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Distribution, abundance and seasonal flux of pteropods in the Sub-Antarctic Zone

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ABSTRACT

Pteropods were identified from epipelagic net and trawl samples in the Sub-Antarctic Zone during the 2007 mid-summer (January 17–February 20) Sub-Antarctic Zone Sensitivity to Environmental Change (SAZ-Sense) voyage, as well as in a moored sediment trap in the same region. Overall pteropod densities during SAZ-Sense were lower than those reported for higher-latitude Southern Ocean waters. The four major contributors to the Sub-Antarctic Zone pteropod community during the SAZ-Sense voyage, *Clio pyramidata* forma *antarctica*, *Clio recurva*, *Limacina helicina antarctica* and *Limacina retroversa australis*, accounted for 93% of all pteropods observed. The distribution of the two dominant pteropods collected in the Sub-Antarctic Zone, *L. retroversa australis* and *C. pyramidata* forma *antarctica*, is strongly related to latitude and depth. *L. retroversa australis* is typical of cold southern (50–54°S) polar waters and *C. pyramidata* forma *antarctica* is typical of shallow (top 20 m) Sub-Antarctic Zone waters. A moored sediment trap deployed to 2100 m at 47°S, 141°E in 2003/04 showed the pteropod flux in the Sub-Antarctic Zone had late-Spring and mid-summer peaks. The diversity, abundance and distribution of pteropods collected during SAZ-Sense provide a timely benchmark against which to monitor future changes in SAZ ocean pteropod communities, particularly in light of predictions of declining aragonite saturation in the Southern Ocean by the end of the century.

1. Introduction

Increasing amounts of anthropogenic carbon dioxide have been entering the global ocean since the industrial revolution, decreasing the carbonate-ion concentration and pH of the surface ocean. The ecological effects of this process, known as ocean acidification, are uncertain, with a variety of studies suggesting the ability of marine calcifying organisms to form carbonate shells may be reduced (e.g. planktonic foraminifera: Spero et al., 1997; Bijma et al., 1999, 2002; Moy et al., 2009, corals: Gattuso et al., 1998; Kleypas et al., 1999; Gattuso and Buddemeier, 2000 and some coccolithophorids: Riebesell et al., 2000; Zondervan et al., 2001), while others suggest marine calcifiers may benefit from increasing carbon dioxide (e.g. some coccolithophorids: Iglesias-Rodriguez et al., 2008). The importance of calcification in the survival of shell-making organisms may vary among different groups and taxa (e.g. Fine and Tchernov, 2007). However, calcification plays an important role in the marine carbon and alkalinity cycles, with aragonite precipitation and dissolution being particularly prominent components of the upper-ocean alkalinity cycle (Betzer et al., 1984; Gangstø et al., 2008).

Quantifying the distribution, abundance and seasonal flux of calcifying organisms in the Sub-Antarctic Zone (SAZ) is an important and current issue, as these calcifiers will be among the first organisms to respond to the impacts of ocean acidification as it spreads throughout the global ocean. One important marine group of calcifiers in the Sub-Antarctic Southern Ocean are the thecosomatous (shelled) pteropods, planktonic gastropods (Lalli and Gilmer, 1989) that produce aragonitic shells. Aragonite is a metastable mineral phase of calcium carbonate under oceanic conditions, more vulnerable to dissolution at depth than calcite, and potentially more vulnerable to ocean acidification than calcite in terms of shell formation. Not only are pteropods sometimes important in terms of carbonate flux to the deep-sea, but also when abundant they can be significant grazers on phytoplankton and smaller mesozooplankton (reviewed in Lalli and Gilmer, 1989). Given their biogeochemical and ecological importance, there is a particular urgency in determining the present distribution and abundance of SAZ pteropods, as it is likely that parts of the Southern Ocean will begin to become undersaturated

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with respect to aragonite in the next 50 years (Orr et al., 2005; McNeil and Matear, 2008).

We document the distribution and abundance of pteropods collected during SAZ-Sense. Pteropod flux data collected from a sediment trap moored at 2100 m at 47°S, 141°E in the austral summer of 2003/04 puts the pteropod assemblage observed during the SAZ-Sense voyage into a seasonal flux context.

2. Materials and methods

2.1. Survey region

The Sub-Antarctic Zone Sensitivity to Environmental Change voyage (SAZ-Sense) covered an area from 44–54°S and 140–155°E between 17 January and 20 February 2007 during which three process stations and 24 transit stations were occupied. Pteropod samples for our analyses were collected at transit stations 2, 5, 9, 10 and 12 and process stations 1, 2 and 3 (Fig. 1).

SAZ-Sense focused mainly on the Sub-Antarctic Zone (SAZ) south of Tasmania. The SAZ is typically considered those waters bounded to the north by the Subtropical Front (STF) and to the south by the Polar Frontal Zone (PFZ). The STF generally lies near 45°S in this sector and is associated with strong gradients in temperature and salinity. Its southern boundary usually coincides with the 14 °C surface isotherm in summer (e.g. Orsi et al., 1995; Sokolov and Rintoul, 2002). The Sub-Antarctic Front (SAF) makes up the main frontal zone of the Antarctic Circumpolar Current.

