CCAMLR

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Scientific background document in support of the development of a CCAMLR MPA in the Weddell Sea (Antarctica) - Version 2015 - Part C: Data analysis and MPA scenario development

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Contents

Introduction

Part C of the scientific background document informs on the data analysis and the MPA scenario development that were carried out within the framework of the Weddell Sea MPA (WSMPA) project.

Chapter 1 contains an update of the data analysis of environmental and ecological parameters that has been presented in our scientific background document SC-CAMLR-XXXIII/BG/02, and had welcomed and endorsed as a foundation reference document for the Weddell Sea MPA planning by the Scientific Committee (SC-CAMLR-XXXIII, § 5.21). Some newly conducted data analyses (e.g. distribution pattern of Antarctic silverfish, sponge presence) were recently presented and discussed at the 2nd International Expert Workshop on the WSMPA project (28-29 April 2015; Berlin, Germany). Members of the German WSMPA project team prepared Chapter 1.

Chapter 2 provides a systematic overview of the MPA scenario development. First, we present the defined general and specific conservation objectives for the WSMPA planning area. Then, we provide a systematic overview of the parameters and their specific regional objective for the Marxan analysis (see Tab. 2-1). Subsequently, we set out the Marxan approach, and finally substantiate the Marxan analysis for a MPA proposal. Members of the German WSMPA project team together with the Marxan expert Lucinda Douglass (Centre for Conservation Geography, Australia) compiled Chapter 2.

1. Data analysis

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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), QGIS (Version 2.1.0) and the ESRI`s GIS desktop software suite (ESRI 2011).

1.1 Environmental parameters

1.1.1 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. 2015). 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. 1-1.

In total 17 geomorphic classes were used to describe the structures at the sea floor of the Weddell Sea MPA planning area (see Fig. 1-1) (Jerosch et al. 2015). For more details on the diversity of 'landscape' see Part A of the scientific background document.

This benthic regionalisation approach 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). Applying the BPI approach to the new IBCSO data (Arndt et al. 2013) resulted in a much more detailed mapping of the geomorphic features. Comparably small features (troughs and ridges) indicate a very diverse environment and facilitate our understanding of a wide range of processes, i.e., deposition of reworked sediment, deformation and melt-out, subaqueous mass-movements, fluvial processes, and settling through the water column.

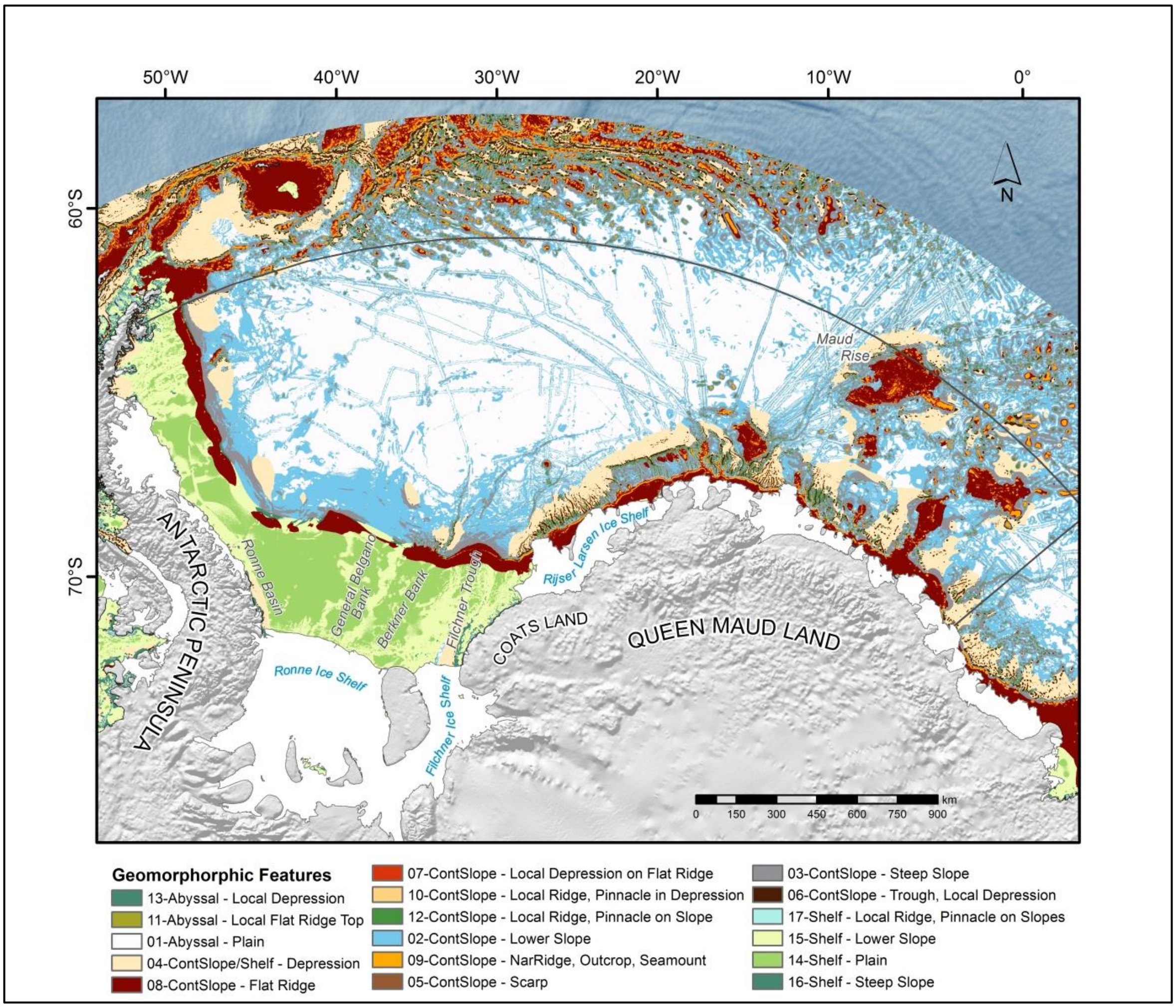


Figure 1-1 Geomorphology of the Weddell Sea which derived from bathymetry (IBCSO; Arndt et al. 2013) and its bathymetric derivatives, i.e. slope and bathymetric position index (Jerosch et al. 2015). Black box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

1.1.2 Sedimentology

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. 1-2): (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).

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. 2015). However, the analysis shows the relation between grain size distributions and geomorphic features, although the values display high standard deviations (see Table 1-1). 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. 1-3).

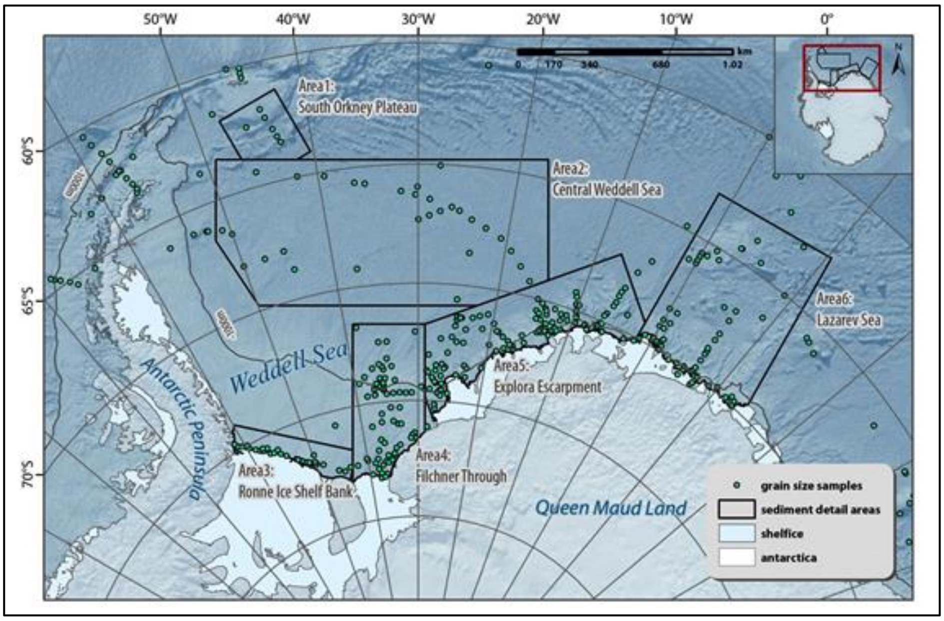


Figure 1-2 Data density of the grain size data restricted the ground truthing to six parcelled-out areas: (1) South Orkney Plateau, (2) Central Weddell Sea, (3) Ronne Basin, (4) Filchner Trough, (5) Explora Escarpment, (6) Lazarev Sea according to IBCSO (Arndt et al. 2013). Sediment grain size data are 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.

Table 1-1: 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

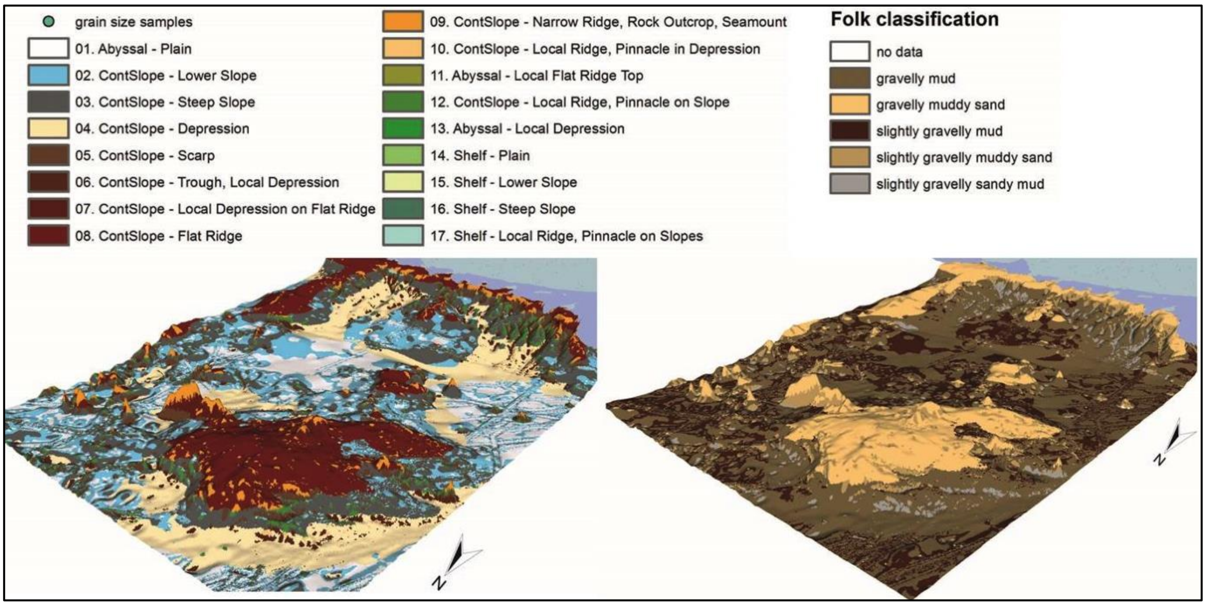


Figure 1-3 Display of the Folk (1954) classified mean grain sizes adapted to the geomorphic features of Maud Rise area.

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. 1-2) (Jerosch et al. in prep.). 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. 1-4). Please note that areas potentially characterised by hard substrate are not represented, they only can be indicated by high slope values resulting in geomorphic features.

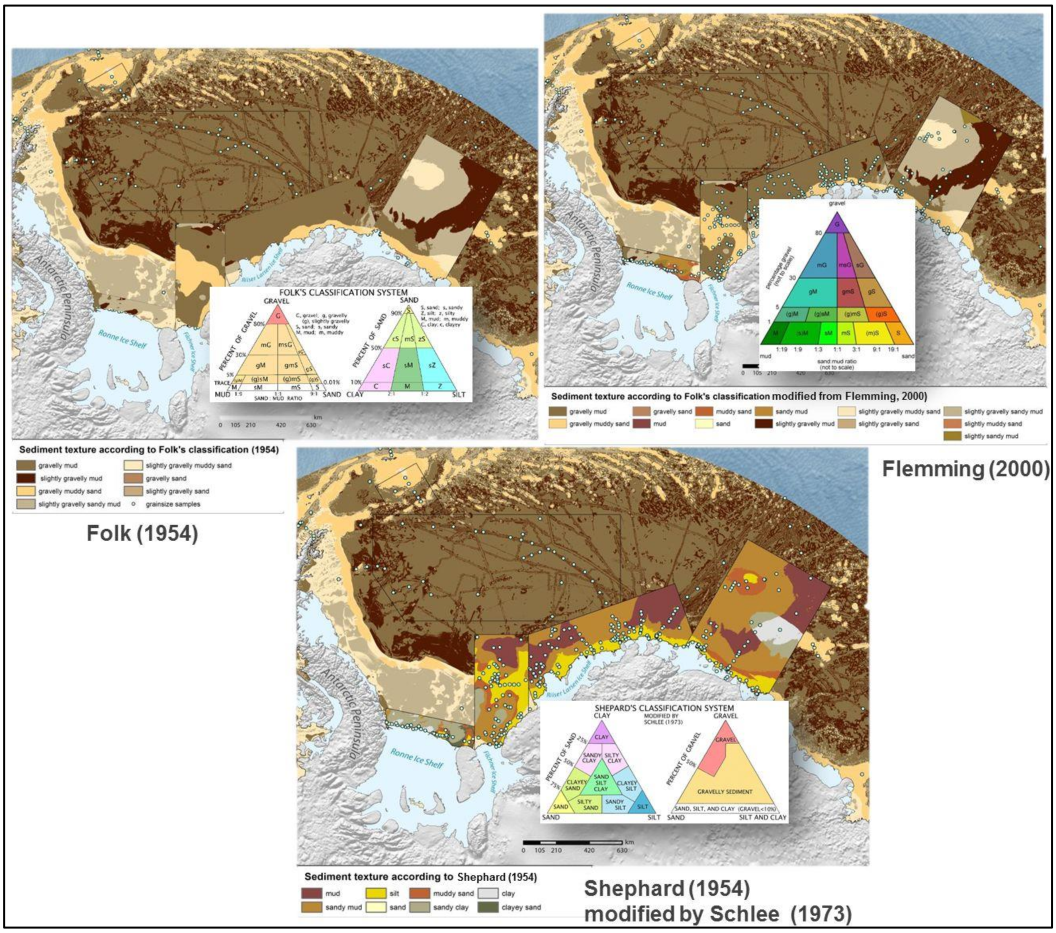


Figure 1-4 Application of sediment classification schemes according to Folk`s (1954), Flemming`s (2000) and Shepard`s classification (1954) to the interpolated grain size maps. Interpolation methods were successfully applied for area 4, 5 and 6 due to data density (Jerosch et al. in prep.).

1.1.3 Oceanography

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 1.1.5).

1.1.4 Sea ice

Two 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 1.2.5.

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, but were used as additional background information to support the distribution pattern of 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 so that those data are comparably with ordinal data on coastal winter polynyas from the ICDC (University Hamburg), and we refrained from calculating means from categorical data on winter polynya distribution.

1.1.5 Pelagic regionalisation

Each data layer, which was incorporated into the pelagic regionalisation analysis, was generated with a raster of 6.25 km x 6.25 km. 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 parameters chosen for the pelagic regionalisation analysis are major structuring components of the pelagic Weddell Sea ecosystem. Furthermore, these parameters coincide to some extent with the variables which were incorporated in a circumpolar pelagic regionalisation of the Southern Ocean by Raymond (2011; WG-MPA-11/6). The highest weighting factor was assigned to sea ice concentration, as the main aim of our analysis was to detect high productive areas (polynyas) in the WSMPA planning area.

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. 1-5. '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 1.1.1.; Fig. 1-1) 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.

1.2 Ecological parameters

1.2.1 Chlorophyll-a concentration

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. 1-6). 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 inter-annual variation and/or outliers, e.g. due to measurement errors.

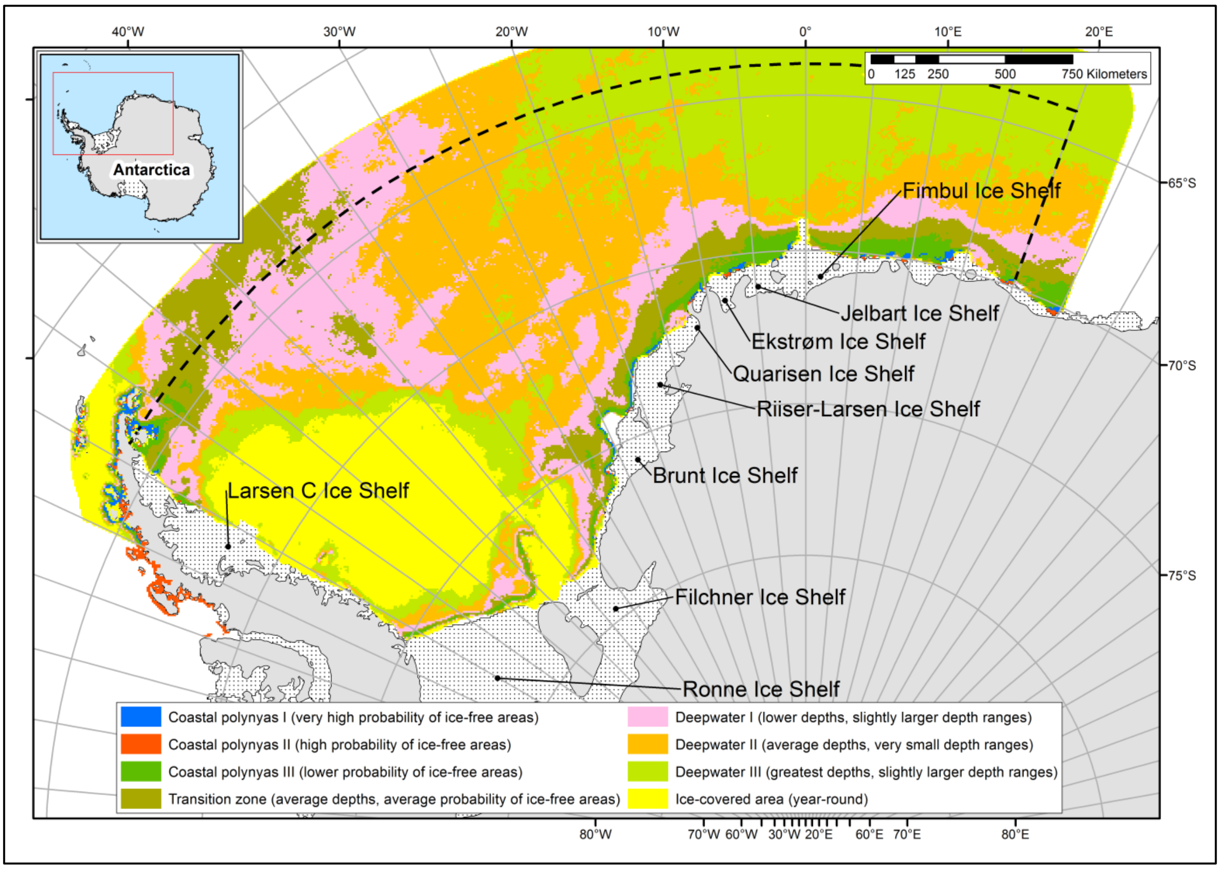


Figure 1-5 Pelagic regionalisation analysis based on *(i)* AMSR-E 89 GHz sea ice concentration data (Spreen et al. 2008), *(ii)* bathymetric data (i.e. depth and 'depth range') by IBSCO (Arndt et al. 2012), and *(iii)* FESOM model data on sea water temperature and salinity at the sea surface and the 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 (WSMPA). Boundaries of the planning area do not resemble the boundaries of any proposed WSMPA.

