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Commission pour la conservation de la faune et la flore marines de l'Antarctique
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Scientific background document in support of the development of a CCAMLR MPA in the Weddell Sea (Antarctica) – Version 2016 – Part A: General context of the establishment of MPAs and background information on the Weddell Sea MPA planning area

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Scientific background document in support of the development of a CCAMLR MPA in the Weddell Sea (Antarctica) – Version 2016

-Part A: General context of the establishment of MPAs and background information on the Weddell Sea MPA planning area-

This report has been compiled by members of the German Weddell Sea MPA project team and by experts from other CCAMLR member states and acceding states:

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1. Background and relevant international agreements

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This background document is provided the scientific basis, rationale and justification for the evaluation and potential establishment of a marine protected area (MPA) in the Weddell Sea planning area. It has been prepared in accordance with the provisions of the CAMLR Convention and the relevant CCAMLR agreements and measures, such as the general framework for the establishment of CCAMLR MPAs (CM 91-04).

The contents and structure of the whole document reflect its main objectives, i.e. to set out the general context of the establishment of MPAs and to provide the scientific background information on the Weddell Sea MPA (WSMPA) planning area (Part A; WG-EMM-16/01); to inform on the data retrieval process (Part B; WG-EMM-16/02) and to describe the means and the results of the scientific analyses and the development of objectives and priority areas for a Weddell Sea MPA (Part C; WG-EMM-16/03).

The scientific background document has been prepared on purpose as a single volume, so that all information necessary for considering the establishment of a marine protected area (MPA) in the Weddell Sea planning area is available in one place. However, it should be noted that this document can only ever be a snapshot in time. Despite the scientific efforts over the last decades to improve our knowledge of Antarctica and its surrounding Southern Ocean, every expedition and research cruise into the Weddell Sea provides fascinating new data and information. If readers are aware of such new findings, please let us know, so that we can take this information into account in the regular review of this scientific background document.

Data, information and evidence summarized in this scientific background document constitute our actual scientific knowledge base regarding the Weddell Sea ecosystem. From this foundation, reasons and arguments will be developed, why certain habitats, communities and partial ecosystems in the Weddell Sea may require enhanced protection by means of MPAs.

The principal aim of the establishment of MPAs within the framework of the CCAMLR convention is to support the prime objective of this Convention, i.e. the conservation of Antarctic marine living resources, including their rational use. As specified in the Conservation Measure 91-04 (2011), the Commission, with the development of a representative system of Antarctic Marine Protected Areas (MPAs), aims to conserve marine biodiversity in the Convention Area.

However, establishment of Antarctic MPAs also helps to achieve and implement a number of international agreements, targets and goals. First and foremost, the Antarctic Treaty (1959) and its Environmental Protection Protocol (1991) designate Antarctica as a natural reserve, devoted to peace and science. In effect, in accordance with the advice by the Scientific Committee of CCAMLR (SC-CAMLR XXIV), the whole CAMLR Convention Area may be seen to be equivalent to an IUCN Category IV MPA, but there are areas within the Convention Area that require further special consideration in a representative system of MPAs (CM 91-04). The establishment of MPAs in Antarctica also is in line with further

international commitments, as outlined in Part A of the scientific background document (see chapter 1).

Part A of the document contains (i) a synopsis in terms of the establishment of MPAs (chapter 1); (ii) a description of the boundaries of the WSMPA planning area (chapter 2); (iii) a comprehensive, yet succinct, general description of the Weddell Sea ecosystem (chapter 3); (iv) and finally a guidance regarding the future work beyond the development of the scientific basis for the evaluation of a WSMPA (chapter 4).

Please note that Part A of the document presents the final version.

Part A of the document was prepared by members of the German WSMPA project team and working group, except of chapter 3, the general description of the Weddell Sea ecosystem. For chapter 3, many renowned international scientific experts of several CCAMLR member states and acceding states kindly contributed the *state of the science* parts, in addition to scientists from the Alfred Wegener Institute and from other German science institutions.

1.1 Global conventions and organisations

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At the World Summit on Sustainable Development (WSSD) in 2002, the international community made the commitment to establish ecologically representative and effectively managed networks of MPAs by 2012 and to effectively conserve at least 10% of coastal and marine areas (A/CONF.199/20 2002). In 2004 the 7th Conference of Parties (COP 7) to the Convention on Biological Diversity (CBD) confirmed this target and adopted the Programme of Work on Protected Areas (PoWPA). The Parties further agreed that “...*marine and coastal protected areas are one of the essential tools and approaches in the conservation and sustainable use of marine and coastal biodiversity...*” (CBD 2004). The COP 10 to the CBD in 2010 adopted the “Strategic Plan for Biodiversity 2011-2020” reconfirming and including this objective within its Aichi Biodiversity Targets while setting a new timeframe for 2020 as goals had not been met globally (CBD 2010).

In parallel to those developments, various organisations and initiatives started enforcements to facilitate and further foster the establishment of ecologically representative networks of Marine Protected Areas. Since 2006 the General Assembly of the UN has been calling for the protection of Vulnerable Marine Ecosystems (VMEs) in Areas Beyond National Jurisdiction (ABNJ) while in 2009 the Food and Agriculture Organization of the United Nations (FAO) adopted criteria for its identification and developed Technical Guidelines on MPAs as a Fisheries Management Tool. The CBD elaborated and has been applying a set of scientific criteria to identify “Ecologically or Biologically Significant Areas” (EBSAS) in Areas Beyond National Jurisdiction which are in need of protection. The Global Ocean Biodiversity Initiative (GOBI) aims to advance the scientific basis for conserving biological diversity in the deep seas and open oceans as well as to support countries and international relevant regional organizations to identify EBSAS (www.gobi.org).

Although there is a worldwide trend to establish further MPAs, to date only 2.8% of the world's oceans are protected by MPAs, of which the majority is located in coastal areas and under national legislation. The establishment of networks of MPAs in regional seas and in particular in Areas Beyond National Jurisdiction is still at its beginning and the process is far from meeting the goals. This is mainly caused by the lack of explicit mandates and international governance frameworks regarding the establishment and management of MPAs in ABNJ as well as the need of international cooperation and coordination.

Because of the lack of an explicit legal framework and as e.g. neither the CBD nor the United Nations Convention on the Law of the Sea (UNCLOS) do possess an explicit mandate, the task of establishing networks of MPAs regionally or in ABNJ is taken over by various global and regional conventions and organisations. Examples are OSPAR (Convention for the Protection of the marine Environment of the North-East Atlantic), HELCOM (Baltic Marine Environment Protection Commissions of the Helsinki Convention) or the Barcelona Convention (Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean). In 2003 OSPAR and HELCOM adopted a Joint Work Program in order to establish a coherent network of well-managed MPA in the Baltic Sea and the North-East Atlantic by 2010 and by ministerial declaration are seeking to combine efforts with the EU. OSPAR, on the base of the EBSAS process, has so far designated 9 MPAs in ABNJ (plus 324 in national waters) in the North-East Atlantic. HELCOM has created a network of 163 MPAs including coastal as well as offshore areas covering more than 10% of the Baltic Sea. Under the Barcelona Convention, France, Italy and Monaco established the Pelagos Sanctuary containing next to territorial waters, Areas Beyond National Jurisdiction. Regional Fisheries Management Organisations (RFMOS) on the other hand are applying specific high seas protection measures including species-specific or area-specific fishery closures.

Nevertheless, the competencies and mandates of conventions and RFMOS for protecting and applying conservation measures are usually limited to specific aspects or areas. In order to overcome this gap, an integrated approach to the management of MPAs in ABNJ is often required. OSPAR e.g. established such an approach to enable effective and comprehensive conservation measures in its MPAs. OSPAR cooperates with relevant international authorities and bodies with sectoral competencies in the North-East Atlantic. Those include inter alia IMO, ISA and the North East Atlantic Fisheries Commission (NEAFC). The latter enabling the management of fisheries and all area-based management measures pertaining to fisheries in its areas overlapping with these 9 OSPAR MPAs, while OSPAR is managing measures for the protection of the marine environment, according to its competency.

CCAMLR as a further example of a relevant regional convention is in the unique and favourable position to possess mandates and competencies to establish a network of MPAs in the Southern Oceans and at the same time to implement conservation measures for marine living resources as well as management measures for fisheries and thus could contribute substantially to the above mentioned goals.

1.2 Antarctic Treaty and Environment Protocol

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The *Antarctic Treaty* (AT) provides the basis for the international law of Antarctica. The Antarctic Treaty System comprises the Treaty itself and a number of related agreements, particularly the *Protocol on Environmental Protection to the Antarctic Treaty* (EP), the *Convention on the Conservation of Antarctic Marine Living Resources* (CCAMLR) and the *Convention for the Conservation of Antarctic Seals* (CCAS). Within this legal system the designation of marine protected areas (MPA) are not only possible in the scope of CCAMLR. Article IX (1) f of the AT is the general legal basis for the designation of a MPA, because the Contracting Parties (CPs) are allowed to adopt “*measures regarding the preservation and conservation of living resources in Antarctica*”. On the other hand areas of Antarctica which are particularly worthy of protection, including marine areas, could be designated as an Antarctic Specially Protected Area (ASP) subject to the regulation of Article 3 of Annex V of the EP. But marine areas could only be designated as an ASP with the prior approval of the CCAMLR-Commission (Article 6 (2) of Annex V of the EP). The entry into a protected marine area under Article 3 of Annex V of the EP is prohibited except in accordance with a permit of a CP.

Up to now the marine part of ASPs or Antarctic Specially Managed Areas (ASMAs) are localized to small areas along the coast. During the ATCM in 2010 the United Kingdom and Belgium submitted Working Paper 44 (“*Complementary Protection for Marine Protected Areas Designated by CCAMLR*”) in order to adopt provisions complementary to those in the MPA “*South Orkney Islands southern shelf*” designated by CCAMLR in 2009. The aim of the draft Measure annexed to this Working Paper was to adopt the provisions of the relevant CCAMLR MPA contained in the respective CCAMLR Conservation Measure by the ATCM. The draft ATCM Measure should apply to all non-fishing vessels in the defined area. Any scientific research activities should be allowed, but coordinated with the CCAMLR Scientific Committee (SC-CAMLR). The proposal does not contain a requirement for a permit to enter the protected area. For the purposes of monitoring traffic within the protected area, all non-fishing vessels transiting the area should inform the Antarctic Treaty Secretariat. The United Kingdom explained that the aim of the paper was to highlight the need to develop a mechanism for the ATCM and CCAMLR to adopt a harmonized approach to the protection of the marine environment. It also made clear, that the adoption of the Measure would not preclude the separate development of an ASP or ASMA in the future. Several CPs expressed their support for the designation of the “*South Orkney Islands southern shelf*” as a MPA by CCAMLR, but in reference to other legal requirements (Annex V of the EP and the MARPOL-Convention) the CPs refused the mechanism proposed in this ATCM Paper.

After several years of unsuccessful negotiations within CCAMLR about further MPAs – both for Ross Sea and East Antarctica – the participants of ATCM 2014 have admitted to the legal framework of CCAMLR and the aim to develop a representative network of MPAs. The meeting encouraged all parties to continue the discussions on MPAs up to the CCAMLR meeting in autumn 2014, and to work constructively towards reaching a consensus on the establishment of MPAs. Also the Committee of Environmental Protection (CEP) has agreed to establish an Intersessional Contact Group (ICG) to identify the “outstanding values” of the

Antarctic marine environment, to analyze how they may be affected by activities and to discuss options to include these “outstanding values” when establishing or reviewing ASPAs, in accordance with Article 3 of Annex V of the EP. In addition a further workshop of the CEP and the SC-CAMLR will be held in 2015 continuing the discussion on the opportunities of the future cooperation between both bodies on this issue starting in 2009.

1.3 CCAMLR

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1.3.1 MPA planning domains

At the 27th Meeting of the Scientific Committee in 2008 (Hobart, Australia) it was agreed that further work to identify marine areas for protection should be focused, but not be limited to, 11 priority areas identified by the Working Group on Ecosystem Monitoring and Management (WG-EMM) in 2008 (St Petersburg, Russia) (SC-CAMLR-XXVII, § 3.55 (iv), and § 3.77, Fig. 12 of Annex 4).

Then, at the Workshop on Marine Protected Areas (WS-MPA) in 2011 (Brest, France) the continued utility of the 11 priority areas designated in 2008 was discussed (see SC-CAMLR-XXX, § 6.5 - 6.8 of Annex 6). Subsequently, the Workshop agreed that the 11 priority areas are not sufficient anymore for ensuring comprehensive spatial planning throughout the Convention Area. As a result, the Workshop developed nine large-scale planning domains that cover the entire Convention Area, and were endorsed by the Scientific Committee in 2011 (SC-CAMLR-XXX, § 5.20, and Table 2, Figure 3 of Annex 6) (see also Fig. 2-1).

The planning domains cover all 11 priority areas, reflect well the scale and location of current and planned research efforts and, thus, can be helpful as reporting and auditing units. In addition, the planning domains provide comprehensive coverage of bioregions in the Southern Ocean and allow for effectively nesting fine-scale analyses of biological data within larger-scale analyses to help ensure that the system of MPAs developed for the Convention Area is representative as well as comprehensive. However, the boundaries of the planning domains are not intended to confine or restrict research or other work to develop MPAs.

In 2012, Belgium kindly hosted a MPA Technical Workshop - Circumpolar Gap Analysis (10 - 14 September 2012, Brussels). The main aim of this workshop was to examine those planning domains in which (at that time) conservation planning was not underway and thereby facilitate the completion of CCAMLRs circumpolar consideration of a representative system of MPAs. Scientists of the AWI attended this Technical Workshop and presented data and information from the Weddell Sea. The outcome of the Workshop was presented at the meeting of the CCAMLR Scientific Committee in 2012, at which Germany offered to take the lead on the MPA planning in Domain 3 (Weddell Sea) (SC-CAMLR XXXI, § 5.26-5.28).

1.3.2 Relevant CCAMLR conservation objectives

The establishment of marine protected areas under CCAMLR is guided by a number of objectives set out in the CCAMLR Convention itself and in subsequent measures adopted by CCAMLR.

Article II of the CCAMLR-Convention sets out that:

- "(1) *The objective of the Convention is the conservation of Antarctic marine living resources.*
- (2) *For the purposes of this Convention, the term 'conservation' includes rational use.*
- (3) *Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation*"

Article IX of the Convention declares "*The function of the Commission shall be to give effect to the objective and principles set out in Article II of this Convention. To this end, it shall:*

- (a) *facilitate research into and comprehensive studies of Antarctic marine living resources and of the Antarctic marine ecosystem;*
- (b) *compile data on the status of and changes in population of Antarctic marine living resources and on factors affecting the distribution, abundance and productivity of harvested species and dependent or related species or populations;*
- (c) *ensure the acquisition of catch and effort statistics on harvested populations;*
- (d) *analyse, disseminate and publish the information referred to in sub-paragraphs (b) and (c) above and the reports of the Scientific Committee;*
- (e) *identify conservation needs and analyse the effectiveness of conservation measures;*
- (f) *formulate, adopt and revise conservation measures on the basis of the best scientific evidence available, subject to the provisions of paragraph 5 of this Article;*
- (g) *implement the system of observation and inspection established under Article XXIV of this Convention;*
- (h) *carry out such other activities as are necessary to fulfil the objective of this Convention."*

In 2011 CCAMLR adopted Conservation Measure 91-04 (*General framework for the establishment of CCAMLR Marine Protected Areas*), which sets out in paragraph 2 that "*CCAMLR MPAs shall be established on the basis of the best available scientific evidence, and shall contribute, taking full consideration of Article II of the CAMLR Convention where conservation includes rational use, to the achievement of the following objectives:*

- (i) *the protection of representative examples of marine ecosystems, biodiversity and habitats at an appropriate scale to maintain their viability and integrity in the long term;*
- (ii) *the protection of key ecosystem processes, habitats and species, including populations and life-history stages;*
- (iii) *the establishment of scientific reference areas for monitoring natural variability and long-term change or for monitoring the effects of harvesting and other human activities on Antarctic marine living resources and on the ecosystems of which they form part;*
- (iv) *the protection of areas vulnerable to impact by human activities, including unique, rare or highly biodiverse habitats and features;*
- (v) *the protection of features critical to the function of local ecosystems;*
- (vi) *the protection of areas to maintain resilience or the ability to adapt to the effects of climate change."*

The overarching objectives given in the CCAMLR Convention and the objectives set out in CM 91-04 to be achieved by a MPA were taken into account in the preparation of this background document, which intends to provide the best scientific data and information available for establishing a MPA in the Weddell Sea planning area.

The present state of our scientific evaluation provides convincing evidence already that the Weddell Sea planning area includes features and regions that may be relevant to the achievement of objectives formulated in CM 91-04. As indicated by this background paper,

- there are *representative examples of (Antarctic) marine ecosystems, biodiversity and habitats* located in the Weddell Sea, e.g., the complex “sponge communities” on the south-eastern shelf or the rich diverse Deep Sea communities to the east of the Antarctic Peninsula,
- *key ecosystem processes, habitats and species* include, e.g., crabeater seals with 50% of the Antarctic stock located in the Weddell Sea, the largely unknown life cycle of *Dissostichus mawsoni*, or the spawning grounds of demersal Notothenoid fishes,
- *scientific reference areas*, e.g., regarding the effects of ice berg scouring on the shelf benthos, and reference areas are meaningful tools to monitor effects of fishing, e.g. of further *Dissostichus* research and exploratory fisheries in the Weddell Sea planning area,
- *the protection of areas vulnerable to impact by human activities*, e.g. areas qualifying for VMEs, rich sponge communities, fish nesting sites, benthic three-dimensional suspension feeder communities as well as areas of importance to life cycles of key species. Although human activities appear less in the Weddell Sea planning area as compared to other planning domains, increasing (actual and predictable) human activities like fishing in the area highlights the need for the WSMMPA to consider the protection of areas vulnerable to impact by human activities.

• *the protection of areas to maintain resilience or the ability to adapt to the effects of climate change* may refer to large areas of the Weddell Sea planning area, as it is assumed that its particular oceanography – the Weddell gyre - will maintain cold polar conditions in this region much longer than in adjacent areas, making it a potential refuge for Antarctic organisms (e.g., Emperor penguins) from ocean warming. However, the north-western part of the planning area is affected by the rapid warming in the region of the Western Antarctic Peninsula (WAP) and scientific research indicates, that climate change might seriously affect in the next decades the distribution and flow of warm water masses - and thus might influence ecosystems and species - especially in the southern part (Filchner trough and overflow area) of the planning area. This would cause increased melting of the Ronne-Filchner ice shelf and potentially a reduction in the formation of cold Antarctic Bottom Water, which is the main driver for the thermohaline circulation of the Worlds oceans.

Further analyses of these scientific data and information outlined in Teschke et al. (2016; WG-EMM-16/02) led to the formulation of specific objectives for the Weddell Sea MPA and the identification of priority areas for conservation.

2. Boundaries of the Weddell Sea MPA planning area

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At the 2013 Ecosystem Monitoring and Management (EMM) Meeting in Bremerhaven the area to be considered in the scientific data compilation and analyses to form the base line study for a potential Weddell Sea MPA (WSMPA) was discussed (see SC-CAMLR-XXXII/03, Annex 5, §§ 3.4-3.6).

The WSMPA project group stressed the fact that the boundary between MPA Planning Domain 3 (Weddell Sea) and Planning Domain 4 (Bouvet-Maud) cut right through the middle of a biogeographically homogeneous region, particularly on the Antarctic shelf. Therefore, the WS-MPA project group proposed to extend the planning area into Planning Domain 4. The EMM recognized these difficulties, but asked for a meaningful and distinct definition of the extended planning area (see SC-CAMLR-XXXII/03, Annex 5, § 3.6).

Correspondingly, the WSMPA project group proposes the planning area for the evaluation of a WSMPA to consist of Planning Domain 3 (Weddell Sea) and that part of Priority Area 6 (one of 11 priority areas identified by WG-EMM / SC-CAMLR-XXVII, later substituted by the 9 MPA Planning Domains, SC-CAMLR-XXX) located in Planning Domain 4 (Fig. 2-1). **Please note** that these boundaries do **not** resemble the boundaries of any proposed WSMPA.

- **Northern border**
 - 64°S from The Antarctic Peninsula to 20°W (= northern border of Planning Domain 3)
 - 64°S from 20°W to 20°E (covers Priority Area 6 in Planning Domain 4)
- **Eastern border**
 - 20°E (= eastern border of Priority Area 6 in Planning Domain 4)

- **Western border**
 - Antarctic Peninsula
- **Southern border**
 - Continental margin and shelf ice margin respectively

The whole WSMMPA planning area covers an area of approximately 4.2 million km², which almost corresponds to the current size of the European Union.

The Scientific Committee (SC-CAMLR-XXXII) noted that the progress report on the scientific data compilation and analyses carried out by Germany in support of the development of a CCAMLR MPA in the Weddell Sea (SC-CAMLR-XXXII/BG/07) described the boundaries of the planning area (SC-CAMLR-XXXII, § 5.23). The extension of the planning area, beyond MPA Planning Domain 3 into the southern parts of Planning Domain 4, ensures that the specific oceanographic and ecological conditions as well as the biological communities of the Weddell Gyre system (Geibert et al. 2010) as a whole can be considered as one entity in the data compilation and analyses.

3. Description of the Weddell Sea ecosystem

3.1 Environmental parameters

The Weddell Sea MPA (WSMMPA) planning area covers an area of approximately 4.2 million km². For details of the boundaries of the WSMMPA planning area see chapter 2.

Water depths in the WSMMPA planning area range from about 100 m at the edge of the ice shelf to about 5.300 m in the Weddell Sea abyssal plain (see Fig. 3-1). Prominent bathymetric features of the WSMMPA planning area are the relative narrow, complex structured shelf and steep slope in the eastern Weddell Sea, and the broad shelf in the southern Weddell Sea that extends up to 500 km from the coast and is cut through by the deeper Filchner Trench.

The Weddell Sea plays an important role for driving global thermohaline circulation ("global ocean conveyor belt") and ventilating the global abyssal ocean, as a considerable part of the Antarctic Bottom Water is generated in the Weddell Sea (Knox 2007, Fahrback et al. 2009). The formation of those dense water masses in the Weddell Sea is facilitated by the large-scale cyclonic Weddell Gyre (see Fig. 3-3).

Probably the most pronounced feature of the Weddell Sea is the sea ice and its extreme seasonal variability (see Fig. 3-4). Each summer, sea ice cover with more than 75 % shrinks to a minimum of approx. 1.420.000 km² (Feb - Mar), representing approx. one third of its maximum winter extent in September (approx. 4.480.000 km², i.e. ~ 98 % of total MPA planning area). Multi-year sea ice (ice surviving the summer melt) with more than 3 m ice thickness predominantly occurs in the western Weddell Sea and covers approx. 595.000 km² (~ 13 % of total planning area). The maximum sea-ice formation rates (up to 0.1 m/day) occur in the coastal polynyas that have a width of only a few km (Haid & Timmermann, 2013).

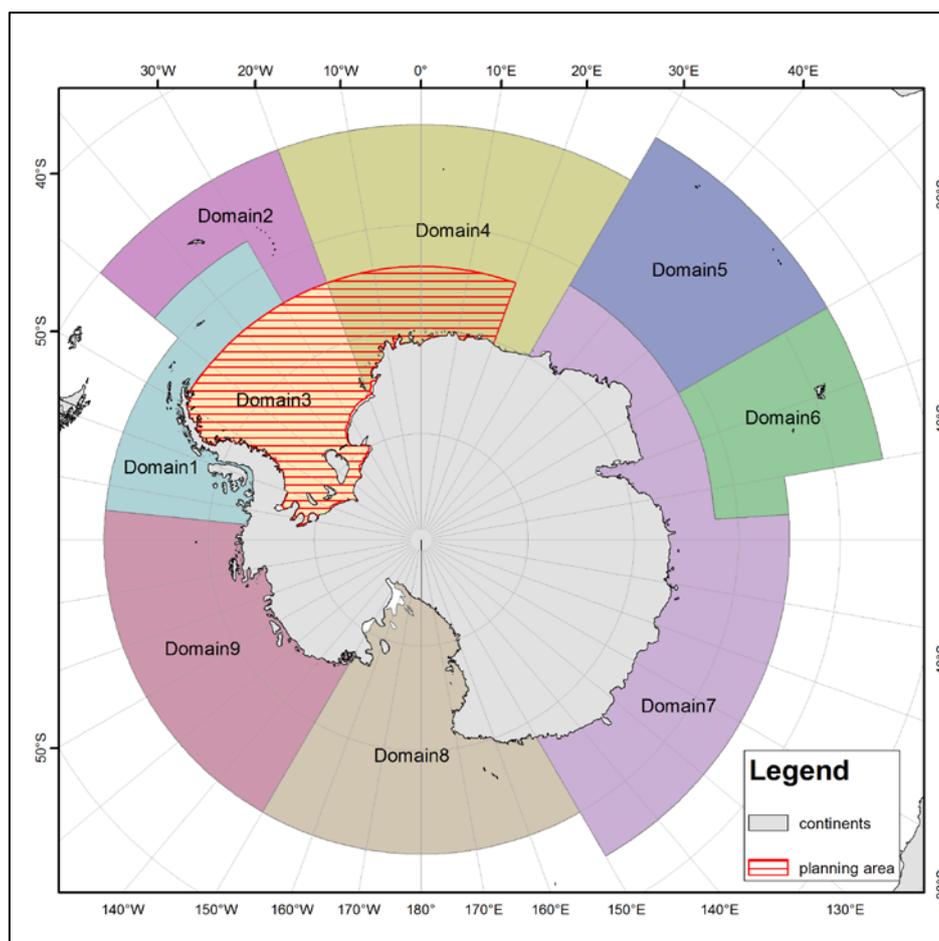


Figure 2-1 CCAMLR MPA Planning Domains and the proposed planning area for the evaluation of a Weddell Sea MPA (red shaded area). Please note that the boundaries of the proposed planning area do not resemble the boundaries of any proposed Weddell Sea MPA. Domain 1: Western Peninsula - South Scotia Arc, Domain 2: North Scotia Arc, Domain 3: Weddell Sea, Domain 4: Bouvet Maud, Domain 5: Crozet - del Cano, Domain 6: Kerguelen Plateau, Domain 7: Eastern Antarctica, Domain 8: Ross Sea, Domain 9: Amundsen - Bellingshausen.

3.1.1 Bathymetry, Geomorphology & Sedimentology

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Water depths in the Weddell Sea range from about 100 m at the edge of the ice shelf to 800 - 4.000 m on the continental shelf and slope and to about 5.300 m in the Weddell Sea abyssal plain. The Weddell Sea shelf is comparatively deep with a mean depth of 500 m (Haid 2013), and thus the shelf break is located approx. two to four times deeper than the 200 m seen in other oceans (Knox 2007). This is caused by the immense weight of the ice sheet burdening the continent and depressing the earth's crust to where the isostatic equilibrium with the mantle is reached. For the Weddell Sea shelf the vertical displacement amounts to 100 – 400 m (increasing toward the continent) (Huybrechts 2002). However, the area underlies a

constant deglacial process that causes an uplift rate of several mm yr^{-1} (Whitehouse et al. 2012a, 2012b).

Prominent bathymetric features of the Weddell Sea are the relative narrow, complex structured shelf and steep slope in the eastern Weddell Sea and the broad shelf in the southern Weddell Sea (IBCSO, Arndt et al. 2013; see Fig. 3-1). The southern continental shelf extends up to 500 km from the coast and is composed of two cross shelf valleys (Filchner Trough in the East and low-gradient Ronne Basin in the West) and plain areas (Berkner Bank, General Belgrano Bank) with lower slopes in between (Fig. 3-2, Jerosch et al. 2015). In the south, two large ice shelves adjoin the continental shelf, the Ronne Ice Shelf and the Filchner Ice Shelf. They are often collectively called Filchner-Ronne Ice Shelf (or Ronne-Filchner Ice Shelf) since they are divided at their seaward front by Berkner Island, but connected at their grounding line where they are fed by various ice streams draining the West and East Antarctic Ice Sheets.

During former glaciations Antarctica's ice sheets extended mostly to the shelf break in the Weddell Sea (Hillenbrand et al. 2014). They shaped the seafloor and created typical glacial-geomorphological features like mega scale glacial lineations (MSGs) or grounding zone wedges (GZWs) on the shelf (Larter et al. 2012). Icebergs since the last ice sheet retreat continuously scour the mostly shallower outer parts of the shelf that is structured in gullies and shows structures of submarine landslides (Gales et al. 2014).

The Western and central part of the continental slope contains in general of a broad flat ridge terminating the shelf followed by slopes of steep (around 3%) and lower slope values (1%), respectively, and adjacent canyons (approx. 40-70 km width) in perpendicular positions to the slope classified as depressions in the map (see Fig. 3-2). Only the Eastern part of the continental slope features a narrow ridge with slope values around 15 % that separates the flat ridge from the complex pattern of troughs, flat ridges, pinnacles, steep slopes, seamounts, outcrops, and narrow ridges (structures in approx. 5-7 km wide) (Jerosch et al. 2015).

The abyssal plain of the Weddell Sea up to 5300 m depth is an extensive flat area of about 2 Mio km^2 with slopes less than 0.4° surrounded by the continental slope in the Southeast, the South and the Southwest as well as in the Northern directions by the South Sandwich Fracture Zone with alternating geomorphic features such as troughs, local depressions, plateaus, narrow ridges with steep slopes up 40° to outcrops and seamounts. The abyssal plain has to be featured since it is a section of the exclusive deep connection between the great ocean basins. Only here, a latitudinal circum-navigation of the globe is possible and the west wind belt, which also is unobstructed by continents, gives rise to the world's strongest current system, the Antarctic Circumpolar Current (ACC) (Haid 2013).

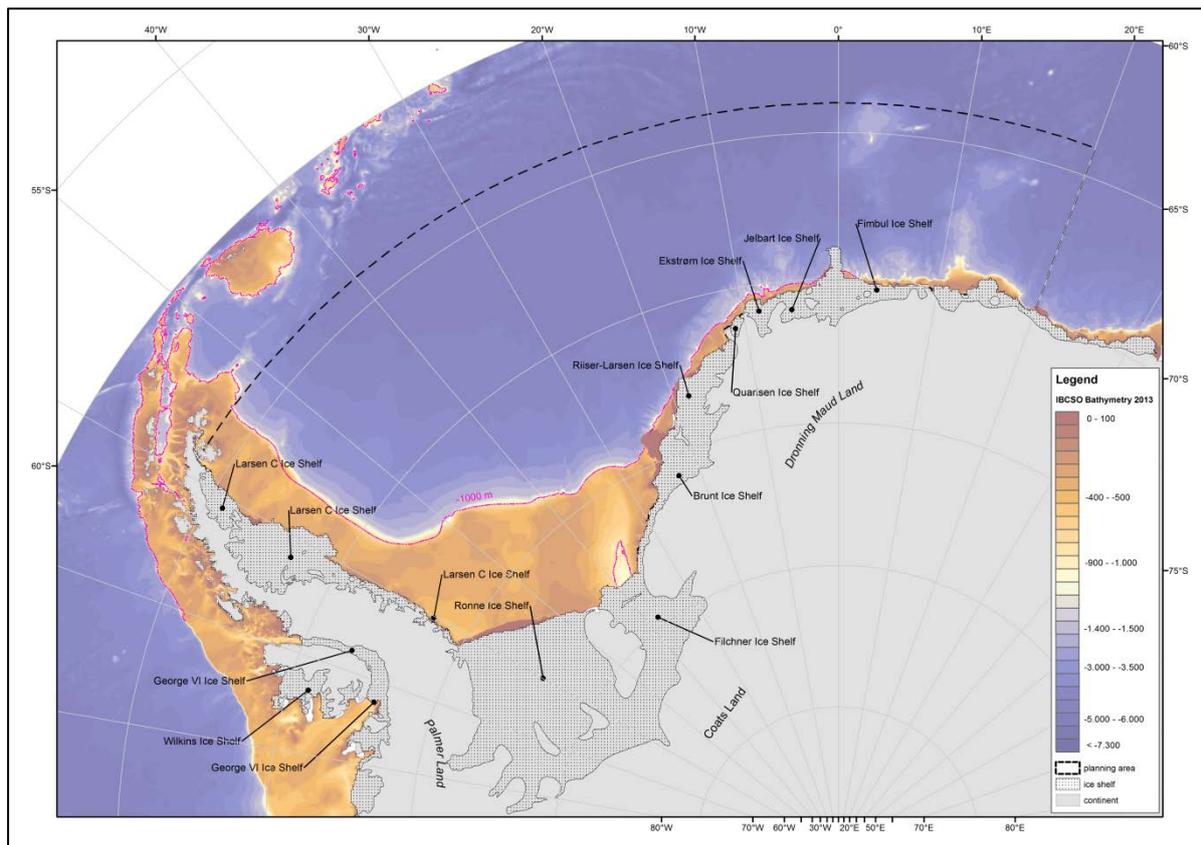


Figure 3-1 Bathymetry (in m) in the planning area (black dashed box) for the evaluation of a Weddell Sea MPA (WSMPA). Please note that the boundaries of the planning area do not resemble the boundaries of any proposed WSMPA. The bathymetric chart of the Southern Ocean (IBCSO) is published by Arndt et al. (2013). The ice shelves are labelled and shown in grey.

