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ACOUSTIC VISUALIZATION OF LARGE SCALE MACROPLANKTON
AND MICRONEKTON DISTRIBUTIONS ACROSS THE NORWEGIAN
SHELF AND SLOPE OF THE NORWEGIAN SEA

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ABSTRACT

We present results from acoustical (38 kHz split beam) surveys, biological sampling (trawling, zooplankton nets), and measurements of physical parameters (salinity, temperature, currents) across and along the shelf off Norway (62-70°N). Major recurrent structures were apparent both geographically and with time. Off the shelf, two deep scattering layers prevailed; one of 50-100 m thickness where the upper border by day fluctuated between 100 and 200 m depth, and one located deeper between 300-500 m. The upper layer was mainly composed of mesopelagic fish (*Maurolicus muelleri*) and krill (*Meganyctiphanes norvegica*), while the lower layer consisted of krill (*Meganyctiphanes norvegica*), mesopelagic fish (*Maurolicus muelleri*, *Benthosema glaciale*), shrimps (*Sergestes arcticus*, *Pasiphaea multidenta*), and jellyfish (*Periphylla periphylla*). During winter, these two layers roughly comprise 95 % of the backscattering volume (biomass) in the upper 500 m. The shallow layer partly intrudes onto the continental shelf, where the bottom topography exerts strong impact on its distribution.

In June/July an additional scattering layer was apparent in the upper 20-30 m throughout most of the study area, though integrated backscattering biomass varied by a factor of 50. In the south the layer was associated with water masses of salinity <35 (i.e. with coastal characteristics). Further north the layer was found off the shelf in water with stronger oceanic characteristics as well. Hydrographic features indicated that coastal water and biomass was transported off the shelf in connection with gyres over the banks. Trawl catches showed that this structure was composed of 0-group herring, fish (mainly seith), and krill. Backscattering volume was positively correlated with abundance of 0-group herring caught in trawl, but was not correlated with the meso-zooplankton biomass (mainly *Calanus finmarchicus*), or other components of the trawl catches. The lack of positive correlations between acoustic backscattering volume, and biomass from net and trawl samples probably reflected differences in selectivity of the sampling methods.

INTRODUCTION

Macroplankton and micronekton are major fauna components in Norwegian coastal waters. Mesopelagic fishes, pelagic shrimps and euphausiids are abundant both in fjords and seaward off the continental shelf. Euphausiids are an essential constituent in the diet of fish, and mesopelagic fishes are important visual predators exploiting and possibly structuring meso- and macroplankton assemblages (Dalpadado 1993, Gjøsæther 1981a, Holst & Iversen 1992, Rudakova & Kaverina 1969).

Despite their apparent abundance and ecological significance, relatively little is known about the distribution and biomass of macroplankton and micronekton in Norwegian waters (Melle *et al.* 1993, Gjøsæther 1981a,b, Bergstad & Isaksen 1987). This partly relates to methodological problems. Organisms of several centimetres in length are not easily captured by conventional sampling methods, and avoidance of nets and pumps is prominent in these highly mobile organisms. While most obvious by day, avoidance may also be important by night. Losses through coarse meshes represent a serious problem when using trawls designed for catching larger organisms like commercial fish. Quantifications by means of submersibles, ROV operations or other video techniques are made difficult by strong behavioral modifications when the animals become exposed to artificial light.

Acoustical surveys have long been applied in the assessment of Norwegian fish stocks and acoustics have to some degree also been included in ecological investigations of, for example, mesopelagic fish and krill (Sameoto 1982). New, high quality scientific echo sounders have improved signal/noise ratios and hold the possibility of resolving size distribution through target strength measurements. Combined with software for visualization of the immense amount of data provided, the stage is now set for increased utilization of acoustical methods in marine ecological investigations.

Acoustic methods have some distinct advantages. They offer unsurpassed spatial and temporal coverage and are relatively non-intrusive (Greene & Wiebe 1990). Their main limitations are the lack of resolving small plankters, a problem related to wave length of the signal and the "multiple echo" phenomenon caused by the rapidly increasing beam volume with depth, and uncertainties in identifying the taxonomic origin of the signals. Increased effort is allocated for development of high frequency sounders so that smaller planktonic organisms may be acoustically resolved. However, the use of acoustics still appears particularly useful for describing organisms from the size class of macroplankton/micronekton and larger;

i.e. encompassing organisms where other methods are the least successful. To identify the taxonomic identity of the targets, acoustics are used in conjunction with sampling and other methods of *in situ* observation.

This paper presents results from acoustical surveys and biological sampling carried out across and along the Norwegian shelf. We present large scale distributional patterns of macroplankton and micronekton, and evaluate the results with respect to water mass characteristics, bottom topography, seasonal production cycles, and migration patterns of nekton.

MATERIAL AND METHODS

Acoustical mapping, biological sampling and CTD casts were carried out during a cruise with RV G.O. Sars in June/July 1991. The survey lines and sampling stations are shown in Fig. 1. Transects were made across and along the continental shelf from about 62 to 70°N. Similar cruises were conducted in April and May in the southern areas between 62 and 64°N.

Acoustical mapping was done with a 38 kHz EK 500 Simrad split beam echosounder. The split beam technique offers the opportunity of resolving target strength of single individuals. The 38 kHz sounder is able to resolve individual organisms of size down to a few cm, yet it efficiently map water columns of several hundred m depth. Signals were stored on tape and later transferred to a Sun work station where the data were processed using the Bergen Echo Integrating system (BEI; Foote *et al.* 1991) and eventually displayed on a colour printer using UNIRAS (Anon. 1988) interpolation and plotting routines. In displaying transects of vertical distribution acoustic scatterers were integrated over 5 nm horizontally and 12 m vertically. Maps of horizontal distribution of backscattering volumes are based on integrated values of the upper 53 m.

To identify main groups of targets, trawling with a "Harstad" midwater trawl with an opening area of 400 m² (Nedreaas & Smedstad 1987) was conducted within major echo layers. Sampling of plankton was done with MOCNESS (Wiebe *et al.* 1985) and vertical Judy net tows.

Fishes from trawl samples were identified to species and their total length and weight were measured. Weight of total catch of euphausiids and pelagic shrimps was recorded and sub samples for species identification were frozen.

Samples from the plankton nets were split in two. One half was fixed in 4% formaldehyde in sea water for later species identification. The other half was separated into size fractions using sieves of 180, 1000 and 2000 µm mesh size. From the 2000 µm size fraction euphausiids, shrimps and fishes

were identified to species. The size fractions and the sorted groups of euphausiids, shrimps, and fishes, were dried and burned for measurements of dry weight and ash free dry weight.

RESULTS

Water mass characteristics

The coastal water mass of the Norwegian coastal current with reduced salinities (33-34) covered the shelf, while Atlantic water with salinity above 35 prevailed offshore (Fig. 2a). Distribution of the coastal water was to a large extent governed by the bottom topography. Above deeper shelf regions the front between water masses was less pronounced and more saline water intruded onto the shelf. Water of coastal origin mixed with Atlantic water was found west of the shelf break, especially in connection with the large coastal banks. Temperature did not show a corresponding cross-shelf gradient; rather the main gradient was related to latitude, with relatively warmer water south of ~67°N (Fig. 2b).

The less saline coastal water appeared as a wedge overlying the Atlantic water. This wedge was confined to the shelf in shallow regions, but extended further out from the coast in the northern, deeper shelf regions (Fig.s 3a,b).

Surface integrated backscattering in upper layers

Surface integrated backscattering volumes in the upper 53 m revealed conspicuous large-scale patchiness, with backscattering varying by a factor of 50 or more from the centre of the patch to more dilute concentrations both in east-west and north-south directions (Fig. 4). Two large scale patches were situated with maximum densities between 62° and 63°N and 65°30' and 67°N. The northern patch, with maximum densities located 60-100 nm off shore, was not restricted to a particular water mass and extended into water with salinity above 35. The northward extension of the patch coincided roughly with the distribution of warmer water. The southern patch was confined to water with salinities less than 35 over the shelf.

During the sampling period in June/July there was more than 20 hours of day light. We observed no signs of vertical migration in and out of the upper layer (Fig. 5).

Pelagic trawl catches from the upper 40 m revealed a mixture dominated by 0-group herring (*Clupea harengus*), adult herring, other pelagic fishes (mainly *Gadus virens*), euphausiids, small squids (*Gonatus fabricii*) and

jellyfishes (Fig. 6). By weight the trawl catches in the centre of the patches were dominated by 0-group herring. Stations nearest land were dominated by other pelagic fishes. A multiple regression analysis between total backscattering volume averaged over 5 nm surrounding trawl stations and weight of components in the trawl catches showed that a significant direct relationship existed between acoustics and 0-group herring ($N= 64$, $r= 0.5$, $P< 0.001$). Other components included in the regression were; other 0-group fishes, amphipods, Müllers pearlside, jellyfishes, adult herring and other pelagic fishes.

