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Exploration of the Sea

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Theme Session on Intermediate-Scale Physical Oceanographic Processes and their Influence on the Transport and Food Environment of Fish

The Influence of Hydrographic Processes on Plankton Distribution and Production in the Bornholm Basin, Baltic Sea.

By

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(ci Gadus morhua ee)

Abstract

In order to clarify mechanisms influencing the long term trends in the reproductive success and recruitment of Baltic cod (as outlined in the Baltic AIR research program AIR 2 1226) the effects and variability of intermediate and mesoscale physical processes on the food environment of larval and juvenile cod is required. A number of cruises have been performed to examine the key physical processes influencing plankton production and distribution in the Bornholm. The data presented here are the results of an integrated oceanographic cruise performed in August 1993 in the Bornholm Basin. In order to identify the key physical oceanographic parameters, a series of stations were examined (on a 20 x 10 nm grid) to create fields of salinity temperature, and current velocities. Biological parameters investigated at these stations included fluorescence, acoustic estimates of pelagic biomass as well zooplankton and fish egg, larval and juvenile abundances. During the grid survey a number physical features influencing the biological parameters were observed. These included upwelling along the Swedish coast, the interaction of the halocline and thermocline with bottom topography. In order to clarify the effects of these processes, a series of transects were examined to identify mechanisms causing variations in plankton distribution and production.

Introduction

In the Baltic Sea as in other marine ecosystems, the limiting factor governing the total biomass is the amount of new primary production and the efficiency of conversion of this production by higher trophic levels (e.g., Runge 1988; Cushing 1989). Temporal and spatial variations in biomass, distribution and species composition of phytoplankton in the marine environment are primarily determined by hydrodynamic processes affecting water column stability. These processes influence the availability of nutrients and light which limit phytoplankton growth (watercolumn stability) and thereby influence phytoplankton distributions due to horizontal and vertical circulation patterns coupled with behavioral or buoyancy characteristics (e.g. Franks, 1992). The spatial and temporal integrity of these intermediate scale physical features (e.g. tidal fronts, wind induced coastal upwelling, riverine plumes and topographically trapped eddies), their circulation patterns, which aggregate or disperse plankton, and the behavior of organisms in the various trophic levels influences the efficiency of transfer of primary production and thereby the species composition of the specific ecosystem (Peterson et al., 1979 Franks, 1992). Physical processes which couple phytoplankton population doubling rates (days) to higher trophic level population increases (weeks for some zooplankton) must be relatively persistent both spatially and temporally to elicit population responses in higher trophic levels (e.g. Kiørboe & Johansen 1986, Runge 1988). These mixing processes may however also occur at a frequency whereby pulsed primary production is at a spatial and temporal frequency whereby higher trophic levels are not limited by food availability (Kiørboe, 1991). The coupling of primary and secondary production directly may however be smoothed due to the effects of small scale turbulence (cm's to meters) which acts to increase the encounter rates of predators and their prey without influencing the actual total abundance of prey organisms (e.g. Mackenzie et al., 1994)

The complexity of the flow dynamics in the Baltic is well known and is mainly influenced by the windstress, the baroclinic field and the complicated bottom topography (e.g. Lehmann , 1994). Intermediate scale physical processes in the Baltic

Sea such as fronts, coastal upwelling and eddies have been demonstrated to be ephemeral in nature especially in comparison to regions of tidal mixing regions in the North Sea (e.g. Aitsam et al., 1982; Kahru et al., 1984; Munk and Nielsen , 1994). The purpose of the present study was to examine the influence of topographic features and coastal upwelling on the distribution and production of planktonic organisms in the Bornholm Basin thereby obtaining an indication of their potential importance for growth and condition of larval fish.

Materials and Methods

Field studies were carried out aboard the RV 'Dana' from August 2 to 17th, 1993. In total 141 stations between 54^{o}40 and 56^{o} 00 (N) latitude and 15^{o}00 and 17^{o}30 (E) longitude were examined in the south western Baltic Sea (Figure 1a). Sampling was performed on a 20 x 10 nautical mile grid with additional stations added in order to examine specific oceanographic features (i.e. wind induced coastal upwelling off the Swedish coast (Figure 1, transect 2) and regions of doming of the thermocline due to bottom topography off the Polish coast (figure 1, transect 1)). On each station vertical profiles of salinity, temperature and fluorescence were performed with a Niel Brown CTD coupled with a rosette sampler (Hydrobio, 10 bottles of 1.7 l) and a fluorometer (Q instruments). Samples for the determination of nutrients concentrations (NO_2^-, NO_3^-, and PO_4^{3-}) were obtained over the watercolumn using a rosette sampler and analysis performed on an automated nutrient analyzer (Dansk Havteknik) following methods described by Grassoff (1976). The chlorophyll *a* concentration was measured for a number of samples taken from the florescence maximum and surface layer over the study area using the method described in Strickland & Parsons (1972). A linear regression of chlorophyll *a* and fluorescence was performed (Chlorophyll a = 0.0132 fluorescence - 0.098; r^2 =0.85, n=82) and this was used in the conversion of fluorescence to chlorophyll *a*. Water samples from the fluorescence maximum and from the surface layer were used for the determination of phytoplankton productivity (particulate) as described in Richardson (1985).

Calculation of daily primary production from ^{14}C incorporation is based on the model presented in Richardson & Christoffersen (1991). The abundance of meszooplankton was investigated using a submersible pump (3000 l. min^{-1}) equipped with a 30 μm mesh conical net. Flow meter recordings taken at pump intake were utilized to determine the volume filtered. Integrated zooplankton samples were obtained by raising the pump through the watercolumn at 10 m.min-1. Samples were successively filtered through 200 and 30 um mesh nitex sieves and the retained fractions were preserved in 4% buffered formalin. In the laboratory, a subsample of 500 copepods from the 200um size fraction was identified to species and the cephalothorax length measured in the smaller size fraction a minimum of 100 copepods was identified to genus and cephalothorax length measured. Other zooplankters were identified to species where possible. Egg production of rates of adult female *Acartia tonsa* and *Centropages hamatus*. were estimated using the following procedure. Copepods were sampled from the thermocline to the surface using a WP-2-net (200 μm mesh) and adult females were transferred immediately to 600 ml glass bottles (1-5 females per bottle) containing filtered seawater. Depending on female availability, up to six replicate bottles were incubated at *in situ* temperature for 24 hrs, whereafter the eggs produced were counted. The rate specific egg production of copepod eggs was assumed in this study to represent the copepod growth rate at all stages according to Bergreen et al., (1988).

