Chapter 9

Plankton and Nekton Acoustics

Exxon Valdez Oil Spill
Restoration Project Annual Report
Nekton-Plankton Acoustics Project 97320N

Nekton-Plankton Acoustics
Restoration Project 97320N
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.

G.L. Thomas P.I., Jay Kirsch, P.L.
Geoffrey B. Steinhart and Nicholas Peters

Prince William Sound Science Center
P.O. Box 705
Cordova, AK 99574
Phone: (907)424-5800
Fax: (907)424-5820
e-mail: loon@grizzly.pwssc.gen.ak.us
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Nekton-Plankton Acoustics (SEAFISH)
Restoration Project 97320N
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 fourth annual report for the Nekton-Plankton Acoustic project. Six technical reports and seven abstracts have been published to date, including chpater 2 of this report, while the remaining chapters in this report are being prepared for submission to journals. 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 fifth year is in place and preliminary budgets have been projected through FY00 (six 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 four years, the primary contribution of the Nekton-Plankton Acoustics project was to develop accurate estimation procedures for animal abundance and distribution information. These data were 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 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 *(Clupea pallasi)*, and pollock populations. The completed products are the stock assessments of adult pollock *(Theragra chalcogramma)*, biomass in Feb-Mar 1995 and 1997 (37 and 38 thousand metric tonnes), and adult herring biomass in Sep 1993, Oct-Nov 1994, April 1995, Oct-Nov 1995, Mar-April 1996, April 1997 and April 1998 (20, 13, 13, 24, 23, 32, 24 thousand tonnes, respectively).

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

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1997 ANNUAL REPORT

Sound Ecosystem Assessment (SEA), Nekton-Plankton Acoustics

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

EXECUTIVE SUMMARY

The Nekton-Plankton Acoustics Project (97320-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.

SEA 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 agency, university, public and commercial interests, and (4) remote sensing with acoustical and optical technologies. We used the existing knowledge and skills of commercial fishers in the design and implementation of surveys. Salmon hatcheries in the region provided 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 five chapters: (1) distribution and abundance of walleye pollock in western Prince William Sound, (2) Co-occurring patches of walleye pollock and zooplankton distribution in Prince William Sound, (3) preliminary herring and rockfish

distribution, (4) data fusion for zooplankton assessment, and (5) juvenile herring. Predator and prey acoustic assessments are major components of the pink salmon investigations and annual 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 Prince William Sound (PWS) since 1994. We found that during the spring and summer, pollock abundance in the northwest PWS increased, while pollock density decreased in southwest passages. We believe that this increase in pollock may have been influenced by the timing and magnitude of the spring zooplankton bloom, one of the primary prey items of pollock in the Sound. In 1994, a year with a relatively late, and small, bloom of Neocalanus spp., pollock were more abundant near Esther Island than during any other year we sampled. We believe this observation supports the Prey-Switching hypothesis: in the absence of abundant plankton, pollock switch to other prey items, including salmon fry.

The Sound Ecosystem Assessment (SEA) program is a multi-disciplinary effort to acquire an ecosystem-level understanding of Prince William Sound (PWS), Alaska. A primary SEA hypothesis is that adult walleye pollock (Theragra chalcogramma) switch from their primary food source, fish, to macro-zooplankton when plankton densities are high. We examined this hypothesis by making acoustic observations of fish and zooplankton during the spring of 1995. We found patches of plankton 50 m to 5 km long in the top 50 m of water. Net tows showed that these patches were over 90% calanoid copepods. Walleye pollock abundance was positively correlated with zooplankton abundance (r2=0.26). Furthermore, copepods dominated the diet of pollock at this time. These results showed that walleye pollock were feeding on, and were attracted to macro-zooplankton patches in PWS. Environmental conditions that result in low macro-zooplankton densities, or prohibit the formation of dense plankton patches, could reduce feeding opportunities for pollock. When macro-zooplankton are not abundant, adult pollock may switch their diet to include more juvenile fish, which could reduce the survival of many important fish species.

Other Predators:

We used acoustics to measure abundance and distribution of many fish species in nearshore environments in western Prince William Sound (PWS) in 1994. We found that both pelagic rockfish (Sebastes spp.) and Pacific herring (Clupea pallasi) were present in many of the areas we surveyed. In addition, aggregations of these predacious fish were easily identifiable in the acoustic data as tall loosely aggregated targets above peaks and slopes (rockfish) an as dense school or balls in open water (herring). Since both rockfish and herring are predators of pink salmon (Oncorhynchus gorbuscha) fry, we analyzed the acoustic data to produce estimates of pelagic rockfish and herring. We found the highest number of rockfish in rocky areas along Culross Island and in the southwest passages. Herring were most abundant in the southwest passages.

Prey (macrozooplankton):

The Sound Ecosystem Assessment (SEA) is a multi-investigator project designed to identify the primary physical and biological factors that affect the production of pink salmon and Pacific herring in Prince William Sound (PWS), Alaska. As part of this assessment, research cruises were conducted to describe the abundance and patchiness of zooplankton in PWS using high-frequency acoustics, an optical plankton counter (OPC), and a multiple-sample zooplankton net, as well as instruments to measure temperature, salinity, and fluorescence. The high-resolution, continuous sampling provided by the acoustics and optics showed that zooplankton aggregate in layers and patches throughout PWS, and that Hinchinbrook entrance had relatively high densities in both 1995 and 1996. In regions where *Neocalanus* copepod dominates the biomass, the optics and acoutics showed similar patterns, but in regions with high pteropod biomass, the acoustics estimate more biomass than the optics.

Pacific herring:

Juveniles:

Diel hydroacoustic surveys were conducted from June 1996 to August 1997, in Simpson, Zaikof, Whale and Eaglek bays, located in Prince William Sound, Alaska. Preliminary investigation of target strength (TS) information has detected seasonal variation in size classes and vertical changes in distribution of fish and plankton. Seasonal fluctuations in the relative frequency of detected targets below -60dB, indicating plankton size targets, mark the spring bloom of plankton. In addition, seasonal shifts in TS range may be due to the influx and growth of new herring recruits. Diel changes in depth distribution showed that some fish may be undergoing daily vertical migrations. Further investigation of the acoustic and catch data sets will be needed to expand on the observed changes. Improvements in hydroacoustic equipment and subsequent data processing are discussed, with suggestions for further research.

Multi-species management and restoration: Collectively, since harvest of all three species (pink salmon, herring, pollock) are being managed in PWS, we are already practicing a form of multispecies management; it is just not a coordinated effort ("ostrich management"). If all three species were independent of each other, this practice might be acceptable. However, 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 next step is up to the three management teams to talk to each other about the information. 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

Distribution and abundance of walleye pollock (*Theragra chalcogramma*) in Prince William Sound, 1994 to 1997. G. B. Steinhart, G. L. Thomas, J. Kirsch, and N. Peters

ABSTRACT

We have used acoustics to measure abundance and distribution of walleye pollock (*Theragra chalcogramma*) in Prince William Sound (PWS) since 1994. We found that during the spring and summer, pollock abundance in the northwest PWS increased, while pollock density decreased in southwest passages. We believe that this increase in pollock may have been influenced by the timing and magnitude of the spring zooplankton bloom, one of the primary prey items of pollock in the Sound. In 1994, a year with a relatively late, and small, bloom of *Neocalanus spp.*, pollock were more abundant near Esther Island than during any other year we sampled. We believe this observation supports the Prey-Switching hypothesis: in the absence of abundant plankton, pollock switch to other prey items, including salmon fry.

INTRODUCTION

Walleye pollock (*Theragra chalcogramma*) are one of the most abundant and ecologically important fish species in Prince William Sound (PWS). Not only do they support a commercial fishery, but they play a large role in the food-web dynamics of the Sound. With over 30,000 tonnes of pollock in the Sound (Thomas and Stables 1996; Kirsch 1997), pollock could have dramatic effects on recruitment of juvenile fishes through predation and/or competition. The goal of this research is to describe the abundance and distribution of pollock in western Prince William Sound in order to better understand their role in the ecosystem.

Many previous studies have looked at the behavior, distribution, and abundance of walleye pollock in the North Pacific (Dwyer et al. 1987; Bailey 1989; Brodeur and Wilson 1996); however, some of theses studies focused on juvenile pollock, and none looked at behavior of pollock in Prince William Sound. These earlier studies found that pollock ate mostly young fish, including juvenile walleye pollock. In PWS, however, adult pollock have been shown to eat mostly macro-zooplankton (Thomas et al. 1997a). The Prey Switching hypothesis (SEA 1993) predicts that as macro-zooplankton availability decreases, pollock will switch from eating primarily zooplankton to juvenile fish and other large invertebrate prey. Given their abundance, if pollock began to prey on salmon fry, they could dramatically affect the survival and recruitment of many fish species in the Sound, including commercially important pink salmon.

In this paper we present the results from four years of acoustic surveys in Prince William Sound. This work was part of the Sound Ecosystem Assessment Project (SEA): an ecosystem level study of PWS. 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 the Sound (M. Willette, pers. com.). 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.

MATERIALS AND METHODS

Study site

Prince William Sound (PWS) is located at the northern edge of the Gulf of Alaska (Fig. 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 four years of this project (Table 1). In 1994, offshore surveys were conducted during the day throughout western PWS (Fig. 2). There were 5 cruises where usable acoustic data were collected: 02a (5/4-5/16/94), 03a (5/17-5/24/94), 04a (6/2-6/15/94), 05a (6/24-6/30/94), and 06a (7/7-7/17/94). There were 88 different parallel transects in Wells, Perry, and Knight Island Passages, Montague Straight and the Southwest passages (Thomas et al. 1996). Many of these transects were repeated in the various cruises; however, not all cruises surveyed all transects. Data were collected with a BioSonics 101-120 kHz dual beam echosounder.

In 1995, there were two different survey designs (Table 1). There were two broadscale surveys of PWS, consisting of approximately 15 long transects throughout open, deep water areas all around the Sound. The broadscale surveys were conducted from 4/27-5/1/95, and from 5/23-5/27/95. Immediately following the broadscale surveys, we commenced sampling for the offshore (> 0.5 NM from shore) diel surveys. These surveys were concentrated in northwest portion of PWS (Fig. 3), and were designed to examine differences between nearshore and offshore distributions of fish (See Thomas et al. 1997a for nearshore survey methods and results). The tow offshore surveys were conducted from 5/2-5/18/95 (Cruise 07a) and 5/28-6/15/95 (Cruise 08a). The offshore surveys were conducted aboard the F/V Alaska Beauty with a BioSonics 101-120 kHz dual beam echosounder, set to collect data to a depth of 250 m.

In 1996, sampling was limited to Wells and Perry Passages, Ester Island, and Unakwik and Kiniklik Inlet. Three cruises were conducted beginning in early May, and ending in early June: 11k (5/3-5/10/96), 12k (5/20-5/19/96), and 13k (6/1-6/8/96). The surveys were conducted nearshore (< .05 NM), and consisted of one long transect parallel to the shoreline, and 5 parallel transects perpendicular to the shoreline (Fig. 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.

During 1997, sampling was conducted in the eastern portion of PWS, as well as some of the western sites surveyed in 1996. The eastern sites sampled included Sheep Bay, Port Gravina, and Fish Bay. 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 (Fig. 4). The surveys were repeated 4 times a night: 2000, 2300, 0200, and 0500. Data were collected with a down-looking 38 kHz digital transducer, however, these data are still being analyzed. The data presented here are from a down-looking BioSonics 101-120 kHz dual beam echosounder that used during the final cruise, 22m (11 June - 18 June, 1997).

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 a BioSonics 101-120 kHz dual-beam transducer. The data were processed in real-time using ESP software on a 486 laptop computer. A Magellan DLX-10 GPS receiver with an external antenna was used to geo-reference the data. 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 most cruises, but at least once per year (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). The calibration of the system was not different from 1995, 1996 and 1997.

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, additional IDL software was used to interactively remove untracked bottom, and to calculate density and biomass estimates.

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. 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).

Our echo-counting consisted of two major steps: target classification and target counting (Fig. 5). First, we identified targets which were not pollock. These targets were identified using information on the paper echograms, electronic target echograms, net catch data, and knowledge of fish behavior and distribution. Targets that were identified as non-pollock, but potentially had a similar TS range as pollock, were interactively selected and removed. Examples of removed targets included: dense plankton aggregations and tightly schooled herring and capelin. Although these species generally have a TS range below that of adult pollock, when found in tight aggregations, coincident targets may sum to a yield a pollock-sized TS. In addition, rockfish, which were easily identifiable as clumps of targets on pinnacles and slopes, were removed since they are similar in TS to pollock, but are not vulnerable to sampling by mid-water trawl.

Once the remaining targets were selected, we counted all targets that fell within a specified TS range (-39 to -25 dB). We chose a TS range based on the observed size distribution of pollock captured in the mid-water trawls and the acoustic data (Figs. 6 and 7). We then expanded the range of counted targets in an attempt to compensate for the inherent variation in TS due to various factors, including: target tilt, target depth, and changes in body condition (Love 1997; Traynor and Ehrenberg 1979; Traynor and Williamson 1983; Mukai and Iida 1996). After counting all qualifying targets, we used the net data (mid-water trawl and pair-trawl only) to examine the species composition at the survey sites.

Since pollock made up almost of all trawl catches of fish greater than 350 mm (a couple salmon were captured, as were a couple large herring), we considered our selected and counted targets to be pollock. The sum of the echo-counted targets was divided by the sample volume of the acoustic beam to compute mean density for each transect. Mean pollock densities were calculated by taking the weighted mean of all transects at a particular site during a single survey. Transect length (the number of reports) was used as the weighting factor in 1994 and 1995. In 1996, due to the short length of the transects, and the repeated survey design, we used each sample period as the sample unit. The sum of reports for each sample period was used as the weighting factor in 1996. All statistical analyses were conducted using $\alpha=0.05$.

RESULTS

1994

Pollock distribution was seasonally variable in the western portion of Prince William Sound in 1994. Pollock densities increased in the northwest passages, but remained nearly constant in the middle passages, and declined in the southwest passages (Fig. 8). In Wells Pass (Site 13), pollock densities increased significantly from mid May to early June (df=17, t=2.09, p=0.026). In Perry Passage (Site 14), another northern area, there was initially a significant decrease in pollock density from early May to mid May (df=18, t=4.64, p=0.00007); however, pollock density significantly increased from early June to early July (df=12, t=2.04, p=0.032).

In the Middle passages, there was little change in pollock densities (Fig. 8). In southern Perry Passage (Site 15), there was a small, but significant decrease in pollock density from early May to late May (df=12, t=1.89, p=0.042). There were no other significant differences in density in this area of the Sound.

In contrast to the northwest passages, the southern passages tended to decrease in pollock density through the spring and summer (Fig. 8). In lower Knight Island Passage (Site 17), there was a significant decline in pollock density from mid May to late June (df=16, t=3.14, p=0.003), and from late June to mid July (df=18, t=10.3, p<<0.05). In Montague Strait (Site 18), there was a significantly higher density of pollock in late June than in late July (df=26, t=6.25, p (<<0.05). There were no significant changes in the observed pollock densities near Elrington and Latouche Passages (Site 19).

The depth distribution of pollock changed during the spring and summer of 1994 (Fig. 9). More fish were found near the surface during the earlier cruises, and they appeared to move deeper as the year progressed. This was especially evident during the July cruise (06a), when pollock densities near the surface were 80% lower than the early May cruise (02a).

1995
Between the two broadscale surveys from 1995, there was a decrease in pollock density in each of four major areas in the Sound(Fig. 10) but none of the differences were significant. However, we did see a rather large change in the vertical distribution of targets (Fig. 11). In the late April broadscale (07a), more targets were found near the surface than in the May broadscale (08a). In addition, the number of pollock deep in the water increased from April to May.

During the 1995 offshore surveys, we saw an increase in pollock during the spring and summer (Fig. 12). There were significant increases in pollock density at Hodgkin Point (Site 502; df=46, t=12.45, p<<0.05), Tipping Point (Site 506; df=111, t=10.35, p<<0.05), and west Esther Island (525; df=73, t=8.42, p<<0.05). There were no significant differences at south Esther Island (501; df=92, t=1.35, p=0.09) or Perry Passage (531; df=18, t=0.89, p=0.19). All other sites did not have repeated surveys.

Most pollock were found in the top 50 m during the 1995 offshore surveys (Fig. 13). However, from April to May, the density of pollock below 40m increased dramatically, while numbers near the surface decreased slightly.

1996
Pollock densities increased in many of the nearshore areas surveyed in 1996, but only by the last cruise (Fig. 14). There were few sites that had data from both the early May and late May cruises, but at the one site where there were repeated surveys, west Esther Island (site 525), there was no significant difference in pollock numbers (df=15, t=0.31, p=0.38). There were significant increase in pollock density from early May to early June at south Esther Island (site 501; df=15. t=6.18. p<<0.05). From late May to early June, pollock densities increase significantly at Tipping Point (site 506; df=6, 2.48, p=0.024), west Esther Island (site 525; df=8, t=2.57, p=0.017), at the mouth of Esther and Quillian Bays (site 526; df=5, t=3.41, p=0.01), and at Kiniklik (site 587; df=5, t=2.19, p=0.04); however, there was no significant difference in pollock density at Culross Island (site 504; df= 12, t=0.81, p=0.23) and Unakwik (site 586; df=5, t=1.6, p=0.085).

The vertical distribution of pollock did not change as much in 1996 as in the other years (Fig. 15). By early June, however, there were more pollock deep in the water column than during the first two surveys. There was not a decline in pollock numbers near the surface, rather pollock densities were generally lower near the surface than in other years.

1997
Only some of the data has been processed from the 1997 cruises (Figs. 16 and 17). The highest pollock densities were found in Fish Bay (site 585), Sheep Bay (site 611), Kiniklik (site 587) and Culross Island (site 505). It should be noted, however, that we have no trawl data from this cruise, so the numbers should be considered adult pollock-sized

targets, and not necessarily as adult pollock. The vertical distribution showed a peak near the surface, and between 150 and 200 m.

DISCUSSION

Pollock in Prince William Sound displayed seasonal changes in abundance and vertical distribution. We believe this behavior is related to food resources in PWS, primarily zooplankton and salmon fry abundance. Our data show 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 in 1994, 1995, and 1996. Commercial fisherman have long reported finding large concentrations of adult pollock in Port Bainbridge and the southwest Passages during winter (Thomas et al. 1996). Our own pollock surveys have also shown this (Kirsch 1997). 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, as pollock numbers increased in the north, they often decreased in southern areas, while remaining nearly constant in the middle portion of western PWS (Fig. 8). These data all supports the hypothesis that the adult pollock migrate northward after the winter.

The one anomaly to the trend of increased pollock abundance in northwest PWS was seen in the 1995 broadscale data. Pollock densities were lower in the later cruise than in the first, although the difference was not statistically significant. The observed decline could be attributed to two factors. First, the broadscale surveys covered vast areas, including central and eastern PWS, but not in great detail, and with no repeated transects. The variability of pollock spatial distribution may therefore be a confounding factor. Second, pollock moved deeper in the water column from the first to the second broadscale survey. The areas covered were in very deep water, and it is very likely that some of the pollock had migrated deeper than 250 m, beyond the maximum range we collected data.

The pollock migration into the Sound is probably part of a seasonal feeding migration after spawning. We did see a strong positive correlation of pollock biomass with zooplankton density (see Chapter 2). One piece of evidence supporting the hypothesis that pollock abundance and migration patterns may be related to zooplankton is shown in the inter-annual differences in timing and magnitude of the spring zooplankton bloom. The Prey Switching hypothesis predicts that when plankton densities are low, pollock will switch to other prey, including salmon fry. In 1994, the *Neocalanus spp.* bloom appeared later, and was smaller, than in 1995 (Fig. 18). Late April/early May pollock densities in the northwest were higher in 1994 than 1995, before the observed peak in the bloom of *Neocalanus spp.*(Fig. 19). It is possible that the high densities observed in this area in 1994 were pollock that had migrated northward more quickly, in order to feed on the salmon fry being released from Wally Noerenbuerg Hatchery. Conversely, in 1995, the late northward migration of pollock may be a result of the abundant plankton that year. With plenty of food available, there was no energetic need to migrate to other areas until later that year. Salmon fry released from Wally Noerenberg hatchery had lower survival in 1994 (low *Neocalanus spp.* densities and high pollock densities) than in 1995 (high *Neocalanus spp.* densities and low pollock densities). These data support the Prey Switching hypothesis; however, we have only 2 years of data from throughout the Sound (we do not have zooplankton numbers from 1996 or 1997), so this inter annual variability is not yet fully understood.

The vertical distribution of pollock also changed throughout the year. In general, as the year progressed, pollock tended to move deeper in the water column. This migration may be to follow the large marine copepods, who migrate down in spring to overwinter in deep waters (Cooney 1987; see Chapter 2). In 1994, the largest decrease in pollock abundance in the top 50 meters occurred between the cruise 02a (early May) and 03a (mid May), and between 05a (late June) and 06a (July). The biomass of *Neocalanus spp.* in the top 50 m dropped to nearly zero in mid June, approximately the same time that pollock migrated deeper in the Sound. In 1995, there was downward seasonal migration of the pollock. It was more evident in the offshore surveys than in the broadscale surveys, but in both cases, there were also large numbers of pollock near the surface. This may demonstrate how some pollock are feeding on plankton (those that migrate down later in the year), while others stay near the surface to feed on salmon fry, where they are present. The areas surveyed in the broadscale surveys were not likely to contain many salmon fry, since the transects were far from shore, this may explain why there was a large decrease in the number of pollock observed in the top 25 m. The 1995 offshore surveys (> 0.5 NM) were much closer to shore than the broadscale surveys, and were areas where one would expect to find salmon fry. In these surveys, pollock densities remained high near the surface, with only a portion of the population migrating deep.

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 transect can have a significant effect on the predicted biomass for a relatively short transect (e.g. the 1996 and 1997 nearshore surveys). In addition, target strengths of fish are highly variable and depend on many factors (Love 1977; 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 reduced cross-section to reflect the acoustic signal. The reduced acoustic return will lead to an underestimate of the total length of the fish. Furthermore, an echo from a fish that is only partially within the acoustic beam will also underestimate the target's size. In both these cases, the reduced signal return may result in a pollock-sized target being incorrectly classified as a non-pollock. Partially overlapped targets, which will occur more frequently with depth, cause the target discriminator to omit targets. This will underestimate the number of targets in deep water. Also, dual beam target strength determination requires some tracking, but at short ranges there are insufficient esonifications to track a target. Future work will focus on overcoming the statistical problems of a small sample volume near the surface to improve our echo-counting procedure.

In conclusion, pollock behavior, abundance, and distribution are dynamic between and within the years of this study. Further analysis will be used to test the hypothesis the migrations are driven by food resources. If low zooplankton biomass results in more pollock in areas with high salmon fry abundance, it could lead to reduced survival of salmon fry. Conversely, when plankton are abundant, pollock may not migrate to areas with high fry numbers, instead choosing to feed on plankton, and undergoing a seasonal vertical migration that follows the seasonal copepod migration. Future work will focus on completing our comparison of pollock distribution with relation to plankton abundance, and comparing salmon fry survival to pollock density and distribution.

ACKNOWLEDGMENTS

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REFERENCES CITED

Bailey, K. M. 1989. Interaction between the vertical distribution of juvenile walleye pollock *Theragra chalcogramma* on the eastern Bering Sea, and cannibalism. Mar. Ecol. Prog. Ser. **53**: 205-213.

Brodeur, R. D., and M. T. Wilson. 1996. Meso-scale acoustic patterns of juvenile walleye pollock (*Theragra chalcogramma*) in the western Gulf of Alaska. Can. J. Fish. Aquat. Sci. **53**: 1951-1963.

Cooney, R. T. 1987. The seasonal occurrence of *Neocalanus cristatus, Neocalanus plumchrus* and *Eucalanus bungii* over the shelf of the northern Gulf of Alaska. Continental Shelf Res. **5**: 541-553.

Cooney, R. T. 1993. A theoretical evaluation of the carrying capacity of Prince William Sound, Alaska, for juvenile Pacific salmon. Fisheries Research, **18**: 77-88.

Dwyer, D. A., K. M. Bailey, and P. A. Livingston. 1987. Feeding habits and daily ration of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea, with special reference to cannibalism. Can. J. Fish. Aquat. Sci. **44**: 1972-1984.

Ehrenberg, J. E. and D. W. Lytle. 1972. Acoustic techniques for estimating fish abundance. Trans. Geosci. Elec. GE-10: 138-145.

Foote, K. G. and D. N. MacLennan. 1982. Use of elastic spheres as calibration targets. p. 52-58. In O. Nakken and S.C. Venema [ed.], Symposium on fisheries acoustics. ICES/FAO. Bergen, Norway.

Grant, U. S. and K. F. Higgins. 1910. Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska. U.S. Geological Survey Bulletin. No. 443. 89 pp.

Kirsch, J. 1997. Acoustic biomass estimate of adult walleye pollock in Prince William Sound, Alaska, in winter 1997. Report to the Alaska Department of Fish and Game. Prince William Sound Science Center. Cordova, AK.

Love, R. H. 1977. Target strength of an individual fish at any aspect. J. Acoust. Soc. Amer. **62**: 1397-1493.

Mukai, T. and K. Iida. 1996. Depth dependence of target strength of live kokanee salmon in accordance with Boyle's law. ICES J. of Marine Sci., **53**: 245-248.

PWSFERPG. 1993. SEA Plan: Innitial science plan and monitoring program. 111 p.

Thomas, G. L, J. Kirsch, T. McLain. 1996. SEA: Nekton-plankton acoustics second annual report, 1995. Restoration Project 95320N. *EXXON VALDEZ* Trustee Council. Anchorage, Alaska. 120 pp.

Thomas, G. L. and T. B. Stables. 1996. Winter 1995 estimates of the prespawning biomass of walleye pollock in Prince William Sound, Alaska. Report to the Alaska Department of Fish and Game. Prince William Sound Science Center. Cordova, AK.

Thomas, G. L, J. Kirsch, G. B. Steinhart, and N. Peters. 1997. SEA: Nekton-plankton acoustics second annual report, 1996. Restoration Project 96320N. *EXXON VALDEZ* Trustee Council. Anchorage, Alaska. 120 pp.

Thomas, G. L., E. V. Patrick, J. Kirsch, and J. R. Allen. 1997. Development of an ecosystem model for managing the fisheries resources of Prince William Sound. pp . 606-613. D. C. Smith, A. Grant, and J. P. Beumer [eds.], Developing and sustaining world fisheries resources. CSIRO. Collingwood, Australia.

Traynor, J. J. and J. E. Ehrenberg. 1979. Evaluation of the dual-beam acoustic fish target strength method. J. Fish. Res. Bd. Can. **36**: 1065-1071.

Traynor, J. J. and N. J. Williamson. 1983. Target strength measurements of walleye pollock (*Theragra chalcogramma*) and a simulation study of the dual-beam method. Proceedings of the Symposium on Fisheries Acoustics. FAO Fish. Rep. No. 300: 112-124.

Table 1. Survey location, design, and purpose for 1994-97 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 monthly	Examined monthly trends and patchiness of pollock distribution
1995	Offshore Broadscale	All PWS	Two repeated surveys covered vast distances	Examined summer trends and patchiness of pollock distribution
	Offshore Diels	NW PWS	Surveyed every 3 h for 24 h period at each site	Examined summer and daily changes in pollock abundance and distribution
1996	Nearshore	NW PWS	Surveyed each site four times at night Monthly repeated sampling at sites	Examined monthly and daily changes in pollock abundance and distribution in nearshore areas
1997	Nearshore	NW and NE PWS	Surveyed each site four times at night	Examined daily changes in pollock abundance and distribution in nearshore areas

Table 2. Parameters of the acoustic equipment used during sampling of Prince William Sound in 1997.

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

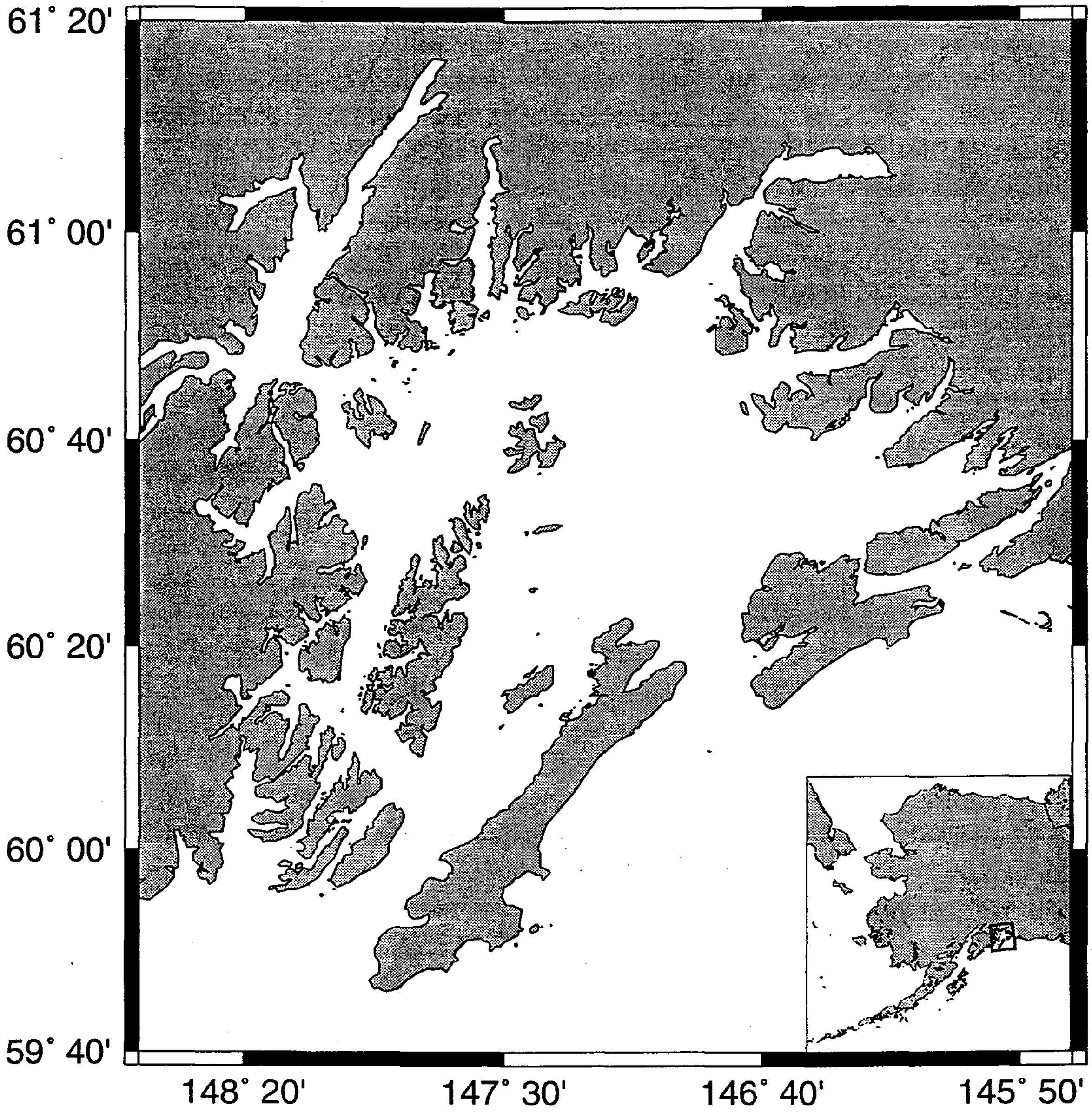
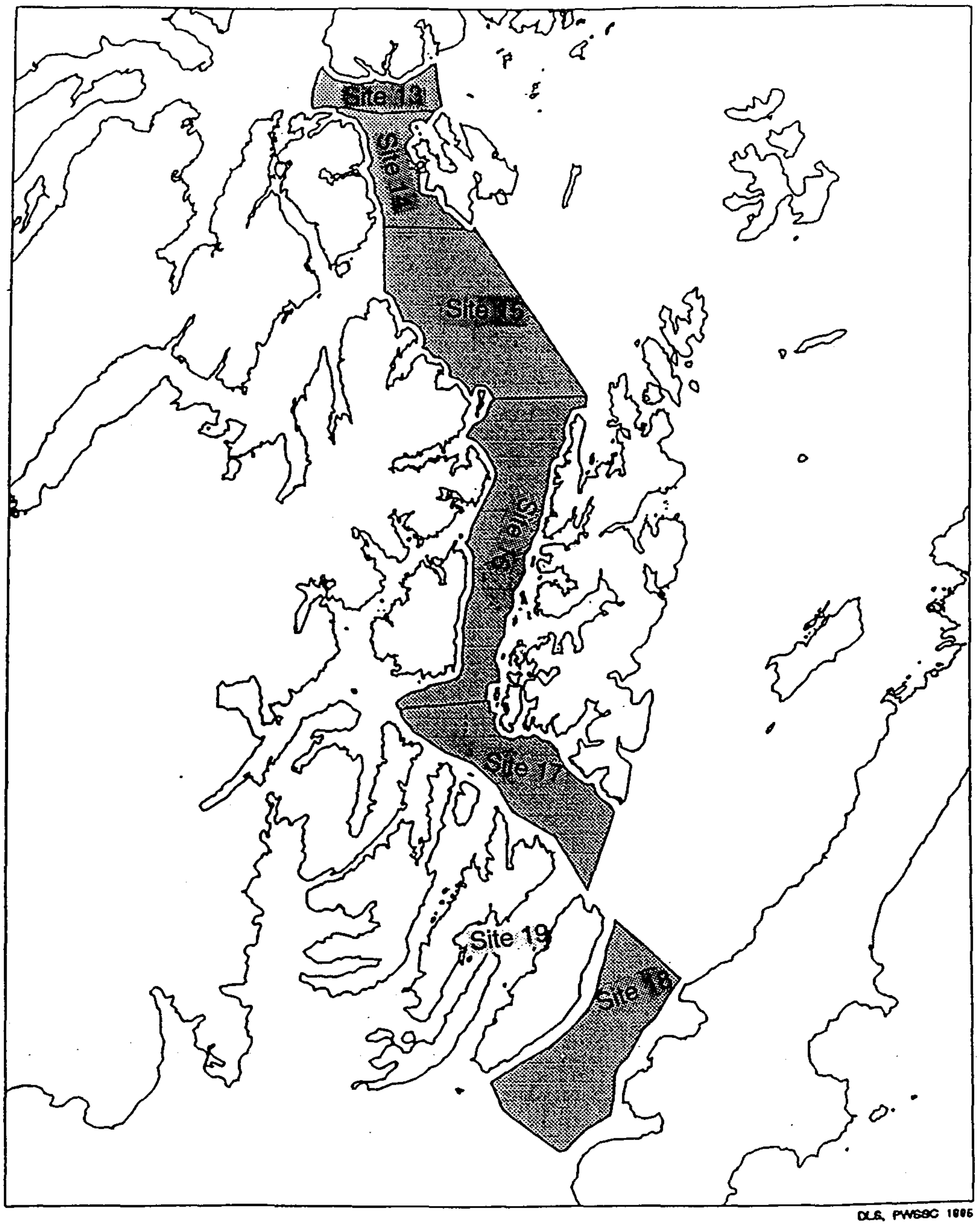


Fig. 1. Map of Prince William Sound, Alaska, USA.



DLS, PWSSC 1995

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

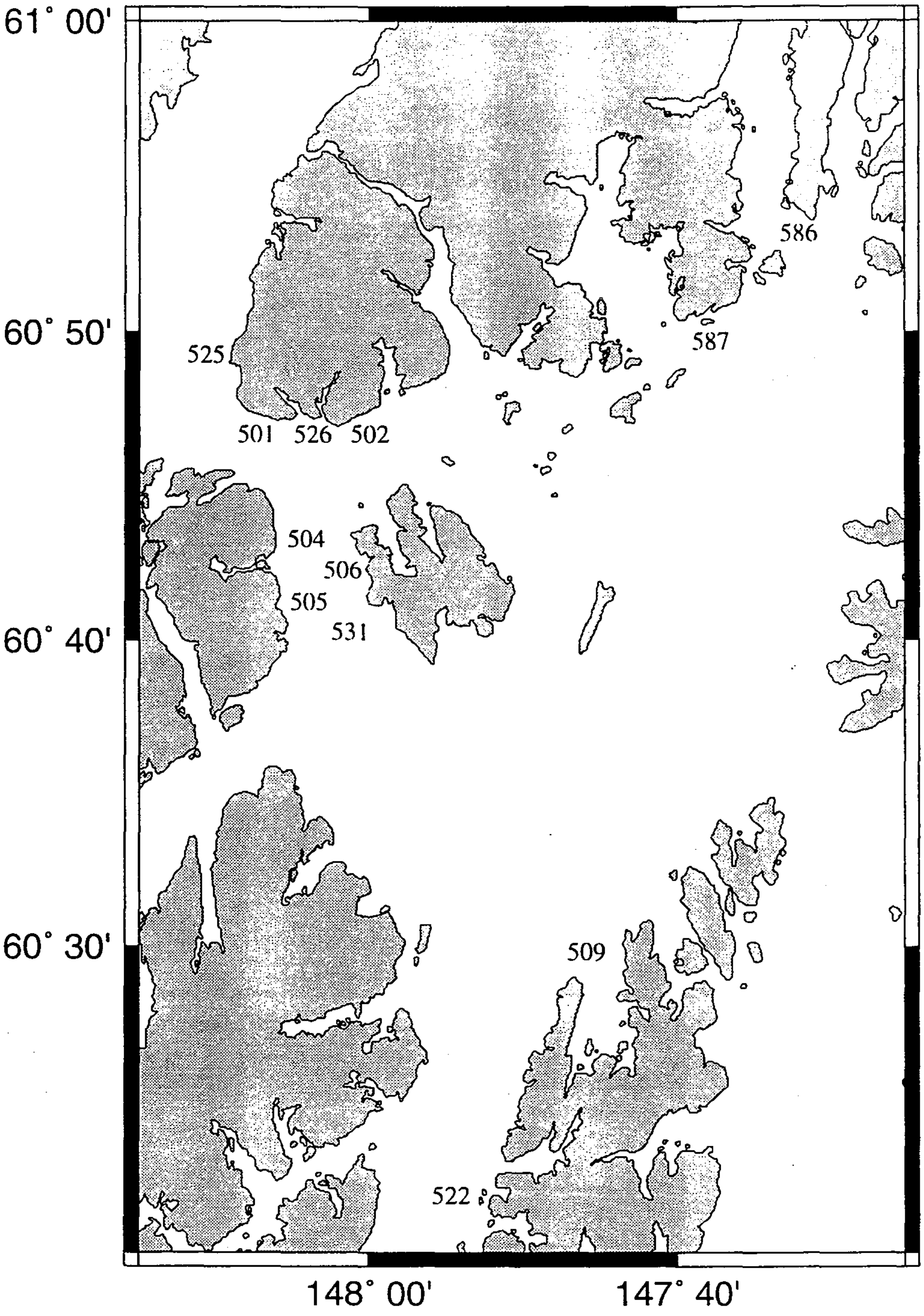


Fig. 3. Map of northwestern Prince William Sound showing where most of the sampling occurred in 1995, 1996, and 1997. The site numbers (from ADF&G) are in the approximate locations of sampling areas.

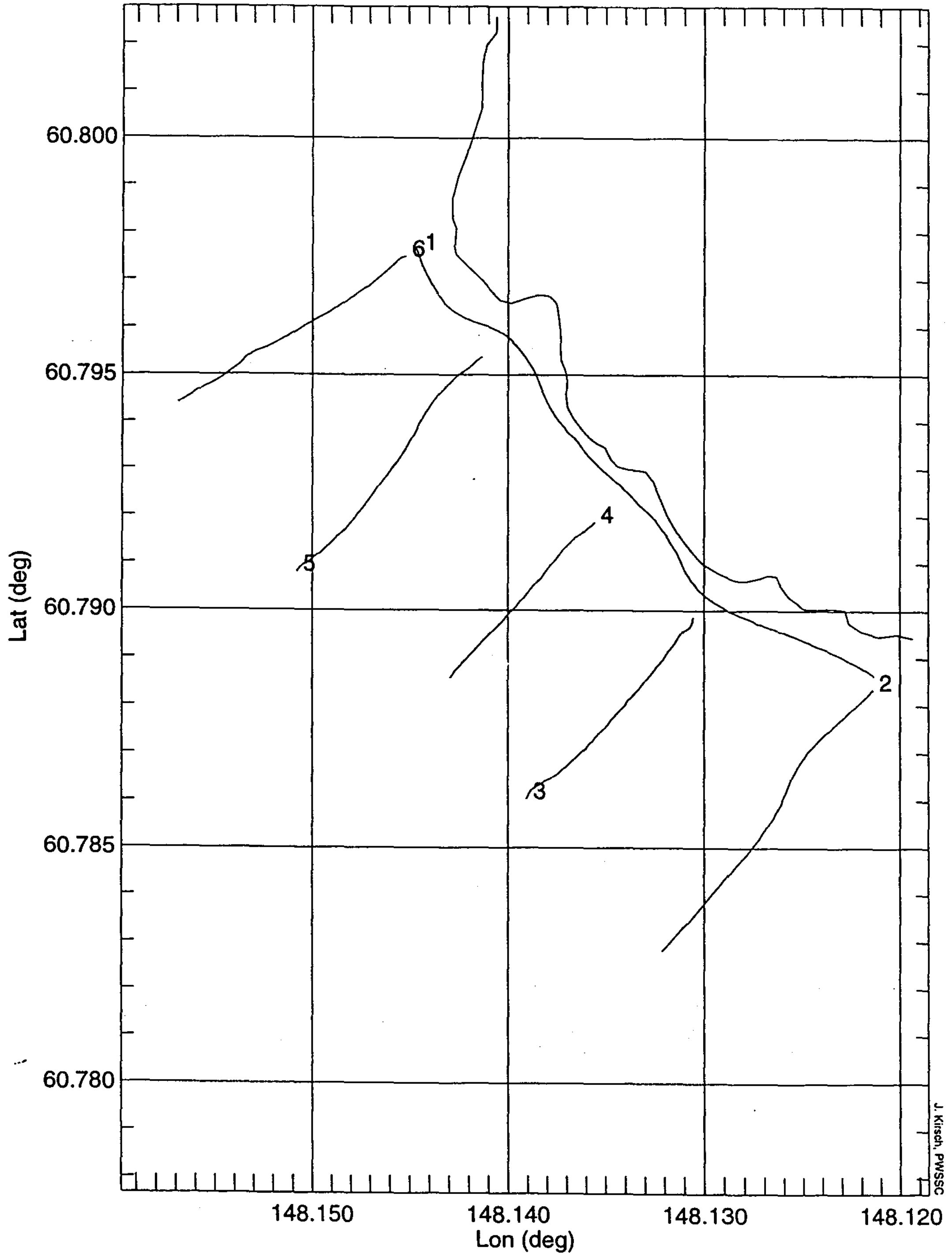


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Fig. 4. Map of transect design used during 1996 and 1997 acoustic surveys: one along shore transect, followed by 5 perpendicular to shore transects.

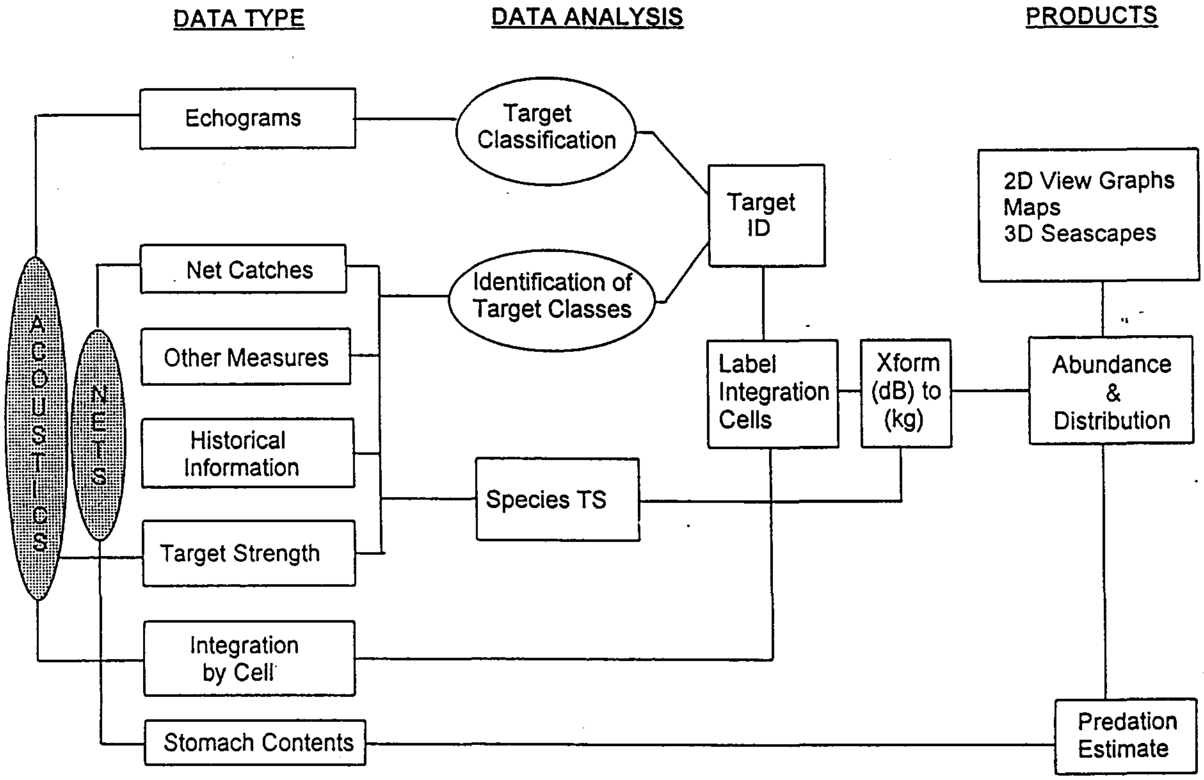


Fig. 5. Flow chart of data processing steps used in analysis of SEA acoustic data collected in 1994-97.

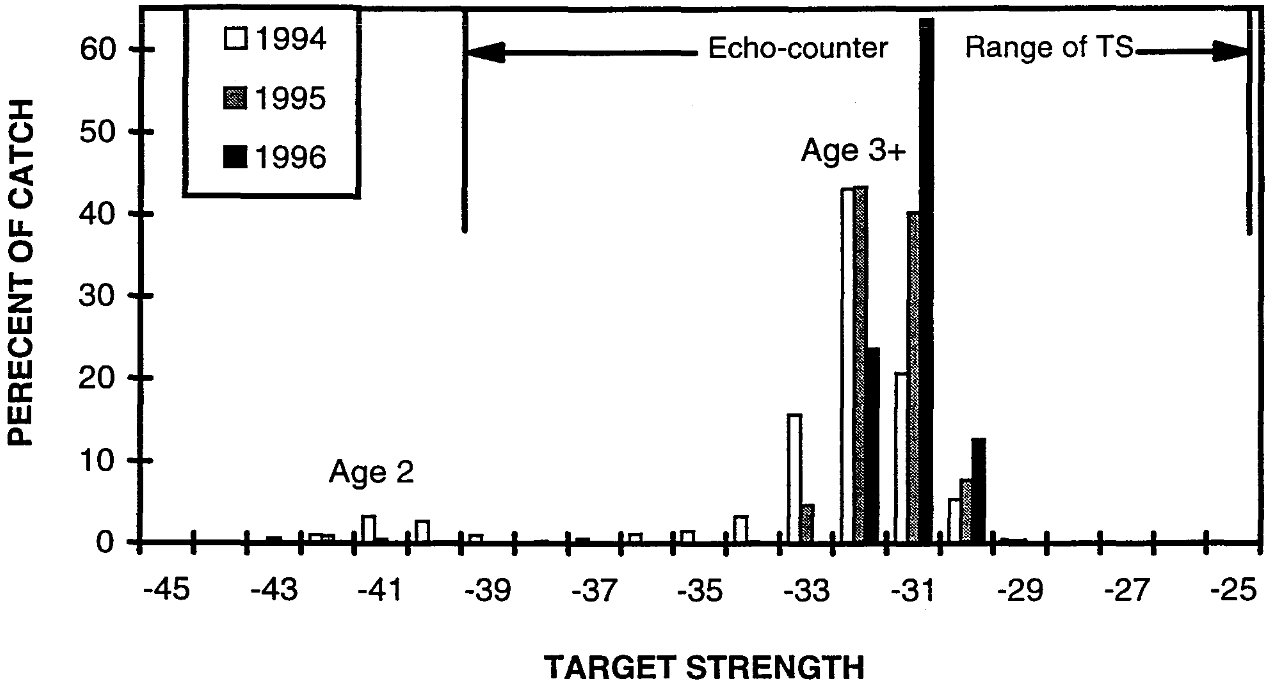


Fig. 6. Predicted target strength (TS) distribution of pollock captured in mid-water trawls in 1994, 1995, and 1996. TS values were calculated using the equation 20 Log(Length -66) (Traynor 1978). Also shown is the range of TS values accepted by the echo-counter.

