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OF ANTARCTIC MARINE LIVING RESOURCES

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МОРСКИХ ЖИВЫХ РЕСУРСОВ АНТАРКТИКИ

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DE LA FAUNE ET LA FLORE MARINES
DE L'ANTARCTIQUE

COMISIÓN PARA LA CONSERVACIÓN DE
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Scientific background document in support of the development of a CCAMLR MPA in the Weddell Sea (Antarctica) – Version 2014

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Abstract

Germany intends to present the Scientific Committee the background document that provides the scientific basis for the evaluation of marine protected areas (MPAs) in the Weddell Sea. Please note, that the current state of the background document presents a comprehensive yet incomplete first version concerning chapters that have to be (further) developed or revised. The contents and structure of the document reflect also its main objectives, i.e. *(i)* to set out the general background and context of the establishment of MPAs, *(ii)* to describe the boundaries of the Weddell Sea MPA Planning Area, *(iii)* to inform on the data retrieval process, *(iv)* to provide - for the first time- a comprehensive, yet succinct, general description of the Weddell Sea ecosystem to reflect the state of the science, and additionally to present the results of the various preliminary scientific analyses that were carried out so far within the framework of the MPA Weddell Sea project, and finally *(v)* to describe future work beyond the development of the scientific basis for the evaluation of a Weddell Sea MPA.

Scientific background document in support of the development of a CCAMLR MPA in the Weddell Sea (Antarctica) – Version 2014

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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Please note that some chapters are incomplete yet and must be developed further
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Contents

1. Background and relevant international agreements

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This background document will provide the scientific basis, rationale and justification for the evaluation and potential establishment of marine protected areas (MPAs) in the Weddell Sea. 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 document reflect its main objectives, i.e. to set out the general background and context of the establishment of MPAs (chapter 1); to describe the boundaries of the Weddell Sea MPA Planning Area (chapter 2) and to inform on the data retrieval process (chapters 3); to provide a comprehensive, yet succinct, general description of the Weddell Sea ecosystem and to present the results of the various preliminary scientific analyses (chapter 4); and finally to give guidance regarding the future work beyond the development of the scientific basis for the evaluation of a Weddell Sea MPA (chapter 5).

Please note, that the current state of the background document presents a comprehensive yet incomplete first version concerning chapters that have to be (further) developed or revised.

The document was prepared by members of the German Weddell Sea MPA project team and working group, except of chapter 4, the general description of the Weddell Sea ecosystem. Here, a different and unique approach was followed. The project team wrote the *preliminary scientific analysis* texts, whereas scientific experts of international renown in the respective field kindly contributed the *state of the science* parts. In addition to scientists from the Alfred Wegener Institute and from other German science institutions, experts of many other CCAMLR member states and acceding states contributed to the paper, for which we are particularly grateful.

The scientific background document has been prepared on purpose as a single volume, so that all information necessary for considering the establishment of marine protected areas (MPAs) in the Weddell Sea 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 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. In so far, MPAs can be seen as an advanced tool for sustainable management.

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 chapter 1.1.

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 (WSSD 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 (ASPA) subject to the regulation of Article 3 of Annex V of the EP. But marine areas could only be designated as an ASPA 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 ASPAs 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 ASPA 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.

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.

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* have been established already, e.g., regarding the effects of ice berg scouring on the shelf benthos, and reference areas might be meaningful tools to monitor effects of further *Dissostichus* research fisheries in the Weddell Sea,

• the *protection of areas vulnerable to impact by human activities* appears to be of less significance in the Weddell Sea planning area as compared to other planning domains. There are few permanent research stations located in this area, tourism is negligible, and exploitation of biological resources is limited to krill fishery at the northern fringe and to *Dissostichus* research fishery on the south-eastern slope,

• *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, as it is assumed that its particular oceanography – the Weddell gyre - will maintain cold polar conditions in this region much longer that in adjacent areas, making it a potential refuge for Antarctic organisms (e.g., Emperor penguins) from ocean warming.

Further analyses of these scientific data and information will lead to the formulation of specific objectives for the Weddell Sea MPA and the conservation measures needed to achieve these, including any management, research and monitoring activities.

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 (WS-MPA) was discussed (see SC-CAMLR-XXXII/03, Annex 5, §§ 3.4-3.6).

The WS-MPA 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 WS-MPA project group proposes the planning area for the evaluation of a Weddell Sea MPA 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 Weddell Sea MPA.

- **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 Weddell Sea planning area covers an area of approximately 4.2 million km², which is slightly larger than twice the size of Mexico.

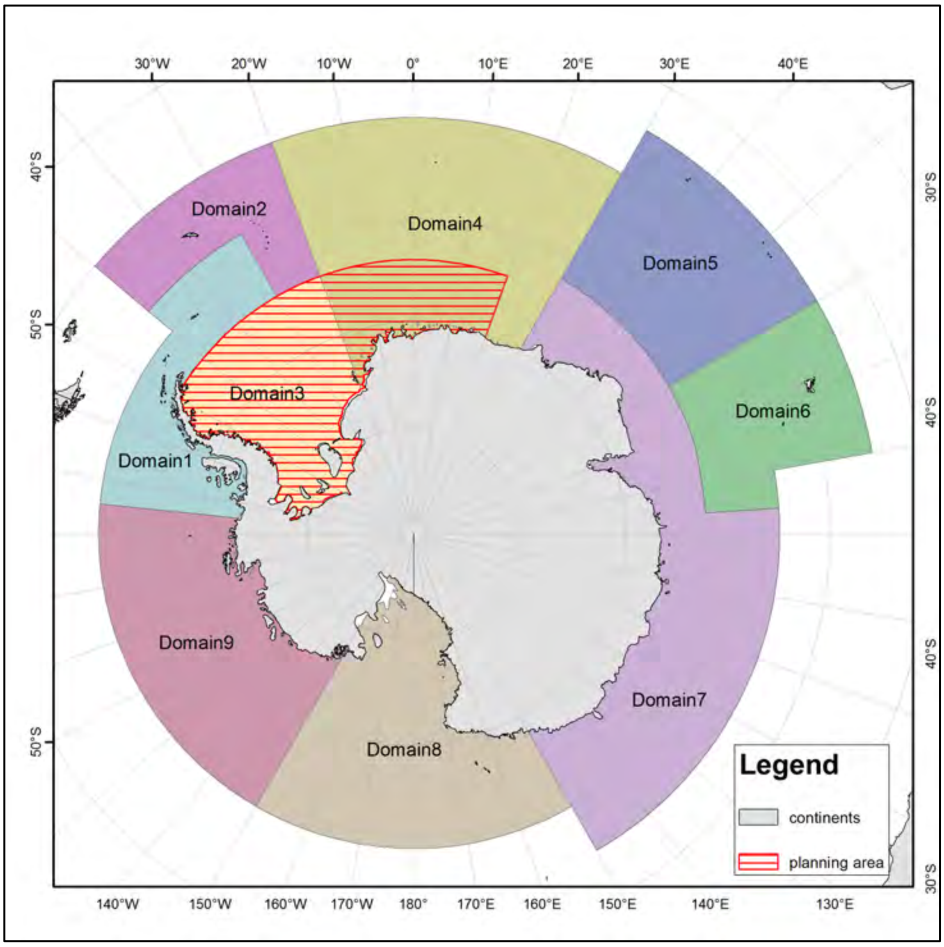

Figure 2-1 CCAMLR MPA Planning Domains and the proposed planning area for the evaluation of a Weddell Sea MPA (red shaded area). Please note that the boundaries of the proposed planning area do not resemble the boundaries of any proposed Weddell Sea MPA. Domain 1: Western Peninsula - South Scotia Arc, 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.

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, paragraph 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. Data sets

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This chapter informs on the data retrieval process within the Weddell Sea MPA project. Table 1 and 2 provide a systematic overview of the current data situation. Complete data sets or parts of it which were already acquired for our study, but were not incorporated into further analyses so far are marked grey. Both tables are based on data already presented in our document WG-EMM-14/19. In addition, some newly acquired data sets are listed (e.g. data on bird breeding colonies).

3.1 Environmental parameters

More than ten large environmental data sets are listed at the moment (see Tab. 3-1). These are satellite data mainly with a high temporal resolution. For example, satellite observations on daily sea ice concentration, derived from the Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-EOS) instrument on board the Aqua satellite, are available by several Internet web sites (see Tab. 1). Further oceanographic data were obtained from the cirumpolar Bremerhaven Regional Ice Ocean Simulations (BRIOS) model (Beckmann et al. 1999; Timmermann et al. 2002) and from the global Finite Element Sea Ice-Ocean Model (FESOM; Timmermann et al. 2009).

3.1.1 Bathymetry & Geomorphology

Bathymetric data are provided by the first regional digital bathymetric model established in the International Bathymetric Chart of the Southern Ocean (IBCSO) programme and published by Arndt et al. (2013; Fig. 1). The bathymetric model Version 1.0 has a horizontal resolution of 500 m x 500 m and a vertical resolution of 1 m. This chart model is based on satellite data and in situ data (multi-beam and single beam data) from many hydrographic offices, scientific institutions and data centres. The derivatives of the bathymetry (e.g. slope, hillshade, geomorphology) are derived from the IBCSO data set.

3.1.2 Sedimentology

A substantial data set on grain size derives from the scientific data information system PANGAEA, an ICSU World Data Centre, hosted by the AWI and the Centre for Marine Environmental Science, University Bremen (doi:10.1594/PANGAEA.730459, doi:10.1594/ PANGAEA.55955). These data are published by Petschick et al. (1996) and Diekmann & Kuhn (1999). The sediment samples were taken with large box corer, multi- or mini-corer during several Polarstern cruises (1983-1997). This data set was complemented by unpublished data that are merged in now in a new compilation (G. Kuhn & K- Jerosch, AWI).

3.1.3 Oceanography

Data on temperature, salinity and currents (speed and direction of water movement) are derived from the coupled Finite Element Sea Ice Ocean Model (FESOM; Timmermann et al. 2009). FESOM combines a hydrostatic, primitive-equation ocean model with a dynamic/ thermodynamic ice model. For the simulations analysed here, FESOM was initialised on February, 1st 1980 with hydrographic data from the Polar Science Center Hydrographic Climatology (Steele et al. 2001) and forced with atmospheric reanalysis data such as wind speed, temperature, humidity, and cloudiness.

3.1.4 Sea ice

Three large data sets on sea ice were acquired:

(1) Satellite observations of daily sea ice concentration derive from the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-EOS) instrument on board the Aqua satellite. High resolution AMSR-E 89 GHz sea ice concentration maps (Jun 2002 – Oct 2011) were downloaded from the Institute of Environmental Physics, University of Bremen (http://www.iup.uni-bremen.de/). The ARTIST Sea Ice (ASI) concentration algorithm was used with a spatial resolution of 6.25 km x 6.25 km (Kaleschke et al. 2001, Spreen et al. 2008). We restrained from using AMSR2 data (available since Aug 2012) on board the new \`Shizuku\` satellite as a thorough calibration of the AMSR2/ASI data has not been accomplished yet.

(2) Data on daily polynya distribution derive from the Special Sensor Microwave / Imager (SSM/I). The data were downloaded from the Integrated Climate Data Center (ICDC) of the University of Hamburg (http://icdc.zmaw.de/polynya_ ant.html; Kern et al. 2007, Kern 2012). Here, polynyas are defined as areas of open water and/or thin (< 20 cm) sea ice in regions of typically thick sea ice (> 20 cm). A basic algorithm, described by Markus & Burns (1995) and Hunewinkel et al. (1998), was used with a spatial resolution of 5 km x 5 km. Data on daily polynya distribution focus on coastal polynyas and temporally cover the austral winter (May - Sept) for a period from 1992 to 2008.

(3) Data on monthly sea ice thickness derive from the coupled Finite Element Sea Ice Ocean Model (FESOM; Timmermann et al. 2009). For analysis, we only used data on ice thickness from the 20 year time period (1990-2009) with a spatial resolution of 6.90 km x 8.65 km.

3.2 Ecological parameters

So far, more than 20 ecological data sets on zooplankton, zoobenthos, fish, birds and mammals were acquired (see Tab. 3-2). These data sets consist of point or areal data mainly, are snapshots in time and are stored in data portals, such as AntaBIF/biodiversity.aq (primarily contains presence/absence data) or PANGAEA.

3.2.1 Chl-a concentration

Chlorophyll-a (chl-a) concentration values were derived from the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) measurements. The data were downloaded via the NASA's OceanColor website (http://oceancolor.gsfc.nasa.gov/) as monthly level 3 standard mapped images with a spatial resolution of 9 km x 9 km.

3.2.2 Pelagic ecosystem

Many data sets on zooplankton, mainly data on krill, were acquired so far (see Tab. 2). Studies focusing on zooplankton communities, including meso-, macro-zooplankton and micro-nekton, were identified as potentially relevant data sources (e.g. Hunt et al. 2011, Flores et al. 2014) and were partly acquired so far (Boysen-Ennen & Piatkowski 1988, Siegel 2012 and unpublished data, unpublished data from Norway, contact: B. Krafft). These data sets are quite diverse taxonomically, and principal groups include salps, juvenile cephalopods or paralarvae, crustaceans (e.g. euphausiids, copepods) and fish (mainly mesopelagic species). Data on adult squid are extremely scarce particularly catch data refer to very few records (e.g. Nesis et al. 1998). Most data on the occurrence of squid are obtained from stomach analysis of birds and marine mammals (Piatkowski & Pütz 1994, Plötz et al. 1991). For additional data, that may be relevant and are in the progress of being analysed, please see the workshop report (WG-EMM-14/19, supplementary material).

Krill

The largest data set on adult Antarctic krill, *Euphausia superba*, consists of more than 700 stations sampled between 1928 and 2013 (see Tab. 2). Next to some snapshot studies from research operations in the 1970s and 1980s (Fevolden 1979; Makarov & Sysoeva 1985; Siegel 1982), most historical abundance data on krill (until 2004) are available in the data base krillbase (http://www.iced.ac.uk/science/krillbase.htm) and are published in e.g. Atkinson et al. (2004, 2008 and 2009) and Siegel (1982). More recent data on krill (2004 to 2008) are published in Siegel (2012) and are complemented by unpublished data from B. Krafft (Institute of Marine Research; Bergen, Norway). Haul-by-haul krill catch data from commercial operations are stored as a summary data base by CCAMLR. Moreover, we acquired data on ice krill, *Euphausia crystallorophias* (Siegel 1982 and 2012; Siegel et al. 2013).

Pelagic fish

Unpublished data are available on the distribution of oceanic pelagic fish (held by R. Knust, AWI). Data from long line fishery operations, mainly *Dissostichus* spp. catches, are stored as a summary data base by CCAMLR, and were already acquired. An additional data source, which was identified by the International Expert Workshop on the Weddell Sea MPA project (see WG-EMM-14/19, supplementary material), focuses on *Pleuragramma* from e.g. Hubold (1984, 1992) and Piatkowski (1987). Furthermore, potentially relevant data sources on mesopelagic fish are available e.g. from the LAzarev Sea KRIll Study (LAKRIS) project (e.g. Hunt et al. 2011, Flores et al. 2014).

3.2.3 Benthic ecosystem

Zoobenthos – Shelf and slope

Two substantial zoobenthic data sets are listed in Table 2. Gutt et al. (2013a) provide a comprehensive data set on the geographical distribution of Antarctic macrobenthic communities. This descriptive data set, consisting of approx. 90 individual data sets, has a temporal coverage from 1956 to 2010 and covers almost the entire Southern Ocean (Gutt et al. 2013a). Although the data show a considerable patchiness at regional scale, the south-eastern Weddell Sea is covered well, and thus the data set provides unique geo-referenced biological basic information. Furthermore, a large quantitative macrobenthos data (abundance, biomass) set exists at AWI. Macrobenthic samples were taken during 10 *Polarstern* cruises in the south-eastern and eastern Weddell Sea shelf area from 1984 to 2011 (e.g. Gerdes et al. 1992). In addition, there is a considerable number of data sets referring to specific taxonomic groups - particularly polychaetes (e.g. Montiel et al. 2005, Stiller 1995), molluscs (e.g. Hain 1990), and echinoderms (e.g. Piepenburg et al. 1997, Brey & Gutt 1991, Gutt 1991) - sampled along the Weddell Sea shelf. In total more than 10 such smaller data sets, partly stored in the ANTABIF data portal (primarily as presence data), and on macrofaunal communities (e.g. Galéron et al. 1992, Voß 1988) were checked (not listed in Tab. 2).

Zoobenthos – Deep Sea

There is a considerable number of data sets on abyssal benthic deep-sea fauna in the Weddell Sea. Most of these data sets are based on ANDEEP I-III (ANtarctic benthic DEEP-sea biodiversity: colonization history and recent community patterns) expeditions in 2002 and 2005 (Brandt & Hilbig 2004, Brandt & Ebbe 2007), and referring to specific taxonomic groups - particularly sponges (e.g. Janussen & Tendal 2007), polychaetes (e.g. Hilbig 2001, Schüller & Ebbe 2007, Schüller et al. 2009), molluscs (e.g. Linse et al. 2006, Schwabe et al. 2007), crustaceans (e.g. Brandt et al. 2007c, De Broyer et al. 2006) and echinoderms (e.g. Bohn 2006). The data were partly acquired so far, but were not listed in Table 2.

Demersal fish

During various *Polarstern* cruises between 1983 and 2011 the demersal fish fauna was sampled particularly along the Weddell Sea shelf, but also in deeper waters (see Drescher et al. 2012, Ekau et al. 2012 a, b, Hureau et al. 2012, Kock et al. 2012, Wöhrmann et al. 2012 and unpublished data held by R. Knust, AWI; Tab. 2). Data on spawning grounds would be useful for the MPA Weddell Sea evaluation, and the International Expert Workshop noted that there is information for some specific spawning areas (approx. 1400 m - 1600 m). For more details see WG-EMM-14/19 (paragraph 8.1., Report of the International Expert Workshop). The data were not acquired so far.

3.2.4 Birds

Seabirds

A few data sets exist on flying seabirds (i.e. petrels or Procellariiformes), their distribution and abundance patterns in the Weddell Sea. Two substantial seabird data sources derive from van Franeker et al. (1999) and Croxall et al. (1995) (see Tab. 2). The comprehensive databases give relevant information about Antarctic Petrel and Snow Petrel breeding colonies from Coats Land, Dronning Maud Land and the Antarctic Peninsula between 1905 and the early 90s. Those data were complemented by published data on flying seabirds with substantial breeding populations near the Weddell Sea MPA Planning Area, such as the Southern Fulmar (Creuwels et al. 2007) and the Southern Giant Petrel (Patterson et al. 2008).

Penguins

Data on emperor penguin population estimates were derived from Fretwell et al. (2012, 2014). This data set was complemented by unpublished data on Adélie penguin colonies from Heather Lynch, Stony Brook University, USA. Further data on Adélie penguin post-breeding habitat use may be obtained from Argentina, UK and USA.