Results

Phytoplankton Distribution and Production

The distribution of primary production observed during the preliminary grid survey of the program is presented in Figure 1 b. The highest rates of production (>1600 mg. $C.m^{-2}$ .day^{-1}) were found in the shallow coastal region near the Polish coast with the mean production of phytoplankton carbon in the Bornholm Basin of 500 mg. $C.m^{-2}$ .day^{-1}. This region also corresponded with the region of highest relative fluorescence (Note: the chlorophyll maximum was seen to range between 20 and 25 meters throughout the basin) in the Bornholm Basin as seen in figure 2 a. This region corresponded with the region of highest temperature at 20m while the region of lowest temperature at 20 m (figure 2b) corresponded with the region of lowest relative fluorescence.

Zooplankton Abundance

The dominant copepods (dry weight) observed in the surface mixed layer (0-25 m) during this study were *Acartia tonsa* and *Centropages hamatus.* The peak biomass of *Centropages h.* (>1.8 mg DW.m^{-2}) was observed to coincide with a tongue of upwelled cold water (< 7.5 °C) off the Swedish coast (figure 2b and 3b) while the peak biomass of *Acartia tonsa* (7.5 mg DW.m^{-2}) was observed slightly to the west of this location Figures 2b and 3a). Interestingly the peak abundance of these to dominant copepods were not related to the regions of peak primary production or chlorophyll a as observed in figures 1 b and 2a). Cladocerans (dominated by *Bosmina coregoni maritma*) comprised up to 4.5 mg DW m^{-2} this peak in biomass was observed to occur in the shallow waters over the southern tip of Midsjø Banke in the region 14 °C water (Figure 2b and 3c).

Transect 1; Thermocline Bottom interactions

Physical Characteristics

The salinity contour along the transect across Schlupsk Furrow (figure 1a, 4a) illustrates the doming of the halocline (note the 7.50 ppt contour) in the shallow waters (<30 m) along the Polish coast. This observation suggests the potential for injection of nutrients into the euphotic zone in this region. The region between where the thermocline and halocline interact with the bottom (figure 4a and c) approximately 20 and 30 nautical miles from the beginning of the transect has the highest relative fluorescence over the surface mixed layer and the maximum primary production observed during this program of 60-70 mg chl *a* .m^{-2} and 1600 mg C.m^{-2} respectively (figure 4b and 5a). However, this region of high primary production and chlorophyll *a* concentration did not correspond to high copepod egg production as the highest rates of egg production (circa 10 eggs .female^{-1} .day^{-1}) by the copepod *Centropages h.* were displaced coast ward from the region of high phytoplankton abundance and production (Figure 5c) . Conversely, the peak in production observed for *Acartia tonsa* occurred with the peak in abundance of this species at the transect position furthest offshore.

Coastal upwelling Transect

The contour plot of the salinity along transect 2 (Figure 1 a and 6a) indicates a rising in the halocline in the more coastal section of the transect (8.00 ppt contour) suggesting the occurrence of a upwelling event in this region. The domed thermocline in this region (figure 5 c) coupled with the contour plot of temperature at 20 meters in the basin (figure 2b) indicate the occurrence of a mixing event in this region. The contour plot of relative fluorescence (figure 6b) shows the highest relative fluorescence observed during this program (circa 3.2 mg Ch *a* .m^{-3}). However the highest chlorophyll *a* concentration observed on this transect was located nearest the coast. As observed in the previous transect, the highest copepod production (Figure 7c , *Centropages h.* , circa 16 eggs. female^{-1}. day^{-1}) was displaced from the region of highest primary production however on this transect the chlorophyll *a* concentration (Figure 7 a) along the transect was quite low except for the aforementioned peak figure .

Discussion

The detailed examination of the effects of intermediate scale physical processes such as coastal upwelling and the interaction of the thermocline and halocline with bottom topography presented here clearly demonstrates the importance of these processes on the distribution and production of planktonic organisms in the Baltic.

The coastal upwelling situation examined (Transect 2) appears to initially influence the distribution of plankonic organisms rather than increase production rates of either phytoplankton or zooplankton. The effects of nutrient injection on population size may be delayed due to a) light limitation of the phytoplankton cells or b) lack of chelation of metals by organics thus delaying the uptake of nutrients and increase in phytoplankton biomass. Discrete circulation or behavior patterns confounded by the ephemeral nature of the circulation patterns in the Basin will be necessary to maintain herbivores in the path of these upwelled patches of nutrient rich water. The effects of this process on population dynamics will probably occur downstream from the site of upwelling resulting in an inefficient transfer of primary production to higher tropic levels. The residual circulation of the surface layer in this region is typically to the west (e.g. Lehmann, 1994) thus suggesting that effects of the increased primary production from this upwelling source will be transported to the western Baltic out of the Bornhom Basin thereby leading to higher secondary and tertiary production in this region.

Examination of the interaction of bottom topography with the halocline/ thermocline examined in transect 1 suggests that this region potentially has a major effect on both phytoplankton and zooplankton production. The high zooplankton production observed in this regions suggests an efficient coupling of primary and secondary production in the shallow waters (< 30 m around the basin in the region between where the theromcline and halocline reach the bottom) thus potentially creating a region of high food abundance for utilization by larval and juvenile fish in the Baltic. Previous studies on the distribution of juvenile spratt and herring in the Baltic (Ojaveer and Kaleis 1974; and Raid 1989) suggest this region is a potential nursery are for the young of the year of these species.

The preliminary results of this study suggest the need for further examination of the influence of specific oceanographic regions and intermediate scale oceanographic features in the Baltic sea on the growth, condition and survival of key fisheries stocks such as the Baltic cod. Further research on these features is planned in conjunction with the research performed during the EU funded Baltic AIR research program (AIR 2 1226) entitled "Mechanisms influencing the long term trends in the reproductive success and recruitment of Baltic cod: Implications for fisheries management".

Acknowledgments:

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Figure Captions

Figure 1a. Location of the study area (survey grid between 54°40 and 56° 00 North latitude and 15°00 and 17°30 East longitude) depth contours and specific transects to examine the effects of intermediate scale oceanographic processes on plankton distribution and production in the Bornholm Basin, Baltic Sea between August 3 and 17th , 1993.

