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NOTE

Impact of iceberg scouring on polar benthic habitats

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ABSTRACT: *In situ* photographs and videos demonstrate that iceberg grounding in both polar regions causes considerable damage to benthic communities. Sessile organisms are eradicated and pioneer species begin to grow in high abundances on the devastated substratum. A preliminary quantitative analysis shows that the sea floor in the Antarctic and Arctic areas of investigation is disturbed by icebergs statistically once every 230 and 53 yr, respectively. Due to the extreme slow growth of many species, particularly in Antarctica, areas frequently disturbed in this manner are likely to be characterised by a continuous natural fluctuation between destruction and recovery. Increased perturbation by iceberg groundings through predicted global warming will result in considerable impairment of this environment.

KEY WORDS: Antarctic · Arctic · Benthos · Iceberg scouring · Global warming

Recently, the calving of Antarctic ice shelves has been discussed with respect to global warming (Doake & Vaughan 1991, Gammie 1995) and the consequences of resulting iceberg scouring on the structure of the sea bed have been documented for both polar areas (Lien et al. 1989, Woodworth-Lynas et al. 1991). Yet the possible effect on the underlying benthic communities, other than by small growlers, has not yet been broached. Our analysis shows for the first time the impact of iceberg grounding and scouring on the Antarctic and Arctic benthos. The results provide an idea of the benthic system's resilience to such natural catastrophic events. They also enable us to assess consequences of a possible atmospheric warming, to which both polar ecosystems are considered particularly sensitive (Houghton et al. 1990).

Material and methods. The sea floor was videotaped by a remotely operated vehicle and photographed in the Antarctic Weddell and Lazarev Seas (47° W to 12° E, 69° S to 79° S) and the Amundsen and Bellingshausen Seas (120° W to 65° W, 67° S to 73° S; Fig. 1a) as well as off northeast Greenland (77° N to