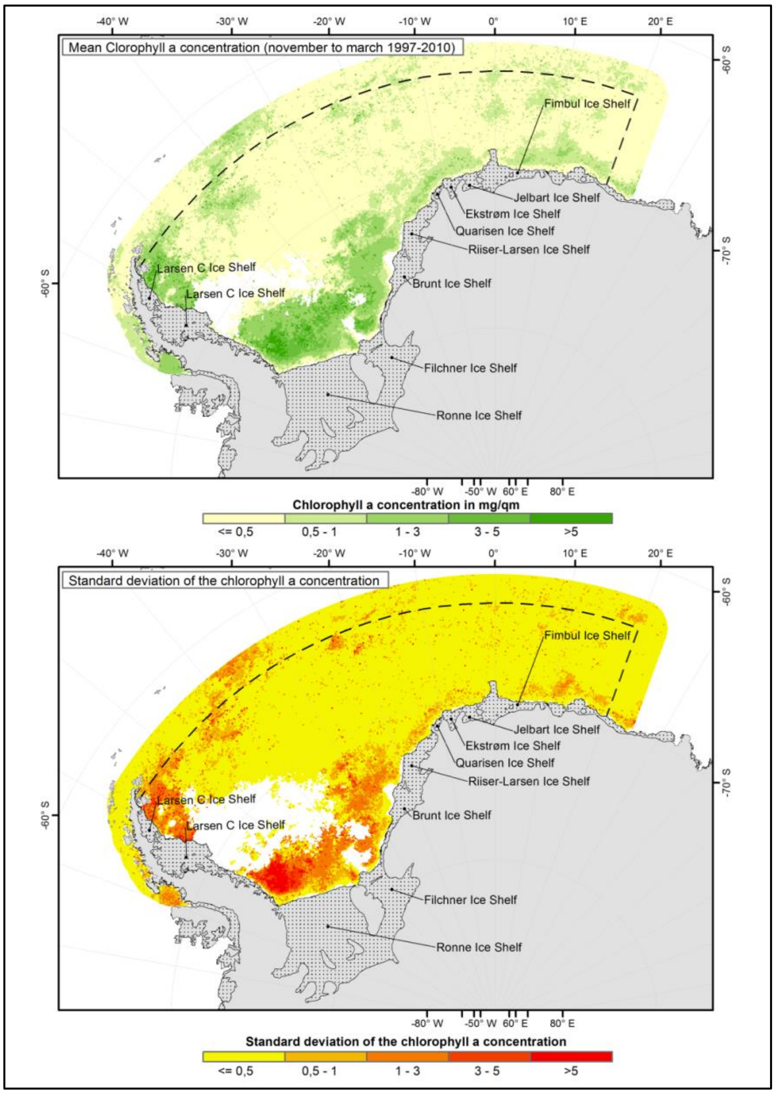


Figure 1-6 Mean value (above) and standard deviation (below) of data on chlorophyll-a concentration (in mg/m³) out of 14 austral spring and summer (Nov-Mar), 1997-2010. Areas in white had no valid chlorophyll data because of heavy sea ice or persistent cloud cover. Monthly data were downloaded via the NASA's OceanColor website. Black dashed box: Planning area for the evaluation of a Weddell Sea MPA (WSMPA). Boundaries of the planning area do not resemble the boundaries of any proposed WSMPA.

1.2.2 Pelagic ecosystem

Antarctic krill (Euphasia superba)

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 non-standardised data. Atkinson et al. (2008) compared the circumpolar krill distribution based on raw, non-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/m²) +/- the n-fold of the standard deviation per grid cell (6.25 km x 6.25 km).

The distribution pattern of Antarctic krill is mapped in Fig. 1-7. Hotspots of adult Antarctic krill abundance (i.e. mean krill densities > 52 individuals/m²) are located:

- *(i)* at the northern border of the Weddell Sea MPA (WSMPA) 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 WSMPA 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/m² (south-eastern/southern shelf area) and 12 individuals/m² (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).

Ice krill (Euphasia crystallorophias)

Efforts to detect hotspots for other pelagic key species, such as ice krill, were discussed at the 1st International Expert Workshop (see WG-EMM-14/19, supplementary material). The data layer on potential ice krill habitats was generated from bathymetric data by IBSCO (Arndt et al. 2013) and temperature data by the FESOM model (Timmermann et al. 2009). We used two parameters, water depth from 0 m to 550 m and SST ≤ 0°C, as proxies of ice krill occurrence. The biological characteristics of ice krill were taken from the Biogeographic Atlas of the Southern Ocean (2014). Acquired data on ice krill (e.g. Siegel 2012, Siegel et al. 2013) are not directly incorporated into the analysis, but were used as additional background information to support potential ice krill habitats in the Weddell Sea. Figure 1-8 shows the probability of ice krill occurrence to the north and to the east of the Filchner Trough.

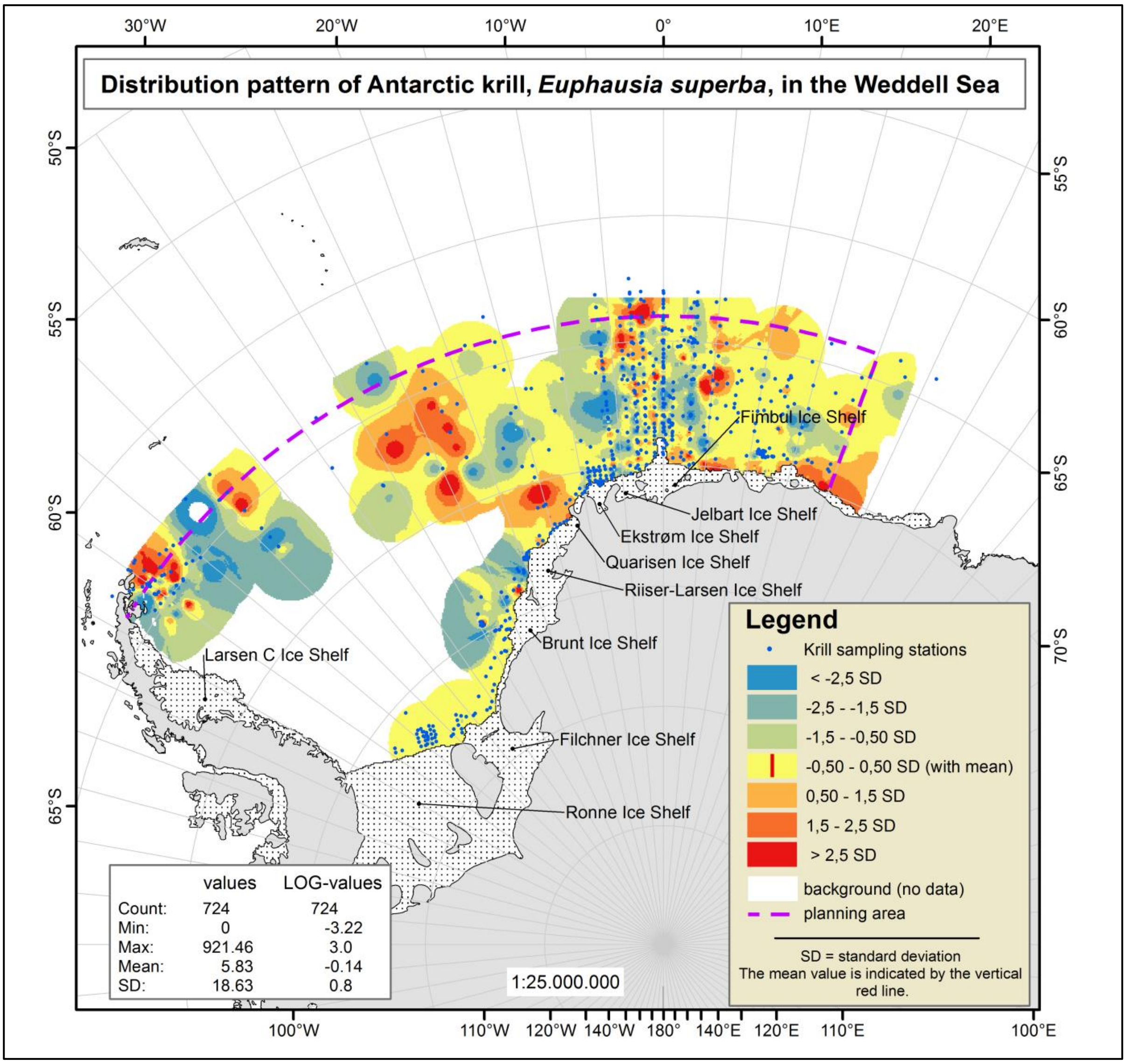


Figure 1-7 Distribution pattern of Antarctic krill, *Euphausia superba*, in the Weddell Sea based on non-standardised, log-transformed data from KRILLBASE (Atkinson et al. 2004, 2008, 2009; Siegel 1982) and (un-) published data held by Volker Siegel, Thünen Institute, Hamburg (e.g., Siegel 2012; Siegel et al. 2013). The interpolated data are plotted as mean krill densities (individuals/m²) +/- n-fold of standard deviation per grid cell (6.25 km x 6.25 km). 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.

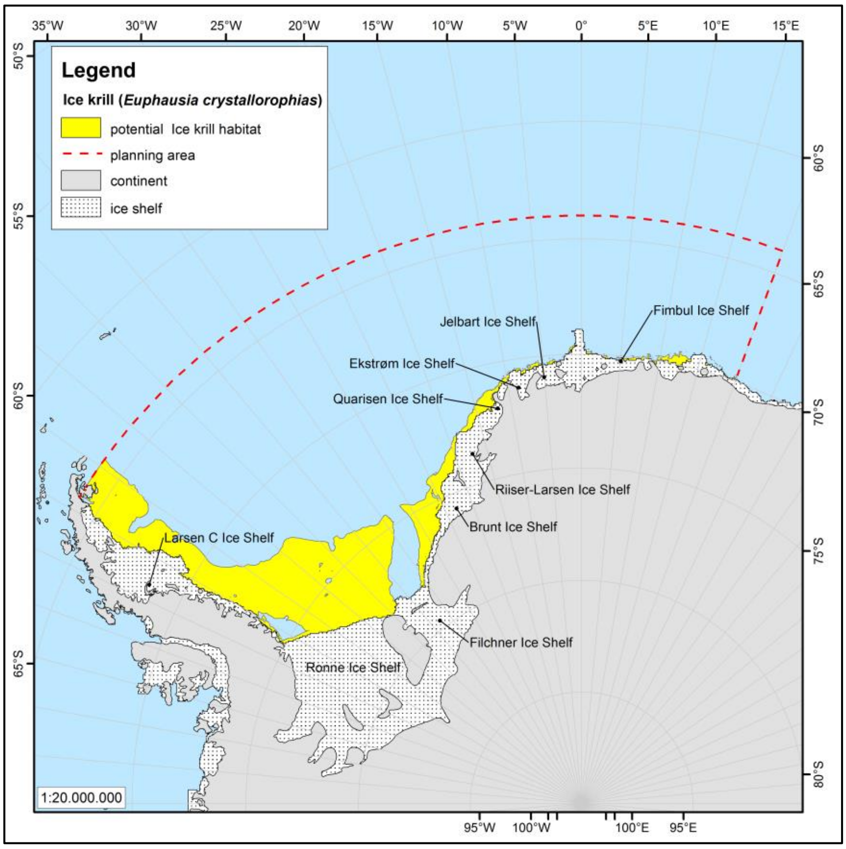


Figure 1-8 Potential habitat of ice krill, *Euphausia crystallorophias*, in the Weddell Sea (yellow coloured area) based on depth range and seawater temperature as proxies. Red dashed box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

Pelagic fish

Here, we focused on Antarctic silverfish, *Pleuragramma antarctica*, a pelagic key species of the Weddell Sea ecosystem that plays a similar role as clupeids do in temperate ecosystems. The distribution pattern of *P. antarctica* in the WSMPA planning area was evaluated from several data sets. Abundance data on adult *P. antarctica* were derived from Boysen-Ennen & Piatkowski (1988), Flores et al. (2014), extracted from PANGAEA (Drescher et al. (2012), Ekau et al. (2012a, b), Hureau et al. (2012), Kock et al. (2012), Wöhrmann et al. (2012)) and obtained from R. Knust (AWI, unpublished data). Abundance data on *P. antarctica* larvae were derived from Boysen-Ennen & Piatkowski (1988) and Hubold et al. (1988).

For data on adult *P. antarctica* 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 densities of adult *Pleuragramma antarctica* (individuals/1000 m²) for a 30 km radius around each record. The IDW settings were chosen as follows:

- Z value: The calculated log10-transformed *P. antarctica* density per 1000 m²
- Output cell size (x, y): 1000 m
- Distance coefficient power P: 2
- Search radius setting, number of points: 10

Figure 1-9 shows high *Pleuragramma* density of adults near Brunt Ice Shelf on the continental shelf at 75°S (100 to 650 individuals/1000 m²), and east and west of the prime meridian near Fimbul and Jelbart Ice Shelf (10 to 100 individuals/1000 m²), respectively.

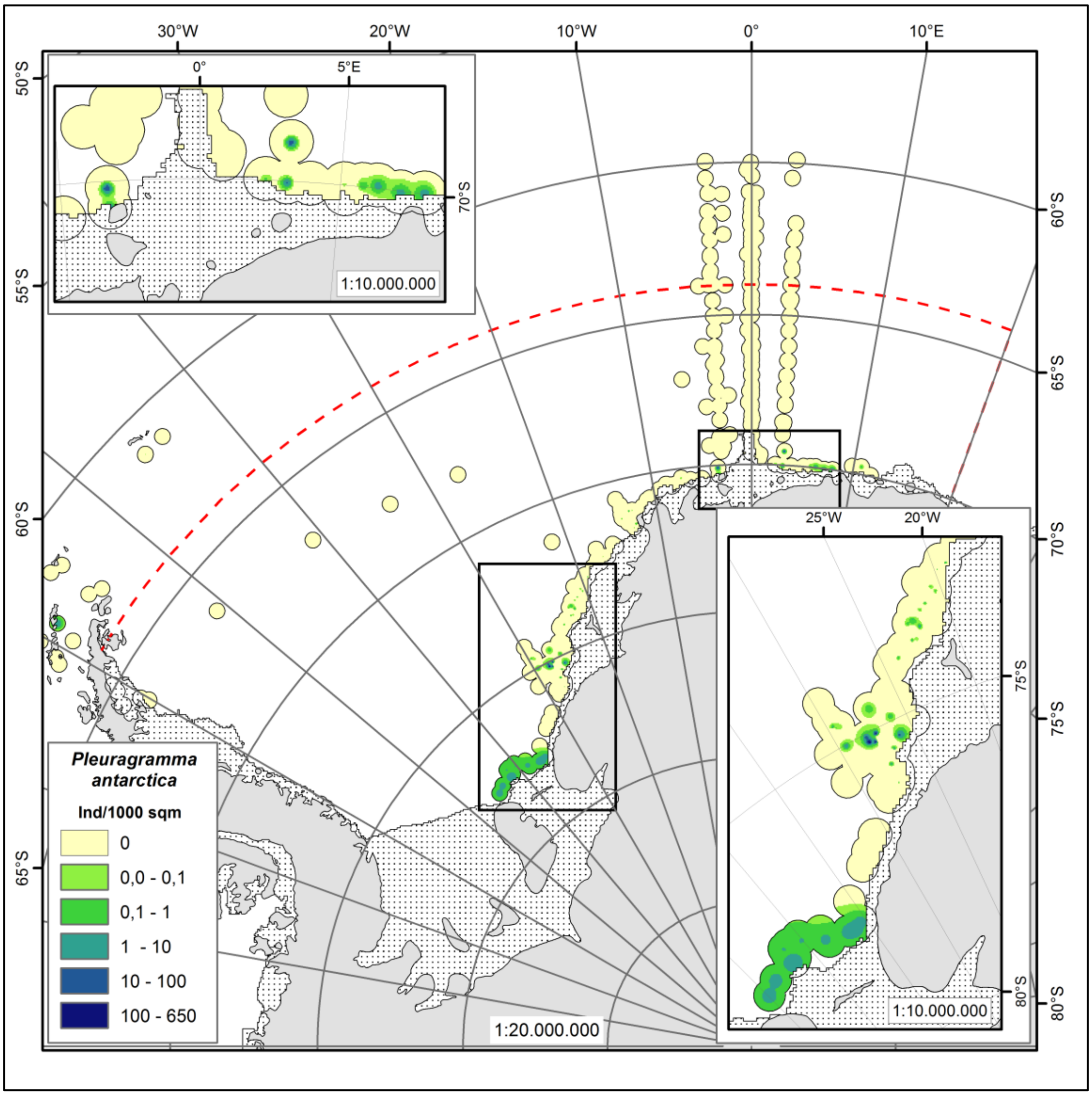
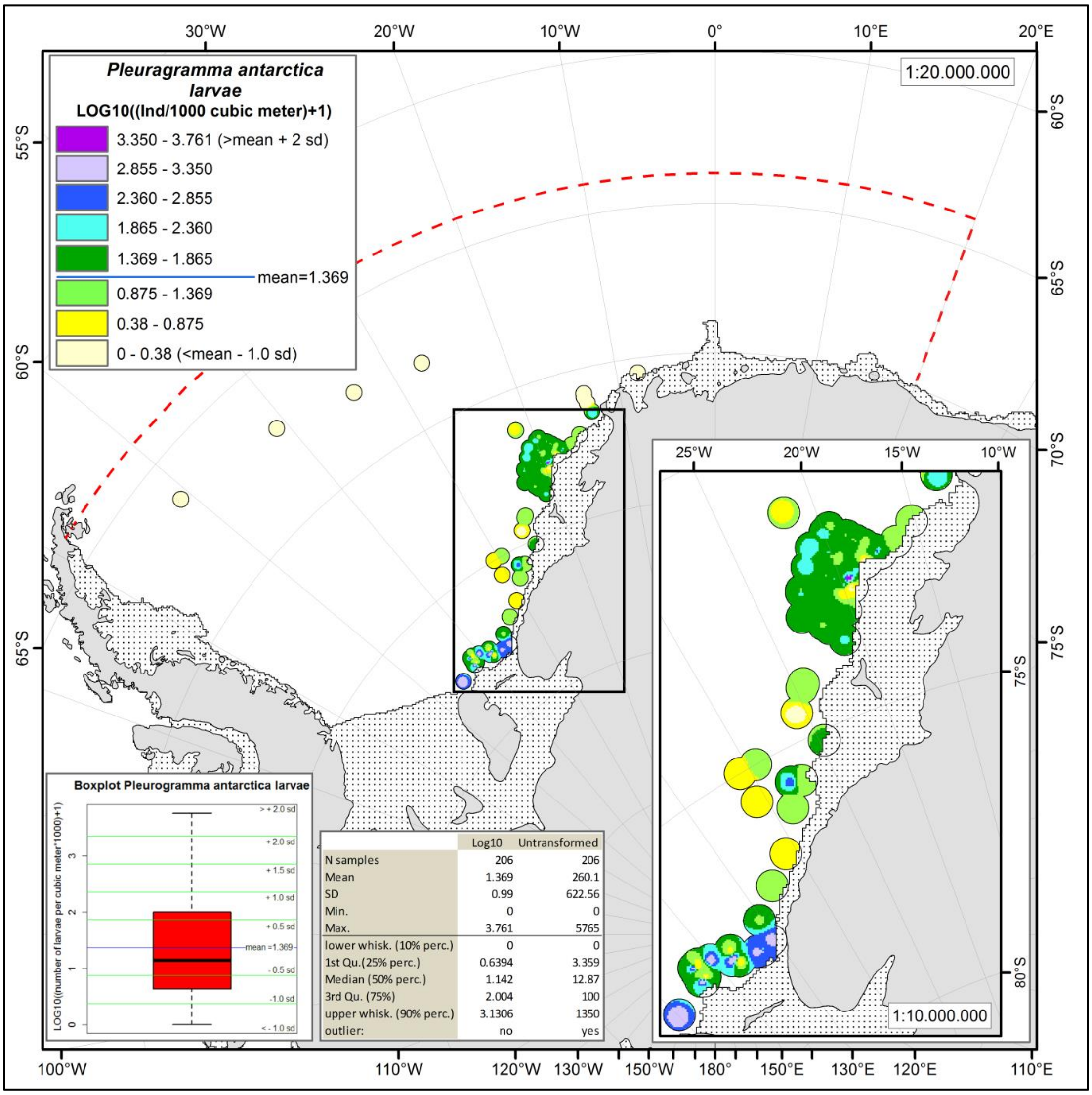


