

6.12. Sea-ice Fauna

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1. Introduction

1.1. Sea Ice as a habitat

Sea ice is a dominant feature of the Southern Ocean marine ecosystem, playing a central role in physical processes and providing an important habitat for organisms ranging in size from viruses to seals. The Southern Ocean experiences extreme seasonal change in its sea ice extent, much of the ice is over very deep water and more than 80% breaks out each year. Maximum ice coverage reaches about 19 million km² in September each year, while a minimum of approximately 3 million km² occurs in February (Map 1). There are important regional differences in sea ice extent and area, with an overall increase in sea ice extent of $17,100 \pm 2300 \text{ km}^2 \text{ yr}^{-1}$. This positive trend has been most pronounced in the Ross Sea, with lesser contributions from the Weddell Sea and Indian Ocean, while the Bellingshausen/Amundsen Seas have experienced significant sea ice decreases of 5 to 6 % per decade (Parkinson & Cavalieri 2012; Stammerjohn *et al.* 2012). This seasonality in ice coverage, coupled with the strong annual cycle in irradiance, regulates biological cycles in ice-covered waters.

The habitats that exist within the sea ice zone can be classified as:

(1) the *sea ice proper*, consisting of the ice crystal matrix interspersed with the brine channel system;

(2) the *ice-water interface*, where seawater flows across the bottom of the ice and there is usually free exchange of nutrients and gases between the top of the water column and the bottom few centimetres of ice;

(3) *platelet ice*, common in the Weddell Sea, which consists of loose layers of ice forming deep aggregations under the solid ice cover; and

(4) *slush ice*, those regions, usually found in summer, where seawater has infiltrated middle layers of ice, creating a slurry.

Quiet hydrological conditions favour the formation of *congelation ice* that results from the growth of large, elongated (columnar) crystals perpendicular to

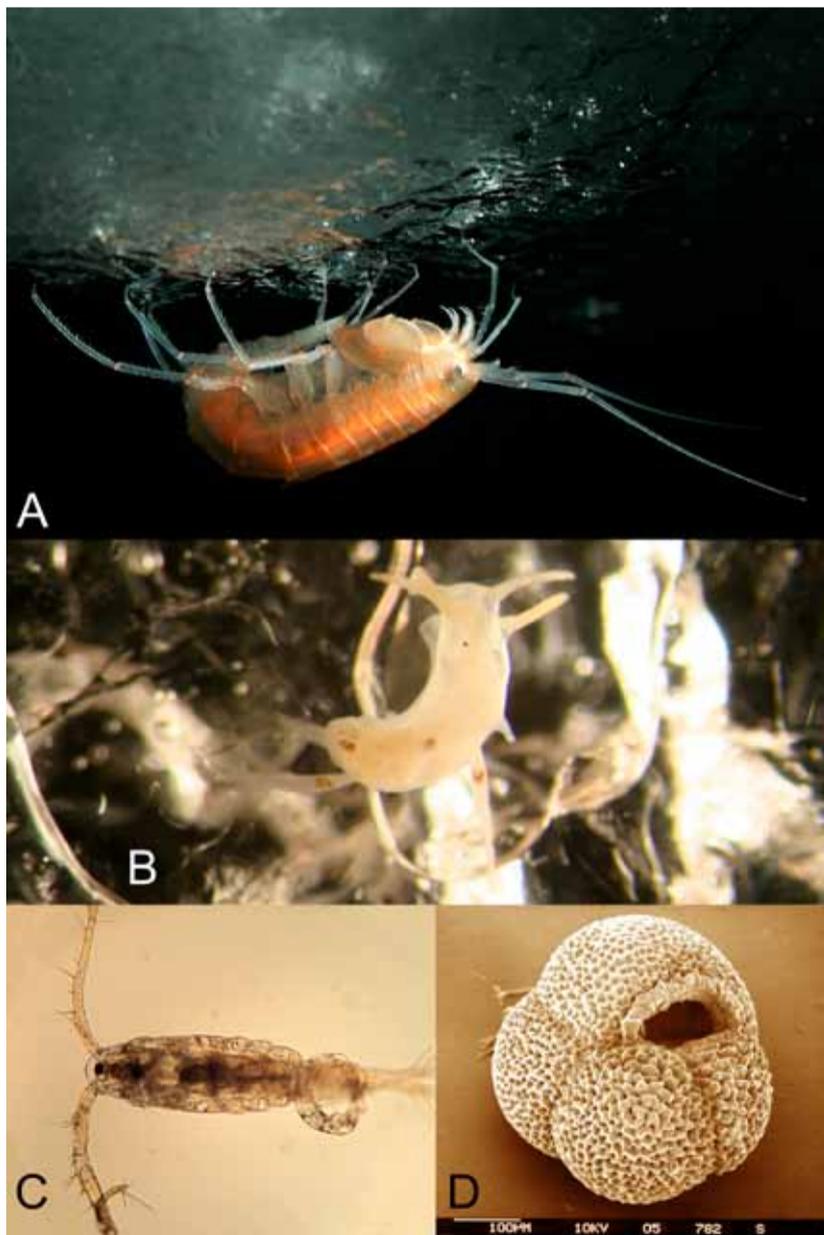
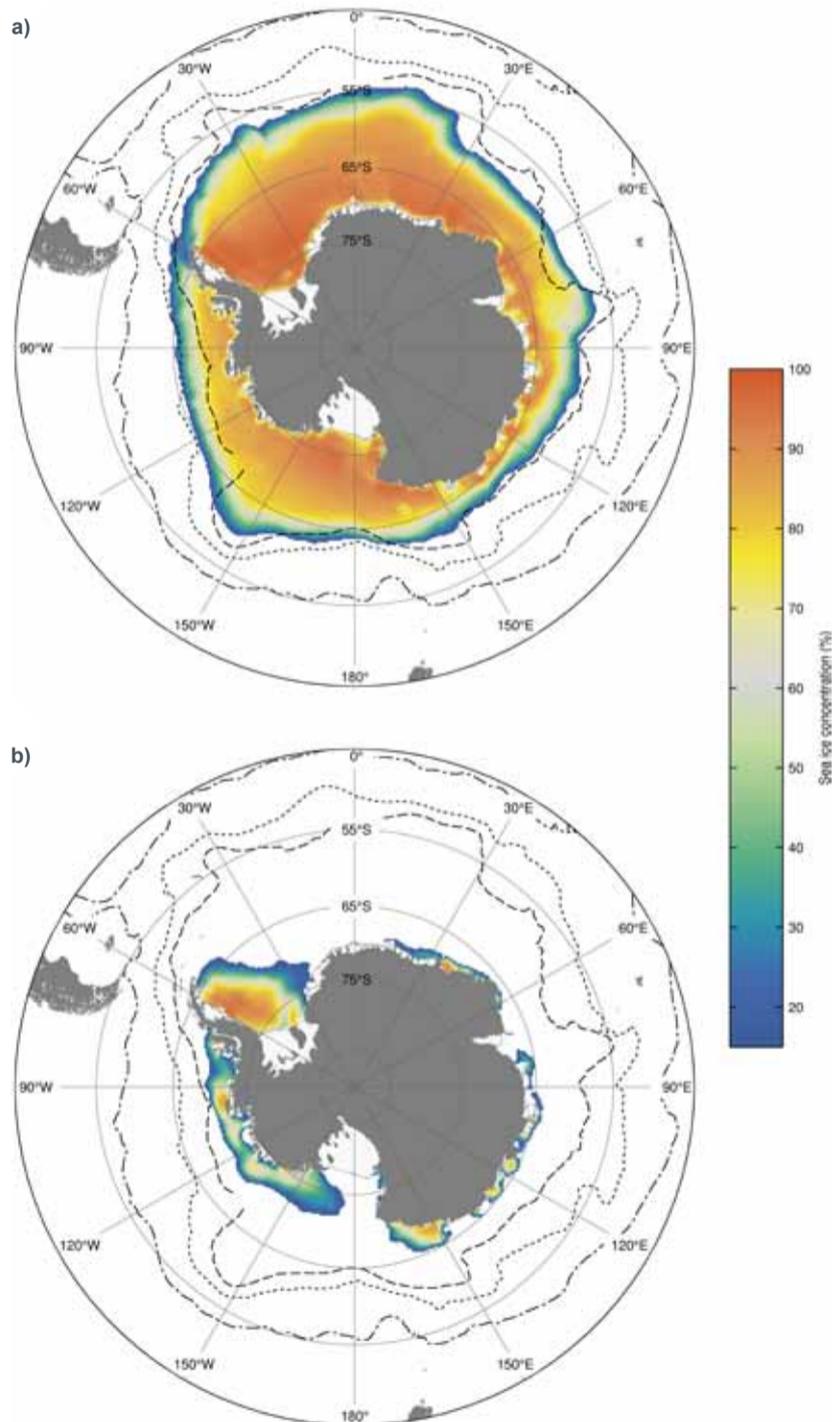