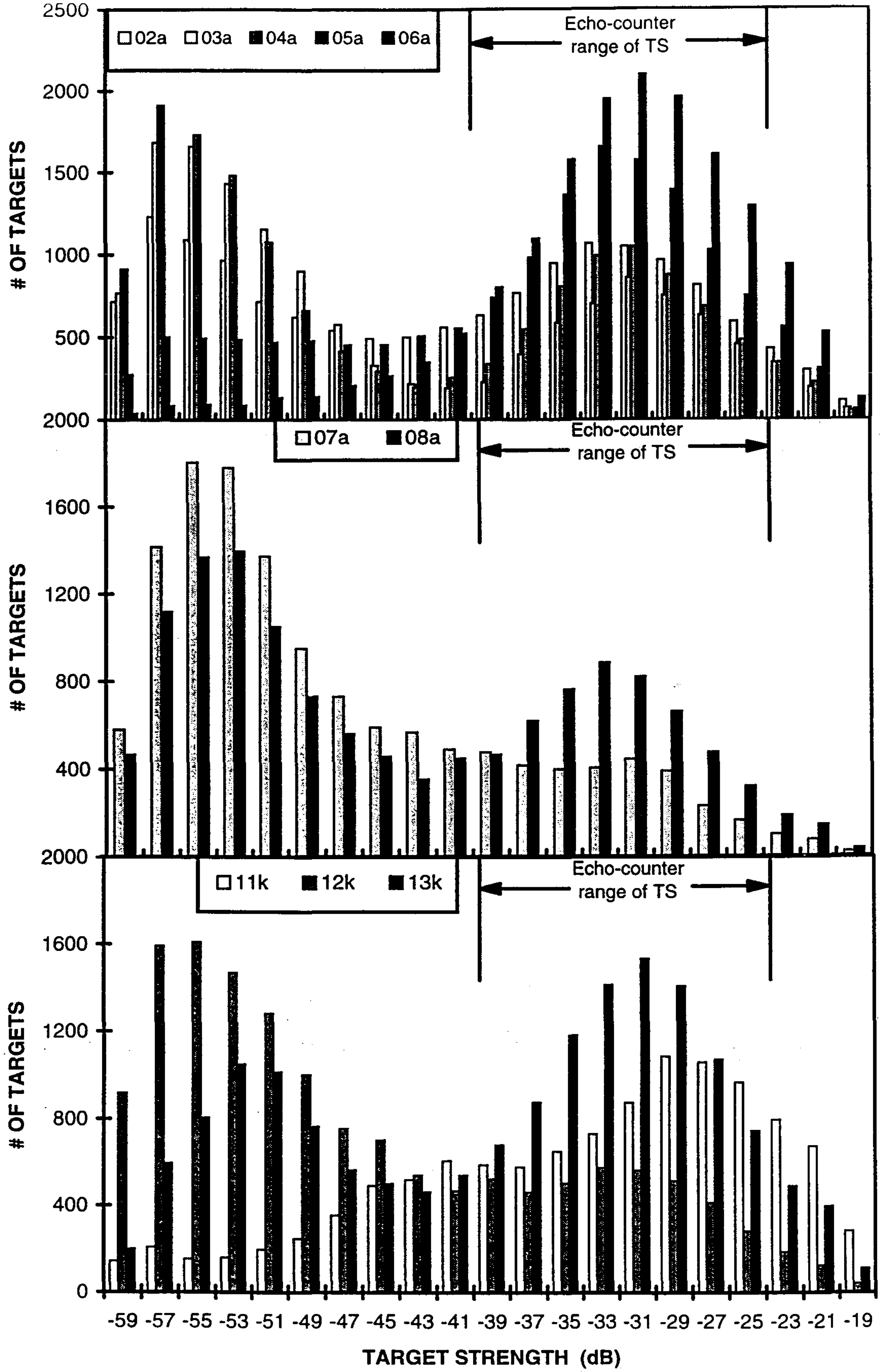


Fig. 7. Target strength (TS) distribution of acoustic data used in our echo-counting procedure from 1994 (02a-06a), 1995 (07a, 08a), and 1996 (11k-13k). Due to the huge amounts of data collected, the data graphed represent systematic random samples of approximately 15,000 targets per cruise. Also shown is the range of TS values accepted by the echo-counter.

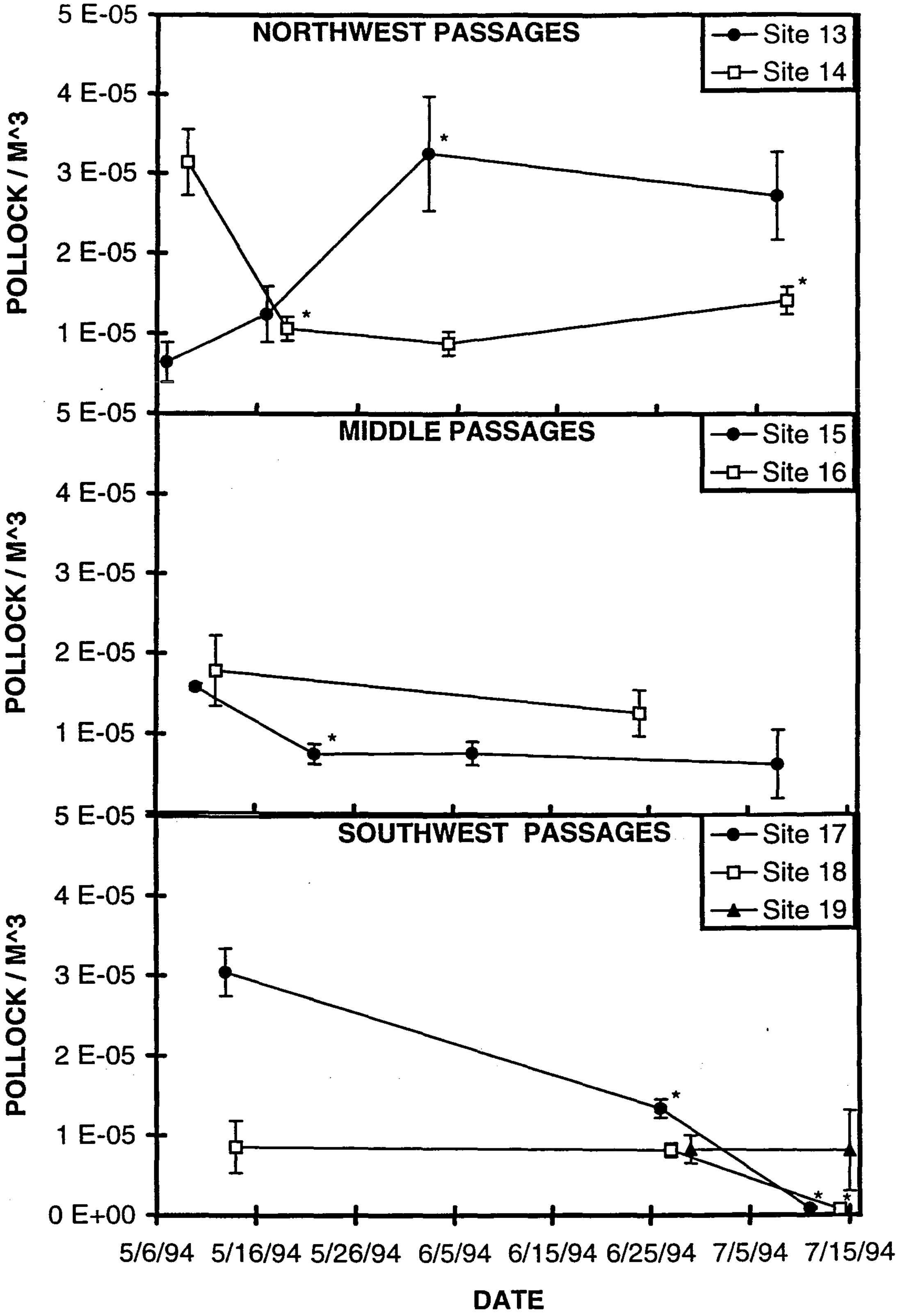


Fig. 8. Weighted mean pollock densities (± 1 S.D.) from 1994 offshore surveys. See Fig. 2 for exact site locations. The asterisks indicate a significant change in density from the previous sample.

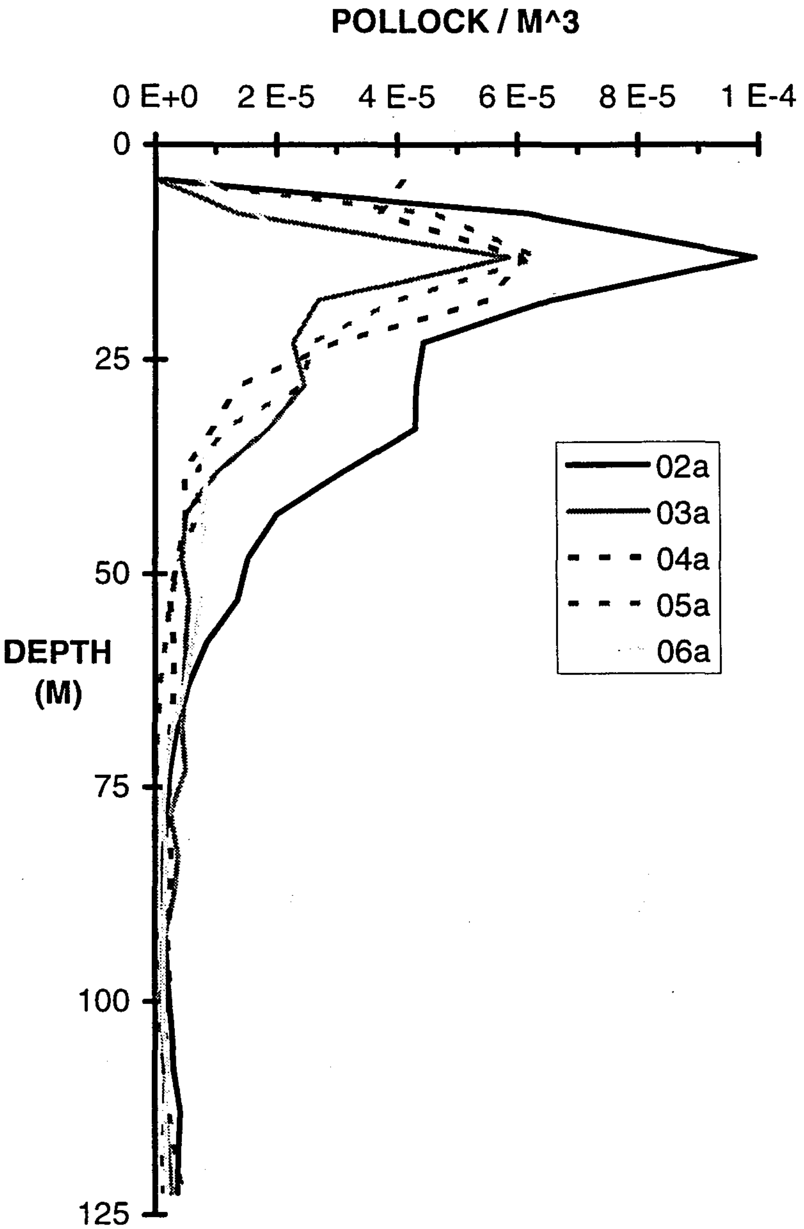


Fig. 9. Seasonal changes in pollock vertical distribution from 1994 offshore surveys in Prince William Sound.

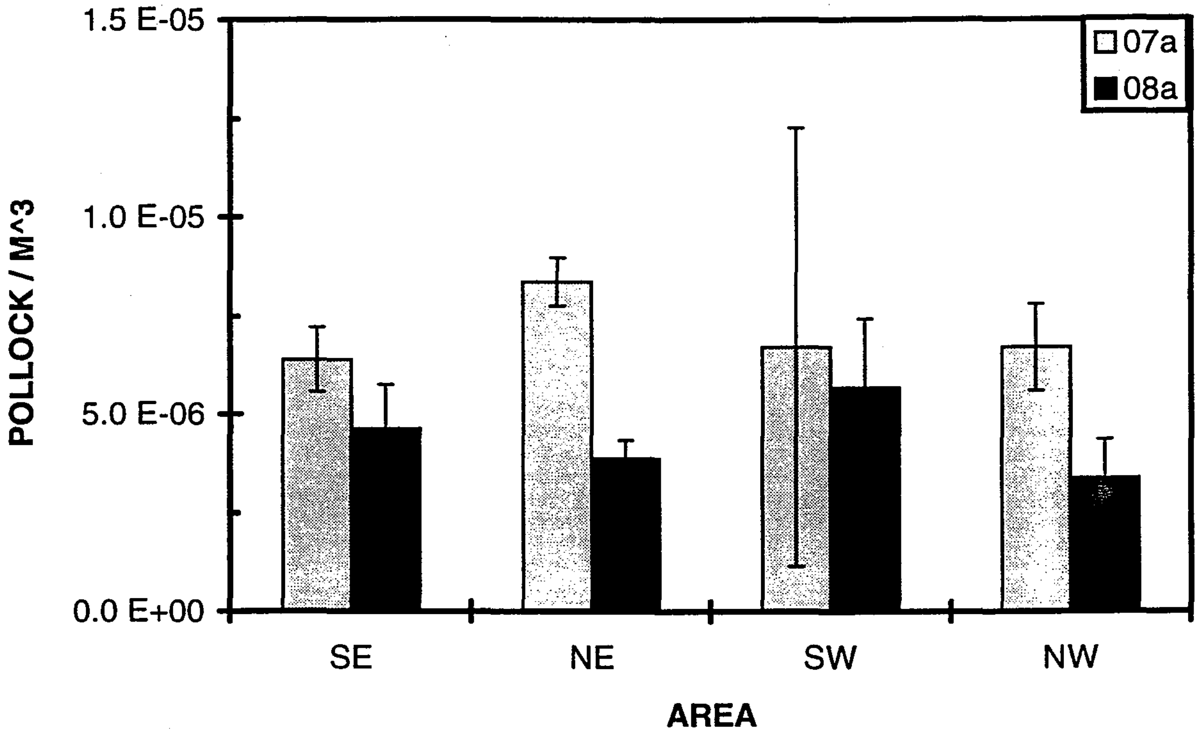


Fig. 10. Weighted mean pollock densities (± 1 S.D.) for offshore regions of Prince William Sound in May (07a) and June (08a) broadscale surveys in 1995.

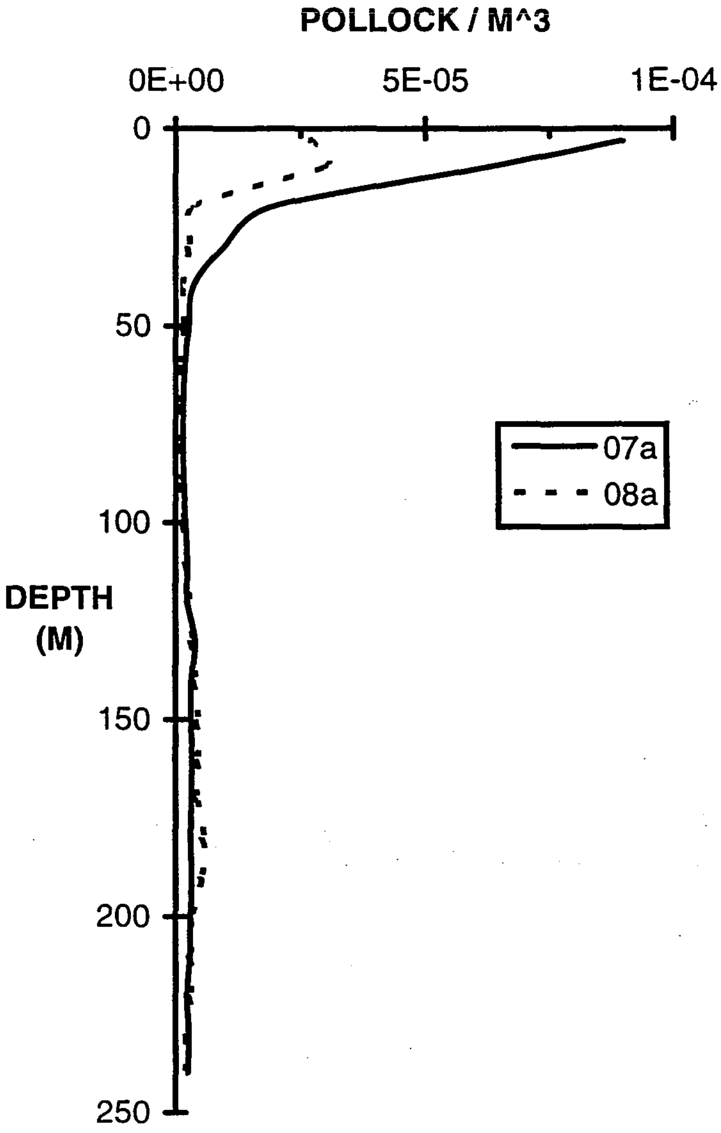


Fig. 11. Seasonal changes in pollock vertical distribution from 1995 broadscale offshore surveys in Prince William Sound.

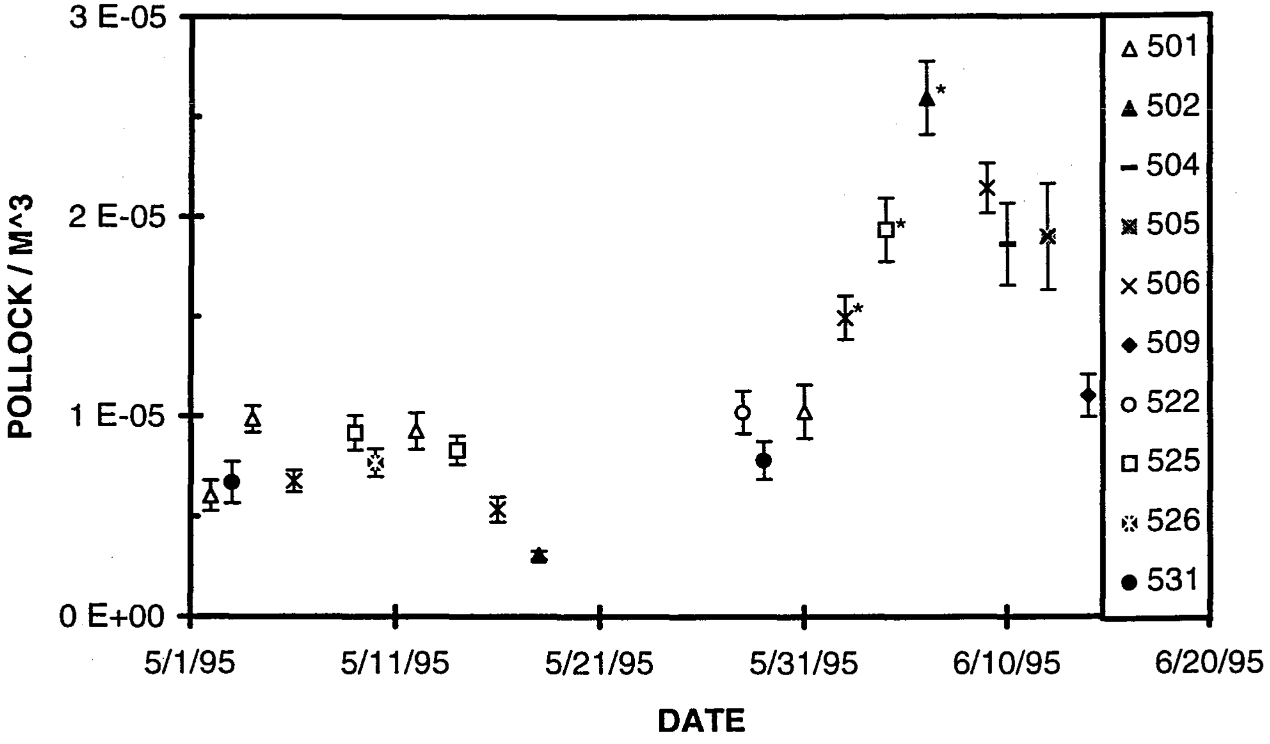


Fig. 12. Weighted mean pollock densities (± 1 S.D.) from 1995 offshore surveys. See Fig. 3 for exact site locations. The asterisks indicate a significant change in density from the previous sample.

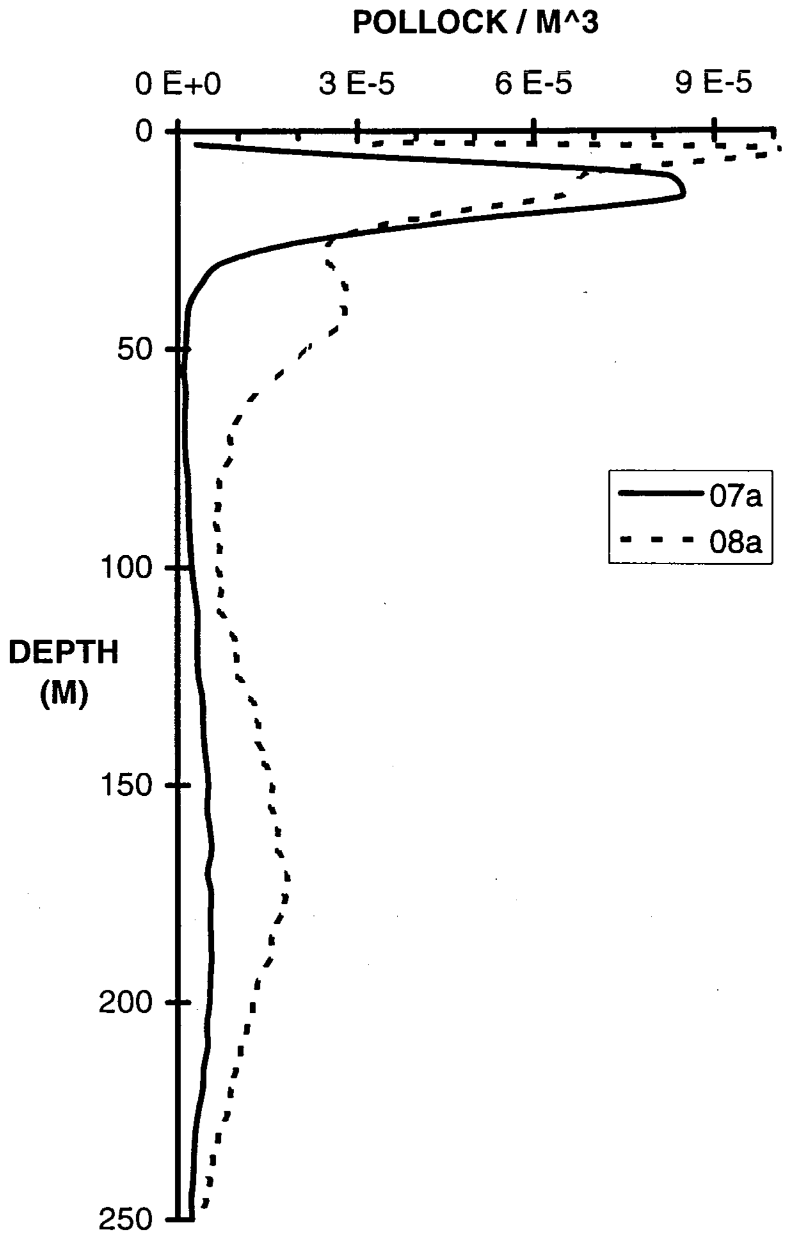


Fig. 13. Seasonal changes in pollock vertical distribution from 1995 offshore surveys in Prince William Sound.

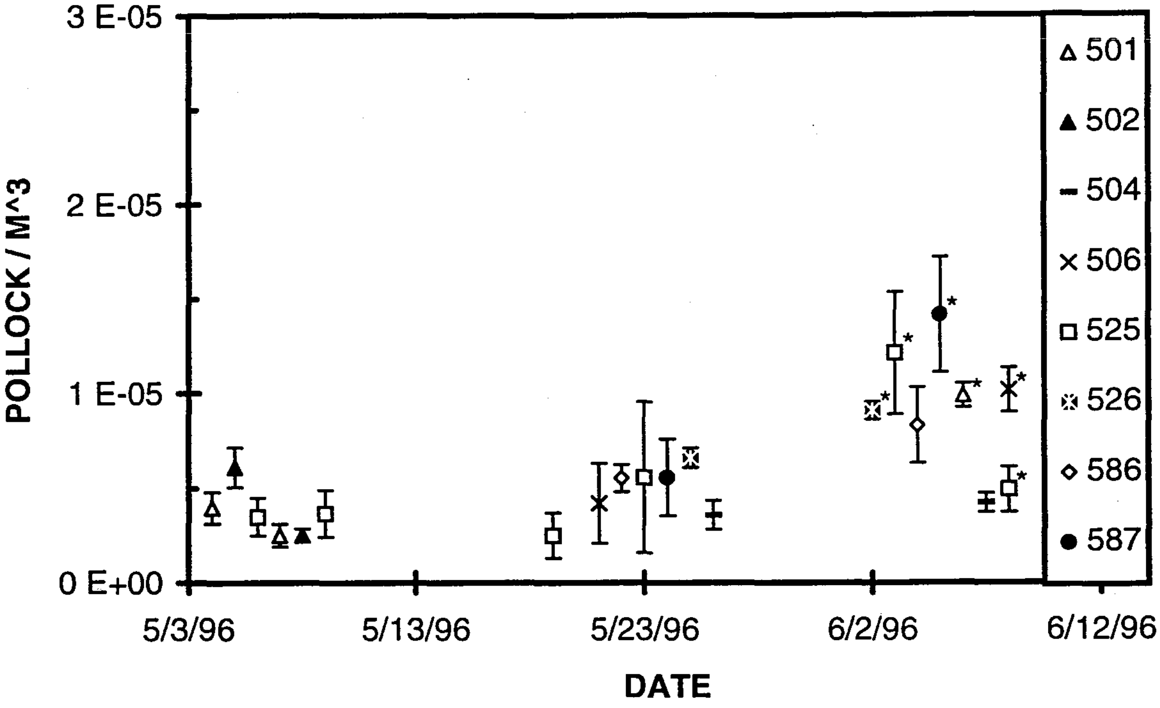


Fig. 14. Weighted mean pollock densities (± 1 S.D.) from 1996 nearshore surveys. See Fig. 3 for exact site locations. The asterisks indicate a significant change in density from the previous sample.

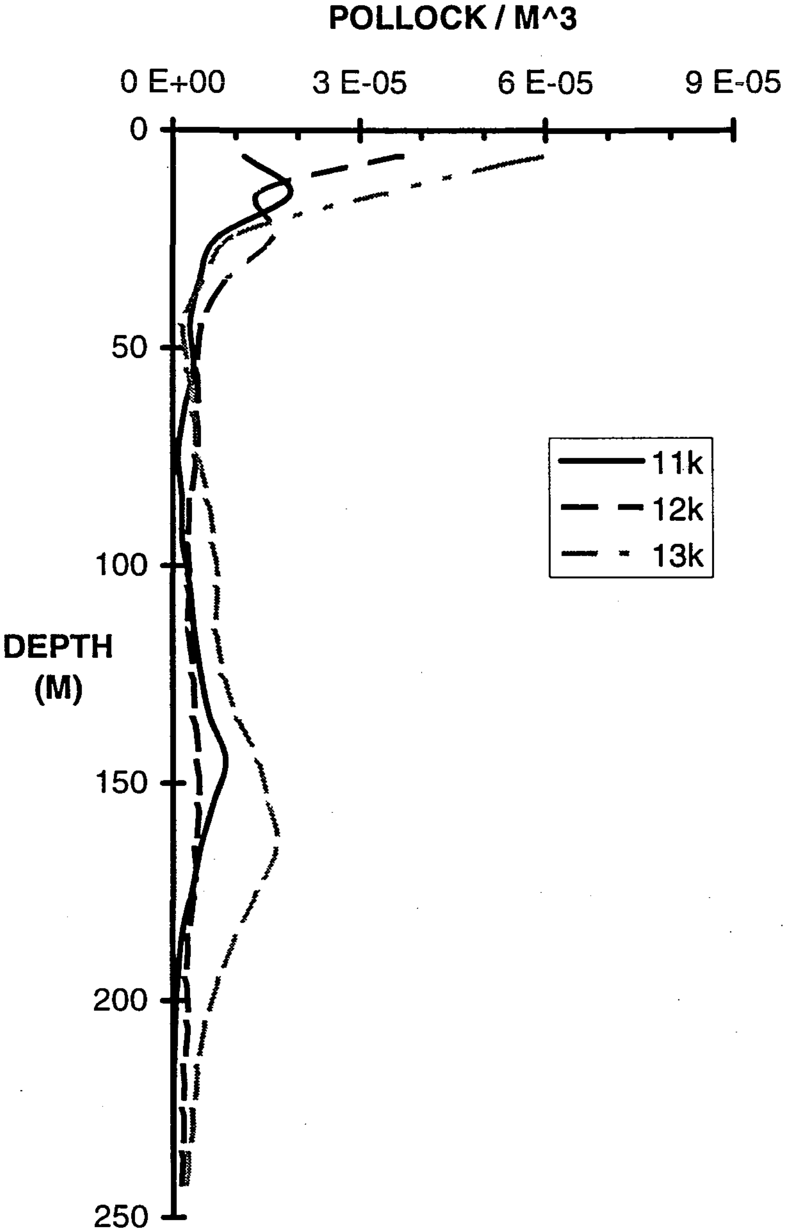


Fig. 15. Seasonal changes in pollock vertical distribution from 1996 nearshore surveys in Prince William Sound.

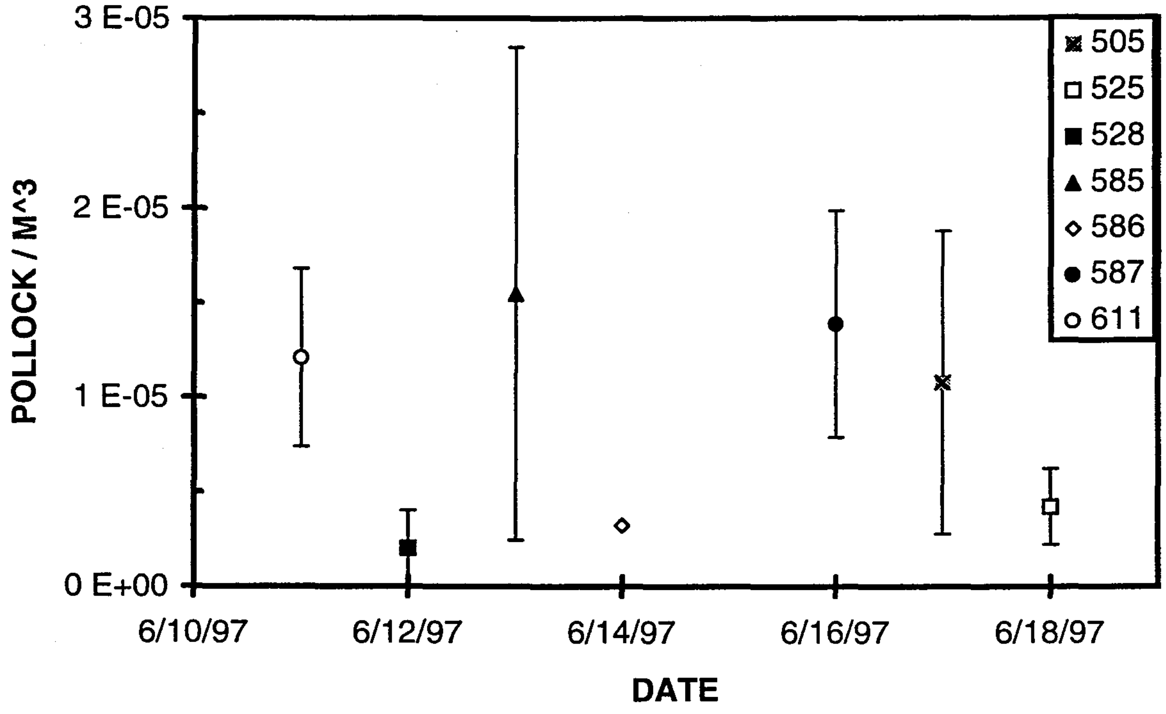


Fig. 16. Weighted mean pollock densities (± 1 S.D.) from 1997 nearshore surveys. Sites 528 (Port Gravina), 585 (Fish Bay), and 611 (Sheep Bay) are in Eastern Prince William Sound. For other site locations, see Fig. 3.

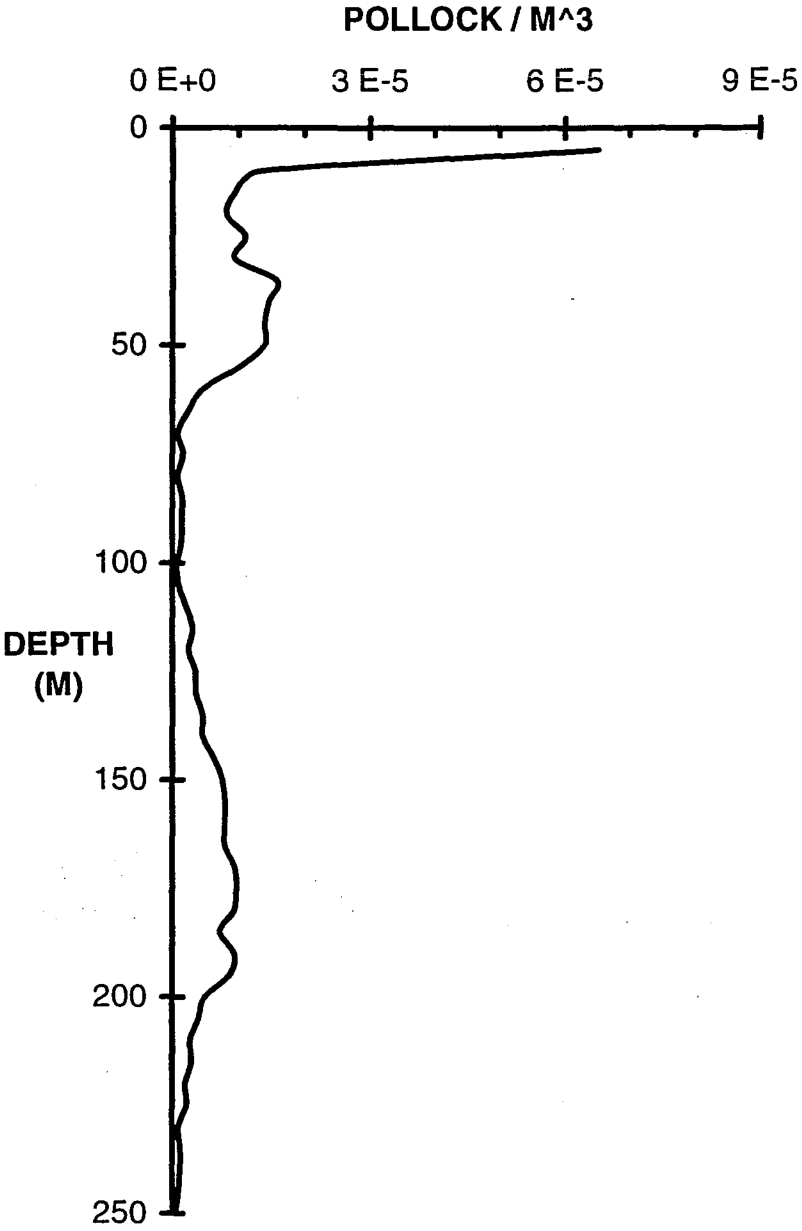


Fig. 17. Vertical distribution of pollock in Prince William Sound from nearshore acoustic surveys in June 1997.

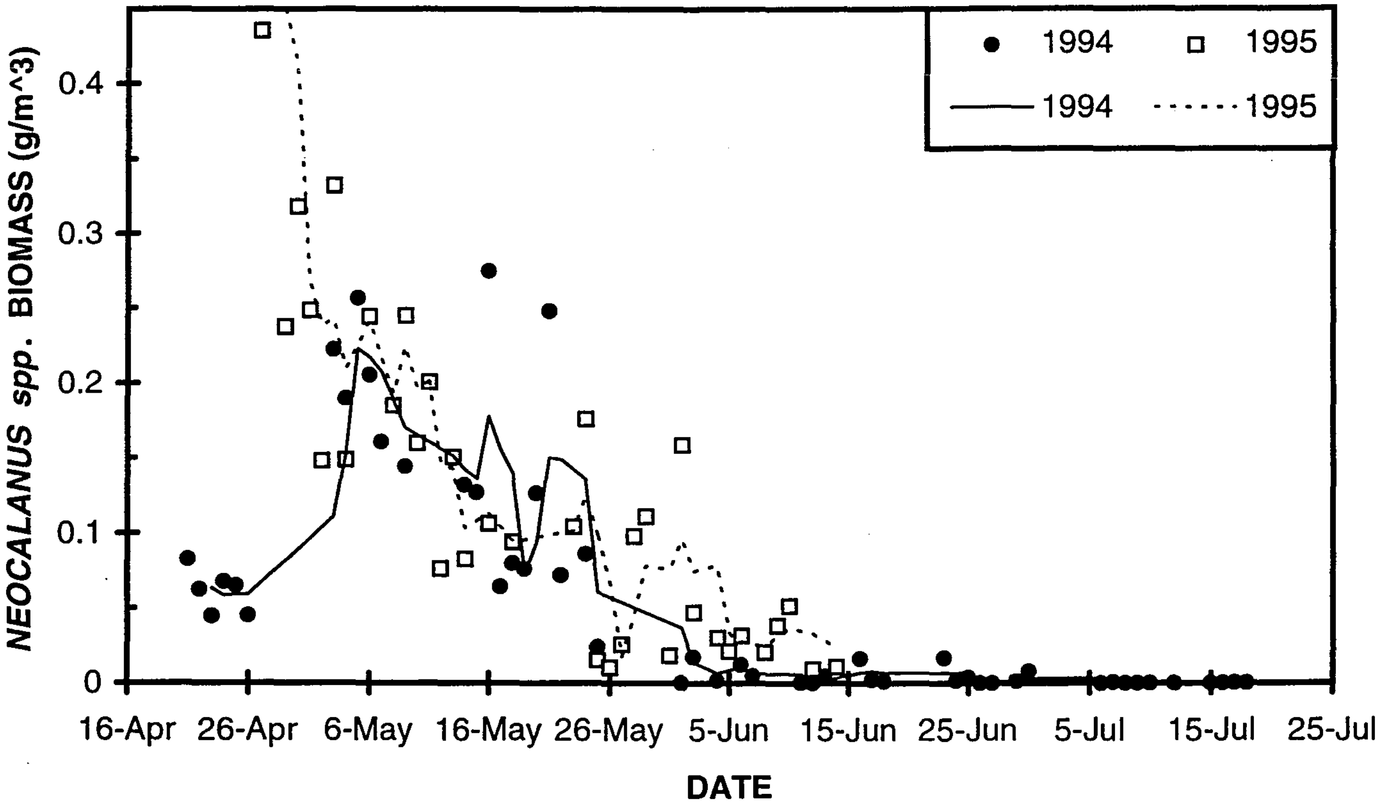


Fig. 18. Biomass of *Neocalanus spp.* in the top 50 m in Prince William Sound during 1994 and 1995. The lines are three-point running averages of 50 m vertical plankton tows (points).

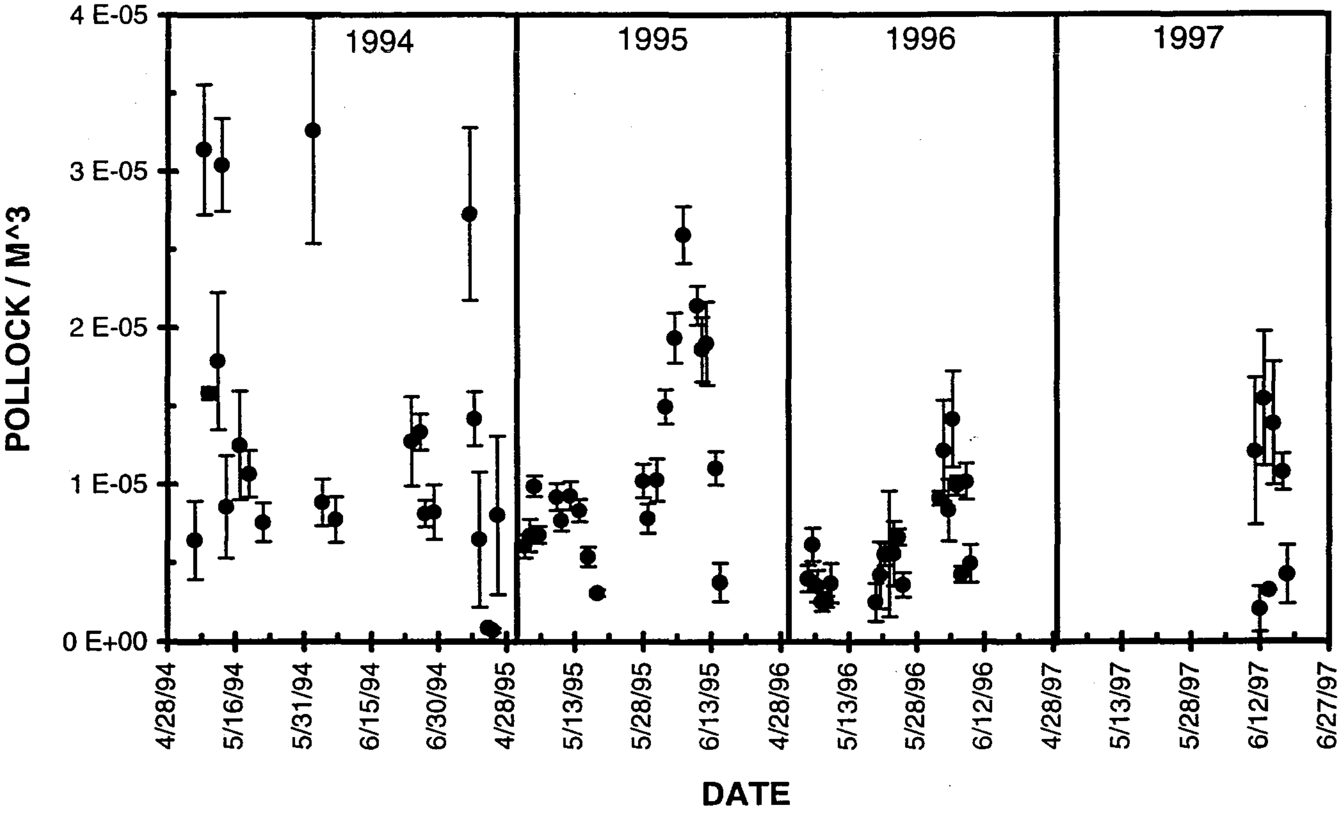


Fig. 19. Seasonal changes in pollock densities (± 1 S.D.) from 1994 to 1997. Note the general increase in pollock density within years, but the slight decline in pollock density between years.

CHAPTER 2

Co-occurring patches of walleye pollock (*Theragra chalcogramma*) and zooplankton in Prince William Sound, Alaska, USA. G. B. Steinhart, G. L. Thomas, and J. Kirsch.

ABSTRACT

The Sound Ecosystem Assessment (SEA) program is a multi-disciplinary effort to acquire an ecosystem-level understanding of Prince William Sound (PWS), Alaska. A primary SEA hypothesis is that adult walleye pollock (*Theragra chalcogramma*) switch from their primary food source, fish, to macro-zooplankton when plankton densities are high. We examined this hypothesis by making acoustic observations of fish and zooplankton during the spring of 1995. We found patches of plankton 50 m to 5 km long in the top 50 m of water. Net tows showed that these patches were over 90% calanoid copepods. Walleye pollock abundance was positively correlated with zooplankton abundance (r^2=0.26). Furthermore, copepods dominated the diet of pollock at this time. These results showed that walleye pollock were feeding on, and were attracted to macro-zooplankton patches in PWS. Environmental conditions that result in low macro-zooplankton densities, or prohibit the formation of dense plankton patches, could reduce feeding opportunities for pollock. When macro-zooplankton are not abundant, adult pollock may switch their diet to include more juvenile fish, which could reduce the survival of many important fish species.

INTRODUCTION

Walleye pollock (*Theragra chalcogramma*) are one of the most abundant fish species in Prince William Sound (Thomas et al. 1997). Acoustic surveys have estimated pre-spawning biomass of pollock at 38,000 to 44,000 tonnes (Thomas and Stables 1996; Kirsch 1997). Many previous studies have looked at the behavior, distribution, and abundance of pollock in the Gulf of Alaska (GOA) and the Bering Sea (Dwyer et al. 1987; Bailey 1989; Brodeur and Wilson 1996); however, little is known about the distribution and behavior of pollock in Prince William Sound (PWS). These previous studies have shown that pollock eat large numbers of young fish, including juvenile walleye pollock. Given their abundance in PWS, walleye pollock play a major role in the trophic structure of the Sound. As in the GOA and Bering Sea, juvenile pollock are important competitors with other planktivores and serve as a major food source for predators (Dwyer et al. 1987). Adult pollock are likely significant predators and could effect the recruitment success of other fish (Walters et al. 1986).

After the *Exxon Valdez* oil spill, stocks of pink salmon in Prince William Sound had highly variable recruitment success. Low returns of hatchery-released salmon in 1992 and 1993 were likely caused by poor survival during their outmigration from PWS (Willette et al. 1996). An assumption of Sound Ecosystem Assessment Program (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 one of the most abundant pelagic fish in PWS, are likely the primary predator of pink salmon fry (Willette et al. 1994). If there are approximately 25 million adult pollock (Thomas and Stables 1996; Kirsch 1997), and 750 million salmon fry in PWS (Thomas and Mathisen 1993), then salmon survival will be negligible if each pollock eats only 30 salmon fry per year. Therefore, it is not hard to imagine that predation by adult pollock could have a profound impact on salmon survival. This paper focuses on the spatial distribution of predators (pollock) and their prey (juvenile fish and zooplankton) to improve our understanding of the trophic dynamics of PWS.

Developing a better understanding or predator/prey interactions is a primary goal of the SEA project. Two primary hypotheses of SEA that relate to these interactions are: the Lake/River hypothesis and the Prey Switching hypothesis (Thomas et al. 1997). The Lake/River hypothesis describes conditions as cold, stormy and turbulent "river" years with lower zooplankton abundance, and fewer dense patches of zooplankton than warmer, calmer "lake" years. The SEA Prey Switching hypothesis predicts that as macro-zooplankton availability decreases, pollock will switch from eating primarily macro-zooplankton to feeding heavily on other large invertebrate prey and juvenile fish. To test these hypotheses, we initiated investigations of pollock behavior in relation to zooplankton abundance and distribution in PWS.

