

Not to be cited without prior reference to the author.

ICES CM2008/C:12

## Abundance and productivity of the pelagic ecosystem along a transect across the northern Mid Atlantic Ridge in June 2003

Hafsteinn G. Gudfinnson (1), Høgni Debes(2), Tone Falkenhaus (3), Eilif Gaard (2), Ástthor Gislason (1), Hildur Petursdottir (1), Thorsteinn Sigurdsson (1), Alexandra Stupnikova (4) and Hedinn Valdimarsson (1).

1) Marine Research Institute, Skúlagata 4, PB 1390, 121 Reykjavík, Iceland, tel.+354 5752000, fax +354 5752001. [hafgud@hafro.is](mailto:hafgud@hafro.is), [astthor@hafro.is](mailto:astthor@hafro.is), [hildur@hafro.is](mailto:hildur@hafro.is), [hv@hafro.is](mailto:hv@hafro.is), [steini@hafro.is](mailto:steini@hafro.is) .

2) Faroese Fisheries Laboratory, Box 3051, FO-110 Torshavn, Faroe Islands, tel. +298 353900, fax. +298 353901. [Eilifg@frs.fo](mailto:Eilifg@frs.fo), [Hoegnid@frs.fo](mailto:Hoegnid@frs.fo)

3) Institute of Marine Research, Flødevigen, N-4817 His, Norway, tel. +47 37059020. [Tone.Falkenhaus@imr.no](mailto:Tone.Falkenhaus@imr.no)

4) P.P.Shirshov Institute of Oceanology, Russian Academy of Sciences; 36, Nakhimovskiy Prospect 117218, Moscow, Russia

### **Abstract:**

A research cruise was conducted into the Irminger Sea west and southwest of Iceland on the Icelandic vessel Árni Friðriksson, from 4-30 June 2003, investigating redfish, *Sebastes mentella*, other pelagic fishes, zooplankton, phytoplankton and the hydrography of the area. Part of the cruise was devoted to a special study on the physical and chemical factors as well as the abundance of phytoplankton, meso- and macrozooplankton and planktivorous fish on a transect across the northern part of the Mid-Atlantic Ridge (MAR). This research is a part of the MAR-ECO project which aims to study the ecosystem associated with the northern MAR. In this paper we analyse the organisation of the pelagic ecosystem on the transect over the northern MAR, from phytoplankton to fish as apex predators.

Keywords: MAR-ECO, Mid-Atlantic Ridge, environmental factors, phytoplankton, zooplankton, fish.

## Introduction

Biological and oceanographic observations have been carried out in the Irminger Sea for a long period. Many of these researches have been pointed to pelagic fishes in the area especially the redfish, *Sebastes mentella* (Magnússon and Magnússon, 1995; Magnússon, 1996; Magnússon et al., 1996; Sigurðsson et al., 2006). Other species of fish in the pelagic area are smaller than redfish which makes the area good feeding ground for redfish (Magnússon and Magnússon, 1995; Sigurðsson et al., 2002).

In the oceanic areas southwest of Iceland there are two deep basins, the Iceland Basin and the Irminger Basin, each of 2000–3000 m depth. The basins are separated by the Reykjanes Ridge, which is a part of the Mid-Atlantic Ridge (MAR), and stretches out to the southwest from the Icelandic continental shelf. Oceanographers have become more aware of the profound role the MAR plays in the North Atlantic circulation. This influence manifests itself both in terms of flows along it and how water approaches and crosses it (Søiland et al., 2008). This will also influence the biology of both sides of the ridge as well as the life on and over it.

A research cruise was made in the Irminger Sea west and southwest of Iceland from 4-30 June 2003 to investigate redfish, *Sebastes mentella*, other pelagic fishes, zooplankton, phytoplankton and the hydrography of the area. Measurements of hydrography, nutrients, chlorophyll *a*, primary production, phytoplankton, mesozooplankton, macroplankton and fishes were made along a transect from the Iceland Basin, across the Reykjanes Ridge and into the Irminger Sea in June 2003 (Figure 1). The goal of this study was to examine the organisation and trophic structure of the pelagic ecosystem over the Reykjanes Ridge, from phytoplankton to fish as apex predators. The research is a part of the MAR-ECO programme which deals with the ecology on the Mid Atlantic Ridge (MAR).

Physical factors influence the plankton biomass and are very important factors for the primary productivity. This paper will deal with the results of the hydrography, nutrients, phytoplankton, zooplankton and pelagic fish on the MAR-ECO transect across the MAR.

## Materials and Methods

Nine stations along a 400 km NW-SE transect from 61°40'N and 32°09'92"W to 59°39'85"N and 26°15'2"W were sampled over a 4-days period from 18th to 21st of June 2003 (Figure 1). On five of these nine stations a full sampling program was carried through while only hydrography and chlorophyll *a* were measured on the remaining stations (Table 1). The transect had large differences in depth with the deepest part on the west side (Station 1) but a little shallower basin on the east side (Station 9). The bottom depth over the ridge crest (Station 5) was less than 1000 m (Table 1).

Table 1. Stations (west to east) overview and data sampling on each station along a transect across the Reykjanes Ridge in June 2003.

| Station               | 1     | 2     | 3     | 4     | 5     | 6     | 7     | 8     | 9     |
|-----------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Longitude (North)     | 61°40 | 61°15 | 60°55 | 60°45 | 60°25 | 60°10 | 60°02 | 59°55 | 59°40 |
| Latitude (West)       | 32°10 | 31°15 | 30°20 | 29°30 | 28°41 | 27°55 | 27°28 | 27°04 | 26°15 |
| Bottom depth (m)      | 2598  | 2414  | 1750  | 1300  | 948   | 1472  | 1701  | 1894  | 2157  |
| Hydrography           | x     | x     | x     | x     | x     | x     | x     | x     | x     |
| Nutrients             | x     |       | x     |       | x     |       | x     |       | x     |
| Chlorophyll- <i>a</i> | x     | x     | x     | x     | x     | x     | x     | x     | x     |
| Phytoplankton         | x     |       | x     |       | x     |       | x     |       | x     |
| Mesozooplankton       | x     |       | x     |       | x     |       | x     |       | x     |
| Macrozooplankton      | x     |       |       |       | x     |       |       |       | x     |
| Fish                  | x     |       |       |       | x     |       |       |       | x     |

### *Hydrography*

Temperature and salinity were measured with a SBE9/11plus CTD instrument in continuous vertical profiles from surface to bottom at 9 stations (Table 1). Water samples were taken for salinity calibration.

### *Nutrients*

Samples for nutrient analyses ( $\text{PO}_4^{3-}$ ,  $\text{NO}_3^-$ ,  $\text{SiO}_2$ ) were collected at five stations (Table 1) at eight depths (0, 10, 20, 30, 50, 75, 100, and 200 m) and analysed by the Icelandic MRI lab according to Grasshoff (1970) for silicate and nitrate and according to Murphy and Riley (1962) for phosphate.

### *Chlorophyll a*

Chlorophyll *a* samples were collected at nine stations along the transect (Table 1) At the five main stations (1, 3, 5, 7, 9) chlorophyll *a* was sampled from nine depths (0, 10, 20, 30, 50, 75, 100, 150, and 200m). Duplicate samples of 200 ml seawater were filtered through GF/C filters (2,5 cm). Chlorophyll *a* samples (1 l) from the other four stations were furthermore collected at 5, 10, and 30 m depth and filtered through 4,7 cm GF/C filters. The filters were put in glass tubes after filtration, filled on with 90% acetone and kept in freezer until measured with fluorometer calibrated against

chlorophyll samples measured spectrophotometrically according to Strickland and Parsons (1972).

#### *Primary production*

Primary productivity measurements for uptake of  $^{14}\text{C}$  were done on samples from 10 m depth at the 5 main stations (Table 1), in a light and temperature regulated incubator on board the ship (For method see Gudmundsson, 1998). Duplicate samples were incubated under various light conditions from supersaturation to very low light intensities (126%, 100%, 45,9%, 21,5%, 13,8%, 1,7% and black bottle) to get a P-I curve at each station. Light intensity of  $316 \mu\text{E cm}^{-2}\text{sec}^{-1}$  was set as equal to 100%. The samples were incubated for 4 hours at the same temperature as measured at 10 m depth in sea at each sampling station. Secchi readings were undertaken when stations turned up in daylight and were 3 meters at the western part of the transect to 5 m at the eastern part.

The result of the P-I curves, the Secchi readings as a measure of the attenuation of light in the sea, the incoming seasurface irradiation (clear sky) calculated from the website <http://www.sci.fi/~benefon/sol.html> for the research area and the chlorophyll values with depth, were used to calculate the daily production of carbon at each station according to Gudmundsson et al. (2002). The values from the black bottle (respiration) are not subtracted in these calculations and the production is calculated to both the compensations depth (8-12 meters) which is where light has decreased to  $4 \mu\text{E cm}^{-2}\text{sec}^{-1}$  and to 1% depth which gave values of little difference.

#### *Phytoplankton identifications and enumerations*

Quantitative samples (100 ml) for phytoplankton identifications and enumerations were collected at five stations (Table 1) from the same depths as for the chlorophyll *a* samples and preserved in neutralized (hexamine) formaldehyde. Counting and identifications were made on samples (50 ml) from 10 and 30 m depth at the five main stations (Figure 1). In addition surface samples (0 m) from three of the stations (1, 5, 9) were analysed. The phytoplankton was identified to species when possible but otherwise to the lowest possible taxonomic level according to Tomas (1997). Ciliates were also counted and identified to the lowest possible taxonomic level.

