

## **Reply to public comments from the topical editor**

Dear Mr Fleischer,

We thank you for your report on our updated version of the manuscript entitled "*An integrated compilation of data sources for the development of a marine protected area in the Weddell Sea*".

We have revised our manuscript according to your recommendations, i.e. we have made the following changes to the manuscript:

- 1) We have changed the PANGAEA internal DOI resolver to the official DOI resolver, i.e. <https://doi.org/>, in Table 1 and Table 2 (see pp. 14-19).
- 2) All data sets from our group of authors are now published in the data repository PANGAEA, i.e. (a) the semi-quantitative dataset on zoobenthos (p. 6) and (b) the datasets on fishes (p. 7). Please note that the DOI resolver of the data collection "fishes" is already officially registered (<https://doi.org/10.1594/PANGAEA.911972>), but the individual data sets on fish are still "in review" and password protected until the PANGAEA team uploads the data. You can view the data with this temporary access key, which was created especially for us: <https://www.pangaea.de/tok/f07d0042ef0360f809c916870b7371150d03c4ae>.
- 3) We have written an additional paragraph in the Supplementary Material, which focuses on data preparation and cleaning.

Please see the changes - we did as track changes - in the main text and the Supplementary Material.

Kind regards,

Katharina Teschke and co-authors

## **Reply to non-public comments from the topical editor**

Dear Mr Fleischer,

We thank you for your offer to participate in the ESSD pilot project to publish our R scripts. We are fully aware of the importance of reproducibility and thus of the greater transparency of scientific work. Especially in our study area, which is located at the interface between science and politics, transparency of work is a basic requirement for successful negotiations, e.g. on the establishment of MPAs. Therefore, efforts are already underway to publish our R scripts as packages in the GitHub or CRAN environment.

Best regards,

Katharina

# An integrated compilation of data sources for the development of a marine protected area in the Weddell Sea

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Abstract. The Southern Ocean may contribute a considerable part to the proposed global network of Marine Protected Areas (MPAs) that should cover about 10% of the world oceans in 2020. In the Antarctic, the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) is responsible for this task, and currently Germany leads a corresponding scientific evaluation of the wider Weddell Sea region. Compared to other marine regions within the Southern Ocean, the Weddell Sea is exceptionally well investigated. A tremendous amount of data and information has been produced over the last four decades. Here, we give a systematic overview of all data sources collected in the context of the Weddell Sea MPA planning process. The compilation of data sources comprises data produced by scientists / institutions from more than twenty countries and were either available within our institutes, provided by our collaborators, downloaded via data portals, or transcribed from the literature. It is the first compilation for this area that includes abiotic data, such as bathymetry and sea ice, and ecological data from zooplankton, zoobenthos, fish, birds and marine mammals. All data layer products based on this huge compilation of environmental and ecological data are available from the data publisher PANGAEA via the six persistent identifiers at <https://doi.org/10.1594/PANGAEA.899595> (Pehlke and Teschke, 2019), <https://doi.org/10.1594/PANGAEA.899667> (Teschke et al., 2019a), <https://doi.org/10.1594/PANGAEA.899645> (Teschke et al., 2019b), <https://doi.org/10.1594/PANGAEA.899591> (Teschke et al., 2019c), <https://doi.org/10.1594/PANGAEA.899520> (Pehlke et al., 2019a) and <https://doi.org/10.1594/PANGAEA.899619> (Pehlke et al., 2019b). This compilation of data sources with the final data layer products will serve future research and monitoring well beyond the current MPA development process.

## 1 Introduction

Marine Protected Areas (MPAs) have experienced a significant increase in number and coverage at a global scale during recent decades (e.g. Mora and Sale, 2011; McDermott et al., 2018; UNEP-WCMC and IUCN, 2019). The number of MPAs has increased almost 1.5 times since the 1990s and the total area protected is currently almost 30 million km<sup>2</sup>. At the United Nations World Summit on Sustainable Development in 2002 the international community of states reached an agreement about the establishment of a representative network of MPAs for the purposes of long-term conservation of marine biodiversity by 2012 (A/CONF.199/20, 2002). The

adopted *strategic plan for biodiversity 2011-2020* of the Convention on Biological Diversity aims at the conservation of at least 10 % of the coastal and offshore marine areas by 2020 based on a MPA network (CBD, 2010). The Southern Ocean may contribute a considerable proportion of this MPA network due to its size, and the uniqueness of the Antarctic environment renders its conservation the more urgent.

5 The Weddell Sea represents the southerly part of the Atlantic Sector of the Southern Ocean. About one quarter of the Weddell Sea's entire marine area covers the continental shelf along the eastern contour of the Antarctic Peninsula and the Antarctic continent up to 20°E as a non topographic delineation. The Weddell Sea is deserving protection in multiple respects. On the one hand, all arguments for the conservation of the Southern Ocean hold true for the Weddell Sea, too: An extreme environment mostly dominated by the seasonal dynamic of the sea ice  
10 with an excellent adapted biota. The biodiversity is - particularly in the benthos - very high (e.g. Brey et al., 1994; Brandt et al., 2007), and there is a significant number of endemic species, i.e. unique to the Antarctic or even to the Weddell Sea (e.g. Arntz et al., 1994; Clarke and Johnston, 2003; Linse et al., 2006). Moreover, the Weddell Sea plays an important role for seabirds, penguins and marine mammals. Almost one third of the entire population of emperor penguins (Fretwell et al., 2012) and a major part of the circum-Antarctic population of  
15 crabeater seals (*cf.* Bester and Odendaal, 2000; Southwell et al., 2012; Gurarie et al. 2017a, b) apparently occurs in the Weddell Sea. Sponge associations which are comparable to tropical reef systems in terms of their structural and functional complexity occur along the eastern Weddell Sea shelf (Barthel and Gutt, 1992), and on the broad shelf in the southern Weddell Sea a special benthic community - adapted to very cold water temperatures - seems to resident (Teschke et al., 2016).

20 The Weddell Sea is - despite being one of the most remote and inaccessible places on earth - relatively well investigated compared to other Antarctic regions.

Since approximately 30 years the Weddell Sea is the geographical focus area of the German Antarctic research. In addition, there are manifold research activities of other nations. Consequently, we were able to compile a tremendous amount of environmental and ecological data to support the development of a Weddell Sea MPA  
25 (hereafter: WSMPA) under the Commission for the Conservation of Antarctic Marine Living Ressources (CCAMLR). Here we present a systematic overview of all environmental and ecological data sources collected for the development of a WSMPA and provide data layer products that are based on this data compilation.

## 2 Data description

### 2.1 Study site

30 The WSMPA Planning Area in which we acquired the environmental and ecological data is located between the Antarctic Peninsula and 20°E (Fig. 1). The northern border is at 64°S and the continental margin forms the southern border. This area is defined by CCAMLR's MPA Planning Domains in the CCAMLR Convention Area (SC-CAMLR-XXX, 2011) and by aiming at a bio-geographically homogeneous area, particularly on the shelf (Teschke et al., 2016). In addition to the WSMPA Planning Area (approx. 4.2 million km<sup>2</sup> in size) we compiled  
35 data for a 200 km wide buffer area near the Antarctic Peninsula, which is part of an MPA initiative led by Argentina and Chile (CCAMLR-XXXVII/31, 2018). This buffer zone is adjacent northerly to the northern border of the WSMPA Planning Area and has the eastern and western boundaries at 30°W and 60°W, respectively. Some data (e.g. seal tracking data), extend beyond the WSMPA Planning Area (plus buffer) and

originate from adjacent regions of the Weddell Sea, such as the Bellinghausen Sea along the west side of the Antarctic Peninsula.

## 2.2 Data availability

All raw data sets of environmental and ecological parameters collected by the end of 2016 and further processed as part of the WSMMPA planning process are systematically described and the primary reference is mentioned, such as the data portal on which the data are publically available, the institute/organisation on which the data can be requested on demand or the contact to the respective data provider (see Table 1 and 2; see all data records in Fig. 2 and Fig. S1). In addition, we offer data layer products that we developed on the basis of the raw data sets whose sources are described here. The methods used to process and analyse the data and to develop each data layer are described in detail in the Supplement. All data layer products with metadata description are freely available from the data publisher PANGAEA via the six persistent identifiers at <https://doi.org/10.1594/PANGAEA.899595> (Pehlke and Teschke, 2019), <https://doi.org/10.1594/PANGAEA.899667> (Teschke et al., 2019a), <https://doi.org/10.1594/PANGAEA.899645> (Teschke et al., 2019b), <https://doi.org/10.1594/PANGAEA.899591> (Teschke et al., 2019c), <https://doi.org/10.1594/PANGAEA.899520> (Pehlke et al., 2019a) and <https://doi.org/10.1594/PANGAEA.899619> (Pehlke et al., 2019b) (see Table 1 and 2). The data layers are available either as ArcMAP packages (as mxd file, containing a map document with all associated files) or as individual GIS files for those who use another GIS-software instead of the ESRI software (ArcMap). The shape and raster files, all with the same spheroid (WGS 1984) and projection (South Pole Lambert Azimuthal Equal Area, EPSG 102020), were processed in such a way that they can be easily used for the analysis of MPA scenarios or other geostatistical analyses in the Weddell Sea without direct access to the underlying raw data. For example, the shape and raster files could be stacked to identify hot- and coldspots of biodiversity, or certain layers could be used as explanatory variables in species distribution models.

## 2.3 Environmental data

### 2.3.1 IBCSO data

The bathymetric data used in the context of the WSMMPA planning initiative originate from the first regional digital bathymetric model (DBM) established in the International Bathymetric Chart of the Southern Ocean (IBCSO) Version 1.0 programme (data request: April 2013) (Table 1; Fig. 3a). This chart model is based upon bathymetric data of different origin, such as multi-beam and single beam data, digitized depths from nautical charts, predicted bathymetry, from many hydrographic offices, scientific institutions and data centres. The IBCSO Version 1.0 DBM has a horizontal resolution of 500 m x 500 m and a vertical resolution of 1 m based on a polar stereographic projection with true scale at 65° referenced to WGS84 ellipsoid (Arndt et al., 2013a, b).



### 2.3.2 AMSR-E sea ice maps

Daily high resolution sea ice maps of the Antarctic Ocean are provided by the PHAROS group (PHysical Analysis of RemOte Sensing images) at the Institute of Environmental Physics, University of Bremen, Germany. The sea ice raster maps, which were used in the context of the WSMMPA planning initiative, are derived from satellite observations of daily sea ice concentration by the Advanced Microwave Scanning Radiometer - Earth Observing System (AMSR-EOS) instrument on board the Aqua satellite. Daily AMSR-E sea ice concentration data (Jun 2002 - Oct 2011) were downloaded from IUP, University of Bremen (data request: 18-12-2013) (see Table 1; Fig. 3b). The ARTIST Sea Ice (ASI) concentration algorithm was used with a spatial resolution of 6.25 km x 6.25 km (Spreen et al., 2008) and a polar stereographic projection (EPSG: 3976).

### 2.3.3 FESOM data

Monthly mean values of seawater temperature, salinity and current velocity from 1990 to 2009 were derived from the Finite Element Sea Ice - Ocean Model (FESOM) (Table 1; Fig. 3c, d). The model run was initialised on January, 1st 1980 with hydrographic data from the Polar Science Center Hydrographic Climatology (Steele et al., 2001), and forced with NCEP daily atmospheric re-analysis data (Kalnay et al., 1996) for 1980 to 2009. For more information on FESOM and the atmospheric forcing data sets see e.g. Timmermann et al. (2009) and Haid and Timmermann (2013), respectively. The FESOM raster has a resolution of 0.18° (x) x 0.05° (y); in the vertical, two z-levels (i.e. sea surface and sea bottom) are used. The raster bases on WGS84 geographic coordinate system (EPSG: 4326).

IBCSO data, AMSR-E sea ice maps and FESOM data were used in a pelagic regionalisation analysis for the Weddell Sea. The respective data layer products are available at <https://doi.org/10.1594/PANGAEA.899595> ("Pelagic regionalisation - clustering approach"). The clustering approach to classify different pelagic provinces is described in the Supplement. In addition, the data sets were used as environmental variables in various geostatistical approaches to develop spatial distribution maps for (i) adult Antarctic krill (AMSR-E), (ii) ice krill (IBCSO, FESOM), (iii) echinoderms (FESOM), (iv) demersal fish (IBCSO, FESOM), (v) Antarctic toothfish (IBCSO), (vi) Antarctic petrel (IBCSO, AMSR-E, FESOM) and (vii) emperor penguins (AMSR-E). The methods used to develop the different spatial distribution maps are described in the Supplement and the PANGAEA link to the respective data layer products (incl. file names) is given in the corresponding subsection under "2.4 Ecological data".

### 2.3.4 SeaWiFS data

Near-surface chlorophyll a concentration values stem from the Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) measurements on board of the OrbView-2 (formerly SeaStar) spacecraft (Table 1). The monthly aggregated data (1997 to 2010) were downloaded as level 3 standard mapped images (SMI) with a spatial resolution of 9 km x 9 km (data request: 09-09-2014).

### 2.3.5 WOA13 data

Data on dissolved oxygen, phosphate and nitrate were obtained from the World Ocean Atlas 2013 version 2 (WOA13 V2) (Garcia et al., 2014a, b) (Table 1). The data (1955 to 2012) were downloaded as monthly statistical means with a horizontal resolution of 1° (x) x 1° (y) and 57 and 37 vertical (z) levels between 0 to 1500 m and 0 to 500 m for dissolved oxygen and phosphate/nitrate, respectively. The data request was on 11-07-2013 (dissolved oxygen), 17-07-2013 (nitrate) and 18-07-2013 (phosphate), respectively.

### 2.3.6 Data on chemical sediment components

A data compilation on total organic carbon content and calcium carbonate and silica in surface sediments were downloaded from the data archive PANGAEA (Seiter et al., 2004a, b, c, and references therein) (see Table 1). Data on biogenic silica of the sediment surface were obtained from PANGAEA, too (Geibert et al., 2005 b).

The data described under 2.3.4 to 2.3.6 were used as explanatory variables in the Antarctic krill species distribution model (SDM) (SeaWiFS, WOA13, chemical sediment components) and in the demersal fish SDM (WOA13, chemical sediment components). The SDMs are described in detail in the Supplement and the PANGAEA link to the respective data layer products (incl. file names) is given in the corresponding subsection under "2.4 Ecological data".

## 2.4 Ecological data

In the following, we describe the sources of raw data sets used in the WSMMPA planning process and indicate which data layer product was developed on the basis of which raw data sets per higher taxonomic group. In addition, the methods for processing and analysing the data and for developing each data layer are described in detail in the Supplement.

### 2.4.1 Zooplankton

#### Antarctic krill (adults)

The WSMMPA data collection on adult Antarctic krill (*Euphausia superba*) originates from (i) historical UK data from "Discovery Expeditions" (1928-1939) and data collected during the SIBEX cruise by British Antarctic Survey, (ii) five South African data sets from the 1990s, (iii) four Soviet data sets from 1998 and 1990, (iv) Polish data (Witek et al., 1985) and (v) German data from location discovery cruises with MV "Polarsirkel" in 1979/80 and 1980/81 (Siegel, 1982), RV "Walther Herwig" cruises (1975/76, 1977/78) and the 2004 Lazarev Sea Krill Survey (LAKRIS) (RV "Polarstern" cruise ANT-XXI/4) (Siegel, 2012). All the data are publicly available via the database KRILLBASE (doi.org/brg8) (Atkinson et al., 2017) (see Table S2 in the Supplement that provides a detailed list of data used from KRILLBASE). The data from KRILLBASE were complemented by abundance data on *E. superba*, which were collected (a) during the Norwegian Antarctic research expedition 1976/77 (MV "Polarsirkel"), (b) during two Soviet research cruises in 1977 and 1983, (c) in the context of the Lazarev Sea Krill Survey as well as (d) during RV "Polarstern" cruises ANT-V/1-3, ANT-VII/4, ANT-XVIII/4

and ANT-XXIX/3 (Table 2). Furthermore, Fisheries data on *E. superba* for the WSMMPA Planning Area (i.e. Statistical Subarea 48.5 and southern part of Subarea 48.6) stem from the CCAMLR database (data request through CCAMLR Secretariat: 03-10-2013) (Table 2).

All these data were used in a species distribution model (SDM) of adult Antarctic krill and ultimately led to a data layer product showing habitat suitability for adult Antarctic krill in the WSMMPA Planning Area (see doi 10.1594/PANGAEA.899667; file name: "Adult Antarctic krill, *Euphausia superba* - habitat suitability prediction").

#### **Antarctic krill (larvae)**

Abundance data on Antarctic krill larvae stem from (a) the Antarctic research expeditions 1976/77 and 1979/80 with MV "Polarsirkel", (b) the First International BIOMASS Experiment survey (FIBEX), (c) the Lazarev Sea Krill Survey (LAKRIS) as well as (d) RV "Polarstern" cruise ANT-VII/4 and the combined RV "Polarstern" (ANT-VIII/2) and RV "Akademik Fedorov" cruises (see Table 2).

All data on Antarctic krill larvae were used for an interpolation approach and led to a map of the interpolated abundances of krill larvae in the WSMMPA Planning Area (see doi 10.1594/PANGAEA.899667; "Antarctic krill larvae, *Euphausia superba* - interpolated abundance").

#### **Ice krill**

Abundance data on adult ice krill (*Euphausia crystallorophias*) originate from pelagic trawl surveys during (a) the German Antarctic research cruise 1975/76 with "Walther Herwig", (b) the "Pre-Site Survey" 1979/80 with MV "Polarsirkel", (c) the Lazarev Sea Krill Survey as well as (d) RV "Polarstern" cruises ANT-V/1-3, ANT-VII/4 and ANT-XXIX/3 (Table 2).

The abundance data on *E. crystallorophias* were used for an interpolation approach and led to a map showing the interpolated abundances of ice krill (see doi 10.1594/PANGAEA.899667; "Ice krill, *Euphausia crystallorophias* - interpolated density"). In addition, the abundance data on *E. crystallorophias* were used for "ground truthing" of the potential ice krill habitat (doi 10.1594/PANGAEA.899667; "Ice krill, *Euphausia crystallorophias* – potential habitat").

All data about *E. superba* and *E. crystallorophias*, which were used additionally to KRILLBASE and the CCAMLR database, are stored in the data warehouse of the Thuenen Institute of Sea Fisheries (<https://www.thuenen.de>; contact: Lara Kim Hühnerlage; [kim.huenerlage@thuenen.de](mailto:kim.huenerlage@thuenen.de)) and can be requested on demand.

### **2.4.2 Zoobenthos**

#### **Sponges**

Abundance data and semi-quantitative data on sponges (higher taxonomic groups), which were compiled in the context of the WSMMPA planning initiative, originate from zoobenthos data sets. The abundance data (Gerdes, 2014 a-o) and the semi-quantitative data (Teschke and Brey, 2020) are publically available via PANGAEA (see Gerdes, 2014 a-o). The semi-quantitative data set can be requested from us if required (contact: Katharina

~~Teschke, AWI) and is available as presence-absence data set in PANGAEA (see Teschke and Brey, 2019a)~~ (see Table 2).

Based on these data, we developed a map of the occurrence of sponges in the WSMMPA Planning Area (doi 10.1594/PANGAEA.899645; "Sponges, Porifera - interpolated presence").

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### Echinoderms

The data set on echinoderms consists of presence-absence data on species level for asteroids, abundance data on ophiuroid taxa as well as holothurian taxa. The first two data sets are available in PANGAEA (Teschke and Brey, ~~2019b~~2019a, eb), the latter in the information system biodiversity.aq (Gutt et al., 2014).

10 These data were used in a clustering approach to ultimately identify the potential habitat for echinoderms in the WSMMPA Planning Area by environmental proxies (doi 10.1594/PANGAEA.899645; "Special echinoderm assemblage - pot habitat").