In this paper, we describe the spatial distribution of pollock and macro-zooplankton in western Prince William Sound. This line of research should lead to an increase in knowledge of the roles of predation in the trophic structure of PWS. Understanding the role of predation on juvenile fish survival is a critical step in improvement of predicting changes in fish populations in Prince William Sound.

MATERIALS AND METHODS

Prince William Sound is located at the northern edge of the Gulf of Alaska (Fig. 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 is exposed to seasonally intense storms moving in from the Gulf of Alaska, resulting in 5-7 m of annual rainfall.

In 1995, two surveys of PWS were conducted during 27 April to 1 May, and 23-27 May (Fig. 1). The cruises were designed to cover all major regions of the Sound. Sampling consisted of hydroacoustic surveys, mid-water trawls, and vertical plankton tows. All sampling was conducted during daylight hours.

Thirty vertical zooplankton tows were collected using a 0.5 m ring net with 333 μm mesh. The net was towed vertically through the top 50 m at several SEA oceanographic stations. The samples were preserved in a formalin solution. In the lab, the zooplankton were enumerated, measured, and identified to species. The mean length of each species was used to calculate the mean weight, and then multiplied by the number of individuals in the sample to yield biomass estimates.

Nine mid-water trawls performed during the two broadscale surveys to provide target verification for the acoustic sampling and to collect pollock for length, weight, and diet analyses. The trawl measured 40 m x 28 m and was equipped with a net. The cod end of the trawl was lined with 1.5 cm stretch-mesh to retain small specimens. The depth and location of the trawling was directed toward layers of fish to verify acoustic targets. The length of trawl hauls was approximately 30 min at depth. Fish from the catch were specified, weighed, measured, and had their stomachs removed and preserved in 10% buffered formaldehyde for later diet analysis.

Acoustic equipment

Acoustic data were collected using a BioSonics 101-120 kHz 6°/15° dual-beam echosounder. The transducer was mounted on a tow-body which was towed alongside the boat at a depth of 2 m at an approximate speed of 3 m/s. The parameters of the acoustic system were: source level = 225.023 dB; receiver gain = -159.282 dB; transducer directivity = 0.0010718; pulse width = 0.4 s. The acoustic system was calibrated before each cruise using a tungsten-carbide ball, of known target strength, suspended within the beam of the transducer (Foote and MacLennan 1982). The data were processed in real-time using BioSonics ESP software on a 486 computer and 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 a tape drive. Raw acoustic signals were stored on Digital Audio Tape and printed on paper echograms.

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 which applied the acoustic calibrations and corrected for absorption (temperature and salinity). After initial processing, we used software written to allow the user to interactively remove untracked bottom, calculate biomass estimates, and produce images of fish distributions.

Echo-counting of pollock-sized targets was chosen over echo-integration because the density of pollock was relatively low, so coincident targets would not cause the target discriminator to fail. Furthermore, dense plankton layers were present and by echo-counting we could easily remove acoustic scattering due to plankton layers from the acoustic data. Our echo-counting technique involved defining the range of possible target strengths that corresponded to an adult pollock-sized target. Targets between -39 dB and -28 dB were counted as pollock-sized targets. The echo-counting software then counted all qualifying targets, which were then divided by the sample volume of the acoustic beam, and averaged to yield densities in fish/m^3.

Multiple targets in the acoustic beam can effect the reliability of any echo-counting technique (Foote 1996). Multiple targets may either overlap just enough to cause the target discriminator to fail to recognize any of the multiple targets, or they may sum their individual returns to yield an artificially high single target strength. A test between the target discriminator and manual counts of pollock-sized targets showed that auto-counting underestimated the number of targets by 13-28 %. A similar comparison between echo-counting and echo-integration showed that echo-counting resulted in an underestimate of pollock density by 18-33 % for some surveys (Thomas et al. 1996).

To estimate zooplankton abundance from our acoustic data, we used echo-integration techniques. Mean backscatter for cells 5 m deep and approximately 50 m long (32 pings) were converted to zooplankton biomass after removing those cells that contained fish. To remove fish, we set a volume backscatter (Sv) threshold of -55 dB. This threshold was selected since there was an anti-mode in the Sv histogram around -55 dB. All cells above that threshold were assumed to contain fish, and were not included in our relative zooplankton estimate.

Once the acoustic data arrays for pollock-sized targets and plankton were generated, we analyzed the data from the top 50 m to look for spatial overlap between the two. A correlation between pollock-sized target densities and relative plankton biomass was performed. In addition, we looked at the differences in the range of densities and biomass between the patches.

RESULTS

Vertical net hauls revealed that the zooplankton community was comprised of several species, but was dominated by calanoid copepods: 87% in April and 68% in May (Fig. 2). *Neocalanus spp.* was the most abundant plankter during the April cruise, comprising over 70% of the total zooplankton biomass. By May, however, *Neocalanus spp.* accounted for only 24% of the total biomass and many other species contributed to the total biomass, most notably *Oikopleura spp.* (8%) and *Metridia spp.* (5%). Overall, zooplankton biomass declined significantly from April to May (df=25, t=2.22, p=0.018), largely due to the decline in *Neocalanus spp.* in the top 50 m.

Zooplankton not only were more abundant during the first cruise (Fig. 2), they were also more patchy. Zooplankton biomass estimates from net hauls ranged from 1.5-17 g/tow (σ=16.6) in April and 1.3- 14 g/tow (σ=1.5) in May. The variance in zooplankton biomass was significantly higher for the April cruise (F=11.31, p= 0.004). In addition, the variance in acoustic backscatter due to zooplankton was significantly higher during April (σ=389) than during May (σ=230; F=1.69, p<0.0001).

The zooplankton patches seen with the hydroacoustic system (Fig. 3) varied in size and biomass. Zooplankton patches averaged 1.5 km across, while patches as small as 100m, and as large as 5 km, were seen during the surveys. Zooplankton biomass estimates varied by about an order of magnitude when sampled with vertical net tows. The hydroacoustics, which have a finer spatial resolution than nets, found up to two orders of magnitude difference in acoustic backscatter attributed to plankton.

To better describe the composition of these patches, we compared the species compostion of the three highest biomass zooplankton tows and the three lowest biomass tows using χ^2-tests and t-tests. During the April cruise, the mean species composition of the three high biomass tows was not significantly different from the mean of all the tows (df=6, χ^2=2.4, p>0.25), but the mean composition of the three low tows was significantly different from the mean (df=6, $\chi^2=14.5$, $p<0.02$). The high biomass tows had significantly more copepods (df=4, t=2.55, p=0.03), and also had a higher percentage of copepods (90% versus 81%) than did the low biomass tows. There were no other significant differences in abundance of the other major zooplankton taxa.

In May, the mean species composition of the high biomass tows was significantly different from the mean of all the tows (df=6, $\chi^2=40.3$, $p<0.0005$). The low biomass tows, however, were not significantly different from the mean tows (df=6, $\chi^2=10.4$, $p>0.05$). The largest contributor to the significant difference was the increased number of pteropods found in the high biomass tows over the mean tows. In addition the high tows had significantly more pteropods (df=4, t=3.6, p=0.012), copepods (df=4, t=2.2, p=0.49), and *Oikopleura spp.* (df=4, t=7.9, p=0.007) than in the low biomass tows. Although there were more copepods found in the high biomass tows, they made up a lower percentage of the total count (82% versus 94%).

The mid-water trawl caught almost exclusively adult walleye pollock. In total, 596 pollock were caught and comprised 93% of the total catch. Additional fish captured included 31 lantern fish (Family Myctophidae), 9 sculpin (Family Cottidae), 2 capelin (*Mallotus villosus*), and 1 chinook salmon (*Oncorhynchus tshawytscha*). The lantern fish were caught in only 1 trawl towed at 125 m depth. The pollock averaged 508 mm fork length and 870 g wet weight. The predicted TS of these pollock was determined using TS=20Log (length) - 66 (Traynor and Williamson 1983). The predicted TS of these pollock overlapped the TS that we used to count pollock-sized targets (Fig. 4). Since pollock dominated the catch, and the other fish captured in the trawl would have target strengths too small to be counted by our echo-counter, we assumed that all pollock-sized targets observed were adult pollock.

In general, there appeared to be two layers of pollock during these cruises: a shallow layer (less than 20 m deep), and a deep layer around 150 to 200 m. The mid-water trawl had the highest catch per unit effort above 20 m, and caught very few pollock below 70 m; however, the trawl was not fished below 140 m (Fig. 5). The acoustics also showed that the highest density of pollock-sized targets was in the top 20 m (Fig. 6). The depth distribution changed between the two surveys: pollock were more abundant near the surface during the April cruise than during the May cruise. The acoustics also showed that there were pollock-sized targets deep in the water column during both cruises, but there were more pollock-sized targets in the deep layer during May.

Pollock stomachs were found to contain nearly 99 % zooplankton (by weight) in April and May (Fig. 7). In April, calanoid copepods, primarily *Neocalanus spp*, comprised 65 % of the stomach contents. In May, however, pteropods were the dominant prey item (43%), while less than 25 % of the diet consisted of copepods. Fish made up less than 1 % of pollock diets during both cruises.

We saw pollock-like targets associated with plankton patches on echograms during both surveys (Fig. 3) and we found a positive correlation between pollock density and relative zooplankton density during both surveys in 1995 (Fig. 8). The correlation coefficient was higher for the May cruise, and both correlation coefficients were significantly different from 0, but they did not explain much of the variation in pollock density (April: $r^2=0.26$, n=420, t=14.33, $p<0.0005$; May: $r^2=0.27$, n=145, t=8.5, $p<0.0005$).

We calculated the correlation between pollock density and zooplankton acoustic backscatter at various spatial scales: cells approximately 50 m to 10 km long. The correlation coefficient was highest when we used cells that were approximately 5 km long.

DISCUSSION

The highest densities of adult walleye pollock in Prince William Sound were found in the top 50 m, and were positively correlated with zooplankton biomass. This behavior may not be unique, but most previous work has shown that adult pollock remain deep in the water column, with only juveniles commonly found near the surface (Traynor 1986; Bailey 1989). We believe that the bulk of adult pollock in PWS feed near the surface in order to exploit the food resources found in the epilimnetic waters in the Sound. Salmon fry are abundant in the top 50 m during their spring out-migration, and are found in pollock diets. However, walleye pollock are so abundant in PWS that feeding exclusively salmon fry cannot sustain the pollock population. Therefore, zooplankton, found to compose the bulk of pollock diets during this study, are also an important food resource. We believe that zooplankton density has a major influence on pollock distribution in PWS. Our data show insight into how pollock are distributed relative to plankton, and will help determine the validity of the Lake/River and Prey Switching hypotheses (Cooney 1993).

The hypothesized migration of adult pollock northward into the Sound after spawning in the southwest corner of PWS is thought to be related to zooplankton distribution (Steinhart et al. 1997). We found a positive correlation between pollock density and relative zooplankton biomass during this study. Correlations between predators and prey are common in the literature (Rose and Leggett 1989; Rose and Leggett 1990; Veit et al. 1993; Deblois and Rose 1995), but correlation analysis does not prove a casual relationship. Pollock diets, however, were dominated by zooplankton, especially *Neocalanus spp.*. This demonstrates that pollock were feeding on plankton during our surveys. In order to maximize food intake, pollock would be expected in the presence of high plankton biomass.

Although zooplankton abundance only explained about 27% of the variation in pollock density that was observed, this type of spatial relationship can be difficult to quantify using simple correlation. Spatial associations between predators and their prey are notoriously weak, with correlation coefficients often less than 0.5 (Veit et al. 1993). Rose and Leggett (1990) suggest that positive correlations between predator and prey densities would occur at scales greater than the dimensions of the predator and prey aggregations. Predators, such as pollock, may be found close to their prey (zooplankton), but not right on top of them. For example, strong currents may concentrate plankton in some areas, but fish may avoid the strongest currents and feed on the edges of the aggregation. Indeed, we did find that the best correlation was when we pooled our acoustic data into 5 km bins. The relatively poor correlation could also be due to other variables that we haven't examined yet. The abundance of other prey items, such as fish, may also influence pollock distribution. Certain areas may also have physical conditions (temperature, oxygen, or currents) that may attract or repel pollock regardless of plankton abundance (Rose and Leggett 1990).

Observations during this study, as well as other research (Simard and Mackas 1989; Barange 1993), suggested that currents may influence zooplankton distribution and the co-occurence of pollock and plankton. Currents encountered during the survey effected plankton distribution by concentrating plankton in some areas, and resulted in varying depth distributions (Fig. 3). The effects of large-scale circulation and turbulence are unknown at this time, but may aid in the formation of dense concentrations of plankton, or may flush plankton into and out of PWS, thereby increasing or reducing the amount of food available for pollock within the Sound.

Neocalanus spp., along with many other marine copepods, undergo a seasonal vertical migration (Cooney 1987). In spring, young copepods migrate up from great depths to respond to the spring phytoplankton bloom. In summer, the matured copepods migrate down to 400 m where they spend the winter. There is also evidence that oceanic copepods enter near-shore and coastal waters in the spring (Incze et al. 1997). Since adult pollock can exploit the copepods as a food source, the seasonal changes in plankton abundance are likely the cause of the observed shifts in the distribution and diet of walleye pollock.

As *Neocalanus spp.* densities in the top 50 m declined from April to May, pollock switched both their diet and their depth distribution in PWS. This behavior pattern has been observed in other years (Willette et al. 1995; Willette et al. 1996). In 1994, as copepod densities in the top 40 m declined, the percent of age-0 fish and salmon fry in pollock diets increased. In addition, pollock moved deeper in the water column as plankton densities near the surface declined. This switch in diet, and the change in vertical distribution, are hypothesized to be related to plankton abundance and distribution.

We not only saw a general decline in copeopod abundance near the surface, but we also observed changes in zooplankton patch densities and species composition. During April, there were more dense patches of plankton, and more variability in plankton density, than in May. In April, the zooplankton patches were made up almost entirely of copepods. During May, however, there were fewer high density zooplankton patches, and less variability in plankton distribution. In May, the observed zooplankton patches may have been aggregations of species other than copepods, since there were lower percentages of copepods in high density tows than in low density tows. Pteropods, on the other hand, were much more abundant in the high density areas, and may have been forming the dense patches we observed during May.

The Prey Switching hypothesis states that in the absence of abundant zooplankton, pollock will switch to juvenile fishes, including salmon fry. During "lake" years, high zooplankton numbers and/or increased density of zooplankton patches may result in less predation pressure on juvenile fishes than during "river" years. However, even when zooplankton are abundant, or in dense patches, pollock may prefer to feed on small fish, including salmon fry but since there are relatively few of these prey, they don't show up as a significant proportion of the pollock diet. Although young fish made up less than 1% of pollock diets during this study, it is important to remember that individual pollock don't need to eat many salmon fry to have a profound effect on salmon survival give the large number of pollock found in the Sound. These observations support prey-switching on a seasonal time scale. The relationship between pollock and zooplankton suggests that annual differences in zooplankton availability should affect the extent of seasonal prey switching, thus causing inter-annual variability. Tying the availability of macro-zooplankton to turbulence, primary production and migration/emigration, and observing inter-annual differences are the subject of the ongoing SEA research.

Our present results, however, may be confounded by several sources of error. The small sample volume of the acoustic beam at short ranges, combined with the near surface distribution of pollock may have underestimated pollock densities. In addition, target strengths of fish are highly variable and depend on many factors (Traynor and Williamson 1983; Mukai and Iida 1996). A fish swimming upward or downward within the acoustic beam may be tilted, and thus presents a smaller cross-section to reflect the acoustic signal. Furthermore, an echo from a fish that is only partially within the acoustic beam may also underestimate the target's size. The reduced acoustic backscatter would lead to an underestimate of pollock density since some fish would not meet the -39 dB criteria for a pollock-sized target. Coincident targets, which will increase in frequency with depth also cause the target discriminator to fail. Furthermore, boat avoidance by pollock near the surface may be a problem. These potential errors will all lead underestimate the number of pollock-sized targets.

Further research is needed, and we are currently improving on our estimates of plankton and fish using acoustic technologies. We are using digital transducers to provide a much finer spatial resolution in our data. This will allow us to more easily remove fish from the echo-integration array, thus providing more accurate zooplankton estimates. Furthermore, we are using multiple frequencies to separate fish targets from plankton targets. The results of this work should clarify some of the results we saw during our April and May surveys in 1995. In addition, by sampling repeatedly over several years, we will be able to more completely examine the SEA hypotheses. How inter-year variability in climatic conditions relates to plankton abundance, pollock diets, and salmon survival will increase our ability to correctly manage and sustain the fisheries in Prince William Sound.

ACKNOWLEDGMENTS

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 processing the zooplankton and trawl data. A special thanks goes to Mark Willette (ADF&G) for sharing his data on pollock diet and to R. Ted Cooney (UAF) for the plankton data. This work is supported by the *Exxon Valdez* Oil Spill Trustee Council, Grant No. 96320-N and 97320-N as part of the Sound Ecosystem Assessment project.

LITERATURE CITED

Bailey, K. M. 1989. Interaction between the vertical distribution of juvenile walleye pollock *Theragra chalcogramma* on the eastern Bering Sea, and cannibalism. Mar. Ecol. Prog. Ser. **53**: 205-213.

Barange, M. 1993. Acoustic identification, classification and structure of biological patchiness on the edge of the Agulhas Bank and its relation to frontal features. S. Afr. J. Mar. Sci. **14**: 333-347.

Brodeur, R. D., and M. T. Wilson. 1996. Meso-scale acoustic patterns of juvenile walleye pollock (*Theragra chalcogramma*) in the western Gulf of Alaska. Can. J. Fish. Aquat. Sci. **53**: 1951-1963.

Cooney, R. T. 1987. The seasonal occurrence of *Neocalanus cristatus, Neocalanus plumchrus* and *Eucalanus bungii* over the shelf of the northern Gulf of Alaska. Continental Shelf Res. **5**: 541-553.

Cooney, R. T. 1993. A theoretical evaluation of the carrying capacity of Prince William Sound, Alaska, for juvenile Pacific salmon. Fisheries Research, **18**: 77-88.

DeBlois, E. M., and G. A. Rose. 1995. Effect of foraging activity on the shoal structure of cod (*Gadus morhua*). Can. J. Fish. Aquat. Sci. **52**: 2377-2387.

Dwyer, D. A., K. M. Bailey, and P. A. Livingston. 1987. Feeding habits and daily ration of walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea, with special reference to cannibalism. Can. J. Fish. Aquat. Sci. **44**: 1972-1984.

Ehrenberg, J. E., and D. W. Lytle. 1972. Acoustic techniques for estimating fish abundance. Trans. Geosci. Elec. GE-10: 138-145.

Foote, K. G. 1996. Coincidence echo statistics. J. Acoust. Soc. Am. **99**: 266-271.

Foote, K. G., and D. N. MacLennan. 1982. Use of elastic spheres as calibration targets. p. 52-58. In O. Nakken and S. C. Venema [eds.], Symposium on fisheries acoustics. ICES/FAO. Bergen, Norway.

Grant, U. S., and K. F. Higgins. 1910. Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska. U.S. Geological Survey Bulletin. No. 443. 89 pp.

Incze, L. S., D. W. Siefert, and J. M. Napp. 1997. Mesozooplankton of Shelikof Strait, Alaska: abundance and community composition. Continental Shelf Res. **36**: 287-305.

Kirsch, J. 1997. Acoustic biomass estimate of adult walleye pollock in Prince William Sound, Alaska, in winter 1997. Report to the Alaska Department of Fish and Game. Prince William Sound Science Center. Cordova, AK.

Mukai, T. and K. Iida. 1996. Depth dependence of target strength of live kokanee salmon in accordance with Boyle's law. ICES J. of Marine Sci., **53**: 245-248.

Rose, G. A. and W. C. Leggett. 1989. Interactive effects of geo-physically forced sea temperatures and prey abundance on mesoscale coastal distributions of a marine predator, Atlantic cod (*Gadus morhua*). Can J. Fish. Aquat. Sci. **46**: 1904-1913.

Rose, G. A. and W. C. Leggett. 1990. The importance of scale to predator-prey spatial correlations: an example of Atlantic fishes. Ecology **71**: 33-43.

Simard, Y and D. L. Mackas. 1989. Mesoscale aggregations of euphausiid sound scattering layers on the continental shelf of Vancouver Island. Can. J. Fish. Aquat. Sci. **46**: 1238-1248.

Steinhart, G. B., G. L. Thomas, and J. Kirsch. 1997. Seasonal and diel movements of walleye pollock (*Theragra chalcogramma)* in western Prince William Sound. Restoration Project 95320N. *Exxon Valdez* Oil Spill Trustee Council. Anchorage, Alaska.

Thomas, G. L. and Mathisen. 1993. Biological interactions of natural and enhanced stocks of salmon in Alaska. Fish. Res. **18**: 1-18.

Thomas, G. L. and T. B. Stables. 1996. Winter 1995 estimates of the prespawning biomass of walleye pollock in Prince William Sound, Alaska. Report to the Alaska Department of Fish and Game. Prince William Sound Science Center. Cordova, AK.

Thomas, G. L., J. Kirsch, and T. McLain. 1996. Sound Ecosystem Assessment: nekton-plankton acoustics second annual report, 1996. Restoration Project 95320N. *Exxon Valdez* Oil Spill Trustee Council. Anchorage, Alaska.

Thomas, G. L., E. V. Patrick, J. Kirsch, and J. R. Allen. 1997. Development of an ecosystem model for managing the fisheries resources of Prince William Sound. pp. 606-613. D. C. Smith, A. Grant, and J. P. Beumer [eds.], Developing and sustaining world fisheries resources. CSIRO. Collingwood, Australia.

Traynor, J. J. 1986. Midwater abundance of walleye pollock in the eastern Bering Sea, 1979 and 1982. Int. North Pac. Fish. Comm. Bull. **45**: 121-135.

Traynor, J. J., and N. J. Williamson. 1983. Target strength measurements of walleye pollock (*Theragra chalcogramma*) and a simulation study of the dual-beam method.

Proceedings of the Symposium on Fisheries Acoustics. FAO Fish. Rep. No. 300: 112-124.

Walters, C. J., M. Stocker, A. V. Tyler and S. J. Westerheim. 1986. Interaction between pacific cod (*Gadus macrocephalus*) and herring (*Clupea harengus pallasi*) in the Hecate Strait, British Columbia. Can J. Fish. Aquat. Sci. **43**: 830-837.

Willette, T. M., G. Carpenter, P. Shields, and S. Carlson. 1994. Early marine salmon injury assessment in Prince William Sound. *Exxon Valdez* Natural Resource Damage Assessment Program, Final Report, Alaska Department of Fish and Game. Anchorage, AK.

Willette, T. M., E. Debevec, and J. Johnson. 1995. Sound ecosystem assessment: salmon predation. . *Exxon Valdez* Oil Spill Restoration Project Annual Report (Restoration Project 94320E). Alaska Department of Fish and Game. Anchorage, AK.

Willette, T. M., M. Clapsadl, P. Saddler, and M. Powell. 1996. Sound Ecosystem Assessment: salmon and herring integration. Restoration Project 95320E. *Exxon Valdez* Oil Spill Trustee Council. Anchorage, AK.

Veit, R. R., E. D. Silverman, and I. Everson. 1993. Aggregation patterns of pelagic predators and their principal prey, Antarctic krill, near South Georgia. J. Anim. Ecol. **62**: 551-564.

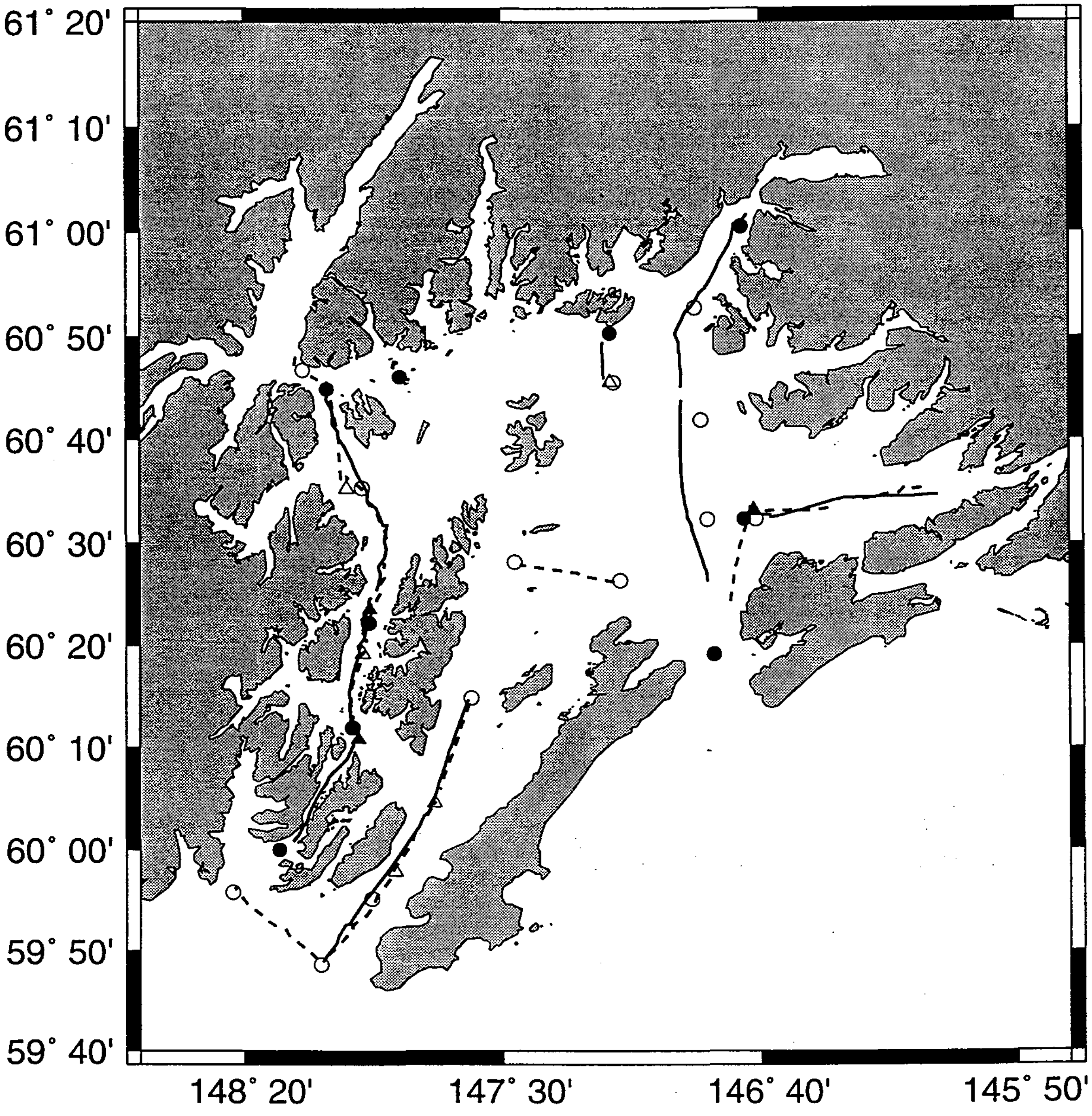


Fig. 1. Map of Prince William Sound showing sampling locations of acoustic transects from April (dashed lines) and May (solid lines) 1995. Also shown are zooplankton tows (circles) and trawls (triangles) from April (empty symbols) and May (filled symbols) 1995.

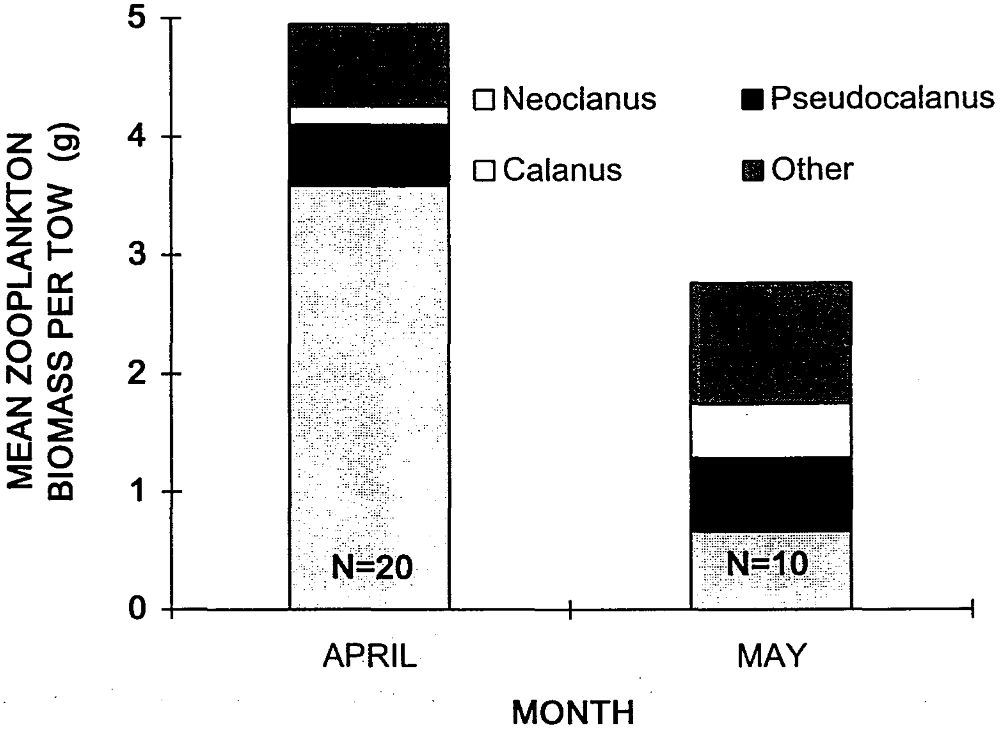


Fig. 2. Zooplankton biomass by species from the top 50 m of Prince William Sound for April and May 1995.

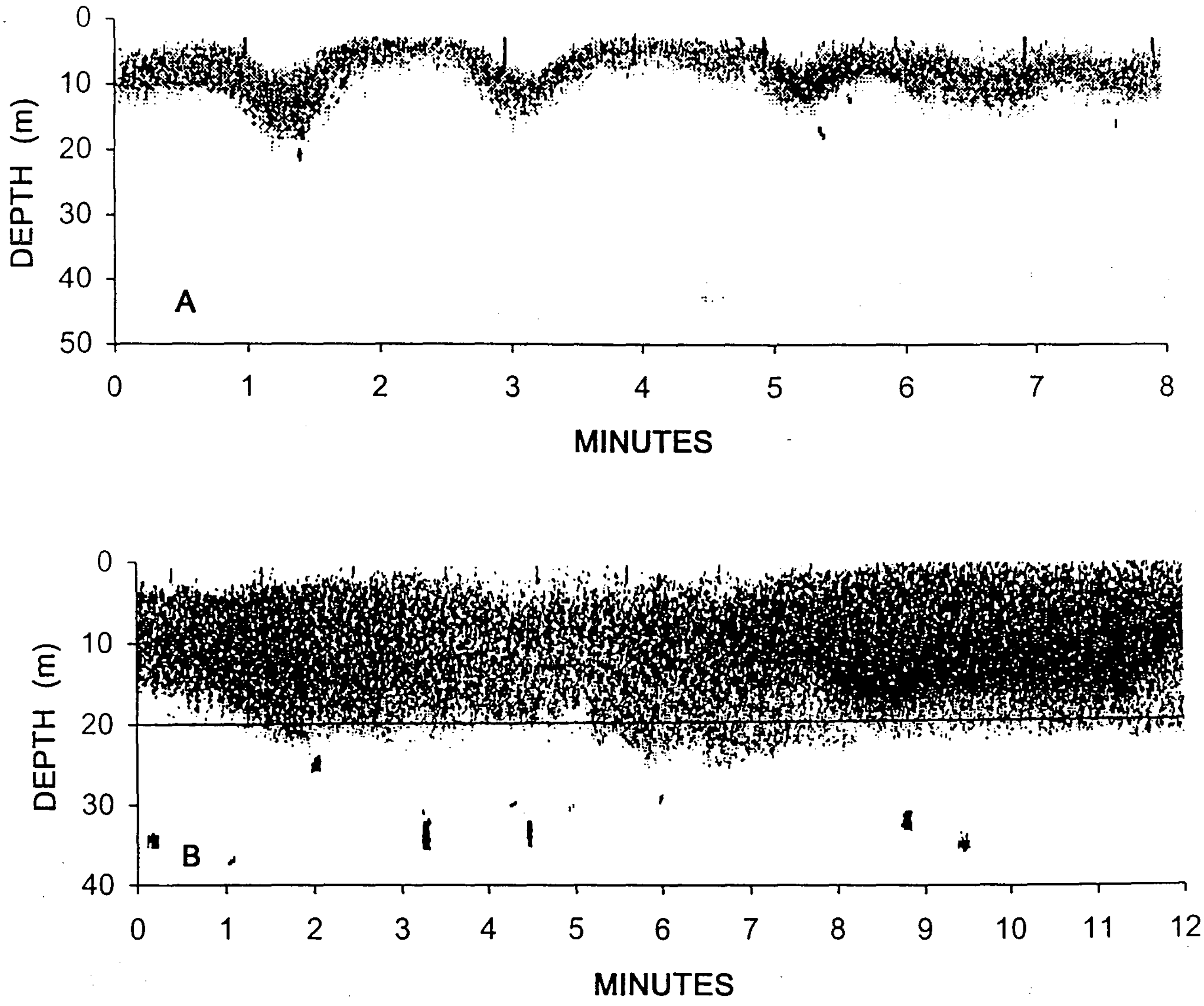


Fig. 3. Paper echograms from two transects during April 1995 showing: A) Plankton layer with varying depth and density due to localized currents; B) Plankton patch with pollock-sized targets associated with areas of high density.

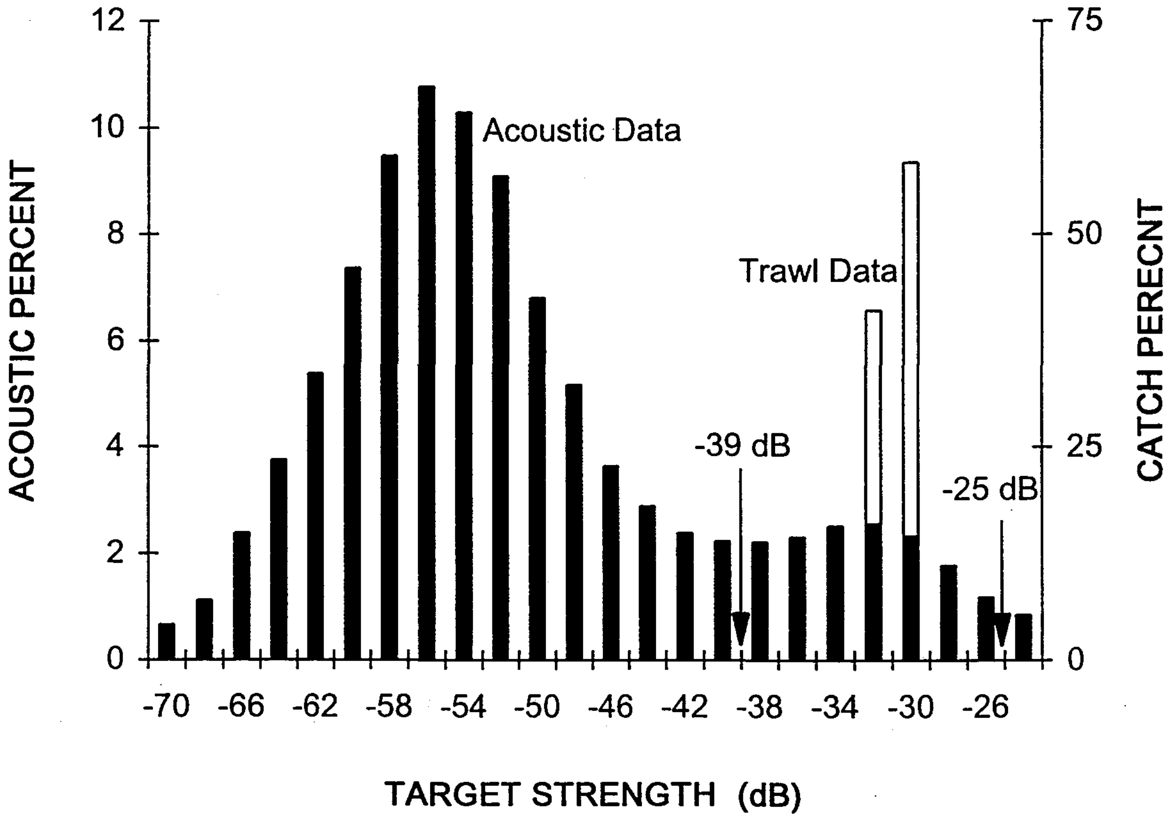


Fig. 4. Target strength (TS) frequencies from acoustic data files (black bars) and estimated TS from walleye pollock captured in the mid-water trawl in Prince William Sound during April and May 1995. Estimated TS were calculated using 20Log (length) - 66 (Traynor and Williamson 1983). The arrows mark the range of TS values that were used to produce estimates of pollock density.

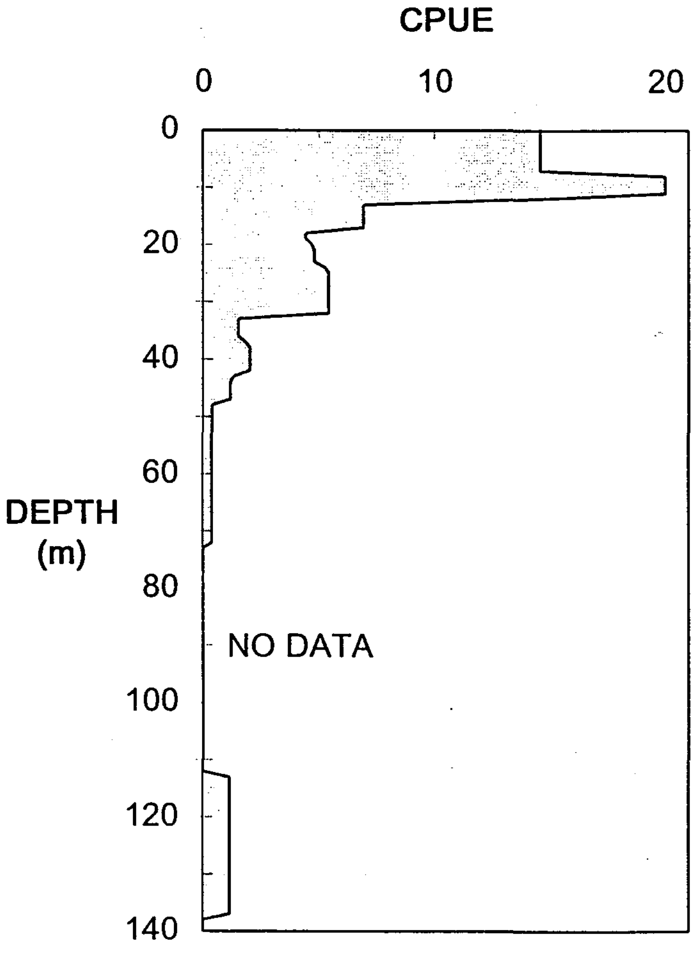


Fig. 5. Catch per unit effort of adult pollock from nine mid-water trawls performed in Prince William Sound in April and May 1995. There were no trawls between 73 and 122 m, or deeper than 138 m.

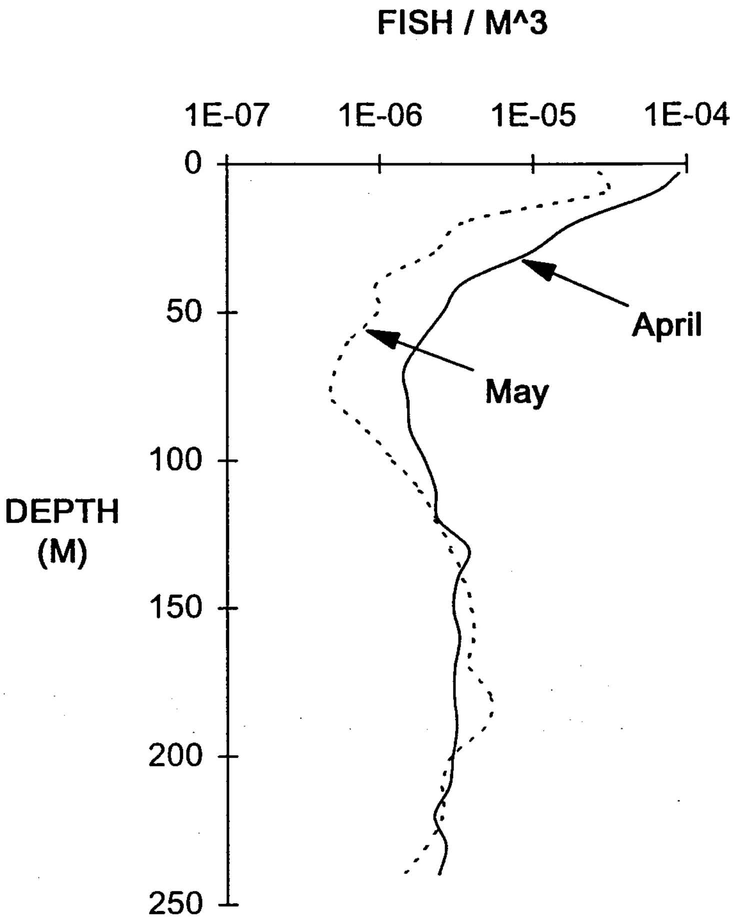


Fig. 6. Depth distribution of pollock-sized targets from acoustic data collected in Prince William Sound during April and May 1995.

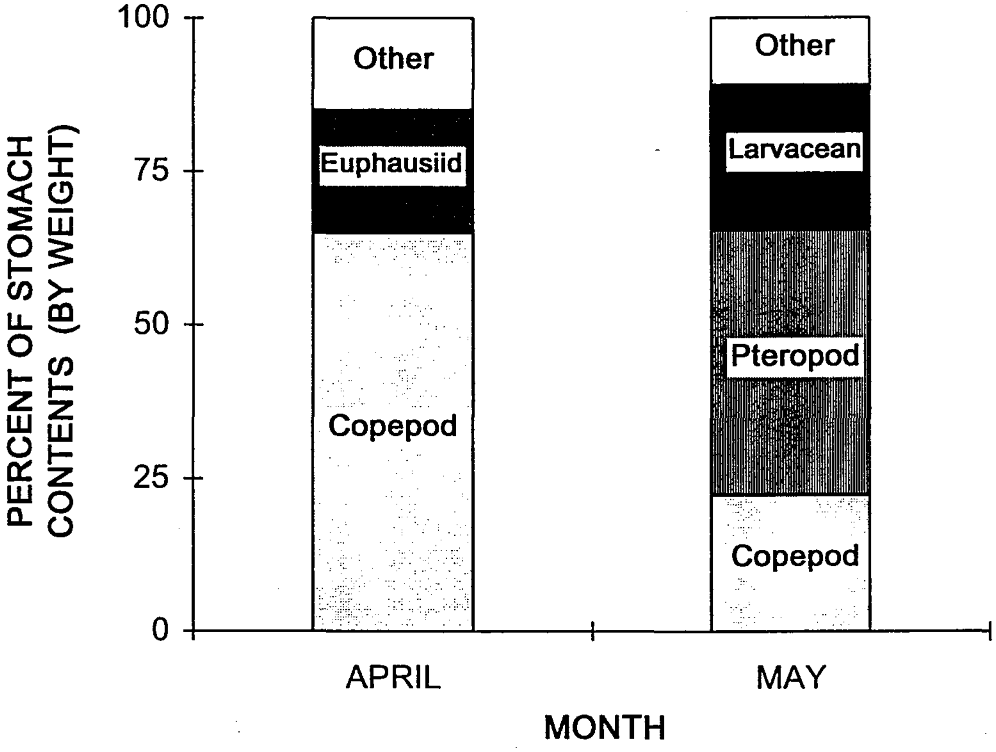


Fig. 7. Adult pollock diet composition (percent by weight) in April and May 1995 in Prince William Sound.

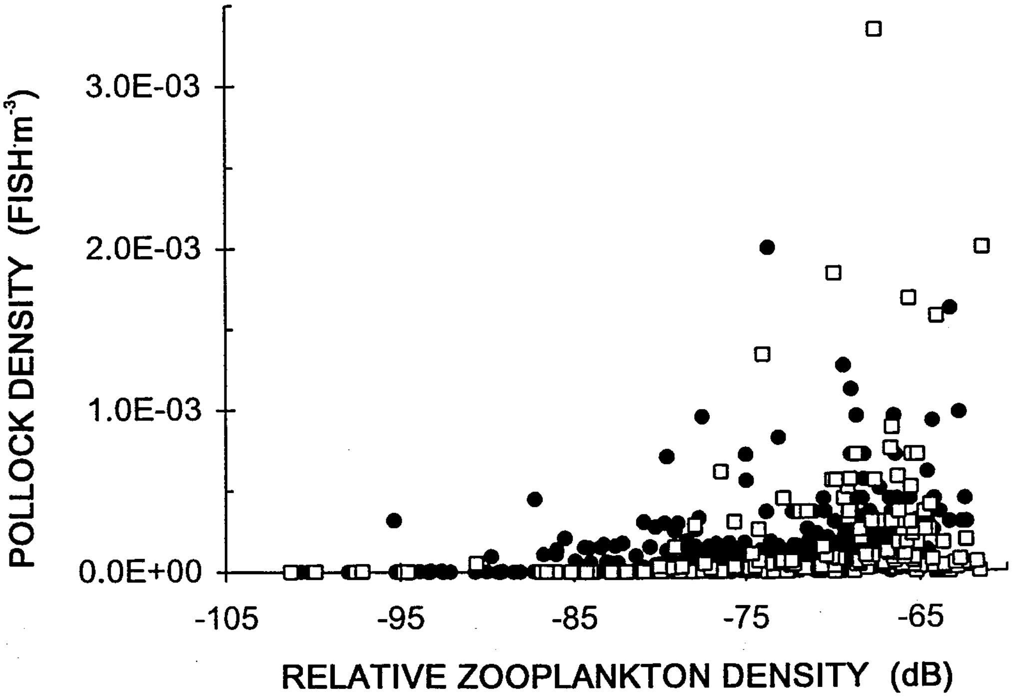


Fig. 8. Relationship between pollock density and relative zooplankton density (acoustic backscatter) in Prince William Sound from cruises in April (filled circles) and May (empty squares) 1995.

CHAPTER 3

Preliminary analysis of the nearshore distribution and abundance of Pacific herring (*Clupea pallasi*) and pelagic rockfish in western Prince William Sound. G. B. Steinhart, G. L. Thomas, J. Kirsch, and M. Blair

ABSTRACT

We used acoustics to measure abundance and distribution of many fish species in nearshore environments in western Prince William Sound (PWS) in 1994. We found that both pelagic rockfish (*Sebastes spp.*) and Pacific herring (*Clupea pallasi*) were present in many of the areas we surveyed. In addition, aggregations of these predacious fish were easily identifiable in the acoustic data as tall loosely aggregated targets above peaks and slopes (rockfish) an as dense school or balls in open water (herring). Since both rockfish and herring are predators of pink salmon (*Oncorhynchus gorbuscha*) fry, we analyzed the acoustic data to produce estimates of pelagic rockfish and herring. We found the highest number of rockfish in rocky areas along Culross Island and in the southwest passages. Herring were most abundant in the southwest passages.

INTRODUCTION

Stocks of pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound (PWS) have had highly variable recruitment success since the Exxon-Valdez oil spill. The cause of this variable recruitment is still under debate. One focus of the Sound Ecosystem Assessment (SEA) Project has been to model pink salmon survival. An assumption of SEA, that was adapted from GLOBEC, is that salmon fry do not die by starvation, but that all mortality is the result of being eaten. The Nekton/Plankton acoustics project has attempted to quantify the numbers various fish species in the Sound. Meanwhile, personnel at the Alaska Department of Fish and Game (ADF&G) have measured diet compostion of these predators. Until recently, it was believed that most of the fry losses by predation have been due to predation by walleye pollock (*Theragra chalcogramma*). There is no doubt that pollock are one of the most abundant fish species in Prince William Sound; however, SEA research has not yet concluded that all salmon mortality is due to pollock predation. In fact, diet analysis on other fish species, such as rockfish and herring, have shown that many other fish species are eating salmon fry (Willette et al. 1997). The goal of this work was to re-analyze the acoustic data to quantify numbers of both pelagic rockfish and Pacific herring.