A Spearman rank correlation analysis between integrated backscattering volume in the upper 50 m (averaged over 5 nm surrounding the plankton sampling station) and biomass values for the size fraction 1000-2000 μm from the net hauls (100-0 m) showed no significant correlation ($N= 50$, $r= 0.02$). This weak relationship can probably not be explained by the different depth strata sampled by the sounder and the net, as MOCNESS samples showed that 79 % of the biomass in the upper 100 m was found above 50 metres (average of 13 tows).

Vertical patterns in backscattering

In June, three main Sound Scattering Layers (SSLs) occurred across the continental shelf and out into oceanic waters (Fig. 7). In general, backscattering was high in the upper 20 m, though total S_A decreased in the westernmost regions. The patchy distributions reflected in transects 5 and 6 correspond to the region of intrusion of saline Atlantic water (cf Fig. 4).

Off the shelf, two deeper layers were evident in southern regions; one of 50-100 m thickness of which the upper border fluctuated between 100 and 200 m depth, and one located between 300-500 m (Fig. 7). The shallowest of these layers partly intruded onto the shelf. In transects taken north of 66°N , this intermediate structure disappeared. The deeper SSL between 300-500 m was found throughout the study area.

In areas of the shelf deeper than ca 150 m there was an approximately 50 m thick SSL associated with the bottom. The depth of this layer fluctuated with the bottom topography. This layer tended to disappear in shallower regions, though occasional patches of high scattering also occurred there.

To indicate how biomass was allocated between the SSLs, we have compared integrated values in the depth zones 5-53 m, 53-197 m and 197-509 m for all transects (where the bottom depth exceeded 509 m). The intermediate layer made up less than 2-12% of the total backscattering of the water column in the northern transects (1-5), but increased to 23-52% in the southern transects (9-6, Fig. 8). The deeper layer made up 40% or more of the total backscattering volume throughout the sampling area.

The upper layer showed a variable but decreasing trend from 30-40% in the north to 10-20% in the south. Absolute backscattering volumes showed a general increase in the deeper and middle layers from north to south (Fig. 9). Backscatter from the upper layer showed the opposite trend, being higher in the north than in the south.

Trawl catches in the intermediate and deeper SSLs were dominated by Müllers pearlside (*Maurolicus muelleri*), krill and jelly fishes in the former, and krill (*Meganyctiphanes norvegica*), myctophides (*Benthosema glaciale*), pelagic shrimps (*Sergestes arcticus*, *Pasiphaea multidenta*), and jelly fishes (mainly *Periphylla periphylla*) in the latter (Fig. 10).

Temporal persistence and variation

In April, May, and June we mapped acoustically more or less the same transect from a fjord (Storfjorden), over the shelf into deep water of the Norwegian Sea (the fjord was not covered in May). From April to June a general increase of total backscatter from the upper layer was observed (Fig. 11). The intermediate and deep SSLs showed no clear-cut temporal changes in volume backscattering.

DISCUSSION

By means of acoustic mapping we have revealed major patterns in large scale distribution of biomass - horizontally (east-west, north-south), vertically, and over time. These patterns have been related to watermass characteristics, bottom topography and local production cycles, and visualized in a way hardly imaginable with any other techniques.

From early spring to summer there was an increase in total backscattering volume of the upper 50 m. A major part of the biomass in trawl and net samples was young organisms spawned during the spring, e.g. 0-group herring and young stages of *Calanus finmarchicus*. We assume that the increase in biomass mainly resulted from biological production associated with the transition from a winter to a summer situation.

The horizontal distribution of biomass in the upper layer as revealed by backscattering volume, was governed by fronts and the current system of the Norwegian shelf and slope of the Norwegian Sea. The acoustic survey in June/July revealed two large scale patches of biomass. The southern patch was confined within the coastal water mass off Møre by a stable front. The northern, more off shore distributed patch showed high biomasses in both coastal and Atlantic water. This was in an area where the shelf was deeper and the front less stable. Between the two patches

there was a region of low biomass probably related to the intrusion of water with high salinity and low biomass onto the shelf. This must be an important mixing zone where packages of coastal water and biomass are dislocated as gyres in connection with the circulation over the banks and frontal instabilities. Within the northern patch the trawl catches in Atlantic water revealed high densities of 0-group herring. Since spawning grounds of the Norwegian spring spawning herring are mainly situated in coastal water further south on the Møre plateau (Fossum & Moksness 1993), a major part of the biomass must have had its origin in the coastal water mass - which supports the importance of the mixing of watermasses for biomass distribution.

Migrating nekton may also have contributed to the biomass of the northern patch. After metamorphosis 0-group herring may influence their own horizontal distribution by swimming. Adult herring, with a known coastal origin, were common in the trawl catches in the northern patch. Both groups could have moved across the front by swimming.

By an acoustic survey we mapped the horizontal distribution of 0-group herring. Linear regression methods showed that 0-group herring in the trawl catches explained 26% of the variation in backscattering volume from the upper layer. Keeping in mind the rather coarse method used to relate trawl catches to backscattering volume, this strong relationship suggests that 0-group herring was quite accurately mapped by the horizontal distribution of backscattering volume in the upper layer. The lack of correlation between other major constituents of the trawl catches and backscattering volume may in part be due to various degrees of escapement by highly motile organisms like adult herring and pelagic fishes from the trawl and the hull mounted transducer, and differences in selectivity of the trawl and resolution of the acoustics with respect to smaller organisms like macrozooplankton and juvenile fish.

Single individuals of *Calanus finmarchicus* are too small to be detected by 38 kHz transducers. However, dense aggregations may be detected due to the multiple target phenomenon, at least at moderate depths (cf. MacLennan & Simmonds 1992). We did not find a correlation between backscattering volume and biomass of net catches in the size range of 1000-2000 µm, which at that time were dominated by *Calanus finmarchicus* in copepodite stages 4-6.

The allocation of biomass between different layers was described, and the major contributors to their biomass were identified. Although the relationship between backscattering volume and biomass will vary with species composition, the relative differences in backscattering volume from the layers more or less reflect differences in biomass between the layers. The deeper layer, usually at 300-500 m depth, was observed off the

shelf throughout the investigated area, and generally made up more than 40% of the biomass in the water column. Thus, a large part of the biomass off the shelf in June/July is found deeper than 300 m. Trawl catches showed that the layer consisted of myctophides (*Maurolicus muelleri*, *Benthosema glaciale*), pelagic shrimps (*Sergestes arcticus*, *Pasiphaea multidenta*), krill (*Meganyctiphanes norvegica*) and jellyfishes (*Periphylla periphylla*).

The intermediate layer, usually found between 90 and 200 m, was dominated by krill (*Meganyctiphanes norvegica*), Müllers pearlside (*Maurolicus muelleri*), and jellyfishes. The biomass of the layer increased from less than 10% of total biomass in the north to 20-50% in the south. Our observations of water mass distribution showed that water of high salinity (<35.2) had a more narrow distribution in the northern region. This may explain why *Meganyctiphanes norvegica* and *Maurolicus muelleri*, two species known to be associated with Atlantic water, occurred in lower densities in the north. On the other hand, concentrations of adult and 0-group herring and other pelagic fishes which may prey on the krill and pearlside of the intermediate layer, were also much higher in the north than further south.

Our main objectives in the future will be to better identify the scattering objects and improve the near surface performance of the acoustic equipment. In general, the use of hull mounted transducers combined with visualization techniques which helps in compressing the data are useful tools in revealing large scale horizontal and vertical distributions of dominant species, and spatial and temporal changes therein. However, hull mounted transducers have several disadvantages; there will be a blind zone from the surface down to 5-10 m below the transducer, in bad weather much noise and bubbles are created near the surface and to reach the deeper objects one has to use low frequencies which has lower resolution. We also need better methods for identifying the scatterers. Presently we depend on traditional methods like net hauls and trawling, and limitations of these techniques were clearly demonstrated in the lack of correlation between volume backscattered and catch of dominant species with the trawl. To us the solution seems to be multi-frequency split beam transducers mounted on towed vehicles and drop sondes to get reliable target strength measurements and biomass estimates at all depths. Observed targets and biomass distributions will be identified by net catches and optic observation of scatterers passing through the acoustic beam.

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FIGURE LEGENDS

Figure 1. Survey lines and sampling stations during cruise with RV G.O.Sars in June/July 1991. Transects are numbered with bold types.

Figure 2a. Horizontal distribution of salinity ($^{\circ}/\text{oo}$) at 20 m in June/July 1991. $62\text{-}70^{\circ}\text{N}$ and $3\text{-}16^{\circ}\text{E}$.