### 2.4.3 Fish

#### Antarctic silverfish and demersal fish

15 The WSMMPA data collection on Antarctic silverfish larvae (*Pleuragramma antarctica*) originates from quantitative zooplankton data sets obtained during the RV "Polarstern" cruises ANT-I/2 and ANT-III/3 and during the Lazarev Sea Krill Survey (LAKRIS) (Table 2). The first mentioned data (ANT-I/2) are stored in the data warehouse of the Thuenen Institute of Sea Fisheries and can be requested on demand (contact: Lara Kim Hühnerlage). Fish larvae data from ANT-III/3 are available from Hubold et al. (1988) and the LAKRIS data can  
20 be requested from Hauke Flores (AWI) if required. Abundance data on demersal fish and adult *P. antarctica* stem from benthic and pelagic trawl surveys from six "Polarstern" cruises between 1996 and 2011 (Table 2), and ~~can be are published in PANGAEA equested from us if required (contact: Rainer Knust 2020 or references therein, i.e. Balguerías and Knust, 2020; Knust et al., 2020a-dAWI; Schröder and Knust, 2020)~~. This data compilation was complemented by data on demersal fish and *P. antarctica* derived from trawl and dredge  
25 surveys published in PANGAEA (Drescher et., 2012; Ekau et al., 2012a, b; Hureau et al., 2012; Kock et al., 2012; Wöhrmann et al., 2012).

All abundance data on Antarctic silverfish (adults and larvae) were used for an interpolation approach and led to a map of the interpolated abundances of *P. antarctica* in the WSMMPA Planning Area (doi 10.1594/PANGAEA.899591; "Antarctic silverfish, *Pleuragramma antarctica* - interpolated abundance").

30 All data on demersal fish were used in a SDM and led to a data layer product showing the habitat suitability for demersal fish in the WSMMPA Planning Area (see doi 10.1594/PANGAEA.899591; "Demersal fish - habitat suitability prediction").

#### Antarctic toothfish (adults)

35 Fishery data on the Antarctic toothfish (*Dissostichus mawsoni*) for the WSMMPA Planning Area (i.e. Statistical Subarea 48.5 and southern part of Subarea 48.6) were taken from the CCAMLR database and requested through the CCAMLR Secretariat (data request: 03-08-2016) (Table 2).

The data were used to determine the potential habitat of *D. mawsoni* in the WSMMPA Planning Area (see doi 10.1594/PANGAEA.899591; "Adult toothfish, *Dissostichus mawsoni* - pot habitat").

### Demersal fish nesting sites

Information about nesting sites of demersal fish was collected during the RV “Polarstern” cruises PS82 (Knust and Schröder, 2014) and PS96 (Piepenburg, 2016). The data collected during RV “Polarstern” cruises were supplemented by data from the literature (Daniels 1978, 1979; Jones and Near 2012). The map with the locations of the nesting sites of demersal fish is available at PANGAEA (doi 10.1594/PANGAEA.899591; "Demersal fish - observation of nesting sites") and is also shown in the Supplement (see Fig. S12).

### 2.4.4 Flying and non-flying seabirds

#### Breeding and non-breeding Adélie penguins

Tracking data on breeding and non-breeding Adélie penguins (*Pygoscelis adeliae*) originate from (i) British Antarctic Survey (BAS) inventory data from Phil Trathan (ID 754) and Mike Dunn and P. Trathan (ID 764 (only data on breeding Adélies), ID 773, 779), (ii) a data set from BAS (P. Trathan) and Instituto Antártico Argentino (Mercedes Santos) (ID 753) and (iii) a data set from the US AMLR Program from Jefferson Hinke and Wayne Trivelpiece (NOAA) (ID 910) (see also Table 2). All the data are stored in the Birdlife International's Seabird Tracking Database (data request: 20-10-2015). Adélie penguins breeding locations and estimated abundances of breeding pairs were derived from Lynch and LaRue (2014).

The tracking data on *P. adeliae* were used to model the probability of breeding and non-breeding *P. adeliae* occurrence during foraging (doi 10.1594/PANGAEA.899520; "Breeding Adélie penguin, *Pygoscelis adeliae* - modelled foraging trips" and "Non-breeding Adélie penguin, *Pygoscelis adeliae* - modelled foraging trips"). The final data layer product for breeding *P. adeliae* also depict breeding locations and estimated abundances of breeding pairs as well as buffer areas around each colony.

#### Breeding Emperor penguins

Data on Emperor penguin (*Aptenodytes forsteri*) colony locations and breeding population estimates were derived from Fretwell et al. (2012, 2014) (Table 2).

These data were used to develop a probability map of foraging areas for *A. forsteri* (doi 10.1594/PANGAEA.899520; "Breeding emperor penguin, *Aptenodytes forsteri* - modelled foraging areas").

#### Antarctic petrels

Information on breeding locations and estimated number of breeding pairs of the Antarctic petrel (*Thalassoica antarctica*) were kindly provided by Jan van Franeker (Wageningen University & Research) and are published in van Franeker et al. (1999) (Table 2).

The information on breeding pairs and their colony locations is shown in the final data layer product next to modelled foraging habitats of *T. antarctica* (doi 10.1594/PANGAEA.899520; "Antarctic petrel, *Thalassoica antarctica* - modelled foraging areas").

### 2.4.5 Pinnipeds

Tracking data from pinnipeds were obtained from the MEOP data portal "Marine Mammals Exploring the Oceans Pole to Pole" (data request: 14-11-2016) (see Table 2 for a detailed list of data used). In addition, we have used MEOP data (UK data: ct27, ct70; German data: ct113, wd06, wd07) for which unconditional sharing were not yet accepted at the time of data retrieval and were provided by Lars Boehme (University of St. Andrews) and us (H. Bornemann), respectively. The UK and German data sets are now also freely accessible from the MEOP data portal. Furthermore, the data from the MEOP data portal were complemented by tracking data sets on southern elephant seals (Tosh et al., 2009a, b; James et al., 2012a, b), Weddell seals (McIntyre et al., 2013a, b) and crabeater seals (Nachtsheim et al., 2016a, b) stored in PANGAEA.

All these tracking data were used to model the probability of seal occurrence during foraging (doi 10.1594/PANGAEA.899619; "Seal abundance - modelled prediction values").

Point data from pack-ice seals (unspecified taxa) based on aerial surveys are from Plötz et al. (2011a-e) and were downloaded from PANGAEA (Table 2). These data were sampled during five flight campaigns from 1996 to 2001 within the Antarctic Pack Ice Seals (APIS) programme. In addition, information on crabeater seal densities (predicted or observed) was derived from Bester et al. (1995 and 2002), Flores et al. (2008) and Forcada et al. (2012; Table 2).

All the APIS point data and information on seal densities were used to develop a map showing the distribution patterns of seals in the WSMMPA Planning Area (doi 10.1594/PANGAEA.899619; "Seal abundance - modelled and interpolated prediction values").

## 3 Outlook

This is the first compilation of data sources for the Antarctic Weddell Sea and adjacent seas, which considers data across the entire ecosystem: i.e., from abiotic data, such as bathymetry and sea ice, to ecological data ranging from zooplankton and zoobenthos to fish, birds and marine mammals. The effort to create such a compilation of data sources was directly coupled with the initiative to develop a WSMMPA. However, our compilation of data sources will facilitate the future research on fauna, ecology and nature conservation in the Weddell Sea. Using our systematic overview of available data for the development of a specific data collection, future projects save the time-consuming multi-parameter data search from the scratch. In addition, our work serves to guide future studies aimed at closing data gaps in the wider Weddell Sea region and/or simply pointing to specific data sets that may be of particular interest to future generations (baseline is a particular issue). For example, some of the ecological data sets were collected in the 1980s and earlier, when the Weddell Sea was still almost pristine and hardly affected by any anthropogenic activities, so that these data sets are optimally suited to describe a reference state for assessing the effect of pressures on the Weddell Sea ecosystem. In addition, the ecological data - with a few exceptions - provide information on abundances of the respective taxa and are therefore better suited as an indicator for environmental changes than presence-absence data or presence data only.

Ultimately, the compilation of data sources serves to motivate researchers to incorporate further data, both from existing "paper sources" and from future measurements, into existing data repositories and archives.

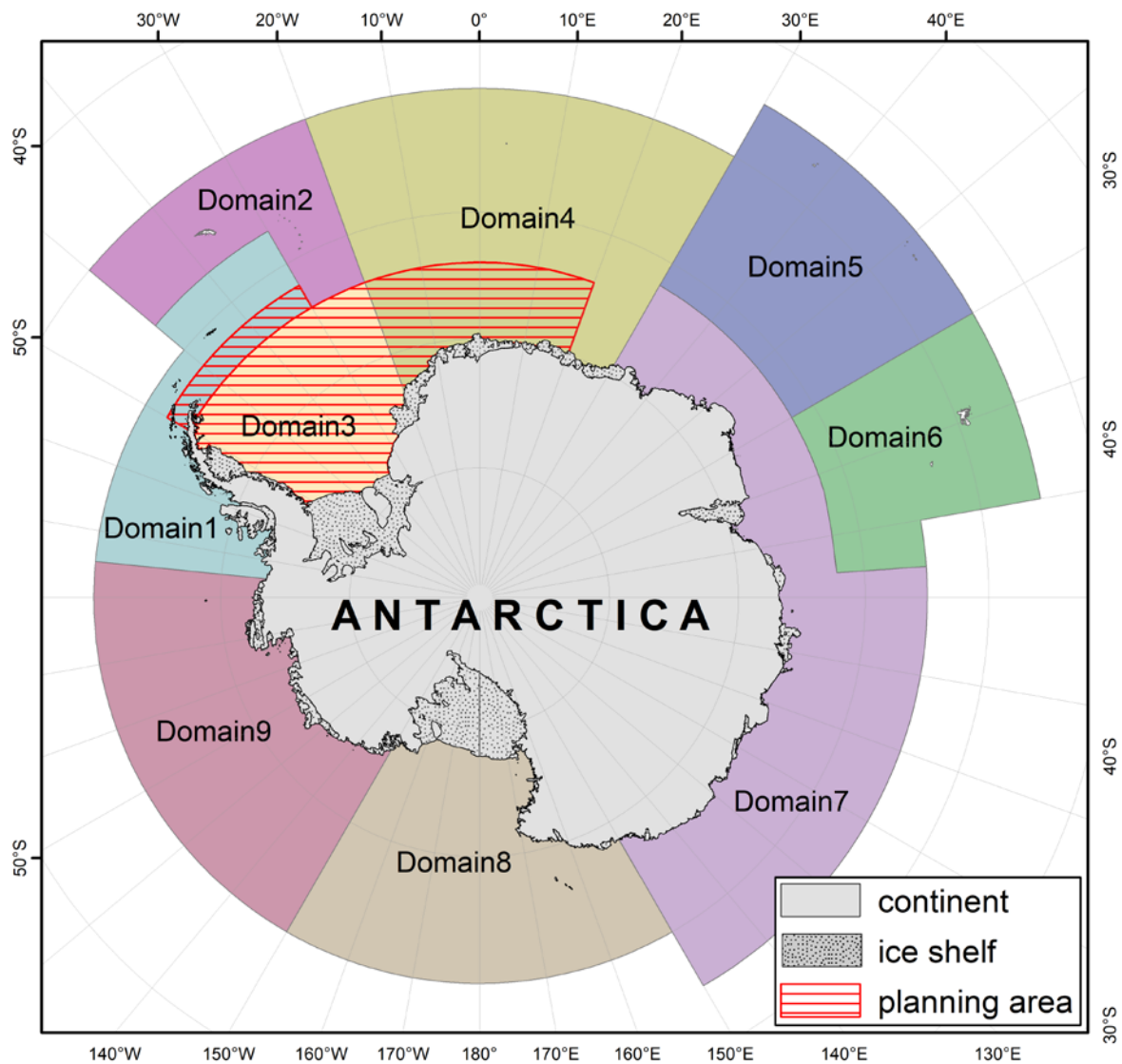
Subsequent work will focus on the development of an efficient and tailor-made management system for the storage of these complex and heterogeneous data and information of WSMPA data compilation and automated data mining, handling and analysis. This system will serve three purposes: (i) to better enable a more holistic and integrative approach towards ecosystem research in the Weddell Sea in general, (ii) to enable the management of the WSMPA to carry out the tasks of the Research and Monitoring Programme as a mandatory part of an MPA under CCAMLR when adopting the MPA, and (iii) to provide key stakeholders and the public with access to data, information and management measures related to the ecosystem of the Weddell Sea region in general and the WSMPA in particular. The CCAMLR MPA Information Repository (CMIR) currently being developed by the CCAMLR Secretariat will also be available in the future as a suitable storage location for metadata on CCAMLR MPAs in Antarctica.

**Author contribution.** KT collected all data together, described the metadata and led the writing of the paper. HP took over the technical part of the data acquisition (retrieval, storage, processing). VS collected and prepared the data on zooplankton for further analyses within the WSMPA planning. HB and RK were significantly involved in the collection of the data on pinnipeds and fishes, respectively. TB collaborated in the paper writing.

**Competing interests.** The authors declare that they have no conflict of interests.

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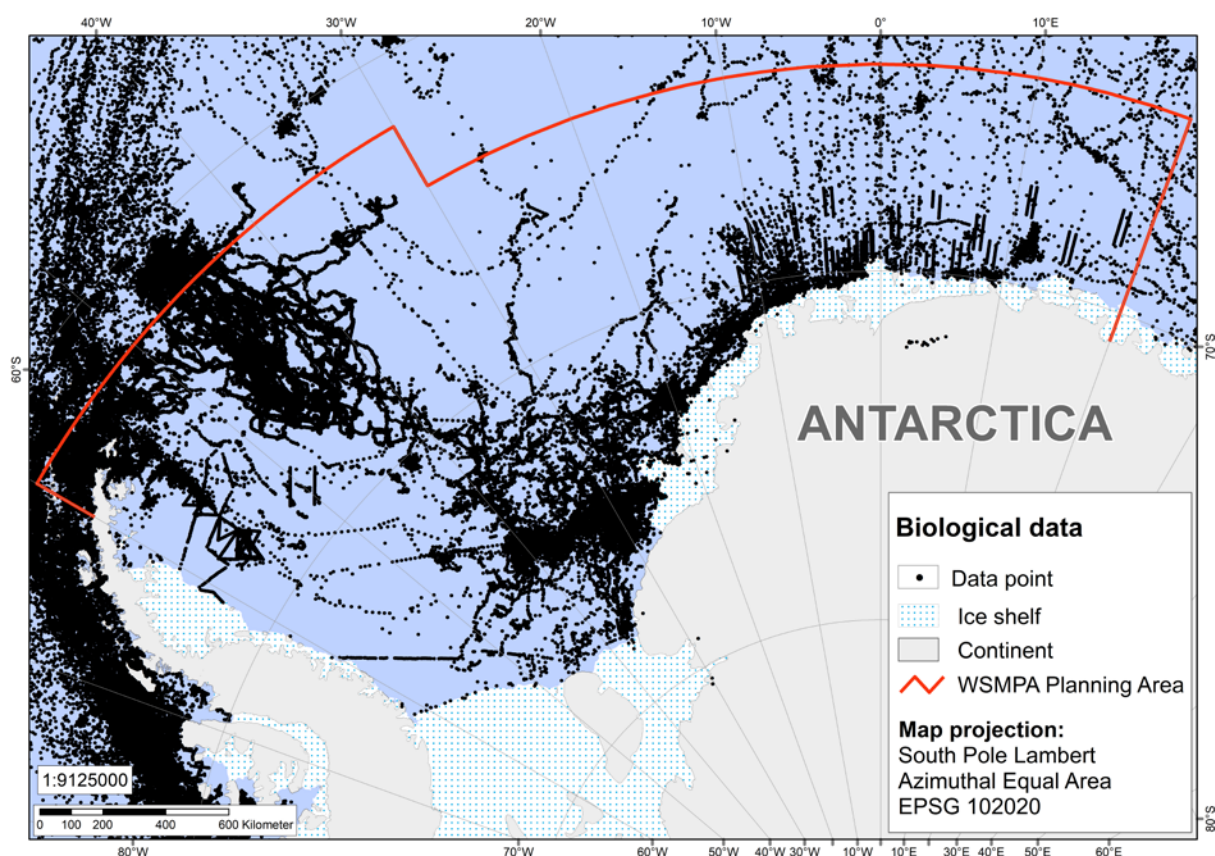
**Figure 1.**



**Figure 1.** CCAMLR Convention Area with its Marine Protected Area (MPA) Planning Domains and the planning area (incl. 200 km wide buffer area near the Antarctic Peninsula) for the development of a MPA in the wider Weddell Sea (red shaded area). 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.

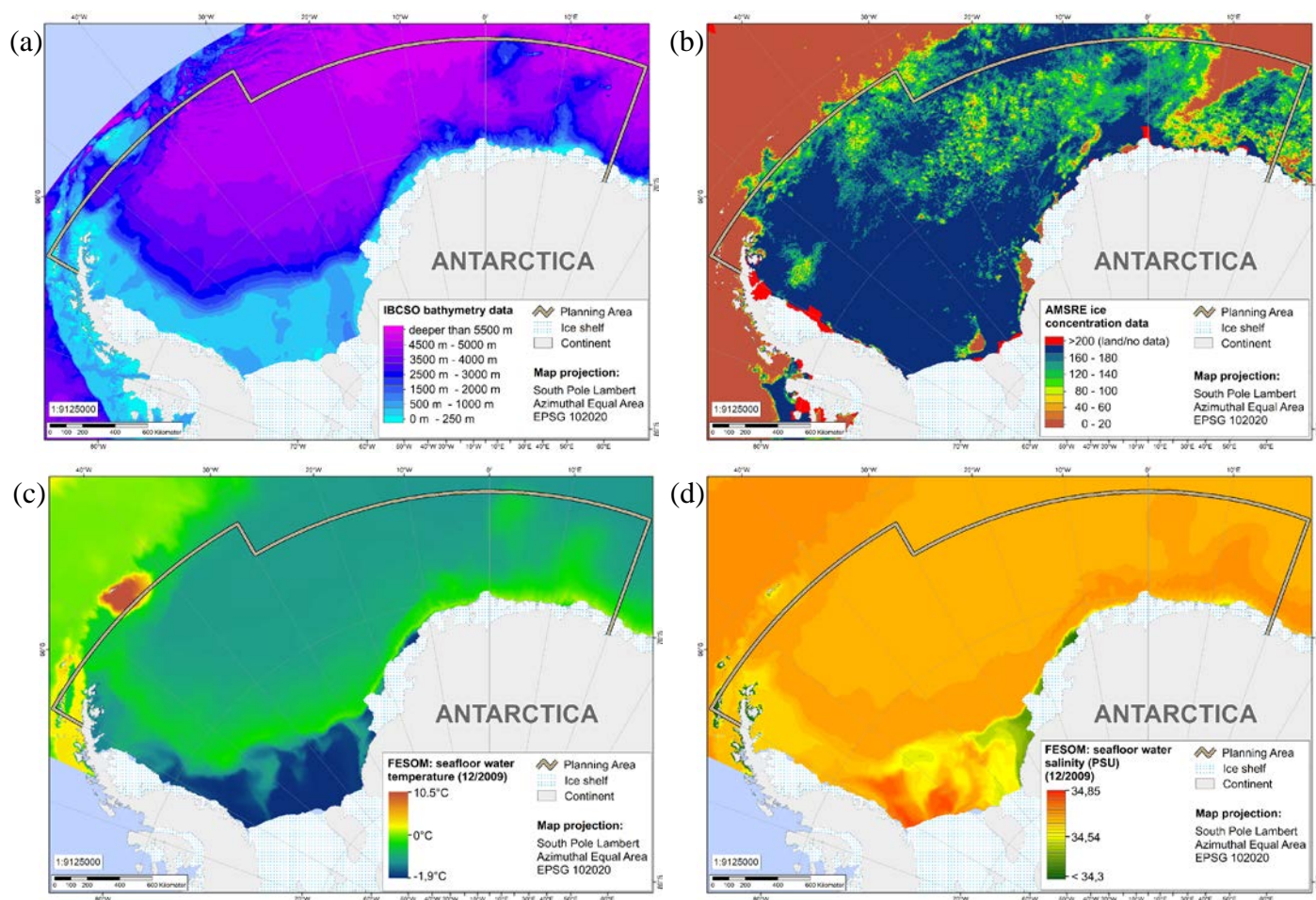


**Figure 2.**



- 5 **Figure 2.** Distribution of all data recordings across the wider Weddell Sea region, which were compiled in the context of the WSMPA planning initiative. Figure S1 in the Supplement provides the distribution of data recordings per higher taxonomic group, i.e. zooplankton, zoobenthos, fishes, birds and pinnipeds.