Next to the continental shelf, slope and abyssal plain small scale geomorphic features characterise the Weddell Sea MPA planning area. Those geomorphic features at smaller spatial scales are of particular importance since they govern physical attributes such as the type of substratum, erosion or deposition of sediment, currents and nutrients, and thus may affect the composition of benthic organisms. For example, depressions on the continental shelf - with low currents eroded during glacial maxima - forming sediment traps for fine sediments, and provide appropriate habitats for mobile deposit feeder and infaunal communities (Gutt 2007, Post et al. 2011). Furthermore, the steepness of slope provides hints for the occurrence of hard rock surfaces which also influences the benthic community structure. In general, (slightly) gravelly muddy sands occur in the cross shelf valley and at the shelf ridge. Slightly gravelly sandy mud is deposited at the plain bank areas of the shelf. In the deeper shelf basins gravelly mud occurs as it dominates the abyssal basin.

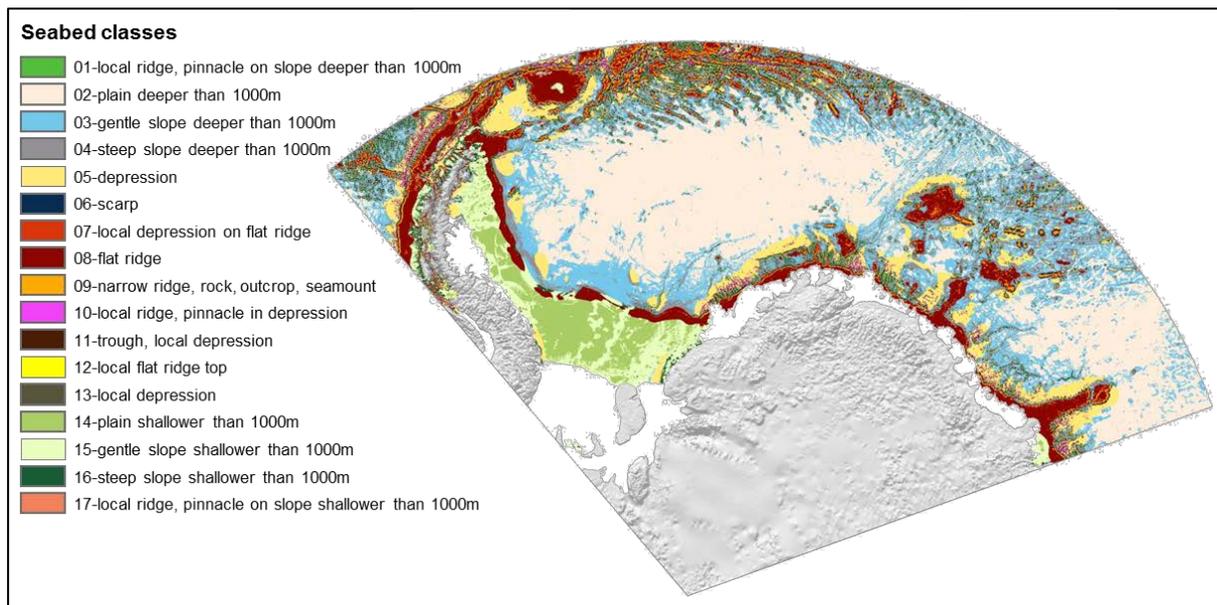


Figure 3-2 The seabed classes which derived from bathymetry (IBCSO; Arndt et al. 2013) and its bathymetric derivatives, i.e. slope and bathymetric position index (Jerosch et al. 2015). Note that areas appearing as lines are artefacts from ship tracks. Black box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

3.1.2 Oceanography

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The circulation in the Weddell Sea is dominated by the cyclonic (clockwise rotating) Weddell gyre (Fig. 3-3) that below the surface shows a double-cell structure with centers on both sides of the Greenwich Meridian (Beckmann et al. 1999). The southern branch of the gyre is part of the circumpolar slope front current, following a water mass boundary that separates cold shelf waters (-1.85°C) from warmer open ocean waters (0.5°C to 0.7°C) and coincides with the position of the continental shelf break. The northern branch is guided by the topography of the South Scotia Ridge, the American Antarctic Ridge and the Mid-Ocean Ridge interacting at most places directly with the Antarctic Circumpolar Current (ACC). The recirculation to the south is poorly defined due to the lack of strong currents but may cover the region between 20°E and the Kerguelen Plateau (~80°E), which represents a natural eastern barrier for dense water masses newly formed in the Weddell Sea. The transport of the Weddell gyre based on in-situ observations and numerical model studies is estimated to 50 Sverdrup (1 Sverdrup (Sv) = 1 million m³ s⁻¹) with an interannual variability of ~15% (Klatt et al. 2005). On the broad southern continental shelf additional cyclonic circulation cells exist transporting between 2 Sv and 5 Sv (Carmack & Foster 1977). Their centers correspond to the position of the deep Filchner and Ronne Troughs. The cells interact with a separate circulation beneath the Filchner-Ronne Ice Shelf, driven by the thermohaline differences between the water masses on the continental shelf and within the deep sub-ice shelf cavern. Although still to be investigated, similar cavern circulations may exist beneath the smaller ice shelves fringing the eastern and western Weddell Sea.

Predominately on the southern Weddell Sea continental shelf intensive atmospheric cooling of the ocean surface below the freezing temperature ($\sim -1.9\text{ }^{\circ}\text{C}$ for salty Antarctic shelf waters) initiates the formation of sea ice while a northward drift shifts its melting to the fringes of the Weddell Sea. The growth rate determines how much brine is expelled to the ocean, resulting in the densification of the surface waters as salinity determines the density at low sea water temperatures. Due to a weakly stratified shelf water column, this density increase causes deep convection, the main oceanic process for bringing heat to the surface and dense water to lower strata.

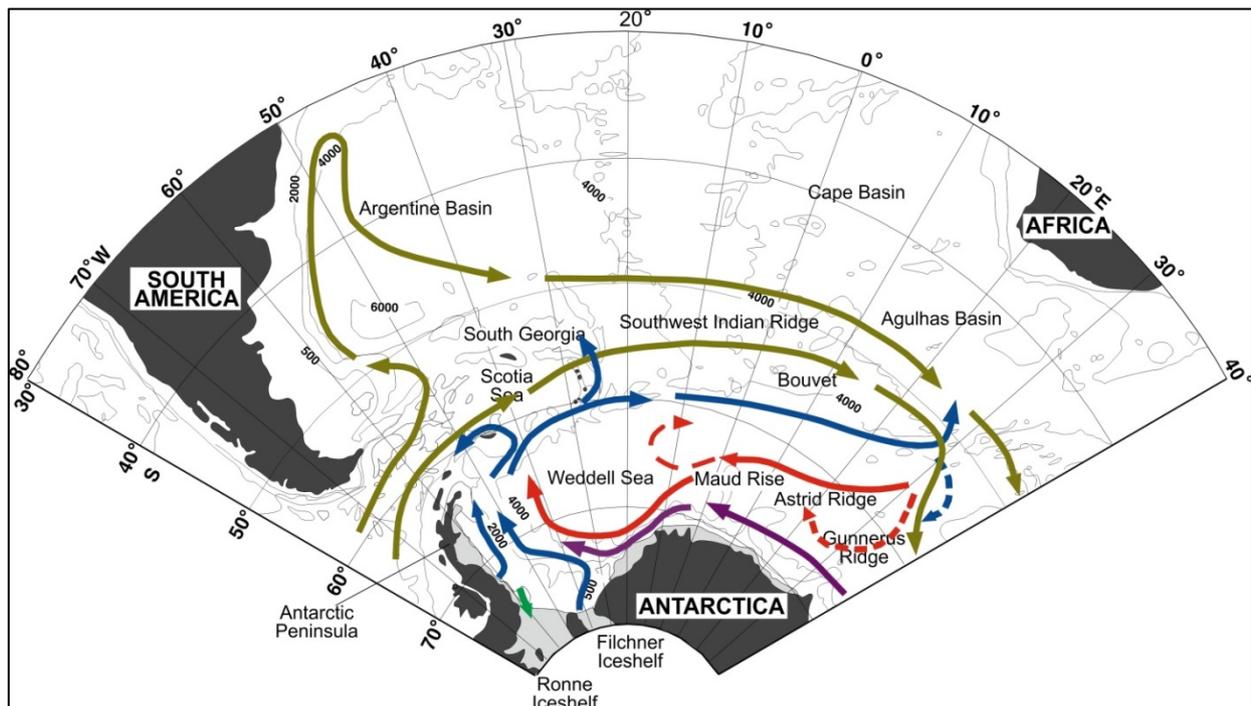


Figure 3-3 Schematic circulation of different water masses in the Atlantic sector of the Southern Ocean: Circumpolar Deep Water (olive), Warm Deep Water (red), Weddell Sea Deep/Bottom Water (blue), and High Salinity Shelf Water (green). The course of the Antarctic Slope Current is shown by the purple arrows. Dashed lines represent unproved paths.

The route dense shelf water takes on the Weddell Sea continental shelf determines by which mixing process this water mass is transformed to new deep and bottom waters. The direct route towards the continental shelf break ends in mixing with open ocean components of circumpolar origin at the slope front causing the formation of Weddell Sea Deep Water (WSDW) (Gordon 1998). This process mainly occurs in the western Weddell Sea where the shelf water masses are modified on the broad continental shelf in front of Larsen Ice Shelf (Absy et al. 2008). Supported by the southward sloping shelf topography, salty shelf water also flows into the Filchner-Ronne cavern participating there in the sub-ice shelf circulation (Nicholls et al. 2001). With a temperature above the pressure dominated in-situ freezing point (-2.6°C at 1000-m depth) this water melts the deep ice shelf base initiating the rise of a melt water plume, defined as Ice Shelf Water (ISW). Depending on the density of the plume and configuration of the Filchner Trough, ISW may reach the sill at the continental shelf break where mixing with open ocean components results in the formation of Weddell Sea Bottom

Water (WSBW) (Foldvik et al. 2004). Numerical model studies indicate that the export of sub-ice melt water affects the stability of the shelf water column with consequences for deep convection and sea-ice thickness (Hellmer 2004). The total sub-ice shelf freshwater flux in to the Weddell Sea is simulated to be roughly 10 mSv (1 mille Sverdrup (mSv) = 1 thousand m³ s⁻¹) representing a significant contribution to the freshwater budget of the Weddell Sea continental shelf (Timmermann et al. 2001). Net precipitation in the coastal seas yields 7.5 mSv based on the NCAR/NCEP 20-year annual mean, but most precipitation falls in winter as snow transported off the continental shelf on top of the sea ice. A reduced sub-ice freshwater flow due to the decay of northern Larsen Ice Shelf might contribute to the temperature and salinity variability observed in the deep north western Weddell Sea (Schröder et al. 2002). Therefore, the processes on the Weddell Sea continental shelf significantly influence the southern water mass characteristics, the ventilation of the deep world ocean, and the transport of natural and anthropogenic substances (tracers) from the ocean surface to the abyss where these can be stored for centuries. Such storage is of climatic relevance in the view of increasing concentrations of greenhouse gases in the global atmosphere.

New bottom water is formed at a rate of 2–5 Sverdrups (Foldvik et al. 2004), depending on the method and data used, which corresponds to 25-60% of the total production of dense bottom water in the Southern Ocean. Though confined to the Weddell Abyssal Plain, WSBW mixes with overlying water masses on its cyclonic voyage within the Weddell gyre. The mixing decreases the density resulting in the ascend to lower strata. From the 55 Sverdrups of ventilated water masses transported by the northern limb of the gyre nearly 10 Sverdrups escape through gaps in the confining ridges (Naveira Garabato et al. 2002). This is a lower estimate based on in situ observations and numerical model studies, because the narrow eastern gaps in the South Scotia Ridge still await an intensive hydrographic survey. Outside the Weddell Sea this water mass is historically called Antarctic Bottom Water which, participating in the global thermohaline circulation has been observed in the Atlantic as far as 40°N.

3.1.3 Sea ice

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The seasonal cycle of the sea ice cover in the Southern Ocean represents one of the most pronounced signals of variability in the Earth's climate system. This is also true for the Weddell Sea, which is covered by thick, partly immobile ice in winter but returns to ice-free conditions in large areas during summer. Formation of sea ice controls the deep and bottom water formation in coastal polynyas and on the southwestern continental shelf (Haid & Timmermann 2013). The importance of these processes for the global thermohaline circulation and the difficulties in directly observing them has motivated numerous modelling studies and international long-term remote sensing efforts. Field studies, however, remain as a crucial contribution to the aim of unveiling the secrets of this remote area.

Substantially lagging behind the seasonal cycle of incoming solar radiation, minimum and maximum sea ice extent occur in February and September, respectively (Fig. 3-4). Typical ice

thickness in the central Weddell Sea is found to be 1.5 m in winter (Behrendt et al. 2013). However, mean ice thickness can increase to 4 m and more in areas where convergent drift causes a lot of sea ice deformation and the extensive formation of pressure ridges. Maximum ice thickness is usually found in the western Weddell Sea along the Antarctic Peninsula; the signature of highly deformed ice being exported northward and eastward can clearly be seen in QuikSCAT data (Fig. 3-5).

Superimposed to the mean seasonal cycle is a substantial interannual variability, most of which is composed of year-to-year fluctuations with a close-to-zero long-term mean. However, there is increasing evidence that sea ice extent (i.e. the area with at least 15 % ice coverage) and sea ice concentration in the Weddell Sea have increased over the last decades, except for the northwestern part near the tip of the Antarctic Peninsula (e.g. Zwally et al. 2002, Parkinson & Cavalieri 2012, Schwegmann 2012). For the period 1979 through 2013, sea ice concentration derived from passive microwave data using the bootstrap algorithm (Comiso 2012) increased by about 2.5% per decade along the eastern coast of the Weddell Sea (Fig. 3-6a). This trend is statistically significant at the 95% confidence level (Schwegmann 2012). For summer, trends are considerably larger than for the long-term mean (e.g. Zwally et al. 2002, Schwegmann et al. 2013). Summer sea ice concentration has increased strongly in the eastern Weddell Sea, with trends exceeding 15 % per decade (Fig. 3-6b). Together with a southeastward trend in sea ice velocities (Holland & Kwok 2012, Schwegmann 2012), these findings indicate a tendency towards a redistribution of sea ice, especially in summer, from the northwestern to the southeastern Weddell Sea.

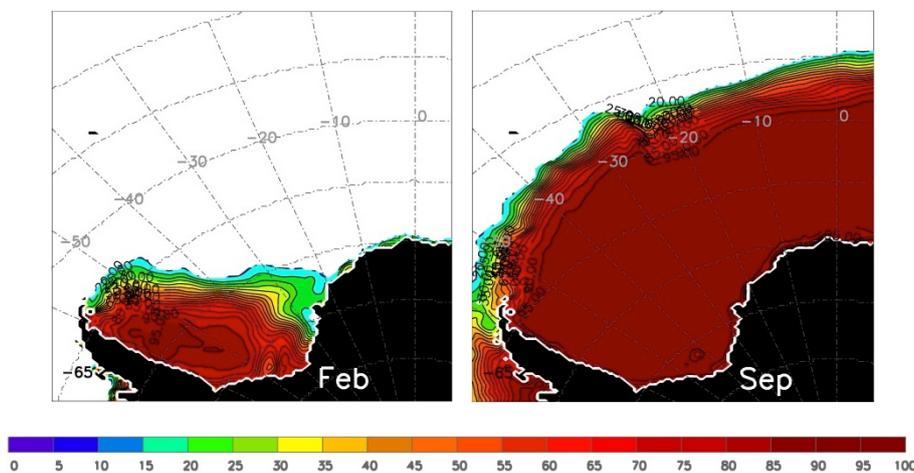


Figure 3-4 Long-term averaged sea-ice concentration (1979 – 2013, in %) at sea ice minimum (February) and sea ice maximum (September). Mean ice concentrations below 15 % have been cut off.

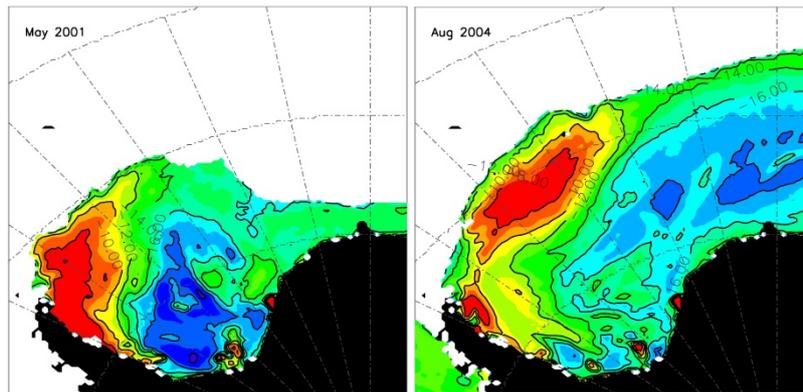


Figure 3-5 Two examples of backscatter maps (dB) derived from QuikSCAT data for May 2001 and August 2004. Patches of highly deformed, multi-year ice are formed along the Antarctic Peninsula and transported northeastward with the large-scale clockwise sea ice drift (after Schwegmann 2012).

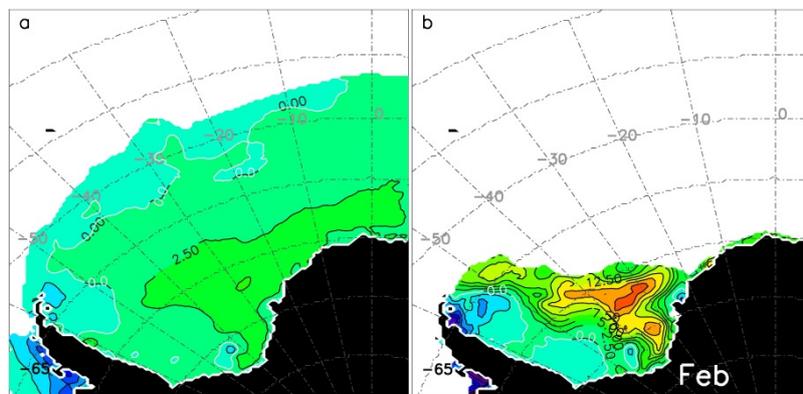


Figure 3-6 Long-term (a) and summer (b) trend in observed Weddell Sea ice concentration (% per decade for 1979-2013). Contour interval is 2.5 %, identical color scales are used in both panels.

3.1.4 Ocean carbon uptake

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The Weddell Sea is a (weak) sink for atmospheric CO₂, thereby slowing the CO₂ growth rate in the atmosphere to some extent and providing an invaluable service to humans. This has not always been the case. The Weddell Sea is an upwelling region, which brings deep water with high carbon loading to the surface, where it starts to equilibrate with the atmosphere. In preindustrial times, i.e., at lower atmospheric CO₂ concentrations, this led to outgassing of so-called ‘natural’ (= preindustrial) CO₂ into the atmosphere (Hoppema 2004a). At present-day atmospheric CO₂ concentrations, the surface layer of the Weddell Sea is undersaturated with respect to CO₂ on an annual basis and acts as a carbon sink. The bottleneck for more and faster carbon uptake is the transport of carbon to the deep ocean and the Weddell Sea is one of the few regions where a conduit to the abyss of the world oceans exists. Bottom and deep water formation takes place along the shelves of Antarctica (see chapter 3.1.2) and constitutes

a shortcut for anthropogenic carbon (i.e., excess CO₂) transport to the deep sea (van Heuven et al. 2014).

While there is a long-term trend of increasing atmospheric CO₂ and marine carbon uptake, the largest mode of variability for air-sea CO₂ exchange in the Weddell Sea is the seasonal cycle. The seasonal course of biological activity with high phytoplankton growth in spring and early summer, followed by remineralization of the earlier produced organic matter in late summer and autumn, has major impact on the carbon cycle of the Weddell Sea (Takahashi et al. 2009, Lenton et al. 2013). CO₂ uptake by phytoplankton lowers the CO₂ levels in the surface layer, which in turn induces uptake of CO₂ from the atmosphere. Later in the season the CO₂ levels may become so high that some CO₂ will be released to the atmosphere again. On the other hand, rapid cooling in autumn can cause additional CO₂ uptake locally (Hoppema et al. 2000). When sea ice is formed, the CO₂ release is strongly impeded and CO₂ concentrations under the ice are high throughout the winter due to entrainment of high-CO₂ waters from deeper layers. In spring, sea-ice retreat is responsible for quickly evolving phytoplankton blooms and rapid carbon uptake (Bakker et al. 2008). On an annual basis, the net export of biological material from the surface to deeper layers causes a depletion of CO₂ and, eventually, uptake of CO₂ from the atmosphere (Hoppema et al. 1999).

The biological carbon pump, i.e., the transfer of CO₂ via organic matter from the surface to the deep ocean where the organic carbon is remineralized and returned to the dissolved inorganic carbon pool, is inefficient in the Southern Ocean due to the limitation of phytoplankton growth by the micronutrient iron (e.g., Smetacek et al. 2012). This holds for the offshore Weddell Sea (De Baar et al. 1990), but not for the extensive coastal regions, the latter of which receive sufficient iron. Those coastal regions are very important sinks of (anthropogenic and natural) CO₂ (Arrigo et al. 2008). An outstanding feature of the Weddell Gyre is that it exports subsurface products of remineralized organic matter also directly to the abyssal Antarctic Circumpolar Current and from there to the world oceans by the lateral outflow of Central Intermediate Water (CIW), a variant of the ubiquitous Circumpolar Deep Water. This process contributes substantially to the abyssal branch of the biological carbon pump on a global scale (Hoppema 2004b)

Whereas air-sea exchange of ‘natural’ (i.e., preindustrial) carbon undergoes the pronounced seasonal cycle, the uptake of ‘anthropogenic carbon’ (i.e., excess CO₂) occurs at similar rates throughout the year, if not impeded by sea-ice coverage that functions as a lid to the ocean. In the more acidic ocean of the future (‘ocean acidification’), however, the ocean will have a lower chemical buffering capacity against carbon perturbations and this will introduce a strong seasonality in the anthropogenic carbon uptake (Hauck & Völker 2015). Model simulations have shown that in this less well buffered system, biological carbon drawdown in summer will cause a twice as high dissolved CO₂ (CO_{2(aq)}) reduction, hence biology will play a much larger role for CO₂ uptake. Specifically the southern part of the Southern Ocean (south of 58°S) will contribute a larger share to the total CO₂ uptake (Hauck & Völker 2015, Hauck et al. 2015).

Climate change affects the carbon uptake by a manifold of processes, such as warming effects on CO₂ solubility. One of the specific perturbations in the Southern Ocean is the observed strengthening of the subpolar westerlies that enhances the overturning circulation. As one of the consequences, stronger upwelling brings more carbon-rich deep water to the surface

which might moderate the expected increase of the carbon sink (Le Quéré et al. 2007). The deep waters, however, are also enriched in nutrients, particularly the growth-limiting micro-nutrient iron, and model studies suggest that this enhanced fertilization effect on biological production may partly counteract the effect of carbon upwelling on CO₂ uptake (Hauck et al. 2013). The sign of future changes in export production will depend on the interplay between the warming and the wind effects on upper ocean stratification. Stronger stratification as expected from warming and sea-ice melting would increase the light level experienced by algal cells, but reduce the amount of nutrients as deep mixing is prevented. A strengthening of the winds works in the opposite direction leading to less light and higher nutrient availability. Currently, models agree on an increase of export production south of 58°S, but not on a dominance of either of these mechanisms at the end of the 21st century (Hauck et al. 2015).

3.2 Ecological parameters

The Weddell Sea MPA (WSMPA) planning area constitutes a unique region in the Southern Ocean in terms of marine biota, their adaptation to short-term environmental variation, and their likely response to long-term climate change.

The Weddell Sea zooplankton communities differ distinctly in species composition and abundance, *inter alia* in the occurrence of Antarctic krill and ice krill. Although the Antarctic krill abundance seems to be relatively low in the Weddell Sea when compared to other regions (e.g. west coast of Antarctic Peninsula, Scotia Sea), the Weddell Sea planning area have to be regarded as a transition zone between the Southwest Atlantic and the Indian Ocean with a briskly exchange rate of krill larvae in either direction.

The most obvious characteristic of the macrobenthos communities on the Weddell Sea shelf is their high spatial heterogeneity in biodiversity, species composition and biomass. Here, world record levels of biomass can be reached e.g. in the structurally and ecologically complex sponge associations. Regarding the deep-sea macrozoobenthos biodiversity is comparable to tropical regions in some areas of the Weddell Sea, and there is an apparent significant number of endemic species, i.e. unique to the Antarctic or even to the Weddell Sea.

The fish assemblages of the WSMPA planning area are diverse. They are distinctly clustered by water depth. In shallower waters (down to 500 - 600 m) the most dominant species are the Antarctic silverfish and bottom fish species of the families Nototheniidae and Channichthyidae. The Antarctic silverfish is an important prey species in the pelagic realm making up significant parts of the diet of other notothenioid fishes, seals and penguins.

Moreover, the Weddell Sea plays an important role for flying seabirds and penguins, as a substantial part of global populations directly or indirectly depending on the marine sector of the planning area. Large breeding populations of seabirds and penguins do exist in and close of the WSMPA planning area. For example, more than over 300,000 pairs of Antarctic Petrels (i.e. > 50 % of the world population) and approx. 33 % of the global population of emperor penguins (IUCN threat status: 'Near Threatened') are known to breed in the WSMPA planning area.

3.2.1 Sea ice ecosystem

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Sea ice cover plays a central role in atmosphere-ocean interaction in polar regions and in the structuring and governing of polar ecosystems (Thomas & Dieckmann 2003). However, the sea ice also constitutes an ecosystem in itself, harbouring a diverse and uniquely adapted biological community, which comprises organisms ranging from viruses to small metazoans. Probably one of its most significant biological features, however, is that it provides a grazing “ground” for pelagic organisms, of which Krill is the pivotal representative.

The physical boundaries for biological activity within sea ice are set by irradiance which is controlled by the optical properties of the snow and ice on the one hand and temperature which controls the salinity and brine volume and indirectly the space available for colonization on the other.

Sea ice all around the Antarctic continent essentially undergoes the same seasonal cycle of growth and decay and the four recognised sea-ice regimes; seasonal pack ice, coastal zone, perennial pack ice and marginal ice zone basically apply everywhere. However, the Weddell Sea and its sea ice cover have specific features, which can be considered unique. One of these are its tremendous expanse relative to other sea ice covered sectors around Antarctica and its oceanographic features, which affect regional sea ice dynamics. A major feature is the Weddell Gyre which ensures a northerly drift of sea ice along the Antarctic Peninsula and consequently a continuous replenishment of highly productive sea ice in the marginal sea ice zone. This fact is probably one of the explanations why the area of the Weddell Gyre outflow between the tip of the Antarctic Peninsula and the Sub Antarctic islands is more densely populated by Krill, in particular the larval stages as well as associated predators than other sectors. For more details of oceanographic features, sea ice characteristics and Antarctic krill in the Weddell Sea MPA planning area, see chapter 4.1.3, 4.1.4 and 4.2.3, respectively.

The sea ice ecosystem in the Weddell Sea as such otherwise, however, does not differ substantially from the circumpolar Antarctic sea ice in general. Fundamental to the sea ice productivity is a diverse microbial community, which thrives in brine pockets and the peripheries associated with the surrounding ocean. This community forms the nutritional basis for protozoans and small metazoans within the brine pockets and ultimately larger metazoans ranging from copepods to krill and fish.

The top end of the food web or sea ice ecosystem entails larger predators, which live on and from the sea ice in that they either consume organisms closely associated with the sea ice, in particular krill and some pelagic fish or require sea ice as a haul out and breeding substrate. This applies particularly to different penguin species, especially Emperor penguins, which breed solely on sea ice.

The significance of the Weddell Sea sea ice ecosystem as a component of the circumpolar sea ice cover is therefore in some senses unique and substantial for the entire Antarctic region.

3.2.2 Pelagic ecosystem

Zooplankton in general

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In relation to the enormous size of the Weddell Sea, the amount of available zooplankton data is low. In the absence of a co-ordinated sampling programme, zooplankton data collection in the Weddell Sea relies on sampling opportunities during individual research expeditions and is therefore rather discontinuous in time and space. On a circumantarctic scale, the eastern Weddell Sea represents an area of high species richness that is not associated with high numbers of samples. As for other regions in the Southern Ocean, pelagic samples reflect the position of national research bases and the logistical routes used to reach them (Griffiths et al. 2014). An overview of digitally archived data (biodiversity.aq; Fig. 3-7) shows that sampling concentrated in 3 regions: 1) The north-western Weddell Sea with the Weddell-Scotia Confluence Zone, 2) the coastal region of the south-eastern Weddell Sea, and 3) the Lazarev Sea surrounding the Prime Meridian.

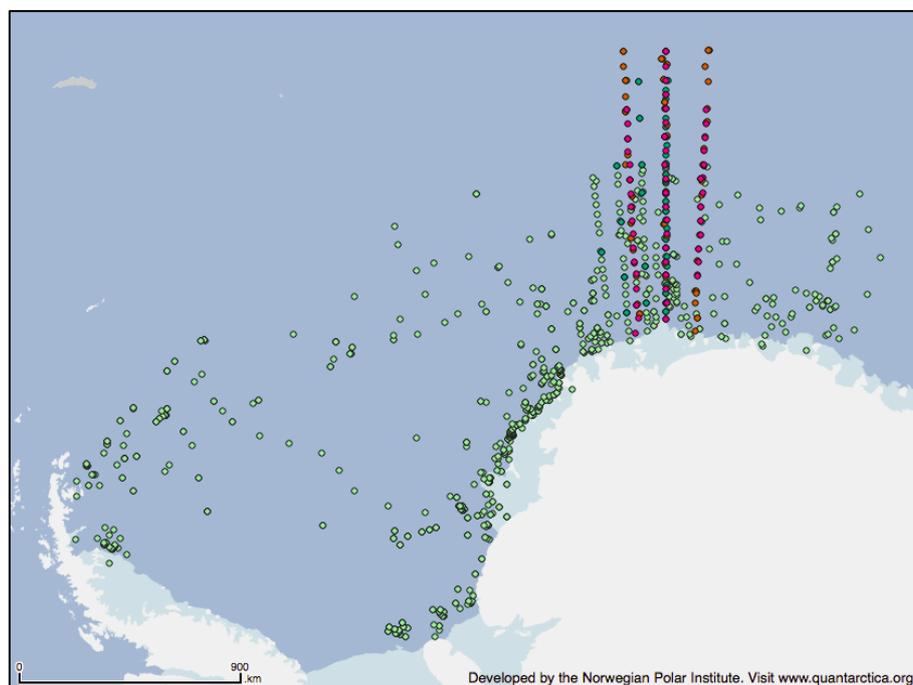


Figure 3-7 Locations of Weddell Sea zooplankton samples included in the SCAR Biogeographic Atlas of the Southern Ocean (green) as well as samples collected in the framework of the LAKRIS expeditions 2004-2008 (red) (source: biodiversity.aq; map was made using quantarctica).

Macrozooplankton species richness in the epipelagic layer of the Weddell Sea ranges between 22 species (Fisher et al. 2004) and 53 species (Siegel et al. 1992). Mesozooplankton species richness is typically higher. In the north-western and north-eastern Weddell Sea, species numbers of calanoid copepods ranged between 55 and 70 (Schnack-Schiel et al. 2008 and references therein). The copepod *Calanus propinquus*, the siphonophore *Diphyes antarctica*, and the euphausiids Antarctic krill (*Euphausia superba*) and *Thysanoessa macrura* show a wide distribution across the entire Weddell Sea area.

