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Near-field zooplankton, ice-face biota and proximal hydrography of free-drifting Antarctic icebergs

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ABSTRACT

A small ROV was used to collect plankton, make video surveys and take hydrographic measurements in close proximity to six free-drifting, Antarctic icebergs. The icebergs studied ranged in size from <0.5 to >32 km in length. Large icebergs have a greater scale of influence than do smaller ones and iceberg-mediated differences in the hydrographic characteristics of their surrounding water depend on the scale sampled. Irrespective of size, temperature generally decreased in close proximity to an iceberg while salinity increased. Chlorophyll *a* was often lower in the surface waters near the iceberg, relative to the surface waters further away. Tabular icebergs typically had 3 distinct underwater features: shelf, side and bottom. Ablation pockets were a common feature of subsurface ice. The ice itself is a dynamic and seemingly harsh environment with relatively few macrofauna living on it. Those that do inhabit the ice face are either highly specialized or highly mobile. Species composition of zooplankton within 40 m of an iceberg did not change relative to distance. However, biomass was generally greater within 5 m of an iceberg than it was 15 to 40 m distant.

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1. Introduction

Tabular icebergs form as glaciers flow from land into the sea and calve or break off. Historically about 5000 icebergs a year calve into Antarctic waters from the Amery, Filchner and Ross ice shelves (Wadhams, 1986). Fewer in number than Arctic icebergs but larger, tabular Antarctic icebergs typically have a depth of *ca* 250 m, the mean thickness of the ice shelf at the point of calving. Large icebergs are prone to ablation by fracture and calving. Smaller icebergs can roll and the smallest icebergs are often rife with complex physical features like caves or ice spires, wrought by erosion and wastage. These dynamic aspects make getting close to icebergs both difficult and dangerous. Consequently, there have been few field observations carried out in close proximity to large, free-drifting icebergs (but see Pisarevskaya and Popov, 1990, as well as Ohshima et al., 1994, for a study done on fast ice).

The occurrence of large icebergs (>18.5 km long) originating from ice shelves in the Ross, Bellingshausen and Weddell Seas has increased during the last decade (Scambos et al., 2000; Bindschadler and Rignot, 2001; Long et al., 2002; Bindschadler, 2006; Jacobs, 2006). Recent evidence suggests that one large iceberg (Lazzara et al., 1999) grounded in the Ross Sea drastically restricted the flow of pack ice, thus reducing the area of open water and resulting in a $>40\%$ decrease in primary production of the region (Arrigo et al., 2002). A reduction of this magnitude impacts all trophic levels including top predators. Large icebergs may have large-scale effects but they are rare compared to the much greater abundance of smaller icebergs. Smaller icebergs have a much larger surface area to volume ratio, provide relatively more substrate for organisms and when considered in total, could impact a vast region of the Southern Ocean. There are an estimated 200,000 icebergs in the Southern Ocean with linear dimensions of tens of meters to tens of kilometers (Orheim, 1988).

Icebergs may have important structuring effects on local pelagic communities (Smith et al., 2007). Increased concentrations of Fe and chlorophyll *a* accompanied by increased abundance of nanoplankton were measured in the wake of a drifting iceberg in the Southern Indian Ocean (de Baar et al., 1995; Raiswell et al., 2008; Schwarz and Schodlok, 2009). At higher trophic levels, the diversity of acoustically-reflective targets, believed to be zooplankton and micronekton, were twice as high under a free-drifting iceberg when compared to surrounding open water in the Weddell Sea (Kaufmann et al., 1995). Fish have been observed in small caves within the walls of a coastal iceberg off Greenland (Holmquist, 1958) and grounded icebergs in the Ross Sea (Line, 2000; Stone, 2003). In addition, fish have been observed attached to the smooth surface of a grounded tabular iceberg in the Davis Sea (Gruzov et al., 1967) and to the subsurface of a marginal ice shelf in the SE

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Weddell Sea (Gutt, 2002). Top predators such as Chinstrap penguins and Antarctic fur seals are known to associate with icebergs in the NW Weddell Sea (Joiris, 1991; Rubic et al., 1991). Communities of seabirds, including Southern Fulmars, Wilson's Storm Petrels, Antarctic Petrels and Mottled Petrels have been associated with icebergs in the Ross Sea (Ainley et al., 1984) as well as in the NW Weddell Sea (Smith et al., 2007; Ruhl et al., 2011). Recruitment of these predators may be an active response to shelter or enhanced productivity, or it may be the result of passive entrapment and entrainment of prey.

Little is known about the organisms associated with icebergs. In this study we used a small, remotely operated vehicle (ROV) to survey, sample and characterize the macro-organisms living in close proximity to and on the submerged faces of free-drifting, tabular icebergs in the Weddell Sea in the late austral spring of 2005 (December) and late summer (March/April) of 2009. At the same time, we recorded salinity, temperature and chlorophyll data to determine how those parameters varied with distance from the iceberg and how that variability affected the associated organisms.