3.2.5 Marine Mammals

Pinnipeds

A pinniped survey within the Antarctic Pack Ice Seals (APIS) programme, which was developed and executed by members of the Scientific Committee on Antarctic Research (SCAR) Group of Specialists on Seals and their national programmes, was carried out along the eastern coast of the Weddell Sea from 1996 to 2001 (Ackley et al. 2006; Plötz et al. 2011a-e; Southwell et al. 2012). During five fixed-wing aircraft flight campaigns, which covered an area of more than 80,000 km of aerial transects, approx. 2,300 seals were counted in total. An additional APIS survey, based on helicopter flights from aboard RV *Polarstern* in 1998 - a year with unusually low sea ice coverage - covered the area from 7°W to 45°W with 15 transects (Bester & Odendaal 2000). Moreover, pack-ice seal line-transect data were collected during an aerial survey, conducted as the UK contribution to the APIS programme, in the western part of the Weddell Sea (Forcada & Trathan 2008; Forcada et al. 2012). A methodologically congruent "pre-APIS"-helicopter survey was carried out more easterly in the Weddell Sea (0° - 5° W) by Bester et al. (1995). Post-APIS-helicopter surveys from aboard RV *Polarstern* were flown in 2004 / 2005 (ANT-XXII/2), and were concentrated north of 69°S (Flores et al. 2008). Most recent photographic and video footage were taken during the research survey of the AWI aircraft *Polar 6* in November 2013, and additional species specific helicopter based counts were carried during RV *Polarstern*'s ANT-XXIX/9 2013/2014 research mission, both in the southern Weddell Sea. The most recent data are currently in analyses. Acoustic data, i.e. year-round records of the presence of pinnipeds since 2005, derive from the coastal Perennial Acoustic Observatory in the Antarctic Ocean (PALAOA) near Neumayer Station, and additionally from several oceanographic moorings distributed along the Greenwich meridian and throughout the Weddell Sea (Van Opzeeland 2010). However, the International Expert Workshop noted that there is limited information available particularly on elephant seal abundance and migration patterns (more details see WG-EMM-14/19, supplementary material, paragraph 8.). Few tracking data sets are available on southern elephant seals (Tosh et al. 2009; James et al. 2012), Ross seals (Blix & Nordøy 2007), leopard seals (Nordøy & Blix 2009), and Weddell seals (McIntyre et al. 2013).

Whales

The presence of cetaceans is also recorded year-round since 2005 by PALAOA, and additionally by several oceanographic moorings distributed along the Greenwich meridian and throughout the Weddell Sea (Van Opzeeland 2010). Regarding cetacean sightings, two data sets were evaluated so far. Since 2005, the AWI systematically and continuously logs all sightings of cetaceans near RV *Polarstern* in the Southern Ocean (Marine Mammal Perimeter Surveillance, MAPS). By means of the MAPS project more than 1300 individuals from nine cetacean taxa were identified in the Weddell Sea from 2005 to date (Burkhardt 2009a-i, 2011, 2012). Those data were used to build a habitat suitability model of humpback and Antarctic minke whales in the Southern Ocean (see Bombosch et al. 2014). The International Whaling Commission (IWC) sightings dataset may provide some additonal data. Furthermore, quantitative cetacean sightings, surveyed during five *Polarstern* cruises from 2006 to 2013, may serve as a basis for estimating Weddell Sea cetacean densities (Herr et al. 2014 and unpublished data held by H. Feindt-Herr, Institute for Terrestrial and Aquatic Wildlife Research, Hannover).

Table 3-1: List of environmental data sets for marine protected area evaluation in the Weddell Sea. Complete data sets or parts of it which were sighted, but were not incorporated into further analyses so far are grey-shaded.

	Spatial and temporal resolution			
Parameter	**Spatial resolution**	**Period**	**Temporal resolution**	**Source (contact person, publication, web site)**
Bathymetry				
Bathymetry (m)	500 x 500 m	not applicable	not applicable	Arndt et al. (2013); www.ibcso.org
Sedimentology				
Grain size, i.e. gravel, sand, silt, clay (%)	> 400 samples were taken with large box corer, multi- or mini-corer	1983 - 1997	depending on local sedimentation rates: 1-1000 years	Petschick et al. (1996) http://doi.pangaea.de/10.1594/PANGAEA.55955 Diekmann & Kuhn (1999) http://doi.pangaea.de/10.1594/PANGAEA.730459 G. Kuhn & K. Jerosch, AWI (compiled data set)
Water column properties				
Sea temperature (°C), salinity (PSU), currents, i.e. speed (m) and direction of water movement (°) Model data (FESOM)	1.5° x 1.5° (horizontal) Surface & bottom value (vert.) Coastal polynia model 3 km – 50 km (horizontal)	1990 - 2009	Monthly	Timmermann et al. (2009) Haid and Timmermann (2013)
BRIOS model data	1° x 1° (horizontal) 24 levels (vert.)	n/a		Beckmann et al. (1999), Timmermann et al. (2002)
Sea surface temperature (°C)	1/8° x 1/8° (MODAS) 1/12° x 1/12° (HYCOM)	1993 - ongoing	daily	Barron & Kara (2006) MODAS: http://www7320.nrlssc.navy.mil/modas/ HYCOM: http://www7320.nrlssc.navy.mil/GLBhycom1-12/skill.html
Sea surface height (cm)	1/3° x 1/3°	1992 - ongoing	daily	Archiving, Validation & Interpretation of Satellite Oceanographic data (Aviso) http://www.aviso.oceanobs.com/en/
Sea temperature (°C), Salinity (PSS), Dissolved oxygen (ml l^{-1}), inorganic nutrients (µM)	1° x 1°	1955 - 2006	Monthly, seasonal, annual	Locarnini et al. (2010), Antonov et al. (2010), Garcia et al. (2010a,b), http://www.nodc.noaa.gov/OC5/WOA09/pr_woa09.html

Table 3-1 (contd.)

	Spatial and temporal resolution			
Parameter	**Spatial resolution**	**Period**	**Temporal resolution**	**Source (contact person, publication, web site)**
Sea ice dynamic				
Sea ice concentration (%)	6.25 km x 6.25 km	Jun 2002 - Oct 2011; Aug 2012 - ongoing	daily	Kaleschke et al. (2001), Spreen et al. (2008) Institute of Environmental Physics, University of Bremen: http://www.iup.uni-bremen.de/seaice/amsr/ Integrated Climate Data Center (ICDC), University of Hamburg: http://www.icdc.zmaw.de/seaiceconcentration_asi_amsre.html
Sea ice thickness (cm)	5 km x 5 km	1992 - 2008	Daily (May-Sept)	Markus & Burns (1995), Hunewinkel et al. (1998), Kern et al. (2007), Kern (2012) Integrated Climate Data Center (ICDC), University of Hamburg: http://icdc.zmaw.de/polynya_ant.html
Sea ice thickness (cm) Model data (FESOM)	1.5° x 1.5° (horizontal) Coastal polynia model 3 km – 50 km (horizontal)	1990 - 2009	Monthly	Timmermann et al. (2009) Haid and Timmermann (2013)
Frontal areas				
Weddell system	8 repeat hydrographic sections, moored instruments and profiling floats on 0°	1984 - 2008	Different time intervals	Fahrbach et al. (1995, 2004, 2007, 2011) Data are available at e.g. http://www.pangaea.de/
Weddell Gyre	206 ice-compatible vertically profiling floats	1999 - 2010	Snapshot in time	Klatt et al. (2007)

Table 3-2: List of ecological data sets for marine protected area evaluation in the Weddell Sea. Complete data sets or parts of it which were sighted, but were not incorporated into further analyses so far are grey-shaded.

	Sampling design and temporal resolution			
Parameter	**Sampling design**	**Period**	**Temporal resolution**	**Source (contact person, publication, web site)**
Chlorophyll-a				
Chlorophyll-a concentration (mg/m³)	0.83 km x 0.83 km	1997 - 2010	daily	National Aeronautics and Space Administration (NASA) Goddard Space Flight Center's Ocean Data Processing System (ODPS) http://oceandata.sci.gsfc.nasa.gov/SeaWiFS/L3SMI/
Zooplankton				
Abundance data on adult Antarctic krill, *Euphausia superba* (N/m²; N/1000 m³)	> 700 stations; e.g. IKMT, RMT nets	1928 - 1997 1977 - 1983 2001 - 2013	Different time intervals	Krillbase: http://www.iced.ac.uk/science/krillbase.htm Atkinson et al. (2004, 2008, 2009); Siegel (1982) Fevolden (1979), Makarov & Sysoeva (1985); Siegel (1982, unpublished data) Siegel (2012, unpublished data), Siegel et al. (2013)
Abundance data on adult Antarctic krill, *Euphausia superba* (N/m²)	21 stations; macroplankton trawl	2008	Snapshot in time	Unpublished data (contact: Bjoern Krafft, Institute of Marine Research, Bergen)
Abundance data on adult ice krill, *Euphausia crystallorophias* (N/1000 m³)	> 400 stations; RMT nets	1976 - 1989 2004 - 2013	Different time intervals	Siegel (1982, unpublished data) Siegel (2012), Siegel et al. (2013)
Abundance data on Antarctic krill larvae and ice krill larvae (N/m²)	> 300 stations; e.g. Juday, RMT1, Bongo nets	1977 - 1989 2004, 2006	Different time intervals	Fevolden (1979, 1980), Hempel & Hempel (1982), Menshenina (1992), Siegel (2005, unpublished data) Siegel (2012)
Krill data from commercial operations (catch in kg)	Bottom and midwater trawls	1974 - 2009	Different time intervals	David Ramm, CCAMLR data manager; www.ccamlr.org
Abundance data on meso- and macrozooplankton (N/1000m³)	39 stations; RMT1, RMT8	1983	Snapshot in time	Boysen-Ennen & Piatkowski (1988)
Abundance data on macrozooplankton and micro-nekton (N/1000m³)	RMT, SUIT nets along 3-4 transects; station spacing 20-30 nm, approx. 50-80 stations per expedition	2004 - 2008	Different time intervals	Hunt et al. (2011), Flores et al. (2014)

Table 3-2 (contd.)

	Sampling design and temporal resolution			
Parameter	**Sampling design**	**Period**	**Temporal resolution**	**Source (contact person, publication, web site)**
Zoobenthos				
Macrobenthic communities (descriptive)	± 90 data sets, Weddell Sea shelf	1956 - 2010	Summary data set, Snapshots in time	Gutt et al. (2013a) and references therein in regards to results and data http://ipt.biodiversity.aq/resource.do?r=macrobenthos
Macrozoobenthos (N/m², g C/m²)	Various German Antarctic expeditions; almost 300 samples	1984 - 2011	Different time intervals	Data originators: Dieter Gerdes (AWI); Ute Mühlenhardt-Siegel (vTI); e.g. Gerdes et al. (1992)
Considerable number on specific higher taxonomic groups (primarily abundance data)	Several *Polarstern* cruises; mainly sampled along the Weddell Sea shelf, but also in deeper waters	1983 - 2005	Snapshots in time	Polychaetes (e.g. Montiel et al. 2005, Schüller & Ebbe 2007, Stiller 1995), molluscs (e.g. Hain 1990), crustaceans (e.g. Brandt et al. 2007), echinoderms (e.g. Piepenburg et al. 1997, Brey & Gutt 1991, Gutt 1991)
Fish				
Mostly abundance and biomass data on demersal fish, but also pelagic fish	> 10 Polarstern cruises, > 300 hauls, mostly Weddell Sea shelf, but also deeper waters	1983 - 2011	Different time intervals	Contact: Julian Gutt (AWI), Rainer Knust (AWI), Karl-Hermann Kock (vTI) Drescher et al. (2012), Ekau et al. (2012 a, b), Hureau et al. (2012), Kock et al. (2012), Wöhrmann et al. (2012) and unpublished data held by R. Knust, AWI doi:10.1594/PANGAEA.786877, doi:10.1594/PANGAEA.786883, doi:10.1594/PANGAEA.786884, doi:10.1594/PANGAEA.786886, doi:10.1594/PANGAEA.786888, doi:10.1594/PANGAEA.786887 Regarding data on *Pleuragramma*: e.g. Hubold (1984, 1992), Piatkowski (1987)
Fishery operations (catch in kg); mainly *Dissostichus* spp. catches	Longline surveys	2005 - 2013	Summary data base (annual and bi-annual)	David Ramm, CCAMLR data manager; www.ccamlr.org
Birds				
Antarctic Petrel breeding localities	± 20 breeding localities, Coats Land and Dronning Maud Land	1971-1994	Summary data set, Snapshots in time	Van Franeker et al. (1999)
Snow Petrel breeding localities	± 60 breeding localities, Coats Land, Dronning Maud Land, Antarctic Peninsula	1905-1992	Summary data set, Snapshots in time	Croxall et al. (1995)
Adélie penguin breeding colonies	high resolution (0.6 m) satellite imagery with spectral analysis, Antarctic Peninsula	2000s	Snapshot in time	H. Lynch, Stony Brook University, USA (unpublished data)
Emperor penguin breeding colonies	High resolution satellite imagery	2009 (Sept-Dec); 2012	Snapshot in time	Fretwell et al. (2012, 2014)

Table 3-2 (contd.)

	Sampling design and temporal resolution			
Parameter	**Sampling design**	**Period**	**Temporal resolution**	**Source (contact person, publication, web site)**
Mammals				
Pinniped line-transect data (N/Km²)	flight campaigns	1992 - 2014	Different time intervals	Bester et al. (1995), Bester & Odendaal (2000), Ackley et al. (2006), Flores et al. (2008), Forcada & Trathan (2008), Plötz et al. (2011 a-e; http://www.pangaea.de), Forcada et al. (2012), Southwell et al. (2012), and unpublished data held by H. Bornemann, AWI
Tracking data on pinnipeds	Tagging of up to 15 individuals of southern elephant seals, Ross seals, leopard seals and Weddell seals, respectively	1999-2008	Snapshots in time, different tracking times	Blix & Nordøy 2007; Nordøy & Blix 2009; Tosh et al. 2009, doi:10.1594/PANGAEA.692856; James et al. 2012, doi:10.1594/PANGAEA.785852; McIntyre et al. 2013
Acoustic data on pinniped and cetacean presence	oceanographic moorings	2006-2012	Daily, different starting times for single recorders	Kindermann (2013), doi:10.1594/PANGAEA.773610 Van Opzeeland (2010)
Opportunistic cetacean sightings	15 *Polarstern* cruises	2005 - ongoing	Snapshot in time	Burkhardt (2009 a-i, 2011, 2012 and unpublished data); Bombosch et al. (2014); http://www.pangaea.de/search?count=10&minlat=&minlon=&maxlat=&maxlon=&mindate=&maxdate=&env=All&q=elke+burkhardt+
Quantitative cetacean sightings (N/km²)	5 *Polarstern* cruises	2006 - 2013	Time interval: 1-2 years	Helena Feindt-Herr, Institute for Terrrestrial and Aquatic Widlife Research, University of Veterinary Medicine Hannover

4. Description of the Weddell Sea ecosystem

This chapter intends to present to the Scientific Committee a short general description of the respective environmental or ecological parameters in the Weddell Sea MPA Planning Area to reflect the state of the science. We could win scientific experts of international renown in the respective field for describing the *state of the science* in the following chapters of this compilation.

Furthermore, we would also like to inform the Scientific Committee on the preliminary scientific analysis that were carried out so far within the framework of the MPA Weddell Sea project and were mostly presented and discussed at the International Expert Workshop on the Weddell Sea MPA project (7-9 April; Bremerhaven, Germany) and at the previous meeting of WG-EMM (7-18 July; Punta Arenas, Chile).

For all environmental and ecological data layers WGS 84 / NSIDC Sea Ice Polar Stereographic South (EPSG-Code: 3967; http://nsidc.org/data/atlas/epsg_3976.html) are used. Where data layers included missing data, "empty" pixels were flagged in using the abbreviation NA (not available) and were not used for the subsequent calculations. Data processing, such as transformation of data formats, statistical analysis and figure compilation was mainly performed using the R software (version 3.0.2; R Core Team 2013) and the ESRI`s GIS desktop software suite (ESRI 2011).

4.1 Environmental parameters

The Weddell Sea planning region covers an area of approximately 4.2 million km², which is slightly larger than double the size of Mexico. For details of the boundaries of the Weddell Sea MPA Planning Area see chapter 2.

Water depths in the Weddell Sea MPA Planning Area range from about 100 m at the edge of the ice shelf to about 5300 m in the Weddell Sea abyssal plain (see Fig. 4-1). Prominent bathymetric features of the Weddell Sea MPA 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, Fahrbach 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. 4-6).

Probably the most pronounced feature of the Weddell Sea is the sea ice and its extreme seasonal variability (see Fig. 4-7). 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).

4.1.1 Bathymetry & Geomorphology

State of the science

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Water depths in the Weddell Sea range from about 100 m at the edge of the ice shelf to 800 - 4000 m on the continental shelf and slope and to about 5300 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 that extends up to 500 km from the coast and is cut through by the deeper Filchner Trough (IBCSO, Arndt et al. 2013; see Fig. 4-1). 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 Eas Antarctic Ice Sheets.

The abyssal plain of the Weddell Sea up to 5300 m depth 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).

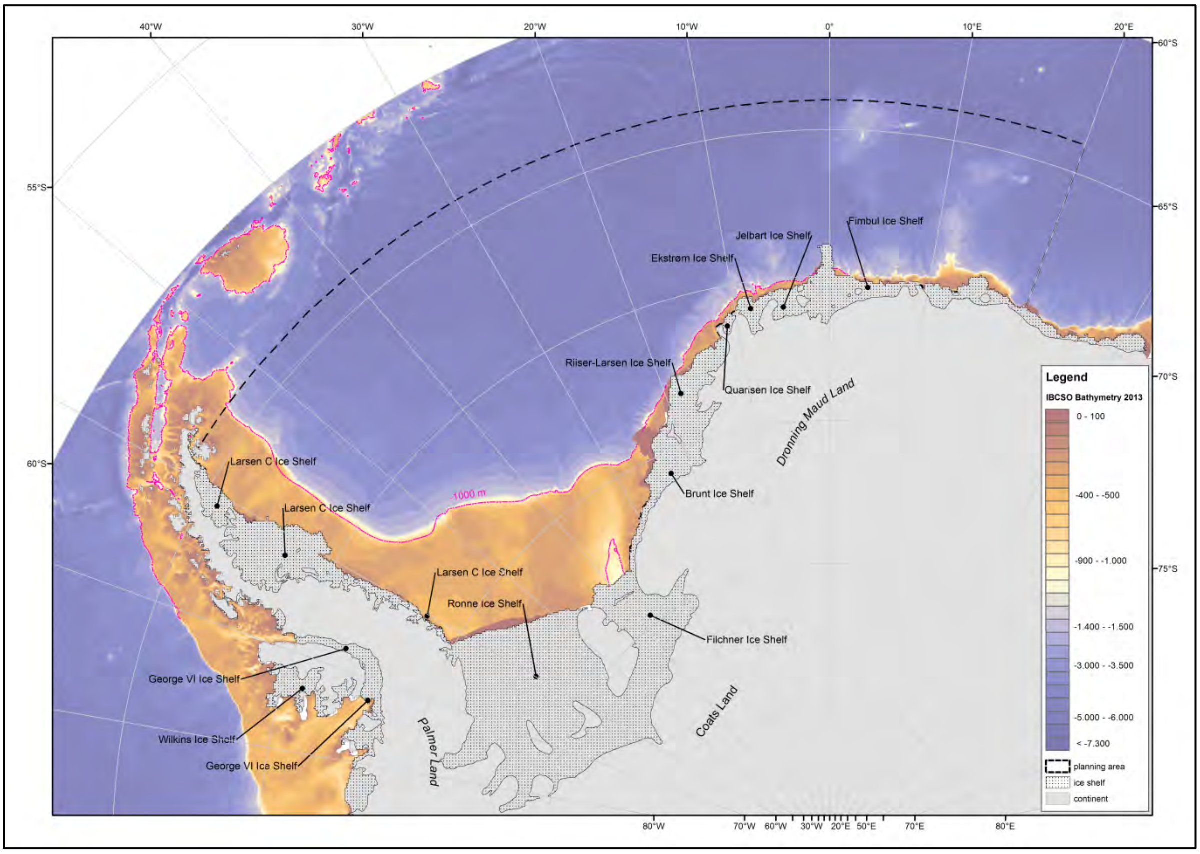

Figure 4-1 Bathymetry (in m) in the proposed planning area for the evaluation of a Weddell Sea MPA (black dashed box). Please note that the boundaries of the proposed planning area do not resemble the boundaries of any proposed Weddell Sea MPA. The bathymetric chart of the Southern Ocean (IBCSO) is published by Arndt et al. (2013). The ice shelves are labelled and shown in grey. Black 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.

