Exxon Valdez Oil Spill
Restoration Project Annual Report
Nekton-Plankton Acoustics Project 96320N

Nekton-Plankton Acoustics
Restoration Project 96320N
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 96320N
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 third annual report for the Nekton-Plankton Acoustic project. Four technical reports and five abstracts have been published to date, and the chapters in this report are being prepared for submission to journals this year. Upon implementation, the Sound Ecosystem Assessment program was recommended by peer reviewers to be a 8-10 year program. Funding from the EVOS Trustee Council is committed for five years. Funding for the fourth year is in place and preliminary budgets have been projected through FY99 (five years). We envision a transition from the intense observational oceanography and modeling program (SEA), into a model-based monitoring program in years four through six. This second phase will focus on the implementation of monitoring to collect the data needed to initialize the SEA numerical models and to verify the model predictions. Developments in the plankton-nekton acoustics are essential to the design of a cost-effective monitoring program.

Abstract: In the first three years, the primary contribution of the Nekton-Plankton Acoustics project is to develop accurate estimation procedures for animal abundance and distribution information. These data are used 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 in the spring, and the fall and winter density and distribution of the juvenile and adult herring, and pollock populations. The completed products are the stock assessments of adult pollock biomass in Feb-Mar 1995 and 1997 (37 and 36 thousand mt), and adult herring biomass in Sep 1993, Oct-Nov 1994, April 1995, Oct-Nov 1995, Mar-April 1996, and April 1997 (20, 13, 13, 24, 23, 40 thousand mt, respectively).

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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1996 ANNUAL REPORT

Sound Ecosystem Assessment (SEA), Nekton-Plankton Acoustics

G.L. Thomas, Jay Kirsch, Geoff Steinhart and Nicholas Peters - PWS Science Center

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 three chapters: (1) Seasonal and diel movements of walleye pollock (*Theragra chalcogramma*) in western Prince William Sound, (2) Acoustic estimates of macrozooplankton distribution in Prince William Sound, spring 1996 and (3) Juvenile herring assessment in Prince William Sound, winter-spring 1995-96. 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:

Predators (walleye pollock):

We have used acoustics to measure abundance and distribution of walleye pollock (*Theragra chalcogramma*) in western Prince William Sound since 1994. Although sampling protocol varied each year, we found trends in seasonal, and diel distributions of pollock. Pollock appeared to be most abundant in 1994, but densities in 1995 and 1996 were not much lower. Seasonally, pollock densities in the northwest portion of the Sound were lowest in early May, and generally increased throughout the sampling period. On a daily time scale, we did not see changes in pollock densities as a function of tide. During the night, pollock moved up in the water column, and at some sites pollock moved closer to shore at night than during the day. These changes in pollock distribution are important components of key hypotheses of the Sound Ecosystems Assessment project.

Prey (macrozooplankton):

A zooplankton survey was conducted in Prince William Sound in May 1996, using a 420 kHz digital sonar and a MOCNESS net. Data from the catch supplied us with zooplankton species, size, and density, which were applied to zooplankton scattering models, allowing us to predict volume backscatter. These predicted values are compared with measured acoustic backscatter to validate the measurement methods. Relative agreement in the two instruments is evident in the occurrence at the same depth of layers. However, more analysis of the catch information is needed for agreement of the absolute densities, since animal sizes are used to estimate the target strength that is used to scale the echo-square integration. The sources of error are discussed, with their potential solutions.

Pacific herring:

Juveniles:

A hydroacoustic-purse seine survey was conducted to examine the density and distribution of juvenile herring in Prince William Sound. We found the juvenile herring to be in a nearshore layer at the surface during the night. This layer included other scatters such as juvenile pollock, jelly plankton and larval fishes but the herring and pollock combined to represent the 95% or more of the backscatter and the juvenile pollock, the smaller component of the backscatter (0-17%) were separated by using purse seine catches. We show that the spatial distribution of juvenile herring is very contagious with a few locations supporting the majority of the herring population. We also have examined the density of the layer and found that it too is contagious but not directly related to where the bulk of the juvenile herring reside. From these results, we believe that it is possible to conduct broad-scale surveys of juvenile herring in the Sound to support development and verification of the herring overwintering model and allow the management agencies more information on future recruitment events. This capability also makes possible the building of an over-summer mortality model for herring. In 1994, the SEA program initially avoided this model building effort.

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[1]. 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.

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[1] Thomas, G.L., Vince Patrick, Jay Kirsch, and Jennifer Allen, 1997. Development of an ecosystem model for managing the fisheries resources of Prince William Sound. 2nd World Fisheries Congress (in press).

CHAPTER 1

SEASONAL AND DIEL MOVEMENTS OF WALLEYE POLLOCK (*THERAGRA CHALCOGRAMMA*) IN WESTERN PRINCE WILLIAM SOUND. G.B. Steinhart, G.L. Thomas, and Jay Kirsch.

ABSTRACT

We have used acoustics to measure abundance and distribution of walleye pollock (*Theragra chalcogramma*) in western Prince William Sound since 1994. We found trends in seasonal, and diel distributions of pollock. Seasonally, pollock densities in the Sound increased from May through July. This increase was greatest in the northwest passage where pollock numbers more than doubled in from May to June, 1995. On a daily time scale, we did not see changes in pollock densities as a function of tide. Pollock did undergo a diel vertical migration; at night, pollock moved up in the water column. In addition to a vertical migration, at some nearshore sites pollock were closer to shore at night than during the day. Where pollock were found, their density was highly correlated with plankton density. The observed patterns of pollock distribution and behavior are important to the testing of the prey-switching hypothesis.

INTRODUCTION

After the Exxon-Valdez oil spill, stocks of pink salmon in Prince William Sound had highly variable recruitment success. The roles of both the oil spill, and natural environmental fluctuations, on variable recruitment are still under debate. There is no doubt, however, that walleye pollock (*Theragra chalcogramma*) are one of the most abundant fish species in Prince William Sound. Not only are they important as a commercial fishery, but they play a large role in the food-web dynamics of the Sound. The goal of this research is to describe the seasonal and diel changes in pollock abundance and distribution in western Prince William Sound (PWS) in order to better understand their role as a predator of pink salmon fry.

Pollock may have both a direct and an indirect effect on juvenile salmon populations. A primary hypothesis of the Sound Ecosystem Assessment project (SEA) is the Lake/River hypothesis (Cooney 1993). This hypothesis states that in "river" years PWS experiences climatic conditions which lead to a relatively quick rate of flushing and increased turbulence in the Sound. This may result in lower zooplankton abundance, and fewer dense patches of zooplankton than during a "lake" year. During a "lake" year, slow flushing rates could result in high overall zooplankton abundance. In addition, in a "lake" year, low turbulence may facilitate the formation of large, dense plankton patches makes them more available as prey for both pink salmon fry and pollock. Since juvenile salmon feed on zooplankton, the abundance of zooplankton directly effects salmon survival. Walleye pollock also prey on zooplankton, and compete with juvenile salmon for this food resource (M. Willette, ADF&G, pers. comm.). Pollock not only compete with juvenile salmon, but they are also predators of salmon. The SEA Prey Switching hypothesis predicts that as zooplankton populations decrease, pollock will feed more heavily on juvenile salmon. Therefore, in order to predict salmon survival, it is essential to understand pollock behavior in PWS.

In this paper we present the results of three years of acoustic surveys in Prince William Sound. An assumption of SEA that was adapted from GLOBEC is that fish fry do not die by starvation, but that all mortality is the result of being eaten. Pollock, being the most abundant pelagic fish, are considered to be the primary predator of pink salmon fry in PWS (M. Willette, ADF&G, pers.comm.). By looking at how pollock abundance and distribution have changed over various time and spatial scales, we increase our knowledge of how this predator behaves. The first step in determining if pollock are feeding on zooplankton and/or salmon is to show that there is co-occurrence of pollock with either zooplankton or salmon. Since pollock are one of the most abundant fish species in PWS, understanding their ecology will aid us in efforts to restore and protect the valuable resources of the Sound.

METHODS

Study site

Prince William Sound (PWS) is located at the northern edge of the Gulf of Alaska (Figure 1). This large fjord/estuary covers an area of approximately 8800 km^2, and has about 3200 km of shoreline (Grant and Higgins 1910). Coastal rainforests, high mountains, and glaciers border the shoreline of PWS. The area receives seasonally intense storms moving up from the Gulf of Alaska, resulting in more than 7 m of annual rainfall.

Survey design

The survey designs differed during the three years of this project (Table 1). In 1994, offshore surveys were conducted during the day throughout western PWS (Figure 2). There were 88 different parallel transects in Wells, Perry, and Knight Island Passages, Montague Straight and the Southwest passages (Thomas et al. 1996). Data were collected with a BioSonics 101-120 kHz dual beam echosounder.

In 1995, acoustic surveys were concentrated in the northwest portion of PWS (Figure 3) and were designed to examine differences between nearshore, within 0.5 NM of the shoreline, and offshore (> 0.5 NM from shore) distributions of fish. Nearshore surveys were conducted from our boat, the R/V Orca Challenger, using a down-looking BioSonics 102-200 kHz dual beam echosounder. The nearshore surveys at each site consisted of 9 to 12 parallel transects perpendicular to the shoreline. Nearshore acoustic data were collected to a maximum depth of 125 m. The offshore surveys were conducted aboard the F/V Alaska Beauty using with a BioSonics 101-120 kHz dual beam echosounder, set to collect data to a depth of 250 m. At each site, the same transects were repeated both offshore and nearshore every 3 h for an entire 24 h diel cycle (Thomas et al. 1996).

In 1996, sampling was limited to Wells and Perry Passages, Esther Island, and Unakwik Inlet. Three cruises were conducted beginning in early May, and ending in early June. The surveys were conducted nearshore, and consisted of a long transect parallel to the shoreline, and 5 parallel transects perpendicular to the shoreline (Figure 4). The surveys were repeated 4 times a night: 2000, 2300, 0200, and 0500. Data were collected with a down-looking BioSonics 101-120 kHz dual beam echosounder.

For all surveys, transects were marked on paper and/or electronic charts to allow repetition of the same transect. At night, or during low tide, some transects were modified for safety purposes. Boat speed during transects was approximately 4-6 kn. The down-looking transducers were mounted on a fin towed alongside the boat at a depth of approximately 2 m.

Personnel from the Alaska Department of Fish and Game (ADF&G) collected numerous fish samples using a variety of fishing gear. Commercial seines and mid-water trawls were used for target verification of the acoustic data. In addition, small purse seines, pair trawls, bottom trawls, gillnets and longlines were used to collect fish. These fish were used for age/length/weight measurements and diet analyses.

Acoustic equipment

The acoustic data presented here was collected using either a BioSonics 101-120 kHz, or a 102-200/420 kHz echosounder. The data were processed in real-time using ESP software on a 486 laptop computer. The data were geo-referenced and time-coded by a connection to a Magellan DLX-10 GPS receiver with an external antenna. Echo-square integration, dual-beam target strength (TS), and GPS data were stored on the computer hard disk, and backed up on tape drives. Raw acoustic signals were stored on digital audio tape.

The acoustic systems were calibrated before each cruise (Table 2). The transducers were attached to a floating platform, and a tungsten-carbide standard target was carefully moved within the beam of the transducer until a large sample of target positions were collected. Using the known TS of the standard target, the peak target strength from the calibration was used to calculate the source level and receiver gains (Foote and MacLennan 1982).

Acoustic processing

Once the cruise was completed, the acoustic files were transferred to UNIX workstations where batch processing of files was performed. To facilitate reduction and processing of acoustic information, software was written in the Interactive Data Language (IDL) which corrected for physical parameters (temperature and salinity), and applied the acoustic calibrations. After initial processing, we wrote more IDL software to remove untracked bottom, to calculate biomass estimates, and to produce images (Figure 5).

Echo-square integration has been shown to be an effective tool for estimating fish biomass when densities are high (Ehrenberg and Lytle 1972); however, pollock densities are relatively low in PWS. Therefore, we used an echo-counting technique to estimate pollock density and biomass. Echo-counting has been used successfully in other studies (Traynor and Ehrenberg 1979; Burczynski and Johnson 1986). A test of our echo-counting technique was performed in 1995, and showed that for our data, echo-counting resulted in a small underestimate pollock density for most surveys (Thomas et al. 1996).

First, possible pollock targets were selected based on known biology and behavior of various fish in the Sound. These selections were made while looking at paper echograms, electronic target echograms, and catch data from that survey. Once unwanted targets were removed, a histogram of the selected target strengths was generated. On this histogram, usually biomodal, we manually selected the lower mode of target strengths, but included all target strengths that were pollock-sized.

Once the targets were selected, and a TS range chosen, the software counted all qualifying targets. These counts were then divided by the sample volume of the acoustic beam, and summed to the surface to yield densities in fish/m^2. Densities may also be converted to biomass using known weights of captured pollock, but since we hadn't received 1996 weight information from ADF&G at the time of this report, we only presented data on pollock numerical densities in this paper.

RESULTS

Seasonal variability

Pollock densities generally increased in Prince William Sound as the summer progressed, especially in the northwest region of PWS. Pollock densities peaked at nearly 0.006 pollock/m^2 in early July, 1994. Pollock densities also increased from May to June in both 1995 and 1996 (Figure 6). Compared with 1994, however, it appears that pollock may have moved into the northwest Sound later in 1995 and 1996 than in 1994. Since sampling ended in early July in both 1995 and 1996, it is possible we did not measure peak of pollock abundance in the northwest portion of the Sound. The increase in pollock numbers occurred in both the offshore and nearshore environments (Figure 7), although the offshore region usually had a higher areal biomass. The broadscale surveys in 1995 demonstrated that pollock densities increased throughout PWS from May to June (Figures 8, 9, and 10).

Diel variability

We found that pollock abundance and distribution changed on a daily cycle. However, we found no effect of tide height on pollock abundance (Figure 11). In addition, we saw no effect of current velocity or tide range on pollock density. It appeared that much of the diel variability was the result of the time of day, and probably was related to changing light intensities.

There appeared to be two layers of pollock during most surveys: A shallow layer (< 20 m deep) was present throughout the day, and a deep layer that migrated up and down in the water column. The depth of the deep layer was influenced by time of day. During the short nights, the pollock were shallower than during the day. At offshore sites, pollock were around 150 to 200 m deep during the day, but moved up to top 100 m at night (Figure 12). In nearshore areas, very few pollock were seen during the day, except an occasional shallow surface layer. At night, however, a deep layer of fish appeared around 2200 and migrated up to the top 100 m (Figure 13).

In addition to a diel vertical migration, at nearshore sites there was an occasional inshore migration of pollock. In 1995, the only data analyzed for horizontal migrations so far, pollock at most nearshore sites moved closer to the shore (Figure 14). We saw this pattern in approximately 50% of our 1995 nearshore diel surveys. We did not see changes in density between offshore and onshore sites.

We found a positive correlation between pollock density and relative zooplankton density in 1994 (Figure 15). In addition, echograms and computer visualizations have shown co-occurrence of pollock and plankton patches (Figure 16; Thomas et al. 1996). There results are preliminary due to sampling problems. Our acoustic equipment on the 1995 offshore cruises was limited to 120 kHz, so it was not ideal for measuring zooplankton.

DISCUSSION

Pollock in Prince William Sound display seasonal and diel changes in abundance and distribution. As a dominant predator in the Sound, the location, number, and behavior of pollock can have wide ranging effects on other populations. Pollock are predators of, and competitors with, juvenile salmon. Our data begin to show some insight into how pollock populations behave in PWS, and when combined with oceanography and zooplankton data, will help determine the validity of the Lake/River and Prey Switching hypotheses (Cooney 1993).

Pollock migrated northward into Prince William Sound as the year progressed. Commercial fisherman have long reported finding large concentrations of adult pollock in Port Bainbridge and the southwest Passages during winter (Thomas et al. 1996). These pollock probably begin migrating northward after the winter, eventually reaching as far north as Port Wells. Our data showed an increase in pollock densities in northwest PWS from May to June. Furthermore, in 1994, the increase in pollock in the northwest was accompanied by a decrease in pollock numbers in the southwest. This supports a hypothesis that the adult pollock migrate northward after the winter.

The reason for this migration is still unclear, but adult pollock are probably moving northward to feed on zooplankton. We did see a strong positive correlation of pollock biomass with zooplankton density, but we need to refine our methods for measuring and estimating zooplankton using acoustics (see Chapter 2). We also need to examine cases where pollock are not found with high zooplankton densities.

The Prey Switching hypothesis suggests that in the absence of abundant zooplankton, pollock will swtich to juvenile pink salmon. We did not see a relationship between pollock density and the density of small fish targets in 1994 or 1995. In 1994, however, the percent age-0 fish in pollock diets did increase in June (Figure 17), corresponding with the release and outmigration of juvenile salmon from the hatchery on Esther Island. In addition, the percentage of age-0 fish in the stomach were highest during nighttime hours (Figure 18). This suggests that pollock fed more heavily on juvenile fish as the year progressed, and that most of this feeding occurred at night.

We observed two layers of pollock during these surveys: a shallow layer that did not appear to vertically migrate, and a deep layer that did migrate. The presence of two layers of pollock presents many questions. It is possible that the upper layer represents a group of pollock feeding on plankton near the surface. In the offshore region, the deep layer migrates up at night and down during the day. Trawl catches showed a similar vertical migration of squid an euphausiids (Thomas et al. 1996). Therefore, the offshore vertical migration of the deep layer might be the result of pollock feeding on euphausiids, squid, or shrimp. In the nearshore region, the deep pollock layer moved up and close to shore at night, probably to feed on juvenile fish. The increase in % age-0 fish in the diet at night supports this hypothesis. The observed diel vertical migrations are to maximize feeding opportunities, but could be a combination of feeding rate, bioenergetic advantages and predator avoidance (Neilson and Perry 1990).

Although we found no diel changes in aerial densities between nearshore and offshore sites in 1995, this does not disprove a horizontal migration, but may be a problem of the correct spatial scale. If pollock are moving inshore to feed on juvenile salmon, it is likely that the offshore-onshore migration in occurring within our designated nearshore sites, and not between our nearshore and offshore sites. This is evident by the frequent reports of salmon fry schools that were closer to shore than we surveyed in our boat. It is unlikely, however, that a large portion of the pollock population is moving inshore to feed at night. If this were true, we would have seen a decrease in offshore densities at night.

The lack of tidal effects on pollock is not surprising given our sampling design. With many confounding variables, such as site, day, and time, it is difficult to isolate the tidal effects. Furthermore, tidal effects are likely to be acting on only a small spatial scale, since current velocities are highly variable. Our tidal data were from the Tides and Currents computer software (Nautical Software, Inc.). This information, especially the information on ocean currents, is highly variable based on a number of climatic and morphometric conditions. This does not mean that pollock don't react to changing tides: there may still be changes in behavior or distribution. But, the absolute abundance of pollock at our sample sites does not change over a given tidal cycle. When we get more accurate tidal information from ongoing oceanographic work, we may elaborate on these results.

Pollock in Prince William Sound feed heavily on zooplankton (M. Willette, ADF&G, pers. comm.), so the positive correlation we found between zooplankton and pollock density was not a surprise. Since zooplankton abundance and patch size are dependent on climate and oceanographic conditions, however, this relationship may be dependent on how many zooplankton are present. During "lake" years, high zooplankton numbers, and increased density of zooplankton patches may result in a higher correlation than during "river" years. When zooplankton are less abundant, or in less dense patches, pollock may prefer to feed on small fish, so the observed relationship may not hold true.

Our present results may be confounded by statistical problems. The small sample volume of the acoustic beam in shallow water, combined with relatively low overall fish densities, lead to high variability in our density estimates. The addition of one target in the top 10 m of a file can radically alter the predicted biomass for that site. In addition, target strengths of fish are highly variable and depend on many factors (Traynor and Williamson 1983; Mukai and Iida 1996). For example, a fish swimming up or down within the acoustic beam is tilted and thus presents a smaller cross-section to reflect the acoustic signal. The reduced acoustic return will lead to an underestimate of the total length of the fish, and therefore may result in that target being correctly classified as a pollock. Furthermore, an echo from a fish that is only partially within the acoustic beam will also underestimate the target's size. Coincident targets, which will occurr more frequently with depth, cause the target discriminator to omit targets. This will underestimate the number of targets in deep water.

To overcome these problems, we are planning on using both echo-square integration and echo-counting techniques to measure pollock. Due to corruption of the acoustic signal by dense scattering layers, the echo-counting technique is preferable to echo integration where dense layers of plankton or other species are present. Future work will focus on overcoming the statistical problems of a small sample volume near the surface to improve or echo-counting proceudre. For deep waters where scattering layers are not present, however, we will begin using echo-integration to more accurately assess pollock biomass.

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We would like to thank all the crews of our research vessels for helping us to collect these data. Without their knowledge and experience, this research would not have been possible. The Alaska Department of Fish and Game and the University of Alaska-Fairbanks were responsible for the daunting task of analyzing the catch data. A special thanks goes to Mark Willette (ADF&G) for sharing his data on pollock diets. This work is supported by the *Exxon Valdez* Trustee Council, Grant No. 96320-N.

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Table 1. Survey location, design, and purpose for 1994-96 SEA Nekton-Plankton Acoustic cruises. Other cruises were conducted, and more data were collected, but this table describes the cruises where data presented in this report were collected.

Year	Surveys	Locations	Survey Design	Survey Purpose
1994	Offshore	Western PWS	Repeated same transects seasonally	Examined seasonal trends and patchiness of pollock distribution
1995	Offshore Broadscales	All PWS	Two repeated surveys covered vast distances	Examined seasonal trends and patchiness of pollock distribution
	Nearshore and offshore diels	NW PWS	Surveyed every 3 h for 24 h period at each site Seasonally repeated sampling at sites	Examined daily changes in pollock abundance and distribution between and within nearshore and offshore areas
1996	Nearshore	NW PWS	Surveyed each site four times at night Seasonaly repeated sampling at sites	Examined daily changes in pollock abundance and distribution in nearshore areas, and how diel changes vary seasonally

Table 2. Parameters of the acoustic equiptment used during sampling of Prince William Sound in 1996.

System	Frequency	Source Level	System Gain	Transducer Directivity	Pulse Duration
101	120 kHz	225.023	-159.282	0.0010718	0.4 ms
102	200 kHz	221.655	-155.765	0.0006515	0.4 ms

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Figure 12. Changes in offshore diel vertical distribution of pollock targets at Herring Point (site 509) on 14-15 June, 1995. These data are representative of migrations seen at nearly all offshore sites in 1995.

Figure 13. Changes in nearshore diel vertical distribution of pollock targets at Herring Point (site 509) on 14-15 June, 1995.. These data are representative of migrations seen at most nearshore sites in 1995.

Figure 14. Changes in horizontal and vertical distribution of pollock during nearshore surveys conducted between 13-18 May, 1995. Each point represents the mean vertical and horizontal position of pollock targets during day or night for different sites (site number next to line). The arrows indicate movement from the daytime means to nighttime means. Horizontal position is relative distance from shore measured as the number of reports from the nearshore edge of the transect (8-12 m per report based on boat speed and ping rate).

Figure 15. Relationship between pollock biomass and relative zooplankton density for offshore cruises in 1995. Data were log transformed, and the regression is for both cruises combined. Each point represents one cell 10 m deep, by one report (45 pings) in length. Only cells which contained both pollock and plankton were included on this graph. Note the logarithmic scale.

Figure 16. Echogram from Perry Passage in July 1994 showing high densities of pollock found in a dense plankton layer.

