CCAMLR

Commission for the Conservation of Antarctic Marine Living Resources
Commission pour la conservation de la faune et la flore marines de l’Antarctique
Комиссия по сохранению морских живых ресурсов Антарктики
Comisión para la Conservación de los Recursos Vivos Marinos Antárticos

WG-SAM-17/30
12 June 2017
Original: English

WG-SAM

Scientific background document in support of the development of a CCAMLR MPA in the Weddell Sea (Antarctica) – Version 2017 – Reflection of the recommendations by WG-EMM-16 and SC-CAMLR-XXXV

K. Teschke, H. Pehlke and T. Brey on behalf of the German Weddell Sea MPA (WSMPA) project team

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Scientific background document in support of the development of a CCAMLR MPA in the Weddell Sea (Antarctica) – Version 2017

- Reflection of the recommendations by WG-EMM-16 and SC-CAMLR-XXXV -

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The following list sets out the information in this document which might be of interest for the CCAMLR Working Groups SAM, EMM and FSA as well as to the CCAMLR SC. It also provides easy reference to the answers in respect of the specific questions raised by WG-EMM-16 (SC-CAMLR-XXXV, Annex 6, §§ 3.1-3.14) and SC-CAMLR-XXXV (SC-CAMLR-XXXV, §§ 5.14-5.28).

- ❖ Additional datasets (e.g. flying seabird, seals) and revision of corresponding data layers
  - ➢ **Chapter 1. (pp. 4-6) and Chapter 2 (pp. 6-12)**

- ❖ Revision of the Antarctic toothfish habitat model, and further development of the habitat layer and updates to the cost layer
  - ➢ **Chapter 2.3. (pp. 12-20) and Chapter 3.1. (pp. 21-22)**

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- ❖ Consideration of how the outputs of analyses are used in the development of the current WSMPA management zones
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- ❖ Fisheries Research Zone (Specific objective 12)
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General introduction

The CAMLR Scientific Committee in 2016 reviewed three scientific background documents (SC-CAMLR- XXXV/BG/11, BG12 and BG/13). Germany was asked to carry out further work, in particular as regards the issues and questions raised at WG-EMM-16 and SC-CAMLR-XXXV with respect to the WSMPA proposal (SC-CAMLR-XXXV, Annex 6 and §§ 5.14-5.28).

Chapter 1 of this working group paper informs on the data retrieval process during the 2016/2017 intersessional period. **Chapter 2** presents the updated analyses of relevant data layers, and **Chapter 3** provides the new MARXAN analyses. Please note that major parts of the data retrieval process, the data analyses as well as the MPA scenario development were already reported in the background documents 'Part B: Description of available spatial data' and 'Part C: Data analysis and MPA scenario development' for the meeting of the CAMLR Scientific Committee in 2016 (SC-CAMLR-XXXV/BG/12 and BG/13). In **Chapter 4** we outline the way we transferred the results of our scientific analyses into the structure (i.e. borders and management zones) of the proposed WSMPA.

1. Description of newly acquired data

This chapter reflects the recommendations concerning the WSMPA data acquisition process made by SC-CAMLR-XXXV (report SC-CAMLR-XXXV, §§ 5.14-5.28) and beyond in intersessional discussions with scientific experts of several CCAMLR Members States. New data sets, such as tracking data on flying seabirds and pinnipeds (particularly on southern elephant seals), were collected in the 2016/17 intersessional period to underpin the scientific background in support of the development of a CCAMLR Weddell Sea MPA (WSMPA). Next to the actual collected data we got a general idea of much more potential data sets. In this context we got in touch with more than 15 scientists from seven CCAMLR Members States. In the following, we briefly describe the newly acquired data sets and mention how we proceeded with each data set.

1.1. Data on marine mammals

Tracking data on marine mammals were collected and made freely available by the International MEOP (Marine Mammals Exploring the Oceans Pole to Pole) Consortium and the national programs that contribute to it (http://www.meop.net). From the MEOP-CTD database we downloaded all public tracking data which end up in the WSMPA Planning Area. In addition, private MEOP data that have not yet accepted to share unconditionally were obtained from UK and Germany. Almost 90 % of the MEOP tracks, which end up in the WSMPA Planning Area, originate from tagged elephant seals. For example, there are movements of southern elephant seals in the eastern Weddell Sea during their feeding overwinter trips from Bouvetøya (Biuw et al. 2010). The remaining MEOP tracks derive from tagged Weddell seals and crabeater seals.

The data derived from the MEOP database were complemented by tracking data sets on southern elephant seals (Tosh et al. 2009, James et al. 2012), Weddell seals (McIntyre et al. 2013) and crabeater seals (Nachtsheim et al. 2016) which are publically available via the scientific data information system PANGAEA, and are additionally included in the RAATD dataset (RAATD project - Retrospective Analysis of Antarctic Tracking Data). Based on all these tracking data a new data layer was developed by the *crawl* model (Johnson et al. 2008) that identifies the areas that were used most often by tracked pinnipeds (see chapter 2.1.).

The study from Nøttestad et al. (2014) served as supporting background information for the WSMPA development, but was not directly incorporated into our subsequent spatial planning process.

1.2. Tracking data on flying seabirds

We acquired processed tracking data on Antarctic petrels published in Descamps et al. (2016). The authors kindly provided us with shape files showing the kernel utilization summer and winter distribution of Antarctic petrel breeding at Svarthamaren. In our updated seabird data layer the model from Descamps et al. (2016) was combined with our Antarctic petrel model (see details on our model in SC-CAMLR-XXXV/BG/13).

1.3. Data on demersal fish

Catch and effort data of all long-line sets for Antarctic toothfish in Subarea 88.1 from 1998-2016 in all seasons were requested from the CCAMLR Data Centre. The CPUE data from the Ross Sea region were analysed in the context of our updated Antarctic toothfish (*Dissostichus mawsoni*) habitat model.

1.4. Data on Antarctic krill (*Euphausia superba*)

We checked again the data set on Antarctic krill abundance from the Norwegian 2008 cruise (see Krafft et al. 2010) that we already acquired in 2014 (SC-CAMLR-XXXIII/BG/02), regarding the completeness of the data set within our WSMPA Planning Area. Hereupon, we looked into a presence / absence data set on *E. superba*, which was collected during the Norwegian G.O. Sars cruise in 2008, too. This data set, however, contains samplings north of the WSMPA Planning Area only (northern border of WSMPA Planning Area: 64°S). An additional zooplankton study carried out during the Norwegian G.O. Sars cruise in 2008 (Wiebe et al. 2010) took place to the north of the WSMPA Planning Area, too.

Furthermore, we looked into acoustic data on Antarctic krill to possibly complement our existing Antarctic krill model by presence/absence information from these acoustic data sets. The most extensive acoustic data set in the WSMPA Planning Area was collected within the LAzarev Sea KRIll Study (LAKRIS) project from 2004 to 2008. The spatial coverage of this acoustic data set, however, is already represented in our krill model by the LAKRIS RMT-net-sampling surveys. Thus, we refrain from incorporating the bio-acoustic data from the LAKRIS project into our existing krill model. Regarding acoustic data on Antarctic krill from South Africa we did not yet been able to localise these data. When relevant for the WSMPA development we are ready to use these data as supporting background information.

1.5. Diverse environmental data

During SC-CAMLR-XXXV and CAMLR-XXXV we discussed with Norway a variety of environmental data sets which may be worth to add to our existing environmental database. In detail we discussed oceanographic and bottom topography data from the Norwegian 2008 cruise, oceanographic data from the MEOP-CTD database (see chapter 1.1.) as well as oceanographic data from South Africa.

Oceanographic data from the Norwegian 2008 cruise include CTD data such as temperature and salinity, water samples (e.g. nitrate, phosphate and silicate) and chlorophyll a measurements. Detailed data on bottom topography were collected with a multibeam echo sounder during the same cruise. Oceanographic data which have been collected by instrumented marine mammals and are stored in the MEOP-CTD database are related to temperature and salinity profiles. Regarding oceanographic data from South Africa we did not yet been able to localise these data.

We reckon that these oceanographic and bottom topography data do not constitute a significant improvement of our current WSMPA data base which builds on the broadest data collections available. For example, temperature and salinity data are derived from the Finite Element Sea Ice - Ocean Model (FESOM; Timmermann et al. 2009) and are incorporated in the Marxan analyses *inter alia* by our pelagic regionalisation data layer (see SC-CAMLR-XXXV/BG/12 and BG/13). FESOM is based on the most extensive data base and predicts temperature and salinity of the WSMPA Planning Area with unmatched spatial and temporal resolution: We used monthly mean values of temperature and salinity from 1990 to 2009. Our FESOM raster has a regular horizontal resolution of 0.18° (x) x 0.05° (y); in the vertical, 2 z-levels (i.e. sea surface and sea bottom), are used. By comparison, the data from the Norwegian 2008 cruise refer to ≤ 3 sampling stations at the northern fringe of the WSMPA Planning Area (Krafft et al. 2010), and the MEOP-CTD data are concentrated south of 70°S in the WSMPA Planning Area.