#### *Mesozooplankton*

Mesozooplankton was collected at five stations along the transect: one station over the Ridge crest and two stations at each side of the Ridge (Figure 1 and Table 1). The samples were collected in stratified vertical hauls from near the bottom up to the surface with a Multi Plankton Sampler (MPS) from HydroBios (opening area  $0.25 \text{ m}^2$ , mesh size  $200 \mu\text{m}$ ). The MPS was equipped with five nets and the samples were taken in two or three vertical hauls, depending on the bottom depth, covering seven to thirteen depth strata (0-50, 50-100, 100-200, 200-400, 400-600, 600-800, 800-1000, 1000-1200, 1200-1400, 1400-1600, 1600-1800, 1800-2000, 2000-2200 m). A Hydro Bios flowmeter was used to measure the volume of water filtered by each net.

Samples were preserved in 4% borax buffered formaldehyde solution in seawater for later species identification and enumeration. The larger zooplankton species, such as euphausiids, *Calanus finmarchicus* and *Pareuchaeta norvegica*, were usually counted from whole samples, whereas the smaller species (e.g. *Oithona*, *Oncaea* and *Microcalanus* spp.) were counted from sub-samples (1/2-1/32). The samples were divided with a Motoda splitter (Motoda, 1959), and an aliquot counted. In addition, euphausiids, *C. finmarchicus* and *P. norvegica* were classed to developmental stages.

The densities (number  $m^{-3}$ ) of zooplankton were calculated for each MPS net using recordings from the flowmeters.

#### *Macrozooplankton*

Large zooplankton was collected with a small “macrozooplankton trawl” (Institute of Marine Research, Norway) at three stations along the transect: one station over the Ridge crest and one stations at each end of the transect (Figure 1 and Table 1). The trawl has a  $4 \times 4 m^2$  mouth opening, and  $3 \times 3 mm$  (6 mm stretched) mesh size from the mouth to the cod-end. The trawl was deployed three times at each station to sample three different depth strata: One upper stratum (~0-350 m), one mid-water stratum (~350-700 m), and one deep stratum (~700-1000 m at station 1 and 9 and ~700-900 m at station 5). The trawl was lowered quickly to the upper limit of the depth layer to be sampled and then lowered slowly through the depth layer that was being sampled, after which the trawl was heaved quickly to the surface.. The towing speed was 2.5 knots and the towing distance was ~2.8 nautical miles, giving a filtration volume of sea water of ~30 000  $m^3$  for the upper two strata and ~25 000  $m^3$  for the deepest stratum.

Fish, cephalopods and jellies were removed from the catch and the remainder preserved in 4% borax buffered formaldehyde solution in seawater for later species identification and enumeration. The samples were divided with a Motoda splitter (Motoda, 1959), and an aliquot counted.

#### *Fish and acoustic observations*

A GLORIA-type midwater trawl (#1024 - 46X46 m opening) with cod-end lined with 9 mm mesh net was used to sample pelagic fish, cephalopods and large zooplankton. Three different depth strata were sampled at stations 1, 5 and 9 (Table 1); one upper stratum (~200-350 m), one mid-water stratum (~350-600 m), and one deep stratum (~650-900 m) The towing speed was 2.5 knots and the towing distance was ~2.5 nautical miles.

After each haul, the catches were sorted and all fishes were identified to species whenever possible. A small sub-sample was taken of each fish species for length measurements and total number of each species was registered. Invertebrates were not systematically identified from those hauls. In order to identify food remains, stomach samples were also taken from numerous species throughout the survey area. The stomach content was analysed after the survey.

Acoustic data was collected by means of a 38 kHz SIMRAD EK 500 split beam echo sounder and a BI500 post-processing system (Bodholt et al., 1989, Foote et al., 1991). During the surveys the post-processing systems were used for scrutinising the echograms. Mean integrated values of redfish and of the “scattering layer” were recorded for each 1 n.m. No further scrutinizing of the acoustic data was done in order to identify different species or group of species in the deep-scattering layer.

## Results

### *Hydrography*

The temperature in the surface layers was 10-11°C on the east side of the Reykjanes Ridge, decreasing towards west and lowest temperature was observed at the westernmost station 8.5-9°C (Figure 2a). A strong thermocline was found down to 40-50 m depth. Deeper the temperature decreased sharply, especially on the western side of the Ridge (Figure 2a). Strong stratification due to thermocline was found in the surface layer down to 50 m depth on the east and middle part of the transect but the stratification was weaker on the west side of the MAR (Figure 2c).

The hydrography along the MAR-ECO section (Figure 2a and 2b) revealed the most dominant water masses in the Subpolar North Atlantic. In the uppermost 800 m above and east of the Reykjanes Ridge is Sub Polar Mode Water (SPMW) with salinity above 35.1 and temperature over 6-7°C. West of the ridge Labrador Sea Water (LSW) spreads over water depths of 600-2000 m.

The influence of the Mid-Atlantic Ridge is reflected in the distribution of water masses over the section (Figures 2a and 2b). Where the MAR clearly separates the warmer and more saline waters of the Iceland Basin from the colder and less saline Sub-Arctic surface Water in the the Irminger Sea. Circulation studies in this area have shown strong linkage to the topography and that the SPMW (Sub polar mode water) is transported from the Icelandic Basin southwestward along the eastern flank of the Reykjanes Ridge (Otto and Van Aken, 1996, Pollard et al , 2004, Knutsen et al., 2005).

Drifter observations have shown that from at least 57°N the current is northeastward along the western side of the Ridge but also that the area above and west of the Ridge is one with high eddy activity and mixing (Bower et al., 2002, Reverdin et al 2003). This resulting in a certain water mass with slightly less stratification over the Ridge the Reykjanes Ridge mode Water (Hollyday et al., 2006) .

### *Nutrients*

The nitrate and phosphate concentrations were moderate to high in the middle and western part of the transect but lower values were found on the east side of the MAR (Figure 3a). The silicate concentrations on the other hand were low ( $< 1 \mu\text{mol/l}$ ) in the surface layers at all stations except at the westernmost station of the transect where the values were 1-2  $\mu\text{moles/l}$  (Figure 3b). At 50 m depth the concentrations of silicate were around 3  $\mu\text{mol/l}$  all over the transect and increased further with depth (Figure 3b).

### *Chlorophyll a*

In the surface layer variations in chlorophyll *a* concentrations were small all over the transect (0,5-1  $\text{mg m}^{-3}$ ). The concentrations were higher on the western part of the transect, lower on the eastern side of the Ridge and lowest over the Ridge crest (Figure. 3c). The values decreased sharply with depth and were  $\ll 0.5 \text{ mg m}^{-3}$  below 50 m depth and  $< 0.1 \text{ mg m}^{-3}$  below 100 m depth.

### *Primary production*

Results from the P-I measurements show that maximum production ( $P_{\text{max}}$ ) occurred at light intensity from between 68 – 316  $\mu\text{E cm}^{-2}\text{sec}^{-1}$  with some photoadaptation of the

phytoplankton.  $P_{\max}$  was higher on the western side of the MAR than over it or on the eastern side (Figure 4). Daily production was calculated to  $0.39 \text{ gC m}^{-2} \text{ day}^{-1}$  on the western side of the Ridge,  $0.35 \text{ gC m}^{-2} \text{ day}^{-1}$  on eastern side (mean of two stations on each side) but  $0.25 \text{ gC m}^{-2} \text{ day}^{-1}$  over the Ridge crest. According to the Secchi readings the euphotic zone was shallow, with the compensation depth only 8-12 meters on the western side and 12-18 m on the eastern side of the Ridge.

#### *Phytoplankton identifications and enumerations*

The most abundant phytoplankton group in the samples was the coccolithophorids both in horizontal and vertical view. Results from 10 m depth show that the coccolithophorids were in great abundance on the western side of the MAR with concentration around 1.5 million c/l (Figure 5b). The numbers of coccolithophorids decreased towards east and were in lowest concentration at the easternmost station. *Emiliana huxleyi* was the most important species in the coccolithophorid group. Other species found were *Coccolithus pelagicus* and some unidentified species. The group "small flagellates & monads" were also in great numbers at all stations in 10 m depth but most abundant over the ridge crest and on the eastern side near the ridge (Figure. 5b). Dinoflagellates were found in moderate numbers at all stations in 10 m depth, most probably dominated by heterotrophic organisms. Diatoms were found in small numbers all over the transect except for the easternmost station (st. 9) where they reached >250 thousands c/l. Species of the genus *Pseudo-nitzschia* (pennate diatoms) were the most abundant species, increasing in number from west to east. Centric diatoms are scarce except for the easternmost station where some *Chaetoceros* species and *Cerataulina pelagica* were found to be 10% of the total cell number.

The countings results from samples in the surface (Figure 5a) and 30 m depth (Figure 5c) showed mainly the same distributional trend as for the 10 m samples. The group "flagellates and monads" were more abundant in the surface samples and the coccolithophorids were more abundant in 30m samples than in 10m samples. Countings were made on one sample from 50 m depth at station 5 over the Ridge. All groups decreased sharply in numbers and the coccolithophorids were still the most abundant group.

