Exxon Valdez Oil Spill
Restoration Project Annual Report
Nekton-Plankton Acoustics Project 95320N

Nekton-Plankton Acoustics

Restoration Project 95320N
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Nekton-Plankton Acoustics (SEAFISH)

Restoration Project 95320N
Annual Report

Study History: The small runs of Prince William Sound pink salmon in 1992 and 1993, and the collapse of the herring population in 1993, prompted the EVOS Trustee Council to initiate the ecosystem-level studies to improve existing predictive tools. In 1993, the Sound Ecosystem Assessment science plan was developed using the GLOBEC program as a guide. Funding of research began in the spring of 1994. The Nekton-Plankton Acoustics project (SEAFISH) is evaluating and applying acoustic measurement technology to collect information on fish and macrozooplankton distribution and abundance.

This is the second annual report for the Nekton-Plankton Acoustic project. Three technical reports and four abstracts have been published to date, and the chapters in this report are being prepared for submission to journals this year. The Sound Ecosystem Assessment program was recommended to be a 8-10 program. Funding for the third year is in place and preliminary budgets have been projected through FY98 (five years).

Abstract: The primary contribution of the Nekton-Plankton Acoustics project is to estimate animal abundance and distribution information for testing of the river-lake and prey-switching hypotheses and the development of predictive numerical models. The results are spilt between preliminary and completed products. The preliminary products are the estimates of nekton predators and macrozooplankton prey along the outmigration corridor for the pink salmon and the fall and winter density and distribution of the juvenile herring population. The completed products are the stock assessments of adult pollock biomass in Feb-Mar 1995 (37 thousand mt), and adult herring biomass in Oct-Nov 1993-94, April 1995, Oct-Nov 1995, Mar and April 1996 (20, 13, 13, 24, 23 thousand mt).

Key Words: *Clupea harengus*, *EXXON VALDEZ*, hydroacoustics, macrozooplankton assessment, salmon fry predators, *Oncorhynchus gorbuscha*, Pacific herring, pink salmon, population trends, stock assessment, *Theraga chalcogramma*, walleye pollock.

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EXECUTIVE SUMMARY

The Nekton-Plankton Acoustics Project (96320-N) is evaluating and applying acoustic measurement technology to collect accurate information on the distribution, density and size of specific animal populations. These data are essential for the development and operation of numerical models to improve the prediction of animal population change and the testing of the river-lake and prey switching hypotheses under the Sound Ecosystem Assessment Program (SEA). Improving the prediction of animal population change is a prerequisite for accurate assessment of anthropogenic influences and restoration from damage.

This is a multi-tasked project that relies on: (1) cooperative model development to assist in sampling design, data analysis, and interpretation, (2) shared vessel and facilities for data collection and logistical support, (3) data sharing with the agency, university, public and commercial interests, and (4) remote sensing with acoustical and optical technologies. We use the existing knowledge and skills of commercial fishers in the design and implementation of surveys. Salmon hatcheries in the region provide support for field crews and the hatchery releases of pink salmon are treated as an experimental manipulation of the marine ecosystem. Because of the multi-tasking nature of this project, we have relied on partnerships with other funding sources to accomplish tasks to fill in some of the gaps between SEA projects.

This annual report includes: (1) near-field predation studies in Sawmill Bay, (2) far-field predator-prey studies with an emphasis on northwestern Prince William Sound, (3) winter assessments of walleye pollock biomass, and (4) fall, winter and spring assessments of Pacific herring biomass. Predator and prey acoustic assessments are major components of the pink salmon investigations and incremental stock assessments are a primary part of the herring research.

Pink Salmon: We have partitioned the predation of pink salmon fry into near- and far-field and near- and offshore events. The primary focus of this report is on far-field and offshore predation.

Nearfield: In 1992, we measured a gradient of fish density that increased towards the AFK hatchery net pens in Sawmill Bay, southwest Prince William Sound (PWS). These fish were aggregated in large schools at the bottom of the water column during the day and in a diffuse surface (0-20 m) layer at night. They were identified as juvenile gadids and herring. In spring 1993, we made repeated measurements of juvenile pink salmon schools after their release into Sawmill Bay. The pink salmon fry target strength mode was at -55dB and near-surface schools of fry were easily detected using a 200 kHz side-scan sonar. Also in 1993, larger fish targets considered potential fry predators were observed at higher densities in the vicinity of the pink salmon releases.

These observations in the southwest Sound have not been observed in our northwest Sound study area (Lake Bay). The northwest Sound was selected as the primary study area for the pink salmon predation because of the annual release of over 500 million salmon fry from the Arim Koernig hatchery in Lake Bay. Also, the predation events in Sawmill Bay appear to be a late-season event by juvenile and subadult pollock which are more abundant in the southwest Sound.

Far-field, offshore: In 1994 -95, our acoustic-midwater trawl surveys described adult walleye pollock as the dominant offshore predator and competitor with salmon fry along the outmigration route in western PWS. Adult salmon and pollock were the dominant nearshore fry predators. Plankton densities were highest in the offshore sampling areas. The high concentrations of plankton found offshore overlapped with the vertical distribution of pollock at the surface. This made the use of echointegration to estimate pollock density inaccurate. In 1995, we used a counting technique which provides accurate relative densities of walleye pollock numbers along acoustic transects run in 1994 and 1995. We assumed pollock target strength is length dependent: $TS = 20 \log L - 66$ dB.

Our preliminary estimates of walleye pollock biomass in the Wells-Perry Island passages in May-June to be 160,722+/- 29,798 kg in 1994 and 85,484 +/- 5,619 kg in 1995. In 1994, the Wells-Perry Island estimates were 173,327+/-32,422 in May and 148,117 +/- 27,146 in June. This represented around 15% of the offshore pollock in the western Sound study area. In 1995, the Wells-Perry Island estimates were 26,437 +/- 3556 kg in May and 144,117 kg in June. This represented approximately 20% of the offshore pollock in the western Sound study area. There appeared to be a northward movement of pollock in the Sound between May and June of 1995. We have evidence to suggest that the counting procedure underestimates of pollock numbers because of the presence of multiple targets, the small sample unit volume near the surface and boat avoidance. Currently investigations are being conducted to evaluate and correct for bias.

The offshore population of pollock in the northwest Sound is primarily comprised of adult fish averaging 480 mm in length in the spring of 1994 and 515 mm in 1995. These adult pollock are found primarily in the top 40 meters of the water column where they co-occur with macrozooplankton prey. In general, smaller pollock ranging from 150 to 400 mm were observed in the southwest Sound. In 1995, we found the adult pollock distribution around the Sound to be highly patchy and mobile. In winter 1995, we measured 37+/- 7 thousand metric tons of prespawning pollock in the Knight Island and Port Bainbridge areas of the southwest Sound. It is likely that the prespawning biomass measured on the winter survey had migrated from both the Gulf of Alaska and Prince William Sound.

The winter stock assessment of prespawning pollock in the lower Knight Island passage area in 1995 was 10,587+/- 2,193 metric tons. Springtime acoustic surveys in 1995 suggested that the biomass in the western outmigration corridor was about 1,000 metric tons. It is likely that the 10,000 metric tons of pollock seen at Knight Island in the winter was migrating to Port Bainbridge and had originated from throughout Prince William Sound. By collecting this information we have independent support that the spring pollock numbers may be underestimated. This is important because the initial estimates of predation using the springtime pollock numbers suggest that less than ten percent of the fry are eaten by pollock.

Macrozooplankton: We have made preliminary estimates of the relative abundance and distribution of macrozooplankton layers in the top 50 meters of the water column in 1994 and 1995. Initial examination of the acoustic measurements show 0.1-10.0 kilometer horizontal patchiness in the surface plankton layers and 3-4 orders of magnitude variability in density. Net catches suggest the species composition of the layers to be over 90-99% calanoid copepods early in the season. Pteropods, which have a significantly higher TS than copepods, were not found at the surface in high numbers until later in the season. The data also suggested that high densities of pollock often co-occurred with high density patches of macrozooplankton prey.

In 1994-95, we discovered that the adult walleye pollock population in the Sound was targeting the spring macrozooplankton bloom. Measurement of the density, size, and distribution of macrozooplankton patches may be a key aspect of the Sound's capacity for fish production since both juveniles and adults are dependent upon it. We suspect that extreme tidal conditions can disrupt the plankton patchiness and as a consequence predators such as the pollock move down in the water column and feed on other "more" available organisms. This mechanism would support both the river-lake and the prey-switching mechanisms since the physics affects the macrozooplankton prey availability (a patch response hypothesis), which then affects the feeding of predators (a patch dependence hypothesis). Preliminary analysis suggests the role of turbulence may be more important as a mechanism than flushing rate for testing the river-lake and prey-switching hypotheses.

Pacific herring: The adult herring schools observed in the fall-spring surveys between 1993-96 maintain a unique high density and a distinct vertical distribution at night. Juvenile herring mix with juvenile pollock and form a relatively predictable surface layer at night. Echointegration-seine estimates of adult herring biomass in fall 1993, fall 1994, spring 1995, fall 1995 and spring 1996 were 20, 13, 13, 24 and 23 thousand metric tons. The distribution of adults in the spring and fall have been consistent with the primary concentration of fish found around Green Island in the fall and around Zaikof Bay in the spring. When the fish population was sedentary, repeated surveys indicate a precision level of +/- 20%. The fall and winter-spring estimates of herring biomass (13/13 in 1994/5 and 24/23 in 1995/6) indicated low over-winter mortality for adult herring and was excellent repeatability of the stock assessment. We assume that target strength is length dependent: TS = 20 Log L - 71.9.

Seasonal changes in the abundance and distribution of adult herring were observed from 1993 to 1996. Adult herring have been seen to migrate from the Gulf into the Green Island region of the Sound by mid- October. By late winter they move into the Zaikof and Rocky Bays at the east end of Montague Island where they remain until mid-April. In mid-April they appear to spread out along the beaches to spawn. Juvenile herring have been seen in the same areas as adults in the fall, but perhaps not in the same proportion. Juvenile herring appear to be more inshore and nearer to the surface than the adults.

Multi-species management and restoration: SEA has shown that the pink salmon, herring and walleye pollock populations are dominant competitors and/or predators in the Sound. Since the EVOS Trustee Council is a unique entity in the fact that it represents the agencies that are responsible for establishing harvest strategies for pink salmon, Pacific herring and walleye pollock management, the continued investment in monitoring these populations creates an opportunity to evaluate the use of multi-species harvest strategies to assist the restoration of damaged species. The key to making multi-species management decisions is having reliable estimates of the abundance of each species and knowledge of how they interact. The opportunity to evaluate a multiple-species approach to fisheries management in the Prince William Sound is unique and could be a major contribution to fisheries science by the EVOS Trustee Council.

CHAPTER 1

Near-field pink salmon predation: Predator co-occurrences with pink salmon fry in Sawmill Bay, Prince William Sound, Alaska, 1992-93. G.L. Thomas and J. Kirsch. Note: This paper is not to be cited without permission from the first author

ABSTRACT

We made acoustic observations of pink salmon fry predators near a salmon hatchery in Sawmill Bay, Prince William Sound. Shortly after the fry-release season in 1992, we observed an increasing gradient in fish density in Sawmill Bay as we approached the hatchery. Early in the fry-release season of 1993, we made acoustic measurements of larger fish in the water column after fry were released in the central Bay but large fish densities were relatively low and no gradient was apparent. Sample fishing showed the assemblage of fish in the Bay was dominated by adult Pacific herring *Clupea pallasi*, juvenile walleye pollock *Theragra chalcogramma*, and tomcod *Microgaduus proximus*. The average length of pacific herring was 232 mm (n=36), walleye pollock 270 mm (n=57) and tomcod 241 mm (n=17). No pink salmon fry were found in the herring stomachs, but the juvenile gadids had an average of 6.2 fry per stomach (n=64). One tomcod had 82 pink salmon fry in its stomach. Future sampling to document the magnitude of pink salmon fry predation by the juvenile gadids needs to be either continuous or late in the fry release season.

INTRODUCTION

From 1989-93, the Prince William Sound Aquaculture Corporation (PWSAC) released an average of 431 million pink salmon, *Oncorhynchus gorbuscha,* smolts annually into the nearshore marine waters of Prince William Sound (Thomas and Mathisen 1993). From 1990-1994, these releases produced runs of 44, 23, 14, 11, and 27 million adults (ADF&G recorders). This variability in marine survival of pink salmon is of great concern to hatchery and fisheries management in the Sound.

The major source of mortality for larval and juvenile fish in the marine environment is assumed to be predation (GLOBEC 1991; SEA 1993). It is generally accepted that decreased growth of pink salmon in the nearshore marine environment results in higher mortality because it prolongs the period that the fish are highly vulnerable to predation (Heard 1991; Parker 1962, 1964, 1965, 1968, 1971; Mortensen et al. 1991). Several researchers have shown the number of adult pink salmon that return to be affected by mortality during the early marine period (Parker 1968; Ricker 1976; Bax 1983).

In Prince William Sound, the processes of migration, growth and survival begin anew each spring for hatchery pink salmon when the fry are released from hatchery net pens. Although we understand some of the processes that determine the ultimate strength of the pink salmon return, our predictions of returning adults are poor because of the absence of adequate predictive tools

(GLOBEC 1988) and a general weakness in monitoring processes in the marine environment. Despite such weakness, researchers have shown predators are attracted to hatchery release sites to feed (Bayer 1986; Collis et al. 1995). Thus, PWSAC hatcheries have manipulated the time and location of the release of fry in an attempt to minimize the near-field mortality of fry from predation.

Past PWSAC release strategies primarily involved manipulating time of fry release to promote growth as a method to reduce predation: (1) with high zooplankton densities to promote fast growth, (2) when fry are large (the late spring releases) and (3) during times of the day and at places where near-field fry predators are fewest (such as at night to avoid bird predation). Since we assume that predation is the principal source of fry mortality and that survival is size dependent, fast growth or the release of large fry should minimize predation, and therefore maximize survival.

Historical observations suggest that fry releases at night, during high spring zooplankton densities had high survival. Recently, such releases have been met with mixed results. Although these past release strategies are believed to affect processes throughout the life cycle of pink salmon, there has recently been an increased emphasis to reduce predation near the hatcheries shortly after fry release. Observations of high fish predator abundance in the vicinity of the release site (net pens) and plankton/predator densities along the outmigration route are causal mechanisms that have been advanced to explain the recent observations of lower or inconsistent survival of fry.

Objectives

In spring of 1992 and 1993, we conducted surveys to evaluate near-field predation on pink salmon fry from Armin F. Koering (AFK) hatchery in Sawmill Bay. Specifically, the present study was conducted to document: (1) the presence of salmon fry predators near the Arim F. Koernig hatchery in Sawmill Bill and (2) to monitor predator response to fry releases.

METHODS

Data acquisition

Hydroacoustic surveys were conducted in 1992 and 1993 in Sawmill Bay, Prince William Sound to evaluate fish predation on salmon fry. In 1992, a reconnaissance survey was conducted after the fry release season in Sawmill Bay to determine the relative fish density and distribution. In 1993, a hydroacoustic survey was conducted in Sawmill Bay (AFK hatchery) during fry releases to collect quantitative measurements of fish density and target strength for fish sizing.

Six sonar surveys were conducted between May 22 and 25, 1992 in Sawmill Bay after the fry release season. These surveys were designed to describe the distribution of fish relative to the hatchery net pens. The surveys were conducted to cover morning, midday, evening, night, low tide and high tide conditions. In 1992, a 70 kHz Simrad EY-M scientific echosounder was used to measure fish density.

Twelve acoustic surveys were conducted between April 24 and May 6, 1993 in Sawmill Bay early in the fry release season. These surveys were conducted before and after fry released to measure predator response. In 1993, BioSonics 120 and 200 kHz, models 101 and 102, dual-beam echo sounders, BioSonics Echo Signal Processor (ESP), Sony DAT and DVT recorders, BioSonics model 171 tape interface, BioSonics model 111 thermal chart recorder and a portable oscilloscope were used to estimate fish density and target strength. Transducers were mounted in a V-fin and towed at a rate of approximately 7 knots and at a depth of approximately 1 meter. Data collection, real time processing and georeferencing was conducted and recorded with a 486-66, Compac portable computer, a Magellan GPS and BIOMAP/ESP software. Equipment performance was monitored in the field with oscilloscope and chart recorder.

In 1992, predator identification was limited to hook and line and visual observations. In 1993, fish were captured with a variety of gear types that included horizontal variable mesh gill nets, a commercial herring purse seine, long line and by angling. Information on fish length, weight, and stomach contents was derived from captured fish from all gear types. All fish were identified, weighed, measured and examined for stomach contents. For the purposes of this study only pink salmon fry diet items are reported.

Data analysis

In 1992, fish density and distribution was recorded on echograms. In 1993, densities, distribution and target strength of pink salmon fry and potential predators were determined from voltages obtained from the BioSonics ESP software. Acoustic data were post processed using programs coded in IDL (Interactive Data Language) on a Unix workstation. Sample fishing catch data, target classification data on the paper echograms and target strength data on the target echograms were used to identify fish targets to species.

RESULTS

1992 Sawmill Bay Survey

A series of 38 acoustic transects were run perpendicular to the shoreline encircling Sawmill Bay. Day and night surveys were conducted. Refer to Figure 1 for subsample of transects (13, 15, 17, 22, 24, 26, 28, 31, 33) and design.

There was an increase in fish density along the north shoreline as the survey approached the hatchery net pens, and a corresponding decrease in fish density along the south shoreline as the survey left the hatchery net pen site. Figure 2 illustrates the echograms from a subsample of the night-time transects (13, 15, 17, 22, 24, 26, 28, 31, 33). This gradient in density was also present during the daylight transect, however fish were concentrated in schools (Figure 3, transects 24 and 26, day versus night).

Juvenile walleye pollock (about 230 mm) were captured by hook and line around the net pens. Juvenile walleye pollock and large Pacific herring (>220 mm) were observed in the area at the surface during the night survey.

1993 Sawmill Bay Survey

Twelve acoustic surveys were conducted between April 24 and May 6, 1993 in Sawmill Bay, early in the fry release season. Table 1 demonstrates the density of large fish (>-50 dB) in Sawmill Bay for each survey. Figure 4 depicts the target strength histograms for the twelve surveys. Note that on surveys 4271, 4292 and 5032 there is a mode at -55 dB which corresponds to the presence of pink salmon fry released in the center of Sawmill Bay on three occasions, hence the selection criteria of -50 dB for larger fish (potential predators).

Table 1 and Figure 4 correspond in terms of the presence and absence of these large targets. First, note the absence of a mode above -40 dB in surveys 4292, 427h1, 4291, 4293, 5011, 5031, 5032 and 5061 in Figure 4. Large fish were at very low abundance or absent on these surveys (Table 1). Second, note the large modes above -40 dB on surveys 4261, 4271, 4301 and 5021. Large fish were present at moderate to high densities on these surveys. On survey 4271, the mode for the larger target strength is -32 dB, survey 4301 reflects a mode at -40 dB and possibly another at -32 dB, and survey 5021 shows a mode at -40 dB.

Sample fishing with a purse seine, gillnets, long line and hook and line showed that the schooling fish were adult Pacific herring *Clupea pallasi*, juvenile walleye pollock *Theragra chalcogramma*, and tomcod *Microgaduus proximus*. The average length of pacific herring was 232 mm (n=36), walleye pollock 270 mm (n=57) and tomcod 241 mm (n=17).

No pink salmon fry were found in the herring stomachs. In addition, a number of large (600 mm) Pacific cod, *Gadus macrocephalus*, were captured which did not have pink salmon fry in their stomachs. In contrast, the juvenile gadids had an average of 6.2 fry per stomach (n=64). One tomcod had 82 pink salmon fry in its stomach. The most abundant juvenile gadid, walleye pollock, had an average of 4.9 pink salmon fry per stomach. Other less abundant small fish caught by hook-and-line, such as starry flounder, *Platichthys stellatus*, and a black rockfish, *Sebastes melanops*, also had pink salmon fry in their stomachs. Besides pink fry, the fish stomachs contained a variety of marine invertebrates (Euphasiids, oligocheates, copepods).

DISCUSSION

In 1992, after the pink salmon were released from the Sawmill Bay hatchery, we saw large aggregations of schooling fish (potential predators) that increased in density towards the hatchery. The target strength modes of -40 dB and -25 dB support the fish catch data that there were schools of Pacific herring, juvenile and subadult gadids (pollock and tomcod) and large gadids (Pacific cod) present in the area. Early in the 1993 fry release season, we did not see this aggregation of fish. However, near the end of the fry-release season, hatchery personnel observed predators in high concentrations feeding on fry at the surface immediately after releases (R. Korker and others, AFK Hatchery, personal communication). Similar observations were reported in 1991, 1992 and 1994. It appears that major predation events occur late in the fry release season or are episodic. A continuous monitoring program at the hatchery is needed to document the magnitude of the near-field predation.

In contrast, these major predation events by juvenile gadids are not reported for the Lake Bay hatchery where we have concentrated our research efforts. This could be due to the fact that Lake Bay does not have the amount of rearing habitat preferred by the juvenile gadids at Sawmill Bay. The shoreline slope drops off faster and the average depth is greater for Lake Bay than Sawmill Bay. There are also differences in climate with the northwest Sound having a cooler and later springs (Thomas et al. 1991). Spring, summer and fall surveys have shown that the subadult year classes of pollock are more abundant in the southwest passages than in the northwest study areas (Chapter 2). Thus, the characteristics and magnitude of near-field predation may be significantly different between northwest and southwest areas of the Sound. Scheel and Hough (1996) reported high bird predation events on fry released at the Lake Bay hatchery.

Juvenile gadids were observed and caught within Sawmill Bay on all sampling occasions. The greatest proportion of fish captured with conventional gear (89 %) were 175-350 mm. This size of fish was not seen in abundance in the northwest Sound. However, feeding rates for these smaller fish were a lot higher than for the large (400+mm) pollock seen in the offshore sampling areas in the north. Although the higher numbers of fry eaten by the smaller gadids were probably due to the higher nearfield fry concentrations, it is also likely that the smaller gadids may target salmon fry to a greater extent, especially in the shallower nearshore areas. Because of the sharp dropoff in the Lake Bay area, future nearshore sampling will focus within a 50 m distance from the shoreline to determine a possible concentration of juvenile predators missed by the past nearshore surveys that covered 300 m from the shoreline.

In 1996, the number and size of pink salmon fry schools along the shoreline near Boca de Quadra, southeast Alaska, was estimated using side scan sonar (Marino and Stables 1996). In 1992, we used side-scanning sonar to observe the pink salmon fry at the surface and along the shorelines of the Bay and independently used echosounders to estimate the number of predators under the fry schools. In 1996, we will deploy both side scan sonar and down-looking echosounders to collect distribution of pink fry and predators within 50 m of the shoreline.

ACKNOWLEDGEMENTS

This research was funded by a grant from the Alaska Science and Technology foundation and by the Prince William Sound Aquaculture Association. We thank the PWSAC hatchery personnel for logistic support during this study. We also thank BioSonics Inc. for the generous grant towards the purchase of the 101 echosounder system.

We also acknowledge the EVOS Trustee Council and all who have supported our efforts to improve conservation of fish populations by monitoring with new technologies.

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Table 1. Parameters of the acoustic equipment used during the fall 1994 herring survey in Prince William Sound.

SYSTEM	FREQUENCY	SOURCE LEVEL	SYSTEM GAIN	TRANSDUCER DIRECTIVITY	PULSE DURATION
BioS. 101	120 kHz	-225.075 dB	-165.264 dB	.0010718	0.4 ms
BioS. 102	200 kHz	-221.655 dB	-155.756 dB	.0006515	0.4 ms

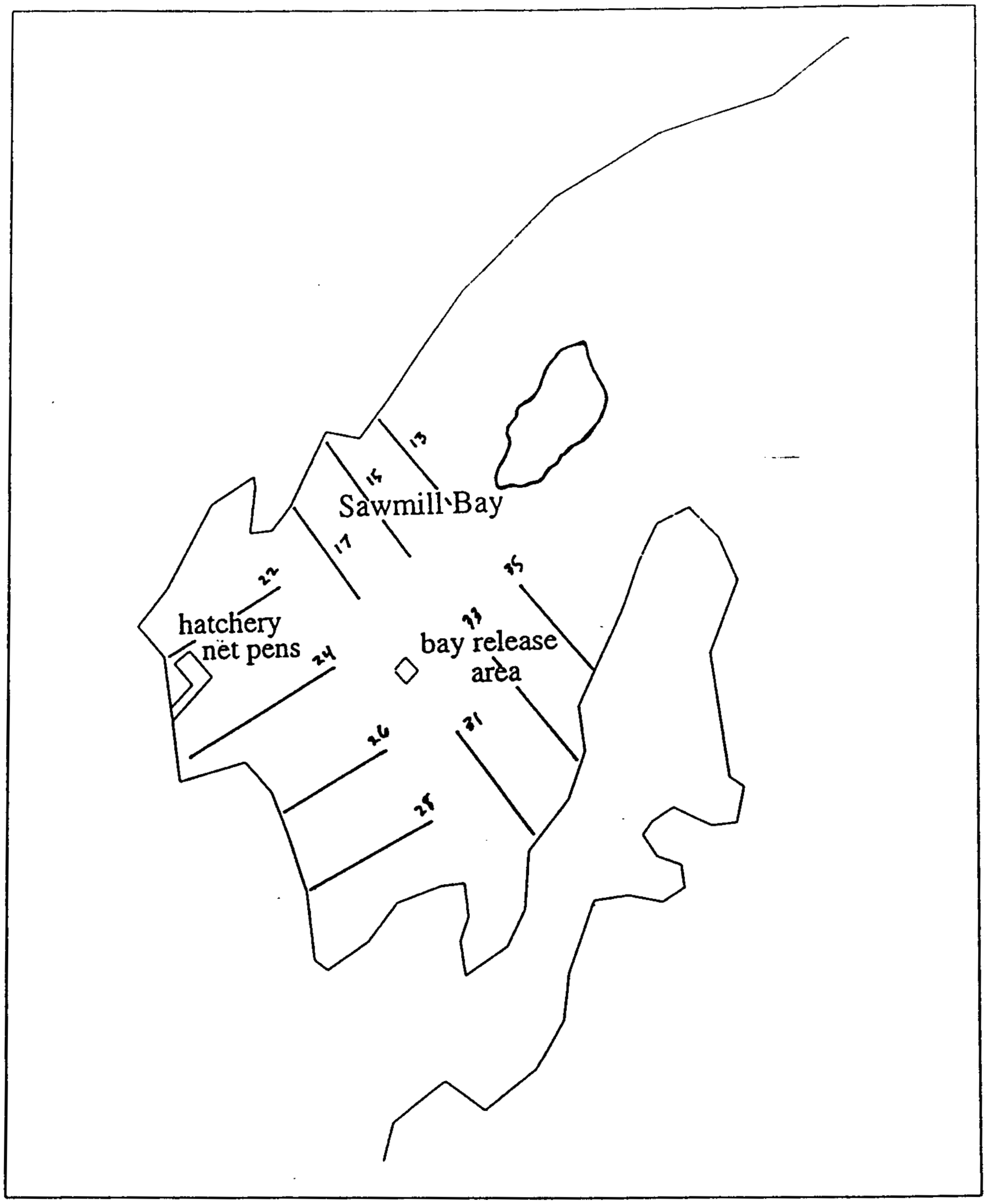

Figure 1. Map of Sawmill Bay showing a subsample of the transects that were run to acoustically measure fish density around the hatchery net pens, May 1992.

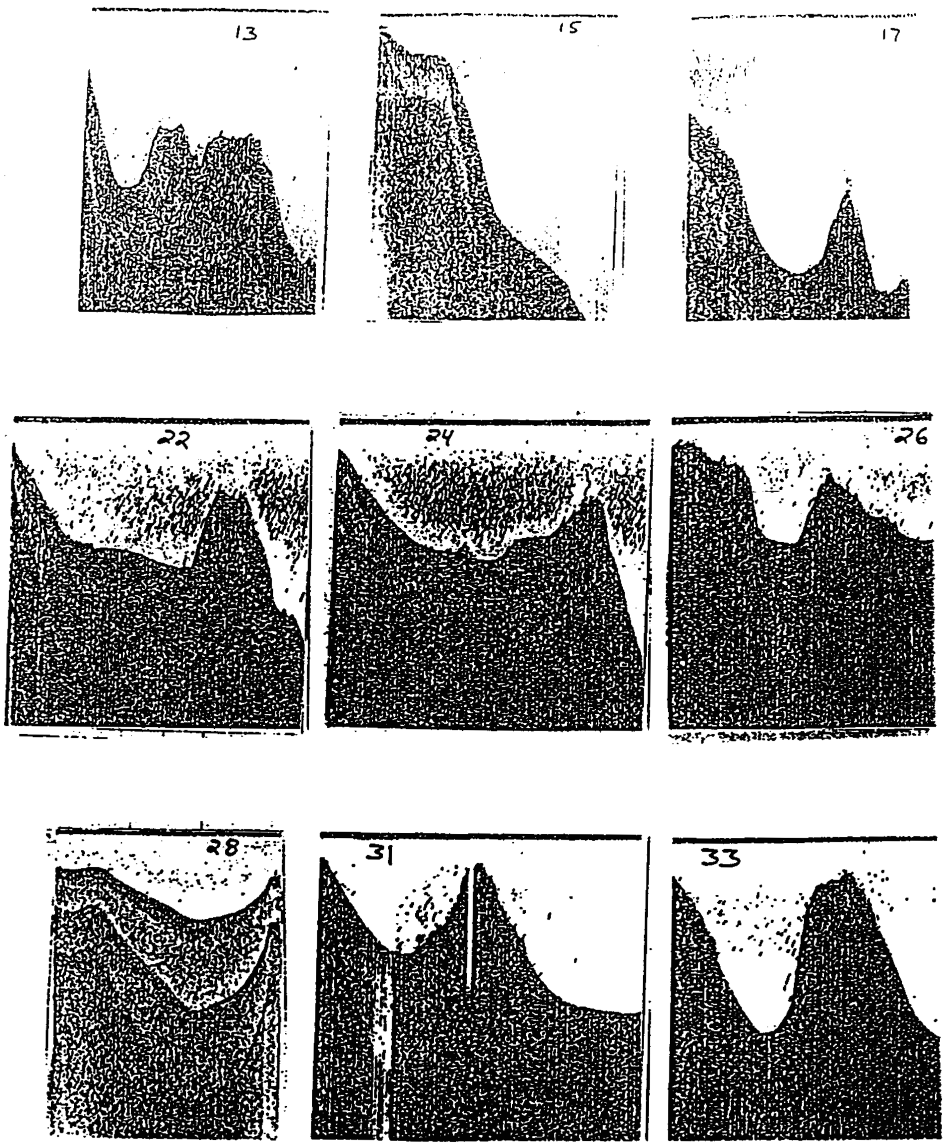

Figure 2. Nine echograms showing the acoustic measure of fish density by depth along a subsample of transects in Sawmill Bay, May 1992. Top line is surface, second line is bottom contour (ranges from 5 to 50 meters). The relative length of transect is shown by width of echogram. Fish targets in the water column are represented as single or clouds of black speckles.

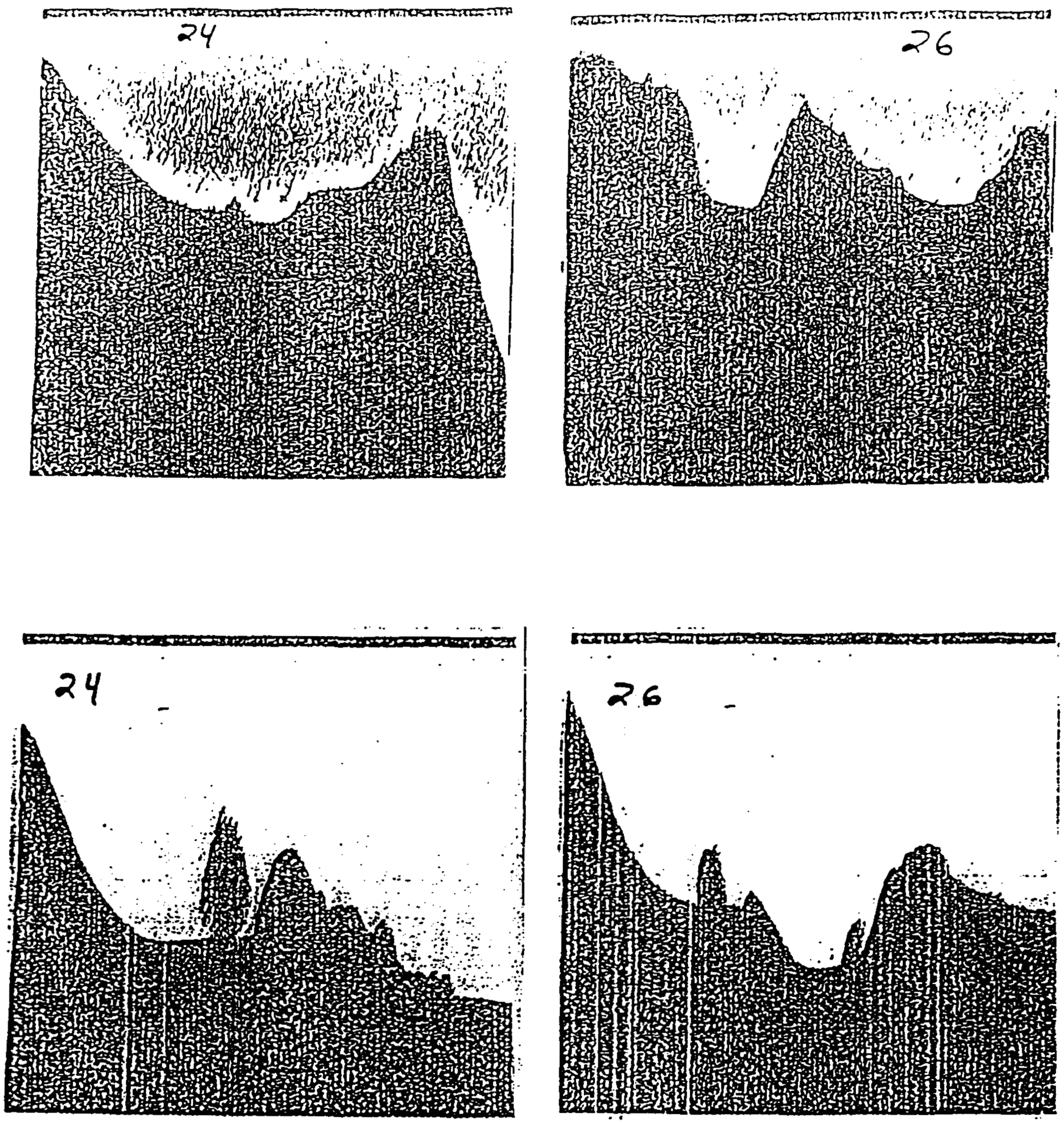

Figure 3. Four echograms showing the acoustic measure of fish density by depth along two transects (24 and 26) in the night (top) and day (bottom). Top line is surface, second line is bottom contour (ranges from 5 to 50 meters). Relative length of transect is shown by width of echogram. Fish targets in the water column at night are represented by single or aggregations of small black speckles, whereas fish targets in the day are large blotches (schools) near the bottom.

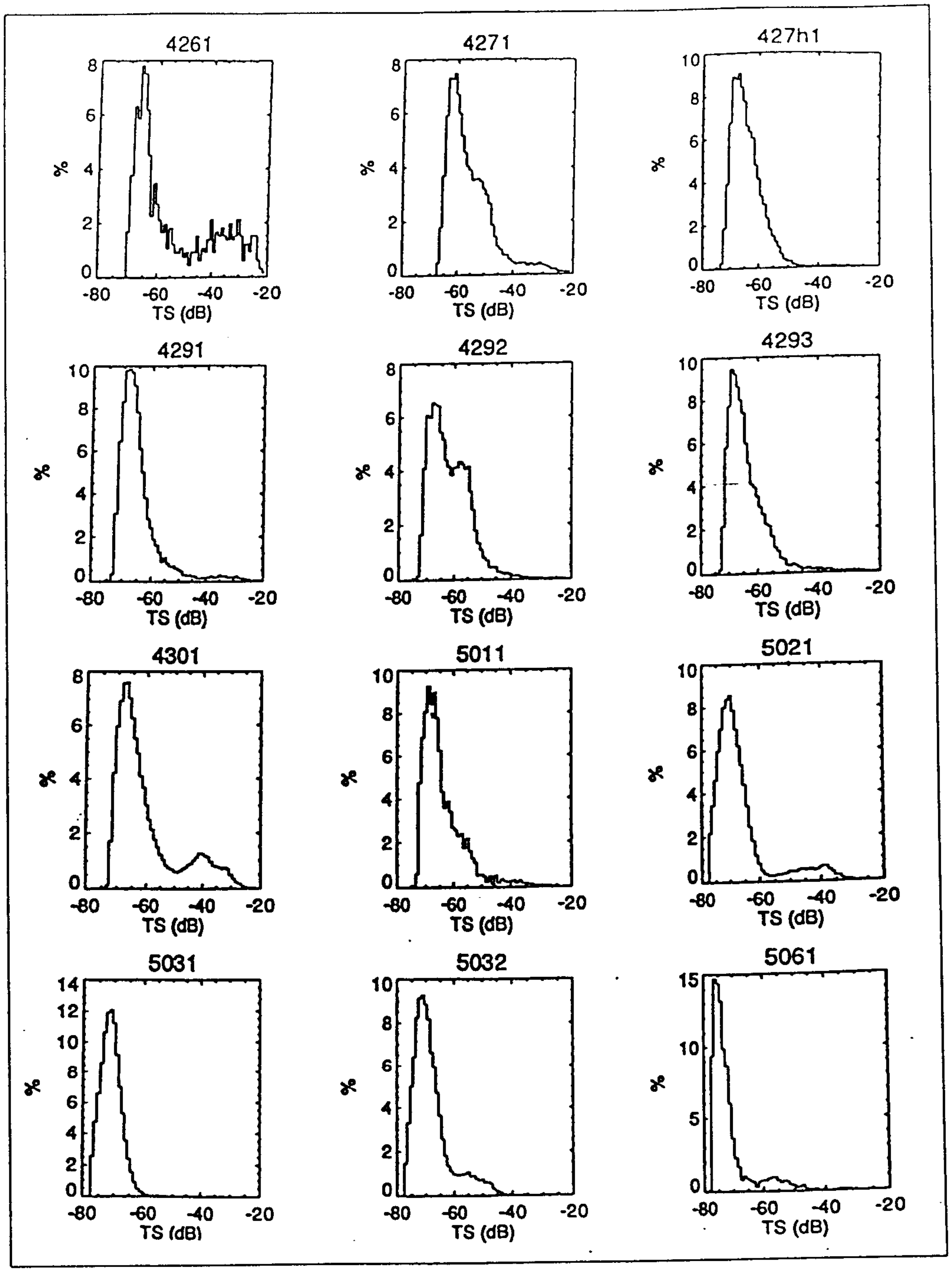

Figure 4. Histograms of fish target strengths by survey in Sawmill Bay, April 26 to May 6, 1993.

CHAPTER 2

Far-field predation: Predator and prey densities along the outmigration path of the juvenile pink salmon in Prince William Sound. G.L. Thomas, Jay Kirsch, Tom McLain, Mark Willette and Ted Cooney. Note: This paper is not to be cited without permission from the first author.

ABSTRACT

We made acoustic observations of nekton and plankton along the outmigration corridor of pink salmon fry in western Prince William Sound in the springs of 1994 and 1995. The greatest emphasis on observations was made in the Wells-Perry Island passages to observe conditions present during and after the release of 500 million pink salmon fry from the Ester Island hatchery in Lake Bay. The nearshore nekton was sparse in contrast to the offshore pelagic assemblage. Adult walleye pollock dominated the offshore pelagic nekton assemblage. Preliminary estimates of walleye pollock in the Wells-Perry Island passages were 160,722 +/-29,798 kg in 1994 and 85,484 +/- 5619 kg in 1995. Due to the fact that over 90% of the walleye pollock were found in the top 40 meters of the water column we are currently investigating the possibility of underestimating abundance as a result of near-surface errors (sample unit volume and boat avoidance).

Larger scale acoustic surveys of the Sound were conducted in 1994 and 1995. In 1994, surveys of the western Sound showed gradients in pollock density between the north- and south-western regions of the Sound. Smaller walleye pollock were concentrated in the southwestern region where several passages lead to the Gulf of Alaska. This is also the location of the Sawmill Bay salmon hatchery. In 1995, acoustic surveys over the entire Sound showed that the density of pollock were notably patchy.