Preliminary scientific analysis - Benthic regionalisation

Based on the digital bathymetric model, i.e. on the depth or bathymetric raster (Arndt et al. 2013), (i) the slope, or the measure of steepness, (ii) the hillshade, (iii) the aspect, (iv) the terrain ruggedness, the variation on three-dimensional orientation of grid cells within a neighbourhood, and (v) the bathymetric position index (BPI) at broad and fine scale were calculated. The slope values (degree units) describe the gradient or the maximum change from each cell to its neighbour cell. The BPI compares the elevation of each cell to the mean elevation of the neighbourhood cells, and thus is a measure of relative elevation in the overall "seascape". The broad and fine scale BPI were standardised to avoid spatial auto-correlation.

To define a classification scheme in terms of the bathymetric derivatives the BTM requires a classification table. A modified version of the classification table of Erdey-Heydorn (2008) and Wienberg et al. (2013) appeared to be most appropriate, by using a fine scale radius of 0 - 5 km and a broad scale radius of 0 - 125 km (Jerosch et al. in prep. a). The continental shelf break was defined as the 1000 m isobath. This was the best suited definition to distinguish between continental shelf to slope and deep sea regions although the slope in some areas starts at a slightly shallower depth. According to natural breaks in the data set, the slope was divided into three classes of different slope angles (in °) for the continental slope and abyssal plain areas (<0.4°, 0.4-1.2°, >1.2°) and the shelf areas (<0.15°, 0.15-1.2°, >1.2°). The spatial resolution of the bathymetric derivatives corresponds to the bathymetric data resolution.

The following data layers were generated:

(1) Depth (IBCSO 2013)
(2) Hillshade (ArcGIS 10.2.2, Spatial Analyst tools)
(3) Aspect (ArcGIS 10.2.2, Spatial Analyst tools)
(4) Slope (ArcGIS 10.2.2, Spatial Analyst tools)
(5) Ruggedness (ArcGIS 10.2.2, DEM surface tools)
(6) Broad scale bathymetric position index
(7) Fine scale bathymetric position index

The BPI at broad and fine scale was calculated with the Benthic Terrain Modeler (BTM) Version 3.0 extension for ArcGIS™ (Wright et al. 2005).

(8) Geomorphology derived from data layer (1), (4) and (6)-(7) is shown in Fig. 4-2.

Seventeen geomorphic classes are recognized at the sea floor of the Weddell Sea MPA Planning Area highlighting the diversity of 'landscape' on this glacially carved shelf (see Fig. 4-2) (Jerosch et al. in prep. a).

The continental shelf is composed of two cross shelf valleys mapped as lower slopes and depressions (Filchner Trough in the East and the low-gradient Ronne Basin in the West), plain areas (Berkner Bank (approx. 160 km wide) and General Belgrano Bank (approx. 120 km wide and open to the Eastern plain areas) with lower slopes in between (Fig. 4-2, Jerosch et al. in prep. a).

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. 4-2). 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. in prep. a).

The abyssal plain 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.

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 summary, this benthic regionalisation approach, using the 17 geomorphic features to describe the structures at the sea bottom (see Fig. 4-2), confirms in general the geomorphology of the Weddell Sea described by O`Brien at al. (2009; WS-VME-09/10). and published by Post (2012). During former glaciations Antarcitca'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 (MSGLs) or grounding zone wedges (GZWs) on the shelf (Larter et al. 2012). Ice bergs since the last ice sheet retread continously scour the mostly shallower outer parts of the shelf that is structured in gullies and shows structures of submarine landslides (Gales et al. 2014). Channel - levee structures are found at the continental slope reaching out to the Weddell Sea abyssal plain (Kuhn & Weber 1993, Michels et al. 2001, 2002).

A more detailed mapping of the geomorphic features was possible by applying the BPI approach to the new IBCSO data (Arndt et al. 2013). Comparable small features (troughs and ridges) are identified pointing out a very diverse environment helping to understand a very wide range of processes: deposition of reworked sediment, deformation and melt-out, subaqueous mass-movements, fluvial processes, and settling through the water column.

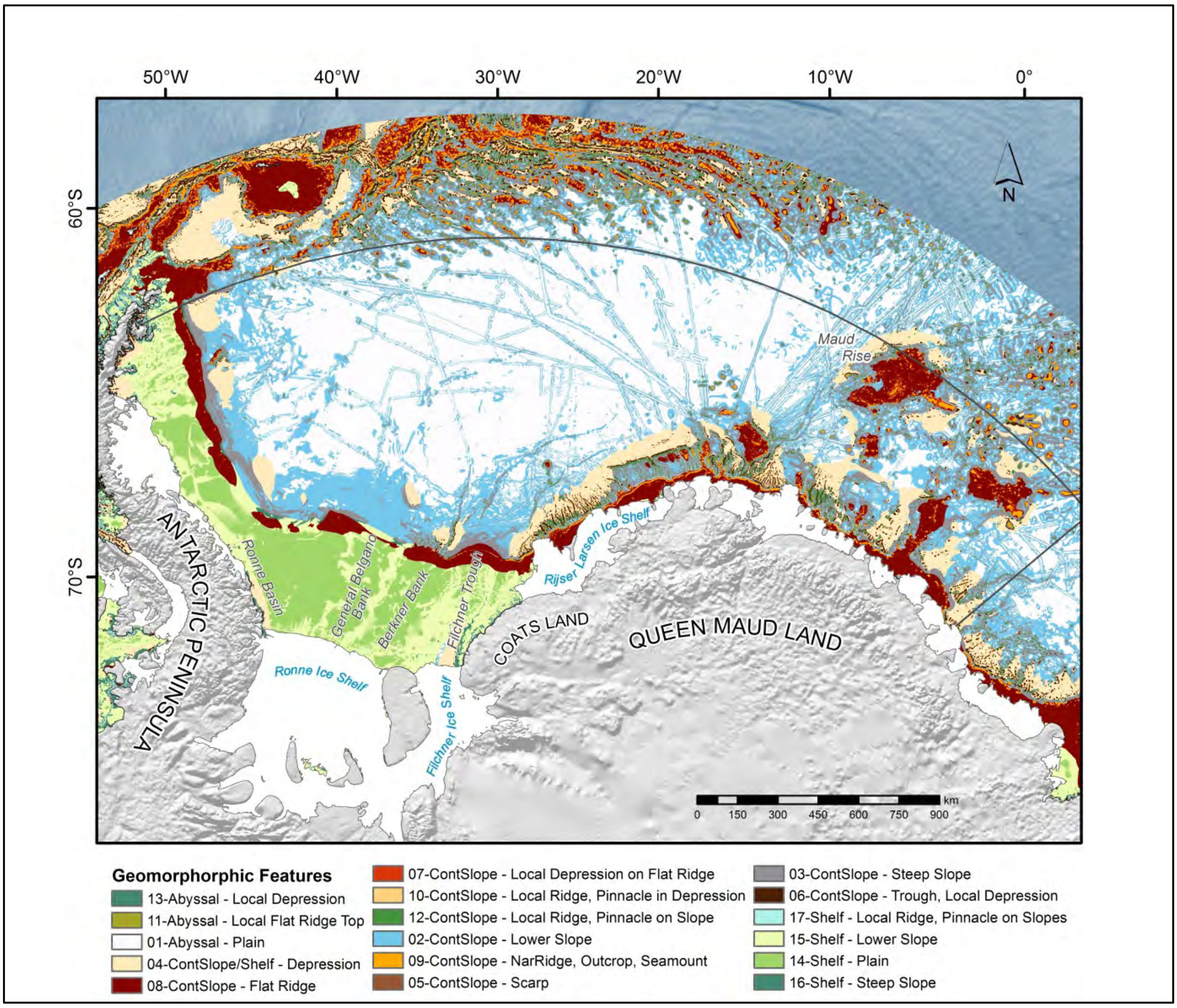

Figure 4-2 Geomorphology of the Weddell Sea which derived from bathymetry (IBCSO; Arndt et al. 2013) and its bathymetric derivatives, i.e. slope and bathymetric position index (Jerosch et al. in prep. a). Black box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

4.1.2 Sedimentology

State of the science and preliminary scientific analysis

Kerstin Jerosch[1] and Gerhard Kuhn[1]

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In total more than 400 grain size samples were standardised from absolute content values of gravel, sand, silt and clay to percentages. The data density of the grain size data restricted the ground truthing to six parcelled-out areas (see Fig. 4-3): (1) South Orkney Plateau, (2) Central Weddell Sea, (3) Ronne Basin, (4) Filchner Trough, (5) Explora Escarpment, (6) Lazarev Sea, according to IBCSO (Arndt et al. 2013).

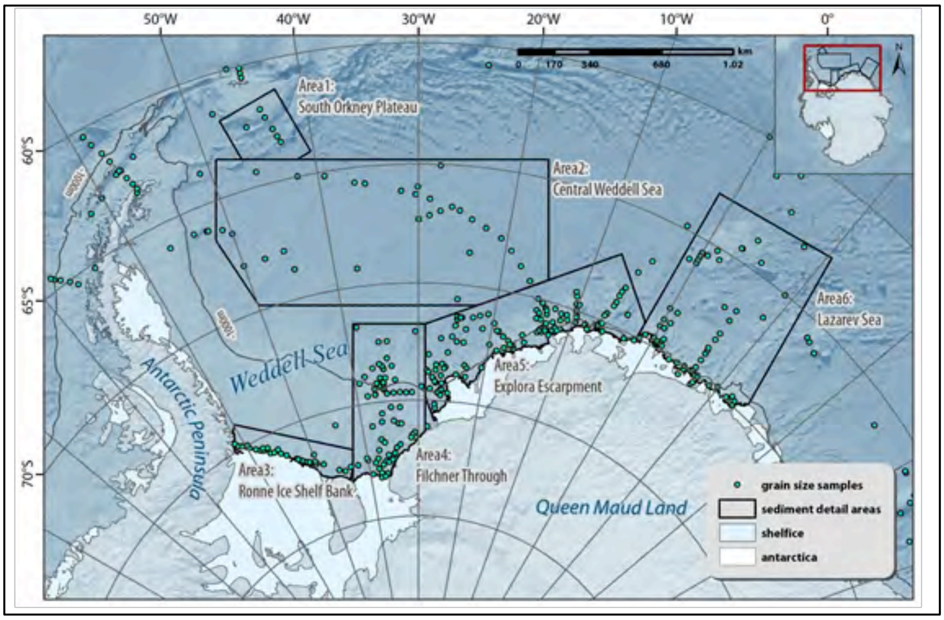

Figure 4-3 Data density of the grain size data restricted the ground truthing to six parcelled-out areas: (1) South Orkney Plateau, (2) Central Weddell Sea, (3) Ronne Basin, (4) Filchner Trough, (5) Explora Escarpment, (6) Lazarev Sea according to IBCSO (Arndt et al. 2013). Sediment grain size data are shown as green dots. Data were downloaded from PANGAEA and are published in Petschick et al. (1996) and Diekmann and Kuhn (1999), and were completed by unpublished data held by G. Kuhn, AWI.

Primarily, the potential link between geomorphology and sediment distributions was approved, since e.g. steep slopes do not provide the environment for accumulation. Furthermore, the shelf is a region influenced by ice keel scouring and strong currents with geological evidence for erosion of the sea floor. In contrast, the abyssal plain with its lower slope supplies areas of depositional sediment accumulation. For the analysis of this correlation, the mean grain size of all samples falling into one geomorphic feature was calculated and assigned to a sediment texture class according to Folk (1954). Note that not all geomorphic features were covered with samples significantly also due to their differences in area size and number of samples (Jerosch et al. in prep. a). However, the analysis shows the relation between grain size distributions and geomorphic features, although the values display high standard deviations (see Table 4-1). Exemplarily, the Maude Rise area (Area 6, Lazarev Sea) shows evidently that coarser grain sizes appear on more exposed geomorphic features like flat ridges (ID 08) and narrow ridges, outcrops and seamounts (ID 09) (see Fig. 4-4).

Table 4-1: Grain size distribution (mean in %) and standard deviation (σ) per geomorphic feature.

ID	Geomorphic feature	gravel		sand		silt		clay		Folk class (1954)
		mean	*σ*	*mean*	*σ*	*mean*	*σ*	*mean*	*σ*	
Abyssal										
1	Plain	5.59	17.43	7.60	22.13	37.59	28.64	49.22	31.80	gravelly mud
Continental Slope										
2	Lower Slope	3.95	12.62	10.48	32.14	42.57	24.87	43.00	30.36	slightly gravelly mud
3	Steep Slope	8.05	13.89	33.81	35.00	34.01	27.42	24.12	23.69	gravelly mud
4	Depression	6.32	16.49	16.35	34.65	41.59	24.12	35.75	24.73	gravelly mud

5	Scarp	3.56	9.94	51.84	40.91	29.61	26.92	14.99	22.23	slightly gravelly muddy sand
6	Trough, Local Depression	3.98	9.68	20.58	41.00	45.69	29.23	29.76	20.09	slightly gravelly sandy mud
7	Local Depression on Flat Ridge	4.33	17.45	51.20	37.78	30.17	27.03	14.30	17.74	slightly gravelly muddy sand
8	Flat Ridge	6.44	13.90	56.48	39.64	24.08	23.49	13.00	22.96	gravelly muddy sand
9	Narrow Ridge, Rock Outcrop, Seamount	10.51	16.42	57.41	38.77	21.10	24.87	10.98	19.94	gravelly muddy sand
10	Local Ridge, Pinnacle in Depression	2.30	2.69	34.68	47.12	32.15	23.72	30.87	26.47	slightly gravelly sandy mud
12	Local Ridge, Pinnacle on Slope	7.42	14.84	27.86	37.37	35.81	19.52	28.91	28.27	gravelly mud
Continental Shelf										
14	Plain	0.50	1.67	47.61	40.02	17.88	18.92	34.01	39.39	slightly gravelly sandy mud
15	Lower Slope	3.26	9.79	51.81	36.08	16.10	14.72	28.83	39.42	slightly gravelly muddy sand
16	Steep Slope	0.65	2.32	56.80	59.10	30.47	36.25	12.09	2.33	slightly gravelly muddy sand
17	Local Ridge, Pinnacle on Slopes	7.00	47.16	41.58	2.84	33.09	41.02	18.33	8.98	gravelly mud

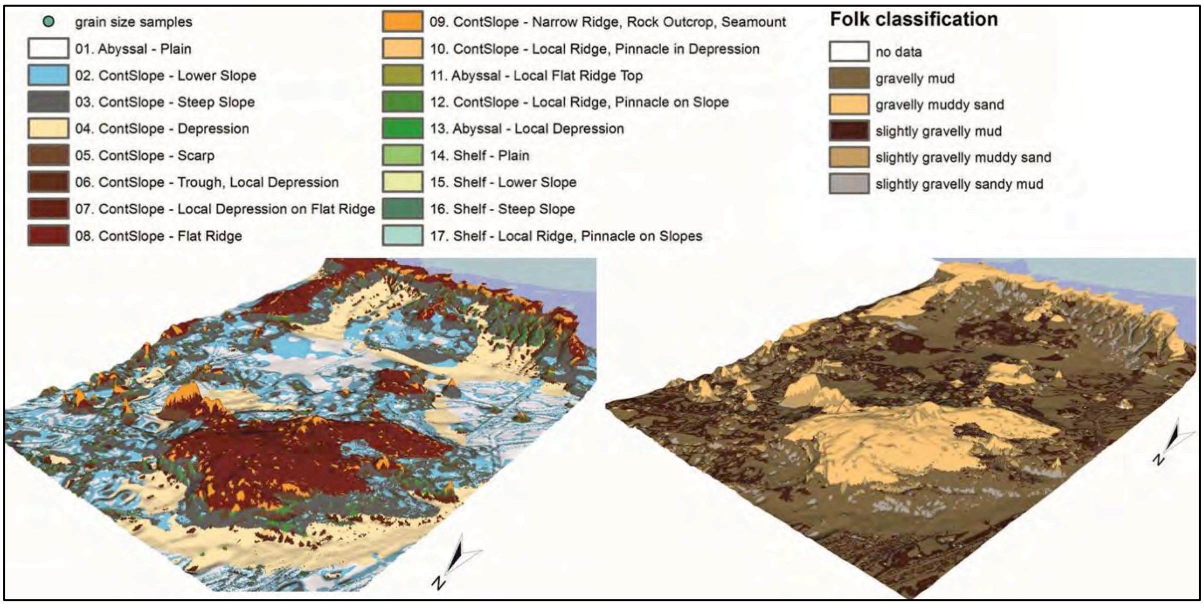

Figure 4-4 Display of the Folk (1954) classified mean grain sizes adapted to the geomorphic features of Maud Rise area.

The second approach in mapping the sediment texture was based on the geostatistical analysis of the sediment samples in areas of satisfying sampling densities, i.e. areas 4, 5 and 6 (see Fig. 4-3) (Jerosch et al. in prep. b). Sediment texture maps were interpolated from the grain size data relying on other variables more densely available: bathymetry, geomorphology, distance to shelf ice and speed. Three different interpolation methods were applied in ArcGIS™ geo-statistical analyst extension and were evaluated: Ordinary Kriging, collocated Cokriging and Empirical Bayesian Kriging. The statistical mean values of the errors, such as mean, mean standardized, average standard error, of the three different interpolation methods have been calculated and analysed extensively for each area and each sediment grain size class (i.e. clay, silt, mud, sand and gravel). The results were consolidated and compared in a table of 45 best-fit-analyses. The collocated Cokriging was mainly adapted to small grain sizes such as clay and silt, while Ordinary Kriging and Empirical Bayesian Kriging were best suited for coarser grain sizes (i.e. sand, gravel). According to Jerosch (2013) the single grain size grids where combined to sediment texture maps applying different sediment texture classification schemes published by Folk (1954), Shepard (1954) and Flemming (2000) (see Fig. 4-5).

In general, the resulting maps show (slightly) gravelly muddy sands 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. Please note that areas potentially characterised by hard substrate are not represented, they only can be indicted by high slope values resulting in geomorphic features.