**Figure 3.**



**Figure 3.** Raster data sets of environmental parameters, which have been used as basic data in a regionalisation analysis of environmental provinces in the context of the WSMPA planning. IBCSO bathymetry (a), AMSR-E sea ice maps (exemplarily for 15 December 2009) (b), FESOM sea bottom temperature and salinity data (exemplarily for December 2009) (c, d).

## Tables

**Table 1.** Data collection of environmental parameters compiled for the development of a marine protected area (MPA) in the wider Weddell Sea (Antarctica). For each raw data set, the name of the data source, the primary reference, such as the data portal on which the data is publicly accessible or the contact to the respective data provider, as well as examples of publications that have used the respective primary data set are listed. In addition, DOI links to the final WSMMPA data layer products is provided, which includes the respective raw data set.

Content of Data	Name of data source	Reference to primary data set or data provider	Reference to publications, which have used primary data set (exemplarily)	DOI link to ArcMap packages
Depth	International Bathymetric Chart of the Southern Ocean (IBCSO) Version 1.0	Arndt et al. (2013a) [data request: April 2013]	Arndt et al. (2013b) Jerosch et al. (2016)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899595">https://doi.pangaea.de/org/10.1594/PANGAEA.899595</a> <a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a> <a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Temperature, salinity, current velocity	Finite Element Sea Ice - Ocean Model (FESOM)	Contact: Ralph Timmermann(AWI) ralph.timmermann@awi.de [data delivery: 20-11-2013]	Danilov et al. (2004) Timmermann et al. (2009) Haid and Timmerman (2013)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899595">https://doi.pangaea.de/org/10.1594/PANGAEA.899595</a> <a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899645">https://doi.pangaea.de/org/10.1594/PANGAEA.899645</a> <a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a> <a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Sea ice concentration	Daily AMSR-E Sea Ice Maps	<a href="https://seaice.uni-bremen.de/data/">https://seaice.uni-bremen.de/data/</a> Contact: Gunnar Spreen, Christian Melsheimer or Georg Heygster (Institute of Environmental Physics, University of Bremen) [data request: 18-12-2013]	Spreen et al. (2008)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899595">https://doi.pangaea.de/org/10.1594/PANGAEA.899595</a> <a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Chlorophyll a concentration	Sea-Viewing Wide Field-of-View Sensor (SeaWiFS) measurements	NASA's OceanColor website [data request: 09-09-2014]	Moore and Abbott (2000) Gregg and Casey (2004)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Dissolved oxygen, phosphate, nitrate	World Ocean Atlas 2013 version 2 (WOA13 V2)	<a href="https://www.nodc.noaa.gov/OC5/woa13/woa13data.html">https://www.nodc.noaa.gov/OC5/woa13/woa13data.html</a> [data request: 11 to 18 July 2013]	Garcia et al. (2014a, b)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a> <a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Total organic carbon content		Seiter et al. (2004b)	Seiter et al. (2004a)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Calcium carbonate, silica		Seiter et al. (2004c)	Seiter et al. (2004a)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Biogenic silica		Geibert et al. (2005b)	Geibert et al. (2005a)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>

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**Table 2.** Data collection of ecological parameters compiled for the development of a marine protected area (MPA) in the wider Weddell Sea (Antarctica). For each raw data set, the name of the data source, the primary reference, such as the data portal on which the data is publicly accessible or the contact to the respective data provider, as well as the respective cruise reports and/or examples of publications that have used the respective primary data set are listed. In addition, DOI links to the final WSMMPA data layer products is provided, which includes the respective raw data set. The raw data sets are structured according to higher taxonomic groups, i.e. zooplankton, zoobenthos, fishes, birds and pinnipeds. Within each higher taxonomic group, the individual raw data sets are sorted by taxa and the oldest data set is listed first each time.

Data content	Name of data source	Reference to primary data set or data provider	Cruise reports	Reference to publications, which have used primary data set (exemplarily)	DOI link to ArcMap packages
<b>Zooplankton</b>					
Adult Antarctic krill (abundances)	KRILLBASE (doi.org/brg8) See detailed list of data in Table S2 in Supplement	Atkinson et al. (2017)		Atkinson et al. (2004) Atkinson et al. (2008) Piñones and Fedorov (2016) Atkinson et al. (2019)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult Antarctic krill (catch and effort)	Japanese, Norwegian and Soviet fisheries data	CCAMLR database; Contact: CCAMLR Secretariat [data request: 03-10-2013]			<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult Antarctic krill (abundances)	MV Polarsirkel 1976/77	Database of Thuenen Institute of Sea Fisheries Contact: Lara Kim Hühnerlage kim.huenerlage@thuenen.de		Fevolden (1979)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult Antarctic krill (abundances)	Soviet cruises: RV Gizhiga 1977 and RV Volny Vetter 1983	Database of Thuenen Institute of Sea Fisheries			<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult Antarctic krill (abundances)	ANT-XVIII/4	Database of Thuenen Institute of Sea Fisheries	Fahrbach et al. (2003)		<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult Antarctic krill & ice krill (abundances)	Lazarev Sea Krill Survey (LAKRIS) data (ANT-XXI/4, ANT-XXIII/2, ANT-XXIII/6, ANT-XXIV/2)	Database of Thuenen Institute of Sea Fisheries	Smetacek et al. (2005) Strass (2007) Bathmann (2008, 2010)	Siegel (2012)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult Antarctic krill & ice krill (abundances)	ANT-XXIX/3	Database of Thuenen Institute of Sea Fisheries	Gutt (2013)	Siegel et al. (2013)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult Antarctic krill & ice krill (abundances)	ANT-V/3	Database of Thuenen Institute of Sea Fisheries	Schnack-Schiel (1987)		<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>

Adult Antarctic krill & ice krill (abundances)	ANT-VII/4	Database of Thuenen Institute of Sea Fisheries	Arntz et al. (1990)		<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult ice krill (abundances)	RV Walther Herwig 1975/76	Database of Thuenen Institute of Sea Fisheries			<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Adult ice krill (abundances)	MV Polarsirkel 1979/80	Database of Thuenen Institute of Sea Fisheries		Siegel (1982) Hempel et al. (1983)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Larval Antarctic krill (abundances)	MV Polarsirkel 1976/77 MV Polarsirkel 1979/80	Database of Thuenen Institute of Sea Fisheries		Fevolden (1979) Siegel (1982)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Larval Antarctic krill (abundances)	First International BIOMASS Experiment survey (FIBEX), RV "Walther Herwig" 1981	Database of Thuenen Institute of Sea Fisheries		Trathan and Everson (1994) Siegel (2005)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Larval Antarctic krill (abundances)	ANT-VII/4	Database of Thuenen Institute of Sea Fisheries	Arntz et al. (1990)		<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Larval Antarctic krill (abundances)	ANT-VIII/2 and RV Akademik Fedorov, 1989	Database of Thuenen Institute of Sea Fisheries	Augstein et al. (1991)	Menshenina (1992)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>
Larval Antarctic krill (abundances)	Lazarev Sea Krill Survey (LAKRIS) data (ANT-XXI/4, ANT-XXIII/6)	Database of Thuenen Institute of Sea Fisheries	Smetacek et al. (2005) Bathmann (2008)	Siegel (2012)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899667">https://doi.pangaea.de/org/10.1594/PANGAEA.899667</a>

## Zoobenthos

Sponges (abundances)	ANT-III/2, WH85 ANT-V/1 ANT-VI/3 ANT-VII/4 ANT-IX/3 ANT-X/3 ANT-XIII/3 ANT-XIII/4 ANT-XV/3 ANT-XVII/3 ANT-XIX/5 ANT-XXI/2 ANT-XXIII ANT-XXVII	Gerdes (2014a-o)	Hempel (1985) Schnack-Schiel (1987) Fütterer (1988) Arntz et al. (1990) Bathmann et al. (1992) Spindler et al. (1993) Arntz and Gutt (1997) Fährbach and Gerdes (1997) Arntz and Gutt (1999) Arntz and Brey (2001) Arntz and Brey (2003) Arntz and Brey (2005) Gutt (2008) Knust et al. (2012)	Gerdes et al. (1992) Gerdes et al. (2003)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899645">https://doi.pangaea.de/org/10.1594/PANGAEA.899645</a>
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Sponges (presence-absence)	ANT-VII/4 ANT-IX/3 ANT-XIII/3 ANT-XV/3 ANT-XXI/2	Teschke and Brey ( <del>2019a</del> 2020)	Arntz et al. (1990) Bathmann et al. (1992) Arntz and Gutt (1997) Arntz and Gutt (1999) Arntz and Brey (2005)	Galéron et al. (1992)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899645">https://doi.pangaea.de/org/10.1594/PANGAEA.899645</a>
Echinoderms - Asteroids (presence-absence)	ANT-I/2 ANT-II/4 ANT-V/3 ANT-VI/3 ANT-XV/3 ANT-XVII/3	Teschke and Brey ( <del>2019b</del> 2019a)	Drescher et al. (1983) Kohnen (1984) Schnack-Schiel (1987) Fütterer (1988) Arntz and Gutt (1999) Arntz and Brey (2001)	Voß (1988)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899645">https://doi.pangaea.de/org/10.1594/PANGAEA.899645</a>
Echinoderms - Ophiuroids (abundances)	ANT-I/2 ANT-II/4 ANT-V/3 ANT-V/4 ANT-VI/3 ANT-VII/4 ANT-IX/3 ANT-X/3	Teschke and Brey ( <del>2019e</del> 2019b)	Drescher et al. (1983) Kohnen (1984) Schnack-Schiel (1987) Miller and Oerter (1990) Fütterer (1988) Arntz et al. (1990) Bathmann et al. (1992) Spindler et al. (1993)	Brey et al. (1994) Dahm (1996)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899645">https://doi.pangaea.de/org/10.1594/PANGAEA.899645</a>
Echinoderms - Holothurians (abundances)	ANT-I/2 ANT-II/4 ANT-III/3	Gutt, Piepenburg and Voß (2014)	Drescher et al. (1983) Kohnen (1984) Hempel (1985)	Gutt (1988) Piepenburg et al. (1997)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899645">https://doi.pangaea.de/org/10.1594/PANGAEA.899645</a>
<b>Fishes</b>					
Fish larvae - <i>Pleuragramma antarctica</i> (abundances)	ANT-I/2	Database of Thuenen Institute of Sea Fisheries	Drescher et al (1983)	Boysen-Ennen and Piatkowski (1988)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Fish larvae - <i>Pleuragramma antarctica</i> (abundances)	ANT-III/3	Hubold et al. (1988)	Hempel (1985)		<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Fish larvae - <i>Pleuragramma antarctica</i> (abundances)	Lazarev Sea Krill Survey (LAKRIS) data: ANT-XXI/4, ANT-XXIII/6, ANT-XXIV/2	Contact: Hauke Flores (AWI) Hauke.Flores@awi.de	Smetacek et al. (2005) Bathmann (2008, 2010)	Flores et al. (2014)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>

<i>Pleuragramma antarctica</i> & demersal fishes (abundances)	ANT-XIII/3 ANT-XV/3 ANT-XVII/3 ANT-XIX/5 ANT-XXI/2 ANT-XXVII/3	<a href="#">Balguerías and Knust (2020)</a> <a href="#">Knust and Schröder (2020)</a> <a href="#">Knust et al. (2020a)</a> <a href="#">Knust et al. (2020b)</a> <a href="#">Knust et al. (2020c)</a> <a href="#">Knust et al. (2020d)</a> <del>Contact: Rainer Knust (AWI)</del> <a href="mailto:Rainer.Knust@awi.de">Rainer.Knust@awi.de</a>	Arntz and Gutt (1997) Arntz and Gutt (1999) Arntz and Brey (2001) Arntz and Brey (2003) Arntz and Brey (2005) Knust et al. (2012)	Mintenbeck et al. (2012) Caccavo et al. (2018)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
<i>Pleuragramma antarctica</i> & demersal fishes (abundances)	ANT-I/2 ANT-III/3 ANT-V/3 ANT-VII/4 ANT-IX/3 ANT-XXIII/8	Drescher et al. (2012) Ekau et al. (2012a) Ekau et al. (2012b) Hureau et al. (2012) Wöhrmann et al. (2012) Kock et al. (2012)	Drescher et al (1983) Hempel (1985) Schnack-Schiel (1987) Arntz et al. (1990) Bathmann et al. (1992) Gutt (2008)	Ekau (1988) Caccavo et al. (2018)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Antarctic toothfish (catch per unit effort)	Japanese, Korean, Norwegian and South African fishing data	CCAMLR database; Contact: CCAMLR Secretariat [data request: 03-08-2016]			<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Demersal fish nesting sites	PS82 (ANT-XXIX/9) PS96 (ANT-XXXI/2)	Knust and Schröder (2014) Piepenburg (2016)	Schröder (2016)	La Mesa et al. (2019)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
Demersal fish nesting sites		Daniels (1978, 1979) Jones and Near (2012)			<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899591">https://doi.pangaea.de/org/10.1594/PANGAEA.899591</a>
<b>Birds</b>					
Adélie penguin colonies (estimated abundances of breeding pairs)		Lynch and LaRue (2014)			<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899520">https://doi.pangaea.de/org/10.1594/PANGAEA.899520</a>
Breeding and non- breeding Adélie penguins (tracking data)	US AMLR Program (ID 910)	Birdlife International`s Seabird Tracking Database [data request: 20-10-2015]		Hinke et al. (2015)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899520">https://doi.pangaea.de/org/10.1594/PANGAEA.899520</a>
Breeding and non- breeding Adélie penguins (tracking data)	BAS / Instituto Antártico Argentino data (ID 753)	Birdlife International`s Seabird Tracking Database [data request: 20-10-2015]		Warwick-Evans et al. (2019)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899520">https://doi.pangaea.de/org/10.1594/PANGAEA.899520</a>
Breeding and non- breeding Adélie penguins (tracking data)	BAS Inventory (754, 773, 779)	Birdlife International`s Seabird Tracking Database [data request: 20-10-2015]		Dunn et al. (2011)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899520">https://doi.pangaea.de/org/10.1594/PANGAEA.899520</a>
Breeding Adélie penguins (tracking data)	BAS Inventory (ID 764)	Birdlife International`s Seabird Tracking Database [data request: 20-10-2015]		Lynnes et al. (2002)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899520">https://doi.pangaea.de/org/10.1594/PANGAEA.899520</a>

Emperor penguin colonies (populations estimates)	Fretwell et al. (2012) Fretwell et al. (2014)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899520">https://doi.pangaea.de/org/10.1594/PANGAEA.899520</a>
Antarctic petrel Colonies (estimated number of breeding pairs)	Van Franeker et al. (1999)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899520">https://doi.pangaea.de/org/10.1594/PANGAEA.899520</a>

### Pinnipeds

Seal taxa (tracking data)	Data from: Australia (ct109, ct96), Brazil (ct56, ct46, ct39, ct22), China (ct105), UK (ct1, ct8, ct27, ct27x, ct40, ct43, ct45, ct49, ct58, ct70), France (ct16, ct62, ft01, ft02, ft11, ft12), Germany (ct21, ct35, ct35b, ct44, ct54, ct68, ct87, ct99, ct102, ct113, wd06, wd07), Norway (ct34), South Africa (ct33, ct50, ct73), USA (ct9, ct14, ct25, ct29, ct37, ct48)	Marine Mammals Exploring the Oceans Pole to Pole (MEOP) data portal [data request: 14-11-2016]	Treasure et al. (2017) Nachtsheim et al. (2019) Boehme et al. (2016)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899619">https://doi.pangaea.de/org/10.1594/PANGAEA.899619</a>
Southern elephant seals (tracking data)		Tosh et al. (2009a) James et al. (2012a)	Tosh et al. (2009b) James et al. (2012b)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899619">https://doi.pangaea.de/org/10.1594/PANGAEA.899619</a>
Weddell seals (tracking data)		McIntyre et al. (2013a)	McIntyre et al. (2013b)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899619">https://doi.pangaea.de/org/10.1594/PANGAEA.899619</a>
Crabeater seals (tracking data)		Nachtsheim et al. (2016a)	Nachtsheim et al. (2016b)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899619">https://doi.pangaea.de/org/10.1594/PANGAEA.899619</a>
Pack-ice seals (aerial surveys)	Antarctic Pack Ice Seals (APIS) programme EMAGE-I to -V	Plötz et al. (2011a-e)	Southwell et al. (2012) Gurarie et al. (2017a, b)	<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899619">https://doi.pangaea.de/org/10.1594/PANGAEA.899619</a>
Crabeater seal densities (predicted or observed)		Bester et al. (1995, 2002) Flores et al. (2008) Forcada et al. (2012)		<a href="https://doi.pangaea.de/org/10.1594/PANGAEA.899619">https://doi.pangaea.de/org/10.1594/PANGAEA.899619</a>



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## Supplementary Material

### S1 Data processing and analysis

The workflow of data preparation and cleaning always followed the same pattern. First we downloaded the data from the respective repository or requested the data from contact persons (see details in the main text, Section 2.3.1 to 2.4.5 and Tab. 1, 2). The collected data, which were available in various file formats (e.g., \*.csv, \*.shp, \*.dat, \*.hdf), were then checked for quality, i.e. for missing data/information, duplicates and correctness of Lat/Long coordinates. Where data sets contained missing data, "empty" cells were marked with the abbreviation NA (Not Available) and were not used for the subsequent calculations. Duplicates in the data set were deleted. If Lat/Long coordinates were missing these were subsequently added from cruise reports or other sources if possible, otherwise the data entry was also deleted. In addition, Lat/Long coordinates were checked for the correct position. Obviously wrong Lat/Long coordinates (e.g. coordinates on land, in another geographical region, etc.) were corrected along the cruise reports or checked against the principal investigators of the data sets. After the data quality check a shape file was created for each data set, which was then projected onto South Pole Lambert Azimuthal Equal Area (<https://spatialreference.org/ref/esri/102020/>). When working with raster data sets, the default raster cell size was 6.25 km x 6.25 km (raster size of AMSR-E 89 GHz sea ice concentration maps). Finally, the data layers were cut to the size of the study site (see main text, Section 2.1). Our data processing and statistical analyses as well as the map compilation were mainly performed using the R software (Version 3.1.2, R Core Team, 2014), QGIS (Version 2.10 "Pisa", QGIS Development Team, 2015) and the ESRI's ArcGIS desktop software suite (Version 10.2, ESRI 2013).