Figure 17. Mean percentage of age-0 fish in the diet of pollock during 1994 cruises. Error bars show the maximum value from each cruise and the numbers indicate the number of net sets used in the diet analyses. Data are from Mark Willette, ADF&G.

Figure 18. Percentage of age-0 fish in the diet of pollock versus time of day during 1994 sampling. Data are from Mark Willette, ADF&G.

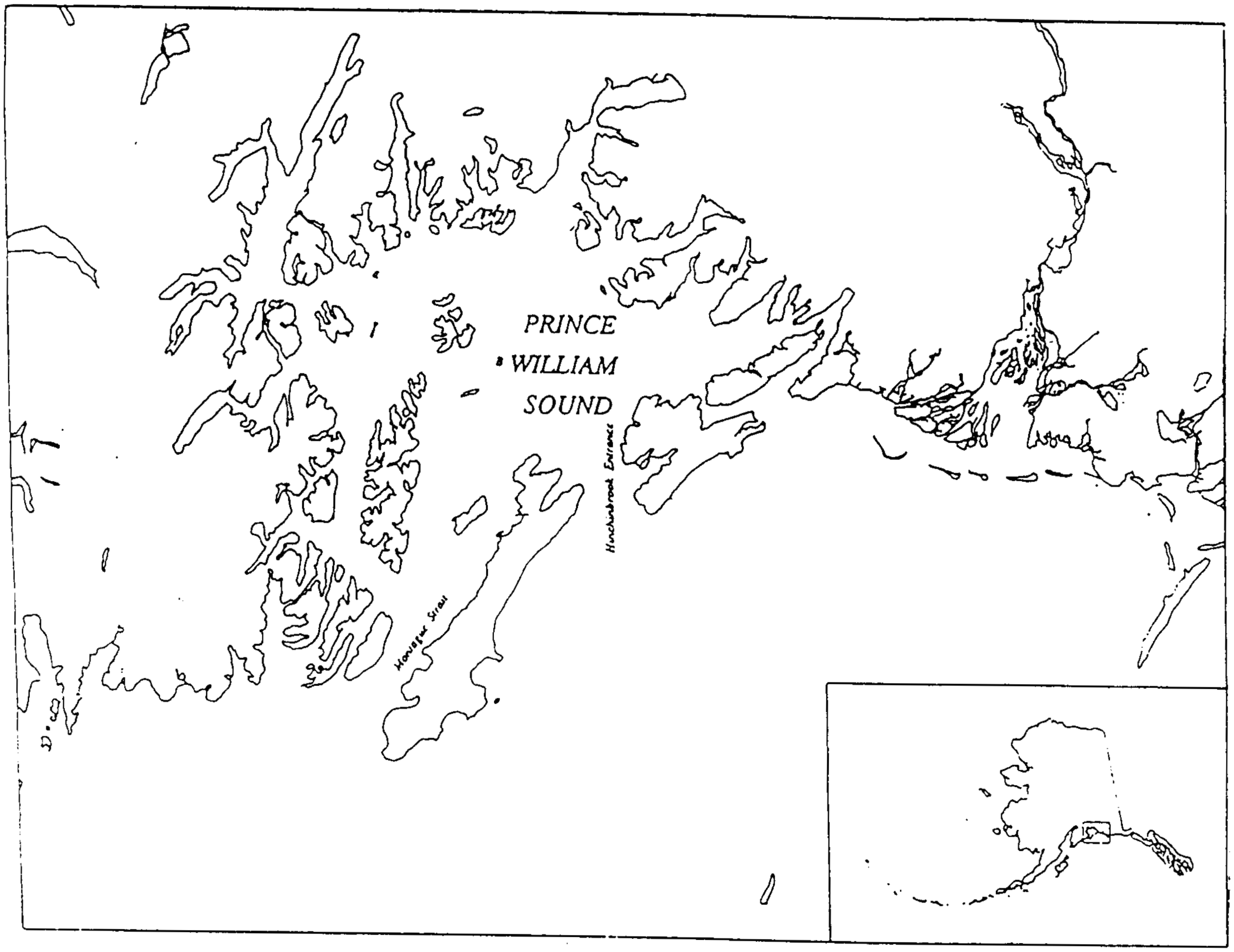


Figure 1. Map of Prince William Sound, Alaska, USA.

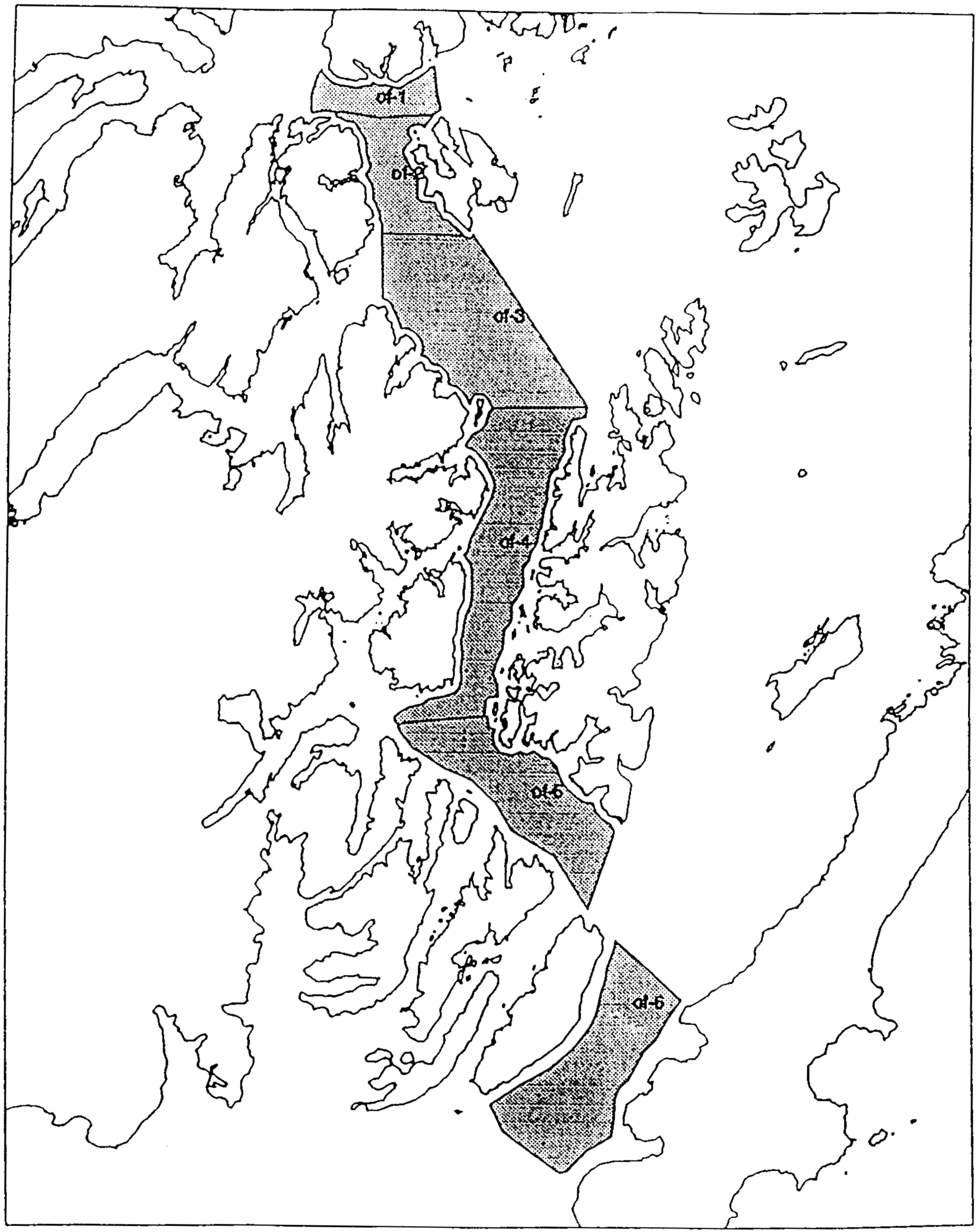
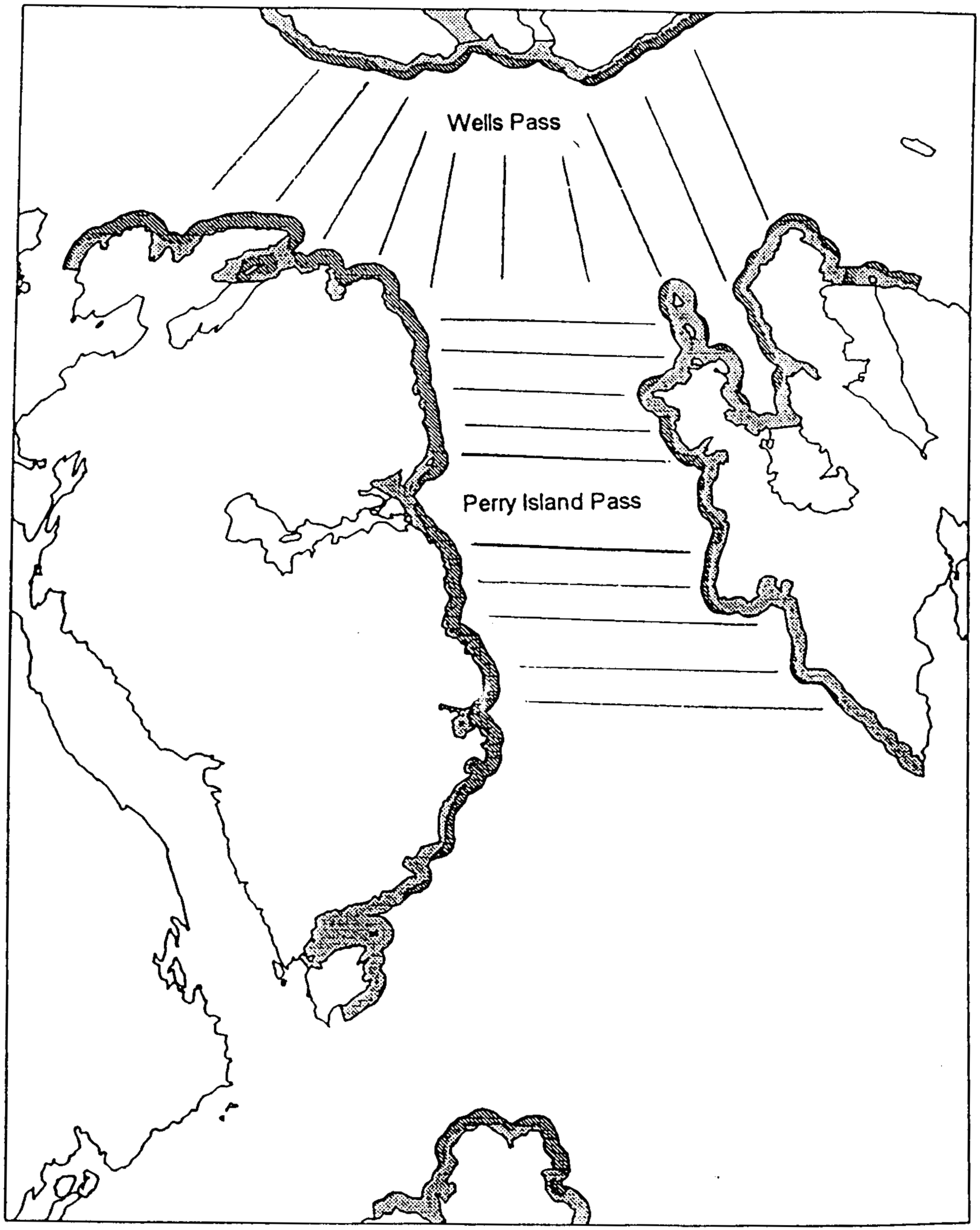


Figure 2. Map of western Prince William Sound showing the offshore areas surveyed in 1994.



DLS, PWSSC 1996

Figure 3. Map of northwestern Prince William Sound showing where most of the sampling occurred in 1995 and 1996.

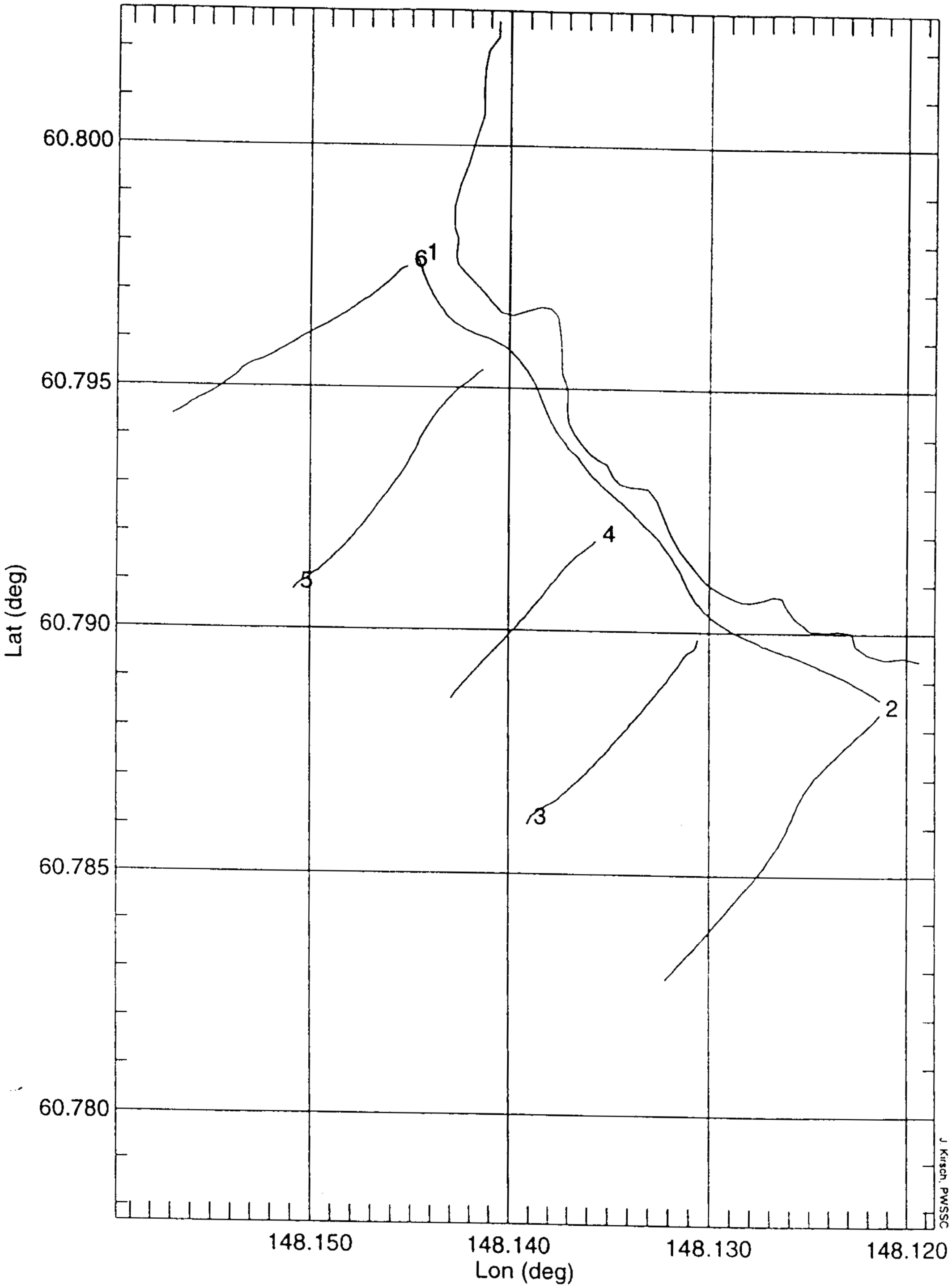


Figure 4. Map of transect design used during 1996 pollock sampling. Esther Island is located in northwest Prince William Sound.

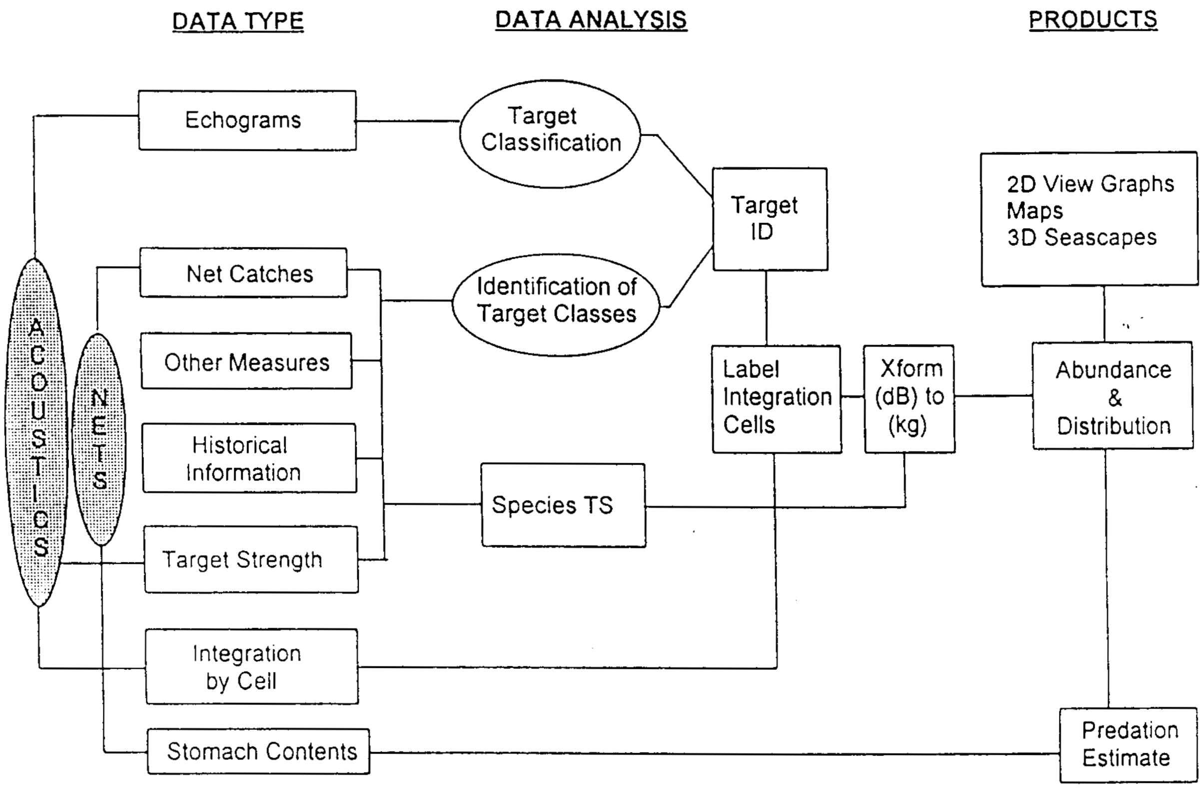


Figure 5. Flow chart of data processing steps used in analysis of SEA acoustic data collected in 1994-96.

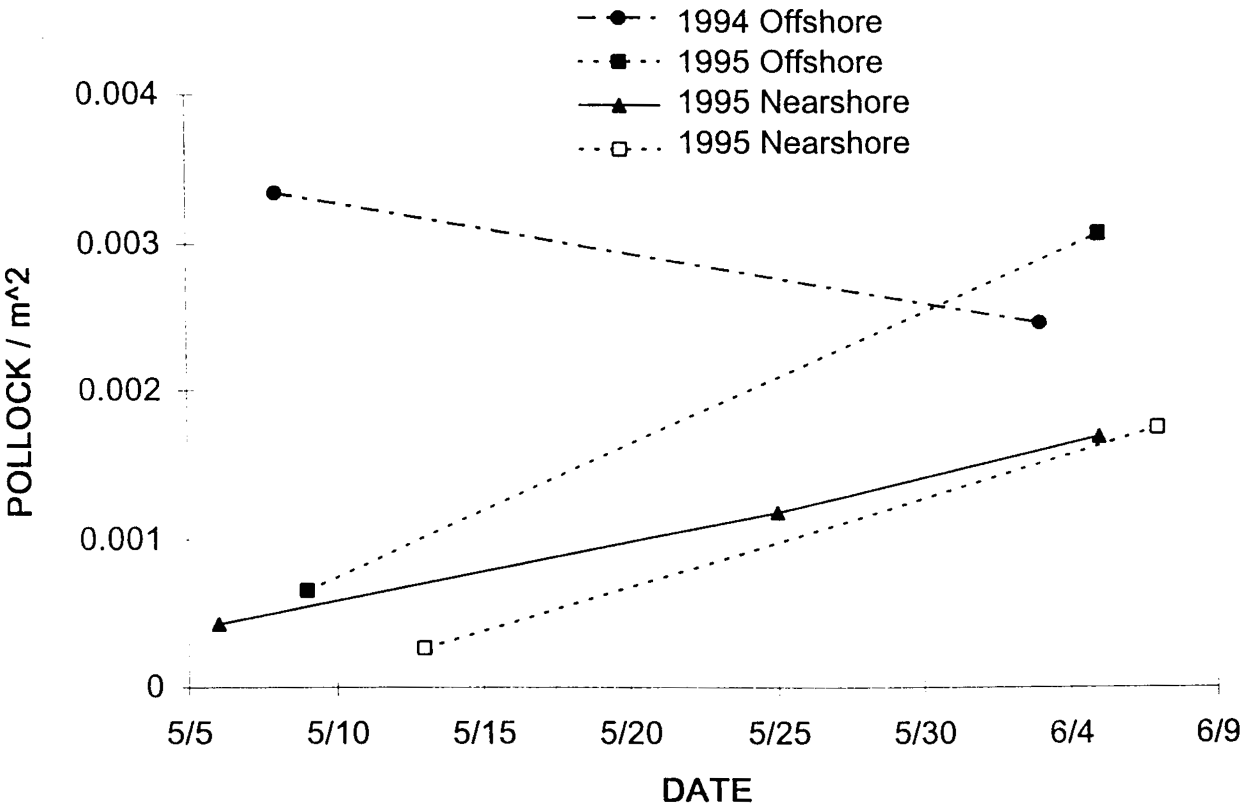


Figure 6. Mean pollock per unit surface area (fish/m^2) for northwestern Prince William Sound from 1994-96. Weighted means were calculated for all sites sampled during the different cruises.