Horizontal and vertical patterns in zooplankton distribution

The distribution of pelagic samples from the Southern Ocean reflects the methodologies used to sample planktonic invertebrates, such as the CPR and CCAMLR krill sampling protocols (Griffiths et al. 2014). High zooplankton biomass can be associated with shelves, hydrographic fronts, or seamounts. At the Maud Rise seamount for example, current jets at its flanks and ice edge blooms enhance primary production, and subsequently zooplankton abundance. A stable Taylor Column over the central rise enhances vertical export and stabilises a midwater food web reaching from the surface to the seafloor at about 2000 m depth (Brandt et al. 2011).

Boysen-Ennen & Piatkowski (1988) and Boysen-Ennen et al. (1991) provide one of the few large-scale studies of Weddell Sea epipelagic zooplankton composition and abundance. Three different zooplankton communities were distinguished in the seasonally and permanently ice-covered parts of the Weddell Sea: an oceanic community, a northeastern shelf community, and a southern shelf community. The oceanic community samples consisted of 61 zooplankton species on average. In terms of abundance and biomass, the oceanic community of the central Weddell Sea was dominated by copepods smaller than 5 mm, which accounted for about 50% of the total biomass there (2.8 g DWm⁻²). Antarctic krill accounted for 14% of the biomass. The north-eastern shelf community had highest abundances (Boysen-Ennen & Piatkowski 1988). It was dominated by large copepods (*Calanus propinquus* and *Calanoides acutus*). The faunal composition was characterized by both oceanic and neritic species (64 species on average). The northeastern shelf community also showed the highest zooplankton biomass of the three different plankton communities (3.4 g DWm⁻²). The biomass composition was dominated by juvenile and adult ice krill *Euphausia crystallorophias*. The southern shelf community had lowest abundances. Ice krill and the copepod *Metridia gerlachei* were predominating. Compared with the low overall abundance, the number of regularly occurring species was high (55 species on average per sample). The southern shelf community also had the lowest biomass values (1.2 g DWm⁻²). Species with the highest biomass contribution were ice krill (25%) and the pteropod *Limacina helicina* (17%) (Boysen-Ennen et al. 1991).

The pelagic zooplankton fauna is not only characterized by latitudinal/horizontal zonation of communities, but species composition also changes with depth from the epipelagic to the mesopelagic layers (e.g. Siegel & Piatkowski 1990, Schnack-Schiel et al. 2008). From the multi-seasonal Lazarev Sea Krill Study (LAKRIS), a change in species composition within the epipelagic zone was evident (Flores et al. 2014). Changes in zooplankton community structure occurred with depth from a euphausiid-dominated community in near-surface waters (0-2 m) to a siphonophore-dominated community in the epipelagic layer (0-200 m). The deeper layers below 200 m down to 3000 m again experienced another change to a community dominated by chaetognaths (arrow worms). The diversity in these deeper water

layers is significantly higher than in the epipelagic depth range. In the Lazarev Sea, about 68% of all macrozooplankton species were confined to depths between 200 and 3000 m (Flores et al. 2014). Meso- and bathypelagic zooplankton communities, however, are sampled rarely, and their diversity is probably heavily under-estimated.

Zooplankton and sea ice

Besides hydrography and bottom topography, sea ice is an important factor structuring oceanic zooplankton communities in the Weddell Sea. In the north-western Weddell Sea, Siegel et al. (1992) described a gradual change from a copepod-dominated community in open waters to a krill-dominated community in closed pack-ice. In the Lazarev Sea, two separate ecological zooplankton zones have been described south of the Polar Front: the northern permanently ice-free zone between the Polar Front and approximately 60°S, and the marginal ice zone (MIZ) to the south of 60°S (Pakhomov et al. 2000). LAKRIS results indicated that changes in the epipelagic community were associated with hydrographical gradients, such as temperature, salinity and particle concentration (Flores et al. 2014). In contrast, the community of the largely ice-covered 0-2 m surface layer mainly changed along gradients of sea surface temperature and sea ice conditions, indicating a decisive role of sea ice for structuring near-surface zooplankton communities (Flores et al. 2014). The ice underside can often accommodate the bulk of zooplankton abundance (Flores et al. 2012, Flores et al. 2014). Besides Antarctic krill (e.g. Marschall 1988, Meyer et al. 2010), abundant copepods, such as *Stephos longipes* and *Paralabidocera antarctica*, as well as amphipods (e.g. *Eusirus* spp.) spend at least a part of their life cycle in close association with sea ice (Hoshiai et al. 1987, Krapp et al. 2008, Schnack-Schiel et al. 2008, Flores et al. 2011).

Conclusions

The oceanic zooplankton community of the Weddell Sea is highly influenced by the Weddell Gyre, which constitutes its own biogeographical domain (Grant et al. 2006). This biogeographic peculiarity is reflected in a unique community structure compared to other regions of the Southern Ocean. In contrast to the well-investigated Western Antarctic Peninsula – Scotia Arc domain, the information available from the Weddell Sea indicates that copepods rather than Antarctic krill dominate the zooplankton community in abundance, and often also in biomass. Sea ice is an important factor controlling zooplankton distribution and productivity. This habitat, however, is extremely dynamic due to seasonal fluctuations, but is also highly susceptible to global warming. Hence, the pelagic and under-ice habitats of the Weddell Sea are representative of a largely copepod-based food web under strong influence of sea ice. This system may respond differently to environmental change than the ‘classical’ krill-based ecosystem in the southwest Atlantic sector. At the current low level of detected environmental change in this region, systematic baseline studies of the present system state in selected areas are timely. Such areas could serve as excellent observatories of potential ecosystem change, if human perturbation is kept to a minimum.

Antarctic krill (Euphasia superba)

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Despite the collection of some Antarctic krill data in the southern Lazarev and Weddell Sea by the 'Discovery' research (Fraser 1936, Marr 1962, Mackintosh 1973), this region of the Atlantic sector is poorly studied compared to other regions of the Southern Ocean. Even less information is available on euphausiid larvae distribution and abundance. Around the 0-degree meridian in the Southeast Atlantic krill is present from the Polar Front at approximately 51°S all the way to the Antarctic continent at 70°S and up to 74°S in the southeastern Weddell Sea, which is the widest latitudinal coverage in its entire circumpolar distribution.

In general, krill abundance seems to be relatively low in high latitudes of the Weddell Sea and the Southeast Atlantic when compared with long-term results from west of the Antarctic Peninsula and Scotia Sea region. All abundance and biomass values from the Lazarev and Weddell Sea are well below the long-term mean density of the Antarctic Peninsula/Scotia Sea surveys. During the multi-year LAKRIS cruises average numerical or biomass densities in the southern Lazarev Sea never exceeded 7 adult krill m⁻² and 2 g m⁻², respectively (Siegel 2012). The symptom of the lower abundance and biomass in the Southeast Atlantic and Indian Ocean sector can also be deduced from studies on krill aggregation characteristics. Miller & Hampton (1989) found that mean length, size, density and biomass of krill aggregations were substantially smaller, and inter-aggregation spacing substantially greater than those observed for the West Atlantic. However, aggregation characteristics are certainly another proximate cause for lower abundance values in the east, and the ultimate cause is probably the difference in primary production, hence food concentration and growth potential for the species as indicated by Atkinson et al. (2008).

In autumn, greatest abundance of krill larvae was located in the central part of the Lazarev Sea between 62° and 68°S. Highest and average densities of larvae were relatively low compared to the historic data of the FIBEX 1981 or the CCAMLR 2000 surveys in the Scotia Sea. To the west - in the eastern Weddell Sea - records on *E. superba* larvae had been given for the Coastal Current by Fevolden (1979, 1980) and Hempel & Hempel (1982), although it was quite obvious that south of 73°S *E. superba* larvae became extremely sparse. North of 63°S krill larvae diminished quickly from the diverging Weddell Flow.

The krill length composition is spatially and temporally not uniform across the Lazarev and Weddell Sea with substantial interannual differences. Obviously, large interannual variations occur in the recruitment success of the species, similar to those described for lower latitude areas (Siegel & Loeb 1995). The 20- to 30-mm size group of recruits concentrated in the central and northern part of the Lazarev Sea, although according to published data at least in some years juvenile krill can be found up to the continental shelf and to the west of the survey area in the eastern Weddell Sea (Fevolden 1979, Siegel 1982). In general, the distribution pattern of krill size classes in the Lazarev and Weddell Sea is different to the concept described by Siegel (1988) for the Antarctic Peninsula, where small/juvenile krill concentrate in coastal waters and the large sized spawning stock occurs in slope and oceanic regions. The

stock composition in the eastern Weddell Sea tends to show the reverse with smaller krill to the north and larger krill size classes further south and closer to the continent.

Comparison of published data from adjacent areas indicate some long-distance connection of krill stocks across ocean boundaries, which can be explained by the major current system related to the Weddell Gyre. In the following, the Weddell Gyre and its sphere of influence on the krill population shall be discussed in some detail. Waters from the southern Lazarev Sea flow across the Weddell Sea and form the outflow of the Weddell Sea into the Scotia Sea (see Fig. 3-3 in chapter 3.1.2). Between the South Orkneys and South Sandwich Islands (Deacon 1979, Beckmann et al. 1999) the outflow of the Weddell Sea join water masses and the krill population derived from the Antarctic Peninsula / Drake Passage and side by side these current branches transport krill via South Georgia / South Sandwich Islands to the Bouvet area. From there, krill can be traced via the Prime Meridian until 45°E into the Indian Ocean sector (Williams et al. 2010). The medium sized krill from 30°E are transported back into the Lazarev Sea where they meet the slightly larger krill from the narrow but strong Coastal Current originating from East Antarctic waters, thus indicating a coherence of the krill population over a vast geographical range in the Weddell Gyre system.

In their detailed analysis on the oceanic circumpolar habitats of krill, Atkinson et al. (2008) realised that the sector between 20°W and 50°E has been neglected in the past, despite containing a large part of the Antarctic krill stock – at least in its northern habitat - and representing a potential connection between the two postulated subpopulations in the Scotia Sea and the Indian Ocean. If, however, the Weddell Gyre is the source of high krill densities in the Scotia Sea (Mackintosh 1973, Maslennikov 1980), then the westward moving water masses of the Lazarev Sea should be inhabited by a recognizable krill spawning stock that seeds substantial amounts of krill larvae into the system to sustain the large population observed at the northern outflow of the Weddell Gyre.

Ocean circulation models suggest that krill may be transported into the area around Bouvet Island from the Weddell Sea via the northern eastward flow of the Weddell Gyre (Thorpe et al. 2007). This is supported by published krill net sampling data that show a high proportion of very large krill in the waters around Bouvet Island (Marr 1962, Fevolden 1979, Krafft et al. 2010).

In the waters of the Coastal Current - according to Makarov et al. (1985), Beckmann et al. (1999) and Schröder & Fahrbach (1999), which is the Antarctic Slope Current according to Williams et al. (2010) - krill sizes of 30-50 mm dominate. They are similar to those in the adjacent northern area; however, often a larger size mode of 50 mm is found in the area slightly to the north of the Coastal Current. The distribution of this size group extends north to 68° or 67°S; however, Makarov et al. (1985) indicated that the boundary between the Coastal Current and the adjacent Weddell Drift is not sharp, but forms a broad transition zone. So these krill concentrations are probably not only confined to the Coastal Current, but also inhabit the transition zone. One important point is that this size class has also been observed by Kawaguchi et al. (2010) in the western Indian Ocean around 30°E in connection with the Coastal Current. This leads to the conclusion that we do not only have a long-distance connection between the krill stocks of the Atlantic and Indian Ocean sectors at the northern fringes (large adult krill west and east of Bouvet), but a similar connection in the opposite direction along the continental margin following the drift of the Coastal Current (see Fig. 3-3

in chapter 3.1.2). The two southern current bands south of 63°S are transported westward into the southern and central Weddell Sea and krill are finally advected to the Scotia Sea mainly between 30° and 45°W, that is between the South Orkney and the South Sandwich Islands. Around 75°S the Coastal Current splits into two branches, one turns west in the direction to the Antarctic Peninsula following the deep continental slope, whereas the other branch flows south to the Filchner/Ronne ice shelf. For the first current we have no sampling data for krill, since this current is entering the permanently multi-year ice covered central Weddell Sea. For the southward moving current, data show that Antarctic krill is almost absent from these waters and is solely replaced by the ice-krill *Euphausia crystallorophias* (Fevolden 1979, Siegel 1982).

For the northern outflow areas of the Weddell Sea data are sparse, and few earlier studies have managed to penetrate into the marginal ice zone of the north-western Weddell Sea to study krill by net sampling, divers or ROV observations such as the EPOS project in early spring 1988 (Bergström et al. 1990) or the AMERIEZ project that studied the area in spring, autumn and winter 1983–1988 with random net samples and acoustic methods (Daly & Macaulay 1991). Melnikov & Spridonov (1996) reported on the occurrence of low densities of old furcilia and post-larval stages under the permanent sea ice of the western Weddell Sea. This could have been an effect of a poor year-class, but it may be that the composition of the stock in the Weddell Sea during February–April was very typical for late winter early spring situation in a permanently ice covered zone (Daly 1990). Furthermore, these late furcilia did neither grow nor develop further during the study period. Therefore, Melnikov & Spiridonov (1996) concluded that these krill could not belong to the 0 group originating from the studied season, but must have been born in the summer before and developed extremely slowly under poor feeding conditions under perennial sea ice. The authors further suggested that the observed larvae in the north-western Weddell Sea could not be krill of local origin, but are subject of advection from the eastern Weddell Sea where krill are known to be spawning (Hempel & Hempel 1982). These findings contradict the assumptions made by Capella et al. (1992) for modelling the drift of early krill life stages and which resulted in a hypothesis that the Weddell Sea is an important source of krill larvae in the Bransfield Strait. Most probably these larvae had taken the long and ice-covered route through the southernmost Weddell Sea and drifted north again along the eastern Antarctic Peninsula.

In summary, the Lazarev and Weddell Sea have to be regarded as a transition zone between the Southwest Atlantic and the Indian Ocean with a briskly exchange rate in either direction. This flux contradicts the hypothesis that the Weddell Sea might be inhabited by a local self-maintaining krill stock. Krill are actively spawning in the southeastern high-latitude areas; however, prevailing currents will carry the offspring westwards into the Weddell Sea and new recruits are transported in from the Indian Ocean. Krill in the Antarctic Peninsula/Scotia Sea region attain a larger maximum size than krill in the high-latitude areas of the southern Weddell Sea. The occurrence of larger size classes in the Peninsula/Scotia Sea also means that the proportion of adult mature specimens increases and because of the exponential relationship between size and fecundity the reproductive output should be substantially greater (Ross & Quetin 1983, Siegel 1985). Maybe, this difference in additional spawning capacity between the Scotia Sea and Lazarev Sea populations can at least explain part of the lower abundance of krill larvae in the Weddell Sea, although the actual overall density of the spawning stock will also have a great influence on the reproductive output.

Pelagic fish

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The fish fauna of the Southern Ocean is distinctly dominated by a single taxonomic group: the perciform suborder Notothenioidei, particularly in shelf and upper slope areas (e.g. Andriyashev 1986, Eastman 1993). The majority of species is endemic to the Antarctic and belongs to four different families: the Nototheniidae (Antarctic cods), the Channichthyidae (Icefishes), the Artedidraconidae (Plunderfishes) and the Bathydraconidae (Dragonfishes). The uniqueness of the Antarctic fish fauna with its high degree of endemism and a single dominant group is the result of a long evolutionary history of adaptive radiation in isolation at sub-zero temperatures (e.g. Eastman 1991, 1993). However, due to the lack of a swim bladder, only few notothenioid fish species occupy the pelagic realm. In these species, buoyancy is attained by secondary adaptations, such as accumulation of lipids or reduction of bone (Eastman 1985a, 1988, Eastman & DeVries 1982). Compared to the demersal community, the pelagic fish community in the Southern Ocean is therefore in general characterized by poor species diversity.

In the Weddell Sea, most studies on the pelagic fish community were carried out in the southern part and on the north-eastern shelf, including the Lazarev Sea (e.g. Flores et al. 2008, Hubold 1992, Hubold & Ekau 1987, Kellermann & Kock 1984, Knust et al. 1999, Mintenbeck et al. 2005, White & Piatkowski 1993). One more recent expedition to the area of the former Larsen shelf ice provided some data on the pelagic fish community along the western Weddell Sea shelf (Mintenbeck & Krägefsky 2012). Some data on the pelagic fish fauna in the central, deep Weddell Sea are available from Lancraft et al. (1989). The distribution pattern of pelagic fish is related to water masses and it can be distinguished between a neritic, high Antarctic shelf community, and a more oceanic community. This pattern applies to adult fish (Hubold & Ekau 1987, Lancraft et al. 1989) as well as to the larval/postlarval fish community (e.g. Flores et al. 2008).

The oceanic community is composed of rather cosmopolitan (non-notothenioid) families, such as the mesopelagic Myctophidae, Bathylagidae, and Paralepididae. Most common species are *Electrona antarctica* and *Gymnoscopelus* spp. (Myctophidae), *Bathylagus antarcticus* (Bathylagidae) and *Notolepis coatsi* (Paralepididae). A similar community is also found more in the north, in the central Scotia Sea (Torres et al. 1984) and in the vicinity of the Weddell-Scotia confluence (Lancraft et al. 1991). All these species undertake diel vertical migrations: during the day individuals tend to stay in deeper water layers, while at night they show peak abundances in the upper 200/300m of the water column (Lancraft et al. 1989, 1991, Torres et al. 1984).

The neritic community is largely composed of notothenioid fish and distinctly dominated by a single species: *Pleuragramma antarctica* (Nototheniidae), the Antarctic silverfish (e.g. Hubold 1992, Hubold & Ekau 1987, Mintenbeck et al. 2012, White & Piatkowski 1993, Shust 1998, 2001). *P. antarctica* is neutrally buoyant and the lack of a swim bladder is compensated

by a reduction of bone mass and density, and by large lipid deposits stored in subcutaneous and intramuscular lipid sacs (DeVries & Eastman 1978, Eastman 1985a, Eastman & DeVries 1982). This species often dominates the pelagic fish community contributing more than 90% of both abundance and biomass. Other occasional guests in the water column include *Aethotaxis mitopteryx* (Nototheniidae), *Akarotaxis nudiceps*, *Gerlachea australis* and *Racovitzia glacialis* (Bathydraconidae), and icefishes (Channichthyidae) such as *Chionodraco myersi*, *Ch. hamatus*, *Dacodraco hunteri*, *Chaenodraco wilsoni* and *Pagetopsis maculatus* (Flores et al. 2012, Hubold & Ekau 1987, White & Piatkowski 1993). The ichthyoplankton community on the shelf includes larvae and postlarvae of different notothenioid species and is also distinctly dominated by early stages of *P. antarctica* (e.g. Boysen-Ennen & Piatkowski 1988).

P. antarctica is a herring-like zooplankton feeding fish species which occurs in loose shoals (Fig. 3-8). Stock biomass in the southern Weddell Sea was estimated with at least 1 ton km⁻² (Hubold 1992). Life history is characterized by slow growth and late maturity (Hubold & Tomo 1989, Kock & Kellermann 1991). Relative fecundity is high compared to most demersal notothenioid species (Gerasimchuk 1987, Kock and Kellermann 1991), but distinctly lower than fecundity of other small pelagic fish species such as clupeids (e.g. Alheit & Alegre 1986). The southern Weddell Sea is an important spawning ground of *P. antarctica* (Hubold 1992). Spawning and early life history of this species is closely coupled to the sea ice and its seasonal dynamics. *P. antarctica* spawns pelagic eggs which are floating in the platelet ice under the sea ice (Vacchi et al. 2004). Hatching of larvae starts in austral spring (October/November), and larvae are drifted via currents along the shelf towards the coastal polynyas, which usually form between December and January (Hubold 1984, 1992).

To avoid intraspecific competition, different size/age classes of this species are vertically separated within the water column: Larvae are mainly concentrated in the upper 50m in well stratified surface water, juveniles occur slightly deeper and adults are usually found in deepest layers, close to the seafloor (Hubold 1984, 1992). Adults, however, undertake extensive diel vertical (feeding) migrations into upper water layers (Fuiman et al. 2002, Plötz et al. 2001). On the western Weddell Sea shelf *P. antarctica* and juveniles of the cryopelagic *Pagothenia borchgrevinki* (Nototheniidae) were found associated with swarms of ice-krill, *Euphausia crystallorophias*, in 100-150m water depth (Mintenbeck & Krägefsky 2012). On the eastern Weddell Sea shelf, in the Drescher Inlet, peak abundances were found at night in about 40-120m water depth (Mintenbeck 2008, Plötz et al. 2001).



Figure 3-8 Catch of *Pleuragramma antarctica* in the Drescher Inlet, eastern Weddell Sea, during RV *Polarstern* expedition ANT XXI-2 in 2003/04 (Photo: J. Plötz, AWI).

Similar to myctophid fish offshore in the seasonal sea ice and the ice free zones, *P. antarctica* is an important link in the neritic's zone short pelagic food chain phytoplankton – zooplankton – fish – apex predators. Due to the absence of myctophides in neritic high Antarctic water masses, *P. antarctica* occupies a key role in the food web on the high Antarctic shelf (e.g. Hureau 1994, La Mesa et al. 2004). The dense shoals provide an important and easily exploitable food source for warm-blooded animals living on the ice or on the coast, such as seals, penguins and seabirds (Burns et al. 1998, Castellini et al. 1984, Green 1986, Klages 1989, Plötz 1986, Plötz et al. 2001) as well as for piscivorous fish species (Eastman 1985b, 1999, Schwarzbach 1988).

Owing to its particular life style and life history characteristics, the key fish species *P. antarctica* is assumed to be highly vulnerable to changes in environmental parameters, making the entire pelagic system on the high Antarctic Weddell Sea shelf extremely susceptible to disturbances and alterations (La Mesa & Eastman 2012, Mintenbeck et al. 2012, Mintenbeck & Torres in press).

Squid

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Knowledge about Antarctic squids in general is rather limited. Very few records exist for adult squid. During an ice drifting station in the western Weddell Sea two large squids were caught in an ice hole. The two specimens had a mantle length of 42 and 47 cm, respectively and were identified as adult mated spent females of the cranchiid squid *Galiteuthis glacialis* (Nesis et al. 1998). *G. glacialis* is one of the most numerous and widely distributed Antarctic squids. Its distribution range is circumpolar. The paralarvae and juveniles are eurybathic and

live in the epi- and mesopelagic zones between 0 and 400 m depth. Adolescent and adult squids move deeper into the lower mesopelagic and bathypelagic water layers between 500 and 2500 m.

Usually data on the occurrence of squids are obtained from stomach sample analysis, e.g. emperor penguins *Aptenodytes forsteri* (Piatkowski & Pütz 1994). Mostly the occurrence of squid as food item can only be recorded from the presence of beaks in the stomachs. The squid diet of adult emperor penguins on the fast ice of the Drescher Inlet, Vestkapp Ice Shelf in the eastern Weddell Sea consisted principally of *Psychroteuthis glacialis*. Other species were *Kondakovia longimana* (50% of total estimated squid mass in the diet), *Alluroteuthis antarcticus*, and *Gonatus antarcticus*. Stomach analyses of seals, such as the Weddell Seals *Leptonychotes weddellii* proved that *Psychroteuthis glacialis* was represented in samples from the eastern Weddell Sea (Plötz et al. 1991).

Small squid specimens are sometimes caught in epipelagic plankton samples. In those cases we are usually observing juvenile specimens or paralarvae. Boysen-Ennen & Piatkowski (1988) reported paralarvae from three species in the southeastern Weddell Sea, i.e. *Psychroteuthis glacialis*, *Alluroteuthis antarcticus*, *Galiteuthis glacialis*. During the LAKRIS study RMT 8 samples from the Lazarev Sea east of the Weddell Sea revealed *Galiteuthis glacialis* (52% presence in summer, 92% in winter), *Mesonychoteuthis hamiltoni* (54% presence in summer, 6% in winter), *Alluroteuthis antarcticus* (35% presence in summer, 9% in winter), *Slosarckovia circumantarctica* and *Onychoteuthis sp.* (Siegel unpublished data). The regular occurrence of paralarvae and juveniles suggests that all the species reproduce in the Antarctic. Juvenile vertical distribution appears to differ between species with *P. glacialis* concentrated relatively near the surface.

3.2.3 Benthic ecosystem

Zoobenthos – Shelf and slope

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Continuous research on benthos has been carried out in the Weddell Sea since the 1980s. The first scientific exploratory surveys were followed by question driven studies (see e.g., Arntz & Gallardo 1994), whose results were already partially suited to be later uploaded to data repositories (e.g., Gutt et al. 2000, Gutt et al. 2014) and their scientific products (DeBroyer et al. 2014). Traditional sampling with grabs and towed nets as well as the use of imaging methods, experiments, analyses in the labs and modelling approaches contributed to a comprehensive knowledge of the structure and functioning of the benthic system. The regional focus of the macrobenthos surveys was the shelf of the South-eastern Weddell Sea but also the most difficultly reachable South was sampled at an early stage. Recently the areas

of disintegrating Larsen A & B ice shelves east of the tip of the Antarctic Peninsula in the Western Weddell Sea were added to the portfolio of this research approach.

The most obvious characteristic of the macrobenthos communities on the Weddell Sea shelf is their high spatial heterogeneity in biodiversity, species composition and biomass at all spatial scales ranging from meters to hundreds of kilometres (Gutt et al. 2013a, Fig. 3-9). The most conspicuous community is that dominated by suspension feeders (Voss 1988, Gili et al. 2006); it resembles coral reefs due to its high abundance of sessile animals living on the sediment and the three-dimensional structure but is differently organised. This community comprises a variety of types; it can be dominated by barrel shaped glass-sponges or more diversely shaped demosponges (Barthel 1992), solitary and colonial sea-squirts, coral-related cnidarians or erect soft or calcified bryozoans. In such communities world record levels of biomass can be reached (Gerdes et al. 1992). Rarely, "true" (hydro-) corals, bivalve-like brachiopods and goose barnacles can also be abundant. Contrasting to such sessile assemblages are communities dominated by mobile animals such as ophiuroids or the generally rare mobile holothurians of the deep-sea type and infauna. However, boundaries between all these assemblages are mostly not discrete instead a decrease in the biomass of sessile suspension feeders coincides with an increase in relative abundance of mobile and infaunal animals (Galéron et al. 1992).

For all these communities an estimation based on extrapolations revealed up to 14000 macrobenthic species, which is high compared to known estimations for comparable areas in the Arctic and temperate seas but low compared to the deep-sea and coral reefs. Generalities in the spatial occurrence and composition of these communities are difficult to make due to the heterogeneity of their ecological drivers (Gutt 2000, 2006), even the dominance of high species and biomass richness along the eastern shelf is not consistent and exceptions exist everywhere along the coast. Despite an obvious eurybathy of many, but not all species, (Brey et al. 1996) a clear decrease of biomass and abundances with increasing water depth exists, however the depth at which this decline becomes most obvious can vary between approximately 250 and 450m.

The spatial patchiness emphasized above indicates a high complexity of ecological driving forces, of which some important have been deciphered in comprehensive ecological studies. The sessile suspension feeder community seems to be most abundant on the narrow shelf above which in intensive coastal current provides food in the form of horizontally drifting phytodetritus. Erect species which have a stalk or simply large sessile animals extend with their main body and feeding apparatus into the current a few decimetres above the sea-bed, where an advective food supply for the filter feeders, which at least partially differ in their food demands (Orejas et al. 2003), is much higher than at the sediment surface food. A similar feeding strategy of other organisms is to settle on elevated substrata, which can be larger animals or big drop stones.

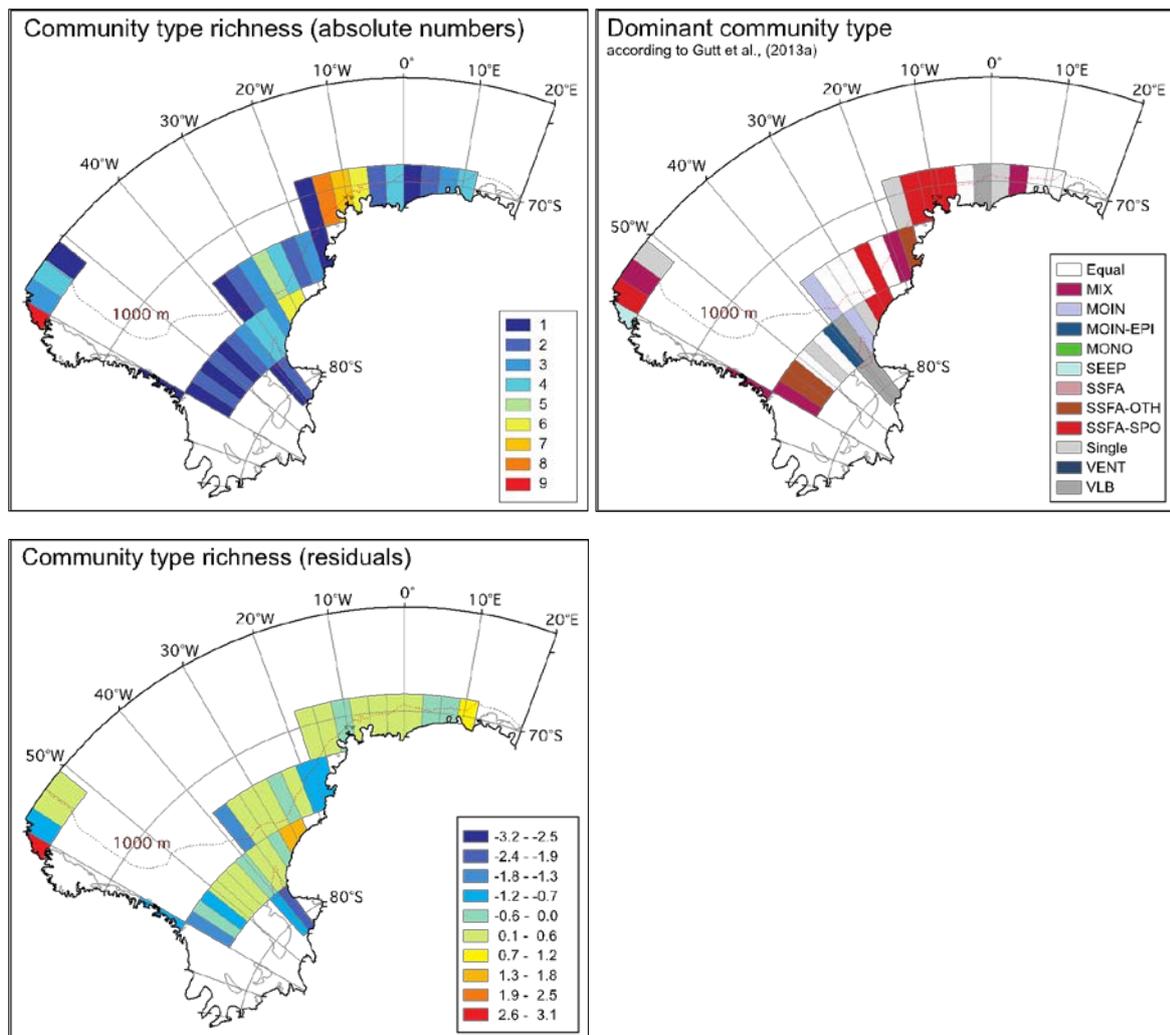


Figure 3-9 Macrobenthic communities in the MPA planning area, adopted from the circumpolar data set published by Gutt et al. (2013a). Dominant community types per cell are shown as well as species richness expressed as absolute number of community types and as residuals of the expected number of community types at a given number of records. For data repository see: <http://ipt.biodiversity.aq/resource.do?r=macrobenthos>.