Figure 2b. Horizontal distribution of temperature ($^{\circ}\text{C}$) at 20 m in June/July 1991. $62\text{-}70^{\circ}\text{N}$ and $3\text{-}16^{\circ}\text{E}$.

Figure 3. Salinity ($^{\circ}/\text{oo}$) versus depth and distance from western startpoint of transect. a) transect from northern region, b) transect from southern region.

Figure 4. Horizontal distribution of surface integrated area backscattering coefficient, 10-53 m, ($\text{m}^2 \text{ nm}^{-2}$), S_A (cf Fote *et al.* 1991), and salinity ($^{\circ}/\text{oo}$) at 10 m. $62\text{-}70^{\circ}\text{N}$ and $3\text{-}16^{\circ}\text{E}$. Legend shows scale of S_A .

Figure 5. Surface integrated area backscattering coefficient ($\text{m}^2 \text{ nm}^{-2}$) from 10 to 53 m versus time of the day.

Figure 6. Weight (kg nm^{-1}) of major groups in trawl catches (0-40 m) in June/July. See Fig. 1.

Figure 7. Area backscattering coefficient ($\text{m}^2 \text{ nm}^{-2}$) versus depth and distance from western startpoint of transect. Solid line is bottom topography as detected by the echo sounder. Legend shows scale of S_A .

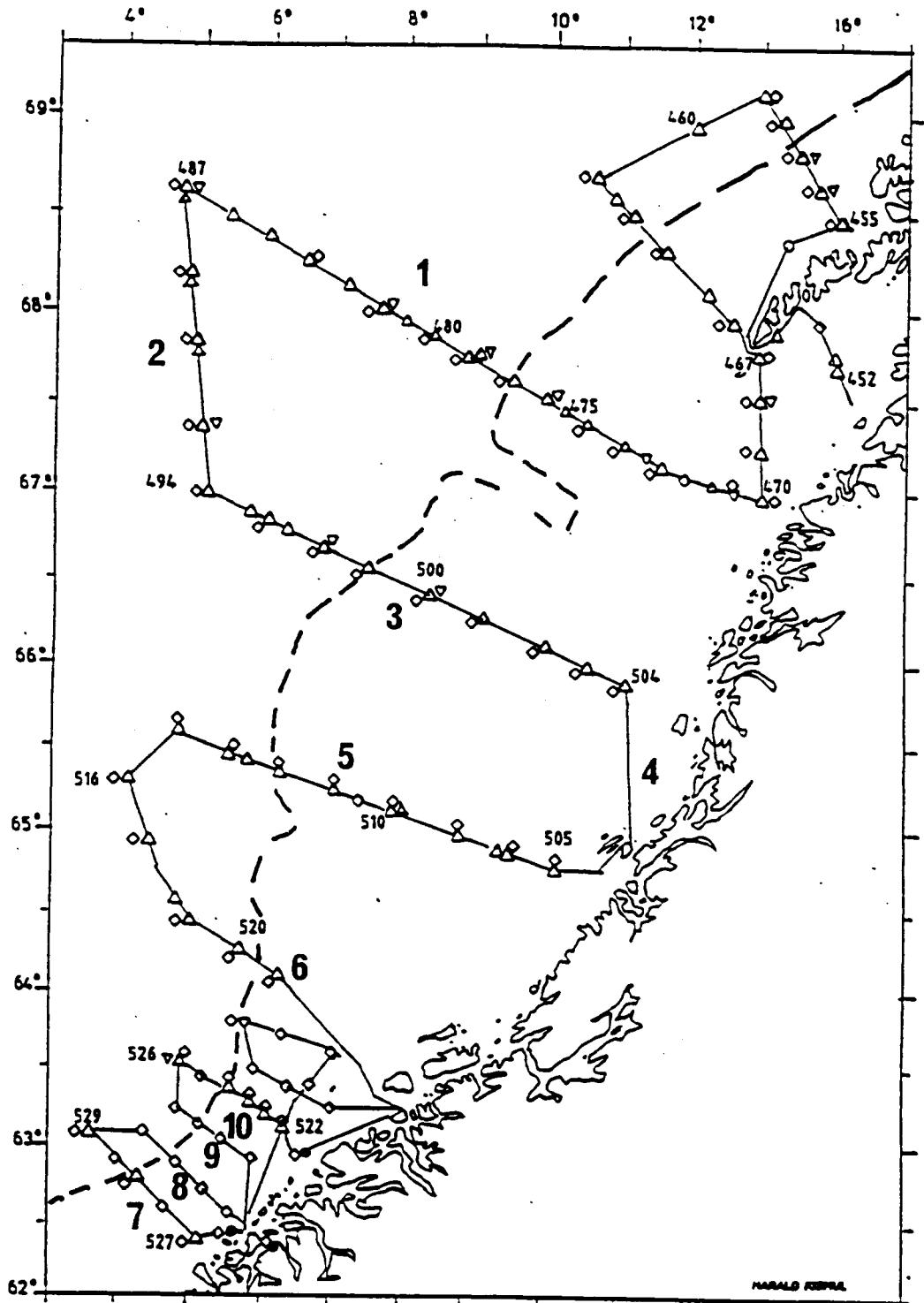
Figure 8. Integrated area backscattering coefficient (S_A) in layers 10-53 m, 53-

197 m and 197-509 m, as percentage of total integrated S_A for the water column. Averaged over transects where bottom depth exceeded 509 m.

Figure 9. Integrated area backscattering coefficient (S_A) in layers 10-53 m, 53-197 m and 197-509 m. Averaged over transects where bottom depth exceeded 509 m.

Figure 10. Weight of major groups in trawl catches within deeper SSLs in June/July. Jellyfishes and fishes (kg nm^{-1}), krill, myctophides and shrimps (g nm^{-1}). See Fig. 1.

Figure 11. From cruises in April, May and June: area backscattering coefficient ($\text{m}^2 \text{nm}^{-2}$) versus depth and distance from western startpoint of transect. Solid line is bottom topography as detected by the echo sounder. Legend in Fig. 7.



18 JUN.-2 JUL. 1991 Δ TRAWL ST. NO. 452-529 ∇ 13 MOCNESS ST.
 > 82 JUDAY NET ST. • 3 GRAB ST. \circ 1 ISAAC KIDD "G.O.SARS"

Figure 1.

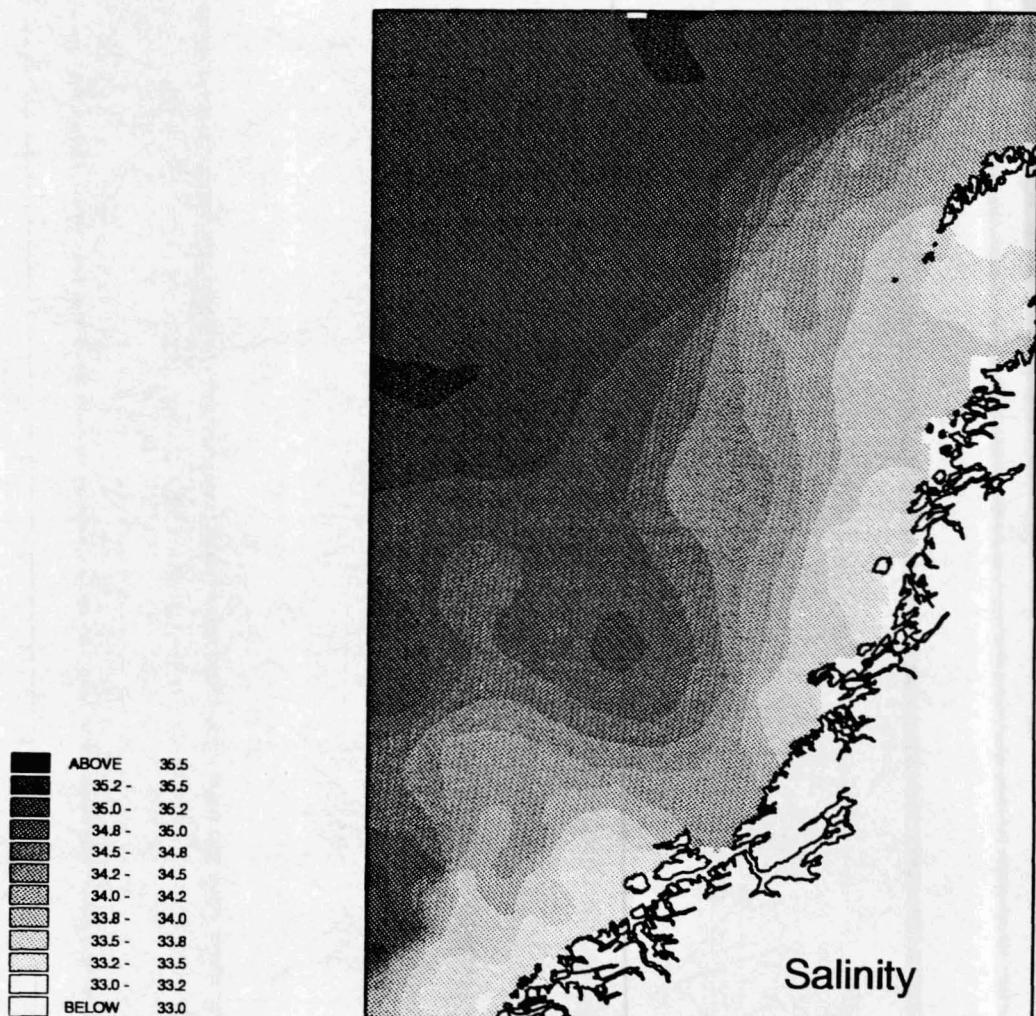


Figure 2a.