To represent the bottom topography in the WSMPA Planning Area we used the benthic environmental analysis published by Douglass et al. (2014) (SC-CAMLR-XXXV/BG/12 and /13).

For these reasons we did not incorporate these additional oceanographic and bottom topography data into our further analyses.

2. Revision of data analysis

Chapter 2 of the working group paper informs on the newly analysed data layers on pinnipeds, seabirds and demersal fish in the 2016/2017 intersessional period. All recommendations made by WG-EMM-16 and SC-CAMLR-XXXV (see report SC-CAMLR-XXXV, Annex 6 and §§ 5.14-5.28) are reflected and described in the following chapters. For example, we explore whether weighting the toothfish habitat by depth using catch per unit effort data from the Weddell Sea and the Ross Sea may provide an alternative approach towards the modelling of the Antarctic toothfish habitat.

2.1. New data layer on pinnipeds

SC-CAMLR-XXXV (SC-CAMLR-XXXV, §§ 5.14-5.28) recommended that the WSMPA should consider movements of seals in the WSMPA Planning Area, *inter alia* southern elephant seal migration and habitat usage of the Dronning Maud Land coast (Biuw et al. 2010).

For analysing the migration pattern of pinnipeds in the Weddell Sea MPA Planning Area and adjacent regions, such as the Bellingshausen Sea along the west side of the Antarctic Peninsula, we used the tracking data sets described in chapter 1.1., and are mapped in Figure 2-1.

The tracking data were processed with a state-space model described by Johnson et al. (2008) and implemented in the R package *crawl* (Version 1.5; www.rdocumentation.org/packages/crawl/versions/1.5). We used the fitted continuous-time correlated random walk model to generate 100 simulated track-lines between the temporally successive ARGOS positions for each tracking data set. Only random track-lines were generated where the maximum speed of a seal between successive positions was $\leq 2.5 \text{ m s}^{-1}$. Setting the maximum speed allowed by the filter to 2.5 m s^{-1} is conservative as the mean and maximum speeds per tracking data set were always $\leq 1.5 \text{ m s}^{-1}$ and $\leq 2.5 \text{ m s}^{-1}$, respectively. Thus, the simulated tracks shown here probably contain more variation than actually displayed by the seals.

The simulated track-lines were binned onto our standard spatial grid (cell size: 6.25 km x 6.25 km) and were pooled per grid cell so that the final data layer identifies the areas that were used most often by tracked pinnipeds.

The pooled values per grid cell were log10-transformed, scaled to the range 0 - 1, and were grouped into four classes. For our MARXAN scenario we computed the arithmetic mean of each group and multiply the mean by 100 (see Tab. 2-1). The weighting factor for class 1 was set to 1. An exponential function was used to calculate the weighting factors for all other classes:

Weighting factor = EXP(0.05*x)-(EXP(0.05*a))+1

where *x* is the mean of the corresponding class and *a* is the mean of class 1.

Table 2-1 Calculated mean and corresponding weighting factor of the four classes representing the probability distribution of seal occurrence.

Class	Probability of occurrence (%)	Mean	Weighting factor
1	0.00 - 0.25	13	1.0
2	0.26 - 0.50	38	5.77
3	0.51 - 0.75	63	22.42
4	0.76 - 1.00	88	80.54

Regarding the WSMPA planning area, the tracking data analysis indicates the most frequent occurrence of seals in a larger area off the Brunt and Filchner Ice Shelf (approx. 25°W-40°W), and in smaller patches along the eastern and south-eastern ice shelfs as well as in the region at the tip of the Antarctic Peninsula (see Fig. 2-2).

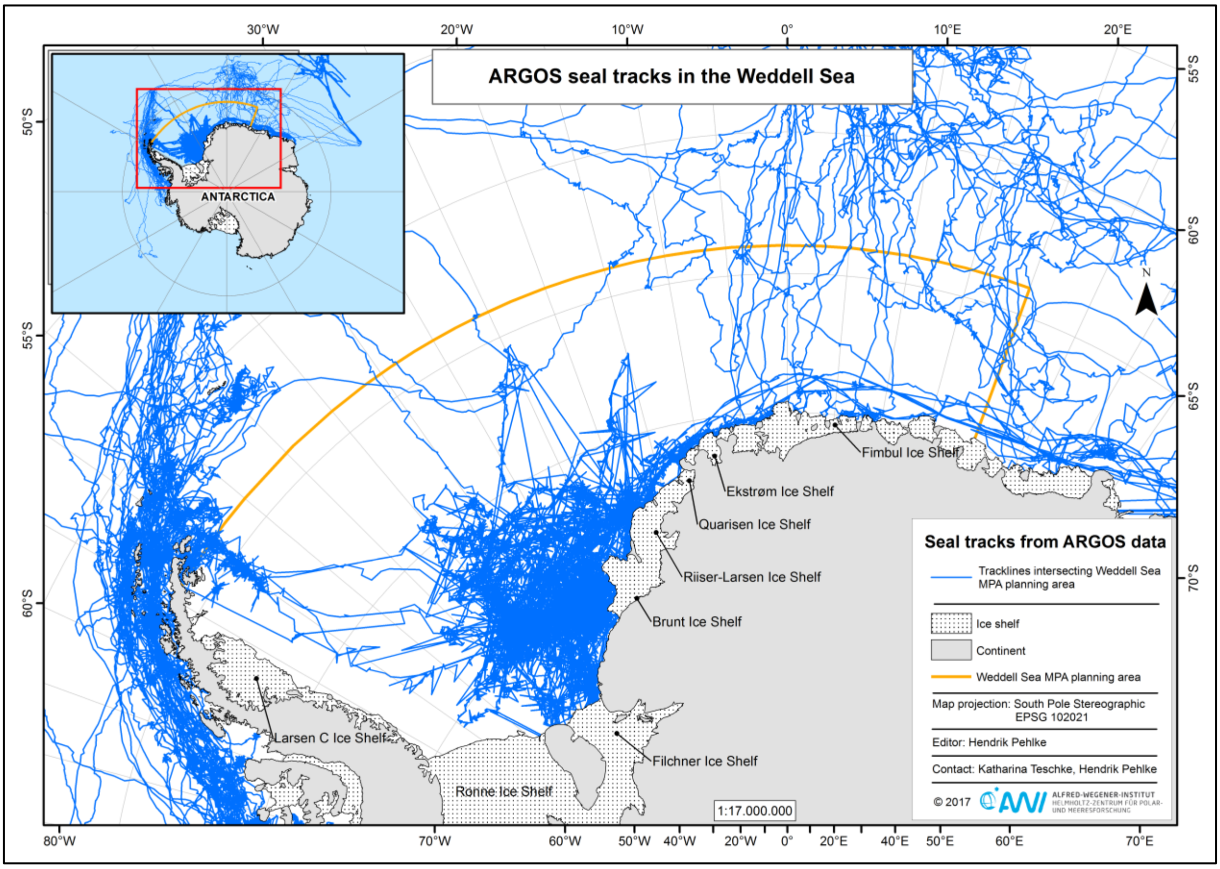

Figure 2-1 Overview of tracking data on seals in the Weddell Sea MPA Planning Area and adjacent regions. Approximately 90 % of the tracks originate from tagged elephant seals. The remaining tracks derive from tagged Weddell seals and crabeater seals.

