preliminary report does not include the results of the target strength measurements conducted in 1994 as that work is yet to be completed.

METHODS

Two 48-hrs surveys were conducted: the first during July 13 and 14, and the second during July 19 and 20. The acoustic equipment consisted of a dual-frequency (120 and 420 kHz) dual-beam BioSonics Model 102 Scientific Echo sounder, a BioSonics Model 111 Thermal Chart Recorder, a BioSonics Model 171 tape recording interface, a Sony Walkman Digital Analog Tape Recorder (DAT), and associated test equipment, cables, dual-beam transducers and a BioSonics BioFin towing vehicle. Primary settings and connections of the equipment are listed in Table 1. The survey was conducted with the charter vessel, Angeline.

Both 48-hr area wide surveys consisted of twelve transects. The first survey used the identical transects as in 1993 (Fig. 1). The second series altered the location of one transect to improve the statistical characteristics of the data (Fig. 2).

The two acoustic transducers, one at 120 kHz and one at 420 kHz, were mounted on the BioFin towing vehicle in a side-looking mode. The nominal beam widths were 7 degrees for the 120 and 6 degrees for the 420. During 1993, the towing vehicle was towed behind the boat at a depth of about 3 m and the two acoustic beams were oriented perpendicular to the vessel track, one looking starboard and the other port. In 1994, following recommendations of the 1993 study, the towing vehicle was towed along the starboard side of the boat, at a depth of about 2 m, and both transducers were aimed in the same direction, perpendicular to the vessel track pointing starboard. Both frequencies were operated simultaneously. All data were recorded on the DAT. Echograms were produced in real-time on only one frequency at a time. Initially, the frequencies were alternated at 15 min periods, but later on the 120 kHz frequency was primarily used because of better propagation conditions. Echograms were produced for both frequencies for all sampling periods in post processing. Echogram range was 100 m. For the initial survey, July 13 and 14, the same marking threshold was used as in 1993. It corresponded to a -47 dB acoustic target strength based on the calibration data for the 1993 survey.

Data for the real-time population estimate were obtained from the echograms in a same fashion as in 1993. For each transect, the number of fish were counted within 20 m wide range intervals from 0 to 100 m. Based on protocols developed previously, the highest interval count was used for the estimate unless two or more were similar, in which case the average was used. Sampled area was calculated as 20 m times the length of the transect. Fish density

was estimated as the number of detected fish along the transect divided by the sampled area. The fish population estimate for each transect was the fish density for the transect extrapolated over the total area represented by the transect.

The total surface area of the survey, 3,295 million square meters, was divided into three regions, south, central and north. For the first survey, four orthogonal transects were run within each of the three areas. Means and variances were obtained for each area, then summed for the total population estimate as in the 1992 study (Scheaffer, Mendenhall and Ott, 1979; Thorne and Salomone, 1993). For the second survey, five transects were run in the south area, where the largest numbers of fish were typically observed, four transects were run in the central area, and three in the north area.

During post survey analysis, the DAT tapes were used to produce echograms for all transects at both frequencies. These echograms were then examined to obtain echo counts in 20-m range intervals to 100 m and to compare frequencies. These data were used to investigate detectability as a function of range and noise conditions. Also, portions of the taped data were processed with a BioSonics Model 281 Dual-Beam Signal Processor to investigate target strength characteristics of the adult salmon.. Finally, target characteristics were evaluated to examine the spatial characteristics of the salmon, especially schooling tendencies that would result in multiple target echoes, as well as sources of false targets that could result in error.

RESULTS

Real-Time Population Estimates

The number of fish detected during the first series, July 13-14, based on the 1993 threshold, was much lower than expected. The series was reanalysed with a 2 dB lower threshold to evaluate the possibility that the system gains had changed in the intervening year. Noise levels were still very reasonable at the lower threshold, and there was a substantial increase in the number of targets that were detected. The population estimate from the lower threshold was 630,000 fish with a confidence interval of plus or minus 166,000 fish (Table 2).

The lower threshold was maintained for the second series, July 19-20. The resulting population estimate was 300,000 fish with a confidence interval of plus or minus 89,000 fish (Table 3).

The number of fish detected by 20 m range interval for various sections of transects for both series, based on the revised threshold, are given in Appendix 1.

There was a district wide fishery opening immediately after the first series. Total salmonid catch was 471,000 fish. Assuming a 40% exploitation rate, the estimated number of fish in the district was about 1,175,000 fish, or almost twice as many as were detected by the acoustic survey.

A district wide fishery was open the day before the second acoustic series. The total salmonid catch was 354,000 fish. Assuming a 40% exploitation rate, the estimated fish population at the time of the fishery was 885,000 fish. The number at the time of the survey would have been reduced by the amount of catch and would have had some immigration, which would suggest a population on the order of 550,000 to 600,000 fish at the time of the survey, again, almost twice as many as were detected by the acoustic survey.

Evaluation of Factors Affecting Fish Detections

The 1993 study showed that several factors can affect the capability of the acoustic system to detect fish. These factors can be categorized as range dependent factors, and range independent factors. Range dependent factors include winds which affect the smoothness of the water surface boundary, and reflections off the bottom from peripheral portions of the acoustic beam at

shallower depths. Range independent factors include echoes from rips, kelp and other non-fish objects.

Under perfect conditions, the number of fish that are detected should increase with range until the depth extent of the fish is encompassed. The average number of fish that were detected during the July 13-14 series as a function of range is shown in Fig. 3. Both frequencies had very similar detections in the first 20 m, as would be expected since both have similar beam widths, and range effects would be minimal. Detections on the 120 kHz systems increase with range to a peak in the 60 to 80 m interval, then decline. The decline after 80 m may represent a combination of noise effects and expansion of the beam to below the depth range of the adult salmon. At 80 m, the 120 kHz beam would have about 12 m vertical coverage. Detections at 420 kHz fall off more rapidly. The frequency difference most likely represents the increased attenuation loss at 420 kHz which makes it more vulnerable to increasing noise at range.