Figure 1 b) Contour plot of the horizontal distribution of primary production (mg C.m^{-2}.day^{-1}) in the surface mixed layer in the Bornholm Basin between August 3 to 17, 1993.

Figure 2. Horizontal contour plots generated from CTD stations taken on a 10 x 20 Nm grid in the region between 54°40 and 56° 00 North latitude and 15°00 and 17°30 East longitude a) Relative fluorescence, b) Temperature.

Figure 3. Horizontal contour plots of the dry weight of the dominant zooplankon species (µg.DW.m^{-2}) in the surface mixed layer of the Bornholm as determined using a submersible pump (3000 l. min^{-1}) equipped with a 30 µm mesh conical net. a) *Acartia tonsa* b) *Centropages hamatus* and c) Cladoceran spp.

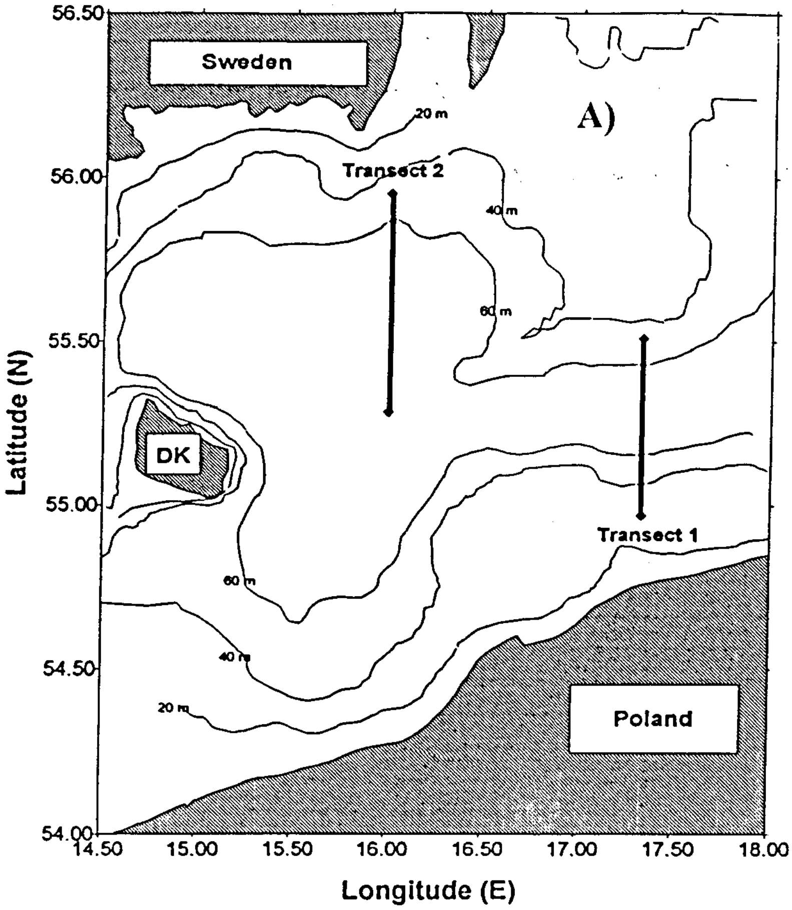
Figure 4. Vertical contour plots of a) salinity, b) relative fluorescence, and c) temperature from six stations placed along transect 1 from 54° 58.3' N and 17° 20.3' to E to 55° 30.2' N and 17°29.2 E crossing Schlupsk Furrow in the Southern Baltic Sea.

Figure 5. Plots of a) Primary production (mg C. m^{-2}.day^{-1}) and Chlorophyll a (mg. C.m^{-2}); b) dry weight (mg. m^{-3}) of the copepod species, *Centropages, Eurytemora, Temora, Acartia Tonsa,* and *Pseudocalanus* below the thermocline; c) egg production rates in eggs. female-1.day-1 from the copepods Acartia tonsa and Centropages and; d) dry weight (mg. m^{-3}) of the copepod species, *Centropages, Eurytemora, Temora, Acartia Tonsa,* and *Pseudocalanus* below the thermocline all taken from six stations placed along transect 1 from 54° 58.3' N and 17° 20.3' to E to 55° 30.2' N and 17°29.2 E crossing Schlupsk Furrow in the Southern Baltic Sea.

Figure 6. Vertical contour plots of; a) salinity, b) relative fluorescence, and c) temperature from six stations placed along transect 2 from 55° 57.3' N and 15° 59.7' to E to 55° 17.5' N and 16°00 E.

Figure 7. Plots of a) Primary production (mg C. m^{-2}.day^{-1}) and Chlorophyll a (mg. C.m^{-2}); b) dry weight (mg. m^{-3}) of the copepod species, *Centropages, Eurytemora, Temora, Acartia Tonsa,* and *Pseudocalanus* below the thermocline; c) egg production rates in eggs. female-1.day-1 from the copepods Acartia tonsa and Centropages and; d) dry weight (mg. m^{-3}) of the copepod species, *Centropages, Eurytemora, Temora, Acartia Tonsa,* and *Pseudocalanus* below the thermocline all taken from six stations placed along transect 1 from six stations placed along transect 2 from 55° 57.3' N and 15° 59.7' to E to 55° 17.5' N and 16°00 E.