Figure 1-9 Distribution pattern of adult *Pleuragramma antarctica* in the Weddell Sea. Abundance data on adult *P. antarctica* were derived from Boysen-Ennen & Piatkowski (1988) and Flores et al. (2014), based on data from PANGAEA (Drescher et al. (2012), Ekau et al. (2012a, b), Hureau et al. (2012), Kock et al. (2012), Wöhrmann et al. (2012)) and unpublished data held by R. Knust, AWI. The log-transformed, interpolated data are plotted as densities (individuals/1000 m²) for a 30 km radius around each record. Red dashed box: Weddell Sea MPA planning area. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

Regarding *P. antarctica* larvae IDW interpolation was performed using log-transformed data. The result of the IDW was reclassified, and the interpolated data were finally expressed as log10 ((individuals/1000 m³) +1) for a 30 km radius around each record. The output cell size (x, y) was 1000 m, the distance coefficient power was set at 3.

A hotspot of high *Pleuragramma* densities of larvae (up to 637 individuals/1000 m³) occur on the southern continental Weddell Sea Shelf, i.e. south of 75°S near Filchner Ice Shelf (see Fig. 1-10).



	Log10	Untransformed
N samples	206	206
Mean	1.369	260.1
SD	0.99	622.56
Min.	0	0
Max.	3.761	5765
lower whisk. (10% perc.)	0	0
1st Qu.(25% perc.)	0.6394	3.359
Median (50% perc.)	1.142	12.87
3rd Qu. (75%)	2.004	100
upper whisk. (90% perc.)	3.1306	1350
outlier:	no	yes

Figure 1-10 Distribution pattern of *Pleuragramma antarctica* larvae in the Weddell Sea planning area. Abundance data on *P. antarctica* larvae were derived from Boysen-Ennen & Piatkowski (1988) and Hubold et al. (1988). Log-transformed, interpolated data are plotted as densities (individuals/1000 m³) for a 30 km radius around each record. Red dashed box: Weddell Sea MPA planning area. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

1.2.3 Benthic ecosystem

Zoobenthos – Shelf and slope

Macrozoobenthic taxonomic richness

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 (DZMB). 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. 1-11 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. 2013). In these areas along the shelf the dominant community types are mostly sessile suspension feeder communities dominated by sponges.

Sponge presence

Here, the main objective was to identify areas with important ecosystem functions, i.e. strongly structured habitats. The distribution pattern of sponges in the Weddell Sea MPA (WSMPA) planning area was calculated based on quantitative data held by D. Gerdes (AWI) and U. Mühlenhardt-Siegel (DZMB), and semi-quantitative data (four categories of relative abundance, i.e. absent, rare, common, very common) from W. Arntz (AWI, retired). The latter had to be digitised and consolidated into one data set.

We transformed the quantitative data into the same four-category system as the semi-quantitative data. First, a Monte Carlo sample was built using Sobol low-discrepancy sequences to generate a Weibull distribution (n = 10,000,000). Within the Weibull distribution following values were identified:

(i) Class 0 = 0
(ii) Class 1 = 0 to mean - standard deviation (std.)
(iii) Class 2 = mean - std. to mean
(iv) Class 3 = mean to mean + std.

Then, the classified quantitative data were merged with the semi-quantitative data, and inverse distance weighted (IDW) interpolation was performed. The interpolated data were finally expressed as sponge relative abundance classes (i.e. absent, rare, common, very common) for a 30 km radius around each record. The IDW settings were chosen as follows: output cell size (x, y): 1000 m, and distance coefficient power P: 2.

Figure 1-12 shows sponge hotspots (i.e. very common occurrence of sponges) from Brunt Ice Shelf along Riiser-Larsen Ice Shelf to Ekstrøm 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). Along the shelf near Brunt and Ekstrøm Ice Shelf the dominant community types are mostly sessile suspension feeder communities dominated by sponges (see more details in Gutt et al. 2013).

Please note: Apparently typing errors were made during the digitisation of the coordinates from the cruise reports into the data file. A verification of the raw data and its geographic coordinates is just in progress. Subsequently, a renewed analysis of the presence of sponges in the WSMPA planning area must be performed. Unfortunately, those working steps cannot be finalised before this document will be submitted to the WG-EMM meeting in 2015.

Potential habitats for echinoderms

Cluster analysis with species x station data sets of Asterioidea, Ophiuroidea and Holothuroidea identified specific assemblages on the very cold Filchner shelf. This indicates a particular cold water shelf echinoderm fauna. We approximated this habitat by SBT $\leq$ -1°, based on seawater temperature data by the FESOM model (Timmermann et al. 2009), generated a corresponding data layer (see Fig. 1-13).

Zoobenthos – Deep Sea

The low sampling effort in the deep sea did not allow generating corresponding data layers, i.e. spatially interpolated data layers for the conservation planning software MARXAN. No scientific analyses were carried out within the framework of the Weddell Sea MPA (WSMPA) project. Data on deep-sea isopods (Brandt et al. 2007) were used as descriptive background information to support the identification of potential conservation areas.

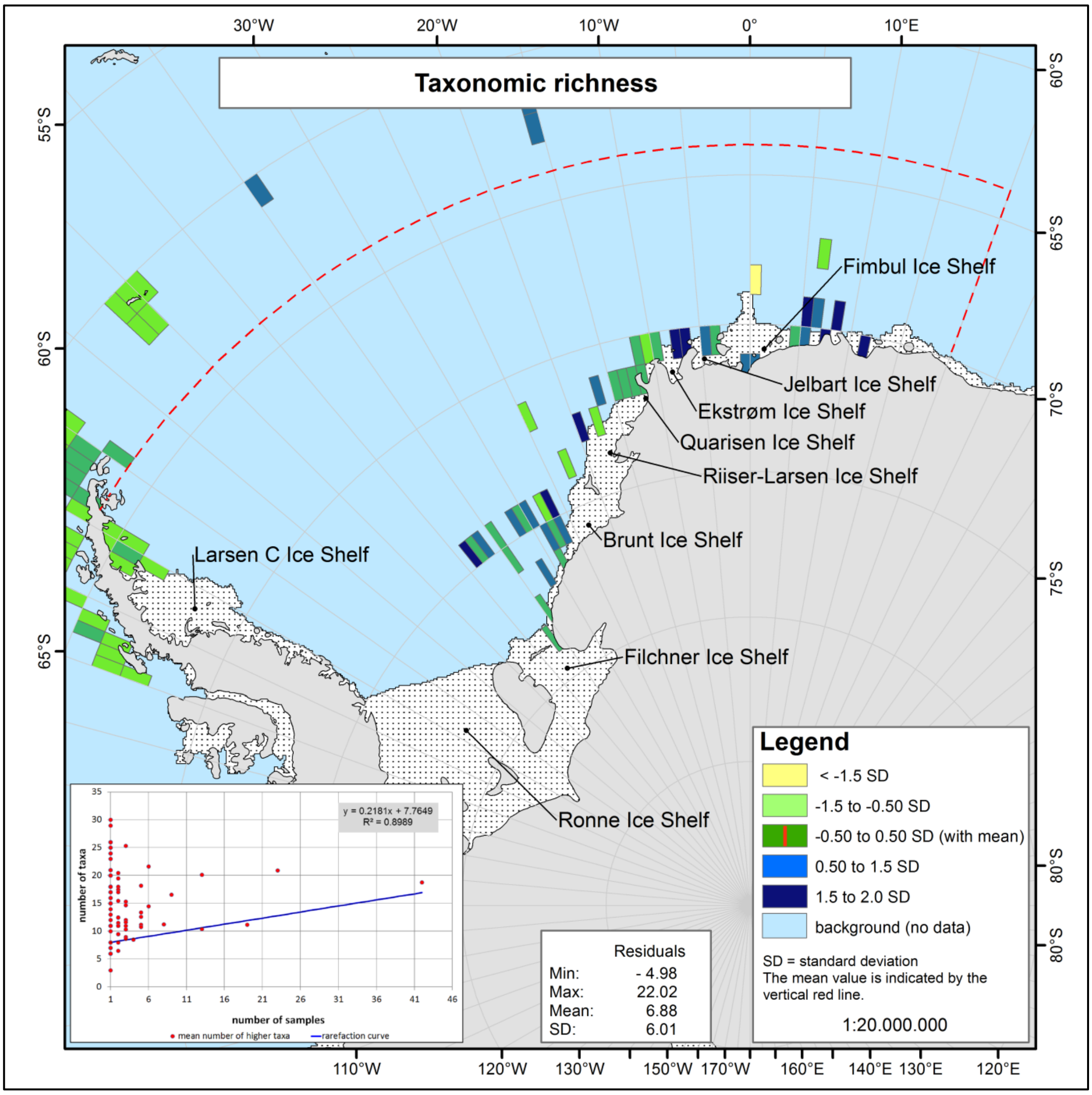


Figure 1-11 Distribution pattern of richness of higher taxonomic macrozoobenthic groups based on a data set held by D. Gerdes and U. Mühlenhardt-Siegel. The data are plotted as raw numbers of higher taxonomic groups, expressed as residuals of the expected number of higher taxonomic groups at a given 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.

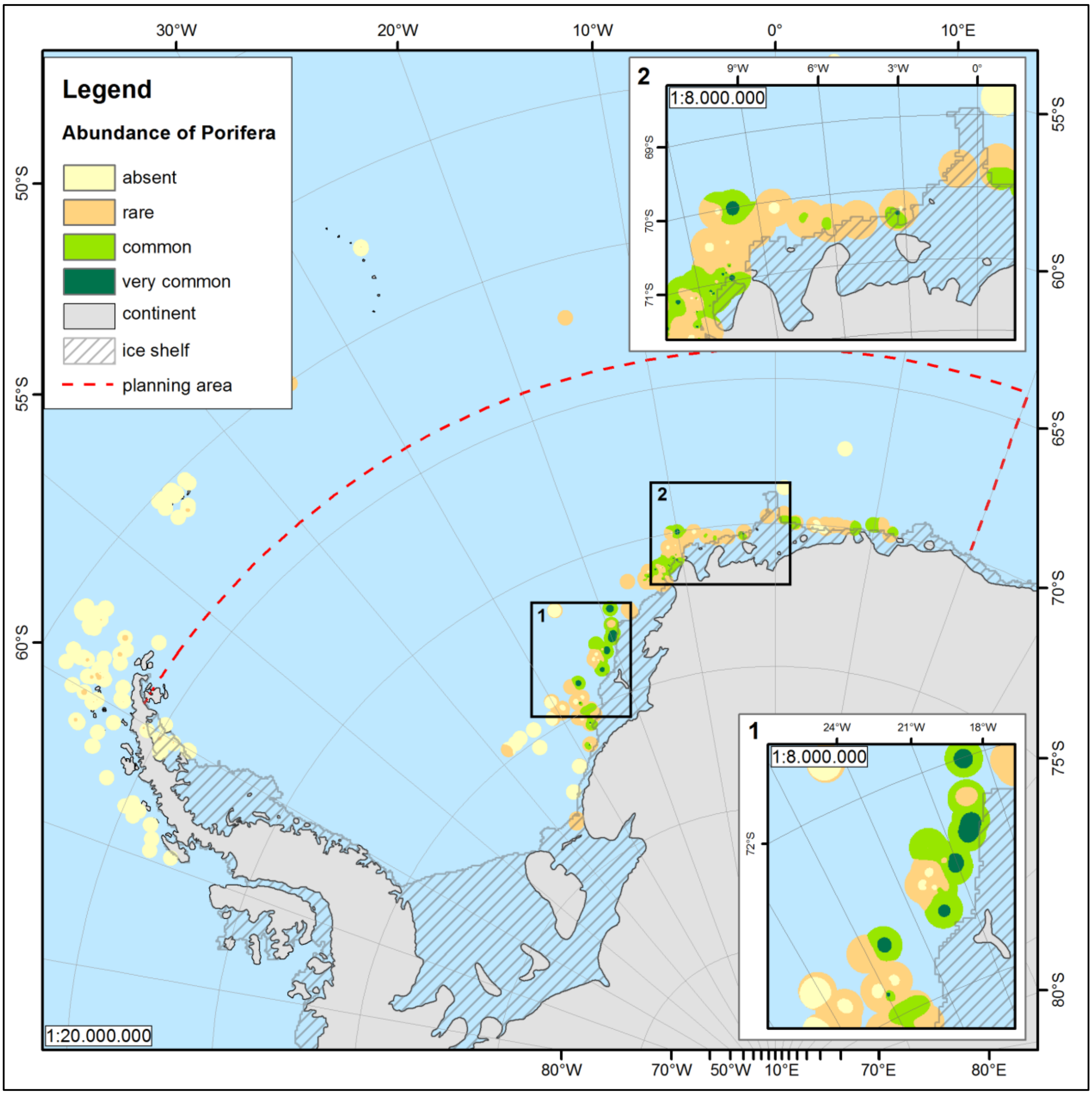


Figure 1-12 Distribution pattern of sponges based on a partly unpublished data set held by D. Gerdes (AWI) and U. Mühlenhardt-Siegel (DZMB), and unpublished data from Wolf Arntz (AWI, retired). The data are plotted as four abundance classes: absent, rare, common and very common. Red dashed box: Planning 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.