If the detections in the 0 to 20 m range represent the true fish density, then, in the absence of range losses, we would expect detections to increase linearly with range as long as the beam is within the depth range of the fish. Based on the 1992 study, the depth extent of the adult salmon is about 12 m, so detections would theoretically level off at that point. Fig. 3 shows that even the 120 kHz system does not increase with range as rapidly as would be expected. If the theoretically derived value at 70 m represents the true detections under ideal conditions, then actual detections are about 35% of true in the 20-40 m range interval, about 45% of true in the 40-60 m range interval, and about 52% of true in the 60-80 m ranges. Since the 48-hr estimates are based principally on the 40-60 m and 60-80 intervals, this indication of detection efficiency is in very good agreement with the observed relationship between the acoustic estimates and those derived from the fishery, which suggest detection efficiency slightly over 50%.

Range independent factors do not appear to be a major problem in the surveys. Kelp does return echoes that are often similar in magnitude to those from fish, but kelp are not widespread and can be visually noted. There were occasions where both fish sign (jumpers) and kelp were in proximity, but the occurrence was rare. Fish were clearly associated with rips, and entrained air and debris can either return echoes that are similar to fish, or mask the presence of fish targets. However, fish appeared to be near the rips, but not actually in the rips, so separation appeared to be possible in most cases.

Spatial Considerations

In the majority of cases, the echoes appeared to represent individual fish. However, there were exceptions, particularly during the first series and in the southern area. Fish clearly became more dispersed as they moved north, and as the season progressed.

Although targets were distributed over a wide area, there were clearly concentrations associated with rips.

DISCUSSION AND CONCLUSIONS

The two 48-hr real-time estimates obtained during this study indicated that the acoustic survey detected slightly better than half the fish. If this efficiency is consistent, it would provide a usable management tool. The numbers appeared to track the true population for the two surveys, and the precision obtainable in 48 hrs was reasonable.

The major source of underestimation appears to be deterioration of signal to noise conditions with range. For accurate estimation it would be necessary to detect all fish over the entire depth extent of the adult salmon. It is clear from the results of the 1993 and 1994 studies that detection losses occur with range before the beam can fully encompass the complete depth extent. Detection loss occurs because of noise that results from surface, and occasionally bottom reverberation.

The problem is compounded by the target characteristics of the fish. Side-aspect target strength is highly variable because of the potential of head or tail aspects, which have low returns. Thus while adult salmon represent large acoustic targets under most conditions and can be readily detected, lower target returns from less favorable aspect orientations are often masked by the noise sources.

There are several avenues to increase detection efficiency. However, as confidence intervals appear to be reasonable at the current level of detection efficiency, it is more important for management purposes for detection efficiency to be as consistent as possible. This means consistency in transducer orientation, corrections for range effects, and consistent target threshold criteria. The latter is simply a matter of timely system calibration information, and should not be a serious problem. Sufficient information has been obtained during the past two years of study to make reasonable adjustments for range effects. However, reasonable weather conditions for most of the 48-hr period is critical for quality data since surface reverberation from rough water conditions is the major source of noise.

Consistent orientation could most readily be insured by overlapping the orientation of the two transducers by a few degrees, then selecting the transducer with the best near-surface coverage, or combining the results to achieve better overall coverage (and higher detection efficiency). After three years of 120 kHz and 420 kHz, it is clear that the 120 kHz provides better detection, as expected with the slightly wider beam and lower attenuation. Conversion to two 120 kHz

transducers that were slightly overlapped would be an improvement over the current configuration.

Analysis of the 48-hr survey data was rapid. Using a simple calculator, it was possible to complete the population estimate and variance within 20 mins of the completion of the survey.

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ACKNOWLEDGMENTS

I would like to acknowledge the cooperation of the crew of the Angeline in the survey effort.

Table 1. Summary of Equipment Settings and Connections

BioSonics Model 102 Scientific EchoSounder

F1/F2 MPX, Tx = -3, pulse width = 0.5 msec, Blank = Normal
Blanking distance = 0.5 m, Range = 100 m, Internal trigger,
Trigger interval = 0.2 sec, X1 receiver gain = -6, X2 = -6
TVG = 40logR salt
10 kHz outs to Model 171 AC ins, Detected out to Model 111
Sync 1 out to 171 sync in
Sync 2 out to 171 bottom detect in

BioSonics Model 111 Thermal Chart Recorder

Range 0 to 100 m, threshold 0.2 v, Gray level 3, Paper speed 1/4
signal in dc, grid on, white line off

BioSonics Model 171 Tape Recorder Interface

All sync, normal, normal
Record sync # 1 to sync in, #2 to bottom detect

Table 2. Results of real-time estimate from 48-hr district-wide survey, July 13-14, 1994

			Cook Inlet	July 13-14		
Area (mil. sq. m.)	Transect	Count	Length (m)	Density (#/1000sq.m)	Population (thousands)	Error Bounds (thousands)
#1	1	153	23040	0.33		
1518	2	173	28080	0.31		
	3	106	27000	0.20		
	4	185	24660	0.38	460	116
#2	5	85	14220	0.30		
1095	6	43	22320	0.10		
	7	41	18900	0.11		
	8	21	18360	0.06	154	118
#3	9	12	17100	0.04		
682	10	10	13680	0.04		
	11	4	13320	0.02		
	12	3	12780	0.01	17	9
				Total	630	166

Table 3. Results of real-time estimate from 48-hr district-wide survey, July 19-20, 1994

			Cook Inlet	July 19-20		
Area	Transect	Count	Length (m)	Density	Population	Error Bounds
(mil. sq. m.)				(#/1000sq.m)	(thousands)	(thousands)
#1	1	103	27540	0.19		
	1B	71	22320	0.16		
1518	2	49	26640	0.09		
	3	30	16200	0.09		
	4	30	16560	0.09	189	62
#2	5	11	10800	0.05		
1095	6	35	11880	0.15		
	7	13	12780	0.05		
	8	11	15300	0.04	78	56
#3	9	28	15120	0.09		
682	10	10	20120	0.02		
	11	5	9000	0.03	33	30
				Total	300	89