Figure 1



Bornholm Basin, August, 1993
Primary Production
(mg C.m-2.day-1)

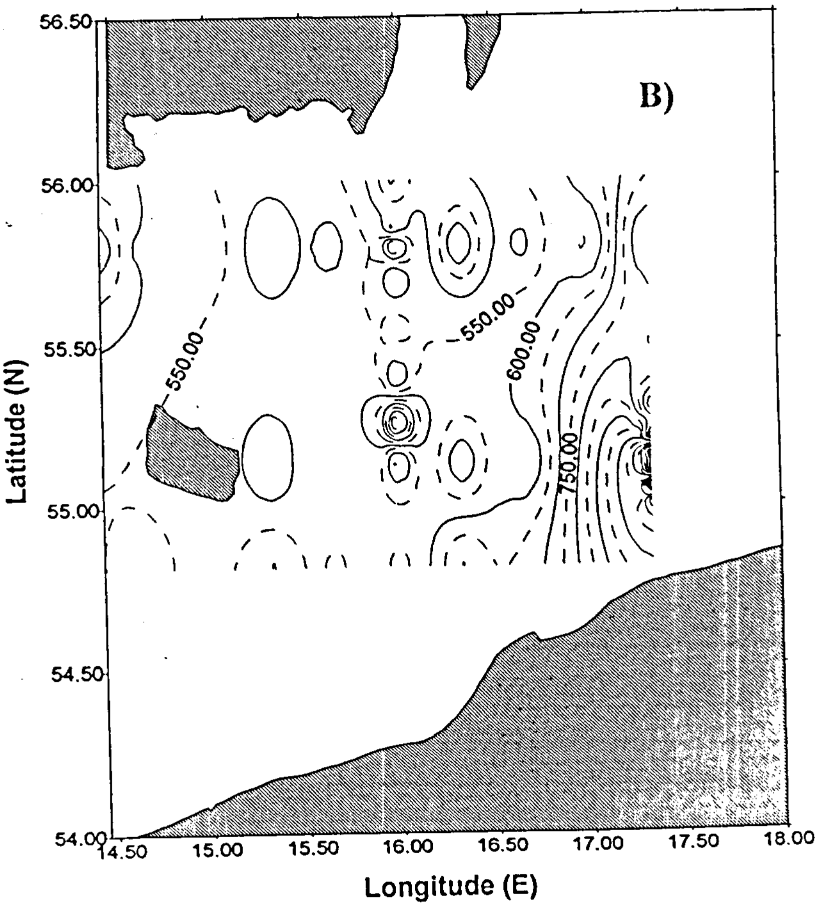
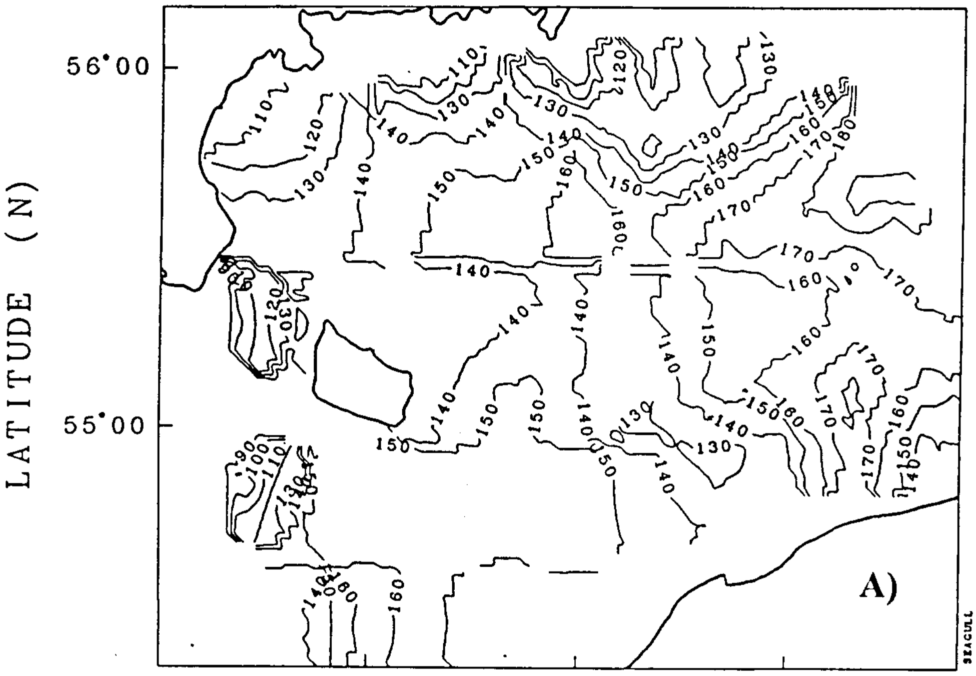


