CellPress

Current Biology
Magazine

Correspondence

Richness, growth, and persistence of life under an Antarctic ice shelf

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Where polar ice sheets meet the coast, they can flow into the sea as floating ice shelves. The seabed underneath is in complete darkness, and may be Earth's least known surface habitat. Few taxa there have been fully identified to named species (see Supplemental information) — remarkable for a habitat spanning nearly 1.6 million km^2. Glimpses of life there have come from cameras dropped through 10 boreholes, mainly at the three largest Antarctic ice shelves — the Ross (McMurdo), Filchner-Ronne and Amery. Pioneering studies of life under boreholes found distinct morphotypes of perhaps >50 species. Here, we report remarkable growth and persistence over thousands of years of benthic faunal species collected in 2018 from the seabed under the Ekström Ice Shelf (EIS), Weddell Sea.

The sites EIS-2 (250 m 'water depth' of which the top 192 m was ice shelf and the bottom was 58 m water, 3.4 km from the modern ice-shelf front) and EIS-3 (300 m water depth of which the bottom 110 m was water, 9.6 km away from seasonally open water) (Figures 1A,B and S1A) revealed 62 and 50 benthic species, respectively (Figures 1C and S1B). Both sampling sites yielded more species than currently named in total from all Antarctic sub-ice shelf studies[1–4]. Four species of cheilostome bryozoans show growth comparable to specimens of the same species at nearby open-water continental shelves (Figure 1D). Growth measures from sub-ice shelf biota show that sessile benthic fauna is able to flourish under Antarctic ice shelves. We found a total of 77 different species of sessile benthic suspension feeders from 49 genera. Those bryozoans do not include new or specialized deep-water species but, as at the former Larsen A and B ice shelves[5], include species typical of the open Weddell Sea continental shelf.

Despite permanent darkness for at least thousands of years, life has been observed even 700 km from ice shelf edges[1–4]. It was thought that richness and abundance of life under ice shelves is highly depauperate[1]. Yet, the biodiversity we found at both borehole sites would be high even for open-marine Antarctic continental shelf