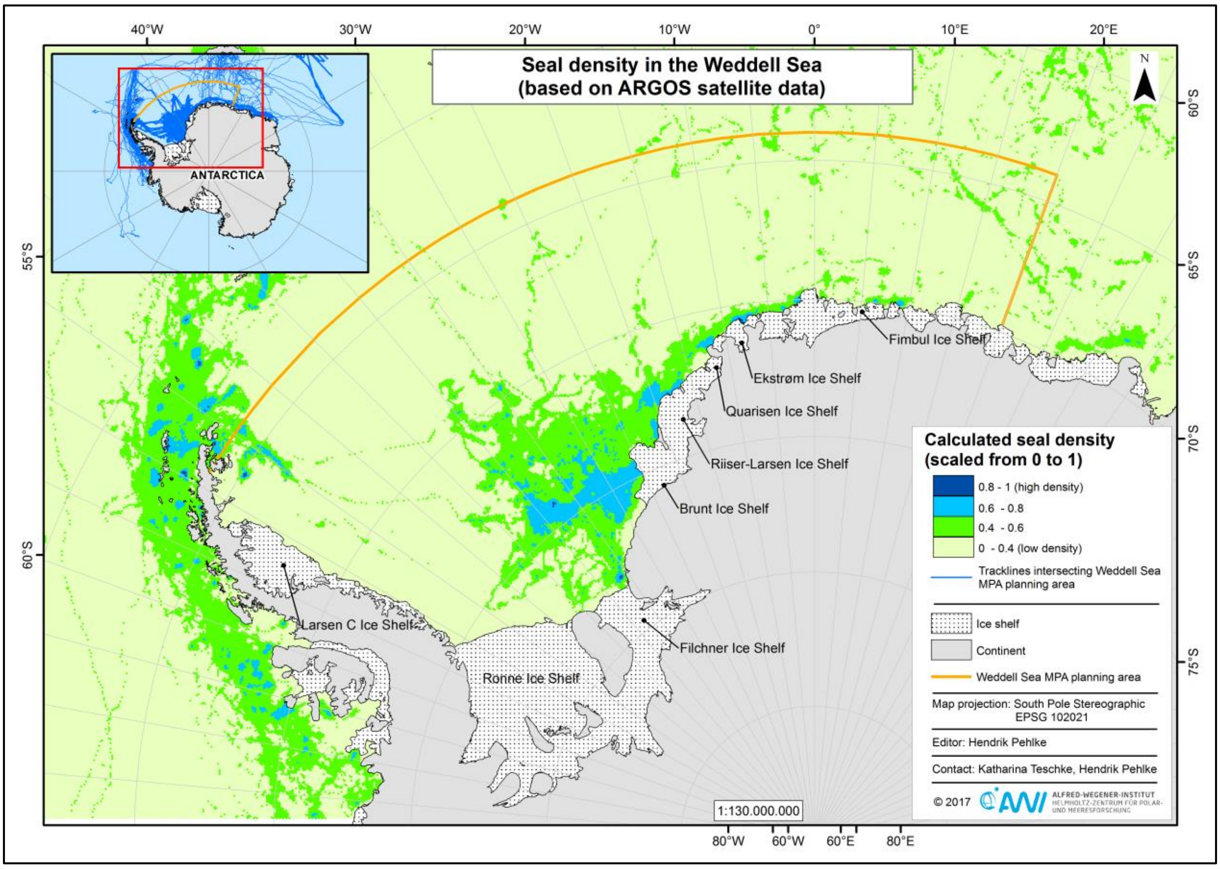

Figure 2-2 Prediction map for seal distribution in the WSMPA Planning area and adjacent regions. Modelled data are plotted as log10-transformed values. Areas that were used most often by tracked individuals are colour-coded with blue colours indicating most often used areas. Orange box: WSMPA Planning Area.

2.2. Updated spatial prediction map for Antarctic petrel

SC-CAMLR-XXXV (SC-CAMLR-XXXV, §§ 5.14-5.28) recommended that we incorporate the survey on Antarctic petrels published in Descamps et al. (2016) into our spatial prediction map for Antarctic petrels in the WSMPA Planning Area. Descamps et al. (2016) modelled the kernel utilization summer and winter distributions of Antarctic petrels breeding at Svarthamaren (see Fig. 2-3). Details on our comparatively simple model of Antarctic Petrel (*Thalassoica antarctica*) are given in SC-CAMLR-XXXV/BG/13.

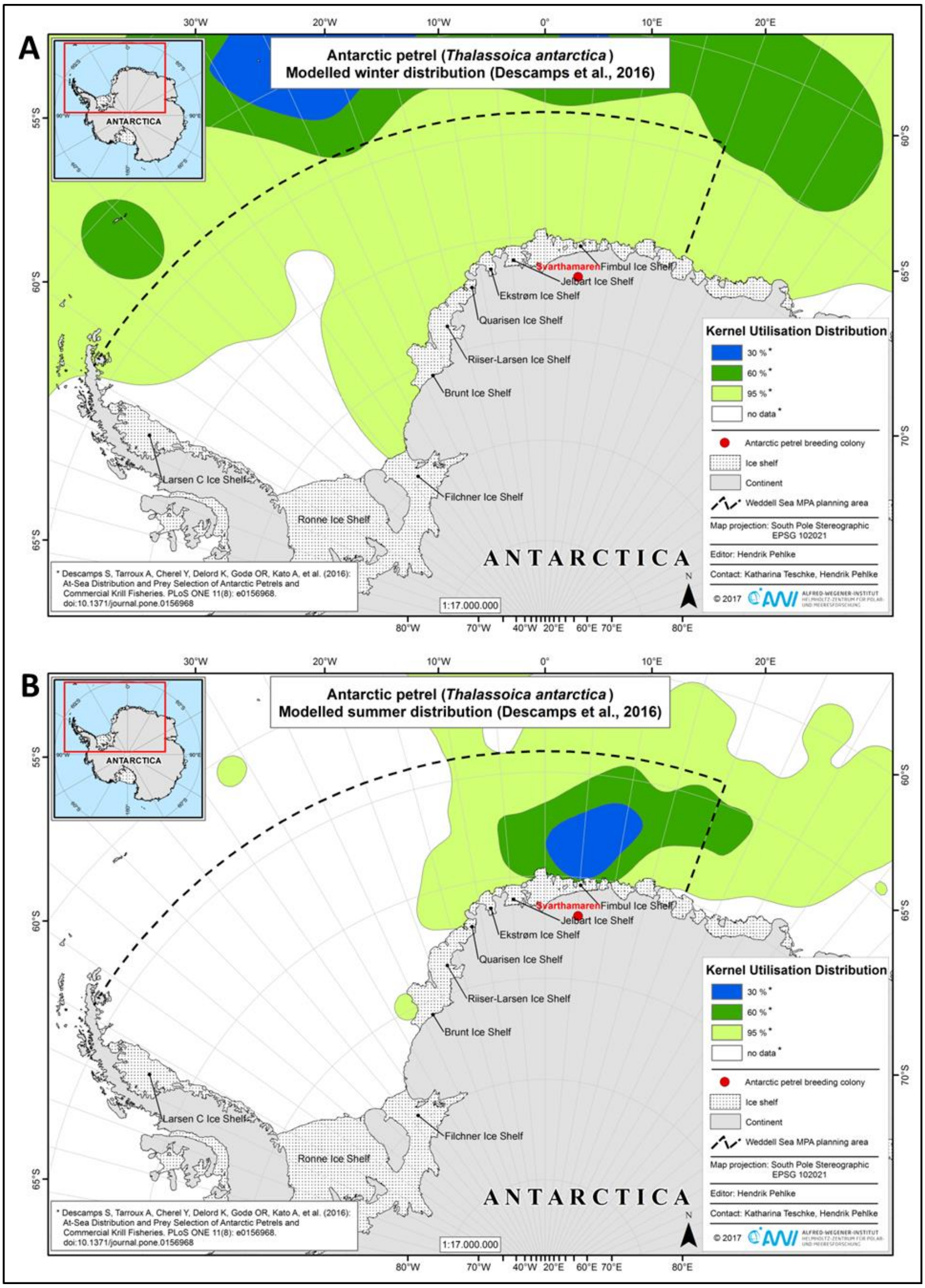

Figure 2-3 Winter (A) and summer (B) distribution of Antarctic petrels breeding at Svarthamaren. Blue, dark green and light green coloured areas show the 30 % (core areas - high intensity of use), 60 % (intermediate intensity of use) and 95 % (almost whole area) kernel utilization distributions, respectively (according to Descamps et al. 2016).

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

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

$$\mathrm{wf_i} = \frac{\max(\mathrm{k_{UD}})}{\mathrm{k_{UD\,i}}} \tag{1}$$

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

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

$$P_i = \frac{\left(\frac{\mathrm{x_i}_{AWI\_model} + (100 * \mathrm{wf_i}_{Descamp\,et\,al.\_summer}) + (100 * \mathrm{wf_i}_{Descamp\,et\,al.\_winter})}{3}\right)}{100 * \max(\mathrm{x_i}_{AWI_{model}}, 100 * \mathrm{wf_i}_{Descamp\,et\,al.\_summer}, 100 * \mathrm{wf_i}_{Descamp\,et\,al.\_winter})} \tag{2}$$

where $\mathrm{x_i}_{AWI\_model}$ is our model value (i.e. 5, 20, 35, 50 or 100).

(iii) Outliers, defined by value > 1.5 interquartile ranges, were set to 100 %. All other values (within the 1.5 interquartile ranges) were scaled to the 0 to 100 % range.

For our MARXAN scenario we grouped the processed data into their five quantiles and computed the arithmetic mean of each group (see Tab. 2-2). A weighting factor for each class was computed by the exponential function:

Weighting factor = EXP(0.05*x)-(EXP(0.05*a))+1

where *x* is the mean of the corresponding class and *a* is the mean of class 1.

The updated spatial prediction map for Antarctic petrels is shown in Figure 2-4. Favourable habitat conditions for Antarctic petrels are predicted for the eastern and south-eastern part of the WSMPA Planning Area, particularly for the area off the Fimbul Ice Shelf and along the coast between approx. 15°E to 10°W within a water depth range from approx. 500 m to 2500 m.

Table 2-2: Calculated mean and corresponding weighting factor of the five classes representing the final probability distribution of Antarctic petrel occurrence. The values in the table are rounded; the calculation of the weighting factor is based on five decimals.