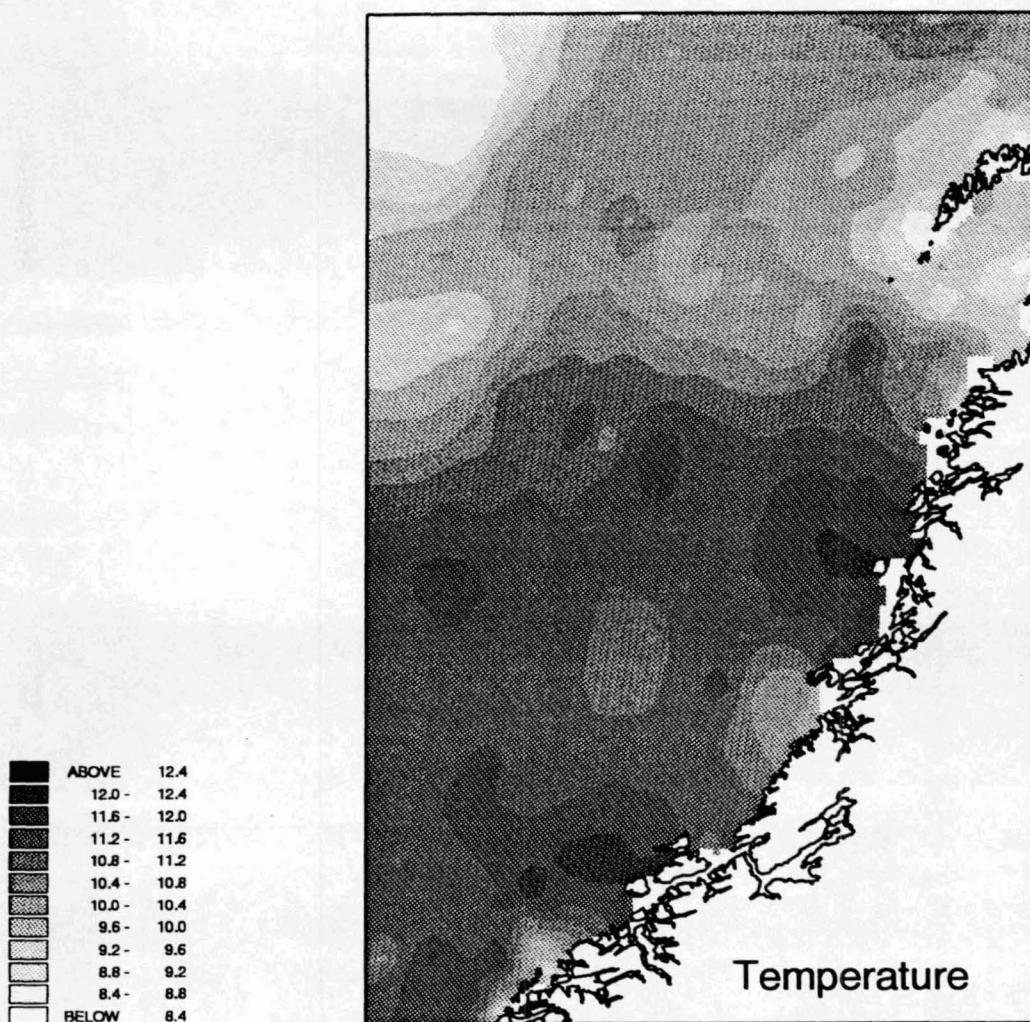


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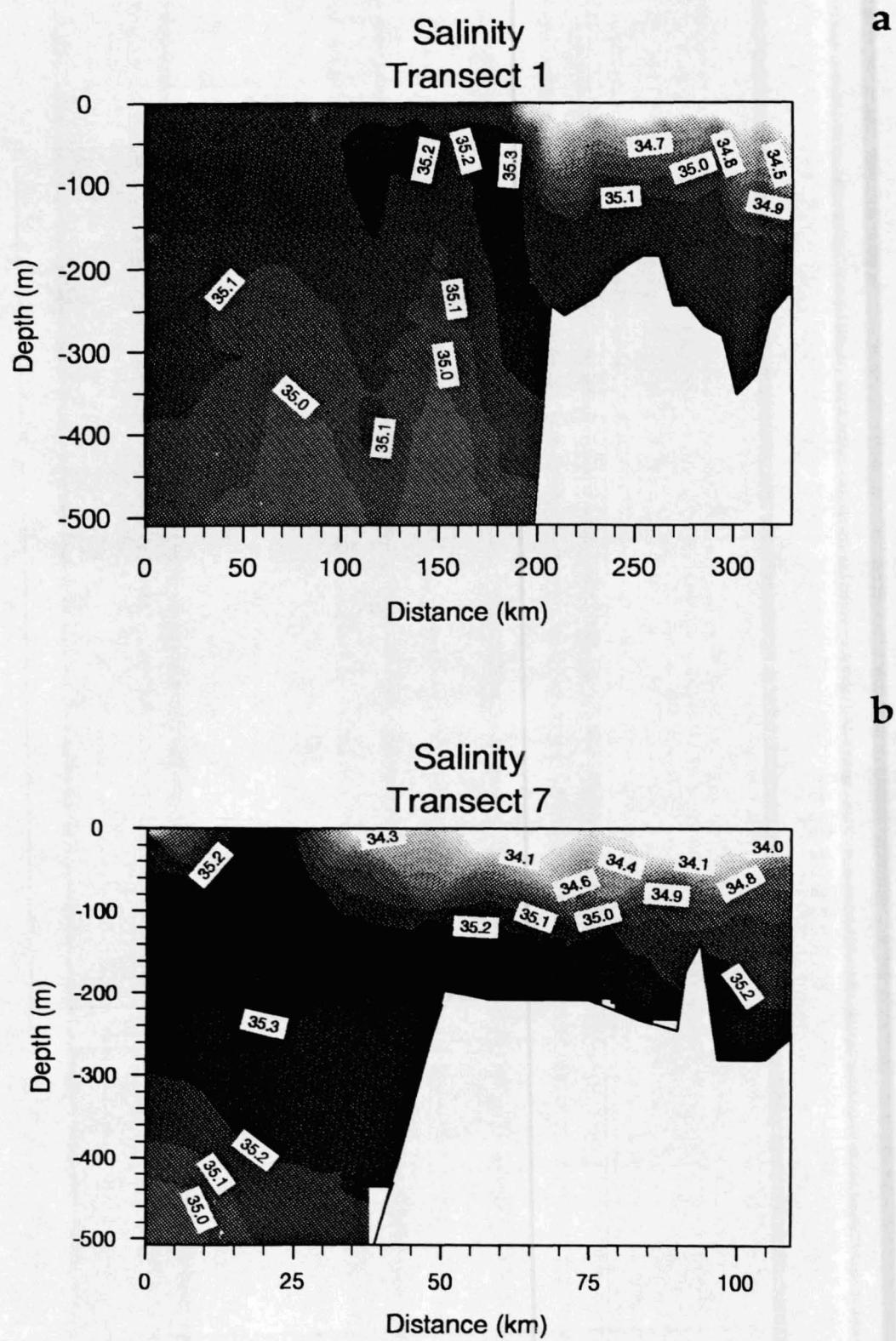