#### S1.1 Environmental data (IBCSO data, AMSR-E sea ice maps, FESOM data)

For our pelagic regionalisation analysis (Fig. S2) we focused on the austral summer (December to March) ~~and used a raster cell size of 6.25 km x 6.25 km (raster size of AMSR-E 89 GHz sea ice concentration maps)~~. For each raster cell (i) the mean of depth (IBCSO data) and depth range (i.e. difference between maximum and minimum depth), (ii) the relative number of days with ice cover  $\leq 70\%$  (AMSR-E sea ice maps) and (iii) the mean of temperature and salinity at the sea surface and the sea bottom (FESOM data) were calculated over the respective time periods of the environmental data sets (detailed description of environmental data sources see main text, Section 2.3, and Tab. 1). The mean of depth and depth range were ln-transformed. The parameters chosen for the pelagic regionalisation analysis are major structuring components of the Weddell Sea ecosystem and are consistent with the variables used by Raymond (2014) in a cluster approach for a circum-antarctic pelagic regionalisation. For clustering, we used *k*-means clustering (Han et al., 2011), the most widely used numerical method for partitioning abiotic and/or biotic data in a predefined number of groups (*k*) (ecological examples from marine realm see e.g., Legendre et al., 2002, Hewitt et al., 2004, Zharikov et al., 2005, Verfaillie et al., 2009). To estimate the optimal number of clusters we used the gap statistic of 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. Due to the large amount of data, the gap statistic could not be applied to the complete data matrix (119,862 samples x 7 variables). Therefore, data subsets were extracted from the complete data matrix using a permutation approach and the gap statistic were applied to each of the data subsets. Finally, the median of the data subsets with respect to the optimal number of clusters was used for *k*-means clustering.

## **S1.2 Ecological data**

### **S1.2.1 Zooplankton**

#### **Antarctic krill (adults)**

The habitat suitability model of the Antarctic krill (Fig. S3) was developed with R (R Core Team, 2014) using the biodiversity modelling package biomod2 (Thuiller et al., 2009 and 2014). Biomod is freely available and is probably the best known and most established software in the modelling world of ecologists, geographers and conservationists, combining predictive results from different models (Hao et al., 2018 and references therein).

All models were run with presence-absence data on Antarctic krill (detailed description of data sources see main text, Section 2.4.1, and Tab. 2). The predictor variables used in our final model were defined in a stepwise procedure. First, we fed biomod2 with more than 20 environmental predictors and the model was run. The relative importance of each variable was evaluated by the following permutation procedure: Once the model is calibrated, a standard prediction is generated. Then, one of the predictor variables is randomised and a new prediction is made. The Pearson's correlation coefficient ( $r$ ) between that new prediction and the standard prediction is used to measure this variable's relative importance in the model ( $= 1 - r$ ; for more details on the permutation procedure see Thuiller et al., 2012). Variables with low importance were then excluded from the subsequent permutation, and the relative importance in the model of each remaining variable was measured again. Based on this permutation procedure (10 permutations in total) we reduced the number of variables to the most important predictors without negatively influencing the model performance. Thus, for our final predictive model we used the following five environmental variables (ranked by decreasing mean importance value calculated by biomod2): (i) dissolved oxygen (WOA13 data), (ii) ice coverage (AMSR-E sea ice maps), (iii) temperature (FESOM data), (iv) bathymetry (IBCSO data) and (v) chlorophyll-a concentration (SeaWiFS data) (detailed description of environmental data sources see main text, Section 2.3, and Tab. 1). All data used in the models came from near the sea surface in austral summer (January to March).

In our modelling approach, we focused on nine commonly used modelling techniques, which include regression, classification and machine learning methods, as described by Elith and Graham (2009): generalised linear model (GLM), generalised boosting model, generalised additive model, classification tree analysis, artificial neural network, surface range envelope, flexible discriminant analysis, multiple adaptive regression splines, random forest). Three evaluation methods, i.e. relative operating characteristic (ROC), true skill statistic (TSS) and accuracy, were used. Each modelling technique was calibrated with 70 % of the data (random sample from the total data set) and the remaining 30 % of the data were used to evaluate their performances (Thuiller, 2003). In total 270 calibrated models (9 different models x 10 replicates of pseudo-absences x 3 evaluation runs) were used for the model synthesis where the different models were combined into a single ensemble model (EM). For the development of our EM, all models were scaled applying a binomial GLM as implemented in biomod2 to ensure comparable model results. Out of the 270 individual models we selected those models for our EM with a TSS threshold higher than 0.65 (i.e., good prediction accuracy accord to Thuiller et al., 2010). Furthermore, we ground-truthed our EM against krill catch data from CCAMLR (see main text, Section 2.4.1, and Tab. 2) by calculating the percentage of krill catches in the areas with different predicted habitat suitability (high to unsuitable).

#### **Antarctic krill (larvae)**

The map of the interpolated abundances of krill larvae in the WSMMPA Planning Area (see Fig. S4) was done with the ArcGIS spatial analyst in the ArcGIS desktop software suite (ESRI Inc., 2011) using the inverse-distance

weighting (IDW) method, one of the most commonly used deterministic models in spatial interpolation (e.g., Lu and Wong, 2008). The interpolation was performed with log-transformed abundance data (detailed description of data sources see main text, Section 2.4.1, Tab. 2). The output cell size (x, y) was set to 1000 m and the distance coefficient power to 2. The interpolated abundances were finally expressed for a radius of 30 km around each data record.

### **Ice krill**

The map of the interpolated abundances of ice krill in the WSMMPA Planning Area (Fig. S5) was developed in the same way as the Antarctic krill map (see use of interpolation in previous paragraph). For a detailed description of the data sources see Section 2.4.1 and Table 2 in the main text.

The potential ice krill habitat (Fig. S6) was approximated by water depth from 0 m to 550 m (IBCSO data) and mean sea surface temperature  $\leq 0^{\circ}\text{C}$  (FESOM data) (detailed description of environmental data sources see main text, Section 2.3, Tab. 1). The biological characteristics of ice krill were taken from the Biogeographic Atlas of the Southern Ocean (Cuzin-Roudy et al., 2014).

## **S1.2.2 Zoobenthos**

### **Sponges**

The map of the occurrence of sponges in the WSMMPA Planning Area (Fig. S7) was finally also generated using the IDW method (see use of interpolation in Section S1.2.1 "Antarctic krill (larvae)"). The previous data processing focused on the consolidation of two different data sets (one quantitative, one semi-quantitative; for detailed description of data sources see main text, Section 2.4.2, and Tab. 2). We transformed the quantitative data into the same four-category system as the semi-quantitative data (i.e. absent, rare, common, very common) by creating a Monte Carlo sample using Sobol low-discrepancy sequences to develop a Weibull distribution ( $n = 10,000,000$ ). Within the Weibull distribution, the following classes were identified (i) class 0 (absent) = 0, (ii) class 1 (rare) = 0 to mean - standard deviation (SD), (iii) class 2 (common) = mean - SD to mean and (iv) class 3 (very common) = mean to mean + SD. The quantitative data were classified according to these classes and merged with the semi-quantitative data. The interpolated data were finally expressed for a 10 nm radius around each data record according to CCAMLR Conservation Measure 22-09 (2012).

### **Echinoderms**

The potential habitat for echinoderms in the WSMMPA Planning Area (Fig. S8) was developed with JMP (S.A.S. Institute Inc.) using Ward's (1963) minimum variance method, which has been widely used for calculating distances between clusters since its first description (examples from marine realm see e.g., Verfaillie et al., 2009, Weise et al., 2010, Neukermans et al., 2016). A cluster analysis with a species x station matrix was performed for Asteroidea, Ophiuroidea and Holothuroidea respectively (detailed description of data sources see main text, Section 2.4.2, and Tab. 2). All species occurred only in two stations or less were excluded from the clustering. The results of the cluster analyses were then linked to various environmental data sets. Water temperature best reflected the occurrence of a particular echinoderm community, and therefore their habitat was approximated by bottom water temperature  $\leq -1^{\circ}$  (FESOM data).

### **S1.2.3 Fish**

#### **Antarctic silverfish (larvae and adults)**

The map of the interpolated abundances of Antarctic silverfish in the WSMPA Planning Area (Fig. S9) was developed using the IDW method (see use of interpolation in Section S1.2.1 "Antarctic krill (larvae)"). For a detailed description of the data sources see Section 2.4.1 and Table 2 in the main text. The interpolated data were finally expressed for a 10 nm radius around each data record according to CCAMLR Conservation Measure 22-09 (2012).

#### **Demersal fish**

The habitat suitability model of demersal fish (Fig. S10) was developed with R (R Core Team, 2014) using the biodiversity modelling package biomod2 (Thuiller et al., 2009 and 2014).

All models were run with presence-absence data on demersal fish (detailed description of data sources see main text, Section 2.4.3, and Tab. 2). The predictor variables that were used for our final predictive model were defined in the same iterative process as described under "Antarctic krill (adults)". The environmental variables finally used for our modelling approach were (with decreasing variable importance): (i) distance to coast, (ii) bathymetry, (iii) calcium carbonate, (iv) broad benthic positioning index, (v) silica, (vi) dissolved oxygen, (vii) biogenic silica, (viii) total organic carbon, (ix) nitrate, (x) salinity, (xi) temperature, (xii) current velocity, (xiii) slope and (xiv) phosphate (detailed description of environmental data sources see Section 2.3 and Tab. 1 in main text). All data used in the models came from the sea bottom in austral summer (January to March). Distance to coast, i.e. the Euclidean distance to the nearest land from each raster cell centroid (cell size: 8.02 km x 8.02 km), was calculated with the GRASS GIS package *v.distance* (Soimasuo et al., 1994) in QGIS 2.10 "Pisa". The coastline derived from IBCSO Version 1.0 DBM (Arndt et al., 2013). Slope and broad scale benthic positioning index (BPI) was also derived from IBCSO and were calculated with the Benthic Terrain Modeler Version 3.0 extension for the ArcGIS desktop software suite (ESRI Inc., 2011). For the calculation of the broad scale BPI, the inner radius was set to 5 km and the outer radius to 125 km according to Jerosch et al. (2016).

In the modelling approach, we focused on the same modelling techniques as described under "Antarctic krill (adults)". ROC and TSS were used as evaluation methods. Each modelling technique was calibrated with 70 % of the data (random sample from the total data set) and the remaining 30 % of the data were used to evaluate their performances (Thuiller, 2003). A total of 135 calibrated models (9 different models x 3 replicates of pseudo-absences x 5 evaluation runs) were used for the EM synthesis where all models were scaled applying a binomial GLM as implemented in biomod2 to ensure comparable model results. Out of the 135 individual models we selected those models for our EM with a TSS threshold higher than 0.9 (i.e., high or excellent prediction accuracy accord to Thuiller et al., 2010).

#### **Antarctic toothfish (adults)**

The probability model of Antarctic toothfish occurrence in the WSMPA Planning Area (Fig. S11) was developed as a function of depth as recommended by the CCAMLR Working Group on Ecosystem Monitoring and Management (WG-EMM). Following analytical steps were performed:

- (i) We calculated the standard descriptive parameters of catch per unit effort (CPUE) data on the Antarctic toothfish (CCAMLR fisheries data) per depth interval  $i$  ( $mCPUE_i$ ) with a depth interval width of 100 m

(depth interval mean depth:  $0 \text{ m} \leq D_i \leq 2600 \text{ m}$ ,  $D_{i+1} - D_i = 50 \text{ m}$ ). Depth intervals with less than five CPUE data points were not considered.

- (ii) A Monte Carlo sample was built for each depth interval  $i$  ( $n = 10,000$ ) by randomly drawn samples from a log-normal distribution with the same mean and standard deviation as the CPUE data in each depth interval.
- (iii) Outliers were defined as data points below  $Q1 - 3.0 \times \text{IQR}$  or above  $Q3 + 3.0 \times \text{IQR}$  per depth interval  $i$  where  $Q1$  and  $Q3$  are the 25% and 75% quartiles, respectively, and  $\text{IQR}$  is the interquartile range, i.e. the difference between  $Q1$  and  $Q3$ . Thus, only extreme data points, that are "far out" (Tukey 1977), were excluded from the subsequent model fit.
- (iv) We fitted a 4 parameter Weibull model to the simulated median  $mCPUE_i$  per depth interval  $i$ ,  

$$mCPUE_i = \begin{cases} 0 & \text{if } (D_i \leq x_0 - b \times ((c - 1)/c)^{(1/c)}) \\ a \times ((c - 1)/c)^{((1 - c)/c)} \times (\text{abs}((D_i - x_0)/b + ((c - 1)/c)^{(1/c)})^c + (c - 1)/c) & \text{otherwise} \end{cases}$$
The model selection based on R (R Core Team 2014) using the package `fitdistrplus` (Delignette-Muller et al. 2014).
- (v) The median water depth (IBCSO data) was calculated for each raster cell ~~of (cell size: 6.25 km x 6.25 km)~~ ~~(raster size of AMSR-E 89 GHz sea ice concentration maps)~~, was assigned to the respective depth interval and the corresponding  $mCPUE_i$  value - calculated by the Weibull model for this depth interval - was mapped (detailed description of IBCSO data see main text, Section 2.3, and Tab. 1). Finally, the potential habitat of the Antarctic toothfish was bounded from 550 to 2 000 m according to CCAMLR Conservations Measures and fishing practice as recommended by WG-EMM (WG-EMM-16 report, para. 3.6).

#### S1.2.4 Flying and non-flying seabirds

##### Breeding and non-breeding Adélie penguins

The probability of occurrence of breeding and non-breeding Adélie penguins during foraging (Fig. S13, S14) was developed with R (R Core Team, 2014) using the R package `crawl` (Johnson, 2015). The continuous-time correlated random walk model developed by Johnson et al. (2008) has become established in Antarctic science in recent years in order to estimate more accurately the locations of tracked seabirds and pinnipeds along their trajectory (see e.g., Warwick-Evans et al., 2018 and 2019; Baylis et al., 2019).

Here, we used the random walk model to generate predictions of the location of each tracked Adélie individual on an hourly time scale (detailed description of penguin tracking data see main text, Section 2.4.4, and Tab. 2). Raw ARGOS data were first processed by assigning error values to the different ARGOS location quality codes, i.e. location code 3 (= highest accuracy of ARGOS position estimate) was set off against the lowest error value, the highest error was assigned to location code B (= lowest accuracy of ARGOS position estimate). Subsequently, simulated track-lines between the temporally sequenced ARGOS positions or each tracked individual, were generated by the continuous-time correlated random walk model, binned onto a 6.25 km x 6.25 km spatial grid and pooled per raster cell so that the final data layers (one for breeding, one for non-breeding Adélies) identifies the areas that were used most often by tracked Adélies. Buffer areas (i.e. a 50 km buffer and a 50-100 km ring buffer) around each colony - shown on the final map of breeding Adélie penguins - were adopted in accordance with the recommendations of the 2<sup>nd</sup> international workshop on the identification of CCAMLR MPAs in Planning Domain 1 (WG-EMM-15/42 and references therein).

### Breeding Emperor penguins

The probability model of Emperor penguins occurrence during foraging in breeding season (Fig. S15) was developed as a function of distance from colony and colony size (Fretwell et al., 2012 and 2014) as well as sea ice concentration (AMSR-E sea ice maps; detailed description of data source see main text, Section 2.3, and Tab. 1).

#### *Analysis 1: Probability model of penguin occurrence as a function of distance from colony and of colony size*

To calculate the distances from colony for foraging, we used a raster grid with a spatial resolution of 6.25 km x 6.25 km (as for sea ice concentration). We calculated the Euclidian distance for each raster pixel centroid  $j$  to each emperor penguin breeding colony  $i$ . Thus, the probability of occurrence  $PI_{i,j}$  of one penguin from colony  $i$  in centroid  $j$  was calculated by the following approximation:

$$P1_{i,j} = \left(\frac{1}{\sqrt{\pi}}\right) * e^{\left(\frac{-\left(3 * \frac{d_{i,j}}{d_{max}}\right)^2}{2}\right)} \quad (1)$$

where  $d_{max}$  is the maximum foraging distance to breeding colony (here  $d_{max} = 190$  km; derived from Zimmer et al. (2008) and reference therein by mean maximum foraging distance to the colony of male penguins in winter of 106 km (standard deviation (SD) = 28 km) plus three SD, i.e.  $106 \text{ km} + 3 * 28 \text{ km} = 190 \text{ km}$ ), and  $d_{i,j}$  is the Euclidean distance (in km) between colony  $i$  and centroid  $j$ , which was calculated by:

$$d_{i,j} = \left(\sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}\right) - d_{ice\_edge_i} \quad (2)$$

where  $d_{ice\_edge_i}$  is the distance of colony to the shelf ice edge. Distances  $d_{i,j} \leq 0$  were set to 1. Subsequently, different boundaries of ice shelf edge were adjusted by a 10 km puffer, which was subtracted from the distances  $d_{i,j}$ , too, and a reclassification was performed again ( $d_{i,j} \leq 0$  were set to 1).

Then, the probability of penguin occurrence  $PI_{i,j}$  from colony  $i$  in centroid  $j$  was normalised between 0 and 1 (i.e.  $0 \leq PI_{i,j} \leq 1$ ). Finally, all  $PI_{i,j}$  were added for each centroid  $j$  and normalised again to a range between 0 and 1:

$$P1_j = \frac{\sum_{i=1}^n P1_{i,j}}{\max(\sum_{i=1}^n P1_{i,j})} \quad (3)$$

where  $n$  is the number of emperor penguin breeding colonies.

To account for breeding colony size (number of animals), each probability of penguin occurrence  $PI_{i,j}$  was weighted with the best population estimate (BE) for this emperor penguin colony according to Fretwell et al. (2012).

$$P1'_{i,j} = P1_{i,j} * BE_i \quad (4)$$

Subsequently, all  $P1'_{i,j}$  were added for each centroid  $j$  and normalised to a range between 0 and 1 (i.e.  $0 \leq P1'_{i,j} \leq 1$ ):

$$P1'_j = \frac{\sum_{i=1}^n P1'_{i,j}}{\max(\sum_{i=1}^n P1'_{i,j})} \quad (5)$$

where  $n$  is the number of emperor penguin breeding colonies.

#### *Analysis 2: Probability model of penguin occurrence as a function of sea ice concentration*

The probability model of penguin occurrence as a function of sea ice concentration was calculated in the following steps: (1) A sigmoid transfer function was applied (eq. 6) to achieve an even distribution of the mean sea ice concentration data; (2) the ice index data ( $IC_j$ ) were normalised to a range between 0 and 1 (eq. 7); and (3) the probability of penguin occurrence was calculated using the transformed data and a hyperbolic *tanh*-function (eq. 8). The mean sea ice concentration was calculated for the breeding period of emperor penguins (June to January) from 2002 to 2011.

$$IC_j = \frac{1}{1 + e^{(-\ln(x+10^{-5}) * gain)}} \quad (6)$$

with  $x$  = mean sea ice concentration/100 and gain set to 6.23.

Subsequently, the ice index data ( $IC_j$ ) were normalised to a range between 0 and 1:

$$IC_j = std_{IC_j} = \frac{IC_j - \min(IC_{j_1}, IC_{j_2} \dots IC_{j_n})}{\max(IC_{j_1}, IC_{j_2} \dots IC_{j_n}) - \min(IC_{j_1}, IC_{j_2} \dots IC_{j_n})} \quad (7)$$

For the probability model of penguin occurrence we have assumed that the penguin preference does not relate linearly to sea ice conditions, but with a sigmoid pattern, i.e. areas with medium sea ice concentration are already suitable foraging grounds. This sigmoid pattern was modelled by the following *tanh*-function:

$$P2_j = \frac{\tanh(\pi * (IC_j * 2 - 1)) + 1}{2} \quad (8)$$

#### *Analysis 3: Combining the distance/colony size model with the sea ice concentration model*

An overall probability of penguin occurrence  $P_j$ , i.e. a combination of the distance/colony size model and the sea ice concentration model, was calculated by the following equation:

$$P_j = \frac{(P1_j * P2_j) - \min(P1_j * P2_{j_1}, P1_j * P2_{j_2} \dots P1_j * P2_{j_n})}{\max(P1_j * P2_{j_1}, P1_j * P2_{j_2} \dots P1_j * P2_{j_n}) - \min(P1_j * P2_{j_1}, P1_j * P2_{j_2} \dots P1_j * P2_{j_n})} \quad (9)$$

### **Antarctic petrel**

The potential foraging habitats of the Antarctic petrel (Fig. S16) was developed as a function of (i) sea ice concentration (AMSR-E sea ice maps), (ii) bathymetry (IBCSO data) and (iii) sea water temperature (FESOM data; detailed description of data sources see main text, Section 2.3, and Tab. 1).