Class	Quantile	Probability of occurrence (%)	Mean	Weighting factor
1	25	0 - 24.4	12.2	1.0
2	50	24.5 - 38.1	31.3	4.0
3	75	38.2- 54.6	46.4	9.3
4	90	54.7 - 71.1	62.9	22.3
5	100	71.2 - 100	85.6	71.2

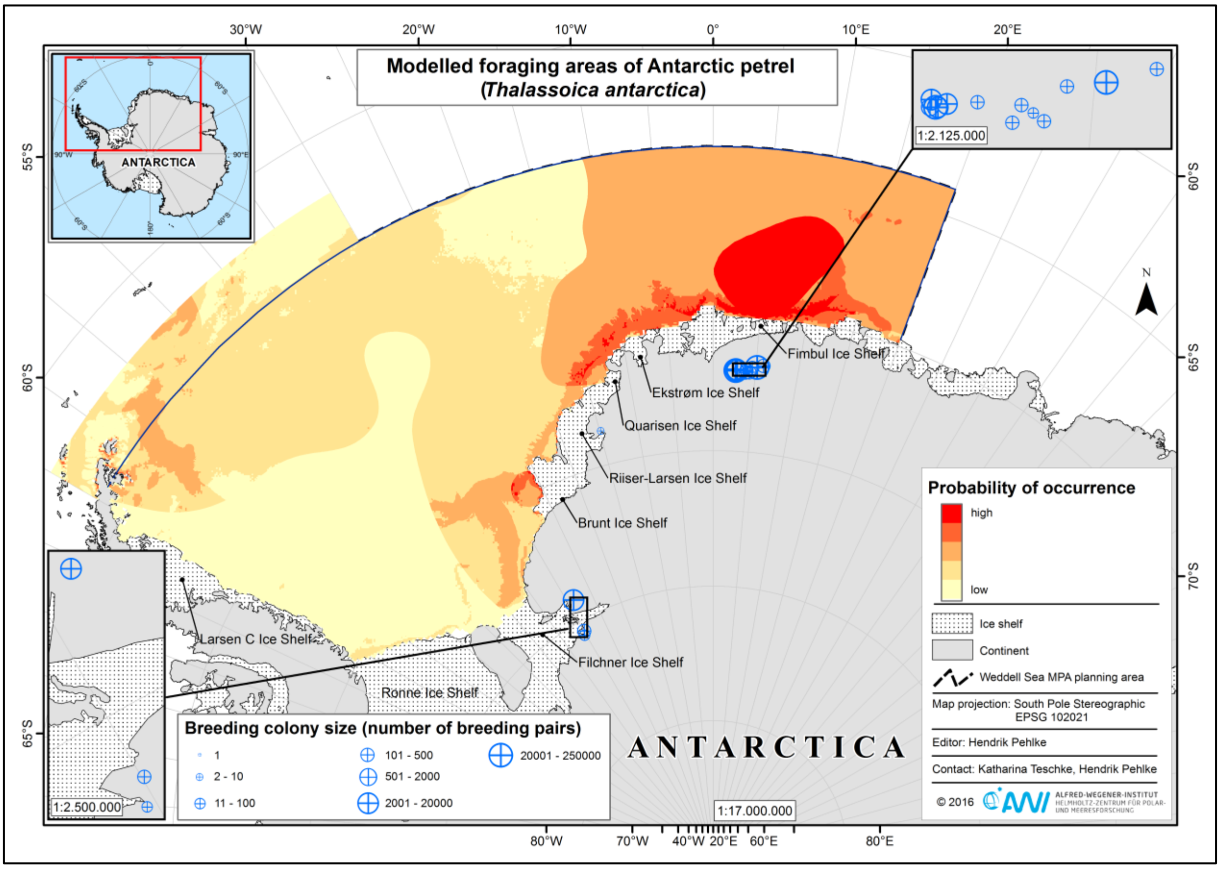

Figure 2-4 Spatial prediction map of Antarctic petrels (*Thalassoica antarctica*) in the WSMPA Planning Area. The map based on a combination of the model developed by Descamps et al. (2016) and the German model that is described in detail in the background paper SC-CAMLR-XXXV/BG/13. Probability of occurrence is colour-coded with yellow colours indicating unsuitable to less suitable habitat and red colours indicating more suitable habitat conditions. Breeding locations and estimated number of breeding pairs based on van Franeker et al. (1999). Black dashed box: WSMPA Planning Area; boundaries of the WSMPA Planning Area do not resemble the boundaries of any proposed WSMPA.

2.3. Progress towards an updated *Dissostichus mawsoni* habitat model

2.3.1. Background

During its meeting in 2016, the WG on Ecosystem Monitoring and Management (WG-EMM-16) identified several discussion points regarding the development of the Weddell Sea MPA (WSMPA) proposal (WG-EMM-16 report, Annex 6, § 3.2). One of the key questions surrounded the spatial distribution and bathymetric range used to define the bounds of the toothfish habitat and the toothfish fishing cost layer used as input into the Marxan models.

The WSMPA project team presented its initial approach in WG-EMM-16/03, whereby the circum-Antarctic habitat suitability model for *Dissostichus mawsoni* developed by CCAMLR (WG-FSA-15/64) was used to predict the *D. mawsoni* habitat in the Weddell Sea. Habitat suitability for toothfish in smaller-scale areas was inferred from water depth and added to the model estimates to achieve spatial consistency. This added up to the depth range of 400 - 3100 m as a proxy for a toothfish potential habitat layer and was used in subsequent Marxan analyses (see WG-EMM-16/03).

WG-EMM-16 discussed this initial approach, i.e. the contiguous unweighted data layer as the potential toothfish habitat, and recommended exploring whether weighting the toothfish habitat and cost layer by depth using catch per unit effort (CPUE) from Subarea 48.6 or the Ross Sea may provide refined habitat availability predictions (WG-EMM-16 report, Annex 6, § 3.6). Under the assumption that stocks are subject to a "low impact" fishery only, such as research fisheries within CCAMLR (CCAMLR Convention, Art. II. 3) CPUE approximates abundance and abundance approximates habitat suitability. Therefore, CPUE data and the relationship between CPUE and depth, respectively, may be used to predict habitat suitability.

Following the recommendations of WG-EMM, we circulated the results of these analyses in the CCAMLR e-group "Weddell Sea MPA" in August 2016 and presented the new *D. mawsoni* habitat model based on CPUE and depth data from the Weddell Sea (Statistical Subarea 48.6). The model fits the CPUE data from Subarea 48.6 reasonably well. However, data become more scattered with increasing depth and goodness of fit decreases accordingly. Feedback from the e-group suggested adding CPUE data from the Ross Sea region to increase sample size for regions where the Weddell Sea data are noisiest, such as at lower depths, and thus reduce depth dependent uncertainty. Here, we present the outcomes of the analyses and the updated habitat suitability model for *D. mawsoni* in the Weddell Sea which contributed to developing:

(i) A Marxan data layer to reflect Specific Objective S5 of the draft WSMPA, i.e. the protection of D. mawsoni, and

(ii) A more accurate toothfish fishing cost layer to reflect suitable areas for the longline fishery.

2.3.2. Data & Methods

Data

Data was extracted from the CCAMLR database on 3 August 2016. All long-line sets for *D. mawsoni* in Subarea 48.6 in the entire time range (i.e. in all seasons between 2005 and 2016) were used to determine catch per unit effort (CPUE) by depth (see Figure 2-5A). Most data were collected from January to March (≥ 300 catches per month). The mostly used fishing gear type was trotlines, while Spanish lines and autoliners were deployed only in 20 % of all catches.

Additionally, we analysed depth and CPUE of all long-line sets for *D. mawsoni* in Subarea 88.1 (Ross Sea) from 1998-2016 (see Figure 2-5B). Most catches were performed in the austral summer months (December to March), but there are also catches in the data set which were sampled from April to July. As gear type mostly autoliners were deployed (almost three-fourths of all catches); however, Spanish lines, trotlines and a few vertical droplines were used, too. Data was extracted from the CCAMLR database on 27 September 2016.

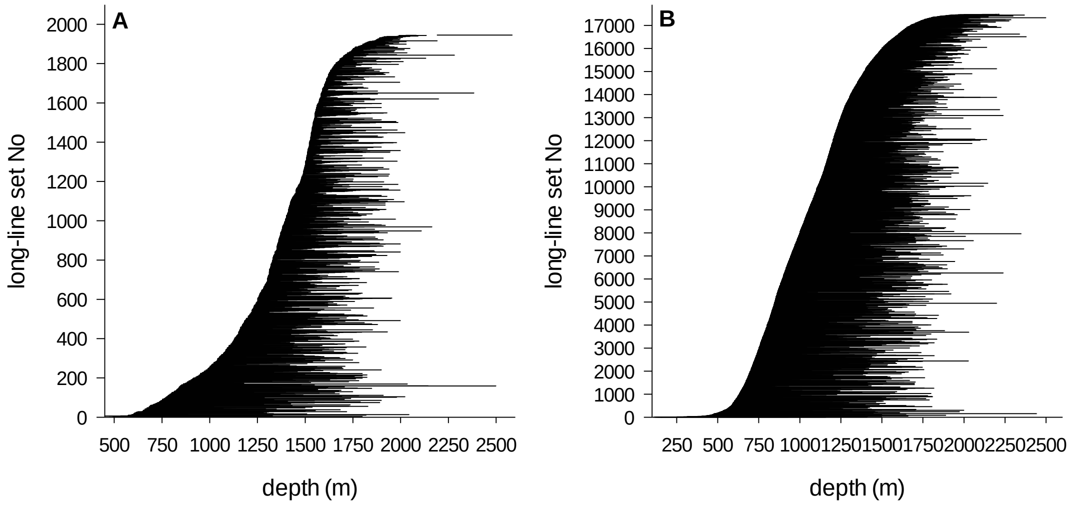

Figure 2-5 Depth frequency diagram of the Antarctic toothfish (*Dissostichus mawsoni*) CPUE data (N = 1944) in Statistical Subarea 48.6 (**A**) and CPUE data (N = 17485) in Statistical Subarea 88.1 (**B**). Each long-line set is represented by a horizontal line covering the depth range between the start and the end depth of this long-line set.