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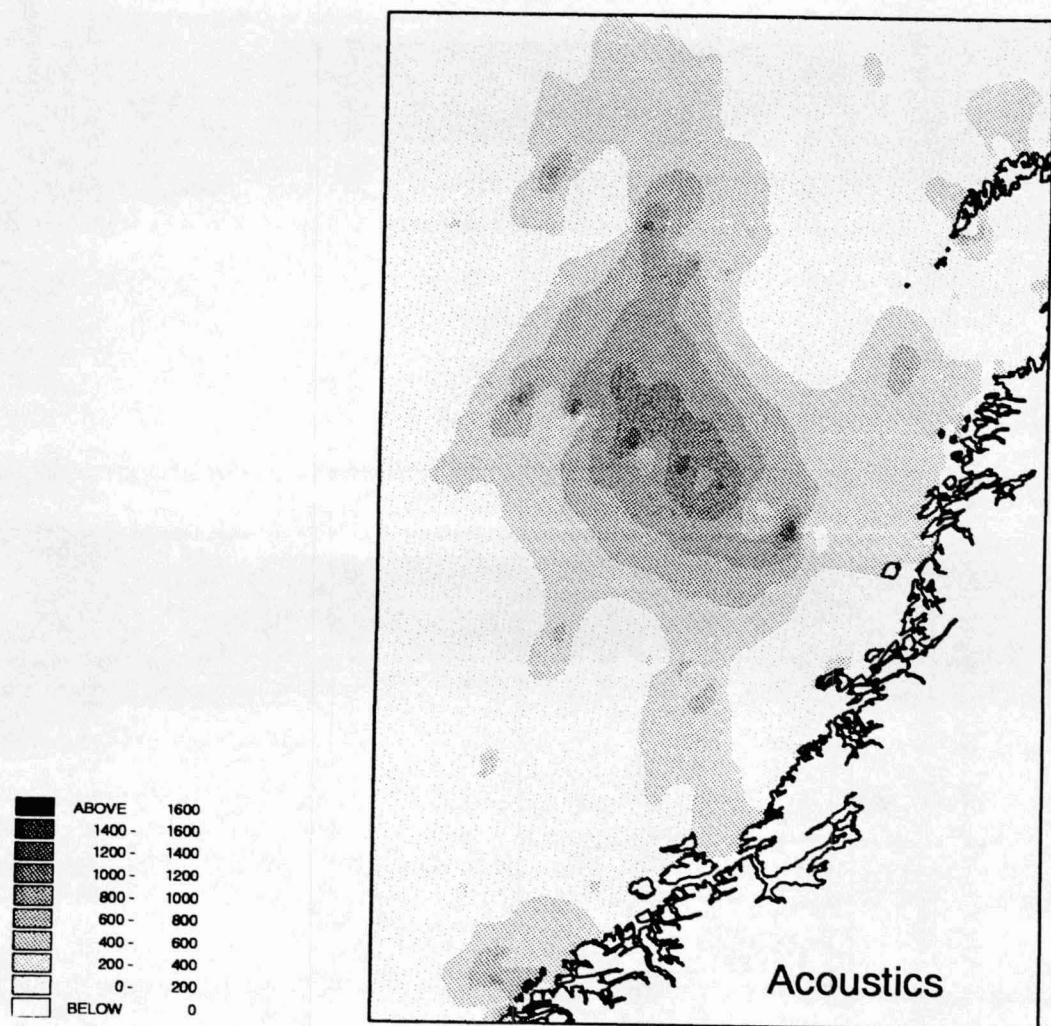


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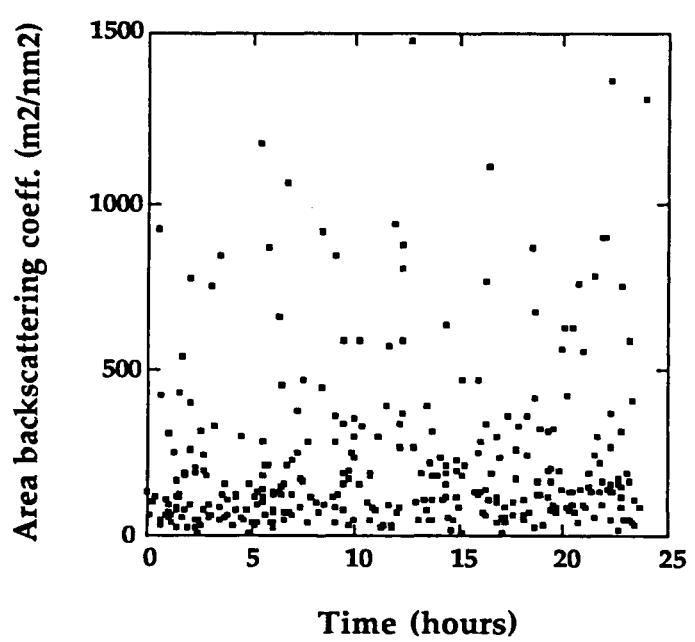


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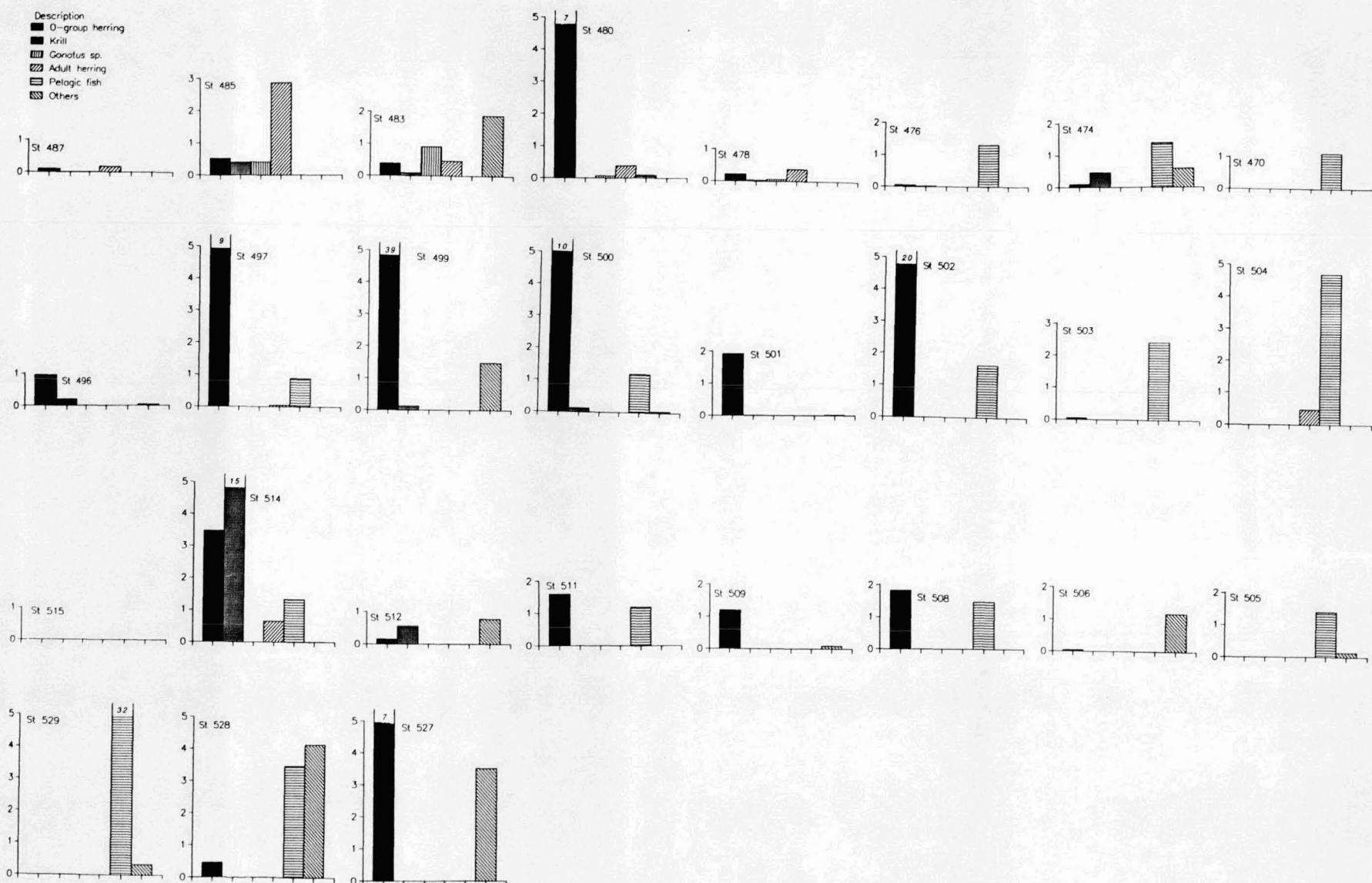