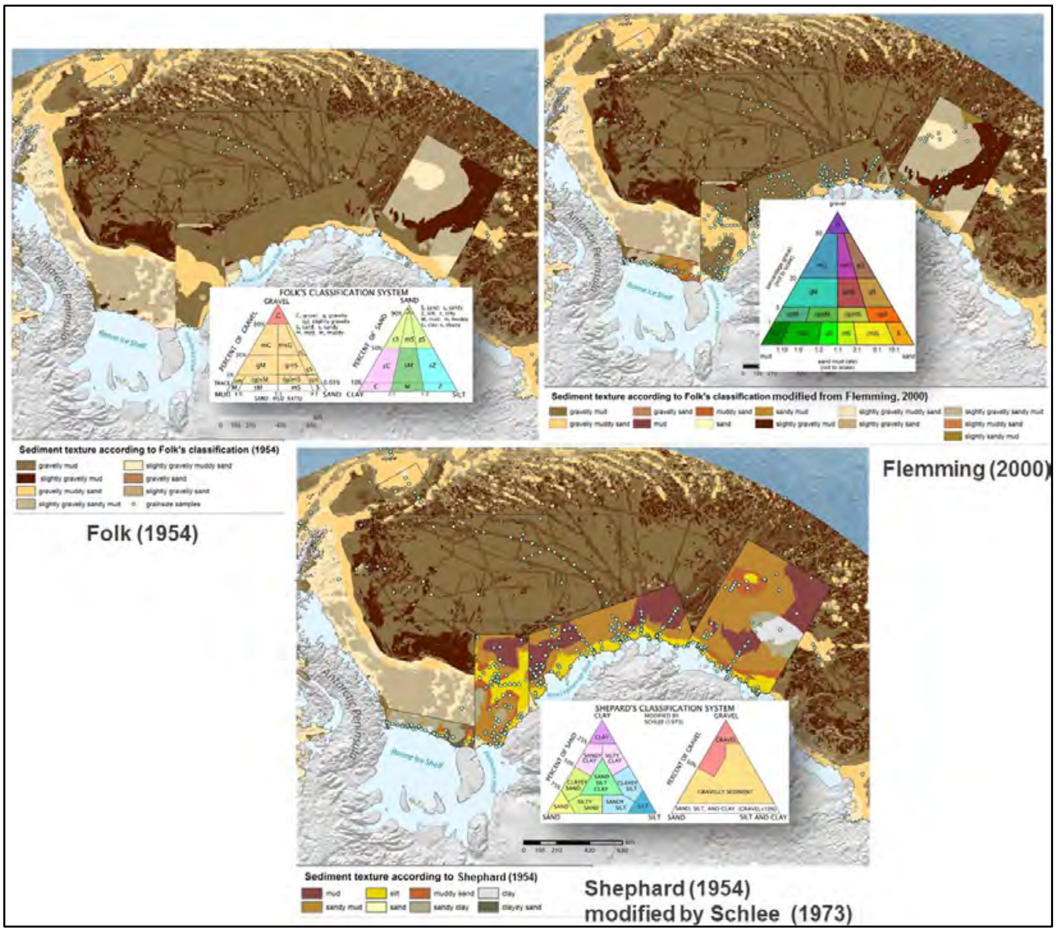

Figure 4-5 Application of sediment classification schemes according to Folk`s (1954), Flemming`s (2000) and Shepard`s classification (1954) to the interpolated grain size maps. Interpolation methods were successfully applied for area 4, 5 and 6 due to data density (Jerosch et al. in prep. b).

4.1.3 Oceanography

State of the science

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The circulation in the Weddell Sea is dominated by the cyclonic (clockwise rotating) Weddell gyre (Fig. 4-6) 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 (~ –1.9 °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.

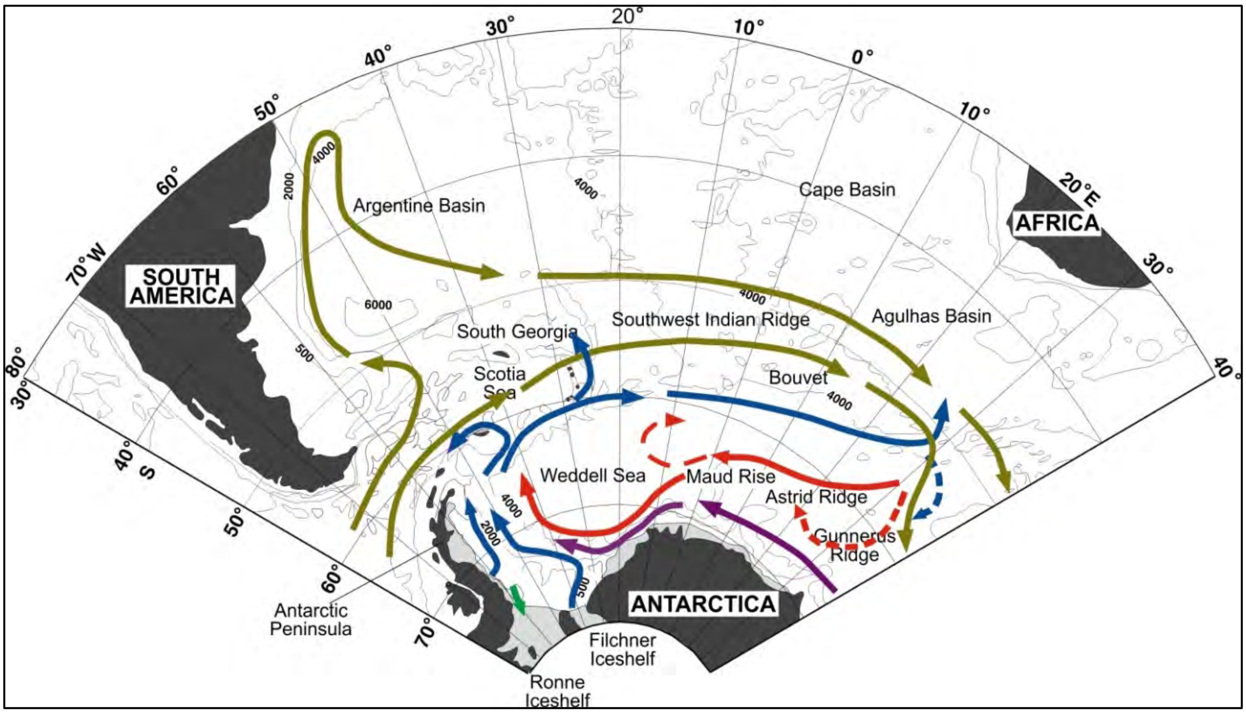

Figure 4-6 Schematic circulation of different water masses in the Atlantic sector of the Southern Ocean: Circumpolar Deep Water (olive), Warm Deep Water (red), Weddell Sea Deep/Bottom Water (blue), and High Salinity Shelf Water (green). The course of the Antarctic Slope Current is shown by the purple 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 m^3 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.

Preliminary scientific analysis

Haid (2013) showed that the Finite Element Sea Ice Ocean Model (FESOM; Timmermann et al. 2009) is able to predict Weddell Sea hydrodynamics with high accuracy. For sea water temperature, salinity and currents, data layers for the sea surface and the sea bottom were established. For further details of the model see Haid (2013) and Haid & Timmermann (2013). Speed was calculated by sqrt (u^2 + v^2) where u is the zonal current with current values from west to east being positive and those from east to west being negative, and v is the meridional current with currents from south to north (positive values) or those from north to south (negative values). Direction (absolute value abs in degree deg from 0° to 360°) was calculated by arcsin [u/(sqrt (u^2 + v^2))] where u is the zonal current and v is the meridional current.

Here, data layers for sea water temperature, salinity and currents are not shown separately. But, sea water temperature and salinity are included as major structuring components of the pelagic Weddell Sea ecosystem in the pelagic regionalisation analysis (see chapter 4.1.5).

4.1.4 Sea ice

State of the science

Ralph Timmermann[1] and Sandra Schwegmann[1]

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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. 4-7). 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. 4-8).

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. Parkinson & Cavalieri 2012, Schwegmann 2012, Zwally et al. 2002). 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. 4-9a). 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. Schwegmann et al. 2013, Zwally et al. 2002). Summer sea ice concentration has increased strongly in the eastern Weddell Sea, with trends exceeding 15 % per decade (Fig. 4-9b). 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.

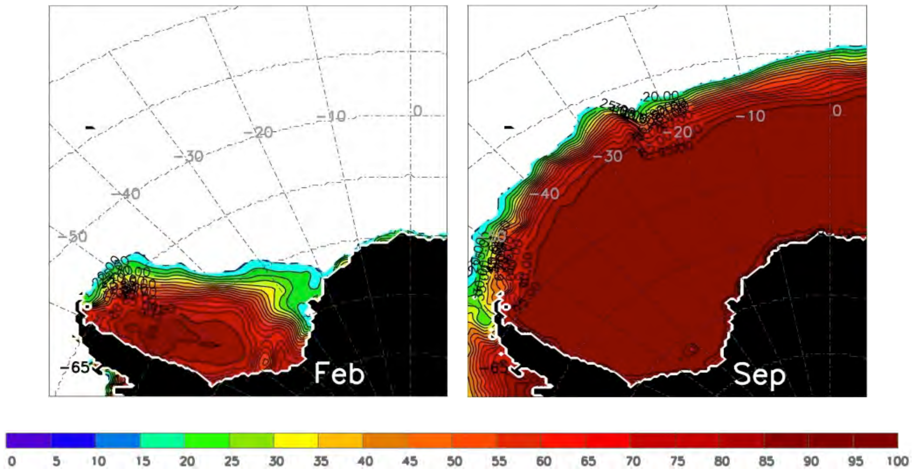

Figure 4-7 Long-term averaged sea-ice concentration (1979 – 2013, in %) at sea ice minimum (February) and sea ice maximum (September). Mean ice concentrations below 15 % have been cut off.

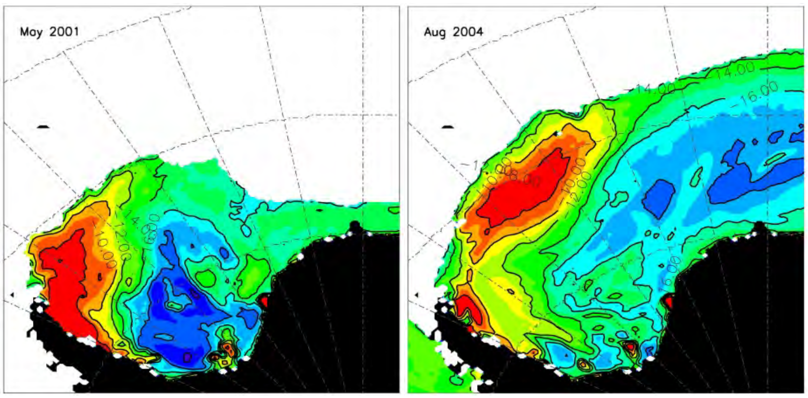

Figure 4-8 Two examples of backscatter maps (dB) derived from QuikSCAT data for May 2001 and August 2004. Patches of highly deformed, multi-year ice are formed along the Antarctic Peninsula and transported northeastward with the large-scale clockwise sea ice drift (after Schwegmann 2012).

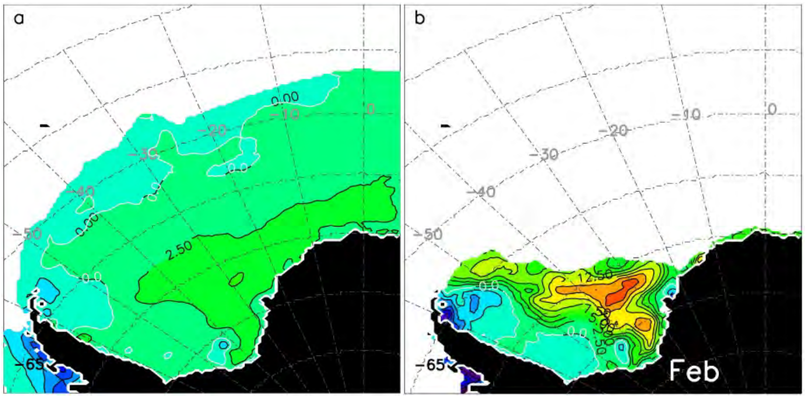

Figure 4-9 Long-term (a) and summer (b) trend in observed Weddell Sea ice concentration (% per decade for 1979-2013). Contour interval is 2.5 %, identical color scales are used in both panels.

Preliminary scientific analysis

Three large data sets were used to describe the overall picture of sea ice dynamics in the Weddell Sea and to detect areas with high sea ice dynamic at different temporal scales. To this end, approximately 100 data layers in terms of dynamic sea ice behaviour were generated. For example, almost 30 data layers were generated to evaluate the inter- and intra-annual variation in open water areas (here: ≤ 15% ice cover).

Satellite data of daily sea ice concentration

Areas of above-average number of days with sea ice cover ≤ 70 % were used as an indication for polynya formation or sea ice edge retreat. Those open water areas have an important ecological role during particular times of year. For example, the lack of sea ice cover in early summer promotes an earlier onset of the phytoplankton bloom, which in turn pushes secondary production (e.g. Arrigo & van Dijken 2003).

The relative number of days, for which a given pixel had ice cover ≤ 70 %, was calculated for the austral summer (Dec - Mar) from 2002 to 2010. Data on daily sea ice concentration were reclassified, i.e. a value of 1 was assigned to each pixel with ice cover less than 70 %, whereas pixels with ice cover > 70 % were set to N/A (not available). The data layer regarding relative number of days with sea ice cover ≤ 70 % was incorporated into the pelagic regionalisation analysis, and the results are described in paragraph 4.1.5.

Moreover, polynyas - here defined as ice free areas - constitute major access points to open water for emperor penguins (Zimmer et al. 2008) and are crucial for marine mammals for breathing (e.g. Gill & Thiele 1997), in particular during winter where almost the whole Weddell Sea MPA Planning Area is covered by ice. Thus, the mean sea ice concentration was calculated for the breeding period of emperor penguins (Jun to Jan) from 2002 to 2011 and was incorporated into a probability model of penguin occurrence. The results are described in paragraph 4.2.5.

FESOM data

FESOM have been shown to be able to reproduce real polynya dynamics very well in space and time. For example, Haid & Timmermann (2013) showed that a certain polynya exhibited similar size and ice concentration values in the FESOM simulation and in satellite observations derived from the Special Sensor Microwave / Imager (SSM/I). For more details of the model see Haid (2013) and Haid & Timmermann (2013).

The data on sea ice thickness, derived from the FESOM model, are not directly incorporated into further scientific analysis so far, but were used as additional background information to support the distribution pattern of summer and winter polynyas in the Weddell Sea. The relative number of days with sea ice thickness ≤ 20 cm per month (Jan – Dec) out of 20 years (1990-2009) was calculated. Data on monthly sea ice thickness were reclassified, i.e. a value of 1 was assigned to each pixel with ice thickness ≤ 20 cm, whereas pixels with ice thickness ≥ 20 cm were set to N/A (not available). We followed this procedure as those data will potentially be compared and intersected with ordinal data on coastal winter polynyas from the ICDC (University Hamburg), and we refrained from calculating means from categorial data on winter polynya distribution.

4.1.5 Pelagic regionalisation

Preliminary scientific analysis

Each data layer, which was incorporated into the pelagic regionalisation analysis, was generated with a raster of 6.25 x 6.25 km². That raster size forms the basis of the AMSR-E 89 GHz sea ice concentration maps. The pelagic regionalisation analysis focuses on the austral summer (Dec – Mar), and used the following parameters:

(1) Sea ice concentration
1. AMSR-E 89 GHz sea ice concentration maps were used (see paragraph 3.1.4.).
2. Data on sea ice concentration were log-transformed.
3. The relative number of days for which a given grid cell had ice cover ≤ 70 % was calculated from 2002 to 2011.
4. Weighting factor: 1.

(2) Bathymetry
1. Bathymetric data by IBSCO were used (see paragraph 3.1.1.).
2. For each grid cell mean and standard deviation of depth and 'depth range' - expressed as the difference between maximum and minimum depth in each grid - was calculated.
3. Data on depth and depth range were log-transformed.
4. Each parameter, i.e. depth and depth range, was weighted with 0.5.

(3) Sea water temperature and salinity
1. FESOM model data were used (see paragraph 3.1.3.).
2. Data on temperature and salinity were log-transformed.
3. For each grid cell mean and standard deviation of temperature and salinity at the sea surface and the sea bottom was calculated from a 20 year time period (1990-2009).

4. Each parameter, i.e. *(i)* temperature at the sea surface, *(ii)* temperature at the sea bottom, *(iii)* salinity at the sea surface and *(iv)* salinity at the sea bottom was weighted with 0.25.

The chosen parameters for the pelagic regionalisation analysis are major structuring components of the pelagic Weddell Sea ecosystem. Furthermore, these parameters overlap with the variables which were incorporated in a circumpolar pelagic regionalisation of the Southern Ocean by Raymond (2011; WG-MPA-11/6).

For clustering we applied the K-means clustering algorithm of Hartigan & Wong (1979). In general, the goal of K-means algorithm is to find the best division of n entities in k groups, so that the total distance between the group's members and its corresponding centroid, representative of the group, is minimized. To determine the optimal number of clusters we used the 'clusGap' function from the R-package 'cluster' (Maechler et al. 2014). The first local maximum in the gap statistic was used to define the optimal number of cluster 'firstSEmax'. Due to the large amount of data, the 'clusGap' analysis could not be applied to the complete data matrix (119,862 samples times 7 variables). Therefore, the matrix was reduced to 4,000 samples x 7 variables by a permutation approach (number of permutations: 150). Finally, the median of the 150 values for optimal number of clusters were used for the K-means cluster analysis.

The result of the pelagic regionalisation approach is shown in Fig. 4-10. 'Coastal polynyas I' (blue-shaded area) denominates areas with a very high probability of ice-free days and high variation in sea surface temperature. Those areas occur along the south-eastern and eastern edge of the ice shelf (from Brunt Ice Shelf to eastern part of Fimbul Ice Shelf) and at the northern border of the Weddell Sea planning area near Larsen C Ice Shelf. Sea ice thickness data (FESOM model) support those results as they show relatively low sea ice thickness (< 20-30 cm) in about the same areas (i.e. from Riiser-Larsen Ice Shelf to Jelbart Ice Shelf and near Larsen C Ice Shelf; results not shown). 'Coastal polynyas II' (red-shaded area) show a high probability of occurrence of polynyas along the edge of the ice shelf. 'Coastal polynyas III' (green-shaded area) denominates areas with an above-average proportion of ice-free days, but significantly less compared to 'Coastal polynyas I and II'. Those areas occur along the south-eastern and eastern edge of the ice shelf (from Filchner Ice Shelf to eastern part of Fimbul Ice Shelf), at the northern border of the planning area near Larsen C Ice Shelf, and near Ronne Ice Shelf. The 'transition zone' (olive-shaded area) is characterised by an average probability of ice-free days and moderate depths (approx. 2000 - 3500 m). 'Deepwater I, II and III' (pink-, orange- and light green-shaded area) are all characterised by above-average water depth. While 'Deepwater I and II' exhibit depths between approx. 3500 m and 5000 m, 'Deepwater III' covers the areas below 4000 m. 'Deepwater I and II' differ in their depth range with 'Deepwater I' covering significantly shallower areas. This coincides well with the benthic regionalisation approach (see paragraph 4.1.1.; Fig. 4-2) that shows distinct canyon structures (alternation of crests, slopes and troughs) at the south-eastern and eastern continental slope. The 'Ice-covered area' (yellow-shaded) on the continental shelf and in deep waters in the south-western Weddell Sea is characterised by the occurrence of perennial sea ice.