Meso-scale patches of plankton were measured in the top 40 meters of the water column with acoustics in the spring of 1994 and 1995. Vertical net tows at this time of year showed that the species composition of the macrozooplankton was over 90% calanoid copepods. The patchiness of pollock appeared to be correlated with high density patches of plankton. The primary diet of the walleye pollock at this time was calanoid copepods. We are currently investigating the sources of error (species composition, target strength, etc.) in estimating the abundance and distribution of plankton using acoustics.

INTRODUCTION

The stocks of pink salmon in Prince William Sound experienced large fluctuations in survival to adulthood after the *Exxon-Valdez* oil spill. At the present time, it is not clear to what extent the oil spill or natural environmental conditions have affected run strength. Efforts to determine EVOS damages were confounded by the poorly understood effects of climate, food and predators which typically account for 76.9-99.8% of marine mortality (Ellis 1969; Taylor 1983). Recruitment to adult salmon populations is strongly affected by high mortality during the early marine period (Parker 1968; Ricker 1976; Hartt 1980; Bax 1983, Willette 1993). During this period, slow growing individuals sustain a higher mortality because they are vulnerable to predators for a longer time (Parker 1971, Healey 1982; West and Larkin 1987).

This research is a component of the Sound Ecosystem Assessment (SEA) program, a multi-disciplinary effort to acquire an ecosystem-level understanding of the marine and freshwater processes that interact to constrain levels of plankton, fish, mammals and birds. Primary SEA hypotheses are that: (1) climate forcing indirectly influences survival of juvenile salmon through control of the available macrozooplankton prey (Cooney 1993), and (2) during periods of low macrozooplankton prey abundance predators shift to juvenile fish. The SEA program adopted the GLOBEC assumption (GLOBEC 1991), that all mortality of juvenile fishes results in a predation event, either by active or passive predation. Passive predation exists when fry no longer have the food reserves (energy) to escape a predator. Considering survival of the juvenile salmon is partially a function of predation and growth rate dependent upon prey availability, knowledge of predator and prey densities along the migratory outpath are essential.

The assessment of predators and prey along the outmigration path is complicated not only by the lack of complete information concerning how the juvenile salmon outmigrate, but also measurement difficulties. In general, areas frequented by salmon fry during the season were known and sampling effort was therefore stratified to appropriate nearshore and offshore areas. However, the salmon fry use of shoreline and offshore areas in response to tidal and diel changes, and behavior around high prey and predator concentrations, is largely unknown.

Accurate measurement of animal abundance and distribution is crucial to SEA. Measurements of animal abundance are needed to initialize and verify the models being developed. Also, simultaneous measurement of ocean physics and animal distributions is one of the keys to advancing our understanding of marine production processes. Underwater acoustics and optics appear to be the appropriate tools for quantitative assessment of fish and zooplankton (GLOBEC 1991). It is evident that development and implementation of these technologies are of critical importance to the success of SEA.

The objectives of this ongoing study are to: (1) acoustically measure nearshore and offshore nekton and plankton densities, their target strengths and characteristics along the outmigration route of the pink salmon, (2) identify acoustic targets using signal processing, net catches and life history information, (3) evaluate techniques to estimate predator and prey population abundance and distribution along the outmigration path, and to use this information in the testing of SEA hypotheses and model development.

In this paper, we present some of the results of these investigations, develop specific criteria for discriminating pollock which appeared as large, single targets within the water column, and were the most abundant offshore predator along the salmon fry migratory path. In addition, the initial assessment of offshore prey density and distribution relative to the walleye pollock population is presented.

METHODS

Prince William Sound (PWS) is a complex fjord/estuary (Schmidt 1977) located at the northern margin of the Gulf of Alaska (Figure 1). Prince William Sound covers an area of about 8800 square km with approximately 3200 km of shoreline (Grant and Higgins 1910). High mountain peaks in excess of 4000 m border the Sound and receive the brunt of the seasonally intense cyclonic storms from the Gulf of Alaska. Much of the shoreline is bordered by coastal rainforest which receives in excess of 7 m of rain annually (Thomas, et al. 1991). Freshwater input to the Sound occurs as runoff from glaciers, icefields and streams. Large scale surface currents are driven by the wind and buoyancy forcing. Depths exceeding 400 m occur in the western and central portions of the Sound which support overwintering populations of oceanic copepods.

Survey design

Acoustic-trawl/seine surveys were designed for nearshore (within about 300 meters of the shoreline) and offshore (>300 m) areas, with emphasis placed upon the Wells-Perry Island passages in the northwestern corner of the Sound near a large source of outmigrating fry (Ester hatchery). Nearshore and offshore areas were stratified because even though schools of outmigrating juvenile salmon have been sampled in shoreline rearing areas since 1989 (Willette 1993), there are several locations that require juvenile salmon to cross large expanses of open water. Since the portion of salmon fry using the offshore versus the shoreline for migration purposes was unknown, a nearshore and offshore strata were established to determine predator fields along the migratory path.

The western corridor of PWS was stratified in north-south and nearshore-offshore directions (Figures 2 and 3). A time series of surveys were conducted over the season to determine the density and distribution of potential predators and prey along the outmigration route. In 1994, the primary effort was to describe conditions in Wells-Perry Island and upper Knight Island passages but some effort was made to describe the nearshore and offshore conditions along the western corridor from Wells Passage to Montague Straits. In 1995, the primary effort was made to describe conditions in the Wells-Perry Island passages (Figure 4), but some effort was also made to describe the predator-prey densities in offshore areas throughout the Sound (Figure 5).

Acoustic transects

Due to the large offshore area, sparse sampling, and unknown predator population, a systematic transect design was chosen over a random design to provide better representation of the north-south gradient in densities. As a result, some precision was sacrificed for accuracy (Cochran 1977). Precision was estimated by assuming the transects to be independent samples and computing the weighted mean densities and biomass (Seber 1973). The offshore sampling was conducted on parallel transects that ran orthogonal to the passage being sampled.

In 1994, a zig-zag transect design was adopted to sample nearshore fish and collect predator density information along extensive shorelines by bottom depth. Post-stratification of the shoreline by bottom depth was conducted to define near from offshore habitat and zigs were treated separately from the zags to establish independent units for computation of precision. In 1995, we used a series of systematic transects perpendicular to the shoreline because the horizontal extent of the nearshore area sampled was reduced to about 4 by 0.3 km.

Transecting was conducted between 2 and 3 meters per second using transducers mounted on a fin which was towed off the side of the vessel at a depth of approximately 2 meters. Boat speed was estimated at 2.5 m/sec. Night-time navigation in shallow littoral areas was hazardous due to the presence of rocky pinnacles and large tidal fluctuations. Consequently some transects were modified for safety purposes.

Survey timing

Both trawling and purse seining are most efficient at night when lower visibility reduces fish avoidance. In general, acoustic surveys are also best conducted at night because the fish are more evenly distributed in the water column (Houser and Dunn 1967; Burczynski and Johnson 1986) which improves the precision of the estimates. However, because latitude creates less than optimal night lengths and light levels, several compromises were necessary. In 1994, acoustic surveying was conducted during the day and midwater trawling was conducted at night. Acoustic sampling was also conducted during each trawl for signal classification purposes. In the nearshore strata, acoustic surveying and purse seining was conducted during both day and night. In 1995, a 24 hour sampling schedule included day and night efforts with acoustics and nets. All large scale surveys of the Sound were conducted in daylight.

In 1994, a time series of six surveys were conducted: late-April, early-May, late-May, mid-June and mid-July (Legs 1-6). Four surveys were conducted in northwest PWS nearshore and offshore strata to assess early season predation at the beginning of the outmigration on Legs 1-6. Two surveys were conducted in the southwest PWS nearshore and offshore strata to assess late season predation at the end of the migratory corridor on Legs 5 and 6. Two offshore surveys to assess predator distributions along the length of the outmigration corridor were conducted with the acoustics-midwater trawler on Legs 2 and 6. Two 24-hour diel surveys were conducted to assess temporal trends in fish behavior.

In 1995, two surveys (Legs 7 and 8) consisting of a series of 24 hour nearshore and offshore transects and one broad-Sound survey with the acoustic-midwater trawler were conducted to describe the predators and plankton during the fry outmigration season.

Acoustic equipment and processing

Geo-time coded acoustic data was collected using BioSonics 101-120 kHz and 102-200/420 kHz dual beam echosounders, processed in real time with ESP and BIOMAP software on a 486 laptop computer. Each sonar system is equipped with a Magellan DX5000 GPS receiver and external antenna to measure geographic position. Data were collected in 1 meter depth strata from 0-20 meters, 2 meter strata from 20-50 meters and 5 meter strata below 50 meters. Sample process distances were established as every 45 pings in offshore strata and every 45 seconds on the inshore strata. Echo integration, dual-beam target strength and GPS data were stored on hard drives and backed up on optical or magnetic disks/tapes. Unprocessed data were stored on DAT recorders. A block diagram of the data acquisition system is shown in Figure 6.

The entire system was calibrated before, during and after the field season using standard calibration techniques. Standard technique included pre- and post- field season tank calibration by the manufacturer, dockside calibrations with standard targets (tungsten-carbide spheres and ping pong balls) and field tests during the survey with ping pong balls. During the cruise the system receiving characteristics and transmit power was routinely monitored using the calibration oscillator.

Noise peaks at 100 meters were approximately 10 mr on the narrow and wide beams, respectively, with 40 log R amplification. A 5.08 mm tungsten carbine ball was used as a standard target for dockside calibrations which produced a constant mean target strength of -41 dB with a SE of 0.3. Standard tungsten-carbide targets which are accurate within 1 dB (Foote and MacLennan 1982) were used for dockside calibrations. Dockside calibrations were made by collecting a large sample of positions in the beam by allowing the target to swing freely within the acoustic beam. Using the known TS of the sphere, the peak in the target strength distributions was used to calculate the combined source level and receiver gains (SL+RGn andSL+RGw). Subsequently, TS distributions are generated for possible values for the wide beam dropoff (w), and w is chosen from the distribution with the minimum variance. The determined calibration parameters are then set so that the expected TS value of the sphere can be obtained regardless of position in the beam. Ping-pong balls that were calibrated against the standard targets at the dock were used in the field on extended cruises to monitor for through-system changes in sensitivity (Foote and MacLennan 1982). Important system parameters and calibration data are presented in Table 1.

Reference voltages and TVG curves are systematically recorded at the beginning of every 2-hour DAT tape, measured on a digital voltmeter, and written in the field log book. This allows us to calibrate the tape playback output in the laboratory to match the echosounder's output from the field. This routine also allows for detecting changes in the receiver gain while in the field (amplifier drift and TVG curve).

Considerable post processing was necessary because of equipment malfunctions in the field which interrupted real time processing. Post processing to collect missing target strength, echo integration and echogram data, and to correct for system parameter changes was conducted by playback of DAT tapes on personal computers and BioSonics processing equipment. All processing of echo-counting, echointegration, target strength determination, and biomass estimation was done in accordance to standard techniques (Traynor and Ehrenberg 1979, Thorne 1983, etc.). Acoustic data for Echointegration was received on the narrow beam element only, and amplified by a 20 Log R time varied gain (TVG). Dual beam processing data were received on both wide and narrow elements of the transducer and amplified by a 40 log R TVG.

After transferring the data to a UNIX workstation, batch processing of data was conducted to correct acoustic data for temperature and salinity, bottom integration, classify and transform acoustic targets from dB to kg and numbers,and estimate and visualize biomass were conducted. All data are stored in the appropriate format for post processing using ARCINFO, interactive data language (IDL), and automated visual systems (AVS) software. ARCINFO is the geographic information system software being used to store and process electronic map information. The Interactive Data Language (IDL) is an array-oriented programming environment which has been chosen for visualization, signal processing, and statistics. Advanced Visualization System software allows for 3D visualization, data I/O, and statistical functions.

In the spring, we expected a multi-species environment, where schools and single targets are interspersed and are difficult to catch, so a combination of dual beam (Traynor and Ehrenberg 1979; Dickie et al 1983; Burcynski and Johnson 1986; and Foote et al 1986), and multifrequency (Holliday 1972; Saetersdal et al. 1984; Zakharia 1990; Simmonds and Armstrong 1990) measurements represented technological considerations in the survey design. Collaboration with other SEA projects was necessary to conduct the net sampling needed to collect the biological information for sea-truthing the acoustics.

Measured target strengths of individual fish were compared with length data of fish captured by the nets. A power function (Traynor and Ehrenberg, 1979) is currently used to simulate a transducer's beam pattern (ideally a Bessel function) so as to estimate TS. The target strengths are therefore compensated for off-axis location, and targets with angle greater than the mode in the angle distribution (usually about 3 degrees) are excluded so as to remove size bias (since off-axis targets require higher noise thresholds). The empirical formula derived by Love (1977) relating target strength to length was used to convert lengths of captured fish into predicted values of target strength. To establish a fish size-target strength relationship, we used the relationships advanced by Thorne (1983) for target strength per kg versus length, and Traynor and Ehrenberg (1979) for target strength versus length of individual fish.

Identification of targets is a problem in Prince William Sound because of the diversity of marine life. While pollock, salmon, and herring are the dominant fish species, other organisms including zooplankton, squid, and jelly plankton are plentiful and capable of reflecting sound. A first step in the identification of targets was to classify target types on the echogram: schools, layers, aggregations of large targets, large single targets (nekton<-60dB) and small single targets (plankton >-60dB). The second step was to code the appropriate echo integration cells and outline the targets in the processed electronic files with the type of classification or mix of classification that represent each. Third, the species composition for target classes was determined and applied to each of the coded integration cells. At this step the lengths of the fish in the net catch was also compared to the target strength data from the dual beam analysis. Those cells which had mixed classifications received prorated estimates of composition. The integration cells were then assigned a species and size, and a meta file for level of reliability was developed to reflect the consistency of the decision from the various data sets. The target strength for the acoustic to biology transformation (dB to weight) was then chosen from the literature values, in-situ target strength measurements and length of fish in the net catch. Weight of cells then was expanded to density per unit volume or surface area for visualization and estimation of biomass. The area estimates of the strata used to expand density to biomass were derived from maps generated in ARCINFO. Weighted mean densities and their variances were computed and extrapolated to biomass and 95% confidence limits via the delta method (Seber 1973). Biomass estimates of predators were then combined with estimates of salmon fry predation by the same technique to estimate total fry consumption. A block diagram of data analysis is shown on Figure 7.

Sampling equipment and data analysis

Purse seining, midwater trawling and 0.5 m vertical ring nets were used by other SEA projects to collect biological information on nekton and plankton. Purse seining was used along the shorelines and conducted in conjunction with the nearshore acoustic transects. Commercial seiners were chartered to deploy 250 by 30 m purse seines with 1.5 cm stretch mesh and a sink depth of 20 meters. Both round hauling and 20 minute hook-set procedures were used. A midwater trawler of 25 m was chartered to fish the 40 by 28 m wing trawl with 1.5 cm mesh in the bunt. The trawl was equipped with a net sounder to determine depth to head rope and measure fish entering the mouth. Time of trawl ranged from 20 minutes to two hours dependent upon catch rates. In 1995, a pair trawl was used for a brief period for nearshore sampling. Vertical ring nets were used to sample surface plankton from 50 m to the surface. All nekton catch information from the trawls and seines was provided by the Alaska Department of Fish and Game (Mark Willette). All plankton catch information from the vertical ring nets was provided by the University of Alaska at Fairbanks (Ted Cooney).

RESULTS AND DISCUSSION

In 1994, three acoustic-midwater trawl surveys, Legs 2-4, showed relatively high densities of nekton and plankton in the offshore sampling areas of Wells-Perry-Upper Knight Island passages. Nearshore surveys in these areas showed low densities of nekton and plankton. In 1995, similar results were observed on Legs 7 and 8. The following results concentrate on these findings.

Species and size composition

In 1994, the offshore sampling with a midwater trawl at night on Legs 2-4 indicated that northern smoothtongue, walleye pollock and squid dominated the nekton assemblage (46%, 36% and 17% of the catch, respectively, Figure 8). In 1995, the offshore sampling with a midwater trawl at night on Legs 7-8 indicated that walleye pollock and squid dominated the nekton assemblage (87% and 12% of the catch, respectively, Figure 9). However, most trawling in 1995 was conducted during daylight hours and walleye pollock dominated the catch (91% of the catch,

Figure 10). Upon closer examination, over 80% of the northern smoothtongue in the 1994 catch came from two back-to-back trawls.

In contrast, the nearshore sampling with purse seines indicated that Pacific herring dominated the nekton assemblage (56% of the 1994 catch, Figure 11, 56% of the 1995 catch, Figure 12). Sampling the nearshore area in 1995 with a pair trawl on Leg 7 supported that the nearshore assemblage was dominated by Pacific herring (91% of the catch, Figure 13).

The dominant mode of the length frequency of the offshore pollock was 480 mm in May 1994 and 515 mm in 1995 (Figures 14 and 15). There was no significant trend in the size of pollock caught in the midwater trawl by depth (Figure 16). The mean size of pollock in the Montague-Passages areas in southwestern Prince William Sound was considerably lower than the Wells-Knight Island pass areas (Figures 17).

The length frequency of non-pollock targets and juvenile pollock show that the midwater trawl retained large numbers of smaller nekton (northern smoothtongue and squid, Figures 18 and 19) with modes at 100 and 220 mm (Figures 20 and 21). Some adult salmon between 400-700 mm were captured each year by the trawl but their numbers were less than 1% of the midwater trawl catch.

The highest catch rates of adult pollock by the midwater trawl were made between 50 and 70 m but there were a limited number of samples at these depths (Figure 22). In contrast,the highest catch rate for squid was at 10 m (Figure 23) which was the shallowest depth that the midwater trawl could fish (squid were only caught at night). In 1994, the catch rate for northern smoothtongue was highest at 40-60 m (Figure 24). Figure 25 shows a biomodal vertical distribution for juvenile pollock.

The midwater trawl was fished offshore and captured primarily pollock, although it was designed as a herring trawl and readily captured smaller fishes. The purse seines were fished nearshore and captured primarily herring, even though they are effective at capturing larger fish such as adult salmon and pollock. We observed few herring schools offshore and believe that the assemblage is dominated by pollock. We observed fewer pollock inshore and believe that the inshore assemblage is dominated by herring. The small midwater trawl sample effort to the below 40 m layer could have introduced some bias to the average catch by depth, therefore care should be taken when interpreting these results.

Target classification

The echograms revealed three major classifications of acoustic targets: loose aggregations of single and multiple nekton targets, dense layers of plankton targets, and an occasional dense school target. The loose aggregations of single nekton targets had a target strength mode of about -32 dB (Figures 26 and 27), consistent with the observed mean polluck length of 480 mm, assuming a target strength of 20 log L -66 (Traynor and Ehrenberg 1979; McLennan and

Simmonds 1992, Figure 28). The depth distribution of these large targets indicated the highest density of pollock targets were at 20 meters, which is higher in the water column than peak trawl catch rate of 60-80 m.

There are several explanations for the discrepancy between the pollock target and the trawl catch rate depth distributions. First is the small sample size of the trawl effort below 40 meters. These trawl hauls were made at these depths to deliberately target a concentration of fish. Normally, the fish observed in real time were targeted at depths of 20-40 meters, hence the trawl effort distribution by depth. Also, the frequency of midwater trawl malfunction increased closer to the surface, which decreased the actual fishing time and underestimated the catch rate. It is also common for catch efficiency of the trawl to decline towards the surface because of the increase in available light (Barranclough and Robinson 1976). Finally, we recognize that there is some contamination by adult salmon, which are large, near-surface, single and multiple targets like the pollock. However, no changes in the vertical distribution of pollock were discerned at times when large concentrations of salmon were known to be present.

The layers of plankton targets had target strength modes of about -60 to -54 dB which may be high relative to the backscatter from the dominant macrozooplankton at this time of year, calanoid copepods (Figures 26 and 27). This is presumed to be due to failure of the target strength discriminator, i.e. the targets are pooled. This is supported by the fact that when the density of the plankton layer was highest the mode of the target strength distribution shifted to about -55 dB, and when it was lowest the shift was towards -65dB. The smallest targets measured at 40 m (the deepest plankton layer) was -67 dB in 1994 and -71 dB in 1995 (Figures 29 and 30).

The occasional dense school target was limited in numbers and primarily observed in the nearshore areas during the day. This behavior is typical for herring which dominated the nearshore catches. The depth distribution of school targets and highest midwater catch rates coincided between 20- 40 m (Figure 31).

Although their target strengths are relatively low the squid and jelly plankton present problems to acoustic assessment via echointegration. First, the midwater and pair trawl catches of squid suggest it is low in abundance relative to the pollock and only at the surface at night (Figures 8-13, and 23). Since squid have a low target strength (-58.6 dB, Jefferts et al. 1987) and the pollock numbers actually declined slightly at the surface at night (Figure 32), we assumed that the effect of squid was negligible (Figure 32). However, the density of the jellyfish in the pair trawl show that despite their low target strength (which is largely unknown) their abundance may confound echointegration. Target strengths of jellyfish and quantitative information on their vertical and horizontal distributions are needed.

Echointegration and counting of targets

Acoustic samples were collected simultaneously with the midwater trawls in 1994. Trawl catches that were dominated by pollock were converted to c/f (kg/min) and compared to the echointegration of acoustic backscatter (Figure 33). Because of the uncertainties of estimating the pollock abundance by echointegration in a surface layer where they mixed with sometimes heavy layers of plankton of unknown backscatter, we investigated the feasibility of thresholding out the plankton and counting the pollock. We established the threshold by choosing the antimode between pollock targets and plankton targets (Figures 26 and 27). Applying this threshold, we made manual counts of pollock (from tape playback to a storage oscilloscope) and auto-counts of pollock using the BioSonics ESP-DB program for the same transects. We compared manual and auto-counts from 0-50 m which included the plankton layer (Figure 34) and we separated the counts into a plankton layer and sub-plankton layers for comparison (Figure 35 and 36). The auto counts underestimated the manual counts by 13-28% and the manual procedure underestimated pollock densities approximately 5% of the time when multiple targets were encountered. Comparisons between the predicted echointegration from autocounts and observed echointegration values in transects containing low plankton densities suggest the counts may be underestimated (Figure 37).

Another possible source of underestimation is the sample unit size relative to the size of the fish. Given the small sample volume of the narrow beam transducers we use to estimate density and target strength, a problem can occur if the sample unit size is not sufficient to adequately ensonify the fish. This relationship can be viewed as a fish volume to cone frustrum volume or a fish length to cone frustum diameter function (Figure 38). The Central Limit theorem suggests that when a sample unit with sufficient size to reduce the possibility of incomplete ensonification to 5% or lower is absent, the estimate may be biased. This should apply to both the estimation of density and target strength. Observations of slight declines in target strength and densities have been made which could be biological or artificial. Hence, additional research is required.

Several sources of error contribute to this relationship. First, the trawl catch per unit effort is far from perfect. The trawl is open as it is deployed and retrieved which changes the effort. It was not uncommon for the trawls to become imbalanced and alter the fishing effort, especially when fished near the surface. The water flow through the net was unknown. Second, the echointegration measures all the backscatter from nekton and plankton. This includes the plankton, jellyfish, squid and other non-pollock targets. Given the accumulation of these errors and more, the relationship observed suggests that our sampling was robust, yet, not adequte to estimate biomass with certainty. Thus, we developed and implemented an echo counting procedure which could be automatically applied to digital files for numerical assessment. The fit between manual and auto-counts is poorer in the plankton layer, but preferable to echointegration, so it was utilized to estimate pollock abundance. Our analysis of echocounting suggests that the pollock numbers are underestimated by approximately 18-33%. Routines for correcting the underestimation of pollock from auto-counting and multiple targets need to be developed.

Preliminary estimates of pollock abundance

We estimated the average biomass of offshore adult pollock in the Wells-Perry Island passages at 160,722+/- 29,798 kg in May-June 1994 and 85,484 +/- 5,619 kg from three acoustic-midwater trawl surveys of the northwest Sound in May-June 1995. Also in May 1994, we conducted an acoustic-midwater trawl survey of the western Sound to determine how the Wells-Perry Island area compared to the rest of the outmigration corridor of the pink salmon fry. We estimated that 15% of the offshore pollock in the western Sound were in the Wells-Perry Island Passages. During the large-scale survey of the western Sound, we estimated the offshore pollock biomass in the Wells-Perry Island Passages to be 138,641+/-40,585 kg and the entire pass to be at least 1,886,147 +/-1,295,713 kg. The biomass estimate for the Wells-Perry Island portion of the large-scale survey agreed with the estimate from the three northwest Sound surveys.

In 1995, we conducted two acoustic-midwater trawl surveys of the Wells-Perry Island Passages in May and June. The Wells-Perry Island estimates were 26,437 +/- 3556 kg in May and 144,117 kg in June. We also conducted a large-scale survey of the Sound after each of the above surveys. We estimated the offshore pollock biomass in the Wells-Perry Island Passages to be 30,786 kg in May and 251,237 kg in June. We estimated that 8% of the offshore pollock in the western Sound were in the Wells-Perry Island Passages in May and 31% in June. The biomass estimate for the western Sound was about 400,000 kg in May and 800,000 in June. There appeared to be a northward shift in the pollock population from May to June on both the east and west sides of the Sound suggesting a possible post-spawning feeding migration in the spring.

The numbers of pollock are important because they allow evaluation of population-level predation on juvenile salmon in the marine environment. We feel that the present counts of adult pollock are underestimates of the fish present for a number of reasons. First, we feel that the auto-counting technique is about 80% as effective as manual counting. This is probably due to the dual beam target discriminator being more rigorous and excluding valid targets. Second, manual counting is an underestimate of the pollock because of the multiple targets, which are also excluded in the auto-count. Estimates of the number of multiple targets that are excluded from the echo-counting are needed to control quality of the procedure. Third, the large (0.5 m) size of the pollock reduces the probability that they will be completely ensonified in the beam at short ranges. In accord with the Central Limit theorem, the diameter of the beam should be 20 times the length of the fish (10 m) to insure that 95% of the fish are completely ensonified. Since the beam is not 10 m in diameter until a depth of 100 m, the target strengths and densities of the fish may be underestimated. This bias needs to be investigated since the depth distribution of the pollock is 0-40 m. Finally with the near-surface depth distribution of the pollock, boat avoidance may be another source of underestimation. The last two problems will be investigated in 1995 with side-looking sonar measurements of pollock depth and distance distributions.

Plankton and nekton patchiness

Initial estimates of plankton density were made by scaling the echocounts into three density bins (high, med and low). Net samplin during the May-June cruises revealed that calanoid copepods represented over 95% of the plankton catches in vertical ring net catches. The vertical distribution of plankton and pollock were both nearsurface, displayed significant overlap and showed the pollock to be slightly deeper (Figures 39). Initial 3D visualizations of plankton and pollock patchiness have demonstrated some co-occurance of patches in horizontal space, but this is difficult to see without color viewgraphs (Figures 40, 41, 42 and 43).

The quasi-continuous nature of acoustic measurement data allows for quantitative descriptions of patchiness. Hjort (1914) advanced the patchiness hypothesis by concluding that if all the food in the ocean was evenly distributed all the fish would starve to death. Lasker (1988) has proposed a climate-driven, food-patch model to explain anchovy larvae survival in the Southern California Blight. We have proposed a similar hypothesis under the guise of the River-lake hypothesis. Presently, the plankton acoustics project is examining the nature of plankton patches relative to physical forcing events such as tides and storms, and predator abundance. The examination of the predator and plankton patches should reveal insights to the predator behavior in response to prey availability which is congruent to the prey switching hypothesis.

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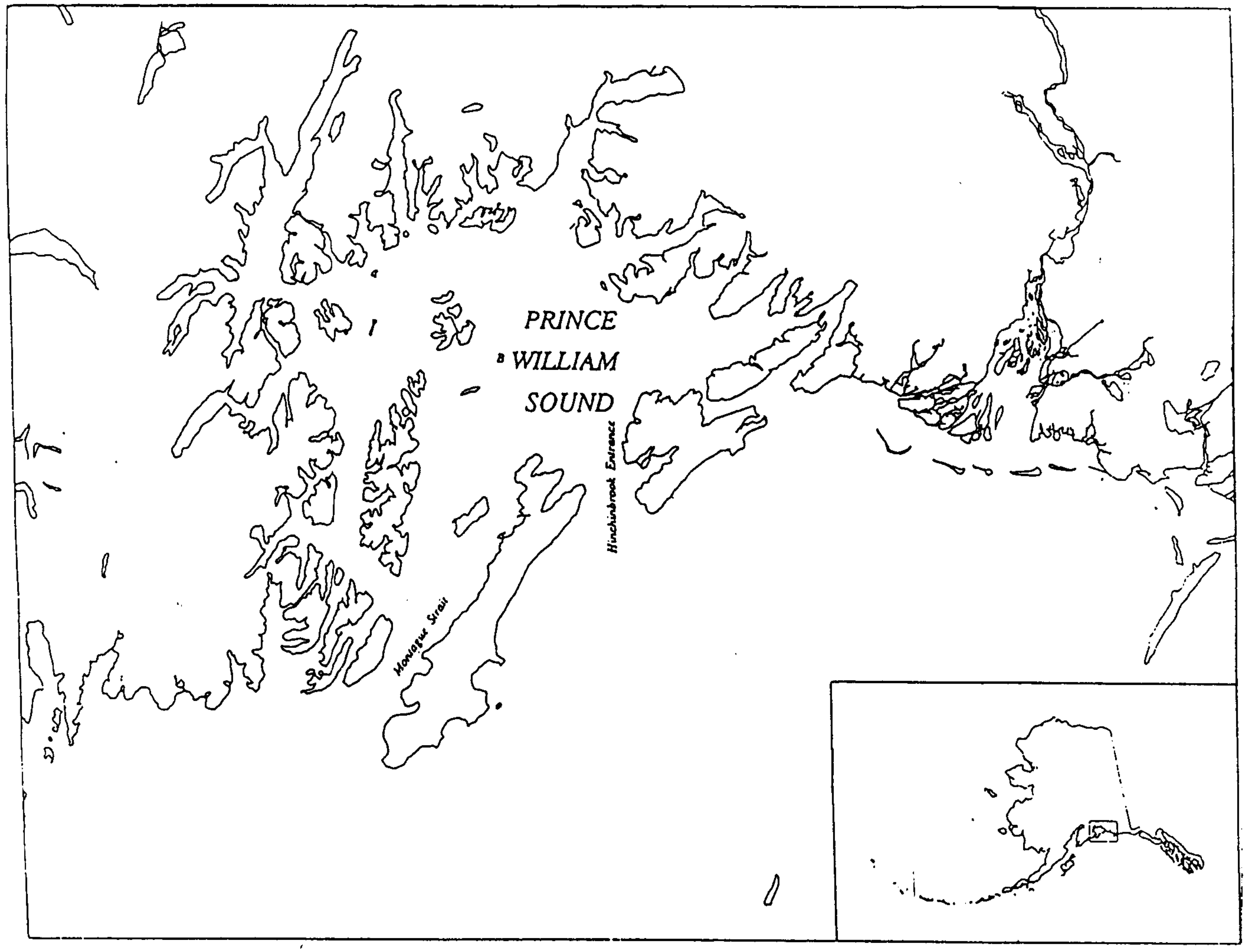

Figure 1. Map of Prince William Sound with a State of Alaska locator.

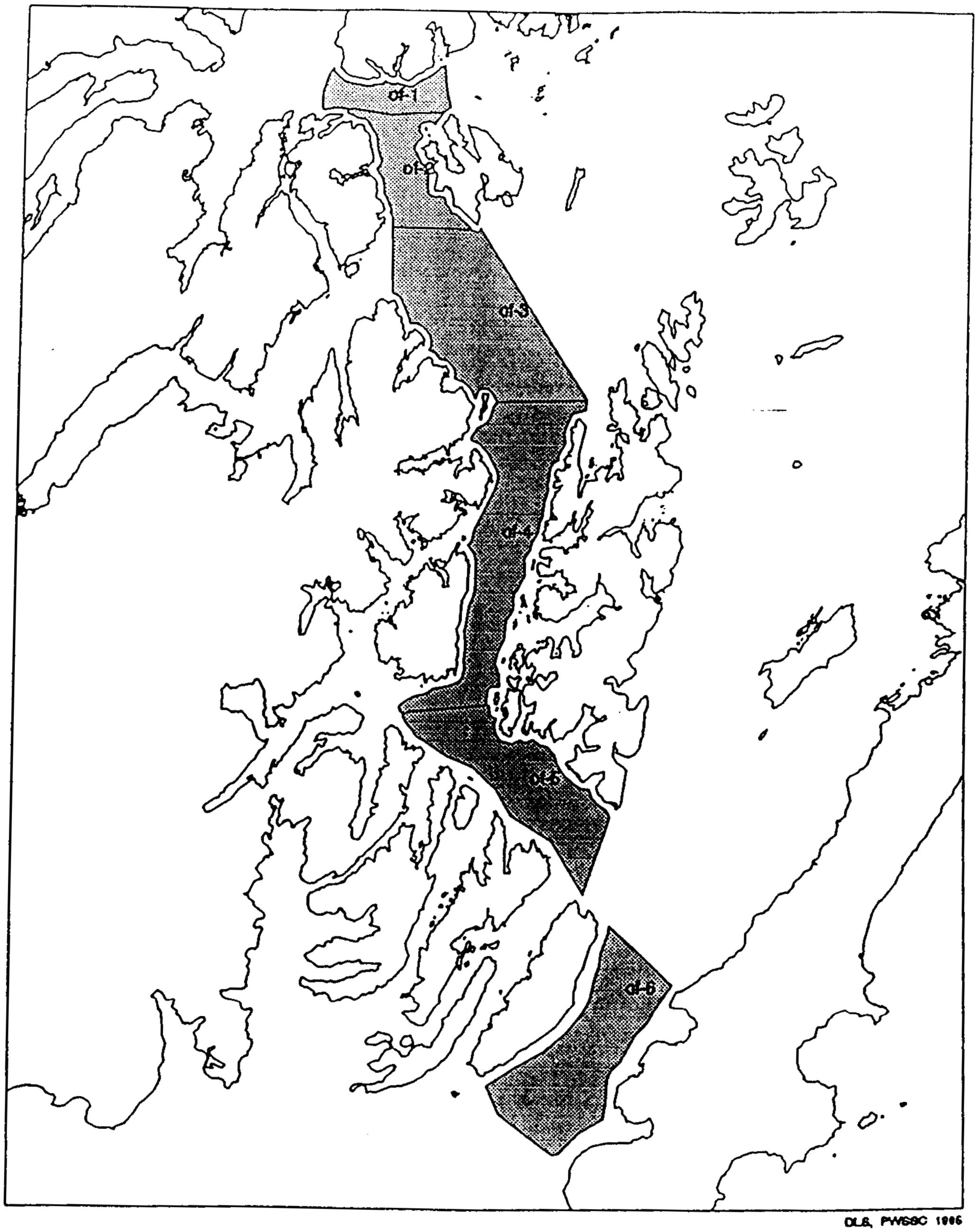

Figure 2. Map of Western Prince William Sound showing offshore areas surveyed with acoustic and midwater trawls. (Codes are: of-1 = Wells, of-2 = Perry Is, of-3 = North Knight Is, of-4 = Chenega Is, of-5 = South Knight Is, of-6 = Montague Is).

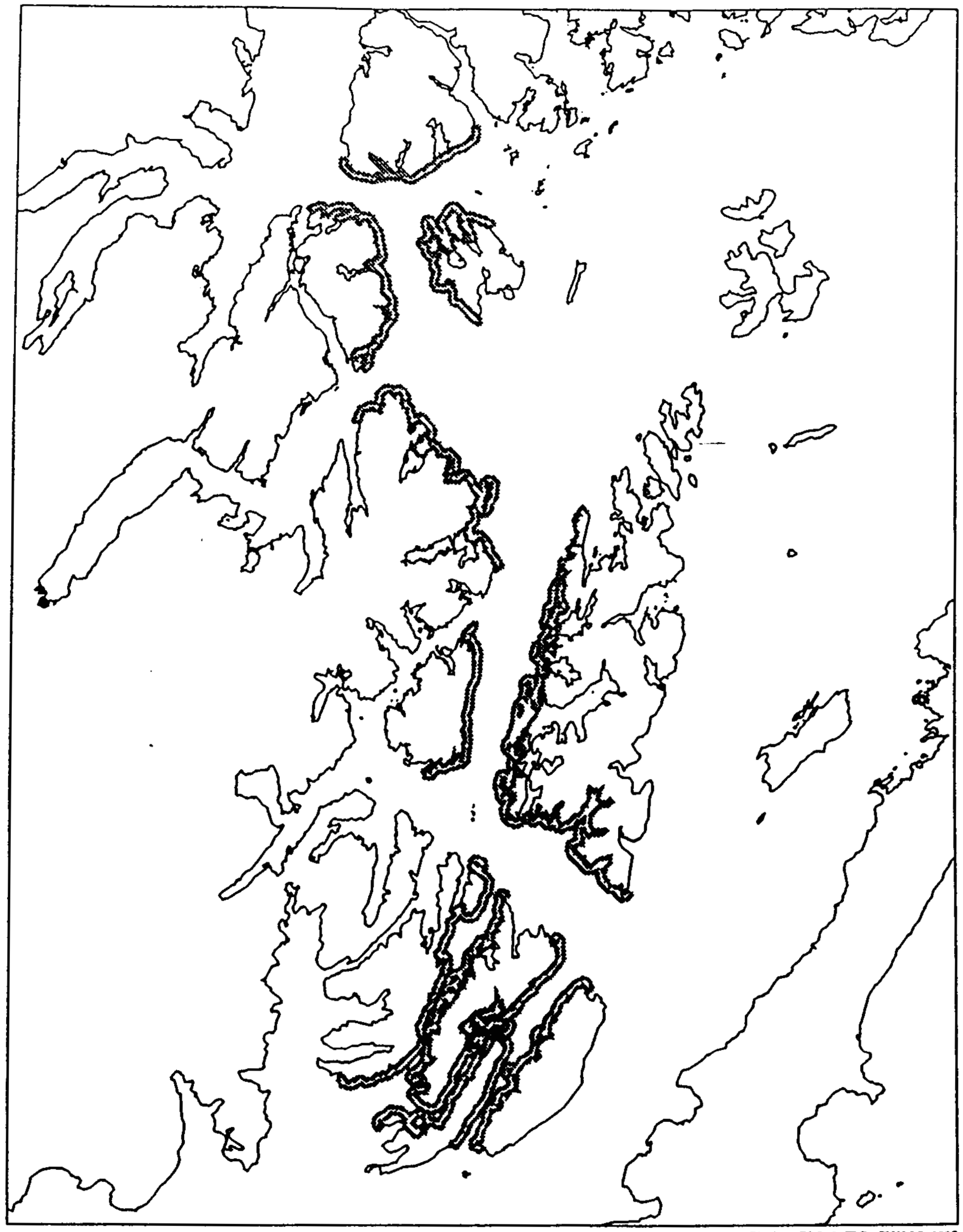

Figure 3. Map of Western Prince William Sound showing nearshore areas surveyed with acoustics and purse seines in 1994.