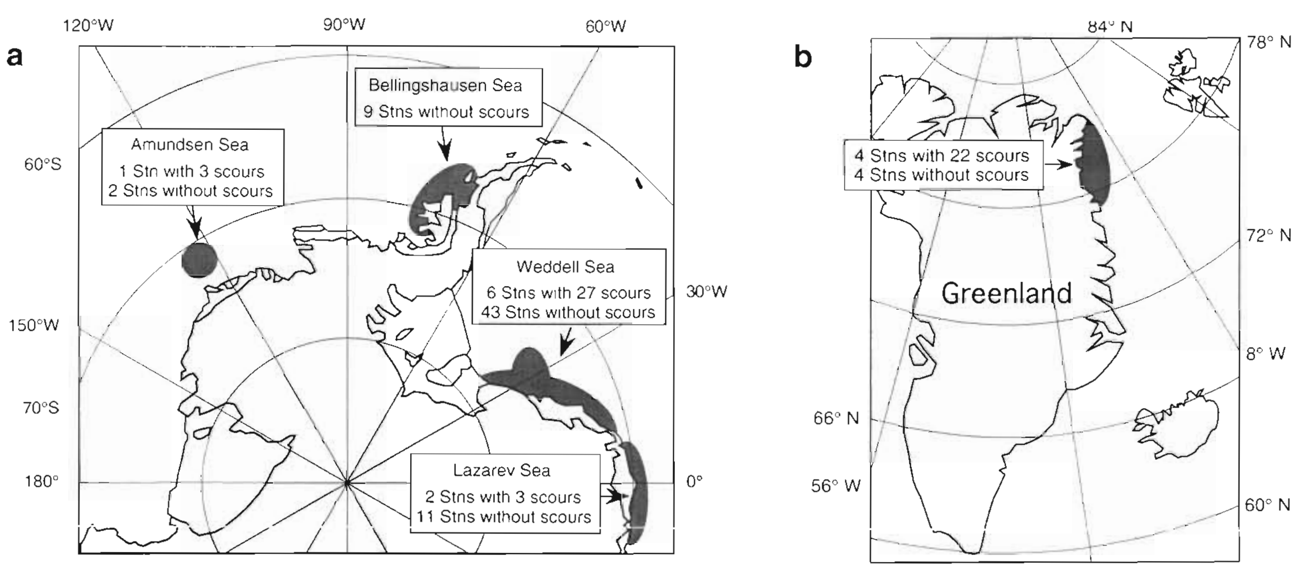

Fig. 1. Areas of investigation: (a) Antarctic, (b) off northeast Greenland

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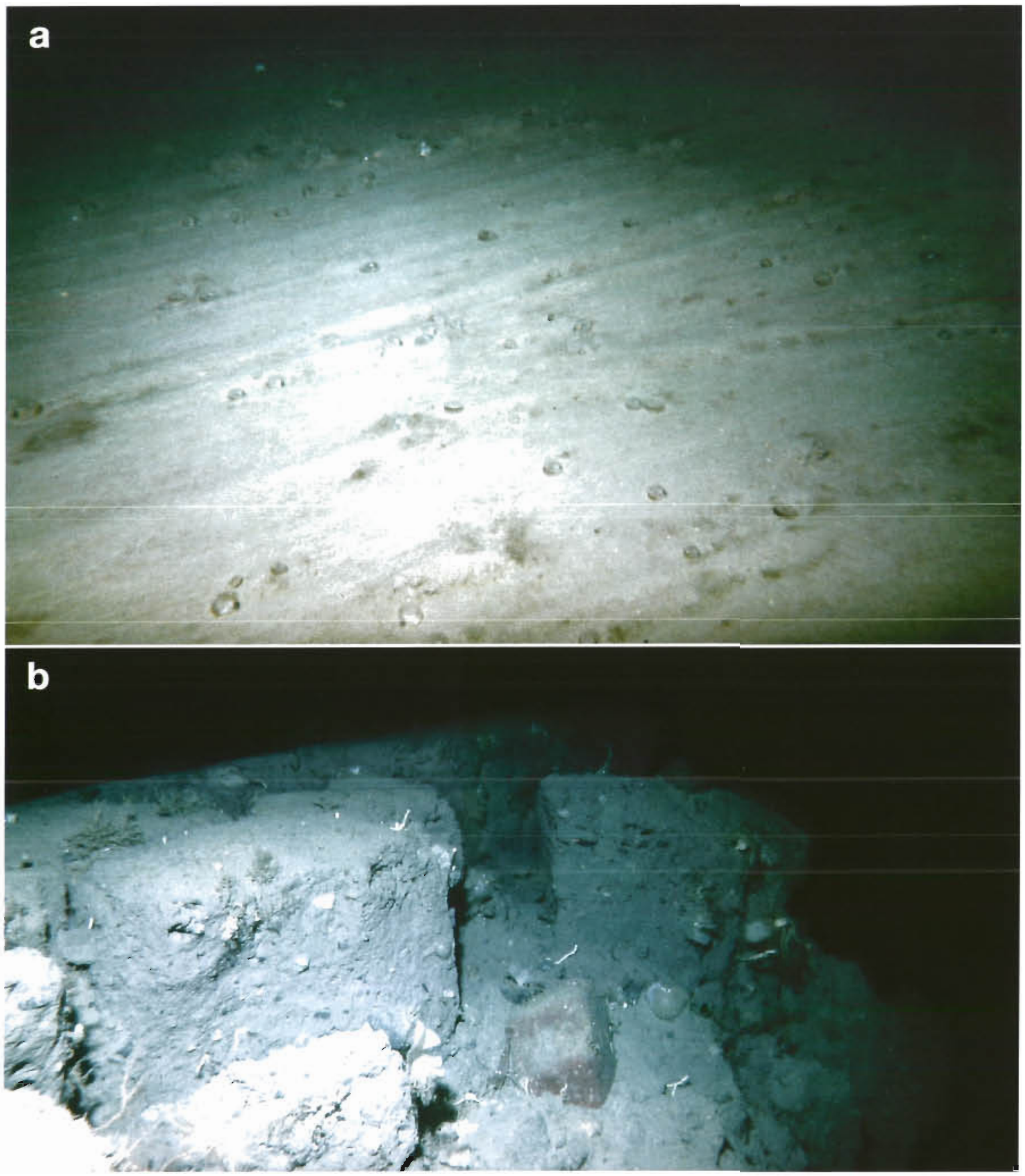

Fig. 2. (a) Sediment surface honed by a horizontally drifting iceberg (off northeast Greenland, 79° 11' N, 15° 09' W, 51 m). First pioneer organism was the motile pectinid bivalve *Arctinula greenlandica*. Width in the foreground: ~80 cm. (b) Crumbling edge of a gouge mark (Amundsen Sea, 72° 50' S, 121° 16' W, 384 m). Width in the foreground: ~100 cm

82° N, 6° W to 17° W; Fig. 1b) between 1988 and 1993. Scour marks were found virtually at all depths on the Antarctic shelf (< 500 m), but only above 70 m in the Arctic. The abundances of all visible organisms were analysed.