Ciliates were most abundant in 10 m depth (around 2000 cells/l) and were evenly distributed along the transect. The numbers were lower in the deeper samples and also in surface samples except for station 5.

#### *Mesozooplankton*

Figure 6A illustrates the vertical distribution of mesozooplankton along the transect. It is evident that the concentration of animals was by far the highest in the uppermost 50 m ( $\sim 1500\text{-}6000 \text{ individuals m}^{-3}$ ), with copepods being the most abundant group at all stations. On the eastern side of the Reykjanes Ridge (Stations 7 and 9) appendicularians and cladocerans were in high numbers.

Among the copepods, *Oithona* spp. was most abundant in terms of numbers, with *Calanus finmarchicus* ranking second (Figure 6B). The abundance of *C. finmarchicus* showed a strong increase from east ( $\sim 60 \text{ individuals m}^{-3}$ , 0-50m) to west ( $\sim 1600 \text{ individuals m}^{-3}$ , 0-50m). The biomass of the copepods probably shows the same trend,

largely reflecting the abundance of *C. finmarchicus*, which is likely to make up the bulk of the biomass due to its large size.

Generally, most of *C. finmarchicus* were at stages C4 (~10-40%) and C5 (~40-80%). An increase in the proportion of the youngest copepodite stages of *C. finmarchicus* (stages C1-3) was observed on the eastern (Stations 7 and 9, 14-16%) and western (Station 1, 15%) side of the Reykjanes Ridge, with lower values at the mid stations (Stations 3 and 5, <3%).

Juvenile stages of euphausiids (calyptopis and furcilia) were mainly caught by the Multinet in the upper layers (0-50 m), and the abundance was much higher on the western side of the Reykjanes Ridge (Station 1, ~40 individuals m<sup>-3</sup>, 0-50m), than over the crest of the Ridge (Station 5, ~25 individuals m<sup>-3</sup>, 0-50m), and on the eastern side (Station 9, ~8 individuals m<sup>-3</sup>, 0-50 m).

#### *Macrozooplankton*

There were observed large differences in abundance of crustacean macroplankton, horizontally across the ridge, as well as vertically. At station 1 (the western end of the transect), the abundance was high in the upper 350 meters (~30 individuals per 100 m<sup>3</sup>) while the abundances in the middle and deepest strata were substantially lower (Figure 7, left panels). Euphausiids dominated among the macrozooplankton with about 88% in the uppermost stratum, but their abundance, relative to the other crustacean groups decreased to 36% in the deepest stratum.

*Thysanoessa longicaudata* dominated entirely among the Euphausiids with 96% of the individuals, while *Meganytiphanes norvegica* occurred in lower abundance and the species *Nematobrachion boopis*, *Thysanopoda acutifrons*, and *Nematocelis megalops* were only sporadically observed. Shrimps occurred in the middle and deepest strata in lower abundance while amphipods (*Themisto* spp.) were only observed sporadically.

On the central ridge (Station 5) the total numbers of macrozooplankton were rather similar at all depths while shrimps were increasingly abundant downwards. *T. longicaudata* occurred in substantially lower abundance than further west although it was still the dominant Euphausiid in the upper 350 m. (Figure 7, right panels). In the middle and deep strata *N. boopis*, *Stylocheiron maximum* and especially *T. acutifrons* were common.

At the eastern end of the transect (Station 9) no Euphausiids were observed. The only macroplanktonic crustaceans were 17 shrimps (Acanthoephyra), caught at the 350-700 m depth.

#### *Fish*

An example of acoustic registration from the BI500 post-processing system along the transect on the Reykjanes ridge is given in Figure 8, showing registration at noon from stations 1, 5 and 9 (Figure 1). The scattering layer from the echogram is located deeper (400-600 m) east of the ridge (Station 9) and over the ridge crest (Station 5) than west of it where the scattering layer was found mostly from 200 to 400 m depth (Figure 8). The distribution of the scattering layer seems to follow the steep gradient in the thermocline from 5-7°C on the transect at noon (Figure 2a)

A total of 49 species were identified from 21 families. Lanternfishes (Myctophidae), pearlsides (Sternoptychidae), barracudinas (Paralepididae), dragonfishes (Stomiidae) and deep-sea smelts (Microstomatidae) dominated fish catches. Results show that the total number of species (Figure 9a) was similar along the transect while number of fishes caught (Figure 9b) was lowest east of the Ridge. At all positions number of species and families increased with depth.

## Discussion

The changes in the Irminger Sea following the extreme NAO conditions in 1995-1996 have been described by Mortensen and Valdimarsson (1999) for the northern and Bersch (2002) for the southern part. These changes were a westward shift of the Subarctic Front from the Iceland Basin towards the Irminger Sea. Over the same period in the deeper layers the Labrador Sea Water (LSW) became warmer and more saline in the Irminger Sea. The temporal variability of water masses in the area have been described by Pedchenco (2005) and Yaschayev et al. (2006).

The Irminger Sea and the sea in the Iceland Basin undergo strong seasonal variation which leads to convective mixing due to wind and temperature changes. Highest nutrient concentrations are found in late winter, after the winter mixing to deeper nutrient rich layer has taken place (Ólafsson, 2003; Ólafsdóttir, 2006). Typical surface concentrations of nutrients in the end of winter in the Irminger Sea are around 14  $\mu\text{moles/l}$  for nitrate and 6-7  $\mu\text{moles/l}$  for silicate (Ólafsson, 2003; Ólafsdóttir 2006). Holliday et al. (2006) have estimated inorganic nitrogen to over 13  $\mu\text{mol/l}$  in March to April. In spring time the phytoplankton uptake of nutrients starts. Diatoms are the main consumers of silicate (Henson et al. 2006a). In June 2003 they had almost depleted the silicate concentration in the very surface at the MAR transect (< 30m) and also consumed half of the winter concentrations down to 50-60 m depth on the western side of the MAR and deeper (>100 m) on the eastern side (Figure 3 b). Nitrate and phosphate concentrations had decreased in similar way. Nitrate and silicate are used proportionally (1:1) by the spring diatoms (Ólafsdóttir, 2006; Henson et al. 2006a) south of Iceland and the same thing seems to happen on our transect. Hence when the diatom bloom is over there are still moderate concentrations of nitrate and phosphate available for phytoplankton summer growth but virtually no silicate. This has been confirmed previously for the Irminger Sea by Kalle (1957), Holliday et al. (2006) and Waniek and Holliday (2006). Silicate flux from deeper water to the very surface (0-30 m depth) will most probably be very sparse through out of the summer due to the strong stratification along the transect (Figure 2c) which will most probably outcompete diatoms for further growth if no change in silicate concentration takes place.

Nutrients depletion occurred deeper in the water column on the eastern side of the Ridge than on the western side (Figures 3a and 3b). One reason for this might be later stratification in the spring time on the eastern side of the Ridge and better light conditions with deeper euphotic zone in the beginning of the phytoplankton growth season. Another reason might be that the pycnocline was deeper and stronger on the eastern side, which eventually will reduce nutrient flux up to the surface layer. Nitrate and phosphate were still in moderate concentrations in the surface layers and can still be material for other phytoplankton groups for further primary production out of the summer. This has also been observed by Waniek and Holliday (2006).

The growth of phytoplankton in oceanic waters south of Iceland and in the Irminger sea usually starts in late April and culminates in late May to early June (Gudmundsson, 1998; Henson et al., 2006b). In the northern North Atlantic, much of the annual export production occurs during the spring bloom (Falkowski et al. 2000). Chlorophyll a concentrations in this study were relatively low (Figure 3c). However similar concentrations have been observed in other studies in this time of year

(Henson et al., 2006b; Holliday et al., 2006; Gaard et al., 2008). Silicate is exhausted in the surface layer because of earlier spring bloom of the diatoms. In agreement to this diatoms were hardly found in our samples along the transect except for station 7 and especially st. 9 on the east end. Waniek and Holliday (2006) made observations and modelling in the Irminger Sea north of our transect. Their results indicate that the phytoplankton pre- to postbloom lasts for 80 days, starting in the beginning of May and peaking in the end of June. The beginning of the bloom in Irminger Sea and Reykjanes Ridge can vary by up to 30 days interannually according to Henson et al. (2006b) starting from late April to late May. Our results show that the spring bloom is over and the phytoplankton is more or less already in the summer growth situation. There was a clear difference in the chlorophyll *a* concentration from west to east with higher values on the west side of the ridge. This is in accordance with the shallower thermocline and somewhat higher surface nutrient concentrations in the western part of the transect (LSW) than in the eastern part (SPMW). This difference could be seen in primary production and zooplankton compositions as well (see later). The main phytoplankton biomass was found in the very stratified surface layer (above 50 m) while very low biomass were found below the pycnocline. This is in agreement to Henson et al. (2006b) who found the mixed layer depth on Reykjanes Ridge fairly constant (30-50 m) during summer.