Mainly echinoderms developed this epibiotic life style. Modern feather stars can opportunistically search for the best microhabitat because they can swim and change the habitat when necessary. Mostly cnidarians and sponges, but also bryozoans and ascidians serve as a living substratum for such species. Some highly specific relationships have developed including; sea-cucumbers adapted to live only on the spines of pencil sea-urchins, polychaetes and isopods living on sea-fans and amphipods encapsulating in the tissue surface of sponges (Kunzmann 1996). The ophiuroid *Ophiuroplinthus* is often overgrown by the encrusting sponge *Iophon spatulatus*. A total of 374 of such symbioses have been found by imaging methods (Gutt & Schickan 1998). Some of such epibiotically living animals do not feed on phytodetritus but on living zooplankton such as the snake star *Astrotoma* or the multi-armed sea-star *Labidiaster* which feeds on krill. Some demersal fish use elevated biological structures for a sit-observe-and-hide strategy (Gutt & Ekau 1996) by which they save energy in the cold environment and can hide inside a sponge when necessary; some even lay their eggs in the big osculum of the glass sponges. This three-dimensional structure also provides

the habitat for specific trophic interactions, e.g. the snail *Margarella* feeds on the surface of sponges and the amphipod *Gnathiphimedia mandibularis* is specialised on calcareous bryozoans. The relatively high number of such specific symbiotic relationships indicates a long-term stability of environmental conditions over evolutionary time scales, which allowed them to evolve. The continuous change between glacial and interglacial conditions obviously did not hamper such developments; it rather supported the speciation by vicariance events. Examples of communities shaped by predation pressure exist but are rare, e.g. where predatory sea-stars feed on sponges and may control their population growth. At a larger spatial scale habitats like inner-shelf depressions and areas on the broader flat shelf seem to function like fjords systems elsewhere in coastal systems, where in a low current velocity regime phytodetritus sinks vertically to the seabed from which mainly grazers such as deep-sea holothurians or infaunal polychaetes and echiuroids benefit, rather than filter feeders. Such a scenario can be superimposed by increased currents along the flanks of the depressions which, in contrast, support filter feeders but close to the ice shelf edge the direction of the current is important. Water masses that flow from under the ice shelf are poor in nutrients and do not allow any rich benthos community whilst benthic life can be rich where the current flows from the open water under the ice shelf.

Some inner-shelf depressions or overdeepened basins close ice shelf edge are generally extremely poor in macrobenthic fauna but have a specific composition of species which can be much more abundant in other areas such as the Ross Sea or area West of the Antarctic Peninsula, as the epibenthic clam *Adamussium* and the infaunal bivalve *Latrunculia*. As a consequence such areas in the Weddell Sea could act as important stepping stone habitats for a dispersal of species in a future with changing environmental regimes. In contrast to such poor communities habitats close to the coast or ice shelf edge can be very rich in biomass and species numbers because the local pelagic conditions might support a high productivity indicated by hyperbenthic krill aggregations close to the sea floor. In the western Weddell Sea krill and mysids displayed a behaviour that is interpreted as benthic feeding.

Besides the small-scale interactions and large scale environmental regimes discussed above iceberg scouring is a specific driver known to be important in the South-eastern Weddell Sea. After calving from the ice shelves icebergs of all sizes drift around the continent in the East Wind Drift Current. When they run aground they devastate the benthic fauna and modify the sediment composition and bottom topography. They either "scalp" elevations producing parallel furrows or plough up to 30m deep scars and through up piles of sediment. This disturbance leads to an obvious habitat fragmentation and increase in regional biodiversity (Gutt et al. 1998, Gutt & Piepenburg 2003). First invaders are fish species such as *Prionodraco evansii*, and ophiuroids. In a next stage pioneers recruit and start growing, which can vary in their species composition from scour to scour. First recruits of sessile organisms are some specific bryozoans, ascidians, gorgonians and the stalked sponge *Stylocordyla chupachups*. The development and succession of such assemblages depends on the dispersal capacity of such pioneers (Potthoff et al. 2006) and is almost impossible to predict until they reach a final stage with the architecting species such as sponges at their adult size. It was recently proved that these sponges can grow fast during an early life stage but their longevity has not been falsified. Under the assumptions that each metre squared is disturbed once in 320 years statistically the entire sea-bed is permanently affected. The relatively small size of glass sponges in the entire Eastern Weddell Sea compared to the Ross Sea might support this

hypothesis. Also other kinds of patchiness can be explained by iceberg disturbance even if the direct effect is not visible anymore. This is the case if the sediment experienced a specific sorting and the bottom topography was permanently changed with consequences for the small-scale food supply by the near-bottom current. It must also not be necessarily assumed that the system returns to its previous state following disturbance. A long-lasting effect results also from an early occurrence of vagrant species in the scours, which behave like bulldozers, feed on the juvenile recruits of sessile animals and hamper their establishment in that area. In contrast vagrant but gelatinous bulldozers such as the locally abundant deep-sea holothurian *Rhipidothuria* permanently avoid habitats, where a spiny epifauna is the first to become established.

Particularly exposed to iceberg disturbance are the very rare shallow-water sites of less than 150m depth. Only two such sites are known in the Eastern Weddell Sea where the coast is shaped by floating ice shelf or glaciated. A distinct topographic elevation on the Norsel Bank was discovered in the 1980s during an intensive ecological survey applying sea bed photography (Fig. 3-10). It is situated close to the ice shelf, occasionally even covered by the ice. Due to a combination of grounding icebergs, the dynamics of the advancing and retreating ice shelf coast, the light regime and wave action at its shallowest part of less than 60m it is an area of extremely high habitat heterogeneity, so-called beta diversity or species turnover (Raguá-Gil et al. 2004).

Due to its shallow depth also this site can act as a stepping stone for shallow water specific species such as the soft coral *Clavularia* and the hydrozoan *Tubularia* in a surrounding characterised by deeper water where different species with a more obvious eurybathy exist. A similar structure was recently described in the Western Weddell Sea, which also provides a habitat for a heterogeneous fauna including macroalgae but not for a shallow-specific fauna despite being situated much closer to a true coast along the Antarctic Peninsula and shallower depth than the comparable site in the Eastern Weddell Sea (Dorschel et al. 2014). A computer-based ecological model showed that the disturbance with an intermediate magnitude as on the Norsel Bank increases the regional diversity due to the coexistence of different successional stages each with a peculiar fauna, whilst the local diversity within each stage is reduced. It is highest in the final stage where in contrast to the well-known Intermediate Disturbance Hypothesis outcompetition of sensitive species by the most robust sponges does not lead to a reduced diversity; obviously these sponges act as a three-dimensional habitat and attract additional species.

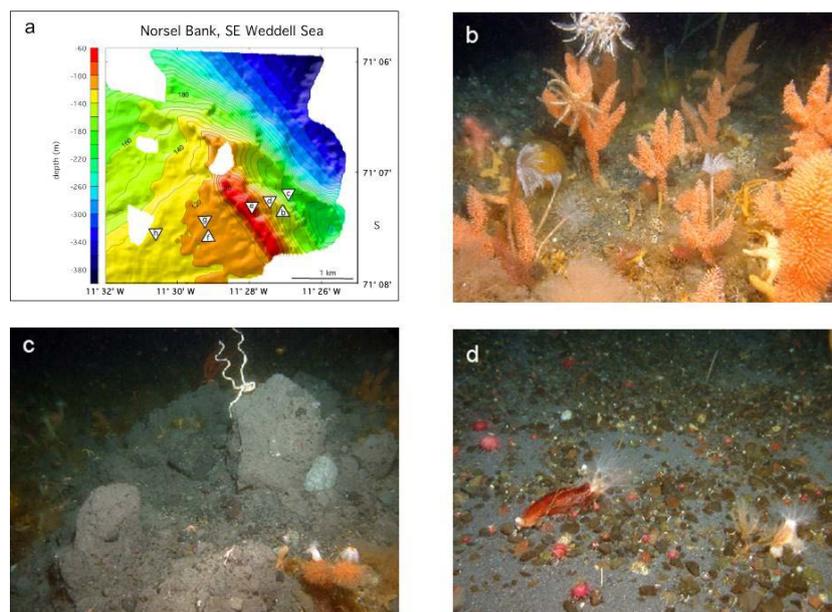
Another "large-scale natural ecological experiment" is the climate-induced disintegration of ice shelves, which changes an extremely oligotrophic system to a normal high-latitude Antarctic marine ecosystem with a rich phytoplankton bloom in summer (Smetacek et al. 1992) and the occurrence of pelagic key species as krill and the Antarctic silverfish (Gutt et al. 2011, Gutt et al. 2013b). The effect of the ice shelves collapse was studied in the Western Weddell Sea in the Larsen A and B areas at the Eastern coast of the tip of the Antarctic Peninsula. The fauna associated to the conditions before the ecosystem shift was comprised of more deep-sea type organisms compared to a "normal" Antarctic shelf community. Genetic analyses must show whether these are unique cryptic species closely related to their deep-sea relatives or whether they belong to the same interbreeding populations as those living at 1000 to 8000 m depth. It is assumed that glass sponges already lived in this area when it was still ice covered. However, their extremely rare occurrence is especially interesting. If there is

enough food for a walnut-sized organism (when it is still young) in an area of the size of a tennis court there must be enough food for more than only one specimen. A hypothesis that can explain this rarity is that early-life stages of these animals are especially sensitive to a predictable food supply, which cannot be guaranteed everywhere. A first response of the benthic system is the fast reproduction of deep-sea holothurians, a phenomenon which was so far only known from the northern hemisphere. Also ascidian populations can grow rapidly but also experience immediate mortality. An ancient cold seep was sampled for the first time in this area at the margin of an overdeepened basin with a unique composition of meiofauna (Hauquier et al. 2011) but no hints for living seep-specific megafauna (Niemann et al. 2009); in addition small spots of bacterial mats were observed in shallow water of approximately 150m.

Another very peculiar environmental condition is sponge spicule mats that form locally the sediment. When sponges die their glass "needles", which can reach decimetres in length, remain in dense concentrations and for long periods of time in the sediment and provide an especially favourable substratum for the next generation of some sponges and their associated benthic fauna (Gutt et al. 2013c). In essence, the Weddell Sea shelf is the habitat of a wide range of communities, which differ in biodiversity and ecosystem functioning and are shaped by a variety of physical and biological "ecological drivers" (Gutt 2000). Some of these communities are unique in their proportions and occurrence of species and life forms, some play a significant role in the entire Antarctic benthic system and some are typical for the entire Antarctic shelf but never occur with the exactly same proportions or composition.

Acknowledgements

We thank all those who contributed to an enormous accumulation of scientific knowledge on the Weddell Sea macrobenthos and its environment in more than the past three decades.



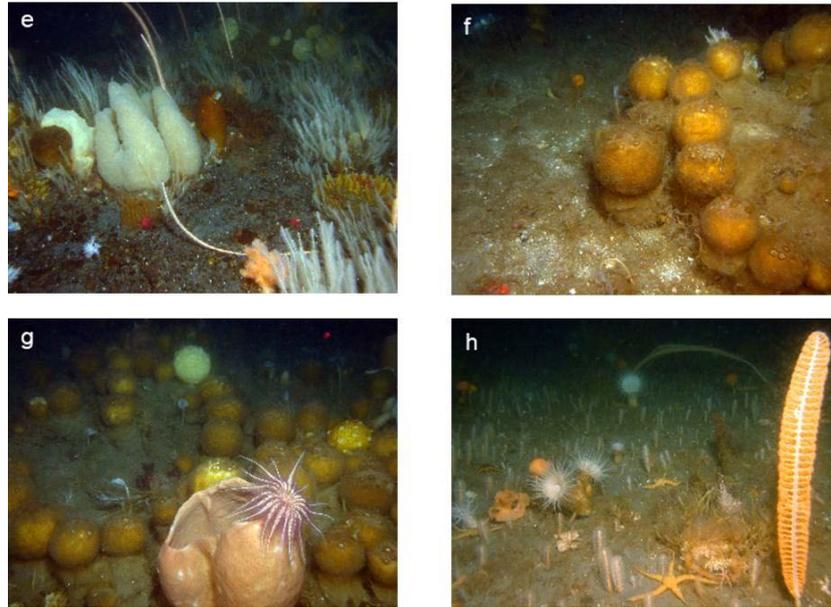


Figure 3-10 A specifically shallow site on the Norsel Bank in the South-eastern Weddell Sea and its megabenthic assemblages. Bathymetric data: AWI bathymetric working group; for data repository of sea-bed photographs see <http://doi.pangaea.de/10.1594/PANGAEA.820693>. a) Bottom topography with positions of the photographs. b)-h) White areas at the right margin indicate the floating ice shelf coast, white spots in the centre indicate the presence of grounded icebergs and, thus, areas could not be surveyed. b) Orange gorgonians dominate this site at the Eastern slope; other organisms are tube worms and feather stars. c) Here an iceberg run aground and disturbed the benthos; a brittle star that feeds with his arms on plankton hangs on a piece of sediment. d) Mostly mobile pink and red sea-stars colonise the almost shallowest area, but also dark and light brown sedentary sea-cucumbers. e) Only a few 10s of metres downhill on the Western side the macrobenthos is abundant comprising compound and solitary sea-squirts, various coral-related cnidarians as the dead-mans-hand and few sponges. f) A "nest" of the generally most abundant demosponge *Cinachyra* demonstrates how patchy even at a small spatial scale the Weddell Sea benthos can be. Spicule mats formed by the "roots" of the sponges become visible at the right margin and below the spheric bodies of the sponges. g) At the slightly deeper site glass sponges occur, which are dominant structures in the South-eastern Weddell Sea that form a three-dimensional habitat for many other species, such as here a feather star. h) Down to approximately 250m icebergs scour frequently the sea-floor. Here such an area is recolonised by a high abundance of little juveniles of the sea-fan *Ainigmaptilon*; an adult specimen is photography at the right margin. Other organisms being also pioneer species are stalked sponges, anemones and the mobile immigrant *Ophioplinthus* overgrown by the sponge *Iophon*.

Zoobenthos – Deep Sea

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The Southern Ocean (SO) deep sea covers 34.8 million km², the abyssal area about 27.9 million km² (Clarke & Johnston 2003). Most of our knowledge on abyssal benthic deep-sea fauna in the Weddell Sea available to date, is based on ANDEEP I-III (ANtartic benthic DEEP-sea biodiversity: colonization history and recent community patterns) expeditions, the most extensive biological deep-sea survey in the SO, incorporating 41 biological, sedimentological and geological stations in 2002 and 2005 (Brandt & Hilbig 2004, Brandt & Ebbe 2007).

Southern Ocean deep-sea biodiversity is reported to be high, higher than in more northern areas of the South Atlantic (Brandt et al. 2007a, b, c). Biodiversity is usually highest at around 3000-4000 m, but this might reflect a sampling artefact, as few stations have been sampled at very deep abyssal and hadal depths (Fig. 3-11, 3-12). Species accumulations curves in the SO deep sea are far from levelling off (Brandt et al. 2007a, b, Brandt et al. 2009), possibly because > 50% of the species sampled are rare (Glover et al. 2002, Brandt et al. 2007a-c, Brandt et al. 2012). In many taxa far more than 90 % of species collected are new to science, however, the high degree of “apparent” endemism reflects undersampling of the area.

At higher taxonomic level the SO deep-sea fauna resembles that of other deep-sea regions of the world oceans. Holocene climate changes increased eurybathy of many SO invertebrate species, and faunal exchange between shelf and deep-sea occurs deeper than elsewhere (1500-2500 m) and is facilitated through the almost isothermal water column. Contrary to the Antarctic shelf where organisms are isolated, the SO deep sea is connected to the adjacent deep-sea basins.

Large-scale biodiversity and biogeography patterns are highly diverse and the biogeography of SO deep-sea meio-, macro- and megafaunal taxa differ (Brandt et al. 2007b). Contrary to the Northern Hemisphere where we find a strong poleward decline in biodiversity (Poore & Wilson 1993, Rex et al. 1993) patterns in the Southern Hemisphere are different (Brey et al. 1994, Brandt et al. 2007b) and increasing species richness with increasing latitude has been observed for some taxa, like Isopoda and Gastropoda (Brandt et al. 2007b, Schrödl et al. 2011).

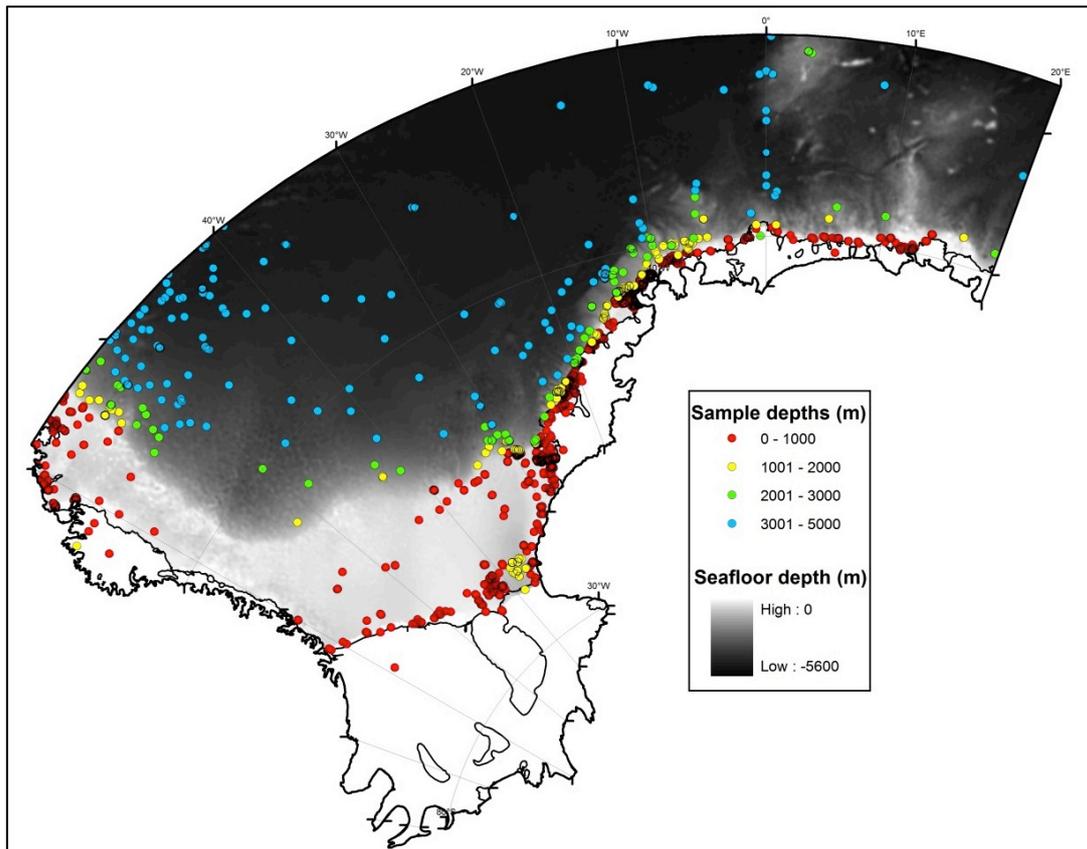


Figure 3-11 Benthic samples at different depths in the Weddell Sea sector of the Southern Ocean. Coloured points show individual sampling locations from which benthic organisms were recorded. On the shelf sampling locations overlap, while in the deep sea stations are more sparse and individual stations are visible.

Twenty-nine meiofaunal taxa have been reported from the SO deep sea, 3-22 co-occur in individual samples (Gutzmann et al. 2004). Within meiofaunal protists foraminiferans dominate (Gooday 2001) and metazoans are dominated by nematodes which occur with 83 – 97 % of the total metazoan meiofauna in the Weddell Sea (compared to 56 – 97 % in the deep Ross Sea (Fabiano & Danovaro 1999), followed by harpacticoid copepods (Vincx et al. 1994) in frequency. However, knowledge of these taxa below 3000 m is anecdotal. Nevertheless, diversity of nematode genera (e.g. Vanhove et al. 2004, De Mesel et al. 2006, Ingels et al. 2006) reveals very high local and regional species diversity, for example, off Vestkapp where high species turnover is reported between sites (beta-diversity). Similar patterns have been observed for harpacticoid copepods and a number of new species are described for the area (e.g. Willen 2009). Other frequently occurring meiofaunal taxa include Polychaeta, Kinorhyncha, Ostracoda, Loricifera, Gastrotricha, Tardigrada and Bivalvia.

Macrofaunal diversity differs across taxa. Decapod crustaceans became impoverished at high latitudes since the Tertiary climatic deterioration (Thatje et al. 2005). Their ecological niche was filled by peracarid crustaceans, of which Isopoda for example are an important component and include 674 species identified from the ANDEEP material. Of these, only 89 (13 %) were previously known, 585 species were new to the area or new to science and 43 genera were recorded for the first time in the Southern Ocean. Asellota comprised 97 % of all ANDEEP Isopoda – as typical for deep-sea areas - and 87 % of the SO deep-sea Isopoda appear to be “endemic” (Brandt et al. 2007b). Depth was the most important factor

determining isopod communities, and abundance and diversity are highest around 3000 m (83 isopod species). Isopods brood their young and this limits their dispersal capacities and might lead to evolution of species in situ at bathyal or abyssal depths (Brandt 1991, Raupach et al. 2009 and references therein). Low sampling effort below 3000 m is illustrated (Fig. 3-11, 3-12). Amphipod crustaceans are among the most speciose taxa in Antarctic coastal and shelf communities (De Broyer et al. 2014) and more than 17,500 amphipod specimens were collected during the ANDEEP expeditions (Brandt & Ebbe 2007) including 53 scavenger species below 1000 m depth (De Broyer et al. 2006 and references therein), mostly belong to the Lysianassoidea including 42 species from 19 genera and 9 families. Hilbig (2001) investigated 800 individuals of SO polychaetes belonging to 115 species from 28 families from depths > 1000 m. Later, Schüller et al. (2009) attributed 11,000 individuals of ANDEEP III polychaetes to at least 241 species in 46 families. More than 270 molluscan macrofaunal species inhabit the SO deep sea. With 150 macrofaunal morphospecies belonging to 37 families, gastropods are the dominant class (e.g. Engl 2005, Schwabe & Engl 2008) in terms of species numbers, followed by bivalves (82 species from 17 families; Linse et al. 2006 and references therein; Schwabe et al. 2007).

More than 26 taxa are recognised among the megafauna of the SO deep sea, and echinoderms dominate in terms of abundance, biomass and species richness (Linse et al. 2007). Within these, holothurians are more diverse than ophiuroids, asteroids and echinoids. The most diverse components of the sessile megafauna are anthozoan taxa including the Alcyonaria, Pennatularia and Actinaria, while sponges are important in terms of biomass. Stalked ascidians and stalked crinoids are rare in occurrence and biomass, with the exception of two sites in the Weddell and Bellingshausen Seas, where dense beds of stalked crinoids were discovered (Bohn 2006). Within porifera Demospongiae are most diverse with about 420 Antarctic species (Janussen & Tendal 2007) followed by the Hexactinellida (~ 60 spp.) and the Calcarea (~ 25 spp.) (Brandt et al. 2007b). Only seven cnidarian species are endemic to the SO deep sea (Pena Cantero 2004). Bryozoans, stalked ascidians and stalked crinoids are rare in the deep sea.

Acknowledgements

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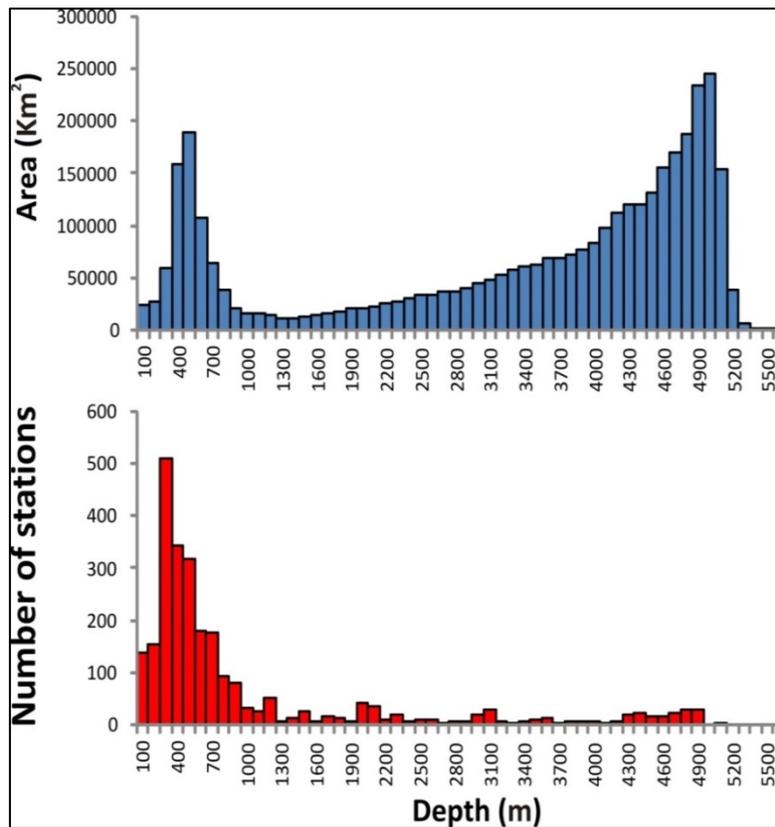


Figure 3-12 Area of seafloor in the Weddell Sea planning area with ocean depth in km² and sampling effort at these depths.

Demersal fish

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In high Antarctic areas, such as the Weddell and Ross Seas, fish play an important role in the ecosystem, both as prey and predator (Hureau 1994, La Mesa et al. 2004). Compared to the pelagic fish fauna, the demersal fish community in the Weddell Sea is diverse, both in terms of species and ecotypes. More than 76 species have been described for the Weddell (Hubold 1992) and Lazarev Seas (Zimmermann 1997) and new species are still being discovered (e.g. Balushkin & Prirodina 2006, Eakin et al. 2015). Most species belong to four families of the perciform suborder Notothenioidei (Nototheniidae, Channichthyidae, Artedidraconidae and Bathydraconidae; see chapter 3.2.2, ‘Pelagic fish’); in some high Antarctic shelf areas, such as the north-eastern Weddell Sea shelf, notothenioids constitute up to 98% of total fish abundance and biomass (R. Knust & K. Mintenbeck, AWI, unpublished data). Non-notothenioid fish in the Weddell Sea mostly belong to typical (cosmopolitan) deep-sea groups such as zoarcids, liparids and macrourids. The occurrence of these groups is largely restricted to the lower slope and the deep sea where notothenioid fishes, except for few species, are absent (Gon & Heemstra 1990, Kock 1992). The suborder Notothenioidei underwent a remarkable diversification by adaptive radiation on the isolated shelf of the Antarctic continent (Eastman 1991). Morphological and ecological diversification allowed for the

expansion into various niches (Eastman & McCune 2000, Ekau 1988); recent species of the suborder, accordingly, occupy benthic, benthopelagic, pelagic (*Pleuragramma antarctica*) as well as cryopelagic (*Pagothenia borchgrevinki*) habitats.

Since the late 1970ies/early 1980ies the demersal (benthic and benthopelagic) fish fauna in the southern and eastern part of the Weddell Sea and in the Lazarev Sea was studied on many expeditions (reviewed in Hubold 1992), and these studies continue (see e.g. Mintenbeck et al. 2012a, Wetjen et al. 2014). Recent expeditions yielded first information on the demersal community on the western Weddell Sea shelf, in the formerly ice-covered Larsen area (Kock et al. 2008a, 2012, Mintenbeck et al. 2012b).

In the western Weddell Sea, on the eastern shelf of the Antarctic Peninsula, the demersal fish community is dominated by typical high Antarctic species such as *Trematomus scotti*, *T. eulepidotus*, *T. hansonii*, *T. bernacchii* (Nototheniidae), *Gymnodraco acuticeps* (Bathypagrusidae), *Chaenodraco wilsoni*, *Chionodraco myersi* and *Pagetopsis* spp. (Channichthyidae), but in the northern part (Larsen A, 64°-65°S) species that are typical representatives of lower latitudes, such as *Gobionotothen gibberifrons* and *Lepidonotothen larseni* (Nototheniidae; Kock et al. 2008a, 2012, Mintenbeck et al. 2012b) are present, too.

On the southern and eastern shelf and slope, the fish community composition changes with water depth (Schwarzbach 1988, Ekau 1990, Ekau et al. 2012a, b, Drescher et al. 2012, Hubold 1992, Hureau et al. 2012, Wöhrmann et al. 2012, Knust et al. unpublished data). On the shelf (< 400m water depth) species of the family Nototheniidae are predominating; *Trematomus scotti*, *T. eulepidotus* and *T. lepidorhinus* are the most abundant species. Other typical components of the shallow shelf community are *Artedidraco skottsbergi* and *A. loennbergi* (Artedidraconidae), *Prionodraco evansii* (Bathypagrusidae) and *Pagetopsis maculatus* and *P. macropterus* (Channichthyidae, Fig. 3-13; Schwarzbach 1988, Knust et al. unpublished data). The deeper shelf community (> 400m water depth) is characterized by increasing presence of the families Channichthyidae, Artedidraconidae and Bathypagrusidae. The channichthyid *Chionodraco myersi* is often found in high biomass (Ekau 1990, Ekau et al. 2012a, b, Knust et al. unpublished data). Other typical species of this community are *Dolloidraco longedorsalis* (Artedidraconidae), *Gerlachea australis* and *Akarotaxis nudiceps* (Bathypagrusidae) (Schwarzbach 1988).

In the slope community below 550m water depth, *C. myersi* still accounts for large biomass. Other channichthyids inhabiting the Weddell Sea slope include *Neopagetopsis ionah* and *Chionobathyscus dewitti*. *Bathypagrus marri* and *B. macrolepis* are characteristic species for this community from the family Bathypagrusidae. The family Nototheniidae is represented by *Aethotaxis mitopteryx*, *Trematomus lepidorhinus* and *T. loennbergi*. Non-notothenioid fish species in the slope community include in particular *Macrourus whitsoni* (Macrouridae), but also e.g. Zoarcidae, Bathyraja sp. (Rajidae) and Muraenolepididae (Knust et al. unpublished data). The large, epibenthic Antarctic toothfish *Dissostichus mawsoni* (Nototheniidae) is mainly found on the deeper shelf and the slope (Ekau 1990, Knust et al. unpublished data).



Figure 3-13 The icefish *Pagetopsis macropterus* (Channichthyidae); © AWI/MARUM, University of Bremen (Photographers: J. Gutt, AWI & W. Dimmler, Fielax).

In the Lazarev Sea, the community composition is similar to the Weddell Sea, with a coastal shelf community and a typical slope community. The main differences are the higher percentage of benthopelagic nototheniids (e.g. *T. lepidorhinus*) and of non-notothenioid species, and the presence of lower-latitude nototheniids such as *Lepidonotothen kempfi* (Zimmermann 1997).

The pelagic species *Pleuragramma antarctica* is often found as a dominating component in bottom trawl catches on the high Antarctic shelf. This is owing to the fact that during daytime this species spends a lot of time close to the sea floor (see above, see chapter 3.2.2, ‘Pelagic fish’). Nevertheless, *P. antarctica* is not considered to be part of the demersal fish community.

Given the fact that ice-free shelf areas are limited and narrow in the Weddell Sea, the number and diversity of sympatric demersal fish species is surprisingly high. Apparently, small-scale niche separation is the key for low competition among the many demersal species. E.g., the 3-dimensional habitat formed by large sponges in many areas allows for the occupation of different vertical levels: the strictly benthic *Trematomus pennellii* and *T. bernacchii*, for example, live and feed directly on the seafloor, while the epibenthic *T. eulepidotus* and benthopelagic *T. lepidorhinus* feed on the “first floor” (Schwarzbach 1988, Ekau & Gutt 1991, Brenner et al. 2001). Quite often both species are observed resting on top of large sponges. Beside this vertical niche separation, horizontal habitat partitioning was observed, too. The high between-habitat diversity on the shelf, often shaped by grounding icebergs (e.g. Gutt 2000), allows for the co-existence of trophically similar species, where some species primarily inhabit areas with rich, 3-dimensional epifauna and other species prefer areas with distinctly less epifauna (Gutt & Ekau 1996, Brenner et al. 2001, Knust et al. 2003).

High Antarctic notothenioid fish are well adapted to life in a cold water environment that is characterized by strong seasonality. One of the key adaptations in their physiology is the ability to synthesize antifreeze glycoproteins (AFGPs) which efficiently prevent body fluids from freezing (DeVries 1971, Fletcher et al. 2001). Concentrations of AFGP differ between species and depend on ambient water temperature, depth distribution, life cycle, activity and

phylogeny (Wöhrmann 1996). Other adaptations to the cold water temperatures involve mechanisms to mitigate adverse effects of body fluids' viscosity which is significantly increased in the cold. For example, cell membranes contain a higher proportion of unsaturated fatty acids and phospholipid classes to maintain membrane fluidity, and an increased blood viscosity is offset by reduced haematocrit and haemoglobin concentrations (Eggington 1996, Macdonald & Wells 1991, and citations therein). Owing to the low metabolic demands of notothenioids (e.g. Clarke 1983, Clarke & Johnston 1996) and the increased physical oxygen solubility at cold temperatures, the reduction in haematocrit and respiratory pigment is not detrimental to aerobic performance. In species of the family Channichthyidae functional red blood cells are completely absent: these fishes do not possess any oxygen-binding pigment (haemoglobin) in their blood and some species also lack intracellular myoglobin (Montgomery & Clements 2000, Sidell & O'Brien 2006). The limited oxygen-carrying capacity of the blood is compensated by a multitude of secondary adaptive body modifications in icefishes, for example, a larger ventricle, increased blood volume and cardiac output, and increased skin vascularity (e.g. Kock 2005 and citations therein). The negative effects of temperature and viscosity on enzyme kinetics and gas diffusion are counterbalanced by metabolic adaptations, such as increased quantities and capacities of intracellular enzymes (Crockett & Sidell 1990). Many notothenioid fish also have relatively high intracellular concentrations of lipids which may be used as energy stores (Crockett & Sidell 1990, Eastman & DeVries 1981). On the one hand, notothenioid fish species are thus well adapted to cold water conditions in the high Antarctic. On the other hand, most species are extremely stenothermal and have, with some exceptions, a narrow thermal tolerance window (Somero & DeVries 1967); most notothenioids, e.g. *Trematomus bernacchii*, *T. hansonii* and *T. pennellii*, have an upper lethal temperature between just 4 and 6°C (Robinson 2008, Somero & DeVries 1967), and physiological performance is already affected well below this lethal limit.