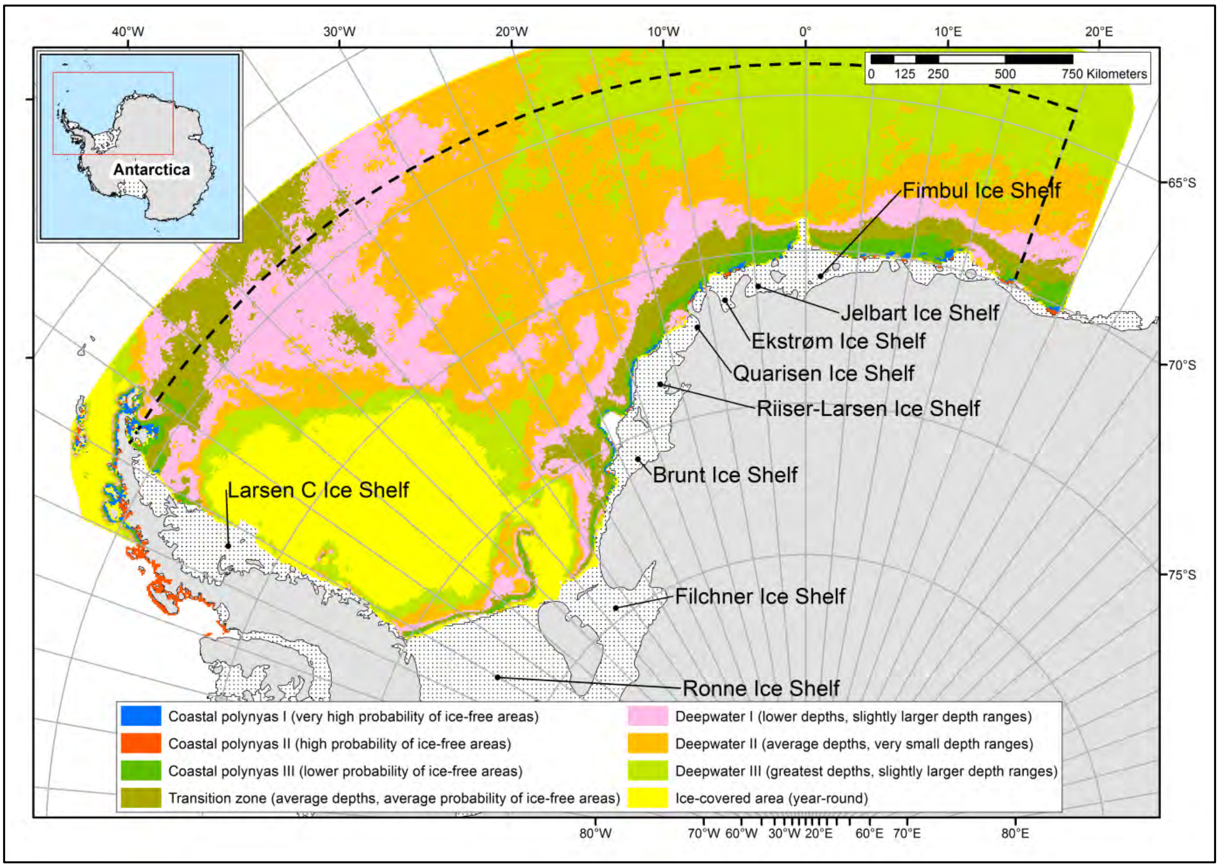

Figure 4-10 Pelagic regionalisation analysis based on *(i)* AMSR-E 89 GHz sea ice concentration data (Spreen et al. 2008), *(ii)* bathymetric data (i.e. depth and 'depth range') by IBSCO (Arndt et al. 2012), and *(iii)* FESOM model data on sea water temperature and salinity at the sea surface and the sea bottom (Timmermann et al. 2009). For more details on the pelagic regionalisation analysis see paragraph 3.2. Black 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.

4.2 Ecological parameters

The Weddell Sea MPA Planning Area constitutes a unique region in the Southern Ocean in terms of marine biota, their adaption 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 Weddell Sea MPA Planning Area are remarkably diverse and are distinctly clustered by water depth. In shallower waters the most dominant species are the Antarctic silverfish and bottom fish species of the genus *Trematomus*. In particular, the Antarctic silverfish is an important prey species in the pelagic environment, 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 Weddell Sea MPA 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 Weddell Sea MPA Planning Area.

4.2.1 Chlorophyll-a concentration

Preliminary scientific analysis

In the monthly data set on chlorophyll-a (chl-a) data gaps naturally occur caused by clouds, ice and low incident light. There are little or no SeaWiFS data in our planning area (south of 64°S) during austral winter owing to the short day length and the inability of SeaWiFS to produce accurate chl-a estimates at very high solar angles (Moore & Abbott 2000). The high sea ice concentration in most parts of the Weddell Sea hampers the measurement of surface chl-a concentration data, too. Thus, only austral summer (Nov - Mar) chl-a data were considered. Mean and standard deviation were calculated for each grid cell of both raw and log-transformed chl-a concentration data of 14 austral summers (Nov 1997 - Mar 2010).

Here, chl-a is used as a proxy measure of phytoplankton biomass (e.g. Moore & Abbott 2000). Furthermore, several studies showed a positive relationship between chl-a concentration and the occurrence of zooplankton species (e.g. Atkinson et al. 2004) or mammals (e.g. Thiele et al. 2000, Širović & Hildebrand 2011) in the Southern Ocean.

Overall, raw and log-transformed data produced the same basic picture in terms of chl-a concentration, and thus the raw data are mapped (Fig. 4-11). Mean chl-a concentration is low in most parts of the planning area despite the available nitrate and phosphate in surface waters (typically < 0.5 mg/m3). Phytoplankton blooms with chl-a concentration values exceeding 1-3 mg/m^3 particularly occur in three areas:

(i) near Larsen C Ice Shelf,
(ii) offshore Ronne Ice Shelf,
(iii) east of Filchner Trough.

Our findings reflect well the chl-a distribution published in Moore & Abbott (2000). High standard deviations are seen near Larsen C Ice Shelf and in the western part offshore Ronne Ice Shelf reflecting considerable intra- and interannual variation and/or outliers, e.g. due to measurement errors.

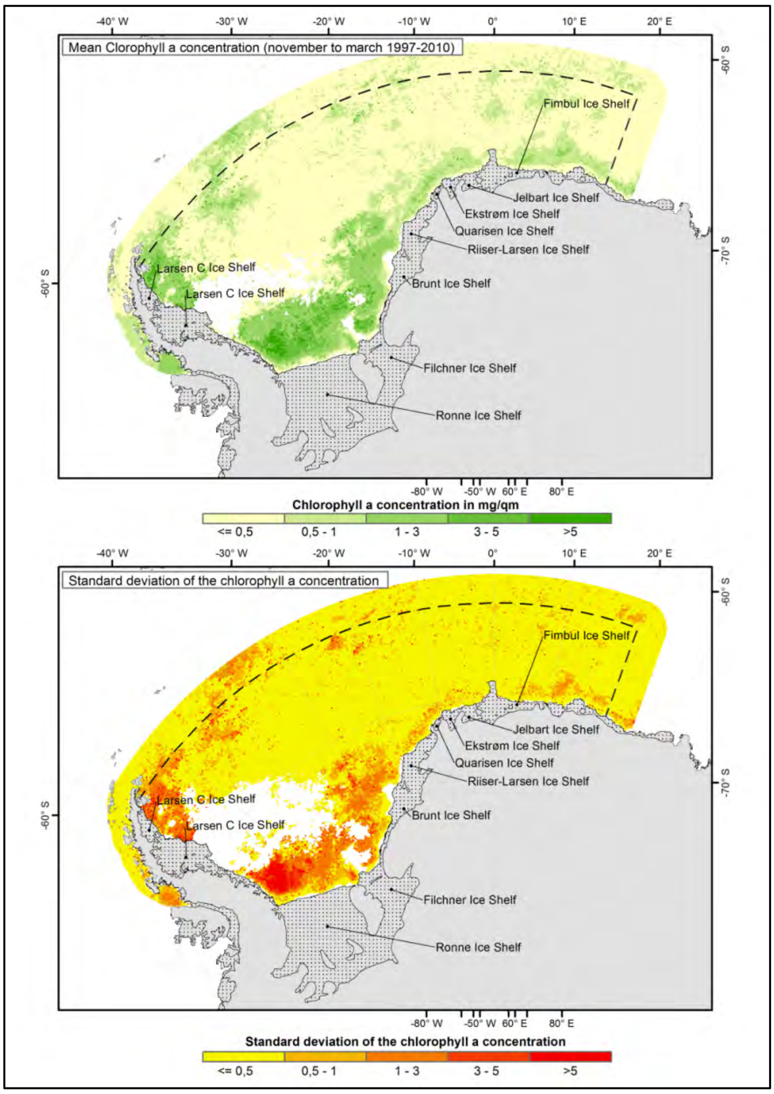

Figure 4-11 Mean value (above) and standard deviation (below) of data on chlorophyll-a concentration (in mg/m³) out of 14 austral spring and summer (Nov-Mar), 1997-2010. Areas in white had no valid chlorophyll data because of heavy sea ice or persistent cloud cover. Monthly data were downloaded via the NASA's OceanColor website. Black 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.

4.2.2 Sea ice ecosystem

State of the science

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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 particularly 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.

4.2.3 Pelagic ecosystem

Zooplankton in general

State of the science

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Introduction

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 (biodervisity.aq; Fig. 4-12) 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.

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 (l.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).

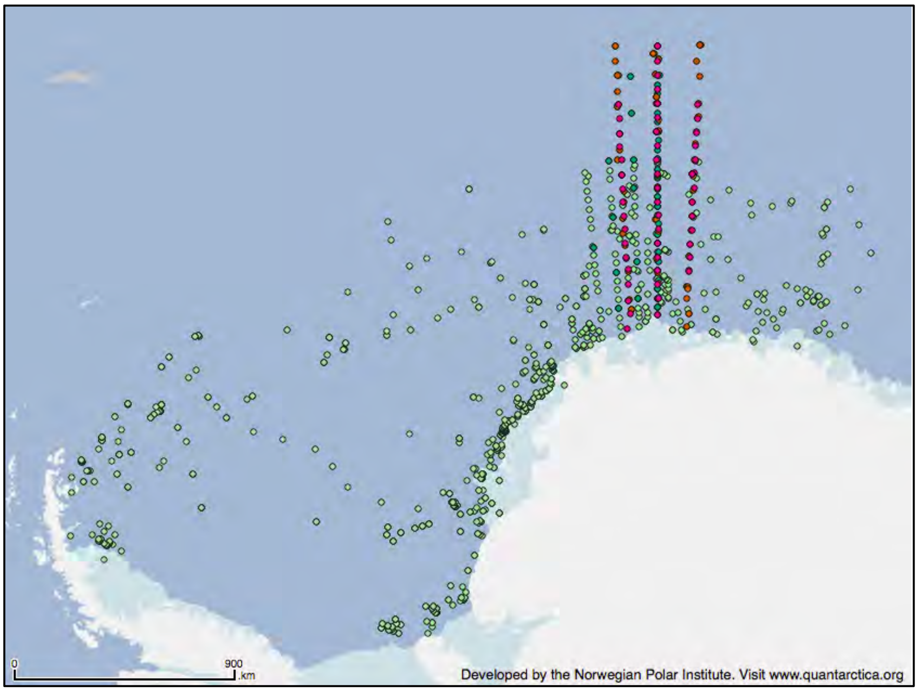

Figure 4.12 Map of data collected in the framework of the SCAR Biogeographic Atlas of the Southern Ocean for the Weddell Sea (green) as well samples collected in the framework of the LAKRIS expeditions 2004-2008 (red) (source: biodiversity.aq; map was made using quantarctica).

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.

Preliminary scientific analysis

Further efforts to detect biomass and abundance hotspots for other pelagic key species (e.g. ice krill) were discussed at the International Expert Workshop (see WG-EMM-14/19, supplementary material), and corresponding analyses are in progress. In addition, biodiversity hotspots concerning zooplankton communities could be a relevant data layer for subsequent conservation planning analyses. Some data on other pelagic key species, such as squid, will serve as background information to support the identification of potential conservation areas, but will probably not incorporated in further analytical approaches due to scarcity of data.

Antarctic krill (Euphasia superba)

State of the science

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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. 4-6 in chapter 4.1.3). 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. 4-6 in chapter 4.1.3). 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 1990). 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.

Preliminary scientific analysis

The data layer on the distribution pattern of adult Antarctic krill, *Euphausia superba*, was derived from KRILLBASE data (Atkinson et al. 2004, 2008, 2009; Siegel 1982), and from published data (Fevolden 1979; Makarov & Sysoeva 1985; Siegel 2012; Siegel et al. 2013) as well as from unpublished data (Volker Siegel, Thünen Institute, Hamburg).

Although data on Antarctic krill differ in sampling depth, proportion of day vs. night hauls and time of year of sampling, we created a krill density distribution layer from un-standardised data. Atkinson et al. (2008) compared the circumpolar krill distribution based on raw, un-standardised data and standardised krill densities. Overall, Atkinson et al. (2008) obtained the same basic picture, despite higher overall Krill densities after standardisation procedures.

Inverse distance weighted (IDW) interpolation was used in the ArcGIS™ spatial analyst tool; see Burrough & McDonnell (1988) and Lu & Wong (2008) for more details. IDW was performed using log-transformed data, and the interpolated data were finally expressed as mean krill densities (individuals/m^2) +/- the n-fold of the standard deviation per grid cell (6.25 x 6.25 km^2).

The distribution pattern of Antarctic krill is mapped in Fig. 4-13. Hotspots of adult Antarctic krill abundance (i.e. mean krill densities > 72 individuals/m^2) are located:

- *(i)* at the northern border of the Weddell Sea Planning Area near Larsen C Ice Shelf and to the east of it,
- *(ii)* in open water at 25°W,
- *(iii)* at the continental slope at 15°W (similar latitude as Quarisen Ice Shelf),
- *(iv)* in open water at the northern border of the Weddell Sea planning area near the Greenwich meridian,
- *(v)* near Maud Rise sea mount (66°S, 3°E), and
- *(vi)* on the continental shelf near Fimbul Ice Shelf.

Along the Weddell Sea shelf area krill densities mostly vary between < 2 individuals/m^2 (south-eastern/southern shelf area) and 12 individuals/m^2 (eastern shelf area).

Our findings coincide quite well with the distribution pattern of Antarctic krill reported by e.g. Atkinson et al. (2008) and Siegel (2012). For example, our interpolated data show mean krill densities never exceed 12 individuals m^{-2} for the southern Lazarev Sea. Similar average numerical densities (never exceeded 7 adult krill m^{-2}) were sampled for the same area during the multi-year LAKRIS cruises (Siegel 2012).

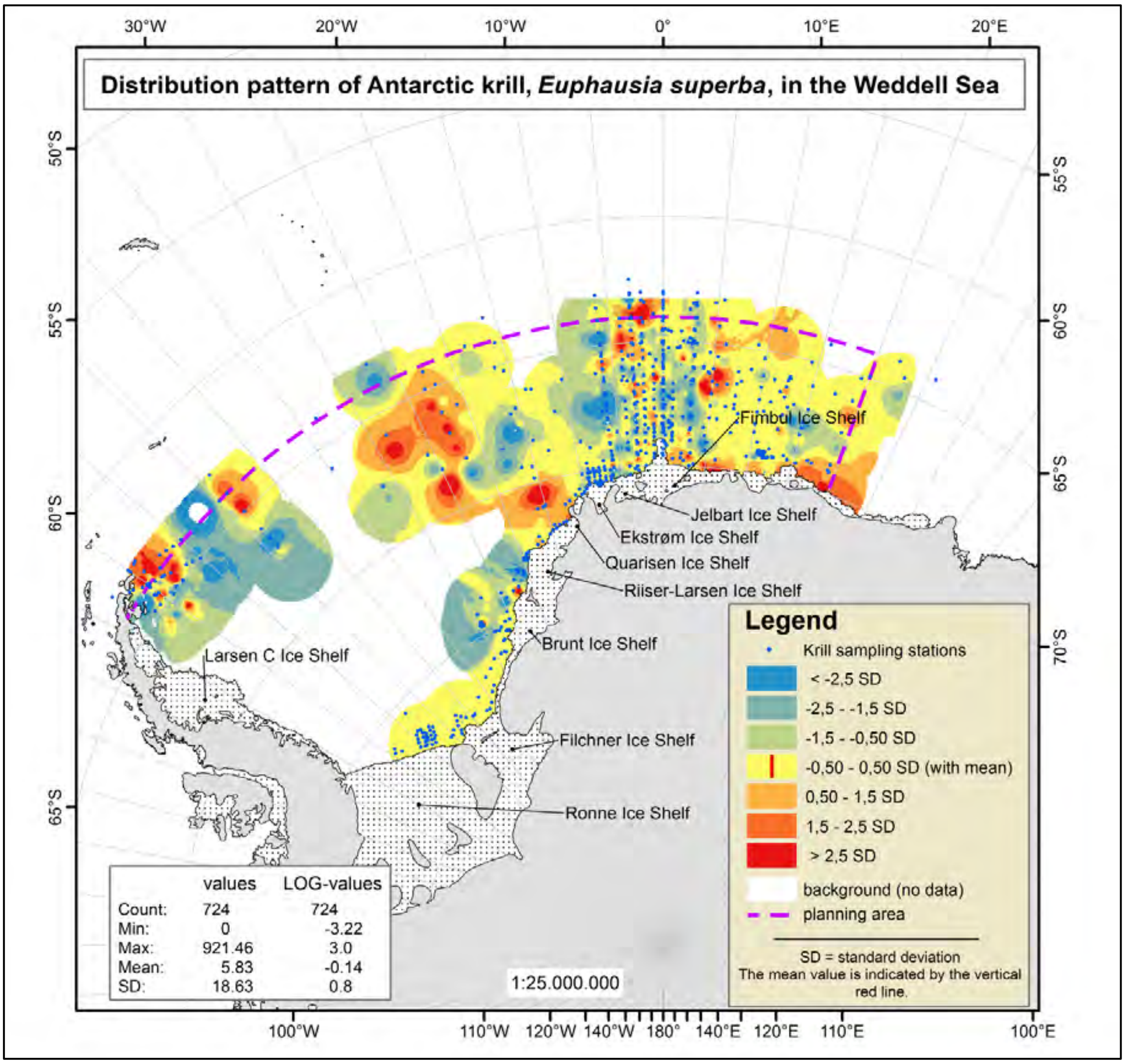

Figure 4-13 Distribution pattern of Antarctic krill, *Euphausia superba*, in the Weddell Sea based on un-standardised, log-transformed data from KRILLBASE (Atkinson et al. 2004, 2008, 2009; Siegel 1982) and (un-) published data held by Volker Siegel, Thünen Institute, Hamburg (e.g., Siegel 2012; Siegel et al. 2013). The interpolated data are plotted as mean krill densities (individuals/m²) +/- n-fold of standard deviation per grid cell (6.25 x 6.25 km²). Blue dots show the distribution of sampling effort. For white coloured grid cells no arithmetic means were calculated; here, less than three stations were sampled. Purple 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.

Pelagic fish

"Editor Note: This chapter has to be developed further".

State of the science

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Preliminary scientific analysis

Work on pelagic fish is in its initial phase still, only the data retrieval process was carried out so far. The International Expert Workshop agreed that analyses should be undertaken to detect hotspots for pelagic biodiversity and abundance, focusing on key species including *Pleuragramma*, mesopelagic fish and larvae of commercial fish species (see WG-EMM-14/19, workshop report). The subsequent data preparation and analysis will show if the data are actually appropriate for creating corresponding data layers.

Squid

State of the science

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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), *Slosarczkovia 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.

4.2.4 Benthic ecosystem

Zoobenthos – Shelf and slope

State of the science

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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. in press). 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 iceshelves 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. 4-14). 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).