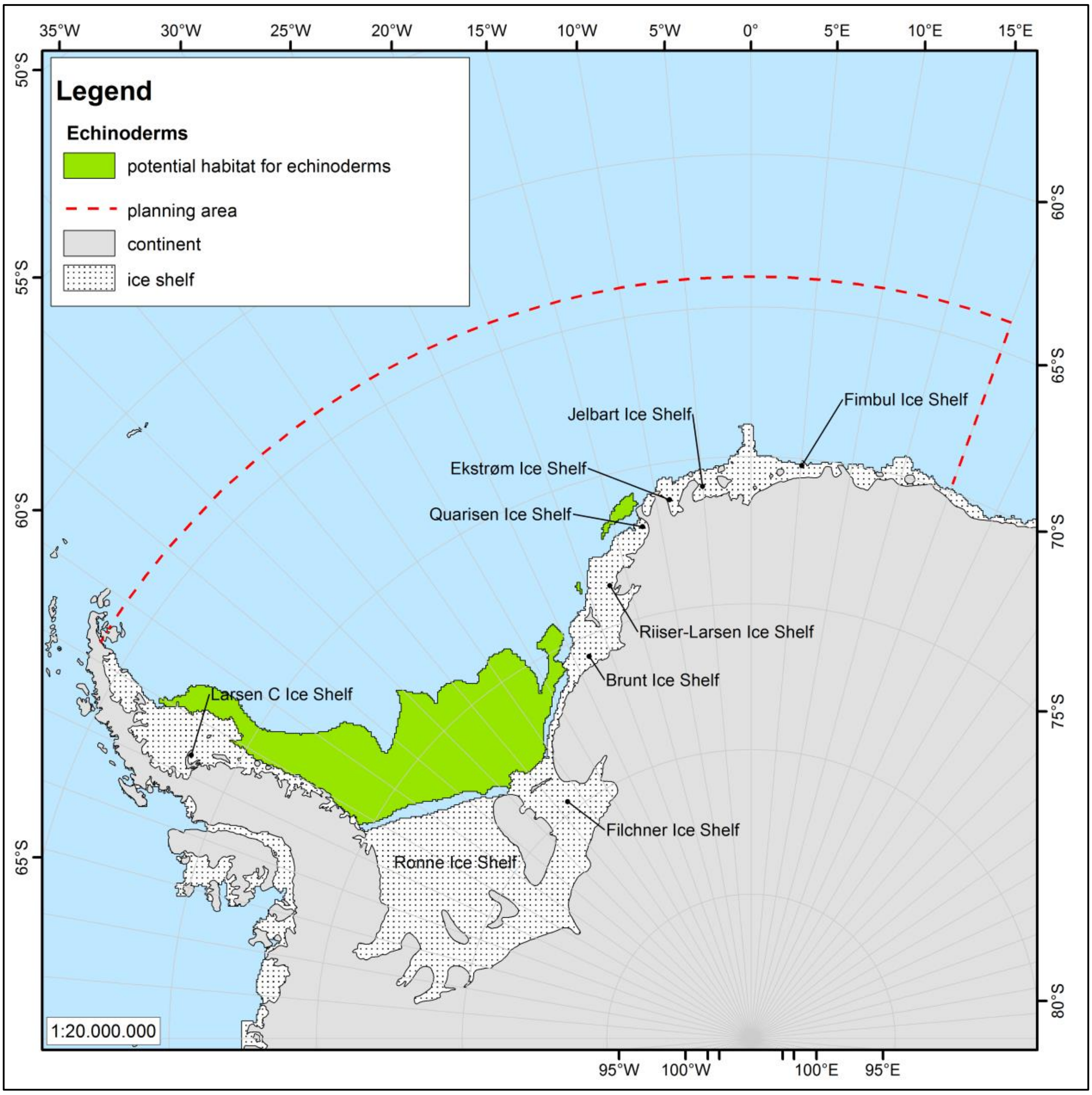


Figure 1-13 Potential habitat of the cold water shelf echinoderm fauna in the Weddell Sea (green coloured area) based on seawater temperature data by the FESOM model (Timmermann et al. 2009) as a proxy. Red dashed box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

Demersal fish

According to the recommendations of the 1st International Expert Workshop (see WG-EMM-14/19, workshop report) we focused on nest guarding fish species and their spawning areas. Furthermore, we concentrated on the Antarctic toothfish as the marine living resource in the WSMPA planning area.

Nest guarding fish observations

Figure 1-14 shows observations on nesting sites from *Chaenodraco wilsoni* and *Neopagetopsis ionah* within the WSMPA planning area. Observations were derived from unpublished data held by D. Gerdes (AWI) and T. Lundäv (Swedish Institute for the Marine Environment).

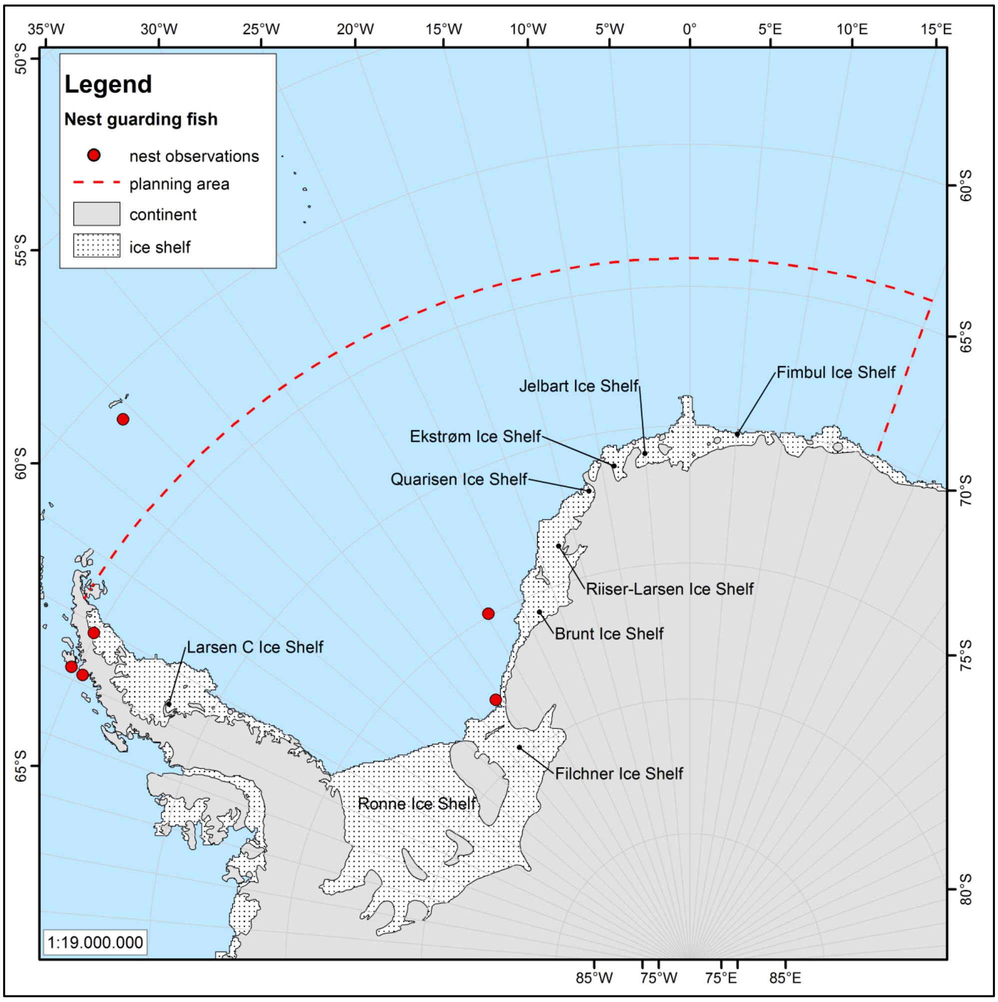


Figure 1-14 Nest guarding fish in the Weddell Sea planning area. Observations on nesting were derived from unpublished data held by D. Gerdes (AWI) and T. Lundäv (Swedish Institute for the Marine Environment). Red dashed box: Weddell Sea MPA planning area. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

Potential toothfish habitat

The data layer on potential habitats of adult Antarctic toothfish (*Dissostichus* spp.) was generated from bathymetric data by IBSCO (Arndt et al. 2013). We used a vertical depth range from 550 m to 2500 m, according to CCAMLR research and exploratory fishery and CM 22-08, as a proxy of adult Antarctic toothfish occurrence. Figure 1-15 shows the probability of adult Antarctic toothfish occurrence in the WSMPA planning area.

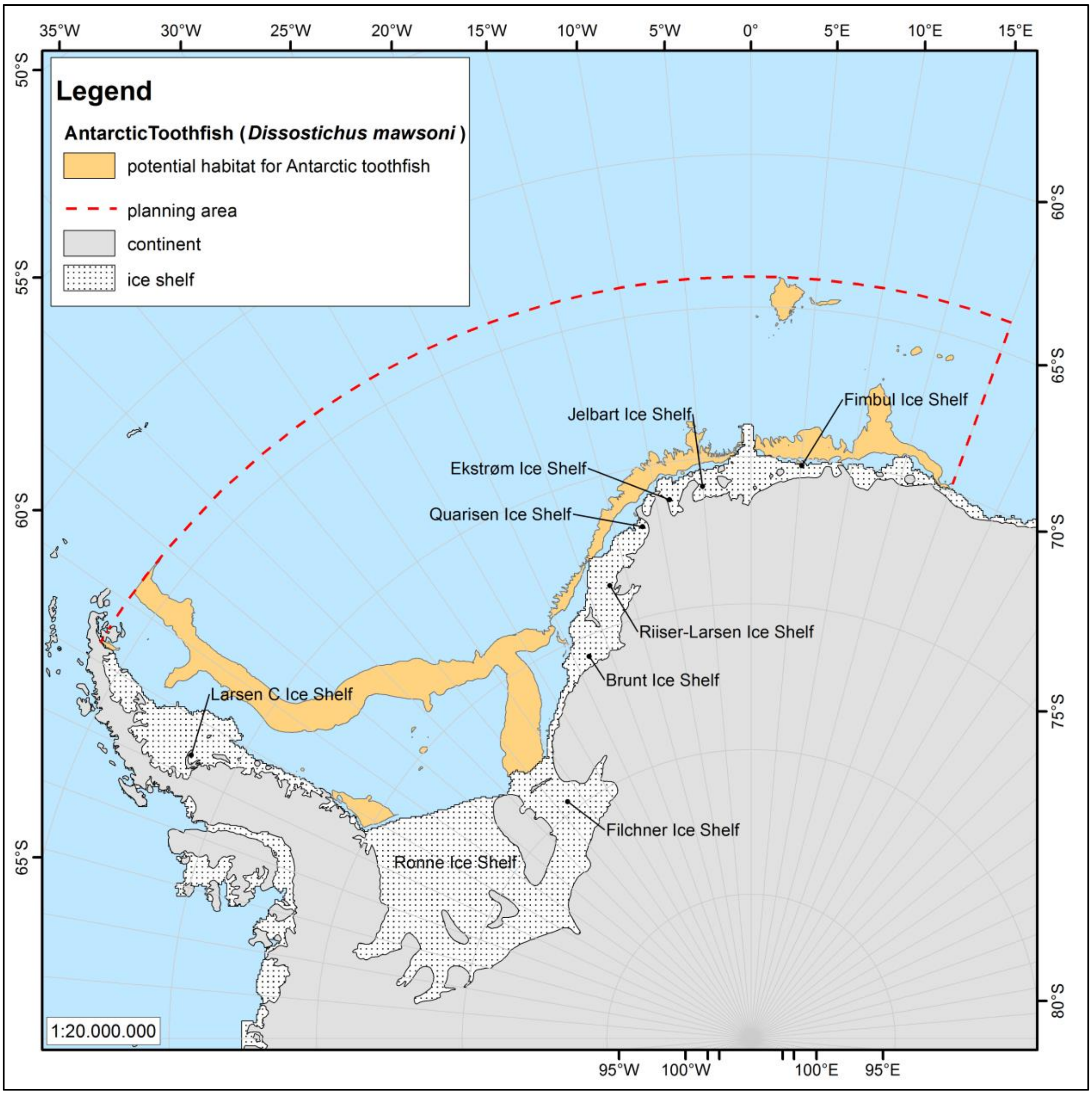


Figure 1-15 Potential habitat of adult Antarctic toothfish (*Dissostichus* spp.) in the Weddell Sea (brown coloured area) based on depth range as a proxy. Red dashed box: Planning area for the evaluation of a Weddell Sea MPA. Boundaries of the planning area do not resemble the boundaries of any proposed Weddell Sea MPA.

1.2.4 Birds

Seabirds

Data on birds are very sparse. Although there are shipboard observations of seabirds there is little tracking data available. At sea observation data can be hard to interpret due to methodological caveats (e.g. ship following). Therefore, no scientific analyses were carried out so far within the framework of the Weddell Sea MPA project.

Adélie penguin

In the Weddell Sea planning area two Adélie colonies situated near the tip of the Antarctic Peninsula with a total estimated abundance of 35,098 breeding pairs, and a 95th percentile confidence intervals from 13,670 to 57,934 breeding pairs (unpublished data from H. Lynch, Stony Brook University, USA).

Emperor penguin

Populations of emperor penguins play a prominent role in shaping biological diversity patterns and ecosystem processes in Antarctica on regional scales, i.e. in those areas where penguin foraging exerts a significant impact on their prey and penguin abundance attracts their principal predators. In the Weddell Sea 15 colonies with more than ~78,000 pairs breed which comprises ~33% of the global population. There is growing consensus that emperor penguin populations will be affected by predicted climate change and by subsequent changes in marine food webs (e.g., increased competition for marine living resources, increased predation). Therefore, solid knowledge of emperor penguin ecological requirements, particularly during sensitive periods such as breeding and chick rearing, is essential for successful Antarctic marine conservation/spatial planning. The spatial distribution of penguins while foraging is of specific interest, as it indicates the hinterland on which a colony depends for alimentation and thus the likely sphere of ecological influence of this colony. Hence, models that can predict emperor penguin distribution patterns would constitute a valuable tool in ecosystem analysis. We presume that the probability of an emperor penguin being present at a certain geographical locality depend on three major factors, the overall density of penguins in the wider area, the distance from the colony and the sea ice conditions, i.e. to which extent entry into the water is possible. Polynyas (i.e. ice free areas) constitute major access points to open water for emperor penguins to forage (Zimmer et al. 2008) in particular during winter where broad areas are covered by ice. Local prey abundance may be of importance, too, but this information is not readily available. Accordingly, we propose a simple model of emperor penguin foraging occurrence and distribution during breeding season as a function of (i) colony size, (ii) distance from colony, and (iii) sea ice concentration.

We used data on emperor penguin colony locations and breeding population estimates from Fretwell et al. (2012). Moreover, daily sea ice concentration data were derived from the Advanced Microwave Scanning Radiometer - Earth Observing System instrument (for more details see Part B of the background document, chapter 1.4).

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

The following assumptions were made (see eq. 1):

1. Under spatially homogeneous ice conditions foraging emperor penguins of one colony show a standard normal distribution (ND) pattern with highest probability of occurrence close to the colony (defined as the centre of the distribution).

2. According to Zimmer et al. (2008) and reference therein mean maximum foraging distance to the colony of male penguins in winter is 106 km (standard deviation = 28 km). We assume that the maximum foraging distance to the colony (***dmax***) is equivalent to the mean maximum foraging distance of 106 km plus three standard deviations, i.e. 106 km + 3*28 km = 190 km. Foraging distribution patterns of emperor penguins beyond ***dmax*** were cut off.

   Please note, that the maximum foraging distance to the colony ***dmax*** is not necessarily synonymous with the maximum length of the foraging trip. Although penguins generally forage with a directional axis, it seems that some foraging movements show more a zig-zag path parallel to the coast than a directional way (see Zimmer et al. 2008). Therefore, the length of the foraging trip may be greater than the maximum Euclidian distance to the colony ***dmax***. For example, winter-foraging females travelled on average a total distance of 1,050 km, but their travelled maximum distance to the colony is much lower (median: 104 km).

To calculate the foraging distances from colony, 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 centre (centroid) ***j*** (in total 119862 raster cells) to each emperor penguin breeding colony ***i*** (in total 15 colonies in the study area plus the Ragnhild colony at the eastern boundary outside the study area; this colony was included in the calculation as we assume a potential influence on the study area, and its breeding populations) (see eq. 1 - 3).

Thus, the probability of occurrence $\boldsymbol{P1_{i,j}}$ of one penguin from colony ***i*** in centroid ***j*** was calculated by the following approximation:

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

where $\boldsymbol{d_{max}}$ is the maximum foraging distance to breeding colony, and ***di,j*** is the Euclidean distance (in km) between colony ***i*** and centroid ***j***, which was calculated by:

$$d_{i,j} = \left(\sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2}\right) - d.ice_{edge_i} \quad (2)$$

where $\boldsymbol{d.ice\_edge_i}$ is the distance of colony to the shelf ice edge (see Table 1-2). Distances $\boldsymbol{d_{i,j}}$ ≤ 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 $\boldsymbol{d_{i,j}}$, too, and a reclassification was performed again ($\boldsymbol{d_{i,j}} \leq 0$ were set to 1).

Then, the probability of penguin occurrence $\boldsymbol{P1_{i,j}}$ from colony $\boldsymbol{i}$ in centroid $\boldsymbol{j}$ was normalized to a range between 0 and 1 (i.e. $0 \leq \boldsymbol{P1_{i,j}} \leq 1$). Finally, all $\boldsymbol{P1_{i,j}}$ were added for each centroid $\boldsymbol{j}$ and normalized to a range between 0 and 1:

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

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

Table 1-2: Emperor penguin breeding colonies in the Weddell Sea and their distance to the shelf ice edge as potential access point to the sea.

Colony	Distance to ice shelf (km)
Astrid	0.00
Atka	2.90
Dawson	1.40
Dolleman	0.00
Drescher	0.00
Gould	0.00
Halley	0.00
Jason Peninsula	6.80
Lazarev	2.80
Luitpold	29.80
Ragnhild	0.00
Riiser	0.50
Sanae	6.20
Smith	2.90
Snowhill	1.60
Stancomb	0.00

To account for breeding colony size (number of animals), each probability of penguin occurrence $\boldsymbol{P1_{i,j}}$ was weighted with the best population estimate (BE) for this emperor penguin colony according to Fretwell et al. (2012).

$$\boldsymbol{P1'_{i,j}} = \boldsymbol{P1_{i,j}} * \boldsymbol{BE_i} \tag{4}$$

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

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

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 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 (*ICj*) 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 (Jun to Jan) from 2002 to 2011 (in total 2265 satellite images).

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

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

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

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

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

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

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

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

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

Please note that $\boldsymbol{P_j}$ was normalized to a range between 0 and 1 (i.e. $0 \leq \boldsymbol{P_j} \leq 1$), and thus relative probability values that indicate differences between centroids, instead of absolute values, are mapped in Figure 1-16.

Our model of emperor penguin foraging distribution during breeding season shows that the probability of occurrence is highest at the Halley and Dawson colony near Brunt Ice Shelf and at the Atka colony near Ekstrøm Ice Shelf.