Results and discussion. Apparent irregularities in the benthic structure were identified as iceberg scour marks under 2 assumptions:

(1) The fine-scale bottom topography revealed an otherwise inexplicable mechanical disturbance, resulting in parallel gouge marks ≤1 m deep (Fig. 2a) or resembling an irregularly ploughed field. Such marks were occasionally bordered by embankments which had begun to crumble (Fig. 2b). Here, as a consequence, all sessile organisms had been eradicated.

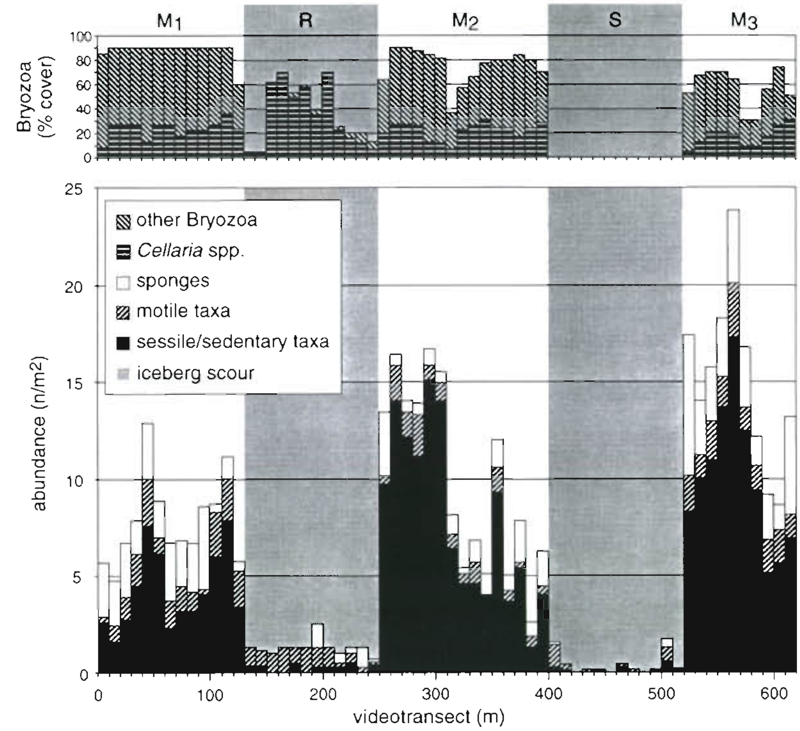

Fig. 3. Underwater video strip transect (Antarctic, Weddell Sea, 71° 23' S, 13° 57' W, 307 m). M_1–M_3 indicate sections with a mature and diverse species assemblage consisting mainly of sessile suspension feeders; dominant 'sessile/sedentary taxa': *Thouarella* sp. (Gorgonaria), *Abyssocucumis liouvillei* (Holothuroidea), *Synoicium addreanum* (Ascidiacea), *Astrotoma agassizii* (Ophiuroidea), Cephalodiscidae spp. (Pterobranchia). Most abundant 'motile taxa': *Pomachocrinus kerguelensis* (Crinoidea), Asteroidea spp., Cidaridae (Echinoidea). 'Sponges': demospongiae (e.g. *Stylocordyla borealis*, *Cinachyra barbata*) and hexactinellida (e.g. *Rossella racovitzae*, *R. nuda*, *R. antarctica*). S: a recent scour mark which was almost devoid of benthos with the exception of a hexactinellid sponge lying in a small depression. R: scour mark partly recolonised by motile species (e.g. the crinoid *Pomachocrinus kerguelensis*) and by the bryozoan *Cellaria* sp. with a higher cover in most parts of R than in M_1–M_3

Table 1. Most common pioneer taxa which occur in much higher abundances within (Within d.a.) the disturbed areas than outside (Outside d.a.) (Weddell and Lazarev Seas, Antarctica). For some taxa only the total number of specimens calculated per unit area (= relative abundance) within and/or outside the disturbed area and the range of abundance (in parentheses) due to the low abundances. For the other data sets the medians were calculated with the 25 and 75% percentiles, since the abundances were sufficiently high