MATERIALS AND METHODS

Study site

Prince William Sound (PWS) is located at the northern edge of the Gulf of Alaska (Fig. 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 data used for this analyses were from the 1994 nearshore surveys. The surveys were conducted during the day throughout western PWS (Fig. 2). There were 5 cruises where usable acoustic data were collected: 02o (5/5-5/9/94), 03o (5/19-5/25/94), 04o (6/2-6/11/94), 05o (6/18-6/29/94), and 06o (7/10-7/18/94). Zig-zag transects were made within 0.5 NM of the shoreline in Wells, Perry, and Knight Island Passages, Montague Straight and the Southwest passages (Thomas et al. 1996). Many of these transects were repeated in the various cruises; however, not all cruises surveyed all transects. Data were collected with a BioSonics 102-200 kHz dual beam echosounder.

For most surveys, transects were marked on paper and/or electronic charts to allow repetition of the same transect at a later date. 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 transducer was 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 a BioSonics 102-200 kHz dual-beam transducer. The data were processed in real-time using ESP software on a 486 laptop computer. A Magellan 5000 DX GPS receiver with an external antenna was used to geo-reference the data, or to record the cruise track in a separate database. 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.

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, more IDL software was used to interactively remove untracked bottom, and to calculate density and biomass estimates.

Our data processing consisted of two major steps: target classification and target counting or echo-integration summing (Fig. 3). Hydroacoustic data can be successfully partitioned into different species based on knowledge of fish behavior, distribution and size (Rose and Leggett 1998; Richards et al. 1991). Rockfish were easily identifiable as clumps of targets on pinnacles and slopes (Wilkins, 1986; Starr et al. 1996; Fig. 4). Herring typically form tight schools, or balls, which were also easily identified (Fig. 5). We identified targets that appeared to be either rockfish or herring using information on the paper echograms, known fish behavior and distribution, electronic target echograms, and net catch data. We then interactively selected on those targets using software written by J. Kirsch in IDL (Fig. 6).

Due to differences in behavior and distribution, we processed the rockfish and herring acoustic data using different techniques. For the rockfish data, we used an echo-counting method that summed the number of identified targets in a transect, and then divided by the sample volume of the acoustic beam, to compute mean density for each transect. Herring biomass was calculated using echo-integration, since the target discriminator often failed to identify all targets in the dense herring schools (Thomas et al. 1997). We converted echo-integration voltages (V^2) to biomass density using mean herring length at each site, and the acoustic calibration (K_{equip}) using the following equations:

[1] $\text{TS re: weight} = 6\text{Log}_{10}\text{Length}_{(mm)}-18$ (Thorne 1983)

[2] $\sigma/W = 10^{(\text{TS re: weight})/10}$

[3] $\text{Biomass density} = (V^2/K_{equip})(W/\sigma)$.

Rockfish densities ($\#/m^3$) and herring biomass (kg/m^3) were then summed to the surface and to provide aerial densities ($\#/m^2$) and biomass (Kg/m^2) . The mean rockfish density and mean herring biomass for each site were calculated by taking the weighted mean of all transects at a particular site during a single survey. Transect length (the number of reports) was used as the weighting factor. Once weighted rockfish densities and herring biomass were calculated for each site, the data were multiplied by the area sampled during the acoustic survey. This yielded estimates of the total number of rockfish, and the total tonnage of herring at each site.

RESULTS

Rockfish

Rockfish distribution was highly variable in the western portion of Prince William Sound in 1994 (Fig. 7). We found the most rockfish, an estimated 8750 fish, on the eastern shore of Culross Island in late May. The southwest passages (sites 8, 9, 10) and sections of Knight Island Passage (sites 13, 14, and 15) also had large numbers of pelagic rockfish. In contrast, few rockfish were found near Esther Island. When data from all sites were combined, we found mean rockfish densities of $9.3e^{-08}$ fish/m^3 in late May, $1.4e^{-06}$ fish/m^3 in early June, $4.4e^{-07}$ fish/m^3 in late June, and $1.4e^{-06}$ fish/m^3 in mid July. After accounting for the area surveyed during these cruises, we measured a total of approximately 400 rockfish in late May, 11,000 in early June, 7,000 in late June, and 21,000 in mid July, in the surveyed nearshore environments.

Herring

Herring abundance was also highest in the Southwest passages (Fig. 8). The largest concentrations of herring were seen in Prince of Wales Passage (sites 7 and 8), where we found approximately 3800 tonnes in late June and 1400 tonnes in mid July. Very few herring were seen north of Knight Island Passage. When all the data from each cruise were pooled, we estimated total herring biomass in the surveyed nearshore environments to be: 30 tonnes in early May, 200 tonnes in early June, 5,000 tonnes in late June, and 2,500 tonnes in mid July.

DISCUSSION

In general, there we found fewer rockfish and herring in the northwest portion of the Sound, than in the southwest passages. This distribution primarily reflects the habitat available in these areas, but since these surveys were not designed to specifically measure the abundance of these species, and therefore did not take habitat into consideration during their design.

There are several characteristics of rockfish distribution that make an accurate estimate of their numbers using acoustics difficult. First, rockfish are typically found over rocky substrates, often over pinnacles and slopes (Moulton 1975; Murie et al. 1994). In addition, rockfish do not often swim vast distances, instead opting to stay within a small, well defined area. The highly variable nature of rockfish distribution means intensive sampling relative to substrate must be conducted to insure an adequate number of samples (Adams et al. 1995). Although these surveys covered vast areas of shoreline, the actual percent of the shoreline and bottom sampled directly by the acoustic beam was relatively small and the surveys were only conducted once per cruise. This may result in misleading results, since a transect may just miss passing over several clumps of rockfish gathered above pinnacles. A subsequent survey may pass over the pinnacles, providing a more accurate sample of the rockfish population.

To overcome this problem, we propose to do a more in depth analysis of the data by defining suitable rockfish habitat, estimating the total amount of suitable habitat, and quantifying rockfish densities within those habitats. Future surveys should be designed with closely spaced repeated transects to reduce the error due to the discrete spatial variability of rockfish.

Many species of rockfish remain very close to the bottom (Starr et al. 1996). We believe the rockfish-like targets we identified were pelagic rockfish, such as the black rockfish (*Sebastes melanops*) and the widow rockfish (*S. entomelas*); however, even these pelagic species are also found close to the bottom, especially during high tidal flows (Moulton 1975). Current hydroacoustic equipment does not have the ability to resolve targets that are resting on, or extremely close, to the bottom. In combination acoustic and submersible surveys along the Oregon coast, it was estimated that the submersible surveys accounted for approximately one-third of the rockfish population (Starr et al. 1996). This portion of the population was missed by the acoustic surveys. Rockfish behavior, and the limitations of current acoustic systems, will generally result in an underestimation of rockfish abundance. This error may be minimized in the future by using digital echo-sounders, which have higher resolution, and by timing surveys so they do not take place during periods of high tidal flow.

Measuring herring abundance with acoustics can also be problematic. During the day, herring often for dense schools near the surface. These school can be relatively small, and could have been missed in the small volume of water sampled. Furthermore, herring schools near the surface are very spooky, and often avoid approaching boats. This problem can be at least partially overcome by doing acoustic surveys at night, when herring are often not as densely schooled during the day. Boat avoidance can also be reduced during periods of low light, however the fish do respond to boat noise, which cannot be eliminated during nighttime surveys. The use of side-scanning sonar in future surveys will allow us to measure the degree of boat avoidance by herring,

In conclusion, our data from the 1994 nearshore surveys are some of the most intensive sampling of the western portion of Prince William Sound. From these surveys, it appears that rockfish and herring were more abundant in the southwest passages than near Esther Island. Rockfish were also abundant in Knight Island Passage. Numbers and biomass of these species appeared to increase later in the year. These data should be further analyzed to provide more accurate estimates of both rockfish and herring populations in order to more accurately quantify the potential losses of salmon fry to predation by these fishes.

ACKNOWLEDGMENTS

We would like to thank all the captains and crews of all the fishing and research vessels that helped us collect these data. Without their knowledge and experience, this research would not have been possible. Thanks to Tom McClain and Paul Salomone for their collection of the acoustic data. We would also like to thank the Alaska Department of Fish and Game, and the University of Alaska-Fairbanks, for they were responsible for analyzing the catch data. This work was supported by the *Exxon Valdez* Trustee Council, Grant Nos. 94320-N and 97320-N.

REFERENCES CITED

Adams, P. B., J. L. Butler, C. H. Baxter, T. E. Laidig, K. A. Dahlin, and W. W. Wakefield. 1995. Population estimates of Pacific coast groundfishes from video transects and swept-area trawls. U. S. Fish. Bull. **93**: 446-455.

Grant, U. S. and K. F. Higgins. 1910. Reconnaissance of the geology and mineral resources of Prince William Sound, Alaska. U.S. Geological Survey Bulletin. No. 443. 89 pp.

Murie, D. J., D. C. Parkyn, B. G. Clapp, and G. G. Krause. 1994. Observations on the distribution and activities of rockfish, *Sebastes* spp., in Saanich Inlet, British Columbia, from the *Pisces IV* submersible. U. S. Fish. Bull. **93**: 313-323.

Richard, L. J., R. Kieser, T. J. Mulligan, and J. R. Candy. Classification of fish assemblages based on echo integration surveys. Can. J. Fish. Aquat. Sci. **48**: 1264-1272.

Rose, G. A., and W. C. Leggett. 1988. Hydroacoustic signal classification of fish schools by species. Can. J. Fish. Aquat. Sci. **45**: 597-604.

Starr, R. M., D. S. Fox, M A. Hixon, B. N. Tissot, G. E. Johnson, and W. H. Barss. 1996. Comparison of submersible-survey and hydroacoustic-survey estimates of fish density on a rocky bank. U.S. Fish. Bull. **94**: 113-123.

Thomas, G. L, J. Kirsch, G. B. Steinhart, and N. Peters. 1997. SEA: Nekton-plankton acoustics second annual report, 1996. Restoration Project 96320N. *EXXON VALDEZ* Trustee Council. Anchorage, Alaska. 120 pp.

Thorne, R. E. 1983. Assessment of population abundance by hydroacoustics. Bio. Ocean. **2**: 253-262.

Wilkins, M. E. 1986. Development and evaluation of methodologies for assessing and monitoring the abundance of widow rockfish, *Sebastes entomelas*. U.S. Fish. Bull. **84**: 287-310.

Willette, M., M. Clapsadl, P. Saddler, and M. Powell. 1997. SEA: Juvenile Salmon Predation annual report, 1996. Restoration Project 96320E. *EXXON VALDEZ* Trustee Council. Anchorage, Alaska.

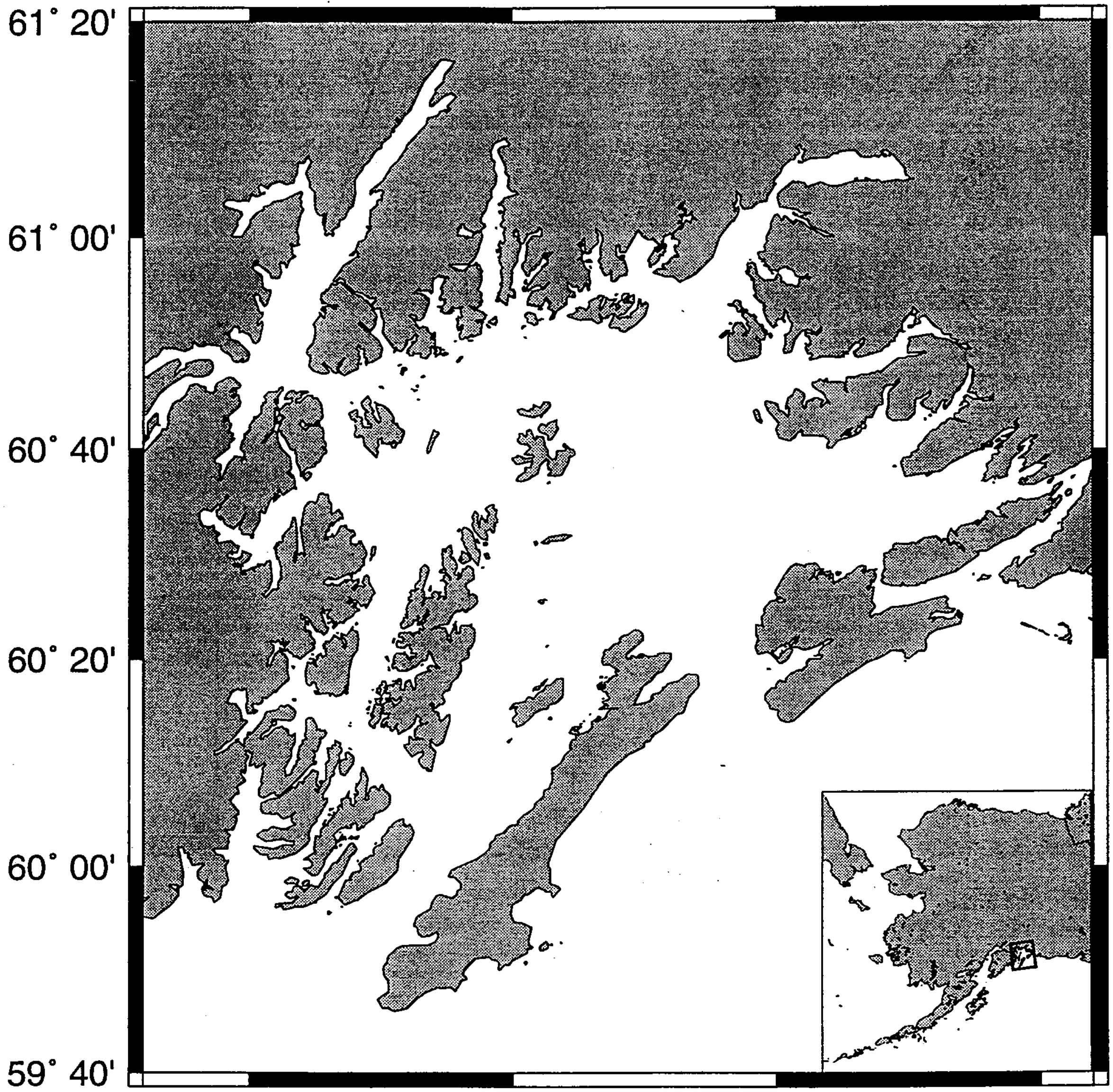


Fig. 1. Map of Prince William Sound, Alaska, USA.

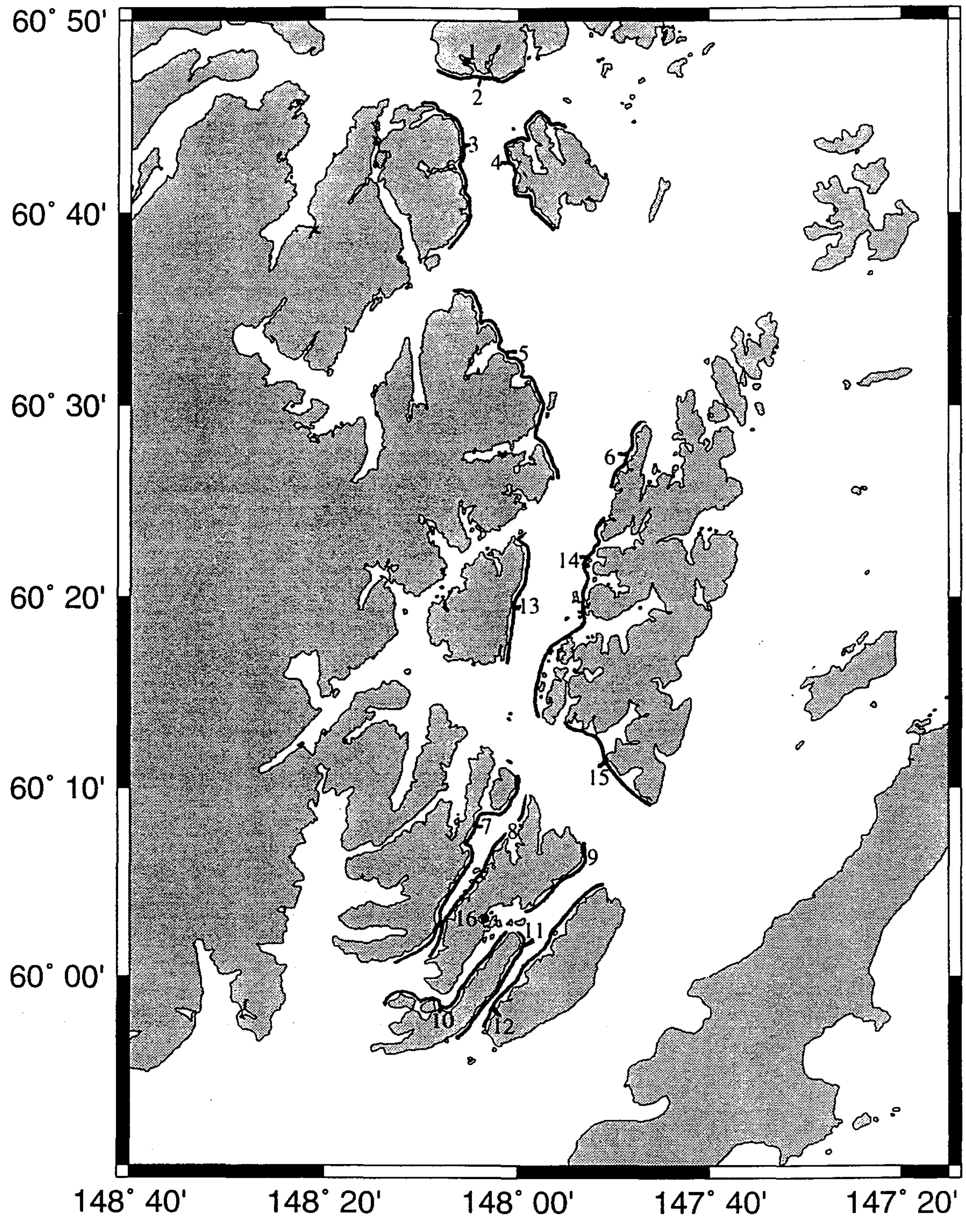


Fig. 2. Map of western Prince William Sound showing the nearshore areas surveyed in 1994.

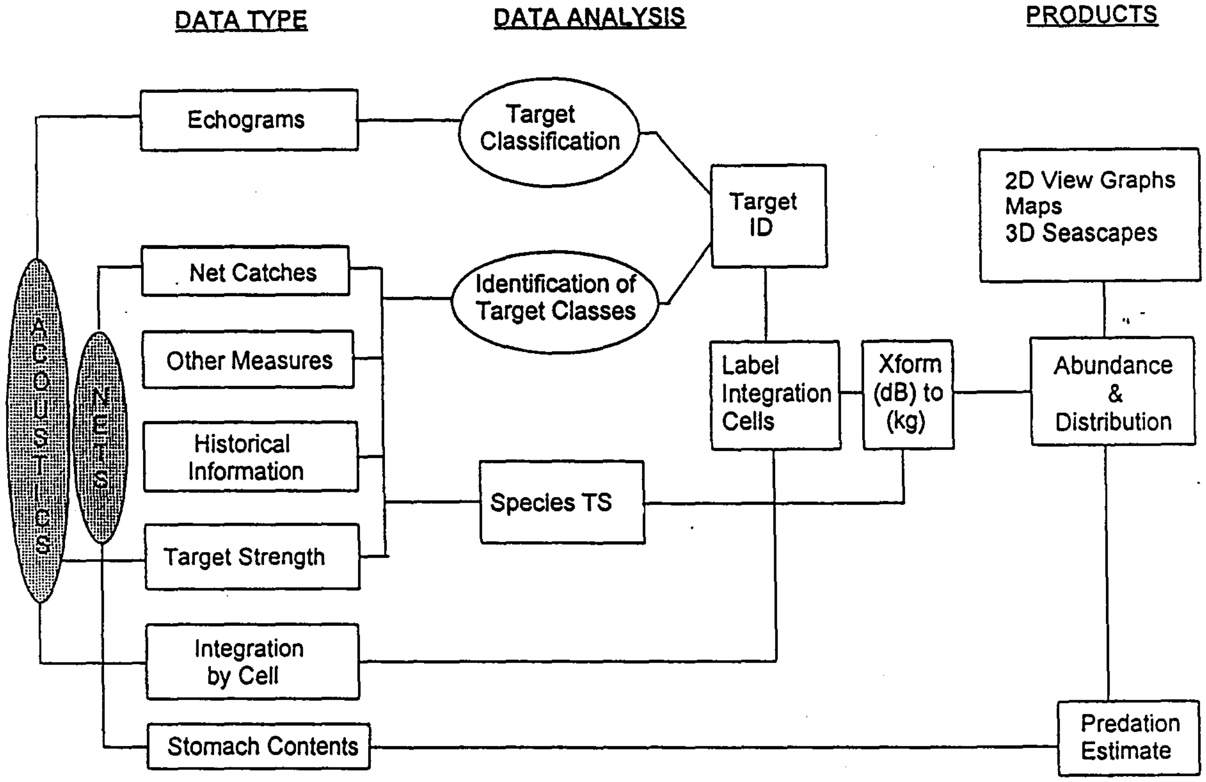


Fig. 3. Flow chart of data processing steps used in analysis of SEA acoustic data collected in 1994-97.

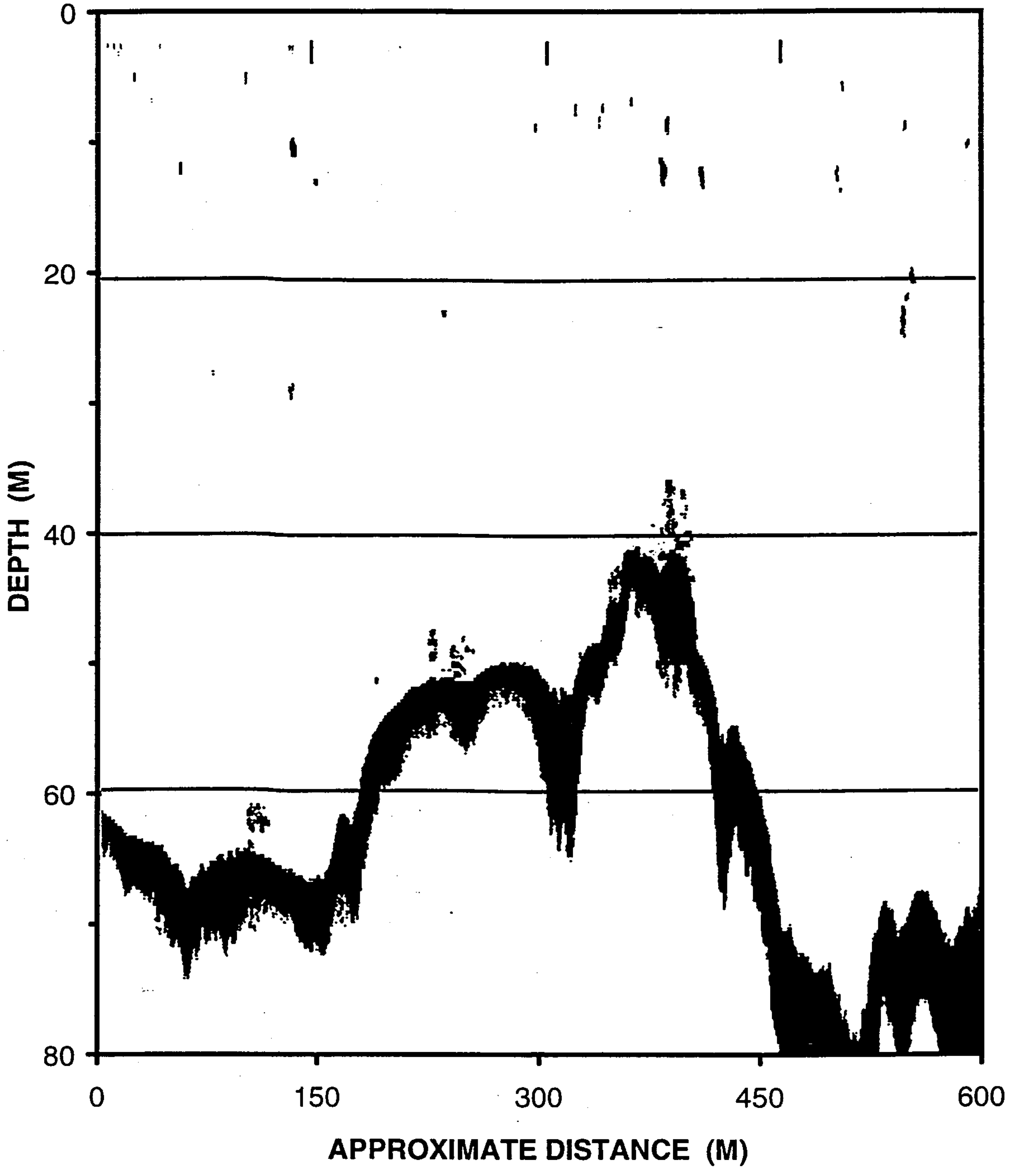


Fig. 4. A paper echogram showing several rockfish from an acoustic survey in Sawmill Bay, 1994. Rockfish are clearly visible as clumped targets 0-10 m above the bottom, especially near pinnacles and slopes.

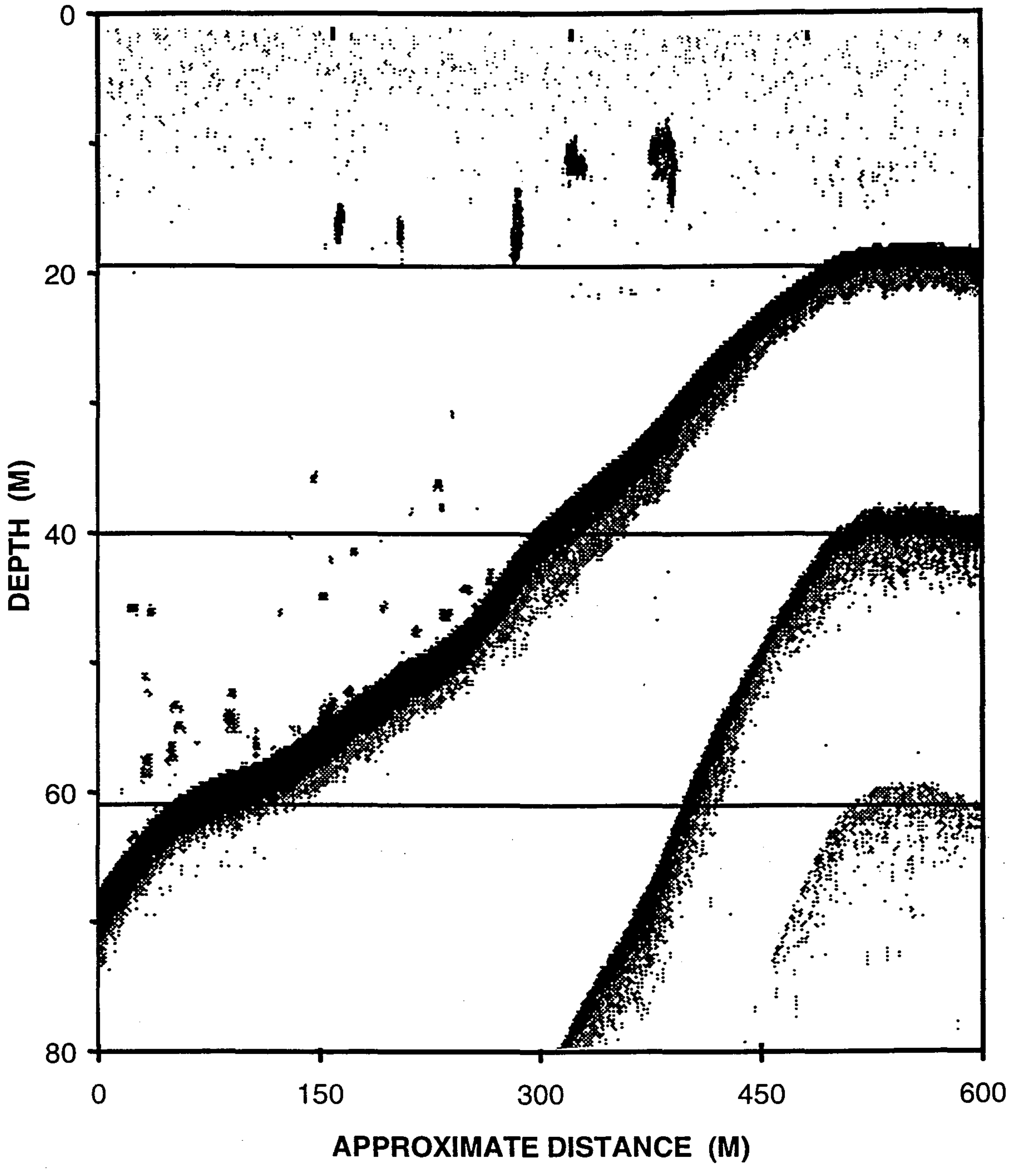


Fig. 5. A paper echogram showing several herring schools from an acoustic survey in Prince of Wales Passage, 1994. Herring typically form dense schools, as seen in the top 20 m of this transect.

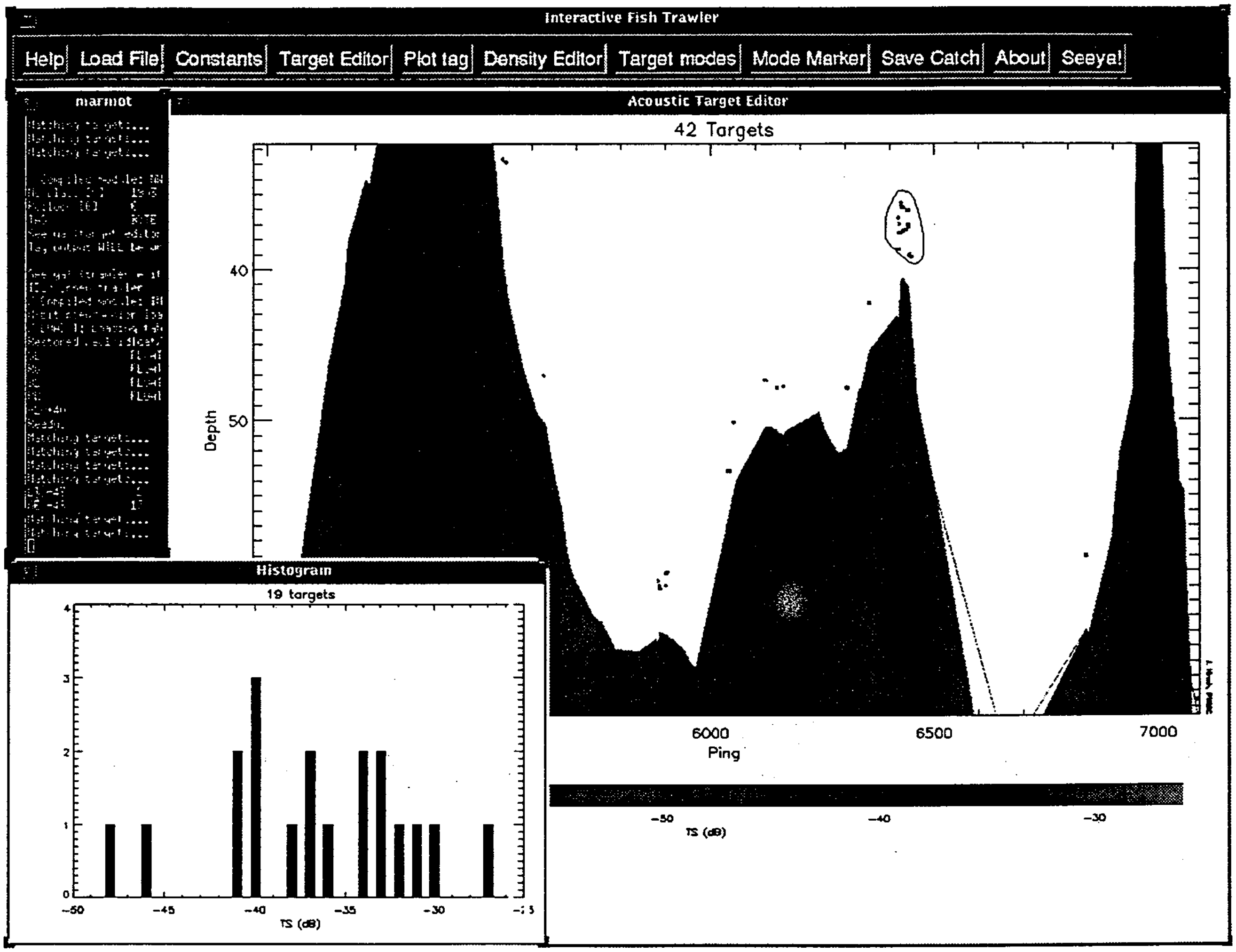


Fig. 6. We used software written by J. Kirsch to interactively select and classify targets. In this picture, the user has selected a group of rockfish swimming above a pinnacle. These date are from the same transect pictured in Fig. 4.

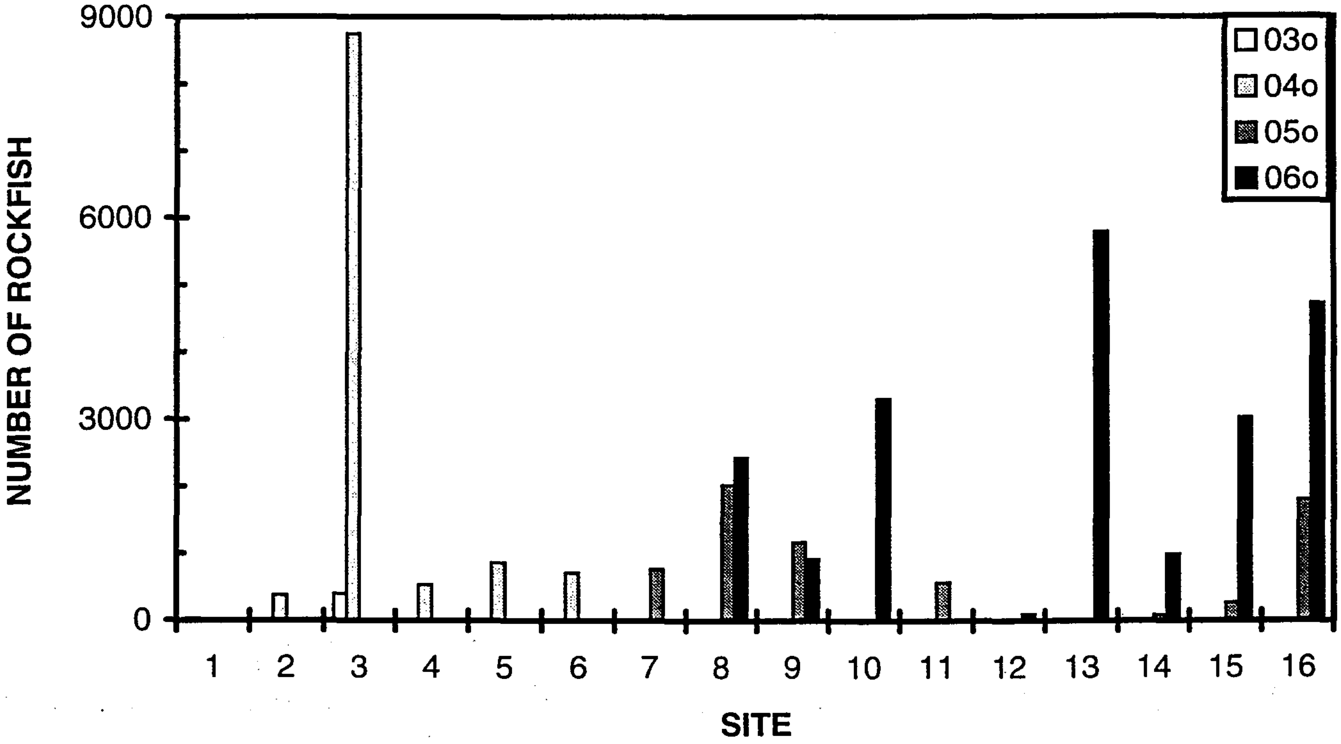


Fig. 7. Weighted mean rockfish numbers from 1994 nearshore surveys. See Fig. 2 for exact site locations.

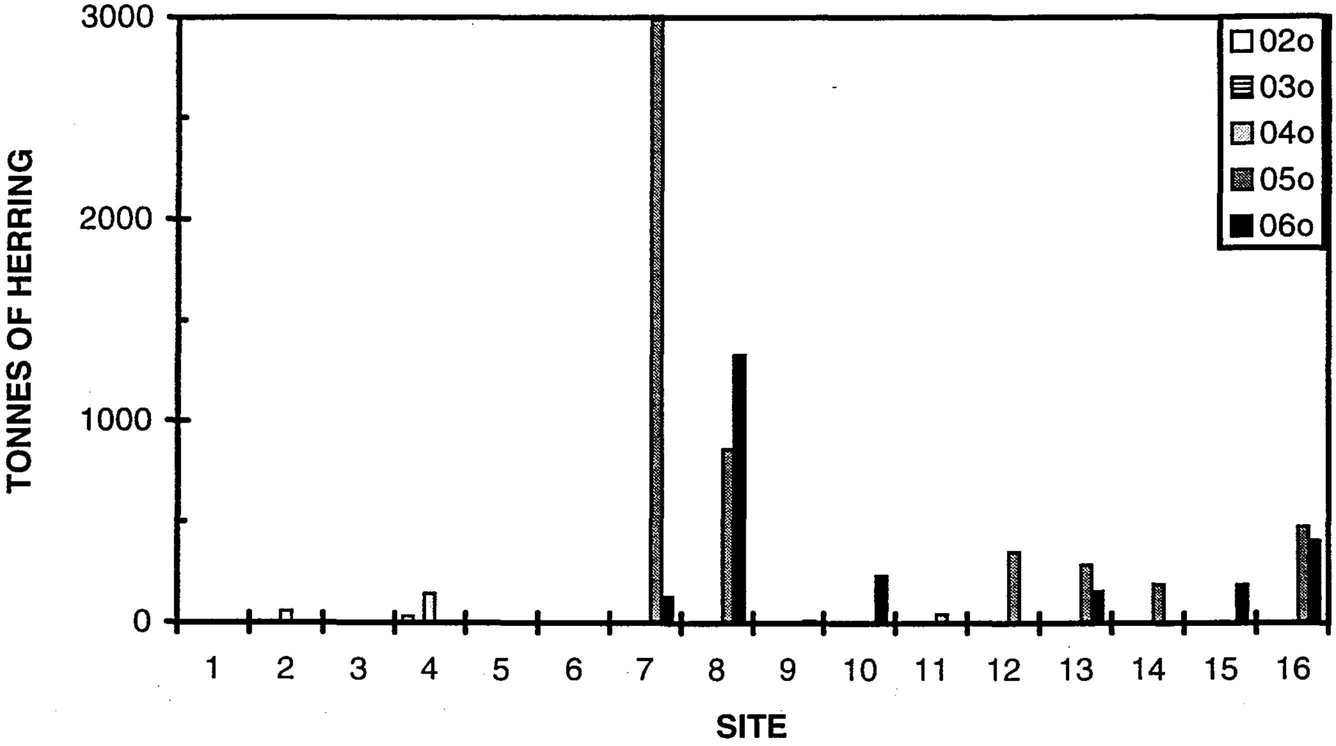


Fig. 8. Weighted mean herring tonnage from 1994 nearshore surveys. See Fig. 2 for exact site locations.

CHAPTER 4

The preliminary fusion of acoustical and optical data with net catch information to assess zooplankton distributions in Prince William Sound, Alaska. L.B. Tuttle, J. Kirsch, R.T. Cooney, and G.L. Thomas

ABSTRACT

The Sound Ecosystem Assessment (SEA) is a multi-investigator project designed to identify the primary physical and biological factors that affect the production of pink salmon and Pacific herring in Prince William Sound (PWS), Alaska. As part of this assessment, research cruises were conducted to describe the abundance and patchiness of zooplankton in PWS using high-frequency acoustics, an optical plankton counter (OPC), and a multiple-sample zooplankton net, as well as instruments to measure temperature, salinity, and fluorescence. The high-resolution, continuous sampling provided by the acoustics and optics showed that zooplankton aggregate in layers and patches throughout PWS, and that Hinchinbrook entrance had relatively high densities in both 1995 and 1996. In regions where *Neocalanus* copepod dominates the biomass, the optics and acoutics showed similar patterns, but in regions with high pteropod biomass, the acoustics estimate more biomass than the optics.

INTRODUCTION

The Sound Ecosystem Assessment (SEA) program was established to identify the primary factors that affect the production of pink salmon and Pacific herring in Prince William Sound (PWS). An understanding of how zooplankton production varies over space and time is important in achieving an ecosystem-level model of PWS since zooplankton is an important link between primary production and the upper trophic levels. The purpose of this research is to describe the abundance and patchiness of zooplankton using high-resolution, continuous-sampling methods. *Neocalanus* spp. constitutes much of the zooplankton biomass during the spring bloom in PWS.

In 1993 on the Scotian shelf, Herman et. al. used an OPC coupled with acoustics and a BIONESS multiple-net sampler to estimate euphausiid abundance. The acoustic and OPC abundances agreed within a factor of two or better. However, Herman (1992) found that in areas with high zooplankton species diversity, separation of individual species is difficult. Sensitivity to zooplankton below 0.5 mm is limited by marine snow, chain-forming phytoplankton, and other detritus in the water column. Because of these problems, the agreement of the OPC and nets was only 30%.

Recent advances in zooplankton scattering models allowed us to predict backscatter for a given species composition and density. Target strength is dependent on animal size, material, orientation, and transducer frequency (Stanton et al 1993, Stanton et al 1994, Stanton et al 1996). These models allow us to compare net catch and acoustic backscatter quantitatively.

METHODS

Broadscale cruises were conducted in both 1995 and 1996 to survey zooplankton in Prince William Sound and north Gulf of Alaska (Figure 1).

1995

A BioSonics 101-120 kHz dual-beam sonar mounted on a tow fin measured scattering layers from 3 m to 50 m depth. Echo signals were acquired on a laptop computer, and were echo-integrated into arrays of volume backscatter S_V. A Chelsea Instruments Aquashuttle was undulated from surface to 50 m depth. The Aquashuttle includes a Chelsea CTD and fluorometer, and a Focal Instruments Optical Plankton Counter (OPC). The CTD collected temperature and salinity data, the fluorometer measured chlorophyll concentrations, and the OPC counted and measured particles in the water.

A ½ meter ring net with .333 mm mesh was deployed at oceanographic stations throughout PWS. At each site, the net collected zooplankton from 50 m to the surface.

1996

A BioSonics DT 420 kHz digital sonar mounted on a tow fin measured scattering layers from 3 m to 50 m depth. Echo signals were acquired on a laptop computer, and were later echo-integrated into arrays of volume backscatter S_V. Data were collected using a Chelsea Instruments Aquashuttle using the same methods as in 1995.

A Multiple Opening and Closing Net and Environmental Sensing System (MOCNESS) net with .333 mm mesh was deployed at 24 sites along the cruise track. At each site, 8 nets collected zooplankton at separate depths, from 50 m to the surface. A flow meter indicated sampled volume, allowing absolute density to be calculated.

RESULTS

The results here are preliminary, as work is still in progress. Acoustic and Aquashuttle data analysis is more complete for 1996 because of the refinement of sampling methods. Data for 1995 are currently being analyzed for comparison.

1995

Figure 2 shows the geographical distribution of acoustic backscatter in 1995. Highest scattering levels were found in the north-central PWS and Hinchinbrook Entrance.

Biomass data from vertical net stations for al zooplankton species are displayed in Figure 3.

Biomass is highest in north-central and northwest PWS in April 1995. In May, biomass remains high in north-central PWS, but the highest biomass is found in the Knight Island Pass region.

1996

Figure 4 presents data from a series of transects on May 2, 1996 in Knight Island Passage, heading from south to north. The top panel illustrates the high-resolution acoustic backscatter, showing patchy distribution of layers ranging from 3 to 25 m. The second and third panels show the oscillating tow track of the Aquashuttle, with layers of chlorophyll (second panel) and *Neocalanus*-sized particle counts (third panel), which correspond well with the acoustic backscatter layers.

Figure 5 presents a series of transects in Montague Strait, from north to south on May 6, 1996. The acoustic backscatter layer is strongest to the south, ranging from 3 to 20 m, on average. Conversely, the strongest chlorophyll layers are seen in northern Montague Strait, concentrated between 10 and 40 m, with a corresponding *Neocalanus*-sized particle layer.

Figure 6 shows the geographical distribution of acoustic backscatter. Highest scattering levels were found in the Gulf of Alaska, Hinchinbrook Entrance, and southern Montague Strait.

Biomass data from MOCNESS stations for stage 5 *Neocalanus*, the pteropod *Limacina helicina,* euphausiids, and stage 4 *Neocalanus* are displayed in Figures 7-10, respectively. Neocalanus biomass is highest in northwest PWS and from Hinchinbrook Entrance into the central sound. Euphausiid biomass is highest in Montague Strait and Orca Inlet, while the highest pteropod biomass is found at the south end of Montague Strait.

Although not discussed here, plots of the remainder of the 1996 data set (days 2,3,4,6,7,8,9) are printed as an appendix.

DISCUSSION

In 1996, regions where pteropod and euphausiid biomass was low, the high-frequency acoustics and the Optical Plankton Counter were able to detect the same patchy horizontal and vertical distributions of the plankton layers, which included concentrations of *Neocalanus*-sized particles. Conversely, in regions where pteropod or euphausiid densities were high, the acoustics and OPC were in disagreement. Target strengths (TS) of pteropods, because of their rigid shell, are much higher than copepod TS. The TS of euphausiids are also higher than copepods, due to their larger average sizes. Higher TS causes these species to be much more visible to the acoustics, while the OPC has difficulty seeing these species due to their larger sizes.

In most cases, there is a good correspondence between the layers of chlorophyll measured by the fluorometer, and the concentration of *Neocalanus*-sized particles. This is expected since *Neocalanus* must incorporate energy from the phytoplankton before it leaves the surface waters to enter diapause at depth in late spring.

Figure 11 shows a comparison of the distribution of volume backscatter S_V between 1995 and 1996. This higher acoustic backscatter indicates higher zooplankton densities in 1995, with increased variability. Also, differences in predicted target strength (TS) seen in figure 12 (Stanton) indicate that the 1995 acoustic density are actually higher than the estimates shown. More work will be required to resolve these differences as acoustical or ecological.

FUTURE WORK

We maintain that acoustic and optical instrumentation offers the promise of high-resolution, large-scale monitoring of patchy plankton populations in PWS. But there is further work to increase the accuracy of the instruments.

As an example, the flow of water through the opening of the OPC is affected by the pitch of the Aquashuttle. Figure 13 shows the density estimations plotted against the pitch for the 9 days of the Alpha Helix cruise. The slope is consistently negative, and the data points are bimodal, indicating the high pitch may have reduced the water flow, and therefore particle flow, available to the OPC.

Alignment of these data over space and time, and synthesis with the species and density data from the nets, lead to an understanding of the biases of the instrumentation, and of the ecology of zooplankton in PWS. These data will then be assimilated into bio-physical models of PWS being developed as part of SEA.