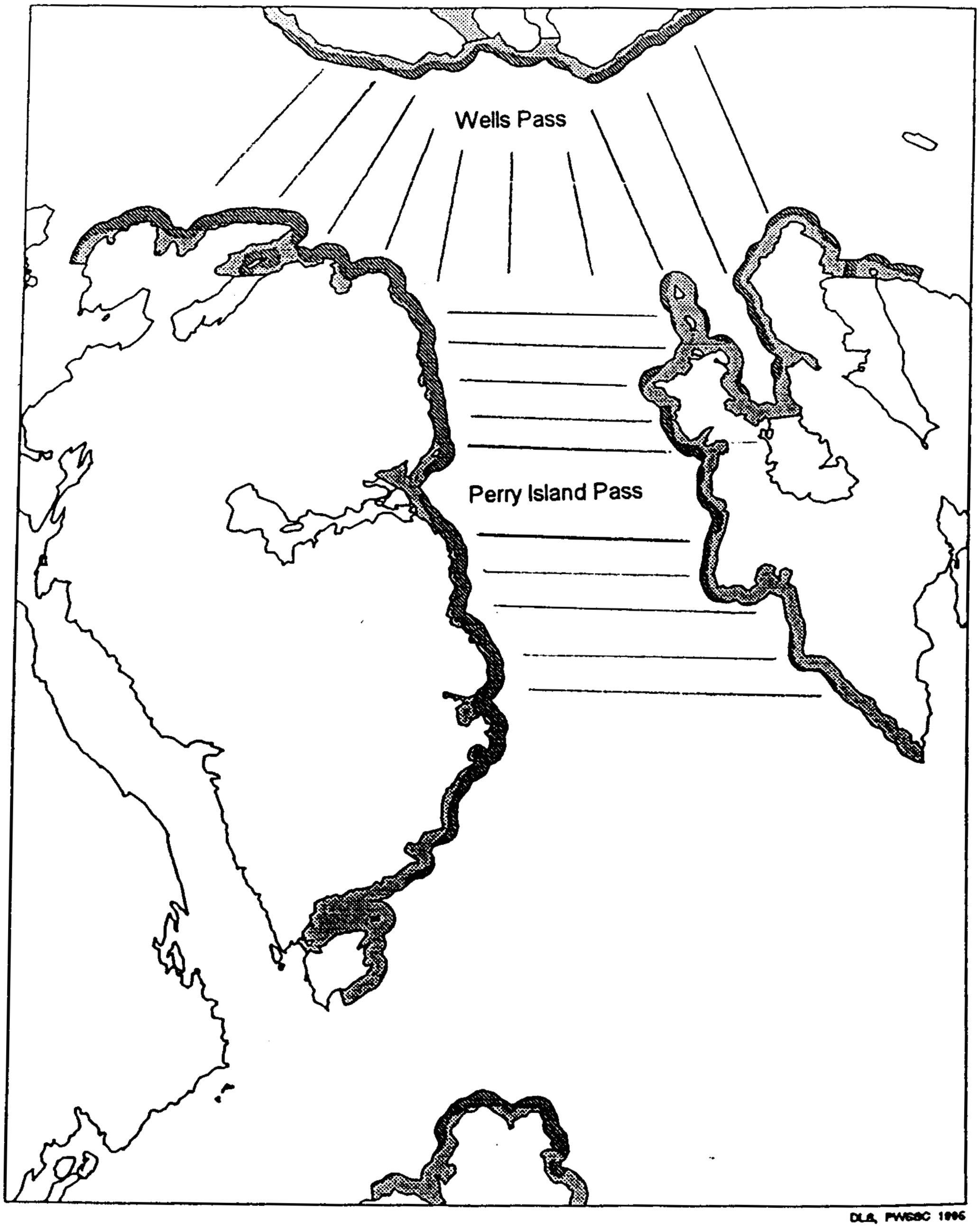

Figure 4. Map of the Wells-Perry Island passages which were surveyed intensively with acoustics, trawls and purse seines in 1994 and 1995.

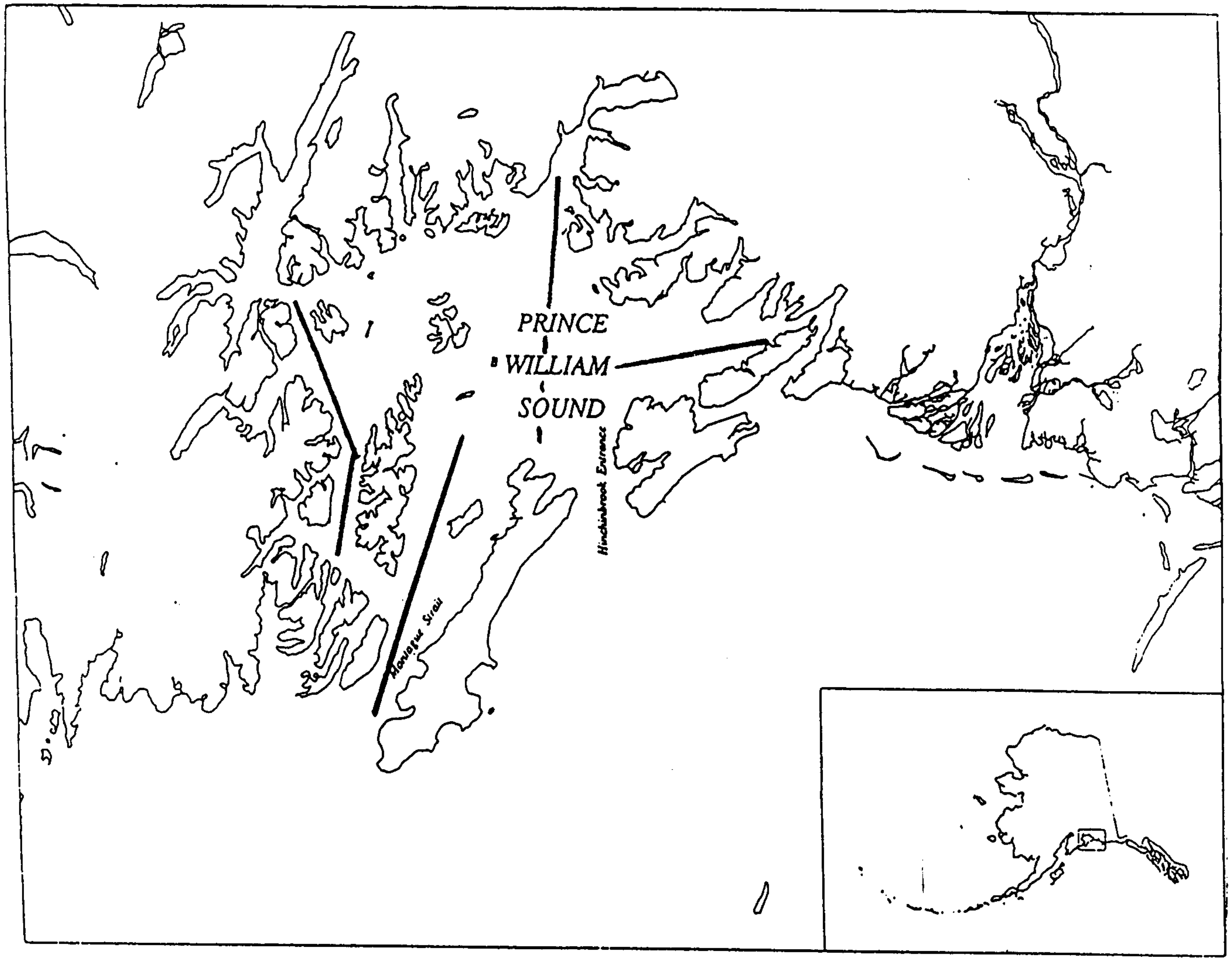

Figure 5. Map of the Broadscale survey of Prince William Sound in 1995 (Legs 7 and 8).

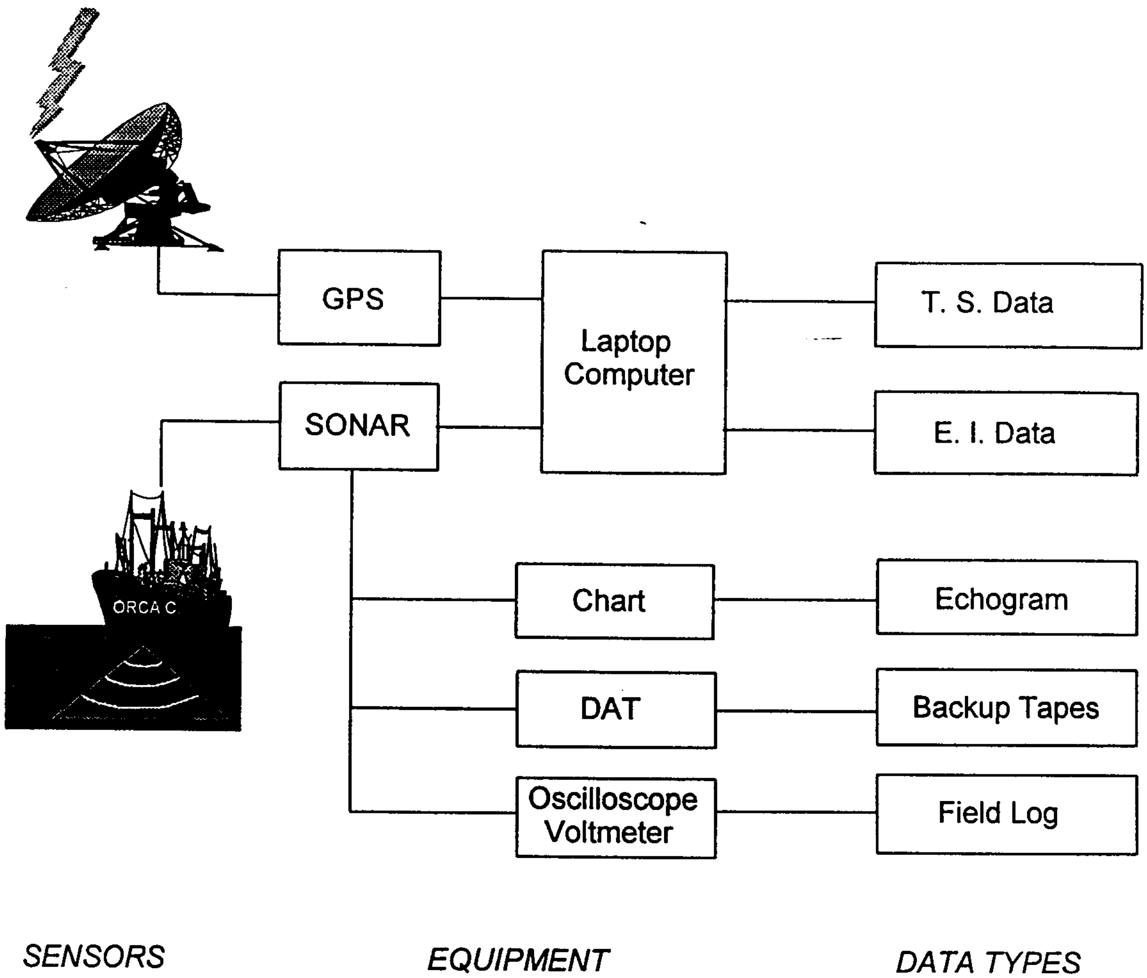

Figure 6. Data acquisition system used in SEA 1994 and 1995 acoustic surveys.

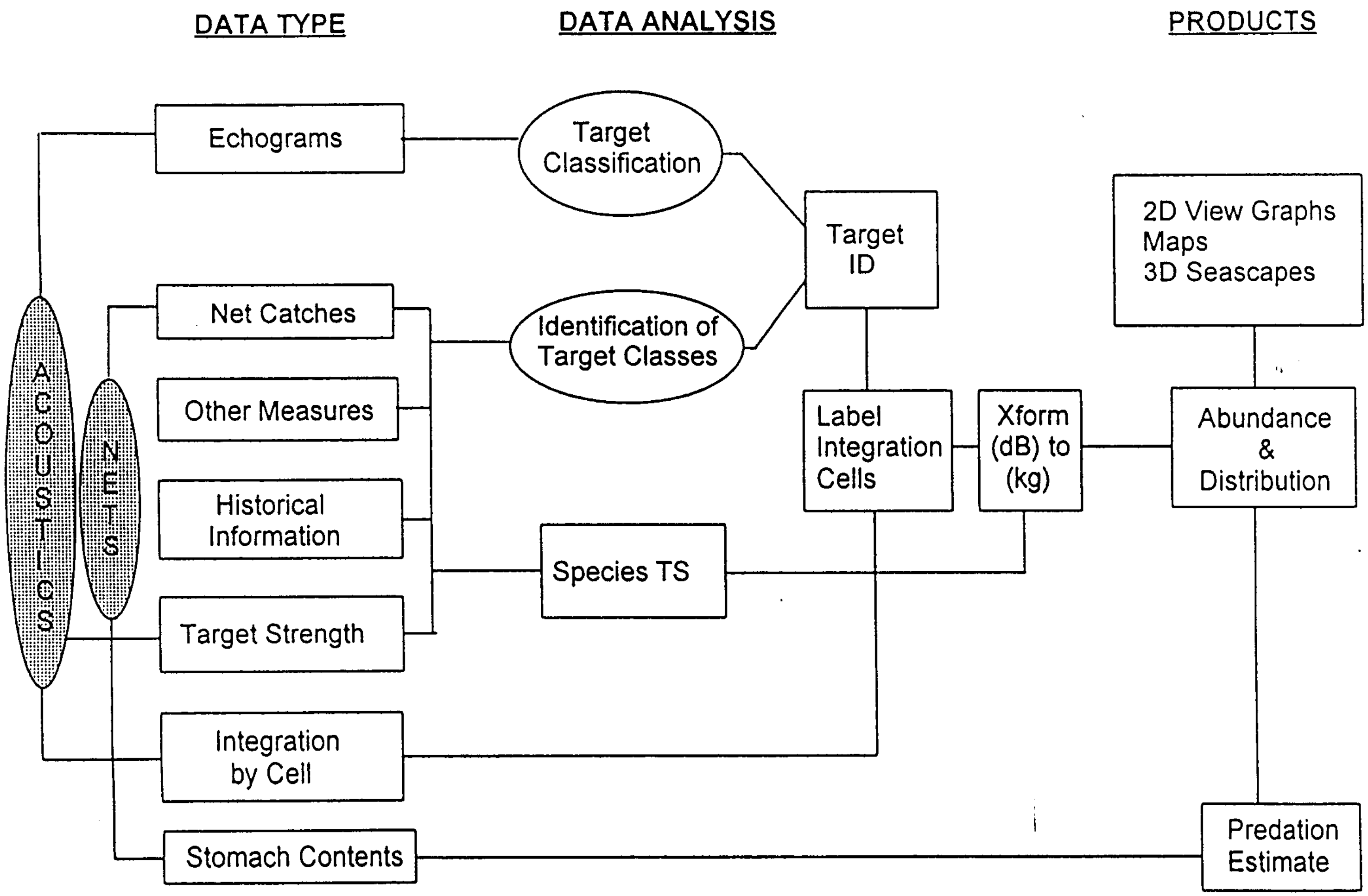

Figure 7. Data processors and analysis system used in SEA 1994 and 1995 acoustics investigations.

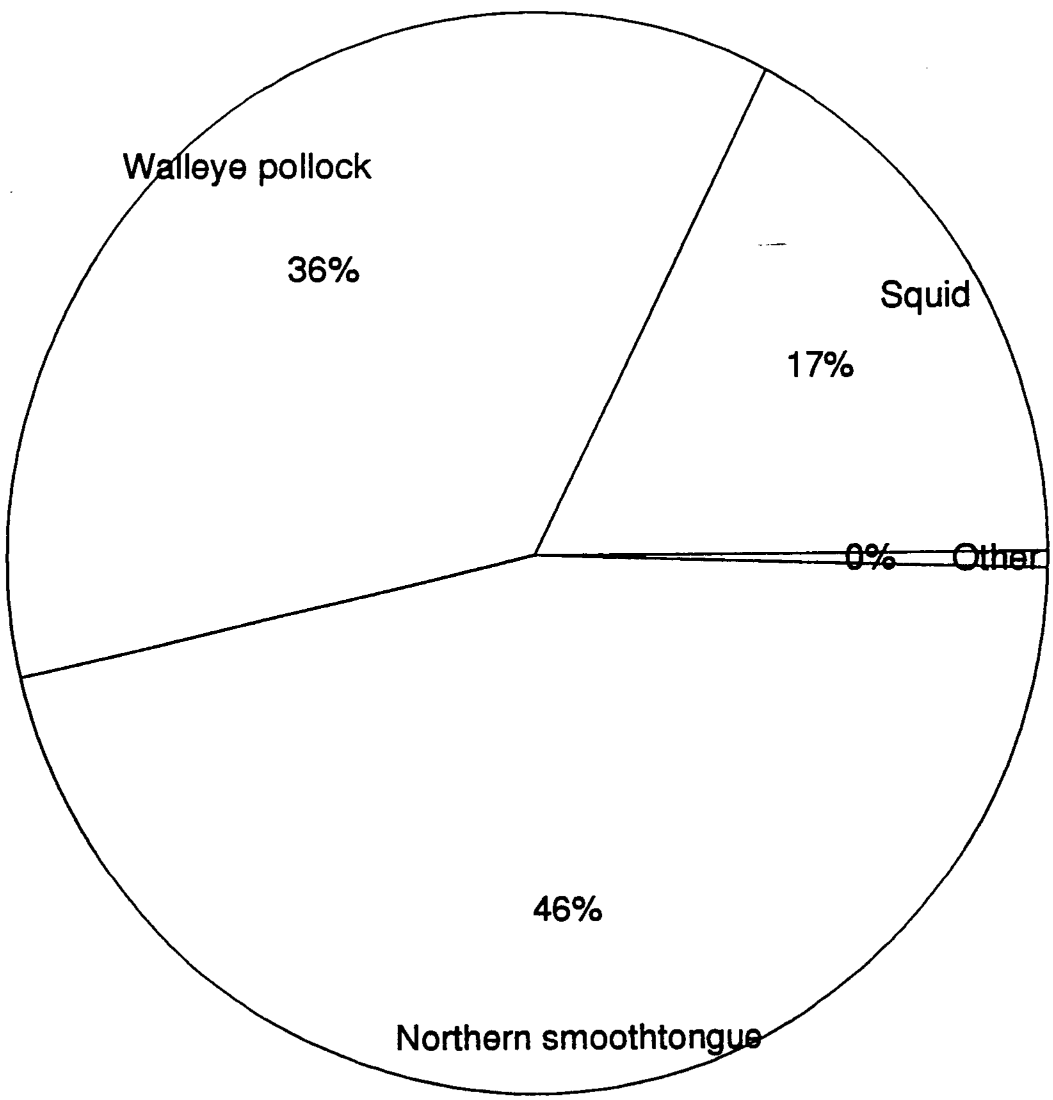

Figure 8. Species composition of night-time midwater trawls in May and June 1994, northwest Prince William Sound.

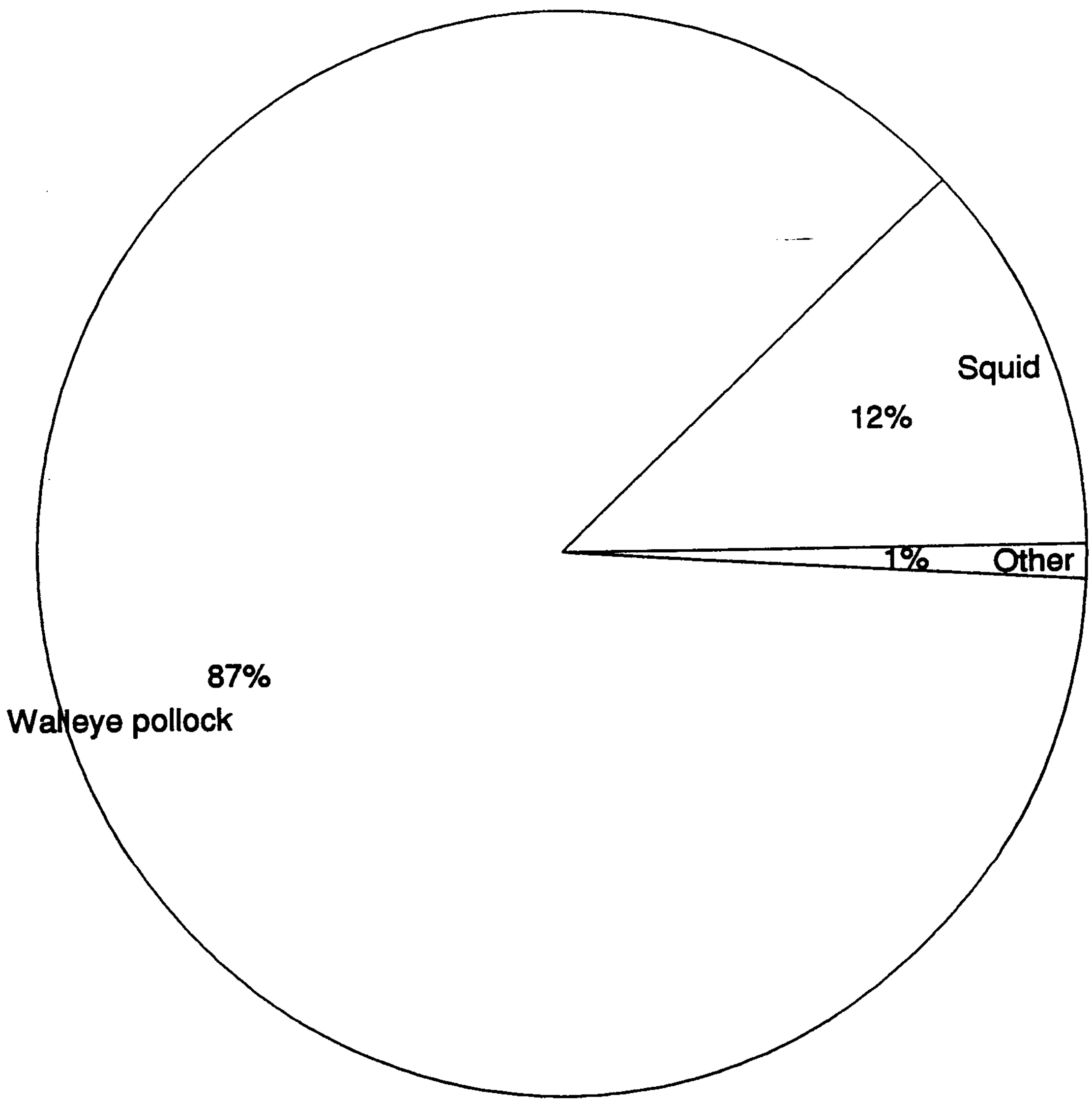

Figure 9. Species composition of night-time midwater trawls in May and June of 1995, northwest Prince William Sound.

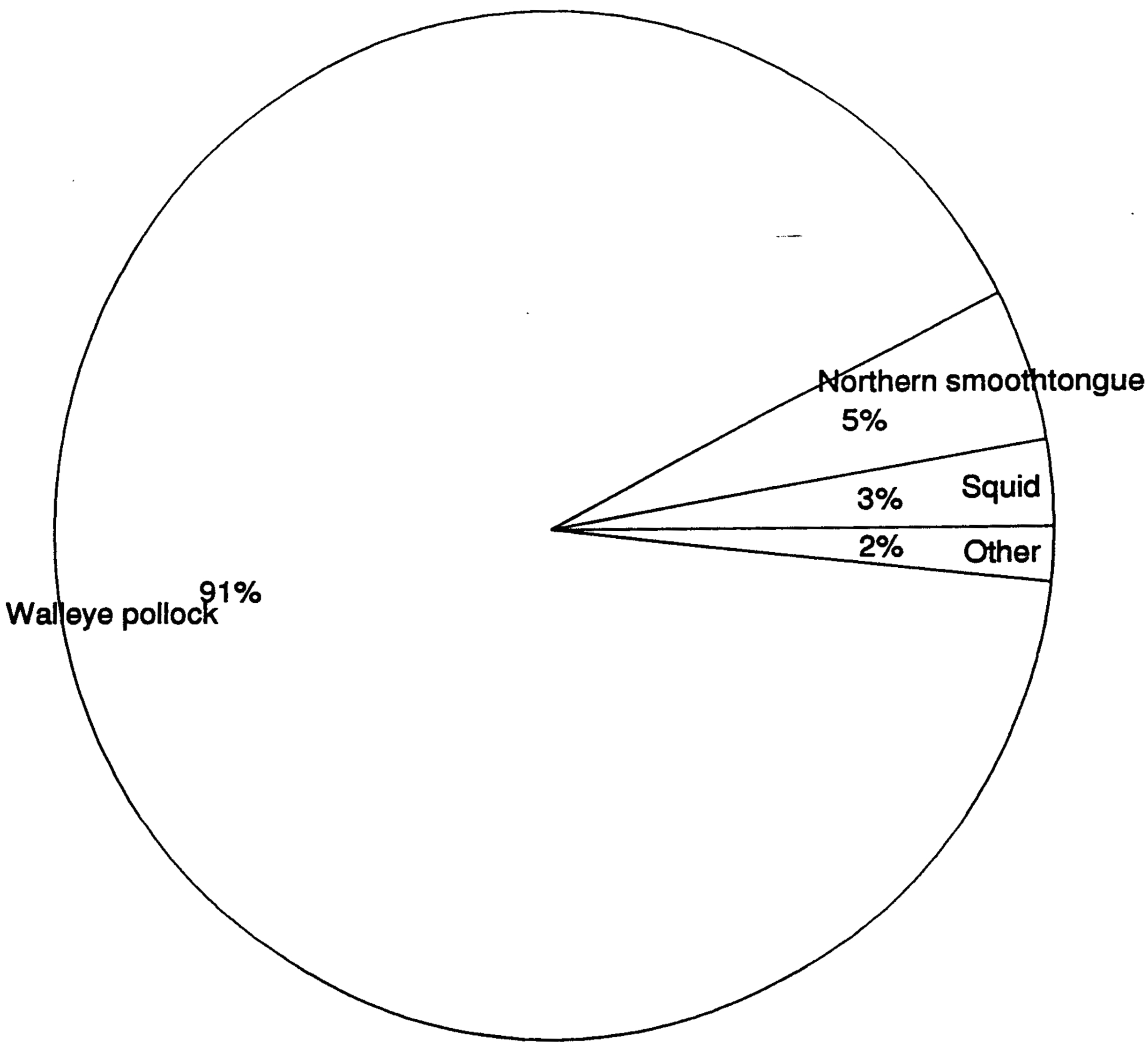

Figure 10. Species composition of day and night-time midwater trawls made in May and June 1995, northwest Prince William Sound.

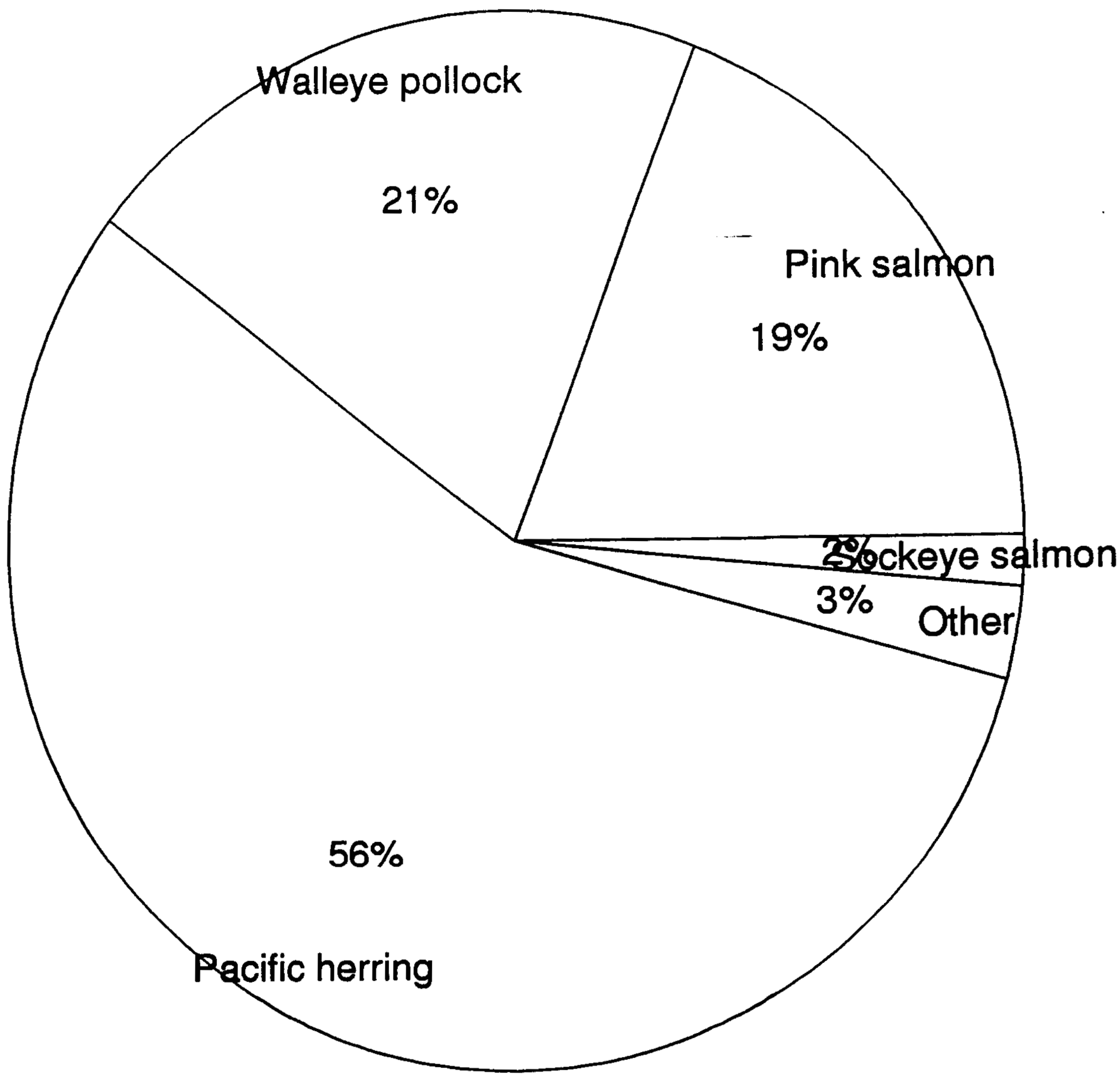

Figure 11. Species composition of purse seine hauls in May and June 1994, northwest Prince William Sound.

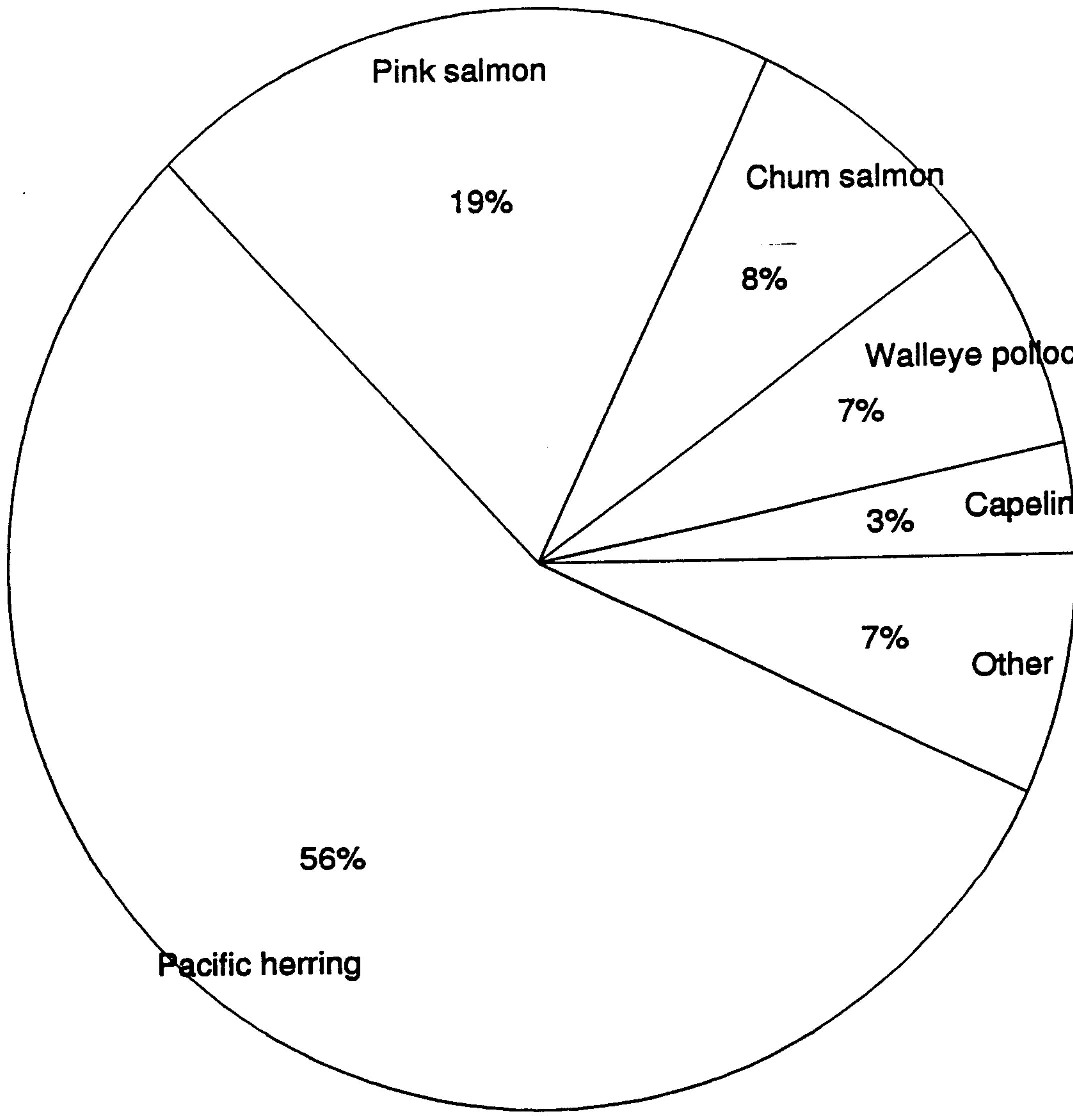

Figure 12. Species composition of purse seine sets made in May and June 1995, northwest Prince William Sound.

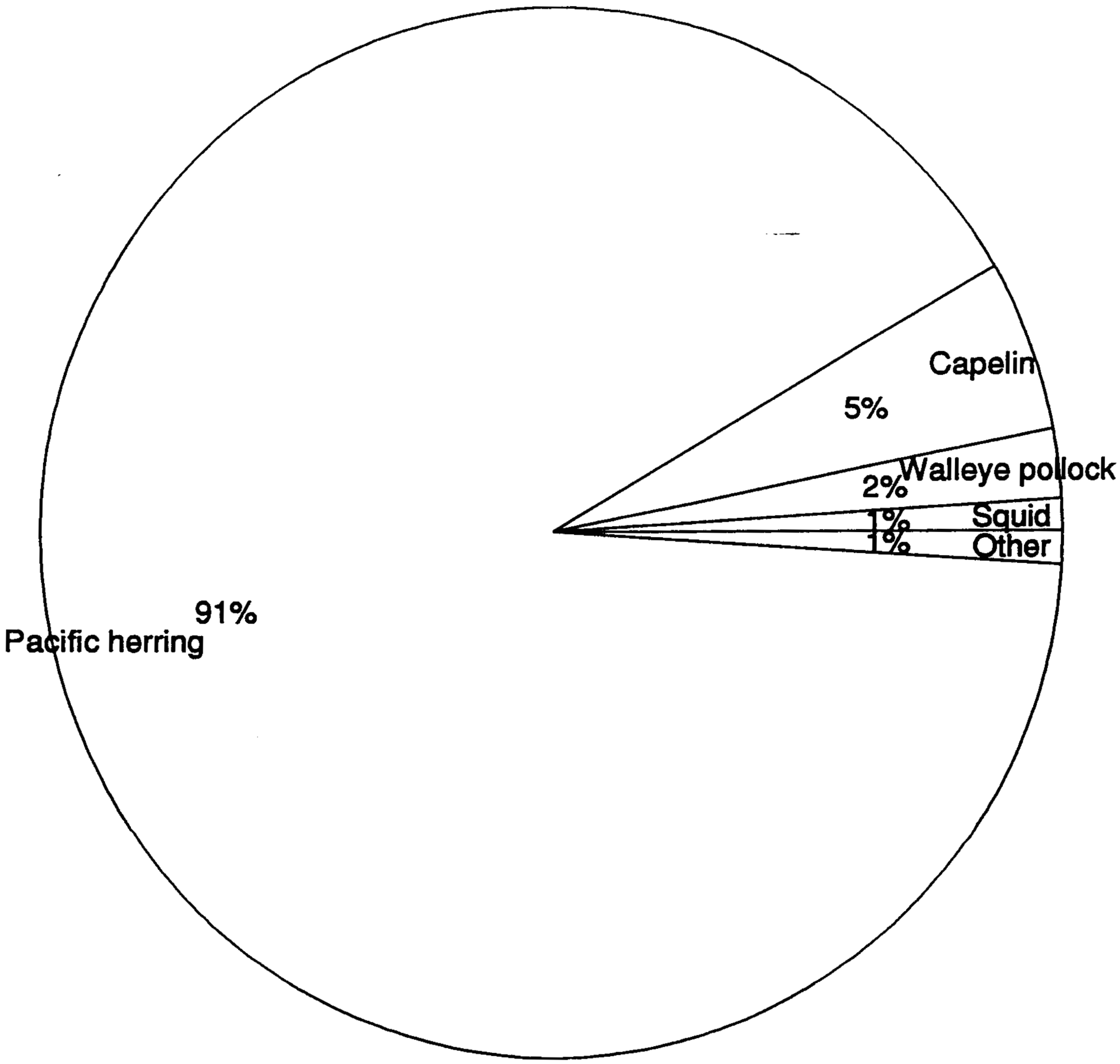

Figure 13. Species composition of pair trawl hauls made in May and June of 1995, northwest Prince William Sound.

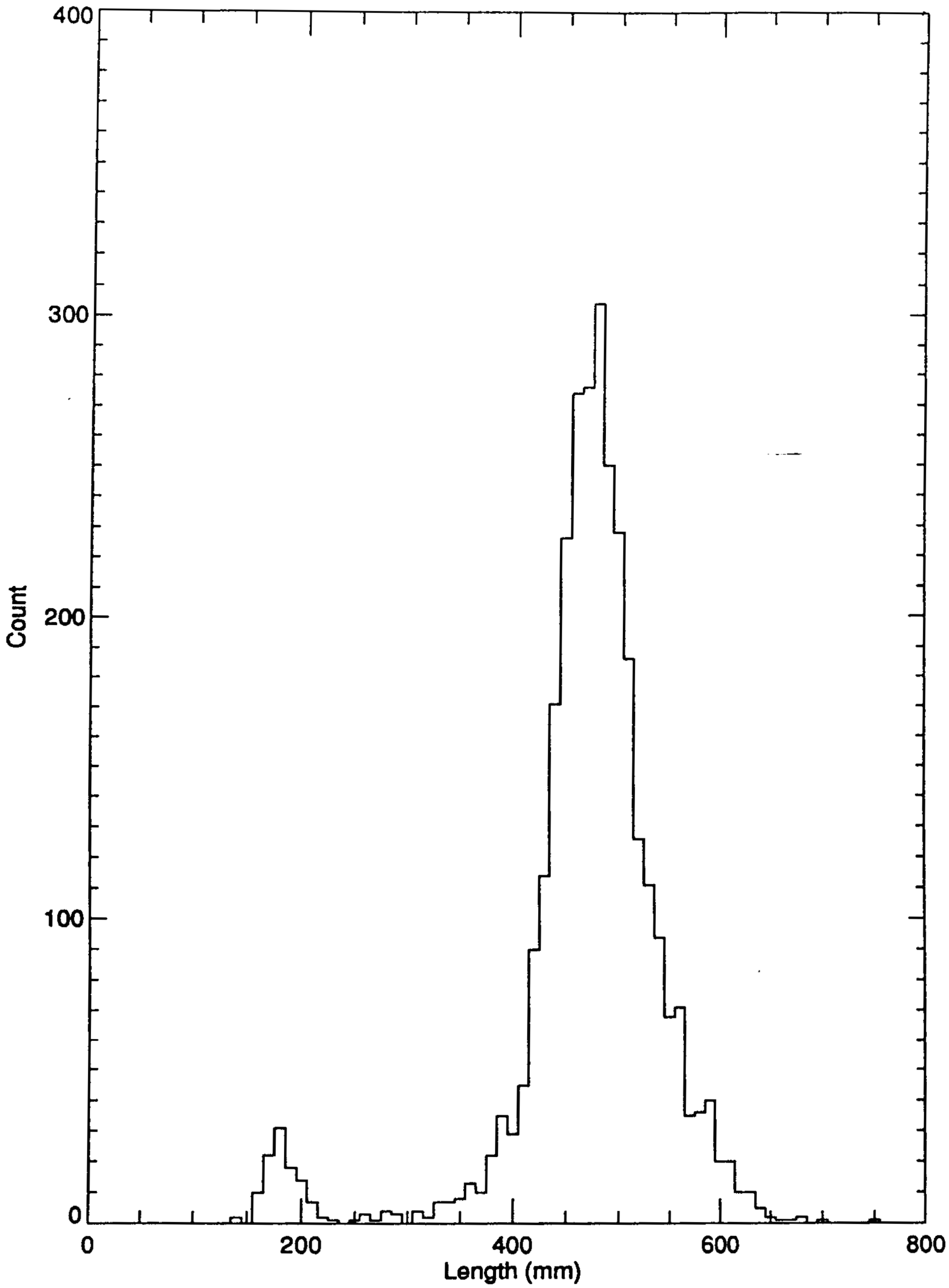

Figure 14. Length frequency of pollock in midwater trawl catch, May - June 1994, northwest Prince William Sound.