Photo 1 Examples of organisms associated with sea ice. (A) Amphipoda: *Eusirus microps* Walker, 1906 (det. C. d'Udekem d'Acoz); Weddell Sea (RV *Polarstern*, ISPOL drift station 2004–05), Image: I. Arndt, © Rupert Krapp, Norwegian Polar Institute. (B) Gastropoda: *Tergipes antarcticus* Pelseneer, 1903, Image © Rainer Kiko. (C) Copepoda: *Paralabidocera antarctica* (I.C. Thompson, 1898), adult male, Image © Sarah Payne. (D) Foraminifera: *Neogloboquadrina pachyderma* (Ehrenberg, 1861), Image: Hannes Grobe © AWI.

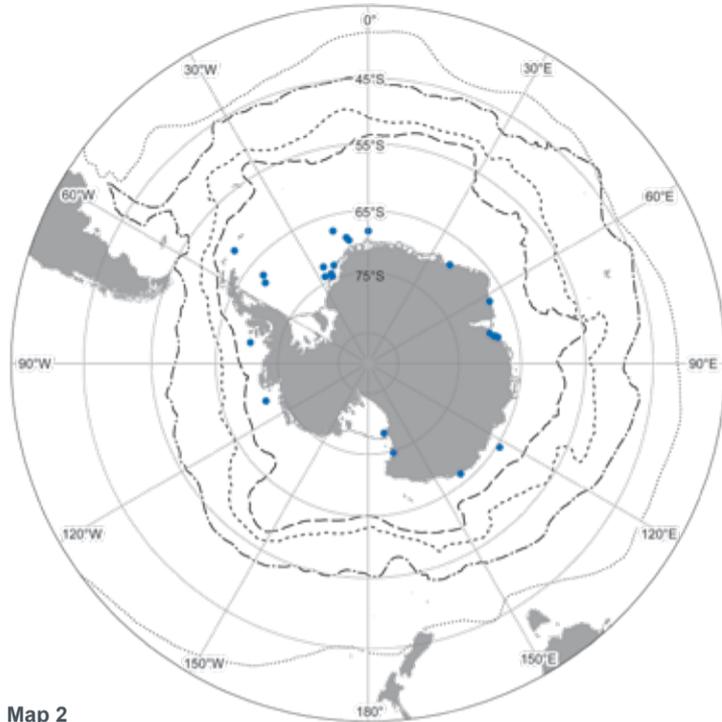
the underside of the ice sheet. *Land-fast ice* generally forms this way, resulting in sea ice that is 'fastened' to the coast or to the sea floor over shallow parts of the continental shelf. Alternatively, turbulent conditions promote consolidation of agglomerations of *frazil ice* crystals into sheets of granular ice. *Pack ice* is moved across the ocean by wind and currents and is predominantly annual, generally reaching a maximum of 2 m thick. The only region that experiences significant perennial pack ice is the western Weddell Sea, which accounts for about 80% of multiyear ice in Antarctica. The Weddell Gyre, a current that circulates clockwise, traps sea ice along the eastern side of the Antarctic Peninsula, where it survives for more than one year. Eventually ice in the Weddell Gyre is transported further north, where it disperses into the ocean and melts. A gyre in the Ross Sea traps a smaller amount of ice in a similar fashion. Movement of sea ice in the Southern Ocean is controlled by the prevailing currents and wind belts, resulting in a dominance of eastward flow within the Antarctic Circumpolar Current and a more westward flow within the Antarctic Coastal Current. These patterns reflect the large-scale/long-term ocean circulation, which is a response to wind stress (i.e., prevailing easterly winds close to the coast and westerlies to the north).