ACKNOWLEDGEMENTS

This work would not have been possible without the captain and crew of the Alpha Helix. Ken Coyle and Elizabeth Stockmar counted and measured the MOCNESS samples. This work was supported by EVOSTC, through Sound Ecosystem Assessment (SEA) projects 9x320-N, 9x320-M, and 9x320-H.

REFERENCES

Exxon Valdez Trustee Council, Restoration Plan, 1995

Grant, U.S., and D.F. Higgins. 1910. Reconnaissance of the geology and mineral resources of Prince Williams Sound, Alaska. U.S. Geological Survey Bulletin. 443:1-89.

Herman, A.W. 1988. Simultaneous measurement of zooplankton and light attenuance with a new optical plankton counter. Contin. Shelf Res. 8:205-221.

Herman, A.W. 1992. Design and calibration of a new optical plankton counter capable of sizing small zooplankton. Deep Sea Res. 39:395-415.

Herman, A.W., N.A. Cochrane, D.D. Sameoto. 1993. Detection and abundance estimation of euphausiids using an optical plankton counter. Mar Eco. Prog. Ser. 94:161-173.

Kirsch, J., G.L. Thomas, R.T. Cooney. 1997. Acoustic estimate of zooplankton distribution in Prince William Sound, spring 1996. SEA-FISH Annual report to EVOSTC.

Kirsch, J. and G.L. Thomas. 1998. On the use of digital sonar systems for practical fisheries acoustics surveys. Fisheries Oceanography. In progress.

MacLennan, D.N. and E. John Simmonds. 1992. Fisheries Acoustics. Chapman & Hall. London. 325pp.

Medwin, H, and C.S. Clay. 1997. Fundamentals of Acoustical Oceanography. Academic Press.

Schmidt, G.M. 1977. The exchange of water between Prince William Sound and the Gulf of Alaska. MS thesis. University of Alaska, Fairbanks. 116pp.

Stanton, T.K., Chu, D., Wiebe, P.H., and Clay, C.S. 1993. Average echoes from randomly oriented random-length finite cylinders: zooplankton models. Journal of the Acoustical Society of America, 94: 3463-3472.

Stanton, T.K., Wiebe, P.H., Chu, D., Benfield, M.C., Scanlon, L., Martin, L., and Eastwood, R.L. 1994. On acoustic estimates of zooplankton biomass. - ICES J. Mar. Sci., 51: 505-512

Stanton, T.K., Chu, D., and Wiebe, P.H. 1996. Acoustic scattering characteristics of several zooplankton groups. - ICES Journal of Marine Science, 53: 289-295

Urick, Robert J. 1975. Principles of underwater sound. McGraw Hill. New York. 384 pp.

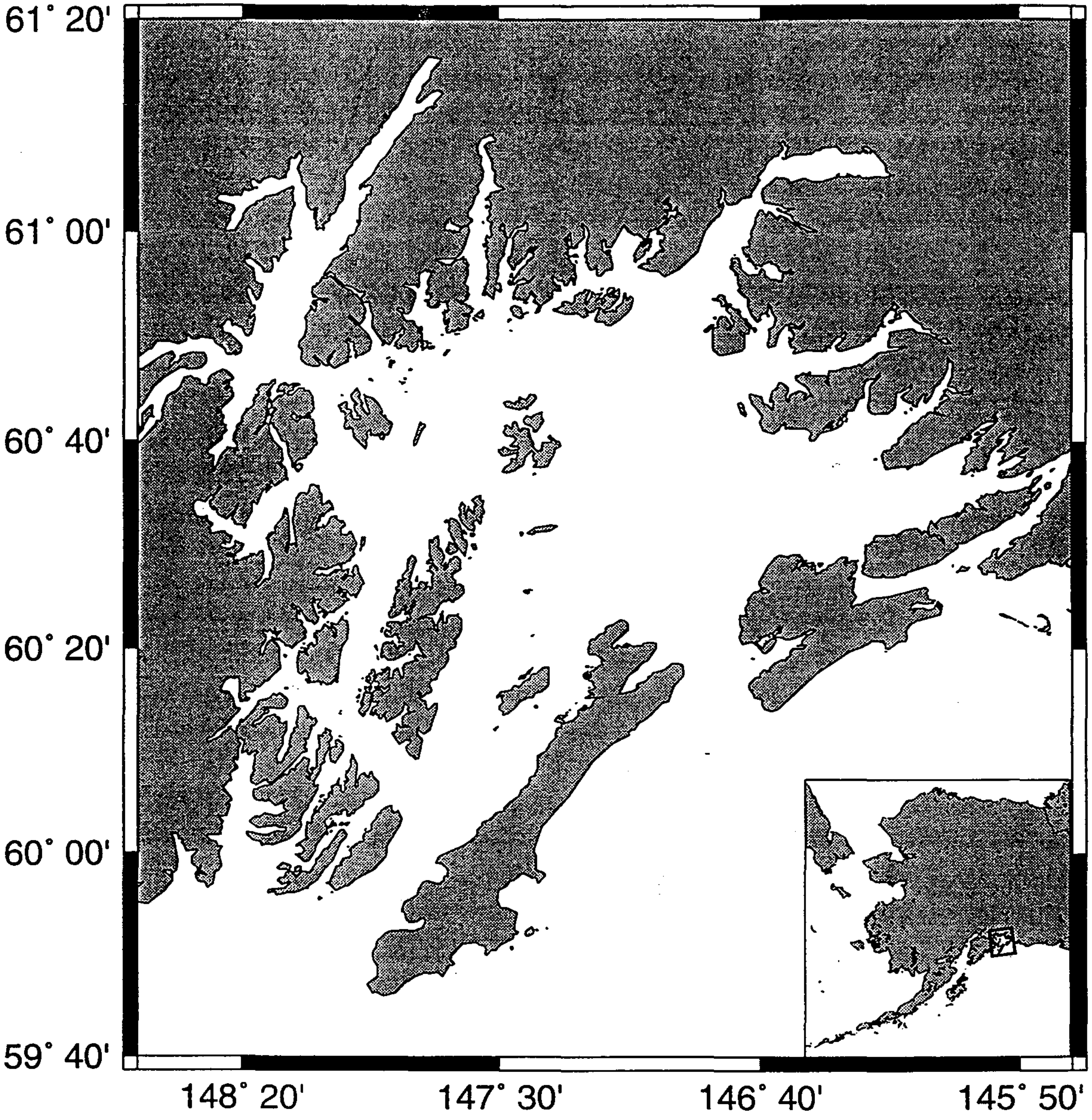


Fig. 1. Map of Prince William Sound, Alaska, USA.

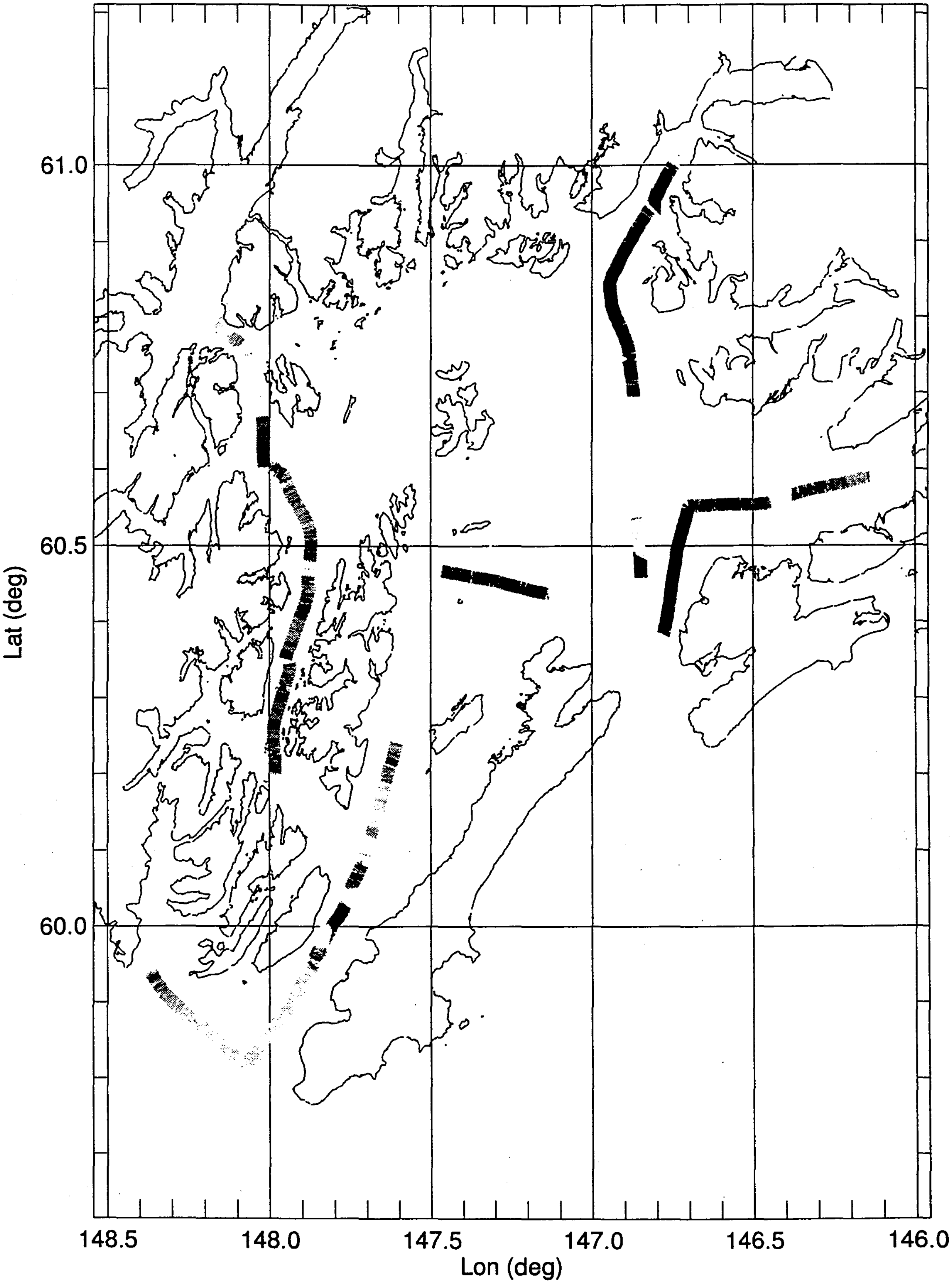


Figure 2. Geographical distribution of acoustic backscatter, 1995.

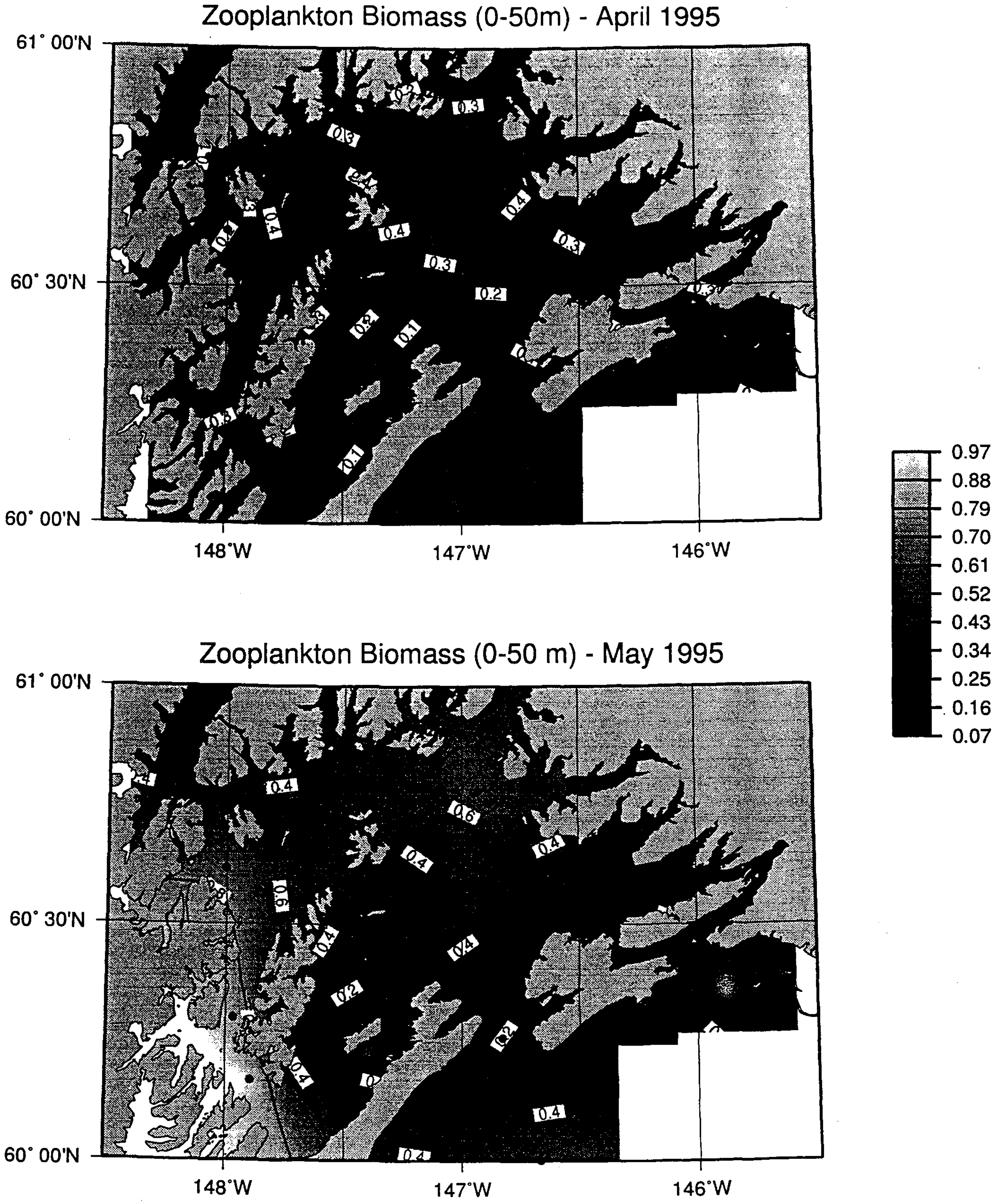


Figure 3. Vertical net zooplankton biomass, 1995.

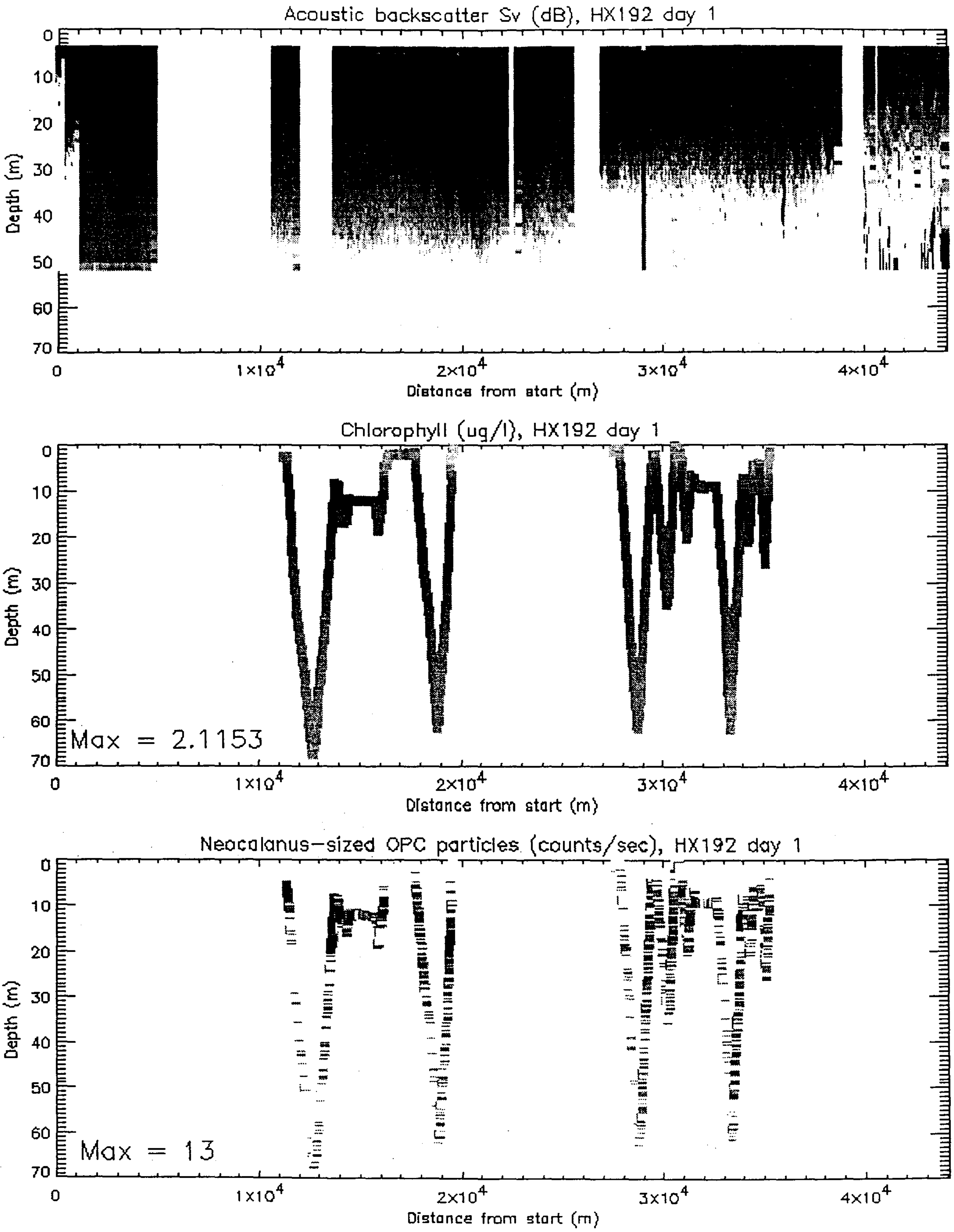


Figure 4. Knight Island Passage plankton distributions, May 1996.

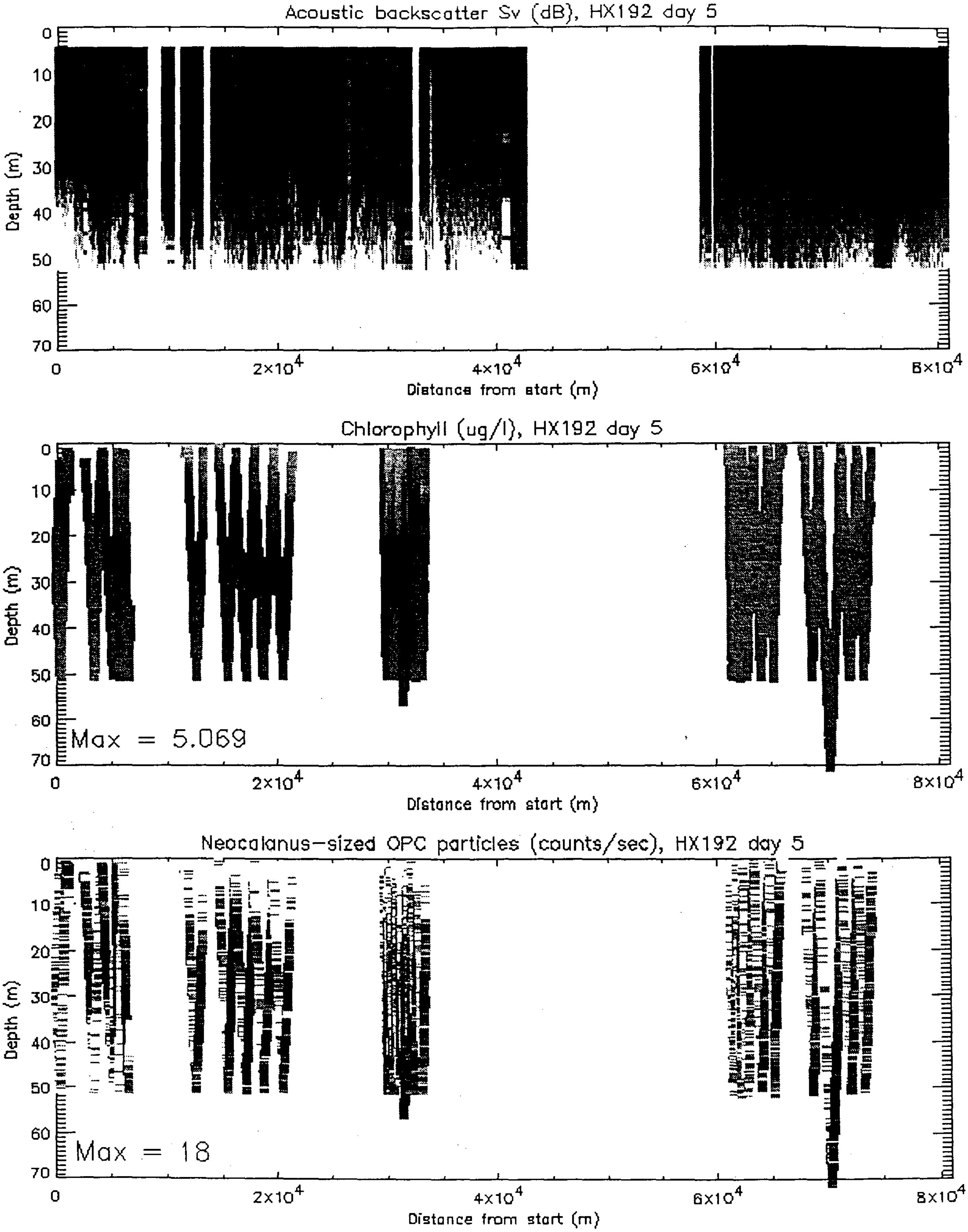


Figure 5. Montague Strait plankton distributions, May 1996.

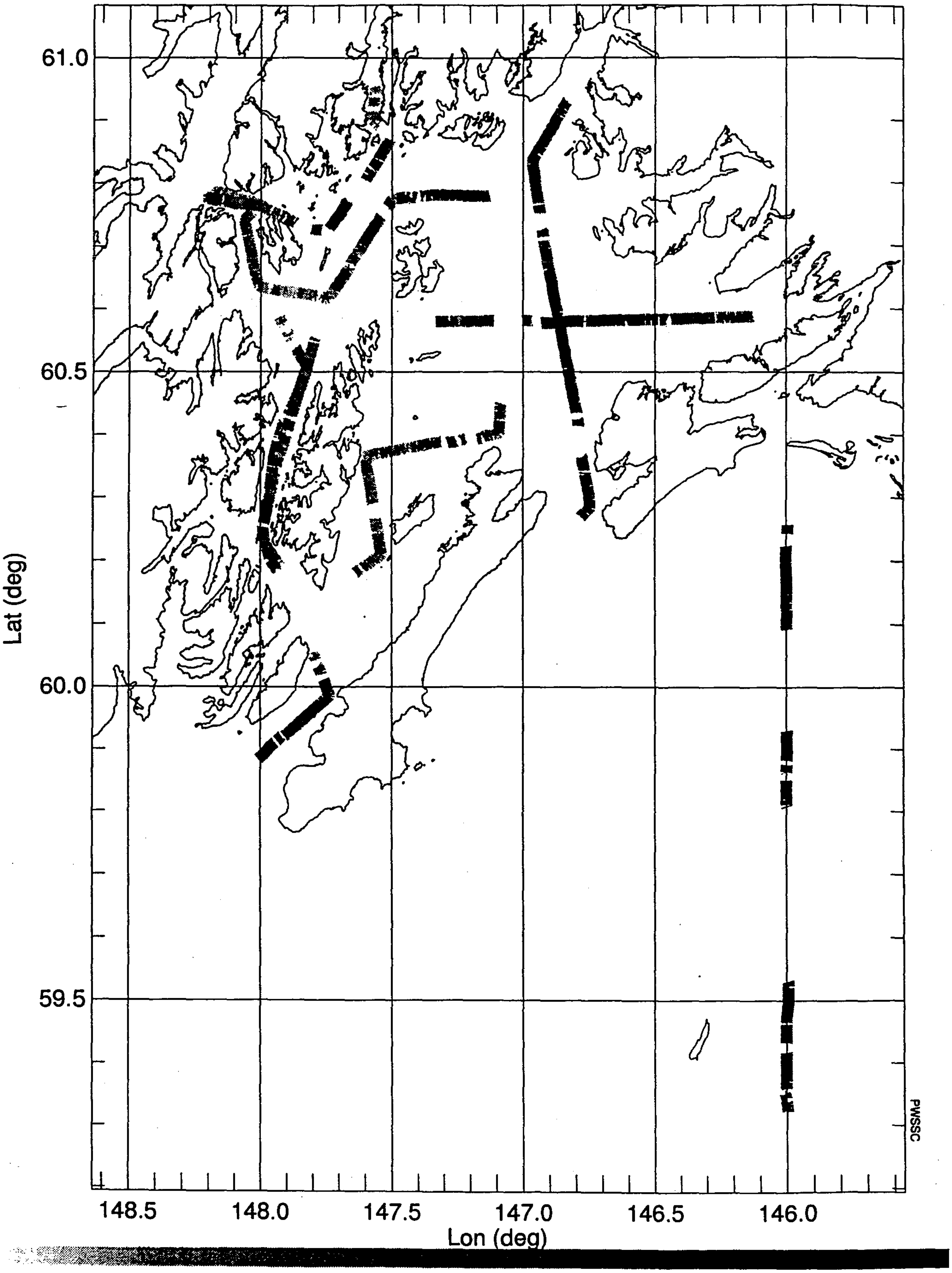
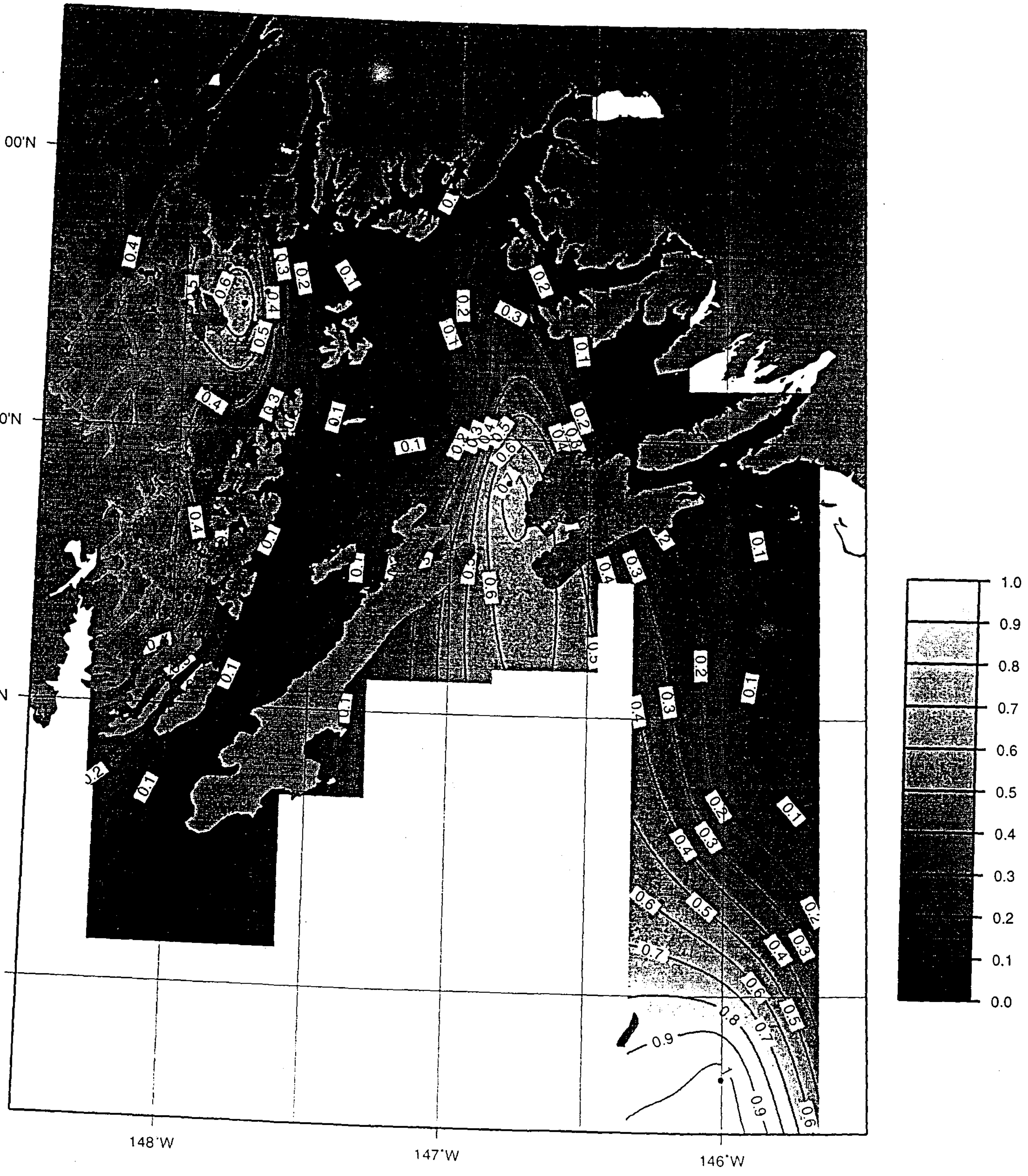


Figure 6, Geographical distribution of acoustic backscatter, May 1996.



HX192 - Neocalanus 5 Biomass - 0-50m

Figure 7. Neocalanus stage 5 biomass (g/m^3), 1996

HX192 - Limacina Biomass - 0-50m

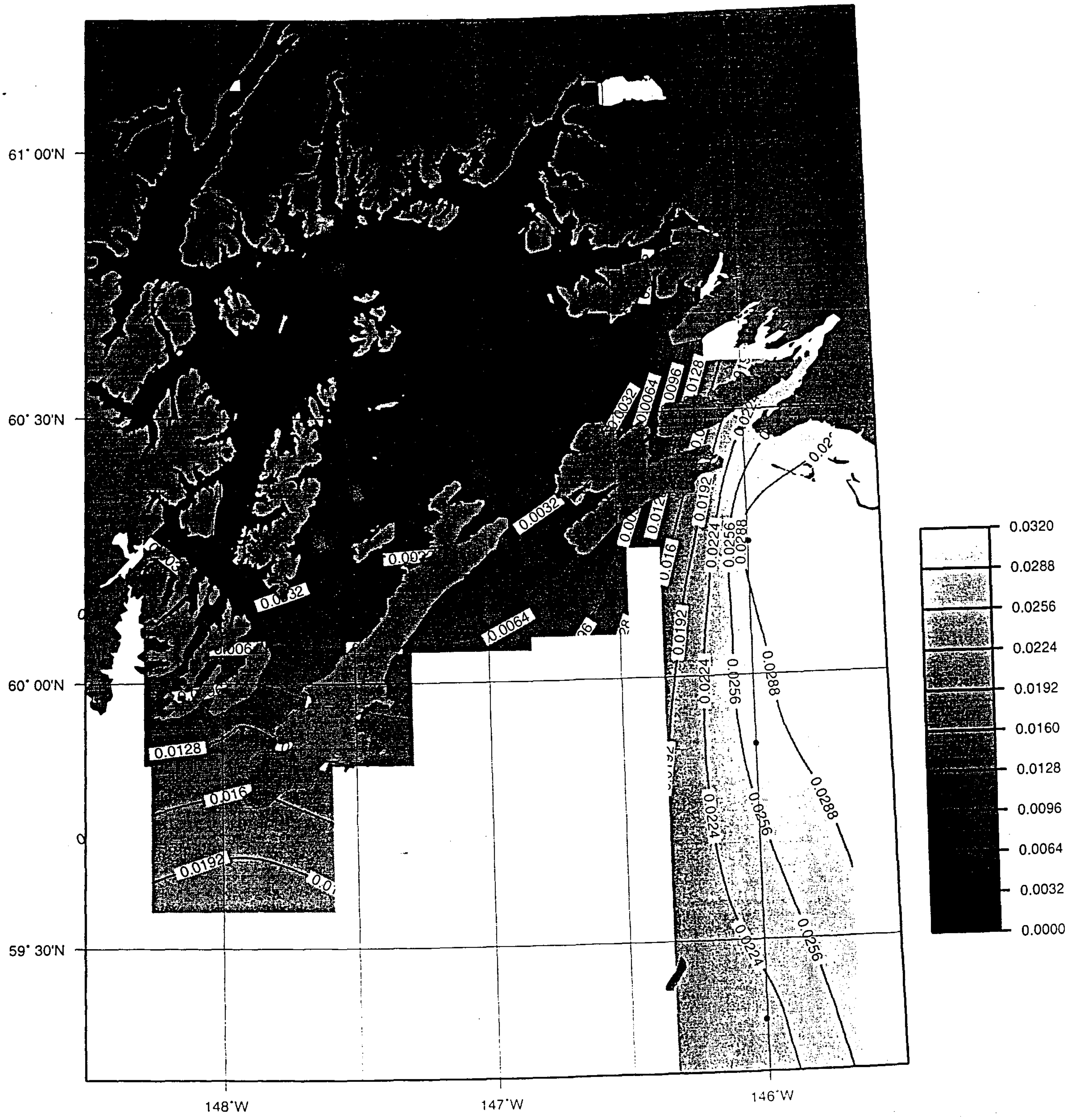


Figure 8. Limacina biomass (g/m^3), 1996

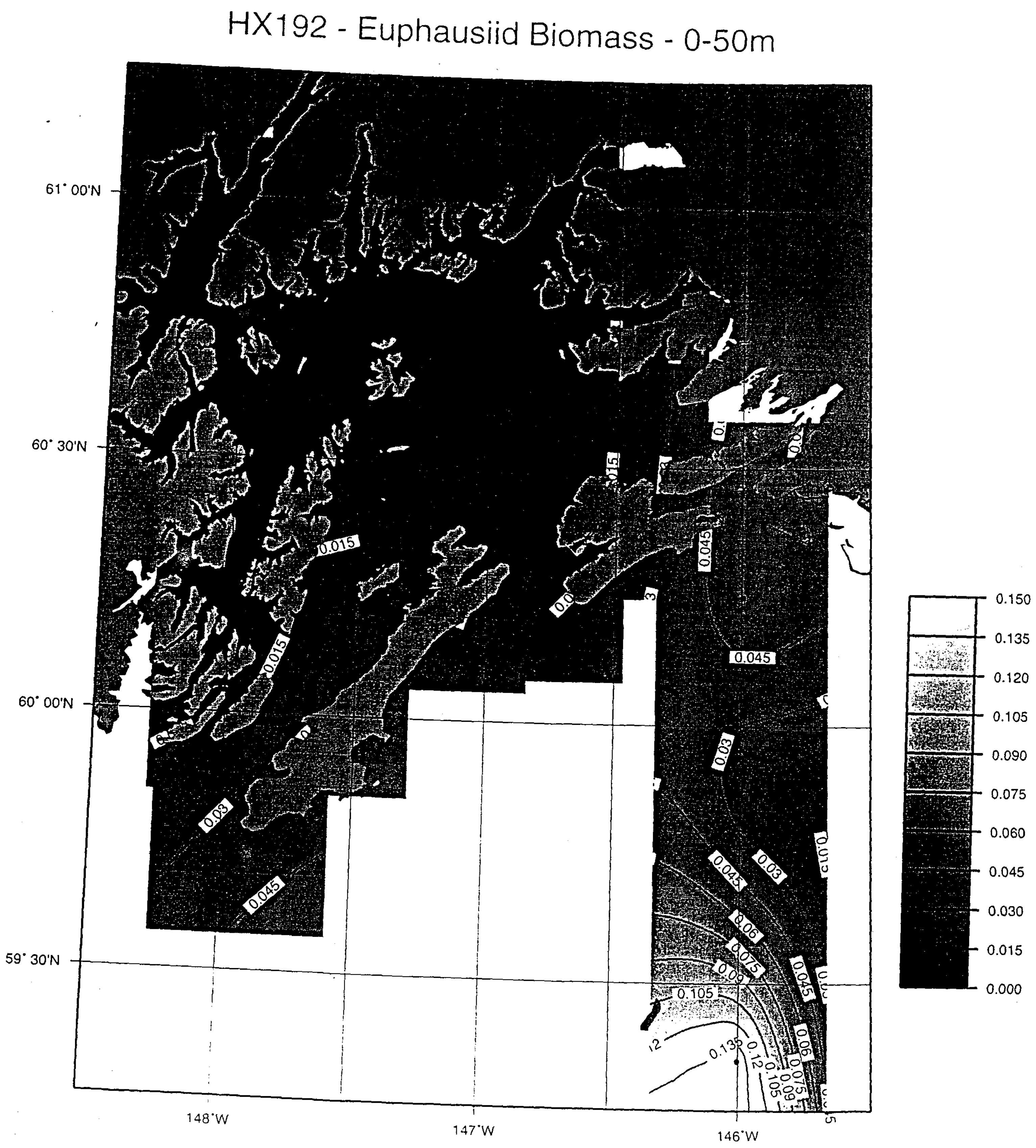


Figure 9. Euphausiid biomass (g/m^3), 1996

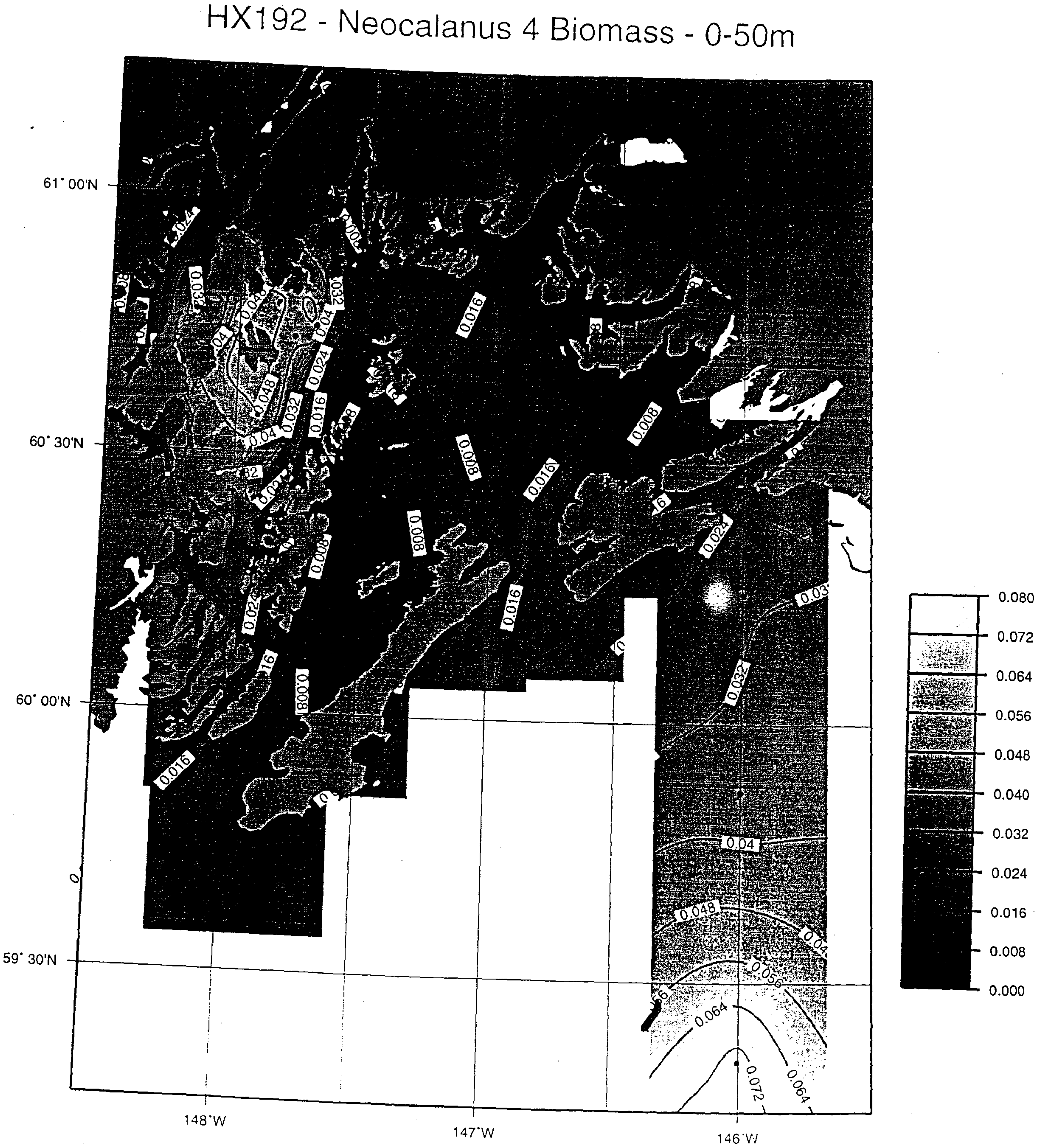


Figure 10. Neocalanus stage 4 biomass (g/m^3), 1996

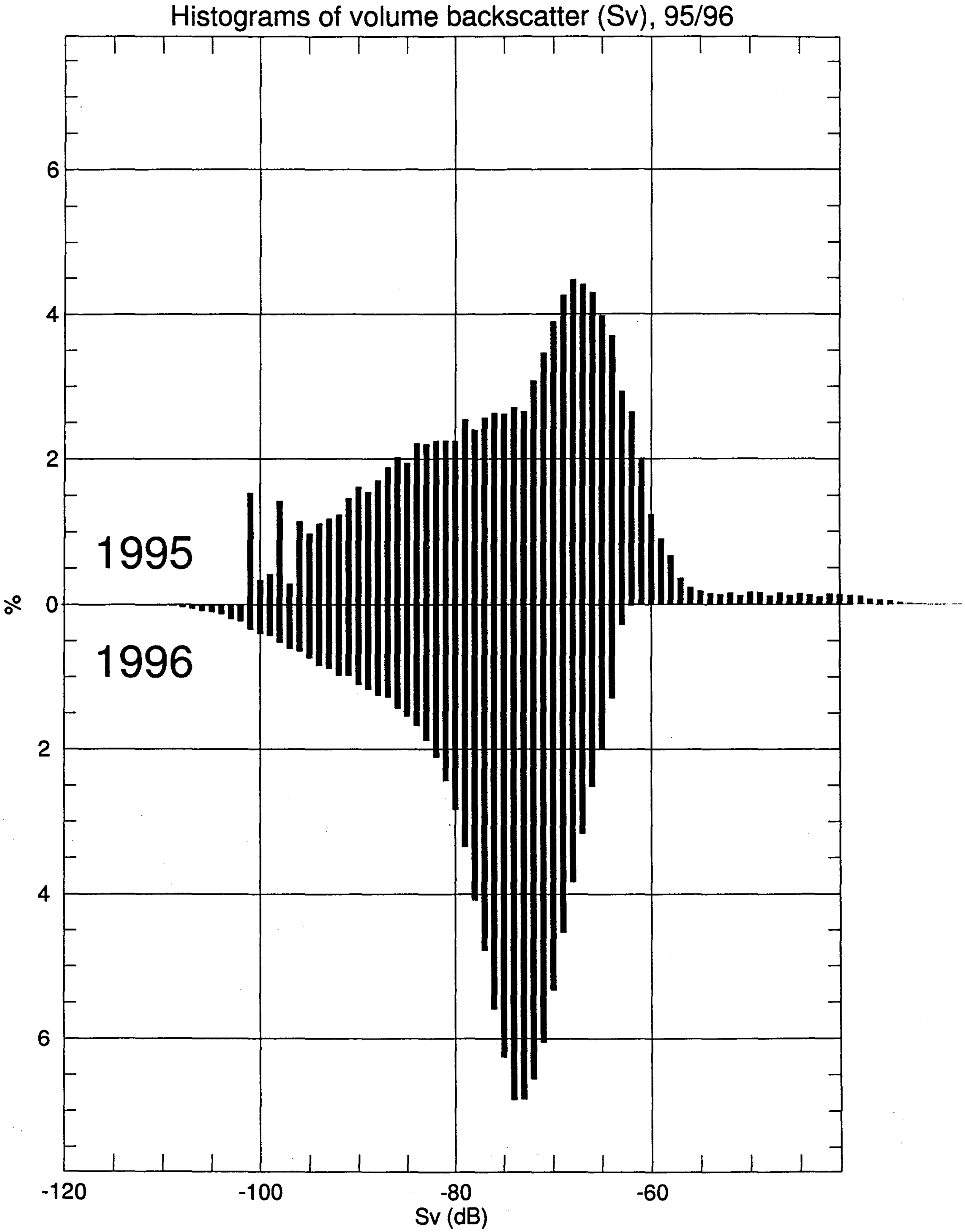


Figure 11. Comparison of volume backscatter, 1995 and 1996.

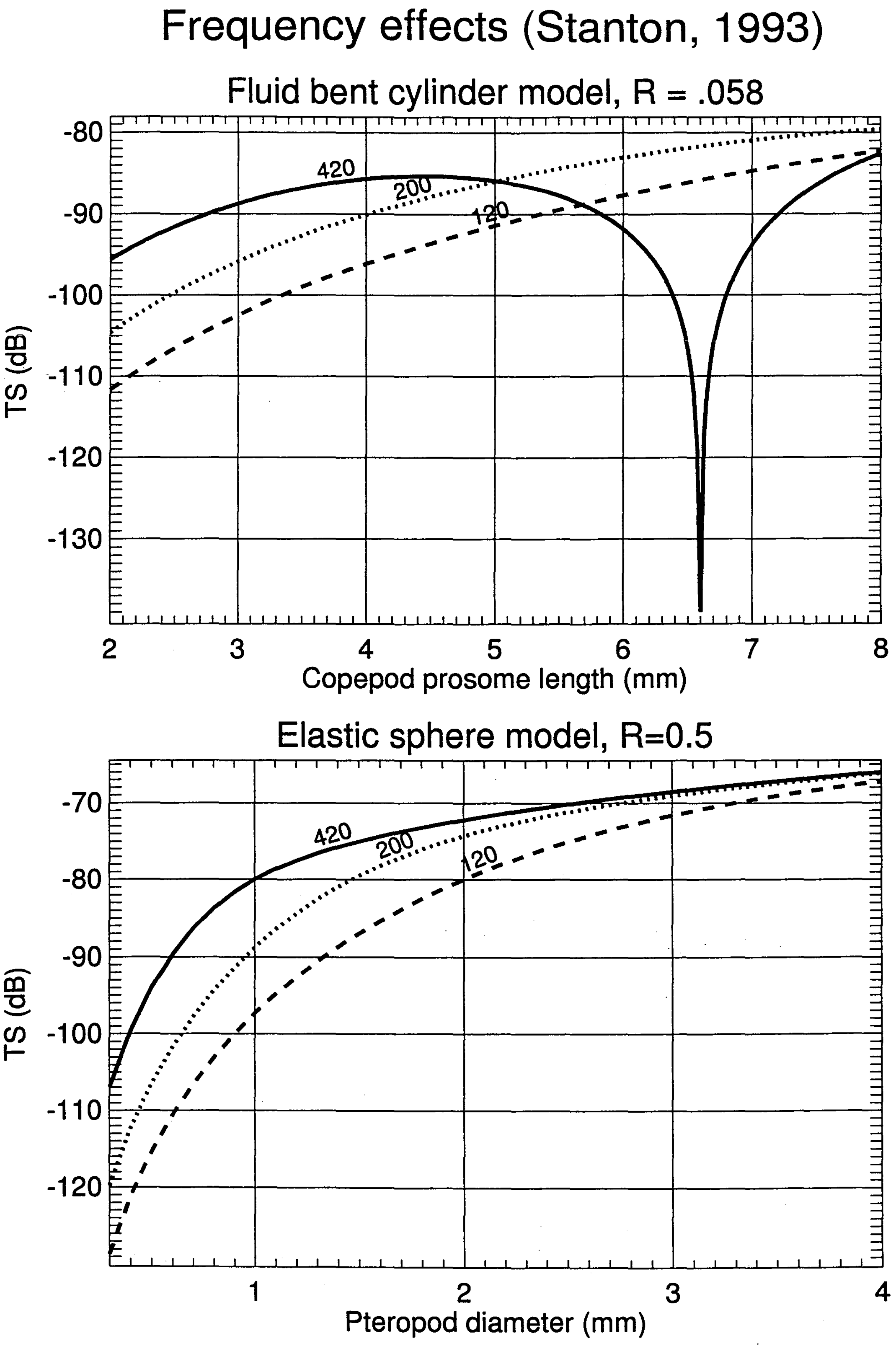


Figure 12. Comparison of frequency effects.