Similar to nutrient and chl. *a* concentrations, the primary productivity ( $P_{\max}$ ) was higher on the western side of the transect than on the eastern side of the Ridge but lowest over the Ridge (Figure 4). Daily primary production was higher on both sides of the ridge ( $>0.3 \text{ gC m}^{-2} \text{ day}^{-1}$ ) than over the ridge crest ( $<0.3 \text{ gC m}^{-2} \text{ day}^{-1}$ ). The higher  $P_{\max}$  on the western side was only partially reflected in higher daily production which might be explained by the light conditions which were more limited on the western side than the eastern side. Therefore the euphotic zone was deeper on the east side of the MAR which results in higher daily production while light was more or less limiting production on the west side of the transect. The difference in phytoplankton composition might also partly explain why daily production on both sides of the ridge is similar since some productive diatoms were found on the eastern end of the transect but not on the western side. Daily primary production was in agreement to that found by Waniek and Holliday (2006).

The phytoplankton composition changed from west to east. On the west end (Station 1 and 3) of the transect the main group of the phytoplankton was coccolithophorids with *Emiliana huxleyi* as the main species. Cell numbers were high (1 -2 million/l) and the numbers decreased eastwards but increased with depth. High numbers of coccoliths were found in the samples which explains low visibility in the sea and the typical milky colour of the sea in the area. Small “flagellates and monads” were more numerous in 0 and 10 m depth but decreasing in numbers in deeper samples. Diatoms were in low numbers except for station 9 on the eastern side of the MAR. It is well known that growth conditions are good for coccolithophorids in the Iceland basin sea and large blooms have been registered there during the last decades (Harris 1994, Harris et al., 1997, Harrison et al., 1993). Satellite images have made it possible to track the way of the bloom from the blooming area south of Iceland around the Reykjanes Ridge to the west coast of Iceland (<http://rapidfire.sci.gsfc.nasa.gov/>). Atlantic water advection was increasing into the Irminger Sea in the years 1999-2003 (Pedchenko, 2005) and it is likely that the coccolithophorids found on the MAR transect have been transferred with currents from the Iceland basin. The dominance of

coccolithophorids in the area is furthermore in agreement with our nutrient measurements, showing silicate depletion (especially in the subpolar water) combined with some remaining nitrate and phosphate in the upper layer.

The copepod composition is in agreement with what has been observed earlier in the area, with dominance of *Calanus finmarchicus* and *Oithona* while a large number of species occur in lower abundance (2001; Beaugrand et al., 2002; Beaugrand and Ibanez, 2002; Continuous Plankton Recorder Survey Team, 2004; Gislason, 2003; Gaard et al., 2008).

Vertical resolution in east-west differences across the ridge has, however, not been studied before and the differences in abundance and species composition show clear differences related to water masses, hydrographic features, and phytoplankton along the transect. On the eastern and central part of the transect *Oithona* dominated. Although the highest abundance occurred in the upper 50-100 meters it was still the dominant species down to 600-800 meters depth. However, in the western part of the transect (influenced by Labrador Sea Water) *C. finmarchicus* increased substantially in number 50-100 meters, and at the western end of the transect it was the dominant copepod, in numbers as well as biomass in the upper 50 meters. The dominance of copepodite stages C4 and C5 was very evident. From available information on development time of *C. finmarchicus* (Campbell et al., 2001) and the temperatures (Figure 2) it can be estimated that these individuals probably were spawned in April-early May and thus most likely belonged to the G1 generation. This is in agreement with the earlier conclusion that the phytoplankton spring bloom was well over and is also the same conclusion as made by Gislason et al. (2008) and Petursdóttir et al. (2007). Thus, the production of this ecologically important copepod apparently has been substantially higher on the western part (the Irminger Sea part) of the transect than in the eastern part, also prior to the samples, i.e. during the spring bloom and post-bloom period.

Similar to the copepods, the Euphausiids also showed clear differences in abundance from east to west of the transect. Although fewer sampling stations the trend was clear, with the highest abundance in the western area. Of the 5 different euphausiids identified *Thysanoessa longicaudata* dominated. This is in agreement with the findings by Lindley (1978) showing this oceanic species to dominate by numbers in the North Atlantic. Estimates of euphausiid abundance in the North Atlantic are scarce. However, recent results from Saunders et al. 2007 show *T. longicaudata* to dominate in the Irminger Sea area together with the somewhat larger species *Meganyctiphanes norvegica*. The highest abundance of euphausiids occurred in the upper 350 meters of the water column in the western area. This was the same area where the highest numbers of juvenile stages were found in the upper 50 meters (calyptopis and furcilia stages), and although these individuals were not identified to species, they most likely have belonged to *T. longicaudata*. Thus, production and abundance of *C. finmarchicus* as well as krill (*T. longicaudata*) were clearly higher in the western part of the transect than in the eastern part.

## Conclusions

In conclusion, the higher chlorophyll *a* values, slightly higher primary production, phytoplankton and zooplankton abundances and the total number of fish caught west

of the Reykjanes Ridge as compared with east of it, indicates the greater biological productivity on the western side of the Ridge. It is significant in this respect that this productive area (together with larger area in the Irminger Sea) supports large stocks of commercially important orange redfish (*Sebastes mentella*).

#### Acknowledgement.

Thank the crews and scientists on the R.V. Arni Fridriksson for assistance during sampling of the material. This work was supported by MAR-ECO, a field project of the research programme Census of Marine Life (CoML) and by the Nordic Council

#### References

- Bersch, M., 2002. North Atlantic Oscillation-induced changes of the upper layer circulation in the northern North Atlantic Ocean. *Journal of Geophysical Research-Oceans*, 107: C10.
- Bodholt, H., Nes, H. and Solli, H. (1989) A new echo sounder system. *Proc. IOA* 11: 123-130.
- Beaugrand, G., F. Ibanez, J.A. Lindley, 2001. Geographical distribution and seasonal and diel changes in the diversity of calanoid copepods in the North Atlantic and North Sea. *Marine Ecology Progress Series*, 219:189-203.
- Beaugrand, G., Ibanez, F., 2002. Spatial dependence of calanoid copepod diversity in the North Atlantic Ocean. *Marine Ecology Progress Series* 232: 197–211.
- Beaugrand, G., Ibanez, F., Lindley, J.A., Reid, P.C., 2002. Diversity of calanoid copepods in the North Atlantic and adjacent seas: species associations and biogeography. *Marine Ecology Progress Series* 232: 179–195.
- Campbell, R.G., Wagner, M.M., Teegarden, G.J., Boudreau, C.A., Durbin, E.G., 2001. Growth and development rates of the copepod *Calanus finmarchicus* reared in the laboratory. *Marine Ecology Progress Series* 221, 161–183.
- Falkowski, P.G., R.J. Scoles, E. Boyle, J. Canadell et al., 2000. The global carbon cycle: a test of our knowledge of earth as a system. *Science* 290: 291-296.
- Foote, K. G., Knudsen, H. P., Korneliussen, R. J., Nordbø, P. E. and Röang, K., (1991) Postprocessing system for echo sounder data. *J. Acoust. Soc. Am.* 90: 37-47.
- Gaard, E., Gislason, A., Falkenhaus, T., Sjøiland, H., Musaeva, E., Vereshchaka, A., and Vinogradov, G. 2008. Horizontal and vertical copepod distribution and abundance on the Mid-Atlantic Ridge in June 2004. *Deep-Sea Research II*, 55: 59-71.
- Gislason, A. 2003. Life-cycle strategies and seasonal migrations of oceanic copepods in the Irminger Sea. *Hydrobiologia* 503: 195-209.
- Gislason, A., E. Gaard, H. Debes, T. Falkenhaus, 2008. Abundance, feeding and reproduction of *Calanus finmarchicus* in the Irminger Sea and on the northern Mid-Atlantic Ridge in June. *Deep-Sea Research II* 55 (2008) 72–82
- Gudmundsson, K. 1998. Long-term variation in phytoplankton productivity during spring in Icelandic waters. *ICES Journal of Marine Science*, 55: 635-645.
- Gudmundsson, K., A. Gislason, J. Olafsson, K. Thorisson, R. Björnsdóttir, S.A. Steingrímsson, S. Ólafsdóttir, and Öivind Kaasa, 2002. Ecology of Eyjafjörður Project. Chemical and biological parameters measured in Eyjafjörður in the period April 1992 – August 1993. *Hafrannsóknastofnun Fjölrit nr. 89*.