As preferred ice regime of the Antarctic petrel we focused on the marginal ice zone, i.e. 15 % - 80 % ice coverage, according to van Franeker (1996) and Ainley et al. (1984, 1994). Data on sea ice concentration were reclassified as first step, i.e. a value of 1 was assigned to each cell with ice cover 15 % - 80 %, whereas cells with ice cover less than 15 % and more than 80 % were set to 0. Then, for each grid cell, the relative number of days (in %) for which a given grid cell had an ice cover between 15 % and 80 % was calculated for the breeding period (January to March) from 2002 to 2011. Subsequently, eight classes regarding the frequency of occurrence of the marginal ice zone were defined and scaled between 0 and 1.

We used abundance data from Ainley and Jacobs (1981) and calculated mean Antarctic petrel densities for three depth classes, i.e. (1) deep ocean: > 2600 m, (2) continental slope and shelf break: 2600 to < 600 m and (3) continental shelf: the remainder of the continental shelf. Then, the mean densities were scaled between 0 and 1. Finally, bathymetric data (IBCSO) were used to identify the three different depth zones in the Weddell Sea Planning Area.

According to Ainley et al. (1984) Antarctic petrels seem to prefer water temperatures colder than 0.5°C. Thus, sea surface temperature (SST) data (FESOM) were reclassified for each raster cell, i.e. value 3 = SST ≤ 0.5°C in all three months (January to March), 2 = SST ≤ 0.5°C in only two months, 1 = SST ≤ 0.5°C in only one month and 0 = SST > 0.5°C in all three months. Subsequently, the values were scaled between 0 and 1.

Finally, we approximated the potential foraging habitat of Antarctic petrel by stacking the three environmental proxies and corresponding data layers, respectively, and assigning different weighting factors to the proxies. The highest weighting factor was assigned to sea ice concentration (weighting factor: 1) as we assume sea ice as the major structuring component of the Antarctic petrel foraging habitat. Bathymetry and sea water temperature, in contrast, got lower weighting factors of 0.75 and 0.25, respectively.

Subsequently, we combined our model approach with the model results from Descamps et al. (2016) as recommended by the CCAMLR Scientific Committee (SC-CAMLR-XXXV report, paras. 5.14 - 5.28). Descamps et al. (2016) kindly provided us with the shape files showing the modelled kernel utilization summer and winter distribution of Antarctic petrel breeding at Svarthamaren.

We combined the kernel utilization distribution (hereafter kernel UD) model from Descamps et al. (2016) with our model by the following procedure:

- (i) We calculated a weighting factor  $wf_i$  for each level of kernel UD (i.e. for 30, 60 and 95 % kernel UD) by the following equation:

$$wf_i = \frac{\max(k_{UD})}{k_{UDi}} \quad (1)$$

where  $\max(k_{UD})$  is 30 derived from the 30 % kernel UD, i.e. core area - high intensity of use, and  $k_{UDi}$  is the respective kernel UD.

- (ii) We computed the probability of Antarctic petrel occurrence  $P_i$  for each grid cell (i) by:



$$P_i = \frac{(x_{iAWI\_model} + (100 * w_{fi\_Descamp\ et\ al.\ summer}) + (100 * w_{fi\_Descamp\ et\ al.\ winter}))}{100 * \max(x_{iAWI\_model}, 100 * w_{fi\_Descamp\ et\ al.\ summer}, 100 * w_{fi\_Descamp\ et\ al.\ winter})} \quad (2)$$

where  $x_{iAWI\_model}$  is our model value (i.e. 5, 20, 35, 50 or 100).

### S1.2.5 Pinnipeds

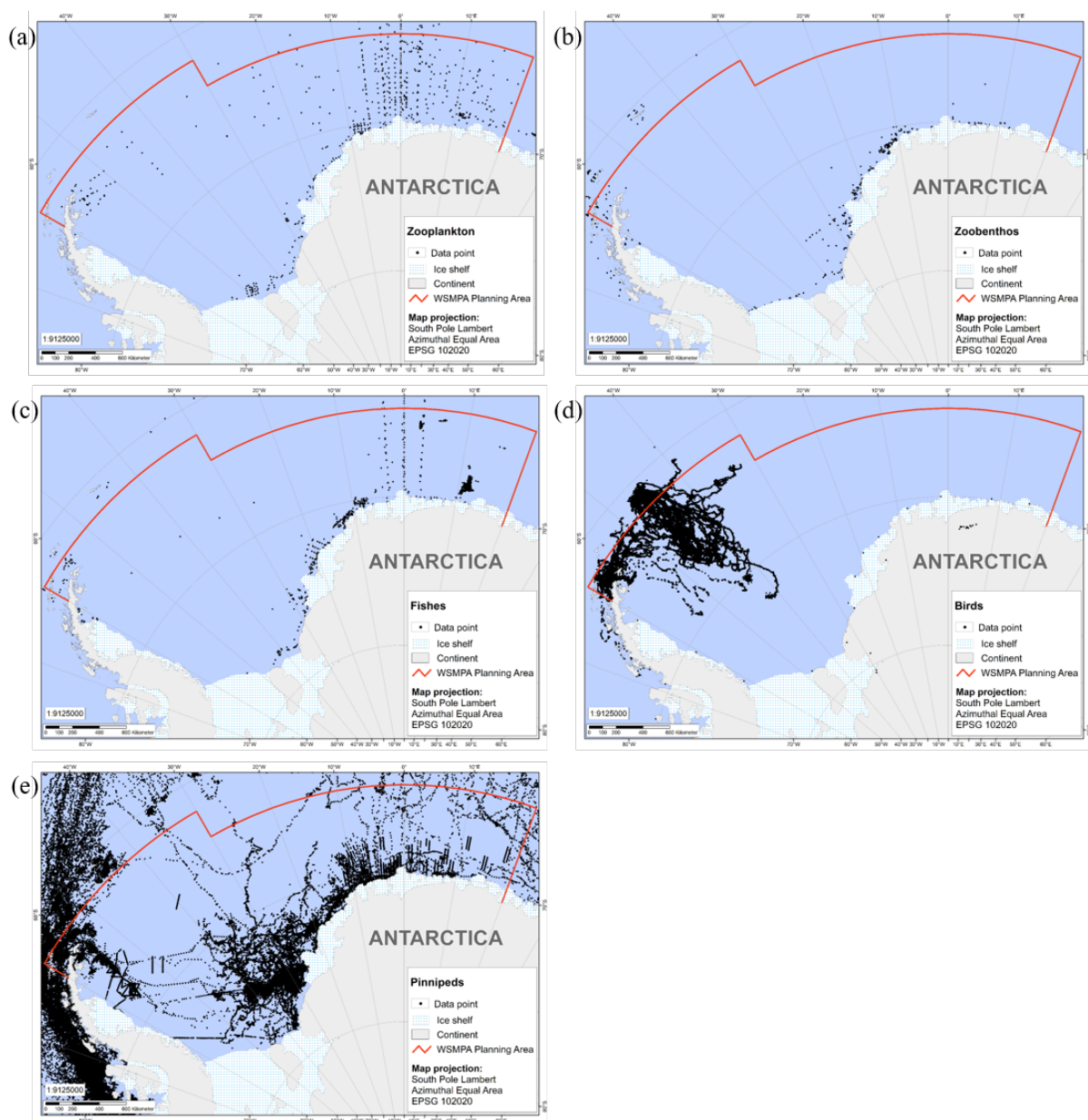
The probability of pinniped occurrence based on tracking data (Fig. S17) was developed with R (R Core Team, 2014) using the R package *crawl* (Johnson, 2015; see examples of Antarctic studies using *crawl* in Section S1.2.4 "Breeding and non-breeding Adélie penguins").

Here, we used the random walk model from Johnson et al. (2008) to generate 100 simulated track-lines between the temporally successive ARGOS positions for each tracking data set on pinnipeds (detailed description of pinniped tracking data see main text, Section 2.4.5, and Tab. 2). Only random track-lines were generated where the maximum speed of a pinniped between successive positions was  $\leq 2.5$  m s<sup>-1</sup>. The simulated track-lines were binned onto our standard spatial grid (cell size: 6.25 km x 6.25 km) and pooled per raster cell so that the final data layer identifies the areas that were used most often by tracked pinnipeds.

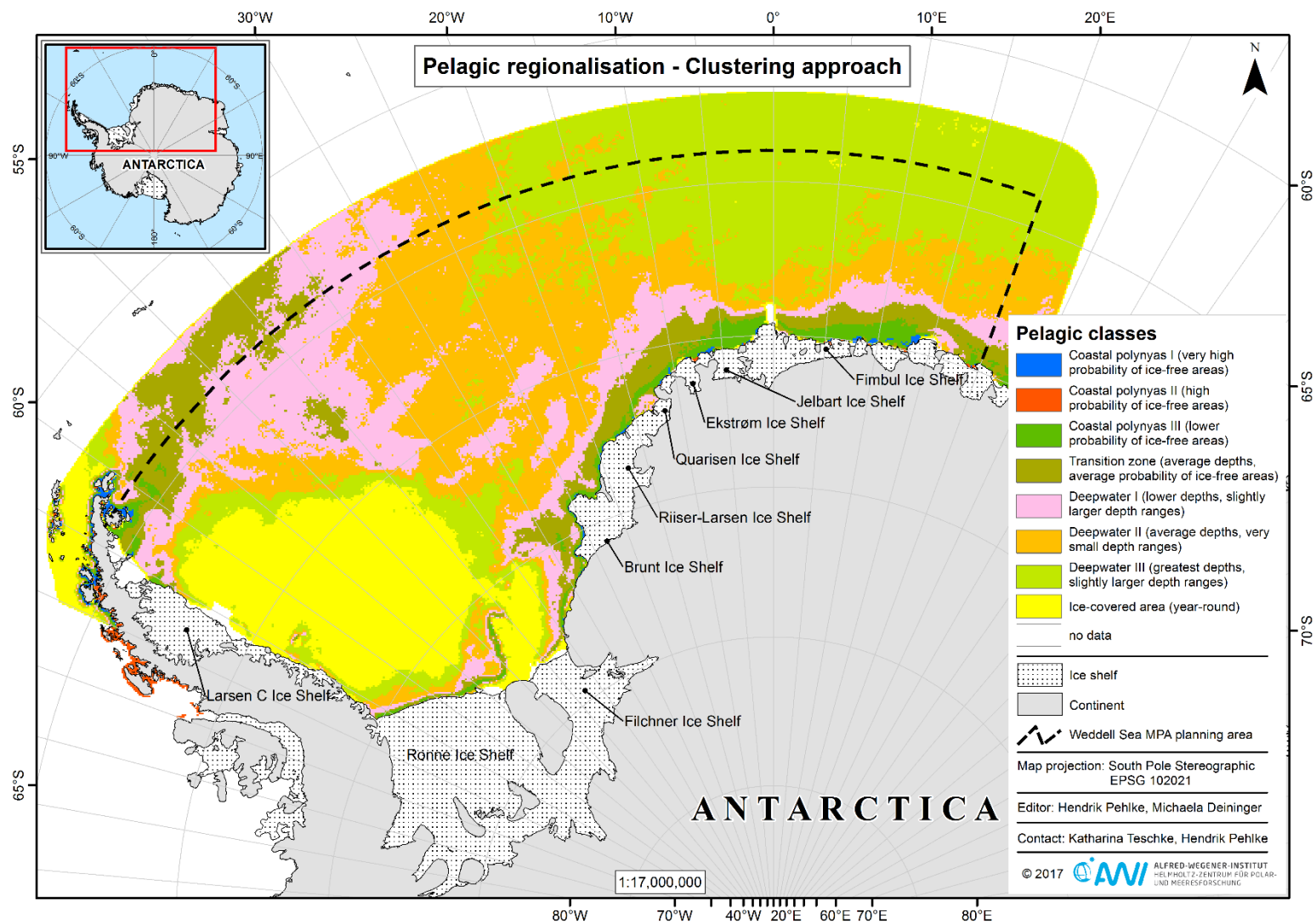
The map on seal densities in the WSMMPA Planning Area (Fig. S18) was developed combining modelled and interpolated densities of seals. Predictive density values on crabeater seals were derived from Flores et al. (2008) and Forcada et al. (2012) and were pooled in case of areas where both studies presented model results.

Interpolated densities of seals were derived from APIS point data (unspecified taxa) and observed crabeater seal densities (see Bester et al., 1995, 2002; see detailed data description data in main text, Section 2.4.5, and Tab. 2). From APIS point data, seal densities (i.e. individuals/km<sup>2</sup>) were calculated using the count method for line transect data (e.g., Bester and Odendaal, 2000, Hedley and Buckland, 2004). We used non-standardised data for the density calculations as the APIS data set is based on video material, and thus at least observer related factors potentially influencing the probability of animal detection are not relevant to consider. The seal densities from Bester et al. (1995) were averaged over the different sampling dates for each transect, and the densities per sampling zones (inner, middle, outer zone; see Bester et al., 2002) were converted from square nautical mile to square kilometer. Finally, all transects were subdivided in sections of circa 5.5 km according to Bester et al. (2002) using QGIS 2.0 "Dufour" with the QChainage plugin and the density values of the respective transect was assigned to each section for the interpolation approach. We applied the IDW method (see also Section S1.2.1 "Antarctic krill (larvae)") with the output cell size (x, y) of 2000 m and the distance coefficient power of 2. The search radius setting, i.e. the number of points, was set to 10.

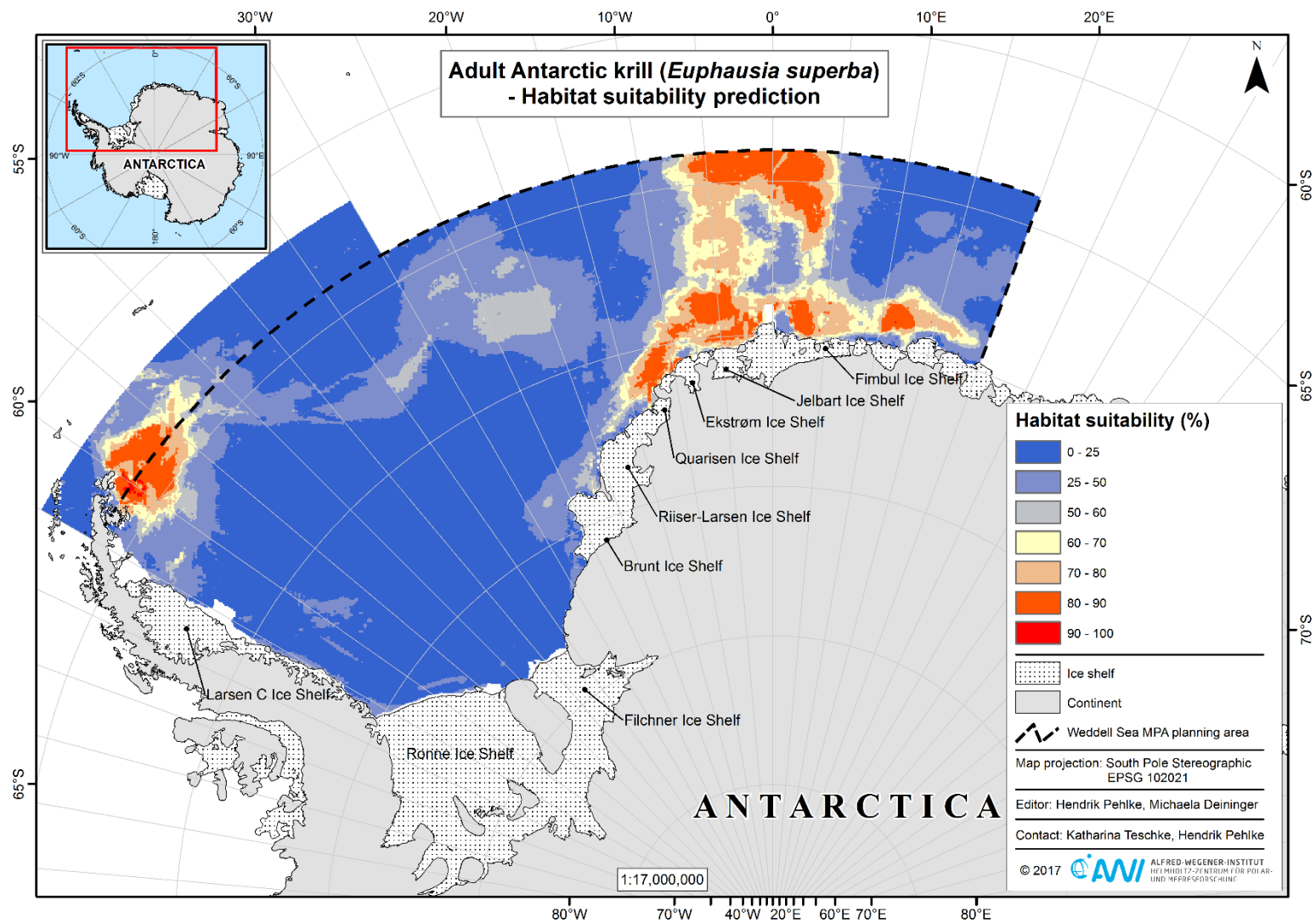
## S2 Figures



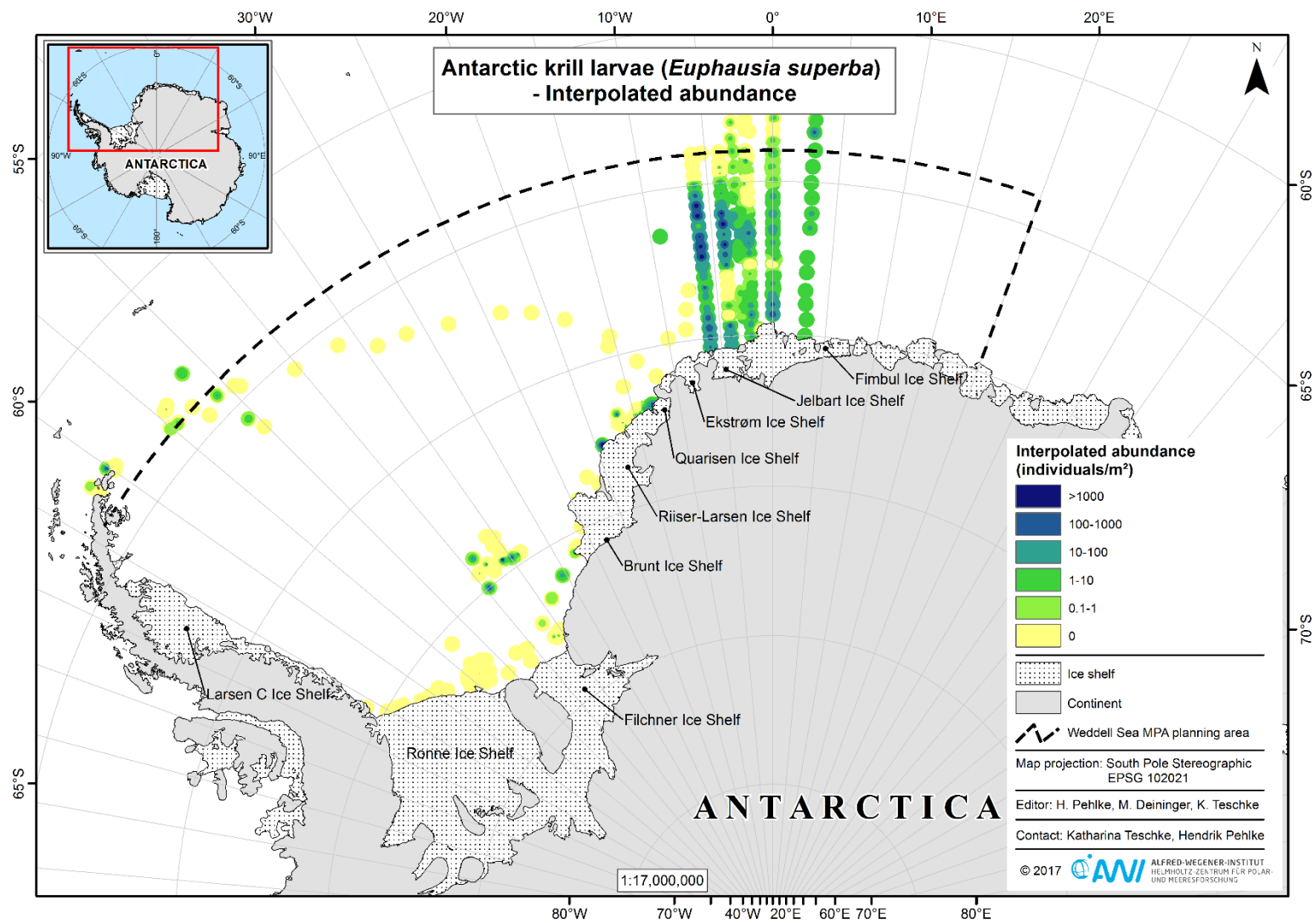
**Figure S1.** Distribution of data recordings per higher taxonomic group, i.e. zooplankton (a), zoobenthos (b), fishes (c), birds (d) and pinnipeds (e), across the wider Weddell Sea region, which were compiled in the context of the WSMPA planning initiative.