Taxa		Within d.a.	Outside d.a.
Ophiuroidea sp.	Median (n m^{-2})	147	59
	25% percentile (n m^{-2})	103	48
	75% percentile (n m^{-2})	218	74
	Area units investigated	7 (= 5.7 m^2)	58 (= 53.1 m^2)
Stylocordyla borealis (stalked demosponge)	Rel. abundance (n m^{-2})	3.9	0.3
	Range (n m^{-2})	0.0–14.3	0.0–1.8
	Area units investigated	23 (= 12.7 m^2)	53 (= 28.4 m^2)
Latrunculia apicalis (demosponge)	Rel. abundance (n m^{-2})	2.3	0.2
	Range (n m^{-2})	0.0–13.3	0.0–1.1
	Area units investigated	75 (= 65.9 m^2)	77 (= 68.4 m^2)
Pista sp. (terebellid polychaete)	Rel. abundance (n m^{-2})	16.6	0.03
	Range (n m^{-2})	4.3-22.1	0.0-3.0
	Median (n m^{-2})	19.8	–
	25% percentile (n m^{-2})	11.5	–
	75% percentile	22.1	–
	Area units investigated	6 (= 14.1 m^2)	234 (= 684.8 m^2)
Young specimens of *Synoicium addreanum* (compound ascidian)	Rel. abundance (n m^{-2})	59.7	1.3
	Range (n m^{-2})	37.4–82.9	0.0–43.4
	Median (n m^{-2})	61.7	–
	25% percentile (n m^{-2})	40.4	–
	75% percentile	74.4	–
	Area units investigated	6 (= 14.1 m^2)	234 (= 684.8 m^2)

(2) Areas were classified as having been disturbed by icebergs if an abrupt change in the epibenthic structure could not be explained by other physical or biological processes (Figs. 3 & 4a–c). In this case ridges gouged by icebergs had already eroded. An alternative explanation is the vertical settlement of an iceberg caused by a rising and falling tide.

First immigrants after such events were motile organisms such as fish, echinoderms, or bivalves (Fig. 2a). Initial recolonising sessile species were hydrozoans (stylasteridae), sabellid polychaetes, different compound ascidians, and bryozoans (e.g. *Camptoplites tricornis*, Antarctica). Occasionally some benthic organisms occurred in higher densities within the disturbed areas than outside those areas (Table 1). On the crumbling edges of gouge marks, locally high numbers of sea anemones and 1 demosponge species were observed in the Antarctic, while in the Arctic dense concentrations of an unidentified infaunal polychaete appeared. This mass occurrence of only a very few species can be explained by their explosive growth or an especially successful recruitment combined with the lack of competition for space and food.

In Antarctica, dense patches of sponges (e.g. *Rossella racovitzae*, *R. nuda*, *Scolymastia joubini*, *Cinachyra barbata*), of which some are extremely slow growing, were frequently observed on small slopes. This can be interpreted as a late recolonisation of exceptionally deep gouge marks, possibly favoured by localised small-scale upwelling. Also, high concentrations of bryozoan debris and sponge spicule mats (Fig. 4b), the possible consequence of iceberg grounding, may constitute the substratum for specifically adapted benthic assemblages.

Quantitative analysis shows the relevance of iceberg scouring for the benthos over a long time span (Table 2). Key organisms in Antarctica, particularly sponges (Dayton 1978), are slow growing (Clarke 1983, Arntz et al. 1994) and other species depend on these (Gutt & Starmans 1996). Consequently, a mature benthic community will theoretically not become established within a period of 230 yr in the Antarctic and 53 yr in the Arctic area of investigation. However, the grounding of icebergs is patchy with the probability being higher in shallow areas, where the richest species assemblages occur. This may be why we find relatively small glass sponges in areas of the Weddell and Lazarev Seas which are prone to scouring, while much larger individuals of the same species were found in shallow areas of the Ross Sea (Dayton 1972) which are not likely to be affected by icebergs.

Based on this, the question arises whether the perpetual change between such destruction and recolonisation is one of the major causes for the development of the high between-habitat biodiversity, especially in Antarctica (Dayton et al. 1994).