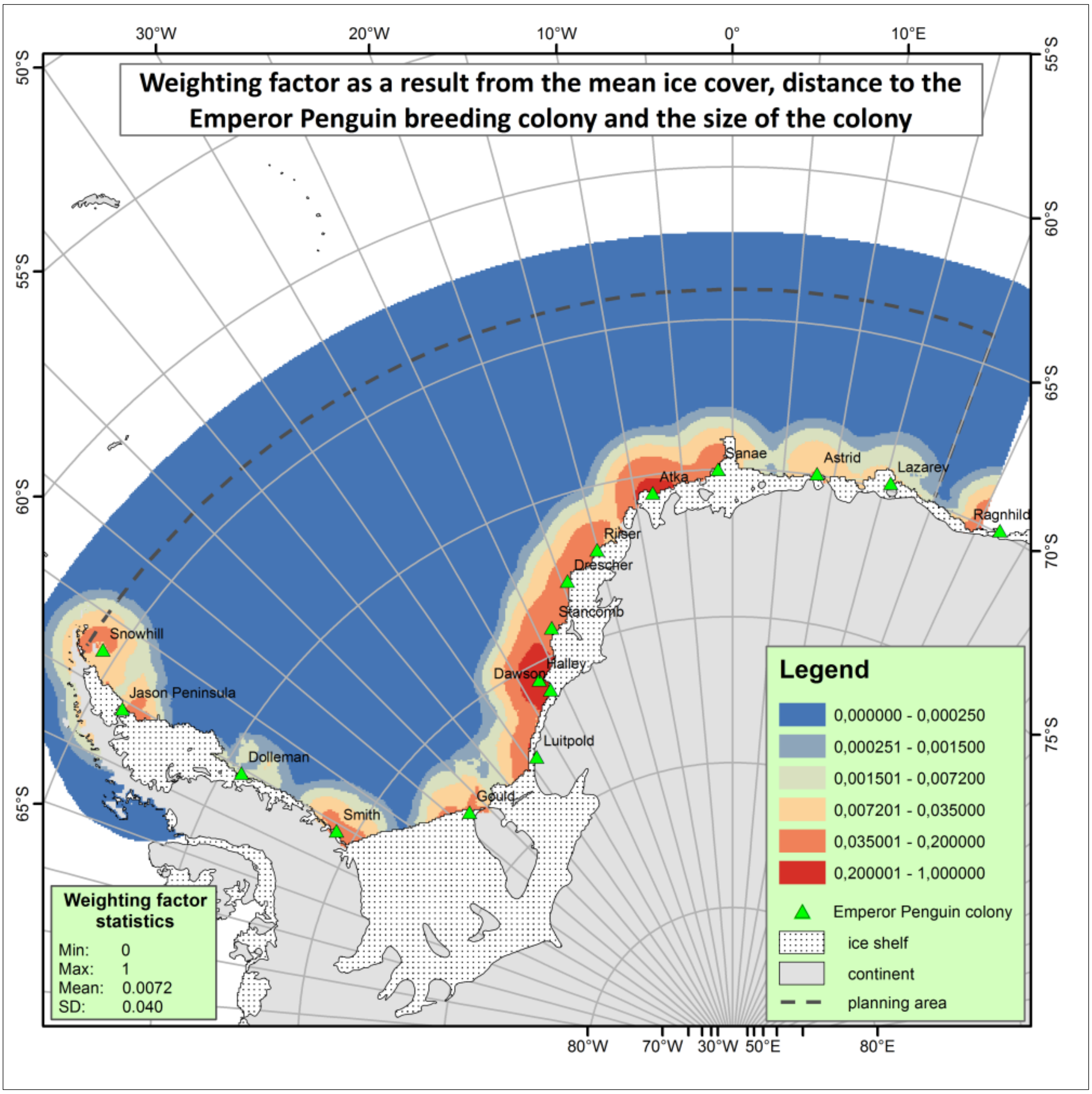


Figure 1-16 Probability of penguin occurrence P_j as a function of distance to colony, colony size and sea ice concentration (see eq. 9).

1.2.5 Marine Mammals

Pinnipeds

Data for the western part of the Weddell Sea MPA (WSMPA) planning area were derived from Flores et al. (2008) and Forcada et al. (2012). Flores et al. (2008) calculated the density of seals (non-standardised data) for each transect, and the average transect densities were calculated for each region. In contrast, Forcada et al. (2012) used standardised data for the density calculations. Several factors potentially influencing the probability of animal detection for their density estimations were considered (e.g. probability of detection for perpendicular sighting distances). To interpolate the seal densities, a more sophisticated approach, i.e. a combination of different generalized additive models, was used in Forcada et al. (2012). Calculated seal densities were pooled in case of areas where both studies collected data.

Data for the south-eastern and eastern part of the Weddell Sea were derived from Bester et al. (1995, 2002) and Plötz et al. (2011a-e). Seal densities (individuals/km²) were calculated for the data from PANGAEA (Plötz et al. 2011a-e) with the count method for line transect data (Bester et al. 1995, Bester & Odendaal 2000, Hedley & Buckland 2004). We used non-standardised data for the density calculations as the data set from Plötz et al. (2011a-e) is based on video material, and thus at least observer related factors potentially influencing the probability of animal detection are not relevant to consider. Regarding seal densities from Bester et al. (1995) we calculated the mean of up to three sampling seasons for each transect. Bester et al. (2002) assigned the transects to three different zones, and then the average transect densities were calculated for each zone.

To interpolate the seal density (point data) in the south-eastern and eastern part of the WSMPA planning area, we applied the inverse distance weighted interpolation method (IDW) in ArcGIS™ spatial analyst tool to the data from PANGAEA (Plötz et al. 2011a-e) and Bester et al. (1995, 2002). Following settings for the IDW were chosen:

- Z value: The calculated seal density for a strip of 60 m width
- Output cell size: 2000 m
- Distance coefficient power P: 2
- Search radius setting, number of points: 10

The following map shows the result of the approaches from Flores et al. (2008) and Forcada et al. (2012) combined with the IDW that we applied. The classification concerning the number of individuals per km² was chosen from Forcada et al. (2012), and a new classification category (> 15 individuals per km^2) was added.

Figure 1-17 indicates highest absolute seal density (i.e. > 15 individuals/km²) on the Riiser-Larsen Ice Shelf to Quarisen Ice Shelf. Seal densities of 2-15 individuals/km² occur more large-scale on the Riiser-Larsen Ice Shelf to Ekstrøm Ice Shelf, and offshore between 5-15°W and 0-5°E. 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).

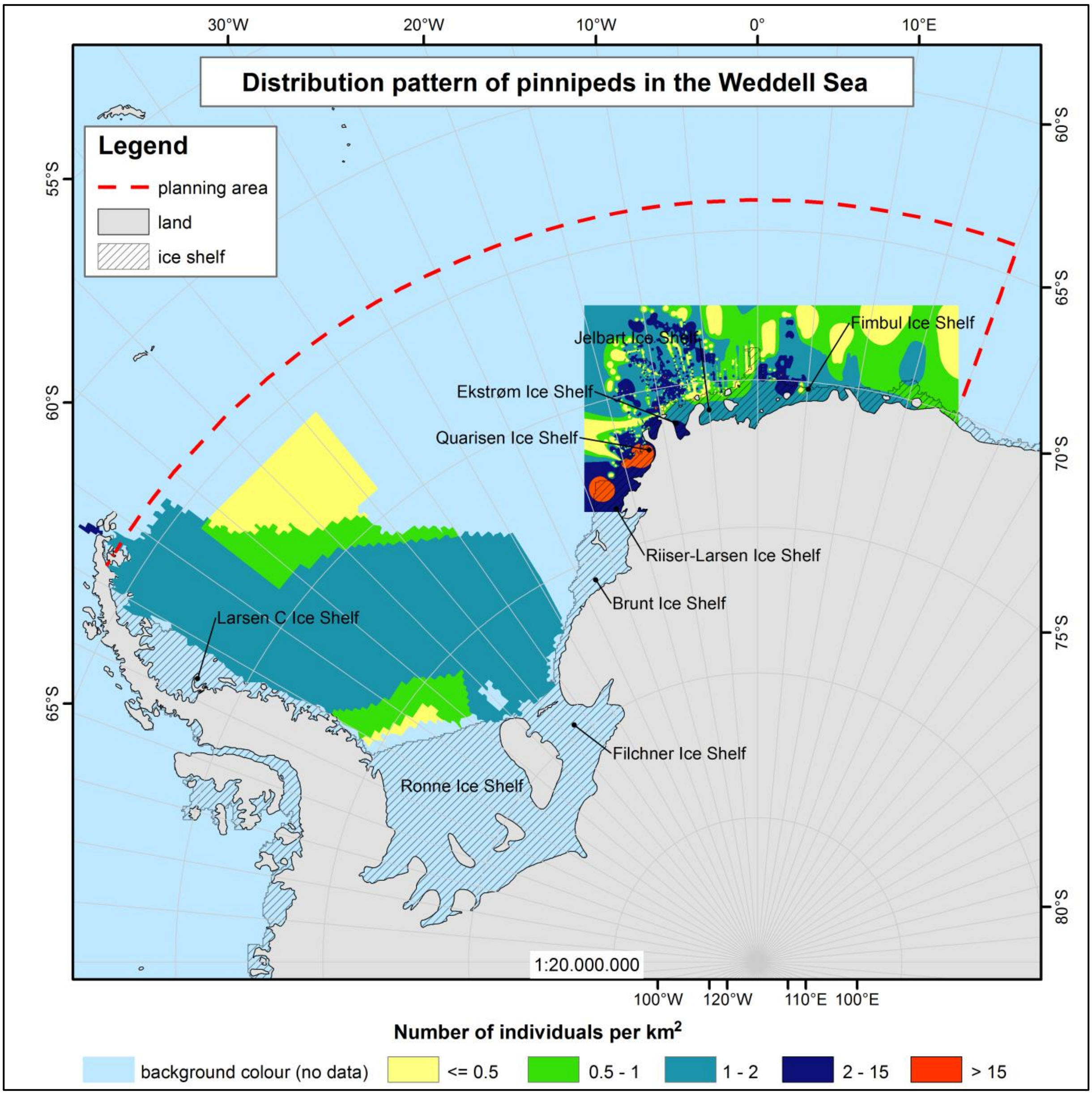


Figure 1-17 Distribution patterns of seals in the Weddell Sea. Abundance data on crabeater seals in the western part of the Weddell Sea MPA (WSMPA) planning area were derived from Flores et al. (2008) and Forcada et al. (2012). Abundance data on seals in the south-eastern and eastern part of the Weddell Sea based on data from PANGAEA (Plötz et al. 2011a-e; unspecified taxa) and Bester et al. (1995, 2002; crabeater seals). The un-transformed, interpolated data are plotted as absolute seal densities (individuals/km²). Purple dashed box: Planning area for the evaluation of a WSMPA. Boundaries of the planning area do not resemble the boundaries of any proposed WSMPA.

Whales

The Antarctic minke whale (*Balaenoptera bonaerensis*) is the most abundant cetacean in Antarctic waters. They are observed within dense sea ice regularly (e.g., Williams et al. 2014, Gutt et al. 2011, Scheidat et al. 2011). During austral summer their distribution concentrates between 62°S and the pack ice (Gill & Evans 2002), with highest encounter rates in late January/early February south of 66°S between 66°E-80°E (Kasamatsu et al. 1996).

There are no systematic surveys for the ice-covered regions of the Weddell Sea so far, but minke whale calls have been recorded regularly at the PALAOA observatory near Neumayer Base (Van Opzeeland pers. comm., Risch et al. 2014). During austral winter, most Antarctic minke whales leave for their breeding grounds (10°-30°S), but some have been reported to overwinter in Antarctic waters (Thiele & Gill, 1999). Minke whales in the Southern Ocean feed on the Antarctic krill *Euphausia superb*a primarily but on smaller zooplankton, too (Ohsumi et al. 1970, Stewart & Leatherwood 1985). Abundance is estimated to 515.000 individuals (95% CI 360.000 - 730.000) by IWC but may be higher as surveys do not include ice-covered areas. Antarctic minke whales are listed as *data deficient* (IUCN Red List of Threatened Species. Version 2014.2). Observation maps (Ropert-Coudert et al. 2014) and habitat models (Bombosch et al. 2014, see Fig. 1-18) indicate that Minke whales occur in the Weddell Sea MPA (WSMPA) planning area. Highly favourable conditions for minke whales throughout the season are predicted for an area around 70°S and 40°W.

The high latitude feeding area of Humpback whales (*Megaptera novaeangliae*) ranges from the Antarctic Convergence to the pack ice region. Higher densities are found in the southern Indian Ocean, around the Antarctic Peninsula and in the northern Ross Sea, and highest encounter rates are reported for December to January (see Branch 2011). So far seven distinct feeding grounds corresponding to six breeding stocks are suggested (International Whaling Commission 2011). Humpback breeding stocks A, B and C are of relevance for the WSMPA planning area, since these individuals migrate between the Weddell Sea and their breeding grounds further north. Some individuals may stay in the Antarctic year-round, presumably to avoid the energetic demands of migration (Van Opzeeland et al. 2013). Humpback whales in the Southern Ocean feed on pelagic crustaceans, mainly krill *Euphausia superba* (Clapham 2002). The 1997/96 IWC population estimate is 42.000 for the Southern Ocean, with approximately 26.630 individuals allocated to breeding stocks A, B and C (Branch 2011). Humpback whales are listed as *least concern* (IUCN Red List of Threatened Species. Version 2014.2). Habitat suitability models indicate that favourable habitat conditions for humpback whales exist in open waters near Larsen C Ice Shelf and in the eastern part of the planning area throughout January and February (Fig. 1-18, Bombosch et al. 2014).

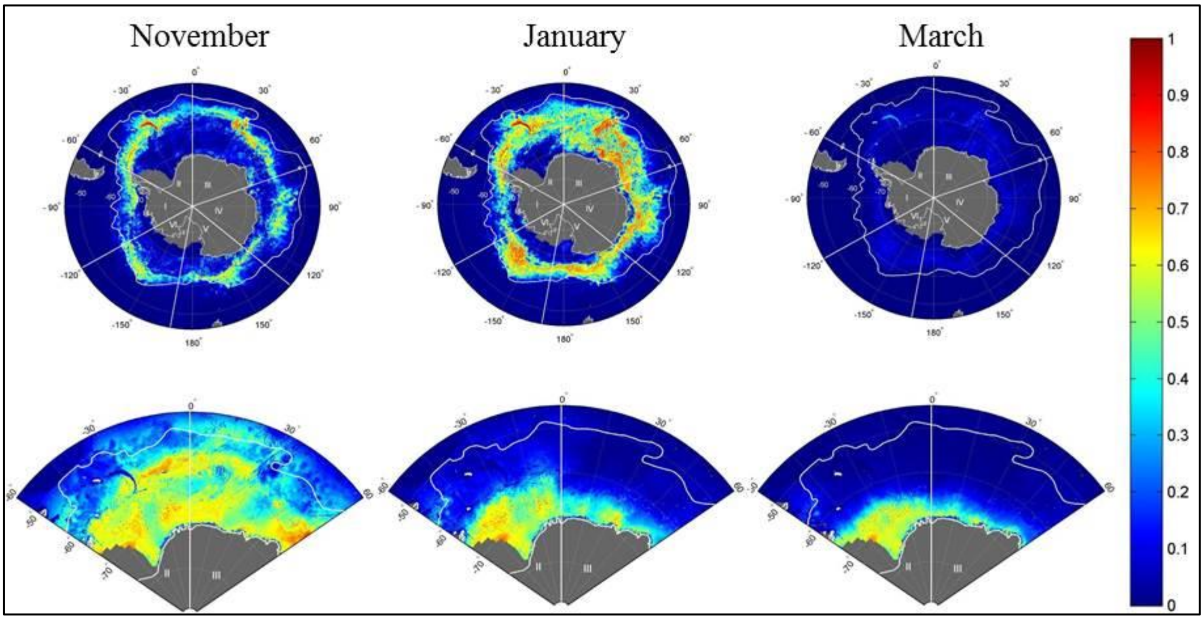


Figure 1-18 Maxent spatial prediction maps for humpback whales (upper row) and Antarctic minke whales from 60°W to 60°E (lower row) for the 15th of November, January and March 2006/2007. Habitat suitability is colour-coded with blue colours indicating less suitable to unsuitable habitat, greenish colours 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).

2. MPA scenario development

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This chapter describes the MPA scenario development that is closely geared to the *Systematic Conservation Planning* approach (Margules & Pressey 2000) under CCAMLR. Firstly, we present the defined general and specific conservation objectives for the Weddell Sea MPA (WSMPA) planning area. Then, we provide a systematic overview of the parameters and their specific regional objective for the Marxan analysis (see Tab. 2-1). Subsequently, we set out the Marxan approach using the QMarxan (version 1.3.1; Ball et al. 2009), and finally substantiate the Marxan analysis for a MPA proposal.

2.1 Conservation objectives & parameters

The conservation objectives were developed by the German Weddell Sea MPA project team and further refined on the basis of the contributions by the participants of the 2nd International Expert Workshop on the Weddell Sea MPA that took place in Berlin (28-29 April 2015).

In accordance with CM 91-04 Article 2, and Article II and IX of the Convention the following six general conservation objectives and, based on those, eleven specific objectives were defined for the WSMPA. The general objectives classify the WSMPA as a tool for the protection of special ecosystems, habitats, features and representative areas of the whole Weddell Sea planning area. The specific objectives focus on the protection of very concrete features within the WSMPA.

The workshop agreed that consistency in wording and clarification of terms in a preamble for the objectives are necessary. A definition would subsequently allow the use of the wording protection within the overall conservation objective coherent with CM 91-04.

On this basis, the following conservation objectives for the WSMPA were defined.

Objectives of the WSMPA

In accordance with CM 91-04 Article 2, and Article II and IX of the Convention the WSMPA will assist the conservation of Antarctic marine living resources while contributing to the following general and specific objectives in the long term:

General objectives

(i) Protection of representative examples of pelagic and benthic ecosystems, biodiversity and habitats (including the environmental and ecological conditions supporting them) of the Weddell Sea planning area.

(ii) Protection of pelagic and benthic habitats and ecosystems which are rare, unique, vulnerable, diverse and/or endemic to the Weddell Sea planning area.

(iii) Protection of areas, environmental features and species (incl. populations and life history stages) on various geographical scales which are key to the functional integrity and viability of local ecosystems and ecosystems processes in the Weddell Sea planning area.

(iv) Establishment of scientific reference areas to study, in particular representative, rare, unique and/or endemic examples of marine ecosystems, as well as biodiversity and habitats, and to monitor the effects of climate change, fishing and other human activities in the Weddell Sea planning area.

(v) Protection of essential habitats for top predators such as marine mammals and seabirds in the Weddell Sea planning area.

(vi) Protection of essential habitats in the Weddell Sea planning area as potential refugia for, inter alia, top predators, fish and other ice-dependent species, in order to maintain and /or enhance their resilience and ability to adapt to the effects of climate change.

Specific objectives

Pelagic conservation objectives

(i) Protection of representative examples of pelagic and sea ice ecosystems and habitats, such as the unique, persistent open ocean areas associated with the Maud Rise submarine plateau, or the areas along the shelf ice edge in the eastern and southern part with no or very low sea ice cover throughout the austral summer.

(ii) Protection of Antarctic krill, ice krill and Antarctic silverfish as key species in the Antarctic food web as well as important areas / habitats for their life cycle, e.g. spawning areas;

(iii) Protection of essential habitats for top predators such as flying seabirds, penguins and seals.

Benthic conservation objectives

(iv) Protection of representative examples of benthic ecosystems and habitats, such as the ecologically important sponge associations on the shelf in the eastern and southern part.