Most demersal fish species in the Weddell Sea are small; about 77% of the species have maximum body sizes < 35cm. Exceptions are, e.g., *Dissostichus mawsoni* and some large icefish species. The majority of notothenioid fish is slow growing, and growth of Weddell Sea nototheniids is lower than that of their subantarctic relatives. Particularly slow growing demersal species are *Trematomus scotti* and *Aethotaxis mitopteryx* (reviewed in Hubold 1991, 1992). Sexual maturity is attained at about 60-75% of maximum body length, at an age of 3-9 years (Duhamel et al. 1993, Hubold 1992, Kock & Kellermann 1991). Among the notothenioid species there are spring, summer, autumn, as well as winter spawners (Ekau 1991, Kock & Kellermann 1991). Fecundity is relatively low and differs between species. Among the notothenioids, highest fecundity is found in species of the family Nototheniidae, lowest fecundity in the genus *Artedidraco* (Artedidraconidae) (Ekau 1991, Kellermann & Kock 1991). The spawned eggs are large and yolk-rich (Hubold 1992) and on the shelf sometimes deposited inside of sponges (pers. obs.). In nototheniids a general trend is apparent in producing less but larger eggs towards higher latitudes (Duhamel 1993, Kock & Kellermann 1991). Nest guarding has been observed in several Weddell Sea species (Moreno 1980, Jones & Near 2012, Kock et al. 2006, 2008b; see also Teschke et al. 2016, WG-EMM-16/02, chapter 1.2.3 'Demersal fish'). On a very recent expedition in 2013/14 a spawning ground of *Neopagetopsis ionah* (Channichthyidae) was found on the eastern Weddell Sea shelf, with adults guarding their eggs (D. Gerdes, AWI, personal communication; Fig. 3-14).



Figure 3-14 *Neopagetopsis ionah* (Channichthyidae) guarding its nest full of eggs on the eastern Weddell Sea shelf (Photo: D. Gerdes, AWI).

Egg incubation time is species-dependent and estimated about 3-6 months; there is no evidence for temperature compensation in developmental times (Hubold 1992). Most Weddell Sea species, particularly nototheniids and channichthyids, have pelagic larvae, which, after hatching, concentrate in surface layers to feed on small zooplankton (Hubold 1992). Larvae are large and the mouth is well developed at hatching; duration of yolk-sac absorption range from about 2 weeks up to 3 months. Metamorphosis to the early juvenile stage usually does not occur until 6-12 months after hatching (reviewed in North 1991). The transformation to the juvenile is followed by a transition to a demersal life style.

Due to slow growth and low fecundity the resilience to fishing pressure is low in most species (see FishBase, www.fishbase.org), and in other areas of the Southern Ocean some populations have been over-exploited severely (Kock 1992). No commercial fisheries are carried out in the Weddell Sea, in particular not in the ice-covered parts. In 2013 and 2014, the Russian Federation carried out for the first time a research fisheries for toothfish (*Dissostichus* spp.) in FAO Fishing Area (=CCAMLR Statistical Area) 48.5, but the resulting data have been quarantined by CCAMLR and are subject to further clarification. In Statistical Area 48.6, a multi-year exploratory fisheries programme for toothfish is carried out by Japan in collaboration with South Africa. In the adjacent waters north of the Weddell Sea, e.g. around the South Sandwich Islands (Statistical Area 48.4) there is a commercial longline fishery for the Antarctic toothfish *Dissostichus mawsoni* and its lower-latitude congener *D. eleginoides* (Patagonian toothfish) (FAO 2011). In the ice-free part of the Weddell and Lazarev Seas illegal, unreported and unregulated (IUU) fishing activities may occur.

3.2.4 Birds

Seabirds

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Any assessment of the spatial patterns and seasonal abundances of flying seabirds within the Weddell Sea MPA (WSMPA) planning area present a number of challenges. Large breeding populations do exist within the area, but details concerning distribution and abundance are generally not very well known. Birds breeding at the colonies on the continent, in the south of the Weddell Sea, are thought to be critically dependent upon the marine sector considered here. Other seabirds from populations breeding along the northern boundary of the planning area (i.e. near the tip of Antarctic Peninsula, at the South Shetland Islands, South Orkney Islands, South Sandwich Islands, South Georgia and Bouvet Island) also make seasonal use of the area. Some seabird species also migrate long distances to visit the Weddell Sea, as shown in the extreme example of the Arctic Tern, which annually migrates from the high Arctic to the marginal sea ice zones of the Antarctic, including those in the Weddell Sea. However, for most species, quantitative information is sparse.

Continental breeders, obligate users of the WSMPA planning area

Perhaps less well known than the penguins, but at least as spectacular in their extreme adaptation to harsh Antarctic environments, are several species of ‘tube-nosed’ seabirds, the petrels or Procellariiformes. Three species of petrel breed on mountain peaks that protrude through the Antarctic icecap like isolated islands. These ‘nunataks’ may be situated hundreds of kilometres distance from the nearest open water, even in the middle of summer, requiring breeders to regularly commute over very long distances to forage for and provide food for their chicks. Although all three species might be considered colonial breeders, only one, the Antarctic Petrel, breeds in dense groups. However, even for this species, estimates of colony sizes are sparse, and there are probably other colonies that remain undetected on other nunataks. Antarctic Petrels breed in the open, but other species such as Snow Petrels and Wilson’s Storm Petrels, nest between boulders or in rock crevices and are thus even more difficult to assess. However, one thing is certain these birds depend totally on the marine environment nearest to their breeding locations.

Antarctic Petrel – *Thalassoica antarctica*

Over 300,000 pairs of Antarctic Petrels are known to breed on nunataks close to the coastline of the Weddell Sea planning area (Table 3-1) (Van Franeker et al. 1999). Almost all breed in a relatively small sector of Dronning Maud Land in and near the Mühlig Hofmann Mountains at 72°S and between 2°E and 6°E (see Fig. 3-15); there are also smaller breeding aggregations far south in Coats Land at 80°S 30°W. These two sectors hold more than half of the world population of this species, estimated to be about 500,000 breeding pairs (Table 3-1). However, as many colonies are still poorly known and some almost certainly remain undetected, the true population size is uncertain. Based on existing data, the world population, including immatures and non-breeders is probably between 10 and 20 million individuals (Van Franeker et al. 1999). New work utilising satellite remote sensing may facilitate

improved population estimates in the future, but this work is only just becoming possible (Fretwell et al. 2014). Detailed counts at sea indicate that up to 5 million Antarctic petrels may aggregate in the marginal sea ice zone of the Weddell Sea in spring in an area close to the Greenwich Meridian (Van Franeker 1996). These birds probably feed here in preparation for their first visits to the nesting areas in early October. At this time of year, these trips may represent almost 2000 km of flying, over sea ice and ice cap. During the breeding season, between October and February, birds regularly commute to the Weddell Sea planning area, on which they completely depend for food.

Snow Petrel – *Pagodroma nivea*

Snow Petrels, like the Antarctic Petrel, breed in nunatak areas as far south as 80°S (Fig. 3-15); however, they also breed on some of the Sub-Antarctic islands. Snow Petrel breeding numbers are hard to assess, as most breed hidden between rocks. As a consequence, there is considerable discrepancy between the counts of breeding pairs and the probable true numbers of birds in the population. Existing counts total to just over 63,000 breeding pairs around all of the Antarctic (Table 3-1); nearly half of this figure breed south of, and thus are users of, the Weddell Sea MPA planning area (Croxall et al. 1995). Based on other evidence, including counts at sea, the population is estimated to be at least 4 million individuals (Croxall et al. 1995, Croxall et al. 2012). In the Weddell Sea they are widely distributed within the dense pack ice zones all year.

Wilson’s Storm Petrel – *Oceanites oceanicus*

Possibly the most abundant, but certainly the most enigmatic of the three petrel species breeding along the continental margin of the WSMMPA planning area, is Wilson’s Storm Petrel. Though similar in size to a swallow, this tiny bird can exist and breed in the high latitude Antarctic. They breed inconspicuously deep down in rock crevices and between boulders; though population estimates are probably underestimates, the species is undoubtedly abundant, with a global estimate of over 13 million breeding pairs (Croxall et al. 2012). No population estimates are currently available for the nunataks and mountain ranges south of the Weddell Sea planning area. Wilson’s Storm Petrel also breed, albeit in smaller numbers, on Sub-Antarctic islands, with estimates of 1,000,000 pairs at the South Shetland Islands, 100,000-1,000,000 pairs on the South Sandwich Islands, 100,000 pairs on the South Orkney Islands, and 1,000,000-10,000,000 pairs on Antarctic Peninsula (Del Hoyo et al. 2014). In winter, the species disperses over a very wide area, even into the northern hemisphere.

South Polar Skua - *Catharacta maccormicki*

The South Polar Skua also breeds south of the Weddell Sea planning area. During the penguin and petrel breeding season the species predate eggs and chicks, but also adults of some species. Virtually all petrel colonies, even those in the distant nunatak areas, have breeding pairs of skuas closely associated, but there are no details for local populations. The overall Antarctic population has been estimated at 7,550 breeding pairs (Croxall et al. 2012).

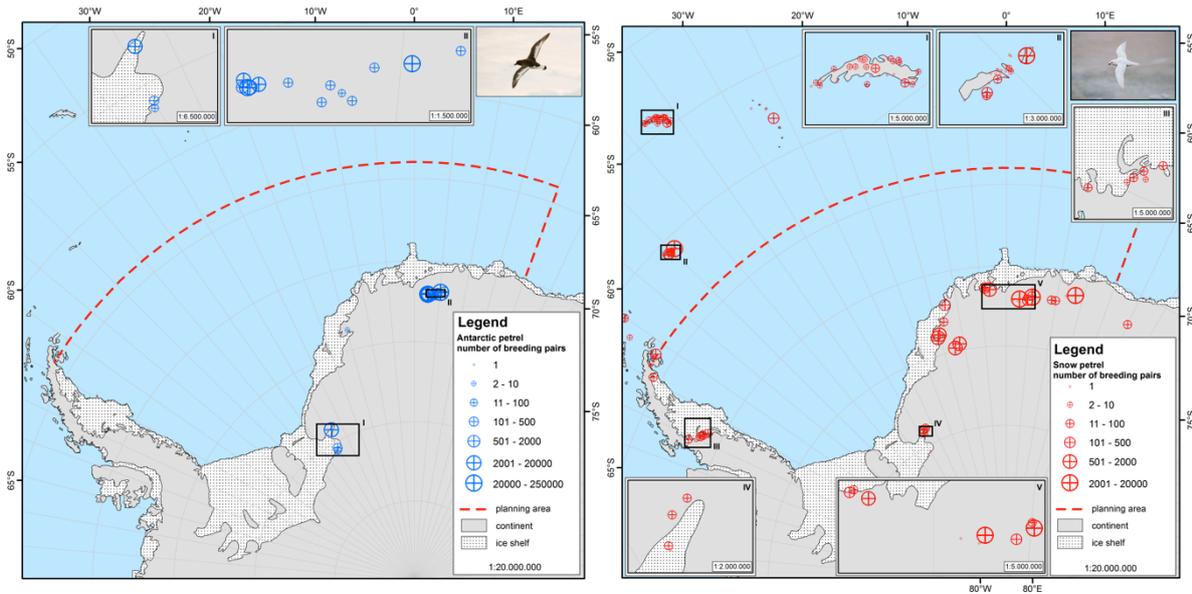


Figure 3-15 Spatial distribution patterns of breeding pairs of Antarctic petrel (left; van Franeker et al. 1999) and Snow petrel (right; Croxall et al. 1995). Snow Petrels have breeding locations also to the north of the planning area, e.g. on South Orkneys and South Sandwich Islands, but birds from these locations are not obligatory users of the planning area. Size of breeding population was set to one in case of missing abundance data. Red dashed box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

Flying seabirds breeding on nearby Sub-Antarctic islands and the Antarctic Peninsula

In summer and autumn seabirds breeding to the west (Antarctic Peninsula and South Shetland Islands) and north of the Weddell Sea planning area (South Orkney and South Sandwich Islands, South Georgia and Bouvetoya) may utilize the marine sector south of 64°S. Few quantitative observations have been carried out in the western part of the region to the south of the main colonies, but some data are available to the east. Nevertheless, spatial quantitative mapping within the planning area will be difficult for these species. Table 3-1 contains information for species from more distant areas utilizing the planning area (Croxall et. al 2012, Del Hoyo et al. 2014). Species with substantial breeding populations that utilize the planning area are: Southern Fulmar (*Fulmarus glacialisoides*; Creuwels et al. 2007), Cape Petrel (*Daption capense*), Southern Giant Petrel (*Macronectes giganteus*; Patterson et al. 2008), Antarctic Prion (*Pachyptila desolata*), and Black-bellied Stormpetrel *Fregetta tropica*. Furthermore, distant species include Blue Petrel (*Halobaena caerulea*), Kerguelen Petrel (*Pterodroma brevirostris*) and Arctic Tern (*Sterna paradisaea*).

Food

Many of the flying seabirds feed on krill. However, during the breeding season Antarctic Petrels, Snow Petrels and Southern Fulmars have a diet that contains a high proportions of fish, including Antarctic Silverfish (*Pleuragramma antarctica*) and lantern fish (Myctophid species, in particular *Electrona antarctica*) (e.g. Ainley et al. 1992, Lorentsen et al. 1998, Van Franeker et al. 2001). Non-breeding individuals often have a more diverse diet including fish, squid and gelatinous prey. Many of the fish species consumed have diets that include different life-stages of Antarctic krill.

Table 3-1 Flying seabird species that strongly or partially depend on the Weddell Sea MPA (WSMPA) planning area.

	Breeding population at southern rim of WSMPA planning area	Breeding population close north of WSMPA planning area (a)	Global Population estimated number of breeding pairs (b, c)
<i>Substantial part of global population directly depending on planning area</i>			
Antarctic Petrel	310,016	0	491,082
Snow Petrel	28,525	21,378	65,462
Wilson's Storm Petrel	breed	2,700,000	13,200,000
South Polar Skua	breed	20	7,550
<i>Substantial part of global population breeding close north of planning area</i>			
Southern Fulmar	0	286,685	396,386
Cape Petrel	0	155,300	481,800
S. Giant Petrel	0	15,159	30,575
Antarctic Prion	0	22,100,000	25,100,000
Black-bellied Storm Petrel	0	39,600	150,000
Blue Petrel	0	70,000	2,170,000
Kerguelen Petrel	0	0	1,000,000
Arctic Tern	0	0	500,000

(a) Estimates include: South Shetland Islands, South Orkney Islands, South Sandwich Islands, Bouvet Island and South Georgia.

(b) Global estimates derived from colony figures in species reviews or from Croxall et al. (2012) or Del Hoyo et al. (2014).

(c) All listed species have an IUCN Red List Status of 'Least Concern' (IUCN 2014).

Note: The number of individuals is much higher than twice the number of breeding pairs due to immatures and non-breeders.

Penguins

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Two penguin species utilize the Weddell Sea Planning Region; these are the emperor penguin and the Adélie penguin. Emperor penguins potentially spend much of their year within the Weddell Sea, feeding, breeding and moulting there, however they may also undertake extended migrations after breeding is complete, including into areas beyond the Weddell Sea. Adélies occupy breeding colonies along the northern boundary of the Weddell Sea and relatively few actually breed within the Weddell Sea itself. During winter, Adélies from breeding sites outside the Weddell may be found actually within the Weddell, either where they moult on stable pack, or when they are foraging within the pack ice zone. No scientific studies have been undertaken on either penguin species at any of their breeding locations within the Weddell Sea. Therefore, better understanding of both species within the Weddell Sea is a priority, especially as the Weddell may become important as a refuge for pagophilic (ice loving) species such as these penguins, especially as the consequences of regional climate

change become more apparent over the course of this century. Some of the key ecological interactions that require focussed study will be with their prey, especially with Antarctic krill and Antarctic silverfish.

Emperor penguins – *Aptenodytes forsterii*

Emperor penguins breed in coastal locations around the Antarctic with most colonies found on stable fixed or ‘fast’ ice; currently 54 colonies are known to exist. Three small colonies (now just two with the loss of the Dion colony at Emperor Island, Dion Island, Marguerite Bay) occur on land (Trathan et al. 2011). Recently, four colonies have also been recorded as existing on ice-shelves, including the colony on the Jason Peninsula in the Weddell Sea (Fretwell et al. 2014). The global population of emperor penguins has been estimated to be ~238,000 breeding pairs (Fretwell et al. 2012), of which 15 colonies with more than ~78,000 pairs (~33%) breed in the Weddell Sea Planning Region (Fig. 3-16). Emperor penguins have been classified by the IUCN to have a threat status of ‘Near Threatened’.

All colonies show a similar breeding schedule regardless of their colony location. Birds gather in autumn, with the development of stable fast ice, usually from April onwards. Courtship, egg laying and incubation take place as winter proceeds, while hatching, brooding and crèche formation occur as spring and early summer approach. Chicks are tended by both parents until fledging occurs in mid-summer, usually during November or December coincident with the breakup of the stable fast ice into ‘pack’ (i.e. ice floes that drift with the winds and currents); however, chicks may still be fed while taking refuge on drifting ice floes. Adults moult in late summer, during February, again usually on fast ice or on consolidated pack. Thus, emperor penguins depend upon stable fast ice for approximately eight months of the year, so late fast ice formation in winter and/or early breakup in spring can strongly reduce the chances of successful breeding at any given colony location (see Trathan et al. 2011).

Recently, changes in sea ice duration and distribution, associated with climate change, have been reported as important factors affecting emperor penguin population processes, with the main drivers of change thought to be reductions in sea ice (Jenouvrier et al. 2014). Emperors forage in polynyas, tide cracks and leads and within the pack ice so other consequences of climate change might also be important, particularly those that alter relationships within the sea ice community, including with their prey which in most locations are principally Antarctic silverfish (*Pleuragramma antarctica*) and Antarctic krill (*Euphausia superba*) (Trathan et al. 2011).

Emperor penguin diet comprises fish (mostly nototheniids, particularly Antarctic silverfish), crustaceans (mostly Antarctic krill) and squid (most commonly *Psychroteuthis glacialis*). The different proportions vary between studies due to season and location: crustaceans tend to dominate in winter at sites close to the continental shelf edge, whereas fish and squid dominate in summer in colonies adjacent to more extensive shelf areas (Ratcliffe & Trathan 2012).

Foraging movements and habitat vary according to season. After laying in the early austral winter, females walk tens of kilometres across fast ice to forage in pack ice or polynyas over shelf areas, usually within 150 km of the colony, in trips lasting c. 76 days. Meanwhile males remain on fast ice to incubate their eggs. Upon hatching in the austral spring, males and females both forage for their chick in trips of shorter duration (2–25 days) in similar areas and

habitats. After completion of breeding, adults undertake long pre-moult foraging movements, often into deep water north of the ice edge, to gain mass before the moult. Moulting occurs in sea areas that support stable areas of fast ice throughout the summer, often far from the colony. Juveniles travel further north, even to the Antarctic Polar Front (APF) for the remainder of the austral summer. With the onset of the austral winter, adults return to the breeding colonies, while juveniles return to the marginal ice and pack ice zones.

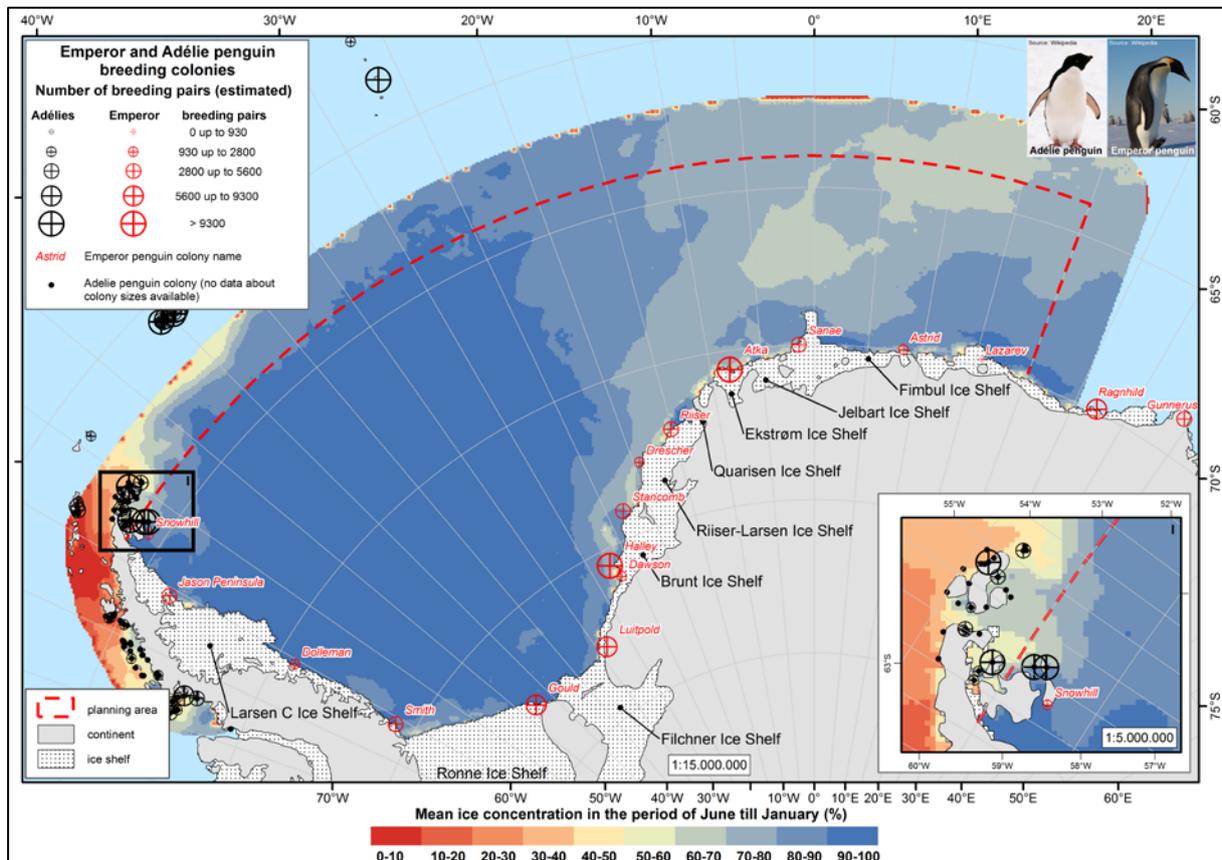


Figure 3-16 Number of breeding pairs estimated for Emperor (red cross hairs; Fretwell et al. 2012, 2014) and Adélie penguin colonies (black cross hairs; Lynch & LaRue 2014). Mean sea ice concentration (Jun-Jan) derived from the Institute of Environmental Physics, University of Bremen (Kaleschke et al. 2001, Spreen et al. 2008). Red dashed box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

Adélie penguins – *Pygoscelis adeliae*

Adélie penguins have a circumpolar distribution, with major breeding aggregations occurring on ice-free land adjacent to the Ross Sea, along the coast of the Antarctic continent, on the west coast of the Antarctic Peninsula, and at the peri-insular islands of the Scotia Arc. The most southerly breeding colonies occur in the Ross Sea at Cape Royds (77° S) whilst the most northerly is at Bouvetøya (54° S) (Trathan & Ballard 2013). Outside the breeding season the distribution is less well documented, but is mainly pelagic, and restricted to areas of seasonal pack ice (Ballard et al. 2010; Dunn et al. 2011).

The global population of Adélie penguins has been estimated to be ~3,790,000 breeding pairs (Lynch & La Rue 2014), of which only a relatively small percentage (approx. 35,098 breeding pairs) actually breeding in the Weddell Sea Planning Region (Fig. 3-16). However, almost ~25% of the global population breeds in areas adjacent to the Weddell Sea with ~57,000 (~1.5%) breeding at the South Sandwich Islands, ~190,000 (~ 5%) at the South Orkney Islands and ~805,000 (~18%) along the Antarctic Peninsula of which most (~641,000; 17%) are on the east side of the Peninsula immediately bordering the northern Weddell Sea. Adélie penguins have been classified by the IUCN to have a threat status of ‘Near Threatened’.

The breeding schedule is similar across the species range, but the onset of breeding varies with latitude, being later at higher latitude sites (Trathan & Ballard 2013). Birds begin to gather in spring, as ice-free land starts to appear. At the South Orkneys, this is usually from late-September onwards. Courtship, egg laying and incubation take place as spring proceeds, while hatching, brooding and crèche formation occur as summer continues. Chicks are tended by both parents until fledging occurs in late-summer, usually during January or February. Adults moult in late summer, during February, usually on fast ice or on consolidated pack. Birds tracked from the South Orkney Islands (Dunn et al. 2011) leave their colonies and head south, spending time recovering body condition in the South Orkney Island southern shelf Marine Protected Area before moulting on consolidated pack. The moulting areas are on the northern boundary of the Weddell Sea Planning Region and appear annually consistent (BAS unpublished data).

Recently, changes in sea ice duration and distribution, associated with climate change, have been reported as important factors affecting Adélie population processes, with the main drivers of change thought to be reductions in sea ice (Fraser et al. 1992), especially in winter (Trathan et al. 1996), and linked with prey availability (Forcada et al. 2006, Forcada & Trathan 2009).

No studies on Adélie penguin population processes, diet, or foraging behaviour have been undertaken within the Weddell Sea Planning Region. Thus it is not known how far Adélie penguins range from their breeding colonies into the Weddell Sea, though based on telemetry studies elsewhere, it is highly likely that they range widely, depending upon the time of the year. The breeding colonies at the northern tip of the Peninsula may well utilize the Weddell Sea Planning Region during summer, and it is clear that penguins from the South Orkney Islands and the South Shetland Islands use the Weddell Sea in winter (Dunn et al. 2011; BAS unpublished data; US AMLR Program).

Elsewhere, diet is dominated by euphausiid crustaceans and fish, with squid and amphipods also occasionally important (Ratcliffe & Trathan 2012). The local habitat also influences diet: in general, birds foraging over the continental shelf feed mostly on crystal krill (*Euphausia crystallophias*) and fish, especially Antarctic silverfish, while those feeding over the shelf slope or in oceanic waters feed on Antarctic krill. The relative contribution of fish in the diet varies among years and seasonally. A single study of winter diet suggests squid may become more important at that time, though krill and fish dominate (Ainley et al. 1992).

Foraging is mainly confined to the seasonal pack ice, and variations in the distribution of ice cause marked temporal and spatial variation in foraging distribution, migration routes and

wintering areas (Ratcliffe & Trathan 2012). Foraging ranges during incubation are generally large (often >100 km), and where necessary, birds commute by walking over fast ice. Fast ice break out in summer often results in birds foraging in pack ice or open water nearer to the colony (often <100 km), although at some colonies ice persists throughout the breeding season forcing birds to forage in tide cracks very close to the colony (<20 km).

3.2.5 Marine Mammals

Pinnipeds

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Six species of seals are considered as “true Antarctic species” according to Boyd (2002), i.e., “species whose populations rely on the Southern Ocean as a habitat, i.e., critical to a part of their life history, either through the provision of habitat for breeding or through the provision of the major source of food”. These include one species from the family Otariidae (Antarctic fur seal), and five species from the family Phocidae (Weddell seal, Ross seal, crabeater seal, leopard seal, southern elephant seal), all of which belong to a single subfamily, the Monachinae (Boyd 2002, Berta & Churchill 2012). All six species have been recorded within the Weddell Sea MPA planning area (Ropert-Coudert et al. 2014). Timing of their presence in the Weddell Sea depends on species specific life histories and association with sea ice, and hence differs between the ice breeding (Weddell seal, Ross seal, crabeater seal, leopard seal), and the land breeding species (Antarctic fur seal, southern elephant seal).

The population of Antarctic fur seals at South Georgia contains more than 70% of the breeding stock. Numerous smaller populations exist on islands off the Antarctic Peninsula (South Shetlands, South Orkneys) and further afield at the South Sandwich Islands. Adult males and females also frequent the northern fringes of pack-ice (Ropert-Coudert et al. 2014). Foraging dives concentrate on the upper water column with overall mean dive depth and dive duration of around 30 m and 90 sec, respectively (Boveng et al. 1996). Maximum dive depths range between 70 and 170 m with a preference for shallower dives during night, likely as a response to the vertical migration of krill (Croxall et al. 1985), the main prey. Depending on the island locality around the fringes of the Weddell Sea, dietary preference for krill is followed by fish (lanternfish and Antarctic silverfish), penguins and cephalopods (Casaux et al. 2003).

Weddell seals breed on fast ice along the coast of the Weddell Sea. Their foraging dives can reach depths in excess of 900 m (Årthun et al. 2012, Årthun et al. 2013) and dive durations (studied at other locations) can exceed 80 min, albeit dive durations of around 20 min correspond with the individual’s aerobic dive limit (*cf.* Kooyman 1966, Schreer & Kovacs 1997). Their preferred foraging depths correspond with the respective environmental features on site. Weddell seals at Drescher Inlet (Riiser-Larsen Ice Shelf) show a tidal activity pattern (Bornemann et al. 1998) and a bimodal dive depth distribution with one mode at 130 to 160 m as a result of foraging excursions under the shelf ice and another one at 340 to 450 m representing foraging at the sea floor, respectively (Plötz et al. 2001, Watanabe et al. 2006).

Foraging dives of seals at the Ekström Ice Shelf are mainly shallower to around 50 m within Atka Bay and deeper to the seafloor inside and outside Atka Bay (Naito et al. 2010; McIntyre et al. 2013). Weddell seals dive even deeper around the Filchner Trough (Filchner Ice Shelf) as a reflection of the seabed topography (Nicholls et al. 2008). Dietary studies on Weddell seals in the eastern and southern Weddell Sea highlight the importance of *Pleuragramma antarctica* as a pelagic food resource over a broad variety of demersal and benthic fish species, cephalopods, and to a small extent, crustaceans (Plötz 1986, Plötz et al. 1991, Plötz et al. 2001, Watanabe et al. 2006).

Among the Antarctic pinnipeds, the Ross seal is the least known (Southwell 2005a, Bester and Hofmeyr 2007). Its circumpolar population status remains enigmatic (Southwell et al. 2008, Bengtson et al. 2011), while their ranging and diving behaviour is poorly known (Southwell et al. 2012). The diving behaviour of only a few animals was investigated in the Weddell Sea off Queen Maud Land (Blix & Nordøy 2007). Ross seals breed on pack ice, and they are more pelagic rather than ice-loving (Nordøy & Blix 2001) outside of the breeding and moulting seasons, and described as *commuters* (Kooyman & Kooyman 2009). Most of the dives in deep water reach depths between 100 and 300 m and take 10 – 15 min. The deepest dive recorded is 792 m, while some dives were very shallow during the time the seals spent in pack ice (Bengtson & Stewart 1997, Southwell 2005b, Blix & Nordøy 2007). Apart from the description of a few stomach contents and scats (Øritsland 1977, Skinner & Klages 1994), stable isotope analyses (Rau et al. 1992) and inferences from diving patterns (Bengtson & Stewart 1997, Blix & Nordøy 2007) and some haul-out data (Southwell 2003), the diet and foraging behaviour of the Ross seal still remains largely unknown. The evidence is consistent with feeding primarily on squid, then fish (*Pleuragramma antarctica*, myctophid fish), and to some extent krill (Blix & Nordøy 2007) and benthic invertebrates (Øritsland 1977). Despite the low detection probability of pack ice seals (Southwell et al. 2007), Ross seals are predictably found in relatively high numbers in the eastern Weddell Sea, off Princess Martha Coast (Bester & Odendaal 2000, Bester et al. 2002), where their density increases progressively from west to east (Condy 1977, Bester et al. 2002).