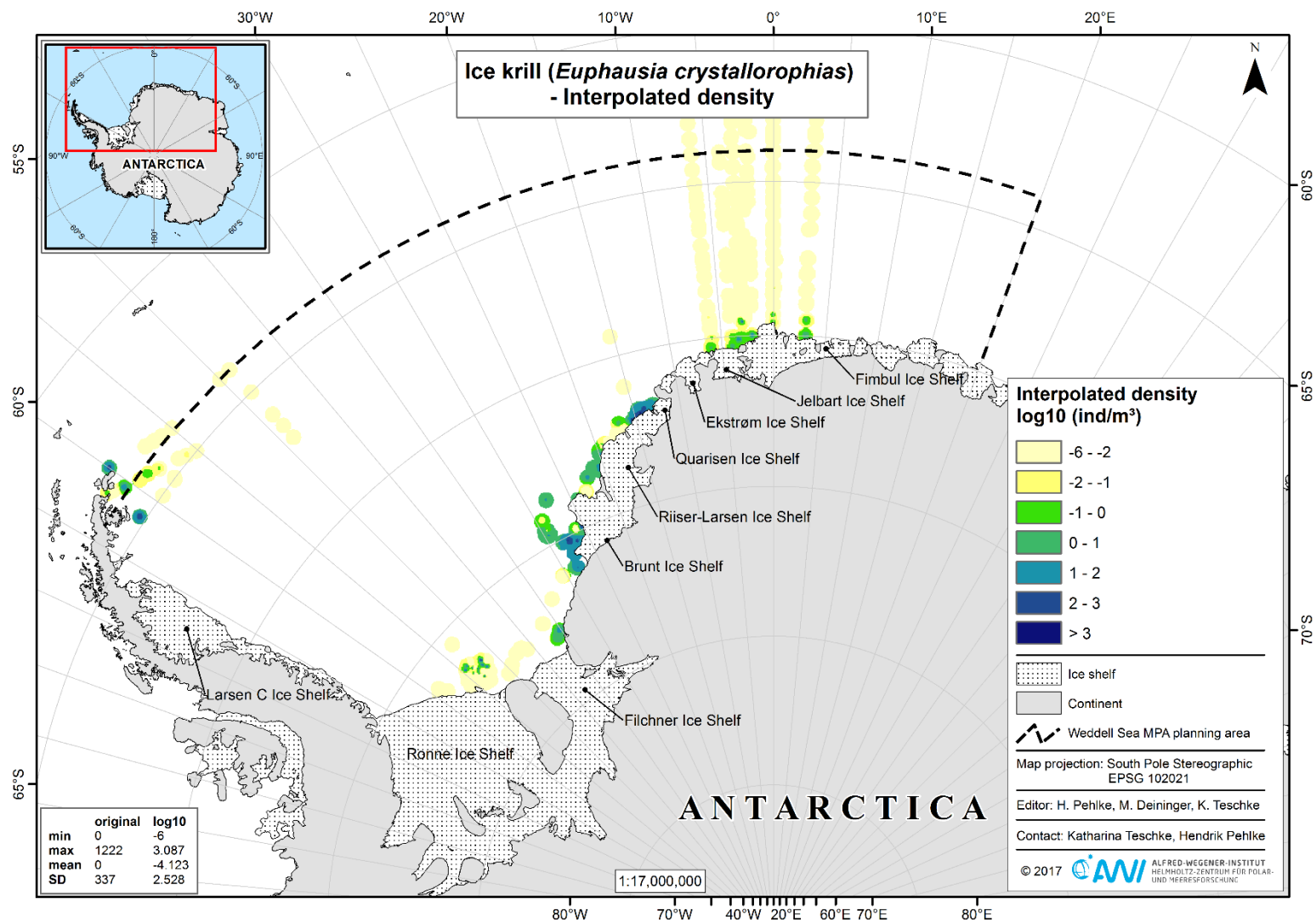
**Figure S2.** Pelagic regionalisation of the WSMMPA Planning Area.



**Figure S3.** Habitat suitability predictions of adult Antarctic krill (*Euphausia superba*) in the WSMPA Planning Area.