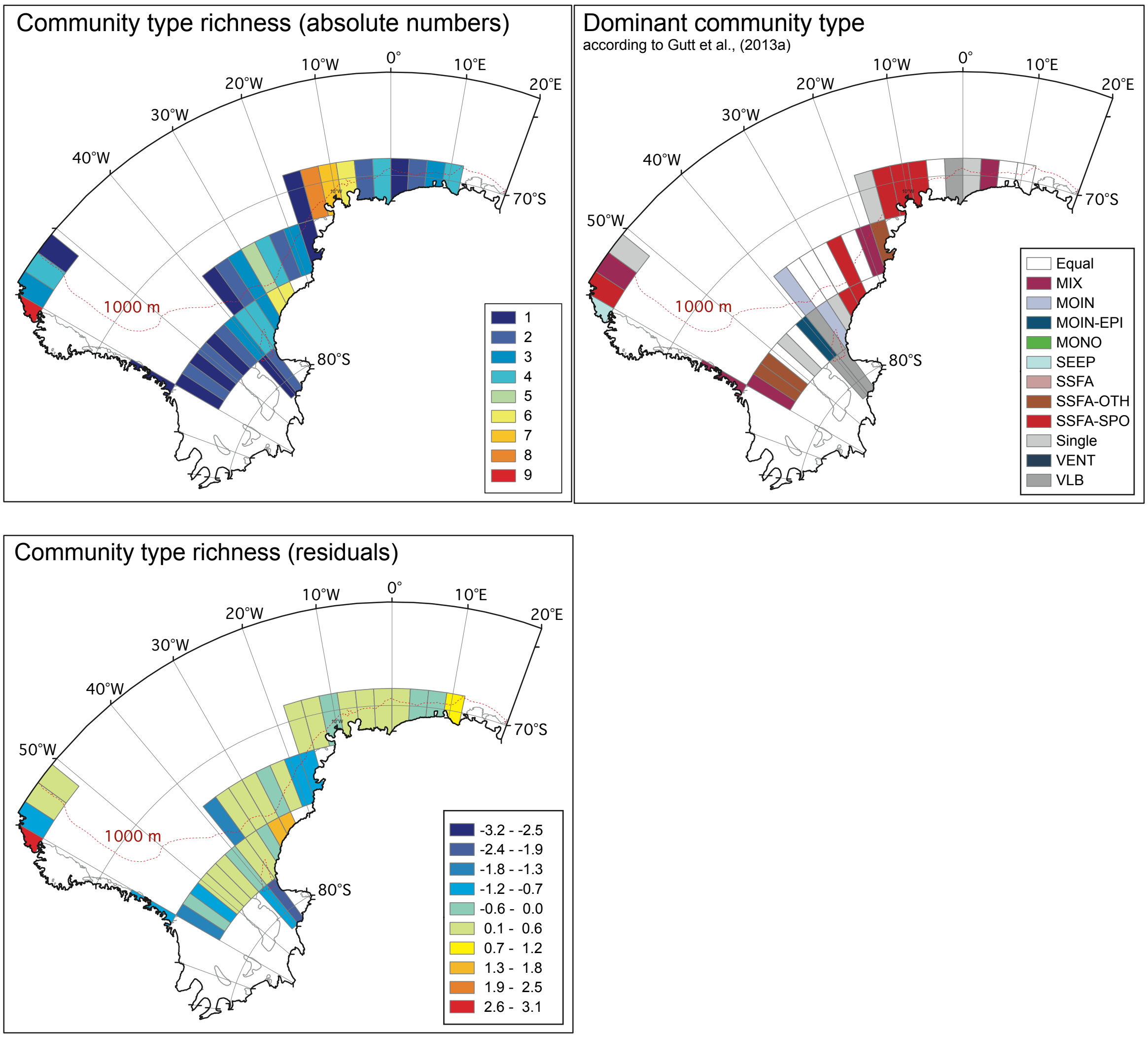

Figure 4-14 Macrobenthic communities in the MPA planning area, adopted from the circumpolar data set published by Gutt et al. (2013a). Dominant community types per cell are shown as well as species richness expressed as absolute number of community types and as residuals of the expected number of community types at a given number of records. For data repository see: http://ipt.biodiversity.aq/resource.do?r=macrobenthos.

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, 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.

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 encapsuling 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 iceshelf.

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 iceshelf 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 iceshelves 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 a 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 architecturing 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 iceshelf 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. 4-15). 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 iceshelf 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 sowed 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 iceshelves, 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 iceshelves 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.

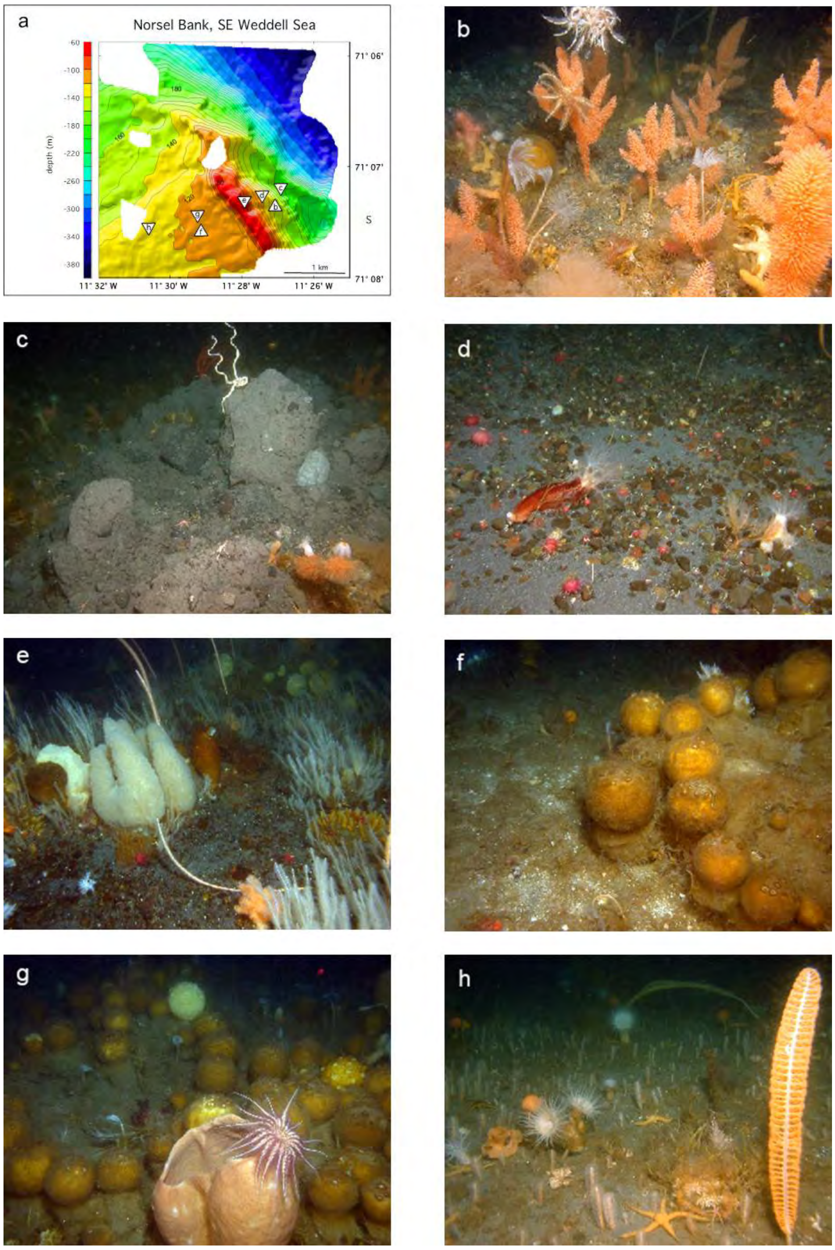

Figure 4-15 A specifically shallow site on the Norsel Bank in the South-eastern Weddell Sea and its megabenthic assemblages. Bathymetric data: AWI bathymetric working group; for data repository of sea-bed photographs see http://doi.pangaea.de/10.1594/PANGAEA.820693. a) Bottom topography with positions 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*.

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.

Preliminary scientific analysis

Macrozoobenthic taxonomic richness at the level of higher taxonomic groups (class or phylum; total number: 35) was calculated from the data set held by D. Gerdes (AWI) and U. Mühlenhardt-Siegel (Thünen Institute). The number of higher taxonomic zoobenthic groups per spatial grid cell (1° of latitude by 1° of longitude) was counted. The residuals resulting from a regression between number of samples (x) and number of higher taxonomic groups (per spatial cell, y) were used to reduce bias caused by regionally varying sampling efforts. Here, we applied the Ugland T-S curve (Ugland et al. 2003), which accounts for the degree of environmental heterogeneity (e.g., depth or sediment properties) and the size of the whole area by partitioning the dataset of the sampled area held by into several subsets.

Fig. 4-16 shows cluster of grid cells with a mean above-average taxonomic richness (i.e. 20-26 higher taxonomic groups):

(i) near Brunt Ice Shelf,
(ii) at Ekstrøm to Jelbart Ice Shelfs, and
(iii) at Fimbul Ice Shelf.

This result coincides quite well with the distribution pattern of macrozoobenthic communities, classified by functional traits after Gutt (2007) and Turner et al. (2009). Functionally rich macrozoobenthic communities also occur near Brunt Ice Shelf, while at Ekstrøm to Jelbart Ice Shelfs and at Fimbul Ice Shelf rather an average number of functional community types is present (see more details in Gutt et al. 2013a). In these areas along the shelf the dominant community types are mostly sessile suspension feeder communities dominated by sponges.

Analyses of macrozoobenthic abundance, biomass, production and further characteristics, such as the distribution pattern of CCAMLR VME (Vulnerable Marine Ecosystem) taxa, are in progress. Objectives are to identify areas with important ecosystem functions (e.g., nursery grounds or strongly structured habitats; more details see WG-EMM-14/19, supplementary material). Different interpolation models will be applied where possible.

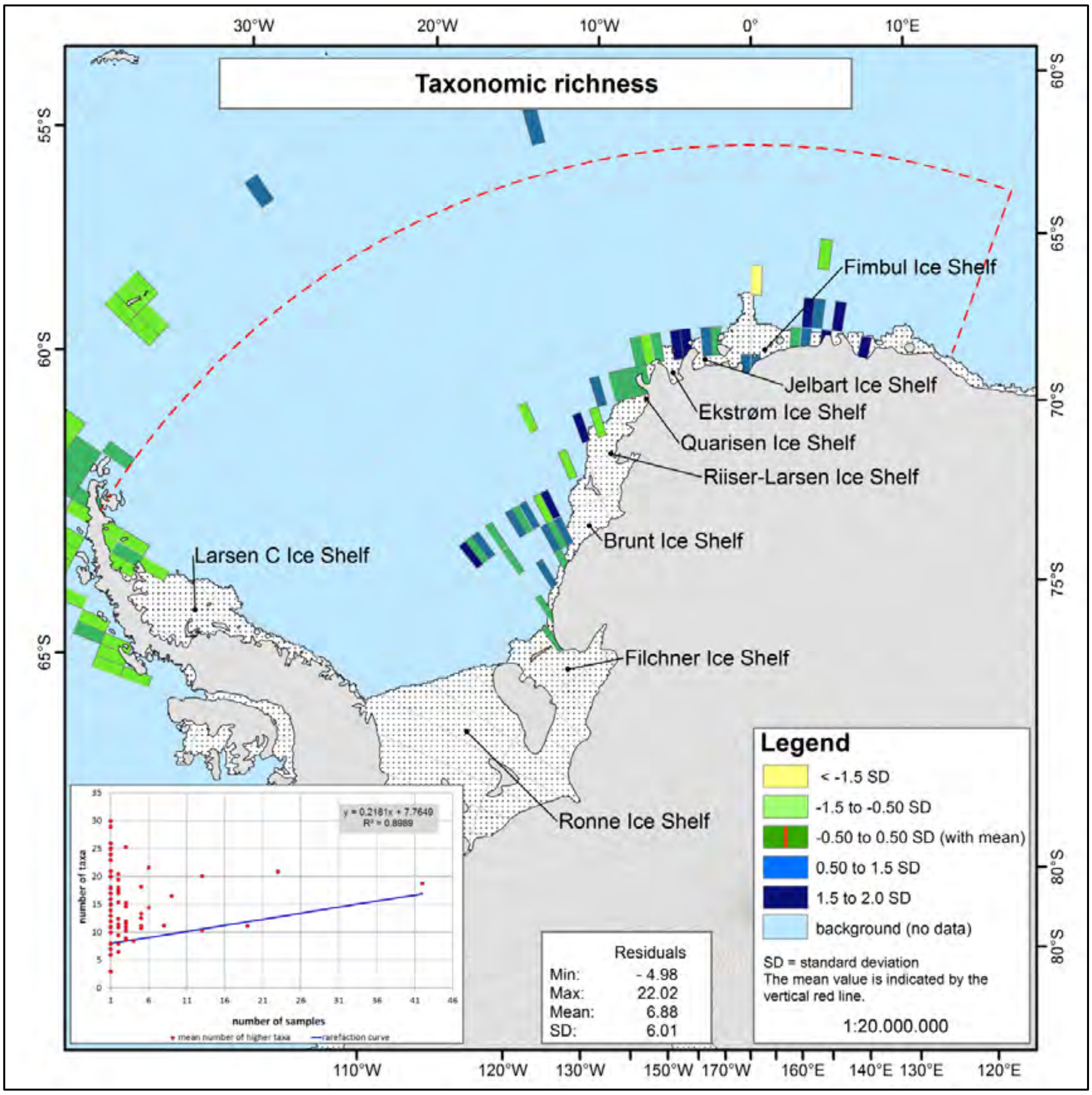

Figure 4-16 Distribution pattern of richness of higher taxonomic macrozoobenthic groups based on a data set held by D. Gerdes and U. Mühlenhardt-Siegel. The data are plotted as raw numbers of higher taxonomic groups, expressed as residuals of the expected number of higher taxonomic groups at a given number of records, +/- n-fold of standard deviation per grid cell (1° of latitude by 1° of longitude). 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.

Zoobenthos – Deep Sea

State of the science

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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 (ANtarctic 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).

SO 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. 4-17, 4-18). 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).

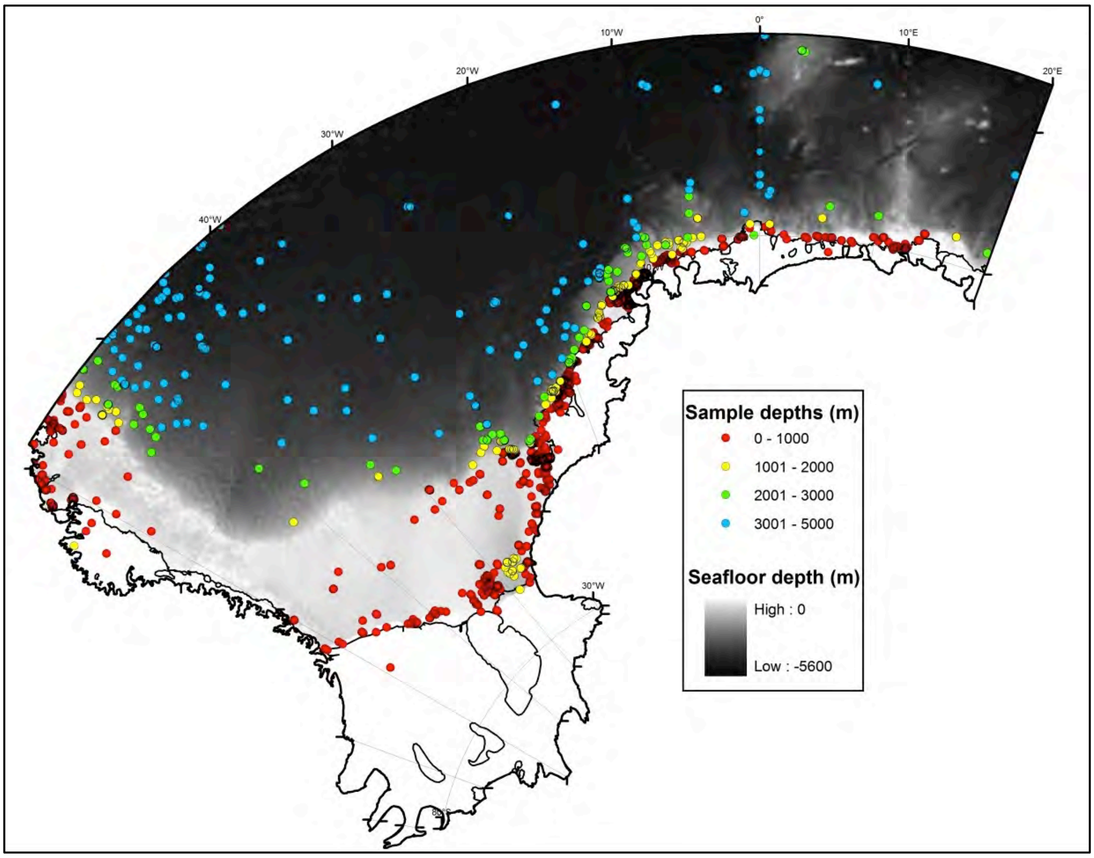

Figure 4-17 Benthic samples at different depths in the Weddell Sea sector of the Southern Ocean. Coloured points show individual sampling locations from which benthic organisms were recorded. On the shelf sampling locations overlap, while in the deep sea stations are more sparse and individual stations 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. 4-17, 4-18). 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. Schrödl 2006, 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).

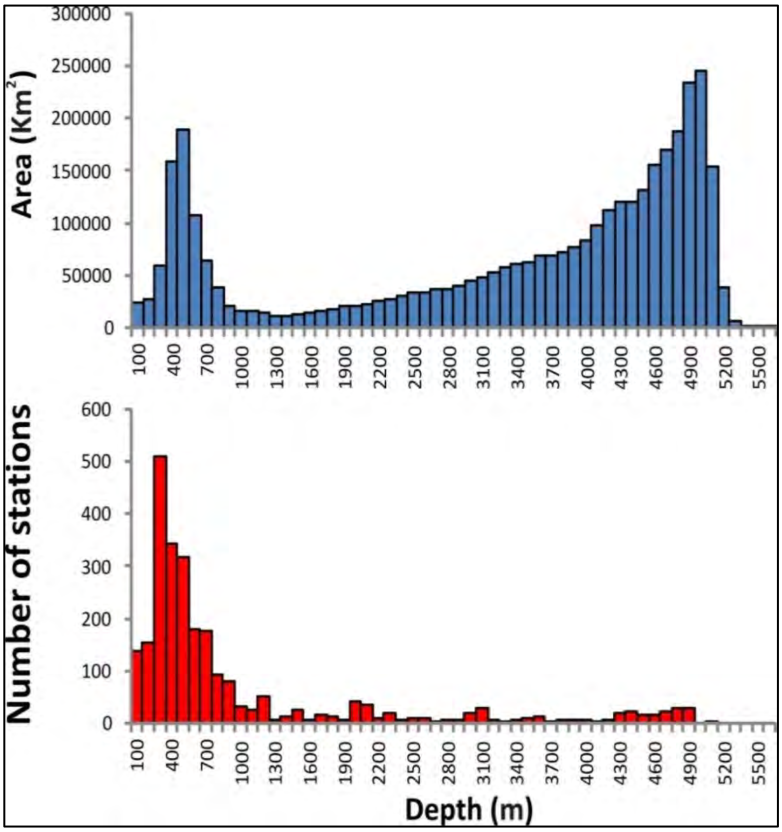

Figure 4-18 Area of seafloor in the Weddell Sea planning area with ocean depth in km² and sampling effort at these depths.

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

The crew of RV *Polarstern* is thanked for their help and logistic support during the expeditions ANT XIX/2-3 and XXII-3 (ANDEEP I - III) and the AWI for logistics. The German Research Foundation is thanked for financial support (Br 1121/22 and 31). All ANDEEP collaborators are thanked for collaboration. This is ANDEEP publication # 201.

Preliminary scientific analysis

So far, no scientific analyses were carried out within the framework of the MPA Weddell Sea project. Very likely the low sampling effort in the deep sea will not allow to generate corresponding data layers (i.e. spatially interpolated data layers for conservation planning software such as MARXAN). Finally, the subsequent data preparation will show how the data can be used to support the identification of potential conservation areas.

Demersal fish

State of the science

"Editor Note: This chapter has to be developed".

Preliminary scientific analysis

Work on demersal fish is in the initial phase still, only the data retrieval process was carried out so far. Concerning demersal fish the International Expert Workshop identified following key topics: *(i)* biodiversity, *(ii)* biomass of the most abundant species, and *(iii)* important spawning areas (see WG-EMM-14/19, workshop report). The subsequent data preparation and analysis will show if the data are actually appropriate for creating corresponding data layers.

4.2.5 Birds

Seabirds

State of the science

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Any assessment of the spatial patterns and seasonal abundances of flying seabirds within the Weddell Sea MPA 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 Weddell Sea MPA 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 4-2) (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. 4-19); 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 4-2). 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. 4-19); 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 4-2); 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.