Figure 2

Contour Plot of Relative Fluorescence at 20 m
Bornholm Basin
August 2-18, 1993



Contour Plot of Temperature at 20 m
Bornholm Basin
August 2-18, 1993

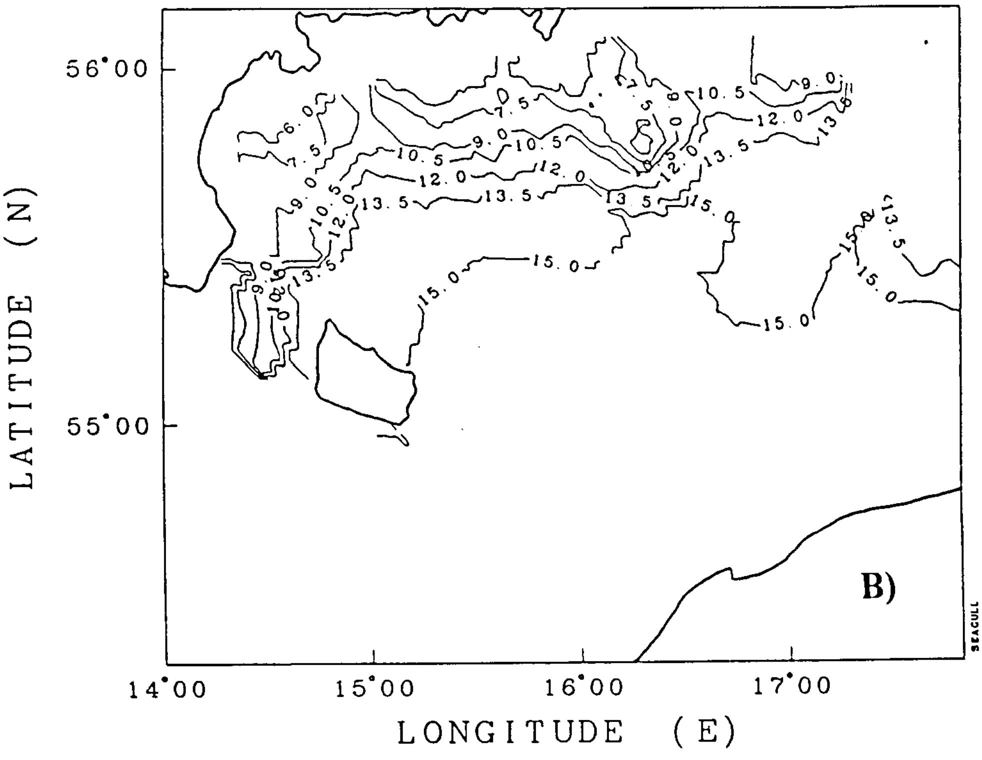


Figure 3

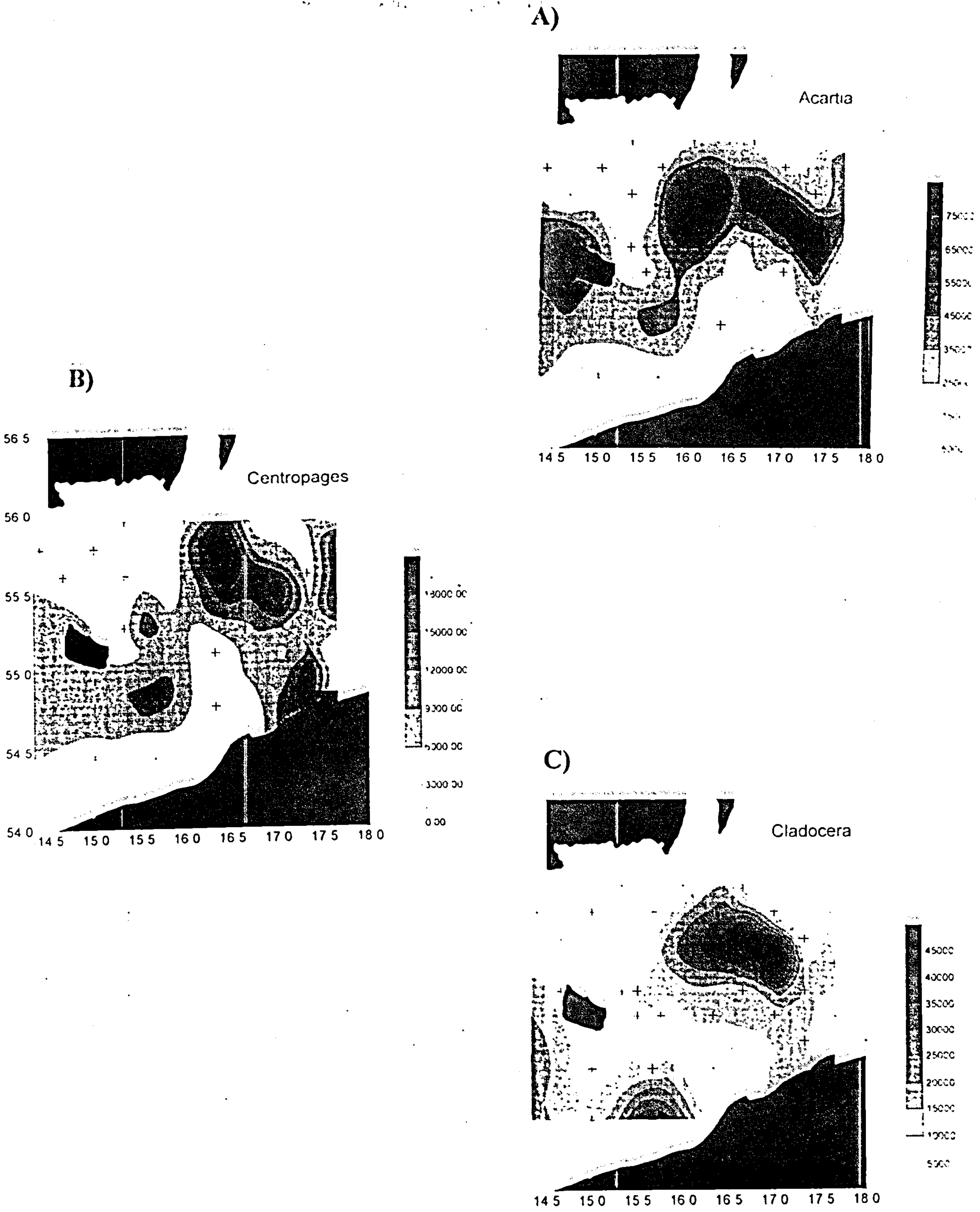
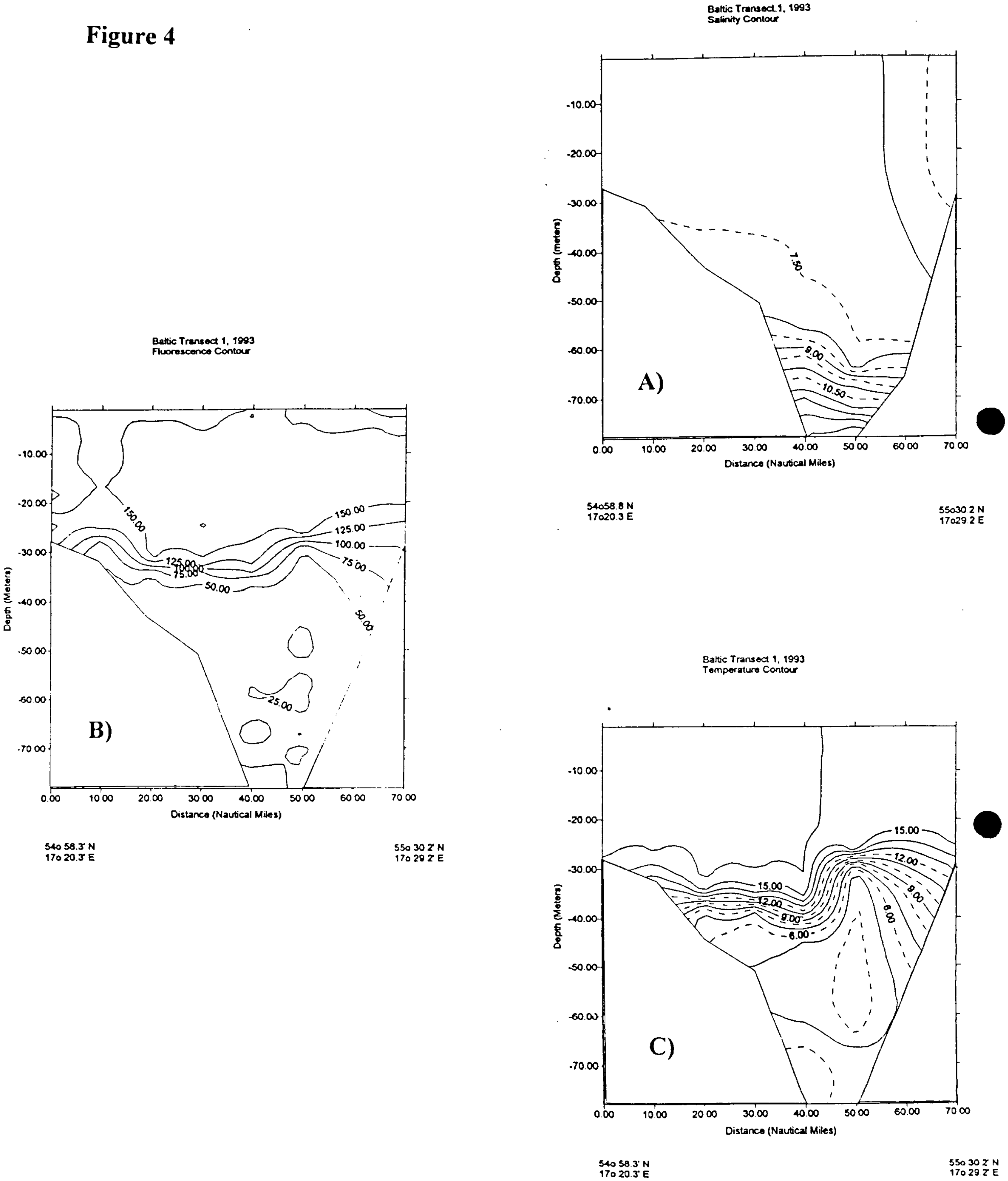