Despite the high abundance of crabeater seals in the Weddell Sea, where approximately 50 % of the circum-Antarctic population is found (*cf.* Bester & Odendaal 2000, Southwell et al. 2012), studies on their foraging behaviour in the Weddell Sea are scarce. Just a few animals have been instrumented at the marginal sea ice zone south of the South Orkneys (Bengtson & Stewart 1992) and off Queen Maud Land for foraging studies (Nordøy et al. 1995, Bornemann & Plötz 1999). Crabeater seals breed on pack ice, and tend to be associated with medium to high sea ice concentrations throughout the year. They move extensively within the Antarctic sea ice zone, and individuals may have a potential range extending throughout the entire area of the Antarctic pack ice (Boyd 2002). Foraging dives of crabeater seals concentrate on depths shallower than 50 m, but may extend to depths beyond 500 m exceptionally. The average dive lasts around 5 min and the longest dives recorded were up to 11 min (Bengtson & Stewart 1992, Nordøy et al. 1995). Crabeater seals are believed to feed almost exclusively on Antarctic krill, but evidently eat fish and cephalopods when krill is not available, although geographic or temporal variability in their diet is data deficient (Southwell et al. 2012).

Information on leopard seal foraging behaviour within the Weddell Sea is restricted to two adult females (Nordøy & Blix 2009). These individuals remained mainly within the pack ice

for some time before moving to the north with the advancing winter sea ice edge. They performed mostly short (<5 min) dives to depths of 10 - 50 m and only occasionally dived deeper than 200 m, with the deepest dive recorded being 304 m. Short duration dives of less than 5 min dominated and contributed 70 - 90% of all dives. A significant proportion of dives (5 - 25% on a monthly basis) were of 5 - 10 min duration, and only one dive was longer than 15 min (Nordøy & Blix 2009). Their diving behaviour and foraging movements suggest that they feed on krill, penguins, juvenile crabeater seals and a variety of fish (Nordøy & Blix 2009). Data from scat analyses at Danco Coast (western Antarctic Peninsula) confirm a strong reliance on krill (Casaux et al. 2009, Casaux et al. 2011).

Southern elephant seal foraging movements are more closely related to sea ice than previously assumed (Bornemann et al. 2000), despite their occasional occurrence in the Weddell Sea pack ice (Cline et al. 1970, Kohlen 1982, Jonker & Bester 1998, Bester & Odendaal 2000). The tendency of southern elephant seals to forage on the Antarctic continental shelf within the Weddell Sea pack ice was illustrated for seals from King George Island (Tosh et al 2009), Marion Island (McIntyre et al. 2010), and Bouvetøya (Biuw et al. 2010). Their foraging behaviour varies in the context of the physical environment (e.g. Tosh et al. 2009, Biuw et al. 2010); i.e. deepest dives of seals satellite tracked from King George Island to the Filchner Trough (Filchner Ice Shelf) reflect sea-floor depths between 1,000 and 1,700 m taking up to >40 min (James et al. 2012), though modal depths range between 300 and 700 m (McIntyre et al. 2010 for animals from Marion Island) with mean durations of 30 min. Southern elephant seal foraging behaviour in the Weddell Sea is assumed to be linked to the Antarctic silverfish *P. antarctica* (Tosh et al. 2009, Biuw et al. 2010). This dominant pelagic fish species forms an important part of the pelagic fish diet of southern elephant seals from King George Island (Daneri & Carlini 2002) and its distribution appears to affect the movement patterns of female elephant seals from King George Island as well (Bornemann et al. 2000). Moreover, the individuals instrumented at Bouvetøya dived to depths of 400 - 500 m on the continental shelf of Dronning Maud Land and are assumed to feed on *P. antarctica* but also on myctophid fish (especially *Electrona antarcticus*), glacier squid (*Psychroteuthis glacialis*), various mesopelagic fishes, and Antarctic toothfish *Dissostichus mawsoni* (Biuw et al. 2010).

All Antarctic ice seals (Weddell, Ross, crabeater, leopard) give birth between September and December, and lactation lasts three to eight weeks. Weaning is more or less abrupt, and mating takes place immediately at around weaning. The land breeding seal species give birth between September and November. Southern elephant seals mate just before weaning their pups after a three week lactation period, whereas Antarctic fur seals mate seven to ten days after giving birth and pups are weaned at about 4 months of age. Life history parameters and acoustic ecology are provided in Van Opzeeland et al. (2010). Southwell et al. (2012) prepared an in depth compilation of all data related to abundance, trends in abundance, habitat utilisation and diet of Antarctic ice seals. As they are among the dominant top predators in Southern Ocean ecosystems, fluctuations in population sizes, growth patterns, life histories, and behaviour constitute a potential source of information on environmental variability integrated over a wide range of spatial and temporal scales (Van Franeker 1992; Bengtson et al. 2011). Furthermore, it is widely anticipated that natural and anthropogenic impacts on marine mammals (Bester 2014) will be mediated primarily via changes in prey distribution and abundance (Simmonds & Isaac 2007, Siniff et al. 2008, Forcada et al. 2012, Kovacs et al.

2012), which has management implications (Trathan & Agnew 2010). Additionally, environmental changes linked to increased water (and air) temperature and to ocean acidification may alter the forage base of marine mammals, ranging from shifts in density and distribution to a potential loss of favoured prey species (Kovacs & Lydersen 2008). Therefore, continued studies of Antarctic ice seals within the Weddell Sea are required, particularly in order to better identify their preferred habitats (*cf.* Raymond et al. 2014).

Whales

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14 species of whales are considered as “true Antarctic species” (Table 3-2), i.e., „... *species whose populations rely on the Southern Ocean as a habitat, i.e., critical to a part of their life history, either through the provision of habitat for breeding or through the provision of the major source of food*” (Boyd 2002). Given their large size and their intensive feeding in the Southern Ocean most Antarctic cetacean species remove substantial amounts of biomass from the ecosystem (e.g. Laws 1977). The ecological role of cetaceans within Antarctic waters, however, is not limited to their influence as predators. Cetaceans interact with the Southern Ocean ecosystem in several ways and play important roles, e.g. in nutrient recycling and in controlling the structure of the living community (e.g. Bowen 1997, Katona & Whitehead 1988).

Most cetacean sighting data – the fundamental data source for population estimates - stem from large survey programs; the International Decade for Cetacean Research (IDCR), Southern Ocean Whale and Ecosystem Research (SOWER), CCAMLR 2000 Survey, Southern Ocean Global Ocean Ecosystems Dynamics (SO-GLOBEC), with additions from smaller survey programs (e.g. Southern Ocean Cetacean Ecosystem Program SOCEP, Baseline Research on Oceanography, Krill and Environment BROKE). Findlay et al. (2014) provides further data, but the authors do not recommend their use prior to final validation. Our knowledge about the functional role and the spatial patterns of cetacean activities in the Southern Ocean ecosystem is still sparse. The animal's high mobility, their often elusive behaviour, the vastness of the Southern Ocean and the limited access to sea ice covered areas all collude to hamper visual surveys, the backbone of information gathering.

Table 3-2 Taxonomic classification of true Antarctic cetaceans (based on Brownell 1974, Boyd 2002 and Pitman & Ensor 2003).

Order Cetacea		
Suborder Mysticeti		
Family	Species (incl. subspecies)	Common name
	<i>Megaptera novaeangliae</i>	Humpback whale
	<i>Balaenoptera physalus</i>	Fin whale
	<i>Balaenoptera musculus intermedia</i>	Antarctic blue whale
<i>Balaenopteridae</i>	<i>Balaenoptera musculus brevicauda</i>	Pygmy blue whale
	<i>Balaenoptera bonaerensis</i>	Antarctic minke whale
	<i>Balaenoptera acutorostrata ssp.</i>	Dwarf minke whale
	<i>Balaenoptera borealis</i>	Sei whale
<i>Balaenidae</i>	<i>Eubalaena australis</i>	Southern right whale
Suborder Odontoceti		
<i>Physeteridae</i>	<i>Physeter macrocephalus*</i>	Sperm whale
	<i>Orcinus orca</i>	Killer whale (ecotype A,B,C)
<i>Delphinidae</i>	<i>Lagenorhynchus cruciger</i>	Hourglass dolphin
	<i>Globicephala melas</i>	Long-finned pilot whale
	<i>Cephalorhynchus commersonii</i>	Commerson's dolphin
	<i>Berardius arnuxii</i>	Arnoux's beaked whale
<i>Ziphiidae</i>	<i>Hyperoodon planifrons</i>	Southern bottlenose whale
	<i>Mesoplodon layardii</i>	Strap-toothed whale
<i>Phocoenidae</i>	<i>Phocoena dioptrica</i>	Spectacled porpoise

* Only males are assumed to enter Antarctic waters

The following chapters summarize our current knowledge on the “true Antarctic” cetaceans.

Baleen Whales

Antarctic blue whales (*Balaenoptera musculus intermedia*) are migratory with a circumpolar distribution. They spend the austral summer in their feeding grounds between the Antarctic Convergence and the pack ice zone, where they feed on their staple food krill. Density increases pole ward south of the Antarctic Convergence, with highest encounter rates observed between 66° and 70°S and in January (Kasamatsu et al. 1996). After February blue whales are thought to migrate to their winter breeding grounds north of 30°S (Stafford et al. 2004), but some animals may overwinter in Antarctic waters (Širović et al. 2004, 2006). Most recent population estimates range from 1700 (Branch et al. 2007b) to 2300 (IWC, <http://iwc.int/estimate>). Annual population growth rate is estimated at 7.3% (Branch et al. 2004) to 8.2% (IWC). Antarctic blue whale calls and choruses have been recorded regularly and year round at the PALAOA Recording Station at Neumayer Base (Van Opzeeland pers. com.). Antarctic blue whales are listed as *critically endangered* (IUCN Red List of Threatened Species; version 2014.2). Observation maps (Ropert-Coudert et al. 2014) indicate this species' occurrence in the Weddell Sea MPA (WSMPA) planning area.

Pygmy blue whales (*B. m. brevicauda*) seem to occur in more northerly waters, while only about 1% of blue whales south of 60°S were identified as pygmy blue whales (Branch et al. 2007a, b). Historic catches indicate that pygmy blue whales were caught quite frequently south of 60°S (Ropert-Coudert et al. 2014) also in the WSMPA planning area. In the Southern Ocean, pygmy blue whales feed on krill, *Euphausia valentini* in particular. No dedicated population estimates exist, but present data suggest that pygmy blue whales are not as depleted as Antarctic blue whales (Branch et al. 2007a, b). Pygmy blue whales are listed as *data deficient* (IUCN Red List of Threatened Species; version 2014.2).

Fin whales (*Balaenoptera physalus*) spend the austral summer in Antarctic waters. They roam between 40°S-60°S in the Indian and Atlantic sector and between 50°-65°S in the South Pacific, but rarely close to the pack ice edge (Miyashita et al. 1995). Their breeding grounds are situated north of 40°S. Fin whales have been detected acoustically in the Antarctic Peninsula region between February and June/July (Thiele et al. 2001, Širović et al. 2004) and their calls have been recorded regularly at the PALAOA observatory near Neumayer Base (Van Opzeeland pers. comm.). Fin whales feed more diversely than blue whales, yet in Antarctic waters their predominant resource is Antarctic krill *Euphausia superba*, whereas in the sub-Antarctic *E. valentini* and *E. frigida* are more important. The population is estimated at about 4000-8000 individuals (Branch & Butterworth 2001). High densities of fin whales were observed between 0°E and 5°E south of Bouvet Island (Ensor et al. 2007), and northwest of Elephant Island (Burkhardt & Lanfredi 2012). Fin whales are listed as *endangered* (IUCN Red List of Threatened Species; version 2014.2). The species occurs in the WSMPA planning area (Ropert-Coudert et al. 2014).

Sei whales (*Balaenoptera borealis*) migrate towards Antarctic waters in great numbers during austral summer, but not as far south as the other baleen whale species. They are found between the subtropical and the Antarctic Convergence mainly, in particular between 40° and 50°S (Leatherwood & Reeves 1983). South of 50°S they appear in specific areas only and they are hardly seen in the pack ice (e.g. Gill & Evans 2002, Gambell 1985). Survey data show highest encounter rates for the area 60-80°E and 50-54°S (Horwood 1987). South of

50°S, encounter rates for sei whales peak in February, later the whales migrate back to their winter breeding grounds north of 30°S. Sei whales preferably feed on copepods but also on krill, amphipods, pelagic decapods, cephalopods and even schooling fish (Ropert-Coudert et al. 2014). The population size is unknown (Leaper et al. 2008). Sei whales are listed as *endangered* (IUCN Red List of Threatened Species; version 2014.2). The species is likely to occur in the WSMMPA planning area.

The Antarctic minke whale (*Balaenoptera bonaerensis*) is the most abundant cetacean in Antarctic waters. They are observed within dense sea ice regularly (e.g., Williams et al. 2014, Gutt et al. 2011, Scheidat et al. 2011). During austral summer their distribution concentrates between 62°S and the pack ice (Gill & Evans 2002), with highest encounter rates in late January/early February south of 66°S between 66°E-80°E (Kasamatsu et al. 1996). There are no systematic surveys for the ice-covered regions of the Weddell Sea so far, but minke whale calls have been recorded regularly at the PALAOA observatory near Neumayer Base (Van Opzeeland pers. comm., Risch et al. 2014). During austral winter, most Antarctic minke whales leave for their breeding grounds (10°-30°S), but some have been reported to overwinter in Antarctic waters (Thiele & Gill, 1999). Minke whales in the Southern Ocean feed on the Antarctic krill *Euphausia superba* primarily but on smaller zooplankton, too (Ohsumi et al. 1970, Stewart & Leatherwood 1985). Abundance is estimated to 515.000 individuals (95% CI 360.000 - 730.000) by IWC but may be higher as surveys do not include ice-covered areas. Antarctic minke whales are listed as *data deficient* (IUCN Red List of Threatened Species; version 2014.2). Observation maps (Ropert-Coudert et al. 2014) and habitat models (Bombosch et al. 2014, see Fig. 3-17) indicate that Minke whales occur in the WSMMPA planning area. Highly favourable conditions for minke whales throughout the season are predicted for an area around 70°S and 40°W.

Dwarf minke whales (*Balaenoptera acutorostrata* ssp.) are encountered in higher latitudes occasionally (Ropert-Coudert et al. 2014). Usually they stay north of 60°S, but have been observed as far south as 65°S (Kato & Fujise 2000). Sightings include the South Shetland Islands, the Gerlache Strait, in the Bellingshausen Sea (during austral winter) and the Antarctic Peninsula region (Acevedo et al. 2011), and peak between December and March (Kato & Fujise 2000). Observation maps (Ropert-Coudert et al. 2014) indicate that this species may occur in the WSMMPA planning area, but to a much lesser extent than Antarctic minke whales. Migration patterns of dwarf minke whales are unknown so far. In Antarctic waters they feed on myctophid fish and to some extent on euphausiids (Kato & Fujise, 2000). Abundance estimates are not available. Dwarf minke whales are listed as *least concern* (IUCN Red List of Threatened Species; version 2014.2).

The high latitude feeding area of Humpback whales (*Megaptera novaeangliae*) ranges from the Antarctic Convergence to the pack ice region. Higher densities are found in the southern Indian Ocean, around the Antarctic Peninsula and in the northern Ross Sea and highest encounter rates are reported for December to January (see Branch 2011). So far seven distinct feeding grounds corresponding to six breeding stocks are suggested (International Whaling Commission 2011). Humpback breeding stocks A, B and C are of relevance for the WSMMPA planning area, since these individuals migrate between the Weddell Sea and their breeding grounds further north. Some individuals may stay in the Antarctic year-round, presumably to avoid the energetic demands of migration (Van Opzeeland et al. 2013). Humpback whales in the Southern Ocean feed on pelagic crustaceans, mainly krill *Euphausia superba* (Clapham

2002). The 1997/96 IWC population estimate is 42,000 for the Southern Ocean, with approximately 26,630 individuals allocated to breeding stocks A, B and C (Branch 2011). Humpback whales are listed as *least concern* (IUCN Red List of Threatened Species; version 2014.2). Habitat suitability models indicate that favourable habitat conditions for humpback whales exist in open waters near Larsen C Ice Shelf and in the eastern part of the planning area throughout January and February (Fig. 3-17, Bombosch et al. 2014).

During austral summer, the southern right whale (*Eubalaena australis*) is found in higher latitudes, usually between 50-60 °S, while remaining north of the Antarctic Convergence and avoiding pack ice regions. Very few sightings are reported south of 60°S (Gill & Evans 2002, Ropert-Coudert et al. 2014). During austral winter, southern right whales are in their breeding areas, e.g., coasts off South Africa, Argentina/Brazil and Australia. In the Southern Ocean they feed on krill and on copepods (Tormosov et al. 1998). The 2009 IWC population estimate for the Southern Hemisphere quotes 12,000 individuals; the average annual increase is about 7% (International Whaling Commission 2001). The species is listed as *least concern* (IUCN Red List of Threatened Species; version 2014.2).

Toothed Whales

The Sperm whale (*Physeter macrocephalus*) is an open ocean species, occurring in ice-free waters with depths >1000m. Information on the occurrence of sperm whales south of 60°S refer to maturing and mature males during austral summer. The Southern Ocean population has been divided into nine 'stocks' (Donovan 1991) and the southward extent of their occurrence corresponds with age and size of the males (Whitehead 2002). Highest densities were observed in the area bounded by 62-66°S, 90-12°E, and south of 66°S, 150-180°E (Kasamatsu & Joyce 1995). Peak encounter rates in Antarctic waters are reported for January-February (Kasamatsu & Joyce 1995). Sperm whales in the Antarctic feed on various squid species as well as on mesopleagic fish (Korabelnikov 1959). Current population estimates south of 60°S are about 10,000 individuals (Branch & Butterworth 2001, Van Waerebeek et al. 2004). Population size increases with rates <1% per year presumably (Whitehead 2002). Sperm whales are listed as *vulnerable* (IUCN Red List of Threatened Species; version 2014.2). Occasional recordings of sperm whale vocalisations at the PALAOA observatory near Neumayer Base (Van Opzeeland pers. comm.) along with observation maps (Ropert-Coudert et al. 2014) indicate their occurrence in the WSMMPA planning area.

In the Southern Ocean, killer whales (*Orcinus orca*) are found up to the pack ice edge (Mikhalev et al. 1981) and may extend well into ice-covered waters, even into dense pack ice and under fast ice (Ford 2002, Fischer & Hureau 1985). Pitman & Ensor (2003) describe three Antarctic ecotypes A, B, and C, differing in size, body pattern and prey preferences. The three forms occur throughout the Antarctic during summer, with concentrations in the Antarctic Peninsula Area (B), and in the East Antarctic Area (C), whereas ecotype A seems to be an open water species. Killer whale occurrence coincides with the northern fringe of the pack ice, peaking at 66°S over the period of November to February, and indicates an almost circumpolar distribution (Kasamatsu & Joyce 1995, Mikhalev et al. 1981). Most killer whales migrate into Antarctic waters in early January and leave in late February, but there is evidence for wintering in the pack ice of ecotype B and C individuals (Pitman & Ensor 2003). Breeding occurs in warmer waters (Fischer & Hureau 1985). Killer whales show a characteristic prey specialization dependent on the various ecotypes; Ecotype A is thought to hunt other cetaceans, mainly minke whales (Pitman & Ensor 2003). Ecotype B preys on a variety of

seals, minke whales, probably humpback whales and penguins (Ainley & Blight 2009, Pitman & Ensor 2003, Visser et al. 2008, Pitman & Durban 2010). Ecotype C feeds on fish mainly, e.g., Antarctic tooth fish (Thomas et al. 1981). The Killer whale population in waters south of 60°S is estimated at ±25.000 animals (Branch & Butterworth 2001), but many of the ice covered areas have not been surveyed properly. This species is listed as *data deficient* (IUCN Red List of Threatened Species; version 2014.2). Occasional killer whale vocalisation recordings at the PALAOA observatory near Neumayer Base (Schall 2013) along with observation maps (Ropert-Coudert et al. 2014) indicate their occurrence in the WSMMPA planning area.

The hourglass dolphin (*Lagenorhynchus cruciger*) is a predominantly oceanic species with a circumpolar distribution in Antarctic and sub-Antarctic regions (Fernández et al. 2006). Most sightings fall between 45° S and 65°S (Rice 1998). Their range extends south to the ice edge but apparently the species seems to keep some distance to the pack ice (Goodall 1997, 2002, Kasamatsu et al. 1988). Hourglass dolphins are spotted around the Antarctic Peninsula regularly in fairly shallow water, clustering along the 200m contour line. However, most sightings occurred in the Drake's Passage at 1200-1400 m water depth (Goodall 1997). Hourglass dolphins prey on squid, crustaceans and small fish (Goodall 1997, 2002). This species is listed as *least concern* (IUCN Red List of Threatened Species; version 2014.2). Observation maps (Ropert-Coudert et al. 2014) indicate their occurrence in the WSMMPA planning area.

The spectacled porpoise (*Phocoena dioptrica*) has a circumpolar distribution in cold and temperate waters of the Southern Hemisphere. Little is known about this species and few sightings at sea have been reported. It may feed on cuttlefish, fish and tunicates (Best 2007). The southernmost sighting was recorded at 64°34'S (Sekiguchi et al. 2006). This species is listed as *data deficient* (IUCN Red List of Threatened Species; version 2014.2). Observation maps (Ropert-Coudert et al. 2014) indicate that they do not occur in the WSMMPA planning area.

Four species of beaked whales - the southern bottlenose whale, Arnoux's beaked whale, Layard's beaked whale and Gray's beaked whale – may occur in the WSMMPA planning area. All four show a circumpolar distribution, but information on these species is scarce, as species identification is rather difficult due to their long and deep dives, wariness of vessels, overall similarity and limited number of physical characteristics to enable differentiation. Therefore many sightings are basically reported as “beaked whales” (Kasamatsu et al. 2000).

The Southern bottlenose whale (*Hyperoodon planifrons*) is the most abundant beaked whale species in the Southern Ocean. It occurs between 30°S and the ice edge, with high encounter rates between 58°S and 62°S (Kasamatsu & Joyce 1995) and migrates northwards in late austral summer (Sekiguchi et al. 1993). Southern bottlenose whales prey on squid, which often occur in deeper water and hence favour water depths >1000m (Culik 2005, Van Waerebeek et al. 2004). Population size south of 60°S is estimated at 54.000-72.000 individuals (Branch & Butterworth 2001, Leaper et al. 2008). The species is listed as *least concern* (IUCN Red List of Threatened Species; version 2014.2.). Observation maps in Ropert-Coudert et al. (2014) indicate the occurrence of this species in the WSMMPA planning area.

Arnoux's Beaked whale (*Berardius arnuxii*) occurs from 30°S to the Antarctic continent, preferably between 58°S and 62°S. Sightings have been associated with shallow regions, coastal waters, continental slopes or seamounts (Rogers & Brown 1999). Arnoux's beaked whales perform deep and prolonged dives (Hobson & Martin 1996) and most likely feed on squid (McCann 1975, Van Waerebeek et al. 2004). No abundance estimates are available. The species is listed as *data deficient* (IUCN Red List of Threatened Species; version 2014.2.). Observation maps (Ropert-Coudert et al. 2014) indicate the occurrence of this species in the Weddell-Sea MPA planning area.

The strap toothed whale (*Mesoplodon layardii*) occurs between 30°S and the Antarctic Convergence (Mead 1989a, Carwardine 1996) presumably. Generally, they are rarely seen in the wild and little is known about their ecology. Probably they inhabit deep ocean waters or continental slopes and feed on squid, and a seasonal migration pattern is likely (Pitman 2002). This species is listed as *data deficient* (IUCN Red List of Threatened Species. Version 2014.2). Observation maps (Ropert-Coudert et al. 2014) indicate that this species may occur in the Weddell-Sea MPA planning area.

Gray's beaked whale (*Mesoplodon grayi*) occurs throughout cold and temperate waters of the Southern Hemisphere (MacLeod & Mitchell 2006, Mead 1989b), with sightings at sea recorded between 31°S and 65°S (Dalebout et al. 2004, Gambell et al. 1975). They usually inhabit deep waters or continental slopes (Pitman 2002) and prey on oceanic squid, particularly on *Taonius pavo* and *Histioteuthis* spp., and on mesopelagic fish (Pitman 2002). There are no population or abundance estimates. The species is listed as *data deficient* (IUCN Red List of Threatened Species; version 2014.2.). Observation maps (Ropert-Coudert et al. 2014) indicate that this species may occur in the WSMPA planning area.

The long-finned pilot whale (*Globicephala meals edwardi*) is found throughout the Southern Hemisphere as far south as the Antarctic Convergence (Olson & Reilly 2002, Van Waerebeek et al. 2004) and more closely associated with the Polar Front than with the sea ice edge (Boyd 2002). South of the Antarctic Convergence, high encounter rates were observed at 90°E – 100°E and 160°W to 170°W during December to February (Kasamatsu & Joyce 1995). Long-finned pilot whales prey mainly on pelagic squid. Abundance is estimated at ± 200.000 individuals in summer south of the Antarctic Convergence (Best 2007). This species is listed as *data deficient* (IUCN Red List of Threatened Species; version 2014.2). Only occasional observations are recorded for the WSMPA planning area (Ropert-Coudert et al. 2014).

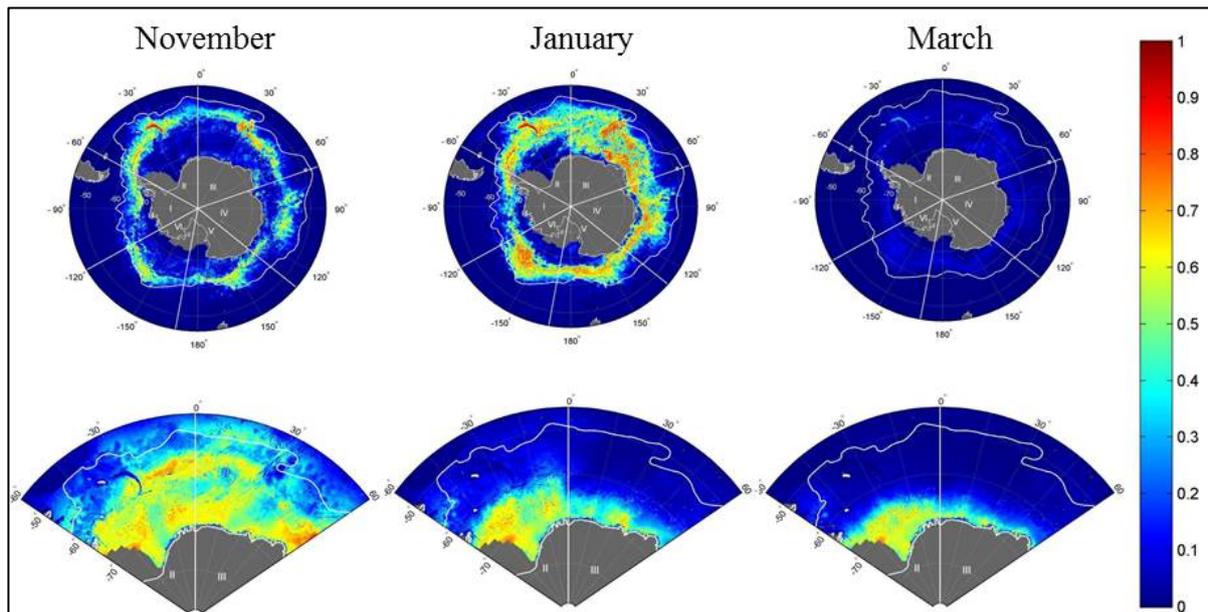


Figure 3-17 Maxent spatial prediction maps for humpback whales (upper row) and Antarctic minke whales from 60°W to 60°E (lower row) for the 15th of November, January and March 2006/2007. Habitat suitability is colour-coded with blue colours indicating less suitable to unsuitable habitat, greenish colours depicting ‘typical’ conditions for humpback whales and red colours indicating more suitable to highly suitable habitat conditions. The white line represents the Polar Front (Harris & Orsi 2001). Grey areas indicate land areas or regions for which values for one of the environmental variables are missing. The white lines extending from the South Pole indicate the 6 IWC management areas. Westerly and southerly coordinates are indicated as negative numbers (from Bombosch 2013).

3.3 Biogeography from a circumpolar perspective

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Introduction

Conservation biogeography provides the conceptual and methodological tools for understanding and helping to predict patterns of marine biodiversity, for identifying knowledge gaps, and assists in marine spatial management and monitoring. In the particular case of the Southern Ocean, a circumpolar perspective adds value to regional marine

protected area (MPA) planning analyses by identifying the occurrence, rarity, uniqueness and abundance of a feature relative to other regions of the Southern Ocean. It also helps identify circumpolar processes that influence local conditions and distribution patterns.

Whole community studies are rare in the Southern Ocean due to highly variable availability and quality of relevant data and therefore biogeographic studies have so far focussed on taxonomic groups, using environmental data as proxies for species assemblages or a mixed approach combining the two (Koubbi et al. 2014). Logistical challenges constrain data collection in the Southern Ocean especially under-ice shelves and at depths greater than 1000 m both of which are widespread in the Weddell Sea Marine Protected Area (WSMPA) planning area (Griffiths 2010, Brandt et al. 2007c). For instance, more than 15% of the WSMPA planning area is under the ice shelf, an additional large area is under almost permanent year round ice and around 80% of the marine region is deeper than 1000 m. Where sampling is limited, environmental information collated from remote sensing, physical or biogeochemical modelling can help build our understanding of biodiversity patterns. Spatial data in the form of bioregional classifications, modelled species distributions and habitat suitability mapping have particular utility for MPA planning. For example, they allow for the inclusion of areas where biological sampling is limited and also enable the use of planning software. Regional classification analyses aim to spatially subdivide an area such that assemblage compositions are expected to be similar within each region relative to adjacent regions and have been noted by CCAMLR as important to achieve a system of MPAs (SC-CAMLR 2005).

Here we outline information relevant to the WSMPA planning area from the recent, comprehensive compilation of biogeographic information for the Southern Ocean (De Broyer et al. 2014). For brevity, we focus on mapped biodiversity patterns, modelled distribution data and two circumpolar bioregional classifications available for the pelagic and benthic realms and to what extent they can inform us about the Weddell Sea planning area. Figure 3-18 summarises some of the findings.

Mapped biodiversity patterns

An overview of the mapped biodiversity patterns in the Southern Ocean show general consensus that in the WSMPA planning area the faunal assemblages from the shallower shelf and slope are distinct to the deeper ocean and there is an east-west divide (De Broyer & Koubbi 2014). For instance, Knox (2007) identified a divide around 50°-55°W. Spalding et al. (2007) identified two main shelf ecoregions namely, the East Antarctic Enderby Land and the Weddell Sea separated at the Prime Meridian. A third ecoregion was also identified classing the tip of the peninsula north of 66°S with the west Antarctic Peninsula.

A synthesis of all of the benthic data in the Biogeographic Atlas of the Southern Ocean identified two distinct east and west Antarctic shelf regions in the WSMPA planning area for gastropods, sea anemones and amphipods (Koubbi et al. 2014). These regions were separated by a transition zone between 25°W and a line cutting the Antarctic Peninsula at around 70°S (see R1, R2, TZ in Figure 3-18). The general distribution of the other included benthic taxonomic groups was expected to be more widespread. Distinct biogeographical divisions have been identified for benthic-pelagic lophogastrid and mysid fauna separating the north eastern side of the Antarctic Peninsula from the eastern Weddell Sea (Petryashov 2014).