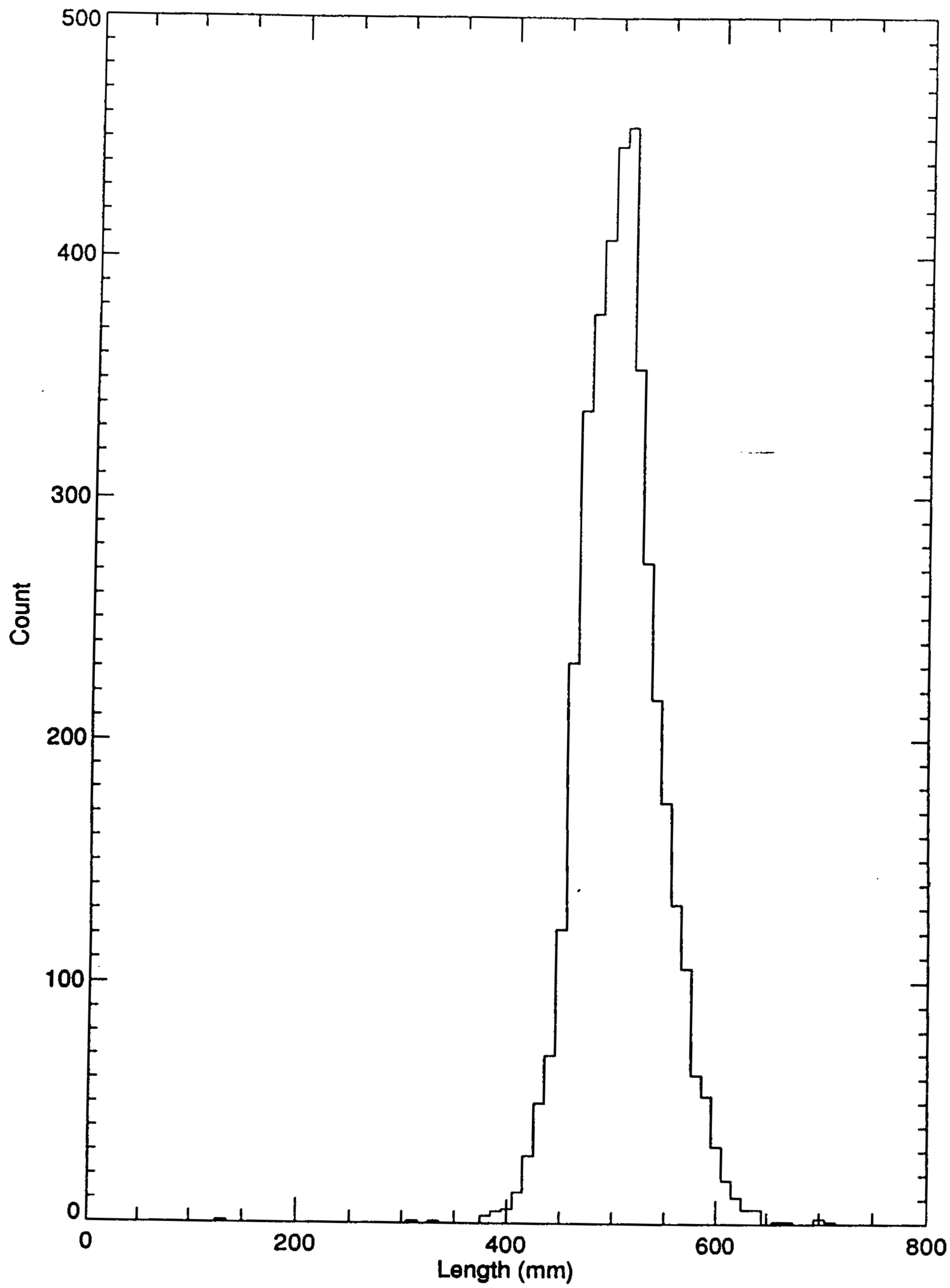

Figure 15. Length frequency of pollock in midwater trawl catch, May-June 1995, northwest Prince William Sound.

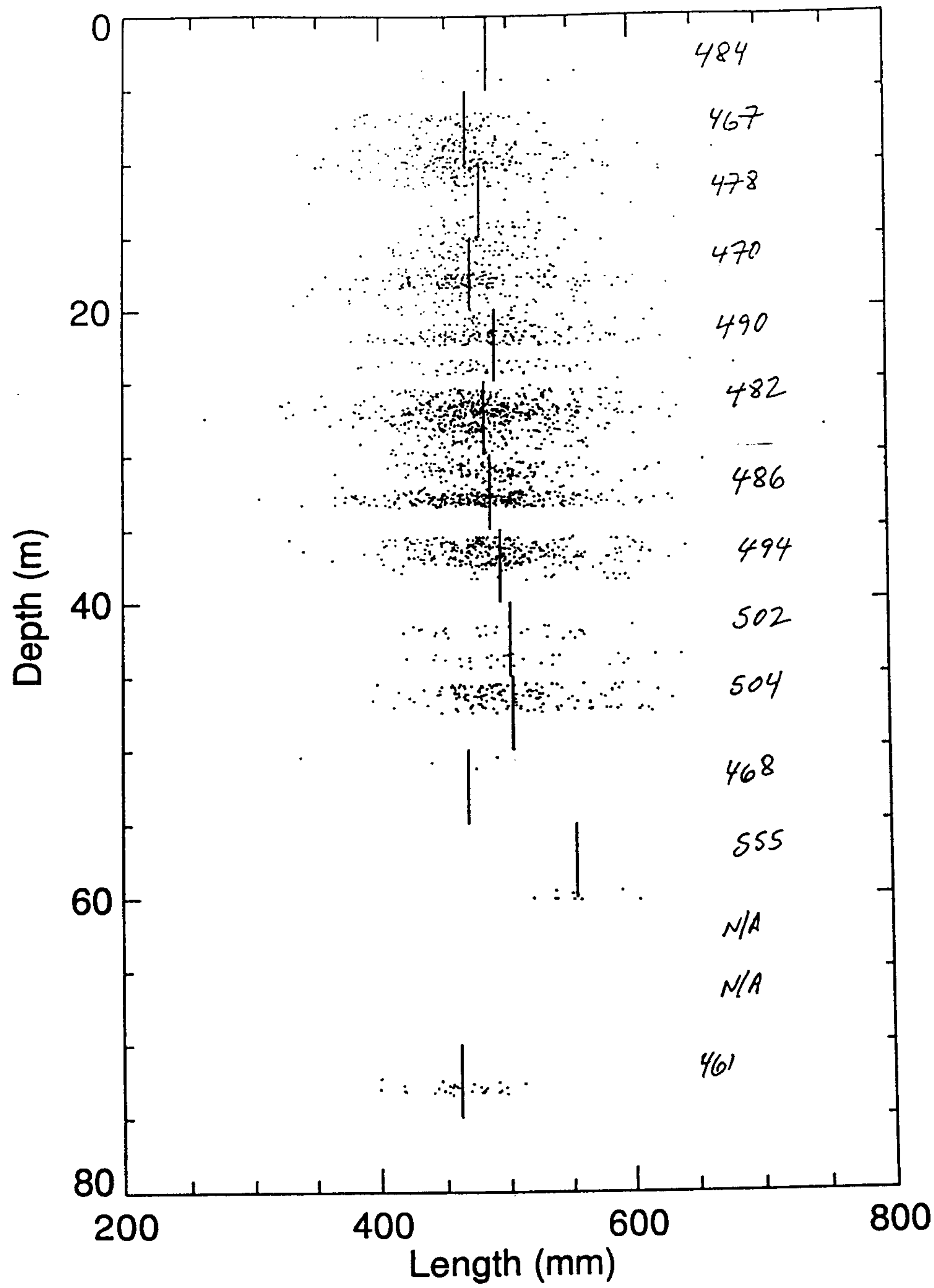

Figure 16. Length of pollock by depth in the midwater trawl catch, May-June 1995, northwest Prince William Sound

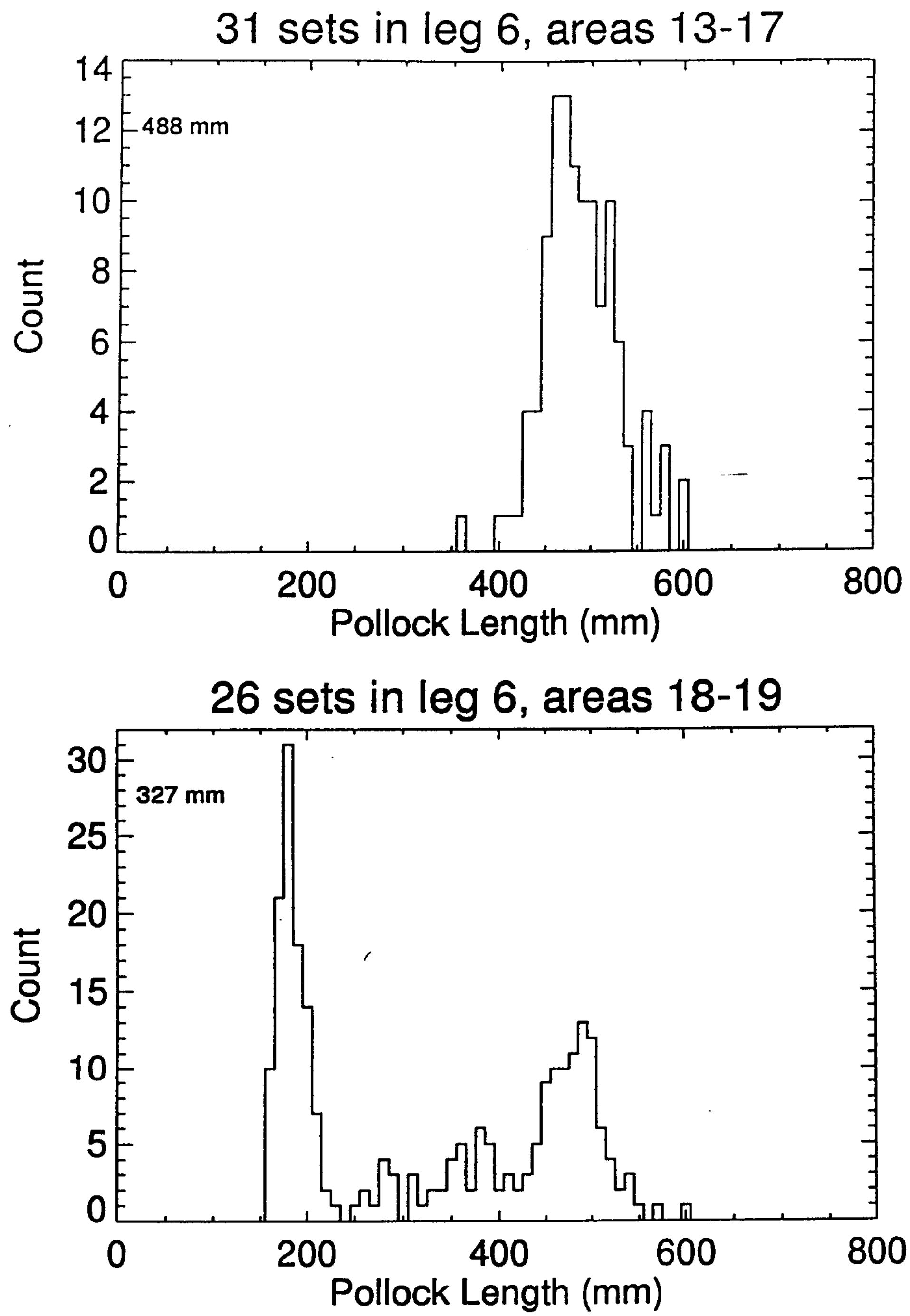

Figure 17a & b. Length frequency of pollock in the midwater trawl catch: (a) northern and central, and (b) southern areas of western Prince William Sound, July 1994.

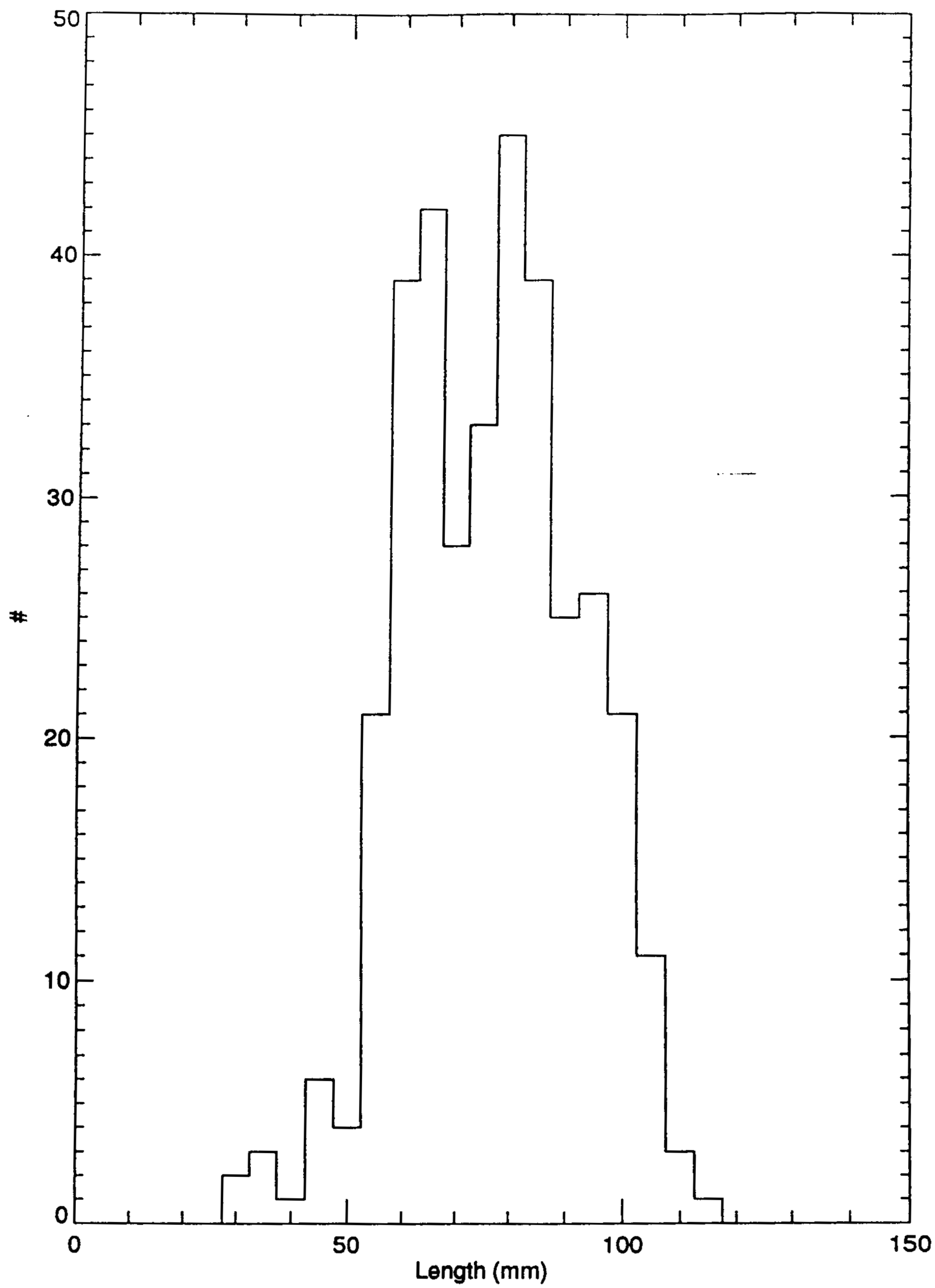

Figure 18. Length frequencies of northern smoothtongue in the midwater trawl catch in May-June 1994, northwest Prince William Sound.

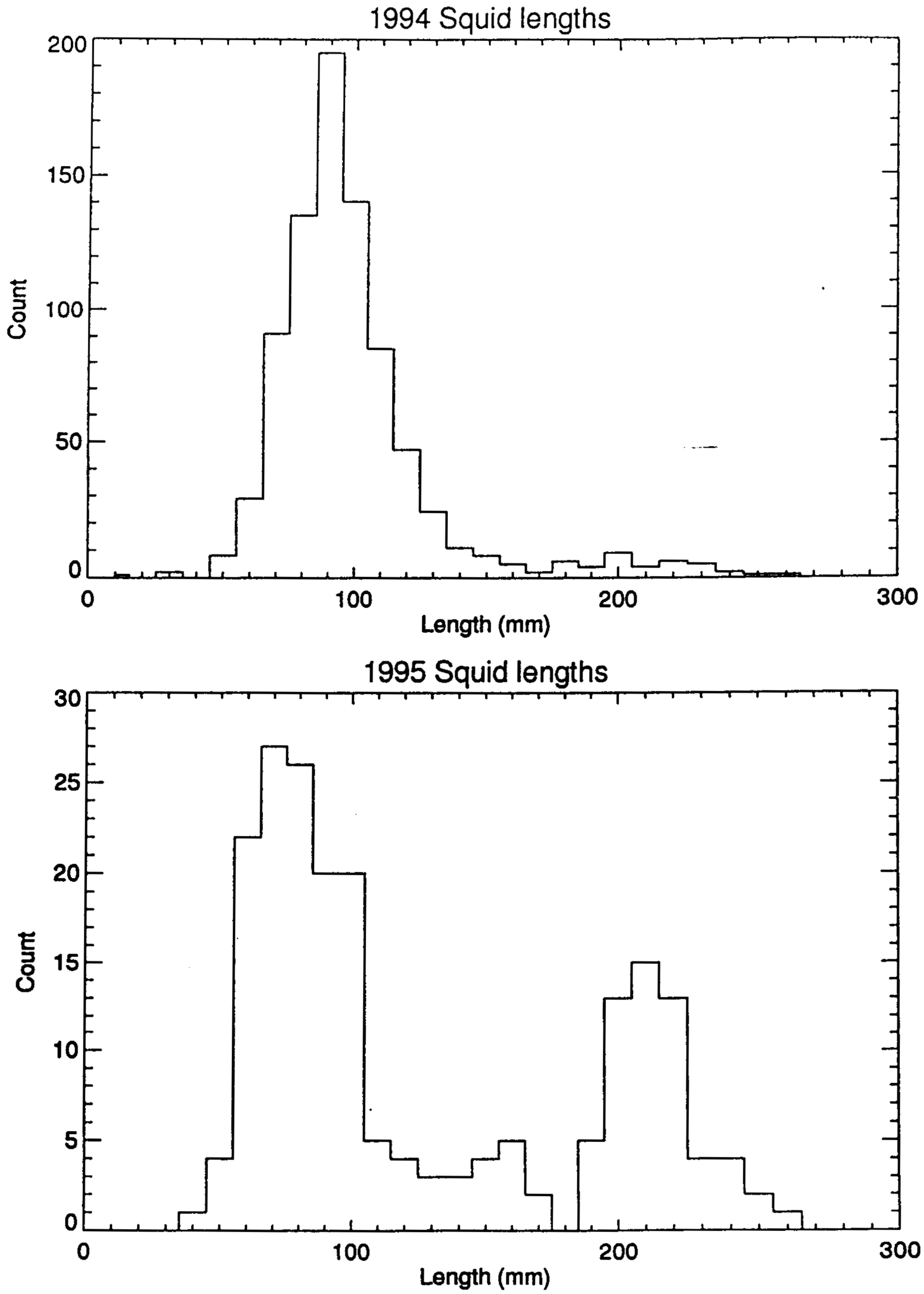

Figure 19. Length frequencies of squid in the midwater trawl catch in May-June 1994(a) and 1995(b), northwest Prince William Sound.

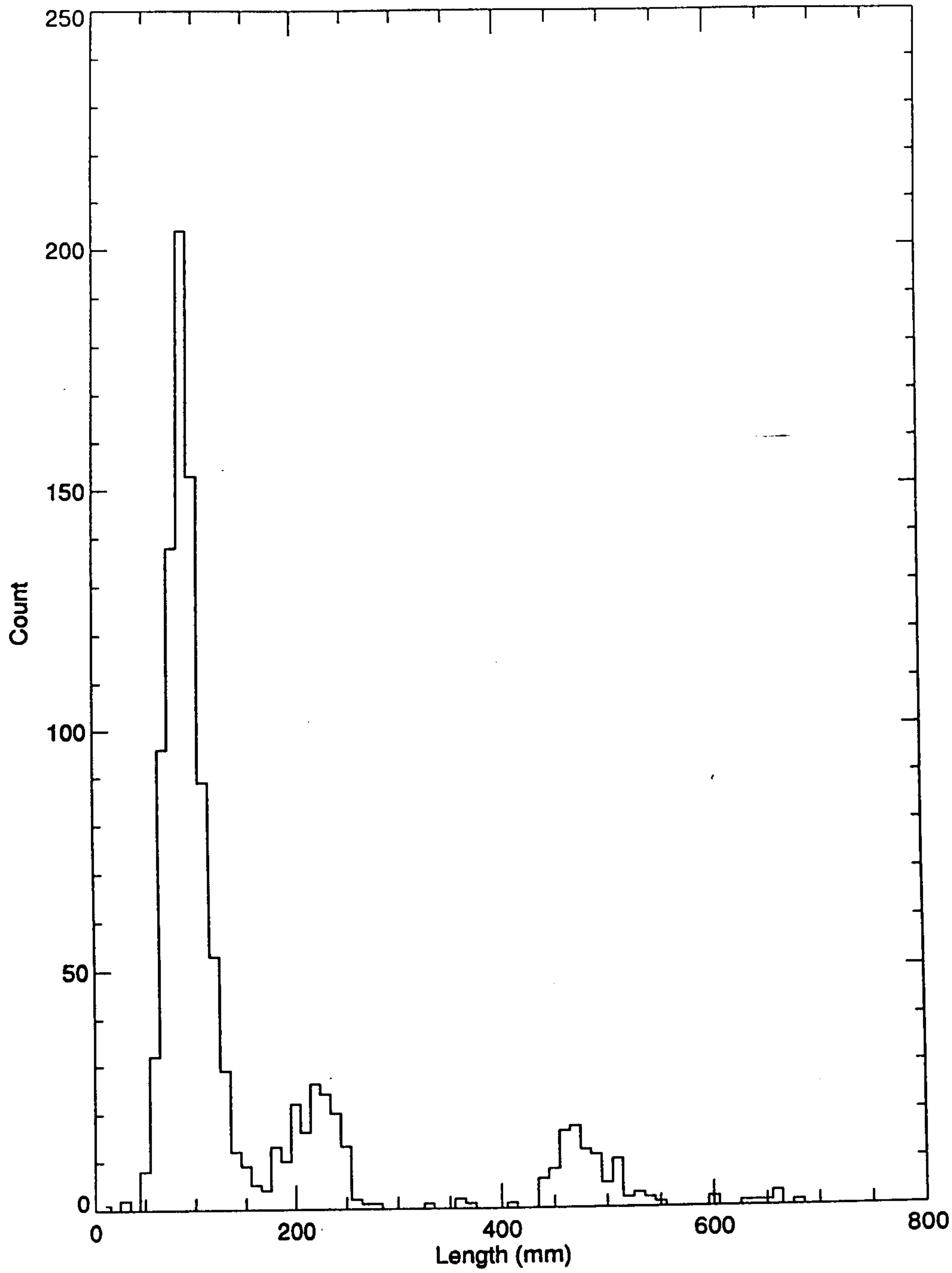

Figure 20. Length frequencies of non-pollock nekton caught by the midwater trawl in May-June 1994, northwest Prince William Sound.

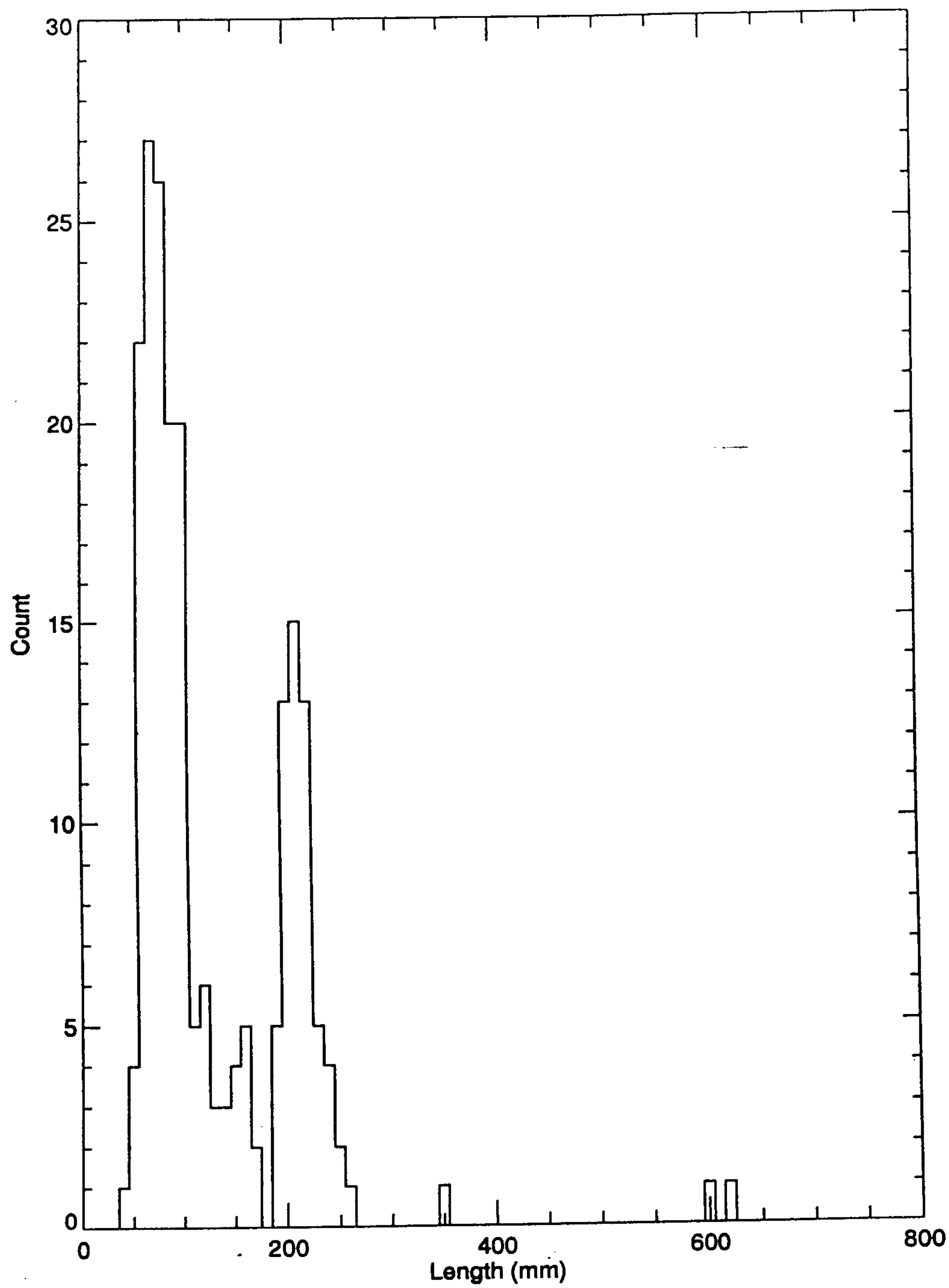

Figure 21. Length frequencies of non-pollock nekton captured by the midwater trawl in May-June 1995, northwest Prince William Sound.

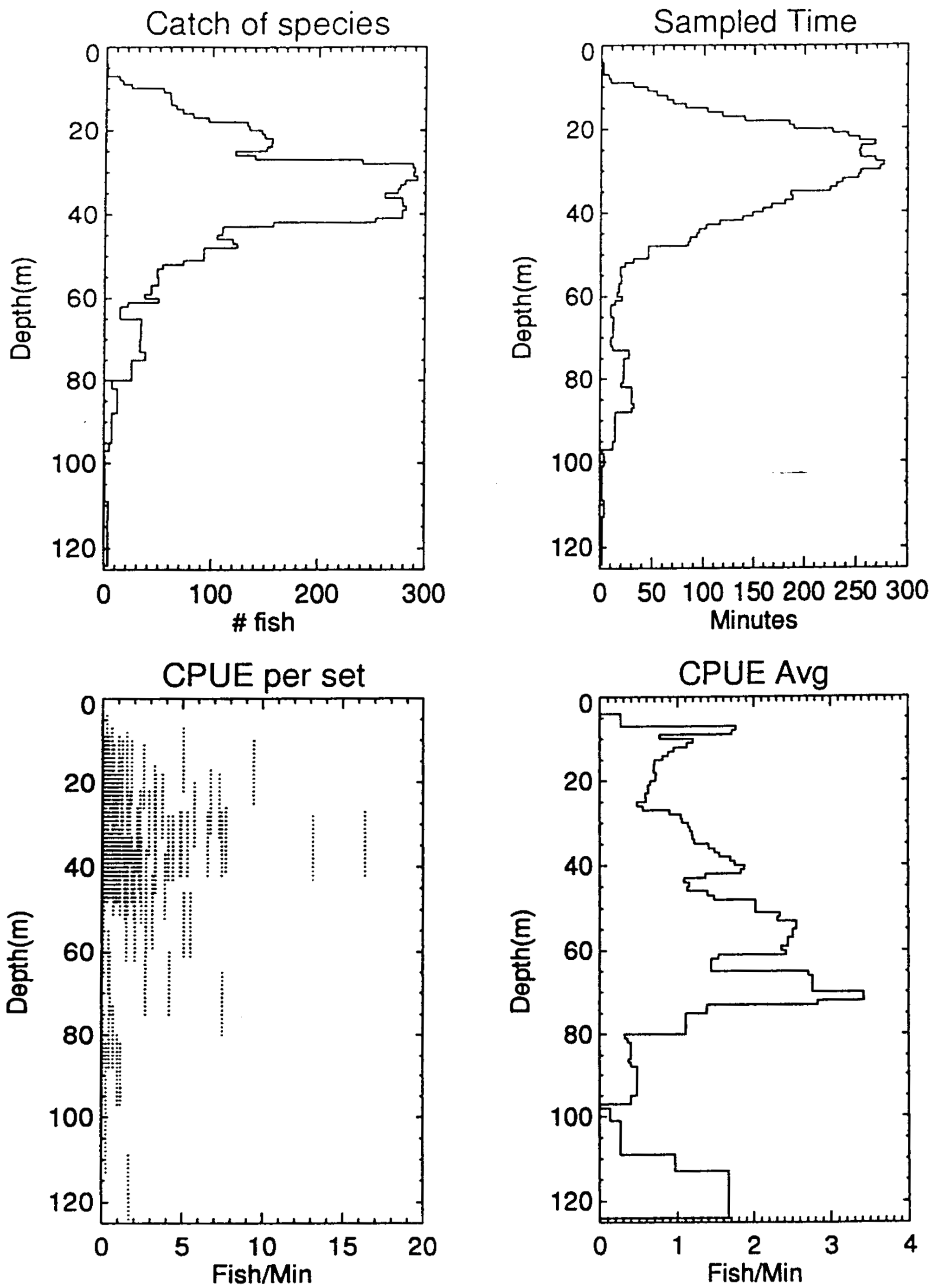

Figure 22. Vertical distribution of adult pollock from midwater trawl catches in 1994, northwest Prince William Sound.

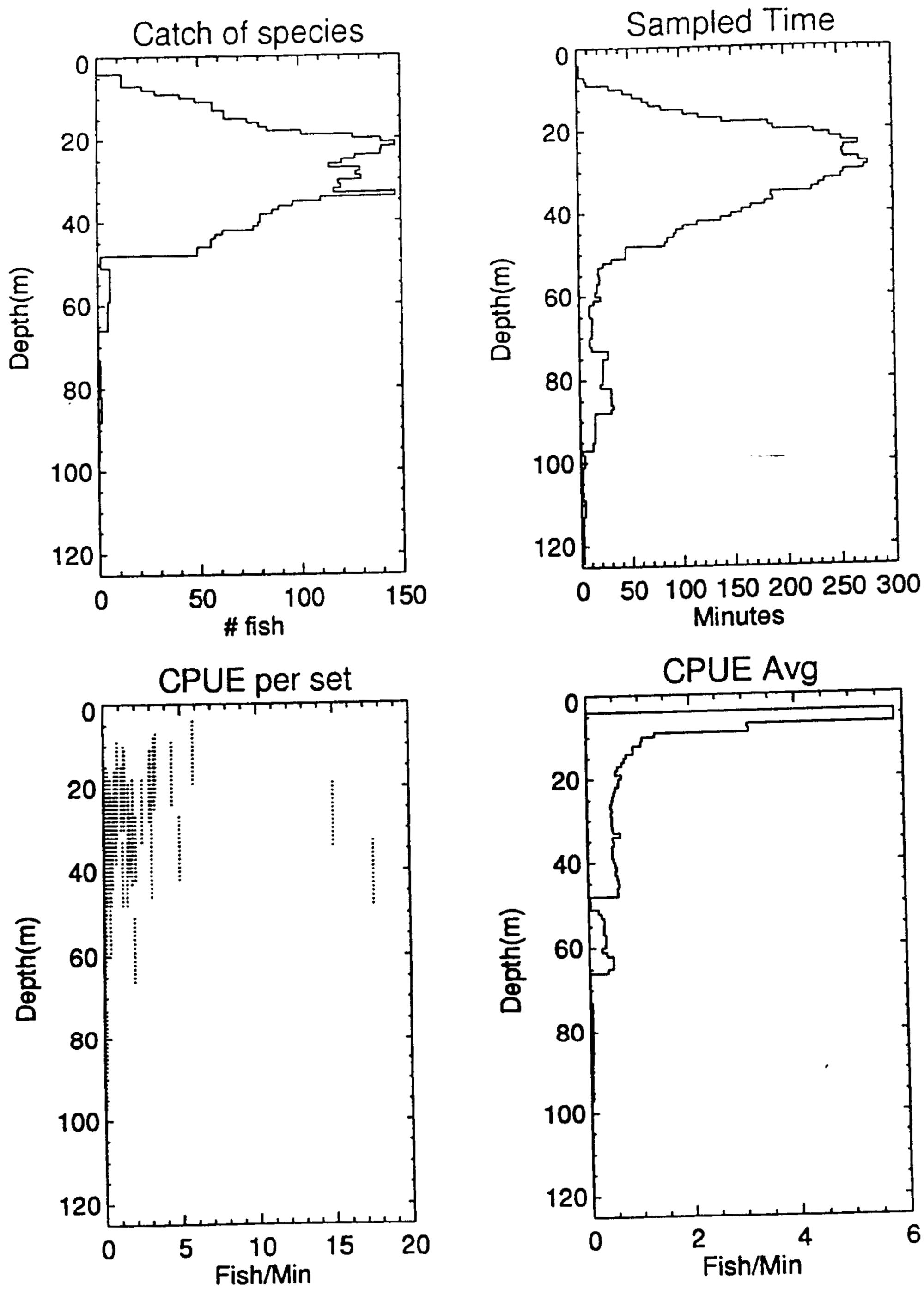

Figure 23. Vertical distribution of squid from midwater trawl catches in 1994, northwest Prince William Sound.

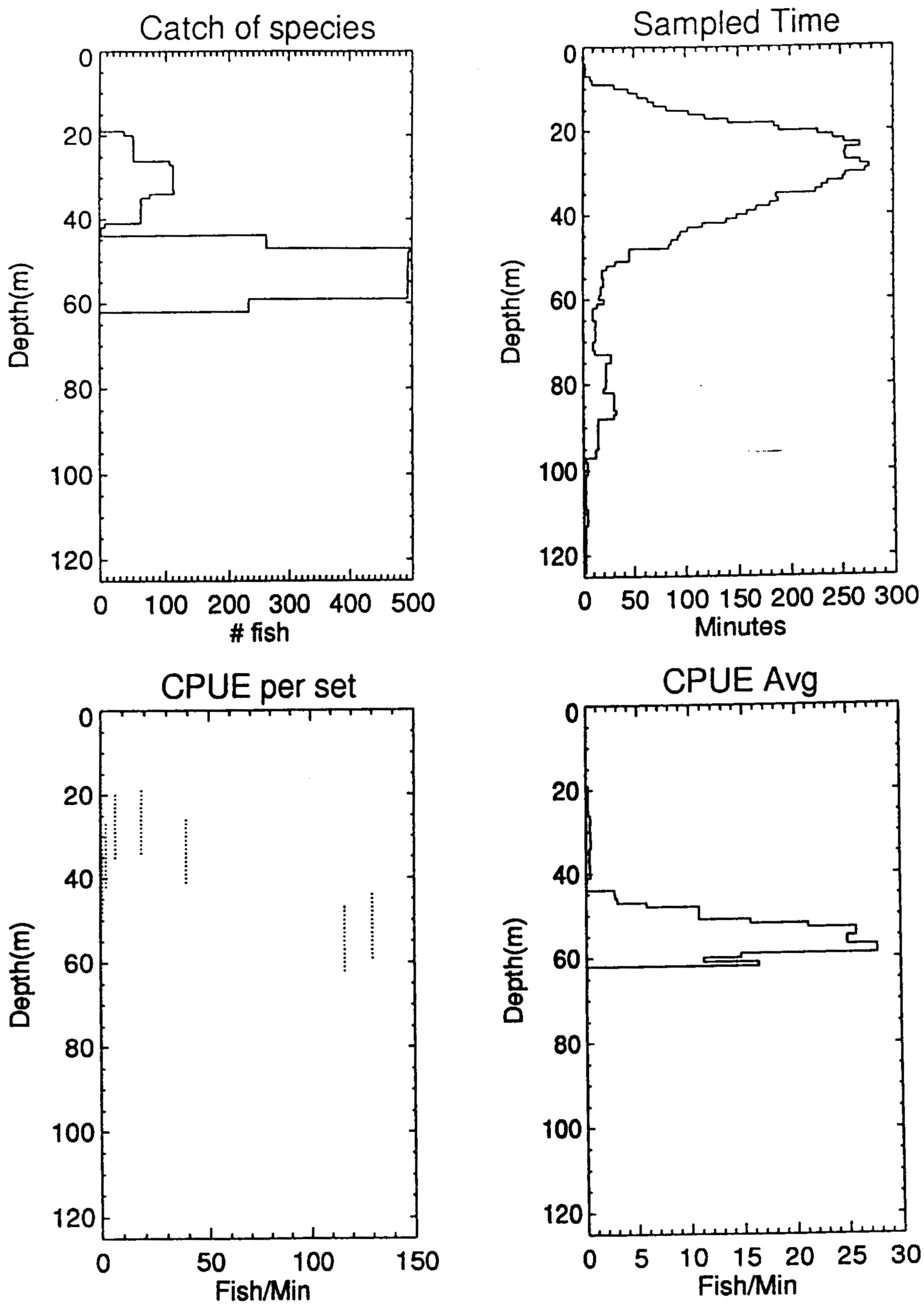

Figure 24. Vertical distribution of northern smoothtongue from midwater trawl catches in 1994, northwest Prince William Sound.