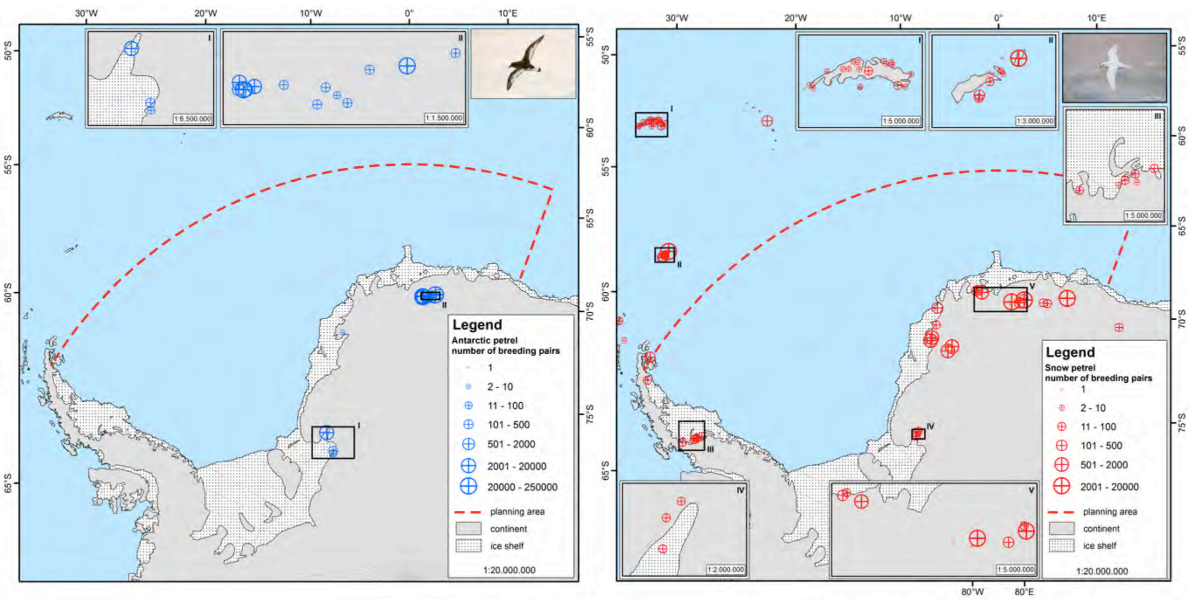

Figure 4-19 Spatial distribution patterns of breeding pairs of Antarctic petrel (left; Franeker et al. 1999) and Snow petrel (right; Croxall et al. 1995). Snow Petrels have breeding locations also to the north of the planning area, e.g. on South Orkneys and South Sandwich Islands, but birds from these 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.

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 Weddell Sea MPA 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 predates 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).

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 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 glacialoides*; 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 antarcticum*) 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 4-2 Flying seabird species that strongly or partially depend on the Weddell Sea MPA Planning Area.

	Breeding population at southern rim of Weddell Sea MPA Planning Area	**Breeding population close north of Weddell Sea MPA Planning Area (a)**	**Global Population estimated number of breeding pairs (b, c)**
Substantial part of global population directly depending on planning area			
Antarctic Petrel	310,016	0	491,082
Snow Petrel	28,525	21,378	65,462
Wilsons Storm Petrel	breed	2,700,000	13,200,000
South Polar Skua	breed	20	7,550
Substantial part of global population breeding close north of planning area			
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.

Preliminary scientific analysis

Data layers on birds must be further developed. The subsequent data preparation will show how the data can be analysed to support the identification of potential conservation areas.

Penguins

State of the science

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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 pagophillic (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 – *Aptenodyptes 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. 4-20). 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 antarcticum*) and Antarctic krill (*Euphausia superba*) (Trathan et al. 2011).

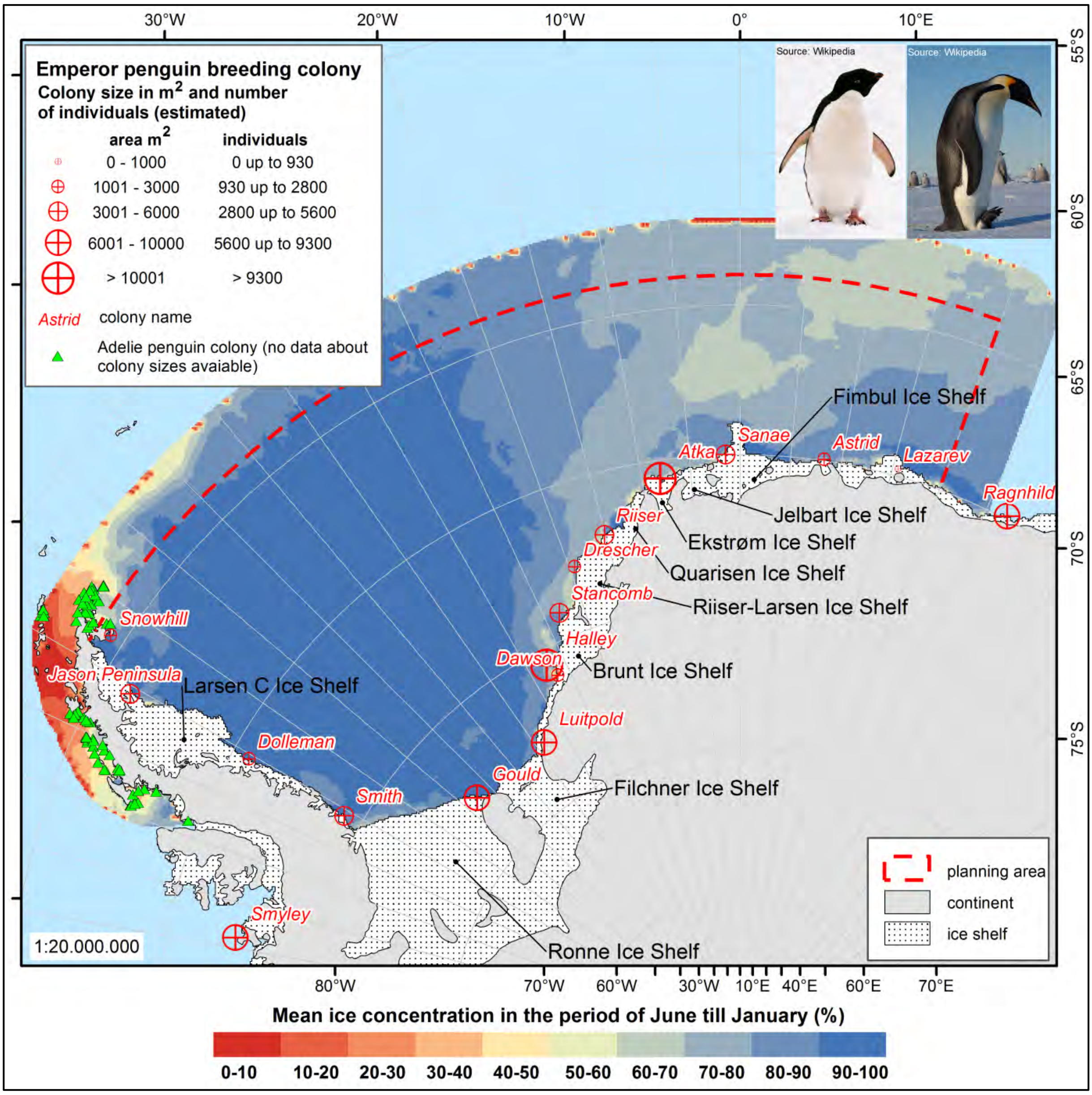

Figure 4-20 Mean sea ice concentration calculated for the breeding period of emperor penguin (Jun-Jan) based on daily data (2002-2011). Data availability: Institute of Environmental Physics, University of Bremen (Kaleschke et al. 2001, Spreen et al. 2008). Spatial distribution patterns of Adélie penguin colonies (green triangles; unpublished data held by H. Lynch, Stony Brook University, USA) and emperor penguin population estimates (cross hairs; Fretwell et al. 2012, 2014). 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.

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 2011).

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.

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 actually breeding in the Weddell Sea Planning Region (Fig. 4-20). 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 use the Weddell Sea in winter (Dunn et al. 2011; BAS unpublished data).

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 crystallorophias*) 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).

Preliminary scientific analysis

Within the Weddell Sea MPA Planning Area there are two Adélie colonies situated near the tip of the Antarctic Peninsula with a total estimated abundance of 35,098 breeding pairs (95th percentile confidence intervals: 13,670 - 57,934 breeding pairs) (Fig. 4-20). Furthermore, there are 15 emperor penguin breeding colonies in the Weddell Sea with a total estimated abundance of approx. 78,000 breeding pairs. The penguin colonies` proximity to persistent or recurrent coastal winter polynyas is shown in Fig. 4-20. Areas which are charcaterised by low mean sea ice concentration occur in the west of the planning area and along the south-eastern and eastern ice shelf particularly:

(i) at the northern border of the planning area near Larsen C Ice Shelf
(ii) near the colony on the Jason Peninsula
(iii) at the Halley and Dawson colony near Brunt Ice Shelf
(iv) at the Atka colony near Ekstrøm Ice Shelf, and
(v) between the Astrid and Lazarev colony near Fimbul Ice Shelf.

Coming analyses will focus on a model evaluating the probability of emperor penguin occurrence during foraging in the breeding period. The model will be driven by colony size, distance to colony and sea ice conditions.

4.2.6 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 (Århun et al. 2012; Århun 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 Eckström 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 antarcticum* as a pelagic food resource over a broad variety of demersal and benthic fish species, cephalopods, and to a small extent, crustaceans (Plötz et al. 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 et al. 2001; 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 1998, 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 2005; 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. 2009) and inferences from diving patterns (Bengtson & Stewart 1997; Blix & Nordøy 2007) and some haul-out data (Southwell et al. 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 antarcticum*, 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 scare. 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 2007). 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 2007). Their diving behaviour and foraging movements suggest that they feed on krill, penguins, juvenile crabeater seals and a variety of fish (Nordøy & Blix 2007). 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. 1960; Kohnen 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 (McInytre 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. antarcticum* (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. antarcticum* 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).

Preliminary scientific analysis

The modelled abundance data on crabeater seals in the western part of the Weddell Sea Planning Area were derived from Forcada et al. (2012). The seal densities (unspecified taxa) in the south-eastern/eastern part of the Weddell Sea based on data from the APIS programme (Plötz et al. 2011a-e).

Absolute seal density (individuals/km²) was calculated with the count method for line transect data (Bester et al. 1995, Bester & Odendaal 2000, Hedley & Buckland 2004). We used un-standardised data for the density calculations as the data set from Plötz et al. (2011a-e) based on video material, and thus at least observer related factors potentially influencing the probability of animal detection are not relevant to consider. In contrast, Forcada et al. (2012)

considered several factors potentially influencing the probability of animal detection for their density estimations (e.g. probability of detection for perpendicular sighting distances). To estimate the absolute seal density, we applied inverse distance weighted interpolation in ArcGIS™ spatial analyst tool to the data from PANGAEA, while a more sophisticated approach, i.e. a combination of different generalized additive models, was used in Forcada et al. (2012).

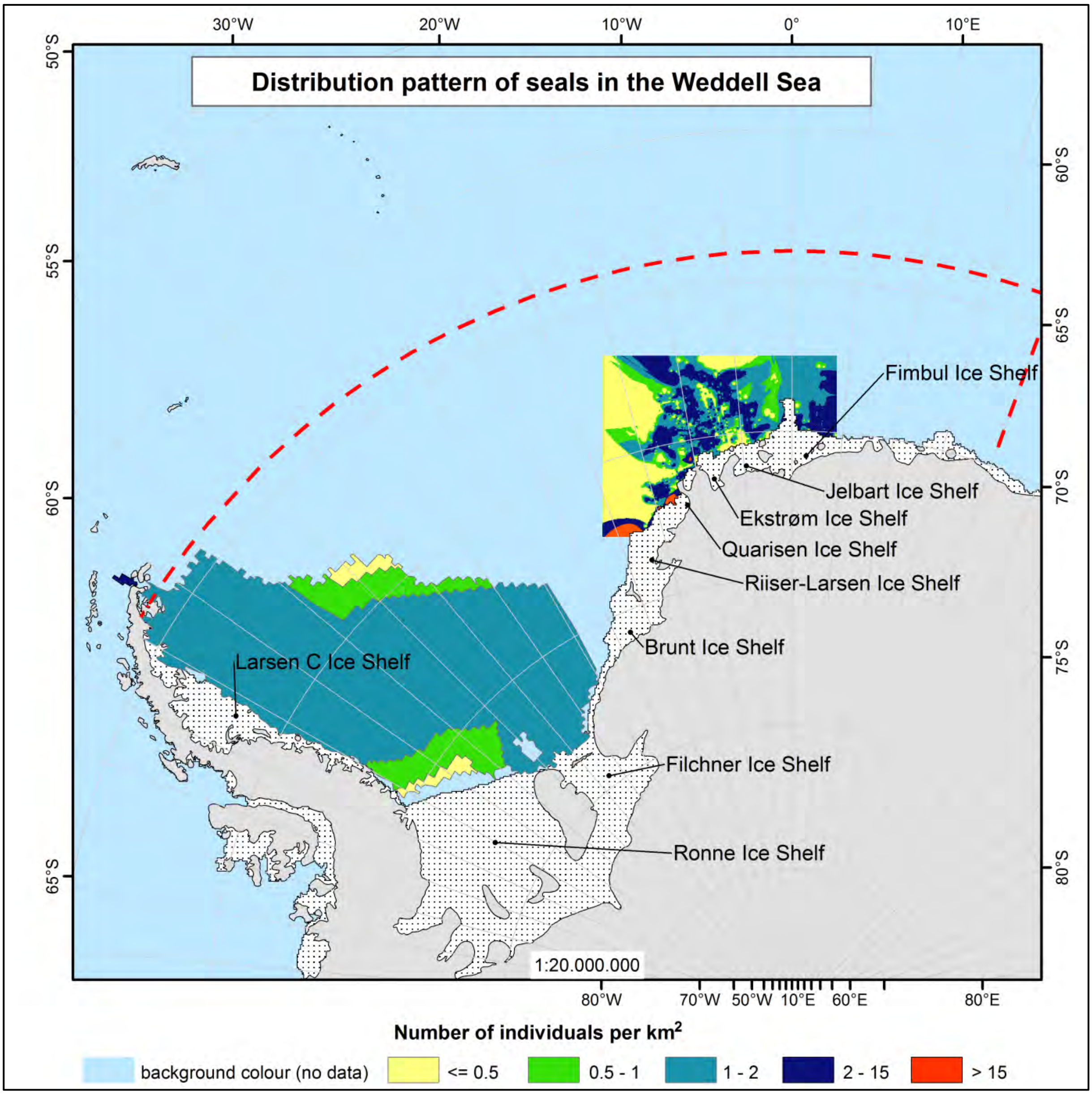

Figure 4-21 Distribution pattern of seals in the Weddell Sea. Abundance data on crabeater seals in the western part of the Weddell Sea planning area were derived from Forcada et al. (2012), un-transformed abundance data on seals (unspecified taxa) in the south-eastern/eastern part of the Weddell Sea based on data from PANGAEA (Plötz et al. 2011a-e). The un-transformed, interpolated data are plotted as absolute seal densities (individuals/km²). Purple 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.

Fig. 4-21 indicates highest absolute seal density (i.e. > 15 individuals/km²) near the edge of Riiser-Larsen Ice Shelf to Quarisen Ice Shelf. The greater part of the western Weddell Sea is characterised by relatively low crabeater seal densities (1-2 individuals/km²). However, crabeater seals are the most abundant pinniped species in the western Weddell Sea compared to leopard seals and Weddell seals with highest estimated densities of ≤ 0.02 individuals/km² and ≤ 0.5 individuals/km², respectively (see Forcada et al. 2012).

We plan to verify the modelled seal densities in the Weddell Sea MPA Planning Area by additional data sets (e.g. from Bester et al. 1995, Bester & Odendaal 2000, Flores et al. 2008), and different approaches regarding data standardisation procedure and modelling techniques. In addition, subsequent analyses will particularly focus on the evaluation of mating areas of pinnipeds based on acoustic data from the AWI (see Table 3-2).

Whales

"Editor Note: This chapter has to be developed"

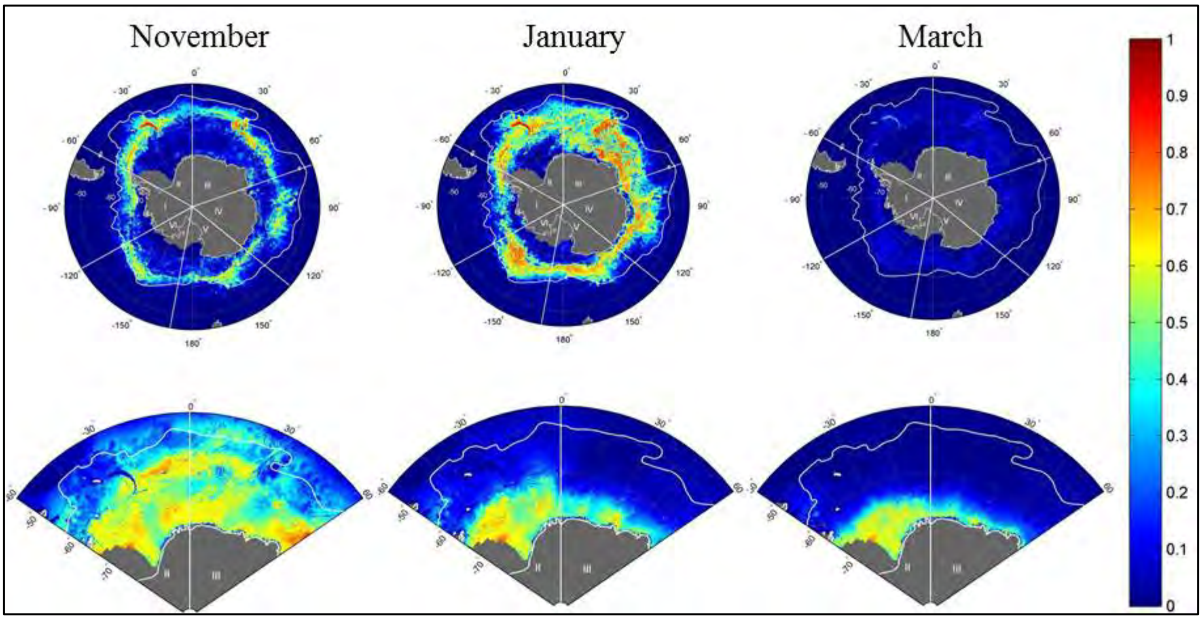

Figure 4-22 Maxent spatial prediction maps for humpback whales (upper row) and Antarctic minke whales from 60°W to 60°E (lower row) for the 15th of November, January and March 2006/2007. Habitat suitability is colour-coded with blue colours indicating less suitable to unsuitable habitat, greenish colours 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).

Habitat suitability models of humpback and Antarctic minke whales indicate (see Bombosch et al. 2014) 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. 4-22). Suitable minke whale habitats are consistently predicted within sea ice covered areas. Throughout November and early December, favourable conditions for minke whales span wide areas of the Weddell Sea (exceptions are e.g., areas directly along the ice shelf edge) (Fig. 4-22). Suitable habitats start to shrink rapidly by mid-December and concentrate towards coastal areas for the following months. By mid-March, habitat suitability reaches its spatial minimum and starts extending again until the end of April. Highly favourable conditions for minke whales throughout the season are predicted for an area around 70°S and 40°W.

4.3 Human activities

4.3.1 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.

4.3.2 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. 4-23). 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 4-23
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. 4-24). 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.

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.