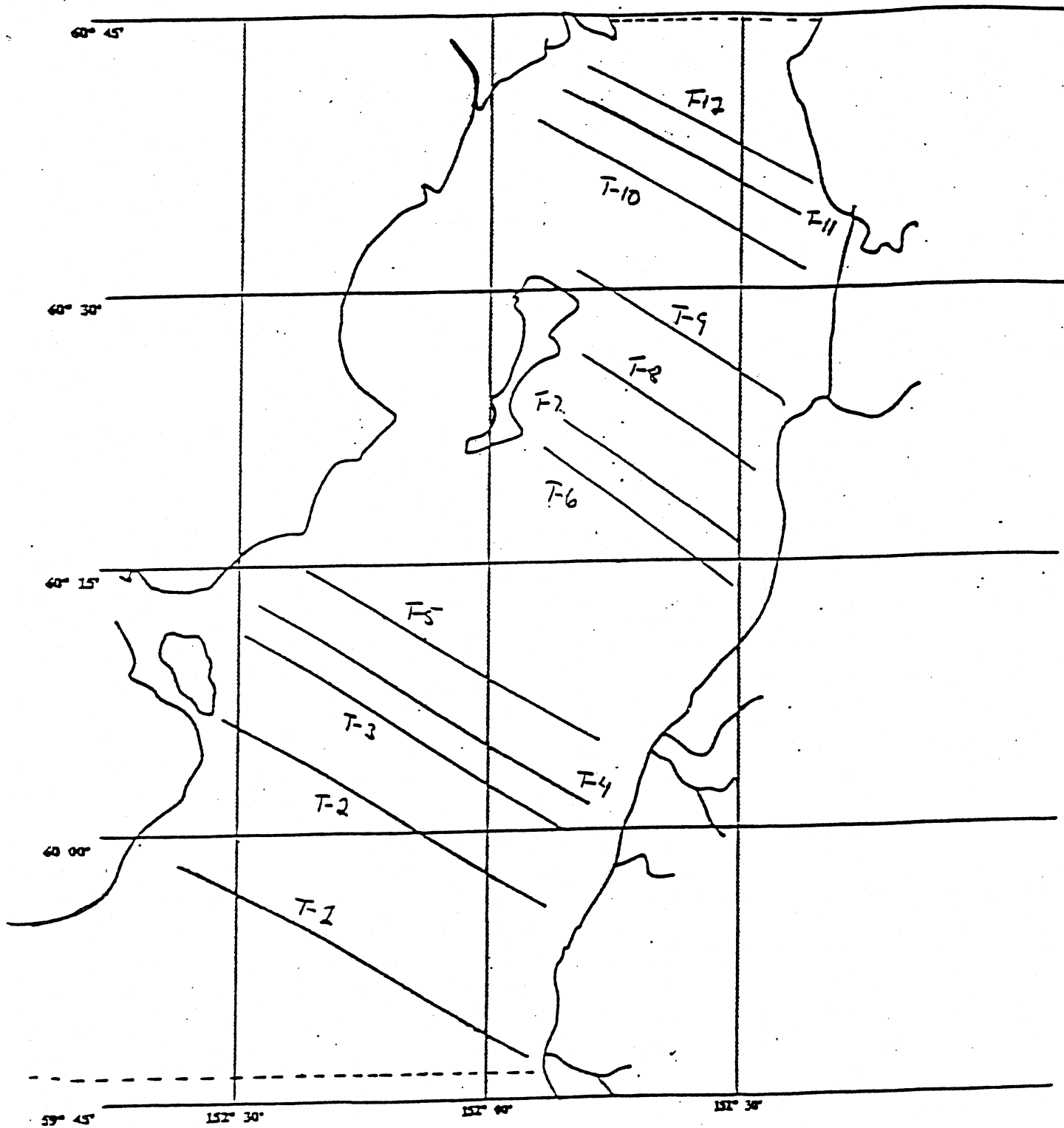


Figure 1. Location of 48-hr survey transects for July 13-14, 1994 series.