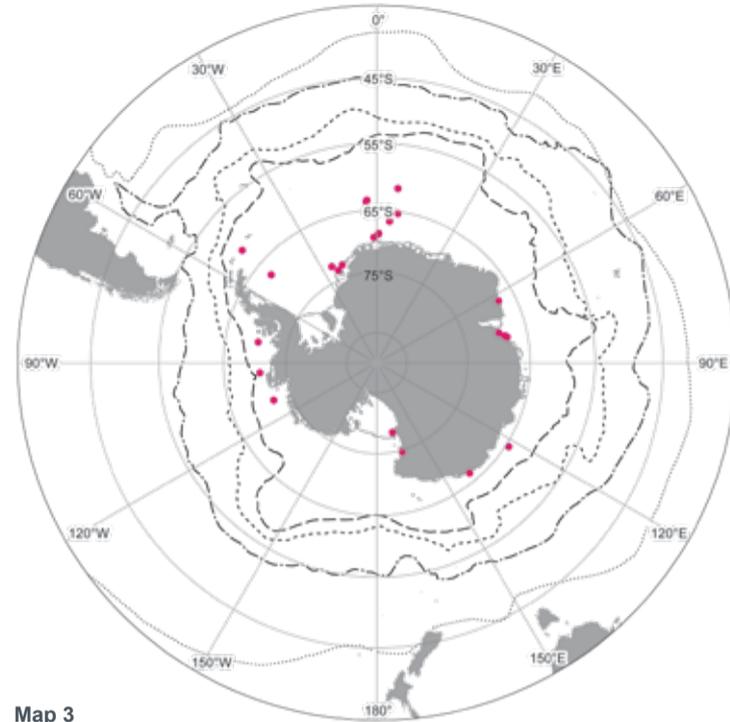
Sea-ice Fauna Map 1 Sea ice concentration in September (a) and February (b). Source: http://earthobservatory.nasa.gov/Features/WorldOfChange/sea_ice_south.php

1.2. Sampling sea ice

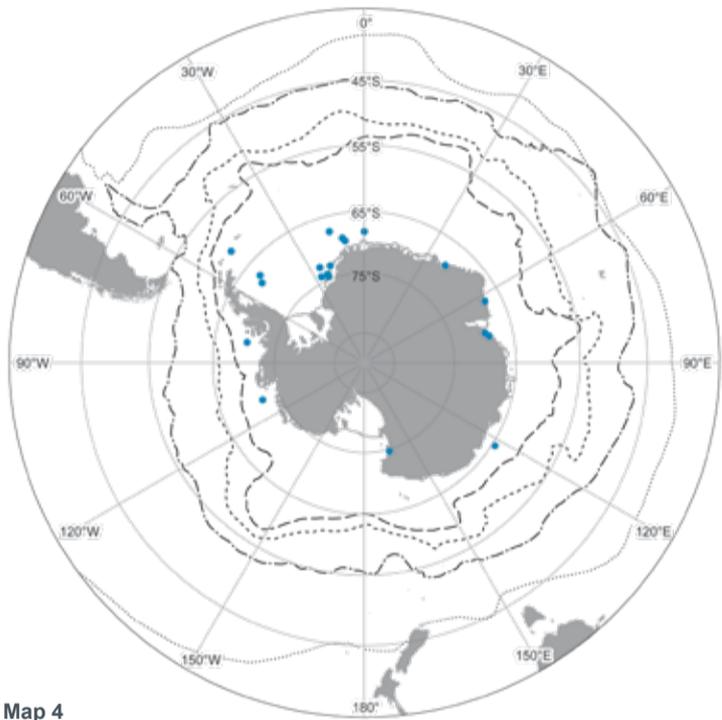
Various methods are used to sample sea ice and its associated organisms (see Eicken *et al.* 2009). Fauna that are usually found in association with the ice matrix proper are generally sampled with simple barrel corers (e.g. SIPRE corer, Kovacs corer) that take a discrete unit of ice, which is then melted and the organisms extracted. Distributions of sea ice organisms can be extremely patchy, both horizontally and vertically, and it is likely that ecologically mean-