A)
Acartia
75000
65000
55000
45000
35000
25000
14 5
15 0
15 5
16 0
16 5
17 0
17 5
18 0
B)
Centropages
56 5
56 0
55 5
55 0
54 5
54 0
18000 00
15000 00
12000 00
9000 00
6000 00
3000 00
0 00
14 5
15 0
15 5
16 0
16 5
17 0
17 5
18 0
C)
Cladocera
45000
40000
35000
30000
25000
20000
15000
10000
5000
14 5
15 0
15 5
16 0
16 5
17 0
17 5
18 0

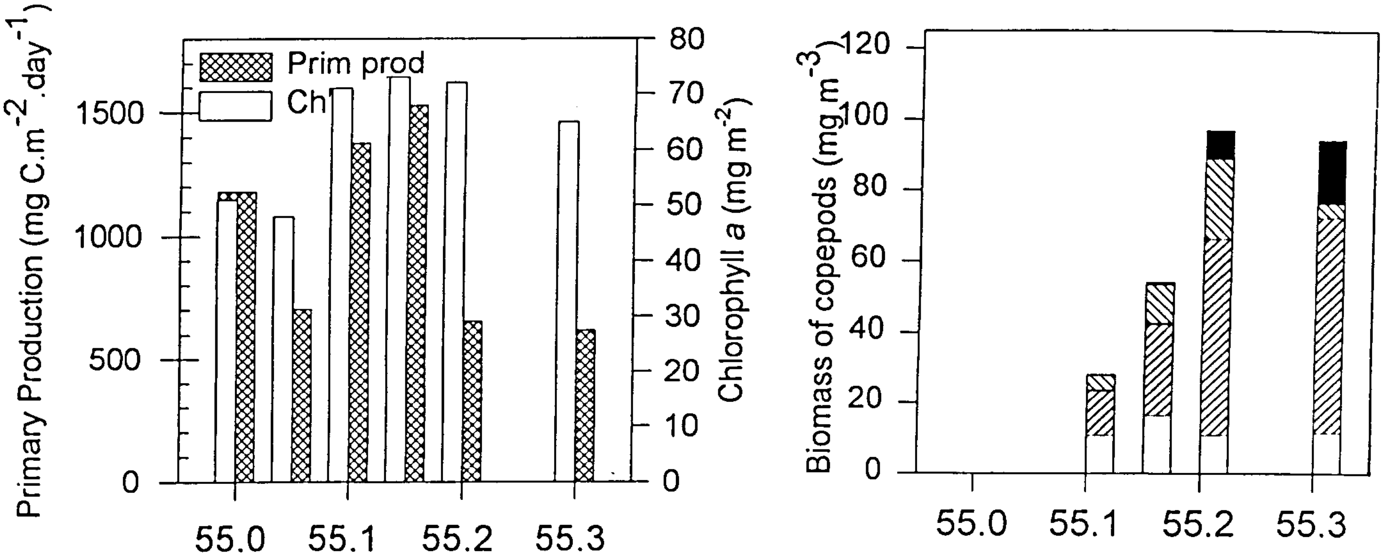
Figure 4


Baltic Transect 1, 1993
Salinity Contour
A)
Depth (meters)
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
7.50
8.00
10.50
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Distance (Nautical Miles)
54o58.8 N
17o20.3 E
55o30.2 N
17o29.2 E
Baltic Transect 1, 1993
Fluorescence Contour
B)
Depth (Meters)
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Distance (Nautical Miles)
54o 58.3' N
17o 20.3' E
55o 30.2' N
17o 29.2' E
Baltic Transect 1, 1993
Temperature Contour
C)
Depth (Meters)
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
15.00
12.00
9.00
6.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
Distance (Nautical Miles)
54o 58.3' N
17o 20.3' E
55o 30.2' N
17o 29.2' E