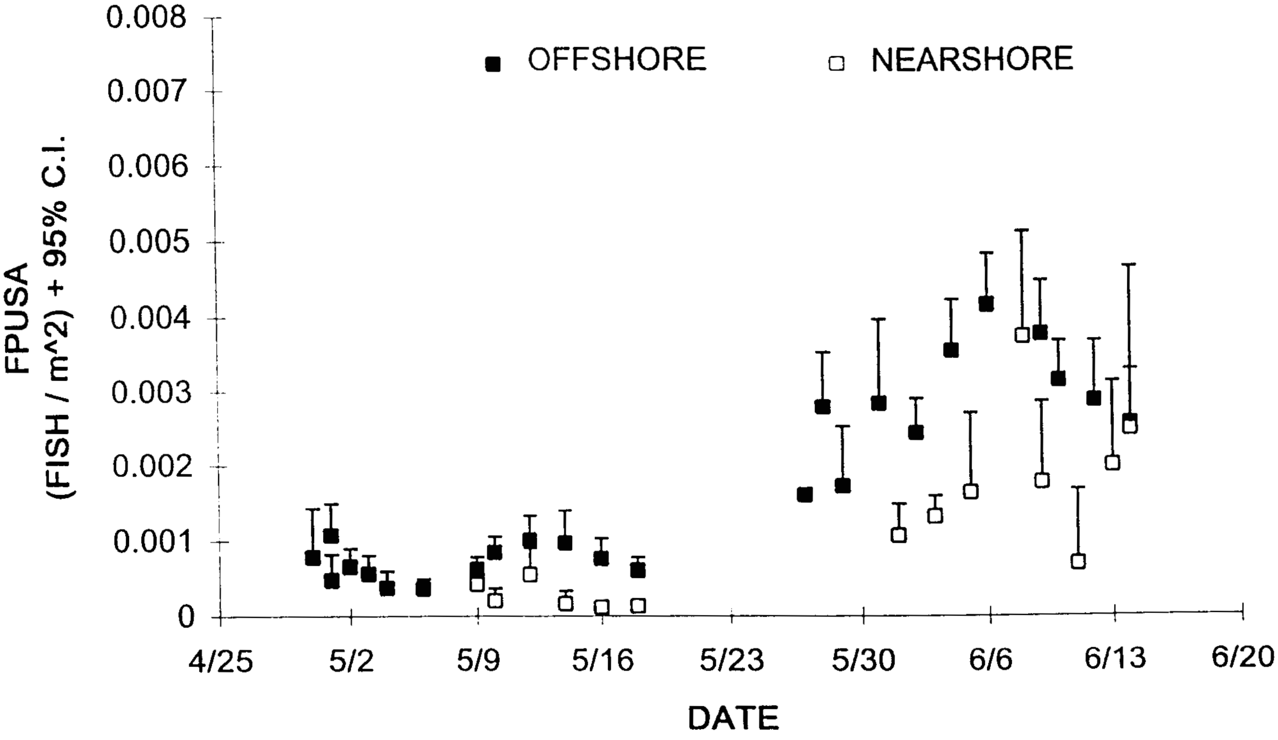


Figure 7. Mean pollock per unit surface area (fish/m^2) for northwestern Prince William Sound for offshore and nearshore sites in 1995. Weighted means were calculated for each area.

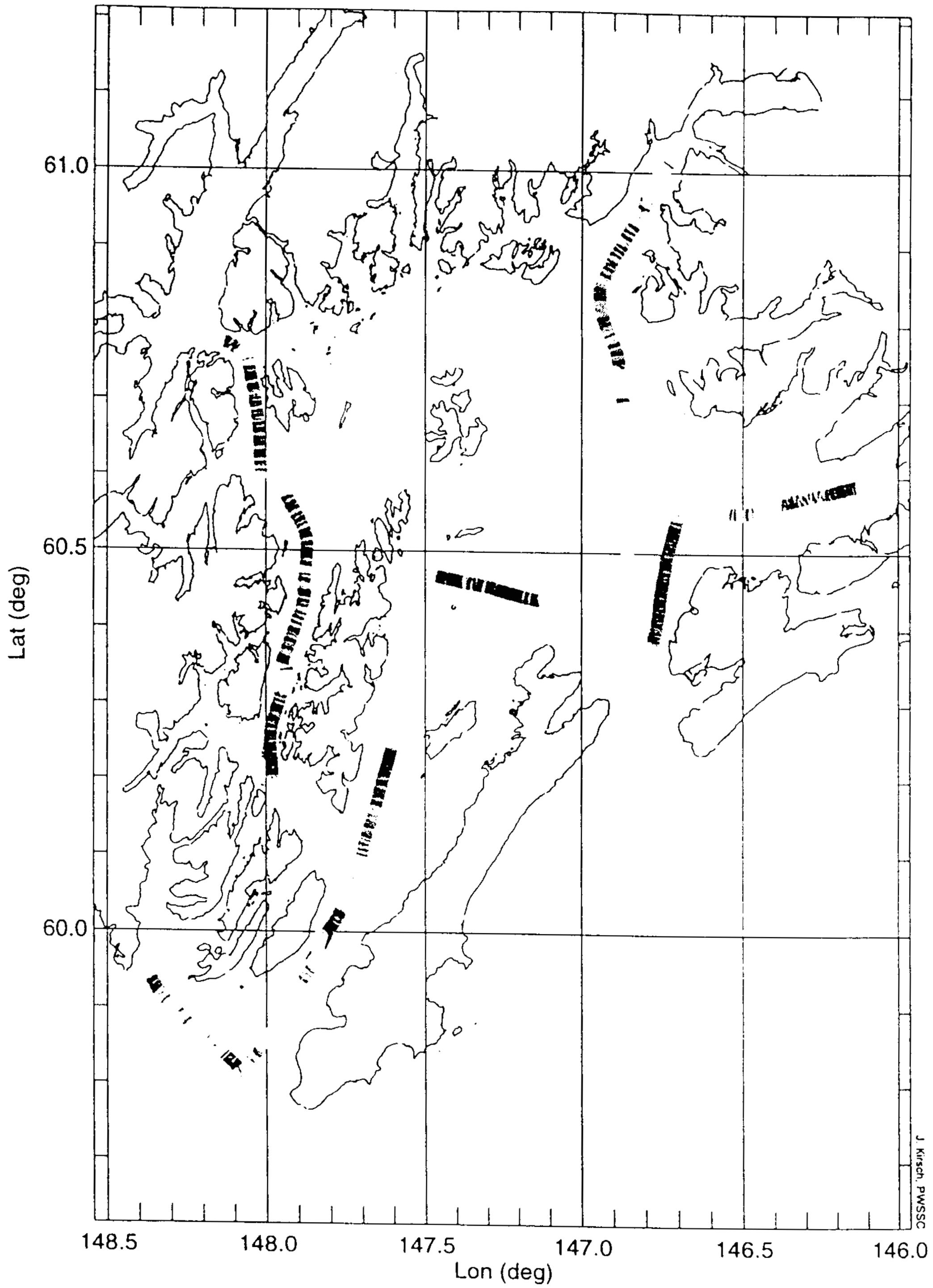


Figure 8. Map of Prince William Sound showing mean pollock per unit surface area (fish/m^2) for transects surveyed in the May 1995. Darker grey indicates higher density than areas of light grey.

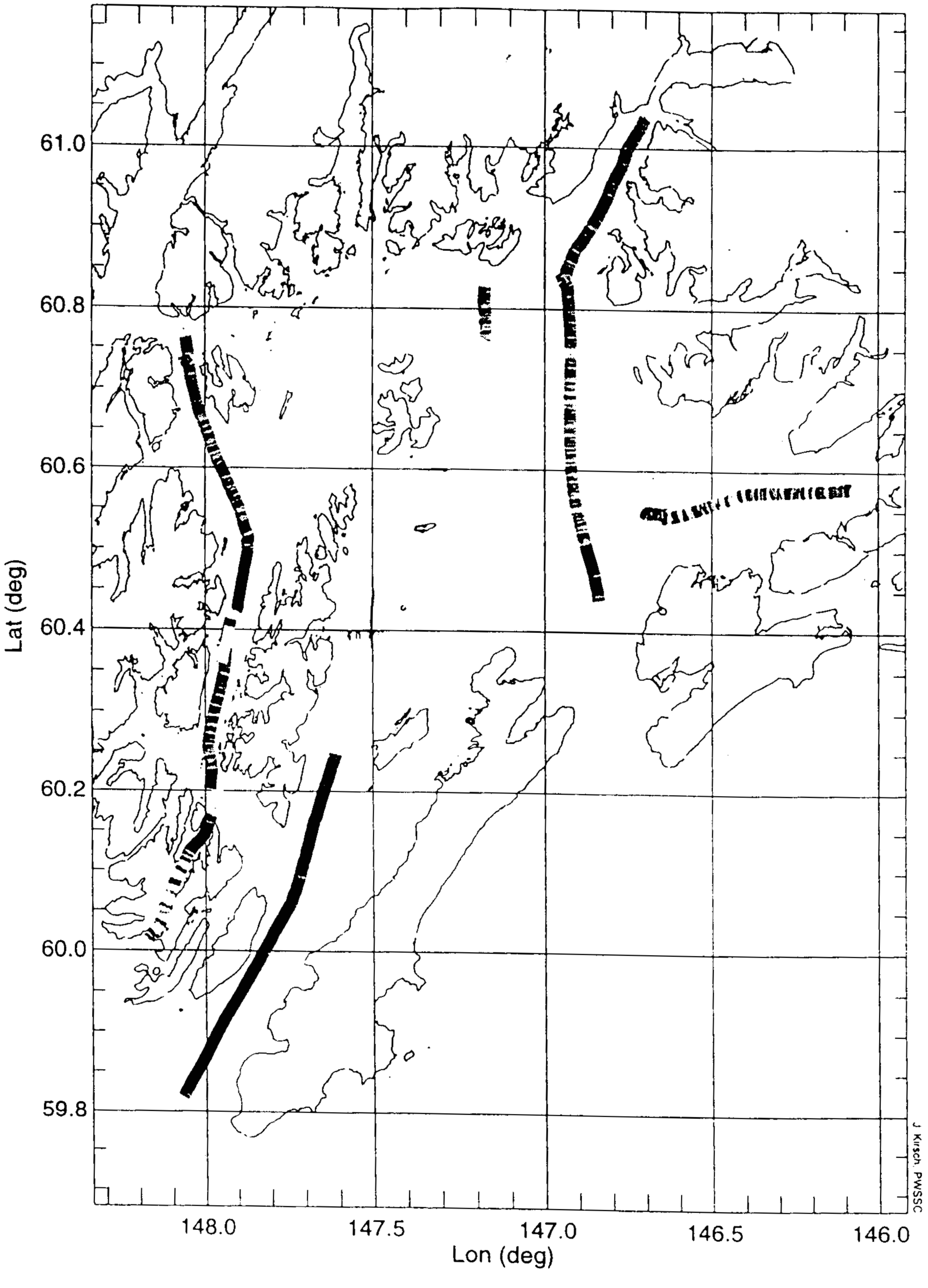


Figure 9. Map of Prince William Sound showing mean pollock per unit surface area (fish/m^2) for transects surveyed in the June 1995. Darker grey indicates higher density than areas of light grey.

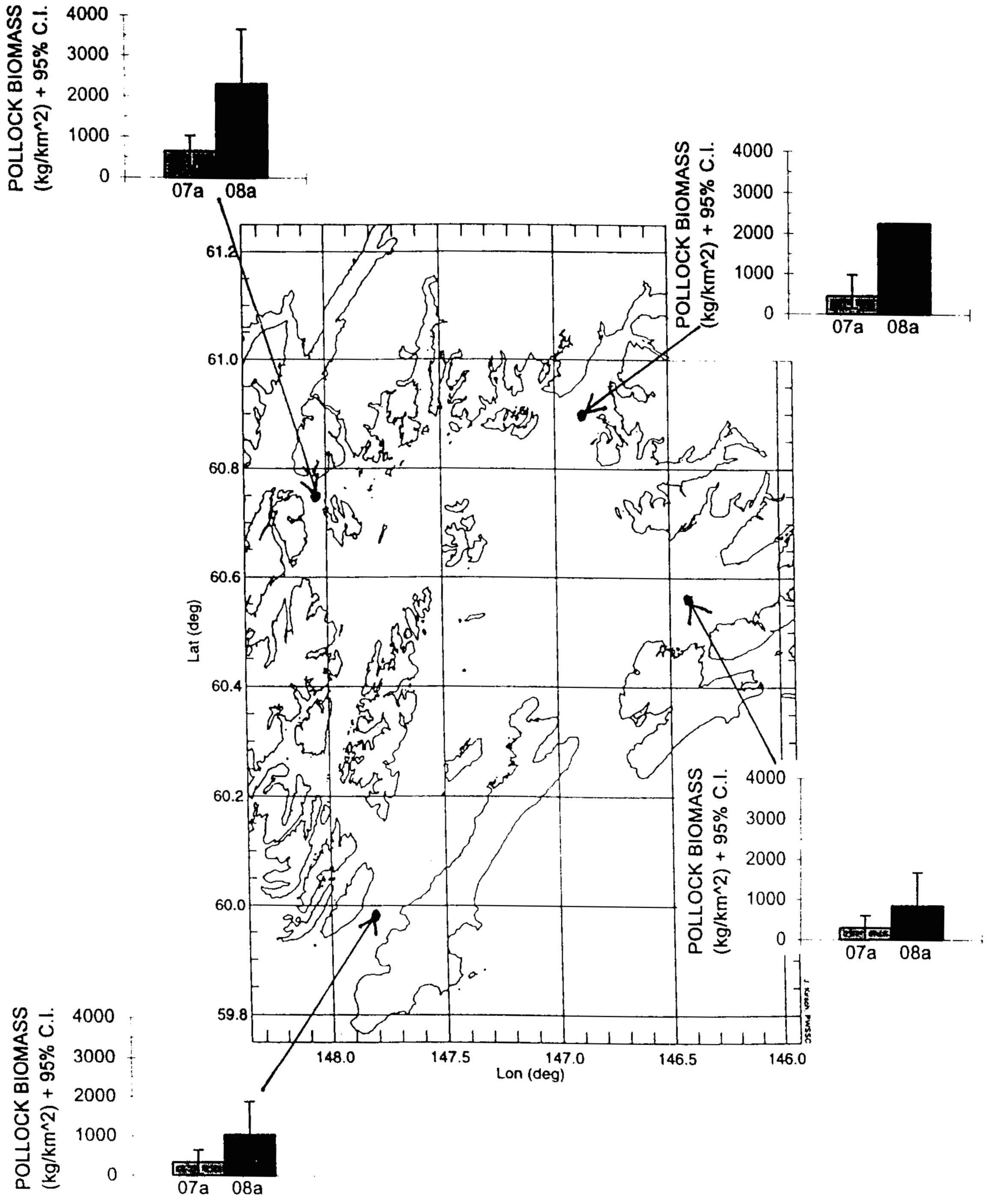


Figure 10. Map of Prince William Sound showing mean pollock per unit surface area (fish/m²) for general areas of the Sound surveyed in May (07a) and June (08a) broadscale surveys in 1995. Weighted means were calculated for each area.

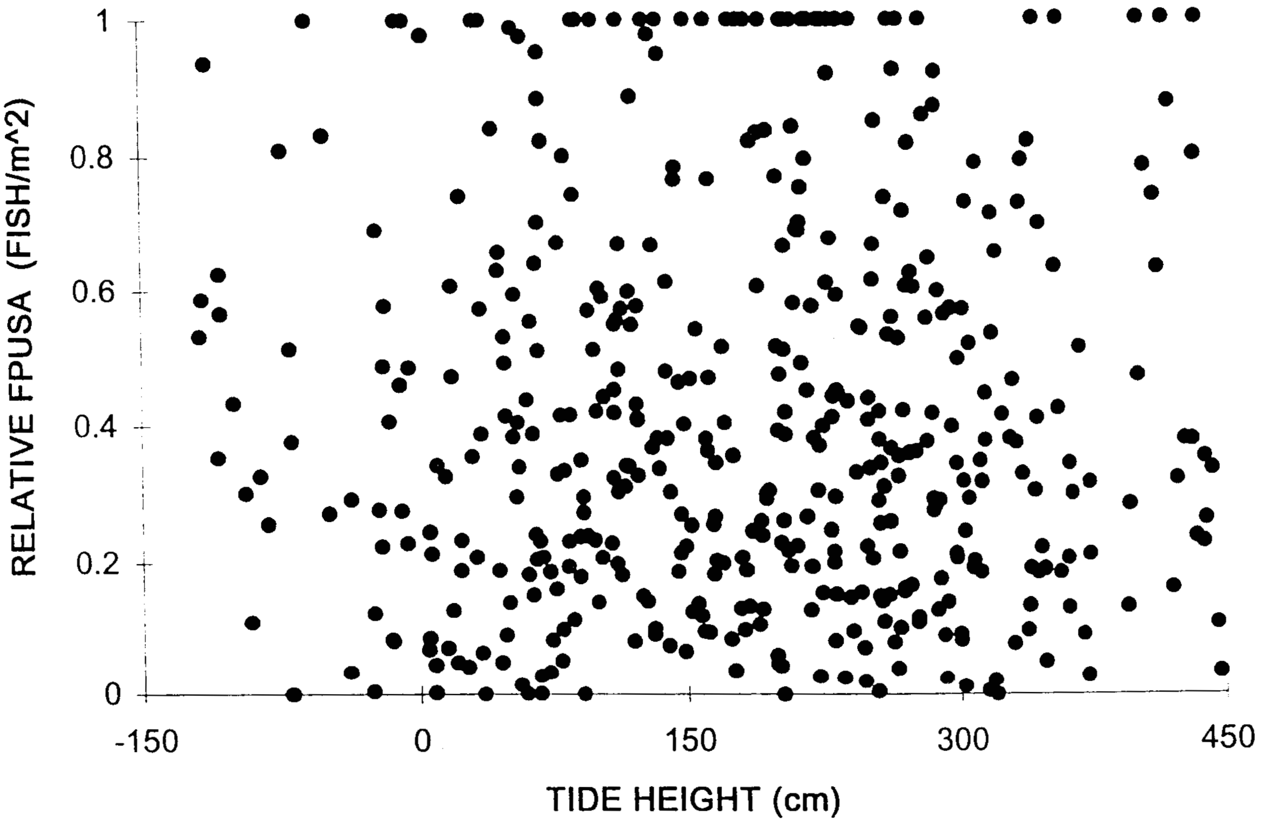


Figure 11. Relative pollock densities (FPUSA) versus tide height for repeated nearshore and offshore surveys in 1995. Each point represents one survey. Relative FPUSA is calculated by dividing the FPUSA for a survey by the maximum FPUSA for all surveys at that site on the same date. This was done to avoid changes in pollock density between sites and between dates. Tide data are from Tide and Currents software (Nautical Software, Inc.).

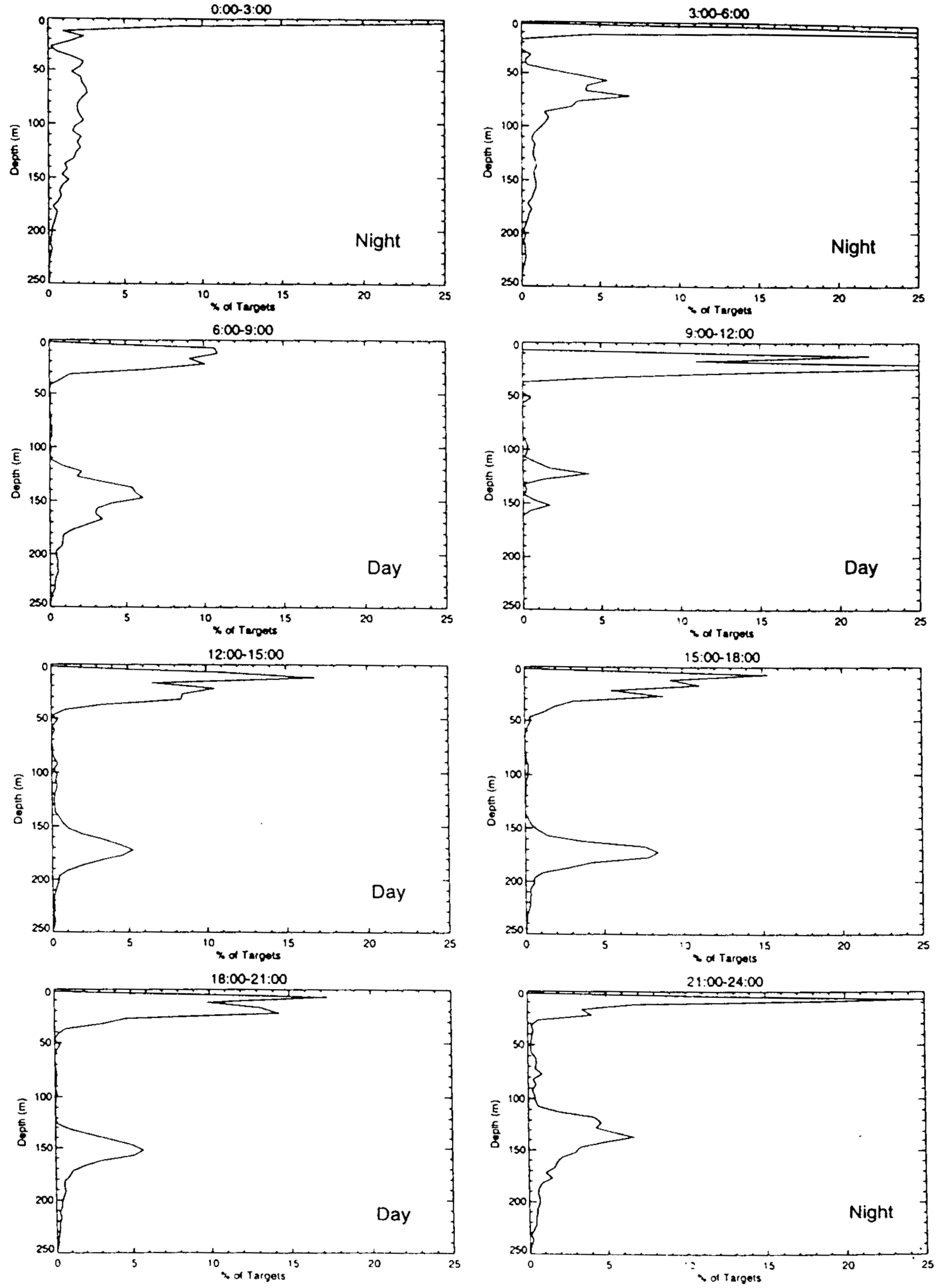


Figure 12. Changes in offshore diel vertical distribution of pollock targets at Herring Point (site 509) on 14-15 June, 1995. These data are representative of migrations seen at nearly all offshore sites in 1995.