- Grasshoff, K. 1970. A simultaneous multiple channel system for nutrient analysis in seawater with analog and digital data record. *Tecnicon Quarterly* 3: 7-17.
- Harris, R.P. 1994. Zooplankton grazing on the coccolithophore *Emiliana huxleyi* and its role in inorganic carbon flux. *Marine Biology* 119: 431-439.
- Harris, R.P., P. Boyd, D.S. Harbour, R.N. Head, R.D. Pingree, A.J. Pomroy. 1997. Physical, chemical and biological features of a cyclonic eddy in the region of 61 degrees 10'N 19 degrees 50'W in the North Atlantic. *Deep-Sea Research Part 1*, 44:(11) 1815-1839.
- Harrison, W.G., E.J.H. Head, E.P.W. Horne, B. Irwin, W.K.W. Li, A.R. Longhurst, M.A. Paranjape and T. Platt, 1993. The western North Atlantic Bloom Experiment. *Deep-Sea Research II* 40: 279-305.
- Henson, S.A., R. Sanders, C. Holeton and J.T. Allen, 2006a. Timing of nutrient depletion, diatom dominance and a lower-boundary estimate of export production for Irminger Basin, North Atlantic. *Marine Ecology Progress Series* 313:73-84.
- Henson, S.A., I. Robinson, J.T. Allen and J.J. Waniek, 2006b. Effect of meteorological conditions on interannual variability in the Irminger Basin, North Atlantic. *Deep-Sea Research I*, 53: 1601-1615.
- Holliday, N.P., J.J. Waniek, R. Davidson, D. Wilson, L. Brown, R. Sanders, R.T. Pollard, J.T. Allen, 2006. Large-scale physical controls on phytoplankton growth in the Irminger Sea Part I: Hydrographic zones, mixing and stratification. *Journal of Marine Systems* 59: 201-218.
- Lindley, J.A. 1978. Population dynamics and production of Euphausiids. *Marine Biology*, 66: 37-46.
- Kalle, K. 1957. Chemische Untersuchungen in der Irminger See im Juni 1955. *Ber. dtsh. Komm. Meeresforsch.*, 14: 313-328.
- Knutsen, Ø., Svendsen, H., Østerhus, Rossby, T., nHansen, B., 2005. Direct measurements of the mean flow and eddy kinetic energy structure of the upper ocean circulation in the NE Atlantic. *Geophysical Research Letters* 32, L14604.
- Magnússon, J., J.V. Magnússon 1995. Ocean redfish in the Irminger Sea and adjacent waters. *Scientia marina*, 59(3-4): 241-254.
- Magnússon, J.V. and J. Magnússon 1995. The distribution, relative abundance and biology of the deep-sea fishes of the Icelandic slope and Reykjanes Ridge. In: Hopper, Alan G. (editor.): *Deep-Water Fisheries of the North Atlantic Oceanic Slope*, NATO ASI Series E: Applied Sciences, vol. 296: 161-199.
- Magnússon, J. 1996 The deep scattering layers in the Irminger Sea. In: McIntyre, A.D, J.E Thorpe (editors): *Deep-water fishes : The Fisheries Society of the British Isles Annual Symposium*. *Journal of Fish Biology*, 49(Suppl. A): 182-191.
- Magnússon, J., J. V. Magnússon, Th. Sigurdsson, C. Hammer, E. Bethke, A. Pedchenko, E. Gavrilov, S. Melnikov, M. Antsilerov, V. Kiseleva 1996. Report on the joint Icelandic/German/Russian acoustic survey on Oceanic Redfish in the Irminger Sea and adjacent waters in June/July 1996. *ICES C.M.* 1996/G:8.
- Mortensen, J. and H. Valdimarsson, 1999. Thermohaline changes in the Irminger Sea. *ICES CM* 1999/L:16
- Murphy J. and J.P. Riley 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27: 31-36.
- Otto, L. and H.M. van Aken, 1996. Surface circulation in the northeast Atlantic as observed with drifters. *Deep Sea Res.* 43: (4) 467-499.
- Ólafsson, J. 2003. Winter mixed layer nutrients in the Irminger and Iceland Seas, 1990-2000. *ICES Marine Science Symposia*, 219: 329-332.

- Ólafsdóttir, S.R. 2006. Nutrient concentrations in Icelandic waters. Hafrannsóknastofnunin. Fjölrit nr. 122.
- Pedchenko A. P., 2005. The role of interannual environmental variations in the geographic range of spawning and feeding concentrations of redfish *Sebastes mentella* in the Irminger Sea. ICES Journal of Marine Science 62:(7):1501-1510
- Petursdóttir, H., Gislason, A., Falk-Petersen, S., Hop, H., Svavarsson, J., 2007. Trophic interactions of the pelagic ecosystem over the Reykjanes-Ridge as evaluated by fatty acid and stable isotope analyses. Deep-Sea Research, II, 55:
- Reverdin, G, P.P.Niiler and H. Valdimarsson, 2003. North Atlantic Ocean surface currents. Journal of Geoph. Research, 108: (C1)
- Saunders, R.A., Ingvarsdóttir, A., Rasmussen, J., Hay, S.J., Brierley, A.S. 2007. Regional variation in distribution pattern, population structure and growth rates of *Meganyctiphanes norvegica* and *Thysanoessa longicaudata* in the Irminger Sea, North Atlantic. Progress in Oceanography, 72: 313-342.
- Sigurðsson, Th., K. Kristinsson, H-J. Rätz, K.H. Nedreaas, S.P. Melnikov, J. Reinert 2006. The fishery for pelagic redfish (*Sebastes mentella*) in the Irminger Sea and adjacent waters. ICES Journal of Marine Science, 63: 725-736.
- Sigurðsson, Th., G. Jónsson and J. Pálsson 2002. Deep scattering layer over Reykjanes Ridge and in the Irminger Sea. ICES CM 2002/M:09, 22 s.
- Strickland J.D.H. and T.R. Parsons 1972. A Practical Handbook of Seawater analysis. Fisheries Research Board of Canada, Ottawa 1972.
- Sutton T. and Th. Sigurdsson, 2008. Vertical and horizontal distribution of mesopelagic fish along a transect across the northern Mid-Atlantic Ridge in June 2003. ICES CM2008:C16.
- Søiland, H., W.P. Budgell and Ø. Knutsen, 2008. The physical oceanographic conditions along the Mid-Atlantic Ridge north of Azores in June-July 2004. Deep-Sea Research II 55: 29-44.
- Tomas C.R. (ed) 1997. Identifying Marine Phytoplankton. Academic Press 858 p.
- Waniek, J.J., N.P. Holliday, R. Davidson, L. Brown, S.A. Henson, 2005. Freshwater control of onset and species composition of Greenland shelf spring bloom. Marine Ecology Progress Series 288: 45-57.
- Waniek, J.J. and N. Penny Holliday, 2006 b. Large-scale physical controls on phytoplankton growth in the Irminger Sea, Part II: Model study of the physical and meteorological preconditioning. Journal of Marine Systems 59: 219-237.
- Yashayaev, Y., M. Bersch, and H. M. van Aken, 2006. Spreading of the Labrador Sea Water to the Irminger and Iceland basins. Geophysical Research Letters, 34: L10602,

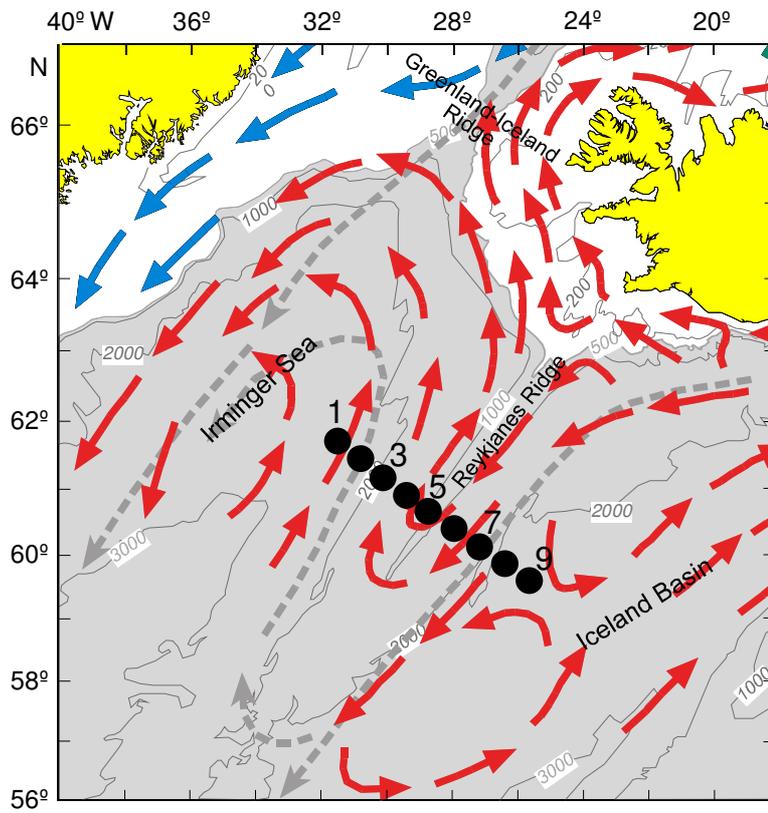


Figure 1 The main currents in the research area and the stations 1-9 (from NW-SE) along a transect across the Reykjanes Ridge in June 2003. Red arrows show Atlantic surface current, blue arrows East Greenland current and the broken grey arrows deep water current.