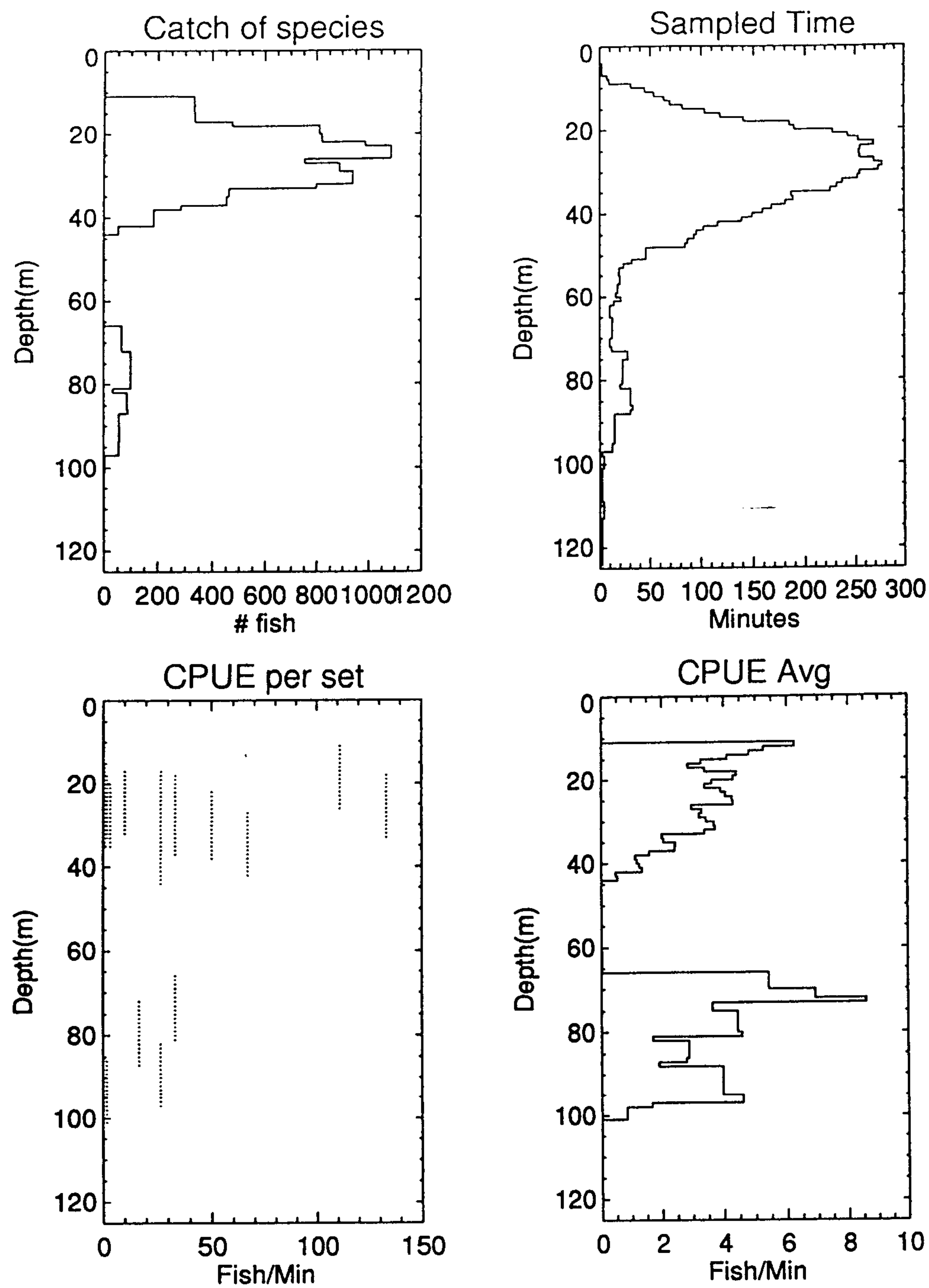

Figure 25. Vertical distribution of juvenile pollock from midwater trawl catches in 1994, northwest Prince William Sound.

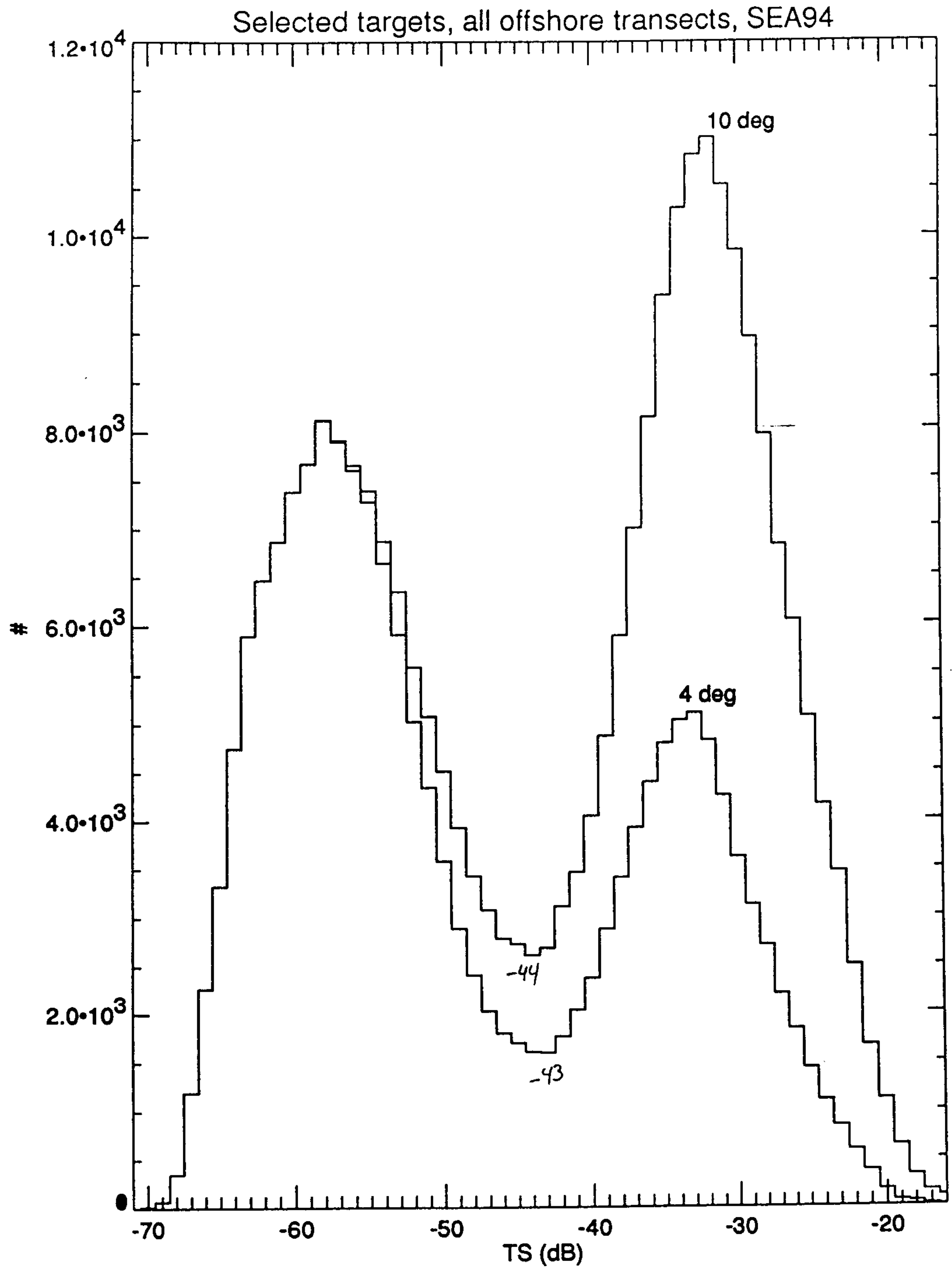

Figure 26. Distributions of acoustic target strengths for offshore surveys in 1995.

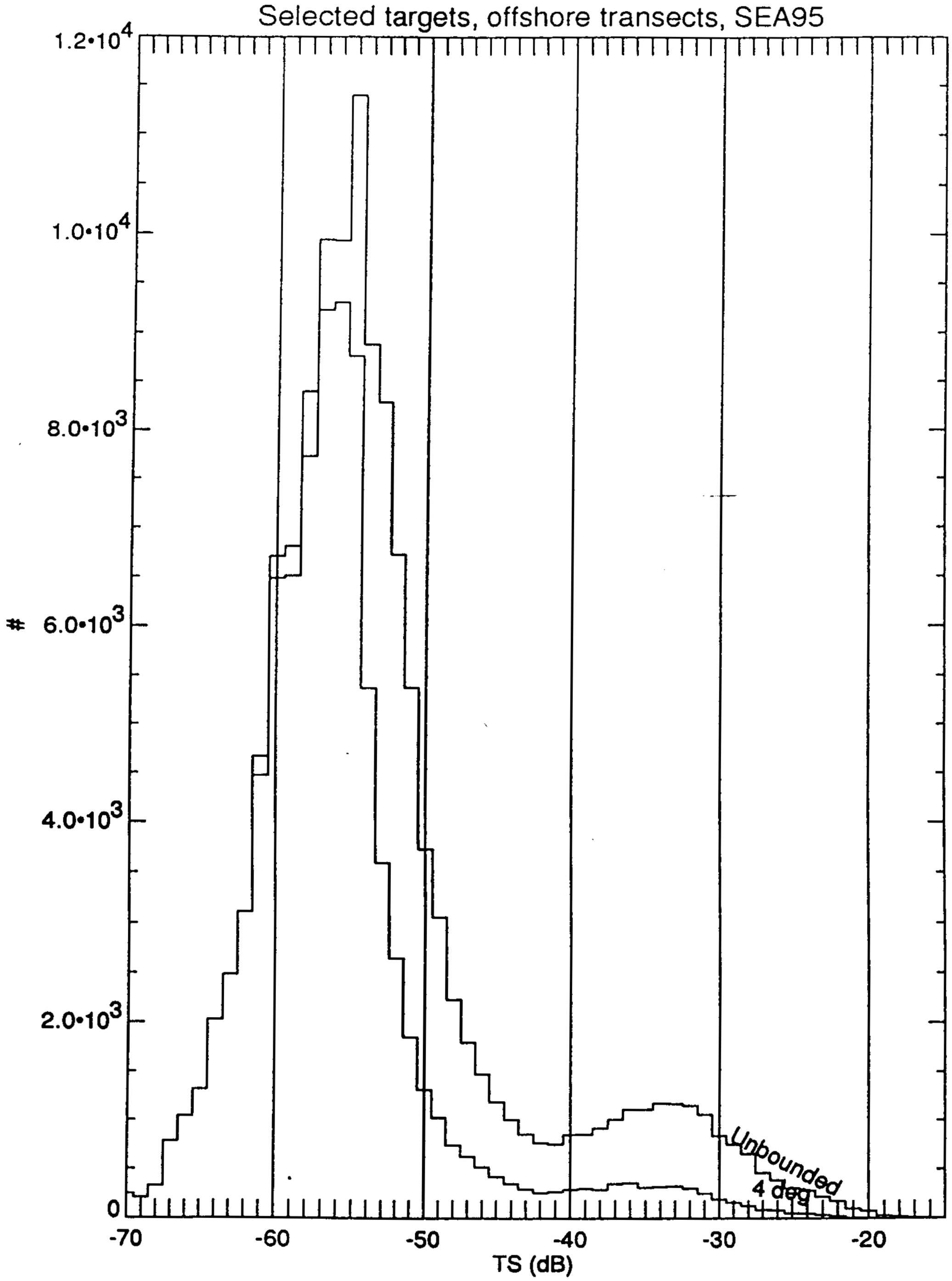

Figure 27. Distributions of acoustic target strengths for offshore surveys in 1995.

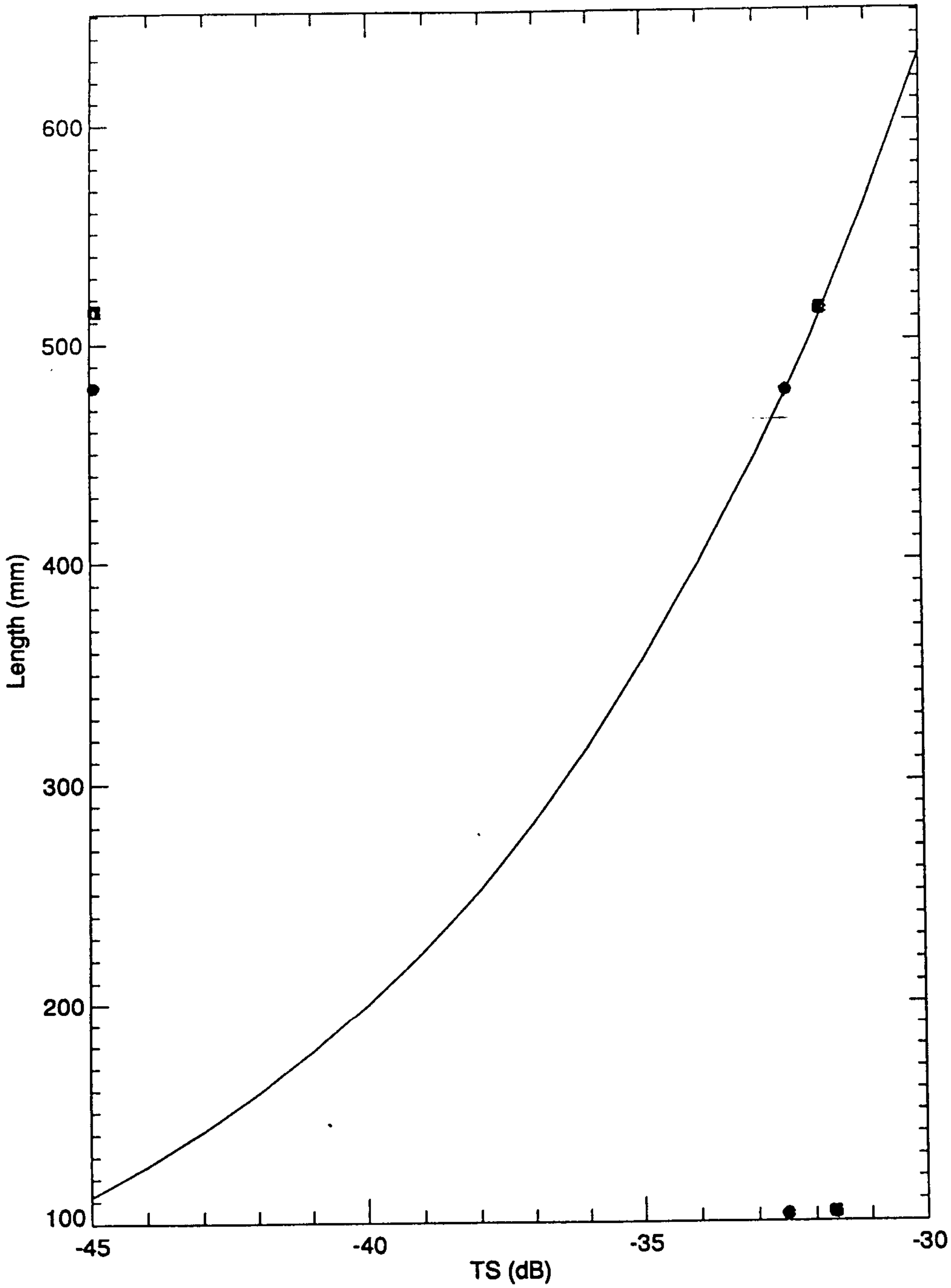

Figure 28. Target strengths of pollock by length: -20 Log L-66 (Traynor and Erenberg 1979). Circles = 1994, Squares = 1995.

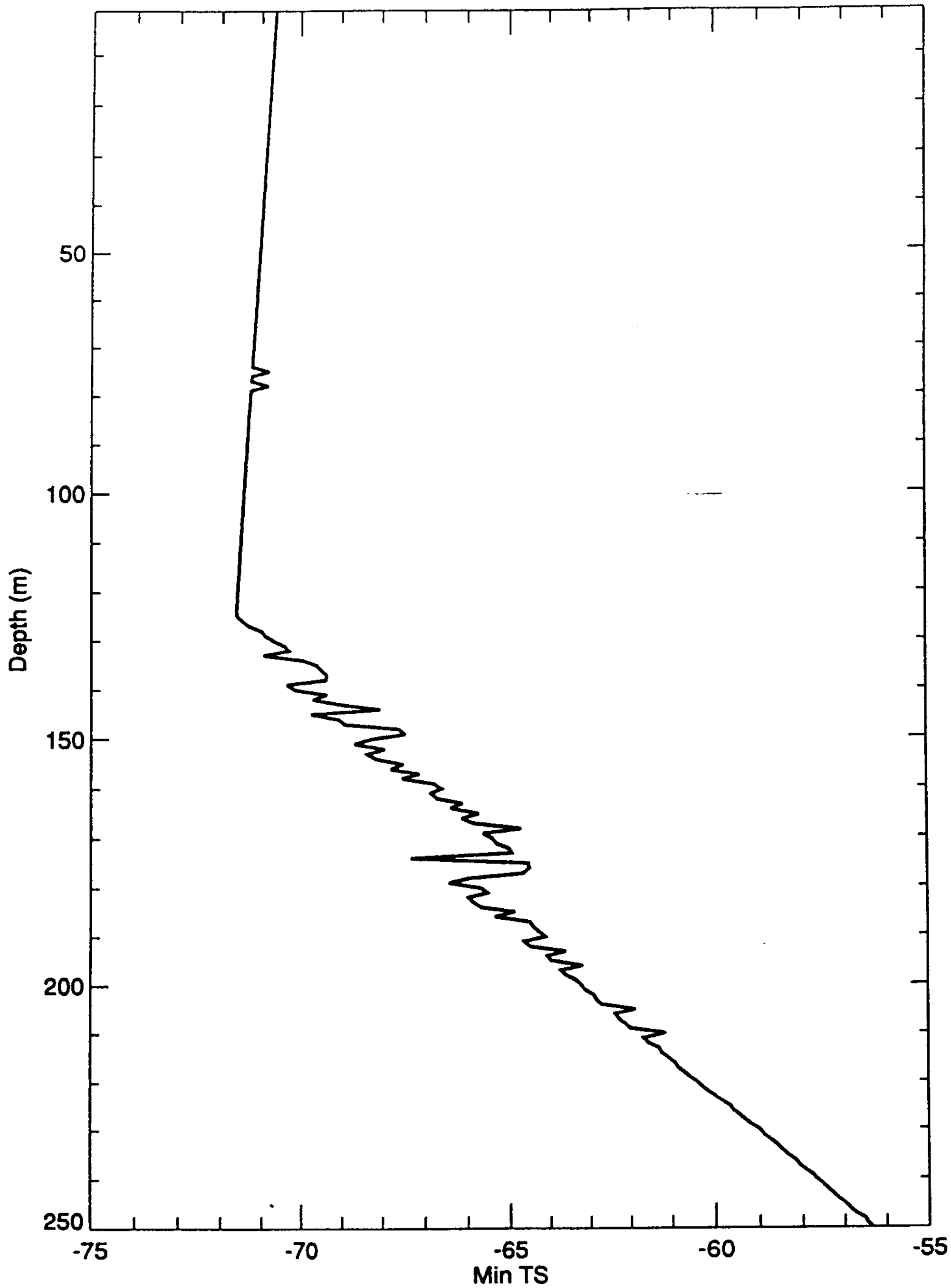

Figure 29. Minimum targets detected by depth in 1994 on offshore surveys, with a 120 kHz echosounder.

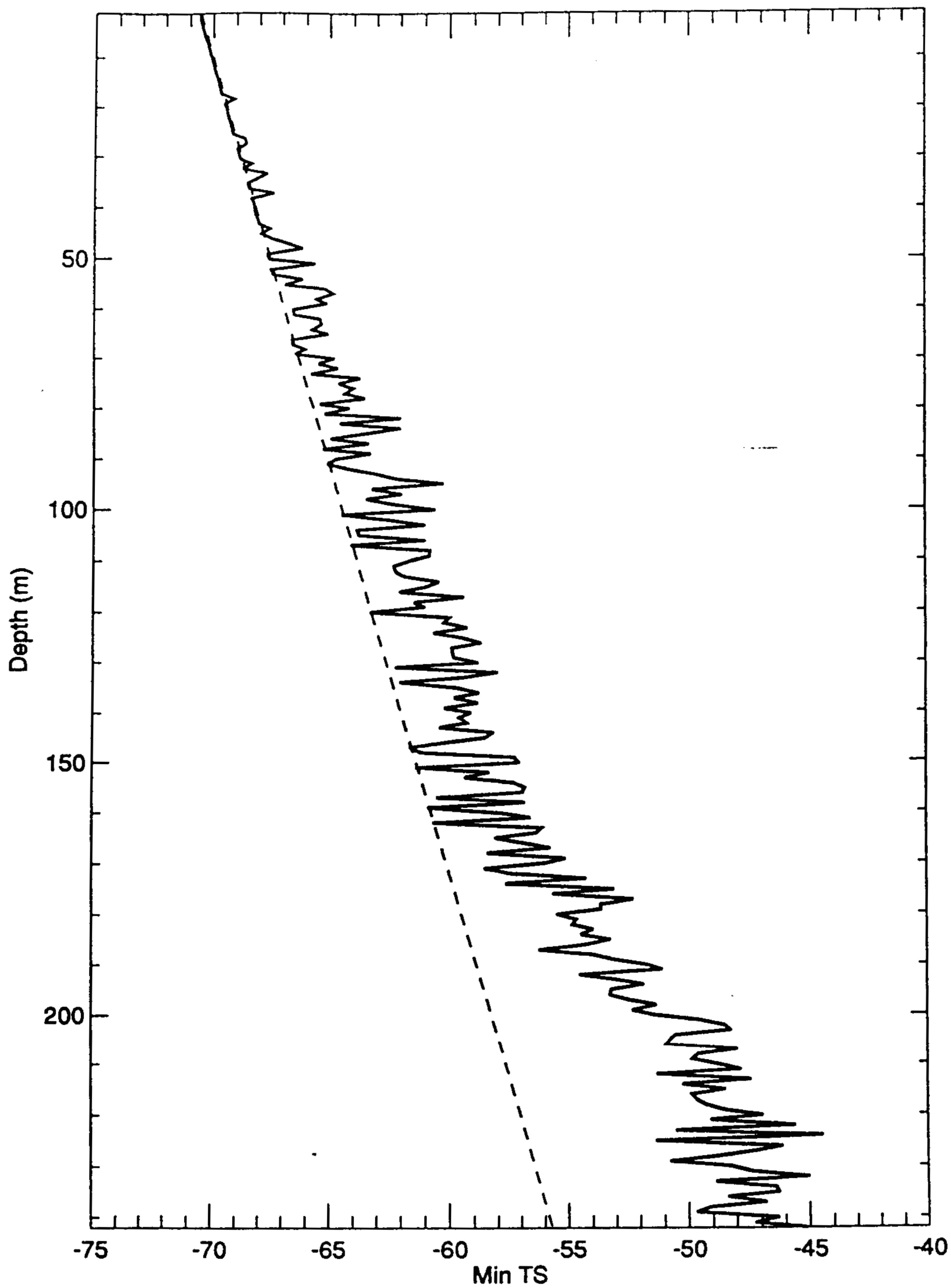

Figure 30. Minimum targets detected by depth in 1995 on offshore surveys, with a 120 kHz echosounder.

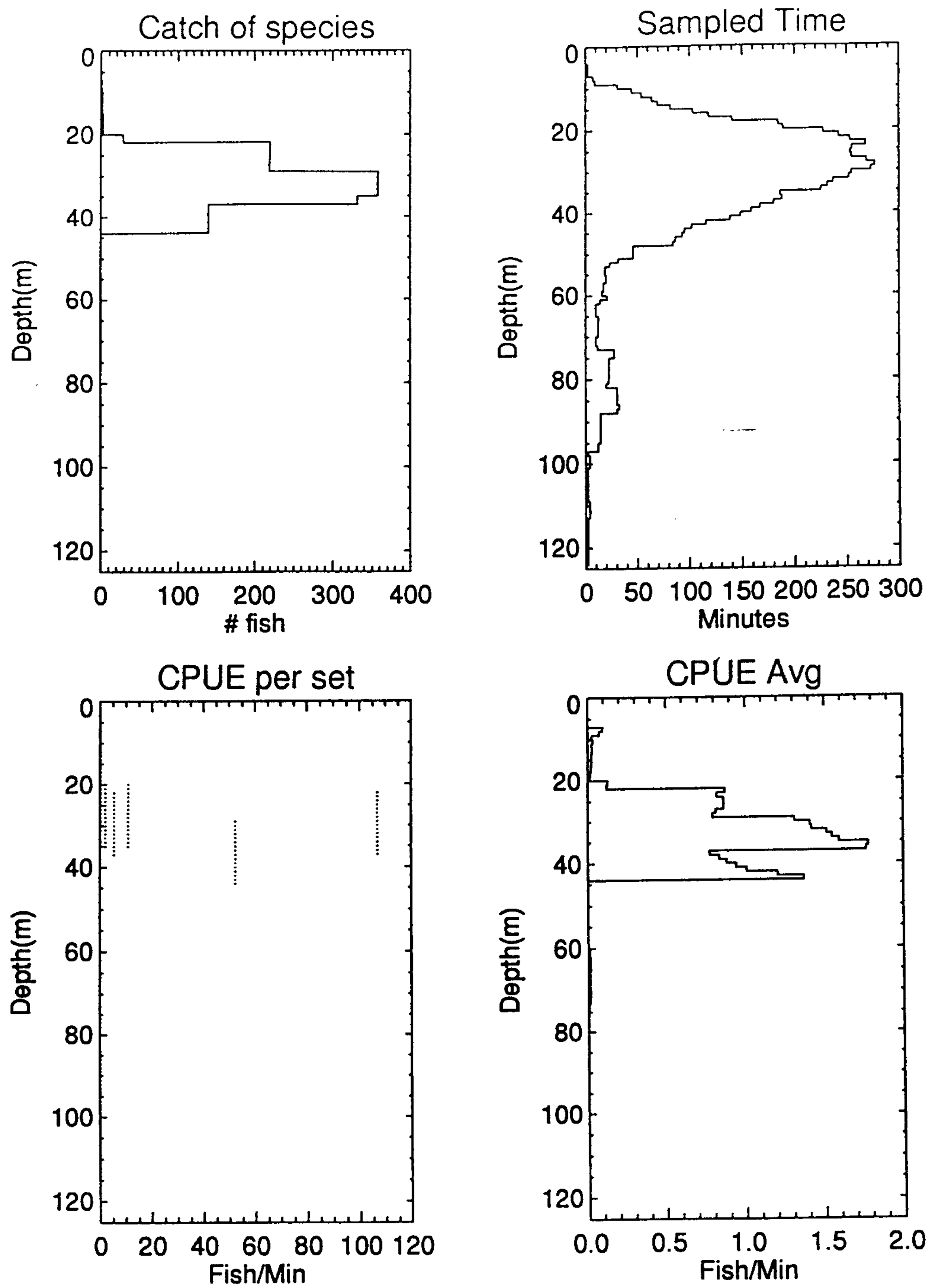

Figure 31. Vertical distribution of Pacific herring from midwater trawl catches in 1994, northwest Prince William Sound.

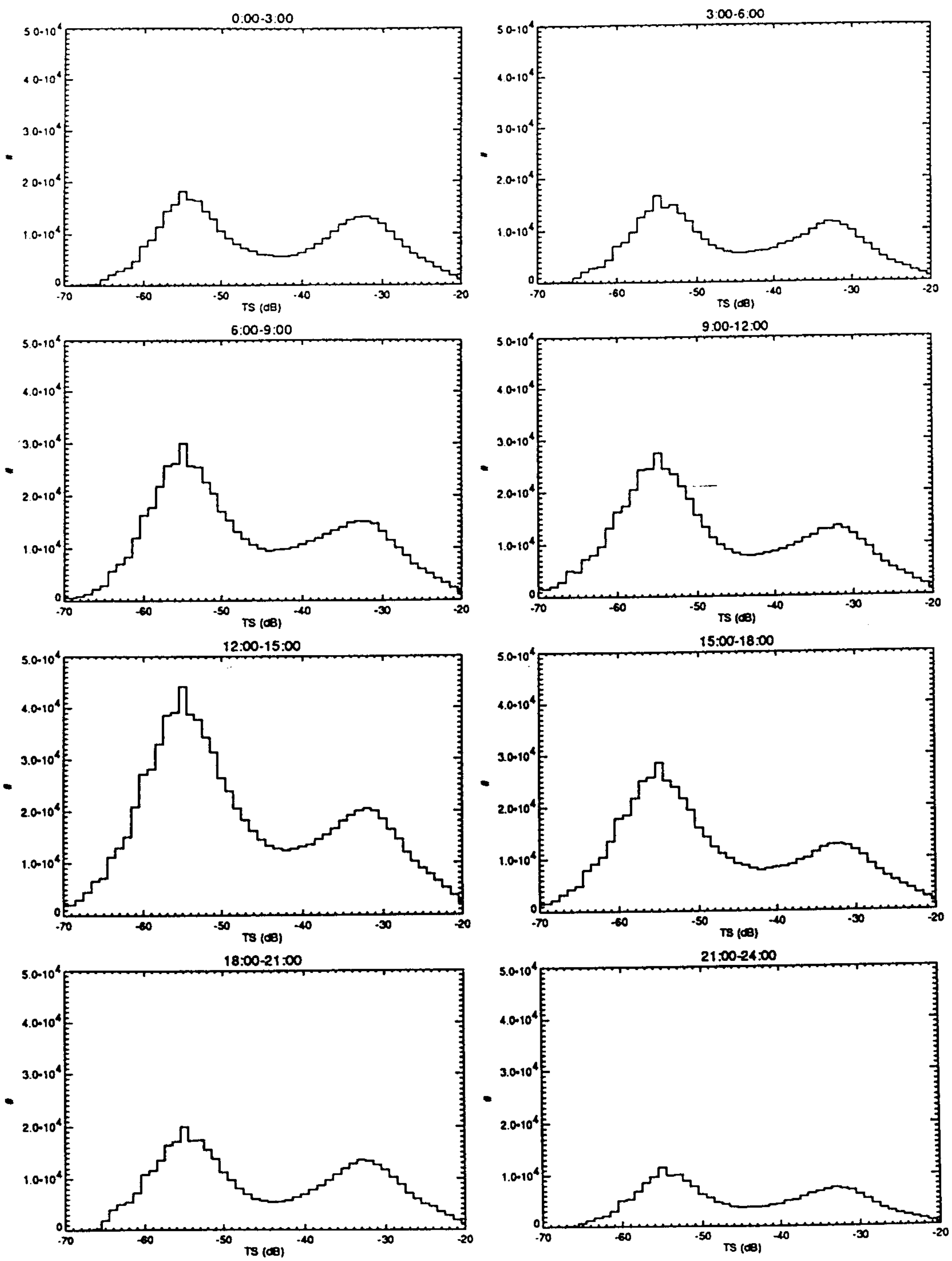

Figure 32. Diel changes in target strength distribution during May-June 1995 surveys, northwest Prince William Sound.

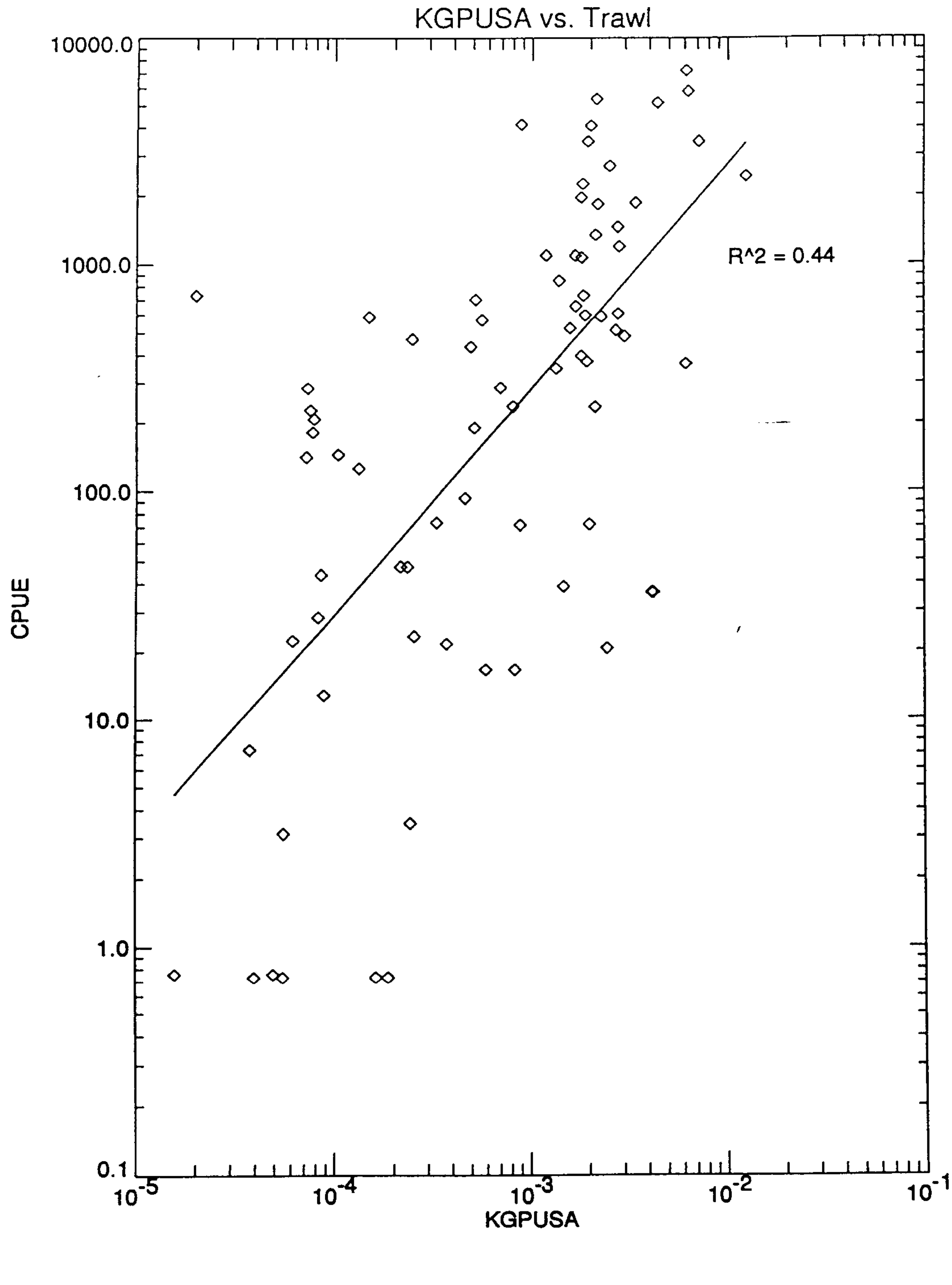

Figure 33. Relationship between echointegration of pollock cells with midwater trawl catches of pollock in 1994, northwest Prince William Sound.

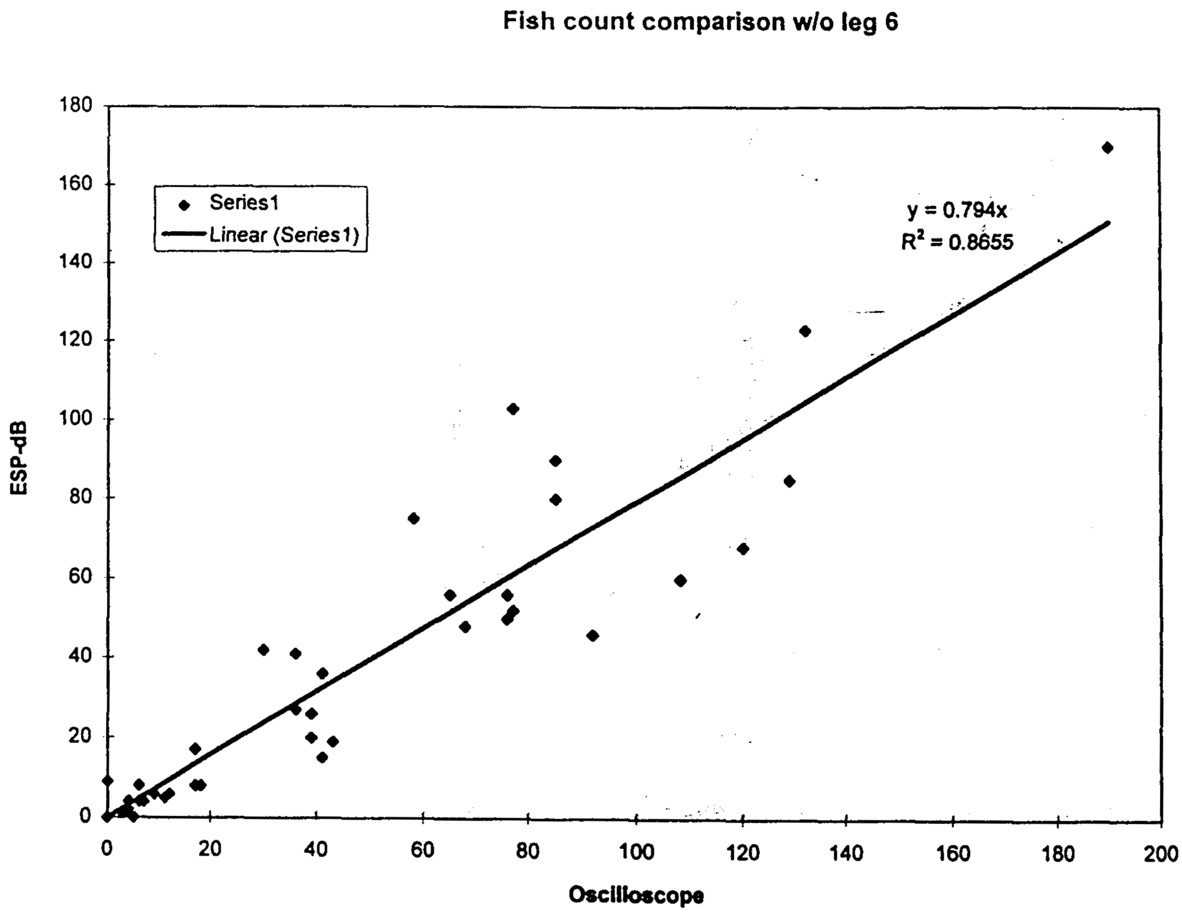

Figure 34. Relationship between manual and auto-counts of pollock on transects from the May-June 1994 surveys of northwest Prince William Sound.

Chart 20 - density of manual and auto counts for legs 2-4 plankton layer

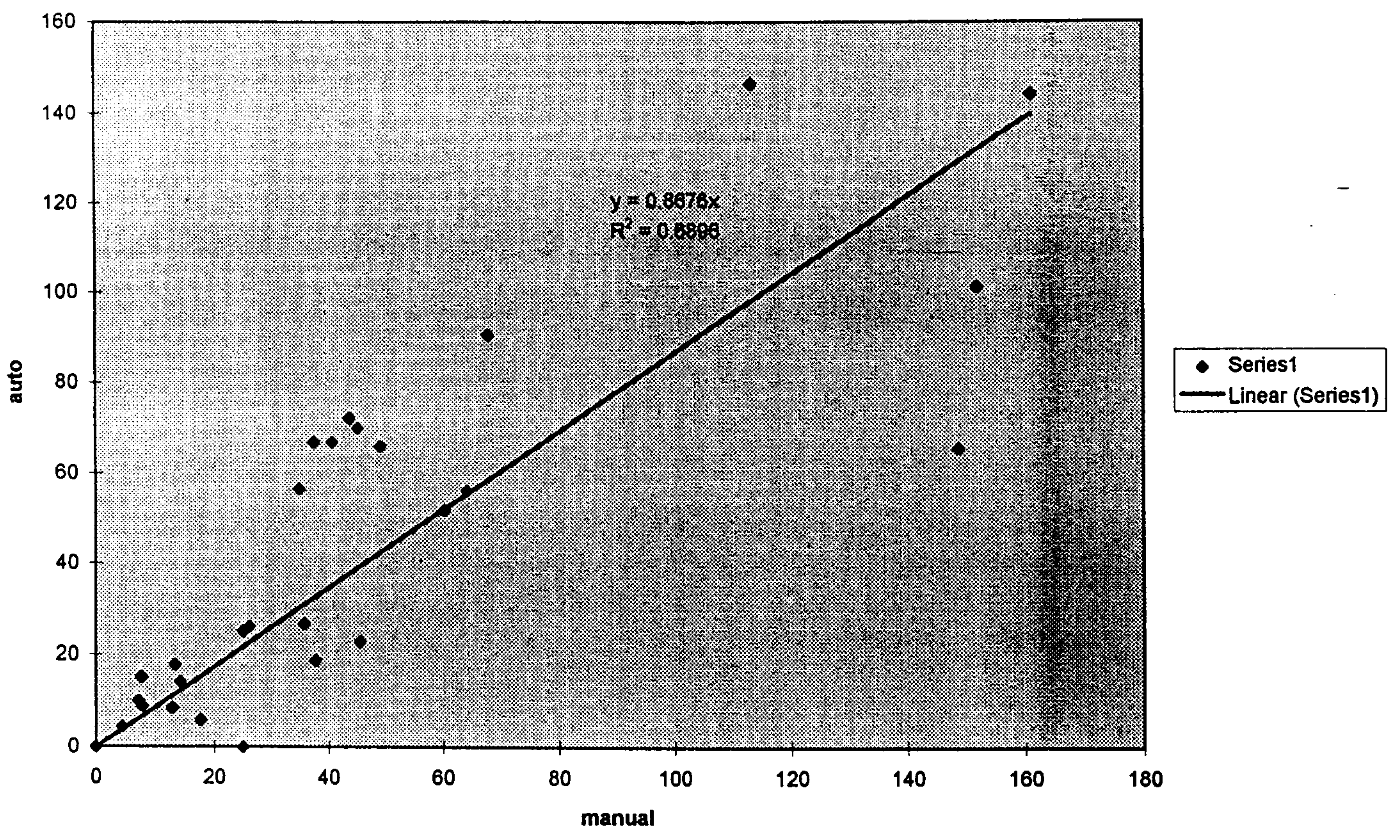

Figure 35. Relationship between manual and auto-counts of pollock in the surface plankton layers. Each point represents a transect conducted in the May-June 1994 survey of northwest Prince William Sound.