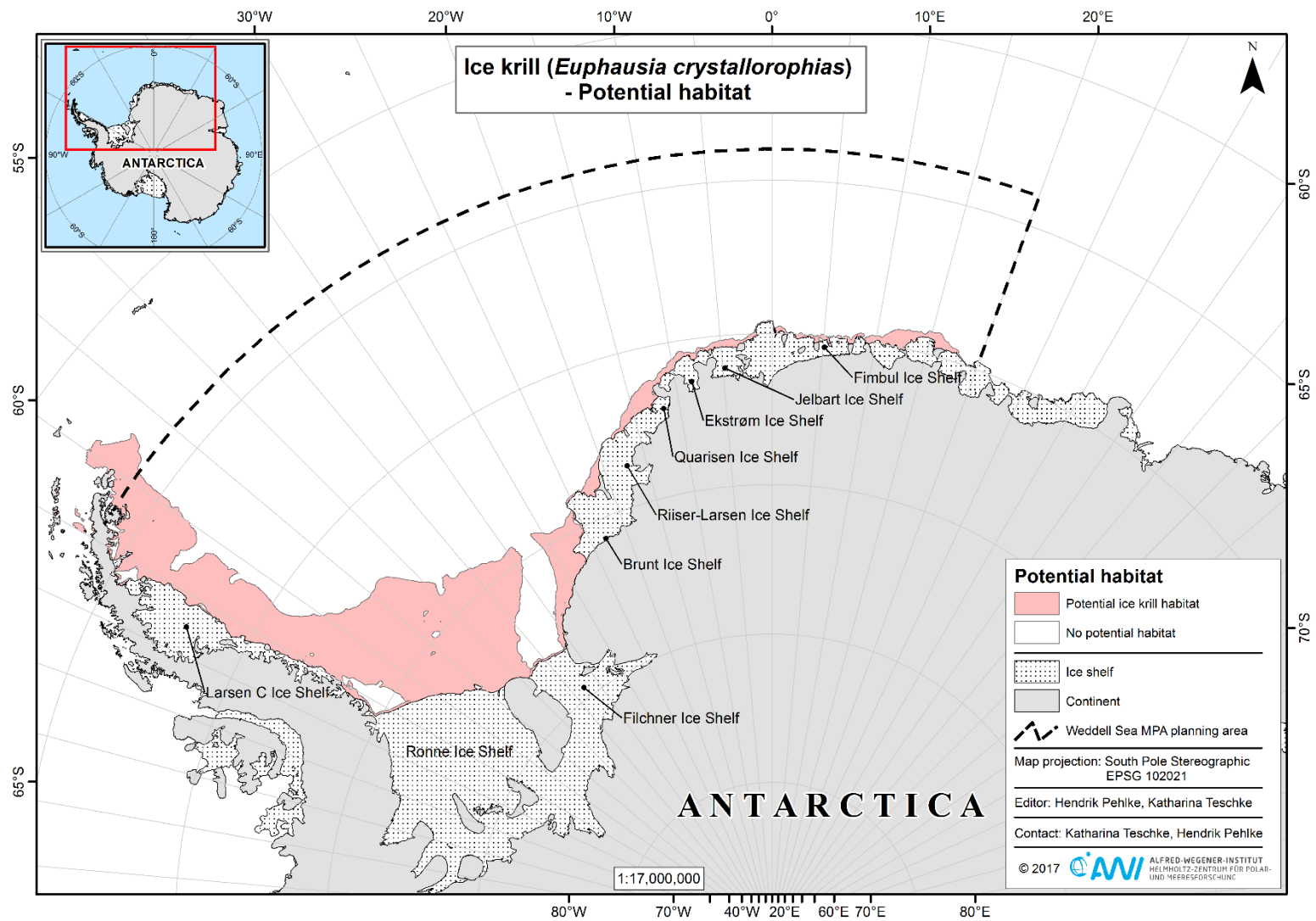


**Figure S4.** Interpolated abundances of Antarctic krill larvae (*Euphausia superba*) in the WSMMA Planning Area.

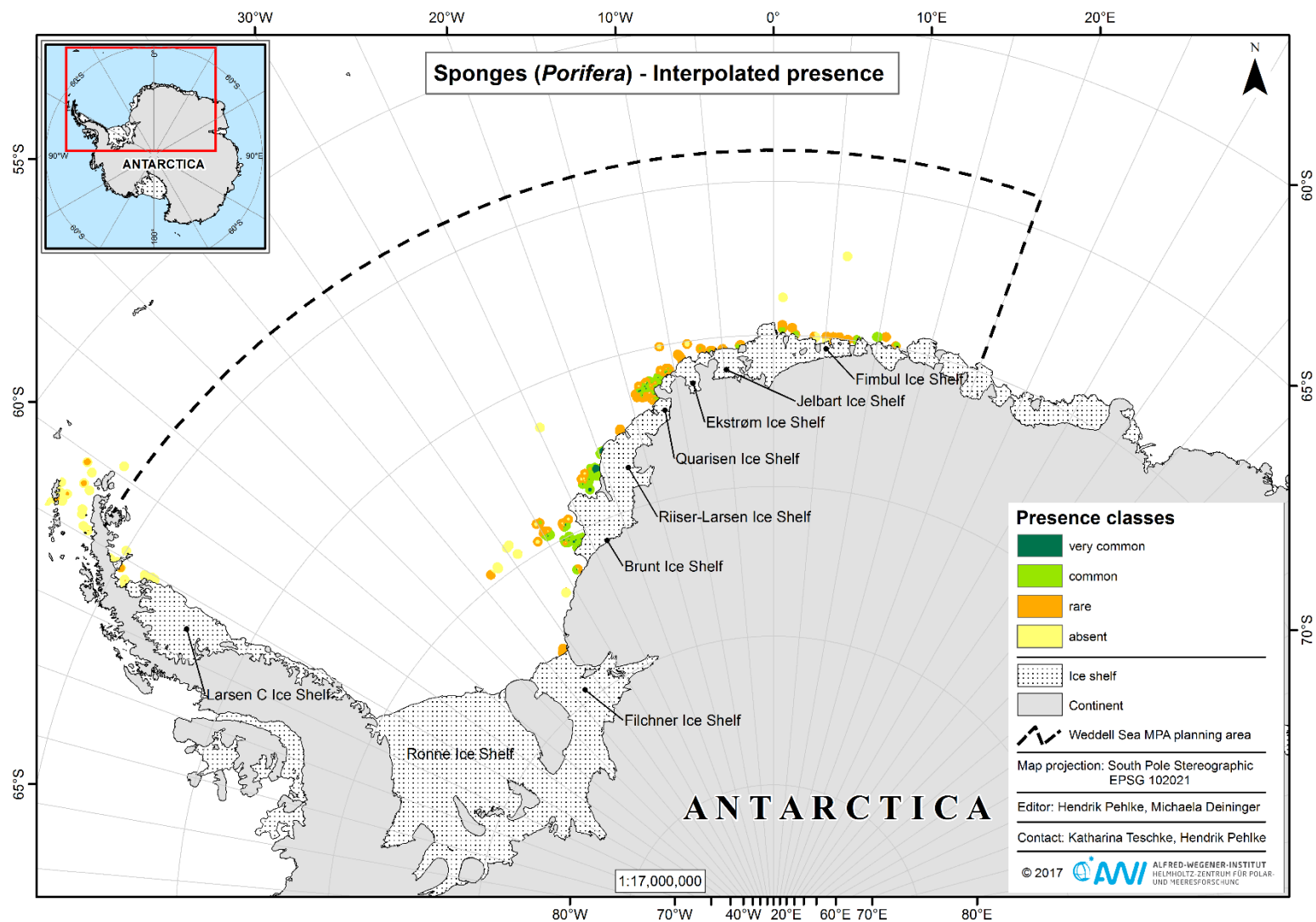


**Figure S5.** Interpolated abundances of ice krill (*Euphausia crystallorophias*) in the WSMPA Planning Area.



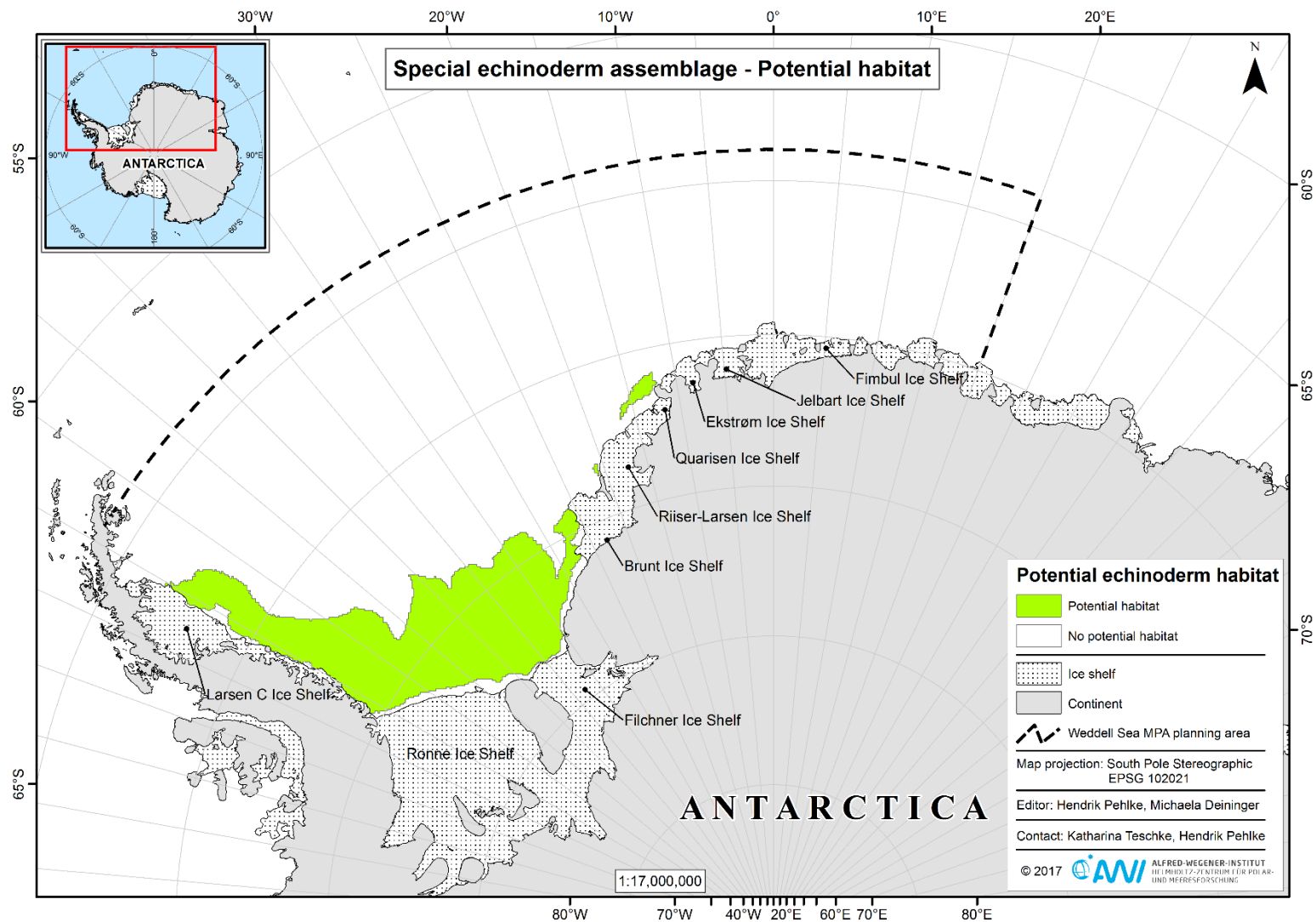


**Figure S6.** Potential habitat of ice krill (*Euphausia crystallorophias*) in the WSMPA Planning Area.

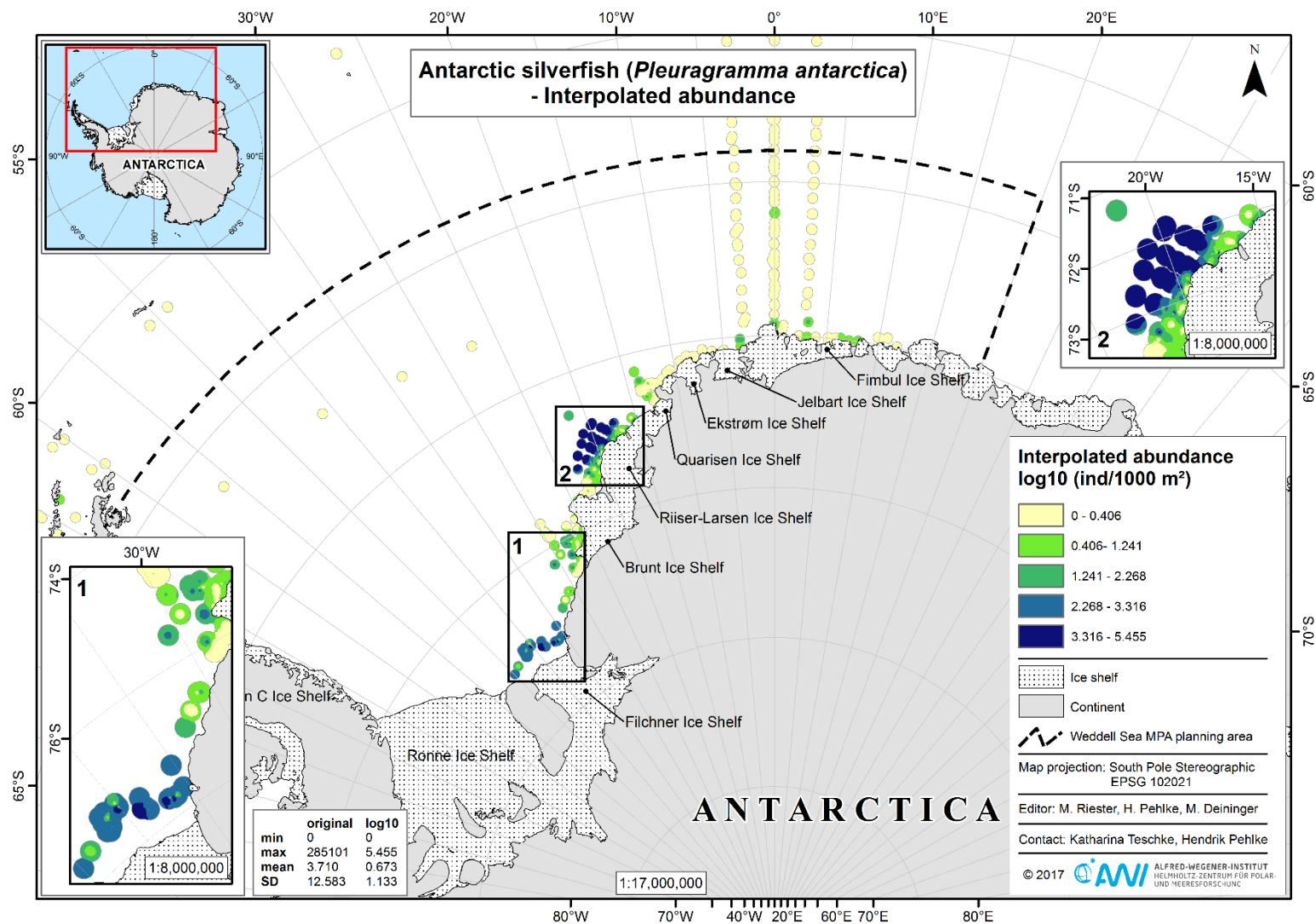


**Figure S7.** Interpolated occurrences of sponges in the WSMPA Planning Area.

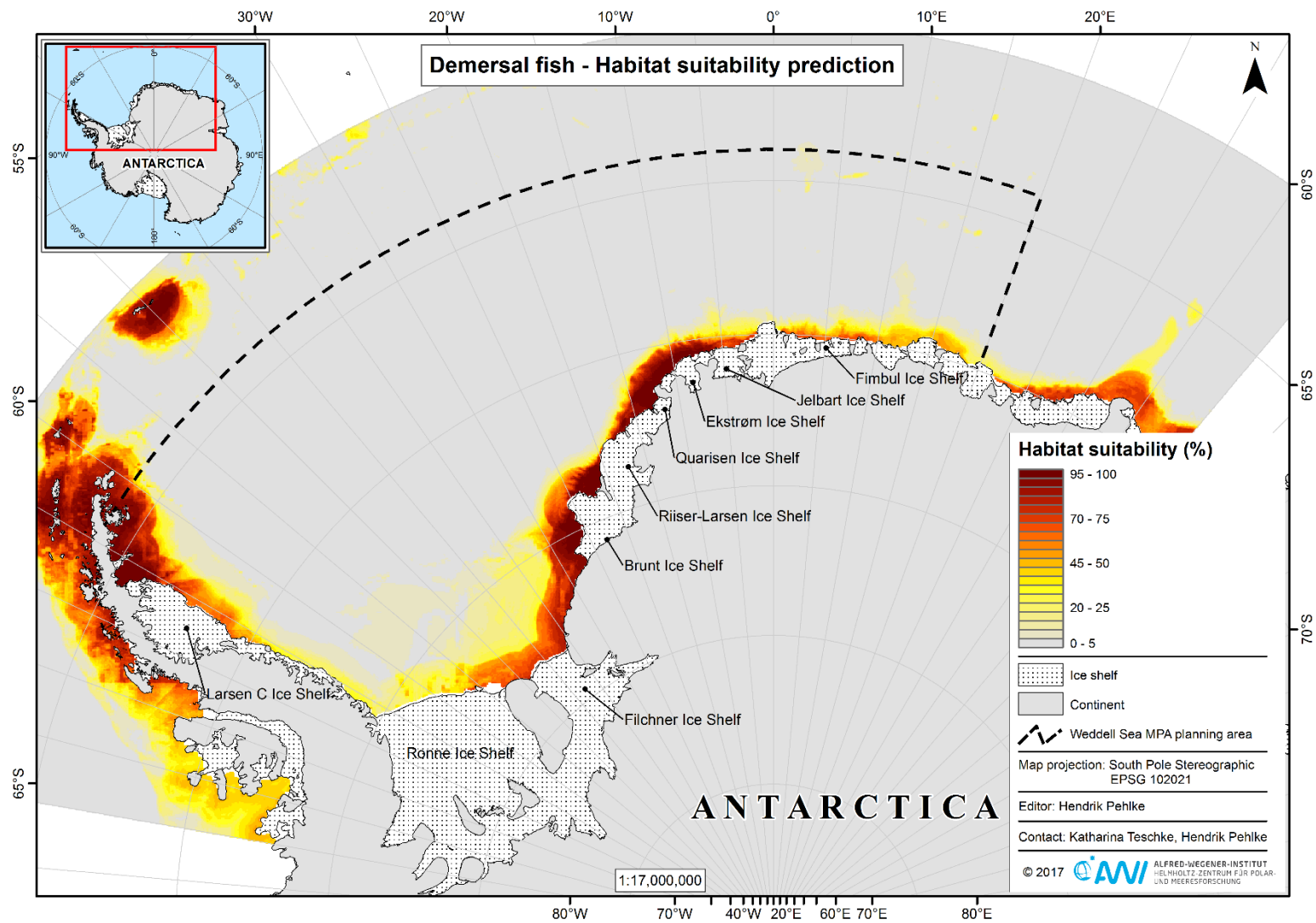




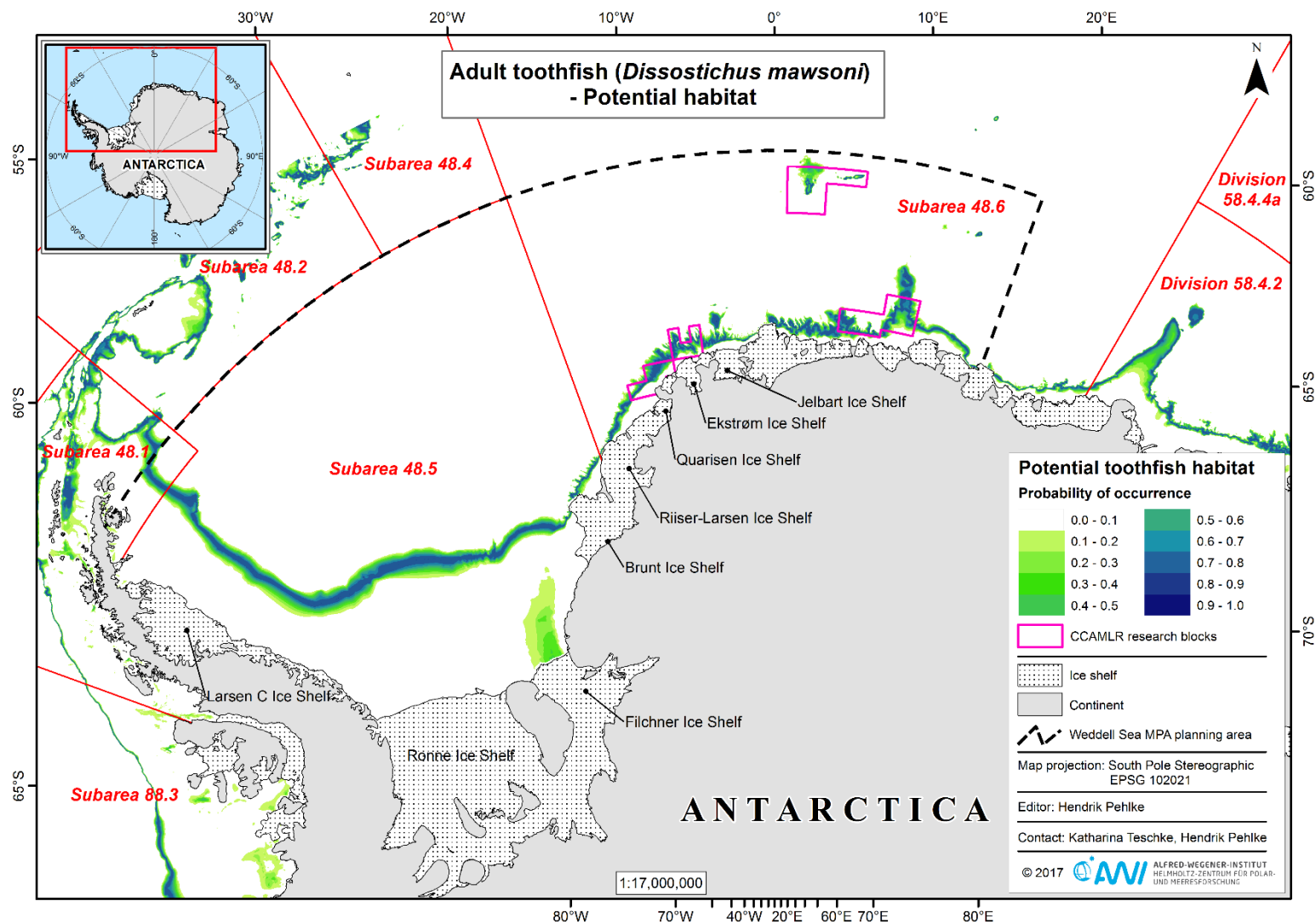
**Figure S8.** Potential habitat of a special echinoderm assemblage in the WSMMA Planning Area.



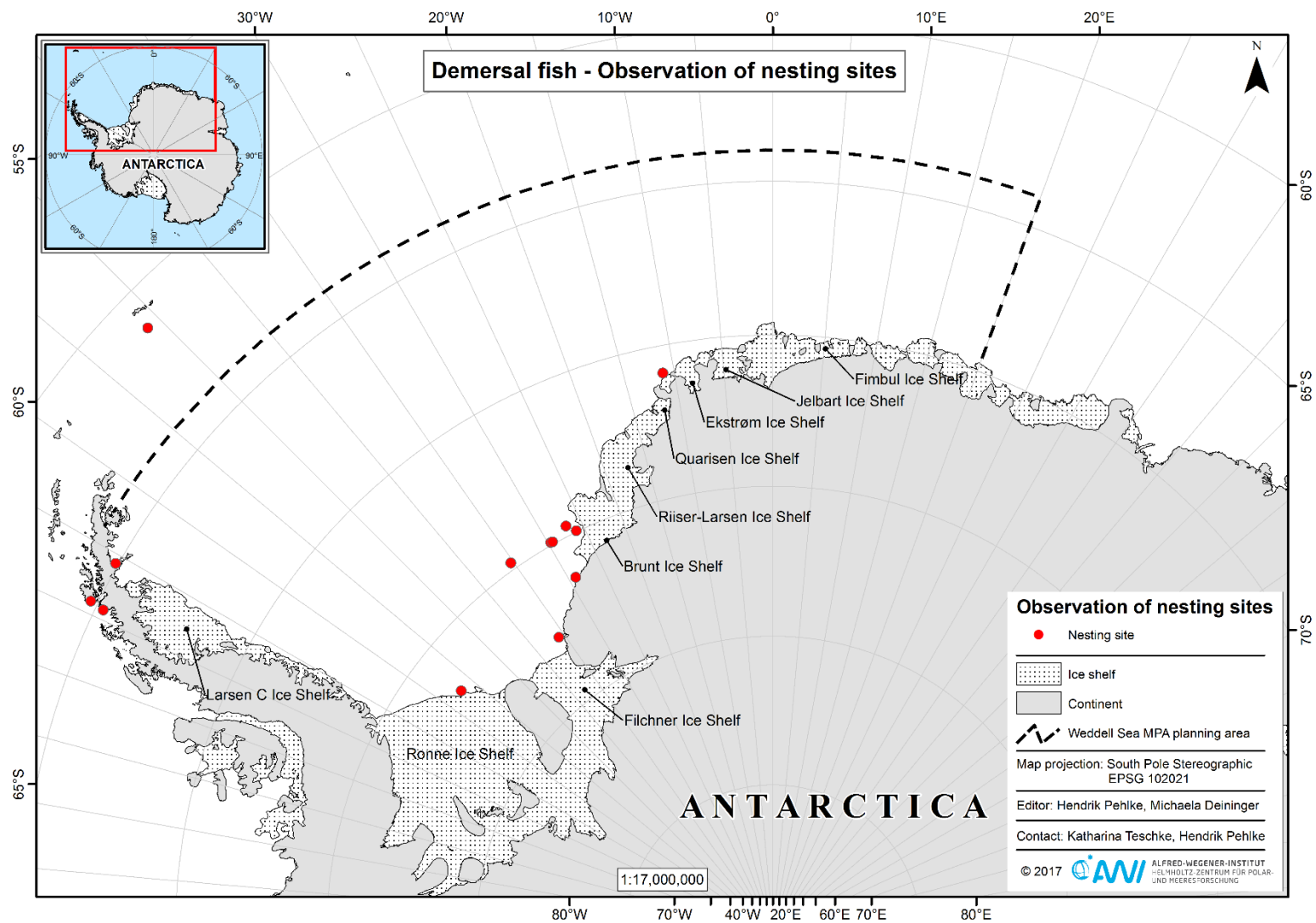
**Figure S9.** Interpolated abundances of Antarctic silverfish (*Pleuragramma antarctica*) in the WSMPA Planning Area.



**Figure S10.** Habitat suitability predictions of demersal fishes in the WSMMA Planning Area.

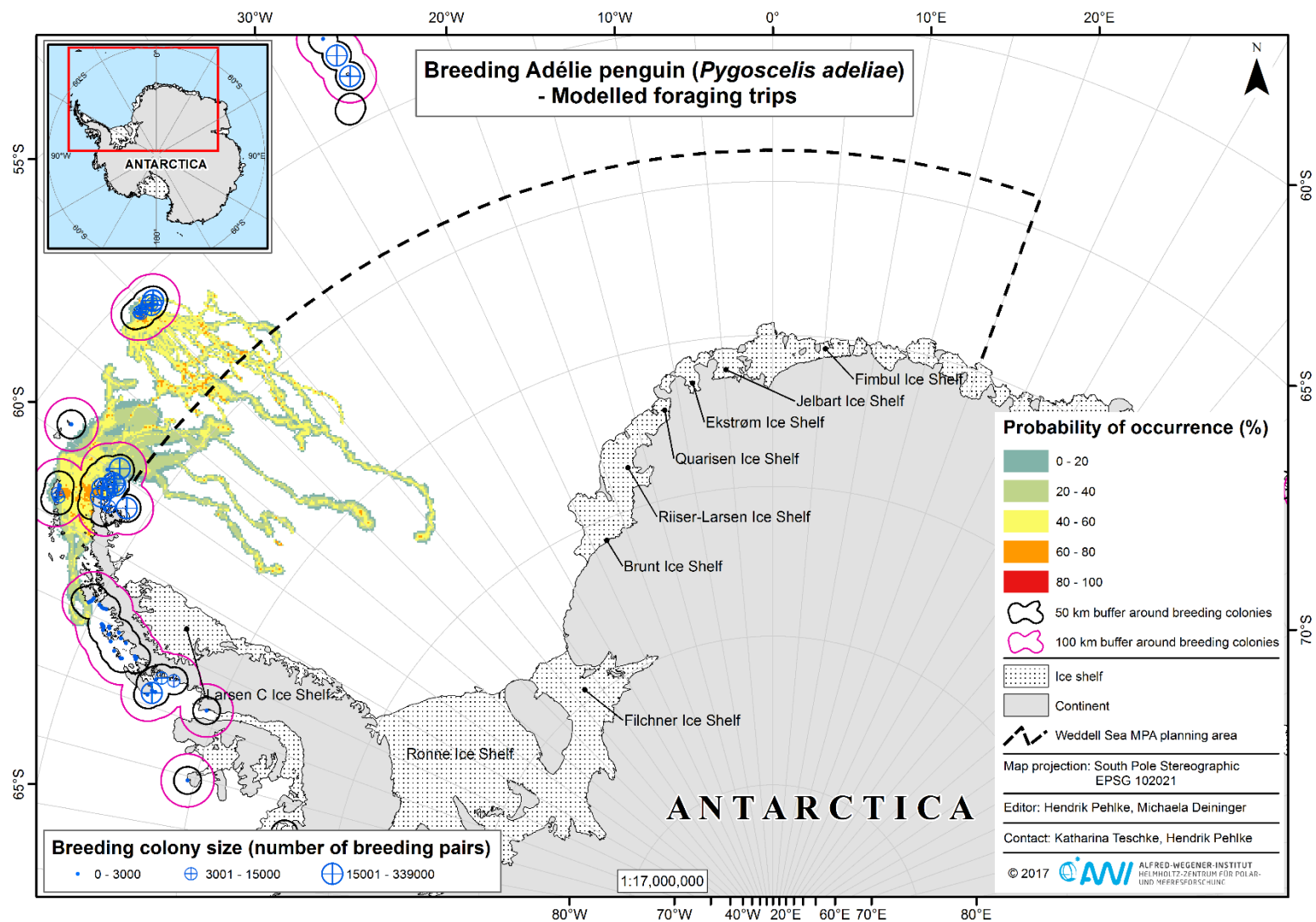


**Figure S11.** Probability model for the potential habitat of Antarctic toothfish (*Dissostichus mawsoni*) in the WSMFA Planning Area.