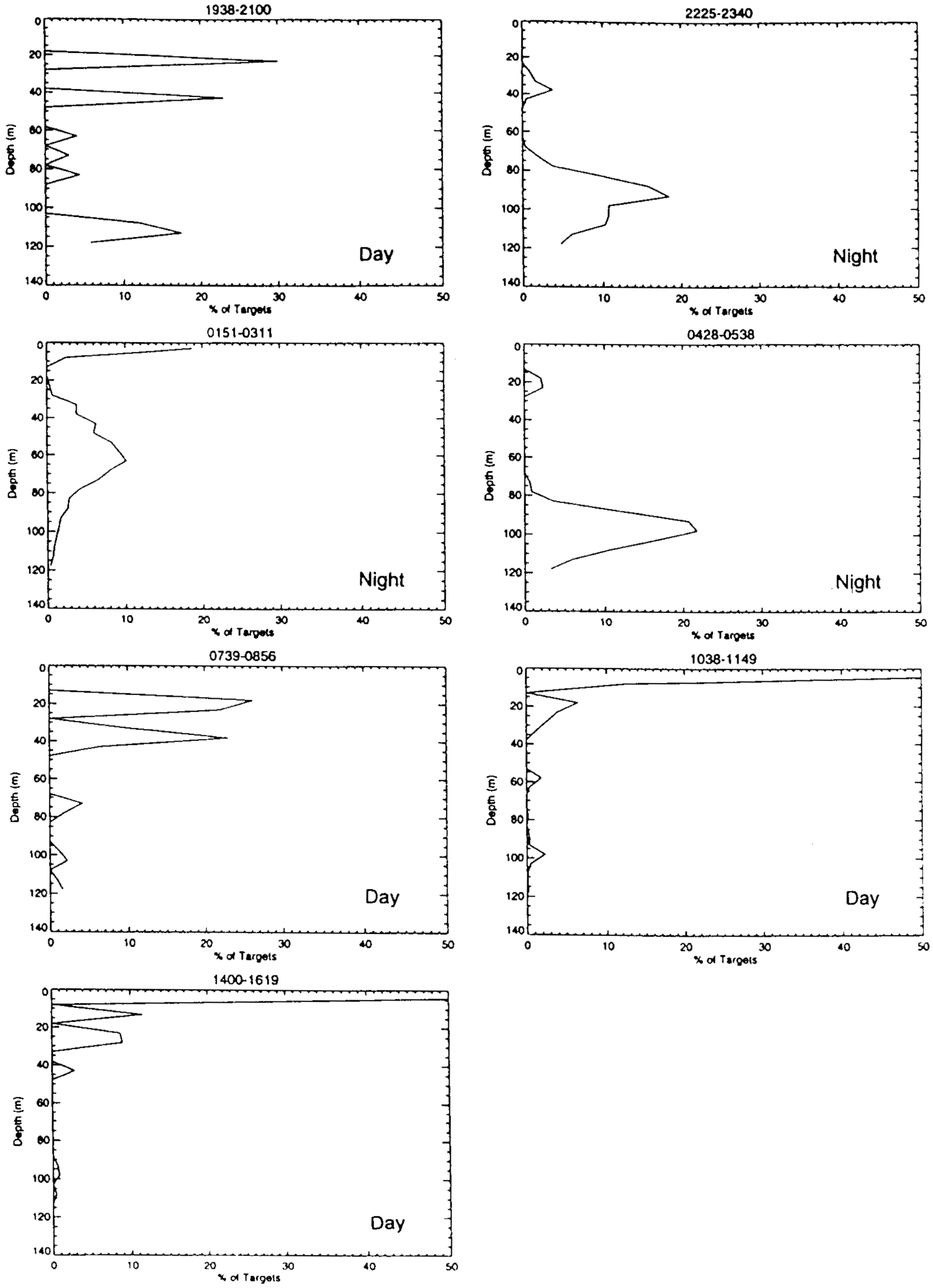


Figure 13. Changes in nearshore diel vertical distribution of pollock targets at Herring Point (site 509) on 14-15 June, 1995.. These data are representative of migrations seen at most nearshore sites in 1995.

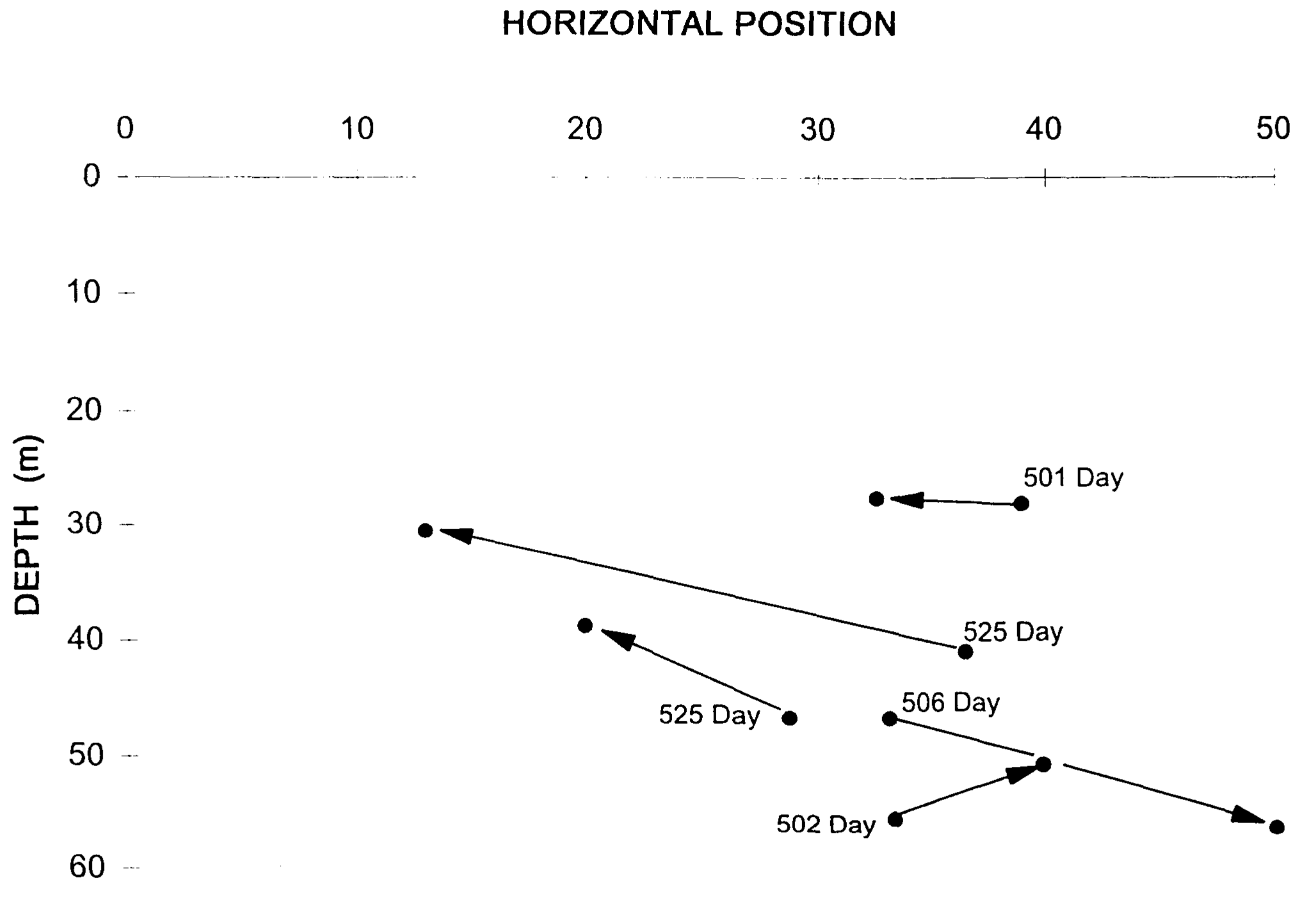


Figure 14. Changes in horizontal and vertical distribution of pollock during nearshore surveys conducted between 13-18 May, 1995. Each point represents the mean vertical and horizontal position of pollock targets during day or night for different sites (site number next to line). The arrows indicate movement from the daytime means to nighttime means. Horizontal position is relative distance from shore measured as the number of reports from the nearshore edge of the transect (8-12 m per report based on boat speed and ping rate).

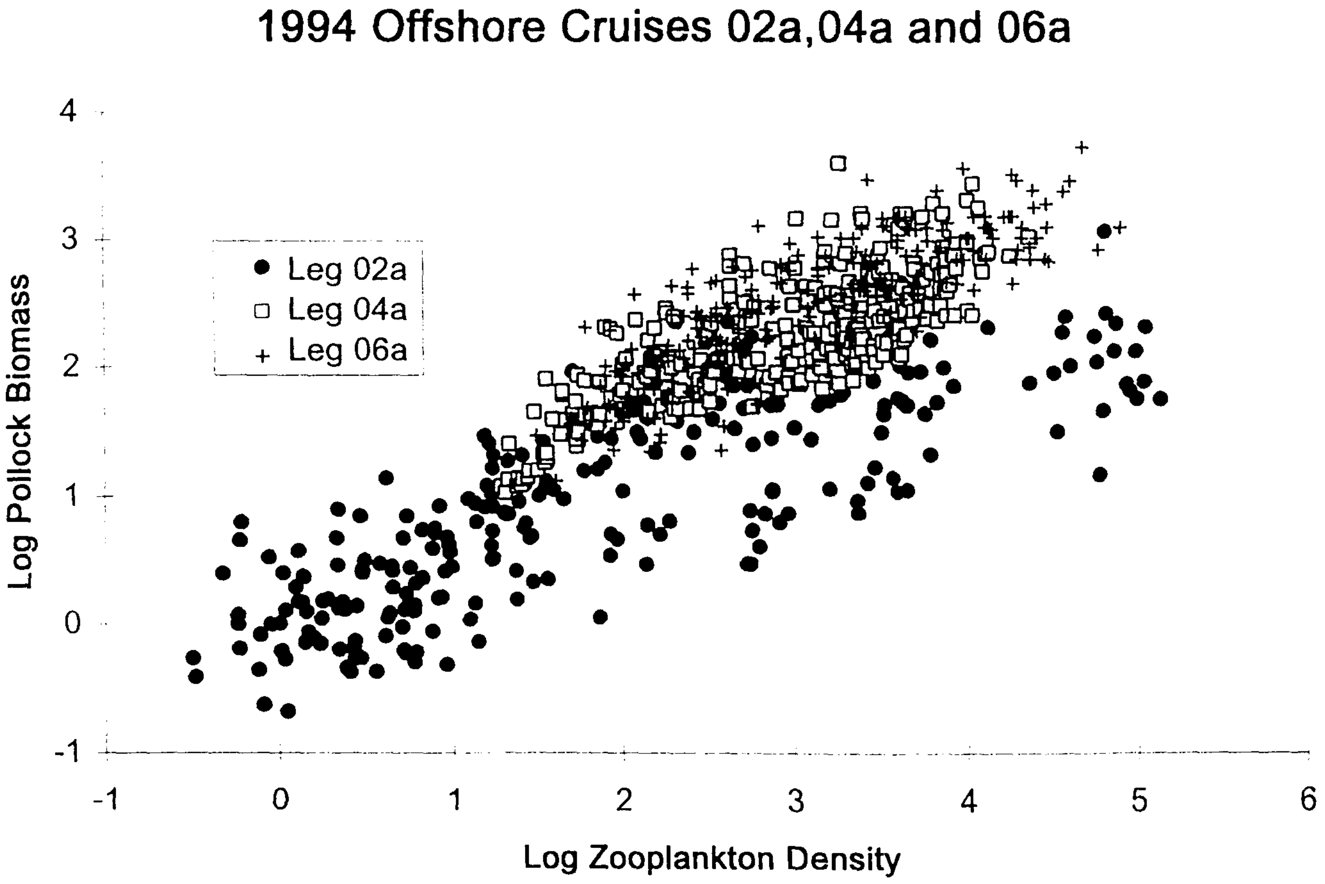
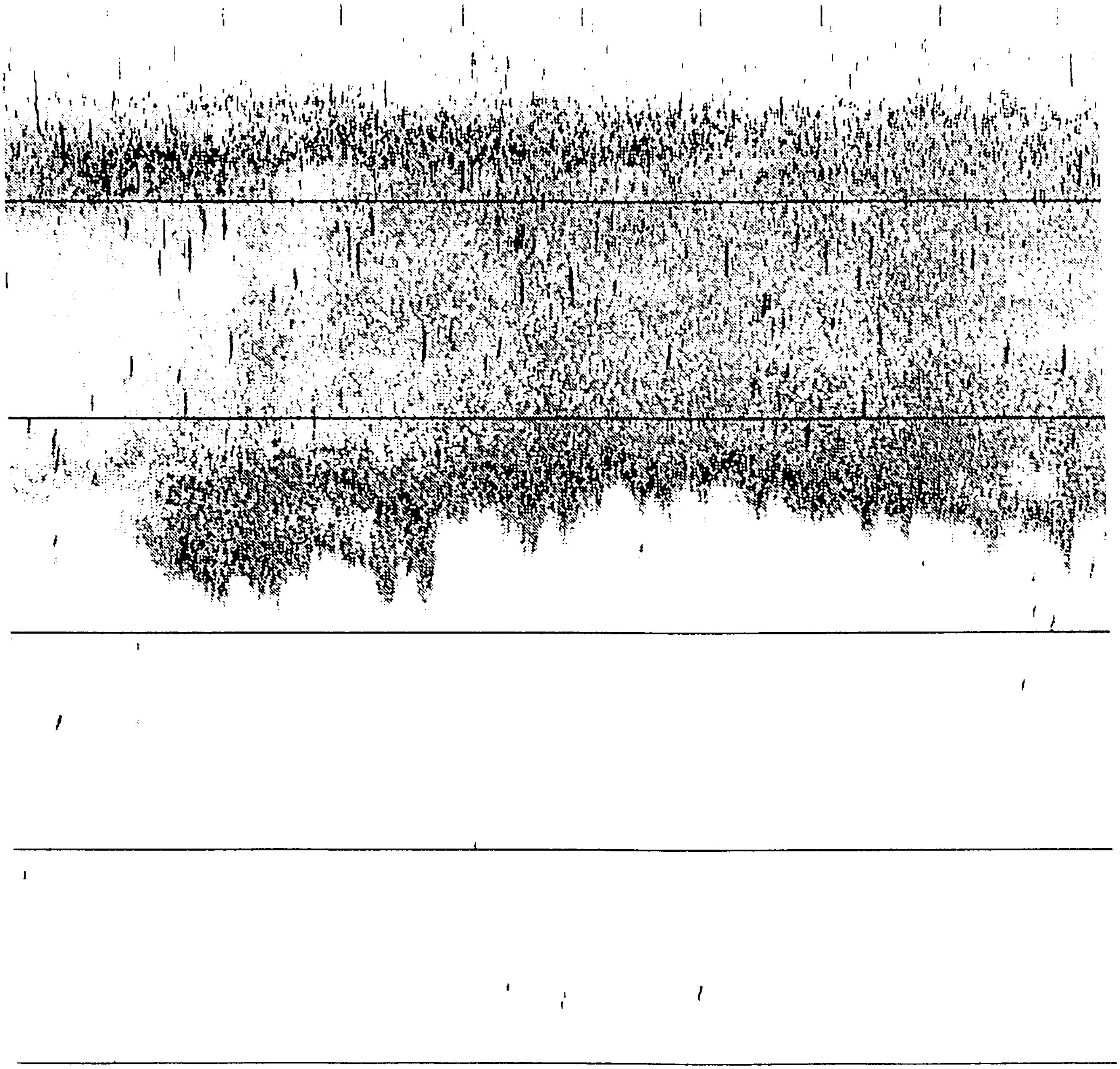


Figure 15. Relationship between pollock biomass and relative zooplankton density for offshore cruises in 1995. Data were log transformed, and the regression is for both cruises combined. Each point represents one cell 10 m deep, by one report (45 pings) in length. Only cells which contained both pollock and plankton were included on this graph. Note the logarithmic scale.



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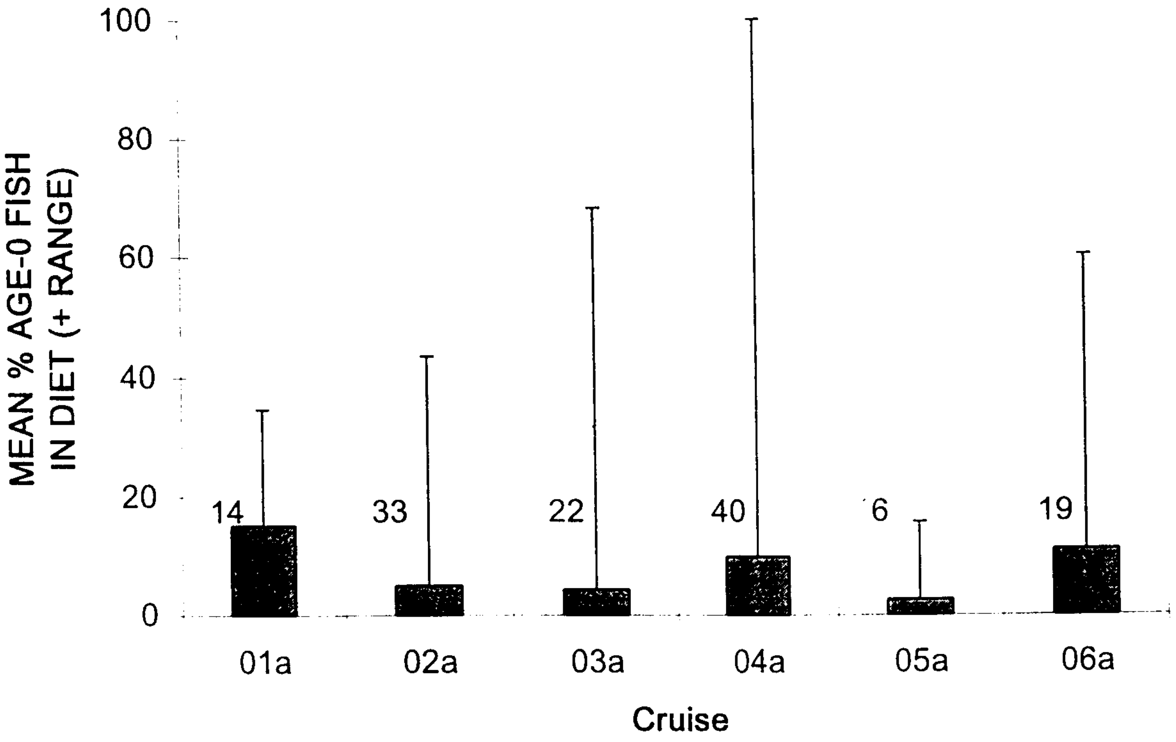

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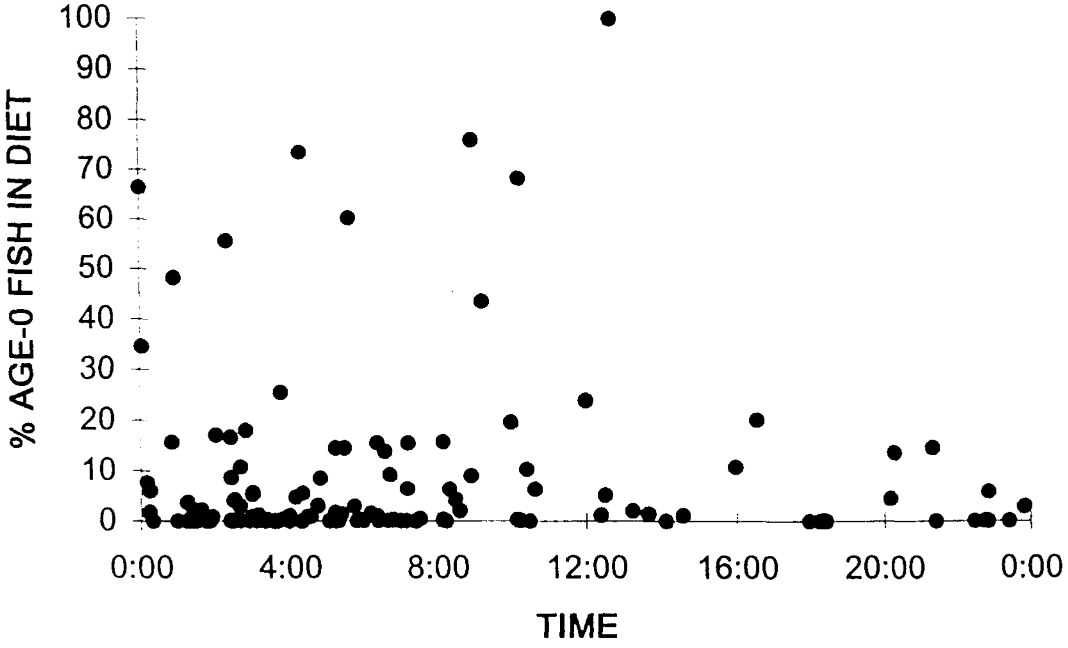

Figure 18. Percentage of age-0 fish in the diet of pollock versus time of day during 1994 sampling. Data are from Mark Willette, ADF&G.

CHAPTER 2.

ACOUSTIC ESTIMATE OF ZOOPLANKTON DISTRIBUTION IN PRINCE WILLIAM SOUND, SPRING 1996

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ABSTRACT

A zooplankton survey was conducted in Prince William Sound in May 1996, using a 420 kHz digital sonar and a MOCNESS net. Data from the catch supplied us with zooplankton species, size, and density, which were applied to zooplankton scattering models, allowing us to predict volume backscatter. These predicted values are compared with measured acoustic backscatter to validate the measurement methods. Relative agreement in the two instruments is evident in the occurrence at the same depth of layers. However, more analysis of the catch information is needed for agreement of the absolute densities, since animal sizes are used to estimate the target strength that is used to scale the echo-square integration. The sources of error are discussed, with their potential solutions.

INTRODUCTION

Acoustics has been used for zooplankton assessment since the early 1970's, but only until recent advances in target strength (TS) models has estimation of absolute density been attempted (Stanton et al. 1994). Density estimation through echo-square integration requires average target strengths of the individual organisms in order to scale the acoustic backscatter array. Measuring *in situ* target strength directly is problematic in that individual peaks need to be detected from the received electronic signal. This requires the infrequent case of low enough zooplankton densities to resolve individual echoes with a beam that spreads with range.

The objective of this survey was to estimate the biomass and distribution of calanoid copepods throughout Prince William Sound in spring of 1996. These zooplankton are a primary source of food for many fishes in Prince William Sound, including pollock, herring, and salmon.

MEASUREMENT METHODS

Acoustic surveys were conducted aboard the University of Alaska Research Vessel *Alpha Helix*. The acoustic system consisted of a 420 kHz BioSonics Digital Transducer scientific echosounder with a dual-beam transducer (although only the narrow beam was used for this analysis) mounted on a 3 meter long towing fin. Transducer signals were acquired on a NEC Versa personal computer via a PCMCIA cartridge, written to hard disk, and moved to a Bernoulli disk each day. Parameters of the acoustic system during the survey were: source level (SL) =+224.0 dB; receiver gain (RG) =-42.9 dB; transducer directivity (b^2) =.000274; and pulse duration=400µs. These parameters result in an echo integration constant of 6.61e+14. The trigger interval was set to .4 seconds (2.5 pings per second), but may have had some variability due to the computer's limited ability to acquire signals rapidly.

A nine day broad scale survey of Prince William Sound was conducted between May 2nd and 10th, 1996 (Figure 1). Knight Island Passage, Wells Passage, Unakwik Inlet, Montague Strait, and Orca Bay were surveyed in Prince William Sound. Another survey was conducted from Middleton Island in northern Gulf of Alaska through Hinchinbrook Entrance. The acoustic survey was conducted after the spring phytoplankton bloom when large calanoid copepod; Neocalanus spp., are found closest to the ocean surface. Measurements were performed in the daytime when many nocturnal organism migrate to deeper water, and contribute less to the acoustic signal.

A MOCNESS with nine 1 m^2, 0.505 mm mesh nets was used during the survey. There were 25 tows throughout the Sound. Each MOCNESS tow sampled from 50 meters to the surface in 5 meter increments. To measure temperature and salinity, a CTD was cast at the end of every net tow (as well as other stations), providing information on stratification in the water column.

Other sensors were operated during the cruise, but these output are not the focus of this paper. A Focal optical plankton counter with a Chelsea Instruments Aquapack (CTD, fluorometer) was towed on a Chelsea Aquashuttle during the acoustic surveys but not during MOCNESS tows. BioSonics 720kHz and 1MHz Digital Transducer systems were operated during the MOCNESS tows, which in the future could provide information for multifrequency inversion methods. Data were also collected by a hull-mounted Acoustic Doppler Current Profiler, and an on-deck weather station.

To facilitate batch processing, the data were processed using in-house software written in the Interactive Data Language (IDL). Our processing scheme included an echo-square integrator with a notch-gate (described later) to remove fish, a map generator for both survey plotting and visualization of geographical distributions, a database scheme to match acoustic files with MOCNESS files, and a program for MOCNESS volume backscatter prediction. The output files included echograms in GIF format, color maps in Postscript format, and ASCII tables.

