Deep-Sea Research II 108 (2014) 85–92

Contents lists available at ScienceDirect

Deep-Sea Research II

journal homepage: www.elsevier.com/locate/dsr2

Intensity of pelagic–benthic coupling in different regions along the Antarctic Polar Front – Clues from abyssal megafauna

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ARTICLE INFO

Keywords:
Deep sea
Pelagic-benthic coupling
Megabenthos
Echinoderms
Antarctic Polar Front

ABSTRACT

The zone surrounding the Antarctic Polar Front is a region characterized by elevated seasonal primary production. Studies on the implications for the fauna inhabiting the underlying deep-sea floor, however, are rare. The present study focuses on the abundance of megafaunal organisms caught by means of an Agassiz Trawl during the SYSTem COupling in the Southern Ocean II (SYSTCO II) expedition (RV *Polarstern* cruise ANT XXVIII/3). Biomass estimates in terms of volume as well as species richness of echinoderms were additionally taken into account. Abyssal stations (ca. 4000 m depth) located in three different regions along the Antarctic Polar Front characterized by different primary production regimes and oceanographic features were sampled. One shallower station (337 m depth) was used as reference station. Highest megafaunal abundances were found at the shallow station (147 individuals per 1000 m^2). Megafaunal abundances were low to moderate at the abyssal stations (7.2–23.5 individuals per 1000 m^2) with the exception of the region northwest of South Georgia, where distinctly higher abundances were found (up to 119.7 individuals per 1000 m^2). The same pattern was observed for biomass estimates. At the other regions, magnitude of megafaunal abundances and echinoderm biomasses were found not to be linked to the surface levels of primary production. This indicates that strong pelagic–benthic coupling likely occurs only downstream of South Georgia. Echinoderm species richness does not appear to be directly related to the environmental conditions as it does not differ statistically between the considered areas.

1. Introduction

The majority of deep-sea fauna (exceptions are faunas of chemoautotrophic habitats) is depending on the export of organic matter derived from primary production in surface water layers (Gage and Tyler, 1991). Generally, deep-sea ecosystems are seen as food limited, as the organic flux arriving on the sea floor has been shown to decrease inversely with water depth (e.g., Buesseler et al., 2007). The portion of surface-derived organic matter reaching the deep-sea floor can do so in time frames of only few days to weeks (e.g., Billett et al., 1983; Lampitt, 1985). In return, rapid responses of deep-sea benthic fauna to increased inputs of organic material also in the range of days have been observed by several authors (Aberle and Witte, 2003; Witte et al., 2003a, 2003b; Moodley et al., 2005).

The megafauna has been shown to be more sensitive to changes in the food input than the smaller benthic size classes (Lampitt et al., 1986). Variations in megafaunal densities and proportions have been attributed to variation in food input to the sea floor (e.g. in the Arctic, Meyer et al., 2012). Echinoderms often dominate the deep-sea megafauna (e.g., Tyler, 1980; Billett, 1991; Linse et al., 2013), and their densities and diversity have been found to vary in response to food supply (Billett et al., 2001; Ruhl and Smith Jr., 2004). Concordantly, the flux of particulate organic carbon to the deep-sea floor proved to be the first order parameter which controls biomass distribution in the deep Atlantic Ocean, where an exponential relationship has been found between deposit-feeder abundances and trophic input (Sibuet et al., 1989).

The region of the Antarctic Polar Front is known to be an area of enhanced seasonal primary productivity, especially south of the Polar Front, where strongest upwelling of nutrient-rich deep water can be

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http://dx.doi.org/10.1016/j.dsr2.2014.09.003
0967-0645/

observed (Sokolov and Rintoul, 2007). Remotely sensed ocean color data indicate that elevated chlorophyll concentrations are tightly coupled to the frontal structures (Moore and Abbott, 2000, 2002). This leads to a zonal "belt" of strong primary productivity and export production, which is located between 50°S and 55°S (Behrenfeld and Falkowski, 1997; Laws et al., 2000; Schlitzer, 2002). These phytoplankton blooms are unevenly distributed and often occur where currents interact with topographic features, e.g. downstream of islands (Moore and Abbott, 2002; Sokolov and Rintoul, 2007). Results from sediment traps showed carbon export in the Southern Ocean to be low to moderate with a pronounced seasonality, whereat highest carbon fluxes (3.7–3.9% of primary production) were calculated for the Polar Front region (Fischer et al., 2000).

For the present study, stations on an east–west transect along the Antarctic Polar Front were sampled during the SYSTCO II cruise (ANTXXVIII/3, January 7th–March 11th 2012). The stations were situated within different primary production regimes (in terms of diatom species abundance, with a dominance of *Fragilariopsis kerguelensis* to the east and *Chaetoceros* spp. to the west; Sachs et al., 2009) and characterized by different phytoplankton bloom conditions (in terms of chlorophyll *a* (chl-*a*) concentrations; Wolf-Gladrow, 2013). Thus, these settings provide optimal conditions for the investigation of differences in the intensity of pelagic–benthic coupling processes.

In order to detect potential differences in abyssal megafauna abundances in relation to different primary production situations, organisms sampled with an Agassiz Trawl (AGT) were analyzed. Overall abundance of selected higher taxonomic groups was taken into account as well as species richness and biomass estimates of echinoderms.