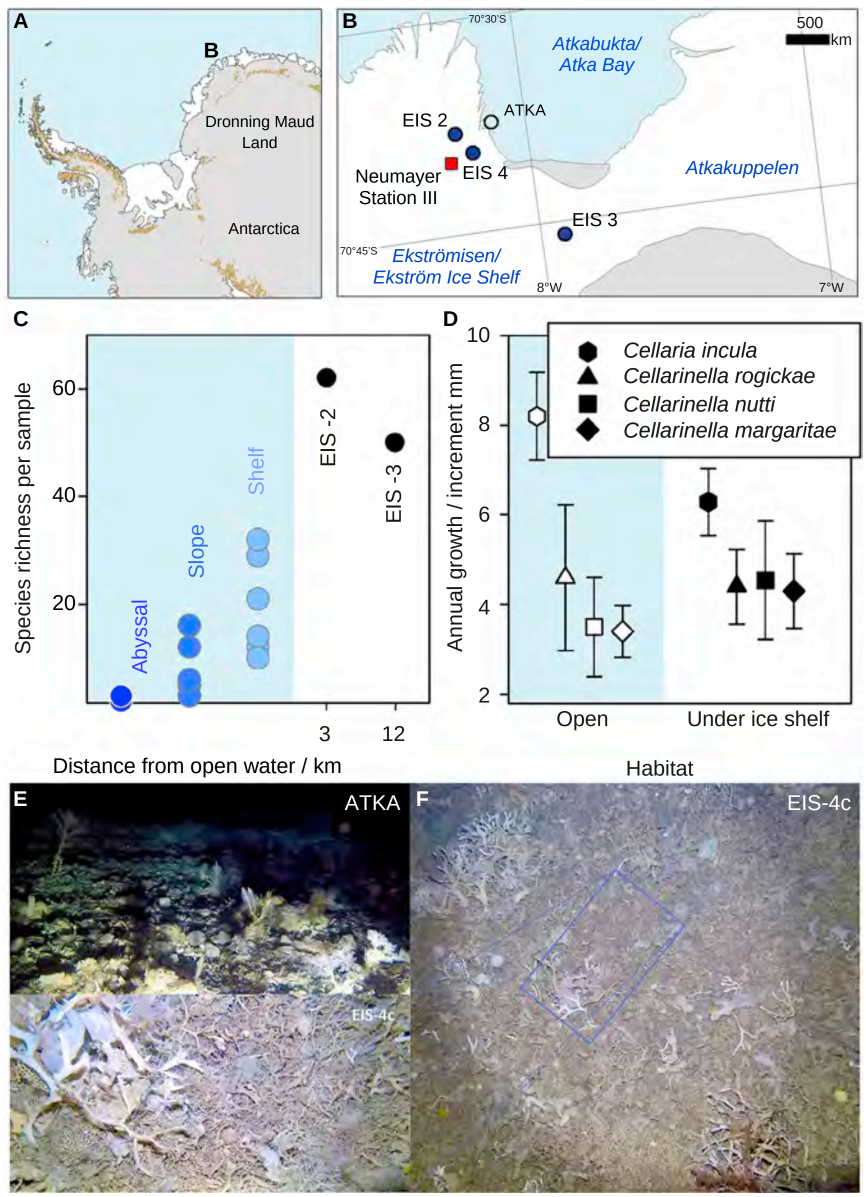

Figure 1. Ekström Ice Shelf and growth of sub-ice shelf bryozoans.
(A) Study region within the wider context of the Weddell Sea. (B) Borehole locations on the Ekström Ice Shelf and sea floor imagery in Atka Bay (Data S1). (C) Richness of bryozoan collections from open water habitats (trawls on abyss, slope and shelf) and under ice shelf samples at EIS-2, -3 and (D) annual growth in four bryozoans in open shelf (open symbols) and under ice shelf (filled symbols) habitats. Growth data are n=7 to 20 for each point and error bars are standard deviation. Data for Weddell Sea non-ice shelf growth increments from the literature[S6]. (E,F) Rich and abundant benthic assemblages at two of the study sites.

samples[2] (for bryozoan richness, see Figure 1C). To date, at least 13 phyla have been found underneath Antarctic ice shelves[1–4] (Data S1A). The variety of primary consumers suggests that sub-ice shelf habitats are more habitable than previously thought.

Fragments of four species — *Cellaria incula*, *Cellarinella margaritae*, *Cellarinella nutti* and *Cellarinella rogickae* — showed intact growth increments (Figure S1). Their growth magnitudes were similar to those established as annual in the same species elsewhere around Antarctica[6] (Figure 1D). This suggests that primary productivity (phytoplankton) was advected under the ice shelf, and was available for a similar duration as in seasonal open water habitats. Comparisons of dry-mass and ash-free dry-mass of carbon were not possible because, firstly, they are proportional to age, which requires an intact origin (first year's growth from ancestrula), and secondly, the four species dichotomously branch, so all branches are required to get those measures. However, linear extensions of each species were comparable to specimens of similar species previously collected from the open Weddell Sea shelf (Figure 1D). Patterns of linear extension in several species and genera, including those studied here, have been found to be consistent with annual increments in mass and accumulated carbon, suggesting them to be a reliable proxy for growth[6]. If normal high-latitude growth of rich primary consumers can be maintained, then such oases of life should be able to support secondary consumers, hence the complexity of sub-ice shelf communities observed using borehole cameras[1,7].

AMS ^{14}C dating (5 double measurements with and without etching) of nine bryozoan and one bivalve shell fragments from Ekström sub-ice shelf samples revealed that five (alive at the time of collection) were of recent age, with the corresponding ^{14}C ages matching the Southern Ocean marine reservoir effect of ca. 1,300 ^{14}C years (Supplemental information). Four specimens had ages of ca. 450–1350 corrected ^{14}C years before present (B.P.), and one bryozoan had an age of ca. 5800 corrected ^{14}C years B.P. (Data S1C). This suggests that despite permanent darkness and thus lack of *in situ* primary production of such habitats, enough phytoplankton is regularly advected underneath ice shelves for long-term sustainability. Alternatively, there is repeated recruitment from more productive regions. Our findings shed light on a long mused puzzle — how could rich, endemic life on the continental shelf survive the last glacial maximum and previous glaciations, when most of the Antarctic shelf was overridden by grounded ice[8]? There is geological evidence that small areas on the Antarctic shelf were covered only by ice shelves and not grounded ice during the last glacial period. Polynyas in front of these ice shelves allowed episodic phytoplankton production, which could have sustained sub-ice shelf benthos through advection[8]. The very low metabolic rates of polar benthos, long evolution in an intensely seasonal environment and flexibility to utilize food when briefly present perhaps allowed survival under ice shelves. This explains why similarities in bryozoan assemblages between different Antarctic shelves, which had established when these areas were last connected, are still detectable and were not wiped out during intervening glacial periods[9]. Cheilostome bryozoans (with short lived benthic larvae) were more represented than spirorbid polychaetes, which have more dispersive planktonic larvae[10]. Any suitable currents for travel may be too slow as to be challenging for larvae which need to feed.

It may be cold, dark and food-scarce in most places but the least disturbed habitat on Earth could be the first habitat to go extinct as sub-ice shelf conditions disappear due to global warming.

SUPPLEMENTAL INFORMATION

Supplemental information includes one figure, one data file, experimental procedures and references and can be found with this article online at https://doi.org/10.1016/j.cub.2021.11.015.

ACKNOWLEDGEMENTS

We thank the 2017-19 Sub-EIS-Obs field teams, especially: Olaf Eisen, Emma C. Smith, Jan Tell, Christine Wesche, Frank Wilhelms (AWI); Christoph Gaedicke, Andreas Läufer (BGR); Pavel Talalay, Fan Xiaopeng (Jilin University), and the AWI MICADAS team for ^{14}C dating. We thank Laura Gerrish and Louise Ireland for maps and Paul Dayton and two anonymous referees for helpful comments.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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