Although daytime surveys provide the least corruption of the macrozooplankton signal due to reduced number of fishes in the surface water, it was still necessary to filter large fish from the signal. The BioSonics Digital Transceiver samples at 41667 samples per second, which at a speed of sound of 1470 meters per second, gives a sampling resolution of 17.6 mm. At this resolution, high zooplankton densities have smaller signals than a single fish. To remove large fish signals, we used the inverse of thresholding; notch-gating, where signals below a threshold are kept but larger ones are omitted. The echo-square integrator that was built into our processing scheme included a notch gate which removed echoes above a specified threshold of -60 dB, based on a histogram of signal values.

MEASUREMENT RESULTS

Figure 2 shows a digital echogram of a typical zooplankton layer. In the daytime, animals were layered typically around 10 to 20 meters. In the evening, there is suggestion of an upward migration, although zooplankton behavior will be the focus of a future paper.

Highest acoustic scattering levels were found in the Gulf of Alaska, Hinchinbrook Entrance, and southern Montague Strait. Other areas had significant scattering, but with values that were an order of magnitude lower (Figure 3).

<u>Neocalanus</u> <u>flemingeri</u> was the overall most abundant zooplankton species found in the MOCNESS tows. A pteropod species, <u>Limacina Helicina</u> was found throughout Prince William Sound, except in Wells Passage. Although these pteropods had low overall densities, their target strengths are higher (because of their hard shells) than target strengths of

copepods (Stanton et al., 1996), so they will more easily contribute to the acoustic backscatter. We predict pteropods to be around 14 dB higher than copepods (see below), while Stanton et al. (1996) has predicted pteropods to be around 19 dB higher than copepods in the Atlantic Ocean. Moreover, the diameters of the pteropod shells varied throughout the Sound, causing more variability in the TS.

MODEL IMPLEMENTATION

In-situ TS measurement of small zooplankton is not typically feasible due to high densities of animals which cause target discriminators to fail in detection of individual echo peaks. Instead, a bent cylinder model was implemented for copepods, while an elastic sphere model was implemented for pteropods (Stanton et al., 1994). Material parameters (R) were assumed to be the same as used on the Georges Bank; 0.058 for copepods, and 0.5 for pteropods.

An alignment algorithm was used to partition the acoustic data into blocks that spatially overlap the same depths sampled by the MOCNESS. Horizontal alignment was more problematic due to the differences in tow point location. For each net in the MOCNESS, densities and species distributions were measured, but at the time of this writing, only a few individual lengths were available to be input to the scattering models. Stage V copepods Neocalanus flemingeri, Neocalanus plumchrus, and Neocalanus crisatus found in the MOCNESS samples had a unimodal length distribution, with a mean of 3.74 mm, and an average width/length ratio of 0.32. Given these data at 420 kHz, the fluid bent cylinder model predicts a TS of -86.2 dB (Figure 4). Catches of adult pteropods had a trimodal diameter distribution, with an overall mean of 1.68 mm. At 420 kHz, the elastic sphere predicts a TS of -72.1 dB (Figure 5). By multiplying σ (arithmetic equivalent of TS) by the catch density, then summing this factor from each species, an expected value of the volume backscatter (Sv) was calculated for each net.

Comparisons of acoustical measurements and MOCNESS samples indicate agreement of depth distributions (Figures 6-12) for cases of high neocalanus catch and low pteropod catch, but matching absolute densities will require more work. Figure 13 shows the comparison for each net. Note that the slope of the comparison is close to unity, however there is an offset of about an order of magnitude. Figure 14 shows a histogram of the ratio of the volume backscatters measured by the 420 kHz and predicted by the MOCNESS, which also indicates about an order of magnitude error.

The accuracy of the density estimates depends on the target strength scaling factor that is applied to the echo square integration, which is a function of the accuracy of the scattering models used, the quality and quantity of the net catch information, and the accuracy of the acoustic calibration, including beam pattern factor.

Comparison error comes from several sources. The animal lengths were available from only a few tows, which doesn't account for geographical variability in animal size. This causes error in the TS prediction. We plan to have the remainder of the animals measured later this year so that more complete TS distributions can be applied. Also, the flowmeter on the MOCNESS is sensitive to fluctuations in ocean currents, so that there will be some variability in the estimated sample volume and therefore the catch density estimates as well.

The comparison error appears to be worse in the deep net catches, labelled by a "2" in figure 13, where fewer animals were caught. This can be explained by thresholding. A flat threshold of -125 dB was used to eliminate noise. At 20 meters, $20\log R=26$ dB, $2\alpha R=4$, so a signal of $-125+26+4 = -95$ dB would be thresholded. At 50 meters, $20\log R=34$ dB, $2\alpha R=10$, so a signal of $-125+34+10 = -81$ dB would be thresholded. This signal thresholding will result in an underestimate in low densities since very low scattering values will be replaced by zeroes.

There is also significant error in the shallower catches, labelled by a "9" in figure 13. In the near future, we will look at the catches of these near-surface nets to determine if there is a species with significant TS that we have not accounted for.

Digital transducer systems are still in the development phase, which can be seen from problems in data acquisition speed. We attempted to ping every .4 seconds, however as the data bus becomes busy, it is difficult for it to accept more data. In this case the next ping will be delayed until the bus is ready for more data. This can also result in an underestimate, as higher densities result in more data to the bus, so ping delays and thus undersampling are more likely in higher densities. This problem is still under investigation.

There are several cases where the acoustics estimates a higher density than the catch. This is a result of not applying every species in the catch to this algorithm. Further work is needed to determine which species should be measured, modeled, and added to the predicted volume backscatter.

Another possible source of underestimation error is the tilt of the organism in situ, since it was not measured in this survey. Tilt of the animals can reduce the overall acoustic backscatter, as the TS models currently assume random orientation. Tilt would result in a smaller surface area as seen by the sonar, and therefore a lower target strength. Copepods may try to orient themselves vertically in the water column to optimize feeding (Peter Wiebe, personal communication). This error can be made worse by the exceptionally calm weather we experienced during the survey, since less ocean turbulence could result in more successful vertical orientation of the animals. The scattering models can be upgraded to include tilt, but an *a priori* knowledge of tilt is still needed.

In future cruises, video plankton recorders can be used to measure tilt as well as classify species, so that the probability density function (PDF) of tilt can be estimated for each species at each depth. Otherwise, a tilt PDF can be estimated which will adjust the acoustic scattering to match the predicted backscatter from the MOCNESS catches.

ACKNOWLEDGEMENTS

We would like to thank the crew of the R/V Alpha Helix for their assistance in operating gear. Geoff Steinhart, Nick Peters, and Loren Tuttle assisted with the acoustic calibration and review of the manuscript. This work is supported by the Exxon Valdez Oil Spill Trustee Council, through grant 96320-N.

FIGURE CAPTIONS

Figure 1. Cruise trackline, R/V Alpha Helix, May 1996.

Figure 2. Echogram of typical zooplankton layer, north of Perry Is, 5/3/96

Figure 3. Relative geographic distribution of zooplankton as measured by 420 kHz acoustics. Darker shades indicate higher density.

Figure 4. Length to TS transformation for bent cylinder model (R=.058), as used for copepods.

Figure 5. Diameter to TS transformation for elastic sphere model (R=.5), as used for pteropods.

Figures 6-12. Typical zooplankton depth distributions, as measured by both 420 kHz (solid line) and MOCNESS (dashed line).

Figure 13. Comparison of predicted Sa (MOCNESS and models) and measured Sa (420 kHz). The numbers indicate net number (depth). The dashed line is a linear fit to the data, which is an order of magnitude lower than the unity (dotted) line.

Figure 14. Histogram of ratio of measured Sv (420 kHz) and predicted Sv (MOCNESS+model). The dashed line indicates an ideal 0 dB shift.

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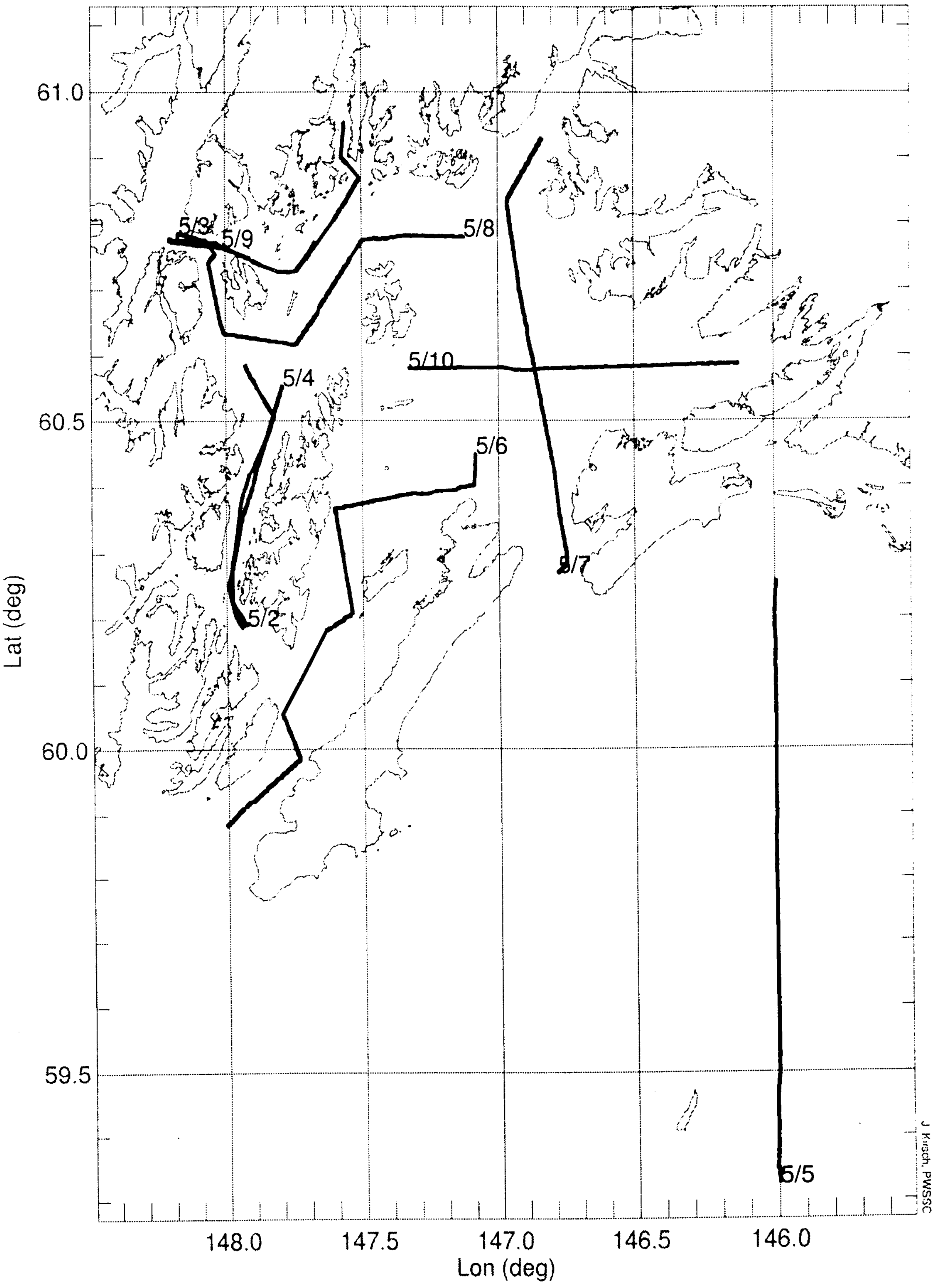
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60.5
60.0
59.5
Lat (deg)
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147.0
146.5
146.0
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5/3
5/9
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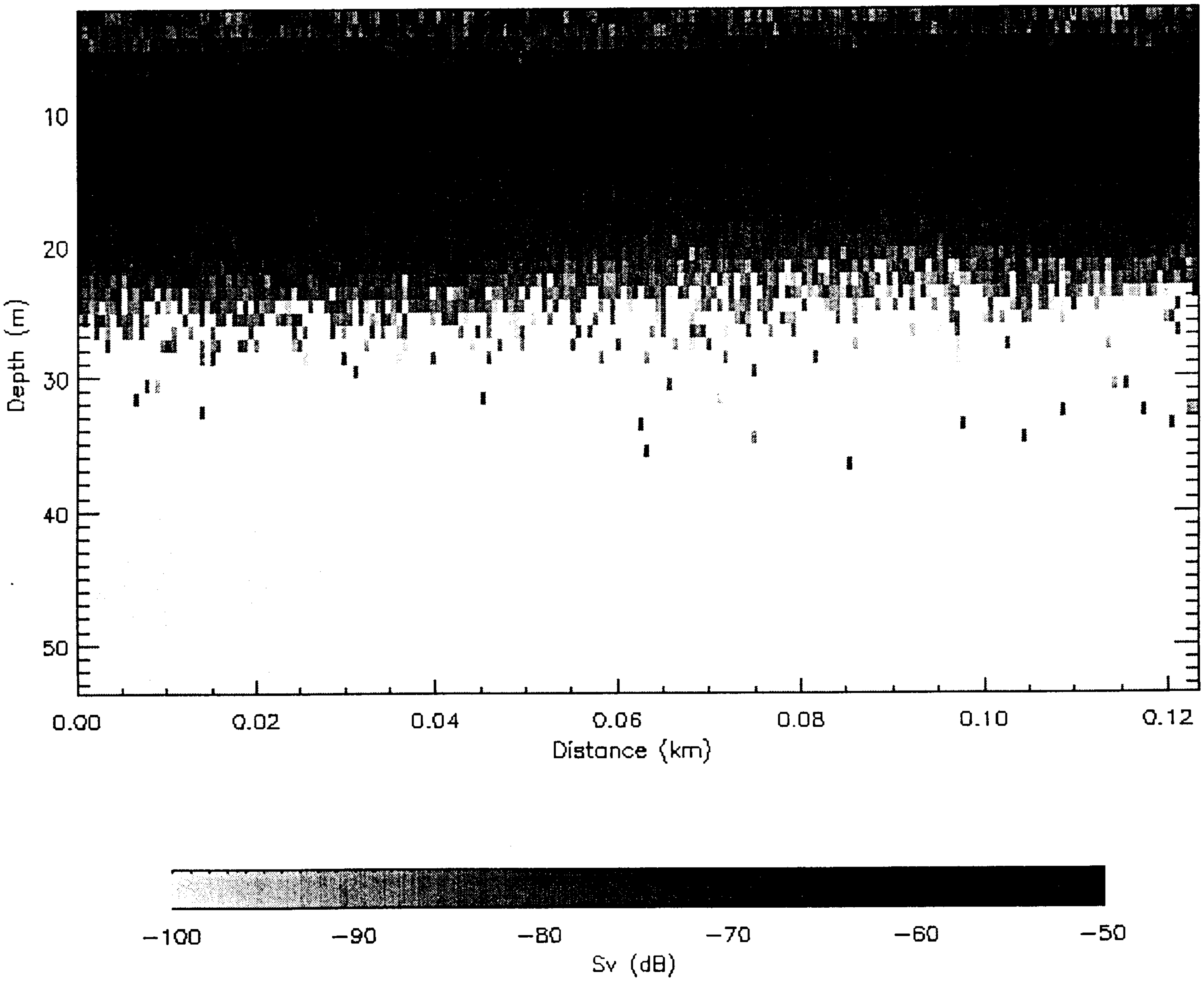
5/7
5/2
5/5
J Kirsch, PWSSC


Depth (m)
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20
30
40
50
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0.02
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0.06
0.08
0.10
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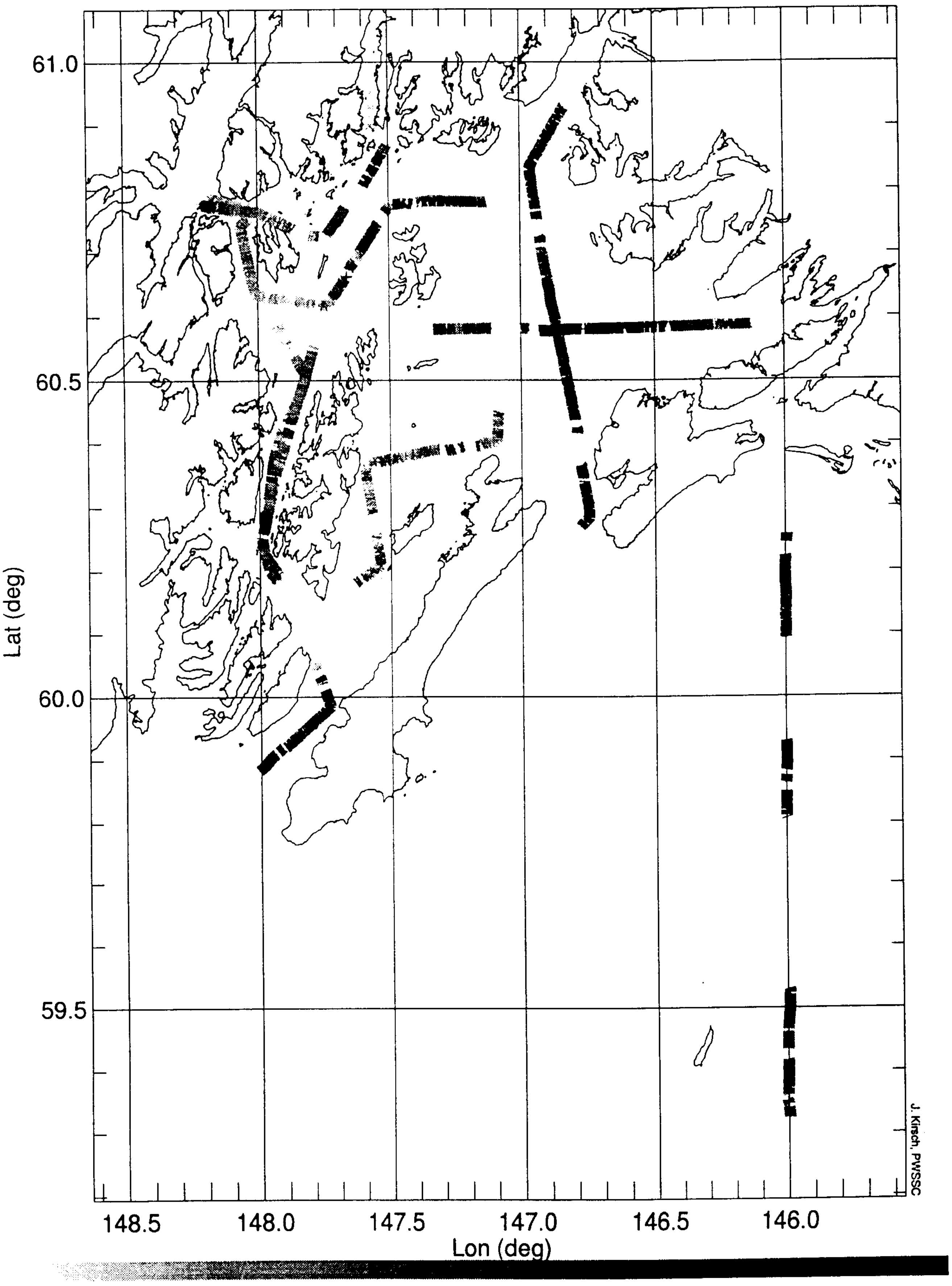
−80
−70
−60
−50
Sv (dB)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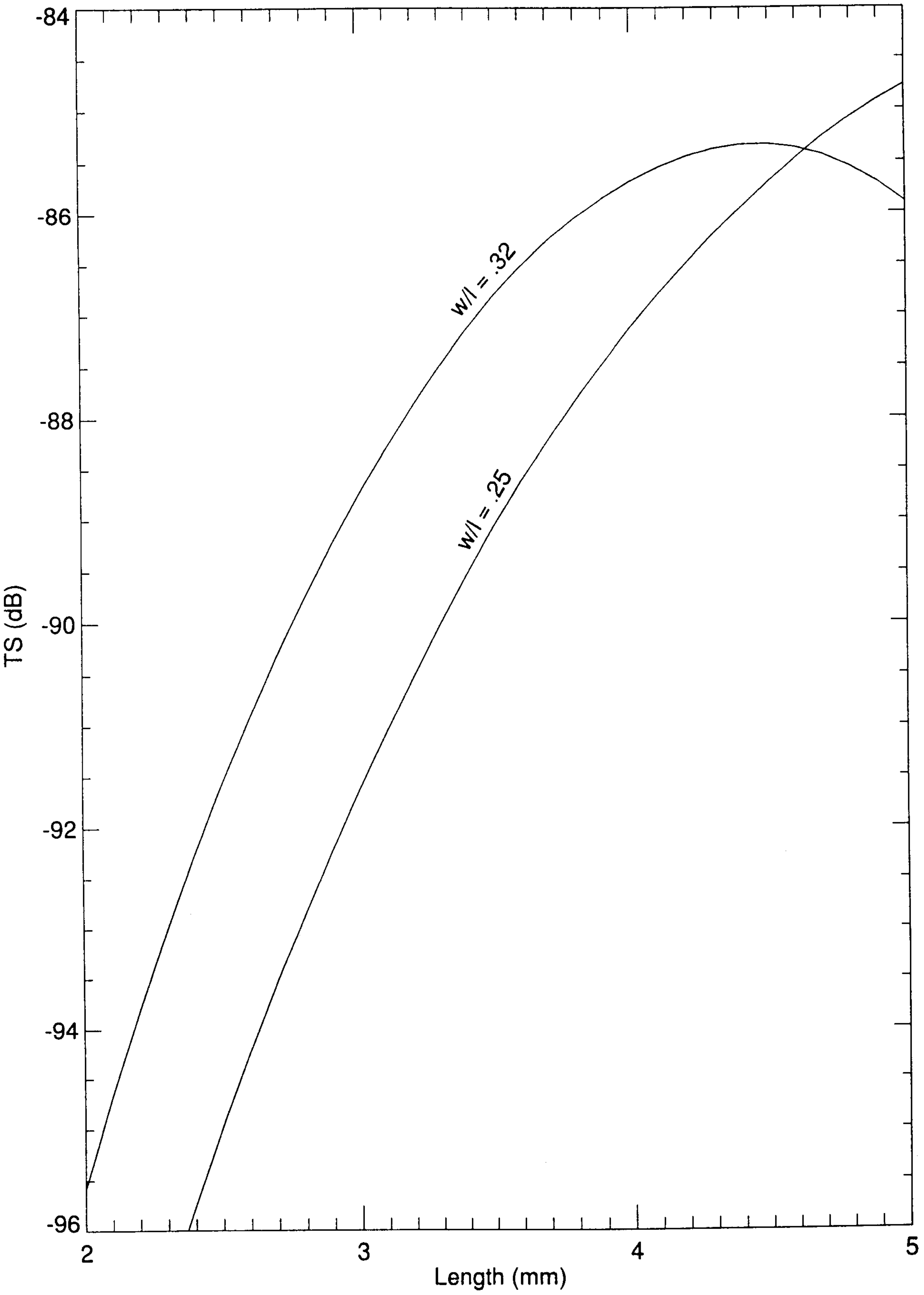
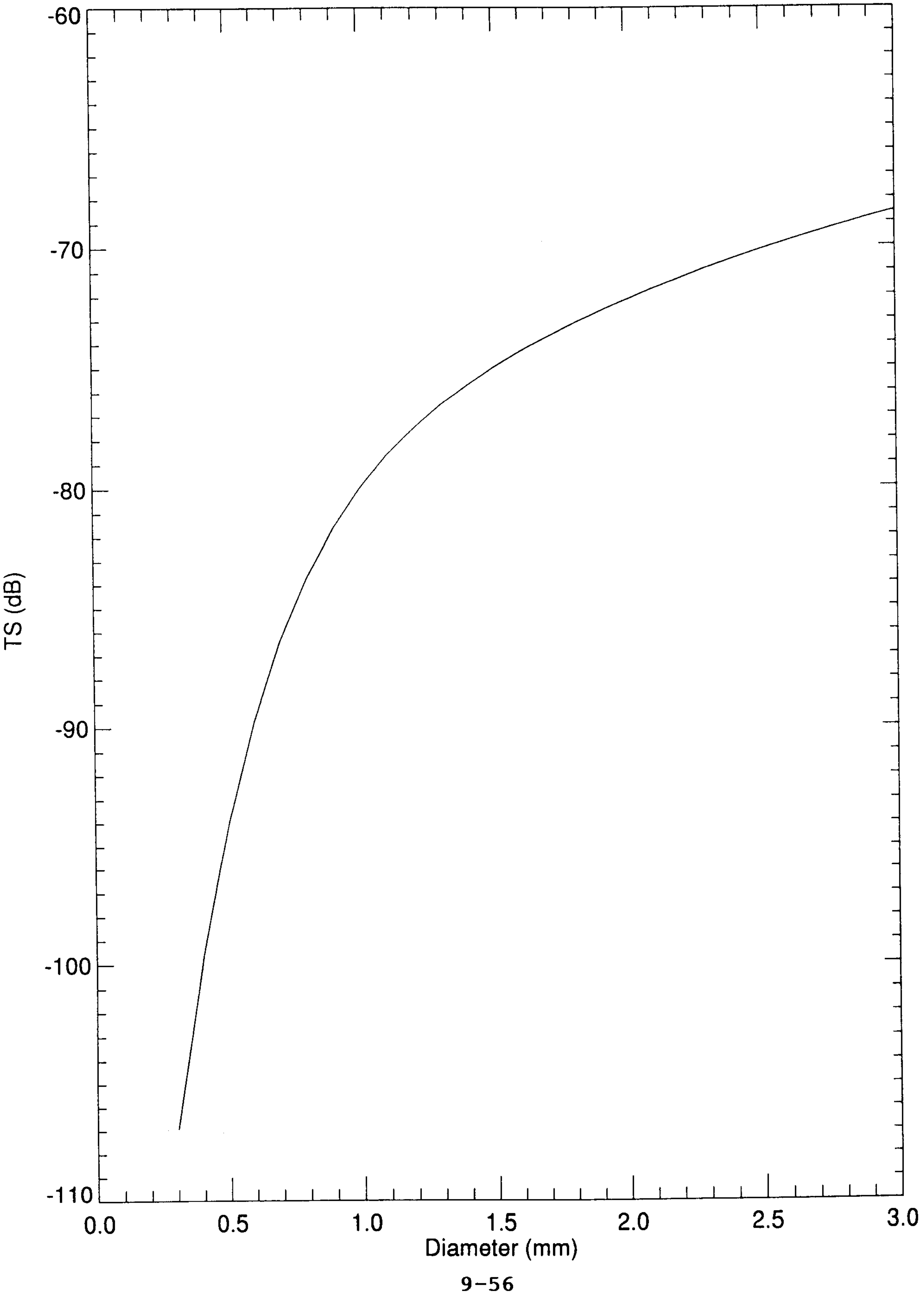
J. Kirsch, PWSSC