Analyses

CPUE depth distribution models

The output from the CPUE depth distribution models were used to develop a new toothfish fishing cost layer to reflect potential areas for toothfish fishing, and to develop a toothfish habitat layer that addresses the WSMPA Specific Objective S5, i.e. the protection of *D. mawsoni* (SC-CAMLR-XXXV/BG/13 and CCAMLR-XXXV/18).

It is important to note that we used a slightly different approach here as for the previous *D. mawsoni* habitat model (SC-CAMLR-XXXV/BG/13). The previous approach had a relatively low level of data pre-processing, and a Gaussian peak model was fitted to the data. This model fitted the CPUE data from Subarea 48.6 reasonably well. However, data become more scattered with increasing depth and goodness of fit decreases accordingly. Feedback from the e-group suggested adding CPUE data from the Ross Sea region to increase sample size for depth zones where the Weddell Sea data are noisiest (e.g. at lower depths).

Instead of pooling the two CPUE datasets from Subarea 48.6 and 88.1 directly, we first performed the analytical steps for each Subarea data separately, i.e. once for CPUE data in Statistical Subarea 48.6 and once for the CPUE data in Statistical Subarea 88.1. This was done to avoid potential confounding of spatial variation with variation in fishing-related parameters (e.g. different gear types) among the two Subareas. Nevertheless, we aimed at reducing the variance particularly with increasing depth. Thus, we performed two additional steps of data pre-processing: a Monte Carlo resampling which allows for an equivalent sampling effort at all depths, and an outlier analysis.

We performed the following analytical steps once for CPUE data in 48.6 and once for CPUE data in 88.1:

(i) We calculated the standard descriptive parameters of CPUE (kg/1000 hooks) per depth interval i ($mCPUE_i$) with a depth interval width of 100 m (depth interval mean depth: $0 \text{ m} \leq D_i \leq 2600 \text{ m}$, $D_{i+1} - D_i = 50 \text{ m}$); for example, if D_1 is 100 m, D_2 is 150 m, etc., so CPUE at 80 m was counted in two depth bands. Depth intervals with fewer five CPUE data points were not included.

(ii) A Monte Carlo (MC) sample was built for each depth interval i (n = 10,000) by randomly drawn samples from a log-normal distribution with the same mean and standard deviation as the CPUE data in each depth interval.

(iii) Outliers were defined as data points below $Q_1 - 3.0 \times IQR$ or above $Q_3 + 3.0 \times IQR$ per depth interval i where Q_1 and Q_3 are the 25% and 75% quartiles, respectively, and IQR is the interquartile range, i.e. the difference between Q_1 and Q_3. Thus, only extreme data points, that are “far out” (Tukey 1977), were excluded from the subsequent model fit.

(iv) We fitted a 4 parameter Weibull model to the simulated median $mCPUE_i$ per depth interval i,

$$mCPUE_i = if(D_i \leq x0 - b \times ((\mathrm{c}-1)/\mathrm{c})\hat{}(1/\mathrm{c}), 0,\ \mathrm{a} * ((\mathrm{c}-1)/\mathrm{c})\hat{}((1-\mathrm{c})/\mathrm{c}) * (\mathrm{abs}((D_i - \mathrm{x0})/\mathrm{b} + ((\mathrm{c}-1)/\mathrm{c})\hat{}(1/\mathrm{c})\ )\hat{}(\mathrm{c}-1)\ ) * \ \exp(-\mathrm{abs}((D_i - \mathrm{x0})/\mathrm{b} + ((\mathrm{c}-1)/\mathrm{c})\hat{}(1/\mathrm{c}))\hat{}\mathrm{c} + (\mathrm{c}-1)/\mathrm{c})) \quad \textbf{(1)}$$

The model selection based on the R package *fitdistrplus* (Delignette-Muller et al. 2014). This package provides various functions to compare the fit of several distributions to a same data set.

Cumulative distribution plots

The cumulative plot of the probability density function (see equation (3)) was used in the draft CM of the WSMPA (see CCAMLR-XXXV/18) to characterise the lower depth range of the Fisheries Research Zone (FRZ), while 550 m - according to CCAMLR CM 22-08 - was set as the upper depth range.

Here, the sole purpose of the updated model is to get a first insight into the distribution pattern of the Antarctic toothfish population in Statistical Subarea 48.6. The final structure of the FRZ with its borders will be specified in accordance with the development of a high level ***fisheries research strategy*** for the Weddell Sea region (see more details in chapter 4 of this working group paper).

We approximated the corresponding probability density function for the depth range 0 m to the depth where CPUE equals CPUE at 0 m. We calculated $mCPUE_i$ values by using equation **(1)** for increasing depth D_i in 1 m incremental steps from $j = 0$ to $j =$ depth where CPUE equals CPUE at 0 m, and divided each value by the area under the curve A (trapezoidal rule)

$$\int_i^j A \approx (CPUE_i + CPUE_j) / 2 \times (D_i - D_j) \quad \textbf{(2)}$$

to obtain a probability value $P_{CPUEj} = \frac{mCPUE_i}{A}$. **(3)**

Marxan data layers

The toothfish habitat layer (see Fig. 2-6) and the toothfish fishing cost layer (see Fig. 3-1) for the Marxan analyses were developed as follows:

a) The CPUE depth distribution model (see above equation **(1)**) was applied to the bathymetric data from IBCSO (Arndt et al. 2013), i.e. median water depth and modelled CPUE data were calculated for 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, and was chosen as standard grid cell size for our analyses;

b) The modelled CPUE data were scaled between 0 to 100 %;

c) The modelled CPUE data were grouped into four classes representing the probability of *D. mawsoni* occurrence, and the arithmetic mean of each group was computed (see Tab. 2-3); a weighting factor for each class was computed by the exponential function:

   Weighting factor = EXP(0.05*x)-(EXP(0.05*a))+1

   where x is the mean of the corresponding class and a is the mean of class 1;

d) For each class, the sum of area (km²) in the WSMPA Planning Area was calculated and was multiplied by the corresponding weighting factor;

e) Finally, the cost layer was bounded from 550 to 2 000 m according to CCAMLR CMs and fishing practise as recommended by the EMM Working Group 2016 (WG-EMM-16 report, paragraph 3.6).

Table 2-3 Calculated mean and corresponding weighting factor for the four classes representing the probability of occurrence for *Dissostichus mawsoni*.

Class	Probability of occurrence (%)	Mean	Weighting factor
1	0 - 15	8	1
2	15 - 30	23	3
3	30 - 45	38	6
4	45 - 100	73	38