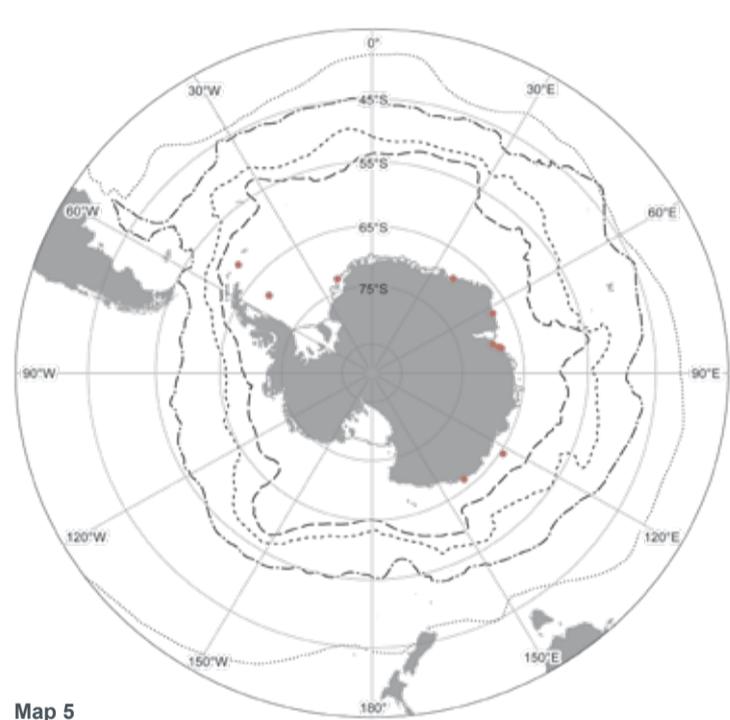
Map 2
● Calanoid copepods



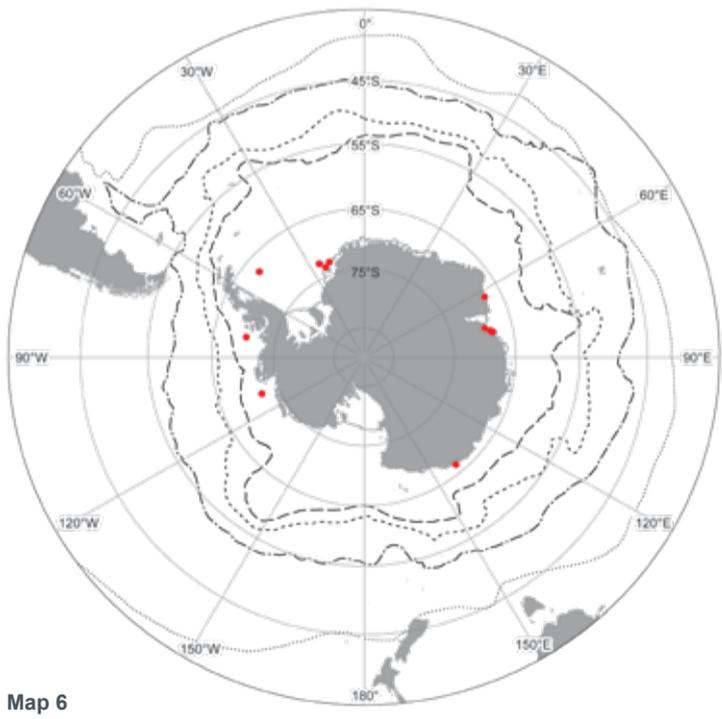
Map 3
● Harpacticoid copepods



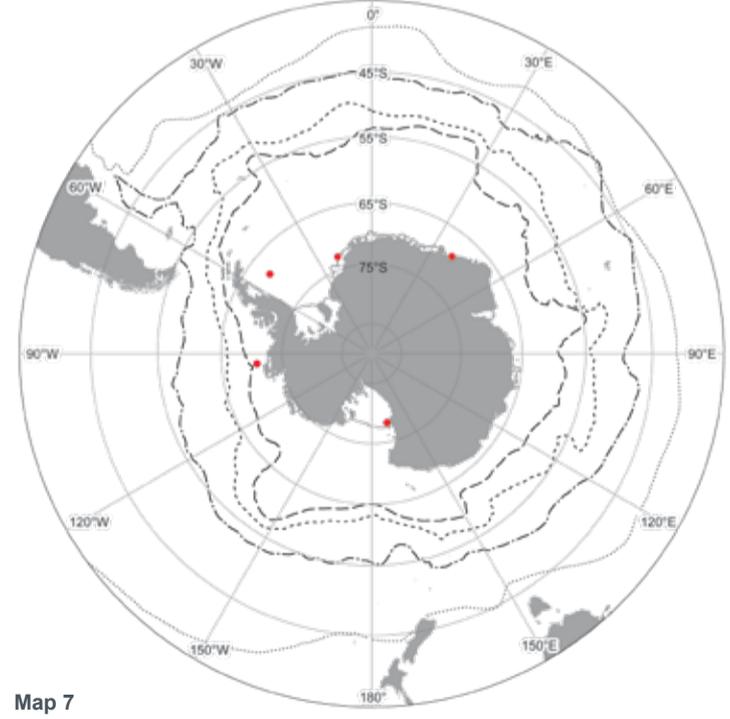
Map 4
● *Stephos longipes*



Map 5
● *Paralabidocera antarctica*



Map 6
● *Drescheriella glacialis*



Map 7
● Cyclopoid copepods

Sea-ice Fauna Maps 2–7 Distribution of sympagic copepods. Map 2. Presence of calanoid copepods in sea ice. Map 3. Presence of harpacticoid copepods in sea ice. Map 4. Presence of the calanoid copepod *Stephos longipes* in sea ice. Map 5. Presence of the calanoid copepod *Paralabidocera antarctica* in sea ice. Map 6. Presence of the harpacticoid copepod *Drescheriella glacialis* in sea ice. Map 7. Presence of cyclopoid copepods in sea ice.

ingful scales for many sea ice organisms are of the order of millimetres; i.e. at a sub-corer scale. Therefore, while ice corers are a relatively cost-effective method for sampling sea ice, they are possibly failing to sample the fauna at appropriate biological scales (Swadling *et al.* 1997a). Loose ice at the ice–water interface is commonly sampled by divers scraping nets and other implements along the under ice surface. In many cases, these samples are qualitative only, which, though adding useful information about species' distributions, cannot be used to determine their abundances accurately. Increasing use of remotely operated vehicles and autonomous underwater vehicles will improve our ability to monitor the under-ice habitat and observe associated organisms in situ.