(v) Protection of Antarctic toothfish as a top predator incl. all life history stages and their habitats.

(vi) Protection of the integrity and life cycles of unique and diverse suspension feeding assemblages, incl. benthic sponge associations and thereby maintaining the associated benthic communities as efficient sources for recolonization.

(vii) Protection of rare and unique shallow (surface to– 150 m water depth) sea floor areas with high habitat heterogeneity and species turnover in order to preserve the ecologic function of these areas as “stepping stones” and sources for recolonization for associated communities and species.

(viii) Protection of spawning areas and nesting sites of demersal fish species including those exhibiting parental care.

Pelagic and/or benthic conservation objectives

(ix) Protection of higher productivity areas to support key ecosystem processes and functional integrity of the ecosystems.

(x) Protection of marine ecosystems and habitats vulnerable to impacts of climate change, fishing and other human activities and critical to the function of local ecosystems, in order to maintain and/or enhance resilience and adaptive capacity, such as benthic three-dimensional suspension feeder communities in the eastern and southern part or the marine areas important for the foraging and life cycle of top predators.

Scientific reference areas

(xi) Provision of scientific reference areas to monitor the natural variability and long-term changes on the Antarctic marine living resources and to study the effects of climate change and human activities on the Antarctic ecosystems in this region, such as the Filchner Overflow Area.

Table 2-1 shows how the different parameters and data sets cover the general and specific conservation objectives. The data sets behind each parameter are described in detail in Part B of the scientific background document, whereas the analyses of the different parameters is depicted in chapter 1 (Part C).

In addition, specific regional conservation objectives for each parameter, i.e. a target value as a proportion of the area of the total distribution of that parameter, i.e., $0 \leq$ target value $\leq$ 100%, are listed. In general, for a common parameter lower values might be sufficient to ensure its conservation, whereas for a unique, rare or sensitive parameter higher target values might be used. For example, 20% was used as the target value for most of the pelagic and benthic (bio) regions. To encompass larger areas for highly mobile species with less predictable distribution patterns values of 30% to 40% were used. Target values of 100% were set for highly productive areas, important or unique geomorphic features and highly sensitive areas, such as spawning areas (see Tab. 2-1). For each parameter a range of proportional target values was compiled at the 2nd International Expert Workshop on the WSMPA project (28-29 April 2015; Berlin, Germany). Our Marxan analyses, using those ranges of target values, showed that the core areas selected by Marxan remained similar across a considerable range of the proportional targets. Thus, the selection of the specific regional objective for the Marxan analysis seems to be robust. However, it is important to note here that the proportional target values are used to guide decision making and do not constrain the final MPA borders. The final MPA may differ from the areas identified by Marxan as background information on other environmental or ecological data and practical considerations are to be taken into account.

2.2 Marxan scenario – Recursive approach

Several preparatory steps were performed before the actual Marxan runs.

The Weddell Sea planning area was subdivided into 35,188 grid cells (hexagons) of 100 km² each. This setting represents a reasonable trade-off between computing speed (number of cells to be handled by the Marxan software) and spatial resolution that remains appropriate for finer-scale parameters.

Some parameters were scaled in categories of different probability of occurrence such as Antarctic krill occurrence (several categories from low probability of occurrence to high probability of occurrence). For such parameters we used nesting to create one single shape file that represented all categories by means of assigning higher weighting factors to areas with high probability.

The planning unit was intersected with each parameter i.e., for each parameter the proportion of occurrence in each hexagon was calculated (planning unit grid values).

Subsequently, all grid cells containing the three important or unique geomorphic types (i.e., Filchner Trough, Astrid Ridge, Maud Rise; see Fig. 2-1) were set as essential areas in the Marxan scenario, i.e., setting a status of 2 to ensure that these cells would be elected in each Marxan run. For more information on these geomorphic features and their importance for the Weddell Sea ecosystem see Part A of the scientific background document (chapter 3.3). Then, it was calculated to which extent the other specific regional objectives (% area; see Tab. 2-1) were covered already by these predefined areas. Each parameter, whose specific regional objective was achieved completely, was excluded from further Marxan analyses. For all other parameters we calculated the percentage still missing for meeting the corresponding specific regional objective. These re-calculated values were set as the specific regional objectives for the first Marxan scenario.

The basic Marxan settings were chosen as follows: (i) Boundary Length Modifier: 0, (ii) number of runs (repetitions): 50, (iii) number of iterations per run: 10 000 000. A brief sensitivity analysis showed that the core area selected by Marxan remained stable across a considerable range of 20 - 500 repetitions. For instance, the scenarios with 20 and with 500 repetitions each elected 6943 identical grid cells with 100 % probability (i.e., in each repetition) and 10048 identical grid cells with 80 % probability. These cells resemble approximately 70 % and 100 % of the 80-100 % area of the summed solution scenario in Fig.2.2, respectively. Thus, running the Marxan analysis with 50 repetitions is sufficient to obtain a robust summed solution scenario.

We defined all cells that were selected in all 50 runs of one Marxan scenario to represent the stable core area of this scenario, i.e., all these cells were set as obligatory MPA areas for the next Marxan scenario, i.e., added to those cells set as obligatory MPA in the previous step. (Please note that in the final Marxan scenario we defined all grid cells that were selected in 40 out of 50 runs to represent the core MPA area).

As before, each parameter, whose specific regional objective was achieved completely by the expanded MPA was excluded from further analysis, and for all other parameters we re-calculated the percentage still missing for meeting the corresponding specific regional objective. With this setting the next Marxan scenario was computed. This process was repeated until all specific regional objectives regarding biological parameters were met within ≥ 0.95 * specific regional objective (% area). The 95 % threshold was set according to Marxan basic settings, i.e. Marxan tolerated a difference of 5 % to the original specific regional objective.

Table 2-2 presents the results of this recursive approach after five recursions. 68 out of 76 parameters are met completely (≥ 0.95 * specific regional objective), this includes all specific regional objectives regarding biological parameters. Those specific regional objective not met sufficiently correspond to geomorphic features, such as deep areas (≥ 4500 m) of abyssal plain, lower slope and rugose ocean seafloor, and one pelagic region ('Deepwater II').

Table 2-1 Description of data sets and conservation objectives for the Marxan scenario.

Parameter	No. features	Description of features	Source (contact person, publication, web site)	Specific regional objective for MARXAN analysis	Relevant conservation objectives
Pelagic regionalisation (in situ data, satellite data, model data)	8	8 pelagic regions: Coastal polynyas I (very high probability of ice-free areas) Coastal polynyas II (high probability of ice-free areas) Coastal polynyas III (lower probability of ice-free areas) Transition zone (average depths, average probability of ice-free areas) Deepwater I (lower depths, slightly larger depth ranges) Deepwater II (average depths, slightly larger depth ranges) Ice-covered area (year-round)	Sea ice concentration: Kaleschke et al. (2001), Spreen et al. (2008) Institute of Environmental Physics, University of Bremen: http://www.iup.uni-bremen.de/seaice/amsr/ Bathymetry: Arndt et al. (2013); www.ibcso.org Seawater temperature and salinity: FESOM model data; Timmermann et al. (2009)	100% of each coastal polynya region 20% of each remaining pelagic region	General objectives: (i) - (iii), (v) & (vi) Specific objectives: (i) - (iii), (ix) & (x)
Benthic bioregionalisation	52	Depth classes nested in 18 geomorphic features resulted in 52 environmental types: Abyssal plain: • -3000m to -4500m • > -4500m Bank: • 0m to -100m • -100m to -200m • -200m to -500m • -500m to -1000m Canyon shelf commencing Canyon slope commencing Coastal Terrane Cross Shelf Valley: • 0m to -100m • -100m to -200m • -200m to -500m • -500m to -1000m • -1000m to -1500m Lower slope: -2000m to -3000m Lower slope: -3000m to -4500m Lower slope: > -4500m Margin Ridge: -500m to -1000m	Douglass et al. (2014)	65% of the following important or unique geomorphic types: - Canyon Shelf Commencing - Canyon Slope Commencing - Marginal Plateau - Seamount - Shelf - Shelf Deep - Upper Slope 20% of all other environmental types	General objectives: (i) - (iii) Specific objectives: (iv) - (x)

Table 2-1 Description of data sets and conservation objectives for the Marxan scenario.

Parameter	No. features	Description of features	Source (contact person, publication, web site)	Specific regional objective for MARXAN analysis	Relevant conservation objectives
		Margin Ridge: -1000m to -1500m Margin Ridge: -1500m to -2000m Margin Ridge: -2000m to -3000m Margin Ridge: -3000m to -4500m Marginal Plateau: -2000m to -3000m Marginal Plateau: -3000m to -4500m Plateau: -2000m to -3000m Plateau: -3000m to -4500m Plateau Slope: -2000m to -3000m Plateau Slope: -3000m to -4500m Ridge: -1500m to -2000m Ridge: -2000m to -3000m Ridge: -3000m to -4500m			
	------ 3	Rugose Ocean Floor: -3000m to -4500m Rugose Ocean Floor: > -4500m Seamount Ridge: -1000m to -1500m Seamount Ridge: -2000m to -3000m Seamount Ridge: -3000m to -4500m Seamount: -1000m to -1500m Seamount: -1500m to -2000m Seamount: -3000m to -4500m Seamount: > -4500m Shelf Shelf Deep: 0m to -100m Shelf Deep: -200m to -500m Shelf Deep: -500m to -1000m Upper Slope: 0m to -100m Upper Slope: -100m to -200m Upper Slope: -200m to -500m Upper Slope: -500m to -1000m Upper Slope: -1000m to -1500m Upper Slope: -1500m to -2000m Upper Slope: -2000m to -3000m Upper Slope: -3000m to -4500m -- 3 important or unique geomorphic types whose structures should be included		-- 100% of the following important or unique geomorphic types:	

Table 2-1 Description of data sets and conservation objectives for the Marxan scenario.

Parameter	No. features	Description of features	Source (contact person, publication, web site)	Specific regional objective for MARXAN analysis	Relevant conservation objectives
		completely: Filchner Trough (Cross Shelf Valley) Astrid Ridge (Margin Ridge) Maud Rise (Seamount Ridge, Seamount, Plateau and Plateau Slope)		- Filchner Trough (Cross Shelf Valley) - Astrid Ridge (Margin Ridge) - Maud Rise (Seamount Ridge, Seamount, Plateau and Plateau Slope)	
Krill density (interpolated abundance data)	1	Adult Antarctic krill (*Euphasia superba*): Categories of different probability of occurrence (low to high) are included by means of a weighting factor	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)	30% of total area in which Krill occurs focusing on areas with high probability of occurrence	General objectives: (i), (iii) & (vi) Specific objectives: (i), (ii), (ix) & (x)
Potential Ice krill habitat	2	Depth (max. 550m) and temperature range (≤ 0°C) describing the probability of occurrence north and east of the Filchner Trough	Proxies: Bathymetry: Arndt et al. (2013); www.ibcso.org Seawater temperature range: FESOM model data; Timmermann et al. (2009)	35% of total area in which a potential Ice krill habitat occur	General objectives: (i), (iii), (iv) & (vi) Specific objectives: (i), (ii), (ix) & (x)
Adult silverfish density (interpolated abundance data)	1	Adult silverfish (*Pleuragramma antartica*): Categories of different probability of occurrence (low to high) are included by means of a weighting factor	Boysen-Ennen & Piatkowski (1988), Drescher et al. (2012), Ekau et al. (2012a, b), Hureau et al. (2012), Kock et al. (2012), Wöhrmann et al. (2012), Flores et al. (2014) and unpublished data held by R. Knust, AWI	35% of total area in which adult silverfish occurs focusing on areas with high probability of occurrence	General objectives: (i) & (iii) Specific objectives: (i), (ii), (ix) & (x)
Larval silverfish density (interpolated abundance data)	1	Larval silverfish (*Pleuragramma antartica*): Categories of different probability of occurrence (low to high) are included by means of a weighting factor	Boysen-Ennen & Piatkowski (1988), Hubold et al. (1988)	35% of total area in which larval silverfish occurs focusing on areas with high probability of occurrence	General objectives: (i) & (iii) Specific objectives: (i), (ii), (ix) & (x)
Potential foraging areas for Emperor penguins during breeding season	1	Emperor penguin (*Aptenodytes forsteri*): Categories of different probability of occurrence (low to high) during breeding	Sea ice concentration: Kaleschke et al. (2001), Spreen et al. (2008) Institute of Environmental Physics,	40% of total area in which potential foraging areas for Emperor penguins during breeding season occurs	General objectives: (i), (iii), (v) & (vi)

Table 2-1 Description of data sets and conservation objectives for the Marxan scenario.

Parameter	No. features	Description of features	Source (contact person, publication, web site)	Specific regional objective for MARXAN analysis	Relevant conservation objectives
(modelled data)		season are included by means of a weighting factor	University of Bremen: http://www.iup.uni-bremen.de/seaice/amsr/ Penguin data (location and size of colonies): Fretwell et al. (2012)	focusing on areas with high probability of occurrence	Specific objectives: (i), (iii), (ix) & (x)
Seal density (combinations of modelled and interpolated abundance data)	1	Combined data for crabeater seals (*Lobodon carcinophaga*) and unspecified taxa: Categories of different probability of occurrence (low to high) are included by means of a weighting factor	Crabeater seals: Forcada et al. (2012) Unspecified taxa: Plötz et al. (2011 a-e; http://www.pangaea.de)	40% of total area in which seals occur focusing on areas with high probability of occurrence	General objectives: (i), (iii), (v) & (vi) Specific objectives: (i), (iii), (ix) & (x)
Sponge presence (interpolated classes of abundance)	1	Categories of different probability of of sponge presence (i.e. rare, common, very common) are included by means of a weighting factor	Partly unpublished data; Dieter Gerdes (AWI); Ute Mühlenhardt-Siegel (DZMB); e.g. Gerdes et al. (1992) Unpublished data (ANT VII/4, ANT VII/5, ANT IX/1-4, ANT XIII/3, ANT XV/3, ANT XVII/3, ANT XXI/2); Wolf Arntz (AWI, retired)	100% of total area in which sponges occur focusing on areas with very common sponge presence	General objectives: (i) - (iii) Specific objectives: (iv), (vi), (ix) & (x)
Potential habitats of cold water shelf echinoderm fauna	1	Temperature range (≤ -1°C) describing the probability of occurrence for special communities regarding sea cucumbers and brittle stars	Proxy: Bottom seawater temperature range: FESOM model data; Timmermann et al. (2009)	35% of total area in which a potential habitat for special echinoderm communities occur	General objectives: (i) - (iv) Specific objectives: (iv) & (x)
Unique shallow water area (700 km² incl. buffer zone)	1	Feature defining the position of a unique area regarding depth range & benthic diversity	Bathymetry: Arndt et al. (2013); www.ibcso.org sc-xxxiii-bg-02 (2014) - Chapter 4.2.4 Benthic ecosystem Zoobenthos - Shelf and slope	100% of those unique shallow water area	General objectives: (i) - (iii) Specific objectives: (iv) (vi), (vii) & (x)
Nest guarding fish observations	1	*Chaenodraco wilsoni* *Neopagetopsis ionah*	Unpublished data (ANT XXIX/9, 2014); Dieter Gerdes (AWI) Unpublished data (ANT XXVII/3, 2011); Tomas Lundäv (Swedish Institute for the Marine Environment)	100% of each observation polygon	General objectives: (ii) & (iii) Specific objectives: (iv), (viii) & (x)

Table 2-1 Description of data sets and conservation objectives for the Marxan scenario.

Parameter	No. features	Description of features	Source (contact person, publication, web site)	Specific regional objective for MARXAN analysis	Relevant conservation objectives
Potential Antarctic toothfish habitat	1	Depth range (550 – 2500m) describing the probability of Antarctic toothfish (*Dissostichus* spp.) occurrence	Proxy: Bathymetry: Arndt et al. (2013); www.ibcso.org	75% of total area in which a potential toothfish habitat occur	General objectives: (i), (iii) & (v) Specific objectives: (iv), (v), (ix) & (x)

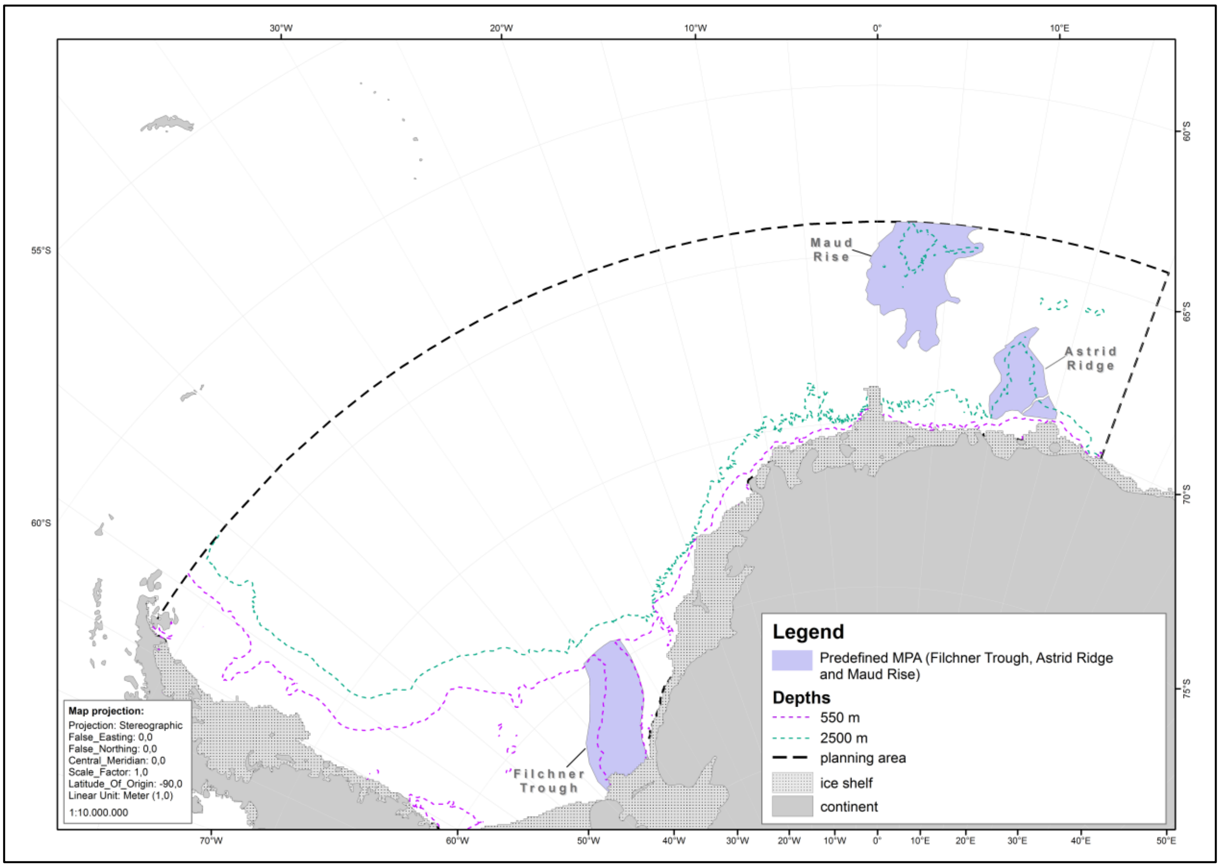

Figure 2-1 Three important or unique geomorphic types, i.e., Filchner Trough, Astrid Ridge, Maud Rise, that were set as essential MPA areas in the Marxan recursive approach.