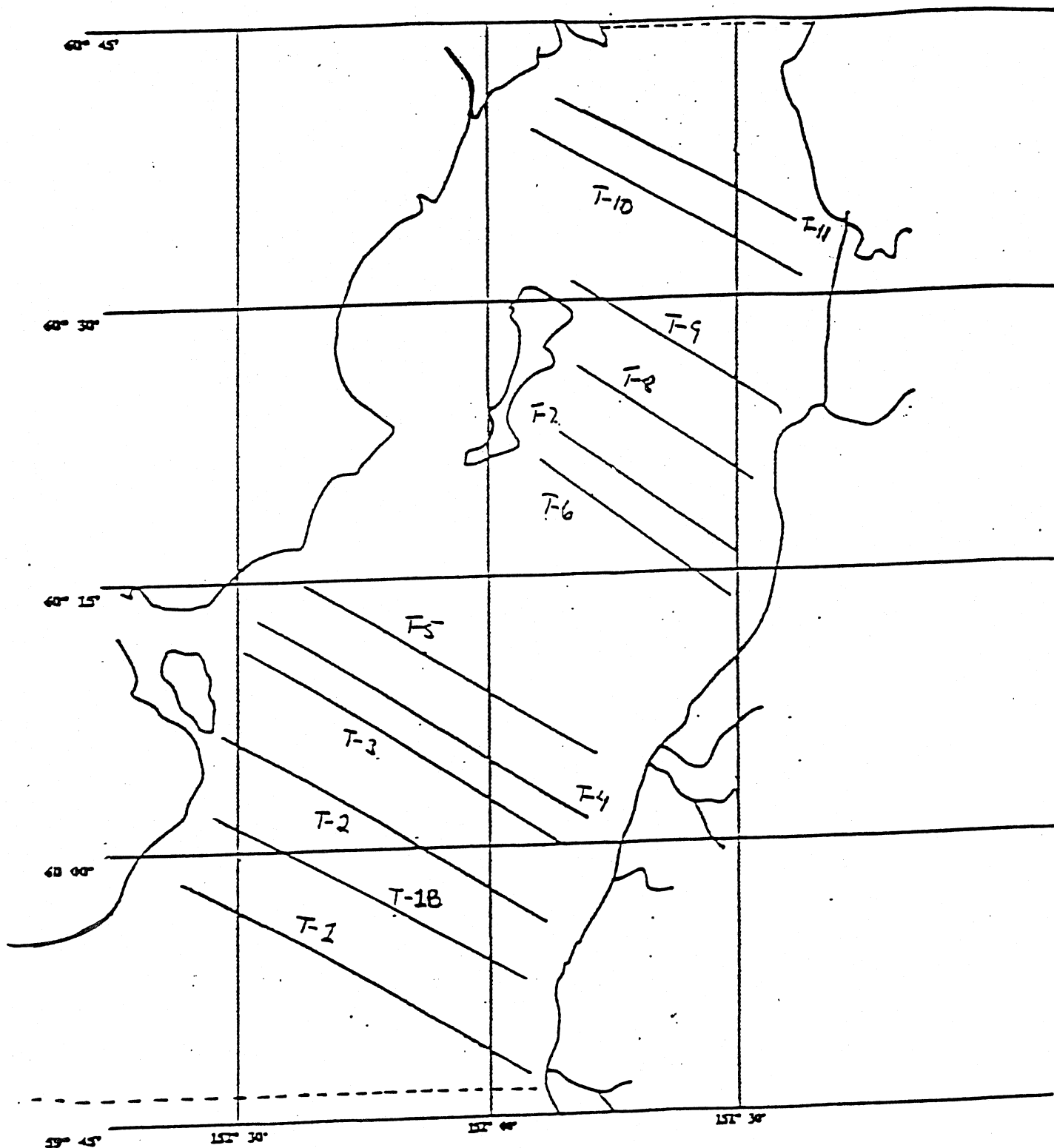


Figure 2. Location of 48-hr survey transects for July 19-20, 1994 series.

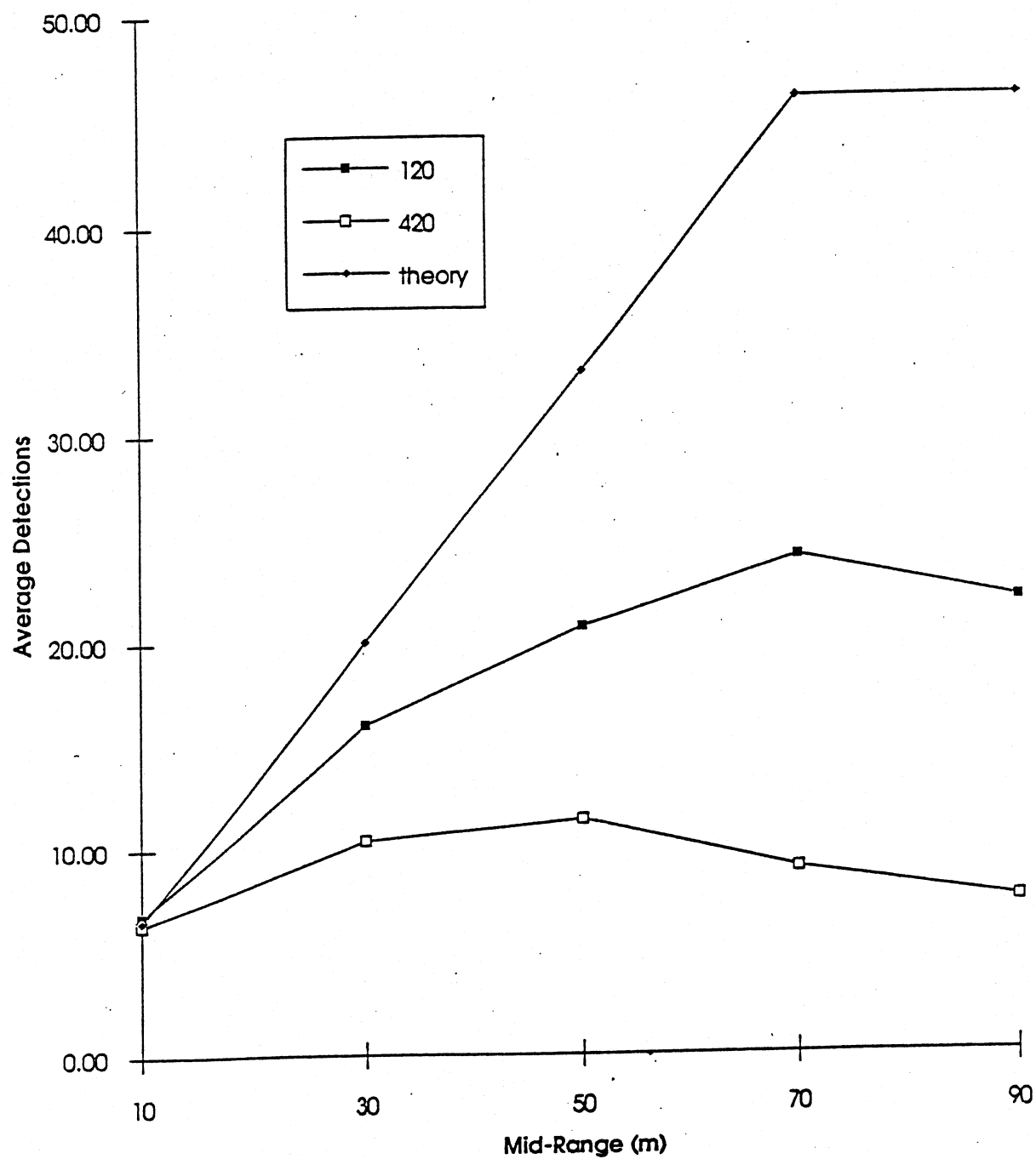


Figure 3. Average number of fish detected by 20 m range interval for 120 kHz and 420 kHz systems compared with theoretical.