-84
-86
-88
-90
-92
-94
-96
TS (dB)
2
3
4
5
Length (mm)
w/l = .32
w/l = .25


-60
-70
-80
-90
-100
-110
TS (dB)
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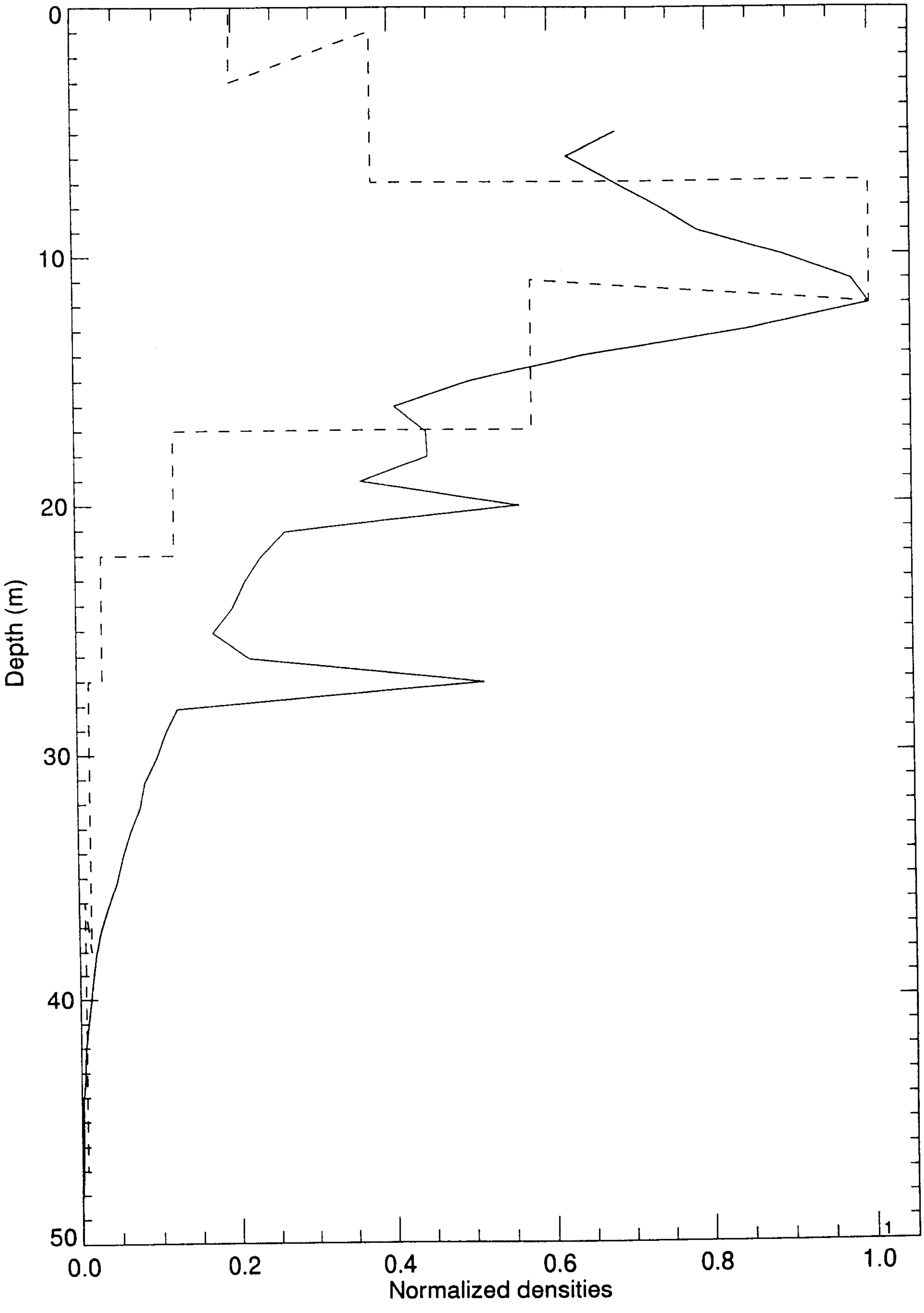
0.5
1.0
1.5
2.0
2.5
3.0
Diameter (mm)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10
20
30
40
50
Depth (m)
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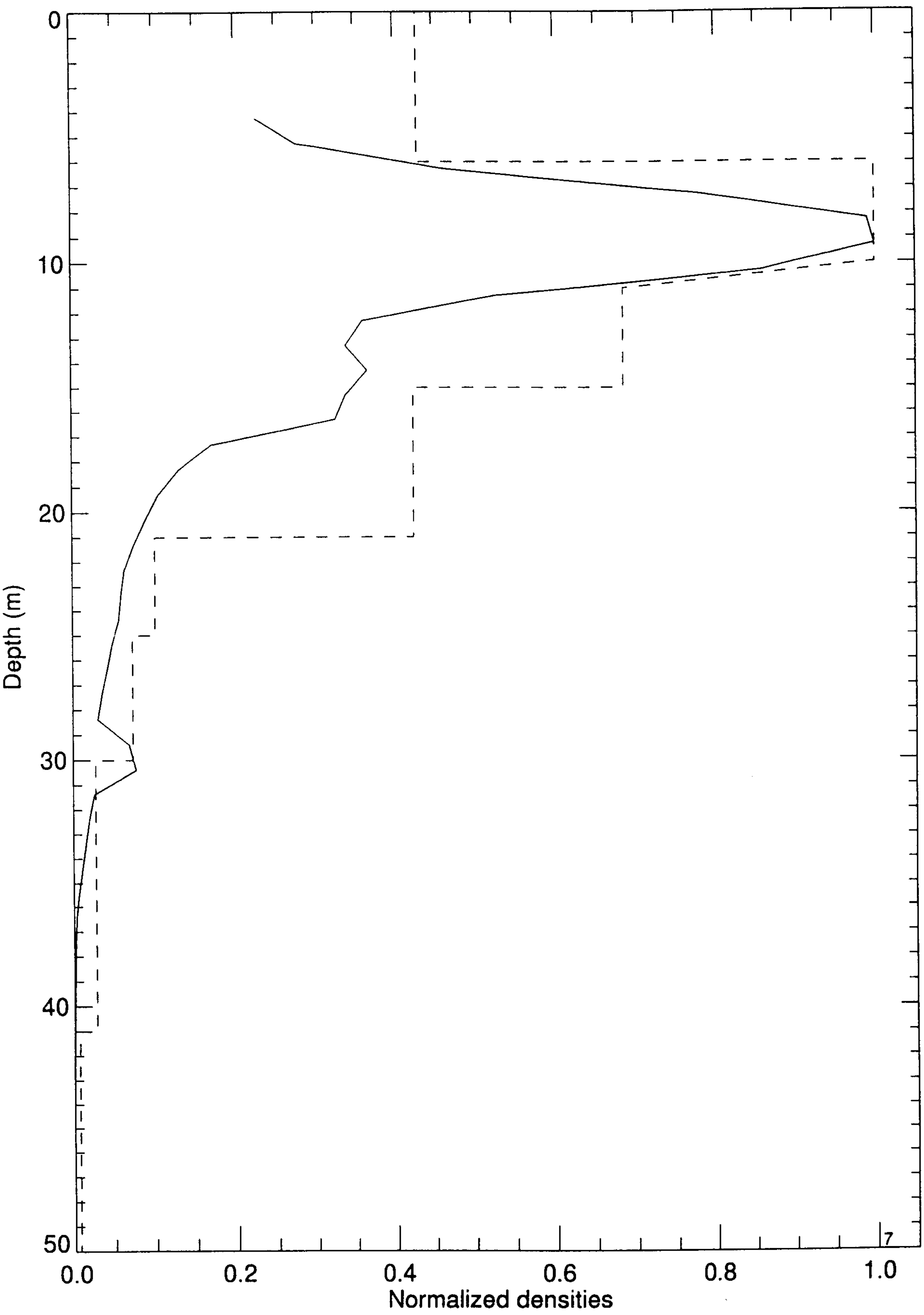
0.6
0.8
1.0
Normalized densities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Normalized densities
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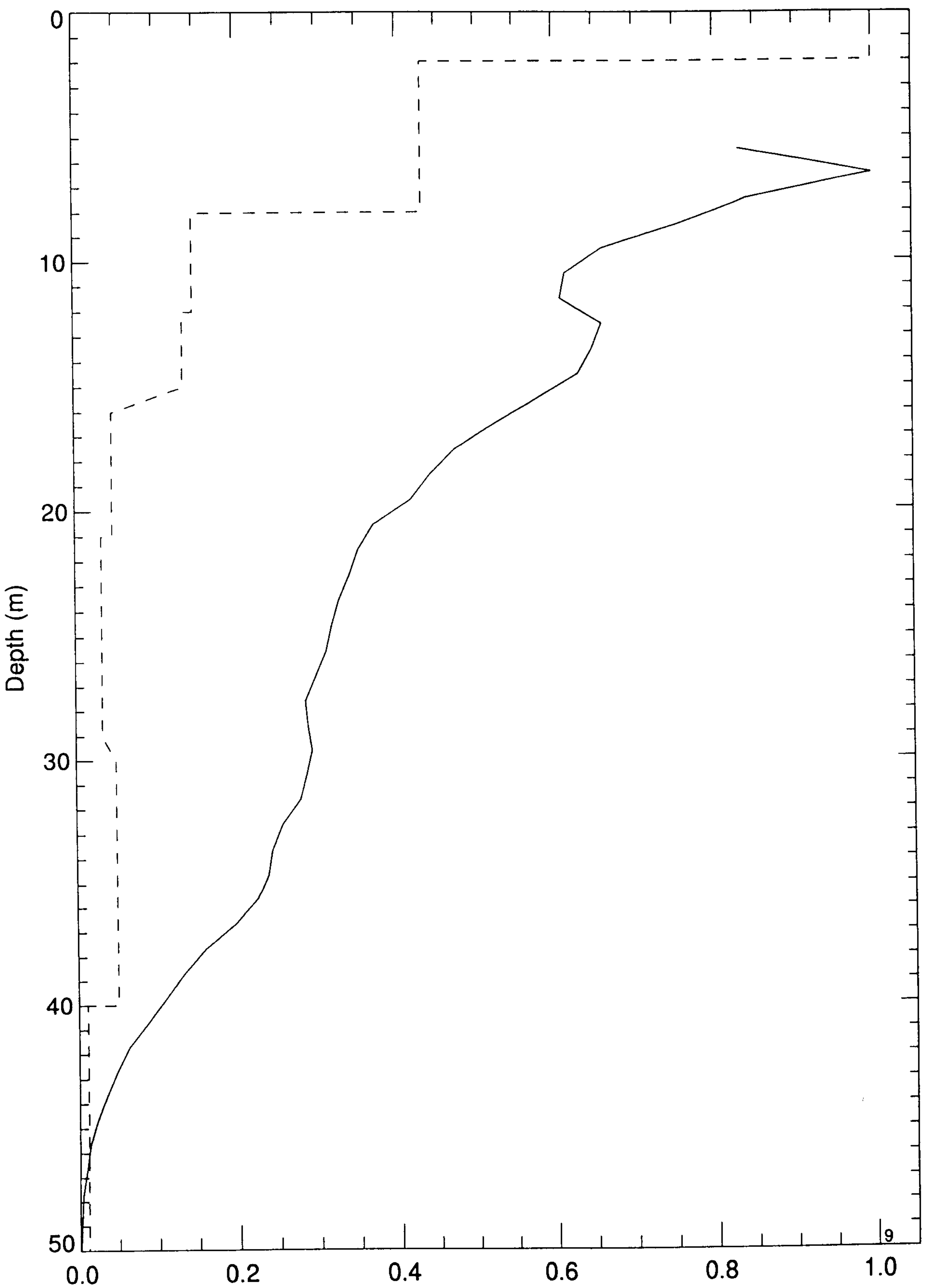
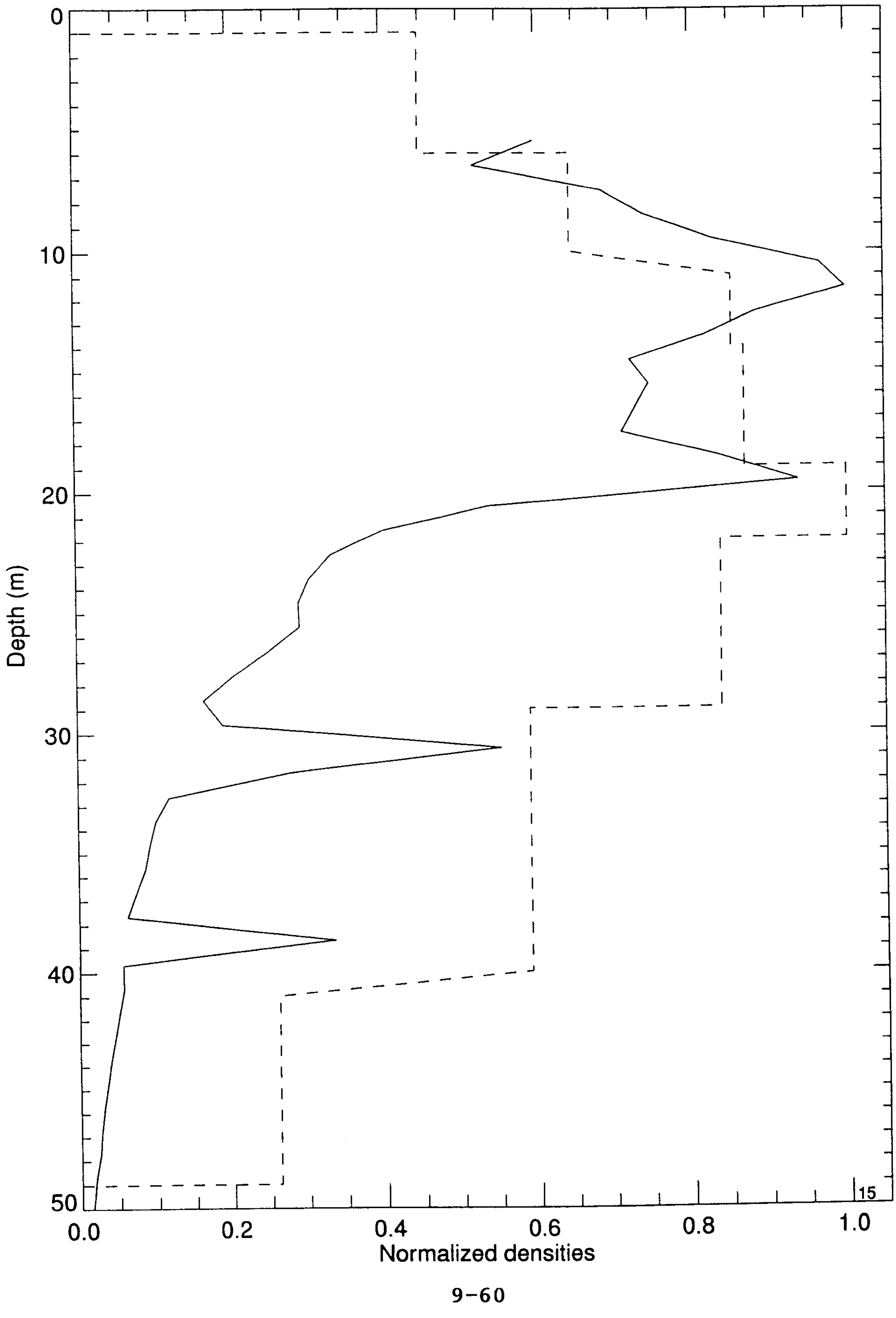
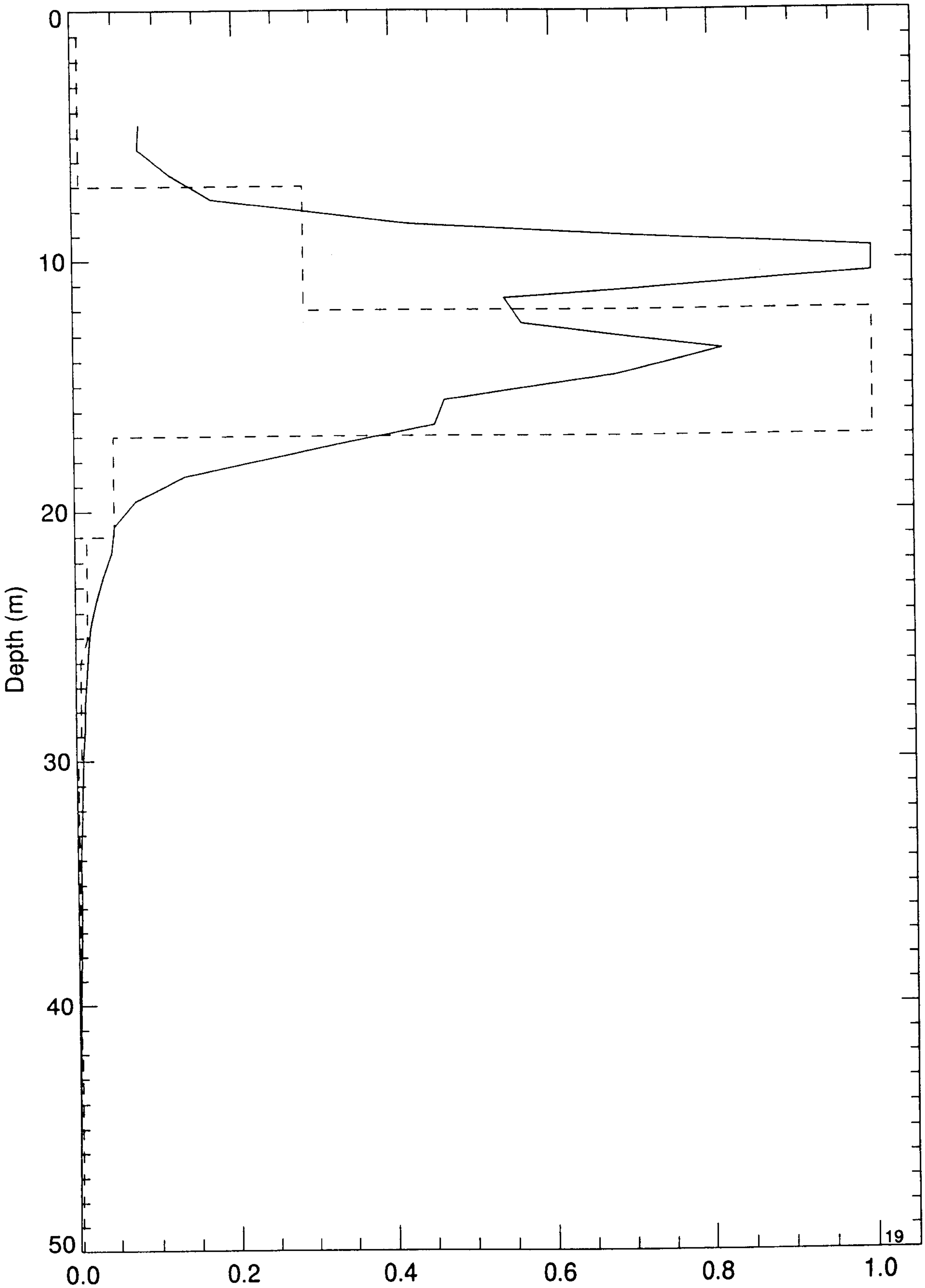


0
10
20
30
40
50
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
Normalized densities
9