2. Patterns of distribution

Sea ice provides habitat for high standing stocks of bacteria, algae, protists and invertebrates (Photo 1; Bluhm *et al.* 2009). The most commonly encountered invertebrates, in terms of both presence and abundance, are crustaceans, principally copepods, which live either within the brine channel system of the ice-crystal matrix or at the under-ice surface. Amphipods and krill are also found living just under the sea ice; particularly around creviced and rough surfaces where they can be protected from predators while foraging on the abundant ice algae that can be present. Other groups that have been observed include foraminiferans, turbellarians, nematodes and gastropods. Ctenophores, *Callianira antarctica* and possibly a species in the genus *Euplokamis*, have also been recorded from sea ice (Kiko *et al.* 2008a; Kramer *et al.* 2011). In the Southern Ocean the ephemeral nature of sea ice means that most species associate with ice for only a part of their life cycle, though the extent of the association varies between species and, possibly, within species between geographic locations (Loots *et al.* 2009).

2.1. Copepods

Calanoid (Map 2) and harpacticoid (Map 3) copepods dominate Antarctic sea ice, sometimes occurring in numbers up to hundreds of thousands per square metre of ice (Swadling *et al.* 1997a, 2000; Schnack-Schiel *et al.* 2001). To date, the highest abundances have been recorded from fast ice in Prydz Bay (68°34'S, 77°58'E) (Swadling *et al.* 1997a, 2000). The three most frequently observed copepod species, the calanoids *Stephos longipes* Giesbrecht, 1902 and *Paralabidocera antarctica* (I.C. Thompson, 1898) (Photo 1c) and the harpacticoid *Drescheriella glacialis* Dahms & Dieckmann, 1987, appear to be circum-Antarctic in distribution and possibly endemic to the sea ice habitat, although there are large gaps around the continent where no samples of sea ice have so far been collected for biological analysis.

Stephos longipes (Map 4) is the dominant calanoid in the Weddell, Amundsen and Bellingshausen Seas, where it reaches up to 200,000 individuals m⁻² (Schnack-Schiel *et al.* 1995, 1998), while in Prydz Bay and Lutzow-Holm Bay (69°10'S, 39°35'E), it has not been observed to exceed 20,000 individuals m⁻² (Hoshiai & Tanimura 1986; Swadling *et al.* 2000). This species has been found in the ice matrix, as well as slushy ice in summer and platelet ice in late spring (Schnack-Schiel *et al.* 1998; Thomas *et al.* 1998; Günther *et al.* 1999), although in general it is more common in the ice matrix. The peak in abundance of *S. longipes* (up to 163 individuals L⁻¹) in the Amundsen Sea (73°S, 112°W) coincided with high chlorophyll concentrations (up to 377 mg L⁻¹) in the saline slush layer in the middle of the ice (Thomas *et al.* 1998). Harpacticoids (up to 200 individuals L⁻¹) were also noted, although no identifications were provided. This is one of few observations where considerable numbers of meiofauna have been shown to inhabit second or multiyear ice in Antarctica.

Paralabidocera antarctica (Map 5) is the dominant copepod in fast ice of eastern Antarctica (Hoshiai & Tanimura 1986; Tanimura *et al.* 1996; Swadling *et al.* 1997a, 2000). Nauplii number up to 900,000 individuals m⁻² in autumn and winter, while young copepodite stages reach up to 200,000 individuals m⁻². Older stages leave the sea ice matrix but remain in close contact with the ice–water interface, where adults have been recorded at up to 200,000 individuals m⁻³ (Tanimura *et al.* 1984). This species has been observed in lower abundance in the Weddell Sea; up to 26,000 individuals m⁻³ in platelet ice in the Drescher Inlet (72°50'S, 19°02'W) (Günther *et al.* 1999). A congener of *Paralabidocera antarctica*, *Paralabidocera grandispina* Waghorn, 1979, was observed in very large numbers (>500,000 individuals m⁻³) in platelet ice collected from a summer tide crack on the Ross Ice Shelf (81°30'S, 175°00'W) (Waghorn & Knox 1988). To date, this is the only published record of *P. grandispina* and almost nothing is known about its ecology. The species was separated from *Paralabidocera antarctica* on the basis of an asymmetrical genital segment in the female, as well as a long terminal spine and well-developed spinose knob on the inner proximal border of the male fifth leg (Waghorn 1979). A third species of *Paralabidocera*, *P. separabilis* Brodsky and Zvereva, 1976, has been described from open water in a fjord near the Bunge Oasis (66°17'S, 100°47'E), East Antarctica (Brodsky & Zvereva 1976). The females of this third species have a genital segment that is almost symmetrical and lacks lobes, while males lack the spinose knob on their fifth legs (Waghorn 1979). As numerous adults were sampled from the surface waters in the summer, it is possible that the younger stages had been present in the ice cover during winter/spring, although no further observations of *P. separabilis* have been made.

Other calanoid copepods have been sampled from the sea ice, although evidence points to them being occasional visitors that graze on the ice surfaces but don't undergo development within the ice matrix. The most frequently

recorded species include *Ctenocalanus citer* Heron & Bowman, 1971, *Calanus propinquus* Brady, 1883, *Metridia gerlachei* Giesbrecht, 1902 and *Microcalanus pygmaeus* (G.O. Sars, 1900). *Ctenocalanus citer* (originally cited as *Ctenocalanus vanus* Giesbrecht, 1888) reached up to 1000 individuals m⁻² in fast ice in Lutzow-Holm Bay (Hoshiai & Tanimura 1986), while *C. propinquus* is a biomass dominant species in the Southern Ocean whose association with sea ice is equivocal and may have been overemphasised in the past.