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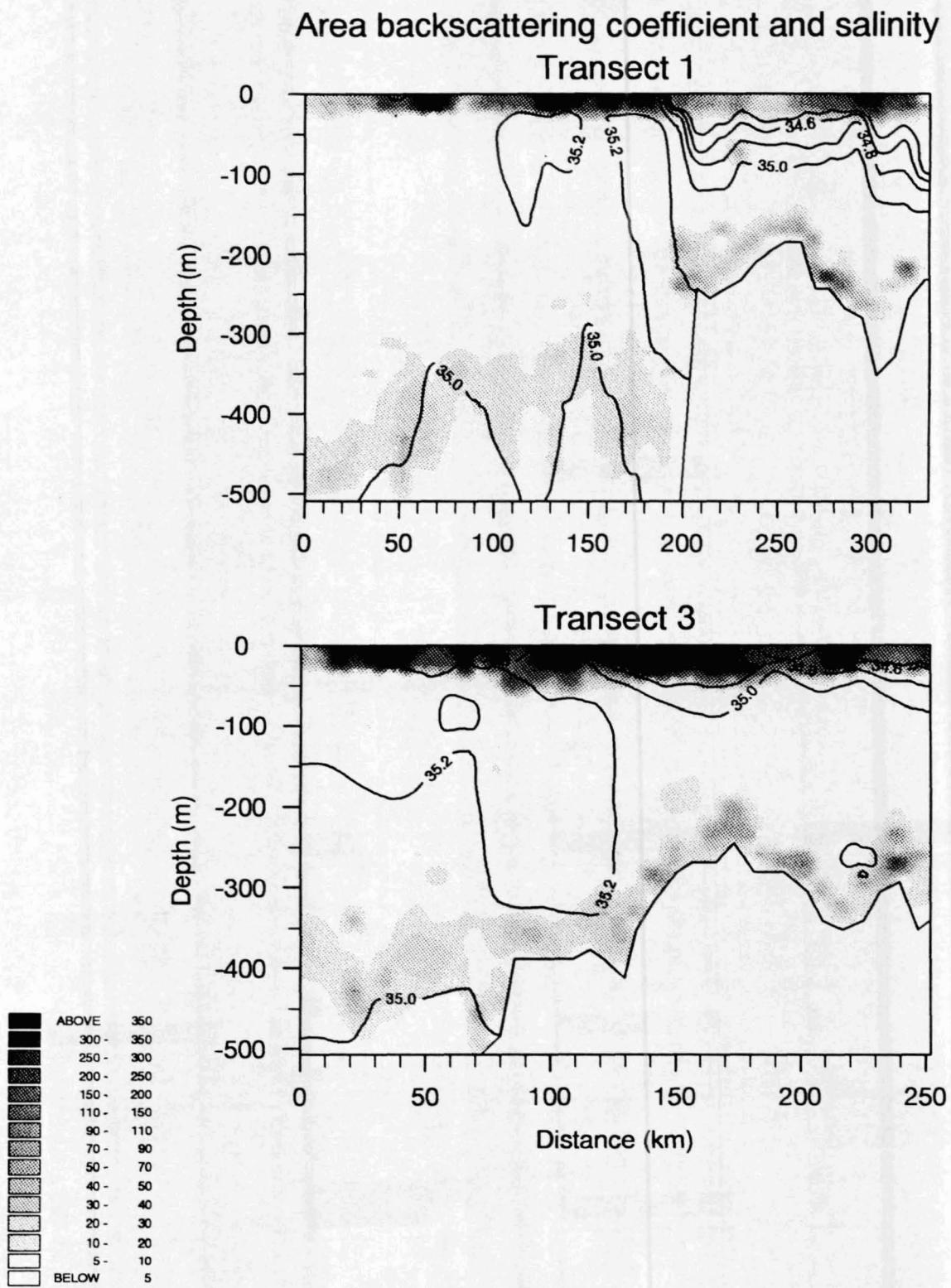


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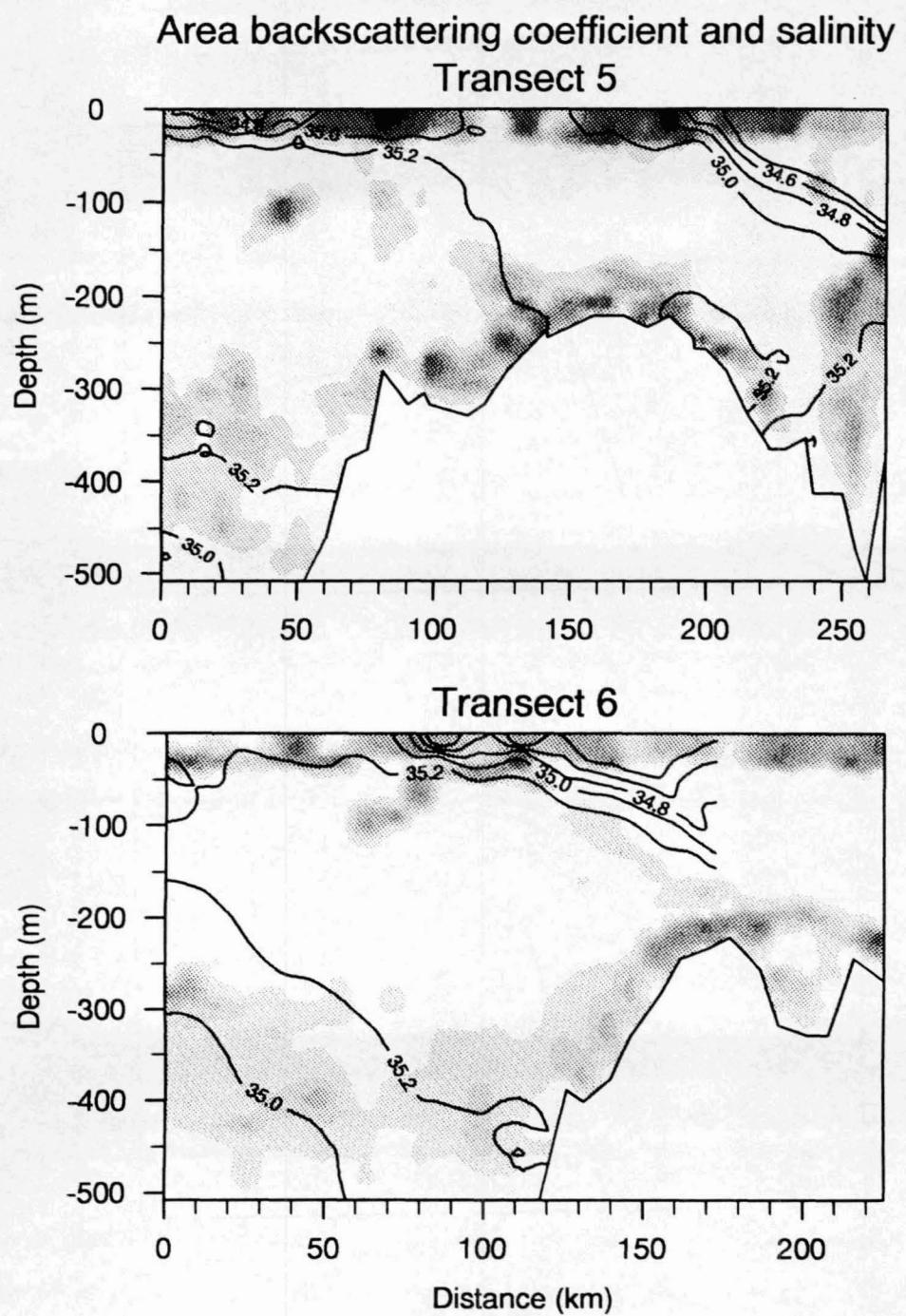


Figure 7 cont.