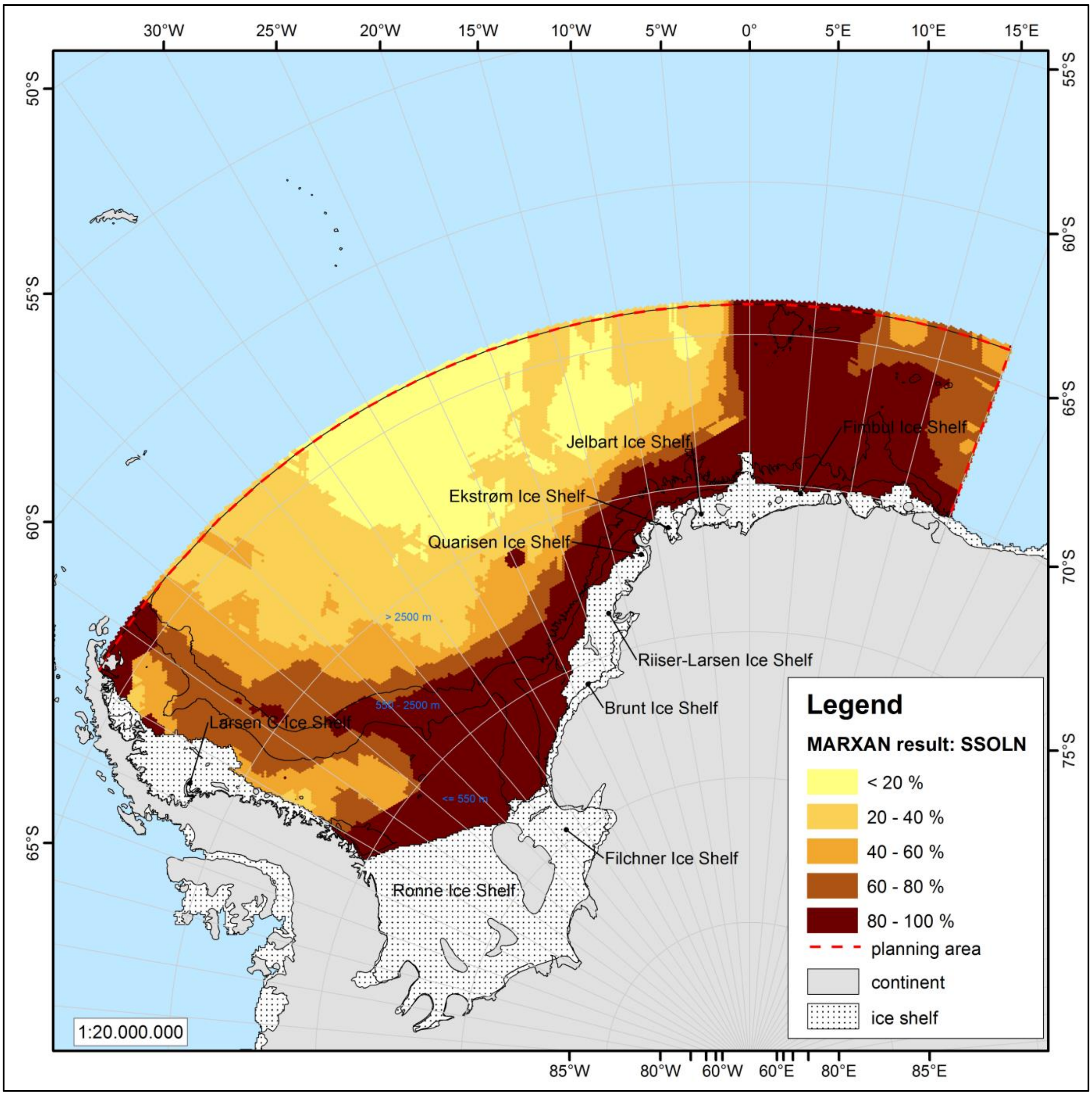

Figure 2-2 Summed solution scenario (SSOLN) of the Marxan recursive approach. Dark brown areas indicate areas of highest MPA importance. Specific regional conservation objectives (% area) of each parameter that were incorporated in the Marxan approach are listed in Table 2-1. The results of the Marxan recursive approach are shown in Tab. 2-2.

Table 2-2 Results of the Marxan analysis after five recursions. Achievement of specific regional conservation objectives (% area) per parameter was calculated for the final Marxan scenario; here, grid cells were defined that were selected in ≥ 80 % of in total 50 runs to set the final MPA borders (see Fig. 2-2, dark brown areas; category: 80 - 100 %).

Parameter	Total area in WSMPA planning area (km²)	Specific regional objective (% area)	Minimal achieving area (km²)	Actual achieving area (km²)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Ecological parameters						
Krill density	840904	35	294316	319069	38	YES (1.09)
Potential Ice krill habitat - Western WSMPA planning area	514498	35	180074	280574	55	YES (1.57)
Potential Ice krill habitat - Eastern WSMPA planning area	44513	35	15580	44513	100	YES (2.86)
Adult silverfish density	299311	35	104759	242217	81	YES (2.31)
Larval silverfish density	162108	35	56738	119087	73	YES (2.09)
Potential Emperor penguin foraging areas	603519	40	241408	524000	87	YES (2.18)
Seal density	3016832	40	1206733	1487960	49	YES (1.23)
Sponges presence	123170	100	123170	153654	125	YES (1.25)
Potential habitats of cold water shelf echinoderm fauna	442426	35	154849	278681	63	YES (1.80)
Nest guarding fish observations - *Chaenodraco wilsoni*	1075	100	1075	1075	100	YES (1.00)
Nest guarding fish observations - *Neopagetopsis ionah*	1075	100	1075	1075	100	YES (1.00)
Potential Antarctic toothfish habitat	391537	75	293653	300237	77	YES (1.03)
Environmental parameters						
Unique shallow water area	700	100	700	700	100	YES (1.00)
Astrid Ridge	43968	100	43968	43968	100	YES (1.00)
Filchner Trough	80797	100	80797	80797	100	YES (1.00)
Maud Rise	100830	100	100830	100830	100	YES (1.00)
Abyssal Plain: -3000m to -4500m	349645	20	69929	85718	25	YES (1.25)
Abyssal Plain: 4500m+	895282	20	179056	20252	2	NO (0.10)

Table 2-2 Results of the Marxan analysis after five recursions. Achievement of specific regional conservation objectives (% area) per parameter was calculated for the final Marxan scenario; here, grid cells were defined that were selected in ≥ 80 % of in total 50 runs to set the final MPA borders (see Fig. 2-2, dark brown areas; category: 80 - 100 %).

Parameter	Total area in WSMPA planning area (km^2)	Specific regional objective (% area)	Minimal achieving area (km^2)	Actual achieving area (km^2)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Bank: 0m to -100m	5587	20	1117	4024	72	YES (3.60)
Bank: -100m to -200m	9871	20	1974	7496	76	YES (3.80)
Bank: -200m to -500m	233937	20	46787	148757	64	YES (3.20)
Bank: -500m to -1000m	51813	20	10363	27204	53	YES (2.65)
Canyon Shelf Commencing	15822	65	10284	9840	62	YES (0.95)
Canyon Slope Commencing	54282	65	35284	28512	53	NO (0.82)
Coastal Terrane	10255	20	2051	10227	100	YES (5.00)
Cross Shelf Valley: 0m to -100m	1635	20	327	404	25	YES (1.25)
Cross Shelf Valley: -100m to -200m	1957	20	391	854	44	YES (2.20)
Cross Shelf Valley: -200m to -500m	81113	20	16223	34054	42	YES (2.10)
Cross Shelf Valley: -500m to -1000m	124005	20	24801	70840	57	YES (2.85)
Cross Shelf Valley: -1000m to -1500m	6914	20	1383	6878	99	YES (4.95)
Lower Slope: -2000m to -3000m	100047	20	20009	53049	53	YES (2.65)
Lower Slope: -3000m to -4500m	610713	20	122143	125150	20	YES (1.00)
Lower Slope: 4500m+	1081	20	216	198	18	NO (0.90)
Margin Ridge: -500m to -1000m	1284	20	257	1284	100	YES (5.00)
Margin Ridge: -1000m to -1500m	3036	20	607	3036	100	YES (5.00)
Margin Ridge: -1500m to -2000m	9097	20	1819	9097	100	YES (5.00)
Margin Ridge: -2000m to -3000m	21456	20	4291	21456	100	YES (5.00)
Margin Ridge: -3000m to -4500m	6039	20	1208	6039	100	YES (5.00)
Marginal Plateau: -2000m to -3000m	5042	65	3277	5042	100	YES (1.54)

Table 2-2 Results of the Marxan analysis after five recursions. Achievement of specific regional conservation objectives (% area) per parameter was calculated for the final Marxan scenario; here, grid cells were defined that were selected in ≥ 80 % of in total 50 runs to set the final MPA borders (see Fig. 2-2, dark brown areas; category: 80 - 100 %).

Parameter	Total area in WSMPA planning area (km²)	Specific regional objective (% area)	Minimal achieving area (km²)	Actual achieving area (km²)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Marginal Plateau: -3000m to -4500m	8877	65	5770	8874	100	YES (1.54)
Plateau Slope: -2000m to -3000m	2020	20	404	2020	100	YES (5.00)
Plateau Slope: -3000m to -4500m	92510	20	18502	80529	87	YES (4.35)
Plateau: -2000m to -3000m	26115	20	5223	26115	100	YES (5.00)
Plateau: -3000m to -4500m	4249	20	850	4249	100	YES (5.00)
Ridge: -1500m to -2000m	1046	20	209	1046	100	YES (5.00)
Ridge: -2000m to -3000m	9338	20	1868	6456	69	YES (3.45)
Ridge: -3000m to -4500m	3278	20	656	836	25	YES (1.25)
Rugose Ocean Floor: -3000m to -4500m	23678	20	4736	4518	19	YES (0.95)
Rugose Ocean Floor: 4500m+	243806	20	48761	24117	10	NO (0.50)
Seamount Ridge: -1000m to -1500m	792	20	158	792	100	YES (5.00)
Seamount Ridge: -2000m to -3000m	2864	20	573	1404	49	YES (2.45)
Seamount Ridge: -3000m to -4500m	2135	20	427	286	13	NO (0.65)
Seamount: -1000m to -1500m	1473	65	957	1108	75	YES (1.15)
Seamount: -1500m to -2000m	2670	65	1736	2670	100	YES (1.54)
Seamount: -3000m to -4500m	1455	65	946	1004	69	YES (1.06)
Seamount: 4500m+	118	65	77	88	75	YES (1.15)
Shelf Deep: 0m to -100m	125	65	81	125	100	YES (1.54)
Shelf Deep: -200m to -500m	34371	65	22341	24568	71	YES (1.09)
Shelf Deep: -500m to -1000m	34074	65	22148	24593	72	YES (1.11)
Shelf: Not applicable	946	65	615	946	100	YES (1.54)

Table 2-2 Results of the Marxan analysis after five recursions. Achievement of specific regional conservation objectives (% area) per parameter was calculated for the final Marxan scenario; here, grid cells were defined that were selected in ≥ 80 % of in total 50 runs to set the final MPA borders (see Fig. 2-2, dark brown areas; category: 80 - 100 %).

Parameter	Total area in WSMPA planning area (km²)	Specific regional objective (% area)	Minimal achieving area (km²)	Actual achieving area (km²)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Upper Slope: 0m to -100m	1525	65	991	1525	100	YES (1.54)
Upper Slope: -100m to -200m	1123	65	730	1123	100	YES (1.54)
Upper Slope: -200m to -500m	7973	65	5182	7207	90	YES (1.38)
Upper Slope: -500m to -1000m	32462	65	21100	18888	58	NO (0.89)
Upper Slope: -1000m to -1500m	49866	65	32413	30134	60	NO (0.92)
Upper Slope: -1500m to -2000m	66864	65	43462	46248	69	YES (1.06)
Upper Slope: -2000m to -3000m	115291	65	74939	78237	68	YES (1.05)
Upper Slope: -3000m to -4500m	151	65	98	151	100	YES (1.54)
Pelagic region - Coastal polynya I	9992	100	9992	9992	100	YES (1.00)
Pelagic region - Coastal polynya II	2682	100	2682	2682	100	YES (1.00)
Pelagic region - Coastal polynya III	85672	100	85672	85660	100	YES (1.00)
Pelagic region – Transition zone	247113	20	49423	187186	76	YES (3.80)
Pelagic region - Deepwater I	599646	20	119929	152550	25	YES (1.25)
Pelagic region - Deepwater II	1025025	20	205005	175744	17	NO (0.85)
Pelagic region - Deepwater III	812107	20	162421	292757	36	YES (1.80)
Pelagic region - Ice covered area	626696	20	125339	212609	34	YES (1.70)

2.3 Modifications of the Marxan scenario

For the final MPA outcome the Marxan recursive approach was modified and concretised by experts regarding a deep sea area in the Weddell Sea MPA planning area (see Fig. 2-3). Based on the Marxan approach adopted, there is high flexibility in terms of where to protect deep water features and the information included in the Marxan analysis was not driving consistent selection of a particular area so expert advice was used to decide on the placement. This modification further contributed to the specific regional conservation objectives by:

1. The achievement of a further environmental parameter ('Pelagic region - Deepwater II');
2. The achievement of the biological parameter for krill density;
3. Increasing representation of the environmental parameter 'Abyssal plain within 4500+' to above 10%.

The area also incorporates:

(i) Areas of higher predicted distribution of the lanternfish *Gymnoscopelus braueri* in the planning area (Duhamel et al. 2014);
(ii) Potential area of higher species richness of deep-sea isopods (Brandt et al. 2007);
(iii) Increased representation of areas with modelled higher Antarctic krill and salp abundance (Penhale & Grant 2007).

2.4 Setting the MPA borders

The borders of the proposed WSMPA are drawn based on three principles:

(i) MPA minimisation, and concurrently achievement of most parameters and their specific regional conservation objectives (% area) - full achievement of all specific regional conservation objectives regarding biological parameters

(ii) further expert knowledge regarding missing or under-represented features

(iii) a consistent area with borders that are easy to recognize and to navigate.

The following modifications were implemented (see Fig. 2-3):

<u>*Shelf and Slope Conservation Zone and Filchner Special Research Zone*</u>

- Northern border: 2500 m isobaths with following exceptions:
  - Westerly of 50°W the border follows the 73°S latitude;
  - Between 15°W and 30°W offshore extension beyond the 2500 m isobath as part of an area with the highest marine scientific research interest world-wide. Here, climate change induced alterations of water masses and circulation could lead to reduction or even disintegration of Ronne Filchner Ice Shelf.
- Eastern border: 01°00’W (= western border of Maud Rise Conservation Zone);

- Western and southern border: Continental margin and shelf ice margin respectively.

Antarctic Peninsula Conservation Zone

- Northern border: 64°00’S (= northern border of the WSMPA planning area);
- Eastern border: 50°46’W;
- Southern border: 65°15’S;
- Western border: Continental margin and shelf ice margin respectively.

Deep Sea Conservation Zone

- Northern border: 65°27’S;
- Eastern border: 24°00’W;
- Southern border: 68°30’S;
- Western border: 29°00’W.

Maud Rise Conservation Zone

- Northern border: 64°00’S (= northern border of the WSMPA planning area) and 64°54’S;
- Eastern border: 10°30’E and 16°54’E;
- Southern border: Continental margin and shelf ice margin respectively;
- Western border: 01°00’W.

Table 2-3 gives a systematic overview of how the final Weddell Sea MPA outcome, based on Marxan recursive approach plus modification by experts (see Fig. 2-3, shaded area), achieves the specific regional objectives (% area) of each parameter. The threshold was set again at 95% according to Marxan basic settings. 67 out of 76 parameters are met completely (≥ 0.95 * specific regional objective), this includes all specific regional objectives regarding biological parameters.

2.5 Preliminary Zoning

Figure 2-4 shows the conservation zones and sub-zones of the final Weddell Sea MPA outcome based on Marxan recursive approach and adjustment by experts. In the following, we provide a systematic overview of the conservation zones and sub-zones and their boundaries. In addition, we describe how the different (sub-) zones cover the general and specific conservation objectives.

1. *Shelf conservation zone*

Southern border: shelf ice edge
Northern border: 550 m depth isobath
Eastern border: 20° E

Western border: 73° S

In the *Shelf Conservation Zone* following conservation objectives are implemented:
General objectives: (i) - (v),
Specific objectives: (i) - (vi), (ix) and (x).

a. Sponge Community Subzone

Southern border: shelf ice edge
Northern border: 550m depth isobath
Eastern border: approx. 9°W
Western border: approx. 18°W

In the *Sponge Community Subzone* following conservation objectives are implemented:
General objectives: (i) - (iii) and (v),
Specific objectives: (iv) and (vi).

b. Shallow Shelf Subzone

Longitude	Latitude
11°32' W	71°06' S
11°24' W	71°06' S
11°32' W	71°08' S
11°24' W	71°08' S

In the *Shallow Shelf Subzone* following conservation objectives are implemented:
General objectives: (i) - (iii),
Specific objectives: (iv), (vi) and (vii).

c. Fish Nest Subzone

Circles with a radius of 10 nm (18.53 km) around the following two points:

	Long	Lat
Point 1	35°56' W	77°43' S
Point 2	29°40' W	74°54' S
Point 3	60°40' W	64°55' S

In the *Fish Nest Subzone* following conservation objectives are implemented:
General objectives: (i) - (iii),
Specific objectives: (viii).