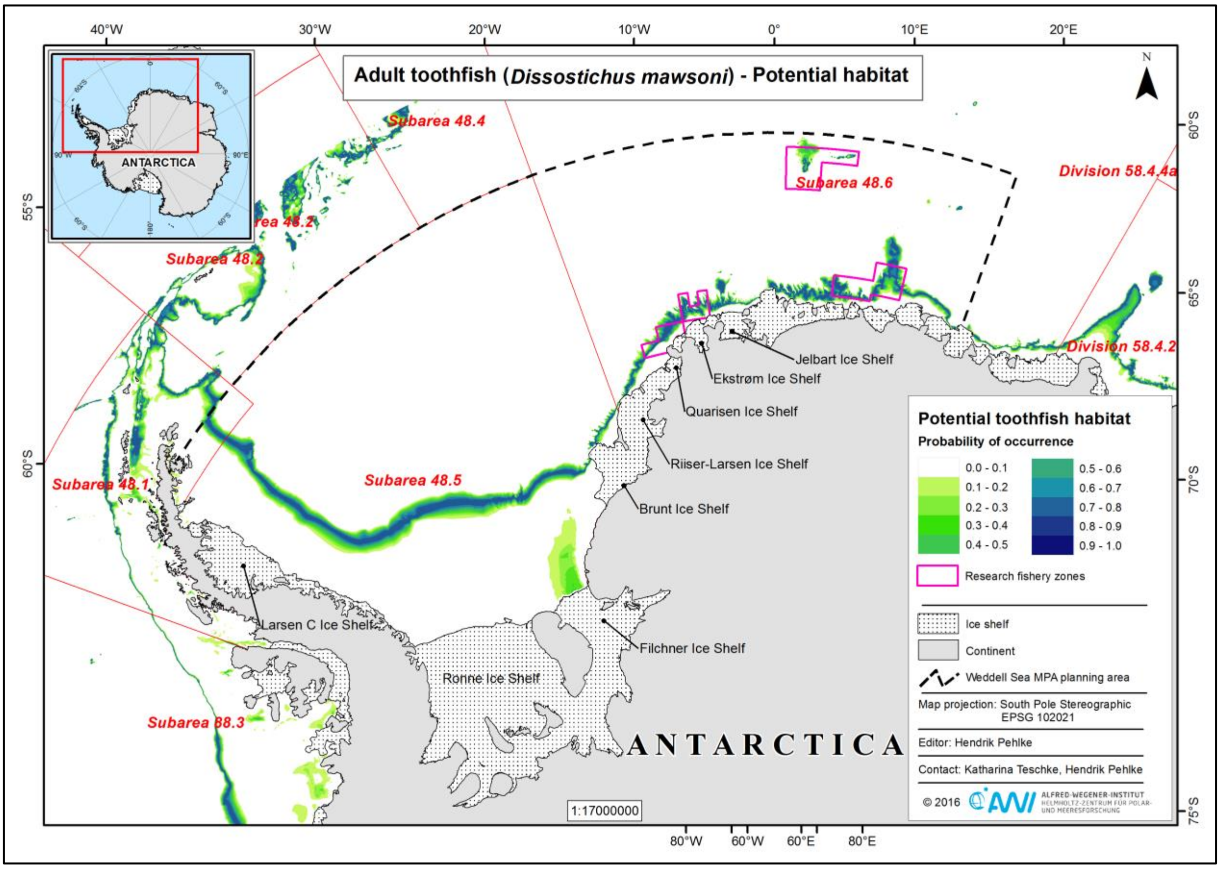

Figure 2-6 Potential habitat of adult Antarctic toothfish (*Dissostichus mawsoni*). Probability of occurrence is colour-coded with green and yellow colours indicating less suitable to unsuitable habitat and blue colours indicating more suitable habitat conditions. The habitat suitability is derived from catch per unit effort (CPUE) data of all long-line sets for *D. mawsoni* in Subarea 48.6 from the entire time range (data extraction from CCAMLR database: 3 Aug 2016). Black dashed box: WSMPA Planning Area.

2.3.3. Results

CPUE depth distribution models

The 4 parameter Weibull model (see above equation **(1)**) fits best to the simulated median $mCPUE_i$ for both Statistical Subareas.

The best-fitting Weibull $mCPUE_i$ model for Statistical Subarea 48.6 (N = 34, R^2 = 0.948) (Fig. 2-7A) has a coefficient (and standard error) of peak amplitude *a* = 148.53 (3.57), peak position *x0* = 1776.04 (13.84), parameter *b* = 93688734.16 (3018026340.05) and parameter *c* = 224265.61 (7222143.81).

For Statistical Subarea 88.1, the best-fitting Weibull $mCPUE_i$ model (N = 41, R^2 = 0.937) (Fig. 2-7B) has a coefficient (and standard error) of peak amplitude a = 249.21 (4.27), peak position x0 = 1227.42 (22.30), parameter b = 1448.34 (43.28) and parameter c = 1.61 (0.05).

Cumulative distribution plots

The cumulative probability density function in Statistical Subarea 48.6 for the depth range 0 to 2529 m, which is the depth where the CPUE value equals the CPUE value at 0 m, shows that approximately 80 % of the Antarctic toothfish population in 48.6 is situated above 2000 m and approximately 90 % above 2100 m (Fig. 2-8A).

For Statistical Subarea 88.1, the cumulative approximated probability density function shows that 80 % of the Antarctic toothfish population is situated above 2300 m, 85 % above 2500 m, and 90 % above 2900 m (Fig. 2-8B). Of note is the difference in median CPUE between the regions, which reaches around 150 kg/1000 hooks at depths between 1500-2000m in Subarea 48.6, and around 250 kg/1000 hooks at depths of 1000-1500m in Subarea 88.1 (Fig. 2-8).

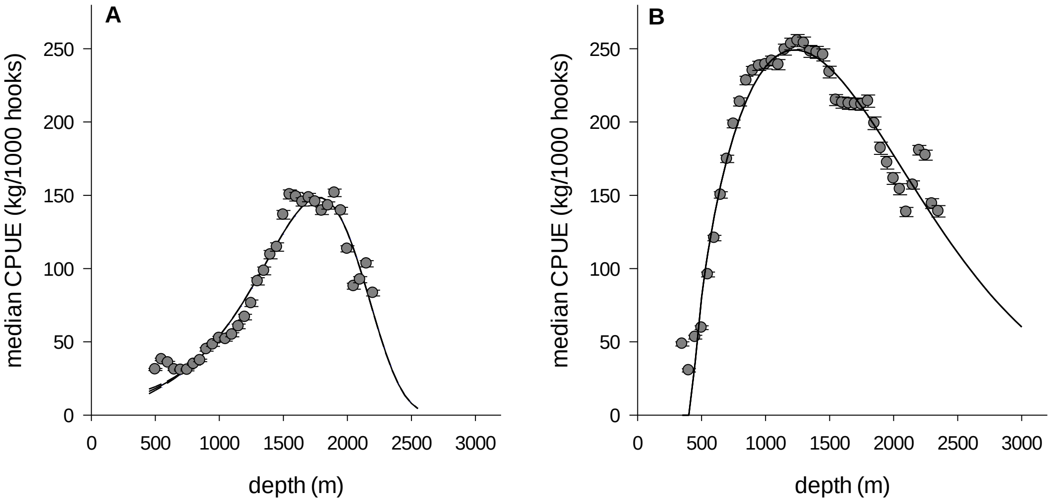

Figure 2-7 Weibull model ± standard error (SE) fits to Weddell Sea (**A**) and Ross Sea (**B**) toothfish simulated median CPUE in kg/1000 hooks ($mCPUE_i$) per depth interval *i*. Please note that SE of the model is too low for representation in the graphs. Median CPUE is shown with SE.

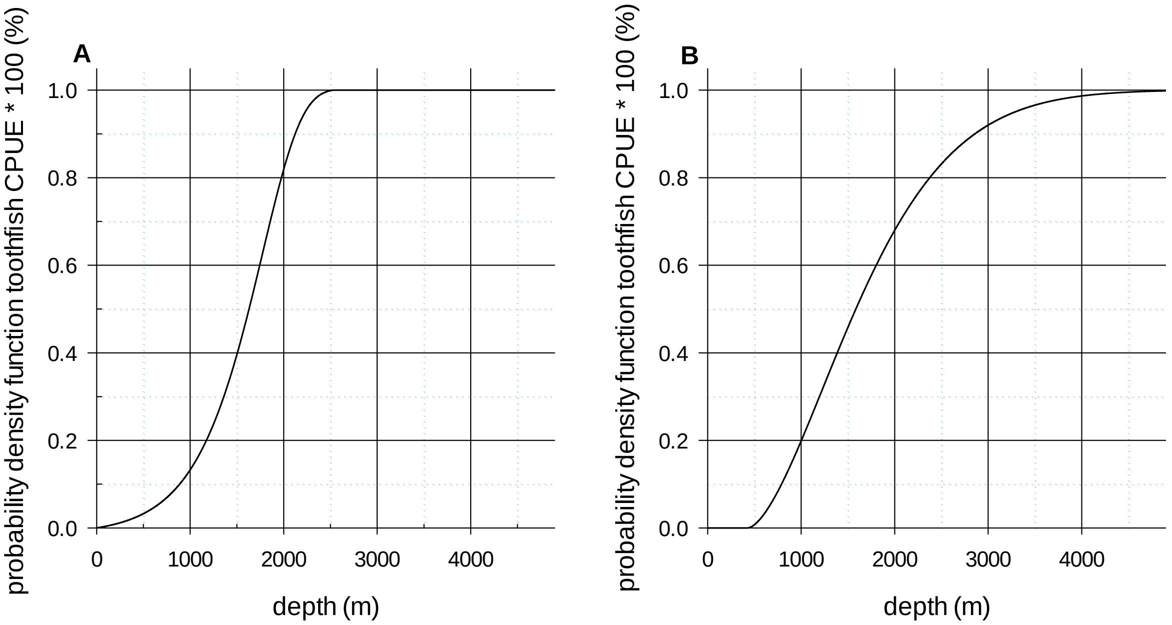

Figure 2-8 Cumulative approximated probability density function of the Weddell Sea (**A**) and Ross Sea (**B**) Antarctic toothfish (*D. mawsoni*) CPUE data.

2.3.4. Discussion

CPUE depth distribution models

The Weibull models fit the toothfish CPUE data from Statistical Subareas 48.6 and 88.1 well. However, the CPUE depth distribution curves for the two Subareas differ from another. The CPUE depth distribution for Subarea 48.6 is slightly skewed to the left, whereas the curve for Subarea 88.1 shows a slightly right skewed distribution. While for Subarea 88.1 the peak of the curve is almost reached already at 1000 m depth, the distribution for 48.6 shows a gentle slope with a peak of the curve at 1800 m depth. Moreover, the distribution for 48.6 shows a relatively steep decline from 2000 m to 2500 m compared to the right tail of the curve for Subarea 88.1. It is important to note, however, that for depths beyond 2200 m the models have increasing statistical uncertainty associated, due to lack of data and reliance on extrapolation at these depths.

The cumulative probability density functions for the two regions differ from another. The cumulative density curve for Subarea 48.6 shows a steeper slope than the density function for Subarea 88.1, which means that 90 % of the Weddell Sea Antarctic toothfish population is situated above 2100 m, while 90 % of the population from Subarea 88.1 is situated above 2900 m.