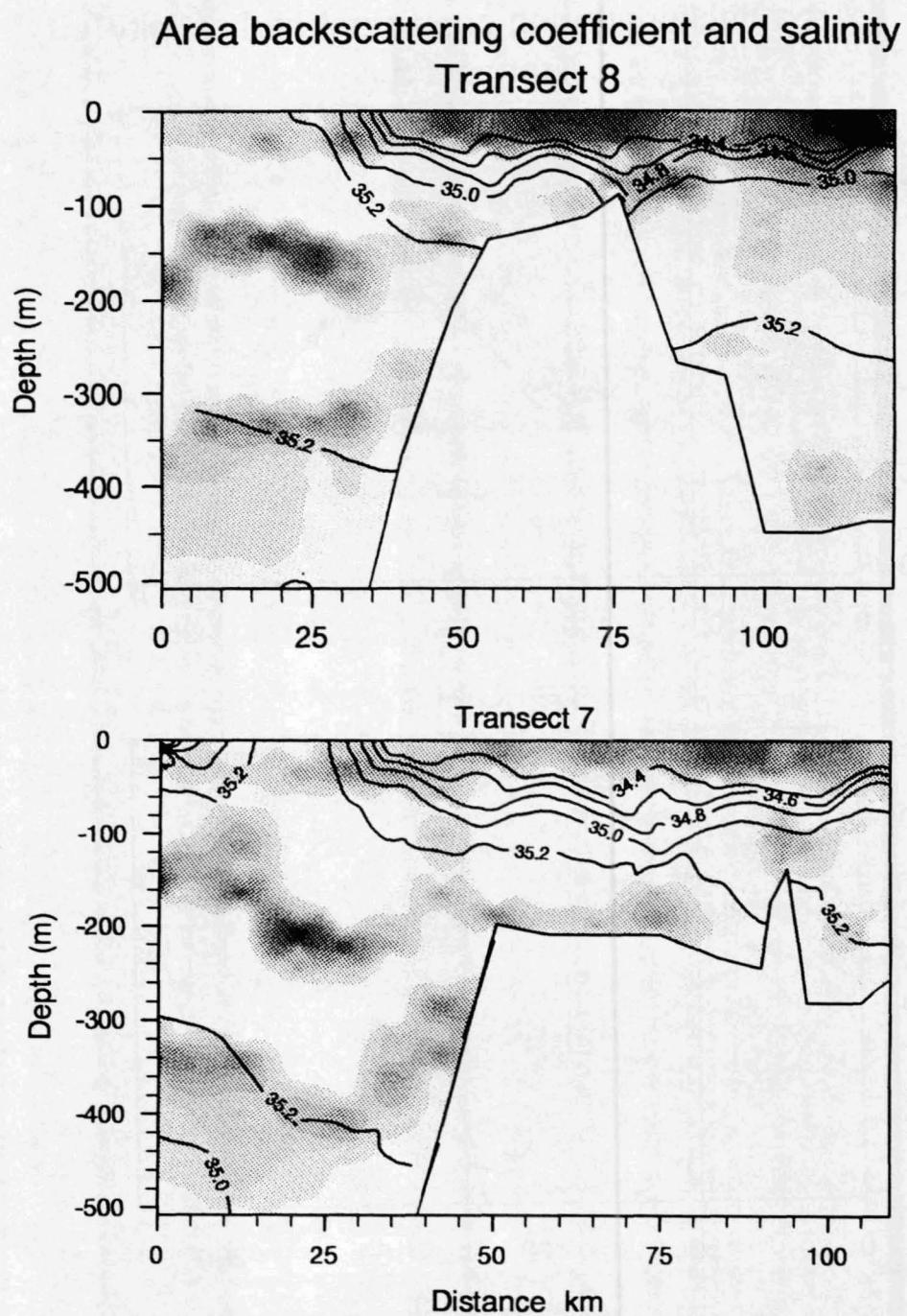


Figure 7 cont.

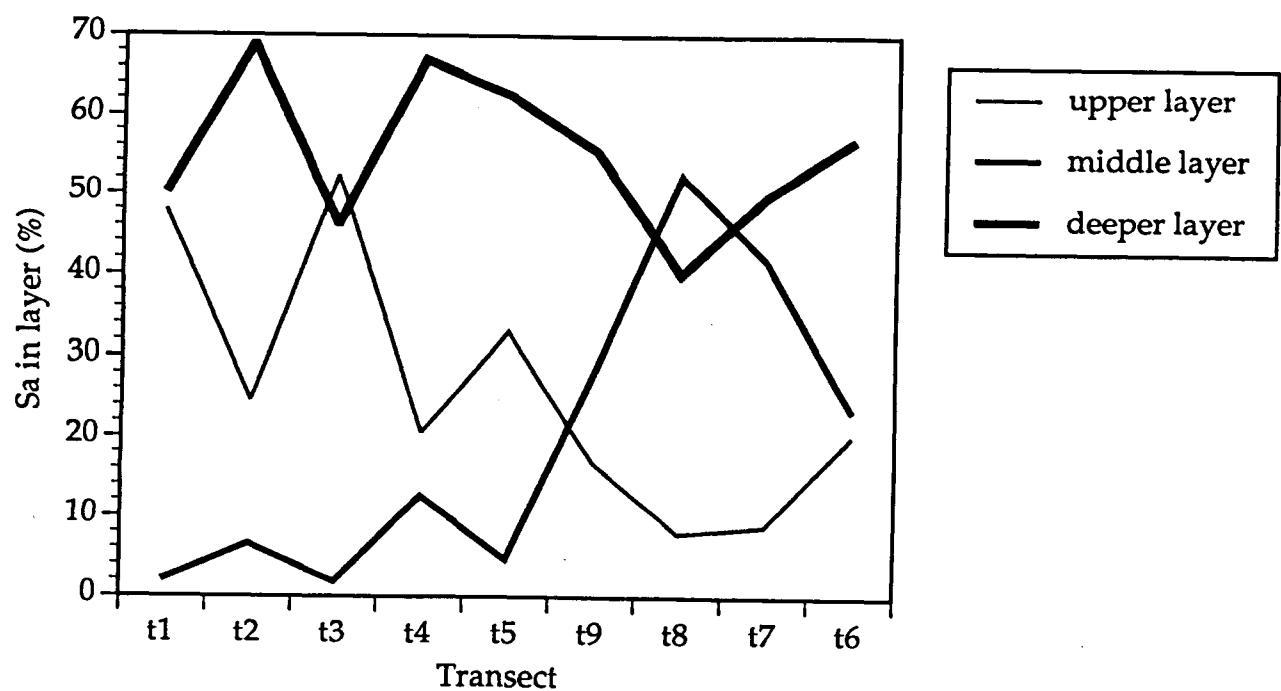


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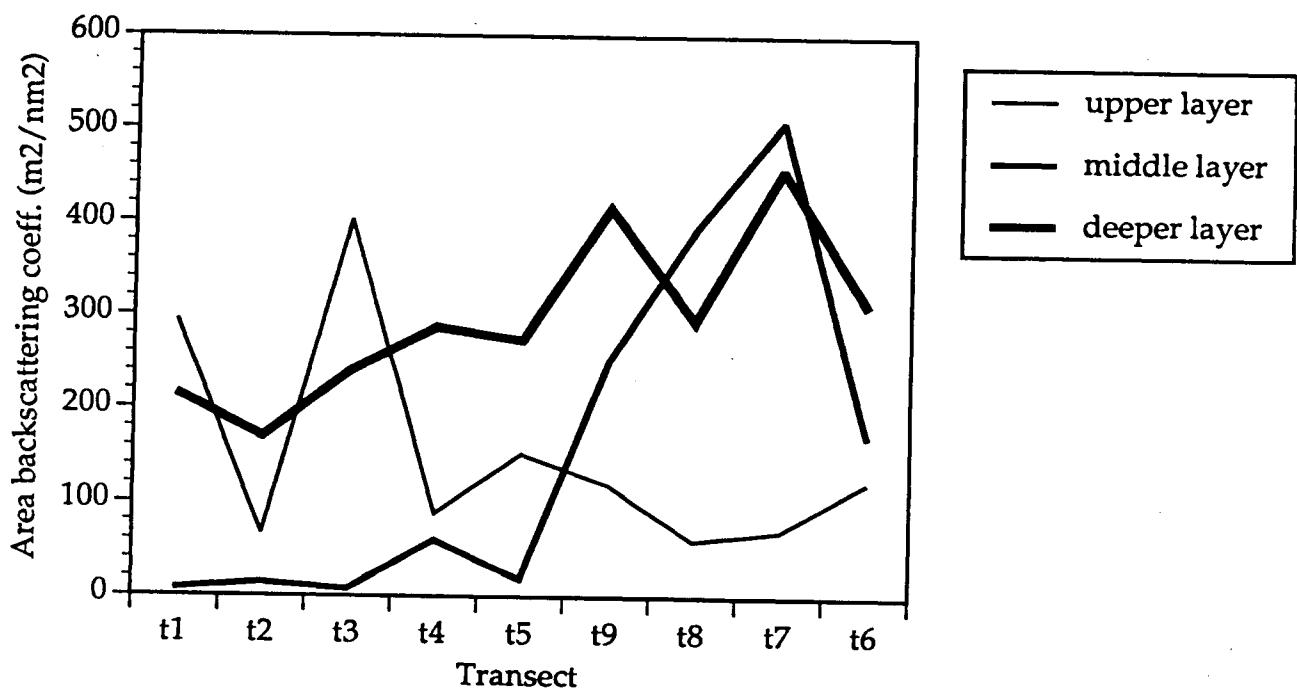


Figure 9.