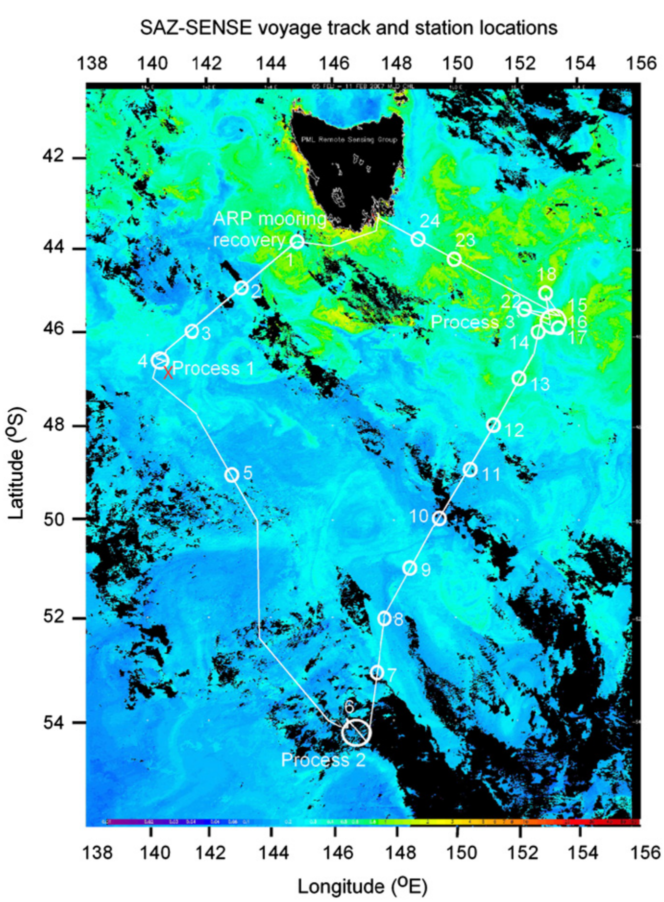

Fig. 1. SAZ-Sense station locations and regional ocean colour field at the time of SAZ-Sense (Bowie et al., 2011). Pteropod collection sites: transit stations 2, 5, 9, 10 and 12 and process stations 1, 2 and 3. Sediment trap mooring location (red "x") at 47°S, 141°E. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The SAF is also characterised by strong surface gradients, and is often split into two branches in this sector (e.g. Belkin and Gordon, 1996). In particular, the SAF forms the southern terminus of deep winter mixed layers, which characterise the thermal structure of the water column in the SAZ (e.g. Rintoul and Bullister, 1999). Summer warming between the SAF branches and the STF tends to produce relatively shallow mixed layers in the SAZ (Rintoul et al., 1997), as seen during SAZ-Sense (Bowie et al., 2011). The Polar Front (PF) formed the southern boundary of the SAZ-Sense sampling region. The PF is generally defined by the equatorward extent of a subsurface minimum in potential temperature, usually coinciding with the 2 °C isotherm in this temperature minimum (e.g. Rintoul and Sokolov, 2001). The north-eastern stations occupied by SAZ-Sense also sampled a region characterised by interactions between SAZ water masses and eddies of the East Australian Current (EAC) and the southward advection of warm, salty water by this western boundary current (Ridgway, 2007).

2.2. Sample collection

Pteropods were collected using a ring net and Rectangular Midwater Trawls (RMT) 1 and 8 (Roe et al., 1980; Pommeranz et al., 1982) (Table 1). Both net and trawl sampling varied in terms of time-of-day, and as a result no attempt has been made to relate pteropod abundance or distribution to diurnal cycles.

2.2.1. Ring net

The ring net was deployed vertically with a mouth area of 0.8 m^2 and was fitted with a 150 μm mesh and a 20 L, 0.3 m wide non-filtering cod-end bucket. Deployments were made at varying times of day between 0 and 100 m depth (Table 1) at a speed of ~0.5 m s^{-1} and the filtering efficiency was assumed to be 100%. Sampling volumes (m^3) were calculated from the net mouth area (0.8 m^2) and deployed depth range (m).

2.2.2. Rectangular midwater trawls

Each RMT deployment consisted of two 15-min trawls. On some occasions only one part of the trawl was successful due to damage to the net and/or cod-end and on two occasions a second trawl was not undertaken. The RMT 1 net (1 m^2 mouth area fitted with 150 μm mesh) and the RMT 8 net (8 m^2 net opening with 2 mm mesh) were deployed for horizontal tows between 20 and 150 m water depths (Table 1) at speeds of 0.5–1.9 knots. Target water depths were chosen to maximise sampling in biomass concentrations near the base of the mixed layer, located using temperature and salinity profiles obtained from conductivity–temperature–depth (CTD) casts just prior to RMT deployments. Distance towed was calculated from the flow metre fitted to the RMT 8. Sampling volumes (m^3) were calculated from the mouth area (1 and 8 m^2) and distance towed (m). The filtering efficiency of the RMT 1 is estimated to be approximately 85% compared to nearly 100% for the RMT 8 (Ikeda et al., 1986). Thus, we take the abundances reported for RMT 1 as a minimum estimate of pteropod density at the depths sampled during SAZ-Sense.

2.3. Physical parameters

At each station a General Oceanics Mark IIC CTD was deployed, sampling from the surface to a maximum water depth of 2500 m. The thermal structure of the SAZ-Sense sampled waters was typical of late summer sub-Antarctic conditions and voyage hydrochemistry, water mass and front positions relevant to the stations discussed are summarised by Bowie et al. (2011).