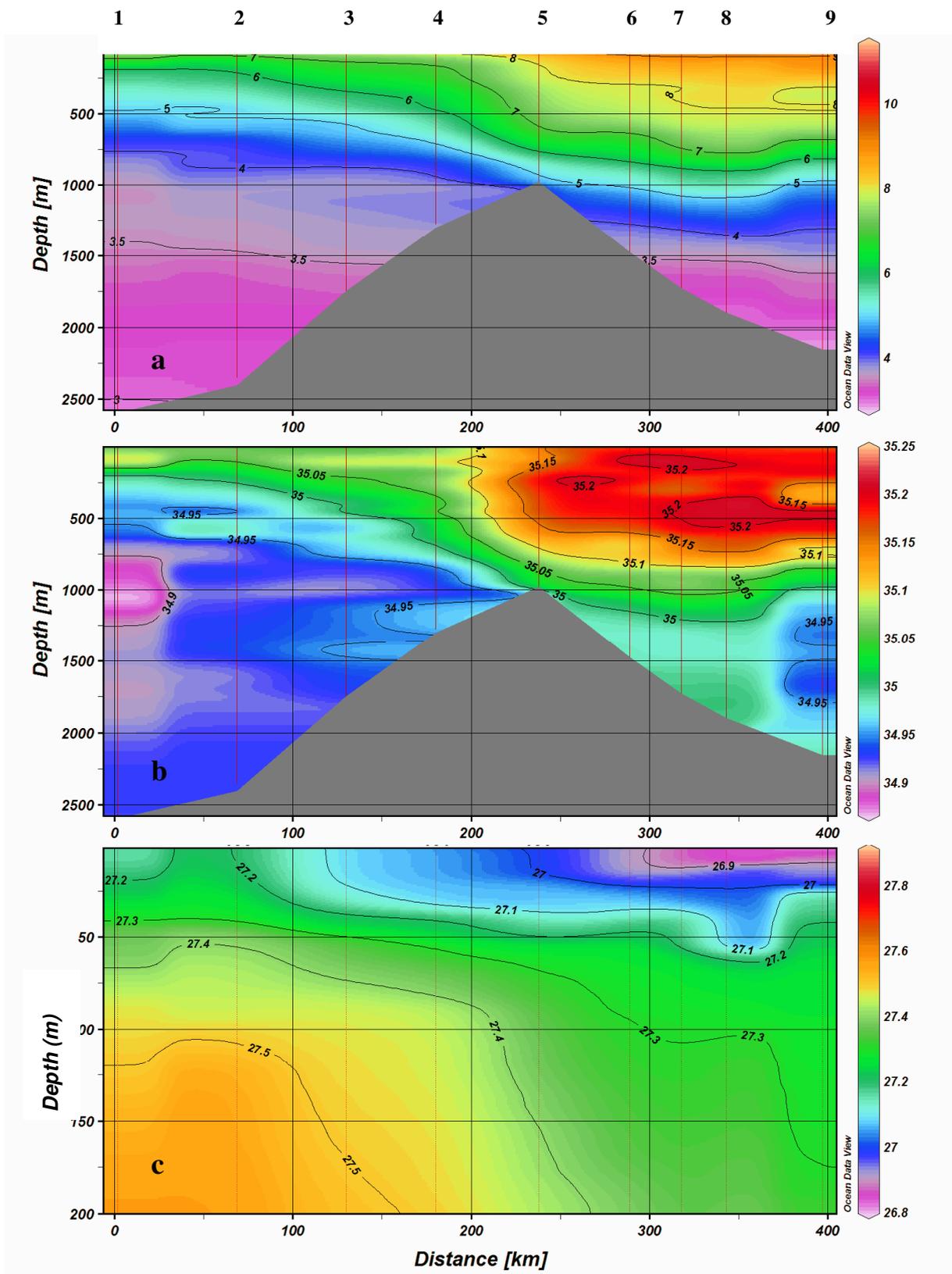


Figure 2. Distribution (st. 1-9) of a) temperature ( $^{\circ}\text{C}$ ), b) salinity from surface to bottom and c) density from 0-200 m depth, along a transect across the Reykjanes Ridge in June 2003.

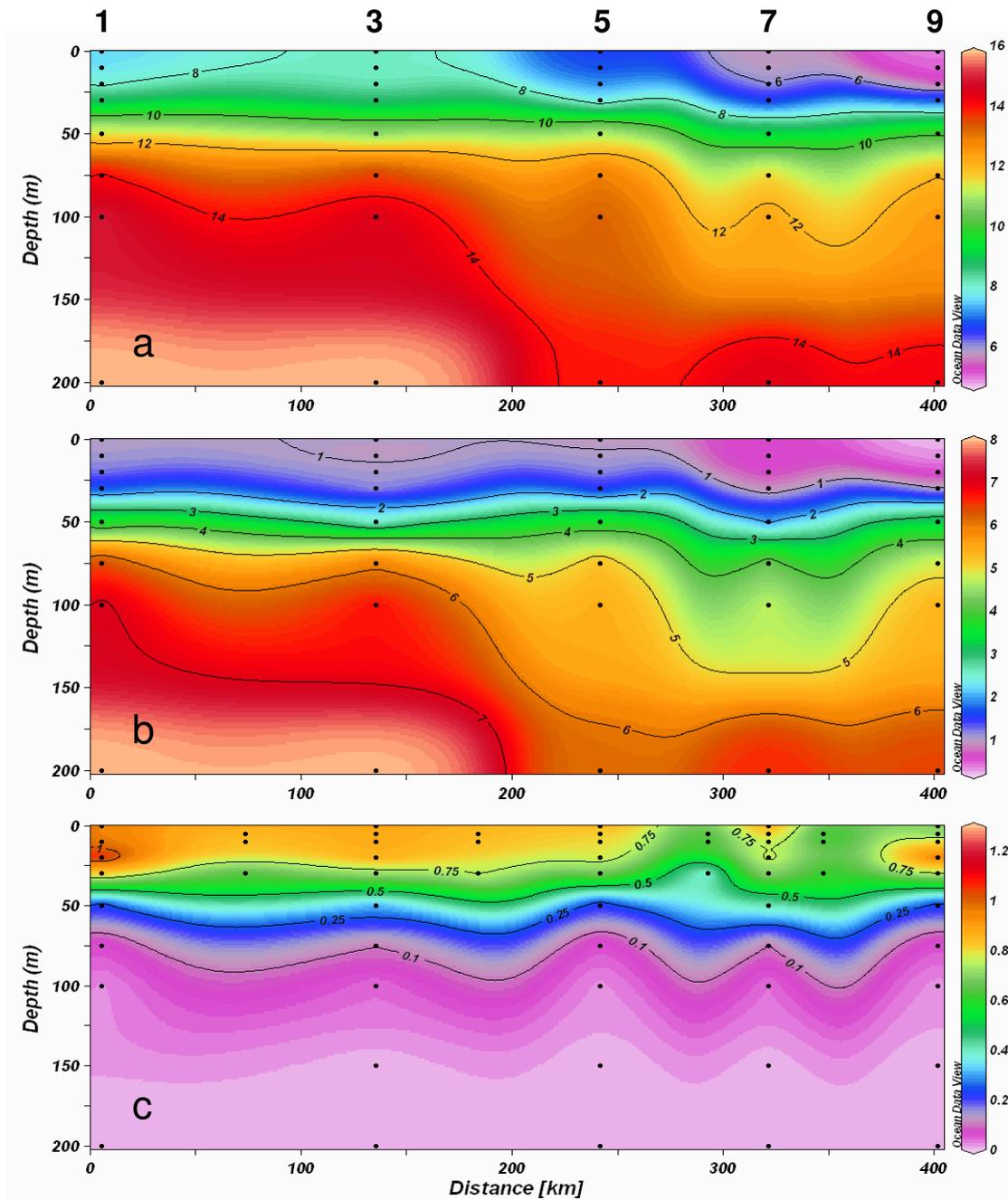


Figure 3. Distribution (st. 1-9) of a) nitrate ( $\mu\text{mol/l}$ ), b) silicate ( $\mu\text{mol/l}$ ) and c) chlorophyll.a ( $\text{mg/m}^3$ ) from 0-200 m depth along a transect across the Reykjanes Ridge in June 2003.

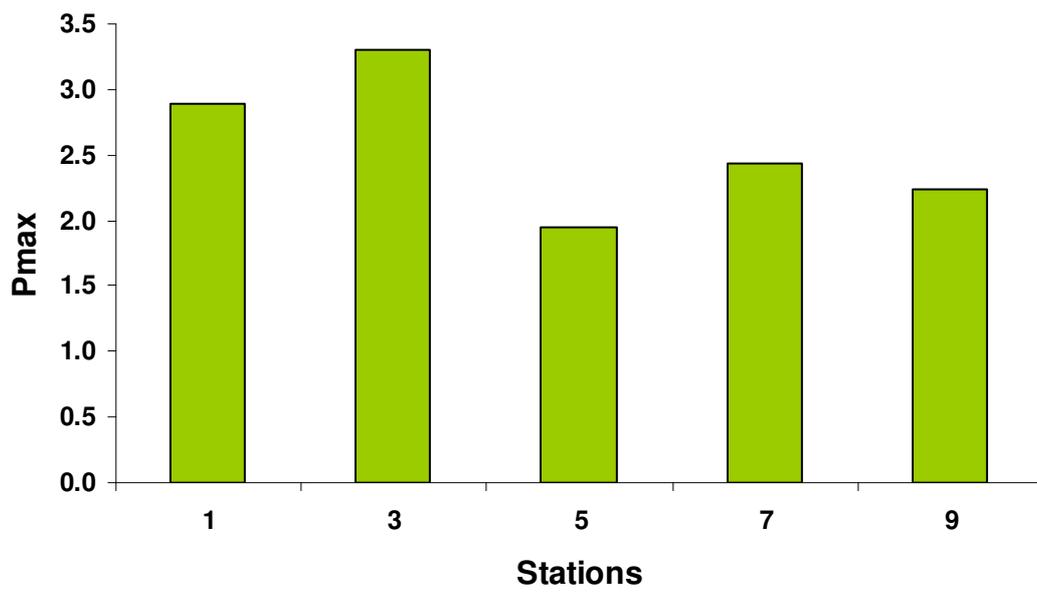


Figure 4. Pmax (10 m) of phytoplankton (st. 1-9) along a transect across the Reykjanes Ridge in June 2003.

