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Protistan communities in the Australian sector of the Sub-Antarctic Zone during SAZ-Sense

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ABSTRACT

Protistan species composition and abundance in the Sub-Antarctic Zone (SAZ) and Polar Front Zone (PFZ) south of Tasmania were determined by microscopy and pigment analysis from samples collected during the Sub-Antarctic Zone—Sensitivity of the sub-Antarctic Zone to Environmental Change (SAZ-Sense) voyage, in January and February of 2007. A primary goal of this voyage was to determine the potential effects of climate change-induced natural iron fertilisation of the SAZ on the protistan community by exploring differences between communities in waters west of Tasmania, which are low in iron, and eastern waters, which are fertilised by continental iron input and mixing across the subtropical front. The SAZ is a sink for anthropogenic CO_2 in spring, but the magnitude of this may vary depending on seasonal changes in protistan abundance, composition and trophodynamics. Protistan species composition and abundance in the western Sub-Antarctic Zone at process station 1 (P1) showed a community in which low carbon biomass was dominated by a *Thalassiosira* sp., which was very weakly silicified under strong silica limitation. Protistan cell carbon was dominated by diatoms and nano-picoflagellates at process station 2 (P2) in the Polar Front Zone (PFZ), while dinoflagellates dominated in the iron-enriched waters of eastern SAZ at station 3 (P3). Iron enrichment enhanced production and favoured proliferation of small flagellates during summer in the silica-depleted eastern SAZ rather than large diatoms, though the effect this may have on the vertical export of particulate organic carbon (POC) is still unclear.

1. Introduction

Marine protists play a vital role in sequestering CO_2 to the deep ocean (Trull et al., 2001a; Blain et al., 2007). The Southern Ocean, due to its cold water temperatures, turbulent environment and deep mixed layer, removes up to 40% of anthropogenic atmospheric CO_2 with much of the drawdown in the Sub-Antarctic Zone or SAZ (Metzl et al., 1999; McNeil et al., 2001; Sabine et al., 2004). Dissolved CO_2 in the SAZ is then removed by both physical (strong cooling which downwells CO_2-rich water) and biological mechanisms (McNeil et al., 2007). Much of this dissolved CO_2 enters the biological pump in the strong seasonal cycle of biological production in the SAZ (Trull et al., 2001a).

Traditionally, various protist groups have been considered as having different effects on net carbon export, with the ultimate fate of this carbon depending on the taxonomic composition of the protistan biomass. For example large cell-size diatoms are traditionally considered to be net exporters of carbon beyond the photic zone, as they are silicified (heavy) and have a large particle size (Boyd and Newton, 1999). In contrast, small cell-size protists, such as autotrophic nanoflagellates and picoplankton, are predated by both heterotrophic nanoflagellates and zooplankton, diverting carbon into the microbial loop, where it was thought to be quickly remineralised (Pearce et al., 2011). However, Richardson and Jackson (2007), working in the equatorial Pacific and the Arabian sea, have recently shown that picoplankton still contribute to carbon export proportionally to their net primary production, despite their small size. Similarly, and of direct relevance to this study, Trull et al. (2001a) challenged the notion that, given a similar biomass, large phytoplankton, particularly diatoms, are significantly higher contributors to carbon export to the deep ocean. They showed that the SAZ exported similar or even higher amounts of POC than did the PFZ, despite the greater proportion of diatoms in the production of the PFZ.

Much of the Southern Ocean, particularly the SAZ and PFZ, is characterised as high-nutrient, low chlorophyll (HNLC) waters, where iron limitation restricts use of other, abundant micro- and macro-nutrients by phytoplankton (Martin et al., 1990; Martinez-Garcia et al., 2009). This results in paradoxically low algal biomass in an otherwise nutrient-rich environment (Boyd, 2008). Land boundaries and bottom topography that create upwelling are almost non-existent, thus making atmospheric dust a hypothesised main source of iron (Jickells et al., 2005;Cassar et al., 2007). However, in

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the Southern Ocean, sources of dust are few (Prospero et al., 2002), and it has recently been proposed that input from the continental shelf margins exceeds that from wind-blown dust (Tagliabue et al., 2009) or even that it is the principal source of iron in the SAZ (Bowie et al., 2009). Nutrient concentrations in the water bodies examined in this study appear in Bowie et al. (2011).

Climate change is predicted to cause changes in atmospheric and oceanic circulation patterns, with diverse effects on the SAZ. Prevailing westerly winds may already be moving further south (Lovenduski et al., 2007, 2008) and are expected to push Southern Ocean frontal areas further south towards the Antarctic continent, logically resulting in a reduction of the ocean area that is contained within the polar front. This reduction in surface area may in itself have an effect on the Southern Ocean's capacity to absorb anthropogenic CO_2 (Le Quere et al., 2007), as the areas of ocean with the highest wind turbulence and mixed layer are contained within this region. The southwards shift of westerly winds may also increase iron availability through several mechanisms (Lyne and Rintoul, 2005). Warming trends may lead to a drier climate, and increased aridity may lead to a net result of increasing iron input to the Australian sector of the SAZ from windblown dust and other sources. In addition, subtropical water may penetrate further south into the SAZ, increasing iron supply to the northern SAZ. It has been suggested that penetration of low nutrient (but possibly higher iron) water from subtropical gyres such as the East Australian Current (EAC) causes SAZ waters to the east of Tasmania to be a proxy for a future, iron enriched SAZ (with increased dust input due to predicted warming and desertification), while those to the west of Tasmania are still typical of the present-day SAZ (Bowie et al., 2011; Westwood et al., 2011). In this light, comparison of waters west and east of Tasmania can provide valuable insights into the effect of climate change on protistan communities in the SAZ.