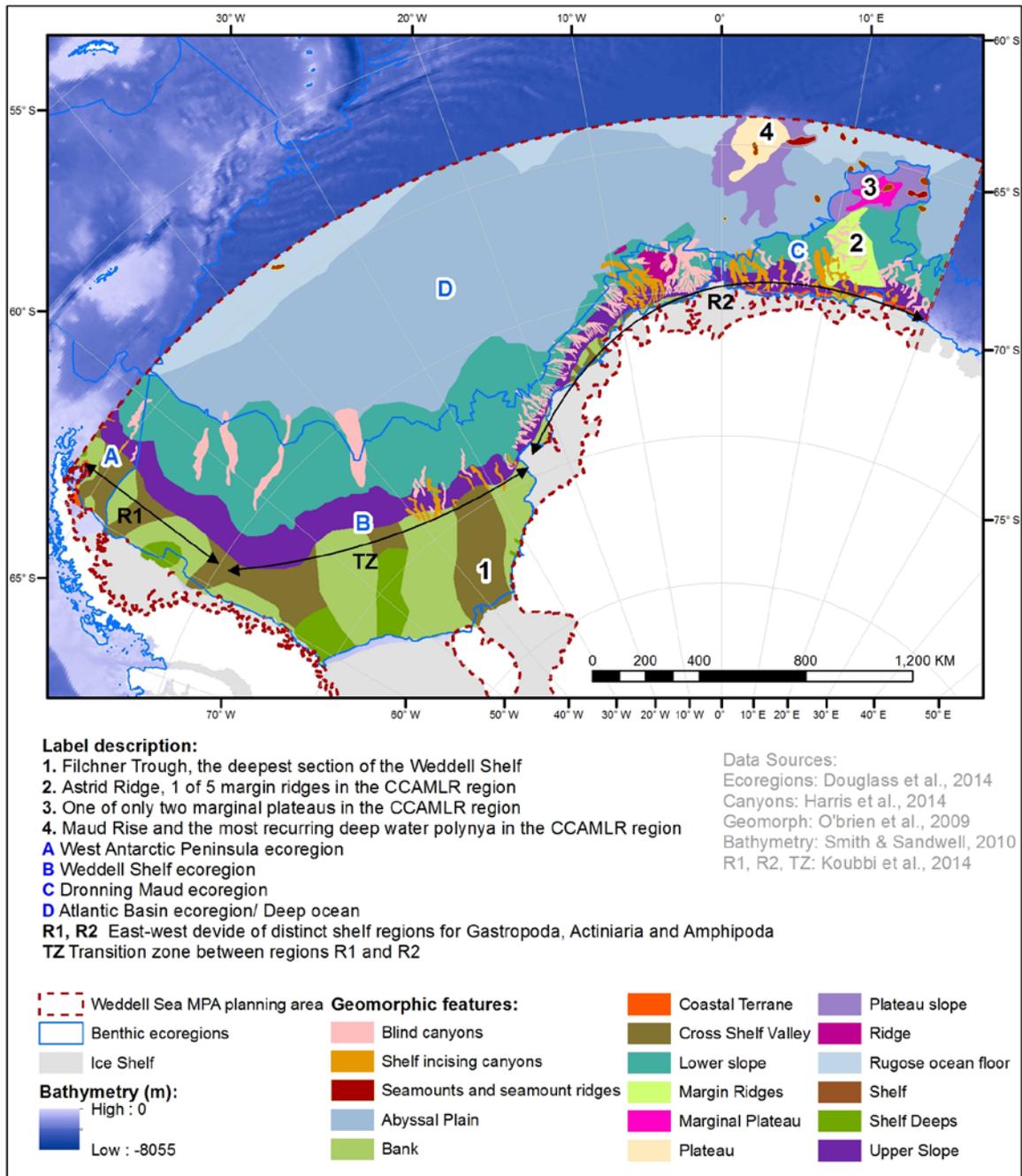


Figure 3-18 Some of the mapped biodiversity patterns and biogeographic features of the Weddell Sea marine protected area (WSMPA) planning area.

Modelled distribution and habitat suitability

A mixed biogeographical approach uses mathematical relationships between species occurrence data and environmental factors to model preferred habitats, based upon the concept of ecological niche. It enables the prediction of species and assemblages even beyond sampled areas. A mixed biogeographical approach has been used to model euphausiids, lantern fish, echinoids, crinoids and an additional 38 pelagic bird and mammal species throughout the Southern Ocean some of which span the WSMPA planning area (Koubbi et al. 2014, De Broyer et al. 2014).

Some of the modelled results show variation across the WSMPA planning area. For example, the modelled high habitat suitability for euphausiids showed *Thysanoessa macrura* to have higher patches over Maud Rise, Astrid Ridge and around 45°W, 65°S (Cuzin-Roudy et al. 2014). *Euphausia crystallorophias* was higher near the sea ice zone around 30°W (Cuzin-Roudy et al. 2014). *Euphausia superba* was widespread but higher between 10-30°W east of 0° and along the edge of the high sea ice zone (Cuzin-Roudy et al. 2014). Two of the mesopelagic fish of the Myctophidae family that were modelled are predicted to occur in the WSMPA planning area (Duhamel et al. 2014). *Electrona antarctica* showed higher levels of predicted distribution along the slope and east of 20°W. *Gymnoscopelus braueri* was highest in the deep abyssal ocean especially north of 70°S between 20°W and 40°W. Modelled echinoid species richness showed the highest values for the Weddell shelf between 0-30°W (Saucède et al. 2014). Similarly, Asteroidea (i.e. sea stars or star fish) also show higher species richness on the shelf in this latitudinal band with higher patches reported at around 15°W and 30°W (Danis et al. 2014). Caution is advised when considering species richness results since levels of uncertainty depend on the number of species for which enough data was available.

Circumpolar pelagic regionalisation

The primary pelagic regionalisation was produced using a clustering process with data of summer sea surface temperature, depth and the proportion of time covered with sea ice (Raymond 2014). It updates prior pelagic regionalisation research and finds similar patterns including higher heterogeneity in shallower areas near the coast (Grant et al. 2006). However, the Weddell Gyre was more pronounced in the original regionalisation due to the inclusion of surface (to 200 m) nutrient data.

The WSMPA planning area includes 12 of the 19 pelagic regions present in the CCAMLR area. The domain mostly consists of pelagic regions 9, 8 and 5 (Table 3-3). Pelagic regions 8 and 9 have a similar sea surface temperature SST and are deep water regions with depths greater than 2000 m. Pelagic region 9 is deeper extending to around 5000 m rather than 4000 m and has a lower ice cover (Raymond 2014). Pelagic region 2 shows polynyas on the continental shelf and pelagic region 1 shows their margins with low ice cover and cold sea surface temperatures. Pelagic region 5 represents shelf areas that are almost always covered with ice (75-100 %). The WSMPA planning area will be important for representing pelagic regions 4, 5 and 8 in a system of MPAs. It contains >50 % of the area of pelagic regions 5 and 9 in the CCAMLR area and the only locations of these regions and pelagic region 8 in the Atlantic Ocean sector. It also contains the majority of the areas of pelagic regions 3 and 7 in the Atlantic sector.

Table 3-3 The coverage of circumpolar pelagic regions in the Weddell Sea MPA planning area.

Pelagic Region	Total of CCAMLR area		Total of Atlantic Ocean sector of the CCAMLR area		Total of Weddell Sea Planning Area	
	Weddell Sea	Area (km ²)	Weddell Sea	Area (km ²)	Weddell Sea	Area (km ²)
1	4.0%	285,205	9.1%	124,753	0.3%	11,391
2	0.6%	166,059	0.8%	126,042	0.0%	1,053
3	18.2%	29,728	64.7%	8,378	0.2%	5,418
4	12.7%	38,520	100.0%	4,898	0.1%	4,898
5	53.7%	1,010,120	99.9%	542,717	16.3%	542,012

Table 3-3 (contd.)

Pelagic Region	Total of CCAMLR area		Total of Atlantic Ocean sector of the CCAMLR area		Total of Weddell Sea Planning Area	
	Weddell Sea	Area (km ²)	Weddell Sea	Area (km ²)	Weddell Sea	Area (km ²)
6	14.1%	157,381	86.1%	25,842	0.7%	22,246
7	6.4%	1,030,657	60.6%	109,753	2.0%	66,463
8	51.7%	1,681,527	100.0%	869,528	26.1%	869,485
9	30.7%	5,170,605	65.8%	2,411,807	47.6%	1,585,960
10	0.0%	3,438,600	0.0%	1,023,675	0.0%	124
11	6.1%	3,579,701	13.7%	1,604,358	6.6%	220,084
12	1.5%	47,529	1.9%	36,114	0.0%	704

Circumpolar benthic regionalisation

Amongst other factors, the abundance and distribution of taxa are driven by environmental processes affecting the connectivity between similar habitats for a given organism. Two main environmental drivers are depth and geomorphology (Kaiser et al. 2011, Koubbi et al. 2011, Post et al. 2010, Brandt et al. 2007a, Beaman & Harris 2005, Barry et al. 2003, Brandt et al. 2004). Other major drivers include seabed temperature, icebergs and sea ice cover, sea-surface productivity and ocean currents (Hall & Thatje 2011, Gutt 2007, Gili et al. 2006, Gutt 2001). Habitats will support different species assemblages where the distance between them is greater than the dispersal ability of species. Steep ecoclines, geomorphic barriers and oceanography can cause higher levels of ecological and/or genetic differentiation, happening at various spatio-temporal scales (Arango et al. 2011, Hoffman et al. 2010, Matschiner et al. 2009, Shaw et al. 2004).

The benthic classification aims to identify where marine species assemblages are likely to differ and is intended for general use in MPA planning. The classification combines ecoregions, bathomes and geomorphic features in a hierarchical framework to avoid false homogeneity and identify finer-scale environmental types (Douglass et al. 2014, Williams et al. 2009). Ecoregions indicate where similar habitats are likely to be separated by distance or environmental barriers or have high levels of endemism. Geomorphic features are a classification of the seabed based on its surface morphology, and have been shown to be an effective guide to the distribution of benthic communities (Harris & Baker 2012, Post et al. 2011, Beaman & Harris 2005, Koubbi et al. 2010). Bathomes are depth classes based on bathymetry-species relationships (Douglass et al. 2014). Environmental types with a restricted spatial distribution were also identified since there are limited options to represent them in a system of MPAs.

The three shelf eco-regions for the WSMPA planning area namely, the Dronning Maud, Weddell Shelf and Antarctic Peninsula ecoregions, are similar to those of Spalding et al. (2012). An additional ecoregion captures the deep sea of the Atlantic Basin (Figure 3-18). The fourteen restricted environmental types are mostly associated with some of the eighteen geomorphic features in the planning area and are concentrated in the Maud-Astrid Ridge and Filchner Trough regions especially where they interact with oceanographic features.

Advection over complex bathymetrical features is well known as areas of high productivity, species diversity and species abundance, with important studies from the Southern Ocean

emerging (Paterson et al. 2015, Genin 2004, Dower & Brodeur 2004, Arrigo & van Dijken 2003, Smith & Gordon 1997, Vetter 1994). The Maud Rise-Astrid Ridge region in the east of the WSMPA planning area is a region where interaction between water mass circulation, including warm deep water, Antarctic Slope Current and deep Weddell Sea gyre water, occurs (see chapter 3.1.2). The north-east side of the Antarctic Peninsula where the slope current and gyre water interact with the Antarctic Peninsula may be another area of water mixing.

At Maud Rise, oceanography, sediment characteristics and sea ice processes have been linked to high biodiversity throughout all trophic levels from pelagic predators to benthic species (Brandt et al. 2011). High local concentrations of higher trophic order predators and zooplankton have been found over the northern slope of Maud Rise in the ice-melt zone. High concentrations of krill are found under denser ice on the southern slope, which attracts whales and seabirds. Maud Rise is an underwater plateau and slope region with two associated seamounts within the Atlantic Basin ecoregion. Four of the six environmental types of Maud Rise have a restricted distribution limiting the options for their representation in a system of MPAs (Douglass et al. 2014). The Maud Rise seamount is suspected to contribute to the formation of a polynya over Maud Rise (A. Brandt, et al., 2011; Martin, 2001). This polynya is the most recurring of only two deep water polynyas in the Southern ocean and is thermally driven rather than mechanically driven like the shelf water polynyas in the region (Maqueda et al. 2004). The convection associated with the polynya enables interaction between surface productivity, the benthos and the upwelling of nutrients all of which may contribute to the rich and prospering food web at Maud Rise (A. Brandt et al. 2011).

Similarly to Maud Rise, Astrid Ridge and the nearby marginal plateau are rare geomorphic features in the Southern Ocean that have unusual substrates and modify local ocean currents and are therefore expected to support distinct and enhanced biological communities (Post et al. 2014). Margin ridges protrude from the continental margin hundreds of meters above the sediment plain. Astrid Ridge (centre near 11°E, 68°S; Figure 3-18) is the only margin ridge in the WSMPA planning area and one of only five margin ridges in the Southern Ocean with the closest being Gunnerus Ridge located approximately 600 km to the east. Astrid Ridge rises over 1500 m above the surrounding seafloor and is shallow enough (1600 m) to substantially modify the flow of the east wind drift causing upwelling and consequently influencing primary productivity and ecosystems (O'Brien et al. 2009). The shallowest part of Astrid Ridge and the region just to its west have persistently high summer productivity and a lower ice region than the surrounding local area. Marginal plateaus have a relatively level seafloor that extends from the continental margin but they are separated from the continental shelf by a saddle. There are only two mapped marginal plateaus in the Southern Ocean, Bruce Rise in eastern Antarctica and the marginal plateau just north of Astrid Ridge (Figure 3-18), which is the deeper of the two.

Seamounts have also been shown to be important for biodiversity and can have high endemism levels (Bowden et al. 2011, De Forges et al. 2000). The WSMPA planning area contains part of the seamount chain associated with Maud Rise. The seamounts to the north in the mid-Atlantic Ridge are 250 km from the most northern seamount in the Maud Rise seamount chain. This northern seamount is around 300 km north of the WSMPA planning area boundary. This distance could hinder dispersal meaning the seamount chain is geographically isolated from other seamounts in the Southern Ocean (Halpern et al. 2006). Seamounts with a mount in different depth bathomes are expected to support different species

assemblages given the importance of depth and related factors as delimiters of biological communities. The WSMPA planning area contains seamounts with mounts spanning four bathomes.

At a broader scale, the shelf, slope and abyssal ocean of the Weddell Sea are distinct biogeographic regions and therefore a representative system of MPAs should include part of each. A clear distinction in the faunal assemblages of the shelf, slope and abyss of the Weddell Sea has been found (De Broyer & Jazdzewska 2014, Kaiser et al. 2011, Barnes & Kuklinski 2010). This distinction is partly attributed to the *in situ* survival of species enduring post-glacial erosions such as in ice-free shelf and slope refugia (Kaiser et al. 2011). Furthermore, the shelf region of the WSMPA planning area has higher productivity corresponding with numerous canyons that are likely to be a conduit for the transfer of nutrient rich water which can support enhanced levels of biodiversity such as the rich coral-sponge communities in shelf cutting canyons in east Antarctica (Post et al. 2010, Schlacher et al. 2007). Some canyons correspond with coastal polynyas which are areas of rapid ice formation and can contain high levels of productivity and drive bottom water formation. Organic matter can be transferred with sinking water rejected from brine during ice formation and can influence benthic biodiversity within deep sea areas (Brandt et al. 2007c, Clarke 2003). The Filchner Trough is a deep cross shelf valley or glacial trough north of the Filchner Ice Shelf and is one of the coldest and deepest seafloor areas on the Antarctic shelf (Figure 3-18). North of the trough sits the Crary Trough Mouth Fan formed from sediment deposition (Kuvaas & Kristoffersen 1991). It is one of only three mapped trough mouth fans in the Southern Ocean and the only one to occur in the Atlantic Ocean Sector.

The inclusion of the deep ocean of the Weddell Sea in a system of MPAs will also be important to account for emerging high levels of benthic biodiversity (Brandt et al. 2007b, also chapter 3.2.3). Furthermore, this trend will likely increase with future sampling given that more than 85 % of taxa found during recent survey efforts were new to science (Brandt et al. 2007c). The abyssal plain of the deep ocean consists of older oceanic crust with a smooth surface. The deep lower slope widens west of 20°W and is cut with large, deep canyons.

Conclusion

Biogeographic classifications aim to identify general patterns within complex and diverse systems and therefore false heterogeneity for some species is inevitable. However, for the purposes of MPA planning, incorporating general geographic and depth distribution patterns will increase the chance of integrating the range of species habitat requirements within the final MPA system. Furthermore, there is increasing evidence from molecular studies that widely distributed Antarctic shelf and deep-sea assemblages contain species complexes with each species having a more restricted range (e.g. isopods: Leese et al. 2008, Held & Wägele 2005, Held 2003; amphipods: Havermans et al. 2011; crinoids: Wilson et al. 2007; and ophiuroids: Hunter & Halanych 2008). Similarly, populations of the circumpolar Antarctic Sea Spiders *Nymphon australe* in the east Weddell Sea and the Antarctic Peninsula are genetically isolated and considered distinct (Arango et al. 2011).

To represent the range of biodiversity assemblages and associated habitat types of the WSMPA planning area in a system of MPAs, it is pertinent to consider the region's unique biogeography. Importantly, the distinct shelf, slope and deep sea regions along with an East - West divide separating the Antarctic Peninsula from the east Weddell Sea. Including the

range of pelagic regions capturing the higher heterogeneity on the shelf and some of the broader distributions in the deep sea will also be important. A north-south transect over the Maud Rise-Astrid Ridge region would provide an opportunity to capture an area important for biodiversity but also represent the latitudinal and temporal changes of some environmental drivers of biodiversity (e.g. sea ice, depth and temperature).

3.4 Human activities

3.4.1 Historic activities

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The first known activities in the South Atlantic region of the Weddell Sea go back to the British captain James Weddell (1787-1834). In 1823 he successfully reached 75°15'S in a small sailing vessel, and, referring to his account, he was not hindered by ice. This voyage suggested the idea this sea would extend until the South Pole which consequently could be approached by ship – an idea that still had followers until the beginning of the 20th century. Weddell named his discovery the “Georg IV Sea”. The name Weddell Sea was suggested by the German geographer K. Fricker in his book “Antarktis” published 1898. The Weddell Sea was discussed as a possible objective for a first German Antarctic Expedition which eventually became true in 1901 under the command of Erich v. Drygalski (1865-1949): The expedition tried to advance south of Kerguelen, presuming that there would exist a passage to the Weddell Sea. This proved to be a fundamental error, as known today.

In 1903 the Scottish Antarctic Expedition led by the biologist William S. Bruce (1867-1921) reached Coat's Land. But only in 1911/12 the Second German Antarctic Expedition under Wilhelm Filchner (1877-1957) was able to prove the southern limits of the Weddell Sea. The construction of a sophisticated station building failed, as the construction area near the ice shelf edge broke off and started to drift away. Filchner's vessel overwintered in the central part of the Weddell Sea captured in densely packed sea ice. Observatory buildings as well as stables for horses and dogs were erected nearby. By tracking the ships drift they got a first hint on a large current system – the Weddell Gyre.

As Filchner before, the 1914/16 expedition under the command of Sir Ernest Shackleton (1874-1922) entered the Weddell Sea with a similar geographic task, namely the exploration of the region between Ross- and Weddell Sea. But Shackleton was not able to reach the Filchner Barrier, as the ice shelf was then called. His ship was crushed by the pack of the Weddell Sea. The interwar period was mainly marked by activities of huge European whaling fleets which also extended into the Weddell Sea. Only in 1947 the American Finn Ronne (1899-1980) managed to discover the southern limits of the Weddell Sea by an aircraft survey in full length. U.S. American activities after WW II resulted in a first comprehensive description of the whole Antarctic Continent, but it was not until 1949/52 that a Norwegian-British-Swedish scientific overwintering took place in the area of the present Neumayer Station. Some material left by these activities can still be found in the hinterland.

Extensive activities on the ice shelf border of the inner Weddell Sea took place in the 1950's associated with the British Commonwealth Transantarctic Expedition. Here Sir Vivian Fuchs (1908-1999) established the Shackleton Station (77°58'S, 37°12'), his basic camp. The remains of a pylon construction could be found in 1985 still. In subsequent years the British founded Halley Bay Station, which, several times renewed, is still occupied today. Remarkably, on their first voyage in 1955 with the polar icebreaker General San Martin (constructed in Bremerhaven), the Argentineans were able to reach the coast of the inner Weddell Sea. Here they built on solid ground Belgrano Station, replaced by Belgrano II in 1979.

Especially in the 1970's the Weddell Sea area became a target for Soviet scientific activities. Extended aerial surveys were performed in which also GDR scientists took part actively. As late as in 1985, Drushnaya Station in Gould Bay area was still in use.

See e.g. Headland (2009) and Krause (2012) for further details.

3.4.2 Modern-day activities (after 1980)

Scientific Research

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The difficult and treacherous sea ice conditions in the Weddell Sea were the main reason, why the scientific study of this part of the Southern Ocean was limited for decades to individual and opportunistic expeditions. This situation changed with the engagement of the Federal Republic of Germany in modern Antarctic research. In 1980, the Alfred Wegener Institute for Polar and Marine Research (AWI) was established. One year later, the overwintering Antarctic research station *Georg von Neumayer* on the Ekström shelf ice in the north east corner of the Weddell Sea was inaugurated and (West) Germany became a consultative member of the Antarctic Treaty. However, the real breakthrough for marine scientific research in the Weddell Sea was the commission of the research vessel and ice breaker *Polarstern* in 1982 (Fig. 3-19). Since then, *Polarstern* has supplied the *Neumayer* station in nearly every Antarctic summer season and carried out research cruises in the Weddell Sea. The particular environmental winter conditions in the Weddell Sea were studied in 1992, 2006 and 2013. Over the last 30 years, the *Polarstern* research cruises in the Weddell Sea visited around 12.000 locations/stations, resulting in over 6000 data sets. These cover a wide variety of environmental and ecological parameters, including those compiled and analysed in this scientific background document.

Figure 3-19
German research vessel and icebreaker *Polarstern*.



Since her launch in December 1982, *Polarstern* has travelled more than 1.5 million nautical miles (2.7 million kilometres, which corresponds more than 67 circumnavigations of the globe at the equator) in the duty of scientific research (Fig. 3-19). She is still one of the highest-performance polar research vessels in the world and spends an average of 320 days a year at sea. However, even the best and most loved 'work horse' has to retire eventually, and Germany is currently planning a new ship which is scheduled to replace *Polarstern* in 2019.

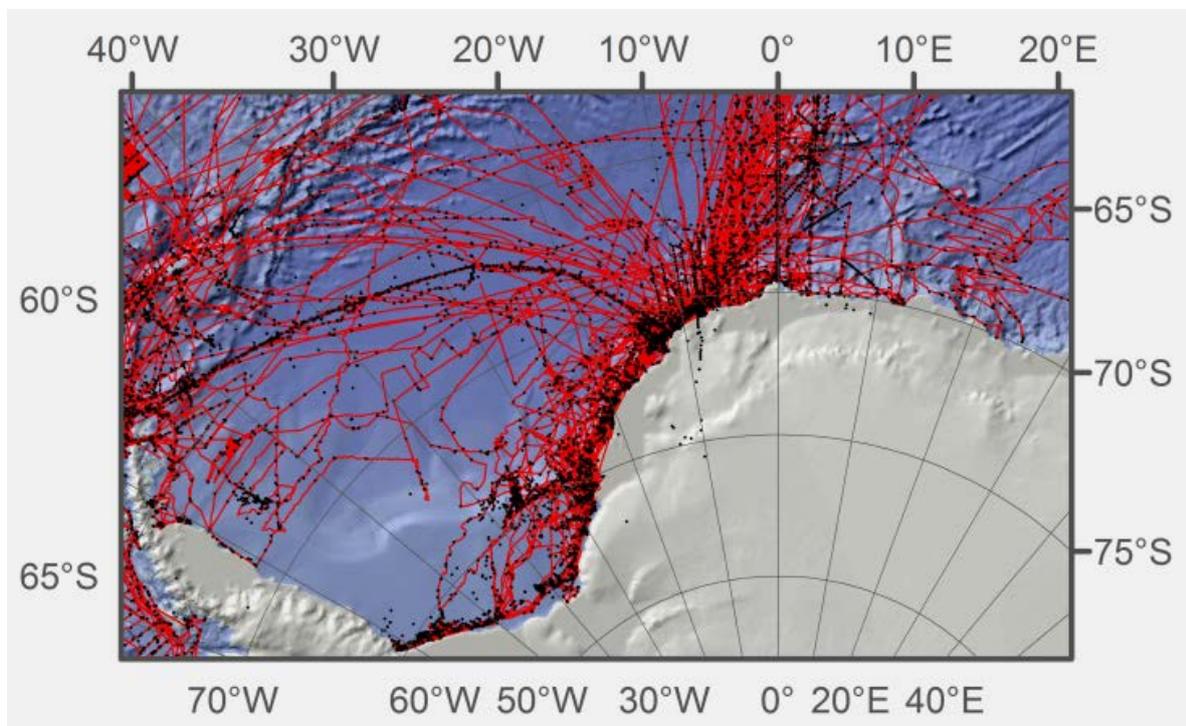


Figure 3-20 Tracklines of *Polarstern* cruises from 1982 to 2014. Further information on *Polarstern* research cruises can be obtained from <http://www.pangaea.de/PHP/CruiseReports.php?b=Polarstern>.

In addition to *Polarstern*, numerous other research vessels - operated by the national Antarctic programmes of CCAMLR members - have worked since 1980 regularly or occasionally in the Weddell Sea. Besides scientific studies carried out on way to land-based stations, there have been a large number dedicated marine scientific research cruises in the area of the Antarctic Peninsula, in the area of Maud Rise and along the coast of Queen Maud Land, and in the Weddell Sea. Just one example of many is the UK marine geoscience and physical oceanography research cruise 244 with RRS *James Clark Ross*, which in 2011 investigated large areas in the eastern and southern Weddell Sea.

Most of the ship borne observations were carried out in areas of the Weddell Sea, which are relatively easy to access, e.g. along the shelf ice in the eastern and southern part of the Weddell Sea, where often during the austral summer less sea ice or even ice free waters (polynyas) are encountered. This is also one of the reasons, why the majority of data on marine biota have been obtained on the continental shelf of the Weddell Sea in water depths shallower than 500 meters. Deep sea areas with perennial sea ice cover, such as the central and western Weddell Sea, have been studied in much less detail. One of the few base-line surveys of the deep-sea fauna conducted in these areas were the ANDEEP cruises in 2002 and 2005 (Brandt & Hilbig 2004, Brandt & Ebbe 2007).

Besides basic research studies on the Weddell Sea biota, CCAMLR members have carried dedicated research on marine living resources in the Weddell Sea MPA planning area. Since 2005/06 appreciable research and stock assessments of Antarctic toothfish (*Dissostichus* spp.) are being carried out by Japan, the Republic of Korea and South Africa, as main fishing nations, in CCAMLR statistical area 48.6. In 2012/13, the Russian Federation started a five-year longline survey of Antarctic toothfish in the Weddell Sea (CCAMLR statistical area 48.5). However, it should be noted that this research programme has currently been suspended and the data reported by the Russian Federation in 2013 and 2014 have been quarantined by CCAMLR (see CCAMLR-XXXIII, § 3.12) and were therefore not considered in this background document and the WSMPA analyses. More information on this specific research on marine living resources under CCAMLR is given in the “Fisheries” chapter. All these research activities on living marine resources are subject to control and regulation by CCAMLR, and the results of these research operations are being regularly reported to the CCAMLR Commission.

In addition to ship borne observations, the use of air borne or satellite-based data has increased our knowledge of the Weddell Sea enormously. Nowadays, a large variety of environmental and ecological parameters can be observed remotely, including atmospheric and climate related studies, gravimetry analyses to improve bathymetric mapping, and biological observations in the water column (e.g. chlorophyll-a concentration) and on land (e.g. distribution of penguin colonies). To obtain time-series of environmental data, the AWI and research institutes of other CCAMLR members regularly deploy oceanographic moorings and ocean or sea ice based automatic measuring stations / buoys, which drift with the currents. An example of the latter is the ARGO float programme which is a key component of the Global Ocean Observing System (GOOS) to observe temperature, salinity, and currents in the oceans, also in the Weddell Sea.

A special trademark of the scientific research carried out in the Weddell Sea since the early 80s is that the studies are often part of large international research projects or programmes.

One example of such a large, multidisciplinary research project was the European *Polarstern* Study (EPOS). EPOS was carried out in 1988/89 under the auspices of the European Science Foundation and brought together 131 scientists from 14 countries, who participated in a series of three cruises to the Weddell Sea (Hempel 1993).

Research Stations and Activities

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There are 12 active research stations and facilities bordering the Weddell Sea MPA planning area (Table 3-4 and Fig. 3-21). These research stations are operated, either year-round or seasonal, by the National Antarctic Programmes (NAPs) of various CCAMLR- and Antarctic Treaty members as part of their interest in and commitment to research in Antarctica. The logistical supply of these research stations and facilities is mostly done via vessel (Fig. 3-21).

Furthermore, research in connection with understanding processes of ocean – sea ice – ice shelf interaction would require frequent and rather continuous logistical ships operations in any future MPA area in order to support land based operations, e.g. scientific expeditions and traverses on the shelf ice and the Antarctic ice cap. In addition, supporting and logistical ship operations will also be required for other research at sea, e.g. in the context of the International Ocean Discovery Program: Exploring the Earth under the Sea (IODP).

In addition to these installations and activities on land (shelf ice), occasionally large ice flows in the western part of the Weddell Sea were used as base for temporary research stations, such as the Ice Station Weddell-I (ISW-I), which was jointly established and operated by the US and Russia from February to late May 1992.

Table 3-4 Research stations bordering the Weddell Sea MPA planning area.

Name	Operated by	Lat / Long	Since	Current status	Population (winter)	Population (peak)
Aboa	Finland	73° 2.537' S 13° 24.441' W	1989	Seasonal	0	20
Belgrano II	Argentina	77° 52.467' S 34° 37.617' W	1955	Year-round	12	12
Dakshin Gangotri ¹⁾	India	70° 5.000' S 12° 0.000' E	1983	Discontinued	0	-
Halley	United Kingdom	75° 34.789' S 26° 43.717' W	1956	Year-round	15	65
Maitri	India	70° 46.010' S 11° 43.847' E	1989	Year-round	25	65
Marambio	Argentina	64° 14.506' S 56° 37.393' W	1969	Year-round	55	150
Matienzo	Argentina	64° 58.552' S 60° 4.257' W	1961	Seasonal	0	15
Neumayer III	Germany	70° 40.635' S 8° 16.296' W	1981	Year-round	9	50
Novolazarevskaya	Russia	70° 46.616' S 11° 49.420' E	1961	Year-round	30	70
Princess Elisabeth ²⁾	Belgium	71° 56.997' S 23° 20,850' E	2009	Seasonal	0	16
Sanae IV	South Africa	71° 40.372' S 2° 50.419' W	1962	Year-round	10	80

Table 3-4 (contd.)

Tor	Norway	71° 53.371' S 5° 9.594' E	1985	Seasonal (Refuge)	0	4
Troll	Norway	72° 0.717' S 2° 31.984' E	1990	Year-round	7	40
Wasa	Sweden	73° 2.568' S 13° 24.775' W	1989	Seasonal	0	20

Source: COMNAP Antarctic Facilities List,
https://www.comnap.aq/Information/SiteAssets/SitePages/Home/Antarctic_Facilities_List_13Feb2014.xls.

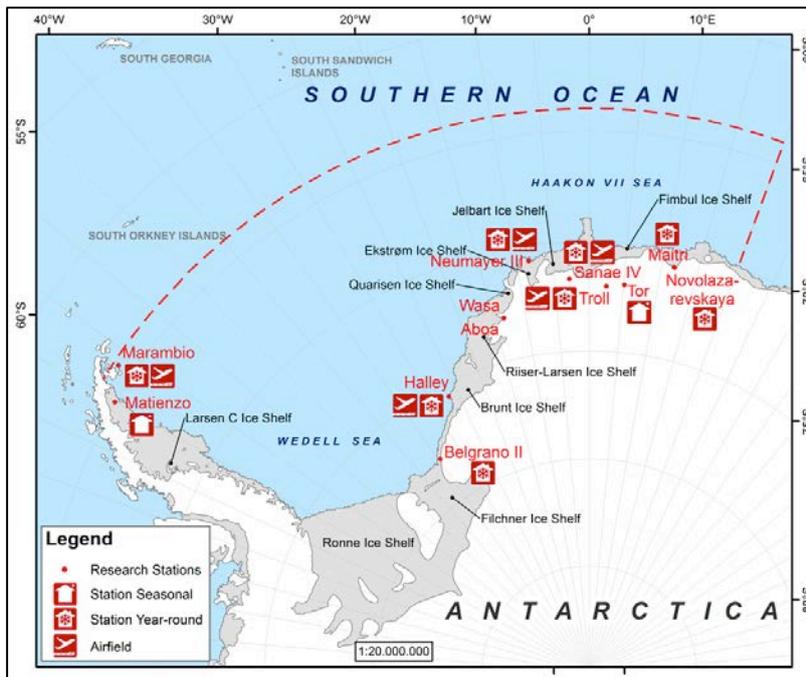


Figure 3-21 Map of the research stations and facilities bordering the Weddell Sea MPA planning area (modified after COMNAP Antarctic Facilities Map, Edition 5 (24 July 2009), available at https://www.comnap.aq/Publications/Comnap%20Publications/comnap_map_edition5_a0_2009-07-24.pdf).