Transect 1 at Schlupsk Furrow

a) Primary production
Chlorophyl a

b) Copepod biomass
Lower part of water column



c) Production of copepod eggs

d) Copepod biomass
Upper part of water colum

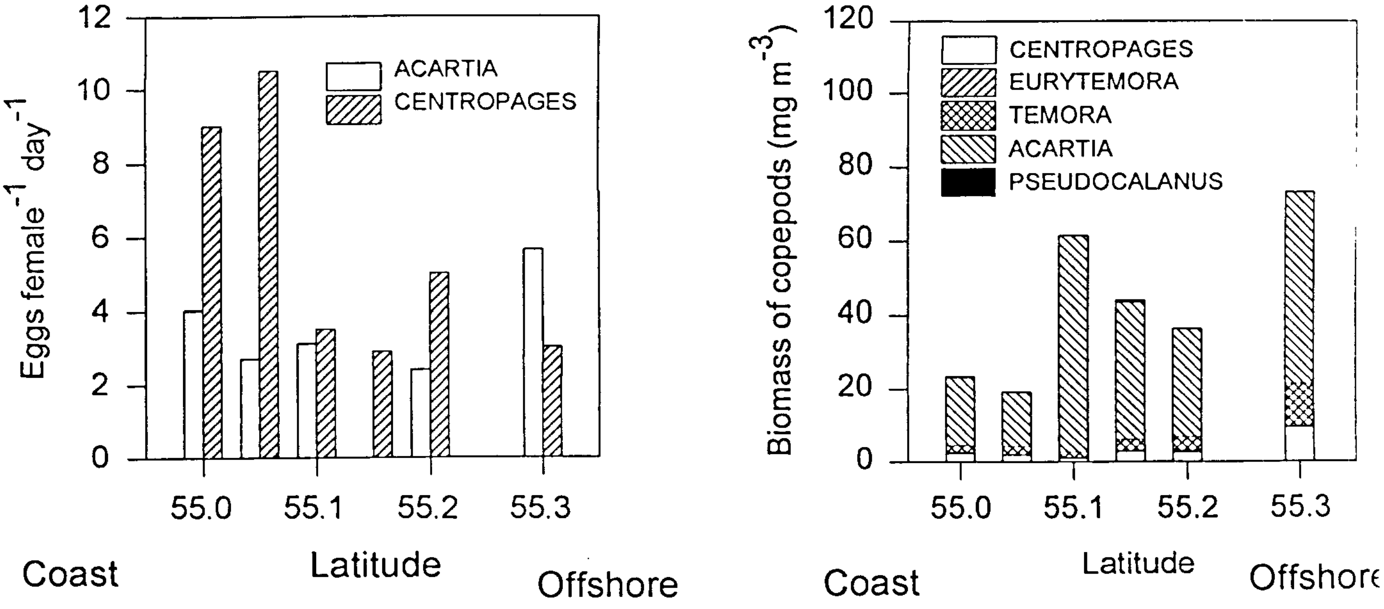


Figure 5

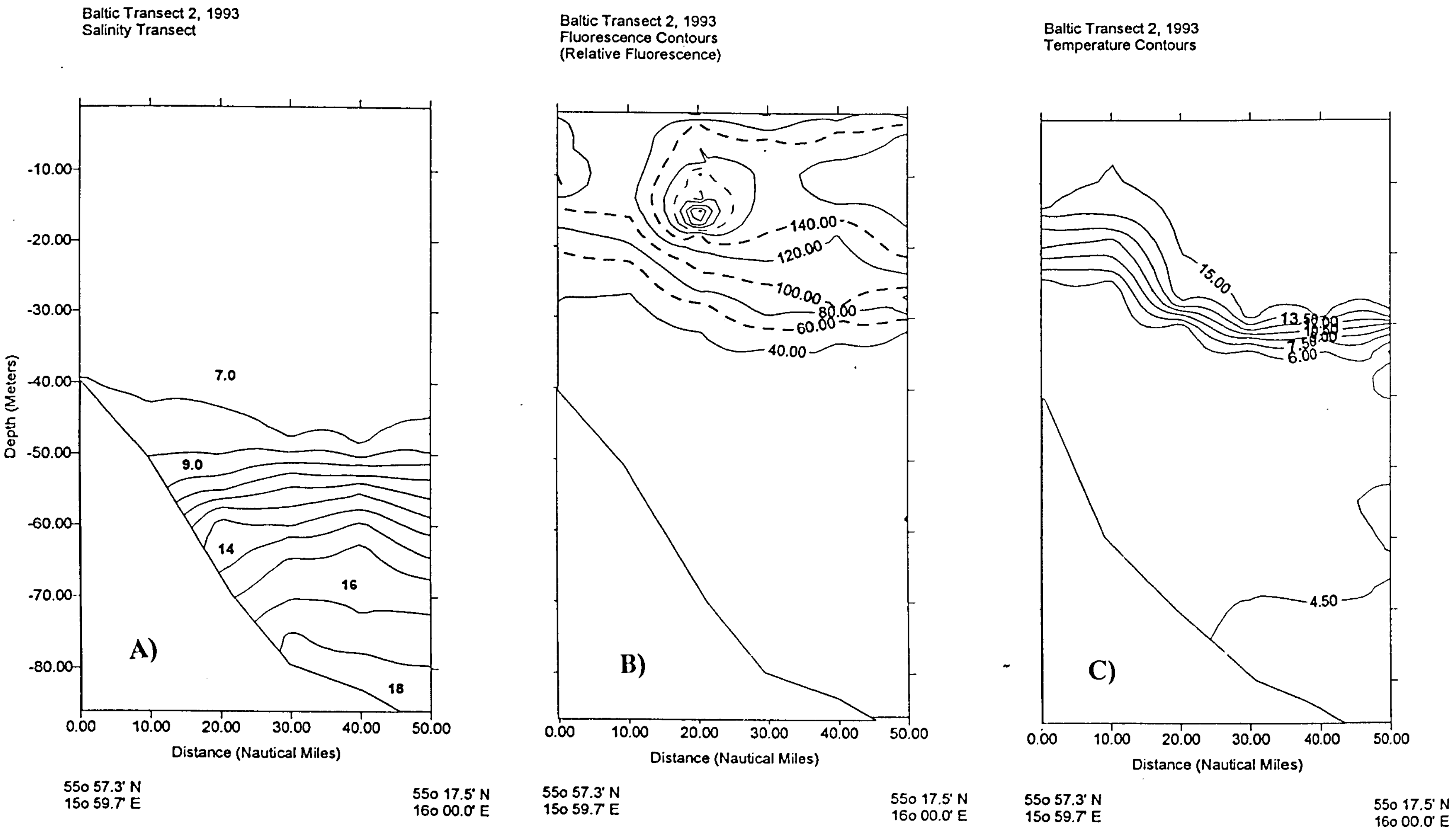
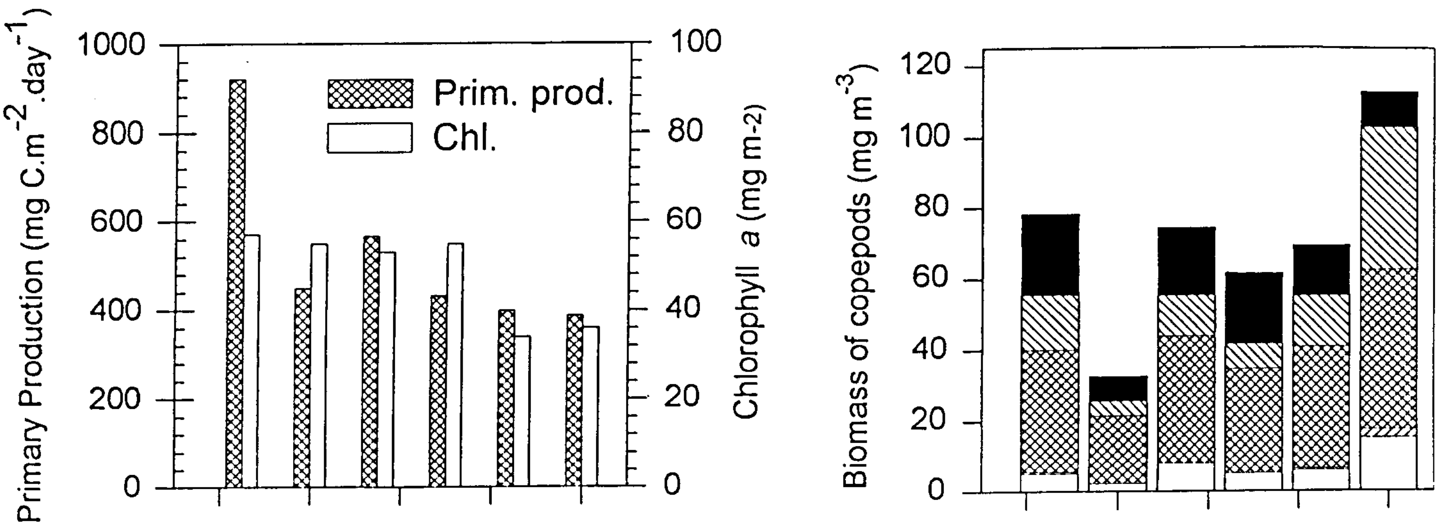