0
10
20
30
40
50
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
Normalized densities
15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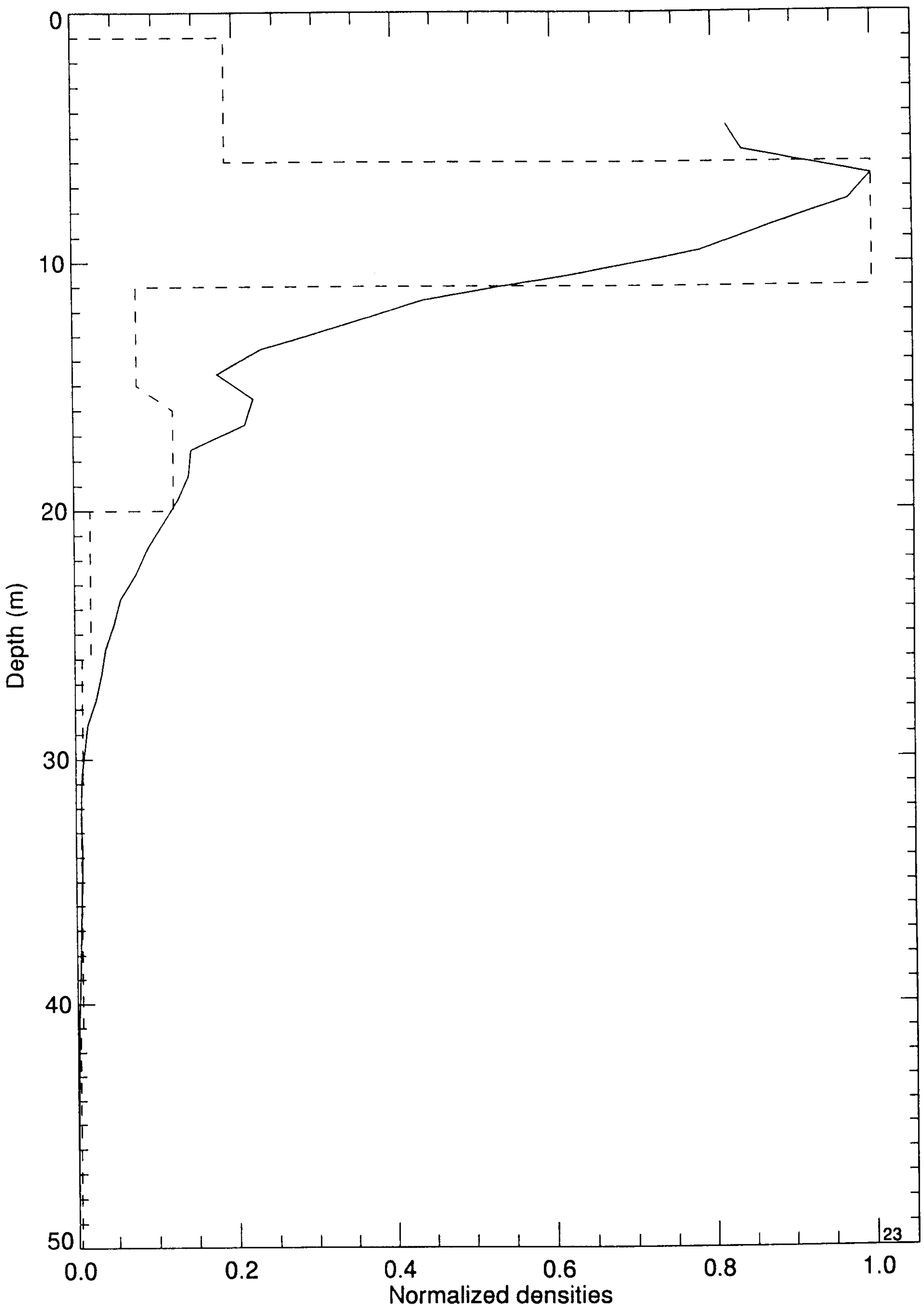
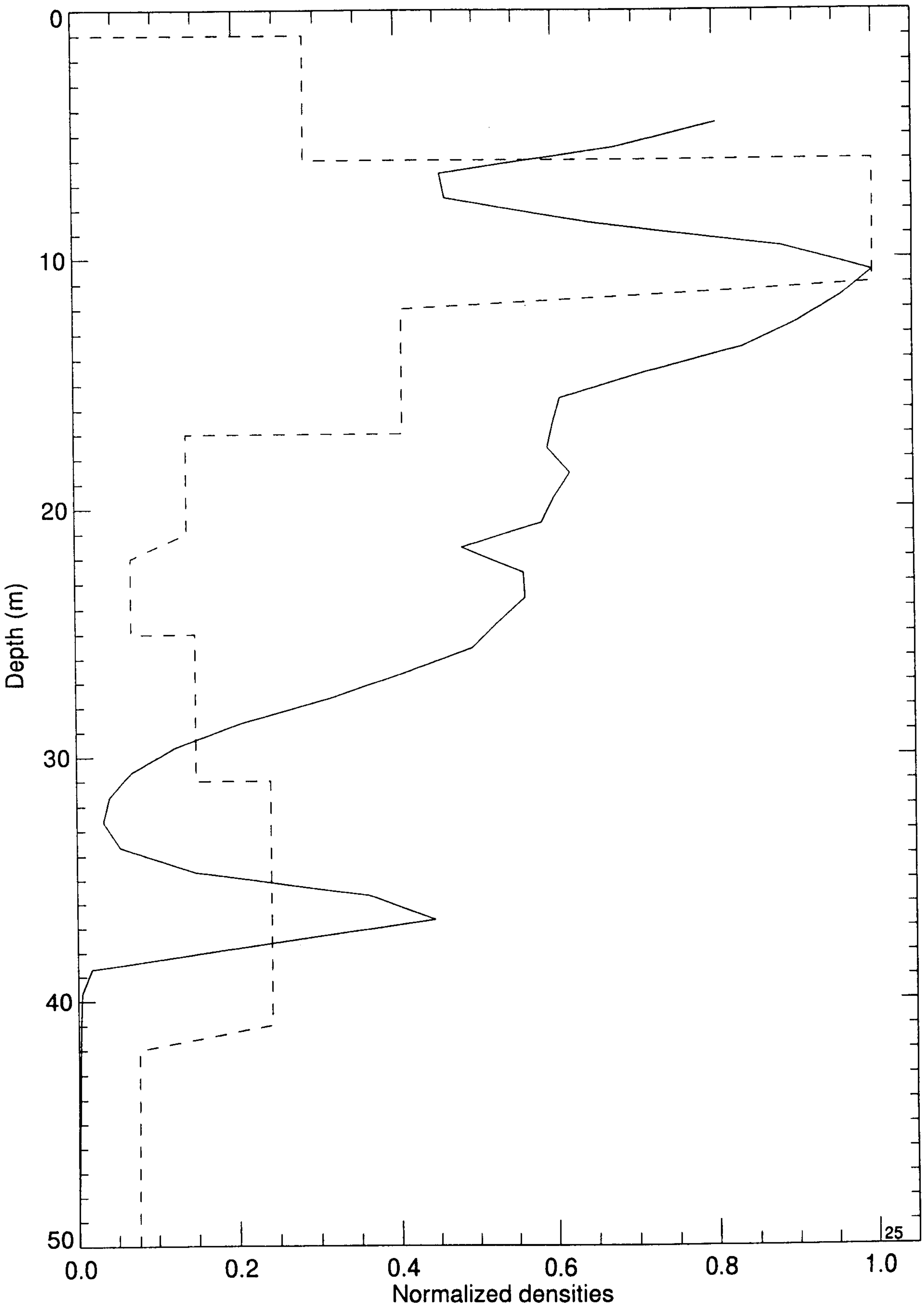
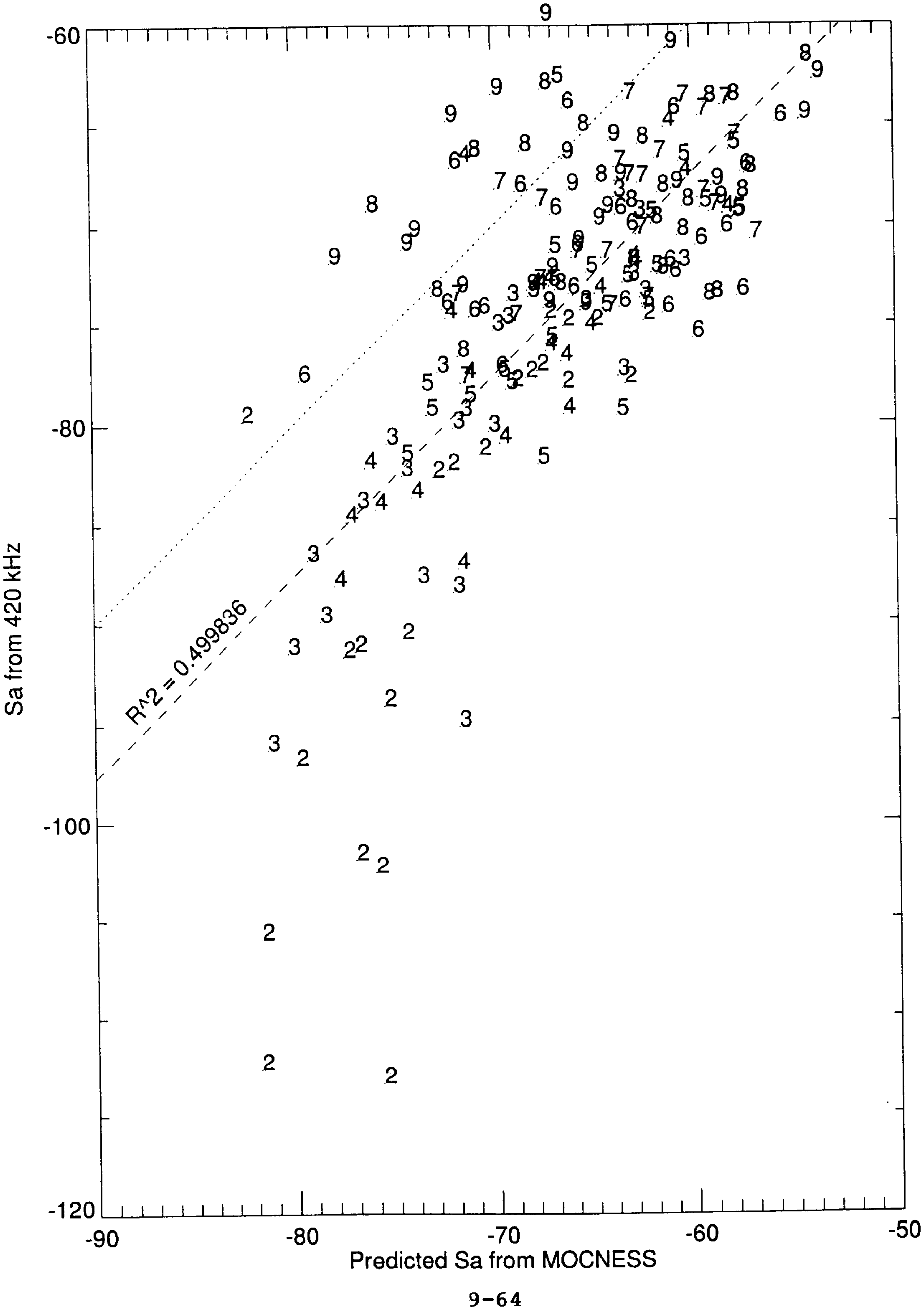
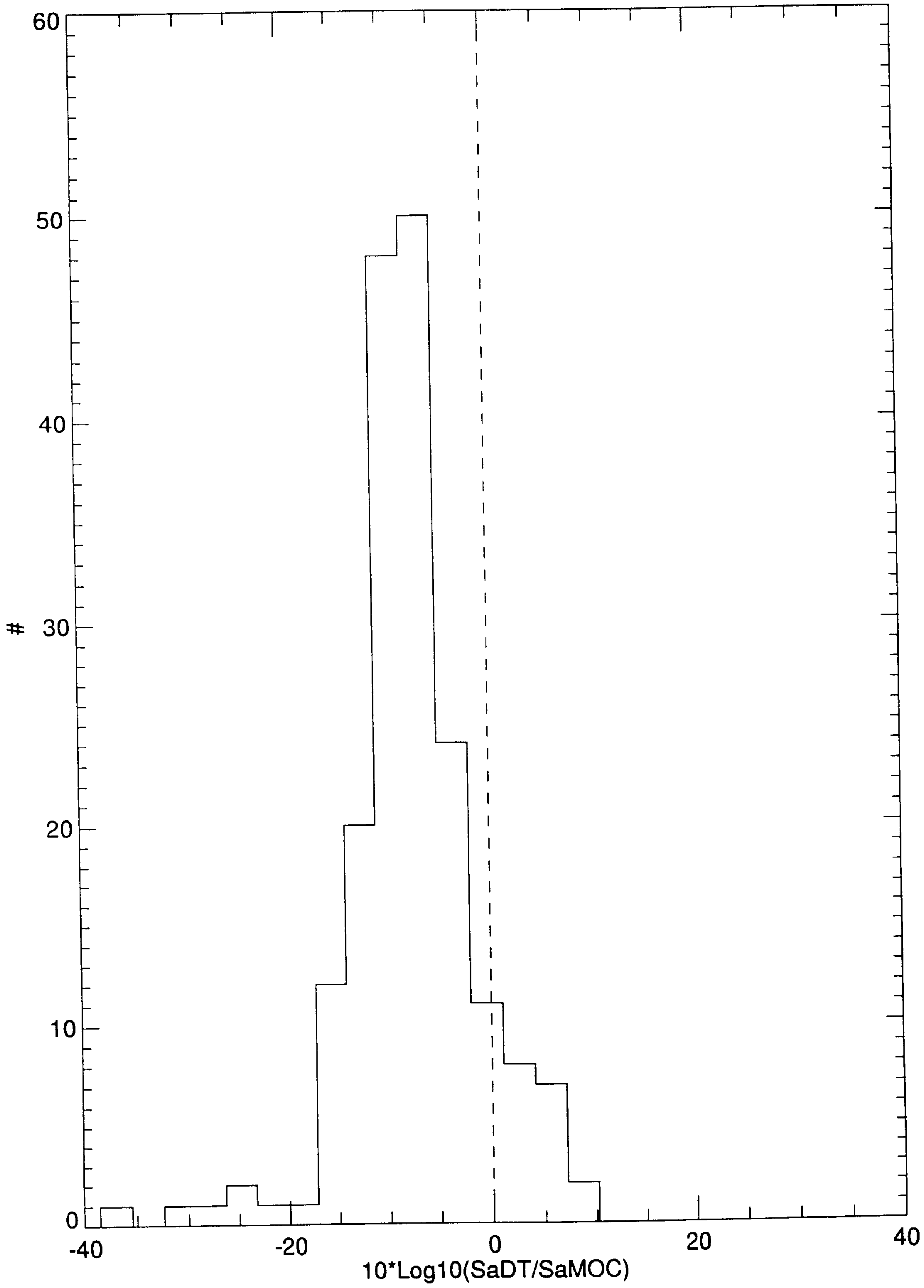
40
50
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
Normalized densities
19


0
10
20
30
40
50
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
Normalized densities
23



0
10
20
30
40
50
Depth (m)
0.0
0.2
0.4
0.6
0.8
1.0
Normalized densities
25


-60
-80
-100
-120
-90
-80
-70
-60
-50
Sa from 420 kHz
Predicted Sa from MOCNESS
R^2 = 0.499836


60
50
40
30
20
10
0
#
-40
-20
0
20
40
10*Log10(SaDT/SaMOC)

CHAPTER 3.

ACOUSTICALLY DETERMINED JUVENILE HERRING DISTRIBUTION IN PRINCE WILLIAM SOUND, FALL 1995

G.L. Thomas, Jay Kirsch, Nicholas Peters

ABSTRACT

A hydroacoustic/purse seine survey was conducted to examine the density and distribution of juvenile herring in Prince William Sound. We found the juvenile herring to be in a nearshore layer at the surface during the night. This layer included other scatters such as juvenile pollock, jelly, plankton and larval fishes, but the herring and pollock combined to represent the majority of the backscatter with the juvenile pollock the contributing the smaller component of the backscatter as separated by using purse seine catches. We show that the spatial distribution of juvenile herring is very contagious with a few locations supporting the majority of the herring population. We also have examined the density of the layer and found that it too is contagious but not directly related to where the bulk of the juvenile herring reside. From these results, we believe that it is possible to conduct broad-scale surveys of juvenile herring in the Sound to support development and verification of the SEA herring overwintering model and allow the management agencies more information on future recruitment events. This capability also makes possible the building of an over-summer mortality model for herring. In 1994, the SEA program

initially avoided this model building effort.

INTRODUCTION

Antidotal information gathered from local fishermen suggest that juvenile herring overwinter in the sheltered nearshore waters of Prince William Sound during the fall to winter months. It has been our observation that the younger year classes (ages 0, 1 and some 2) segregate from adult schools (some age 2 and ages 3+) at this time. Segregation of juvenile herring from adults in nearshore waters has been previously observed in British Columbia (Hourston 1956, 1957, Haegele 1995).

Acoustic-purse seine surveys conducted in falls of 1993 and 1994 to assess the biomass of adult herring provided us the insight to conduct a broad scale survey of juvenile herring throughout the Sound and adjacent waters in the fall of 1995. The fall 1995 survey was conducted as a multi-stage survey. The first stage was a broad scale acoustic survey to establish the areas of concentration of the juvenile herring. This stage consisted of a presence and absence search of nearshore waters for fish, and when fish were located a scientific hydroacoustic system that used GPS information to geo-reference the data was used to map the extent of the concentration and measure density. A second stage of the survey was to deploy a group of boats to areas of mapped fish concentrations to collect biological information and higher resolution information on the density structure of the aggregation. This report discusses the results of stage one of the survey.

METHODS

The broad scale survey consisted of a 10 knot zig-zag search pattern run along the coast of the Sound utilizing the fishing vessels' sonar. All transects started or ended as close to the shoreline that was safe to navigate. The distance offshore of the transects was about 1 km unless the fish concentrations extended further off the shoreline. This was common in areas with shallow shelfs (<50m). Once a concentration of juvenile herring was found, a tow-fin with the 120 kHz pre-amplified, dual-beam transducer was deployed to measure the fish density. Where concentrations were significant, a group of vessel were deployed to conduct intensive net and acoustical sampling. All surveys were conducted at night due to the nocturnal behavior of juvenile herring, who form a semi-discrete band near the surface making them easy to classify, insonify and capture.

The layer of juvenile herring generally ranges in depth from 0m to 20m but sometime to 60m. We assumed that most of the juvenile herring population is contained within this band, which was composed of other species as well as herring. An example of this can be seen on a echogram of a transect run in Sawmill Bay, November 7, 1995 (Figure 1). This figure illustrates the night-time separation of different species throughout the water column. The bottom echo is clearly seen. A layer of large targets just above the bottom is typical of adult and sub-adult pollock that were caught in the area with a mid-water trawl. Also the target strengths for this layer were near -34 dB, a typical value for adult-subadult pollock. The next feature is the pair of dense schools. Due to the discreetness of the school density, the depth (around 30m) and shape, this school was classified as adult herring based upon extensive acoustic-purse seine surveys in this region between fall 1993 and 1994. The surface layer which is much more diffuse, was found to consists of multiple species (juvenile herring and pollock, larval fishes, jelly, plankton and some juvenile salmon), but dominated by juvenile herring (Figure 2a). The purse seine catches were used to determine the size and relative abundance of species in this surface layer.

The lengths were used to estimate the target strength distribution of expected scatters and compared to the in-situ measurements. In-situ target strengths were used a supplemental information because in high densities, the target discriminator either fails or combined nearby fish and overestimates TS, a problem we term "target coincidence". Three seine sets for the Sawmill Bay caught a mix of juvenile herring (mean length = 94 mm), juvenile pollock (mean length = 104 mm), jellyfish, sculpin (mean length = 36 mm), and other miscellaneous fish. Thorne (1983) empirically derived the following equation relating TS to weight in dB per kilogram as a function of length.

$$TS_w = -5.98 * Log_{10}(l_{mm}) - 18.234 \qquad (\frac{dB}{Kg})$$

Target strengths of jellyfish have gone unmeasured during our surveys, so in summer 1996 we conducted an experiment where we measured *Cyanea* jellyfish with a 120 kHz transducer. We found the strongest return to be -60 dB. During the fall herring survey, however, these jellyfish are in an earlier life stage and are therefore smaller, and there are also other types of jellyfish in the water column in the fall which have less mass (and therefore a lower TS) to them. Therefore, -60 dB can be considered a maximum worst-case scenario for jellyfish target strength.

The calculated TS values from the net catch length data from target strength models based give herring; -49.7 dB, pollock; -45.6 dB (from Traynor 1979), jellyfish; -60 dB (field measurements) and sculpin; -56 dB (field measurements). Multiplying the relative catch densities by the modeled target strengths results in percentages of acoustic backscatter for each species present in the catch at the location of interest, as calculated by the following equation,

$$\%\ acoustic\ backscatter_1 = \frac{r_1 \sigma_1}{(r_1 \sigma_1 + r_2 \sigma_2 + \ldots + r_n \sigma_n)}$$

where r is the percentage of each species in the catch, and s is the arithmetic equivalent of the target strength. Figure 2a shows the purse seine catch percentages for Sawmill Bay, while Figure 2b shows the net catch percentages transformed into their respective acoustic backscatter. Note that the expected backscatter increased substantially for the juvenile herring. Upon inspection of the areas where purse seining conducted, Sawmill Bay was a worst case scenario. Figure 3 shows the juvenile herring represented 94% and 93% of the total net catch and total expected backscatter from the surface layer for entire survey. Biomass density is calculated by dividing the single species backscatter by the target strength s/w.

$$B_1 = \left(\frac{v^2}{k}\right)\left(\frac{r_1 \sigma_1}{(r_1 \sigma_1 + r_2 \sigma_2 + \ldots + r_n \sigma_n)}\right)\left(\frac{w}{\sigma}\right)_1$$

RESULTS AND DISCUSSION

The broad scale survey covered the many parts of the sound and adjacent waters of Port Bainbridge to Ressurection Bay (not shown). The areas where fish concentrations were sufficient to warrant slowing the vessel to sample with the scientific acoustic system are shown in Figure 4. The areas that were intensively surveyed, but not reported here, are shown in Figure 5. Figures 6 are juvenile densities for the top 50m, again for the broad. Figures 7 are biomass values for the top 50 m, calculated by multiplying the densities by the survey's surface area.

CONCLUSION

The depth of 50m was chosen as it predominately contained only the band of mixed targets seen at night, and so can be used as a relative comparison of the juvenile herring densities between bays. The net catch data used to extract the acoustic contributions of the different species must be closely associated in both time and space to the acoustically measured layer. This is to ensure an accurate species break down, and reduces the errors associated with a non homogeneous strata.

FIGURE CAPTIONS

Fig 1. Echogram from Sawmill Bay, showing both adult and juvenile herring

Fig 2. Species composition by count and by acoustic backscatter, Sawmill Bay.