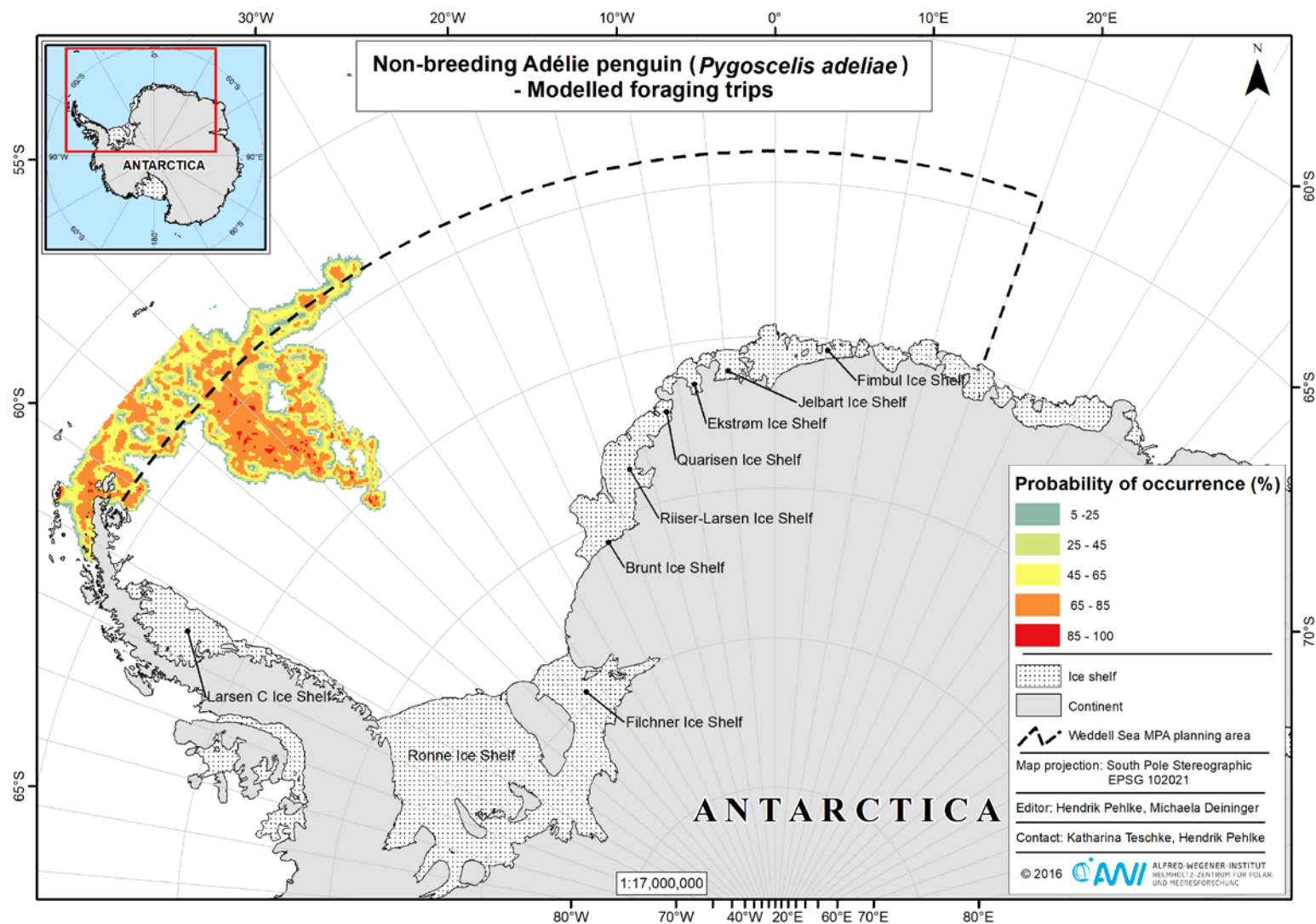


**Figure S12.** Nesting sites of demersal fish observed in the WSMFA Planning Area.

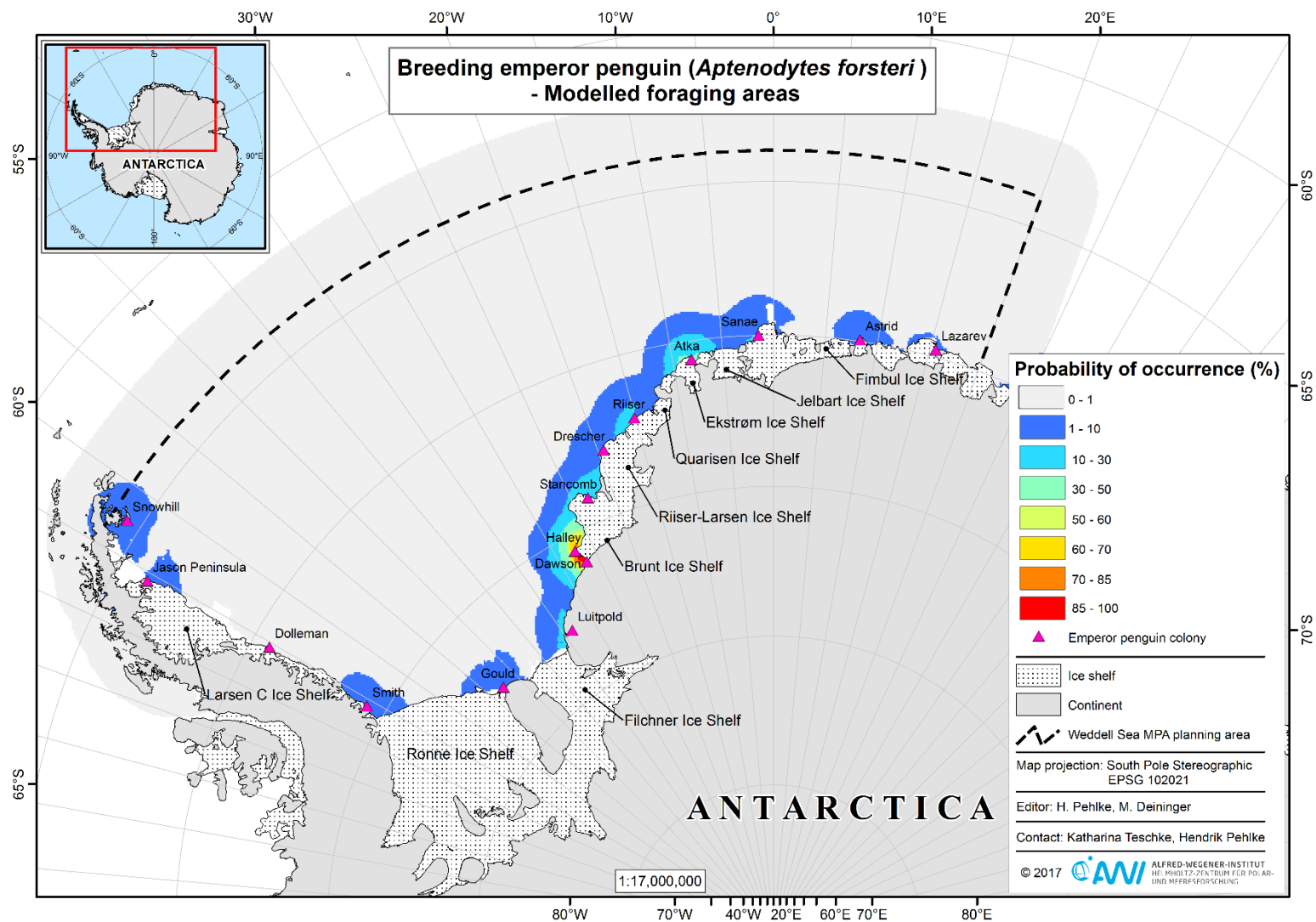




**Figure S13.** Modelled probability of the occurrence of breeding Adélie penguins (*Pygoscelis adeliae*) during foraging in the WSMPA Planning Area.

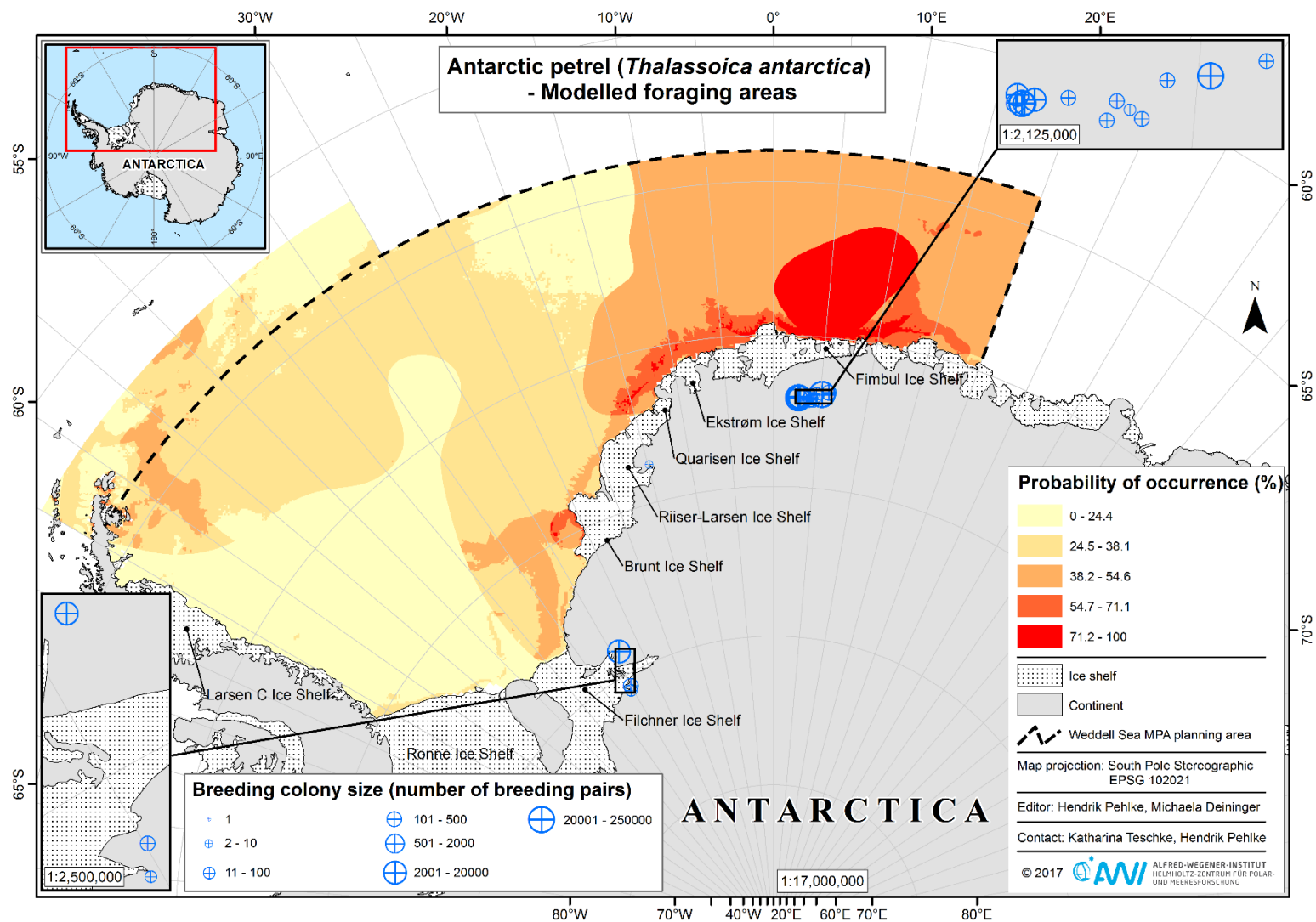


**Figure S14.** Modelled probability of the occurrence of non-breeding Adélie penguins (*Pygoscelis adeliae*) during foraging in the WSMMPA Planning Area.

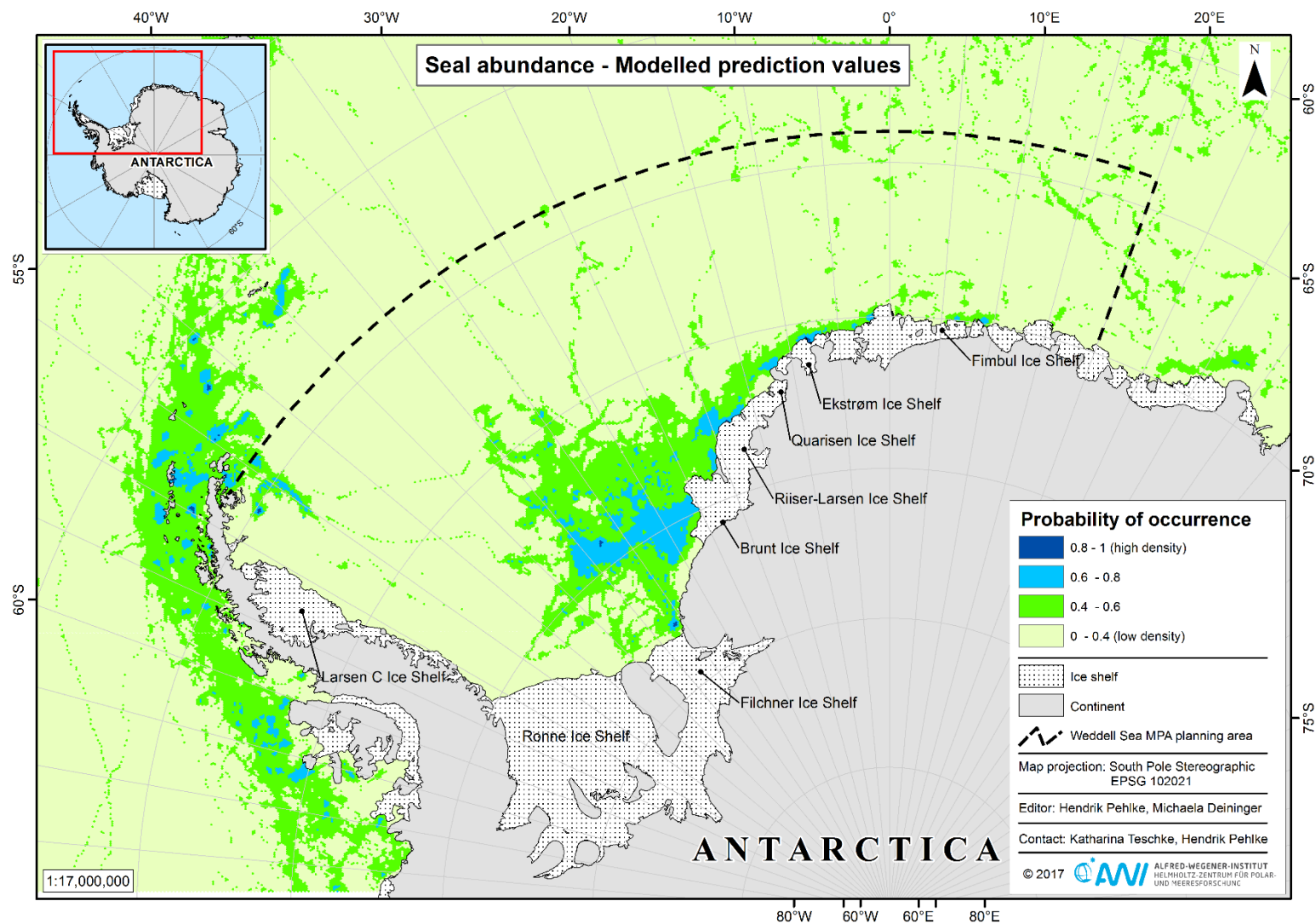


**Figure S15.** Modelled probability of the occurrence of Emperor penguins (*Aptenodytes forsteri*) during foraging in breeding season.

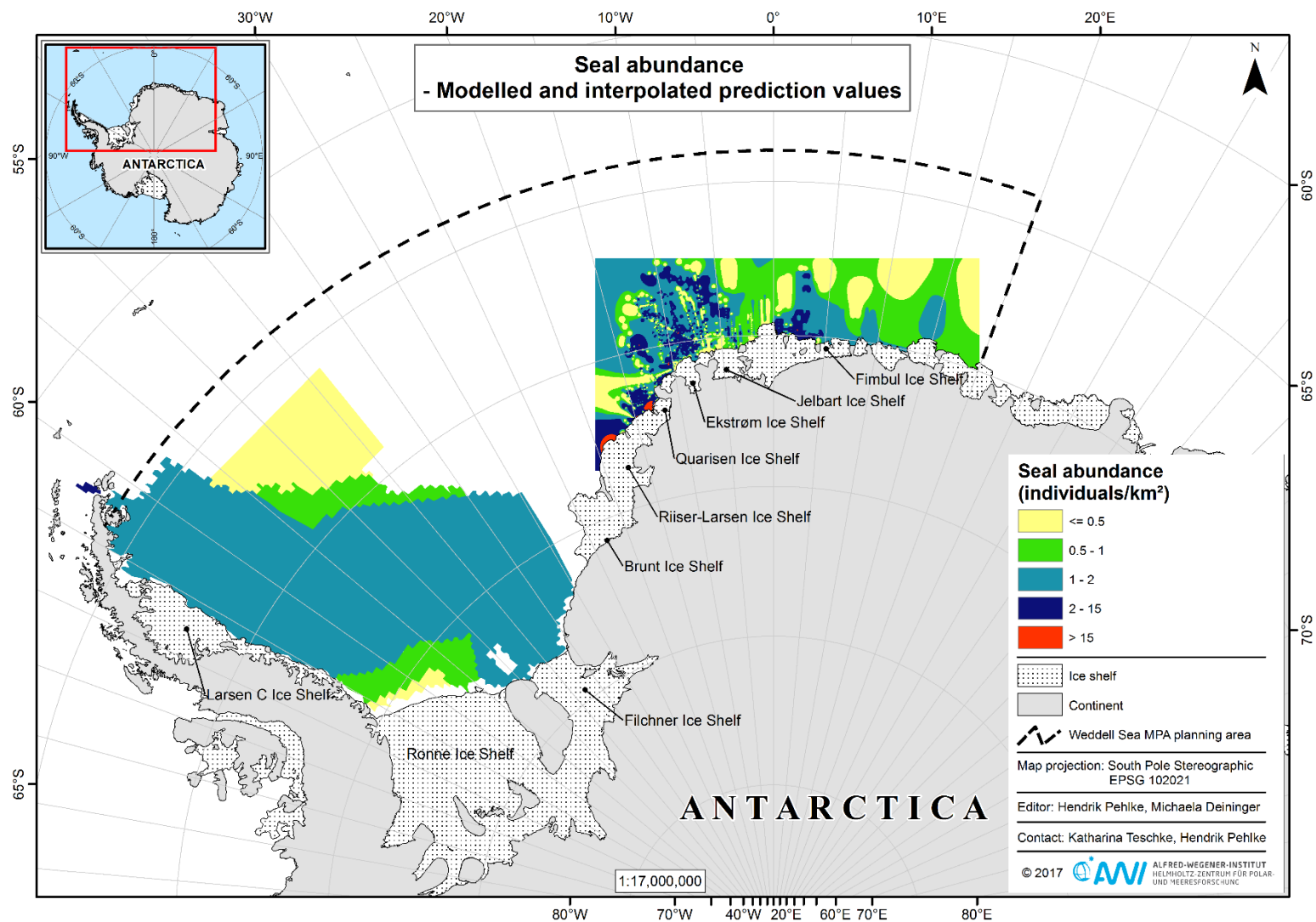




**Figure S16.** Probability model for the potential habitat of Antarctic petrel (*Thalassoica antarctica*) in the WSMPA Planning Area.



**Figure S17.** Modelled probability of seal occurrence in the WSMMPA Planning Area.



**Figure S18.** Modelled and interpolated seal abundances in the WSMPA Planning Area.

## S3 Tables

**Table S2.** Detailed list of adult Antarctic krill (*Euphausia superba*) data with survey name, station number per survey and respective source of data, which were used from the database KRILLBASE within the WSMMPA planning initiative.

Survey name	Station	Data source
bas1985sib	4a and 5	UK data (SIBEX cruise)
epa1993saf	211-216	South African data
epa1995saf	1-14	South African data
epa1998saf	27	South African data
epa1995bon	189	South African data
epa1996xxx	5 and 6	South African data
epa1989ikt	7, 8, 10, 11	Soviet data
epa1990mkx	149-173	Soviet data
epa1989smt	5, 6, 13, 14	Soviet data
epa1989ikt	7, 8, 10, 11	Soviet data
his1928dis-top	46	UK historical data
his1931wsc-top	548-552	UK historical data
his1932dis-str	813a, 815a, 816a, 822a	UK historical data
his1932dis-top	814, 818-820	UK historical data
his1933dis-str	1148a, 1150a, 1151a, 1153a	UK historical data
his1933dis-top	1149, 1152	UK historical data
his1935dis-str	1519a	UK historical data
his1935dis-top	1513-1528	UK historical data
his1935wsc-top	892 and 893	UK historical data
his1937dis-str	2004a	UK historical data
his1937dis-top	1998-2000, 2002, 2003, 2006-2012	UK historical data
his1937dis-ver	2010a, 2012a	UK historical data
his1939dis-str	2596a, 2598a, 2600a, 2606a-2608a, 2010a	UK historical data
his1939dis-top	2543-2563, 2595, 2599, 2601, 2603, 2604, 2609	UK historical data
his1939dis-ver	2543a, 2545a, 2547a	UK historical data
pol1984wit	165 and 168	Polish data; Witek et al. (1985)
vsi2004lak	1021, 1023-1025, 1028-1031, 1033-1037, 100-1042, 1044-1046, 1048-1050, 1053-1056, 1059-1060, 1062, 1065, 1066, 1068-1071, 1075-1078, 1080, 1084, 1086, 1087, 1090-1092, 1095-1097, 1100-1102, 1116-1117	German data (LAKRIS cruise 2004)
vsi1980pol	20, 21, 23, 24, 27-29, 31, 33-35, 51, 52, 54-79, 82-85, 87-101, 105-111	German data (MV Polarsirkel cruise 1979/80)
vsi1981pol	89, 91, 94, 97-99, 101, 106, 108, 110, 111, 126-128, 130, 132, 134, 136, 138, 143, 178, 179, 185, 186, 191, 193, 195, 197, 203, 205, 208-211, 213-215, 217, 219, 224, 226-235, 237, 282	German data (MV Polarsirkel cruise 1980/81)
vsi1976xxx	161, 162, 176, 183, 185, 186, 189, 190	German data (RV Walther Herwig cruise 1975/76)
vsi1978xxx	330-337, 339, 340a, 341b, 342c, 343d, 344e, 345	German data (RV Walther Herwig cruise 1977/78)

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