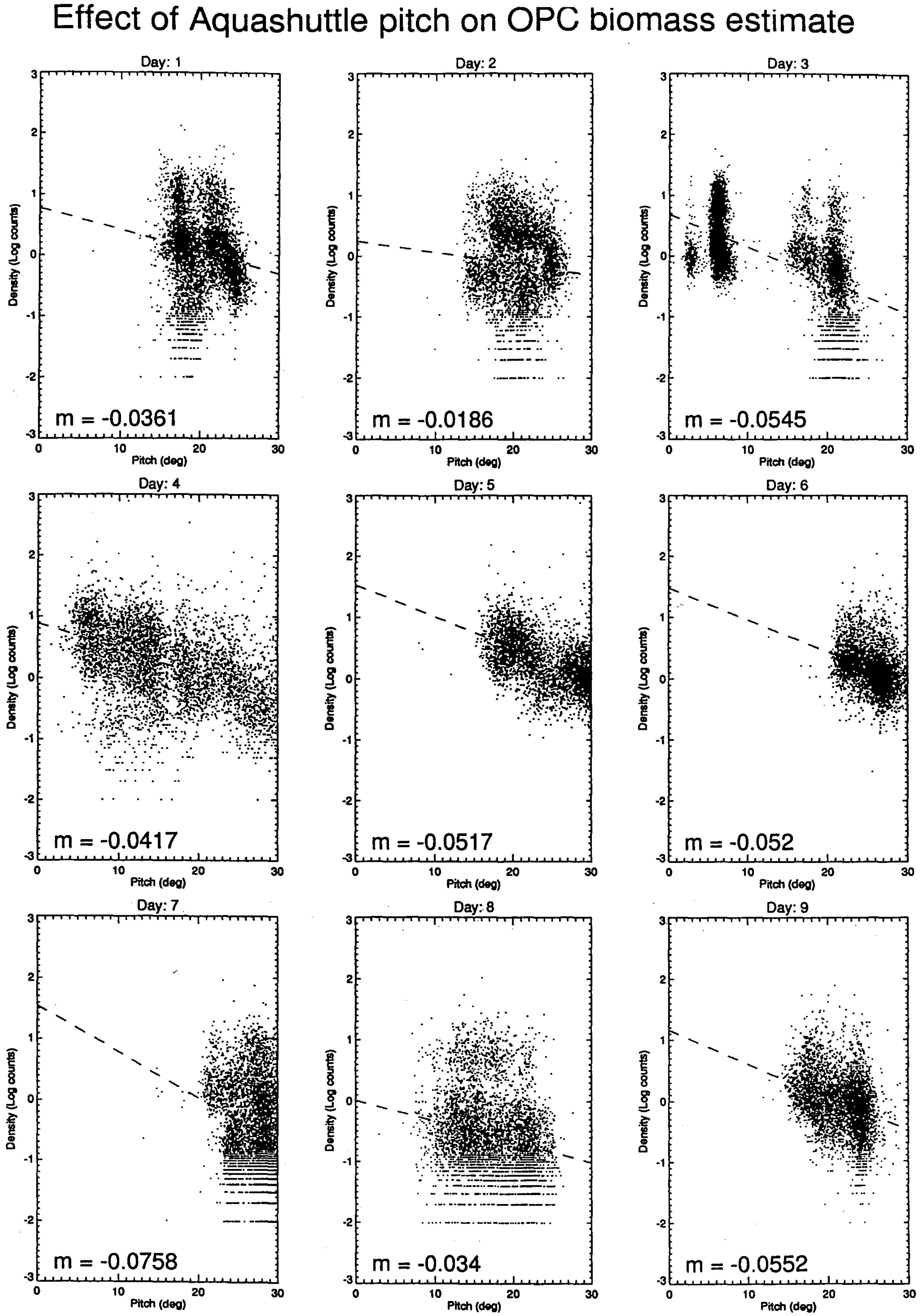


Figure 13. Comparison of Aquashuttle pitch and OPC counts density.

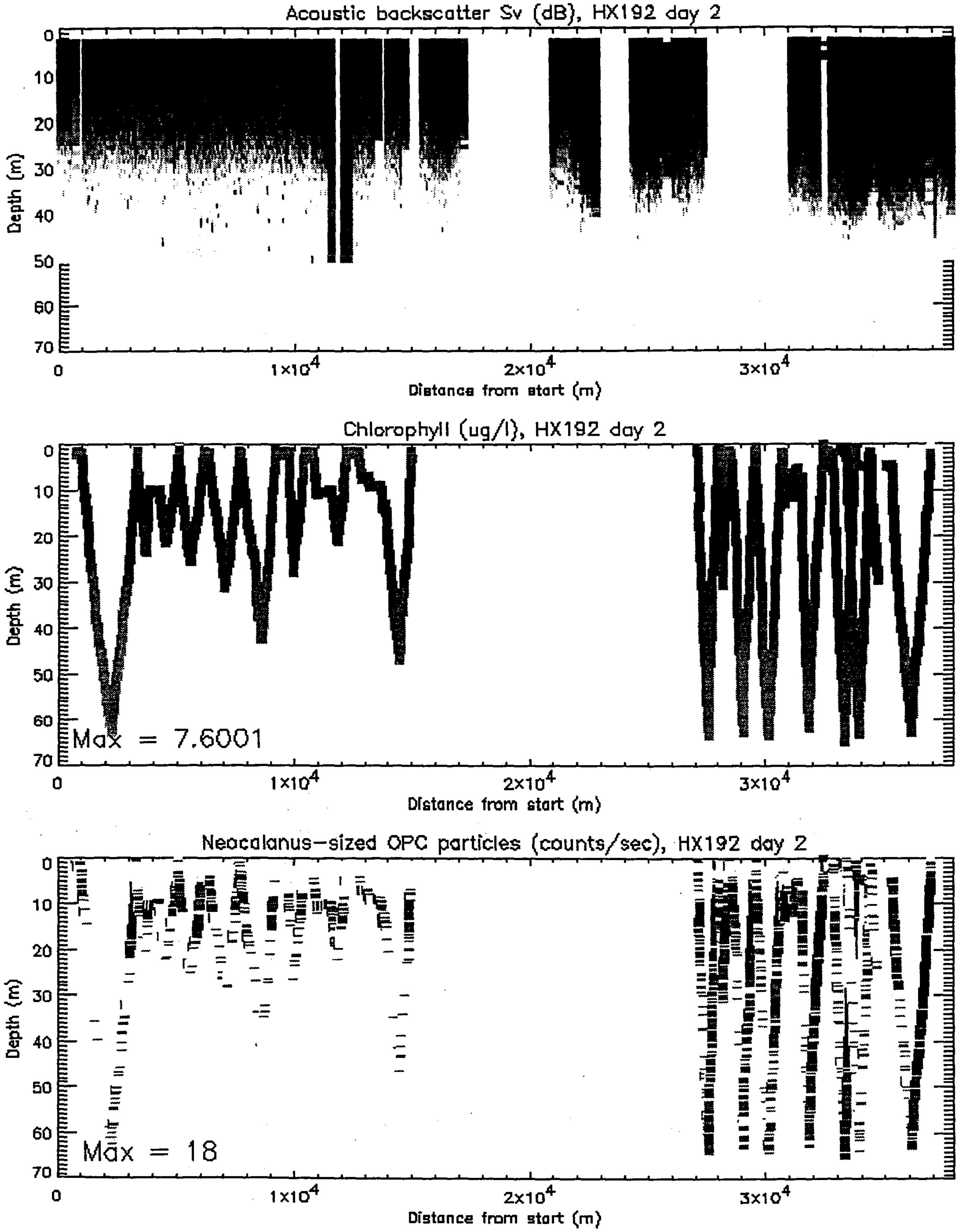


Figure A1. Wells Passage and Unakwik Inlet plankton distributions, day 2.

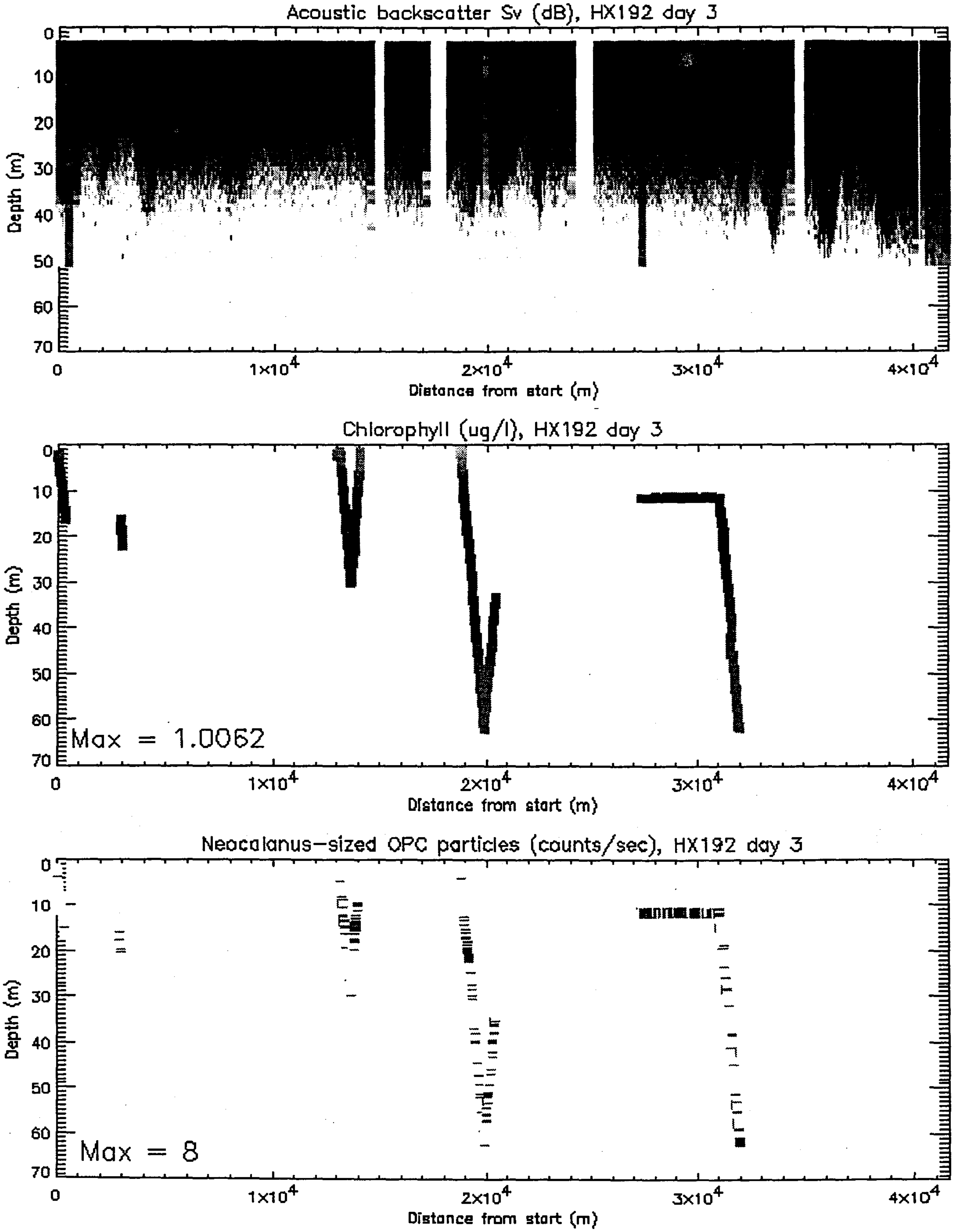


Figure A2. Knight Island Passage plankton distributions, day 3.

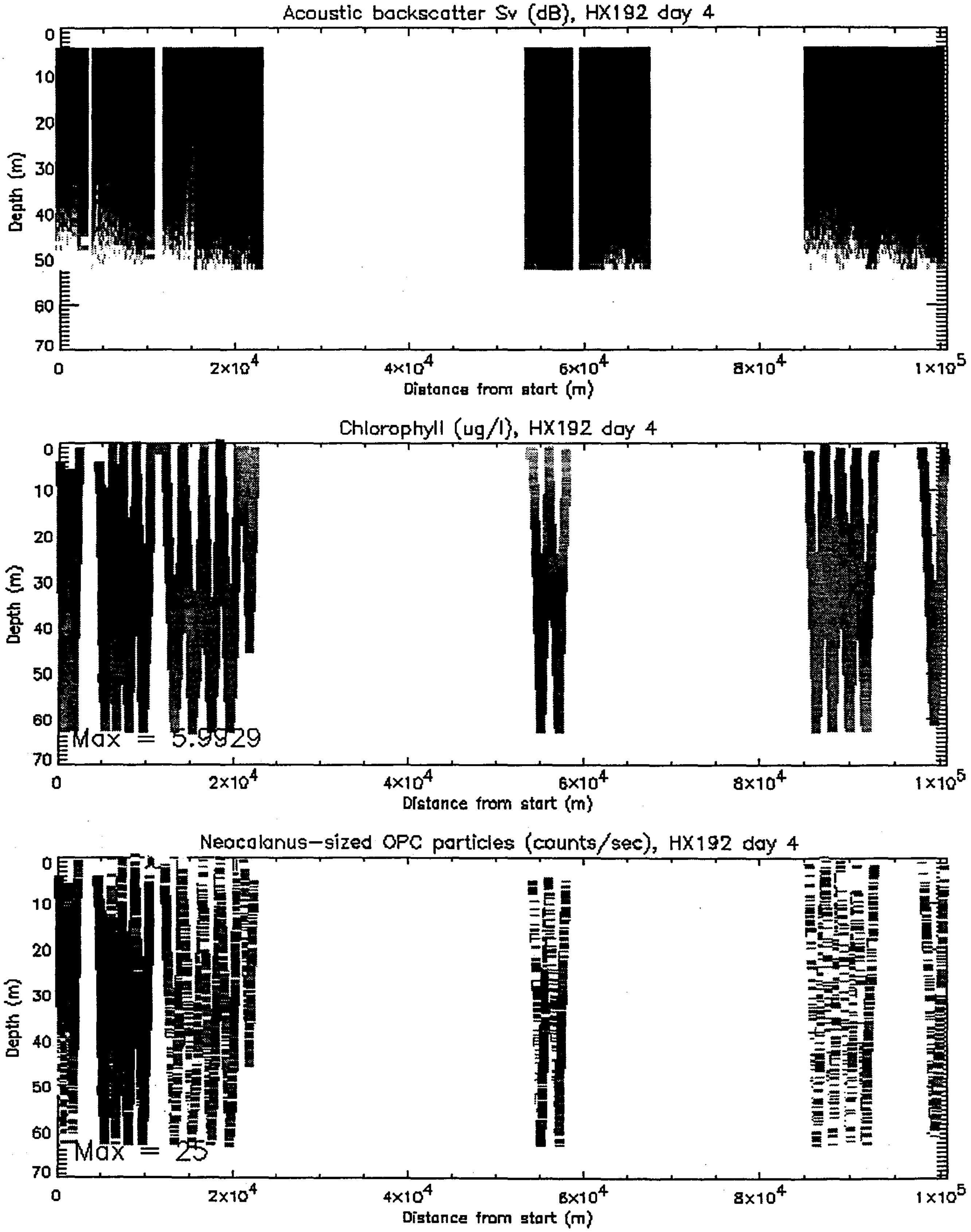


Figure A3. Gulf of Alaska plankton distributions, day 4.

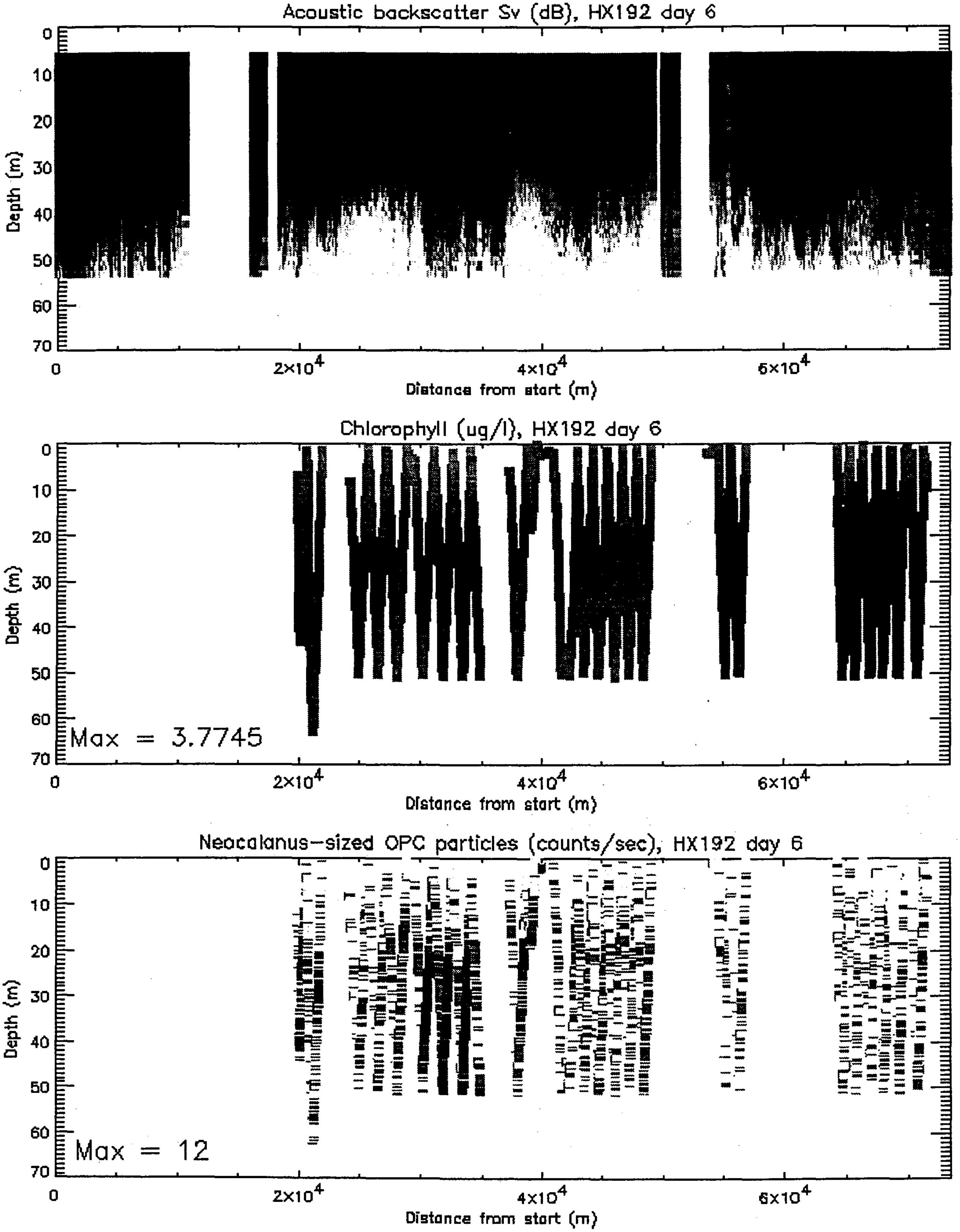


Figure A4. Hinchinbrook Entrance to Valdez Arm plankton distributions, day 6.

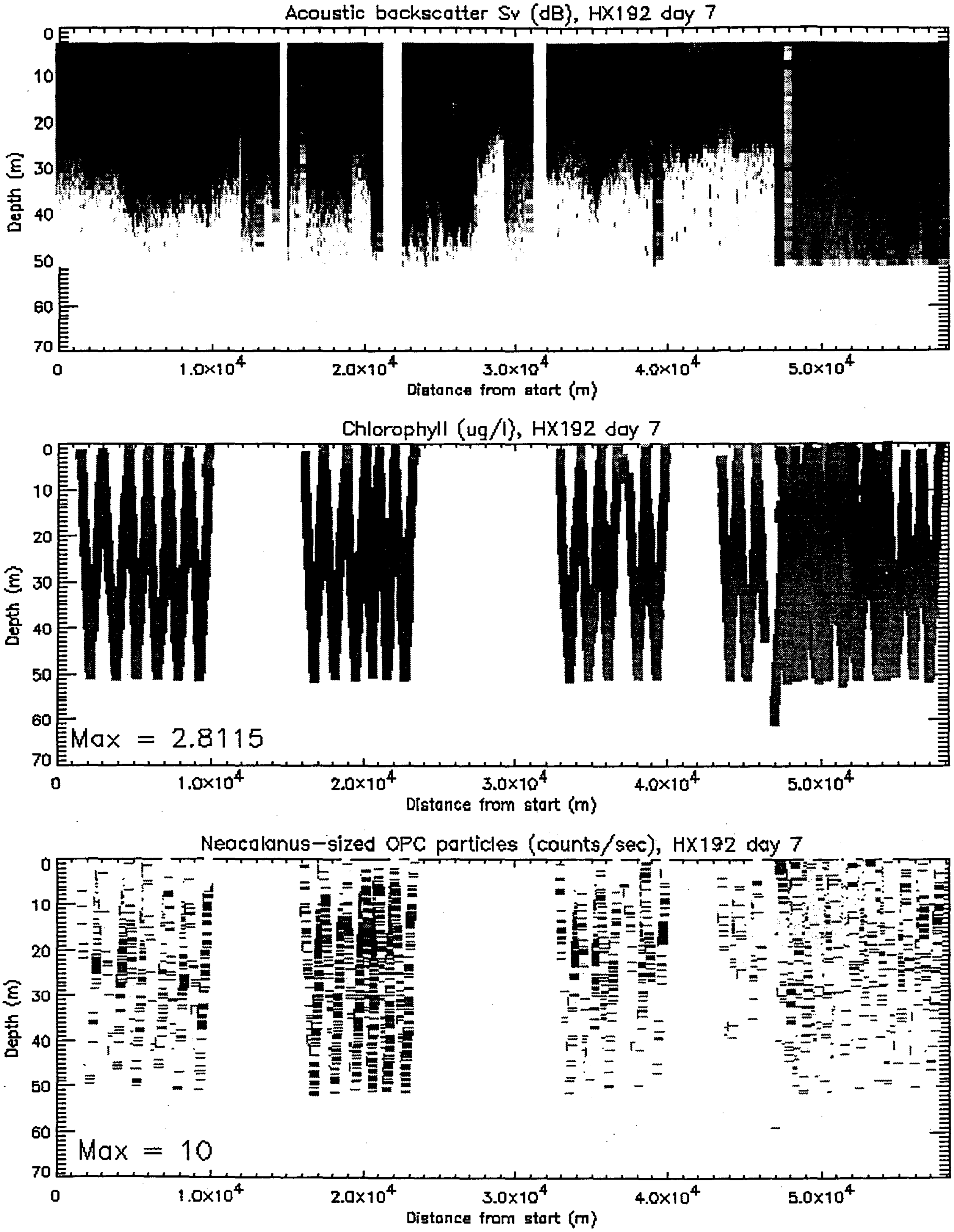


Figure A5. NW PWS plankton distributions, day 7.

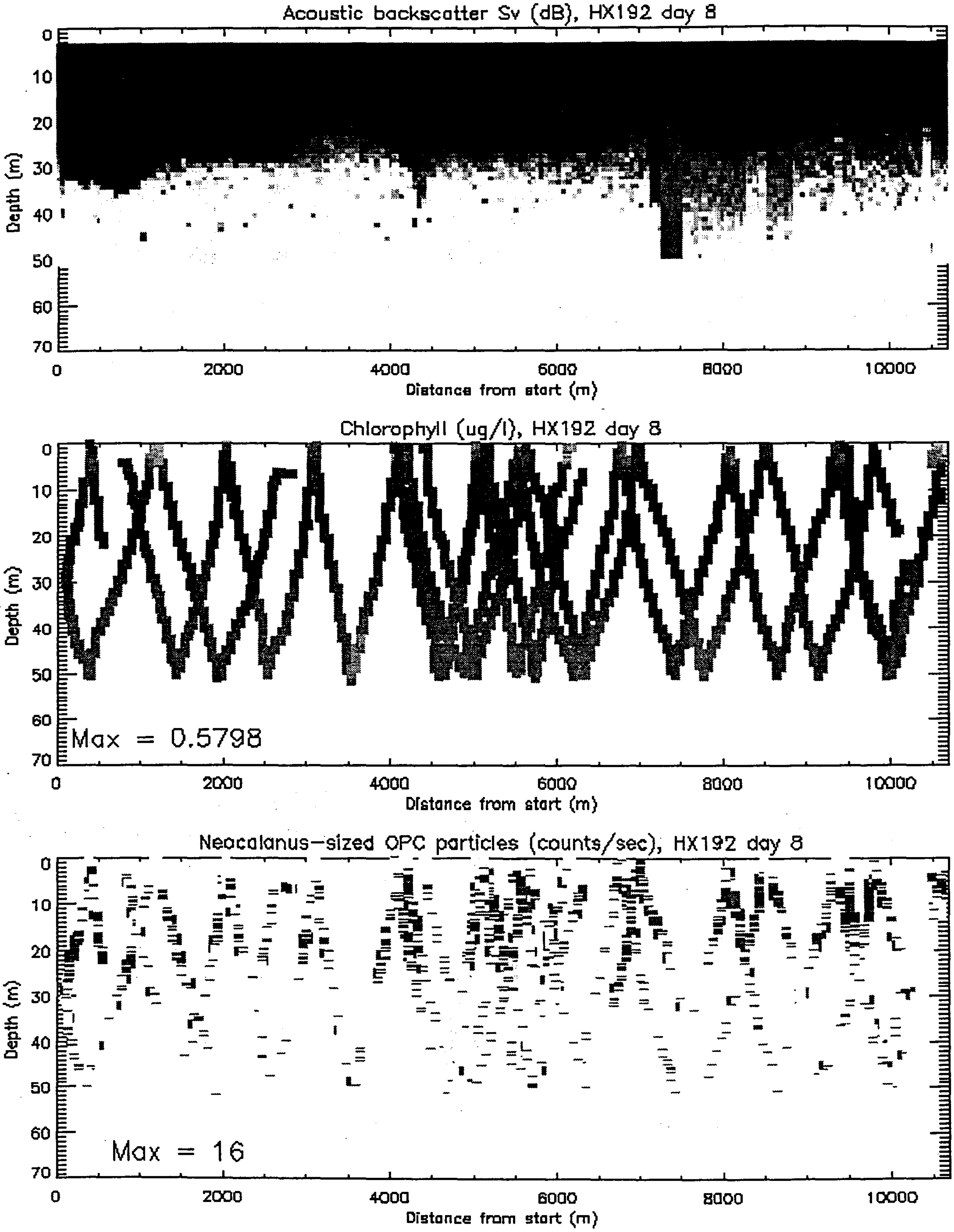


Figure A6. Wells Passage plankton distributions, day 8.

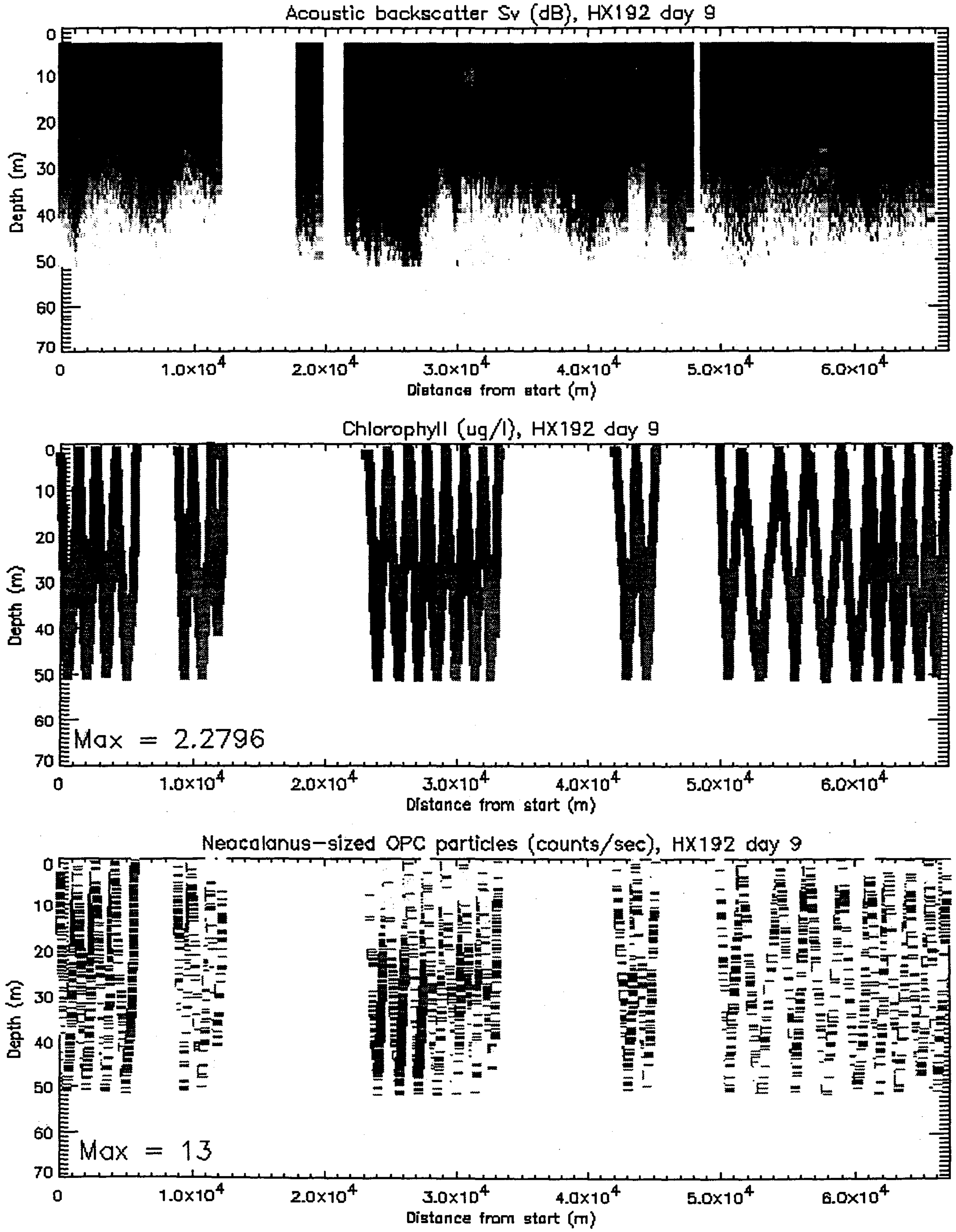


Figure A7. Naked Island to Orca Inlet plankton distributions, day 9.

CHAPTER 5

Preliminary acoustic measurements of juvenile Pacific herring (Clupea pallasi) and plankton in selected bays in Prince William Sound.

N. J. Peters, G. B. Steinhart, J. Kirsch, and G. L. Thomas.

ABSTRACT

Diel hydroacoustic surveys were conducted from June 1996 to August 1997 in Simpson, Zaikof, Whale and Eaglek bays, located in Prince William Sound, Alaska. Preliminary investigation of target strength (TS) information has detected seasonal variations in size classes, and vertical changes in distribution of fish and plankton. Seasonal fluctuations in the relative frequency of detected targets below -60 dB, indicating plankton sized targets, marked the spring bloom of plankton. In addition, seasonal shifts in TS range may be due to the influx and growth of new herring recruits. Diel changes in depth distribution showed that some fish may be undergoing daily vertical migrations. Further investigation of the acoustic and catch data sets will be needed to expand on the observed changes. Improvements in hydroacoustic equipment and subsequent data processing are discussed, with suggestions for further research.

INTRODUCTION

Pacific herring (*Clupea pallasi)* in Prince William Sound are important both biologically and commercially. The decrease in herring abundance after the 1989 Exxon Valdez oil spill has had wide reaching implications for the marine organisms depending of herring as a source of food, and for the fishing industry. There is little information available on the spatial distributions of the early life stages of herring, so it has been difficult to determin the cause of the decline, or to understand how the population is recovering. In order to facilitate the investigation into the juvenile herring abundance and distribution in Prince William Sound, four bays were selected for repeated acoustic and oceanographic surveys. The bays were selected as they are spatially segregated, have overwintering populations of herring, and evidence of spawning and recruitment. The data collected will be used in the overwintering survival model, summer habitat model, and for determination of a monitoring strategy.

A brief overview of new technologies and techniques in fisheries acoustics for species identification in multispecies environments. The methods discussed include changes in field data collection equipment, such as wideband sounders, to supplementary information, gathered by video cameras, and post processing techniques.

The data presented is a first look at the variation in the diel, seasonal and geographic distributions of nekton and plankton using target strength by depth and relative density. Since hydroacoustic sampling is nearly continuous, the utilization of target strength information provides a better evaluation of spatial and temporal variation than net sampling. This paper presents the vertical and size structure of the fish and plankton assemblages seen in the four bays in Prince William Sound, along with the seasonal variations in the fish communities. Separation of the detected targets by depth and size, and the seasonal changes of this layering is evident. The seasonal aggregation of herring in the bays over the fall and winter periods is observed, with indication of acoustic discrimination of cohorts. Relative abundances between bays and seasonal changes in each bay are discussed.

METHODS

Four spatially separated bays in Prince William Sound were repeatedly sampled from June 1996 to August 1997. (Figure 1). The hydroacoustic information was collected using a 120 kHz BioSonic 101 echosounder. The transducer was mounted on a tow fin and towed at approximately 2.5 m/s, about 1 m below the ocean surface. The data was processed in real time with BioSonics ESP (echo signal processor) software. Echo-square integration, dual-beam target strength and concurrent GPS data were recorded. The raw acoustic signal was placed on Digital Audio Tape. Calibration of the transducer was preformed using a standard target to obtain the source level and receive gain (Foote and MacLennan 1982). Equipment parameters were: source level = 255.023 dB; receiver gain = -159.28 dB; transducer directivity = 0.00107; pulse duration = 0.4 ms. The data was then archived and transferred to UNIX platforms for secondary processing.

Each Bay was hyroacoustically sampled three times in 24 hours. The dates of the survey were chosen to co-inside with the new moon, reducing any light dependant behavioral pattern, (Luecke, C. and Wurtsbaugh, W. A. 1993). The three sampling periods began approximately at, 0800, 1600, and 0000, and lasted about four hours. The survey design called for parallel transects perpendicular to the shore separated by 1/4 Nm, connected by along-shore transects between. All surveys were marked on paper and/or electronic charts to allow repeated transects.

Net catch data was collected at each site. For each survey an anchovy seine (250 x 34 m and 20 m 25 mm stretch mesh) was deployed for target validation, length, weight, age analysis, and diet information. The location of the set was determined by the acoustic vessel, based on observed layers of targets. The seine vessel would also deploy a shallow fishing box trawl to capture small organisms. A mod-trawl was used to collect deep targets. (1.52 x 2.13 m Nor'Eastern Astoria V trawl doors, head rope 21.3 m, foot rope 29 m, estimated 3 x 20 m mouth, 10.2 cm mesh wings, 8.9 cm middle, and a 32.0 mm cod end liner). The location of the trawl set was determined by the acoustic vessel. In shallow water a 6 m skiff using a salmon fry seine (50 x 3 m, 3 mm stretch mesh) was used. The captured fish were sub-sampled into approximately 1000 individuals, then identified, these were then randomly sub-sampled and measured for length information. For the purposes of this paper related species were grouped together to aid in reading the graphs of net catches.

DATA PROCESSING

During post processing of the acoustic data, non-biological signals were removed. One common removed signals were surface bubbles: caused by either surface entrainment due to wave action, or by diving mammals and birds. We also removed bottom signals from the data. Loss of bottom tracking, where the ESP fails to recognize the floor signal return, will cause data corruption. This occurred in the presence of a dense schools near the bottom, and where Tte roll and pitch of the vessel caused the loss of the floor signal. Side lobe effects on sharply changes bathymetry can also reduce signal quality. Comparison of the electronic echo-grams with the paper echo-grams allowed the corrupted data to be removed manually.

Target validation was acquired for the acoustic data from the net catches. Species composition and length information were recorded. When geo-referenced with the acoustic survey, the relative acoustic backscatter for each caught species can be determined by use of target strength models and relative catch densities (see Thomas et al. 1996, for complete methods).

The target strength data were corrected for sampling effort and volumetric changes with depth due to the acoustic beam pattern. The volume V, is given by,

$$V=\frac{1}{12}\pi\phi^2(r_2^3-r_1^3) \tag{1}$$

where r_1 is the range to the top and r_2 the range to the bottom of the selected depth, and ϕ is the beamwidth in radians. The problem of coincident targets returning an increased signal was, in a first step, reduced by the removal of unrealistic TS values. The data were then binned into depth and target strength ranges producing a relative density of sampled targets over depth and TS value. Comparison with the net catch data which, where appropriate, were converted into target strength is included. The conversions used are, Thorne (1983), Eq. (2), for herring, and Traynor and Ehrenberg (1979), Eq. (3), for pollock (Figure 2). Here L_{cm} is the length of the appropriate fish species measured in centimeters.

$$TS\ re{:}\ W = 6\log_{10}L_{cm} - 24.2 \tag{2}$$

$$TS = 20\log_{10}L_{cm} - 66 \tag{3}$$

The target strengths were calculated from the average lengths of the fish sampled. Also shown were the depths of catch and the estimated number for each species. There is no accounting for missed catches, or for the targeting of particular species, gear selectivity, or any incurred bias in length measurements.

RESULTS

The data presented are an initial look at the target strength distributions within the water column of the four bays for the period of June 1996 to August 1997. All color scales are the same to allow for inter bay, and seasonal comparisons. However, the reported target strength distributions will have a bias towards higher values as the removal of coincident targets through extraction of unrealistic values is not a robust technique. Due to the duration of the surveys, about four hours per bay, the depth distribution of the detected targets may have changed over the sampling period. This may have lead to an increase in the depth range in which the targets are partitioned. The data were looked at in two ways: first each cruise was examined; then the inter-bay comparisons and the seasonal changes for a particular location are discussed.

June 1996

Simpson Bay

During the June 1996 Simpson Bay surveys, we saw numerous targets throughout the water column (Figure 3a, 3b). At 0800, there were many small targets (-70 to -58 dB) from 5 m to 40 m. In addition, there were two other distinct groups of targets: a peak centered at about -35 dB at 45 m, and a deep layer at 60 m, with two peaks at -30 and -55 dB. By the 1600 survey, there were fewer targets in the bay, but with a similar TS distribution as 0800. At night, however, there was a pronounced increase in the number of large targets (-44 dB found in the top 20 m. There was also an upward movement of large, deep targets from 100 m, at 0800, to 65 m at 0000. Net catches at this site were dominated by herring, which increased in size as the fishing depth increased (Figure 7).

Zaikof Bay

Zaikof Bay had fewer targets than Simpson, but had a large number of small (< -55 dB) targets in the top 40 m during all sample periods (Figure 4a, 4b). During the 0800 survey, there was a second peak of targets around -50 dB found at approximately 70 m. At midnight, there was a distinct increase and upward movement of large targets. This change was seen in the top 30 m, with increases of targets around -55 dB and -40 dB. In addition, there was a group of pollock-sized targets (-30 to -40 dB) at 80 m. The seines caught mostly herring, with larger fish caught at night than during the day (Figure 7). The trawls caught pollock, but in relatively low numbers except for the morning bottom trawl set.

Whale Bay

In June 1996, Whale Bay had few targets deep in the water, but many small and medium targets -(80 to -40 dB) were seen near the surface (Figure 5a, 5b). There was an increase in the number of medium and large-sized targets above 40 m during the 0000 sample period. Fewer adult herring were captured in the purse seine than in the other bays, but thousands of young herring were captured near the surface in the fry seine (Figure 7).

Eaglek Bay

In Eaglek Bay, there was again a large concentration of targets near the surface (Figure 6a, 6b), but unlike the other bays, there were distinct TS modes of the surface targets. Two modes, one at -75 dB and one from -40 to -60 dB, were seen above 20 m during all sample periods. During the 0000 survey, there was a substantial increase in deep (40 to 100 m), large (-30 to -45 dB) targets. The purse seine caught numerous herring, and the deep trawls caught mostly pollock (Figure 7).

August 1996

Simpson Bay

During the day, there were far fewer targets seen than during the July cruise (Figure 3a, 3b). These targets were divided into two distinct groups: a shallow (< 30 m) group of small targets (< -60 dB), and a deep (50 m) layer of -30 to -45 dB targets. At night, however, there were many targets of all sizes throughout the top 80 m, plus additional targets to 120 m. The seines caught almost exclusively herring, again with the larger individuals found deeper than the smaller fish (Figure 8).

Zaikof Bay

The August data from Zaikof also show fewer targets than the July cruise, but with more distinct separation in distribution and TS (Figure 4a, 4b). The largest concentration of targets was in the top 40 m, and ranged from -55 to -80 dB. A second group of targets was seen at 40 m, and had a TS around -35 dB. At night, there were abundant targets from -30 to -80 dB in the top 40 m, again suggesting a vertical migration at night. Seine sets at this time caught adult herring and pollock in the top 20 m, while during the day, the seine caught herring and smelt (Figure 8).

Whale Bay

Whale Bay followed the same pattern as Simpson and Zaikof Bays: fewer targets than the previous cruise, with most targets found near the surface, and an increase in targets at night (Figure 5a, 5b). The targets tended to extend to deeper waters in Whale Bay than in the other bays. Daytime seine sets caught thousands of herring, while the night catches were dominated by pollock (Figure 8).

Eaglek Bay

Eaglek Bay had the fewest targets of the bays sampled during this cruise, but followed a similar diel pattern (Figure 6a, 6b). There were fewer targets greater than - 40 dB detected in Eaglek Bay than in the other bays. Net catches were also lower in Eaglek than in the other bays, and were composed of mostly herring (Figure 8).

October 1996

Simpson Bay

In October, there were more targets than in August, and their numbers and distribution looked more comparable to June (Figure 3a, 3b). During these surveys, there was less separation among the peaks in TS: there were many targets of all sizes, at all but the deepest depths. There was a slight increase of TS with depth. During the morning, the seine caught all herring, while at 1600 and 0000, both pollock and herring were captured (Figure 9).

Zaikof Bay

The October data from Zaikof were almost identical to August, but with more large targets found deep at night (Figure 4a, 4b). The largest concentration of targets was again in the top 40 m. A second group of targets was seen at 40 m at 0800, 80 m at 1600, and from 40 to 100 m at 0000, the time when there were the most targets in the group. The TS of these targets ranged from -30 to -45 dB. The purse seine caught mostly herring, with larger fish caught at night (Figure 9). The mid-water trawl caught many pollock, but only at night.

Whale Bay

In Whale Bay, we saw fewer targets than in Simpson, but a similar amount to Zaikof (Figure 5a, 5b). During the day, there were many small targets (< -55 dB) extending from the surface to 80 m. This was a similar distribution of TS as we saw in August, however it extended deeper into the water column. Another difference was the increase in the number of deep targets at night. While this feature was common during most surveys, the increase was especially large during this cruise, and included targets from -25 to -60 dB. Net catches were also highest at night, with larger pollock caught from deep water and at night (Figure 9). Many herring were also caught by the seine at night, but few during the day.

Eaglek

Unlike the other bays, the number of targets in Eaglek was highest during the October cruise, although still lower than the other bays (Figure 6a, 6b). The distribution, however, was similar to Whale Bay in that there were many small targets (< -55 dB) extending from the surface to 80 m. There was a distinct group of targets around -45 dB seen at 20 m during the 1600 sampling. At night, there were more large (-30 to -55 dB) targets throughout the water column, but concentrated in the top 50 m. The purse seine caught numerous pollock and herring at 1600 and 0000, but little else (Figure 9).

March 1997

Simpson Bay

There were much fewer targets in Simpson Bay in March than during the previous three cruises, but still more targets than seen in the other bays (Figure 3a, 3b). There were two distinct modes of targets during these surveys: a mode seen at 0 to 40 m, and ranging from -60 to -60 dB; and a mode around -35 to -40 dB seen around 60 m. Although this second mode did not show a diel movement, the number of targets measured did increase dramatically at night. The catch data generally agreed with the acoustic data: few fish were caught, except at night, when the purse seine caught mainly adult herring (Figure 10).

Zaikof Bay

There were relatively few targets detected in Zaikof Bay in March, 1997 (Figure 4a, 4b). This was especially true during the day, when only a few small (< -55 dB) targets were seen. At night, however, there was a high density of targets from -25 to -60 dB in the top 30 m. The purse seine caught adult herring near the surface at night, while the trawl only caught adult herring on the bottom during the day (Figure 10).

Whale Bay

Whale Bay had less targets detected in March 1997 than in any other month (Figure 5a, 5b). There were also fewer targets than the other bays, except Eaglek Bay. In daytime, the only TS mode was a small peak of targets less than -60 dB in the top 30 m. At night, there wee small (-50 to -60 dB targets to 50 m, and a second peak of -30 to -45 dB targets at 80 m. Net data were limited, but the bottom trawl caught pollock, herring and smelt (Figure 10).

Eaglek Bay

We found the fewest targets at any time, and in any bay, in Eaglek during March 1997 (Figure 6a, 6b). The targets were distributed in two distinct groups: a low TS surface group, and large (-30 to -45 dB) targets at 100 m. The bottom trawl caught adult herring, pollock, and flatfish during the day, but mostly flatfish at night (Figure 10).

May 1997

Simpson Bay

Simpson bay had fewer targets detected in May 1997 than during any other sampling (Figure 3a, 3b). The observed targets were primarily in the -25 to -25 dB range, and were found at 60 m during the day, but moved above 40 m at night. The number of small targets near the surface dramatically increased at night. During the day, the bottom trawl caught mainly herring, but at night, the highest catches were of herring in the purse seine (Figure 11).

Zaikof Bay

Like Simpson, there were few targets in Zaikof during this cruise (Figure 4a, 4b). During the day, there were some shallow small targets, plus a collection of -30 to -40 dB targets below 60 m. At night, these larger targets moved to the top 40 m, and the overall number of targets increased. A trawl at 100 m during the day caught a few adult herring and pollock, while the seine caught adult herring near the surface at night Figure 11).

Whale Bay

Of the four bays, Whale Bay appeared to have the largest number of targets during this cruise (Figure 5a, 5b). The highest concentration of targets was above 30 m, and consisted of targets less than -55 dB. During the 0800 and 0000 surveys, there were also many large targets (-25 to -45 dB). At 0800, these large targets were found between 20 and 80 m, but at night they were in two more distinct depths: 20 m, and 60 to 80 m. Like the other bays, daytime catches were highest in the bottom trawls and consisted o herring, pollock and flatfish (Figure 11). At night, the seine had high catches of herring and pollock.

Eaglek Bay

The TS distribution in Eaglek was similar to the other bays, but with more small targets near the surface, and fewer large (> -45 dB) targets (Figure 6a, 6b). There was a small peak of large targets at 60 m at night, but not many compared to the other bays. The nets caught mainly herring during both day and night, and caught a few pollock at night, by trawl (Figure 11).

July 1997

Simpson Bay

We found more targets in Simpson Bay in July than in March 1997 (Figure 3a, 3b). The biggest difference was the increase in small targets seen in the top 30 m. We also saw a diel increase in the number of large targets, which was similar to other cruises. During the day, small herring were captured in near the surface in the box trawl and fry seine (Figure 12). The large seine caught predominantly herring in the day, and pollock at night.

Zaikof Bay.

There were more small targets in Zaikof Bay in July than in March 1997, but fewer targets than the summer of 1996 (Figure 4a, 4b). During the 0800 survey, not many targets were seen; however, by 0000, the top 40 m was filled with targets ranging from -30 to -80 dB. Net catches at this time were low, but some adult herring were caught in the seine and bottom trawls during daytime sampling (Figure 12).