2. Slope Conservation Zone

Southern border: 550 m depth isobath or shelf ice edge
Northern border: 2500 m depth isobath

Eastern border:	20° E
Western border:	73° S

In the *Slope Conservation Zone* following conservation objectives are implemented:
General objectives: (i) - (vi),
Specific objectives: (i), (ii) (iv), (v), (x) and (xi).

3. *Filchner Special Research Area (FSRA)*

Southern border:	shelf ice edge
Northern border:	western part of FSRA: 75°S eastern part of FSRA: 72°S
Eastern border:	20° West Longitude
Western border:	western part of FSRA: 45°W Eastern part of FSRA: 35°W

In the *FRSA* following conservation objectives are implemented:
General objectives: (iv),
Specific objectives: (xi).

4. *Maud Rise Conservation Zone*

Southern border:	2500m depth isobath or shelf ice edge
Northern border # 1:	64° S
Northern border # 2:	64°54’ S
Eastern border # 1:	10°30’ E
Eastern border # 2:	16°54’ E
Western border:	01°00’ W

In the *Maud Rise Conservation Zone* following conservation objectives are implemented:
General objectives: (i) - (v),
Specific objectives: (i) - (v) and (viii) - (xi).

5. *Antarctic Peninsula Conservation Zone*

Southern border:	65°15’ S
Northern border:	64° 00’ S
Eastern border:	50°42’ W
Western border:	shelf ice edge or continent

In the *Antarctic Peninsula Conservation Zone* following conservation objectives are implemented:
General objectives: (i) - (iv),
Specific objectives: (i), (iv) and (x).

6. *Deep Sea Conservation Zone*

Southern border:	68°30’ S

Northern border:	65°27’ S
Eastern border:	24°00’ W
Western border:	29°00’ W

In the *Deep Sea Conservation Zone* following conservation objectives are implemented:
General objectives: (i) and (iii),
Specific objectives: (i), (ii), (iv), (x) and (xi).

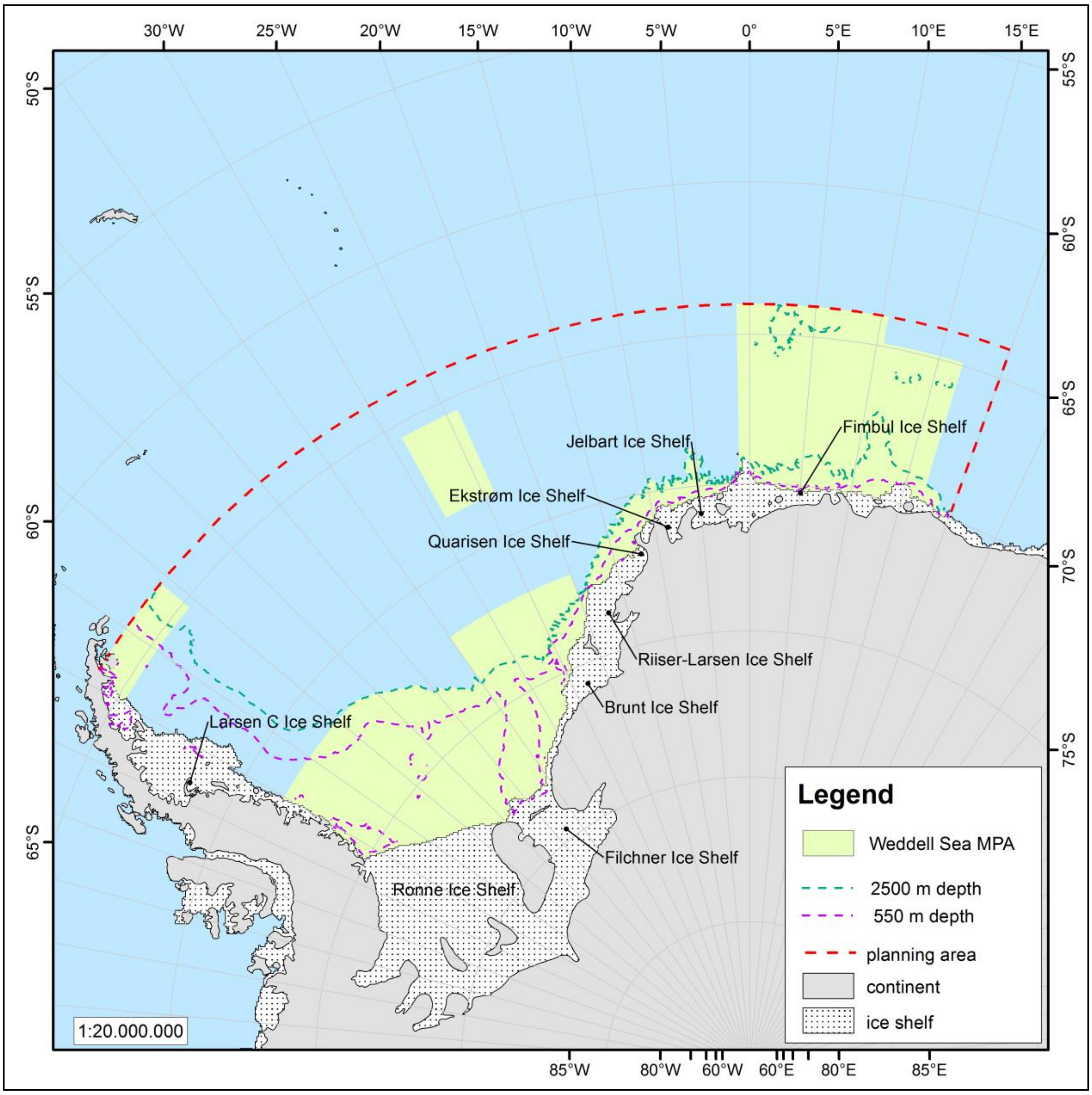

Figure 2-3 Final Weddell Sea MPA outcome based on Marxan recursive approach and adjustment by experts. The fulfilment of the specific regional conservation objectives (% area) per parameter is shown in Tab. 2-2.

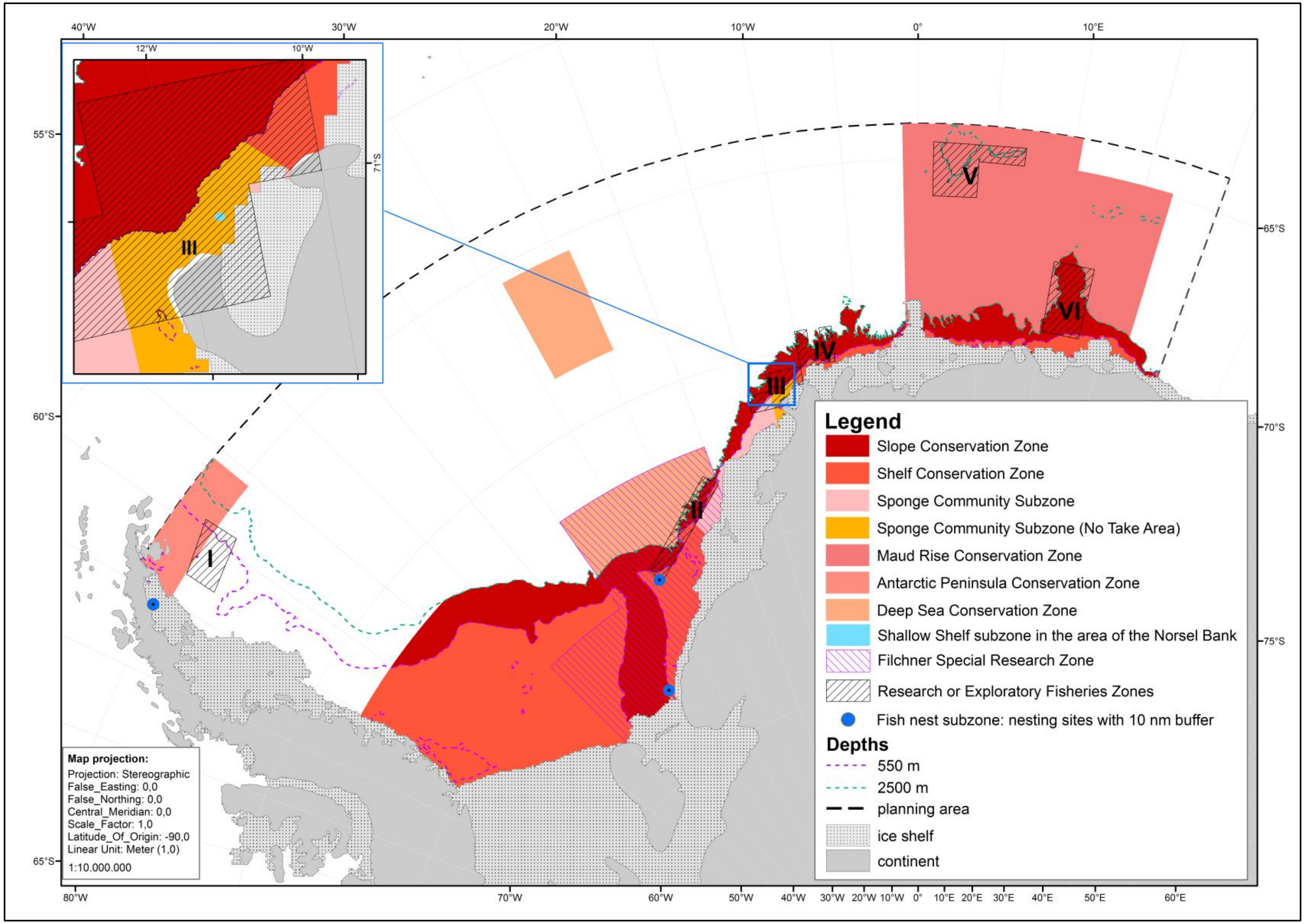

Figure 2-4 Conservation zones and subzones of the final Weddell Sea MPA outcome based on Marxan recursive approach and adjustment by experts.

Table 2-3 Results based on the Marxan recursive approach plus modification by experts (see Fig. 2-2, shaded area). Achievement of the specific regional conservation objectives (% area) for each parameter was calculated. Parameters and corresponding specific regional objectives with a ratio of 0.0 (last column) are not covered at all by the final Weddell Sea MPA outcome.

Parameter	Total area in WSMPA planning area (km^2)	Specific regional objective (% area)	Minimal achieving area (km^2)	Actual achieving area (km^2)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Ecological parameters						
Krill density	840904	35	294316	388501	46	YES (1.31)
Potential Ice krill habitat - Western WSMPA planning area	514498	35	180074	396767	77	YES (2.20)
Potential Ice krill habitat - Eastern WSMPA planning area	44513	35	15580	42128	95	YES (2.71)
Adult silverfish density	299311	35	104759	230713	77	YES (2.20)
Larval silverfish density	162108	35	56738	118553	73	YES (2.09)
Potential Emperor penguin foraging areas	603519	40	241408	501301	83	YES (2.08)
Seal density	3016832	40	1206733	1623701	54	YES (1.35)
Sponges presence	123170	100	123170	126892	103	YES (1.03)
Potential habitats of cold water shelf echinoderm fauna	442426	35	154849	377163	85	YES (2.43)
Nest guarding fish observations - *Chaenodraco wilsoni*	1075	100	1075	1075	100	YES (1.00)
Nest guarding fish observations - *Neopagetopsis ionah*	1075	100	1075	1075	100	YES (1.00)
Potential Antarctic toothfish habitat	391537	75	293653	313282	80	YES (1.07)
Environmental parameters						
Unique shallow water area	700	100	700	700	100	YES (1.00)
Astrid Ridge	43968	100	43968	43968	100	YES (1.00)
Filchner Trough	80797	100	80797	80797	100	YES (1.00)
Maud Rise	100830	100	100830	100830	100	YES (1.00)
Abyssal Plain: -3000m to -4500m	349645	20	69929	96215	28	YES (1.40)
Abyssal Plain: 4500m+	895282	20	179056	101209	11	NO (0.55)
Bank: 0m to -100m	5587	20	1117	4396	79	YES (3.95)

Table 2-3 Results based on the Marxan recursive approach plus modification by experts (see Fig. 2-2, shaded area). Achievement of the specific regional conservation objectives (% area) for each parameter was calculated. Parameters and corresponding specific regional objectives with a ratio of 0.0 (last column) are not covered at all by the final Weddell Sea MPA outcome.

Parameter	Total area in WSMPA planning area (km²)	Specific regional objective (% area)	Minimal achieving area (km²)	Actual achieving area (km²)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Bank: -100m to -200m	9871	20	1974	8315	84	YES (4.20)
Bank: -200m to -500m	233937	20	46787	200739	86	YES (4.30)
Bank: -500m to -1000m	51813	20	10363	32297	62	YES (3.10)
Canyon Shelf Commencing	15822	65	10284	8198	52	NO (0.80)
Canyon Slope Commencing	54282	65	35284	23252	43	NO (0.66)
Coastal Terrane	10255	20	2051	10097	98	YES (4.90)
Cross Shelf Valley: 0m to -100m	1635	20	327	400	24	YES (1.20)
Cross Shelf Valley: -100m to -200m	1957	20	391	560	29	YES (1.45)
Cross Shelf Valley: -200m to -500m	81113	20	16223	66682	82	YES (4.10)
Cross Shelf Valley: -500m to -1000m	124005	20	24801	83267	67	YES (3.35)
Cross Shelf Valley: -1000m to -1500m	6914	20	1383	6912	100	YES (5.00)
Lower Slope: -2000m to -3000m	100047	20	20009	41021	41	YES (2.05)
Lower Slope: -3000m to -4500m	610713	20	122143	149880	25	YES (1.25)
Lower Slope: 4500m+	1081	20	216	21	2	NO (0.10)
Margin Ridge: -500m to -1000m	1284	20	257	1284	100	YES (5.00)
Margin Ridge: -1000m to -1500m	3036	20	607	3036	100	YES (5.00)
Margin Ridge: -1500m to -2000m	9097	20	1819	9097	100	YES (5.00)
Margin Ridge: -2000m to -3000m	21456	20	4291	21456	100	YES (5.00)
Margin Ridge: -3000m to -4500m	6039	20	1208	6039	100	YES (5.00)
Marginal Plateau: -2000m to -3000m	5042	65	3277	5042	100	YES (1.54)
Marginal Plateau: -3000m to -4500m	8877	65	5770	8877	100	YES (1.54)

Table 2-3 Results based on the Marxan recursive approach plus modification by experts (see Fig. 2-2, shaded area). Achievement of the specific regional conservation objectives (% area) for each parameter was calculated. Parameters and corresponding specific regional objectives with a ratio of 0.0 (last column) are not covered at all by the final Weddell Sea MPA outcome.

Parameter	Total area in WSMPA planning area (km^2)	Specific regional objective (% area)	Minimal achieving area (km^2)	Actual achieving area (km^2)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Plateau Slope: -2000m to -3000m	2020	20	404	2020	100	YES (5.00)
Plateau Slope: -3000m to -4500m	92510	20	18502	91798	99	YES (4.95)
Plateau: -2000m to -3000m	26115	20	5223	26115	100	YES (5.00)
Plateau: -3000m to -4500m	4249	20	850	4249	100	YES (5.00)
Ridge: -1500m to -2000m	1046	20	209	1046	100	YES (5.00)
Ridge: -2000m to -3000m	9338	20	1868	5261	56	YES (2.80)
Ridge: -3000m to -4500m	3278	20	656	60	2	NO (0.10)
Rugose Ocean Floor: -3000m to -4500m	23678	20	4736	4823	20	YES (1.00)
Rugose Ocean Floor: 4500m+	243806	20	48761	31378	13	NO (0.65)
Seamount Ridge: -1000m to -1500m	792	20	158	792	100	YES (5.00)
Seamount Ridge: -2000m to -3000m	2864	20	573	2835	99	YES (4.95)
Seamount Ridge: -3000m to -4500m	2135	20	427	1294	61	YES (3.05)
Seamount: -1000m to -1500m	1473	65	957	1473	100	YES (1.54)
Seamount: -1500m to -2000m	2670	65	1736	2670	100	YES (1.54)
Seamount: -3000m to -4500m	1455	65	946	1455	100	YES (1.54)
Seamount: 4500m+	118	65	77	0	0	NO (0.00)
Shelf Deep: 0m to -100m	125	65	81	125	100	YES (1.54)
Shelf Deep: -200m to -500m	34371	65	22341	31043	90	YES (1.38)
Shelf Deep: -500m to -1000m	34074	65	22148	31581	93	YES (1.43)
Shelf: Not applicable	946	65	615	946	100	YES (1.54)
Upper Slope: 0m to -100m	1525	65	991	1525	100	YES (1.54)

Table 2-3 Results based on the Marxan recursive approach plus modification by experts (see Fig. 2-2, shaded area). Achievement of the specific regional conservation objectives (% area) for each parameter was calculated. Parameters and corresponding specific regional objectives with a ratio of 0.0 (last column) are not covered at all by the final Weddell Sea MPA outcome.

Parameter	Total area in WSMPA planning area (km²)	Specific regional objective (% area)	Minimal achieving area (km²)	Actual achieving area (km²)	Actual achieving specific regional objective (% area)	Fulfilment of specific regional objective (ratio)
Upper Slope: -100m to -200m	1123	65	730	1123	100	YES (1.54)
Upper Slope: -200m to -500m	7973	65	5182	7791	98	YES (1.51)
Upper Slope: -500m to -1000m	32462	65	21100	22720	70	YES (1.08)
Upper Slope: -1000m to -1500m	49866	65	32413	32468	65	YES (1.00)
Upper Slope: -1500m to -2000m	66864	65	43462	48326	72	YES (1.11)
Upper Slope: -2000m to -3000m	115291	65	74939	72112	63	YES (0.97)
Upper Slope: -3000m to -4500m	151	65	98	0	0	NO (0.00)
Pelagic region - Coastal polynya I	9992	100	9992	9963	100	YES (1.00)
Pelagic region - Coastal polynya II	2682	100	2682	2605	97	YES (0.97)
Pelagic region - Coastal polynya III	85672	100	85672	80279	94	NO (0.94)
Pelagic region – Transition zone	247113	20	49423	174857	71	YES (3.55)
Pelagic region - Deepwater I	599646	20	119929	141891	24	YES (1.20)
Pelagic region - Deepwater II	1025025	20	205005	278795	27	YES (1.35)
Pelagic region - Deepwater III	812107	20	162421	352856	43	YES (2.15)
Pelagic region - Ice covered area	626696	20	125339	315151	50	YES (2.50)

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