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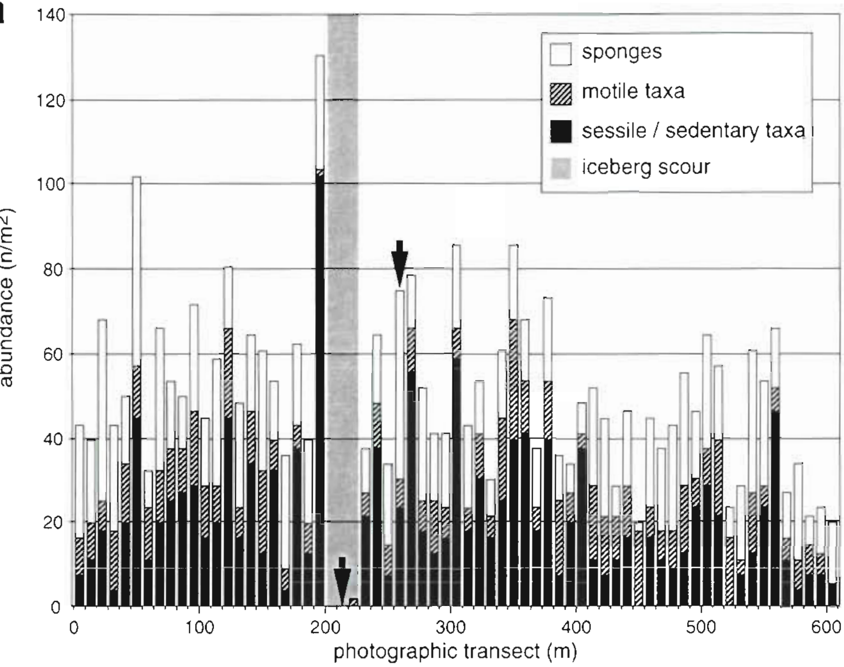

Fig. 4. Photographic transect in the Weddell Sea (71° 06' S, 11° 39' W, 194 m). (a) Abundances of macrobenthic organisms along the transect; each bar represents a photograph covering an area of 0.56 m^2 Dominant 'sessile/sedentary taxa': *Synoicium addreanum*, Didemnidae spp. (both Ascidiacea), Ascidiacea sp., Sabellidae sp. (Polychaeta). Most abundant 'motile taxa': Ophiuroidea spp., *Notocidaris* sp. (Echinoidea), *Pomachocrinus kerguelensis* (Crinoidea), Pycnogonida spp. 'Sponges': *Monosyringa longispina*, *Cinachyra barbata*, *Tedania tantula*, which were disrupted by a gouge mark between 200 and 230 m. Arrows indicate position of photographs (b & c, opposite)

Table 2. Absolute and relative abundance of iceberg scours in the Antarctic and Arctic areas of investigation

	Antarctic	Arctic
Areas of investigation	Lazarev Sea Southeastern Weddell Sea Amundsen Sea Bellingshausen Sea	Northeast Greenland
Investigated depth range (m)	100-500	0-70
Total no. of stations investigated	74[a]	8[b]
Area photographed (m^2)	2107	0
Area video-taped (m^2)	11608	4275
Stations with gouge marks	9	4
Total no. of gouge marks found	33	22
Maximum no. of gouge marks per station	20	9
Estimated maximum age of the gouge marks (yr)	10	5
Disturbed area (m^2)	603	406
Disturbed area (%)	4.4	9.5
Period (yr) in which statistically the area is disturbed once	230	53

[a]30 additional stations below 500 m water depth have been investigated, however, without any indication of gouge marks
[b]17 additional stations below 70 m water depth have been investigated, however, without any indication of gouge marks