APPENDIX 1 - TARGET DETECTIONS BY LOCATION

Anchor	Point	1994		Detections	by	Range		
Series	Transect	Frequency	period (30min)	0 to 20m	20 to 40m	40 to 60m	60 to 80m	80 to 100m
1	1	120	1	11	28	31	11	
			2	8	16	13	8	
			3	9	44			
			4	22	40	35	40	
			5	13	22	10		
	2	120	1	14	45	23		
			2	15	68	59	56	
			3	7	33	45	67	50
			4	2	7	9	3	9
			5	3	12	15	20	
	3	120	1	2	10	10	6	
			2	9	11	9	18	24
			3	1	6	38	50	43
			4	7	8	26	11	16
	4	120	1	5	8	7	4	4
			2	14	4	2		
			3	6	14	4		
			4	6	34	119	81	
			5	9	15	41	22	
	5	120	1	1	13	45	61	
			2	3	9	35	23	35
			3	4	14	6		
	6	120	1	1	9	12	11	
			2	0	8	6	9	12
			3	8	10	12	13	
			4	8	3	9	4	4
	7	120	1	2	4	8	4	
			2	16	6	5	6	
			3	3	5	3		
			4	1	12	11		
	8	120	1	4	4	6		
			2	3	2	1		
			3	5	4	8		
9	120	all				10		
10	120	all			10			
11	120	all			4			
12	120	all			3			

(continued)

[illegible]

APPENDIX 1 - TARGET DETECTIONS BY LOCATION (concluded)

Series	Transect	Frequency	period (30 min)	0 to 20m	20 to 40m	40 to 60m	60 to 80m	80 to 100m
2	1	120	1	2	4	3	4	4
			2	4	3	9	7	4
			3	1	8	7	7	9
			4	5	28	34	32	30
			5	28	58	55	50	
	18	120	1	9	16	20		
			2	2	21	34	39	
			3	6	14	29	20	14
			4	3	3	2	6	3
			5	1	2	0	0	0
	2	120	1	4	10	6	14	8
			2	3	0	0	7	14
			3	9	9	5	16	7
			4	7	16	22	22	
			5	2	9	8	3	
	3	120	1	9	8	9		
			2	6	7	21	12	0
			3	0	7	9	5	5
	4	120	1	3	5	7	2	3
			2	4	7	10	12	2
			3	7	18	13	6	
	5	120	1	6	7	4		
			2	1	4			
	6	120	1	0	2	2	2	
			2	3	13	27		
			3	2	2	2	6	
	7	120	1	4	1	6		
			2	3	3	6	4	
			3	1	1	1	1	
	9	120	1	2	10	9		
			2	6	14	9	5	
			3	0	6	7	3	1
	10	120	1	1	3			
			2	1	5			
			3	0	1	4		
			4	0	1	0	1	
	11	120	1	1	1	2	4	
			2	0	4	2		

Appendix A.2

Assessment of adult salmon in near-surface waters of Cook Inlet, Alaska

K. Tarbox and R. Thorne

Important commercial fisheries occur in the marine and estuarine waters of Upper Cook Inlet management areas in southcentral Alaska as adult Pacific salmon return to spawn in their natal rivers. The most valuable harvests occur on sockeye salmon, *Oncorhynchus nerka*, runs to the Kenai, Kasilof and other regional rivers. Fisheries management has been based on commercial catches, a test fishing index, acoustic counts of the fish in the rivers, and run timing models. However, when run sizes are too low for the fishery to operate, managers require alternate information. Acoustic techniques potentially provide a fishery independent measure of run size. However, the near-surface orientation of these fish preclude a conventional down-looking acoustic approach. Investigations of the feasibility of acoustic estimates were made during July 1992 1993 and 1994. The 1992 study concentrated on various approaches to the near-surface boundary problem, including fixed up-looking, paravanned up-looking and side-looking. Only side-looking techniques achieved sufficient sample coverage to provide a viable assessment. During 1993 and 1994, comparisons were made between side-looking assessments and ground truth information, the detection efficiency of the side-looking system was investigated as a function of sea state and bottom depth, and three district wide-surveys were conducted for comparison with abundance information

from the fisheries data. The results of the three surveys indicated that the acoustic techniques are a viable alternative to the traditional fisheries-based management approach.

Key words: acoustic survey, salmon, Alaska

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Introduction:

The harvest of salmon, *Onchorhynchus* spp., in Upper Cook Inlet (UCI), Alaska (Fig. 1) is regulated by the Alaska Department of Fish and Game (ADF&G) to allow a specific number of salmon to spawn. These spawning objectives are reached by varying commercial harvest areas and times. Management strategies are formulated based on data from the estimation of the commercial harvest, monitoring of spawning numbers, sampling of the harvest for age composition, and run reconstruction analysis (Ruesch and Fox 1994). The value of the UCI commercial fishery has exceeded 100 million dollars annually, and management error can have significant biological, social, and economic costs.

Upper Cook Inlet is over 250 km in length and 64 km in width at its southern boundary. The entire area is characterized by extreme semi-diurnal tidal fluctuations of up to 11 m which produce current velocities in excess of 8 knots and expose extensive mud flats. Substantial freshwater inflow is received from five major glacial river systems: Susitna, Kenai, Kasilof, Matanuska, and Knik. The combination of geographic and tidal features create a complicated circulation pattern of gyres, shear zones, and mixing areas. Various frontal zones, where southward flowing low salinity water meets westward intruding seawater, occur within UCI.

ADF&G estimates the total run of sockeye salmon, *O. nerka*, to UCI by a test fishing program at the southern boundary of the commercial harvest area where salmon first enter the management area. Test fish catches are used in combination with commercial harvest data to describe the salmon migration (Tarbox 1994). However, during periods closed to commercial fishing ADF&G has no ability to estimate the number of salmon entering or in the fishing district. Therefore, an alternative to commercial harvest data was needed. Acoustic techniques potentially provide a fishery independent measure of run size. However, surface orientation by and concentration along frontal zones by migrating salmon presented a challenge to traditional acoustic approaches.

Preliminary investigation of survey procedures were conducted during July, 1992 (Thorne and Salomone, 1993). These included

fixed-location uplooking, paravaned up-looking and towed side-looking transducer orientations. Side-looking orientation gave the best detectability and was selected for the surveys. This paper presents the results of the implementation of side-looking acoustic surveys to estimate the adult salmon run in UCI.

Methods:

A stratified random sampling design was selected following the recommendation of Jolly and Hampton (1990). The total surface area of the survey, $3,295 \times 10^6 \text{ m}^2$, was divided into three regions. Three to five orthogonal transects were randomly selected within each region. Transect lengths varied from 8.8 to 27 km. At the survey speed of about 3 m s^{-1} , each survey was completed within 48 h. Surveys were conducted starting on 14 July, 1993 and 13 and 19 July 1994 (Fig. 1).