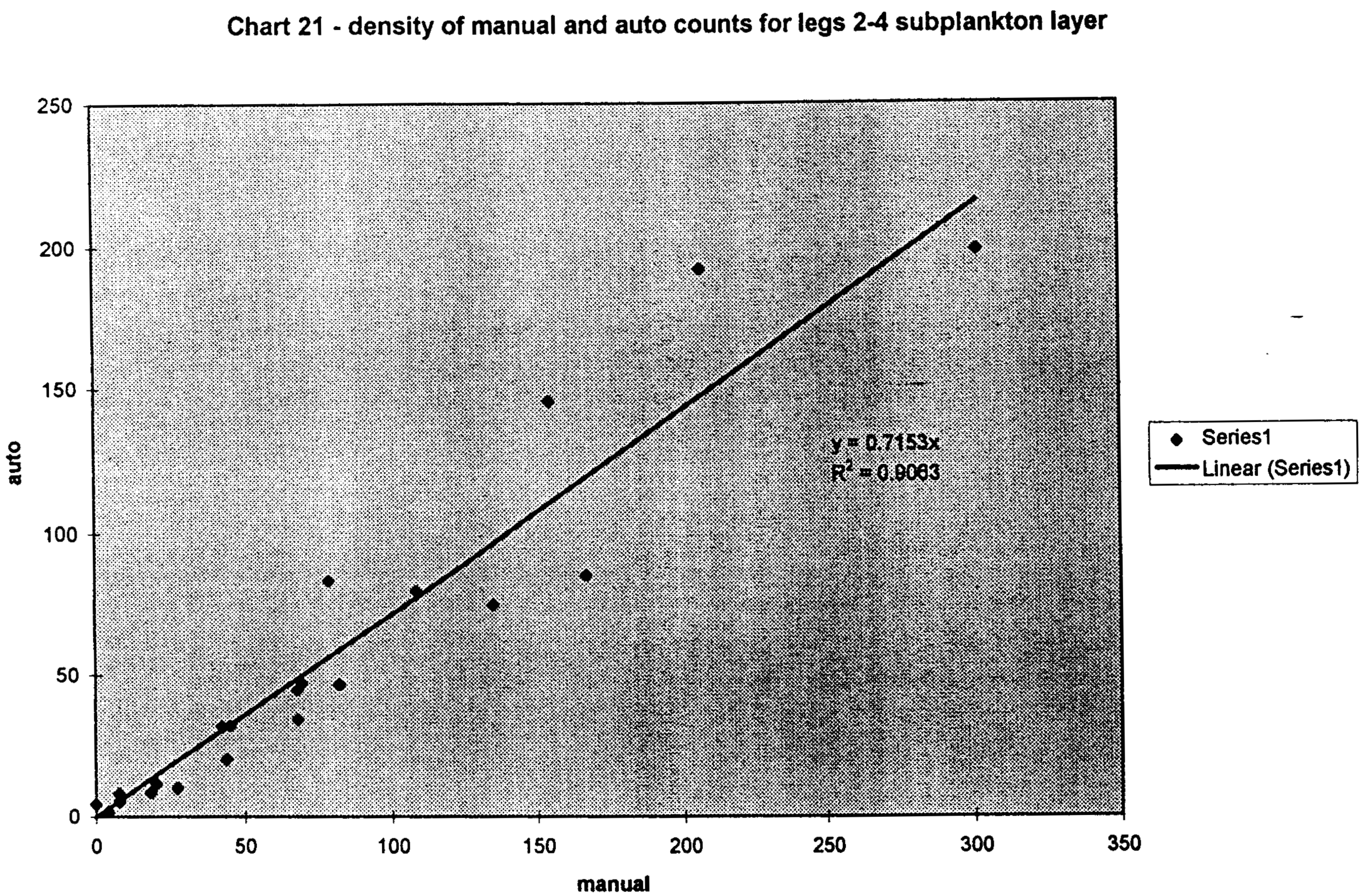

Figure 36. Relationship between manual and auto-counts of pollock beneath the plankton layer. Each point represents a transect conducted in the May-June 1994 survey of northwest Prince William Sound.

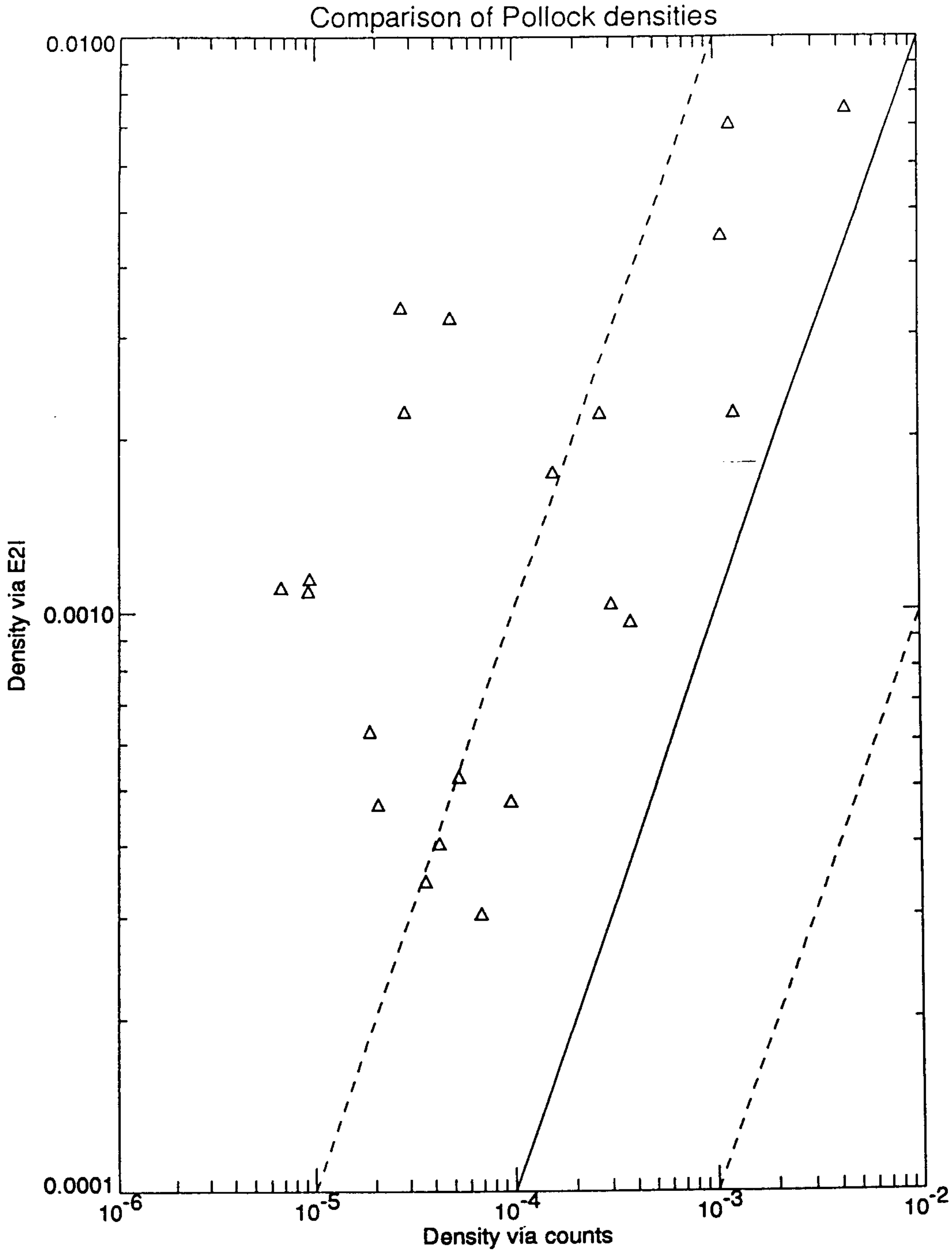

Figure 37. Comparison of the auto-counts of pollock to echointegration for the same cells, May-June 1994, northwest Prince William Sound.

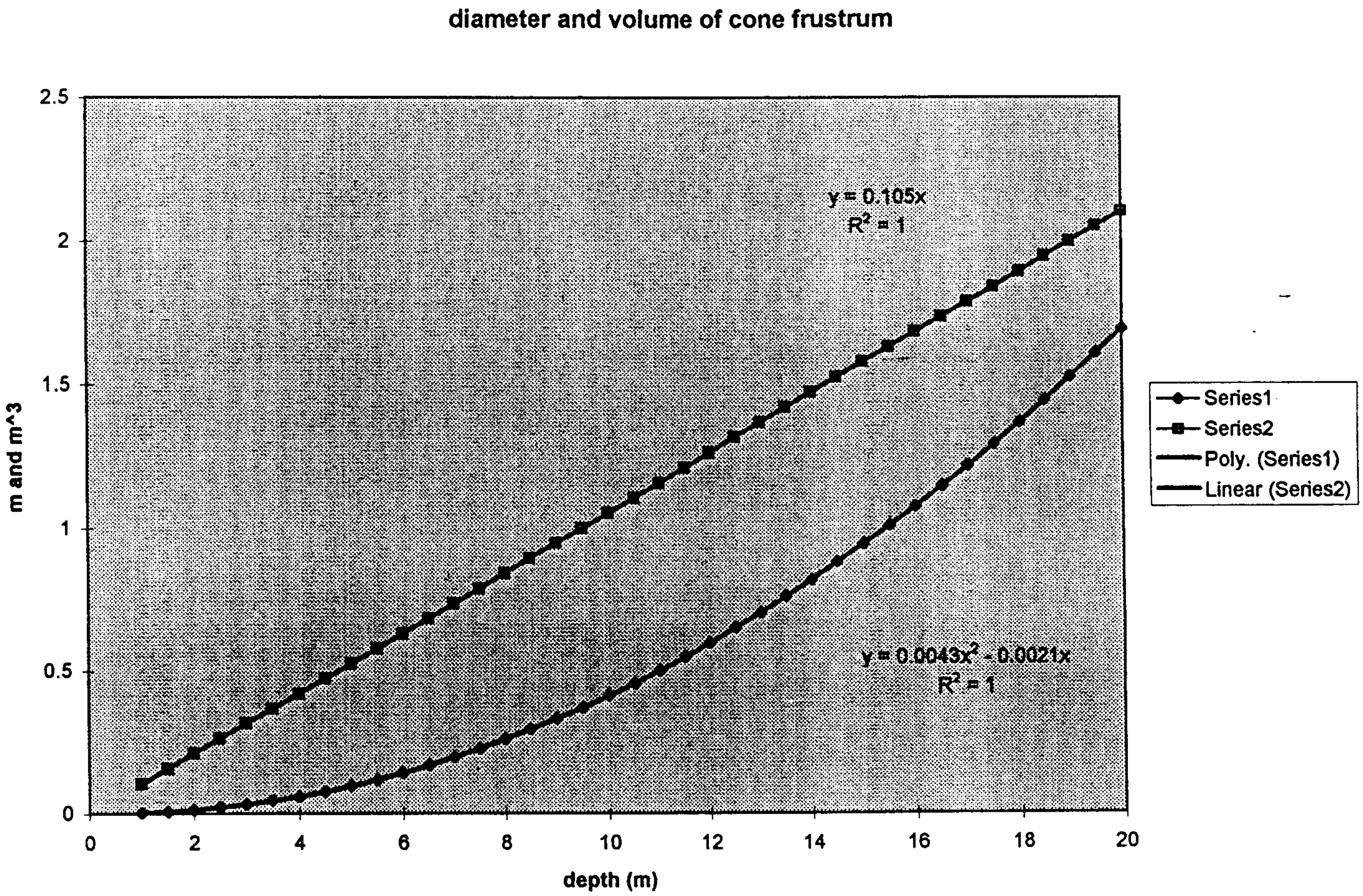

Figure 38. Acoustic sampler volumes and average diameter (of frustrums) by depth assuming a 6° full beam angle.

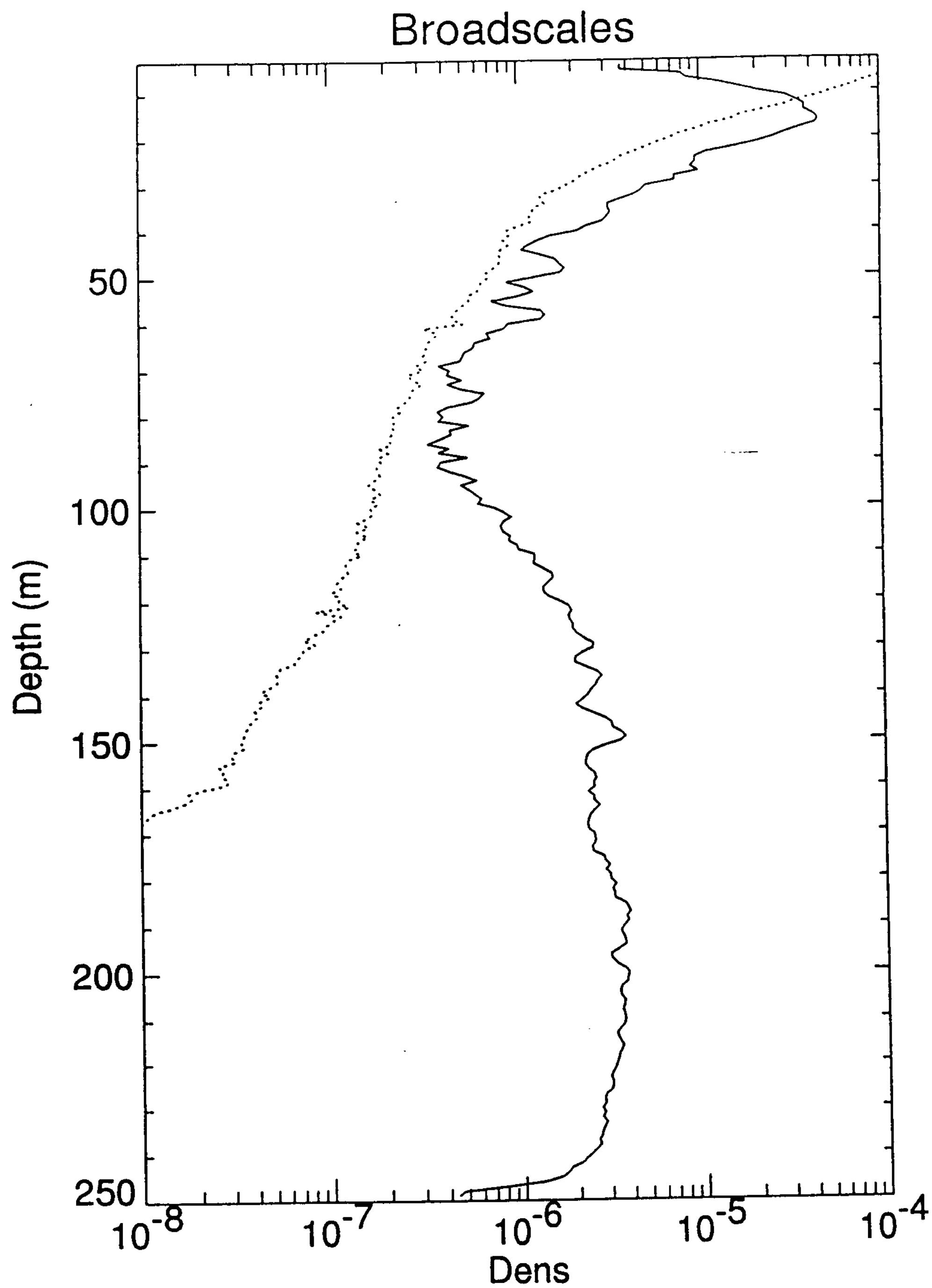

Figure 39. Vertical distribution of pollock and plankton throughout Prince William Sound in May and June, 1996.

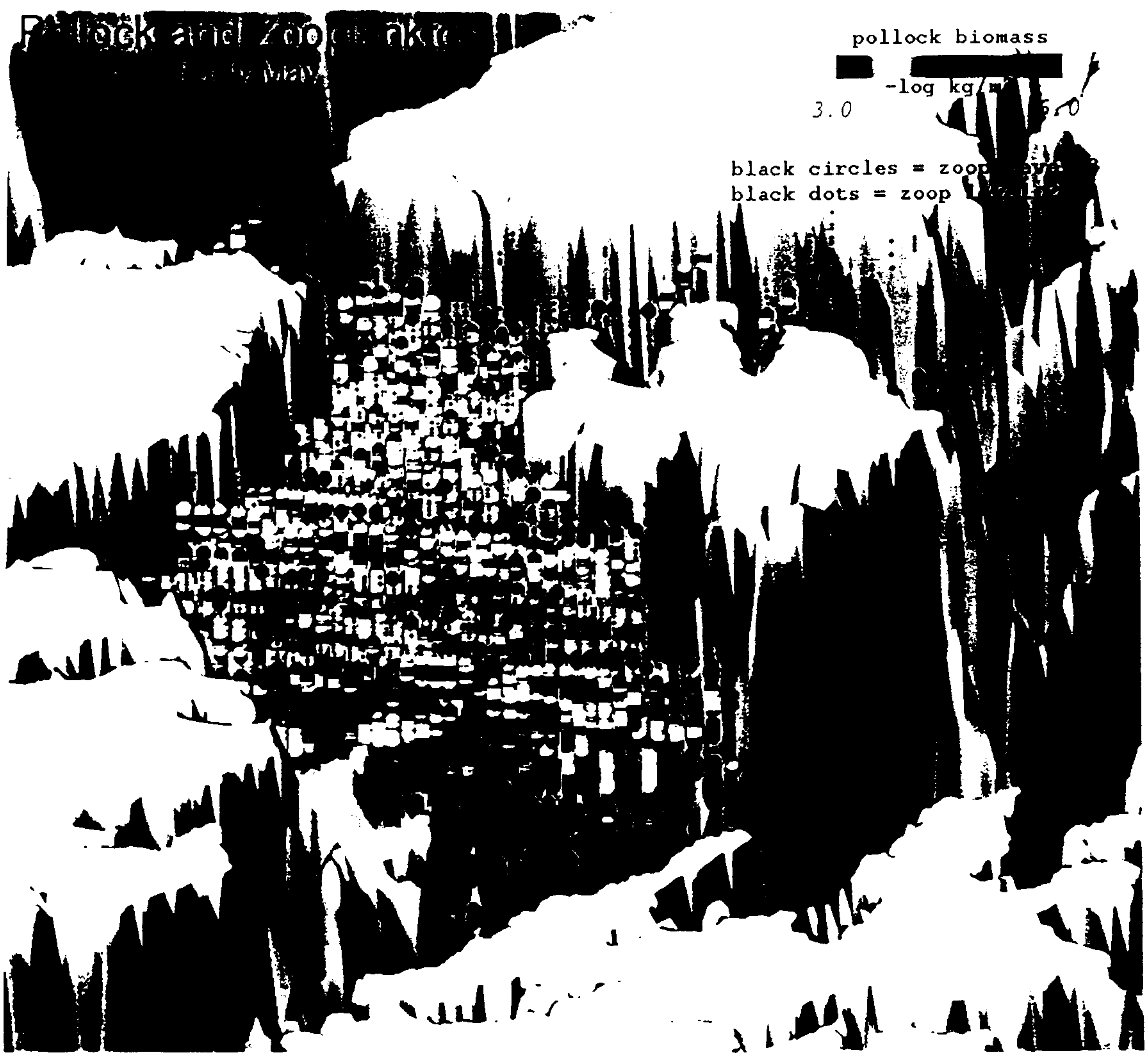

Figure 40. Three dimensional seascape of pollock and plankton patches in northwest Prince William Sound in May 1994.

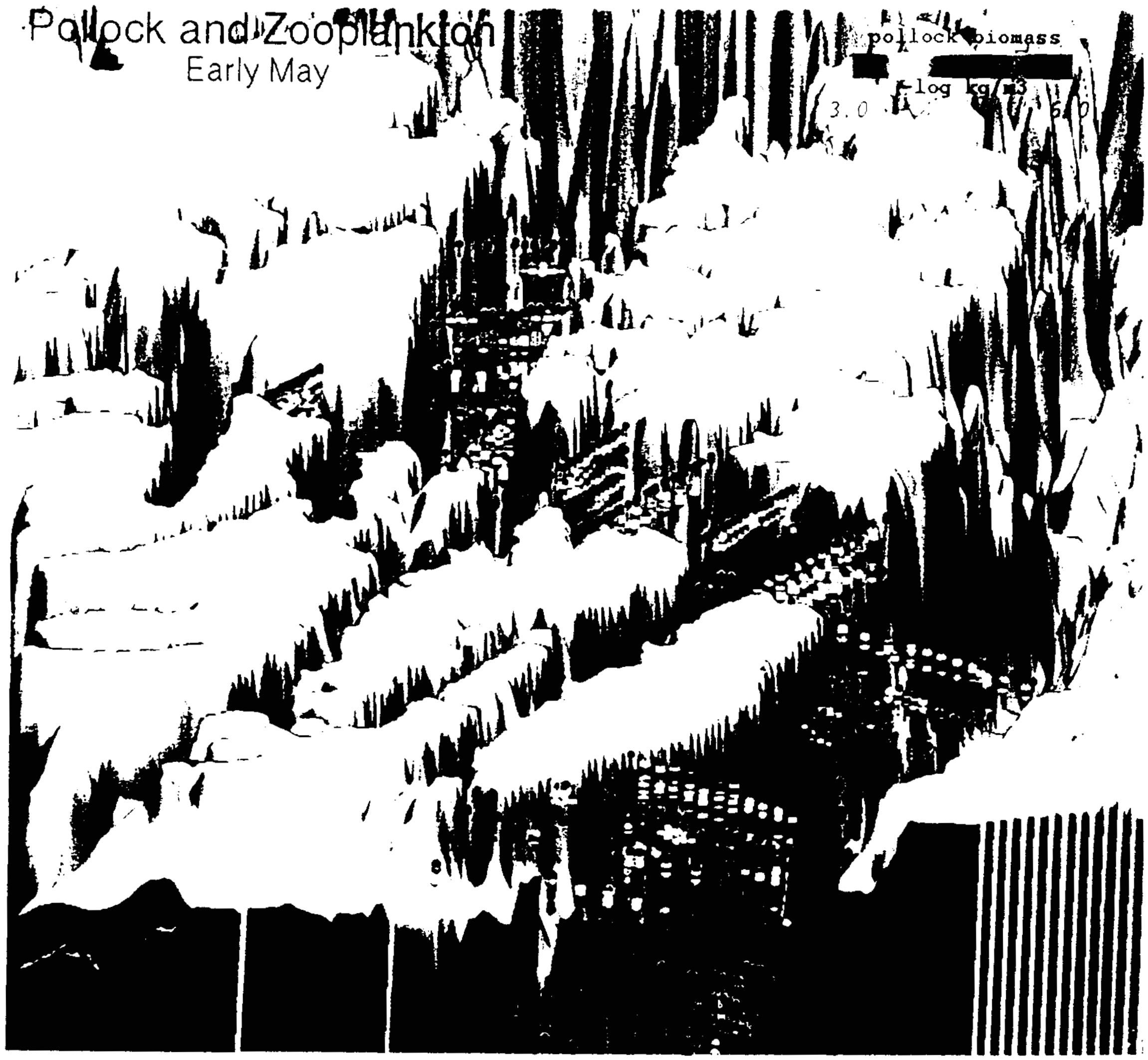

Figure 41. Three dimensional seascape of pollock and plankton patches in southwest Prince William Sound in May 1994.

Figure 42. Three dimensional seascape of pollock and plankton patches in northwest Prince William Sound in July 1994.

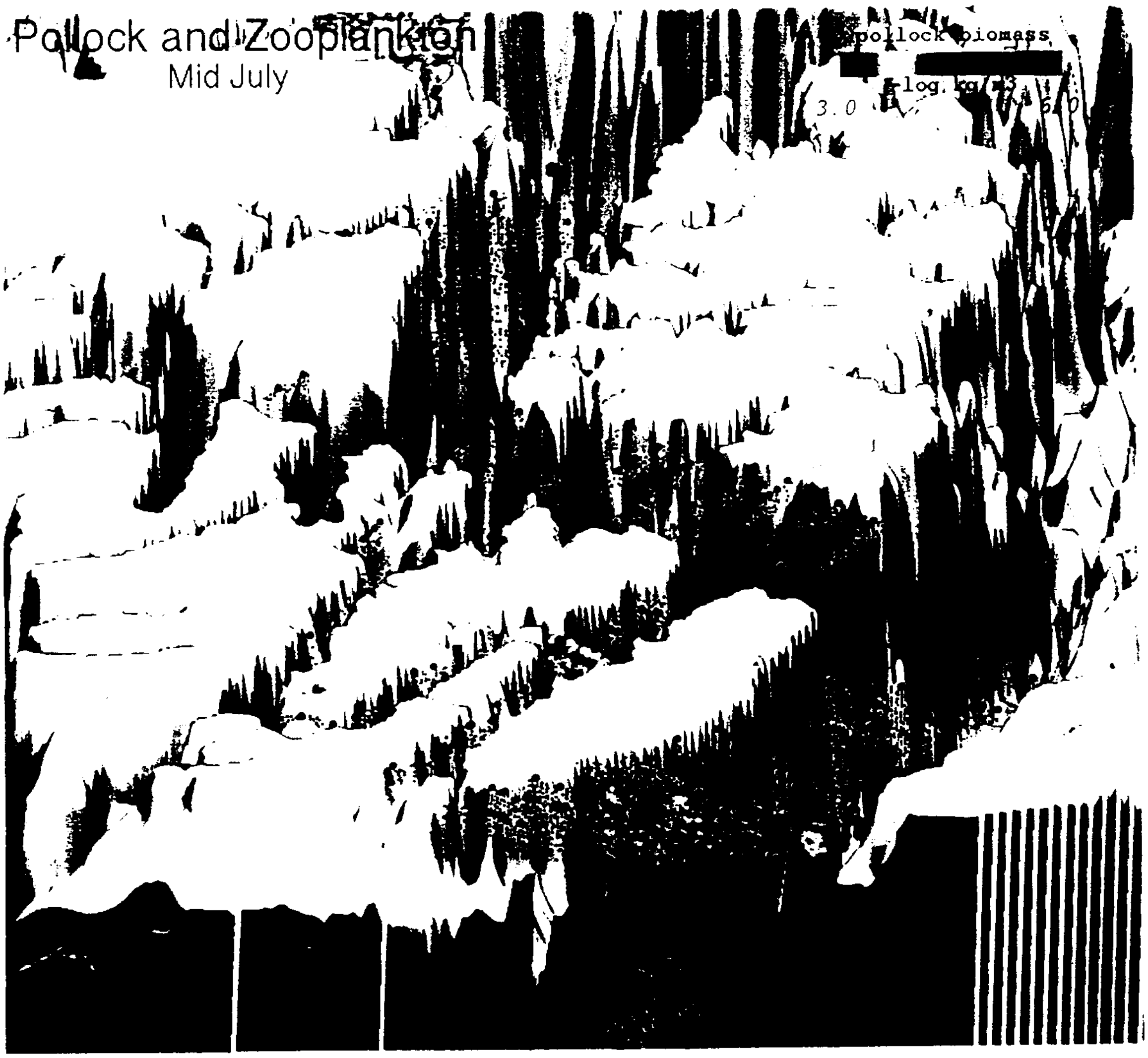

Figure 43. Three dimensional seascape of pollock and plankton patches in southwest Prince William Sound in July 1994.

CHAPTER 3

Winter 1995 estimate of the prespawning biomass of walleye pollock in Prince William Sound, Alaska. G.L. Thomas and T. Brock Stables. **Note: This paper is not to be cited without permission from the first author**

ABSTRACT

In February-March 1995, a commercial midwater trawl fishery located two concentrations of walleye pollock in southeastern Prince William Sound and harvested over 2,300 mtons before the season was closed. The average size of the Port Bainbridge pollock was 532 mm and bycatch was insignificant (<0.0004 by weight). Subsequent to the fishery, an acoustic-net sampling survey was conducted between February 24 and March 1, 1995 to make a minimum estimate of the walleye pollock biomass remaining in these areas. The first and largest concentration of pollock was found in Port Bainbridge. Port Bainbridge was surveyed twice, on February 25 and March 1. The walleye pollock biomass observed on the first survey was 18,456 +/- 1,951 mtons, and 27,366 +/-7,227 mtons on the second survey. We believe that the increase in biomass on the second survey was due to recruitment of prespawning fish into the Port Bainbridge survey.

The second and smaller concentration of fish was found in south Knight Island passage. This area was also surveyed twice, on February 24 and 28. The walleye pollock biomass observed on the first survey was 1,300+/-487 mtons, and 10,587+/-2,193 mtons on the second survey. The first survey of Knight Island passage was conducted in the vicinity of the previous commercial fishery and was unsuccessful. The second survey extended further south andsuccessfully located fish at the north entrance into Prince of Wales Passage. The biomass estimate of pollock from the second survey (February 28 in south Knight Island Passage and March 1 in Port Bainbridge) was 37,953+/-9,178 mtons. Considering Prince of Wales Passage leads to Port Bainbridge, this southerly movement of pollock may have been part of a larger spawning migration.

In addition to the quantitative surveys of Port Bainbridge and Knight Island, we conducted a reconnaissance survey of the Greater Prince William Sound in an attempt to locate other major concentrations of spawning pollock. No other major concentrations were found, but light to moderate echos suggested that most areas of the Sound contained some pollock.

Given the dynamics of the spawning migration, two surveys are insufficient to estimate the total spawning biomass of pollock. A time series of acoustic surveys in Port Bainbridge that encompass the pollock spawning season are needed to improve our understanding of when the stock has fully recruited to the area. For stock assessment purposes the second survey is most representative of the biomass and this is an underestimate since: (1) low densities of fish were observed throughout the Sound, (2) the fish were probably still recruiting in the Port Bainbridge spawning area because the last survey was still weeks prior to spawning and (3) despite the reconnaissance survey the likelihood of another undetected concentration of spawning pollock is high. This last point is illustrated by our need to conduct two surveys of the Knight Island

Passage before finding the second concentration of fish (ca. 11,000 mtons) that the fishery located just two weeks prior.

INTRODUCTION

Acoustic techniques are widely used throughout the world to assess abundance of pelagic fish stocks, including herring (Thorne 1983a, Thomas 1992). These techniques use calibrated, scientific echosounders to measure the amount of energy reflected from individual and schooled fish. Calibration of echosounders includes measurement of the directivity pattern of the transducer which is used to determine the sample volume of the sound pulse. Measurements of single fish are used to estimate target strength, which when combined with sample volume, converts the echo intensity into fish density and biomass. The echointegration and target strength techniques used to process acoustic data are based on sonar theory (Urick 1975; Ehrenberg and Lytle 1972). Net sampling is routinely conducted to subsample the acoustic targets to verify species, size and obtain other biological information on the ensonified fish (Thomas 1992).

Background

In the spring and summer of 1994, the Sound Ecosystem Assessment (SEA) program funded by the *Exxon- Valdez* oil spill (EVOS) Trustee Council found walleye pollock to be the dominant large fish predator of juvenile fishes in western Prince William Sound. In addition to being a primary predator, SEA discovered the walleye pollock were also the primary competitor of juvenile fishes for the spring bloom of macrozooplankton prey by virtue of their numerical abundance. The spring-summer abundance of pollock queried the question, are there sufficient densities of walleye pollock in the Sound to warrant a wintertime commercial fishery? This question was answered by commercial trawlers in the winter of 1995 when they located pollock schools that occupied near 1 billion cubic meters of the water column, and subsequently harvested over 2,300 mtons in a two week season.

Problem

Due to a shortage of funds and several years of declining budgets, the Alaska Department of Fish and Game has relied on stock assessment by the National Marine Fisheries Service (NMFS), who conducts surveys in the Gulf of Alaska and Bering Sea for groundfish information. Thus, the management of the Sound's pollock stock falls under the guidelines established by NMFS for the Gulf Fishery. This condition will likely remain the same into the future with current state budget projections. The National Marine Fisheries Service, also under the pressure of limited funds, conducted surveys of pollock in Prince William Sound in 1984 and 1990 (Chris Wilson, National Marine Fisheries Service, Seattle, personal communication). Results from these surveys have not been reported.

In 1989 and 1990, bottom trawl surveys were conducted in Prince William Sound to assess impacts of the Exxon Valdez oil spill on commercial species of bottomfish and shellfish. Using area-swept techniques, this survey estimated that about 9,500 mtons of pollock resided in PWS (Haynes et al. 1991). This biomass was used to manage the 1995 winter fishery in the Sound. This approach is problematic in that: (1) area-swept estimates from bottom trawl surveys are not representative of pollock populations because pollock are primarily pelagic, and (2) the stock assessment data were six years old and not applicable to current harvest management. Risks to management are high enough when in-season sampling is conducted with accepted methods, so the need for stock assessment information is paramount to sustain a viable population for harvesting.

Potential solution

The State would be interested in management of the groundfish fisheries in the Sound if stock assessment information was available. The Science Center is developing the capability to conduct acoustic assessments for a variety of fishes in the region using multifrequency, multibeam echosounding and commercial fishing vessels to subsample the fish targets for biological information. Commercial fishermen have expressed an interest in paying for the assessment through sale of the catch because of the potential economic benefits of increasing information on commercially viable fish stocks. This data could be used by federal and state agencies for management decisions as well.

Justification

Fishery resources in Prince William Sound were damaged by EVOS. Some fish resources that were particularly vulnerable, such as the Pacific herring, are at historically low biomass levels. The large walleye pollock population may have the ability to suppress the speed of recovery of damaged herring stocks. Re-establishing high herring biomass in the Sound is important to the production of most large fish, marine mammal and bird populations because it is prime forage. Commercial harvesting of the Sound's walleye pollock stock may enhance recovery of the herring population via reduced predation. However,the benefits of creating a new fishery in an economically depressed coastal region are problematic.

Description of Project

This survey was a collaborative effort between the Alaska Draggers Association and the PWS Science Center. The Draggers Association provided the trawl and the crew, while the Science Center provided the acoustician, equipment and measurement program to estimate biomass. Search areas were stratified using bottom depth, historical and recent fisheries information, previous survey information, and real time acoustics data. Sonars and echosounders were employed to locate and map schools, as well as to conduct systematic acoustic transects over individual fish concentrations. Subsamples collected by trawls were used to scale the echointegration acoustic data.

MATERIALS AND METHODS

Study Site

Prince William Sound (PWS) is a complex fjord/estuary (Schmidt 1977) located at the northern margin of the Gulf of Alaska (Figure 1). Prince William Sound covers an area of about 8800 km with approximately 3200 km of shoreline (Grant and Higgins 1910). The areas to be searched intensively were south Knight Island Passage and Port Bainbridge (Figure 2).

Acoustic survey

The acoustic survey was conducted between 23 February and 1 March 1995 using a commercial trawler, the F/V Alaskan. The trawler used a commercial search lite sonar to locate school concentrations in suspected areas, was equipped with a GPS-linked, 38-120 kHz dual frequency, dual beam, echosounder to map and estimate the size and density of schools, and was outfitted with a commercial midwater trawl to sample the acoustic targets. Transducers were mounted on a towfin in a down-looking configuration, and towed at about 6 knots at depths of 2-3 m . A Dantrawl Billionark commercial midwater trawl with a mouth opening of 22 by 10 meters was equipped with a net sounder and fished at 1.5 m/sec.

Survey Design - The acoustic survey was a multistage sampling design (Cochran 1977). The first stage used local fishers' knowledge of the walleye pollock schools location and behavior, and data from the recent commercial herring harvest to reduce the search area for concentrations (school groups) in the Sound. We assume that the adult walleye pollock stock overwinter in these areas of the Sound, spawn in mid- to late March, then disperse into the water column to feed initially on the spring macrozooplankton bloom (SEA 1993).

The second stage of the survey design was to search and locate school groups within and between (along transit path) the strata areas suspected of holding pollock schools. Historical information and fishers knowledge played another role in this stage by identifying specific isobaths pollock schools. Hence, walleye pollock schools were located by cruising within specific depth contours using commercial quality search (sweeping) light sonar and down-looking echosounders. The search-light sonar and down-looking sonar were used by the fishers to assess if commercial quantities of pollock were present.

The third stage of the survey was to map and measure the density of the schools found in the search areas. Mapping was conducted by transecting over the schools and recording GPS information. The density was measured along these transects using a dual beam echosounder. The transects were run in a zigzag fashion over the school(s) to map the concentration and then a series of parallel transects were run over the school to estimate density (Figure 3).

The fourth and fifth stages of the sampling were to trawl the acoustically surveyed schools and subsample the catch for biological information, respectively. First , the species composition of the net catch was used to partition the assessment. Second, the length and weight of the fish were used for target strength analysis.

Acoustic Parameters - Target strength information for herring was derived from average length to target strength (in decibels) per kg fish after Thorne (1983b). Thorne's empirical relationship assumes the following logistical equation: where σ is the mean acoustic backscattering coefficient, W is the mean weight (in kg), l is the mean length (in cm), and a and b are constants.

$$\gamma = \frac{\sigma}{\overline{W}} = a\bar{l}^{-b} \qquad \textbf{(1)}$$

A value for the constant a was obtained from physical data at the site (temperature and salinity) and the literature (speed of sound). A value for the constant b was obtained from a review by Thorne (1983b) using a linear regression of $\log_{10} l$ versus 10 log (σ/w), where 10 log (σ/w) is referred to as "target strength per kg." The average length and weight data were compiled from the net catches which were compared to values obtained in the commercial fishery (federal observer, personal communication). These measured data were applied to Thorne's (1983b) empirical relationship to obtain the ratio γ = σ/w and the mean backscatter coefficient (σ).

As a cross check, we generated *in-situ* measurements of target strength from a subset of dual beam acoustic data. We compared our in situ mean backscatter coefficient with Thorne's (1983b) empirical formula (Table 1).

In-situ target strength data were also collected on a 120 kHz standard target (Table 2).

Biomass estimation - Biomass was calculated for each fish concentration found during the large scale survey. The calculation of biomass per unit volume was made using echointegration by single cells jk along transects:

$$\beta_{jk} = \rho_{jk} \cdot \overline{w}_{jk} = \frac{C(ei)_{jk} \cdot P_{jk}}{\frac{\overline{\sigma}_{jk}}{\overline{w}_{jk}}} \qquad \textbf{(2)}$$

where β_{jk} is the biomass in weight per unit volume (cubic meters), ρ_{jk} is the number of scatterers per unit volume (unknown at high densities), w_{jk} is mean weight of the scatterers (also unknown), or for practical purposes by C, the acoustic constant (calibration settings ie., gain etc.), ei_{jk} is the mean of the voltage squared from echo integration (in lieu of numbers), P_{jk} is percentage of cell *jk* within the water column (where bottoms or shorelines are encountered), and σ_{jk} is mean backscattering voltage for the specific targets within cell *jk* per mean weight (dB per kg).

The biomass for a region of surface area (A in square meters) is determined by using a set of line transects across the region of known fish concentration, along which a total of nrs point estimates of biomass per unit area is obtained. Specifically,

$$B=\frac{\sum_{j=1}^{nrs}\sum_{k=1}^{nst}\beta_{jk}}{nrs}\cdot A \tag{3}$$

where nrs is number of reports (along the line transects), nst is number of one meter depth strata, and A is survey area. Where nst were not one meter bins the appropriate weighting was used to computed means and variances (Seber 1973).

For the biomass estimate, we followed Thorne (1983a). Specifically, we assume that σ_{jk}/w_{jk} is independent of cell *jk*, hence, for all *jk* σ_{jk}/w_{jk} is a constant γ, and γ is given by equation 1. With this assumption, equation 5 simplifies to:

$$\beta_{jk}=\frac{C}{\gamma}\cdot(ei)_{jk}P_{jk} \tag{4}$$

and the biomass B in an area is given as

$$B=\frac{C}{\gamma}\frac{\sum_{j}\sum_{k}\cdot(ei)_{jk}P_{jk}}{nrs}\cdot A \tag{5}$$

When a fish concentration was located, mapped, and surveyed for density, the survey for density was repeated on a later date to estimate error.

RESULTS AND DISCUSSION

Sound Search

The F/V Alaskan surveyed suspected areas of pollock concentration in the eastern and western Sound (Figure 1 and 2). Light sign was observed in several areas from the central to northwestern corner near Wells Passage and to the eastern side from Port Fildalgo to Orca Inlet. However, the only large concentrations were found in the areas that were commercially fished earlier in the month, Port Bainbridge (Figure 4 and 5) and Knight Island Passage (Figure 6). These areas were surveyed twice to evaluate repeatability of the estimate and with a series of 5-16 independent transects to estimate the variability of school density.