Whale Bay

Whale Bay had fewer targets in July than in May, or during the previous year (Figure 5a, 5b). In addition, their was a larger range of target strengths (-45 to -80 dB) than during the previous two cruises. Once again, there was an increase in the number of detected targets at night, especially of targets greater than -50 dB. Net catches were highest at night, when the seine caught mostly juvenile pollock (Figure 12).

Eaglek Bay

The distribution of detected targets in Eaglek Bay was similar in May and June 1997; however, the TS range of the observed targets was slightly larger in June 1997 (Figure 6a, 6b). The diel pattern of higher numbers of large targets near the surface was again seen, although not at the same magnitude as the previous summer. During the day, many small herring were captured by seine and a few pollock were caught in the bottom trawl (Figure 12).

August 1997

Simpson Bay

The number of detected targets in Simpson Bay increased dramatically from July to August 1997 (Figure 3a, 3b). This increase was apparent in the breadth of TS values, and an increase in the depth of their distribution. At night, there were abundant targets ranging from -25 to -80 dB from the surface to 75 m. Net catches were high during these surveys, and were dominated by young herring, with a few adult pollock (Figure 13).

Zaikof Bay

Sampling in Zaikof was limited to just one survey (1600) in August 1998. The distribution and range of target strengths appeared similar to July 1997, with many small target in the top 20 m, plus a few large deep targets (Figure 4a, 4b). Catch data were also limited, but the trawl did catch pollock at 40 m depth (Figure 13).

Whale Bay

The number and distribution of targets in Whale Bay was different from July to August 1997, but August 1997 and August 1998 were similar (Figure 5a, 5b). There were again two groups of targets detected in Whale Bay. The shallow, small targets had a smaller range of TS than in July 1997, but extended deep to 60 m. as seen the previous August. There was also a much larger increase in the number of large targets detected at night in August than in July 1997. Net catches were primarily pollock in Whale Bay (Figure 13).

Eaglek Bay

We found an larger range of TS values for detected targets in August than in July 1997 in Eaglek Bay (Figure 6a, 6b). This was most dramatic at night above 30 m, where we found large numbers of targets ranging from -30 to -80 dB in August, compared to a range of -50 to -80 in July. There were also more large, deep targets in August than in July 1997. Overall, this pattern was similar to August 1996. The highest net catches were in the seines, and were composed of young herring (Figure 13).

DISCUSSION

Inter-Bay Comparison

In June 1996 all the bays displayed plankton sized surface targets throughout the sampling period, (Cooney et al. 1995). A large range of TS values were acquired indicating the presence of a number of size classes, this includes small and large fish sized targets. Simpson and Zaikof displayed the greatest relative number of targets, and also showed a separation of different layers and target values. The increase in detected targets at night is a consistent feature in all bays, and has been in other studies. (Luecke and Wurtsbaugh, 1993). Whale and Eaglek did not display the deep fish sized targets evident in Simpson and Zaikof. In August 1996, the daylight samples displayed a grouping of small surface targets, again plankton sized. The midnight period, however, had an increase in all targets of all sizes. Whale and Eagleks' surface structure of depth distribution and target strength are markedly different than that of the other bays. Both display a narrower range of TS values, and a greater range of depth. This may be due to different zooplankton species.

In October 1996, all the bays had large numbers of surface scatters around the TS value for plankton and fish, and increased in the number deep large targets during the night sampling period. The distinctive small target structure in Whale and Eaglek. Is more pronounced in its difference as compared to Simpson and Zaikof. In March 1997, Simpson showed the surface structure found in the Whale and Eaglek bays. All bays are again consistent, showing a large reduction in the detected surface targets. The presence of fish sized targets is indicated in the bays. At night, in Simpson and Zaikof Bays, the fish sized targets are found in two distinct layers, one at depth around 60 m, the other in the surface waters. This may be due to vertical migration for foraging. In May 1997, Simpson and Zaikof had relatively low surface scattering, whereas Whale and Eaglek had an increase in the plankton sized targets near the surface. All bays but Eaglek had large deep fish sized targets evident at night. In July 1997, the small surface targets were again in increased evidence in all the bays. Simpson and Zaikof also showed an increase in the deeper fish sized targets, as did Whale. Eaglek, however, had very few detected deep targets of that size range. In August 1997, the surface targets were numerous and evident throughout the sampling periods, for all the bays. Whale and Eaglek had the distinctive small target structure, Whale having the more pronounced narrow TS values and corresponding large depth range, and also showed larger targets deeper in the water column.

Seasonal Changes

A major feature evident was the consistency between the bays in the relative abundances of the targets. This is illustrated by the dramatic reduction in small surface plankton sized targets found in the March cruise, and the trends of increasing abundances in similar TS ranges that the bays follow throughout the year. This reduction in plankton sized targets over the winter may be due in part to the climatic conditions and predatory action. However, the five month hiatus of sampling means that the date of the reduction in detected surface targets of this size cannot be accurately determined. The observed increase in the target strengths could be attributed to increases in the length structure of the observed targets, and with further analysis this could yield information on the age structure throughout the sampling periods, thus identifying cohorts and following the changes in the population structure. The increase observed in all the bays of the small plankton sized targets could indicative of the March plankton bloom. The delayed signature is due to the small initial size of plankton targets and to the frequency used in the surveys. As mentioned previously, the plankton sized surface targets found in Whale and Eaglek, have, throughout the year, a different vertical and horizontal structure which is appeared by August. The comparison of the observed acoustic changes in the plankton sized targets to the plankton net information, showing species break up, is ongoing.

All four bays displayed a strong seasonal change, Eaglek, however, had relatively the lowest abundance, with Simpson showing regularly relatively higher abundances. The increase in TS spread seen in all the bays after March could be attributed to length changes of the local fish populations. This increase continues throughout the year, culminating with August 1997. There is good similarity between the two surveys conducted in August 1996 and August 1997. The same relative larger abundances than in other months, and the comparison of the TS to depth distribution structure show a greater fidelity for the individual bays than in comparison to the other bays. This indicates a cyclic fluctuation in the fish populations.

There are numerous instances of the detected fish sized targets separating into distinct layers. There has been some preliminary indication these distributions are being influenced by the physical water mass properties, (unpublished data, Peters and Gay). The comparisons of the acoustic data with the oceanographic will lead into new insights on the distributions of both the juvenile and adult herring.

Although acoustics are the best source of information as yet available for fisheries management of populations, some of the sources of error can be dramatically reduced by the amalgamation of other investigative data sets. For instance the species and size make up of the acoustic targets can be found with net sampling. Nets, however, are selective, and will cause biases in the delivered data. In areas where the fish are separated enough that the frequency of coincident targets is small the target strength information can be used to described the size classes of the observed targets with a fair degree of accuracy. However, as the density of the aggregation increases, the rate of coincident targets also increases, and, as these are rejected by the target discriminator, the quality of the information as representative of the fish assemblage decreases.

Use of underwater cameras can provide species identification, and the ability to measure size of the target can give length comparison. Use of historic data in the form of long term monitoring of the same area will give a greater certainty to the identity of the acoustic signal. Knowing behavioral patterns, seasonal fluctuations and aggregations for the target species, can greatly enhance the ability of hydroacoustic surveys to accurately measure the fish biomass.

The uncertainty in the data interpretation is compounded in multi-species environments. Concentrations of fish can include more than one species and age class. If the size classes overlap in TS, acoustical separation of the species is extremely difficult or impossible. Hydroacoustics are virtually always used in conjunction with a type of capture technique. When dealing with the multispecies layering this becomes a vital source of additional information. It is, however, not always necessary to specifically identify the individuals in the acoustic return. Using the net catches to evaluate the amount of acoustic return that can be attributed to each species, allows the biomass composition to be determined (Thomas et al. 1996).

It is possible to augment the information collected by the acoustics with the use of video cameras. Gledhill et. al. (1996), showed that the differences in the sampling abilities of the instruments can lead to large differences in the resulting abundance of fish species. For example the acoustic estimates of the near bottom species were lower than the video estimates. Whereas the increased sampling volume of acoustics estimated larger abundances of off bottom species. A highlighted difference was in the species identification: video yields precise information on the species, while acoustics produces initially no species specific information.

New techniques that are being implemented include the use of multi frequency and wideband acoustic surveys. Concurrently operating two or more transducers of different frequencies, affords measurement of the size of the gas bladder, due to the difference in frequency response this information can be used to discriminate between species. Wideband sounders are the next logical step in this area. They operate over a continuous frequency range. The returned frequency spectra is then analyzed. Species identification of the wideband signal has been shown to present recognition rates of 95%, Simmons et. al. (1996). Data were processed in eight continuous frequency bands from 27 kHz to 54 kHz, yielding the frequency spectra. Further analysis obtained a mean frequency spectra independent of absolute backscatter. Through the use of neural networks and discriminant analysis the aforementioned recognition rate was obtained. Zakharia et. al. (1996), also utilized a wideband system. Here the methodology of data processing was based on the frequency signature of the individual fish. Use of neural networks on the parameterized power spectrum, a standard technique in signal processing where resonant features occur, produced a classification success rate of 75%.

The two wideband analysis mentioned are independent of the physical surroundings of the fish; however, use of the physical characteristics can also be used to identify fish species. School shape and/or proximity to bathymetric features, has been used to successfully identify fish species. In Richards et. al. (1991), a technique discriminating between bottom habitats to characterize fish schools was implemented. Using such parameters as time of day, mean volume density, dispersion and mean bottom distance of the biomass, with subsequent nearest neighbor analysis on these features produced a 97% success rate.

Due to the constraints of time and survey design the data collected from acoustic transects tended to be separated in spatial measurements over distance. This coupled with the aggregations of the target species led to a few high density estimates with a larger number of low density measurements. If the fish are known to aggregations at certain times of the year, and it can be reasonably assumed that a large percentage of the population, for an area, is contained in these schools, then repeated acoustic surveys, can be used to accurately measure the relative biomass of the target species, when coupled with net catch information.

ONGOING RESEARCH

The preliminary look at this data shows promise in identifying age classes and the continual identification of the cohorts throughout the season. However, much work needs to be done correcting for net biases, and on the post processing of acoustic target strength information. A more exacting methodology of removing the multiple returns on a single fish needs to be investigated, and the physical and positional changes of the fish targets resulting in changes of target strength of the individual warrant further evaluation. The target discriminator, which analysis the raw acoustic signal, needs improvement. Presently there is no information recorded on the coincident signals which are rejected. The improvement of the signal processing will lead to the ability to acoustically measure the size difference in high fish densities will allow the cohorts of the fish population to accurately determined.

The reported data highlights the complicated and highly dynamic nature of the environment. With only one year of this type of information (repeated acoustic and net sampling) it is hard to speculate on the relative importance of each bay, as this may very well change per season. It could be seen, however, that these areas were used for rearing of the juvenile herring. The overwintering populations of fish having been shown, in these areas, to be consisted of almost entirely of herring, the regular influx of larger fish, manifested in increased targets and TS and in net data, lends itself to the idea that, at least for the bays sampled, they have a returning spawning biomass.

ACKNOWLEDGMENTS

We would like to thank all the captains and crews of the fishing and research vessels in the collection of the data. Kevin Stokesbury who conceived the diel study. We would also like to thank the University of Alaska Fairbanks and the Alaskan Department of Fish and Game, as they were responsible for analyzing the net catch data. This work is funded by the Exxon Valdez Oil Spill Trustee Council.

FIGURE CAPTIONS

Figure 1. Location of the four bays. Clockwise from top, Prince William Sound, Alaska. Eaglek, Simpson, Zaikof, Whale Bays.

Figure 2. Variation of calculated target strength with length.

Figure 3a. Relative frequency of detected acoustic targets by TS and depth. Simpson Bay June 1996 to March 1997.

Figure 3b. Relative frequency of detected acoustic targets by TS and depth. Simpson Bay May 1997 to Aug 1997.

Figure 4a. Relative frequency of detected acoustic targets by TS and depth. Zaikof Bay June 1996 to March 1997.

Figure 4b. Relative frequency of detected acoustic targets by TS and depth. Zaikof Bay May 1997 to Aug 1997.

Figure 5a. Relative frequency of detected acoustic targets by TS and depth. Whale Bay June 1996 to March 1997.

Figure 5b. Relative frequency of detected acoustic targets by TS and depth. Whale Bay May 1997 to Aug 1997.

Figure 6a. Relative frequency of detected acoustic targets by TS and depth. Eaglek Bay June 1996 to March 1997.

Figure 6b. Relative frequency of detected acoustic targets by TS and depth. Eaglek Bay May 1997 to Aug 1997.

Figure 7. Net catch data for Simpson, Zaikof, Whale, and Eaglek Bays. June 1996.

Figure 8. Net catch data for Simpson, Zaikof, Whale, and Eaglek Bays. August 1996.

Figure 9. Net catch data for Simpson, Zaikof, Whale, and Eaglek Bays. October 1996.

Figure 10. Net catch data for Simpson, Zaikof, Whale, and Eaglek Bays. March 1997.

Figure 11. Net catch data for Simpson, Zaikof, Whale, and Eaglek Bays. May 1997.

Figure 12. Net catch data for Simpson, Zaikof, Whale, and Eaglek Bays. July 1997.

Figure 13. Net catch data for Simpson, Zaikof, Whale, and Eaglek Bays. August 1997.

REFERENCES

Cooney, R. T. and K. O. Coyle. 1995 The role of zooplankton in the Prince William Sound Ecosystem. Exxon Valdez Oil Spill Restoration Project annual report. Restoration Project 95332-H.

Gledhill, C. T., Lyczkowski-Shultz, J., Rademacher, K., Kargard, E., Crist, G., and Grace, M. A. 1996. Evaluation of video and acoustic index methods for assessing reef-fish populations. ICES Journal of Marine Science, 53:483:485.

Luecke, C. and Wurtsbaugh, W. A. 1993. Efects of moonlight and daylight on hydroacoustic estimates of pelagic fish abundance. Trans. Am. Fish. Soc. 122:112-120

Richards, L. J., R. Kieser, T. J. Mulligan, and J. R. Candy. 1991. Classification of fish assemblages based on echo integration surveys. Can. J. Fish. Aqua. Sc. 48:1264-1272.

Simmonds, E. J., Armstrong, F., and Copland, P. J. 1996. Species identification using wideband backscatter with neural network and discriminant analysis. ICES Journal of Marine Science, 53:189-195.

Stokesbury, K. D. E., E. Brown, R. J. Foy, B. L. Norcross. 1996. Juvenile herring growth and habitats. Restoration project 95320T.

Thomas, G. L., J. Kirsch, N. Peters. 1996 SEA: Acoustically determined juvenile herring distribution in Prince William Sound fall 1995. Nekton-plankton acoustics. 1996 Restoration Project 96320N.

Thorne, R. E. 1983a. Assessment of population abundance by hyroacoustics. Biol Oceanog 2:253-262

Thorne, R. E. 1983b. Hydroacoustics. In: Neilsen L. A., Johnson D. L., (ed) Fisheries techniques. Am. Fish. Soc., Bethesda MD, p239-259.

Traynor, J. J. and J. E. Ehrenberg. 1979. Evaluation of the dual-beam acoustic fish target strength method. J. Fish. Res. Bd. Can. 36: 1065-1071.

Zakharia, M. E., Magand, F., Hetroit, F., and Diner, N. 1996. Wideband sounder for fish species identification ar sea. ICES Journal of Marine Science 53:203-208

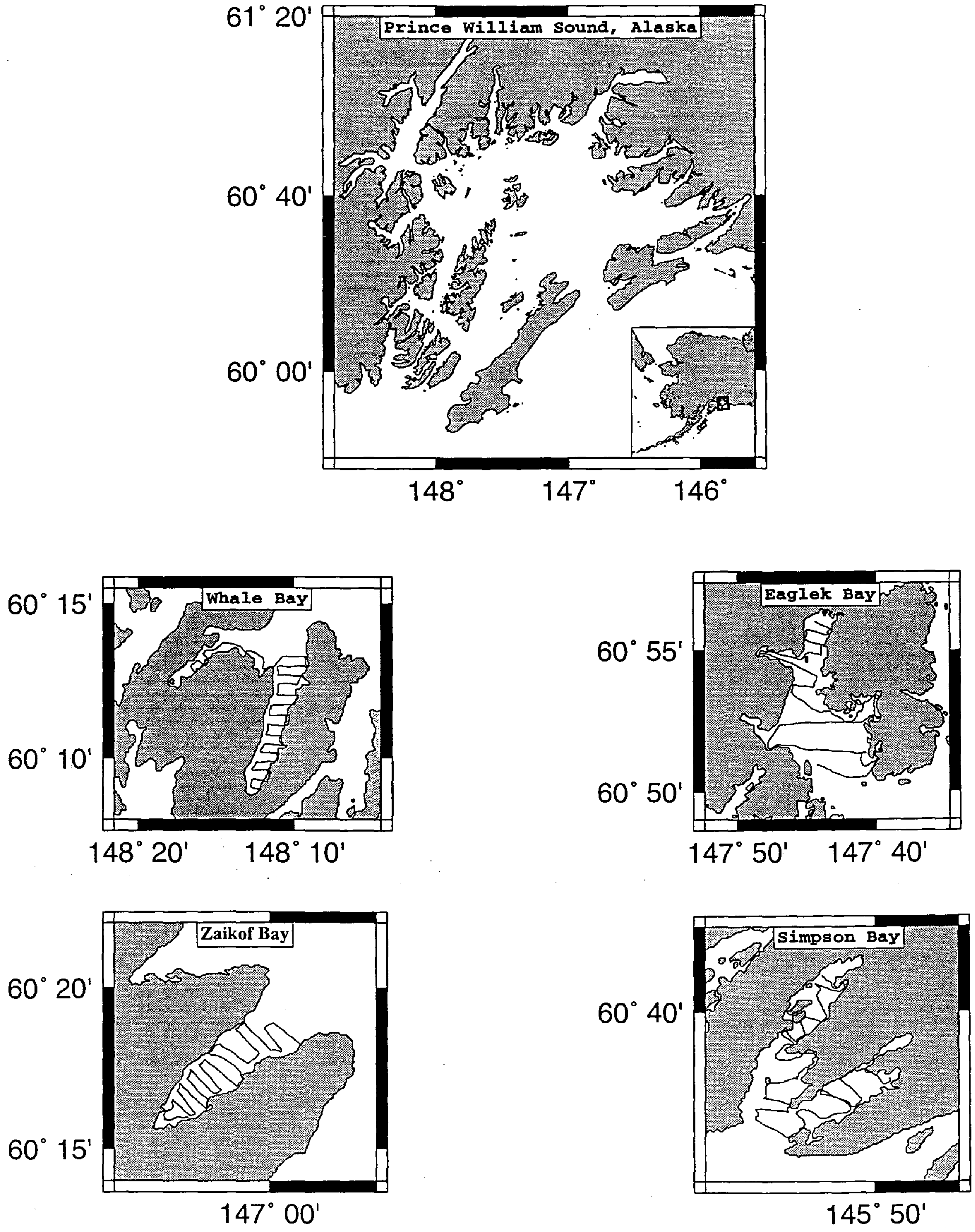

Prince William Sound, Alaska
61° 20'
60° 40'
60° 00'
148°
147°
146°
Whale Bay
60° 15'
60° 10'
148° 20'
148° 10'
Eaglek Bay
60° 55'
60° 50'
147° 50'
147° 40'
Zaikof Bay
60° 20'
60° 15'
147° 00'
Simpson Bay
60° 40'
145° 50'

Figure 1.

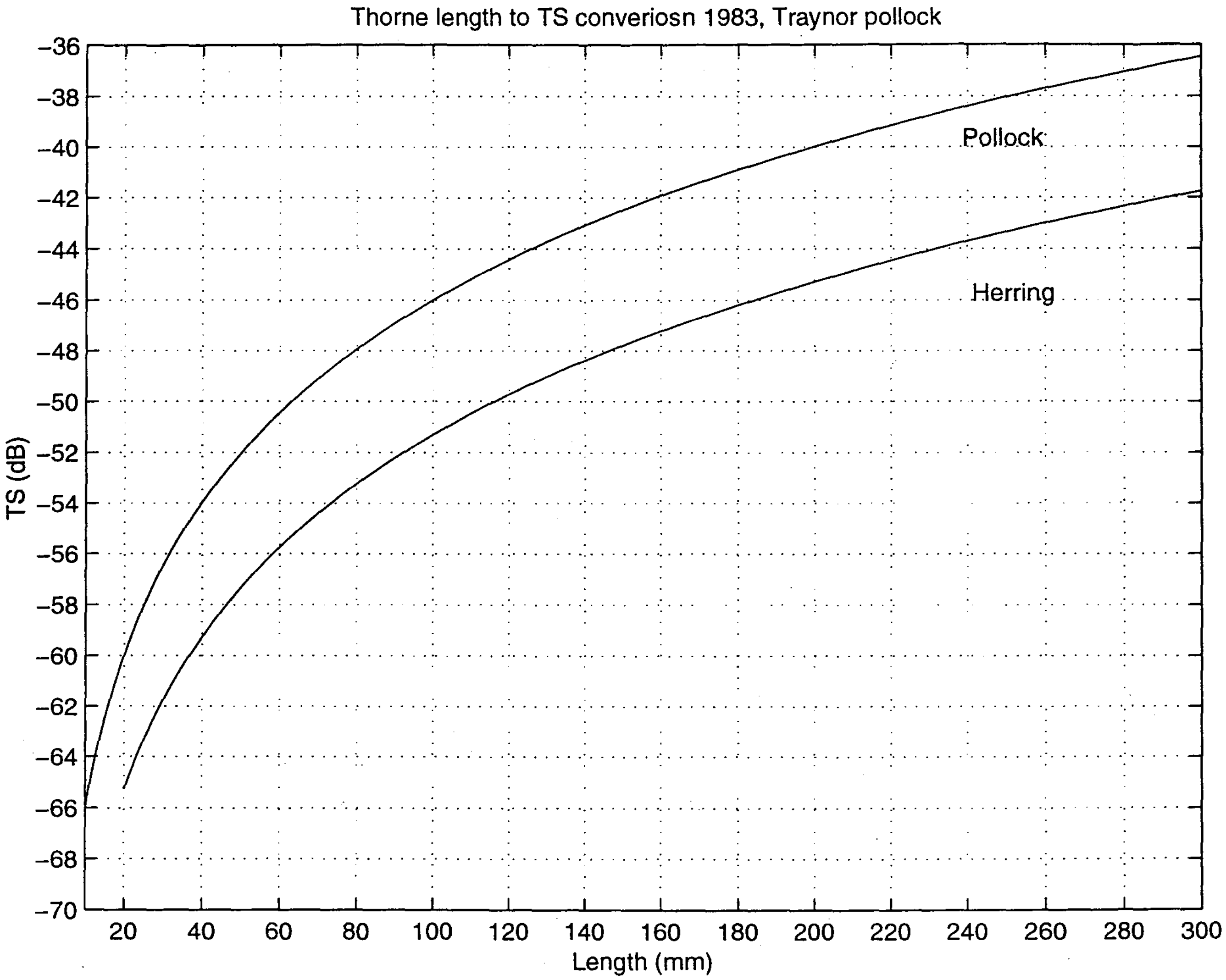
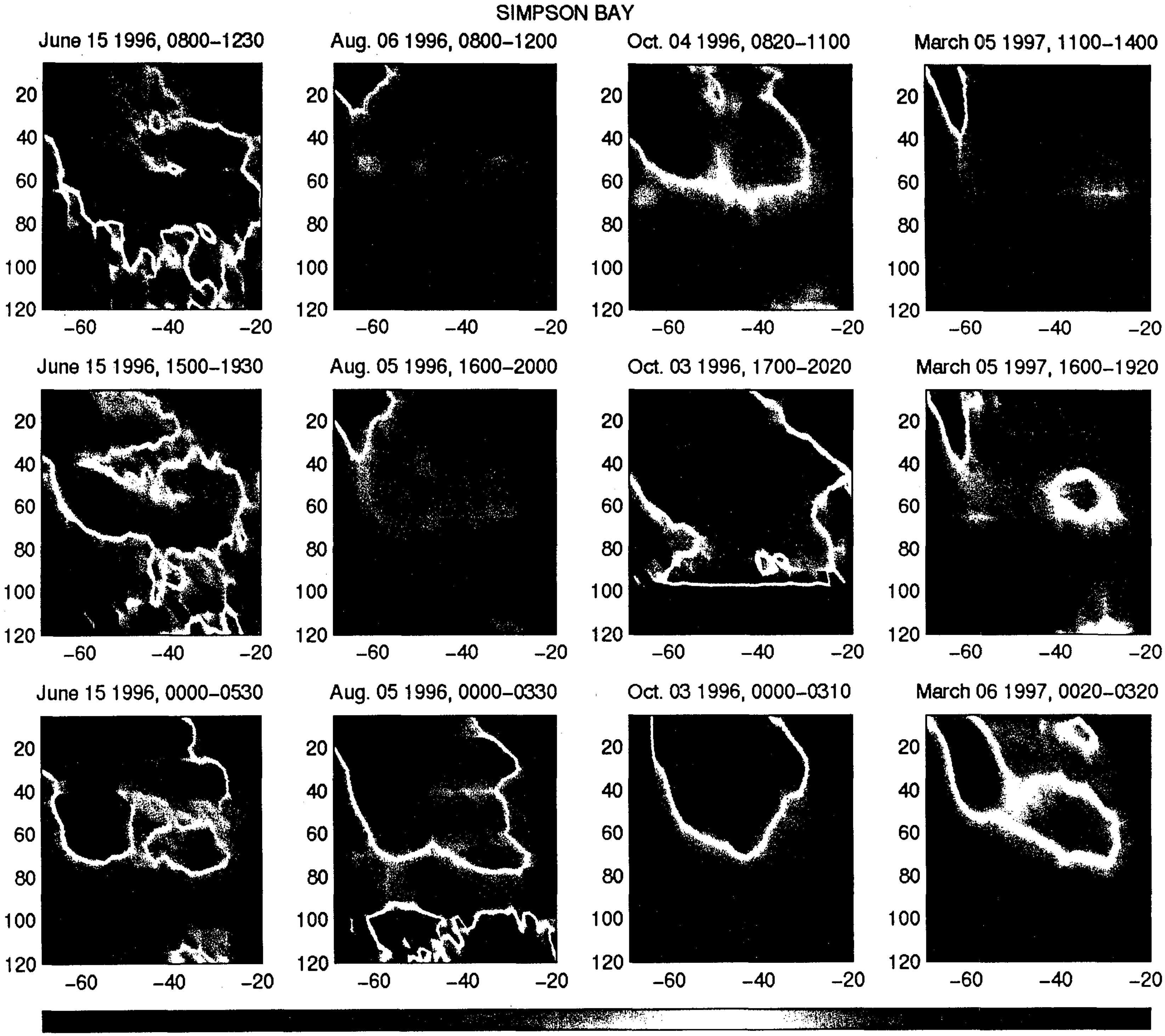

Thorne length to TS converiosn 1983, Traynor pollock
Pollock
Herring
TS (dB)
Length (mm)
−36
−38
−40
−42
−44
−46
−48
−50
−52
−54
−56
−58
−60
−62
−64
−66
−68
−70
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300

Figure 2.



SIMPSON BAY

June 15 1996, 0800-1230

Aug. 06 1996, 0800-1200

Oct. 04 1996, 0820-1100

March 05 1997, 1100-1400

June 15 1996, 1500-1930

Aug. 05 1996, 1600-2000

Oct. 03 1996, 1700-2020

March 05 1997, 1600-1920

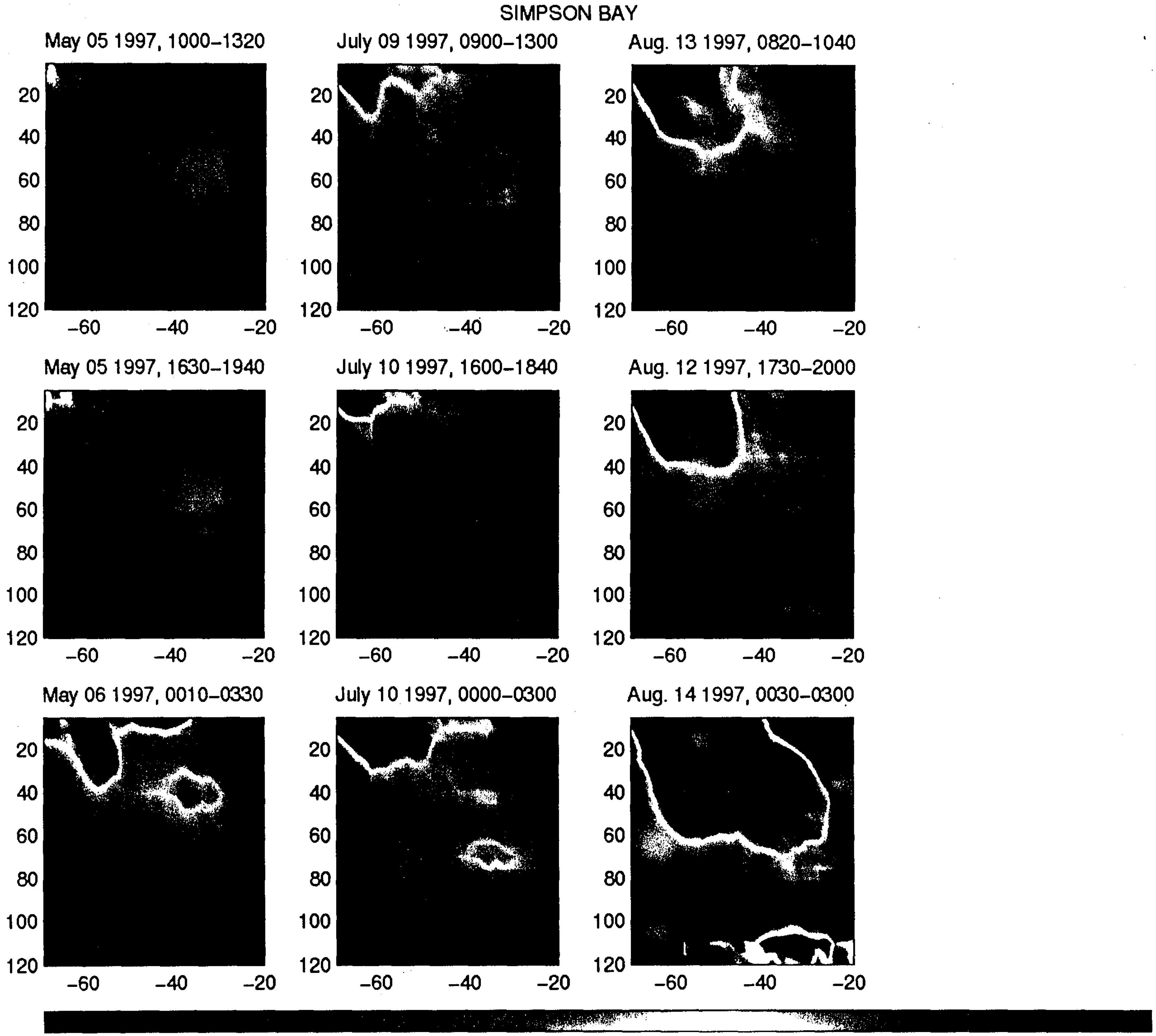
June 15 1996, 0000-0530

Aug. 05 1996, 0000-0330

Oct. 03 1996, 0000-0310

March 06 1997, 0020-0320

Figure 3a.



SIMPSON BAY

May 05 1997, 1000-1320

July 09 1997, 0900-1300

Aug. 13 1997, 0820-1040

May 05 1997, 1630-1940

July 10 1997, 1600-1840

Aug. 12 1997, 1730-2000

May 06 1997, 0010-0330

July 10 1997, 0000-0300

Aug. 14 1997, 0030-0300

Figure 3b.

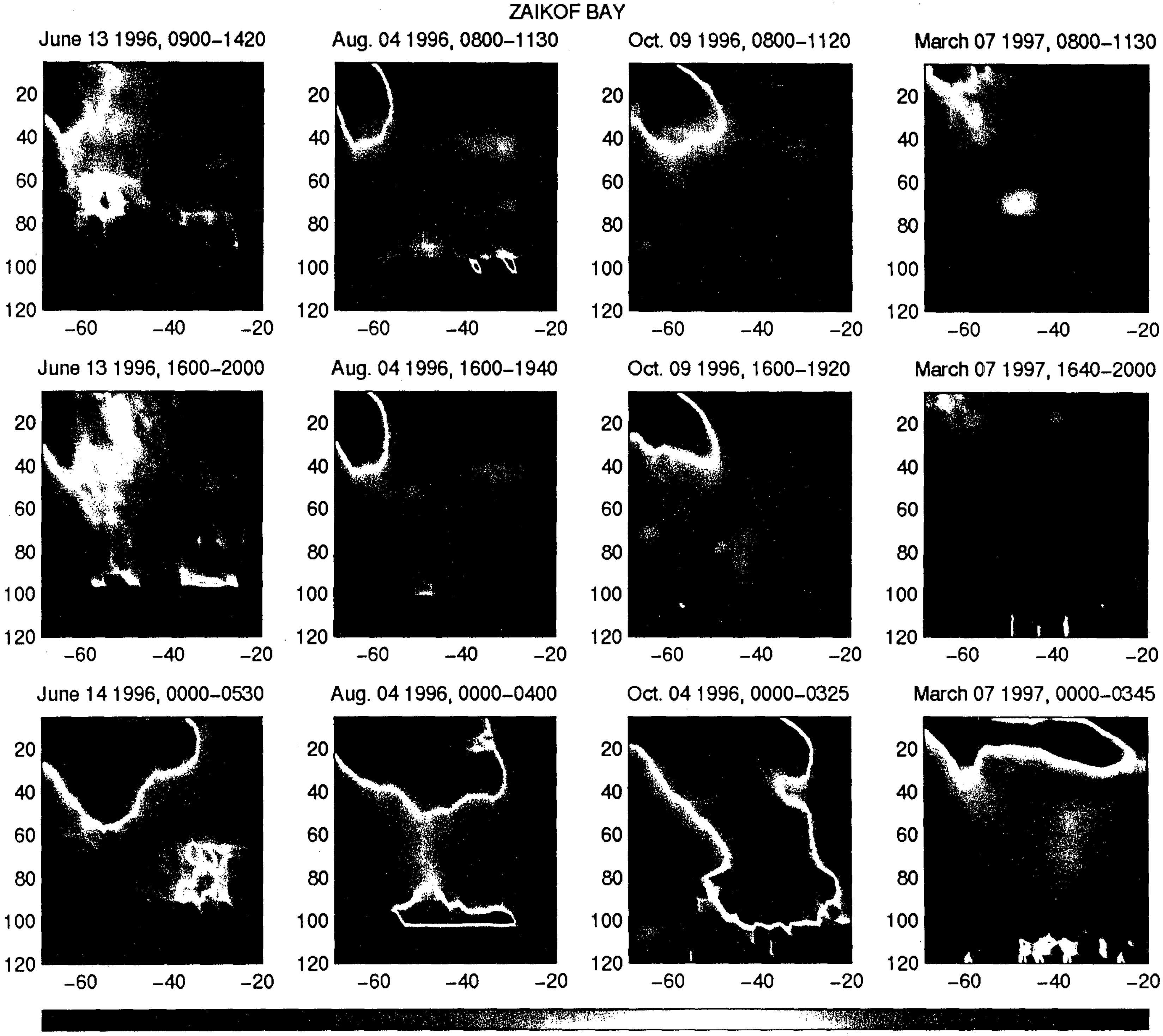
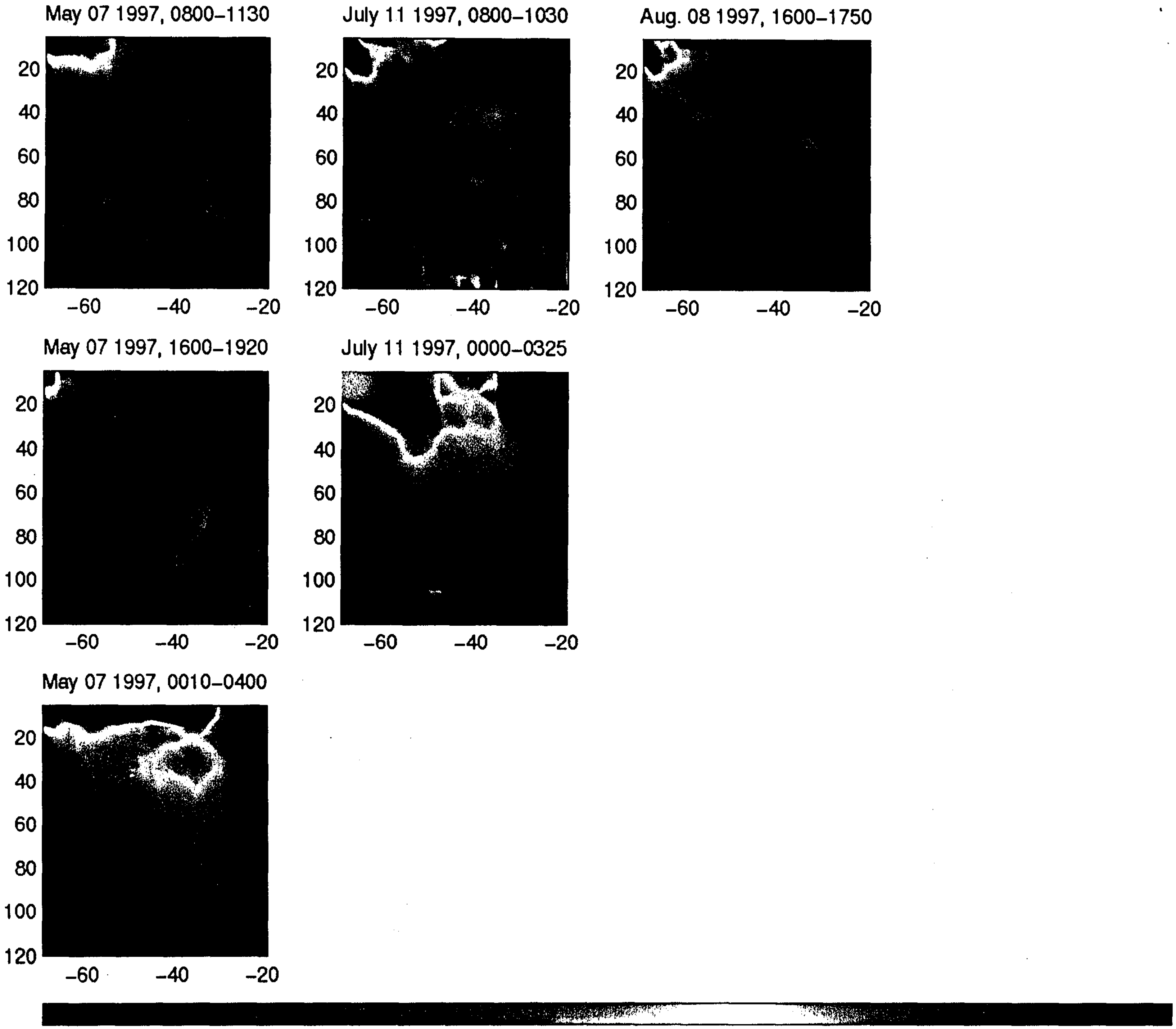

ZAIKOF BAY
June 13 1996, 0900-1420
Aug. 04 1996, 0800-1130
Oct. 09 1996, 0800-1120
March 07 1997, 0800-1130
June 13 1996, 1600-2000
Aug. 04 1996, 1600-1940
Oct. 09 1996, 1600-1920
March 07 1997, 1640-2000
June 14 1996, 0000-0530
Aug. 04 1996, 0000-0400
Oct. 04 1996, 0000-0325
March 07 1997, 0000-0345
20
40
60
80
100
120
-60
-40
-20

Figure 4a.



ZAIKOF BAY

May 07 1997, 0800-1130

July 11 1997, 0800-1030

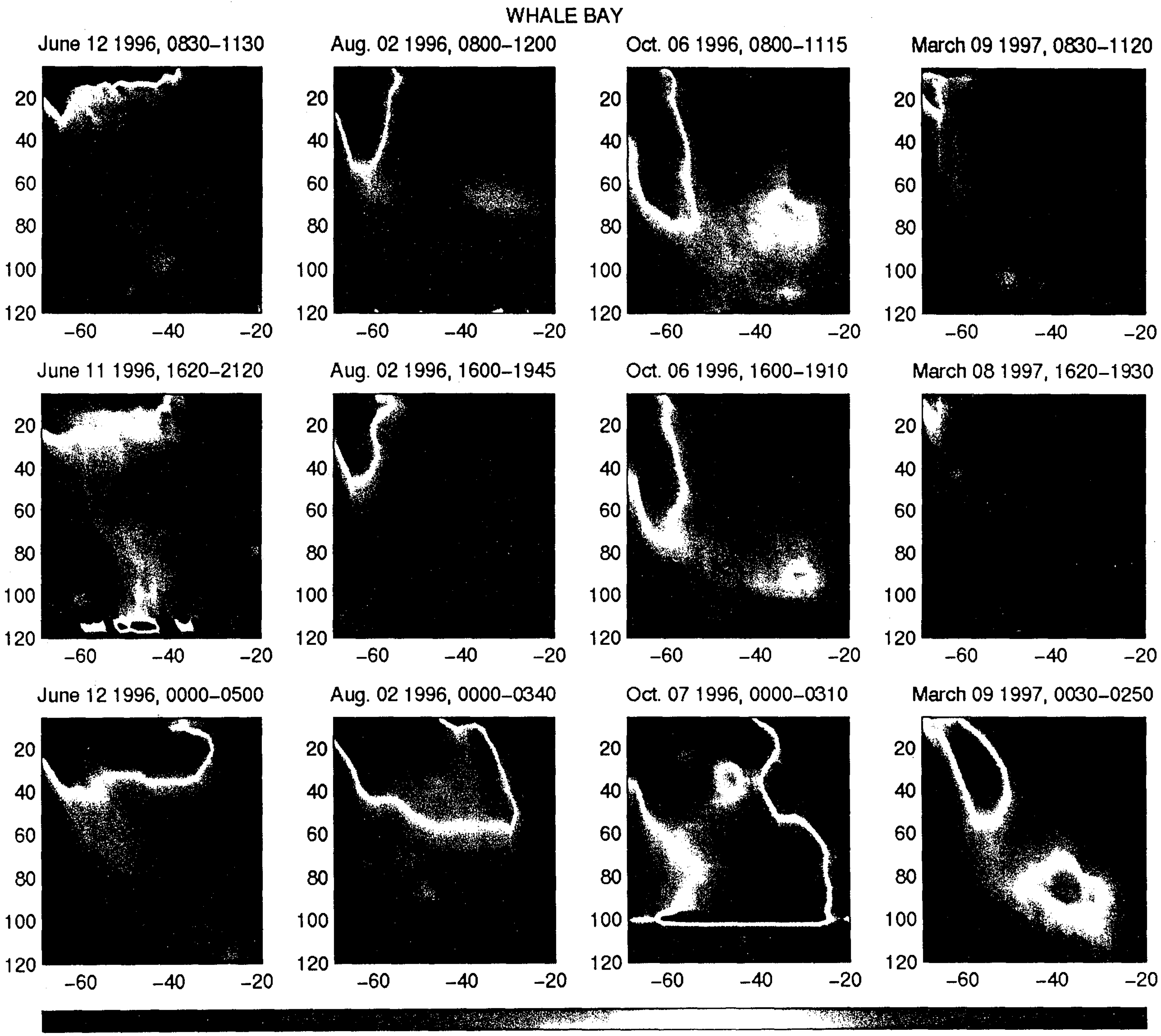
Aug. 08 1997, 1600-1750

May 07 1997, 1600-1920

July 11 1997, 0000-0325

May 07 1997, 0010-0400

Figure 4b.


WHALE BAY

June 12 1996, 0830-1130

Aug. 02 1996, 0800-1200

Oct. 06 1996, 0800-1115

March 09 1997, 0830-1120

June 11 1996, 1620-2120

Aug. 02 1996, 1600-1945

Oct. 06 1996, 1600-1910

March 08 1997, 1620-1930

June 12 1996, 0000-0500

Aug. 02 1996, 0000-0340

Oct. 07 1996, 0000-0310

March 09 1997, 0030-0250

Figure 5a.

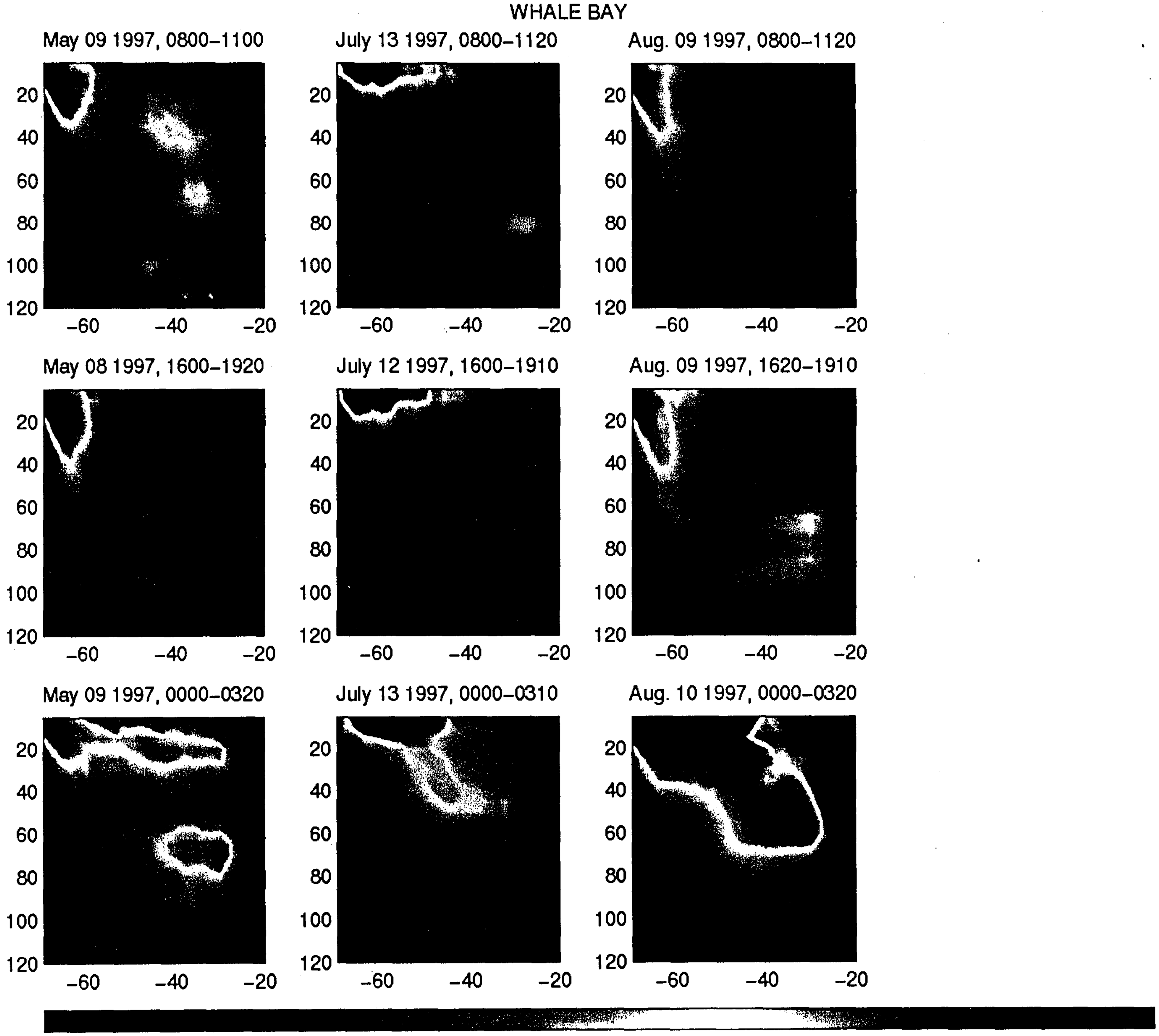

WHALE BAY
May 09 1997, 0800-1100
July 13 1997, 0800-1120
Aug. 09 1997, 0800-1120
May 08 1997, 1600-1920
July 12 1997, 1600-1910
Aug. 09 1997, 1620-1910
May 09 1997, 0000-0320
July 13 1997, 0000-0310
Aug. 10 1997, 0000-0320
20
40
60
80
100
120
-60
-40
-20

Figure 5b.