The acoustic equipment consisted of a dual frequency (120 and 420 kHz) dual beam BioSonics Inc. Model 102 Scientific Echo sounder, a Model 111 Thermal Chart Recorder, a Model 171 tape recording interface, a Sony Walkman Digital Analog Tape Recorder (DAT), and associated test equipment, cables, dual-beam transducers and a towing vehicle. The acoustic system was calibrated before and after the study.

The two acoustic transducers were mounted on the towing vehicle

in a side-looking mode (Thorne and Salomone, 1993). The nominal beam widths were 7° for the 120 kHz and 6° for the 420 kHz. All data were recorded on DAT. Echogram range was 100 m, and the marking threshold corresponded to a -47 dB acoustic target strength.

Numbers of fish were counted from the echograms in 20 m range strata. The area swept by the sonar along each transect was calculated by multiplying each 20-m range strata by the length of the transect. Densities of fish per unit surface area were calculated for each 20-m range and for both frequencies from the echogram counts. Range strata were used to evaluate the detection characteristics as a function of range. The count from the range strata and frequency with the best detection characteristics was used for the population estimates.

Population estimates and variances were determined from the mean densities along each transect according to standard procedures for a stratified random sample (Scheaffer et al. 1986, Thompson 1992).

Estimator of the mean population density for stratum j is

$$\bar{y}_j = \frac{\sum_{i=1}^{n_j} y_{ij}}{n_j} \quad (1)$$

where y_i is the observed density (number of fish/m²) for the i^{th} transect.

Estimated variance of \bar{y}_j is

$$\hat{V}(\bar{y}_j) = \frac{S_j^2}{n_j} \quad (2)$$

where S_j^2 is the sample variance.

Estimator of the population total of stratum j is

$$\hat{t}_j = A_j \bar{y}_j \quad (3)$$

where A_j equals the area (m^2) of stratum j .

Estimated variance of \hat{t}_j is

$$\hat{V}(\hat{t}_j) = A_j^2 \hat{V}(\bar{y}_j) . \quad (4)$$

Total population is estimated by

$$\hat{T} = \sum_{j=1}^3 \hat{t}_j . \quad (5)$$

Total variance is estimated by

$$\hat{V}(\hat{T}) = \sum_{j=1}^3 \hat{V}(\hat{t}_j) , \quad (6)$$

and a 95% confidence bound on the population estimate is

$$\hat{T} \pm t_{df, .05} \sqrt{\hat{V}(\hat{T})} . \quad (7)$$

Independent estimates of salmon in the fishing district were made using commercial harvest data and run reconstruction analysis.

Total district abundance was estimated by

$$Z = \frac{DH}{e_d} + \frac{SH}{e_s} - E \quad (8)$$

where DH and SH are the drift and set gill net harvest respectively, on the day following acoustic surveys, e_d and e_s are the average exploitation rates for the drift and set gill net fisheries as reported in Mundy et al. (1993), and E estimates entry of fish into the district between the acoustic survey and the fishery using methods reported in Tarbox (1994).

Results and Discussion

The numbers of fish detected along transects during the first survey (July 1993) ranged from 7 to 170, corresponding to a range of estimated densities of 0.04 to 0.36 fish/1000 m². The corresponding population estimate was 447 000 ± 201 000 fish (Table 1). The numbers of fish detected along transects during the second survey (13 July 1994) ranged from 3 to 185, corresponding to a range of estimated densities of 0.01 to 0.38 fish/1000 m². The population estimate was 630 000 ± 187 000 fish. The numbers of fish detected along transects during the third survey (19 July, 1994) ranged from 5 to 103, corresponding to a range of estimated densities of 0.03 to 0.19 fish/1000 m². The population estimate was 300 000 ± 100 000 fish.

Run reconstruction estimates were greater than acoustic survey estimates in all three cases. Run reconstruction estimates of

the number of salmon in the district were 617 000, 1 220 000, and 733 000 for the three acoustic survey periods. The acoustic estimates for the three surveys were 73%, 52%, and 41% of the three run reconstruction estimates (Fig. 2). These results suggested that the acoustic techniques detected only about half of the fish in the district.

Useful management information could be obtained from acoustic estimates without 100% detection or absolute population estimates. At issue is the need for an index to substitute for commercial catch data. At detection rates of about 50% the acoustic estimate could replace the drift gill net fleet harvest in the run reconstruction model (assumes average exploitation rate of 40%). However, the factors which affect acoustic detectability need to be understood.

The capability of the acoustic system to detect fish is affected by both range dependent factors and range independent factors. Range dependent factors include winds which affect the smoothness of the water surface boundary, and reflections off the bottom from peripheral portions of the acoustic beam at shallower depths. Range independent factors include echoes from frontal zones, kelp and other non-fish objects.

Under perfect conditions, the number of fish that are detected should increase with range until the depth extent of the fish is encompassed. Based on the initial studies (Thorne and Salomone,

1993), migrating adult salmon occupy the upper 12 m of the water column. This depth extent was covered at about 70 m range for the 120 kHz system and 80 m range for the 420 kHz.

Examination of the acoustic data shows that detections were limited by surface reverberation from moderate to rough water conditions at much shorter ranges. Under calm conditions, maximum detections were achieved as expected in the 60-80 m stratum (Fig. 3). However, under moderate sea conditions (Beaufort sea states 3 to 4) detections increased rapidly over the first 30 m, improved slightly from 30-70 m, then rapidly declined. Under rough conditions (Beaufort sea states 5 and greater) detections did not improve after 30 m.

The overall effect of range limitations can be seen in the results of the 13 July 1994 survey (Fig. 4). Weather conditions varied from calm to moderate during this survey. Both frequencies detected similar numbers of targets in the first 20 m. This would be expected since both have similar beam widths, and range effects are minimal. Detections increased with range, but not as rapidly as expected by the increased depth coverage. Detections at 120 kHz increased with range to a peak in the 60-80 m strata, then declined. Detections at 420 kHz fell off more rapidly. The frequency difference most likely represents the increased attenuation loss at 420 kHz which makes it more vulnerable to increasing noise at range.