The different characteristics of both curves may be caused by the fact that fish are caught at deeper depths in the Ross Sea than in the Weddell Sea. To which extent these differences in the Subareas are related to different fishing-related parameters (e.g. safe fishing locations, fishing experience, different gear types, fishery types, vessel-specific parameters) and / or to variable environmental conditions (e.g. variable topography) is not clear at this point. However, as these differences were apparent among Subarea 48.6 and 88.1, we concluded that pooling these two datasets was not appropriate and instead analysed data from Subarea 88.1 in the same way as the CPUE data from Subarea 48.6.

Moreover, it is important to note that our data pre-processing (i.e. resampling, taking the median, outlier analysis) could have introduced bias into the fitting of the Weibull function linking CPUE with depth. However, our previous cumulative probability density curve for Subarea 48.6, which is based on a relatively low level of data pre-processing and a Gaussian peak model (see SC-CAMLR-XXXV/BG/13), looks similar to the current density curve presented in this chapter (see Figure 2-9). A shift of an approximately 200 m depth range is shown between both curves, i.e. that 90 % of the toothfish population is situated above 2100 m (current curve) and 2300 m (previous curve), respectively. This may lead to the assumption that the data pre-processing has not a significant effect on our Weibull model. However, it would be worth exploring the raw CPUE at depth without using a resampling and taking the median per depth interval.

The results of these analyses update the Antarctic toothfish habitat model as requested by WG-EMM-16, and contribute to developing a Marxan data layer to reflect Specific Objective S5 of the draft WSMPA, i.e. the protection of *D. mawsoni,* as well as a more accurate toothfish fishing cost layer to reflect suitable areas for the longline fishery. The model further provided a characterisation of the lower depth range of suitable habitat for Antarctic toothfish. Going forward, the question of CPUE standardisation needs to be addressed in the near future, and the approaches taken in the CASAL models developed for Subarea 48.6 (WG-FSA-16/32 Rev. 1) will provide a good starting point. To contribute to the population hypothesis development for *D. mawsoni*, we aim to work towards a multi-parametric habitat model which includes further environmental parameters such as topography and temperature. Here, contributions from other CCAMLR experts would of course be welcome.

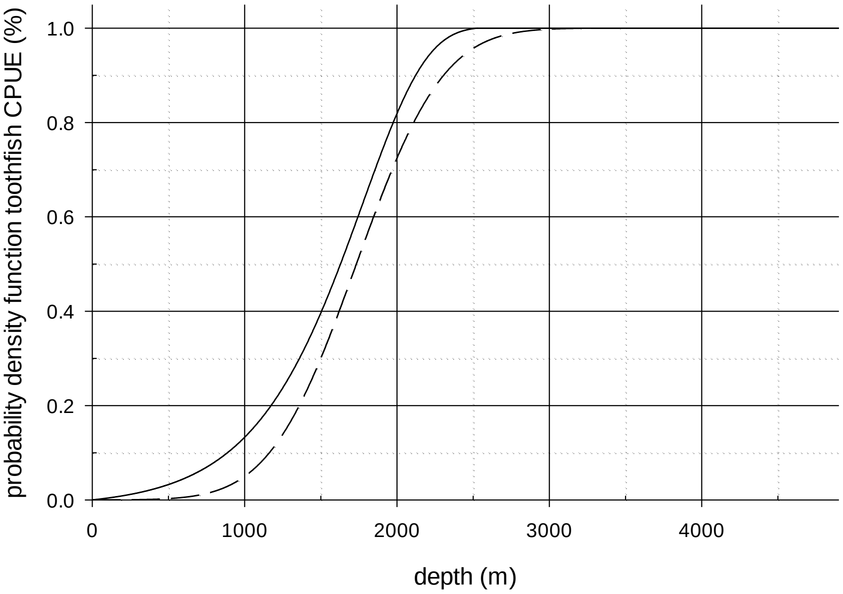

Figure 2-9 Cumulative approximated probability density functions of the Weddell Sea Antarctic toothfish (*D. mawsoni*) CPUE data. The solid line shows the curve based on the current Weibull model; the dashed line describes the function based on the previous Gaussian model.

Acknowledgements

The authors thank Marta Soeffker, Timothy Earl and Chris Darby (Centre for Environment, Fisheries & Aquaculture Science, UK), as well as Bob Zuur (New Zealand) for advice and comment on the *D. mawsoni* habitat model.

3. Marxan analyses

Firstly, we present the revised cost layer analysis, and inform on our analysis of the Marxan sensitivity to the protection level for toothfish and demersal fish. In this context, we show how the cost layer works. Subsequently, we present a revised Marxan approach based on the updated data layers.

3.1. Cost layer analysis

We use a summary cost layer for our Marxan approach that consists of three separate layers as recommended by the EMM Working Group 2015 (see SC-CAMLR-XXXIV report, Annex 6). We developed *(i)* an accessibility cost layer indicating areas accessible for fishery vessels, *(ii)* a toothfish fishing cost layer indicating areas suitable for *D. mawsoni* fishing and *(iii)* a krill fishing cost layer presenting areas suitable for Antarctic krill fishing.

We adopted the development of the three separate cost layers and the summary of the three separate layers into one cost layer as it stands (see SC-CAMLR-XXXV/BG/13; pp. 55-59). However, the toothfish fishing cost layer (Fig. 3-1), and consequently the summary cost layer (Fig. 3-2) have slightly changed as this fishing cost layer is based on our revised toothfish habitat model (see chapter 2). Finally, the toothfish fishing cost layer was limited to the depth 550 - 2 000 m according to CCAMLR CMs and fishing practise as recommended by the EMM Working Group 2016 (WG-EMM-16 report, paragraph 3.6).

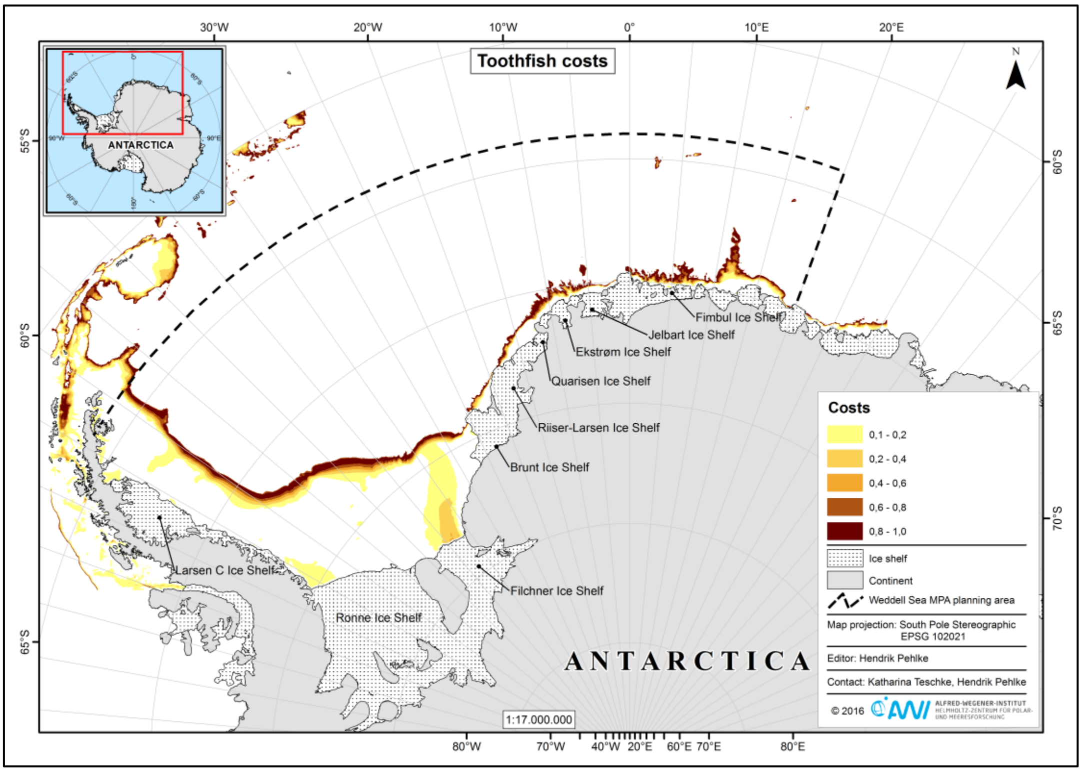

Figure 3-1 Antarctic toothfish (*Dissostichus mawsoni*) fishing cost layer weighted by depth using the CPUE-based toothfish habitat model and bounded from 550 to 2 000 m according to CCAMLR CMs and fishing practise. Costs are colour-coded with brown colours indicating areas potentially suitable for fishing and yellow colours indicating less interesting areas for fishing. Black dashed box: WSMPA Planning Area.