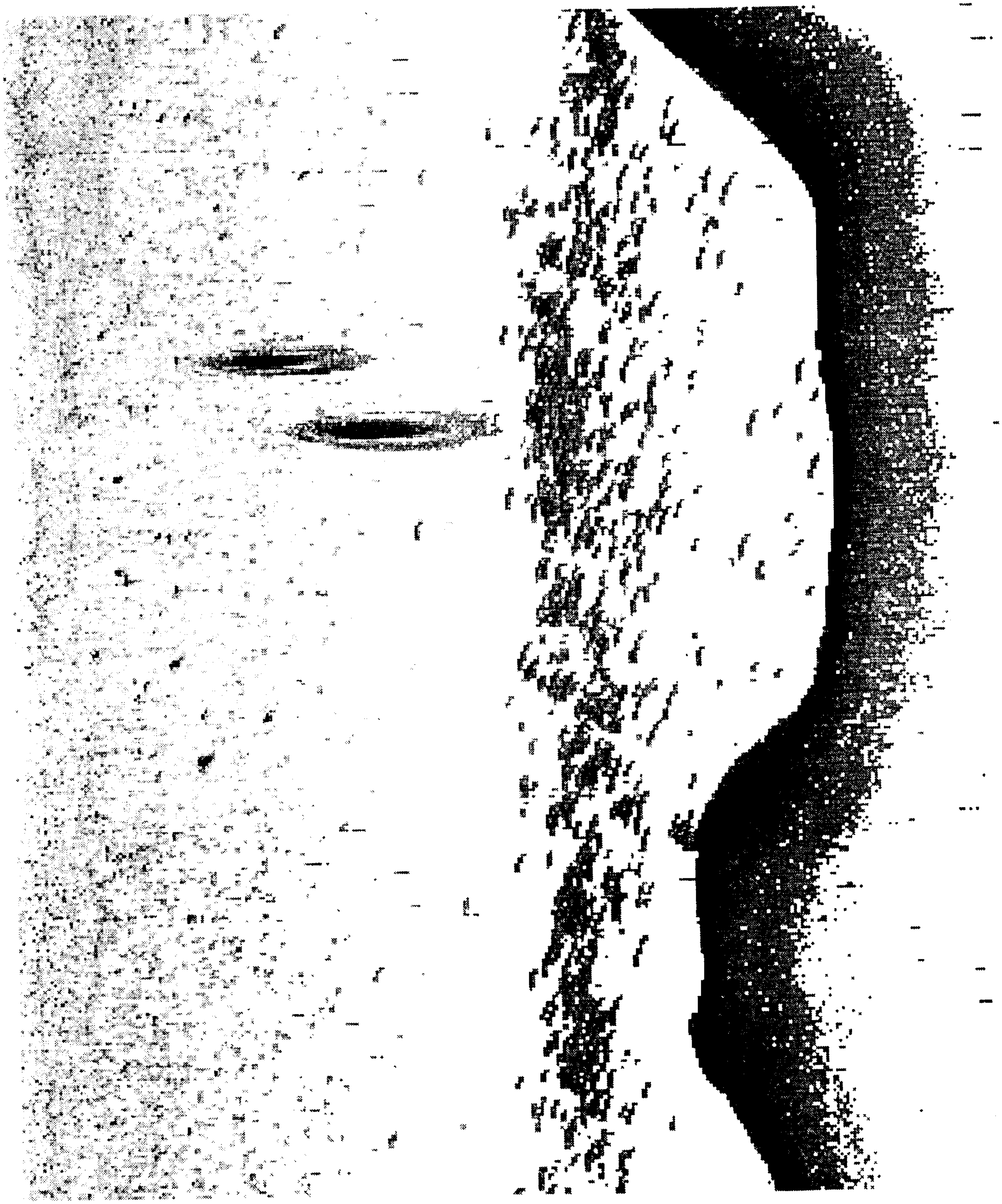
Fig 3. Species composition by count and by acoustic backscatter, all surveys.

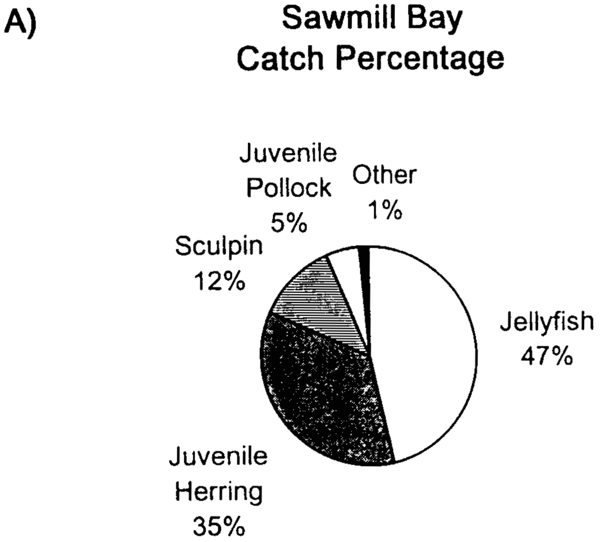
Fig 4. Area covered by broadscale (reconnaissance) survey.

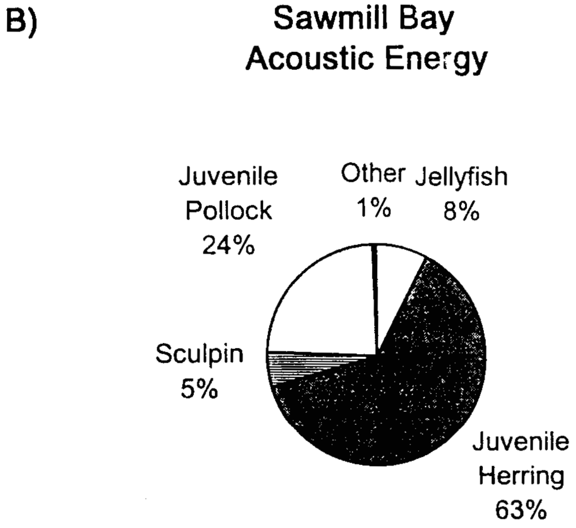
Fig 5. Areas covered by the intensive acoustic survey.

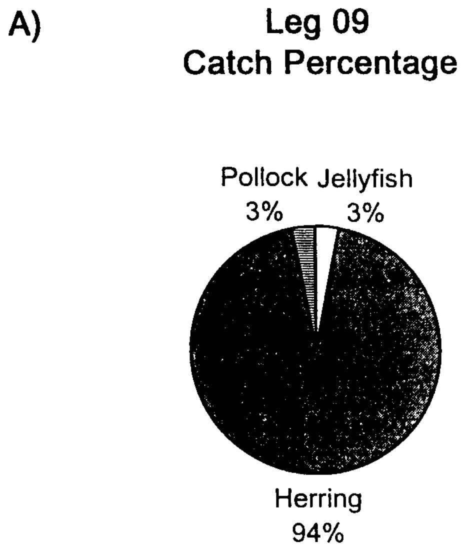
Fig 6. Densities for the top 50m for areas in the broad scale survey.

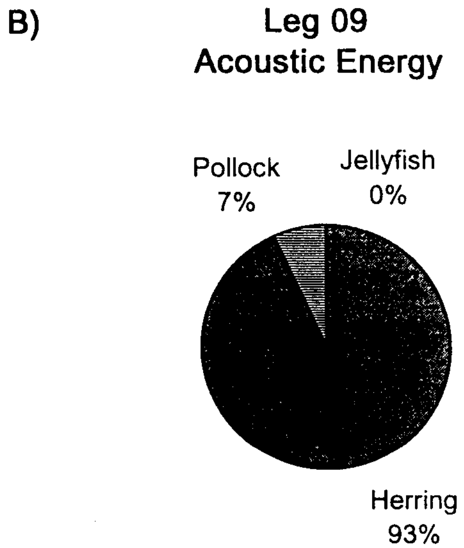
Fig 7. Biomass for the top 50m for areas in the broad scale survey.

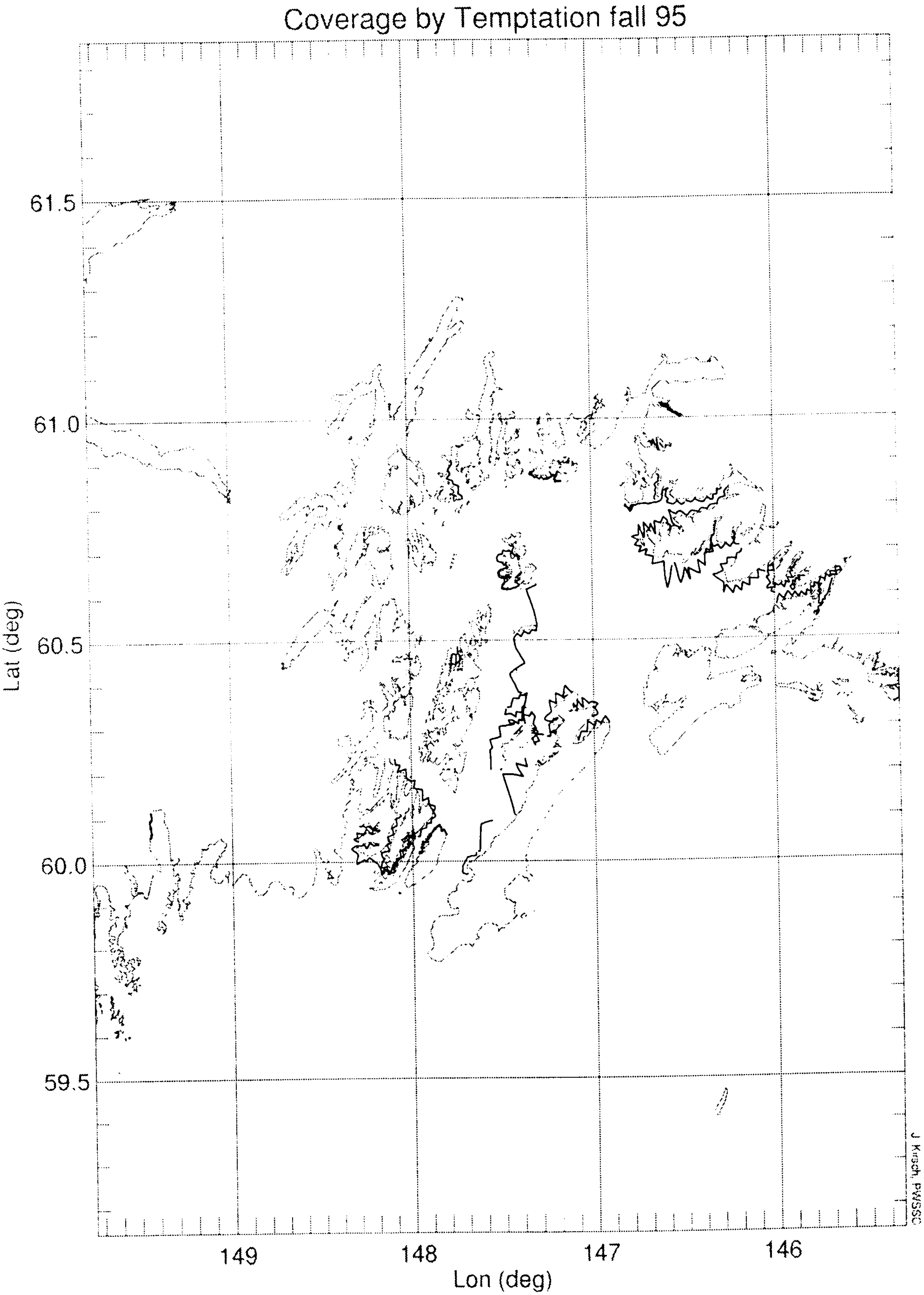


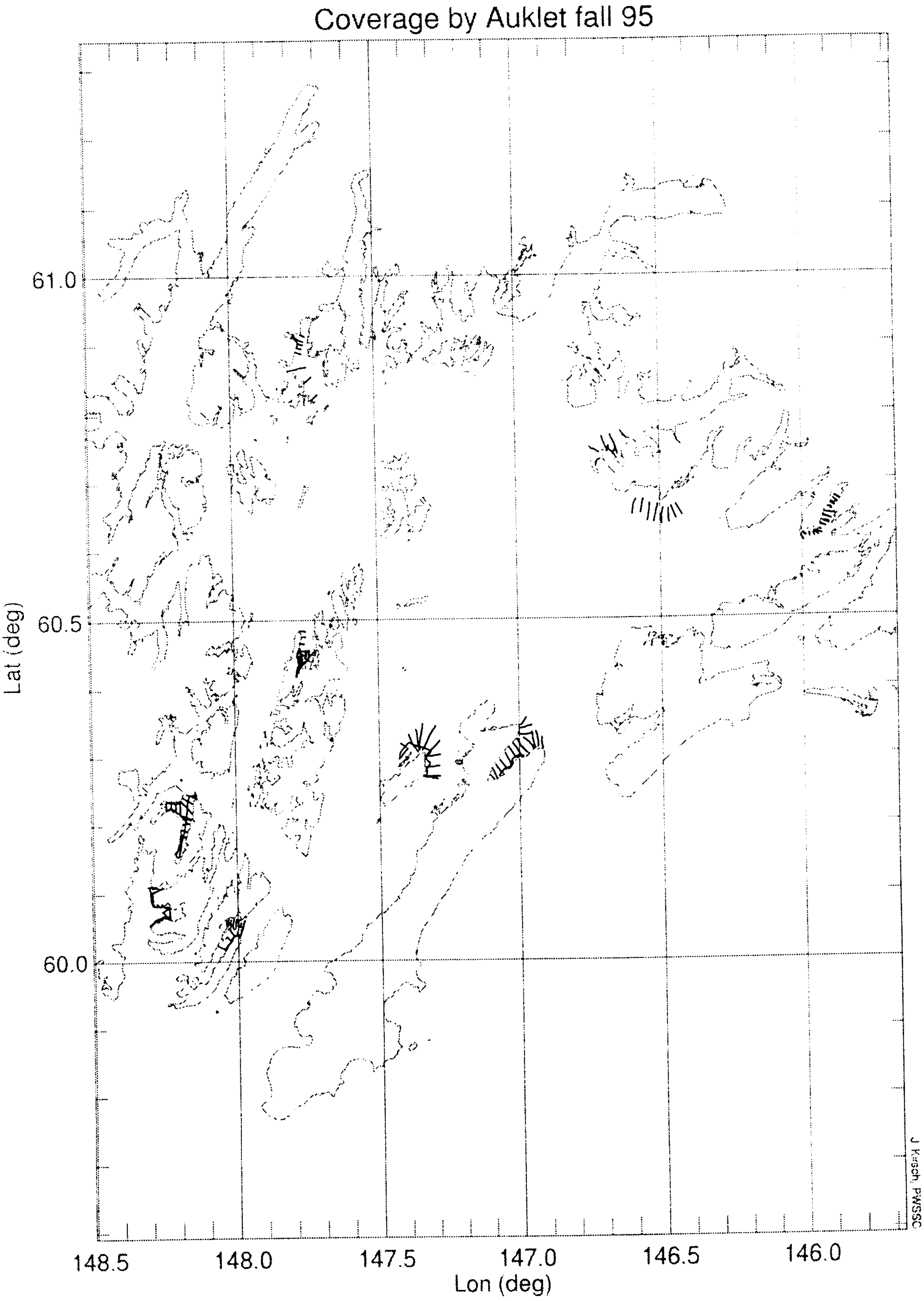

A)
Sawmill Bay
Catch Percentage
Juvenile Pollock 5%
Other 1%
Sculpin 12%
Jellyfish 47%
Juvenile Herring 35%


B)
Sawmill Bay
Acoustic Energy
Juvenile Pollock 24%
Other 1%
Jellyfish 8%
Sculpin 5%
Juvenile Herring 63%

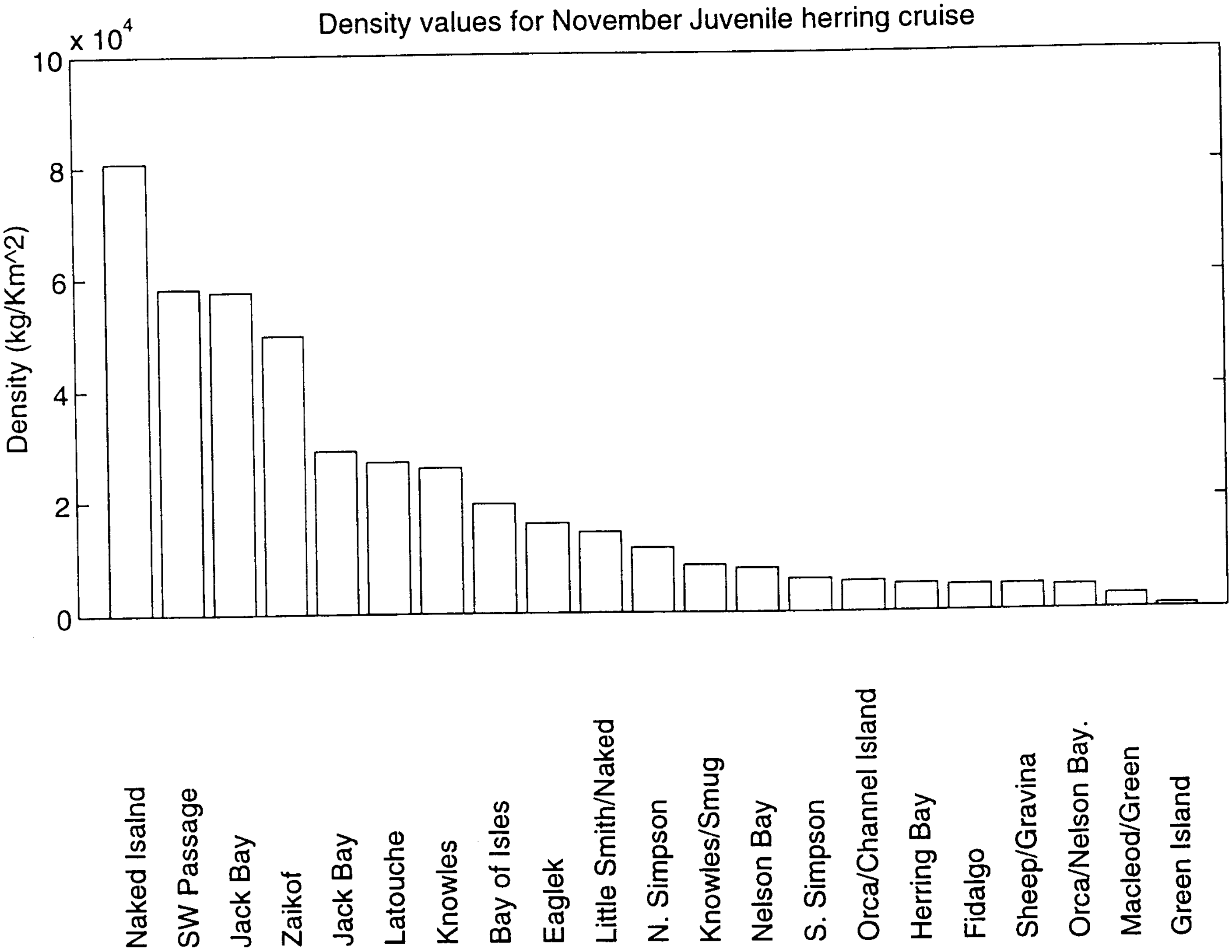

A)
Leg 09
Catch Percentage
Pollock
3%
Jellyfish
3%
Herring
94%

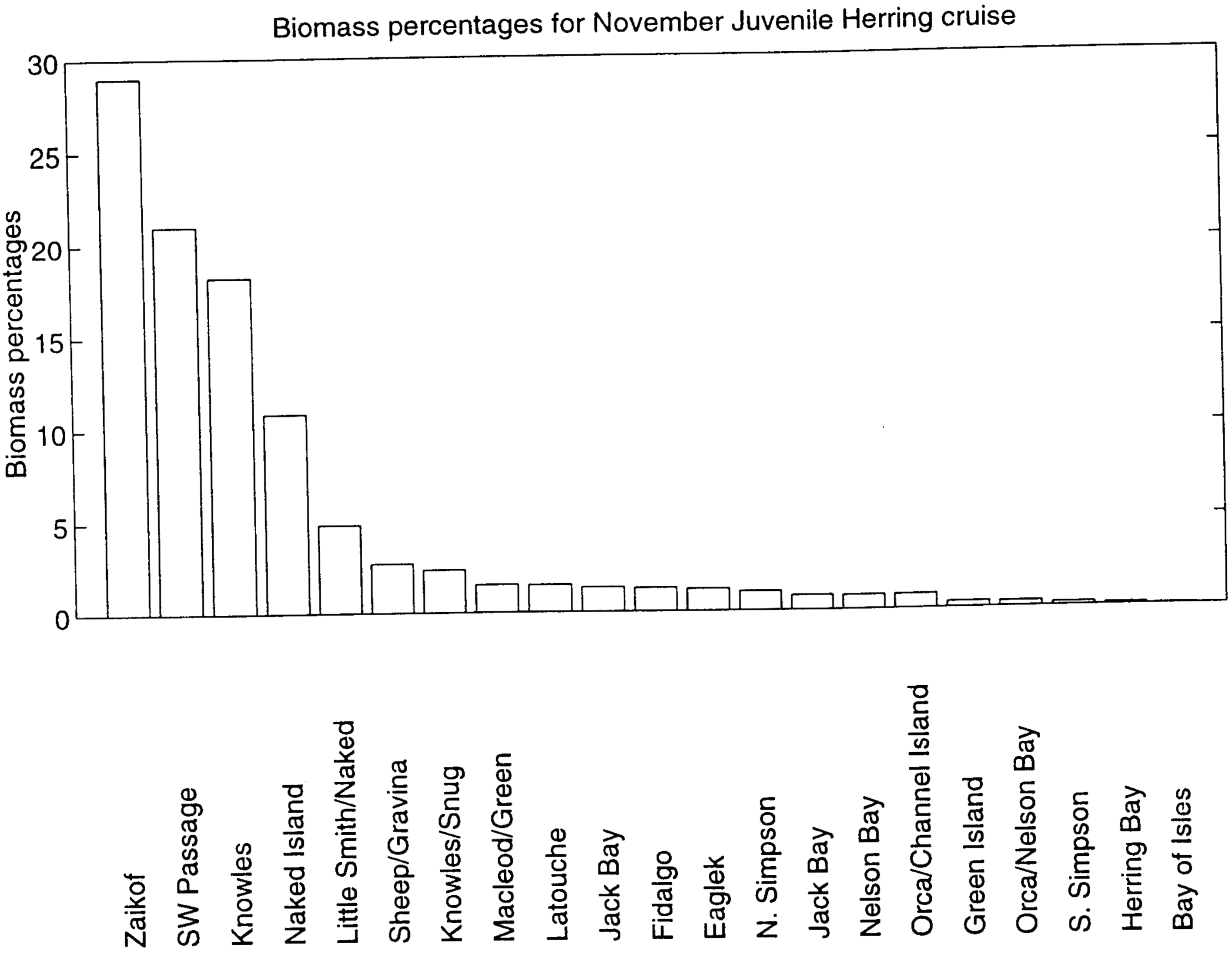

B)
Leg 09
Acoustic Energy
Pollock
7%
Jellyfish
0%
Herring
93%


Coverage by Temptation fall 95



Coverage by Auklet fall 95


Density values for November Juvenile herring cruise
x 10^4
10
8
6
4
2
0
Density (kg/Km^2)
Naked Isalnd
SW Passage
Jack Bay
Zaikof
Jack Bay
Latouche
Knowles
Bay of Isles
Eaglek
Little Smith/Naked
N. Simpson
Knowles/Smug
Nelson Bay
S. Simpson
Orca/Channel Island
Herring Bay
Fidalgo
Sheep/Gravina
Orca/Nelson Bay.
Macleod/Green
Green Island


Biomass percentages for November Juvenile Herring cruise
Biomass percentages
30
25
20
15
10
5
0
Zaikof
SW Passage
Knowles
Naked Island
Little Smith/Naked
Sheep/Gravina
Knowles/Snug
Macleod/Green
Latouche
Jack Bay
Fidalgo
Eaglek
N. Simpson
Jack Bay
Nelson Bay
Orca/Channel Island
Green Island
Orca/Nelson Bay
S. Simpson
Herring Bay
Bay of Isles