Baltic Transect 2, 1993
Salinity Transect
Depth (Meters)
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
-70.00
-80.00
7.0
9.0
14
16
18
A)
0.00
10.00
20.00
30.00
40.00
50.00
Distance (Nautical Miles)
55o 57.3' N
15o 59.7' E
55o 17.5' N
16o 00.0' E
Baltic Transect 2, 1993
Fluorescence Contours
(Relative Fluorescence)
140.00
120.00
100.00
80.00
60.00
40.00
B)
0.00
10.00
20.00
30.00
40.00
50.00
Distance (Nautical Miles)
55o 57.3' N
15o 59.7' E
55o 17.5' N
16o 00.0' E
Baltic Transect 2, 1993
Temperature Contours
15.00
13.50
12.00
10.50
9.00
7.50
6.00
4.50
C)
0.00
10.00
20.00
30.00
40.00
50.00
Distance (Nautical Miles)
55o 57.3' N
15o 59.7' E
55o 17.5' N
16o 00.0' E

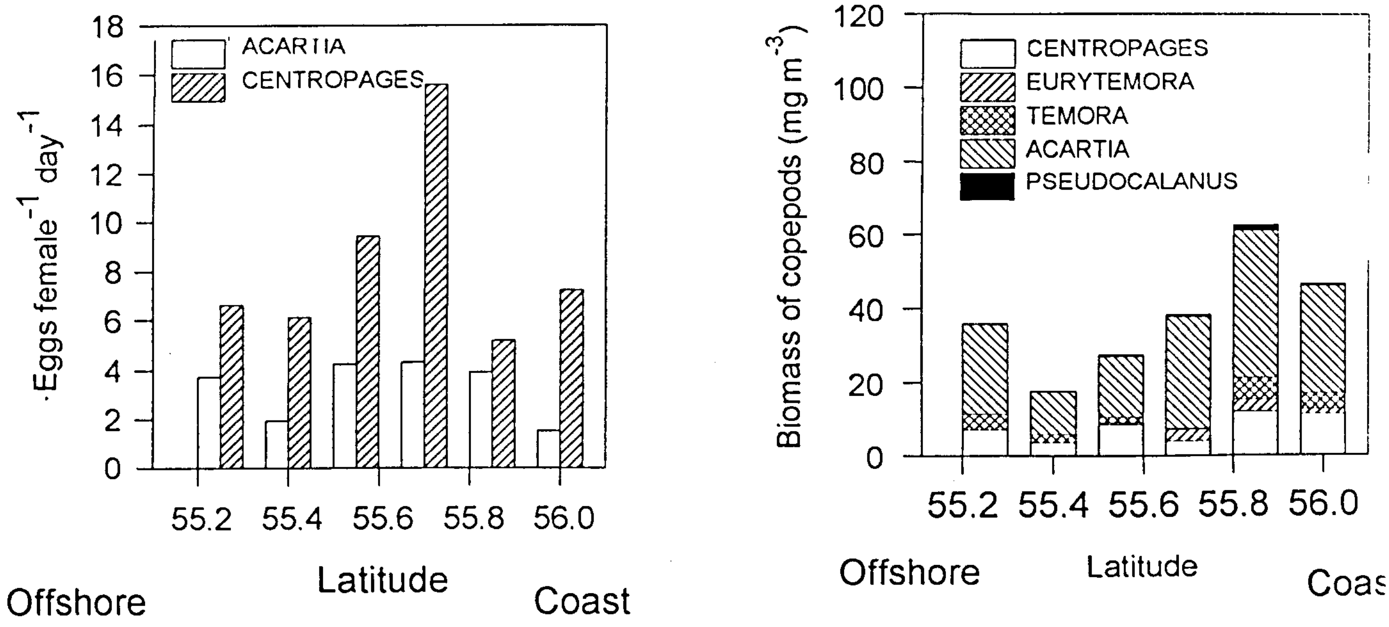
Figure 6

Transect 2 in the Northern part of Bornholm Basin



a) Primary Production
Chlorophyll a

b) Copepod biomass
Lower part of water columı



c) Production of copepod eggs

d) Copepod biomass
Upper part of water columı

Figure 7