If detections in the 0-20 m range strata represent the true fish density, and fish distribution is uniform in the upper 12 m, then detections should increase in direct proportion to the range out to 70-80 m. Results suggest that the 120 kHz system during the 13 July 1994 survey detected about 35% of fish in the 20-40 m range strata, about 45% in the 40-60 m range strata, and about 52% in the 60-80 m strata (Fig. 4). The population estimates were based principally on 120 kHz data from the 40-60 m and 60-80 m strata. This indication of detection efficiency is in agreement with the observed relationship between the acoustic estimates and those derived from the fishery, which suggest average detection efficiency slightly over 50%.

Range independent factors do not appear to be a major source of error in making the acoustic estimates. Kelp did return echoes that were often similar in magnitude to those from fish, but kelp was not widespread and could be visually noted. Occasions in which fish and kelp were in close proximity were rare. Fish were clearly associated with frontal zones, and entrained air and debris can either return echoes that are similar to fish, or mask the presence of fish targets. However, fish appeared to be near these zones, but not actually in the them, so separation appeared to be possible in most cases.

Most echoes appeared to represent individual fish. However, there were exceptions, particularly during the first and third series and in the southern region. Fish clearly became more

dispersed as they moved north, and as the season progressed. This was not unexpected since pink salmon, *O. gorbuscha*, which tend to travel in large schools, were not abundant in UCI during 1993 and 1994. In addition, sockeye salmon probably begin to disperse and move towards their natal rivers soon after entering the district (Tarbox 1988).

The inability to adequately survey nearshore areas may also have affected the accuracy of acoustic estimates. For example, run reconstruction analysis indicated that 22% of the salmon population may have been in these areas during the 13 July 1994 survey. Within UCI a combination of relatively shallow (< 10 m) and extensive nearshore set gill net fishing gear limited transect lengths. Set net fishing gear in some areas extend offshore over 3 km.

All fish detected during acoustic surveys were assumed to be adult salmon, since few fish of other species appear to occur within the upper 12 m of the water column. Few non-salmon species have been reported from drift gill net harvests which are made with nets extending 10 m in depth. In addition, Tarbox (1988) conducted numerous seine hauls in UCI and reports no other species of fish captured except salmon in the surface waters. While, Moulton (1994) captured 18 fish species in the northern portion of UCI surface waters these fishes were predominantly juvenile herring and salmon and should generally be below the -47 dB detection threshold.

The objective of these studies was to determine whether acoustic surveys could provide a viable method with which to estimate UCI salmon abundance when commercial catch data was not available. The acoustic detection rate of about 50% is comparable to the commercial exploitation rate. The major factor in the detectability appears to be range dependent factors. A useful management index should be obtainable from acoustic surveys by accounting for these factors.

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Table 1. Acoustic population estimate of adult salmon in Upper Cook Inlet, Alaska, 1993-94.

Date	Area	Transect	Count	Density (1000/m ²)	Population Estimate (Thousands)	Variance	Confidence Bound (Thousands)
14 July 93 (Survey 1)	1	1	170	0.36	308	7,506	201
		2	89	0.19			
		3	95	0.18			
		4	28	0.08			
	2	5	18	0.03	94	369	
		6	40	0.11			
		7	35	0.11			
		8	39	0.09			
	3	9	26	0.08	45	42	
		10	23	0.06			
		11	22	0.08			
		12	7	0.04			
Total					447	7,917	
13 July 94 (Survey 2)	1	1	153	0.33	460	3,351	187
		2	173	0.31			
		3	106	0.20			
		4	185	0.38			
	2	5	85	0.30	154	3,497	
		6	43	0.10			
		7	41	0.11			
		8	21	0.06			
	3	9	12	0.04	17	20	
		10	10	0.04			
		11	4	0.02			
		12	3	0.01			
Total					630	6,868	
19 July 94 (Survey 3)	1	1	103	0.19	189	959	100
		2	71	0.16			
		3	49	0.09			
		4	30	0.09			
		5	30	0.09			
	2	6	11	0.05	78	785	
		7	35	0.15			
		8	13	0.05			
		9	11	0.04			
	3	10	28	0.09	33	227	
		11	10	0.02			
		12	5	0.03			
Total					300	1,972	