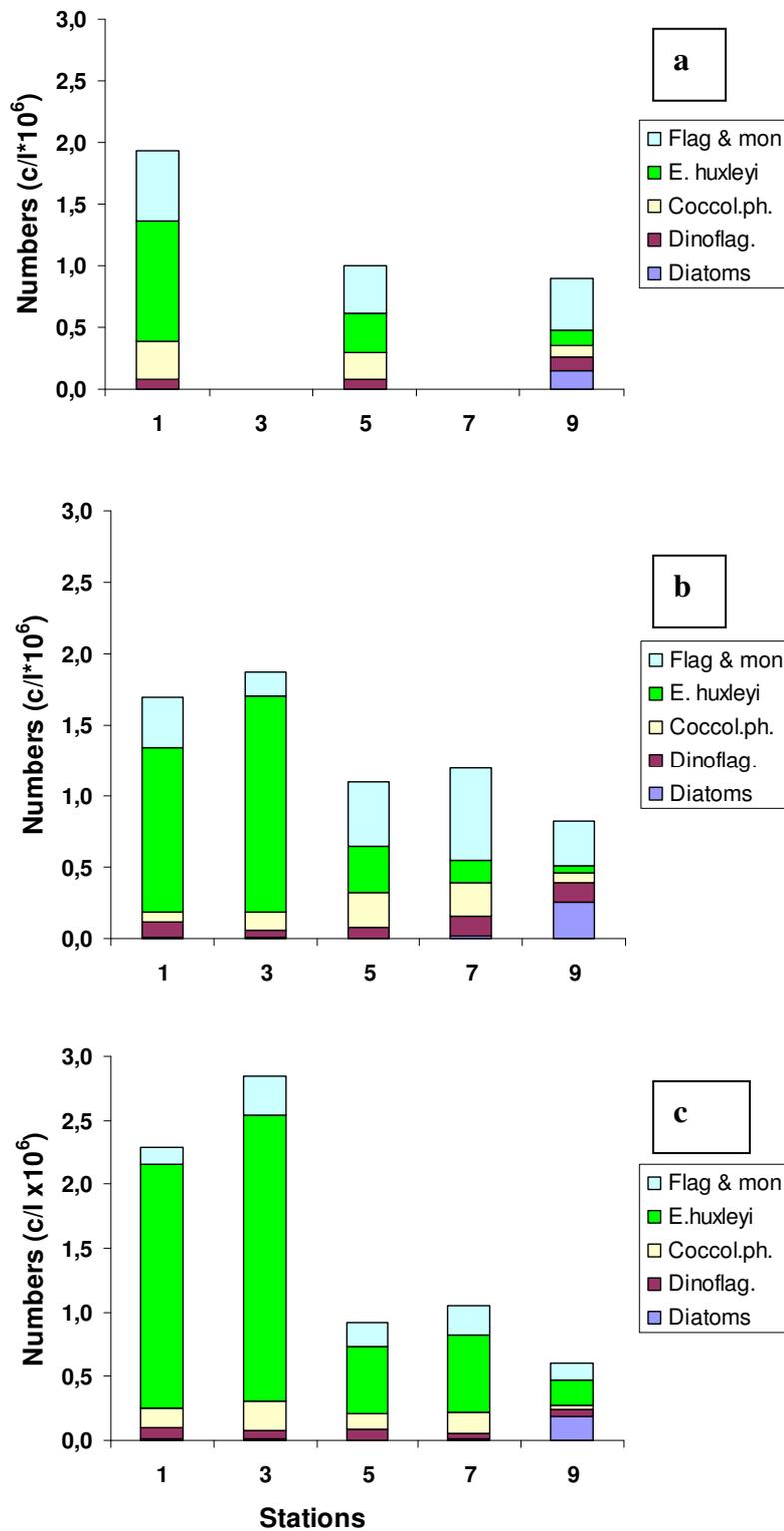
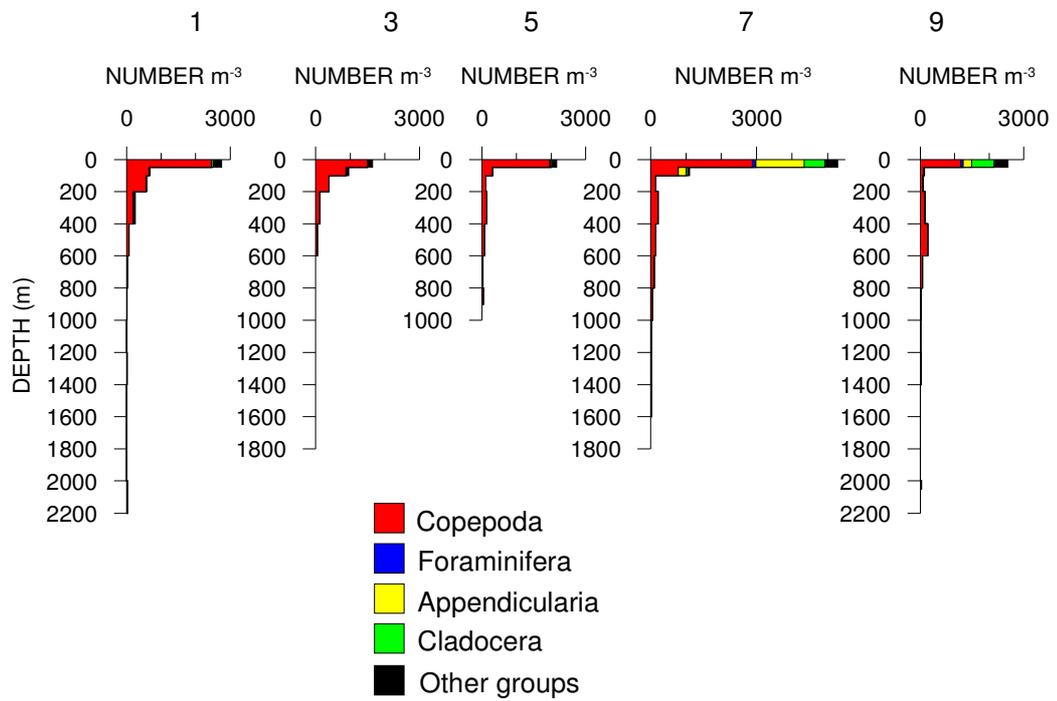


Figure 5. Abundance of phytoplankton groups/species (cells/l) along a transect across the Reykjanes Ridge in June 2003. in 3 depths a) 0 m, b) 10 m, c) 30 m depth.

A



B

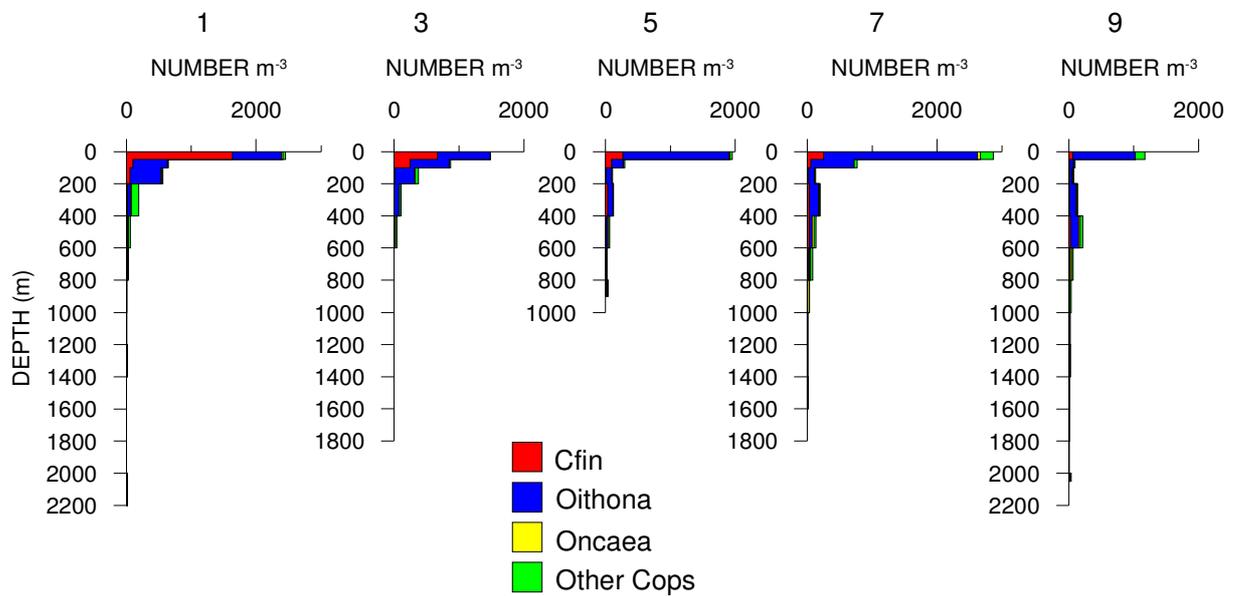


Figure 6. Multinet. Vertical distribution of zooplankton (A) and copepods (B) along a transect across the Reykjanes Ridge in June 2003.