The most common and widely occurring harpacticoid copepod in Antarctic sea ice is *Drescheriella glacialis* Dahms & Dieckmann, 1987 (Map 6). This species has a circum-Antarctic distribution and all stages are found in the ice (Dahms *et al.* 1990, Swadling 2001). It is common in the Weddell, Bellingshausen (71°S, 85°W) and Amundsen Seas, reaching high abundances (168 individuals L⁻¹) in the middle slush layers (Schnack-Schiel *et al.* 1998, 2001, 2008, Thomas *et al.* 1998), and up to 190,000 individuals m⁻² in Prydz Bay fast ice (Swadling 2001). *Harpacticus furcatus* Lang, 1936 is probably the second most common harpacticoid species observed in sea ice, though not in the Weddell Sea, and few measurements of abundance have been made: Costanzo *et al.* (2002) recorded up to 60 individuals L⁻¹ in sea ice of Terra Nova Bay (74°50'S, 164°30'E). *Microsetella rosea* (Dana, 1847) has been observed in association with sea ice on several occasions in the Indian Ocean. Other harpacticoids have been observed far less frequently. This is probably due, in part, to inadequate taxonomy, as individuals are often merely lumped together in the category "harpacticoids." One exception is *Tisbe prolata* Waghorn, 1979, observed in platelet ice in a tide crack on the Ross Ice Shelf, where it reached 75,000 individuals m⁻³ (Waghorn & Knox 1988). Other harpacticoid species that have been recorded on fewer occasions include *Glabrotelson antarcticum* (Dahms & Schminke, 1992), *Drescheriella racovitzai* (Giesbrecht, 1902), *Xouthous antarcticus* (Giesbrecht, 1902), *Nitokra gracilimana* Giesbrecht, 1902 and *Diarthrodes* sp.

To date, it appears that few cyclopoid copepods are strongly associated with sea ice (Map 7), though there have been regular collections of three species from ice cores or at the ice–water interface, namely *Oithona similis* Claus, 1866, *Oncaea curvata* Giesbrecht, 1902 and *Pseudocyclopina belgicae* (Giesbrecht, 1902). *Oithona similis* and *O. curvata* are the dominant small copepods in Antarctic shelf waters, where they occur in high numbers (up to 5000 individuals m⁻³; Metz 1995; Swadling *et al.* 1997b). At an ice station located on drifting perennial ice at the western rim of the Weddell Sea Gyre, *O. similis* and *P. belgicae* were observed in small numbers from samples scraped from the bottom of the ice (Menshinina & Melnikov 1995). *Pseudocyclopina belgicae* has also been recorded from a summer tide crack on the Ross Ice Shelf, where its abundance in late November reached 225,000 individuals m⁻³ (Waghorn & Knox 1988). The status of *O. similis* as an ice-associated species requires some interpretation. Tucker & Burton (1988) suggested that *O. similis* is part of the "true" ice fauna, as both adults and juveniles were found at the ice–water interface, while only juveniles were present in the plankton in October and December. Gruzov *et al.* (1967) and El-Sayed (1971) also listed *O. similis* as part of the true ice fauna. Further, the species is an important prey item of fry of the ice fish *Pagothenia borchgrevinki* (Boulenger, 1902), accounting for 30–70 % of identifiable gut contents (Hoshiai *et al.* 1989). Clearly this species must be often found near to the ice if not actually inhabiting the brine channel system. However, based on the relative abundances of planktonic *O. similis* versus those found in Antarctic ice cores, it is apparent that *O. similis* is not an obligate ice dweller. Similarly, the status of *O. curvata* is not clear. It was far less abundant in the stomach contents of the fry of *Pagothenia borchgrevinki* (<2%; Hoshiai *et al.* 1989), but it is often recorded from ice cores in low numbers.

2.2. Amphipods

Amphipods rarely if ever inhabit the ice crystal matrix, as they are excluded from this habitat by their large size. Most of the taxa recorded near the sea ice are from the predominantly benthic suborder Gammaridea, with only one species, *Hyperia macrocephala* (Dana, 1853), from the pelagic suborder Hyperiea. At present, there is very little information available on the abundance of amphipods associated with Antarctic sea ice. Nevertheless, there are some species, in particular *Paramoera walkeri* (Stebbing, 1906), *Gondogeneia antarctica* (Chevreux, 1906) (cited as *Pontogeneia antarctica*) and *Pseudorchomene* cf. *plebs* (Hurley, 1965) (cited as *Orchomene* cf. *plebs*), which have been recorded in substantial numbers at the ice–water interface, where they probably feed on the under-ice algae. Divers scraping nets along the bottom of the sea ice in nearshore waters of Prydz Bay collected *Paramoera walkeri* and *Orchomene* cf. *plebs* at the ice–water interface from autumn through to late spring (Tucker & Burton 1988). At times these two species were so numerous that they almost covered the undersurface of the ice (Tucker & Burton 1988). Other amphipods recorded from the ice–water interface in Prydz Bay include *Orchomene* sp., *Hyperia macrocephala* and *Eusirus* cf. *fragilis* Birstein & M. Vinogradov, 1960 (Tucker & Burton 1988). These three taxa were represented by single catches of solitary individuals only.

Elsewhere along east Antarctica, Rakusa-Suszczewski (1972) collected *P. walkeri* from the ice–water interface offshore from Molodezvnaya Station (67°40'S, 45°50'E) in Enderby Land, between May and December, using a modified scraping/net device. Although not quantitative, numbers collected per sample ranged from <50 from May to July to >500 from August to December. Gruzov *et al.* (1967) observed up to 4500 *Cheirimedon similis* m⁻² (130 g WM m⁻²) (cited as *Orchomenopsis* sp.; De Broyer C. pers. com.) and *Paramoera walkeri* at the under-ice surface near Mirny Station (66°33'S, 93°00'E), while Gruzov (1977) noted *Cheirimedon similis* Thurston, 1974 (misidentified as Or-

chomene cavimanus Stebbing, 1888; De Broyer C. pers. com.) in pockets at the undersurface of the ice throughout the winter.