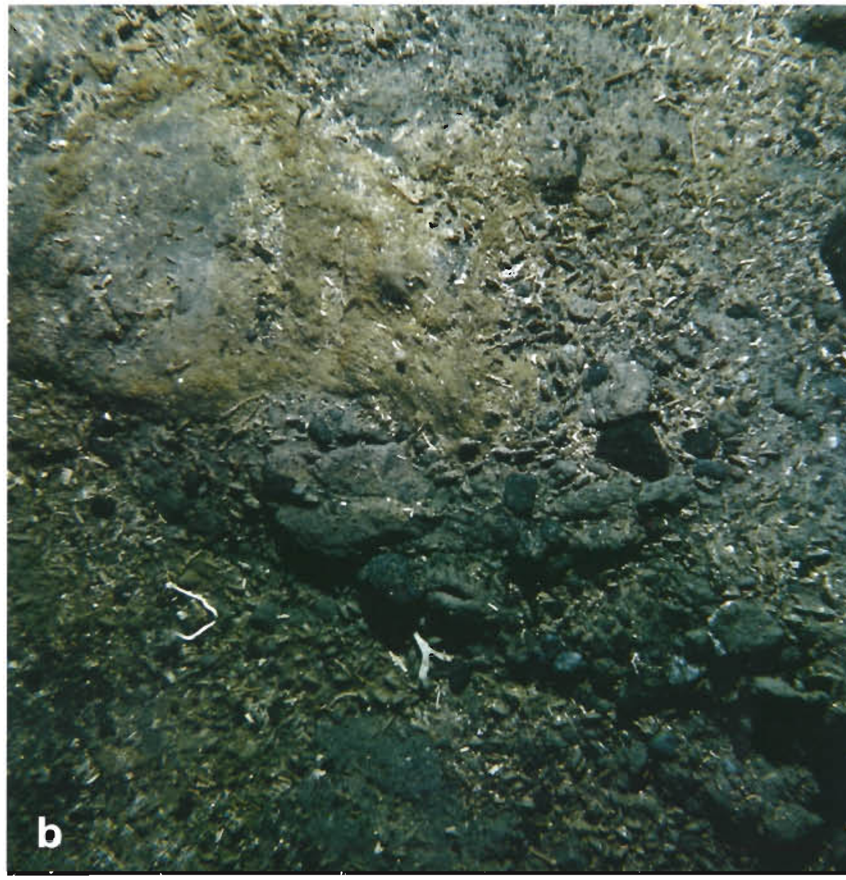

Fig. 4b. Iceberg gouge mark not yet re-colonised. The sediment indicated a mechanical disturbance and consisted of a high proportion of gravel and sponge spicule mats

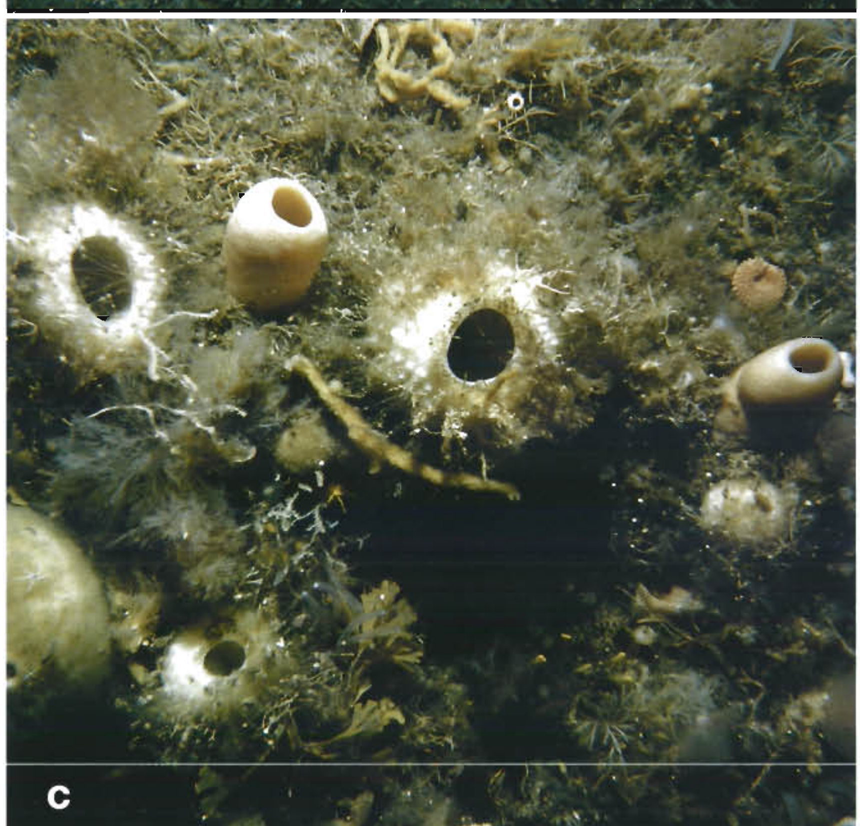

Fig. 4c. Area adjacent to the gouge mark showing a rich and diverse epibenthic assemblage which totally covered the sediment. Sponges: *Rossella racovitzae*, *Scolymastia joubini*, *Isodictya* sp., *Cinachyra barbata*, *Monosyringa longispina*, *Tedania tantula*; Bryozoa: Cheilostomata sp. (Bryozoa), *Cellarinella* sp., *Austroflustra vulgaris*, *Reteporella vulgaris*; others: Gorgonaria, Dendrochirotida (Holothuroidea), different compounds Ascidiacea, Anthozoa, Pterobranchia

A slight increase in the frequency of iceberg grounding in the Antarctic due to global warming (Houghton et al. 1990) could probably be buffered by the benthic system due to its adaptation to natural catastrophic events. However, we predict that above a certain threshold the benthic resilience will not suffice to prevent serious damage or collapse of the entire community. For the Arctic we also foresee serious but less dramatic consequences because of the lower species number (Dayton et al. 1994) and less complex relationships as well as the lower number of large icebergs (Dayton 1990).

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