Biomass and density was highest, up to 27,366+/-7,227 mtons in Port Bainbridge (Table 3). This biomass increased between the two surveys by 8,900 mtons. The biomass in the Knight Island Passage area was relatively low in both surveys, 1,300+/-487 mtons, but in the second survey additional coverage of the northern Montague Straight found the school which was believed to be in the Knight Island passage earlier in the month during the fishing season, 10,597+/-2,193 mtons (Figure 7). Figure 8 shows the increase in biomass estimates between surveys.

The total catch from the trawling was estimated a 106,173 kg for 120 minutes of trawling (4.4E-10 cub. m). The catch was over 99% pollock and the mean length and weight were 51 cm and 1.3 kg. Table 4 lists the target strength for the Port Bainbridge pollock, March 1, 1995.

Minimum biomass survey design

The multistage sampling design used for estimating the winter biomass of pollock has been used for estimating fall herring biomass (Thomas et al. 1995). The precision is high, with 95% confidence limits for the four surveys varying from 11% (n=16), 21%(n=9, 26%(n+13) and 37% (n+5). As expected as the number of transects approaches 10 the precision stabilizes. The bonus is the relatively low cost and robustness of this survey design (less than $50K).

The approach is robust since it uses the best information available on fish distributions via experienced fishers to search for the fish to be measured. If the fish change their distribution in the future, and they often do, it will be most likely that fishers will discover the change, and survey search procedures would become immediately adapted. This later step allows for industry participation and develops their responsibility in the assessment process, a theme long overdue in fisheries science.

This survey does not measure the total population size of the Sound's walleye pollock. A survey to assess total population size would require systematic measurements over the entire Sound and adjacent Gulf of Alaska, and then a complementary genetic assessment to establish the presence of different stocks. This survey allows for estimating the bulk of the population available to the fishery, or in a sense the **minimum biomass estimate** of the population. This estimate should be adequate for management and conservation of the fish population. Future improvements to the survey design may be warranted by industry with the desire to improve the exploitation efficiency of the stock on a sustainable basis.

The nesting of quantitative acoustic procedures within semi-quantitative reconnaissance surveys is practical. Albeit commercial fishing sonars and echosounders are not calibrated measurement tools, when coupled with experienced fishers' knowledge, provide a meaningful judgement on the relative distribution of the fish population. The fact that fishers make a living off making real-time estimates of fish density and distribution makes the reconnaissance step robust and believable. Furthermore, when this reconnaissance is coordinated with quantitative sonars to estimate fish density the design approaches proportional allocation of sampling that is most efficient (Cochran 1977). Advantages of the multistage, minimum biomass sampling design are that expenses are low, precision is high and the design adapts to changes in fish distribution.

By assuming that the fishery harvested 2,300 mtons and the biomass of the second survey was minimal of the spawning biomass, 37,963+/-9,420 mtons, the range in exploitation rates is from 5 to 8% (Figure 9). This exploitation rate is conservative but should allow for sustaining a safe harvest of the stock. As confidence in the stock assessment procedures grows, consideration may be warranted for increasing this exploitation rate.

ACKNOWLEDGEMENTS

This project was funded by a team effort from the EVOS Trustee Council and the Alaska Department of Fish and Game through the commercial sale of the experimental catch. We wish to thank Jay Stinson, skipper of the F/V Alaskan, whose interest in the survey effort was the spark that made things work. His volunteering the use of the vessel charter, regardless of remuneration was commendable and set the tone for cooperation between fishermen, state and federal agencies and the Science Center. We also thank the local commercial fishers and processors for their interest and support of this survey and the Prince William Sound Science Center (PWSSC). Finally, the EVOS Trustee Council and staff (Molly McCammon and others) deserves significant thanks because of their long-term commitment to research and development of better methods. We thank all who have supported our efforts to improve conservation of fish populations by monitoring with new technologies.

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Table 1. Parameters of the acoustic equipment used during the fall 1994 herring survey in Prince William Sound.

System	Frequency	Source level	System gain	Transducer	Pulse duration
BioSonics 101	120kHz	225.075dB	-165.264dB	.0010718	0.4 ms
BioSonics 102	200kHz	221.655dB	-155.765dB	.0006515	0.4 ms

DEPTH INTERVALS

TS	77-102	102-127	127-152	152-177	177-202	202-227	SUM
-50	0	0	0	0	0	0	0
-48	0	6	0	0	3	0	9
-46	2	6	8	1	10	0	27
-44	0	8	14	2	18	0	42
-42	0	14	19	3	13	1	50
-40	0	4	17	11	20	0	52
-38	0	6	28	13	29	1	77
-36	0	0	9	13	18	0	40
-34	0	2	11	14	17	0	44
-32	0	1	3	18	7	0	29
-30	0	0	13	16	9	1	39
-28	0	0	14	24	5	0	43
-26	0	0	7	22	1	0	30
-24	0	0	0	11	0	0	11
-22	0	0	0	1	0	0	1
-20	0	0	0	1	0	0	1
-18	0	0	0	0	0	0	0
SUM	2	47	143	150	150	3	495

Table 2. TS of fish in the Port Bainbridge school at 38 kHz, 77-102 m range, March 1, 1995.

Table 3. Biomass of pollock and the 95% confidence limits for eight areas surveyed in Prince William Sound in the winter of 1995. Leg 2 biomass is presented as total biomass because it was believed that the fish were still recruiting into the spawning area at the time of the first survey.

Date	Area	Leg	Transects	Biomass (mtons)	95% C.I.
02-24-95	Knight Island Passage	1	5	1,300	487
02-25-95	Port Bainbridg	1	16	18,456	1,951
02-28-95	Knight Island Passage	2	9	10,597	2,193
03-01-95	Port Bainbridge	2	13	27,366	7,227

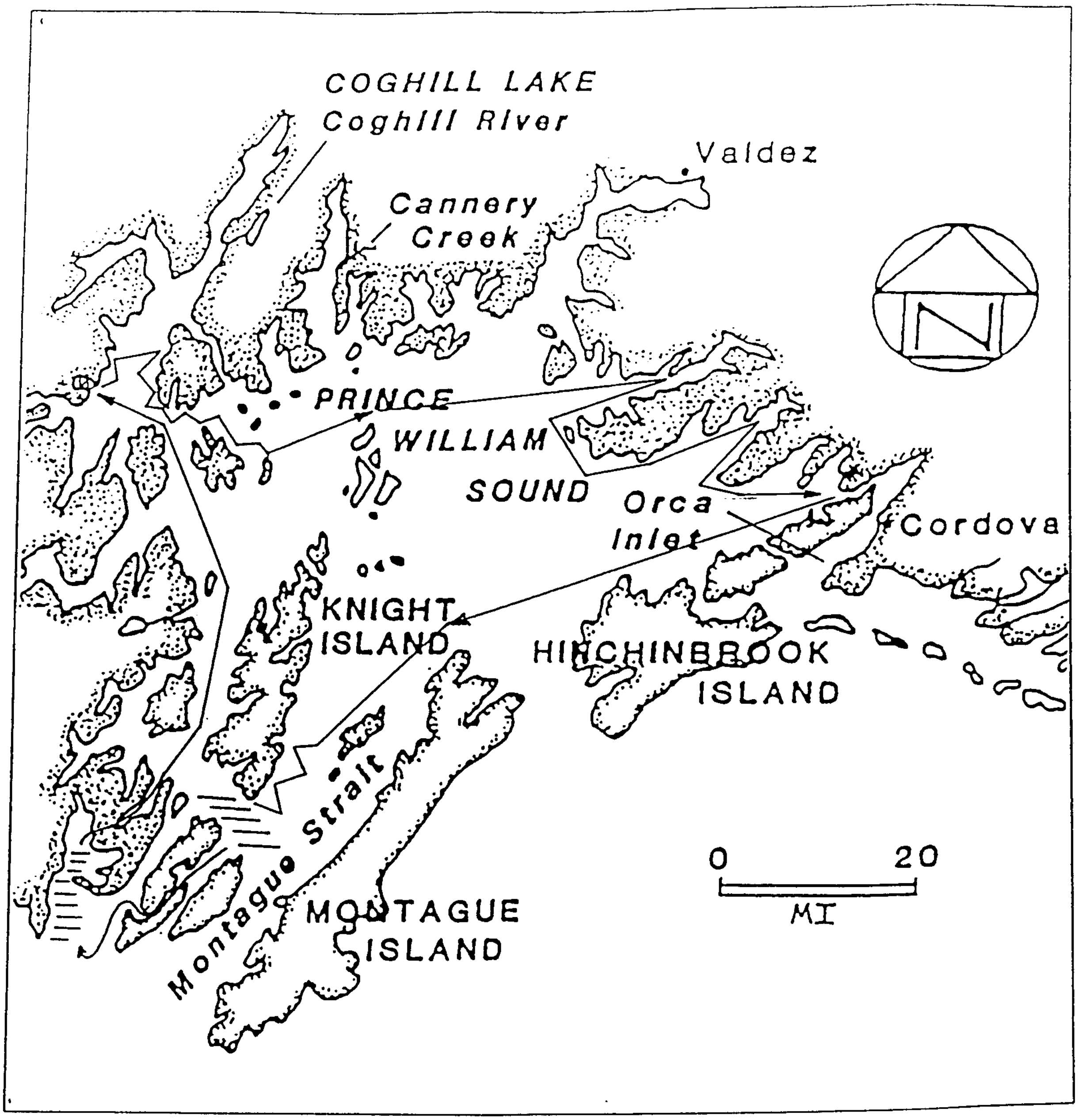


Figure 1. Prince William Sound winter walleye pollock survey Leg 1, February 24-26, 1995.

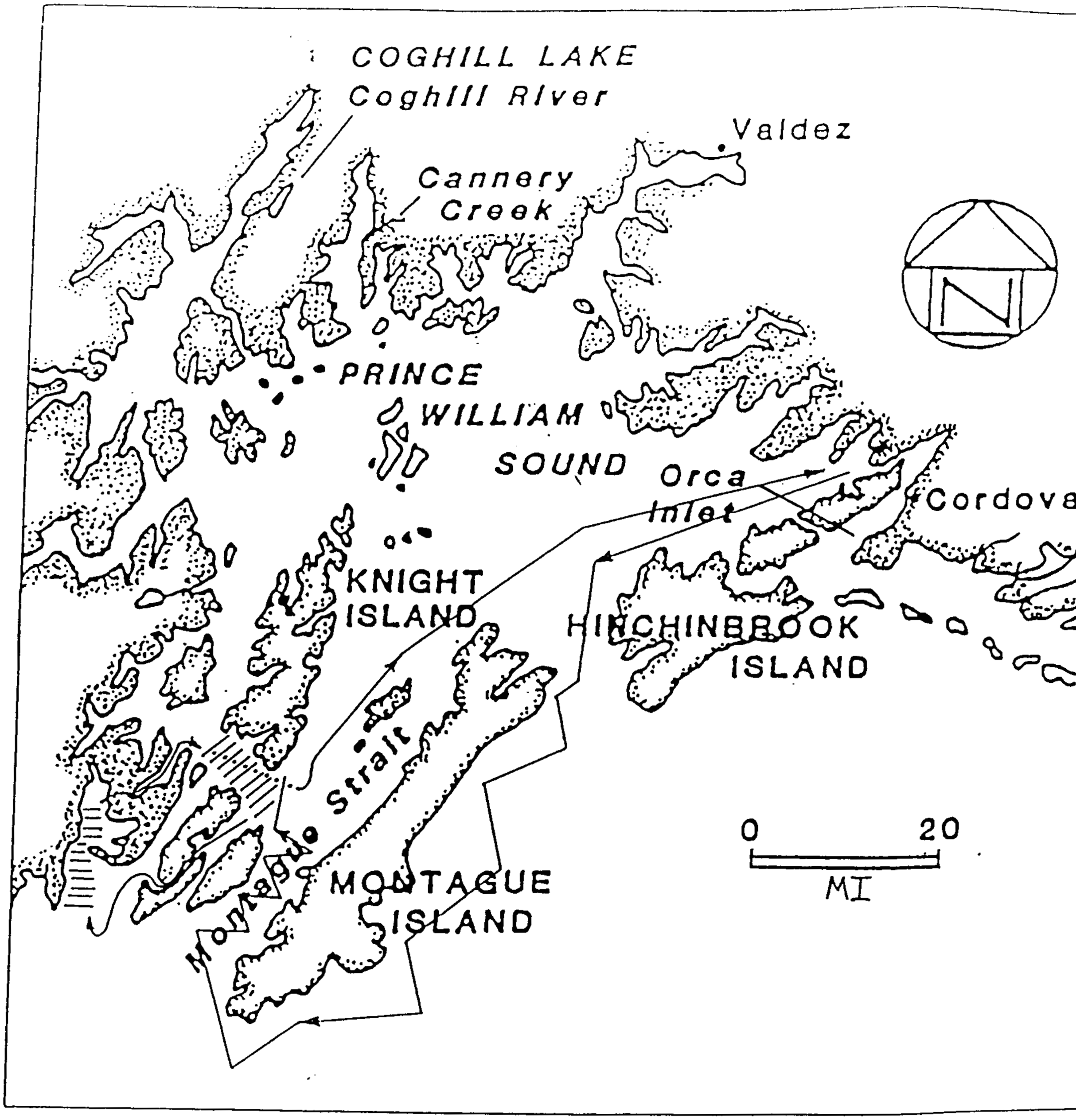
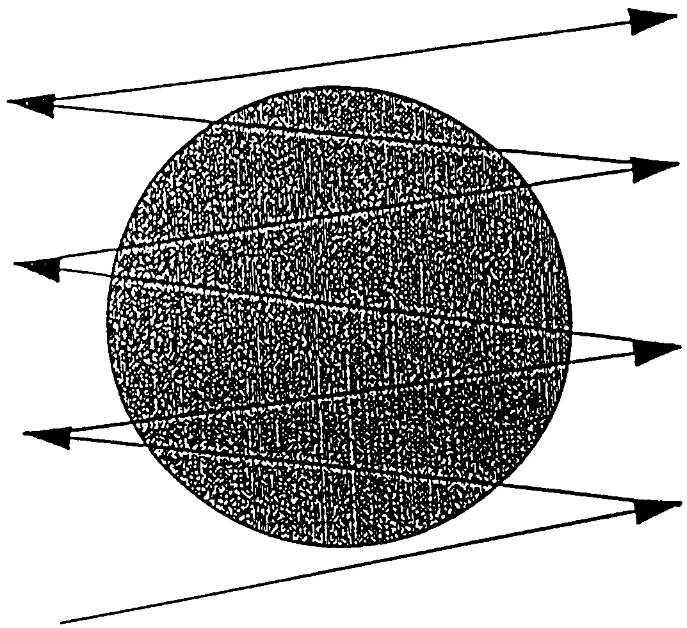
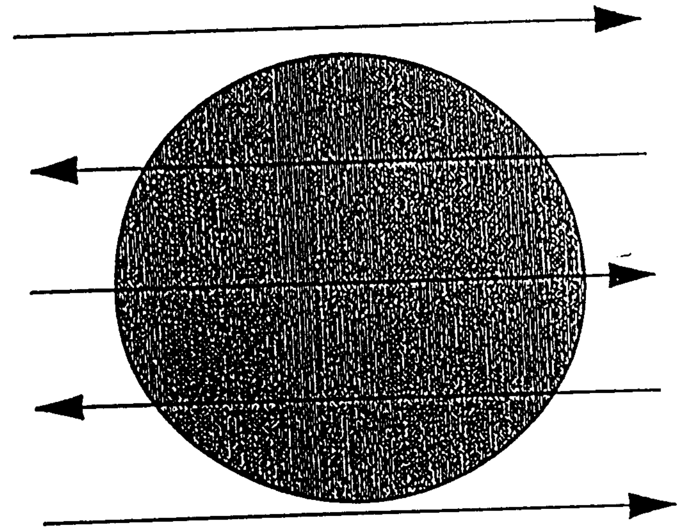


Figure 2. Prince William Sound winter walleye pollock survey Leg 2, Feb. 28 to Mar. 1, 1995.



Transect pattern used to map a known school of walleye pollock, using a dual beam echosounder and GPS.



Transect pattern used to measure the density of the school of walleye pollock.

Figure 3. Transect patterns used to map and measure the density of schools found in the search areas.

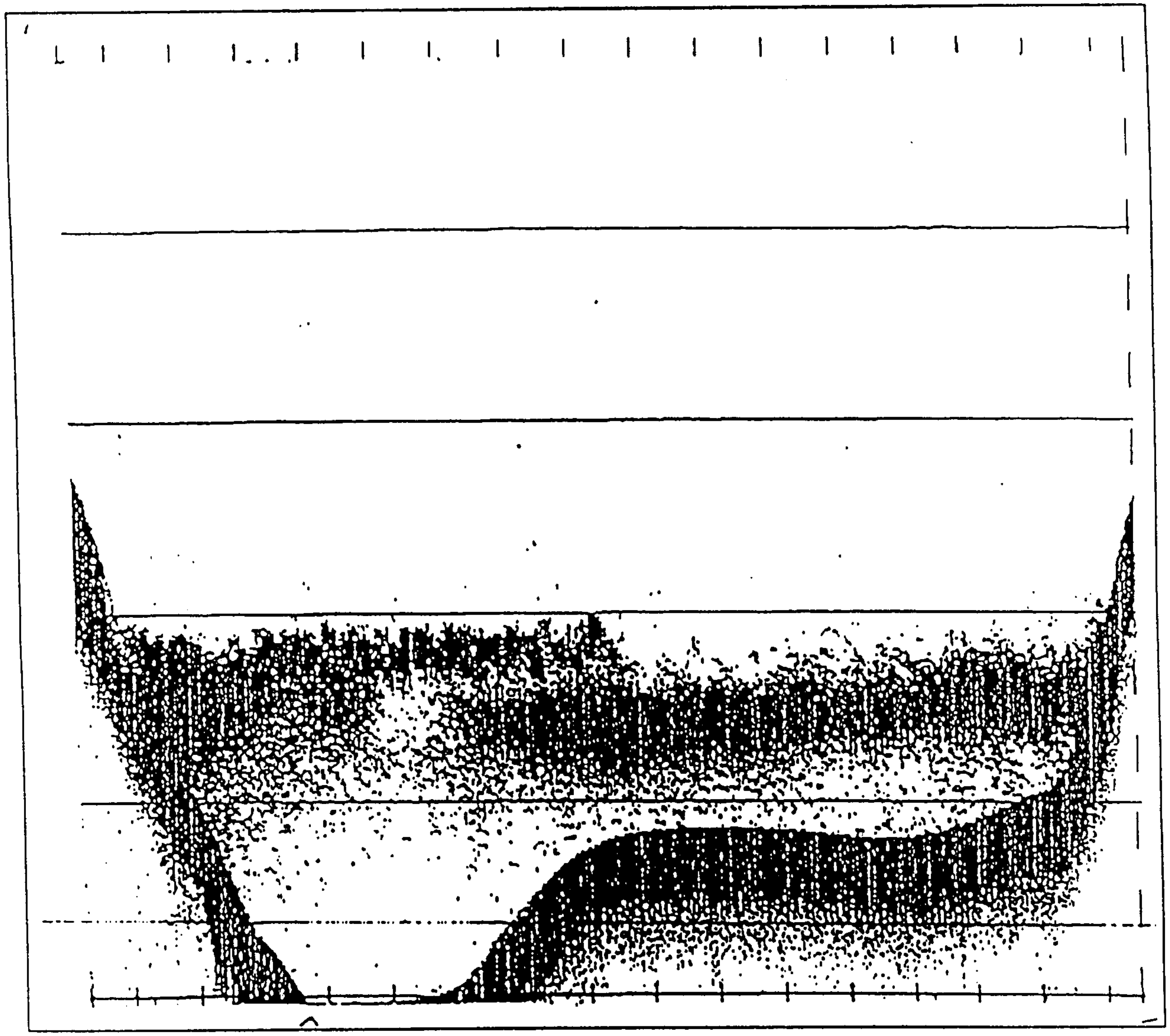


Figure 4. Echogram from Port Bainbridge survey, Leg 1.

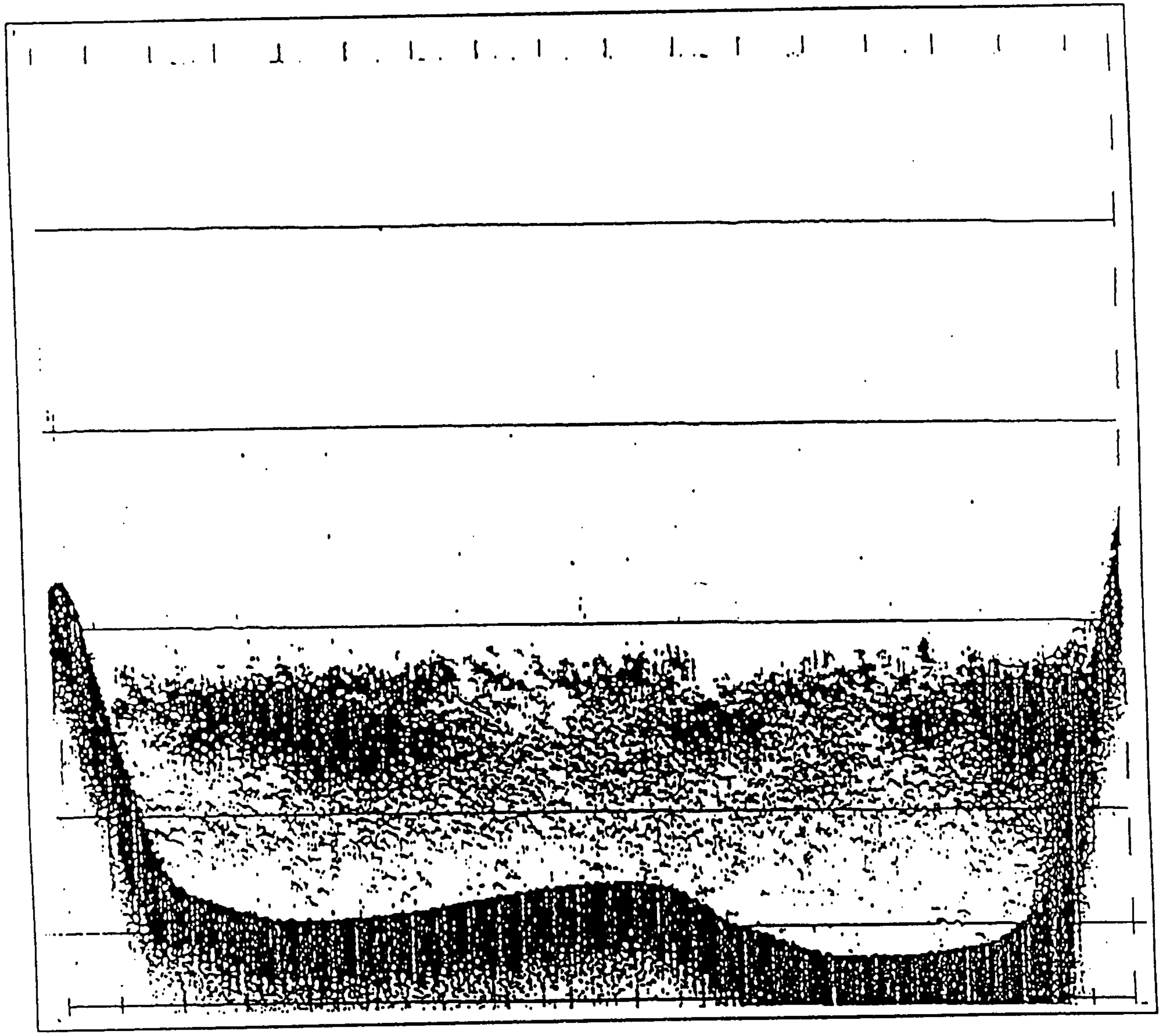


Figure 5. Echogram from Port Bainbridge survey, Leg 1.

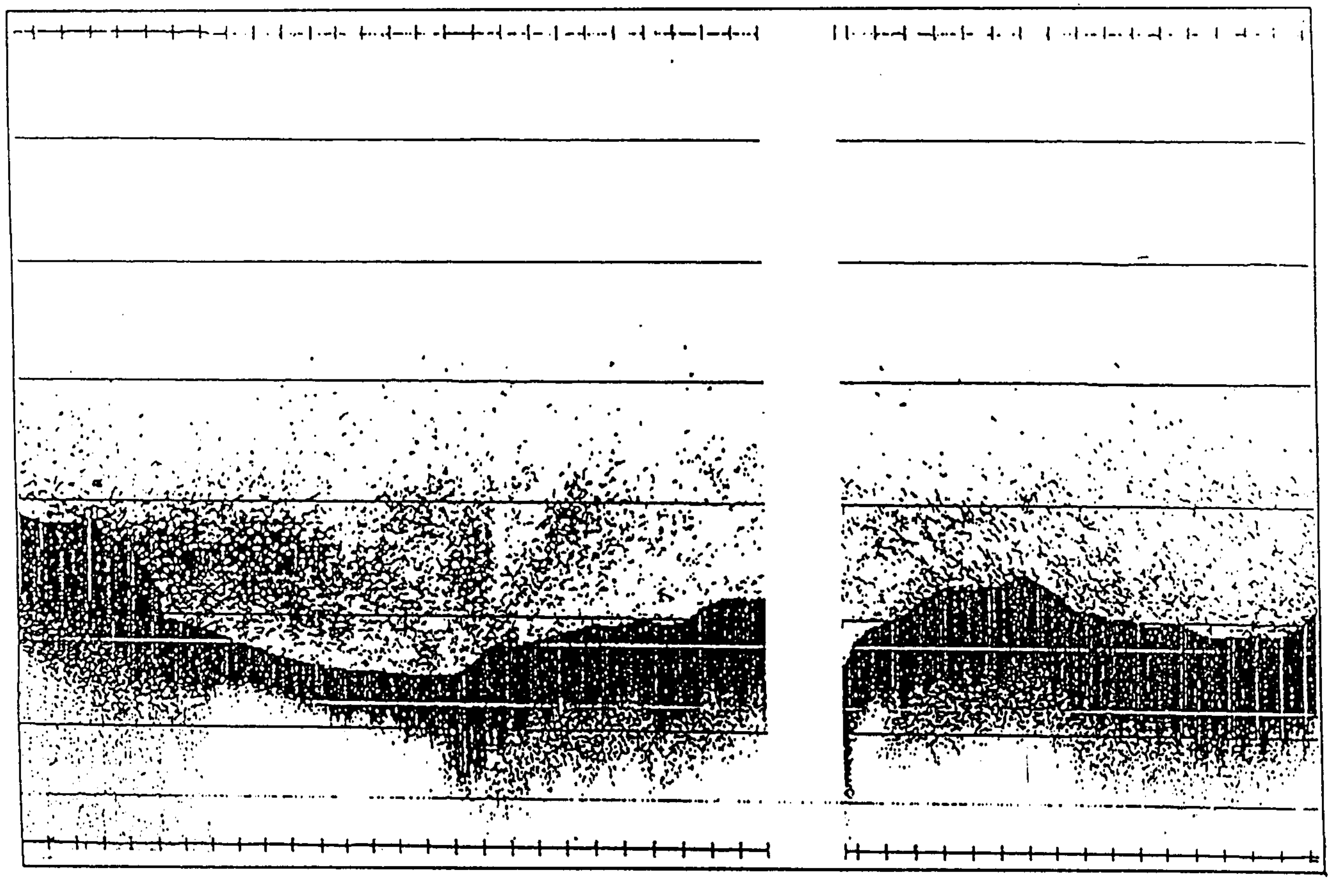


Figure 6. Echogram from Montague Strait/Knight Island Pass survey, Leg 1.

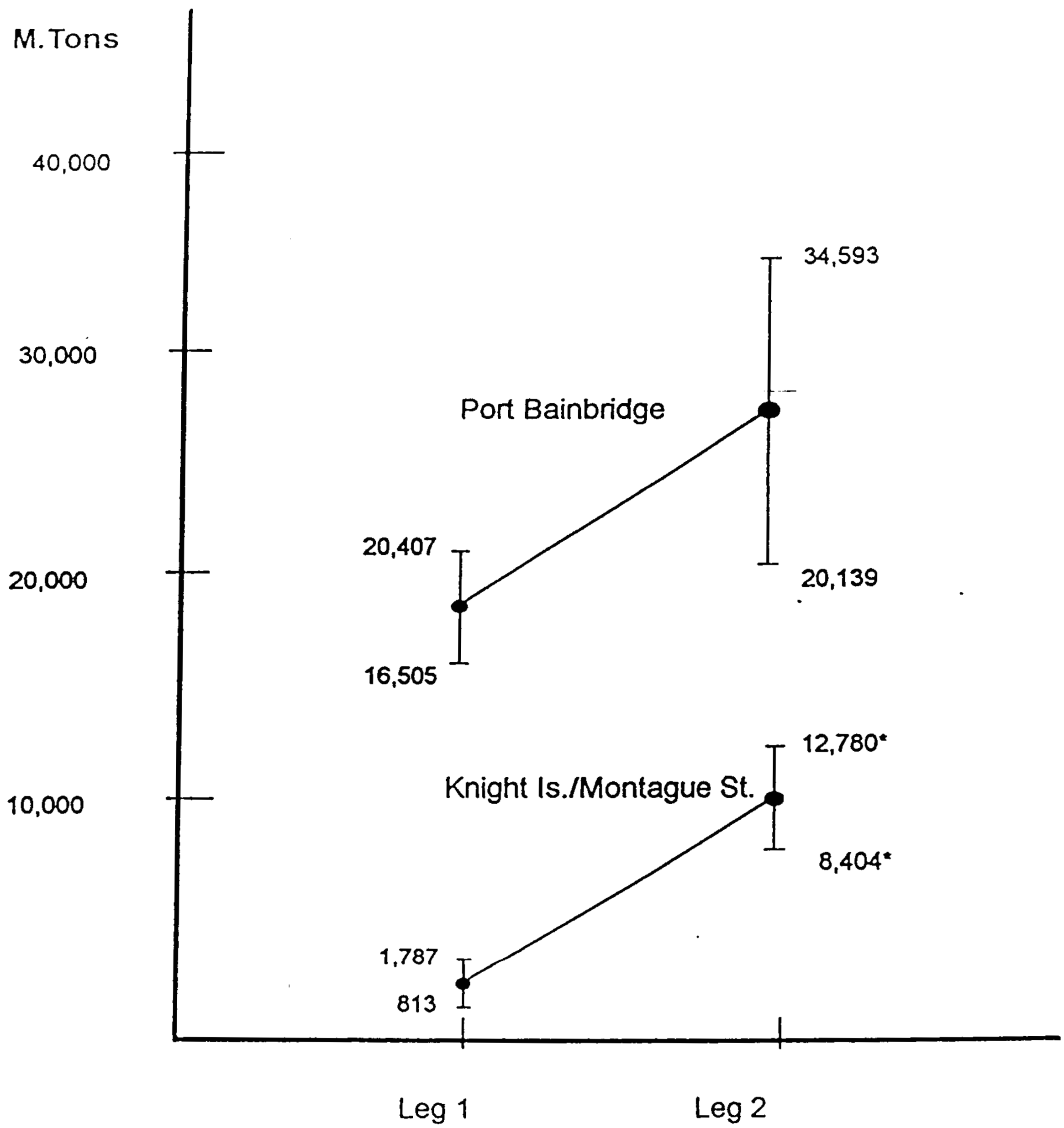


Figure 7. Walleye pollock biomass estimates in Knight Island/Montague Straits and Port Bainbridge survey areas, Legs 1 & 2. *Leg 1 and 2 areas surveyed.

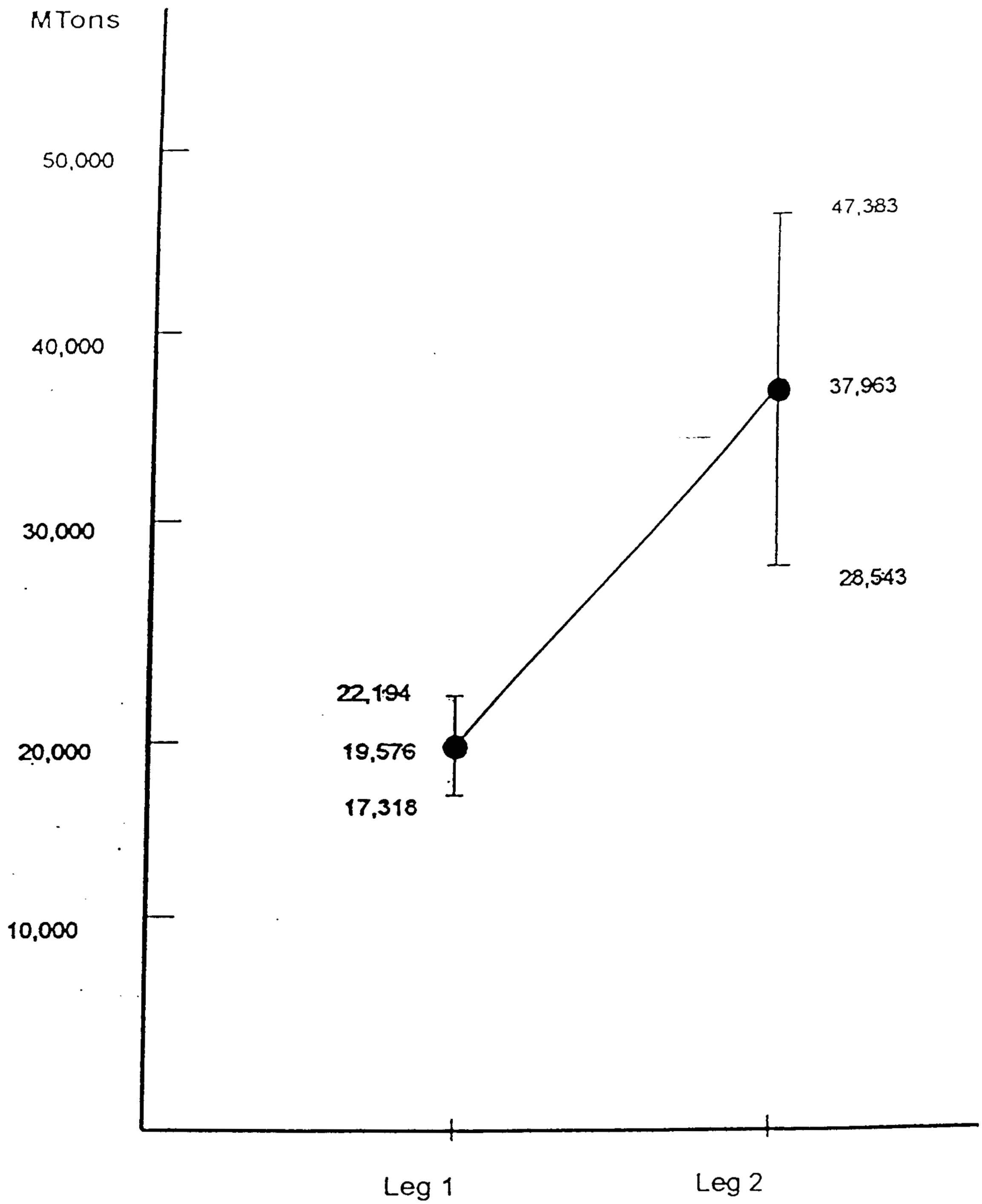


Figure 8. Walleye pollock biomass on repeated surveys, Feb. 26 and March 1, 1995 in PWS.

CHAPTER 4

Acoustic estimates of Pacific herring *Clupea pallisi* **biomass in Prince William Sound between the fall of 1993 and winter of 1996.** G.L. Thomas, Jay Kirsch (1), Richard E. Thorne (2) and John Wilcock (3). 1- PWS Science Center, 2- BioSonics Inc. Seattle, 3- ADF&G, Cordova. <u>Note: This paper is not to be cited without permission from the first author</u>

ABSTRACT

From mid-October to the time of spring spawning, adult herring schools *Clupea pallisi* maintained a uniquely high density and a distinct 20 to 40 meter vertical distribution at night. In contrast, juvenile herring concentrations were observed as 0 to 20 meter surface layers. These behavioral characteristics make herring available to nighttime acoustic stock assessment.

Nighttime acoustic-purse seine surveys were conducted in Prince William Sound in the falls of 1993, 1994 and 1995, springs of 1995 and 1996, and winter of 1996. The surveys used anecdotal and real time acoustic/optical information, and a growing body of knowledge from previous surveys to locate herring concentrations. Survey areas emphasized were the north-central Montague Straits and north-west Orca Sound. Once located, herring concentrations were mapped and their densities measured by running a zig-zag transect course over the concentration. Acoustic data were geotime referenced using GPS. The spring prespawning surveys are aided by aerial overflights by the Alaska Department of Fish and Game to visually spot large herring schools. Extrapolations of density estimates to biomass were limited to the areas where herring were mapped and measured. Where herring concentrations remained in the same area, a series of parallel acoustic transects were conducted using a dual beam scientific sonar to estimate the precision of the fish density estimates and the repeatability of the biomass estimates. Commercial purse seines (herring type) were used to collect species and size composition of the fish targets.

The *in-situ* target strength distribution displayed dominant modes at -43 and -34 dB. The -43 dB mode was appropriate for herring when the target strength discriminator was successful. It was apparent that when the density of herring schools was too large, the discriminator failed because there was a dramatic increase of target strengths within school targets. Overestimation of the target strength was probably due to the discriminator pooling adjacent targets. However, in a few locations there were concentrations of walleye pollock in the water column that produced a valid target strength mode at -32 dB. The vertical distribution of the pollock at night did not overlap with the adult herring schools.

In the 1993-1995 fall surveys, nine concentrations of herring were found that exceeded 1000 metric tons. At least one of these concentrations was found in north-central Montague Straits and the north-west Orca Sound each year. The largest concentrations of herring found in the fall surveys of each year were in the north-central Montague Straits (16,442 metric tons in 1993; 6,526 metric tons in 1994; and 24,291 metric tons in 1995). The largest concentration of herring found during the fall surveys in the north-west Orca Sound was 2,819 metric tons in 1994 and

1995.

In the spring survey of 1995 and winter/spring surveys of 1996, six concentrations of prespawning herring were found that exceeded 1000 metric tons. All of these were located in Zaikof Bay, Rocky Bay and Stockdale Harbor on the north and north-west end of Montague Island. The largest prespawning concentrations seen each year were, 10,480 metric tons in 1994 and 23,203 metric tons in the winter of 1996. The spring 1996 survey commenced after the herring began to spawn and the majority of fish were too nearshore or dispersed to be available to the acoustic survey.

Four of the twelve herring concentrations were surveyed twice at night to determine the repeatability of biomass estimation. In 1993, we estimated a concentration at Applegate Rocks to be 12,875 and 16,442 metric tons on repeated surveys. In the spring of 1995, we estimated a prespawning concentration of herring in Rocky Bay to be 10,480 and 8.05 metric tons on repeated surveys. In the winter of 1996, we estimated a concentration in Zaikof Bay to be 26,309 and 20,097 on repeated surveys. In spring 1996, we estimated a concentration in Stockdale Harbor to be 5,617 and 5,767 metric tons on repeated surveys. A primary source of error in repeating these measurements is to make sure that the repeated survey encompasses the fish concentration. When the fish move, if care is not taken, the first transect can truncate the fish distribution and sometimes the fish move too close to shore to survey. Both of these have lead to underestimation of biomass on repeated surveys. As criteria are established for accepting or rejecting replicates, the accuracy and precision of estimation will improve. Even with this error the estimates only varied by 1% to 13% of the mean.

Another aspect of repeatability is the fall to winter-spring estimates. In 1994, the fall and spring estimates of adult herring biomass were 13,000 metric tons. In 1995, the fall and winter estimates of adult herring biomass were 24 and 23 thousand metric tons. Echointegration-purse seine estimates of adult herring biomass in fall 1993, fall 1994, spring 1995, fall 1995 and winter 1996 were 20, 13, 13, 24 and 23 thousand metric tones, respectively. The observed increase or decrease in the fall estimates of herring biomass is explained by the recruitment of young fish that have grown to sufficient length to join the adult herring schools. The repeatability of the fall and winter/spring measures indicate little over-winter mortality in adults. This is therefore a good time to measure their abundance. This is in contrast to the SEA hypothesis on the importance of overwinter survival of the juvenile herring.

Seasonal changes in the abundance and distribution of adult herring were observed from 1993 to 1996. For decades, commercial fishers have observed the herring to migrate from the Gulf into the north-central Montague Straits in October. In two successive springs, we have seen this fall distribution of herring shift into the Bays on the north side of Montague Island by late winter/early spring. By mid-April, the large concentrations appear to move shallow to spawn and leave the area. Presumably they migrate back to the Gulf where they feed on the shelf until the following fall.