At present levels of iron limitation, diatoms dominate the biomass in the Antarctic Zone, and remove much of the silica before surface waters are transported to lower latitudes (Alvain et al., 2008; Armand et al., 2008a, 2008b; Pike et al., 2008). The SAZ is nitrate and phosphate rich, but both silica and iron depleted year-round. Results from previous research on iron enrichment in the Southern Ocean, such as KEOPS, SOFeX, SAGE and SOIREE surveys have produced mixed results, with some stimulating diatom growth and carbon export (KEOPS, SOFeX), and others (SOIREE) showing little effect (Bakker et al., 2001; Boyd and Law, 2001; Boyd et al., 2007; Blain et al., 2008). Not all of these results are necessarily applicable in the silica-limited SAZ, and thus it is essential to quantify the effects of hypothesised additional iron sources due to climate change.

Two mechanisms are major contributors to carbon drawdown in the SAZ: downwelling of tropical waters that have cooled and taken up CO_2 during their southwards movement, and high biological productivity in spite of nutrient limitations. Both of these mechanisms are vulnerable to change given anthropogenic perturbations to the global carbon cycle (McNeil et al., 2007). Thus in this paper we compare the protistan community of two regions of the SAZ which have naturally different levels and sources of iron. We use two representative stations as proxies for current and future prevailing conditions in the SAZ, with low iron supply to the southwest of Tasmania, and high iron supply to the southeast. We also compare our results to a station in the northern PFZ, which like the SAZ is iron limited and seasonally light limited, but unlike the SAZ, is only silica limited after the spring diatom bloom. By defining the community structure across these three stations, we aim to link the structure of the food web to the efficiency of the biological pump given each site's unique environment. Studies like this one are critical, as they allow us to link environmental conditions, including nutrient conditions, to the biological community structure, and assess subsequent potential impacts of community change on carbon sequestration.

2. Materials and methods

2.1. Sample collection

Seawater samples were collected from 40 sites during the SAZ-Sense oceanographic cruise between 20 January and 16 February 2007. Samples were collected from the three main stations (Bowie et al., 2011), chosen to represent typical SAZ water (P1, approximately 46°S 140°E), the polar front zone (P2, 54°S 146°E), and subtropical-water enriched SAZ (P3, 45°S 153°E). Fig. 1 shows the voyage track and location of each station. Repeated sampling was carried out at several sites within each station. While P2 and P3 were representative of their respective water bodies, P1 was highly stratified and exhibited vertical interleaving of water from both sides of the subtropical front (Bowie et al., 2011). At each sampling site, water was collected using 10 L Niskin bottles attached to a CTD rosette (24 bottles). Samples of ~960 ml were collected into glass bottles, fixed with the addition of 1% Lugol's iodine solution and stored in the dark and under refrigeration, until processed into permanent mounts.

2.2. HPMA slide preparation

Permanent mounts were prepared using a modification of Crumpton's (1981) HPMA (2-hydroxypropyl methacrylate) method (Davidson et al., 2010). Briefly, Lugol's fixed samples were filtered onto 0.45 μm pore-size, 25 mm diameter cellulose filters. The wet filters were placed upside down on a coverslip and

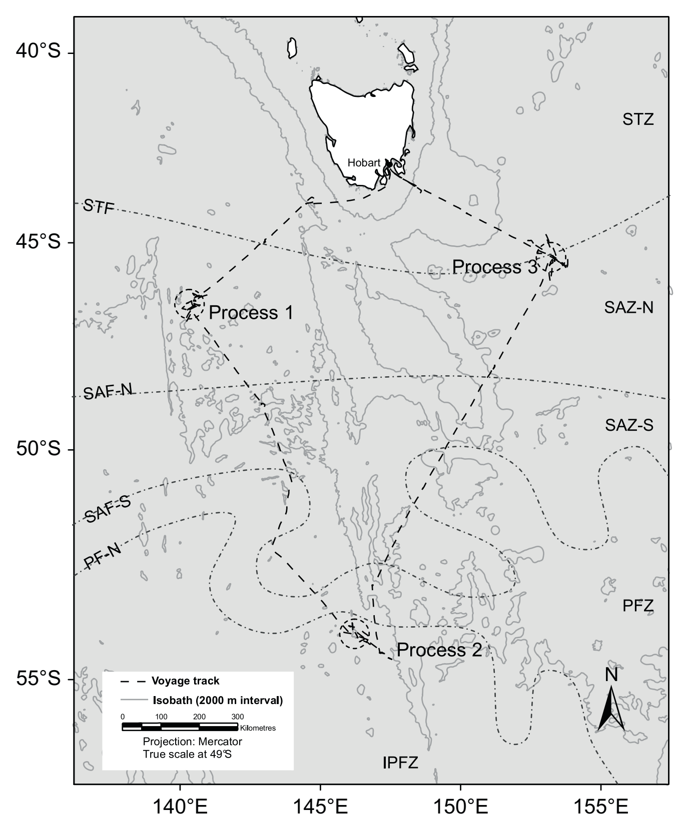

Fig. 1. Track of SAZ voyage showing the location of the three process stations used in this study. Abbreviations: STZ=subtropical zone; STF=subtropical front; SAZ-N=northern SAZ; SAF-N=north Sub-Antarctic front; SAZ-S=southern Sub-Antarctic zone; SAF-*S*=south Sub-Antarctic front; PFZ=polar front zone; PF-*N*=north polar front; IPFZ=inter-polar-frontal zone.