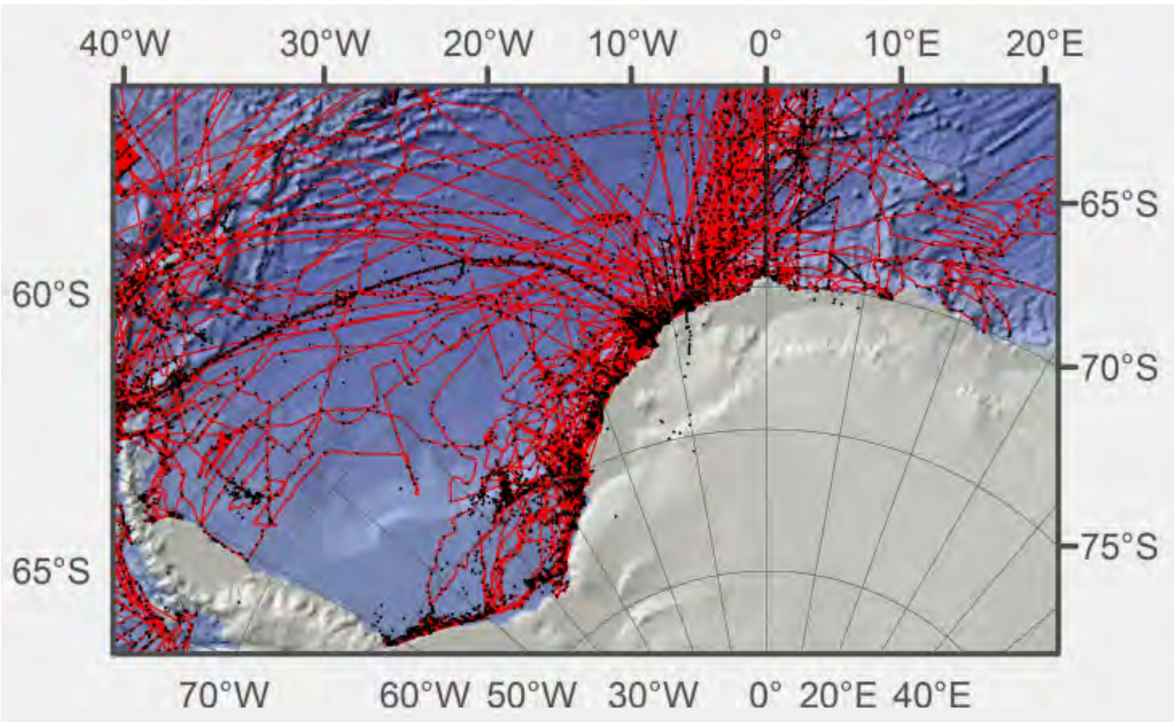

Figure 4-24 Tracklines of *Polarstern* cruises from 1982 to 2014. Further information on *Polarstern* research cruises can be obtained from http://www.pangaea.de/PHP/CruiseReports.php?b=Polarstern

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). 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 4-3 and Fig. 4-25). 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. 4-26).

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).

Table 4-3 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
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)

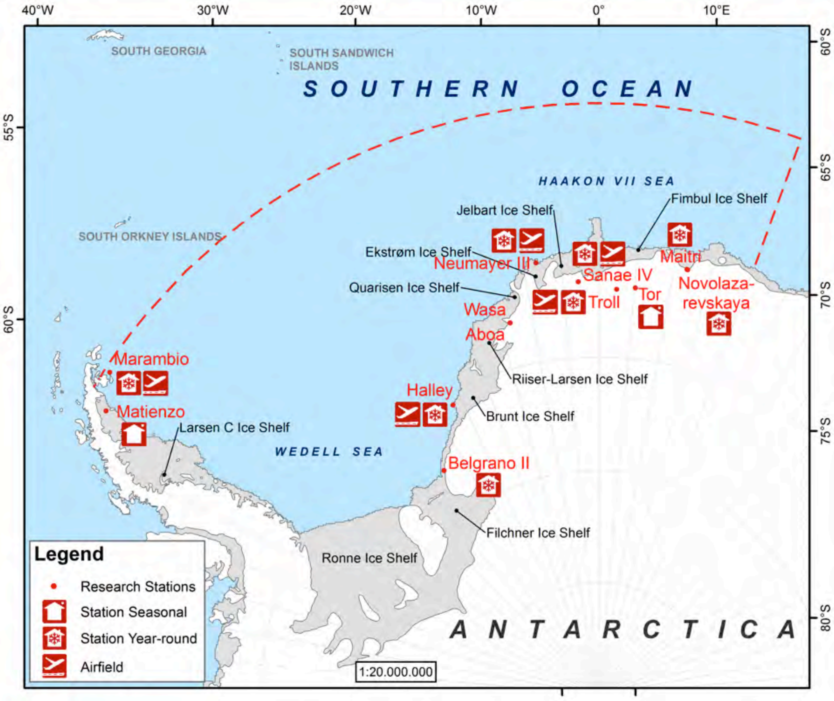

Figure 4-25
Map of the research stations and facilities bordering the Weddell Sea MPA planning area (modified after COMNAP Antarctic Facilities Map, Edition 5 (24 July 2009), available at https://www.comnap.aq/Publications/Comnap%20Publications/comnap_map_ edition5_ a0_ 2009-07-24.pdf).

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.

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 4-26
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 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 2004). 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 4-4). 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 4-4.

Table 4-4 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	*Dissostichus mawsoni* Total catch (tonnes)	*Dissostichus eleginoides* 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
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 for the season 2012/13 was kept flexible and included three optional fishing areas (Petrov et al. 2012, Fig. 4-27). For the season 2013/14 a specific catch limit was assigned to each option, i.e. Option 1 area = 213 tonnes, Option 2 area = 48 tonnes, Option 3 area = 112 tonnes. Prevailing ice conditions limited fishing to Option 1 area, where 60 tonnes of *D. mawsoni* were caught with eight lines (see Petrov et al. 2013b for further details).

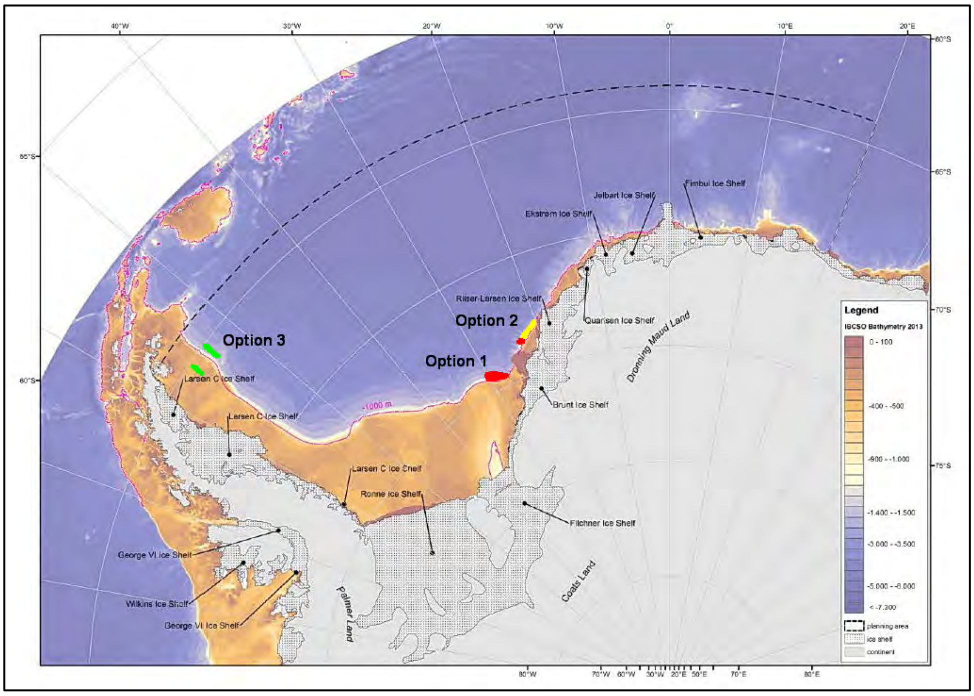

Figure 4-27 Bathymetric map (meters) of the Weddell Sea MPA Planning Area (black dashed box) indicating the three options selected for the Russian exploratory longline fishery. The boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA. The bathymetric chart of the Southern Ocean (IBCSO) is published by Arndt et al. (2013). The ice shelves are labelled and shown in grey.

In the season 2013/14, fishery in areas Option 1 and Option 2 (Petrov et al. 2013a) yielded 229 tonnes of *D. mawsoni* from a total of 34 long lines. Table 4-5 provides a detailed view of the total catch including by-catch, and Fig. 4-28 displays size composition of *D. mawsoni* in the catch. Stomach contents analysed during the 2013/14 season indicate that *D. mawsoni* feed on fish (83% of food by weight) and cephalopods (Petrov et al. 2013a). Table 4-6 summarizes the catch of *Dissostichus* spp. in Subarea 48.5.

Table 4-5 Composition of long line catches in Subarea 48.5 during the season 2013/14.

Species	Weight (kg) / line			Number of ind. / line			% of total by-catch weight	% of total catch weight
	total	min -max	mean	total	min-max	mean		
D. mawsoni	228586	1005 - 15095	6723	11904	119 - 798	350	-	99.12
M. whitsoni	1957	3.8 – 181.4	67.5	1301	3 - 124	45	97.74	0.84
C. dewitti	12.2	0.6 – 4.5	2.0	36	2 - 15	6	0.62	0.01
Muraenolepsis spp.	32.9	1.1 – 7.5	3.7	40	1 – 8	4	1.64	0.02
Rajidae	6.7	6.7	6.7	1	1	1	-	0.01

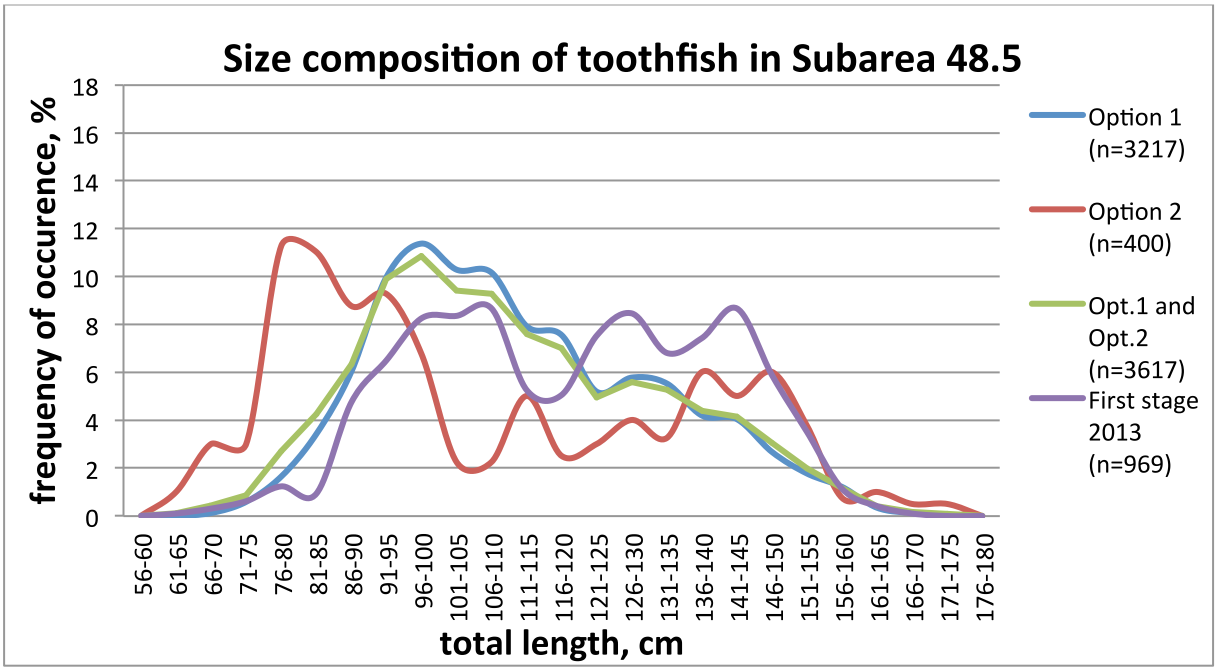

Figure 4-28 Size composition of *Dissostichus mawsoni* caught in Subarea 48.5 by exploratory fishery of the Russian Federation; Option 1 area (blue), Option 2 area (red), overall 2014 (green) and 2013 (violet).

Table 4-6 Catch of *Dissostichus* spp. taken in exploratory long line fisheries in Subarea 48.5 in2012/13 and in 2013/14 (CCAMLR data base).

Fishing season	*Dissostichus mawsoni* Total catch (tons)	*Dissostichus eleginoides* Total catch (tons)	Sum (tons)
2012/13	60	0	60
2013/14	229	2	231

In order to improve the outcome of the surveys, CCAMLR recommended the establishment of a research block bound by 74°42'S/74°32'S and 27°15'W/28°40'W with a catch limit of 60 tonnes in 2012/13.

Research fishery in CCAMLR Subarea 48.2

The southernmost part of Subarea 48.2 extends into the northern part of Domain 3. Ukraine submitted a research proposal to CCAMLR in 2013 to undertake exploratory longlining on *Dissostichus* spp. in the depth range of 600 to 2000 m. CCAMLR members noted that the paperwork and information submitted by Ukraine did not constitute a research plan as required by CM 24-01, Annex 24-01/A, format 2. A research plan adopted by CCAMLR is considered as a prerequisite to start exploratory fishing. To fulfil these requirements, some CCAMLR members recommended that a complete proposal for research by Ukraine should be submitted in the correct format for review in 2014.

4.4 Climate change scenarios

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"Editor Note: This chapter has to be developed".

4.5 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 and 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 4.1.3) is assumed to maintain cold polar conditions much longer that 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. However, there are developments of specific significance for the Weddell Sea MPA planning area.

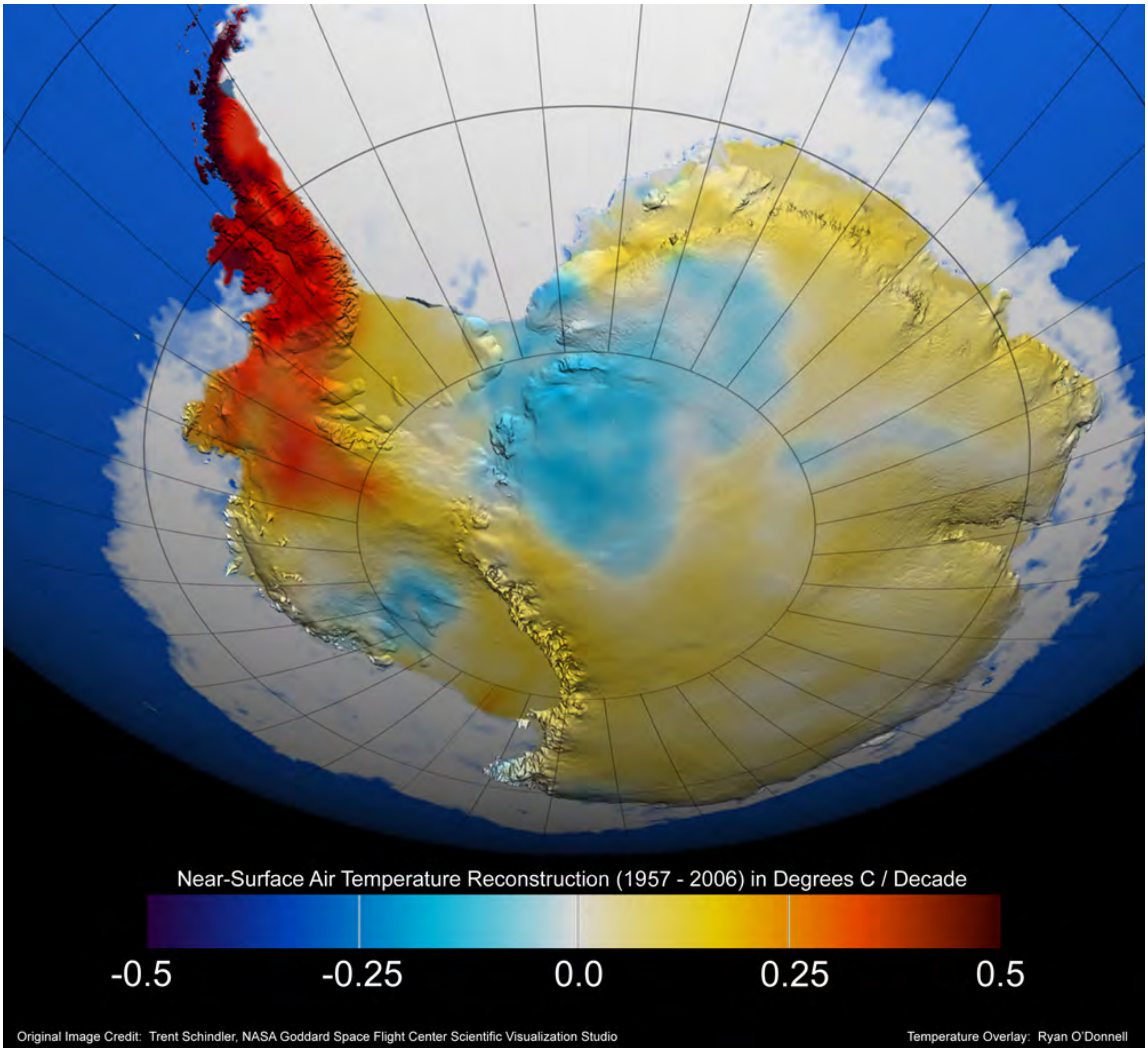

Figure 4-29 Antarctic land and shelf ice surface temperature anomalies 1957 – 2006 (°C / decade) according to O'Donnell et al. (2006). Image created by T Schindler, NASA-Goddard Space Flight Center Scientific Visualization Studio.

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. 4-29). Over the past half century, surface air and seawater temperatures increased, glaciers on the WAP and the adjacent islands retreated and the annual period of sea ice cover shortened in the area northwest to the WAP (e.g., Turner et al. 2005, Whitehouse et al. 2008, Stammerjohn et al. 2008). The most spectacular consequences of this warming so far were the disintegration of the Larsen A and Larsen B Ice Shelfs, 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 Shelfs (e.g., Gutt et al. 2013b, see also chapter 4.2.4). 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. (2007) for a synopsis.

Modelling studies by Hellmer et al. (2012) indicate that in the 2nd half of the 21th century a redirection of the Weddell Sea coastal current could would lead to increased movement of warm waters under the Filchner-Rønne Ice Shelf, staring to melt this ice shelf. With >430.000 km^2, 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 4.2.4) 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. 20111, 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 km^2 recorded in September 2014. In the Weddell Sea, sea ice extent and concentration increased particularly in the north-eastern part (Schwegmann 2012, see chapter 4.1.4). Over the last 35 years, the sea ice edge moved further north west 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 Weddell Sea MPA 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 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 4.3) 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 first research and exploratory long-line fisheries on *Dissostichus* spp. on the southeastern Weddell Sea slope hints at a rich standing stock of *Dissostichus mawsoni* (see chapter 4.3 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 4-30
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 4-3, Fig.4-25). 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 Weddell Sea MPA planning area, 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.

5. Future work

"Editor Note: This chapter has to be developed".

Major issues to be addressed would be:

- Better understanding and prediction of shelf ice disintegration: (i) advancement of deep warm water on the continental shelf below the shelf ice, (ii) thawing owing to further atmospheric warming in the Peninsula region, (iii) changes in the dynamics of the Antarctic ice shield
- Uniqueness of the Weddell Sea fauna: biodiversity, regional endemism and evolutionary history
- Resilience of the Weddell Sea ecosystem to future environmental change and accompanying gain and loss of species

- Evaluation of the role of exploited species in the Weddell Sea food web: *Dissostichus* spp. will be of particular significance

Ref: Kennicutt & Chown (2014) ?

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