INTRODUCTION

Acoustic techniques are widely-used throughout the world to assess the abundance of pelagic fish stocks, including herring (MacLennan and Simmonds 1992; Thorne 83a,b). Acoustic echointegration and dual beam processing of target strength are based on sonar theory (Urick 1967; Ehrenberg and Lytle 1972). Basically, scientific echosounders are used to measure the amount of energy reflected from fish concentrations, which can be converted to fish density with information on the energy reflected from a single fish (its target strength) and knowledge of the sample volume (transducer directivity). Net sampling is routinely conducted to subsample the acoustic targets to collect biological information (species, size, etc.) on the ensonified fish (Thomas 1992).

Historically, information on the abundance of Pacific herring *Clupea pallisi* in Prince William Sound (the Sound) consists of commercial catch records, aerial estimates of the length of milt patches along beaches and herring spawn deposition surveys (Donaldson et al. 1993; Funk 1994). Single beam acoustic surveys without net sampling support had been used for estimating the biomass in the Sound in the fall from 1980 to 1985 (Merritt et al. 1993). Between 1988-92, the Alaska Department of Fish and Game used spawn deposition surveys in the spring to estimate the biomass of adult herring. A record run of adult herring (134,000 metric tons) was forecast to return in 1993 from the 1992 spawn deposition survey. In 1993, a spawn deposition survey was not conducted.

The spring 1993 aerial survey of the length of milt patches along the beaches suggested that the returning biomass was far less than the expected 100,000+ metric tons. This in-season assessment was used to limit the commercial harvest to about 1,000 metric tons, substantially lower than in 1992 (about 20,000 metric tons). In addition, the herring spawning stock was found to be infected with a potentially lethal virus, viral hemorrhagic septicemia,(VHS) (Meyers et al. 1994). The low biomass of herring and the presence of disease raised serious concerns about continued mortality and the long-term viability of the stock. The collapse of the herring fishery in the spring of 1993 and the absence of a spawn deposition study to estimate herring abundance created the opportunity for a fall acoustic-purse seine survey to estimate biomass.

This paper presents results from six acoustic-purse seine surveys that were conducted in the falls of 1993-6, the winter of 1996 and the springs of 1995-6.

METHODS

Study Site

Prince William Sound is a complex fjord/estuary (Schmidt 1977) located at the northern margin of the Gulf of Alaska (Figure 1). The Sound covers an area of about 8800 km with approximately 3200 km of shoreline (Grant and Higgins 1910).

Acoustic survey

The fall surveys were conducted between mid-October and November using experienced herring fishers on commercial purse seiners for acoustic transecting and to sample the fish targets. The seiners used commercial search-light sonars to locate school concentrations in suspected areas. They were also equipped with GPS linked, dual-beam scientific echosounders to map and estimate the size and density of schools, and were outfitted with commercial purse seines to sample fish concentrations. Transducers were mounted on towfins in a down-looking configuration and towed at about 6 knots at depths of 2 m. The purse seines used ranged from 20 to 60 meters deep with mesh sizes of approximately 3.18 cm stretched.

Survey Design - The acoustic survey was a multistage sampling design (Cochran 1977). The first stage used historical information and local fishers' knowledge of herring behavior to reduce the search area for herring concentrations in the Sound. The areas to be searched intensively were Orca Inlet and Montague Strait (Figure 1). We assume that the adult herring stock over-winters in the Sound and that the stock has completed this migration by the middle of October (DeCino et al. 1994). In general, we attempted to survey during intervals of small tidal exchange to minimize the probability of inclement conditions.

The second stage of the survey design was to search and locate herring school groups within the eastern and western Sound survey areas. This was done with aerial surveys in the spring and with search-light sonars on all surveys. Historical information and fishers' knowledge played another role in this stage by identifying depths where herring schools are found. Hence, herring schools were located by zig-zagging within the 40-100 depth contours using commercial search-light sonar and down-looking echosounders. The search-light sonar and down-looking sonar were used by the fishermen to assess if there were commercial quantities of herring present. When this condition was satisfied, the third stage of the survey was to map and measure the density of herring schools found in the search areas (Northern Hawkins Is., St. Mathews Bay, Knowles-Red Head, Danger Island, Needles, west of Green Island, east of Green Island, Applegate Rocks, Rocky Bay, Zaikof Bay areas).

Mapping was conducted with the geotime-referenced scientific echsounder by running a series of zigzag or parallel transects over the area suspected of containinga fish concentration. The transects were run in a zigzag fashion over the school(s), turning when schools were no longer visible on the echosounder (Figure 2a). In analyzing this data, the zig portion of the transects was considered independent of the zag and two estimates were obtained with precision. In cases where the fish concentration was stable, a systematic series of parallel transects was run to estimate precision (Figure 2b). This survey was repeated, if possible, to develop independent estimates of the biomass of specific fish concentrations.

The fourth and fifth stages of the sampling were to purse seine the acoustically surveyed schools and to subsample the catch for biological information. In general, the species composition of the net catch was used to partition the seine catch subsampling. The length and weight of the fish in the subsample were used to determine target strength using -20 log L -71.3 (MacLennan and

Simmonds 1992) and Thorne (1983).

Acoustic Parameters - Target strength information for herring was derived from the relationship of length to target strength (in dB/kg, Thorne 1983). Thorne's empirical relationship assumes the following logistical equation:

$$\gamma=\frac{\bar{\sigma}}{\bar{W}}=a\bar{l}^{-b} \tag{7}$$

where σ is the mean acoustic backscattering coefficient, W is the mean weight (in kg), l is the mean length (in cm), and a and b are constants. A value for the constant a was obtained from physical data at the site (temperature and salinity) and the literature (speed of sound). A value for the constant b was obtained from a review by Thorne (1983) using a linear regression of $\log_{10}l$ versus 10 log (σ/w), where 10 log (σ/w) is referred to as "target strength per kg." The average herring length and weight data were compiled from samples obtained from the net catches. These measured data were applied to Thorne's (1983) empirical relationship to obtain the ratio $\gamma = \sigma/w$ and the mean backscatter coefficient (σ).

As a cross-check, we generated *in-situ* measurements of target strength from a subset of dual beam acoustic data. We compared our *in -situ* mean backscatter coefficient with Thorne's (1983) empirical formula. We also converted *in-situ* measurements to length using -20 log L -71.3 for comparitive purposes. Parameters of the acoustic equipment used during the fall herring surveys are presented in Table 1.

Biomass estimation - Herring biomass was calculated for each fish concentration found during the large scale survey. The calculation of biomass per unit volume was made using echointegration by single cells *jk* along transects:

$$\beta_{jk}=\rho_{jk}\cdot\bar{w}_{jk}=\frac{C(ei)_{jk}\cdot P_{jk}}{\frac{\bar{\sigma}_{jk}}{\bar{w}_{jk}}} \tag{8}$$

where β_{jk} is the biomass in weight per unit volume (cubic meters), ρ_{jk} is the number of scatterers per unit volume (unknown at high densities), w_{jk} is mean weight of the scatterers (also unknown), or for practical purposes by C, the acoustic constant (calibration settings ie., gain etc.), ei_{jk} is the mean of the voltage squared from echo integration (in lieu of numbers), P_{jk} is percentage of cell *jk* within the water column (where bottoms or shorelines are encountered) , and σ_{jk} is mean backscattering voltage for the specific targets within cell *jk* per mean weight (dB per kg).

The biomass for a region of surface area (A in square meters) is determined by using a set of line transects across the region of known fish concentration, along which a total of nrs point estimates of biomass per unit area is obtained. Specifically,

$$B = \frac{\sum_{j=1}^{nrs} \sum_{k=1}^{nst} \beta_{jk}}{nrs} \cdot A \tag{9}$$

where nrs is number of reports (along the line transects), nst is number of one meter depth strata, and A is survey area. Where nst were not one meter bins, the appropriate weighting was used to compute means and variances (Seber 1973).

For the herring biomass estimate, we followed Thorne (1983). Specifically, we assume that σ_{jk}/w_{jk} is independent of cell *jk*, hence, for all *jk* σ_{jk}/w_{jk} is a constant γ, and γ is given by equation 1. With this assumption, equation 2 simplifies to: April 27, 1996

$$\beta_{jk} = \frac{C}{\gamma} \cdot (ei)_{jk} P_{jk} \tag{10}$$

and the herring biomass B in an area is given as

$$B = \frac{C}{\gamma} \frac{\sum_{j} \sum_{k} \cdot (ei)_{jk} P_{jk}}{nrs} \cdot A \tag{11}$$

When a fish concentration was located, mapped and surveyed to estimate the mean and variance of the fish density, and it was relatively stationary, the survey was repeated to determine error in biomass estimation.

RESULTS AND DISCUSSION

Behavior

From mid-October to early spring, adult herring schools display a unique diel migratory behavior. During the day they are found in dense schools in deep water (Figure 3), and during the night they are found in dense schools layered between 20 and 40 meters in the water column (Figure 4). This behavior breaks down as the adult herring approach spawning. In contrast, from fall to early spring the juvenile herring are found layered between 0 and 20 meters in the water column, nearer to the shoreline and at lower densities than the adults.

Target strength

In general, the *in-situ* target strength distribution displayed modes between -43 and -40 dB but sometimes >-34 dB (Figure 5). The -43 dB mode was appropriate for herring when the target strength discriminator was successful (MacLennan and Simmonds 1992). However, the herring schools were almost always too dense to estimate single fish target strength and these observed modes suggest that the target strength discriminator had failed. Often, there was a gradient of increasing target strengths towards the center of dense school targets which suggested that the discriminator was pooling adjacent targets.

Although the purse seine catches directed at adult herring schools indicated almost pure herring, there were a few areas (primarily in the Green Island area) that walleye pollock were observed to co-occur with the herring. This was also the area where most often the highest biomass of herring was found. In these areas, the walleye pollock were observed as single targets within the water column below 40 meters. There was a corresponding -32 dB mode in the target strength distribution. The vertical distribution of these pollock at night did not overlap with the adult herring schools (Figure 6).

Because of the uncertainty over the representation and accuracy of the *in-situ* target strength measures, the mode of the *in-situ* measurements was only used where other information were unavailable for analyses, such as when net catch data were unavailable to determine the size of fish in the survey area and when the within-school densities were not high. Where purse seine catch data were available to identify the targets, the target strength information was derived from average length of the catch.

Population Trends

Large aggregations of herring were consistently observed during late fall and early winter in the northern Montague Strait area between 1988 and 1992 (Donaldson et al. 1993). From 1993 to the present, this distribution has prevailed. In the past, it has been assumed that these herring represent between 50 and 75% of the herring biomass in the Sound (Gaudett 1984; Funk 1994).

In the fall of 1993, the survey was aided by the fact that two weeks earlier a commercial fishery had taken place which located the herring concentrations. In 1994 there was no fishery, therefore two purse seiners were used to search the Orca Sound and Montague Straits areas of the Sound over a period of 14 days. In the fall and winter of 1995, the primary objective of the survey was to map juvenile herring (which also serves to map adults). A group of five vessels was used for over 20 days throughout the Sound, Port Bainbridge, and Resurrection Bay. Thus, there was increasing coverage of the Sound for determining population distribution from 1993 to 1996. Furthermore, aerial surveys were conducted in the spring to locate herring concentrations, although these often focused on the herring after they began spawning. These surveys show that the bulk of the adult herring population has over-wintered in the northern Montague Straights over the past 3 years.

Biomass estimation

Four of the twelve herring concentrations observed over the three years on six surveys were surveyed twice at night to determine the repeatability of biomass estimation. In 1993, we estimated a concentration at Applegate Rocks to be 12,875 and 16,442 metric tons on repeated surveys. In the spring of 1995, we estimated a prespawning concentration of herring in Rocky Bay to be 10,480 and 8.05 metric tons on repeated surveys. In the winter of 1996, we estimated a concentration in Zaikof Bay to be 26,309 and 20,097 on repeated surveys. In spring 1996, we estimated a concentration in Stockdale Harbor to be 5,617 and 5,767 metric tons on repeated surveys. A primary source of error in repeating these measurements is to make sure that the repeated survey encompasses the fish concentration. When the fish move, if care is not taken, the first transect can truncate the fish distribution and sometimes the fish move too close to shore to survey. Both of these have lead to underestimation of biomass on repeated surveys. With more experience, distributional criteria can be established for accepting or rejecting replicates as valid for estimation. Even with this error the estimates only varied by 1% to 13% of the mean.

Another aspect of repeatability is the fall to winter-spring estimates. In 1994, the fall and spring estimates of adult herring biomass were 13,000 metric tons. In 1995, the fall and winter estimates of adult herring biomass were 24 and 23 thousand metric tons. Echointegration-purse seine estimates of adult herring biomass in fall 1993, fall 1994, spring 1995, fall 1995 and winter 1996 were 20, 13, 13, 24 and 23 thousand metric tones, respectively (Figure 7). The observed increase or decrease in the fall estimates of herring biomass is explained by the recruitment of young fish that have grown to sufficient length to join the adult herring schools. The repeatability of the fall and winter/spring measures indicate little over-winter mortality in adults. Therefore, this is a good time to measure their abundance. This is in contrast to the SEA hypothesis on the importance of overwinter survival of the juvenile herring.

Seasonal changes in the abundance and distribution of adult herring were observed from 1993 to 1996. For decades, commercial fishers have observed the herring to migrate from the Gulf into the north-central Montague Straits in October. In two successive springs, we have seen this fall distribution of herring shift into the Bays on the north side of Montague Island by late winter/early spring. By mid-April, the large concentrations appear to move shallow to spawn and leave the area. Presumably they migrate back to the Gulf where they feed on the shelf until the following fall.

Survey Design

The nesting of quantitative acoustic procedures within semi-quantitative reconnaissance surveys is practical. Albeit commercial fishing sonars and echosounders are not calibrated measurement tools, when coupled with experienced fishers' knowledge, they provide a meaningful judgement on the relative distribution of the fish population. The fact that fishers make a living from these real-time estimates of fish density and distribution makes the reconnaissance step robust and believable. Furthermore, when this reconnaissance is coordinated with quantitative sonars to estimate fish density the design approaches proportional allocation of sampling, which is most efficient (Cochran 1977). Advantages of the multistage, minimum biomass sampling design are that expenses are low, precision is high and the design adapts to changes in the fish distribution.

Acoustic-purse seine estimates of fall-winter herring biomass provide a practical approach for stock assessment. The precision is high with 95% confidence limits on the density estimates of schools typically under 20%, and the repeatability of the biomass estimate varying less than 20%. Although this level of error is very low relative to other assessment techniques, it should get even smaller as acceptance criteria are developed.

Although the acoustic survey does not measure the total population size (presumptuous for any assessment technique) the approach is robust since it uses the historical and recent fisheries information, and experienced fishers to search and locate fish concentrations. The use of commercial fishers is advantageous since it is in their best interests not to miss fish concentrations that contribute to the population estimate that determines the harvest levels. Geotime linkage of the acoustic data insures its independenceas well.

Acoustic surveys to assess total population size would require systematic measurements over the entire Sound and adjacent Gulf of Alaska, and complementary genetic assessment to establish the presence of different stocks. Given the contagiousness of the herring, such a design is impractical and unnecessary. The present survey design estimates the bulk of the population available to the fishery with minimal extrapolation. In a sense it is a **minimum biomass estimate** of the exploitable population.

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Table 1. Parameters of the acoustic equipment used during the fall 1994 herring survey in Prince William Sound.

SYSTEM	FREQUENCY	SOURCE LEVEL	SYSTEM GAIN	TRANSDUCER DIRECTIVITY	PULSE DURATION
BioS. 101	120 kHz	-225.075 dB	-165.264 dB	.0010718	0.4 ms
BioS. 102	200 kHz	-221.655 dB	-155.756 dB	.0006515	0.4 ms

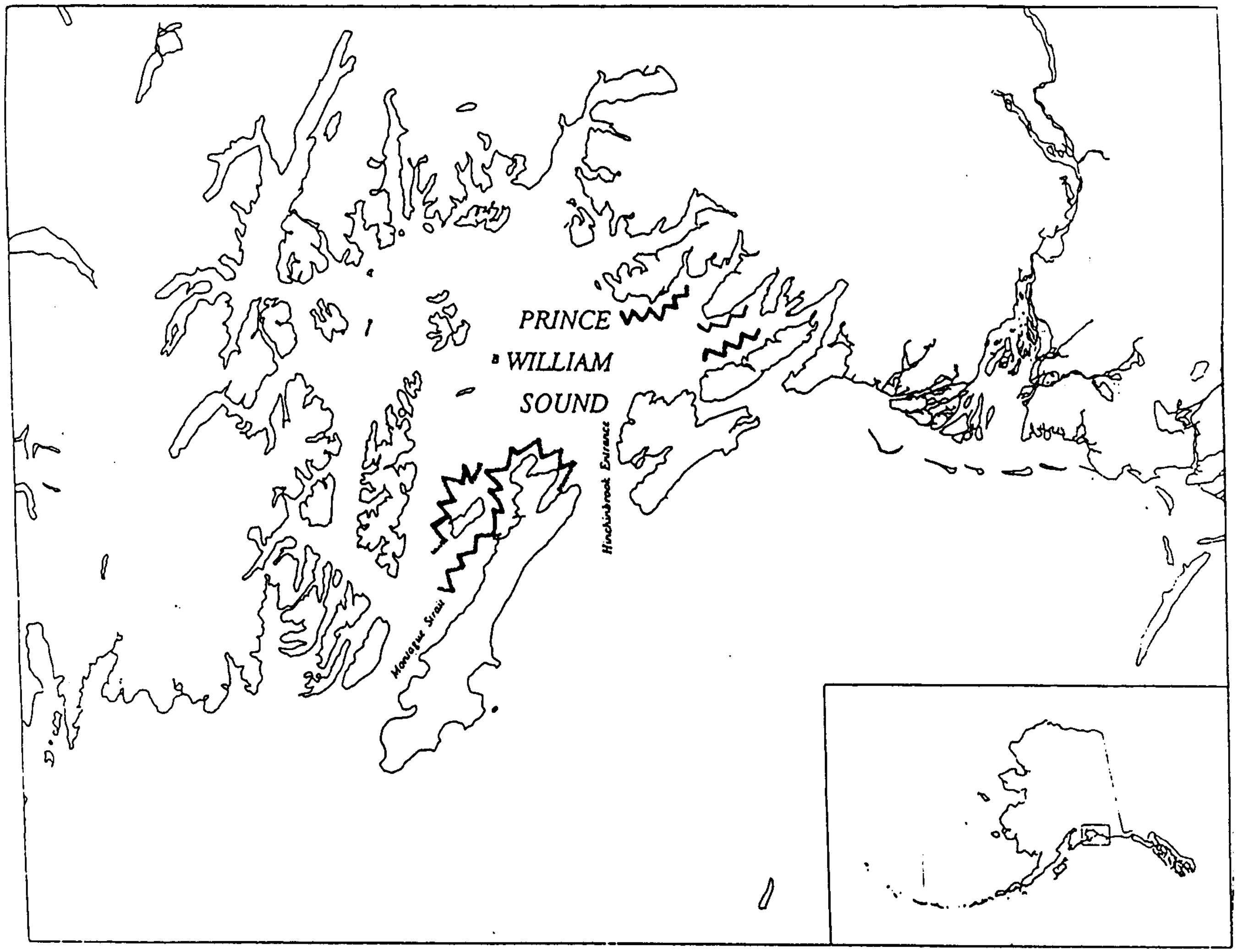

Figure 1. Map of Prince William Sound showing principal survey areas for adult herring between 1993-1996.

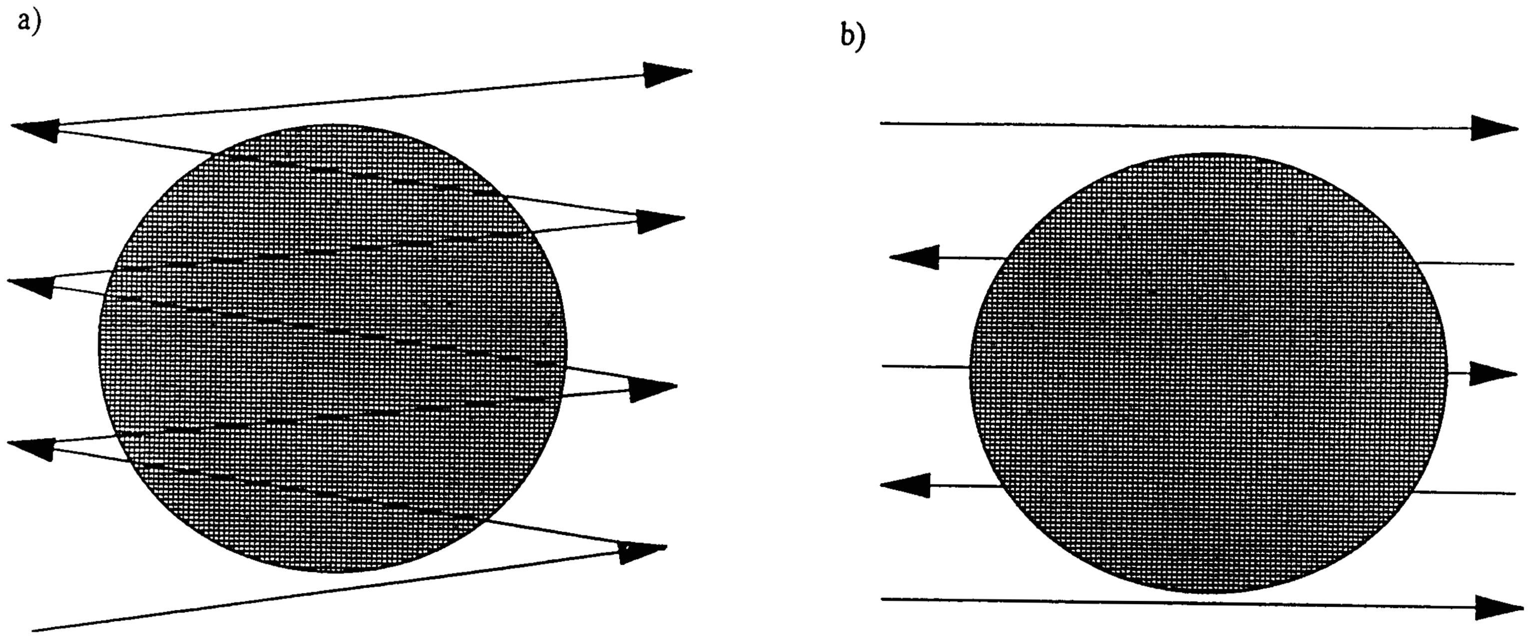

Figure 2. Transect patterns used to map and measure the density of schools found in the search areas. Figure a) Transect pattern used to map a hypothetical concentration of herring, using a dual beam echosounder and GPS. Figure b) Transect patterns used to repeat the measurements of the density of a hypothetical herring concentration when it was stable.

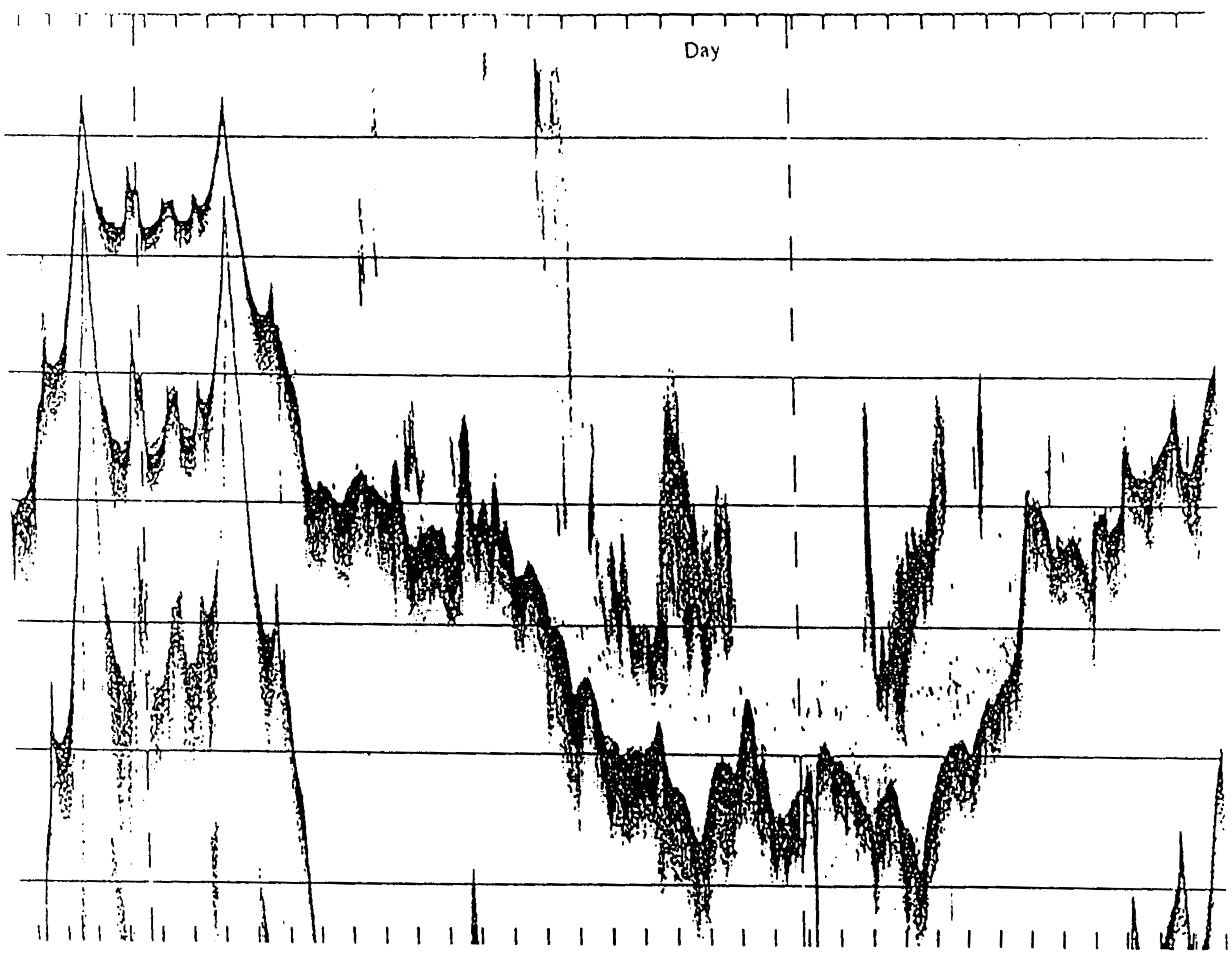

Figure 3. Echogram showing a typical day-time distribution of adult herring in the fall in Prince William Sound.

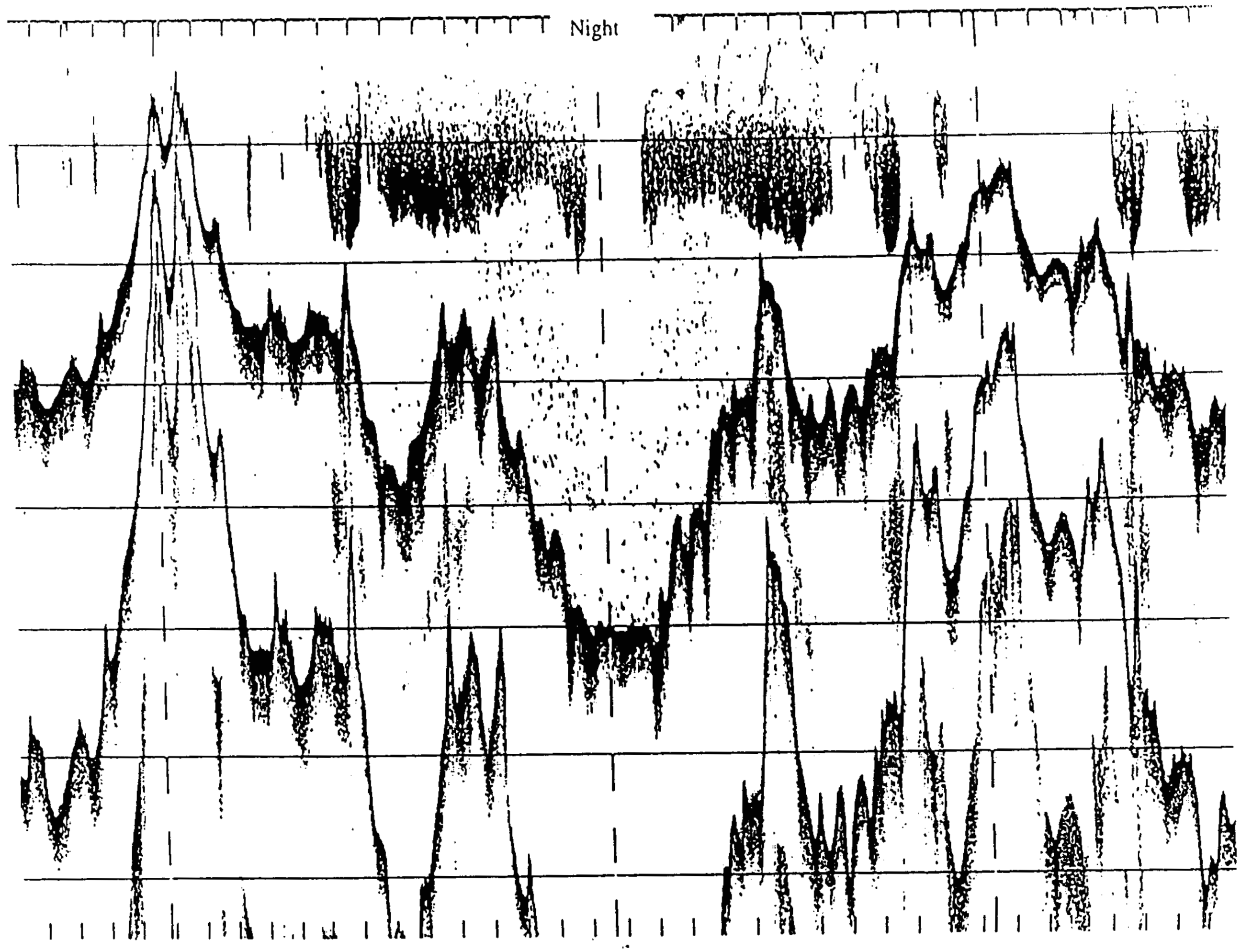

Figure 4. Echogram showing a typical night-time vertical distribution of herring during the fall in Prince William Sound.

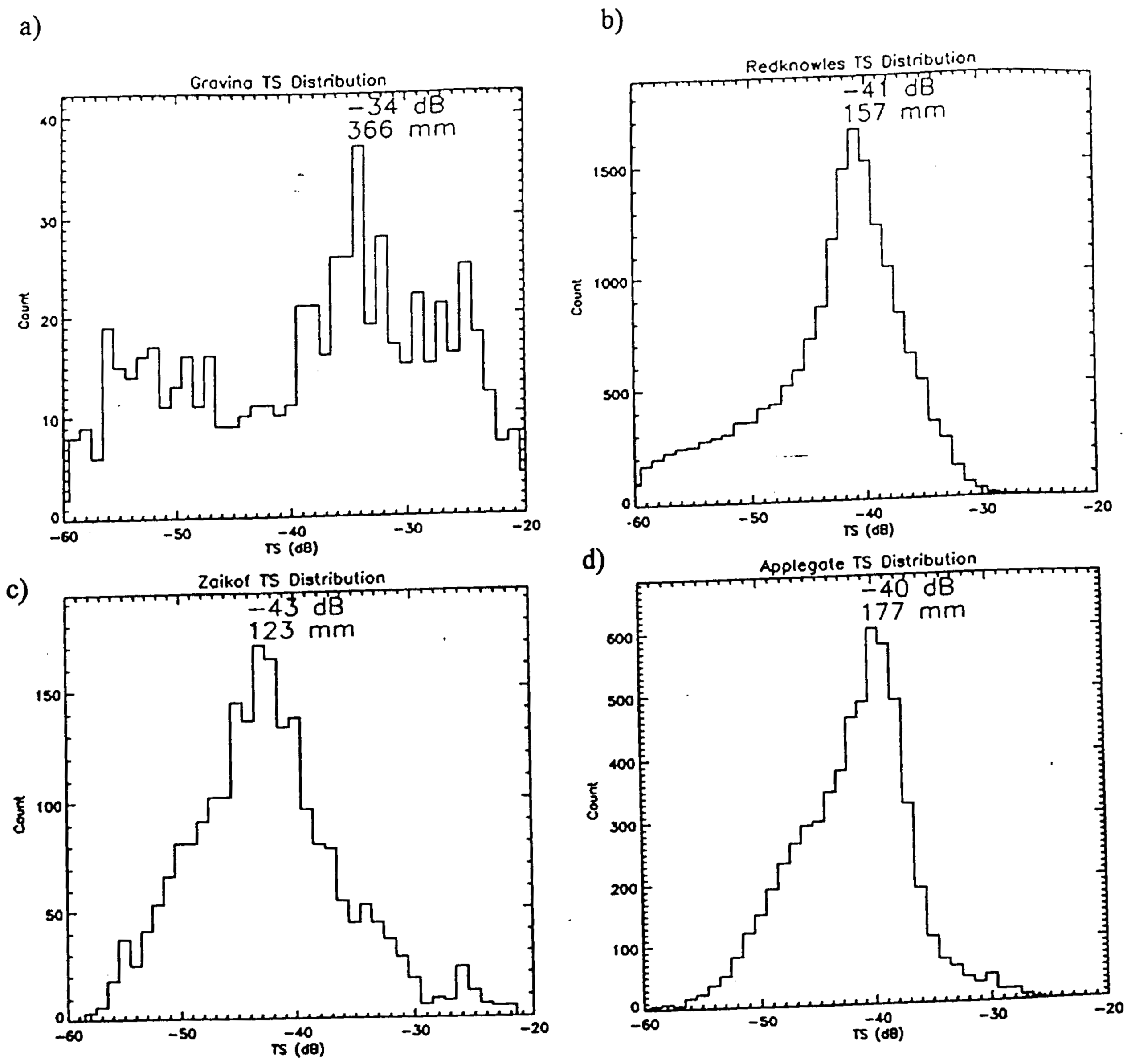

Figure 5. In-situ target strength measurements of herring in Prince William Sound. Figure a) The highest density school was observed at Gravina Point.

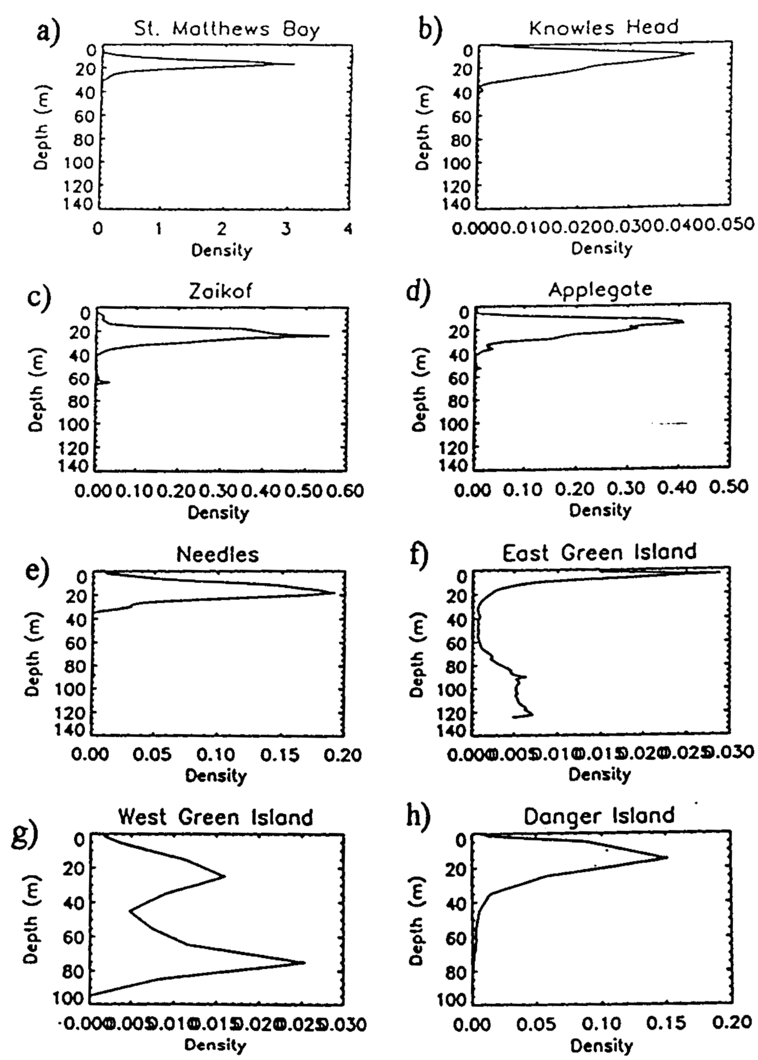

Figure 6. Vertical distribution of adult herring at eight locations in the fall of 1994. Figures (f) and (g), east Green Island and west Green Island respectively, are where large concentrations of pollock were seen below 40 meters.

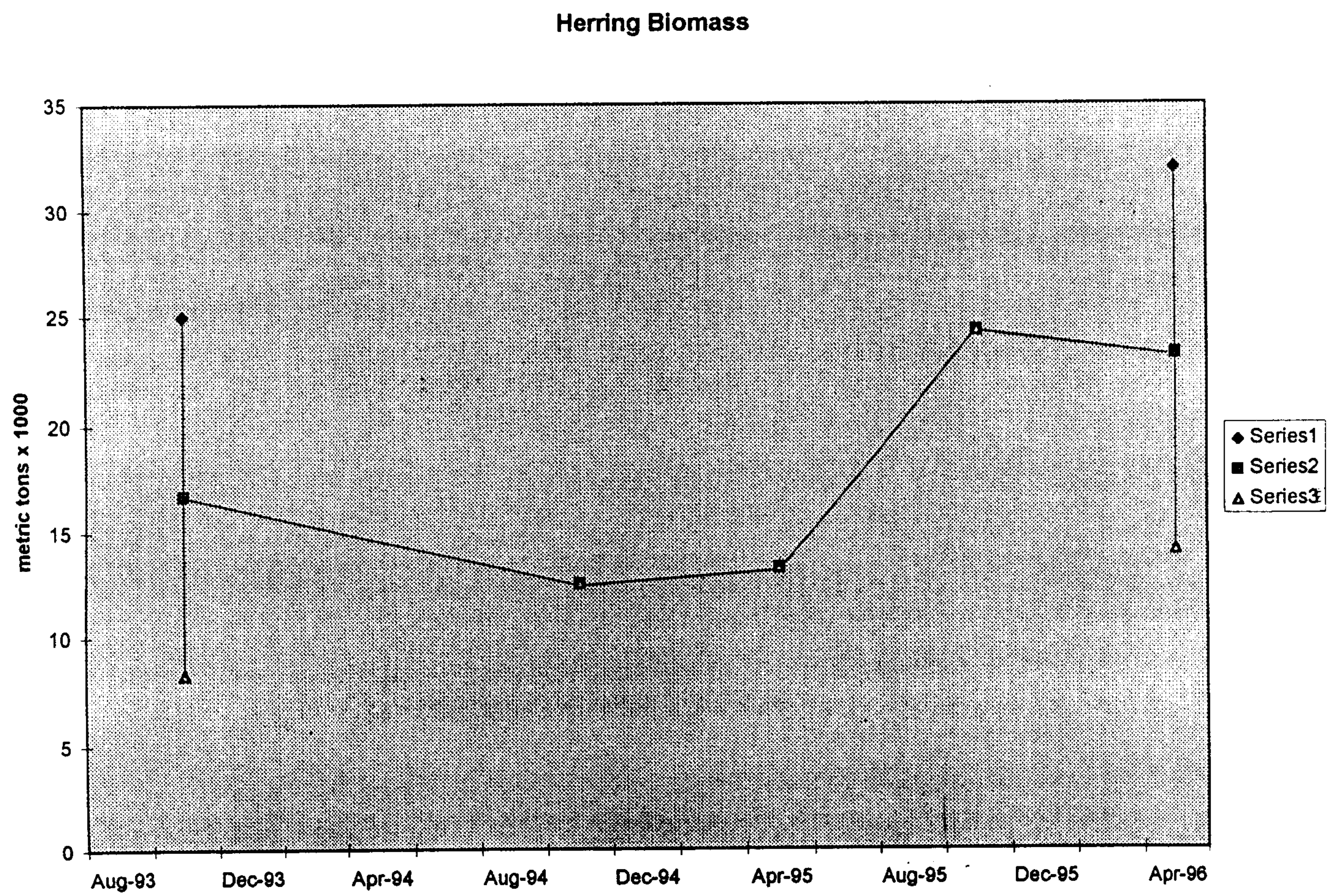

Figure 7. Herring biomass measured on the fall 1993 to winter 1996 surveys in Prince William Sound.