2. Material and methods

2.1. Study area

During the SYSTCO II cruise (ANTXXVIII/3), the AGT was successfully deployed eight times at stations situated close to the Antarctic Polar Front from board of RV *Polarstern*. In order to compare the effect of different primary productivity settings on megabenthic organisms, four areas with distinct characteristics were chosen for sampling. Most stations were at abyssal depths of ca. 4000 m, besides one station at 337 m depth (Fig. 1 and Table 1). Area 1 (stations 81 and 84) lies east of the Mid-Atlantic Ridge and was exposed to a short, intermediate phytoplankton bloom, which had its peak 20 days before sampling took place. Chl-*a* values integrated over the 0–100 m water layer were at about 0.58 μg/l at the sampling date (Ruff et al., 2014), and sediment chl-*a* values were very low (Lins et al., 2014). The second area (stations 86 and 141, hauls 7 and 8), situated in the central South Atlantic Ocean, is regularly exposed to large-scale phytoplankton blooms lasting up to several months. Between our first and second sampling (18 days later), a slight decrease in surface chl-*a* values (from 2.58 to 1.55 μg/l) was observed (Ruff et al., 2014). Accordingly, a slight increase in sediment chl-*a* values from the first to the second sampling was observed (Lins et al., 2014), indicating a moderate export of bloom remains to the seafloor. Stations in the third area were northwest of the Island of South Georgia (station 175, hauls 3 and 4), a region regularly featuring dense phytoplankton blooms (Atkinson et al., 2001). It was sampled about 50 days after the peak of an extensive phytoplankton bloom; chl-*a* values in the surface water layer were about 0.67 μg/l at our sampling time (Ruff et al., 2014), and sediment chl-*a* values several magnitudes higher than at the other stations were observed (Lins et al., 2014), indicating strong export of bloom-derived organic matter to the seafloor.

The shallow station (station 177) lies in a fourth region more further west close to the South American continent; unfortunately, it was neither possible to conduct replicate sampling nor chl-*a* measurements here due to shiptime constraints (further information on station characteristics in Wolf-Gladrow (2013); information on integrated seasonal chl-*a* concentrations in Brandt et al. (2014)).

An additional distinctive feature is that the sampling areas are situated in different diatom-regimes. In the easternmost and central stations in our sampling areas 1 and 2, *F. kerguelensis* has been shown to regularly be the dominant diatom species. In contrast to that, the stations of our sampling areas 3 and 4 are more influenced by *Chaetoceros*-dominated phytoplankton blooms, a diatom species known to be more of a carbon sinker than *F. kerguelensis* (Sachs et al., 2009; Assmy et al., 2013).

2.2. Sampling

Sampling was conducted by means of an Agassiz-Trawl (AGT, frame width 3 m) with an inner fine-meshed (500 μm) net in the cod end of the outer net (mesh-size of 1 cm), in order to collect smaller animals.

Trawling was performed according to a protocol by U. Grundmann (1st officer on RV *Polarstern*, unpublished written communication). The AGT is lowered by 0.7 m/s. The length of wire put out should be approximately two times the water depth, until the gear reaches the seafloor (as indicated on the winch tension display). When the desired length of wire has been put out, the AGT trawls for 10 min at a ship velocity of 1 knot. Then the ship is stopped, and the wire and AGT are pulled back with 0.5 m/s. The approximate trawling distance can later on be roughly calculated by subtracting the length of wire when the AGT gets free from the ground (as seen on the wire tension display) from the total length of the wire stretched out, and subsequently adding the distance trawled (10 min by 1 knot, equaling 309 m). For example, total length of wire stretched out = 700 m, length of wire still out when the AGT leaves the ground = 370 m. Approximate trawling distance: 700 m − 370 m = 330 m + 309 m = 639 m.

For the first two deployments a symmetrical trawl (AGT in the strict sense) was used. However, for the remaining stations, an asymmetrical trawl of analog dimensions was deployed. As the function of both trawls is similar and the name is commonly used for both trawls, we refer to the term AGT for both.

As soon as the catch was on deck, detectable organisms were directly picked and transferred into buckets with pre-cooled seawater (i.e. at 0 °C) and brought to the wet lab. The rest of the (usually muddy) sample was sieved through two successive sieve fractions (1 mm and 300 μm). All animals visible by eye during sieving were also picked. All collected organisms were immediately transferred into sorting dishes with pre-cooled seawater resting on ice for further analyses (taxonomic sorting and/or sampling for biochemistry and genetics). Subsequently, samples were stored either in 96% ethanol or 4% formalin–seawater solution.

A substantial proportion of the organisms caught with the AGT belongs to the macrofaunal fraction (retained in the 300 μm sieve; Gage et al., 2002). However, for direct comparison, only those taxa belonging to the megafauna (organisms of >1 cm) were taken into account (Fig. 2). By-catch of obviously pelagic organisms is excluded from Table 2 (jellyfish, ctenophores, calanoid copepods, salps, chaetognaths, pteropod gastropods, decapod larvae). The Scyphozoa listed in Table 2 are exclusively polyps of the order Coronatae.

Considering that the AGT is not a quantitative gear, abundances per 1000 m^2 sampled area were though calculated in order to improve comparability of the data.