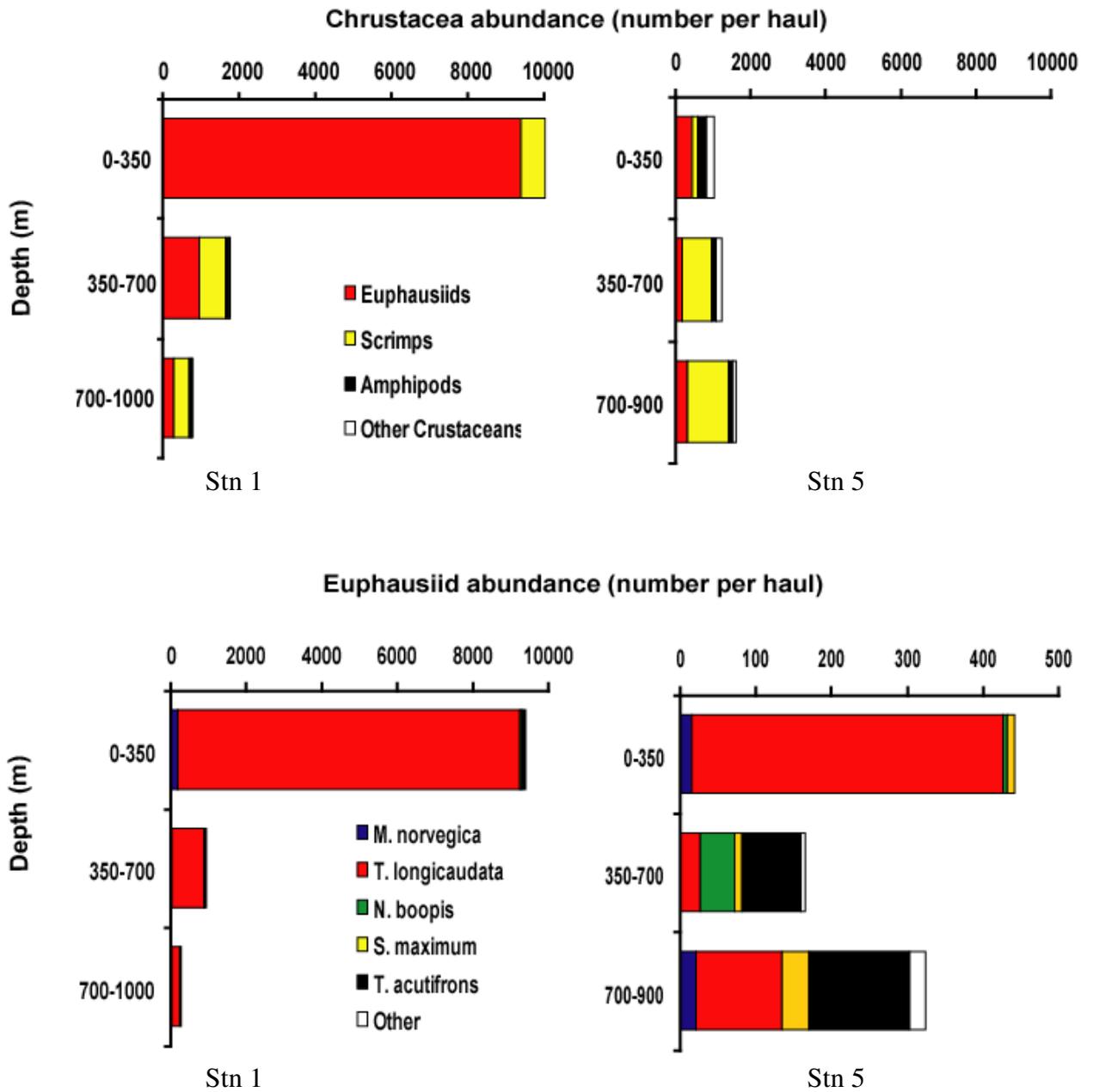


Figure 7. Macrozooplankton trawl. Depth stratified total Crustacean abundance (upper panels) and total Euphausiid abundance (lower panels) at station 1 and 5. Please note the different scale on the x-axis for Euphausiids at station 5 (For location of the stations, see Fig. 1).

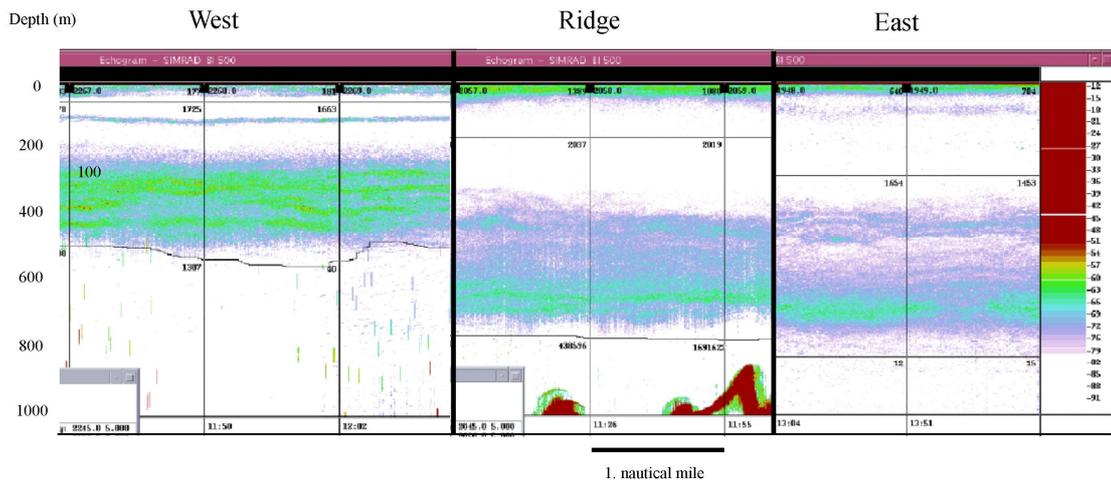


Figure 8. Example of acoustic registration west of the Reykjanes Ridge (station 1), above the Ridge (station 5) and east of it (station 9). The depth is from surface down to 1000 m and the distance between thin vertical lines indicates one nautical mile. All the examples shown are taken around noon.

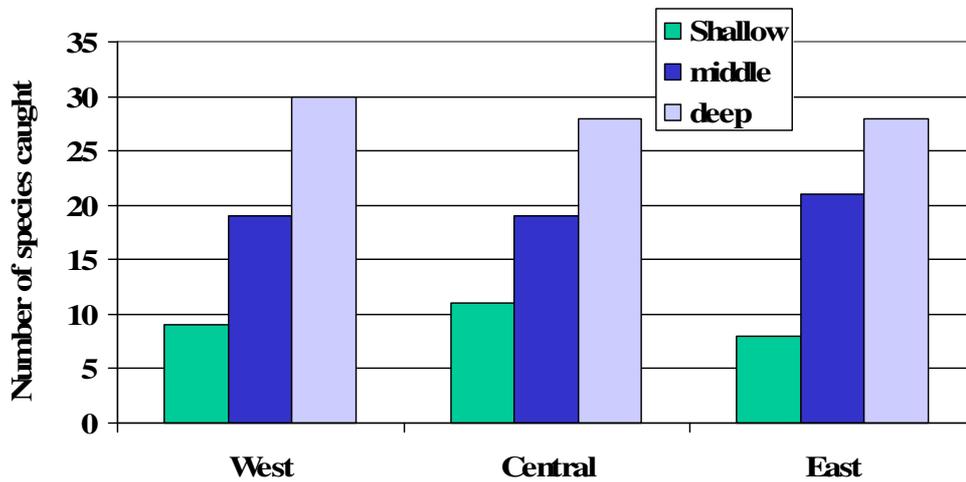


Figure 9a – Number of fish species caught at different areas and depths along a transect across the Reykjanes Ridge in June 2003.

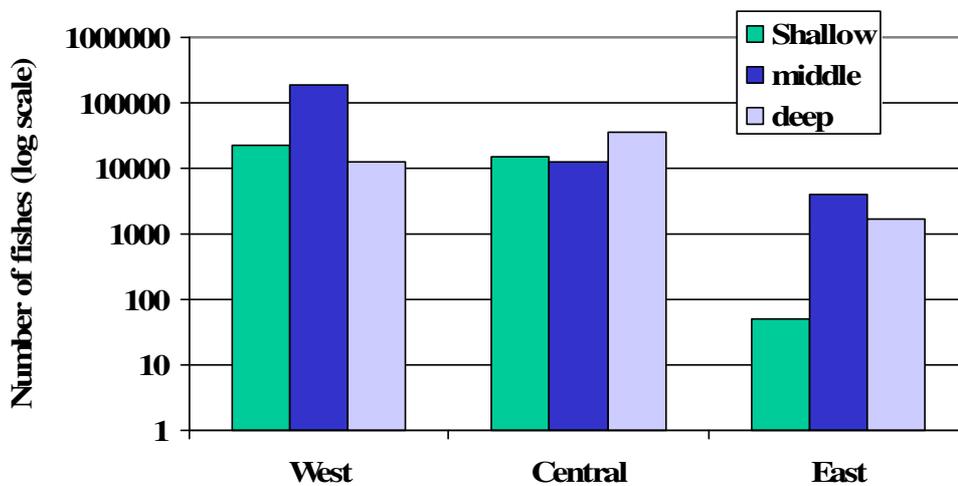


Figure 9b. Number of individuals caught at different areas and depths along a transect across the Reykjanes Ridge in June 2003.