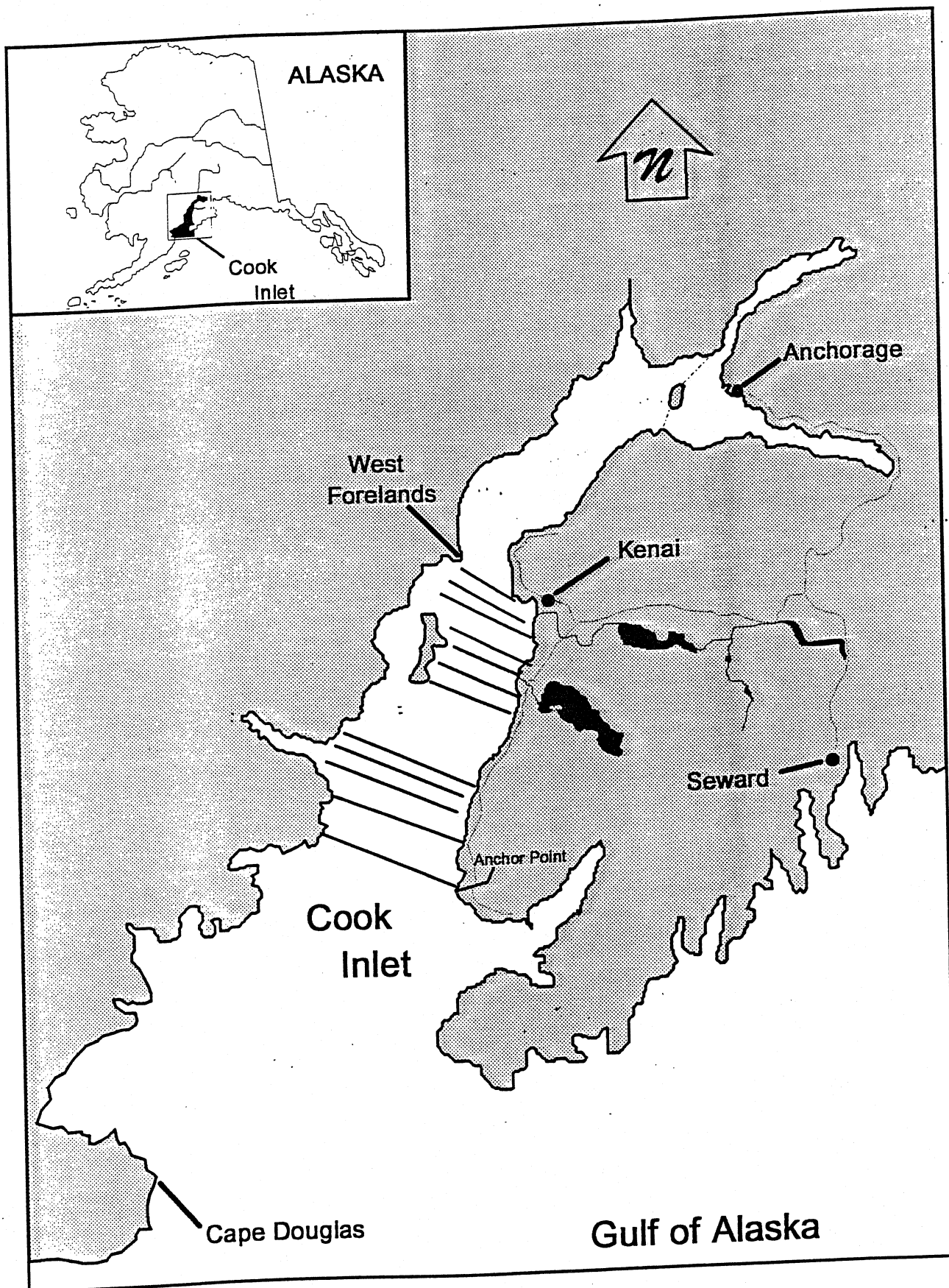
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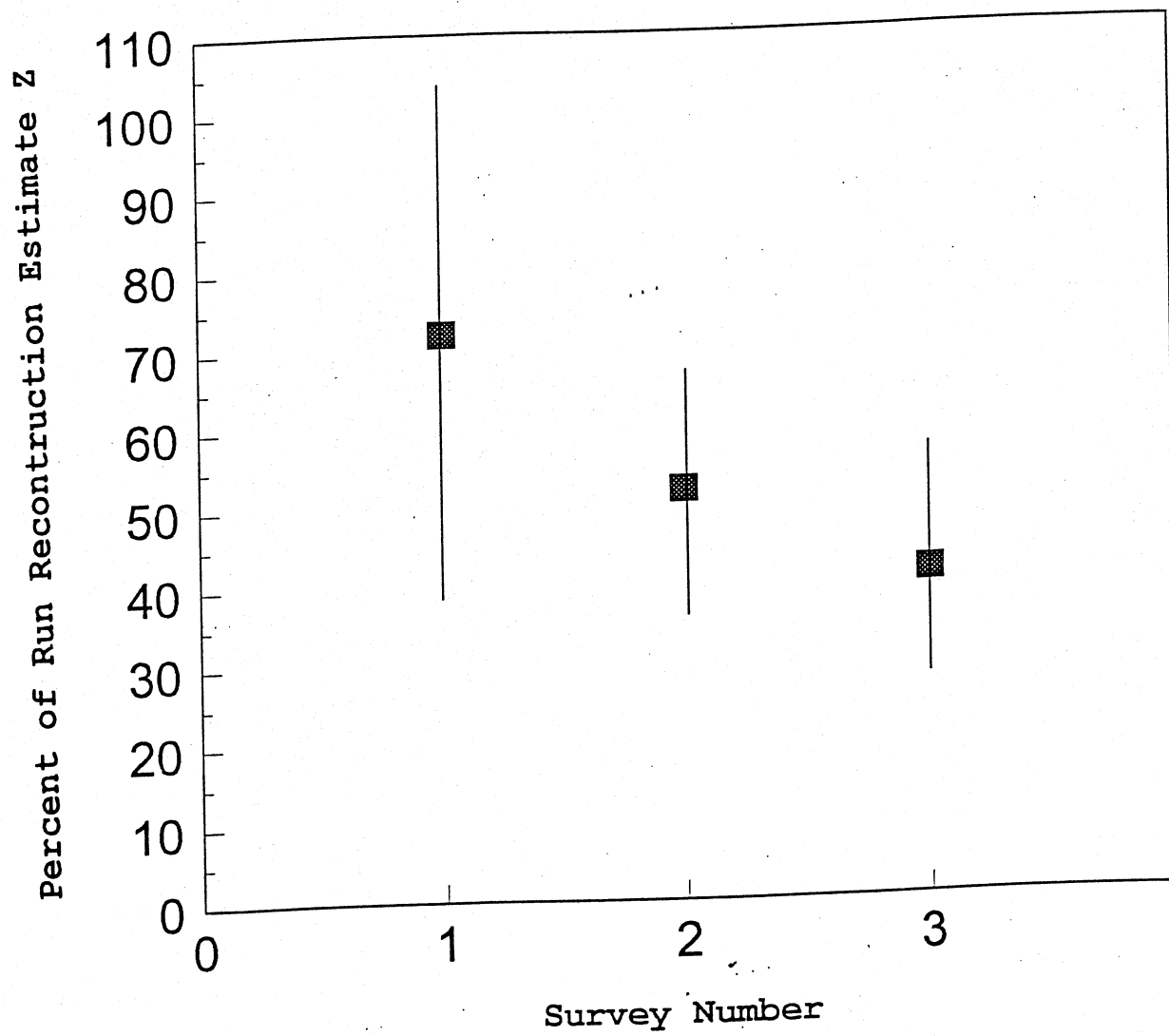
Fig. 1. Map of Cook Inlet, Alaska with acoustic survey transects used on 19 July 1994. Transect 1 starts at the southern boundary.

Fig. 2. Acoustic estimates of salmon abundance in Upper Cook Inlet, Alaska as a percentage of run reconstruction estimate (Z). Confidence bounds are 95%.

Fig. 3. Fish detections as a function of range under three sea states (solid box is calm, open box is moderate, and star is rough). Note that the maximum count refers only to that sea state.

Fig. 4. Average number of fish detected by 20 m range interval for 120 kHz and 420 kHz systems compared with theoretical (open box is theoretical, solid is 120 kHz, and star is 420 kHz).





Percent of Maximum Count