Observations of ice-associated amphipods in Antarctica at other locations are also sparse. Four species, *P. walkeri*, *Gondogeneia antarctica*, *Cheirimedon femoratus* (Pfeffer, 1888) and *Lepidepecreum cingulatum* K.H. Barnard, 1932, were observed in fast ice near Signy Island (60°43'S, 45°36'W), though only the abundance of *Gondogeneia antarctica* was documented: Up to 12,730 individuals m⁻³ were recorded at the ice–water interface, with juveniles accounting for 97% of the total (Richardson & Whitaker 1979). De Broyer *et al.* (2001) noted the presence of three species in ice in the eastern Weddell Sea, while Günther *et al.* (1999) sampled *Oradarea* sp., *Probolisca* sp. and *Cheirimedon similis* from Drescher Inlet (Weddell Sea). Explorations in the pack ice in the Weddell Sea applied SCUBA, baited traps and a Surface and Under Ice Trawl (SUIT) to catch amphipods in the sympagic zone and to record their feeding behaviour. Eusirid amphipods, including *Eusirus antarcticus* Thomson, 1880, *E. tridentatus* Bellan-Santini & Ledoyer, 1974 and *E. microps* Walker, 1906 (Photo 1a), all seem to be able to exploit the under-ice habitat during their life cycles (Krapp *et al.* 2008). Specimens were observed by divers to swim very close to the ice, even entering cracks and fissures on occasion. Further, laboratory observations showed that individuals would attach themselves to surfaces of artificially produced sea ice. Grazing experiments revealed the Eusirids to be predatory and carnivorous (Krapp *et al.* 2008). The second family observed in this study, a species of lysianassoid amphipods, identified as *Cheirimedon* cf. *femoratus*, did not appear to have a strong association with sea ice. Finally, on the Ross Ice Shelf *Probolisca* sp. reached up to 20,000 individuals m⁻³ in early December in the platelet ice of a tide crack (Waghorn & Knox 1988), but it is unknown whether this is the same species listed by Günther *et al.* (1999).

2.3. Euphausiids

Antarctic krill, *Euphausia superba* Dana, 1850, are found throughout the Southern Ocean, although they are not distributed uniformly. Over 50% of the biomass has been estimated to be in the southwest Atlantic sector (Atkinson *et al.* 2004). An early deployment of an ROV in the Weddell Sea filmed individuals from the undersurface of the ice down to 50 m depth between July and December (Marschall 1988). These surveys indicated that *E. superba* occurred almost exclusively in close association with the ice, where krill density was estimated to be 40–400 m⁻². During the same time only one to two individuals were caught in the water column. Juvenile Antarctic krill are strongly associated with ice, reaching up to 3000 individuals m⁻² in under-ice crevices in spring (Daly & Macaulay 1991). Schools of furciliae have been found with pieces of ice as small as 1.6 m diameter, while dense aggregations beneath bigger floes (10–20 m diameter), reached 106 individuals m⁻³ (Hamner *et al.* 1989). Detailed studies of larval krill during winter at the Palmer Long Term Ecological Research station revealed that larvae and juveniles occupied both the sea ice and the water column, but that the size structure was different in each environment, with animals captured by divers being larger than those captured with nets (Frazer *et al.* 2002). Daly (2004) examined the distribution of larval stages west of the Antarctic Peninsula and found that their abundance and depth distribution varied between locations and years. In autumn 2001, densities reached 5627 individuals m⁻² at stations furthest offshore and young stages (calyptopsis 2 to furcilia 2) were most abundant. The younger stages were concentrated between 50 and 200 m, while older stages (furcilia 3 to furcilia 6) were found between 25 and 100 m. Closer inshore, older larvae were more common and often concentrated in a narrow band near the surface. More recent surveys using Surface and Under Ice Trawls (SUIT) in the Lazarev Sea have documented an almost year round association of Antarctic krill with the under-ice habitat, particularly highlighting the presence of post-larval krill in winter (Flores *et al.* 2012).

Euphausia crystallorophias Holt & Tattersall, 1906 replaces *E. superba* as the dominant euphausiid in shelf waters (Pakhomov & Perissinotto 1996) and high Antarctic ecosystems (Boysen-Ennen *et al.* 1991). Its distribution does not extend northward beyond the Southern Antarctic Circumpolar Current Front (formerly Antarctic Divergence). Perhaps surprisingly, it appears that *E. crystallorophias* is not always found in strong association with sea ice. The species was originally named *E. crystallorophias*, which means 'exclusively a dweller beneath the roof of ice', because specimens were first known only from those caught through holes in the ice (Holt & Tattersall 1906, Brinton & Townsend 1991). *Euphausia crystallorophias* can form large swarms of up to 10,000 individuals m⁻³ in the 1 to 5 m band below the sea ice (O'Brien 1987), but it is also found in large numbers much deeper in the water column (e.g. Foster 1987).

2.4. Other meiofauna

To date, observations on sea ice fauna other than copepods are limited to a small number of studies that have occurred in the last decade. These observations highlight the need for improved sampling of the sea ice, including promoting opportunities to melt large quantities of thin and slush ice. Preservation of samples is also important, especially when considering small, soft-bodied animals such as acœl turbellarians. It is possible that these organisms have been overlooked in the past due to inappropriate preservation and/or the availability of inferior microscopes. As these techniques improve it is expected that numbers of both species and individuals associated with sea ice will increase.