2. Materials and methods

ROV dives for this study were made in December of 2005 and March/April of 2009 from the *ARSV L.M. Gould* and *RVIB N.B. Palmer*, respectively (Smith, 2011). The ROV was equipped differently during each of those years. The 2005 expedition was primarily a reconnaissance mission made on a limited budget and the ROV (Deep Ocean Engineering Phantom HD2) initially had no hydrographic or biological sampling capability, only a video camera and incandescent lights. The ROV was subsequently outfitted with a modified 0.25-m^2 plankton net during the cruise and with it we sampled tufts of attached diatoms, as well as a rock lying on the shallow shelf of a tabular iceberg. Although the ROV was rated to a depth of 600 m, it was limited to depths that could be reached with its 300-m tether (Hobson et al., 2011). Over the course of 7 dives made in the NW Weddell Sea in the late Austral spring, we obtained video footage of fish and diatoms on the ice, and krill, salps and other gelatinous zooplankton nearby (Smith et al., 2007; Table 1).

Based upon what we learned during our 2005 cruise, the ROV was upgraded to provide more power and was outfitted to collect High Definition (HD) video imagery, biological samples and hydrographic data in 2009. A Sony HJDR-HC5 camcorder transmitted live video to the surface where it was recorded on mini-DV tape. HD video images were captured and stored to the camera's flash memory. The ROV was equipped with a 29-chamber suction sampler carousel and a fluorinert-filled, pressure-compensated Rule 24 VDC suction pump. The suction sampler carousel served as a repository for individual samples drawn into the carousel through either a 0.14-m^2 plankton net (202 μm) mounted on the forward portion of the ROV toolsled, or a suction nozzle mounted in front of the ROV on the bumper bar. The plankton net was used for collecting zooplankton during transecting operations. The suction nozzle was used to collect attached diatoms and macroplankton from the ice face and water column. The plankton net and suction nozzle could not both be used on the same dive. An individual suction sampler chamber consisted of a 5.1 cm diameter by 7.6 cm long, open-ended acrylic tube fitted with 202-μm mesh nylon sock to retain the sample as water was drawn through by the suction pump.

Conductivity, temperature and depth data were collected with a Falmouth Scientific Micro-CTD MCTD III, while chlorophyll *a* and turbidity were measured with a WETLabs ECO FLNTU fluorometer and turbidity sensor attached to the CTD. Because these instruments were mounted near the bottom of the ROV, measurements made while descending were more likely to represent the undisturbed water column; however, in some cases only ascending data were obtained (Table 1). For calibration, the ROV CTD/fluorometer was removed and mounted alongside the CTD/fluorometer used aboard the *RVIB Nathaniel B. Palmer's* CTD rosette. Measurements of chlorophyll *a* made with the ROV were thus cross-calibrated over a cast to 600 m and corrected via bottle samples analyzed in the shipboard lab. Speed through water and distance traveled was determined with a General Oceanics Model 2031 H electronic flowmeter with a low-speed impeller. Distance and orientation to the iceberg face were determined and recorded for later analysis with a Kongsberg-Simrad Mesotech 1000 scanning sonar. See Hobson et al. (2011) for more detail on the ROV's specifications and capabilities.

In 2009 the better-equipped ROV made 7 complete biology dives on 3 icebergs that ranged in size from <0.5 to 32 km in greatest dimension. All the icebergs we examined in 2009 occurred over the Powell Basin of the Weddell Sea (Fig. 1). During a typical dive the ship usually moved 1-2 km (Table 1) due to linear or rotational movement of the iceberg.

Most dives were made on the lee side of an iceberg. Choosing a dive site depended on several factors, among them were iceberg surface topography and the apparent likelihood of calving as well as the current relative to the iceberg and other icebergs in the vicinity. The ROV was deployed with the ship's starboard A-frame. Once in the water, the vehicle transited to the iceberg on the surface and then dove upon reaching the ice face. Occasionally, conditions like brash ice in the water required that we make the last part of the approach to the ice face submerged. A floating tether configuration was used for these missions due to the long stand-off distance required between the ship and iceberg. This allowed the tether to be continuously visible to the ship's bridge crew and tether handlers as it streamed out 100 to 300 m to the iceberg. However, this left it vulnerable to being snagged by passing growlers or brash ice.

The position of the ROV relative to the movement of the iceberg was calculated from the ship's track, heading, and the fact that the ROV was always deployed off the starboard side. Shipboard GPS was used to calculate the distance and direction traveled (Table 1). ROV speed varied greatly based on prevailing conditions. Current effects on the tether were by far the largest factor in determining speed. Whether the ROV dove up or downstream of an iceberg varied and, in some cases, changed during a dive.

Two types of ROV missions were performed for this study: ice face surveys and vertical transects. The primary purpose of the surveys was to explore the ice face from close to the surface waterline down to the apparent bottom of the iceberg. Detailed observations of the ice structure and associated biota were made on these dives, and targeted specimens were collected for identification in the lab using the 0.25-m^2 plankton net as a scraper/collector in 2005, or with the suction sampler in 2009. In addition to the dedicated survey dives, a single descending ice-face survey was also conducted on each of the transecting dives prior to initiating those activities. The relative abundance of diatom tufts was estimated during ice face surveys and scored on a scale of 0 (no diatoms visible) to 5 ($>$ 6 tufts/ablation cup). In total, ice-face surveys were completed on 5 dives in 2005 and 7 dives in 2009. Vertical transecting missions were run to quantify and compare organisms living on and very close to the iceberg with those living up to 45 m away. No dives were repeated in the same place on any iceberg.

Whenever possible, vertical transects were made at 3 distances from the iceberg: 0-5, 10-15 and 30-45 m (Table 1). The operational goal for these transects was to move diagonally up or down the face of the iceberg and/or water column at about a 45° angle to maintain movement forward into undisturbed water, as well as to maintain

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