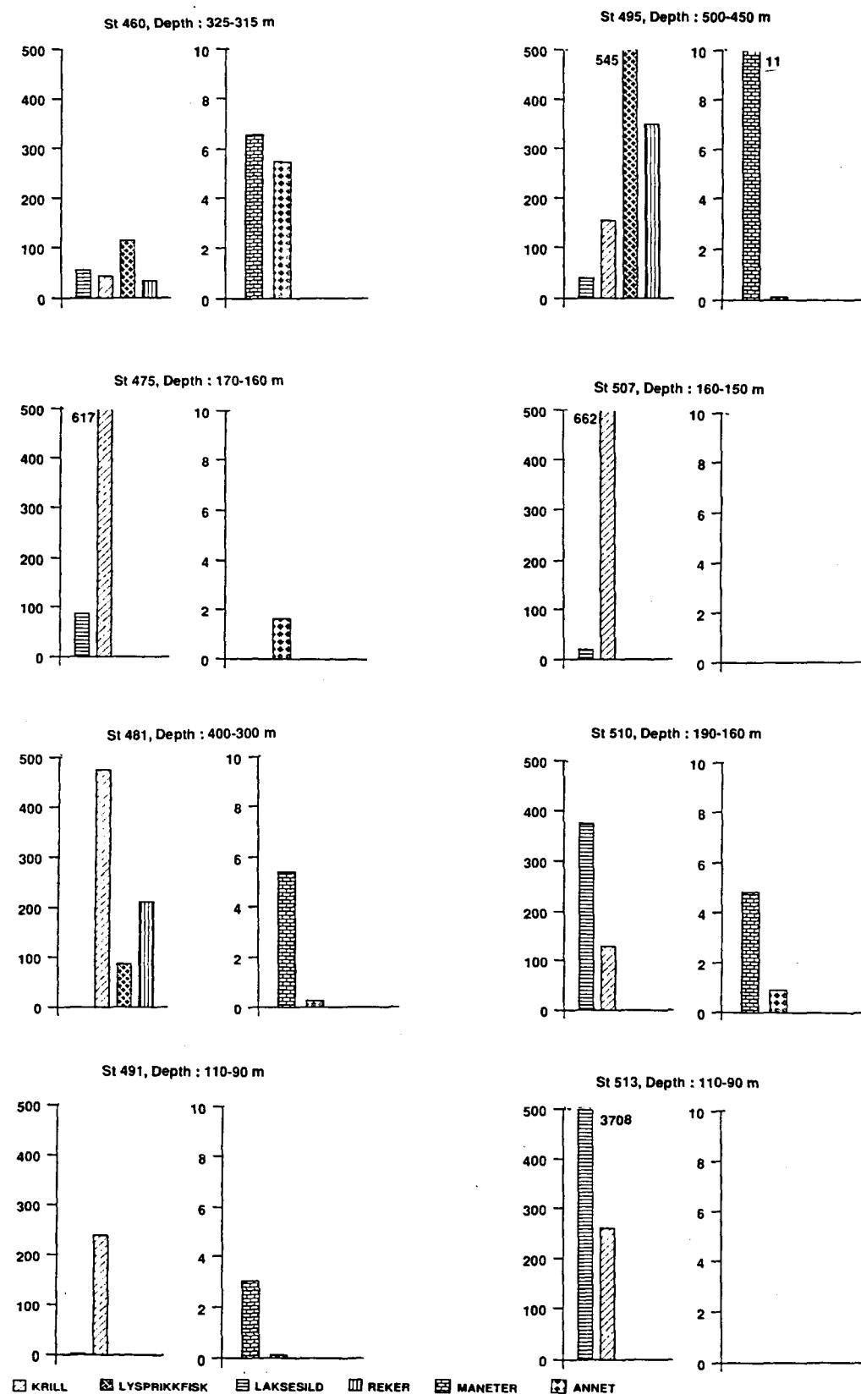
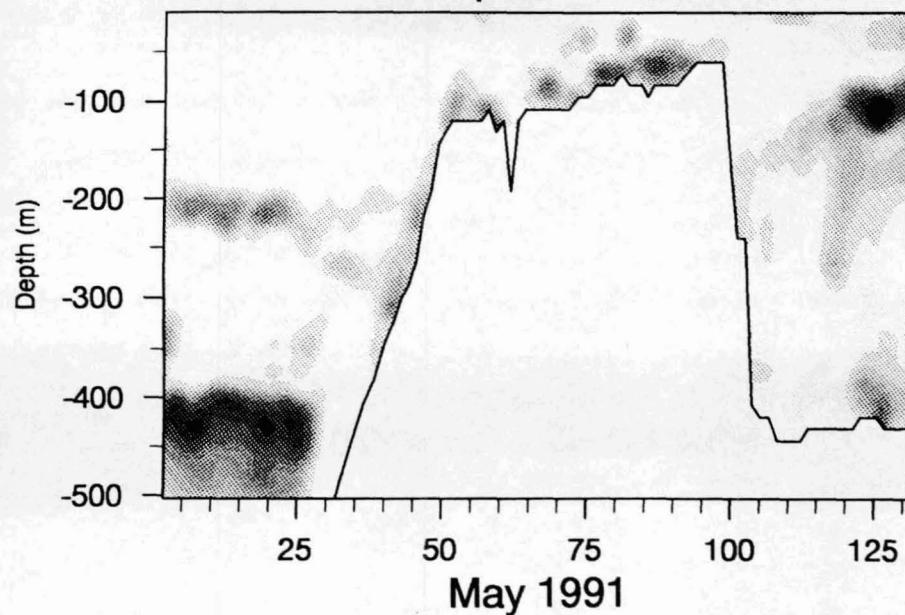


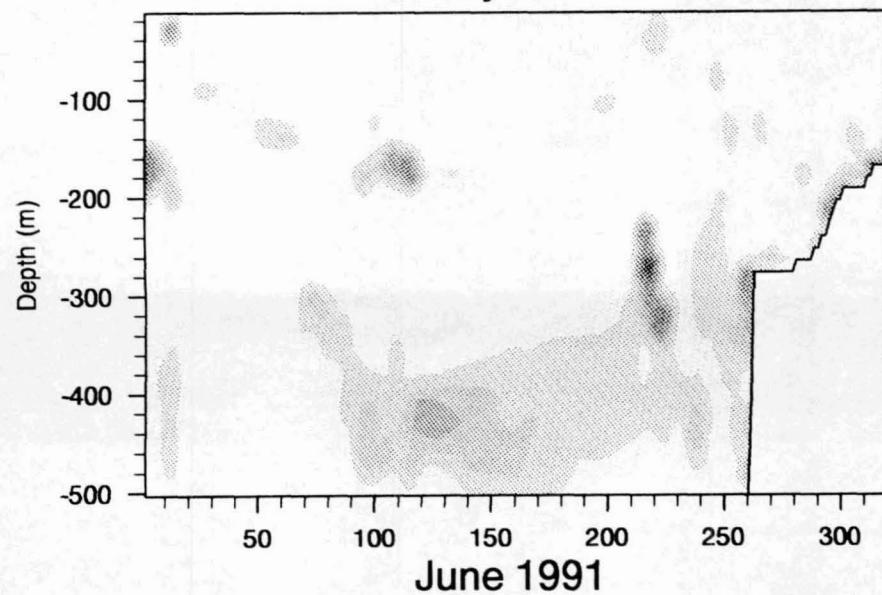
Figure 10.

Area backscattering coefficient
April 1991

25



May 1991



June 1991

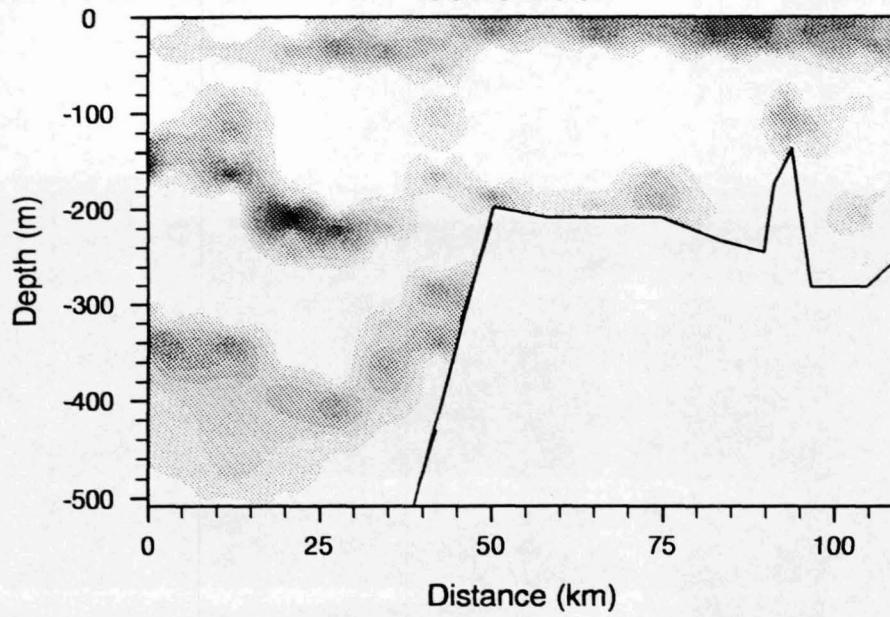


Figure 11.