The nudibranch gastropod *Tergipes antarcticus* Pelseneer, 1903 (Photo 1b) was first observed from sea ice in the Bellingshausen Sea (Pelseneer

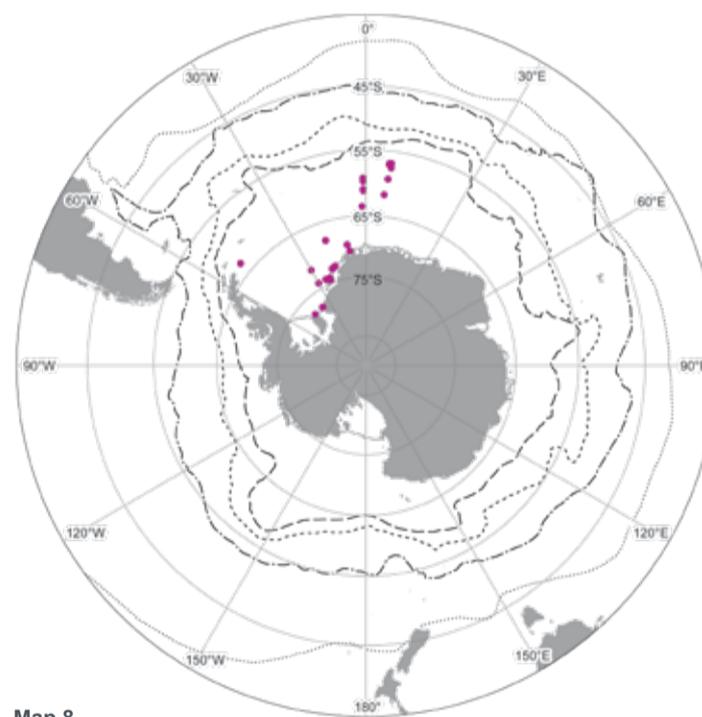
1903), and was not mentioned in the literature again until it was recorded by Kiko *et al.* (2008a) in sea ice from the Weddell Sea. Eggs clutches were isolated from ice samples, and both juveniles and adults have been sampled from sea ice (Kiko *et al.* 2008b), indicating that *T. antarcticus* is a true inhabitant of the Antarctic sea ice. This is further supported by observations that the adults are not able to swim actively and egg clutches are not buoyant (Kiko *et al.* 2008b), highlighting a diminished capacity for this nudibranch to embrace a pelagic life style. While not widely observed in sea ice yet, it appears that it can reach high abundances during its veliger larval stage (~12,000 individuals m⁻²; Kiko *et al.* 2008b), and occurs in lower numbers as juveniles and adults.

Platyhelminthes, of the acœl and rhabditophor types, were found in Weddell Sea pack ice in numbers up to 133,000 individuals m⁻², while lower maximum abundances have been recorded for the Indian Ocean (4500 individuals m⁻²; Kramer *et al.* 2011). Ctenophores of the species *Callianira antarctica* Chun, 1897 were observed in the pack ice of the Western Weddell Sea (Kiko *et al.* 2008a). A second species, possibly in the genus *Euplokamis*, has also been observed in winter pack ice samples from the Weddell Sea and the Indian Ocean (Kramer *et al.* 2011). Abundances of ctenophores tend to be low, and they appear to be more common in the Weddell Sea than in the Indian Ocean.

Finally, there has been only one observation of nematodes in Antarctic sea ice: *Geomonhystera glaciei* Blome & Riemann, 1999 was noted, along with three other unidentified taxa (Blome & Riemann 1999).

2.5. Foraminiferans

Neogloboquadrina pachyderma (Ehrenberg, 1861) (Photo 1d, Map 8) is a planktonic foraminiferan that has been found in high numbers living within the sea ice matrix. It is a heterotrophic protist that grazes on other protozoa, phytoplankton and bacteria. It is widely distributed and has been recorded from sea ice cores from the Weddell Sea (Spindler & Dieckmann 1986; Dieckmann *et al.* 1991), the Antarctic Peninsula (Lipps & Krebs 1974) and the Indian Ocean sector (Kramer *et al.* 2011). At all sites it shows a highly heterogeneous distribution, both horizontally and vertically in the sea ice. Over 1 million forams per m³ of melted sea ice have been recorded from the Weddell Sea (Dieckmann *et al.* 1991). A second species, *Turborotalita quinqueloba* Natland, 1938, has recently been recorded from Southern Indian Ocean pack ice, although in low numbers (Kramer *et al.* 2011).



Map 8

● *Neogloboquadrina pachyderma*

Sea-ice Fauna Map 8 Distribution map showing presence of the foraminiferan *Neogloboquadrina pachyderma* in sea ice.

3. The future

As outlined in the Introduction, changes in the extent and area of the sea ice habitat have not been uniform or unidirectional, so the implications for sea ice associated organisms are not clear. It appears that few species are obligate ice dwellers, with the nudibranch *Tergipes antarcticus* perhaps being the most likely candidate. It is possible that many species will continue to thrive under scenarios of thinner or less frequent ice cover, although it is hard to predict how they will respond to changes associated with sea ice change, such as increasing temperatures and altered primary productivity. Plasticity will be the key to a species' continual success, in terms of both their diets and life cycles. Understanding the relative importance of factors that drive organisms to colonise sea ice (e.g., response to predation versus reproductive needs) would enhance our ability to predict their responses to environmental change. In the Antarctic, much work has focused on Weddell Sea pack ice, with some

sampling in parts of the Indian Ocean and lesser amounts in the other regions. Furthermore, there is a strong seasonal bias where most sampling has occurred during spring-summer cruises. There are limited winter data available for most ice-covered regions. For fast ice, the Indian Ocean sector is characterised by geographically distant station-based studies that have enabled study of the temporal dynamics. Biogeographical patterns for Antarctic sea ice are therefore based on patchy sampling efforts in both time and space. There are large areas that have not yet been visited for the purposes of sampling the ice-associated metazoans.

Acknowledgements

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