The research being carried out at these stations and facilities and on land- or sea-based expeditions contributes to a better understanding of the environmental conditions in the Weddell Sea. For example, the results of meteorological, atmospheric and glaciological studies will provide important data to study whether and how the Weddell Sea environment and ecosystems will be affected by climate change. In addition, there are marine biological investigations carried out at some stations, such as the recording of the underwater soundscape in the vicinity of the shelf ice edge near the Germany research station Neumayer III. For this purpose, the PerenniAL Acoustic Observatory in the Antarctic Ocean (PALAOA) was established in 2005 to allow long-term recordings and continuous studies of the acoustic repertoire of whales and seals in an environment almost undisturbed by humans. The data will be analysed to (1) register species specific vocalizations, (2) infer the approximate number of animals inside the measuring range, (3) calculate their movements relative to the observatory, and (4) examine possible effects of the sporadic shipping traffic on the acoustic and locomotive behaviour of marine mammals.



Figure 3-22 The Russian-flagged transport vessel "Vasily Golovnin" in the southern Weddell Sea (photographed by the German Research plane *Polar 6* on February 2nd 2014 at approx. S 77.75° S, 035.2° W). This vessel had been chartered by Argentina for supplying and shipment of cargoes to the Argentine Antarctic stations.

The necessary work to operate and maintain these research stations and facilities and to carry out large scientific expeditions/programmes is internationally coordinated by the Council of Managers of National Antarctic Program (COMNAP). COMNAP was formed in 1988 and brings together the NAPs of most Antarctic Treaty members. These NAPs have responsibility for delivering and supporting scientific research in the Antarctic Treaty Area on behalf of their respective governments and in the spirit of the Antarctic Treaty. COMNAP's purpose – as stated in its constitution - is to “develop and promote best practice in managing the support of scientific research in Antarctica”. It does this by:

- Serving as a forum to develop practices that improve effectiveness of activities in an environmentally responsible manner;
- Facilitating and promoting international partnerships;
- Providing opportunities and systems for information exchange; and
- Providing the Antarctic Treaty System with objective and practical, technical and non-political advice drawn from the National Antarctic Programs' pool of expertise.

Taking into account the importance of the research stations and facilities on the shelf ice areas bordering the Weddell Sea MPA planning area, it is imperative, that their operation, including the logistical movements necessary to supply them, is not hindered or jeopardised by any marine protected area (MPA) and conservation / management measures adopted under CCAMLR.

Fisheries

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The Weddell Sea Domain 3 and the southern part of Domain 4 encompass CCAMLR Statistical Areas 48.5 and the southern part of Statistical Area 48.6 although they are not fully congruent. An exploratory long line fishery targeting Antarctic toothfish, *Dissostichus mawsoni*, has developed in the High-Antarctic Province in the second half of the 1990s, starting in the Ross Sea in 1997/98. This exploratory fishery became extended successively to all statistical subareas and divisions around the Antarctic continent by 2012/13. North of 60° S, the proportion of its more northerly distributed congener Patagonian toothfish, *D. eleginoides*, increases and replaces *D. mawsoni* the further north the fishery is conducted.

Exploratory fishery in CCAMLR Subarea 48.6

Exploratory longline fishery started in Subarea 48.6 in 2003/04. Only 7 tonnes were taken north of 60° S (SC-CAMLR-XXIII, Annex 5). The catch limit for the subarea was set at 455 tonnes north of 60° S and 455 tonnes south of 60° S from 2004/05. The annual catch until 2007/08 did not exceed 163 tonnes. Main fishing nations were Japan, Republic of Korea, and South Africa. Until 2007/08, most exploratory fishing had been conducted north of 60° S and took *D. mawsoni* and to a lesser extent *D. eleginoides* (Table 3-5). The announcement to extend the fishery further to the south prompted CCAMLR in October 2008 to subdivide Subarea 48.6 into small scale research units (SSRUs), SSRUs A and G north of 60° S and SSRUs B-F south of 60° S. The catch limit was reduced to 200 tonnes for SSRUs A and G and 200 tonnes for SSRUs B-F. A map of Subarea 48.6 showing the SSRUs is provided in the Fishery Report, Annex P. Conservation Measure (CM) 41-04 applied with respect to the conduct of the fishery, the data collection and a research plan. CM 33-03 applied with respect to by-catch, just as CMs 21-02, 24-01 and 41-01 (see CCAMLR Conservation Measures 2013). From 2008/09, most fishing was conducted south of 60° S. Consequently, the catch of the more southerly distributed Antarctic toothfish increased while those of Patagonian toothfish rapidly declined. Catch figures are provided in Table 3-5.

Table 3-5 Catch of *Dissostichus* spp. taken in exploratory longline fisheries in Subarea 48.6 from 2003/04 to 2013/14 (from CCAMLR Fishery Reports 2013 and CCAMLR data base).

Fishing season	<i>Dissostichus mawsoni</i> Total catch (tonnes)	<i>Dissostichus eleginoides</i> Total catch (tonnes)	Sum (tonnes)
2003/04	0	7	7
2004/05	2	49	51
2005/06	63	100	163
2006/07	34	78	112
2007/08	11	12	24
2008/09	265	17	282
2009/10	342	50	392
2010/11	359	33	392

Table 3-5 (contd.)

Fishing season	<i>Dissostichus mawsoni</i> Total catch (tonnes)	<i>Dissostichus eleginoides</i> Total catch (tonnes)	Sum (tonnes)
2011/12	376	5	381
2012/13	275	15	290
2013/14	145	9	154

First attempts to assess stocks of *D. eleginoides* and *D. mawsoni* in Subarea 48.6 north of 60° S (SSRUs A and G), and *D. mawsoni* in Subarea 48.6 south of 60° S (SSRUs B, C, D, and E) were conducted by Japanese scientists in 2013. Their assessment methods (the Petersen method and the CPUE x seabed analogy method) were developed in direct response to advice provided by WG-SAM in 2012. They closely resemble assessments currently taking place in South Africa. The *Working Group on Fish Stock Assessment* (WG-FSA) provided a number of suggestions how to improve the assessments. The developers were advised to submit their stock assessments first for evaluation by WG-SAM and using the CCAMLR exploitation rates to estimate yields. Currently estimated yields based on their assessments were used for decision for catch limits in this Subarea. The developers plan an assessment implemented in CASAL stock assessment software near future. This would offer the opportunity to compare results from the two different assessment methods.

CCAMLR re-estimated catch limits for *D. eleginoides* in SSRUs 48.6A and 48.6G and for *D. mawsoni* in SSRUs 48.6B, 48.6C, 48.6D, and 48.6E in 2013. The catch limit for *D. eleginoides* for the 2014/15 season was set at 28 tonnes and *D. mawsoni* at 170 tonnes in Subarea 48.6 north of 60° S (SSRUs A and G). Once the catch of *D. eleginoides* reaches 27 tonnes in research block 486_1, fishing would move to research block 486_2 and research lines would be set in deeper water in order to avoid areas where *D. eleginoides* are known to occur.

Research fishery in CCAMLR Subarea 48.5

According to CM 24-01 the Russian Federation started a research programme on *Dissostichus* spp. (primarily *D. mawsoni*) in Subarea 48.5 in 2012/13 based on a plan approved by CCAMLR in 2011/12. The programme is envisaged to last for five years; its main objective is a first stock assessment for *Dissostichus* spp. in this data-poor area. Given the rapidly changing sea-ice conditions in Subarea 48.5, the research plan was kept flexible and included three optional fishing areas (Petrov et al. 2012, Fig. 3-23). The Russian Federation reported data and information from this research fishery in 2013 and 2014. Upon evaluation of the latter, CCAMLR quarantined in 2014 all data obtained by the Russian Federation in the 48.5 research fisheries (see CCAMLR-XXXIII, § 3.12) and therefore these data are not been reflected in this background document, nor were they considered in the WSMPA analyses.

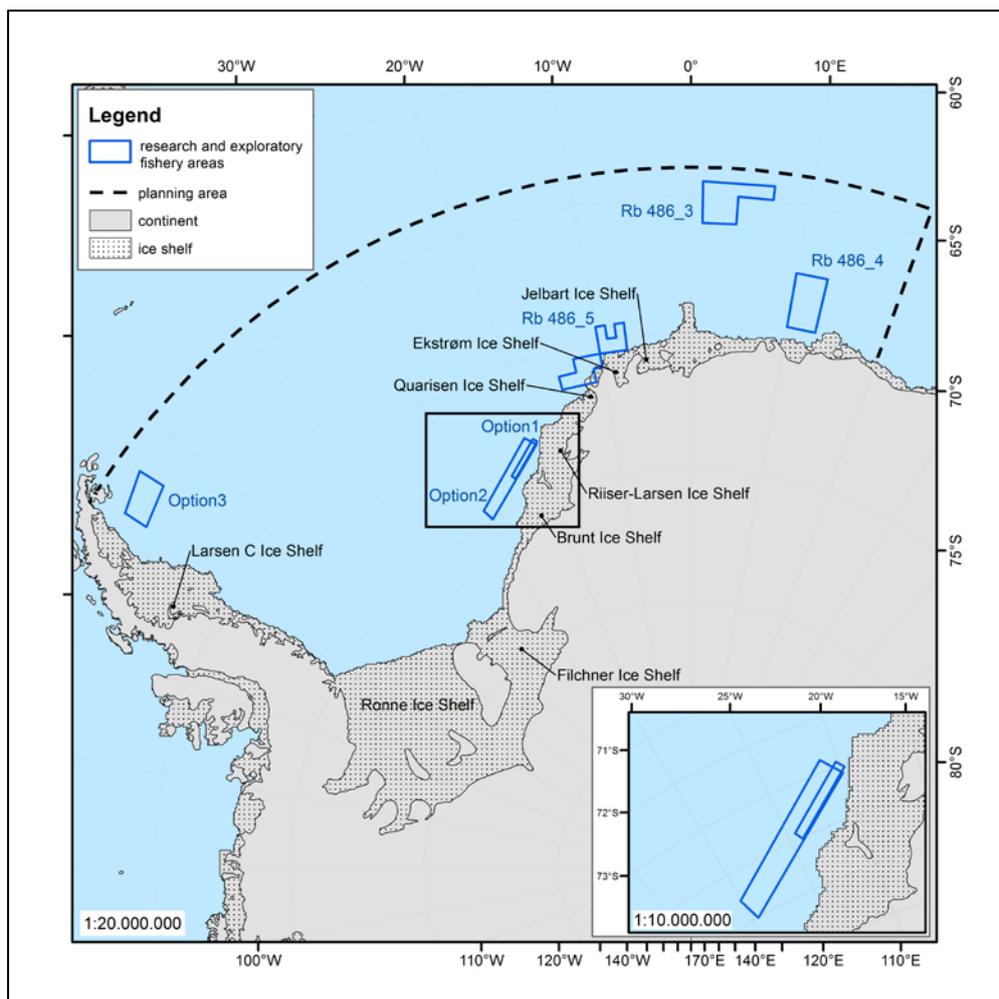


Figure 3-23 Map of the Weddell Sea MPA planning area (black dashed box) indicating the areas (Option 1, 2 and 3) selected for the Russian exploratory longline fishery. The boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA. The ice shelves are labelled and are shown as grey dotted areas.

3.5 Scenarios for the future of the Weddell Sea climate

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The Weddell Sea is the major region of bottom water formation in the world's ocean. With its sea ice cover waxing and waning through the seasonal cycle it provides a vast home for a very specialized and rich ecosystem ranging from tiny algae to the largest animals on Earth, the whales. At the southern and western shores, massive ice shelves fringe the Weddell Sea. These are outflow regions of the huge Antarctic Ice Sheet, which play an important role for the deep and bottom water formation and for sea level rise. Significant changes in the recent past indicate a changing role of the Weddell Sea in the climate system.

Sea ice

Over the satellite era, the sea ice covered area in the Weddell Sea has increased by 1% per decade, whereas the ice extent has grown by 0.5% per decade, indicating a more densely

packed sea ice cover. This development is in contrast to the rapid sea ice decline in the Arctic Ocean.

The future outlook is mixed. The CMIP5 coupled climate models project for the near term (the next two decades) a decrease of Antarctic sea ice, but there is low confidence in Antarctic sea ice model projections that show near-term decreases of sea ice cover because of the wide range of model responses and the inability of almost all of the models to reproduce the mean seasonal cycle, interannual variability and overall increase of the Antarctic sea ice areal coverage observed during the satellite era. In addition, there is the possibility that melting of the Antarctic ice sheet could be changing the vertical ocean temperature stratification around Antarctica and encourage sea ice growth (Kirtman et al. 2013).

The long-term projections to the end of this century show a significant decrease of Antarctic sea ice, especially in winter, depending on the emission scenario human society is to realize (see Fig. 3-24). Currently the world is following the RCP8.5 with a high probability of a 30% reduction of the maximum sea ice extent in winter and a nearly complete loss of the summer sea ice.

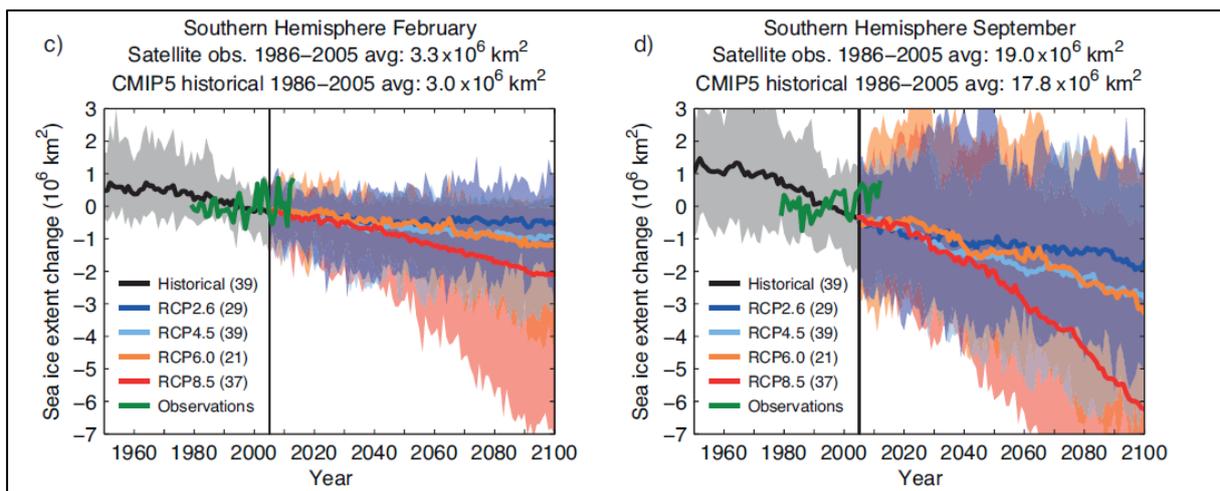


Figure 3-24 Changes in sea ice extent as simulated by CMIP5 models over the second half of the 20th century and the whole 21st century under RCP2.6, RCP4.5, RCP6.0 and RCP8.5 for (c) Southern Hemisphere February and (d) Southern Hemisphere September. The solid curves show the multi-model means and the shading denotes the 5 to 95% range of the ensemble (Collins et al. 2013).

Many of the processes determining the development of the Weddell Sea ice cover are still to be understood. In situ observations (especially sea ice thickness in winter and summer) and modelling improvements are required for understanding the interaction of atmosphere, sea ice and ocean, including the effects of the stratosphere on the troposphere and its wind systems.

Ice shelves

Approximately 74% of ice discharged from the grounded ice sheet in Antarctica flows through ice shelves. Ice shelves help to buttress and restrain flow of the grounded ice, and, therefore, changes in thickness and extent of ice shelves influence current ice sheet change. Nearly all of the outlet glaciers and ice streams that are experiencing high rates of ice loss

flow into thinning or disintegrated ice shelves, such as the Larsen Ice Shelves, fringing the western Weddell Sea. The IPCC AR5 states that there is high confidence for ice shelves round the Antarctic Peninsula to continue a long-term trend of retreat and partial collapse that began decades ago, which has been mostly related to changing atmospheric temperatures. Many of the larger ice shelves however, so far exhibit stable conditions.

This may change in the future. There are three distinct processes that could link climate change to dynamical change of the Antarctic ice sheet and potentially trigger increased outflow. These may operate directly through the increased potential for melt ponds to form on the upper surface of ice shelves, which may destabilize them, or by increases in submarine melt experienced by ice shelves as a consequence of oceanic warming, which leads to their thinning, as well as indirectly by coupling between SMB and ice flow.

More detailed regional modelling using scenario A1B illustrates the potential for warm water to invade the ocean cavity underlying the Filchner-Ronne ice shelf in the second half of the 21st century, with an associated 20-fold increase in melt (Hellmer et al. 2012). In the IPCC AR5 (Church et al. 2013) it is stated that based on the limited literature, there is medium confidence that oceanic processes may potentially trigger further dynamical change particularly in the latter part of the 21st century, while there is also medium confidence that atmospheric change will not affect dynamics outside of the Antarctic Peninsula during the 21st century.

Oceanic observations near and under the ice shelves, especially the Filchner-Ronne Ice Shelf, are required to better understand the role of the ice shelf – ocean interaction for the stability of ice shelves, the discharge of ice sheets and sea level rise.

Ocean

The ocean is at present globally warming and taking up 93% of the excess energy resulting from the increased greenhouse effect. Recent global coupled climate models project that warming at depths below 1000 m is most pronounced in the Southern Ocean, with the largest heat uptake occurring at the end of the 21st century (Collins et al. 2013).

Beginning in 1984, a high resolution repeat hydrographic section along the Prime Meridian (Fahrbach et al. 2011) represents the longest time series in the otherwise severely undersampled Southern Ocean. Temperature variations in the order of 0.06 °C were observed in the deep water, with a positive trend of 0.04 °C over the 25 years. Changes in the interior of the Weddell Sea may result from the interaction with the atmosphere and the ice shelves as well as from changes in the oceanic circulation that connects it to the Antarctic Circumpolar Current (ACC). The only pathway by which the interior Weddell Sea gains significant amounts of heat is the inflow of warm (>1.3°C) and saline Circumpolar Deep Water (CDW) from the ACC, which enters with the southward oriented eastern limb of the Weddell Gyre between 20°E and 30°E (Schröder & Fahrbach 1999). When the CDW enters the Weddell Sea proper across the Prime Meridian its warm core occupies the depth range 150 m to 600 m, with the inflow split in two branches, one associated with the topographic slope north of Maud Rise and the other associated with the continental slope of Antarctica (Cisewski et al. 2011). Downstream of Maud Rise the two cores mix mainly isopycnally (Leach et al. 2011) to form the so-called Warm Deep Water (WDW) in the Weddell Sea. Whether the observed deep water warming at the prime meridian is related to the mean warming of the ACC south

of the Subantarctic Front (Rhein et al. 2013), to fluctuations in the mixing of the two CDW branches that form the WDW, or to atmospheric forcing, cannot be resolved with the existing data. Also uncertain at present is whether the interior Weddell Sea is freshening similarly to the Australian-Pacific sector of the Southern Ocean (Rintoul 2007). In consequence it remains an open question in which direction changes in the Weddell Sea will alter the density driven global ocean deep overturning circulation.

Key to understanding the future role of the Weddell Sea in global climate change is to maintain and further develop the long-term observational programs, and to combine these with dedicated studies of processes that control the interaction between ocean, atmosphere and ice shelves, which then can be used to optimize numerical models.

3.6 Potential threats to the Weddell Sea ecosystem

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There are a number of known and on-going developments and activities that constitute a potential threat to the Weddell Sea ecosystem. These may be categorized as either (i) consequences of large-scale climate and/or oceanographic change or (ii) consequences of on-site human activity.

(i) Consequences of large-scale climate and oceanographic change

The current general trend in ocean warming and acidification will affect the Weddell Sea marine organisms at the ecophysiological level (e.g., Wittmann & Pörtner 2013) in the same way as in other polar seas, with consequences for ecosystem structure, stability and productivity (Storch et al. 2014, Woodward et al. 2010). However, as the Weddell gyre (chapter 3.1.2) is assumed to maintain cold polar conditions much longer than adjacent regions owing to its capacity to transfer surface heat to deeper water layers quite efficiently (Fahrbach et al. 2011), at least parts of the Weddell Sea may show a distinct time lag in their response to global ocean change. Nevertheless, there are developments of specific significance for the Weddell Sea MPA (WSMPA) planning area.

The most obvious current large-scale trend in the Antarctic climate and ocean system is the rapid warming in the region of the Western Antarctic Peninsula (WAP) that also affects the north-western part of the Weddell Sea planning area (Fig. 3-25). Over the past half century, surface air and seawater temperatures increased, glaciers on the WAP and the adjacent islands retreated, WAP ice shelves thinned considerably and the annual period of sea ice cover shortened in the area northwest to the WAP (e.g., Turner et al. 2005, Stammerjohn et al. 2008, Whitehouse et al. 2008, Paolo et al. 2015). The most spectacular consequences of this warming so far were the disintegration of the Larsen A and Larsen B Ice Shelves, but in addition there are a multitude of effects both at smaller scales, e.g., increased sedimentation rates owing to higher coastal erosion (Monien et al. 2011) and with potentially wider impact, e.g., increased release of iron from suboxic sediments (Monien et al. 2014). We already see ecological response locally, e.g., in the plankton and benthos of small coves at King George Island (Brey et al., 2011, Schloss et al. 2012), as well as at regional scales, e.g., in plankton

and benthos on the shelf formerly covered by Larsen A and B Ice Shelves (e.g., Gutt et al. 2013b, see also chapter 3.2.3). Continued warming in the WAP region will impose further adaptation stress on the ecosystem, particularly for that biota adapted to shelf ice areas (e.g., the still enigmatic fauna on the underside of the shelf ice, Watanabe et al. 2006) or on organisms depending on the seasonal cycle in sea ice cover (e.g., krill), see Schofield et al. (2010) for a synopsis.

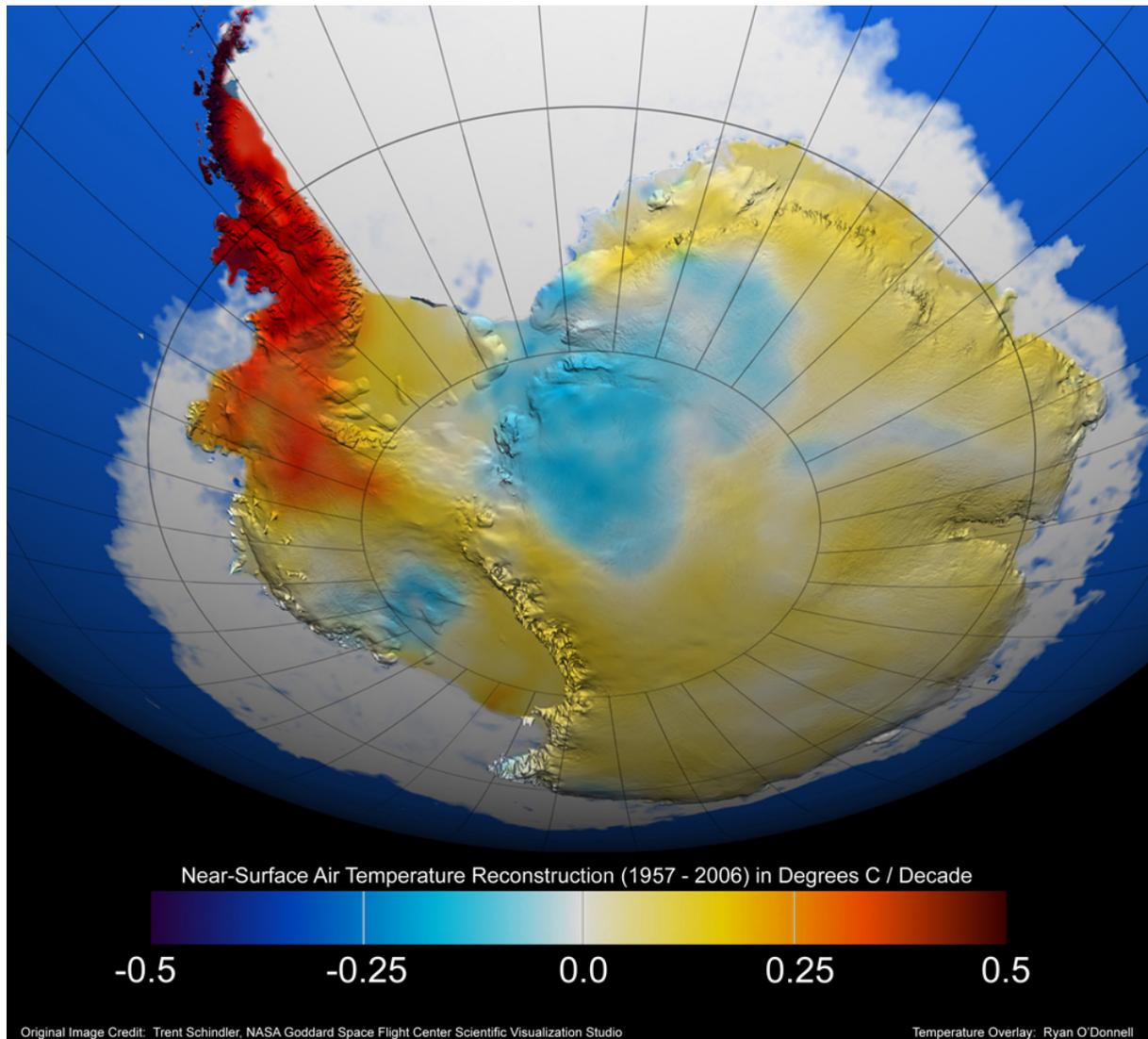


Figure 3-25 Antarctic land and shelf ice surface temperature anomalies 1957 – 2006 (°C / decade) according to O’Donnell et al. (2006). Image created by T Schindler, NASA-Goddard Space Flight Center Scientific Visualization Studio.

Modelling studies by Hellmer et al. (2012) indicate that in the 2nd half of the 21st century a redirection of the Weddell Sea coastal current could lead to increased movement of warm waters under the Filchner-Rønne Ice Shelf, starting to melt this ice shelf. With >430.000 km², the Filchner-Rønne Ice Shelf constitutes the second largest ice shelf in Antarctica. The melting of this up to 600 m thick ice layer would release enormous amounts of freshwater into the Weddell Sea (with potential effects on the oceanographic current system and the Weddell Sea gyre) and would add significantly to the global sea level. In the long run, the loss of this

southernmost ice shelf of the Weddell Sea would cause dramatic changes in these high-Antarctic pelagic and benthic shelf communities (see chapter 3.2.2 and 3.2.3) on a much larger scale than those observed in the WAP region. The loss and gain (invaders) of temperature sensitive species would lead to severe alterations in biodiversity and would reduce community stability substantially, thereby disrupting the food web through cascading loss of species (Jacob et al. 2011, Woodward et al. 2010).

A further long-term trend in the Weddell Sea ecosystem is constituted by the change in sea ice extent and concentration over the last decades. Contrary to the situation in the Arctic, the sea ice around Antarctica is increasing with a 30-year record high of approximately 20 Million km² recorded in September 2014. In the Weddell Sea, sea ice extent and concentration increased particularly in the north-eastern part (Schwegmann 2012, see chapter 3.1.3). Over the last 35 years, the sea ice edge moved further northwest of 30°W, but retreated further south east of 30°W (Turner et al. 2013). Such change in sea ice may have various consequences: e.g., it can alter the export of organic matter from the pelagic realm to the deep sea, or it may affect air breathing marine predators, i.e., penguins, seals, and whales, forcing these animals to relocate foraging and/or breeding activities.

(ii) Consequences of on-site human activity

Today and in the foreseeable future, human activity in the WSMPA planning area is restricted to research, fisheries and tourism. Mineral resource activities (other than scientific research) and military activities are prohibited under the Antarctic Treaty and its Protocol on Environmental Protection. To our knowledge, such activities have not been reported for this area.

Fisheries in the Weddell Sea planning area are currently limited to research and exploratory long-line fisheries on the Antarctic toothfish *Dissostichus* spp. (see chapter 3.4.2) and to commercial krill fishery at the northern fringe of the area. This may change, however, in forthcoming decades. Projected long-term climate change may shift the most favourable krill habitats further south into the Weddell Sea (Hill et al. 2013), and the krill fishery would have to follow. The exploratory long-line fisheries for *Dissostichus* spp. carried out in the 48.6 part of the WSMPA planning area indicate a reasonable sized standing stock of *Dissostichus mawsoni* (see chapter 3.4.2 and references therein).

However, long-lived, slow-growing species with late maturity such as the Antarctic toothfish have to be managed extremely carefully to avoid overexploitation, as stocks would take a long time to recover. Hence, in particular illegal, unreported and unregulated (IUU) fishing may become a major concern if access to Weddell Sea fishing grounds becomes less restricted by sea ice. The consequences of overfishing may reach well beyond the toothfish stock, as reducing / eliminating of this key top predator may cause irreversible changes in the marine community structure and energy flow and may also reduce the food base of its mammal predators.



Figure 3-26 Weddell seal with captured Antarctic toothfish (photo by Jessica Meir).

There are thirteen active research stations situated in the vicinity of the Weddell Sea planning area, eight of which are manned permanently year round (Table 3-4, Fig. 3-21). In addition, research expeditions take place on the shelf ice or the Antarctic ice cap. On the scale of the

Weddell Sea planning area, these activities seem negligible. However, research stations / expeditions and the human activity associated with them (e.g., logistical operations) may lead locally to disturbance or destruction of habitats and biota. The Antarctic Treaty System has adopted rules and regulations to eliminate or reduce the environmental impact of research stations and expeditions, e.g., regarding the disturbance of birds and pinnipeds, especially in places where they rest, forage or breed (e.g., Giese and Riddle 1999, Viblanc et al. 2012). Regular international inspections ensure the compliance with these ATS rules and regulations.

So far, organized commercial tourism barely penetrates our WSMPA planning area (see summary in Deininger 2015), albeit chartered yacht tour operators offer trips that go as far south as Paulet Island (63°35'S) and Seymour Island (64°14'S), see e.g. www.charterworld.com. Tourism may increase, however, with improving sea ice conditions that would make the waters close to the West Antarctic Peninsula more navigable in particular, allowing larger tourist ships to access this area.

4. Future work

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For almost 30 years, the Weddell Sea has constituted one focus area of international Antarctic research. Nevertheless, our actual knowledge of the Weddell Sea environment and ecology is far from being comprehensive. Size, remoteness, and restricted accessibility (regarding time and space) constrain on-site research work in the Weddell Sea seriously and thus scientific progress towards a thorough understanding of the system is comparatively slow compared to non-polar regions.

Kennicutt & Chown (2014) formulated “six priorities for Antarctic science” that address the Antarctic itself as well as its global significance. Obviously, future research on the Weddell Sea ecosystem with a particular view on potential effects of environmental change constitutes a subset of these priorities. It should address a number of major issues, i.e.:

- Shelf ice disintegration. We need a better understanding and prediction of this process as it will affect the productive and diverse shelf communities on large scales. Three processes are of particular concern, (i) the advancement of deep warm water on the continental shelf below the shelf ice, (ii) shelf ice thawing owing to further atmospheric warming in the Peninsula region, and (iii) changes in the dynamics of the Antarctic ice shield.
- Long term development of sea ice. Seasonal sea ice dynamics are a key factor in the Weddell Sea ecosystem. Hence, future research should address (i) the high resolution observation and prediction of sea ice long term development and (ii) the coupling of key species life cycles (e.g., Antarctic krill) to sea ice.
- Uniqueness of the Weddell Sea fauna. Growing evidence points towards the uniqueness of the fauna, but the picture remains extremely patchy. Future research should focus on biodiversity, regional endemisms and evolutionary history and should apply advanced quantitative bioinformation methods.
- Resilience and adaptive capacity of the Weddell Sea ecosystem. Resilience and adaptive capacity decides the fate of an ecosystem facing environmental change and disturbance. Hence, efforts should focus on (i) future environmental change to be expected in specific parts of the Weddell Sea, and (ii) applied and theoretical studies on the response of affected ecosystems and communities, in particular on processes mediated by gain and loss of species.
- The role of exploited species in the Weddell Sea food web. So far, *Dissostichus* spp. is the only species subjected to research and exploratory fisheries in the Weddell Sea. However, the trophic role of this species remains enigmatic so far. Future research on the role of *Dissostichus* spp. in the Weddell Sea food web is essential for a proper evaluation of the systemic effects of any future fishery on this species.

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