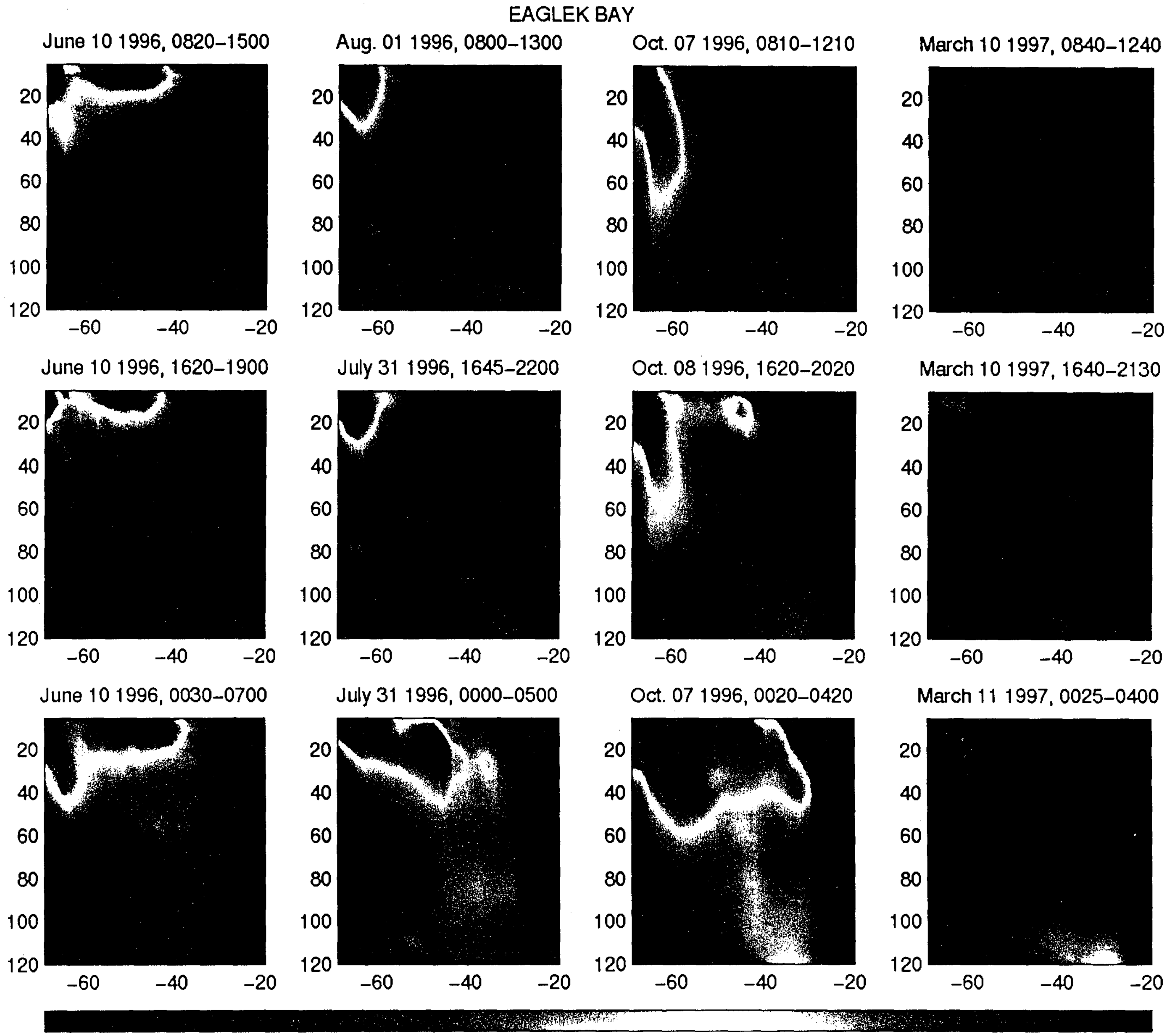

EAGLEK BAY
June 10 1996, 0820-1500
Aug. 01 1996, 0800-1300
Oct. 07 1996, 0810-1210
March 10 1997, 0840-1240
June 10 1996, 1620-1900
July 31 1996, 1645-2200
Oct. 08 1996, 1620-2020
March 10 1997, 1640-2130
June 10 1996, 0030-0700
July 31 1996, 0000-0500
Oct. 07 1996, 0020-0420
March 11 1997, 0025-0400
20
40
60
80
100
120
-60
-40
-20

Figure 6a.

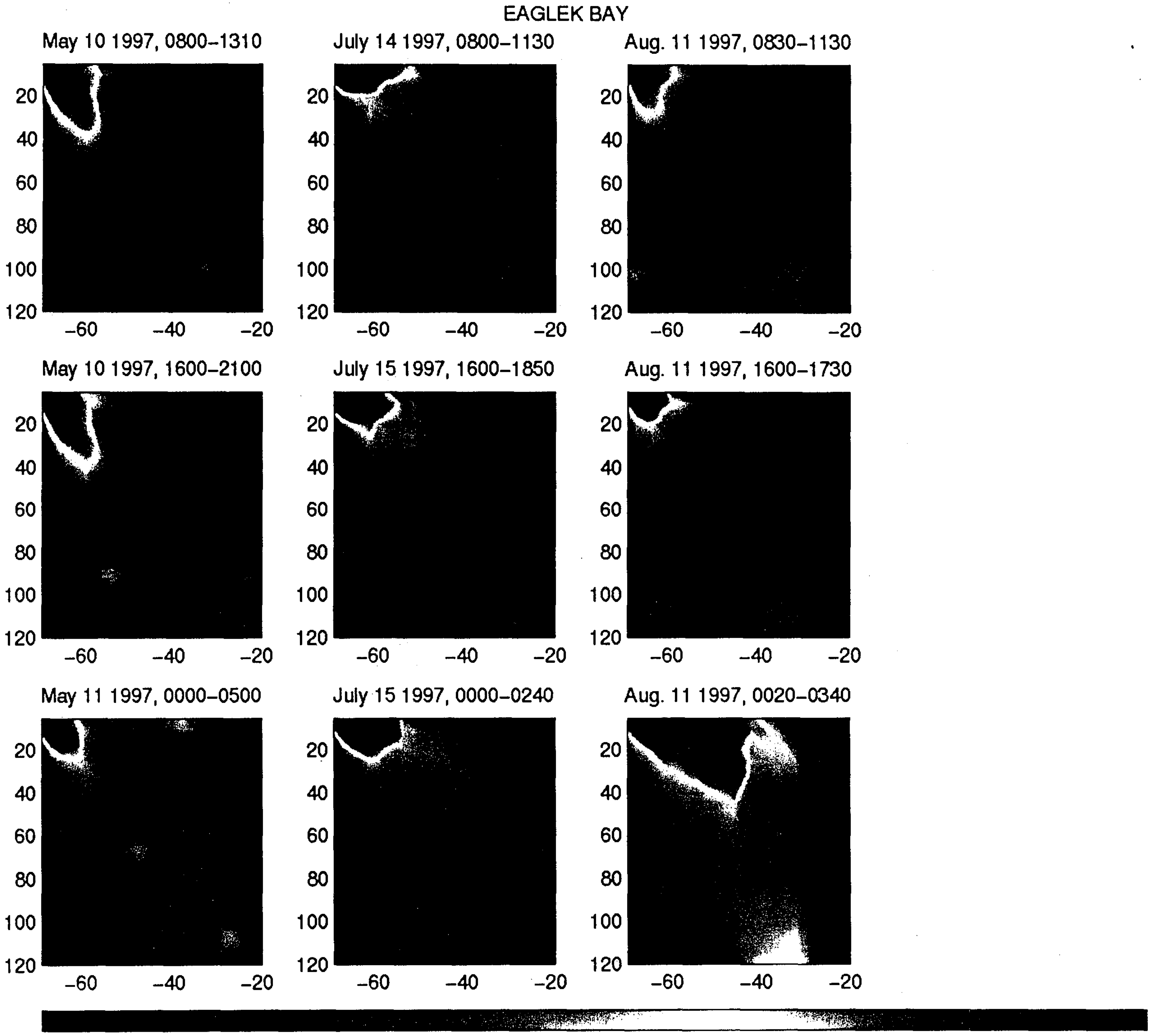

EAGLEK BAY
May 10 1997, 0800-1310
July 14 1997, 0800-1130
Aug. 11 1997, 0830-1130
May 10 1997, 1600-2100
July 15 1997, 1600-1850
Aug. 11 1997, 1600-1730
May 11 1997, 0000-0500
July 15 1997, 0000-0240
Aug. 11 1997, 0020-0340
20
40
60
80
100
120
-60
-40
-20

Figure 6b.

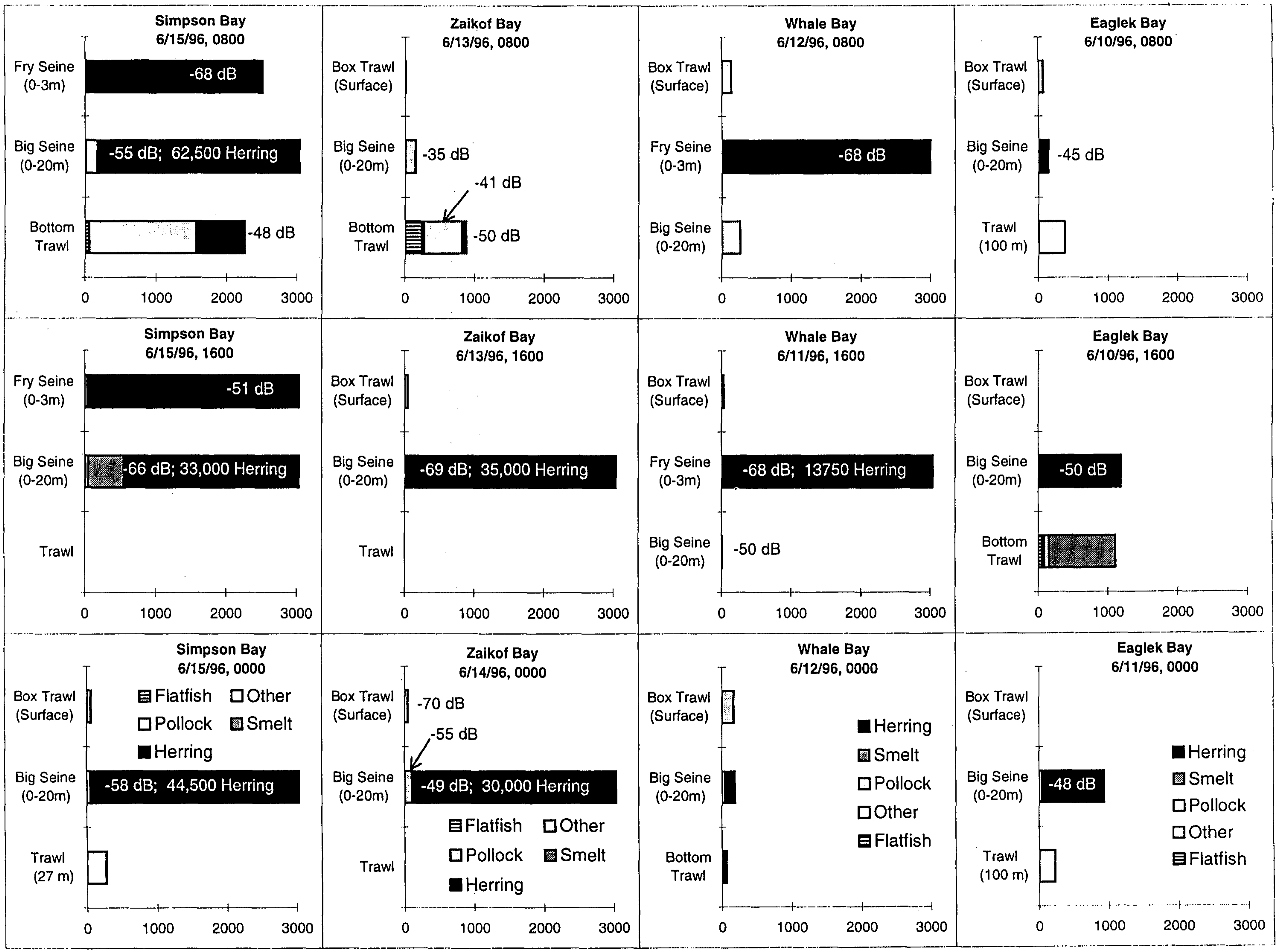

Simpson Bay
6/15/96, 0800
Fry Seine (0-3m)
-68 dB
Big Seine (0-20m)
-55 dB; 62,500 Herring
Bottom Trawl
-48 dB
0
1000
2000
3000
Zaikof Bay
6/13/96, 0800
Box Trawl (Surface)
Big Seine (0-20m)
-35 dB
-41 dB
Bottom Trawl
-50 dB
0
1000
2000
3000
Whale Bay
6/12/96, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
-68 dB
Big Seine (0-20m)
0
1000
2000
3000
Eaglek Bay
6/10/96, 0800
Box Trawl (Surface)
Big Seine (0-20m)
-45 dB
Trawl (100 m)
0
1000
2000
3000
Simpson Bay
6/15/96, 1600
Fry Seine (0-3m)
-51 dB
Big Seine (0-20m)
-66 dB; 33,000 Herring
Trawl
0
1000
2000
3000
Zaikof Bay
6/13/96, 1600
Box Trawl (Surface)
Big Seine (0-20m)
-69 dB; 35,000 Herring
Trawl
0
1000
2000
3000
Whale Bay
6/11/96, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
-68 dB; 13750 Herring
Big Seine (0-20m)
-50 dB
0
1000
2000
3000
Eaglek Bay
6/10/96, 1600
Box Trawl (Surface)
Big Seine (0-20m)
-50 dB
Bottom Trawl
0
1000
2000
3000
Simpson Bay
6/15/96, 0000
Box Trawl (Surface)
Big Seine (0-20m)
-58 dB; 44,500 Herring
Trawl (27 m)
▤ Flatfish
☐ Other
☐ Pollock
▩ Smelt
■ Herring
0
1000
2000
3000
Zaikof Bay
6/14/96, 0000
Box Trawl (Surface)
-70 dB
-55 dB
Big Seine (0-20m)
-49 dB; 30,000 Herring
Trawl
▤ Flatfish
☐ Other
☐ Pollock
▩ Smelt
■ Herring
0
1000
2000
3000
Whale Bay
6/12/96, 0000
Box Trawl (Surface)
Big Seine (0-20m)
Bottom Trawl
■ Herring
▩ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
1000
2000
3000
Eaglek Bay
6/11/96, 0000
Box Trawl (Surface)
Big Seine (0-20m)
-48 dB
Trawl (100 m)
■ Herring
▩ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
1000
2000
3000

Figure 7.

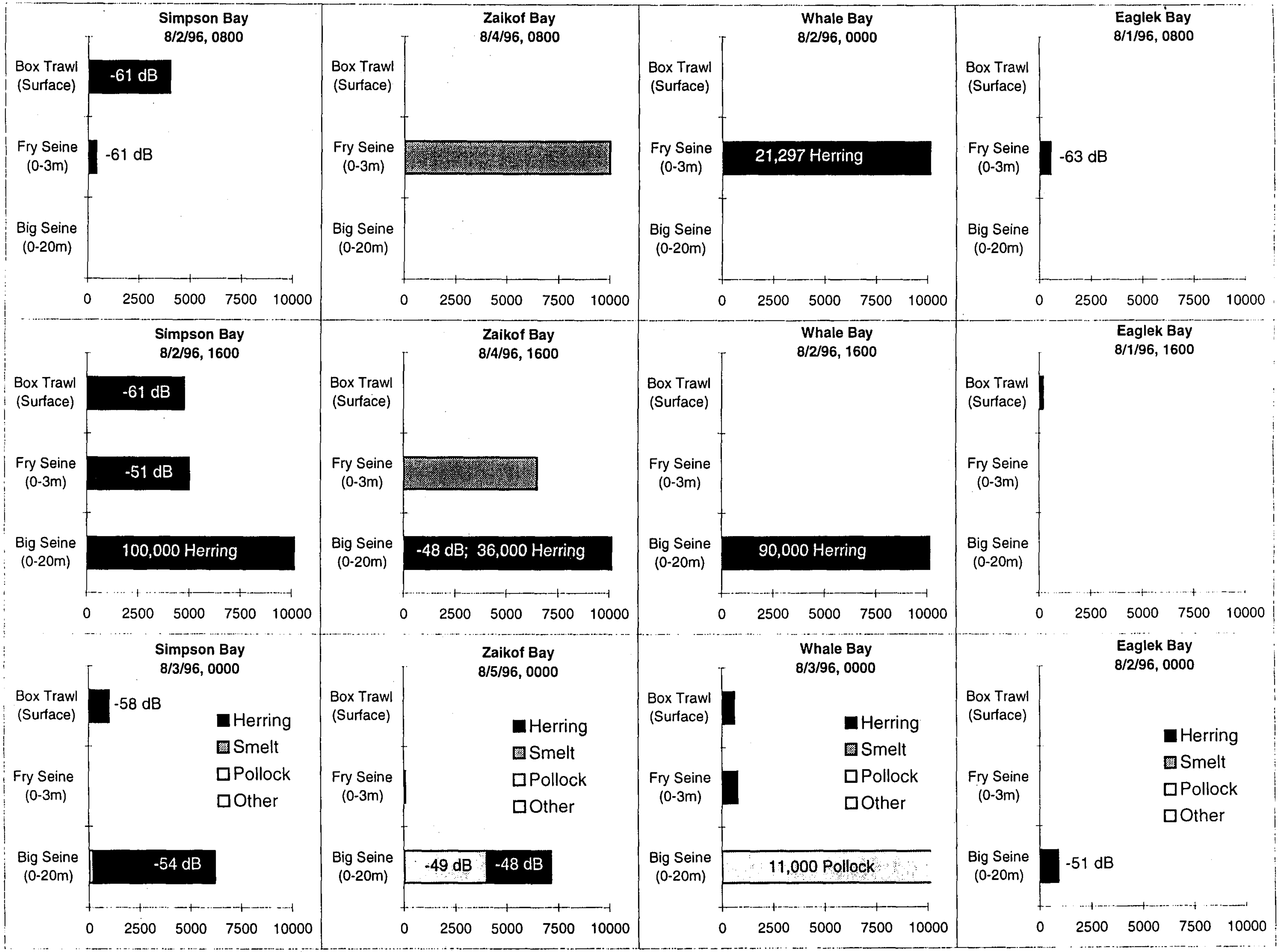

Simpson Bay
8/2/96, 0800
Box Trawl (Surface)
-61 dB
Fry Seine (0-3m)
-61 dB
Big Seine (0-20m)
0
2500
5000
7500
10000
Zaikof Bay
8/4/96, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-20m)
0
2500
5000
7500
10000
Whale Bay
8/2/96, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
21,297 Herring
Big Seine (0-20m)
0
2500
5000
7500
10000
Eaglek Bay
8/1/96, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
-63 dB
Big Seine (0-20m)
0
2500
5000
7500
10000
Simpson Bay
8/2/96, 1600
Box Trawl (Surface)
-61 dB
Fry Seine (0-3m)
-51 dB
Big Seine (0-20m)
100,000 Herring
0
2500
5000
7500
10000
Zaikof Bay
8/4/96, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-20m)
-48 dB; 36,000 Herring
0
2500
5000
7500
10000
Whale Bay
8/2/96, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-20m)
90,000 Herring
0
2500
5000
7500
10000
Eaglek Bay
8/1/96, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-20m)
0
2500
5000
7500
10000
Simpson Bay
8/3/96, 0000
Box Trawl (Surface)
-58 dB
Fry Seine (0-3m)
Big Seine (0-20m)
-54 dB
■ Herring
▨ Smelt
☐ Pollock
☐ Other
0
2500
5000
7500
10000
Zaikof Bay
8/5/96, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-20m)
-49 dB
-48 dB
■ Herring
▨ Smelt
☐ Pollock
☐ Other
0
2500
5000
7500
10000
Whale Bay
8/3/96, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-20m)
11,000 Pollock
■ Herring
▨ Smelt
☐ Pollock
☐ Other
0
2500
5000
7500
10000
Eaglek Bay
8/2/96, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-20m)
-51 dB
■ Herring
▨ Smelt
☐ Pollock
☐ Other
0
2500
5000
7500
10000

Figure 8.

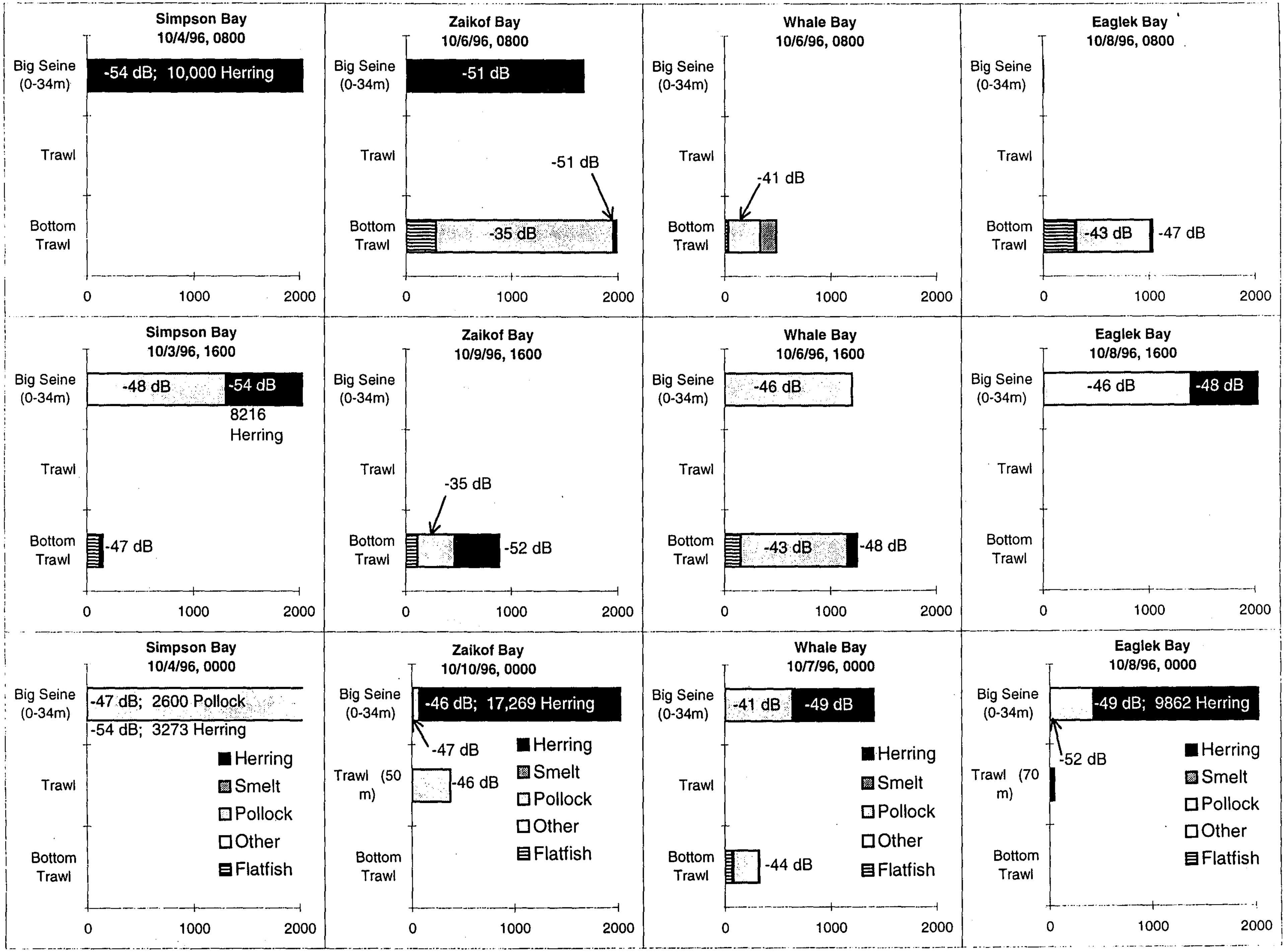

Simpson Bay
10/4/96, 0800
Big Seine (0-34m)
Trawl
Bottom Trawl
-54 dB; 10,000 Herring
0
1000
2000
Zaikof Bay
10/6/96, 0800
-51 dB
-51 dB
-35 dB
Whale Bay
10/6/96, 0800
-41 dB
Eaglek Bay
10/8/96, 0800
-43 dB
-47 dB
Simpson Bay
10/3/96, 1600
-48 dB
-54 dB
8216 Herring
-47 dB
Zaikof Bay
10/9/96, 1600
-35 dB
-52 dB
Whale Bay
10/6/96, 1600
-46 dB
-43 dB
-48 dB
Eaglek Bay
10/8/96, 1600
-46 dB
-48 dB
Simpson Bay
10/4/96, 0000
-47 dB; 2600 Pollock
-54 dB; 3273 Herring
Zaikof Bay
10/10/96, 0000
-46 dB; 17,269 Herring
-47 dB
Trawl (50 m)
-46 dB
Whale Bay
10/7/96, 0000
-41 dB
-49 dB
-44 dB
Eaglek Bay
10/8/96, 0000
-49 dB; 9862 Herring
-52 dB
Trawl (70 m)
■ Herring
▨ Smelt
☐ Pollock
☐ Other
▤ Flatfish

Figure 9.

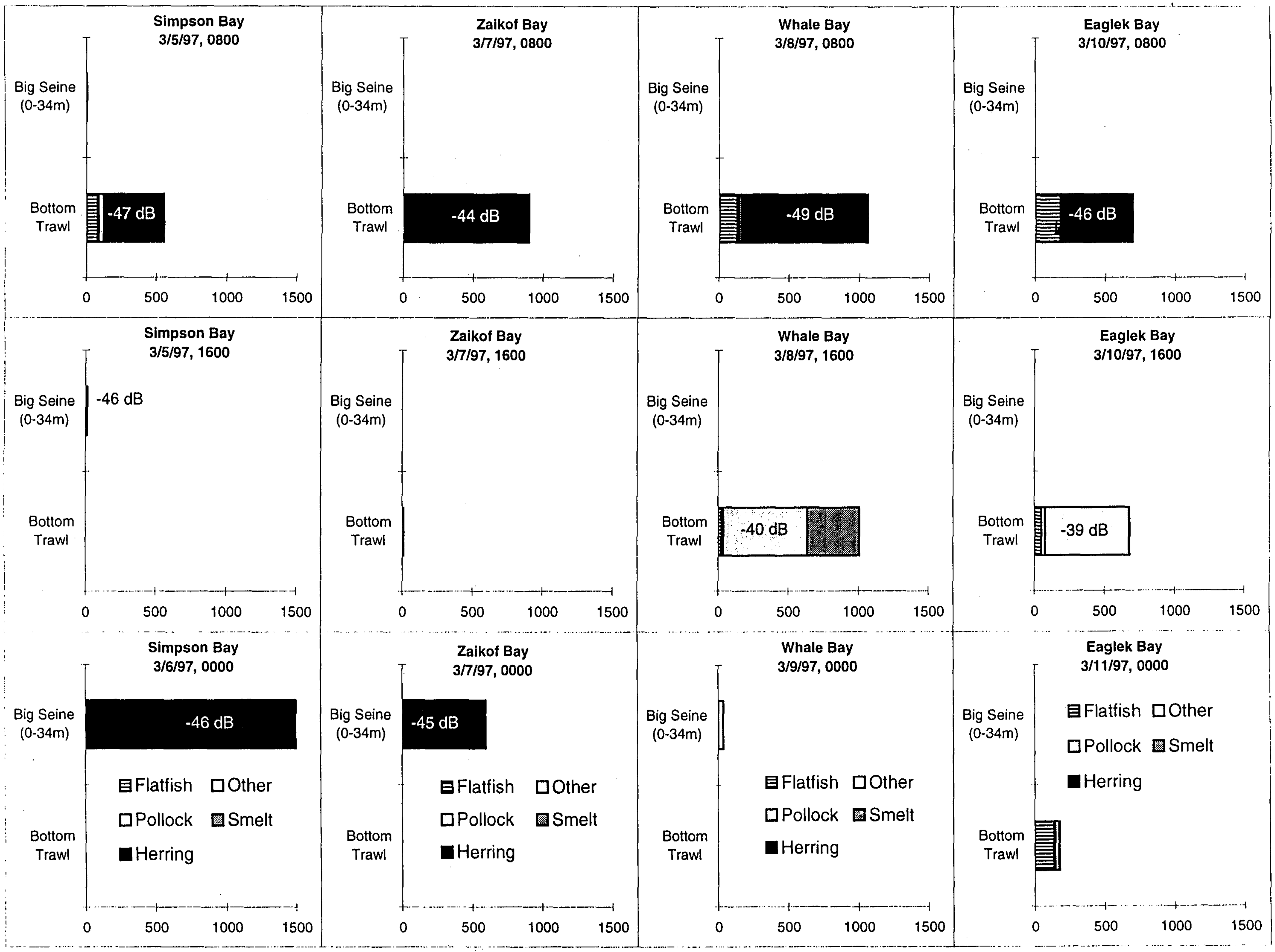

Simpson Bay
3/5/97, 0800
Big Seine (0-34m)
Bottom Trawl
-47 dB
0
500
1000
1500
Zaikof Bay
3/7/97, 0800
Big Seine (0-34m)
Bottom Trawl
-44 dB
0
500
1000
1500
Whale Bay
3/8/97, 0800
Big Seine (0-34m)
Bottom Trawl
-49 dB
0
500
1000
1500
Eaglek Bay
3/10/97, 0800
Big Seine (0-34m)
Bottom Trawl
-46 dB
0
500
1000
1500
Simpson Bay
3/5/97, 1600
Big Seine (0-34m)
-46 dB
Bottom Trawl
0
500
1000
1500
Zaikof Bay
3/7/97, 1600
Big Seine (0-34m)
Bottom Trawl
0
500
1000
1500
Whale Bay
3/8/97, 1600
Big Seine (0-34m)
Bottom Trawl
-40 dB
0
500
1000
1500
Eaglek Bay
3/10/97, 1600
Big Seine (0-34m)
Bottom Trawl
-39 dB
0
500
1000
1500
Simpson Bay
3/6/97, 0000
Big Seine (0-34m)
-46 dB
Bottom Trawl
▤ Flatfish ☐ Other
☐ Pollock ▨ Smelt
■ Herring
0
500
1000
1500
Zaikof Bay
3/7/97, 0000
Big Seine (0-34m)
-45 dB
Bottom Trawl
▤ Flatfish ☐ Other
☐ Pollock ▨ Smelt
■ Herring
0
500
1000
1500
Whale Bay
3/9/97, 0000
Big Seine (0-34m)
Bottom Trawl
▤ Flatfish ☐ Other
☐ Pollock ▨ Smelt
■ Herring
0
500
1000
1500
Eaglek Bay
3/11/97, 0000
Big Seine (0-34m)
Bottom Trawl
▤ Flatfish ☐ Other
☐ Pollock ▨ Smelt
■ Herring
0
500
1000
1500

Figure 10.

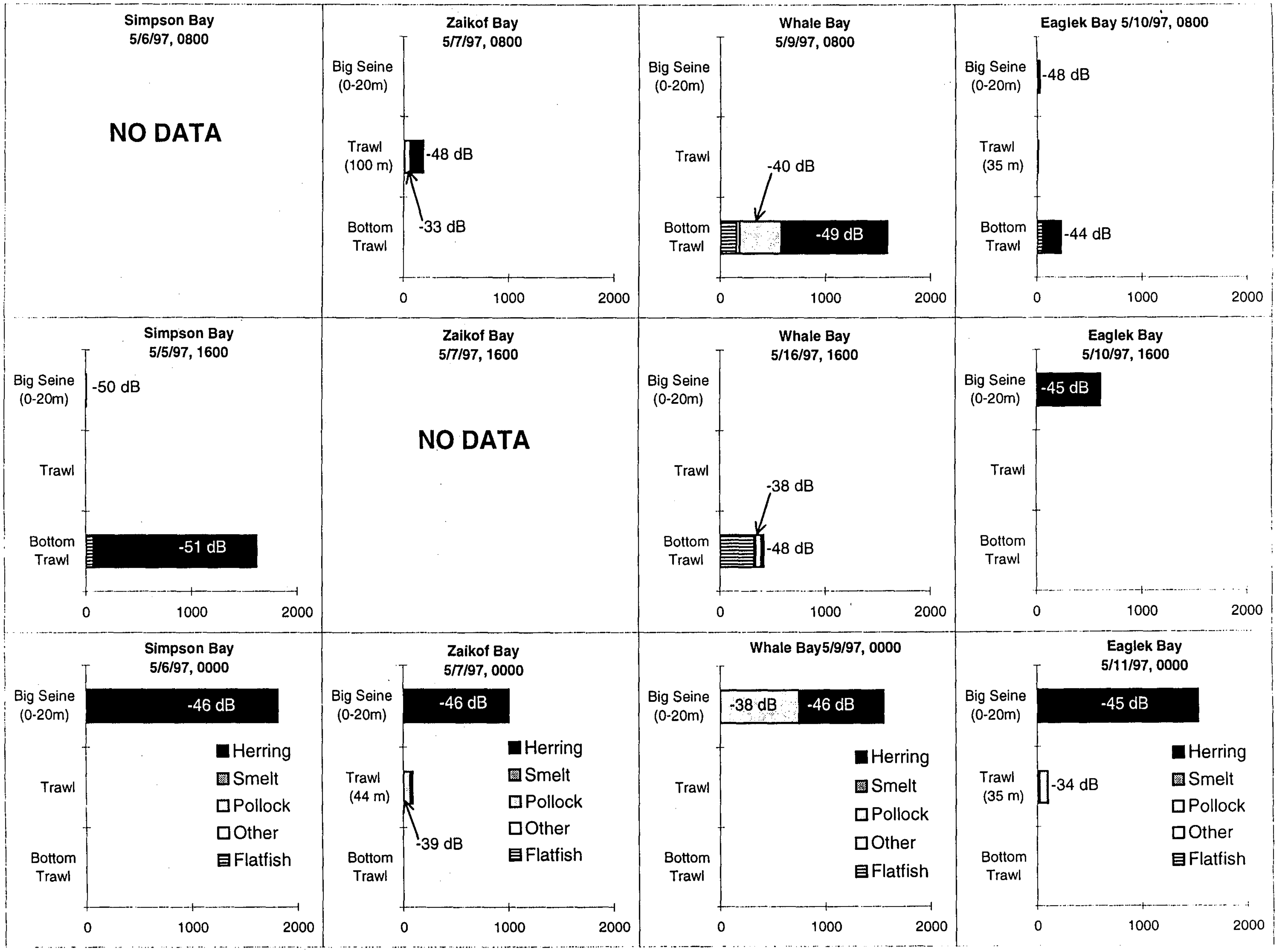

Simpson Bay
5/6/97, 0800
NO DATA
Zaikof Bay
5/7/97, 0800
Big Seine
(0-20m)
Trawl
(100 m)
-48 dB
-33 dB
Bottom
Trawl
0
1000
2000
Whale Bay
5/9/97, 0800
Big Seine
(0-20m)
Trawl
-40 dB
Bottom
Trawl
-49 dB
0
1000
2000
Eaglek Bay 5/10/97, 0800
Big Seine
(0-20m)
-48 dB
Trawl
(35 m)
Bottom
Trawl
-44 dB
0
1000
2000
Simpson Bay
5/5/97, 1600
Big Seine
(0-20m)
-50 dB
Trawl
Bottom
Trawl
-51 dB
0
1000
2000
Zaikof Bay
5/7/97, 1600
NO DATA
Whale Bay
5/16/97, 1600
Big Seine
(0-20m)
Trawl
-38 dB
Bottom
Trawl
-48 dB
0
1000
2000
Eaglek Bay
5/10/97, 1600
Big Seine
(0-20m)
-45 dB
Trawl
Bottom
Trawl
0
1000
2000
Simpson Bay
5/6/97, 0000
Big Seine
(0-20m)
-46 dB
Trawl
Bottom
Trawl
■ Herring
▨ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
1000
2000
Zaikof Bay
5/7/97, 0000
Big Seine
(0-20m)
-46 dB
Trawl
(44 m)
-39 dB
Bottom
Trawl
■ Herring
▨ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
1000
2000
Whale Bay5/9/97, 0000
Big Seine
(0-20m)
-38 dB
-46 dB
Trawl
Bottom
Trawl
■ Herring
▨ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
1000
2000
Eaglek Bay
5/11/97, 0000
Big Seine
(0-20m)
-45 dB
Trawl
(35 m)
-34 dB
Bottom
Trawl
■ Herring
▨ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
1000
2000

Figure 11.

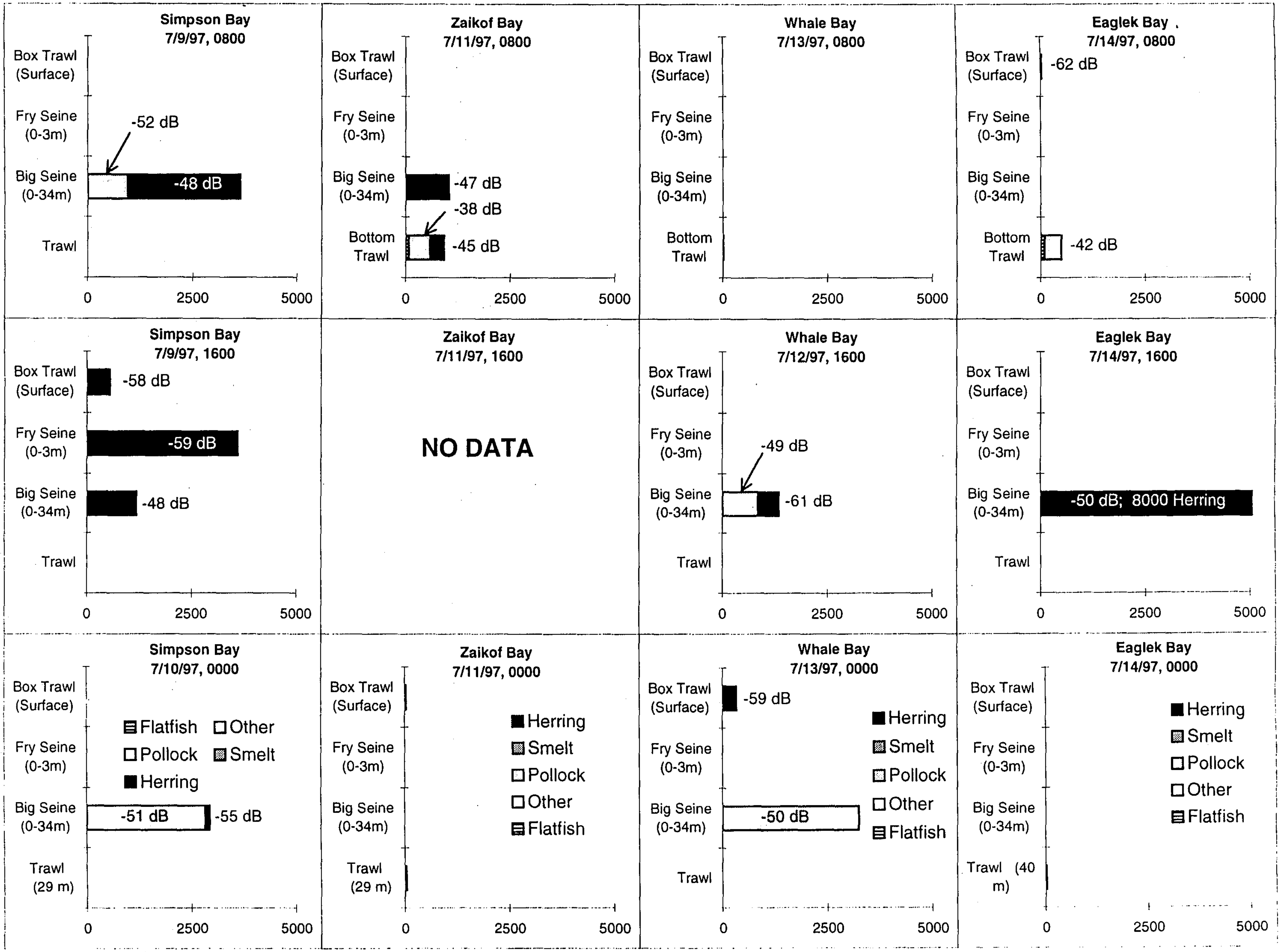

Simpson Bay
7/9/97, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl
-52 dB
-48 dB
0
2500
5000
Zaikof Bay
7/11/97, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Bottom Trawl
-47 dB
-38 dB
-45 dB
0
2500
5000
Whale Bay
7/13/97, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Bottom Trawl
0
2500
5000
Eaglek Bay
7/14/97, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Bottom Trawl
-62 dB
-42 dB
0
2500
5000
Simpson Bay
7/9/97, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl
-58 dB
-59 dB
-48 dB
0
2500
5000
Zaikof Bay
7/11/97, 1600
NO DATA
Whale Bay
7/12/97, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl
-49 dB
-61 dB
0
2500
5000
Eaglek Bay
7/14/97, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl
-50 dB; 8000 Herring
0
2500
5000
Simpson Bay
7/10/97, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl (29 m)
⊟ Flatfish
☐ Other
☐ Pollock
▨ Smelt
■ Herring
-51 dB
-55 dB
0
2500
5000
Zaikof Bay
7/11/97, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl (29 m)
■ Herring
▨ Smelt
☐ Pollock
☐ Other
⊟ Flatfish
0
2500
5000
Whale Bay
7/13/97, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl
-59 dB
-50 dB
■ Herring
▨ Smelt
☐ Pollock
☐ Other
⊟ Flatfish
0
2500
5000
Eaglek Bay
7/14/97, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl (40 m)
■ Herring
▨ Smelt
☐ Pollock
☐ Other
⊟ Flatfish
0
2500
5000

Figure 12.

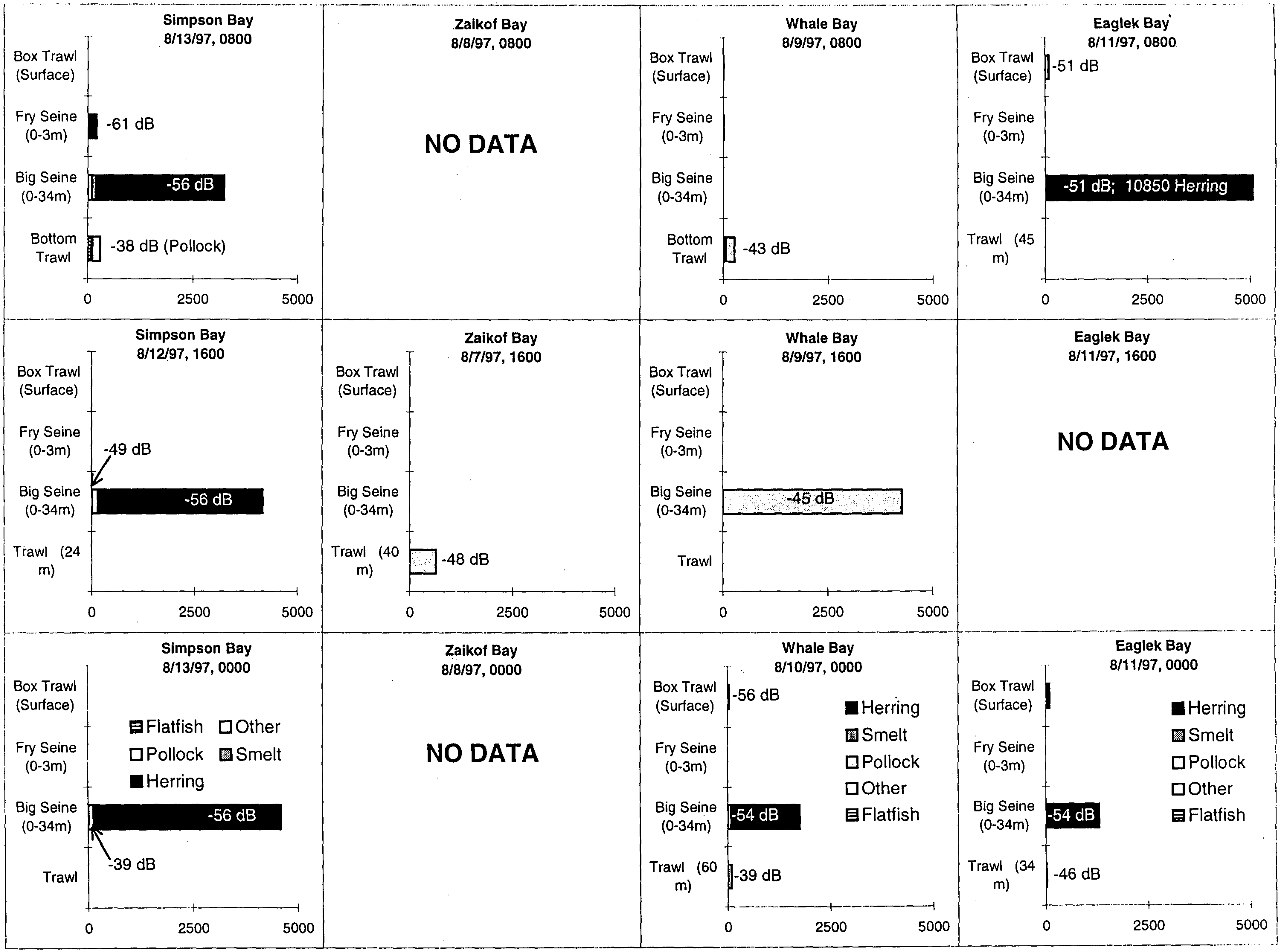

Simpson Bay
8/13/97, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
-61 dB
Big Seine (0-34m)
-56 dB
Bottom Trawl
-38 dB (Pollock)
0
2500
5000
Zaikof Bay
8/8/97, 0800
NO DATA
Whale Bay
8/9/97, 0800
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Bottom Trawl
-43 dB
0
2500
5000
Eaglek Bay
8/11/97, 0800
Box Trawl (Surface)
-51 dB
Fry Seine (0-3m)
Big Seine (0-34m)
-51 dB; 10850 Herring
Trawl (45 m)
0
2500
5000
Simpson Bay
8/12/97, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
-49 dB
Big Seine (0-34m)
-56 dB
Trawl (24 m)
0
2500
5000
Zaikof Bay
8/7/97, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
Trawl (40 m)
-48 dB
0
2500
5000
Whale Bay
8/9/97, 1600
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
-45 dB
Trawl
0
2500
5000
Eaglek Bay
8/11/97, 1600
NO DATA
Simpson Bay
8/13/97, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
-56 dB
-39 dB
Trawl
▤ Flatfish
☐ Other
☐ Pollock
▩ Smelt
■ Herring
0
2500
5000
Zaikof Bay
8/8/97, 0000
NO DATA
Whale Bay
8/10/97, 0000
Box Trawl (Surface)
-56 dB
Fry Seine (0-3m)
Big Seine (0-34m)
-54 dB
Trawl (60 m)
-39 dB
■ Herring
▩ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
2500
5000
Eaglek Bay
8/11/97, 0000
Box Trawl (Surface)
Fry Seine (0-3m)
Big Seine (0-34m)
-54 dB
Trawl (34 m)
-46 dB
■ Herring
▩ Smelt
☐ Pollock
☐ Other
▤ Flatfish
0
2500
5000

Figure 13.