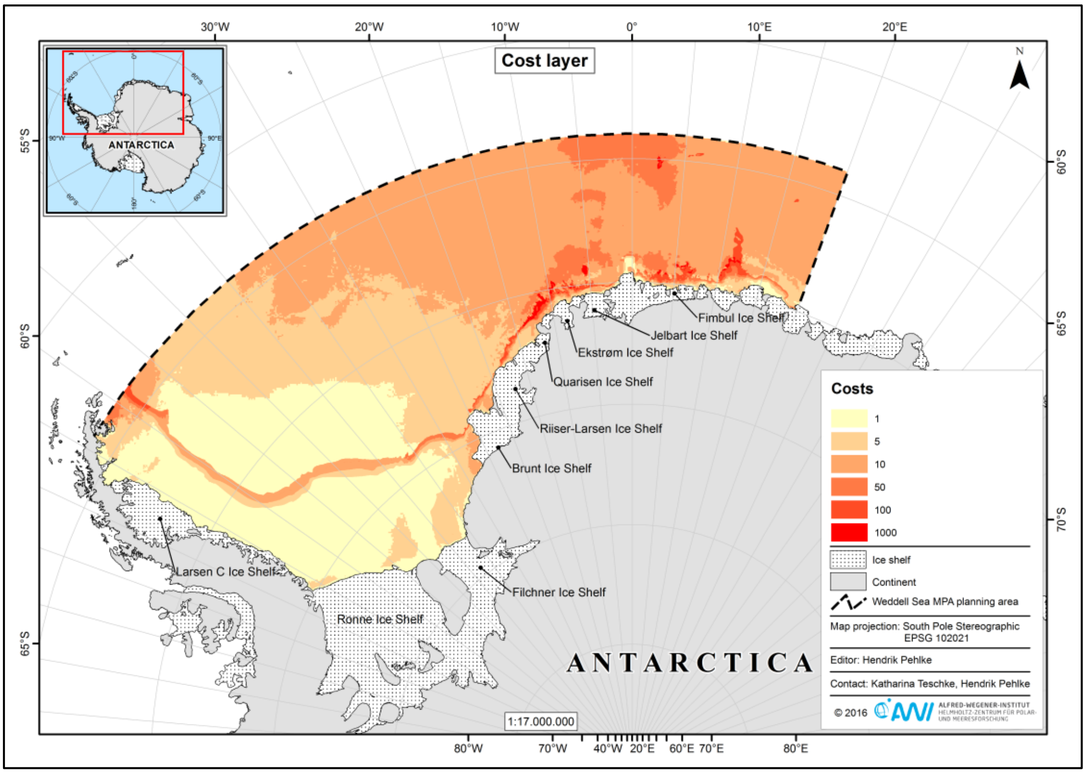

Figure 3-2 Summary cost layer. Areas in red are relatively easy to access and represent suitable Antarctic toothfish and Antarctic krill fishing areas. Black dashed box: WSMPA Planning Area.

3.2. Marxan sensitivity analysis

3.2.1. Background

WG-EMM-16 identified several discussion points regarding the development of the Weddell Sea MPA (WSMPA) proposal (WG-EMM-16 report, Annex 6, § 3.2). One of the key questions surrounded the target levels of protection for Antarctic toothfish and demersal fish (both target levels were currently set at 75%).

The Working Group recommended a two-factor sensitivity analysis of the level of protection for Antarctic toothfish and other demersal fish to explore a range of protection-level scenarios. WG-EMM-16 suggested the exploration of a range of protection levels from 20% to 80% in 20% increments and 65% to 85% in 10% increments to assess the sensitivity of the Marxan analyses to the level of protection for Antarctic toothfish and demersal fish, respectively.

To evaluate the significance of protection-level scenarios regarding *D. mawsoni* and demersal fish, we try to answer two questions:

(i) Does the cost layer affect the MARXAN analysis at all?

(ii) To what extent is protection level variability reflected in the MARXAN results?

3.2.2. Methods

For the Marxan sensitivity analysis we used the same input file preparation and basic settings as for our recursive Marxan approach presented at the last years Scientific Committee meeting (see SC-CAMLR-XXXV/BG/13; pp. 59-60).

In total 36 Marxan scenarios were defined to explore a range of protection-level scenarios regarding *D. mawsoni* and demersal fish (see Tab. 3-1A, B). We used the range of protection levels suggested by WG-EMM-16, except of the protection level of 80% for *D. mawsoni*, as this target level would a priori exclude research fishing in the WSMPA Planning Area. The target levels for the other conservation features remained unchanged throughout the different scenarios (see Annex 2, Tab. A2-1). For the scenarios, a single restart of 250 runs was used to produce summed solution scores ranging between 0-250. Recursions were unnecessary since the sole purpose of analysing these scenarios was to compare solution similarity and to clarify in this context how the cost layer drives the Marxan output, rather than to identify important areas for protection. The species penalty factor (spf) of each conservation feature was defined as the tenfold of the corresponding target level. The status of all planning unit grid cells was set to 1.

To identify cost layer effects, we run 18 scenarios with the conservation features with *D. mawsoni* and demersal fish only, i.e. excluding the remaining 73 features (see Annex 1, Table A1-1). To analyse the effects of protection level variability, we run 18 scenarios with all conservation features (Table 3-1B).

Table 3-1A Overview of the two-factor Marxan scenarios (S_2) analysed exclusively with *Dissostichus mawsoni* and demersal fish. Codes in cells indicate scenario ID.

Target level *D. mawsoni* Target level demersal fish	**20%**		**40 %**		**60%**	
Cost layer included	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
65%	S_2-20-65-C	S_2-20-65-0	S_2-40-65-C	S_2-40-65-0	S_2-60-65-C	S_2-60-65-0
75%	S_2-20-75-C	S_2-20-75-0	S_2-40-75-C	S_2-40-75-0	S_2-60-75-C	S_2-60-75-0
85%	S_2-20-85-C	S_2-20-85-0	S_2-40-85-C	S_2-40-85-0	S_2-60-85-C	S_2-60-85-0

Table 3-1B Overview of the multi-factor Marxan scenarios (S_{all}) analysed with *Dissostichus mawsoni* and demersal fish as well as all other conservation features (see Tab. A1-1 in Annex1).

Target level *D. mawsoni* Target level demersal fish	**20%**		**40 %**		**60%**	
Cost layer included	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
65%	S_{all}-20-65-C	S_{all}-20-65-0	S_{all}-40-65-C	S_{all}-40-65-0	S_{all}-60-65-C	S_{all}-60-65-0
75%	S_{all}-20-75-C	S_{all}-20-75-0	S_{all}-40-75-C	S_{all}-40-75-0	S_{all}-60-75-C	S_{all}-60-75-0
85%	S_{all}-20-85-C	S_{all}-20-85-0	S_{all}-40-85-C	S_{all}-40-85-0	S_{all}-60-85-C	S_{all}-60-85-0

3.2.3. Results & Discussion

The two-factor Marxan scenarios (S2) - analysed exclusively with *Dissostichus mawsoni* and demersal fish - were run to test if our cost layer affects the Marxan analysis at all. Furthermore, the multi-factor scenarios were particularly analysed to evaluate to what extent the protection level variability is reflected in the MARXAN results. We do not calculate the target achievement of the conservation features per scenario as the sole purpose of analysing these scenarios was to compare solution similarity and to clarify in this context how the cost layer drives the Marxan output, rather than to identify important areas for protection.

Figure 3-3 shows for each two-factor (S_2) Marxan scenarios the total number of planning unit grid cells that were selected in >= 90 % of all runs in only one scenario of each pair, i.e. without *vs.* with cost layer. This number indicates to what extent the cost layer alters the Marxan result. In each S_2 scenario the cost layer produces a difference. This difference varies almost 4-fold with target level combinations regarding the S_2 scenarios. Smallest difference occurs between S_2-60-75-C (Figure A1-1) and S_2-60-75-0 (Figure A1-2), while scenario S_2-60-65 (Figure A1-3, A1-4) shows largest difference.

Even more clearly, differences occur between each pair of multi-factor scenario (e.g. S_{all}-20-65-0 *vs.* S_{all}-20-65-C) where *D. mawsoni* and demersal fish as well as all other conservation features were included in the analysis (see Fig. 3-3). Compared to the S2 scenarios the S_{all} scenarios show a relatively consistent pattern in the relationship between target level combinations and cost layer effects with small difference among the target level combinations. This similarity among scenarios indicates that other conservation features superimpose the impact of *D. mawsoni* and demersal fish features.

A closer look on multi-factor scenarios with an active cost layer, such as S_{all}-60-65-C (Fig. A1-7), S_{all}-60-75-C (Fig. A1-11), S_{all}-60-85-C (Fig. A1-15), shows that areas with highest cost values within Fisheries Research Block II (Astrid Ridge; 48.6_4) and III (Maud Rise; 48.6_3) were not identified by >= 90% selection frequency. In their corresponding scenarios (Fig. A1-8, -12, -16) with an inactive cost layer, however, those areas were identified as areas with “MPA importance” (>= 90% selection frequency). Within Fisheries Research Block I, however, the cost layer is not effective in leaving out areas with high cost values. This indicates that important or unique conservation features (e.g. Norsel Bank, nesting site, demersal fish) with high target levels occur in Fisheries Research Block I which cannot be compensate by the identification of other areas in the Weddell Sea Planning Area.

If you consider Figure 3-4, which shows the total number of planning unit grid cell (>= 90% selection frequency) for all multi-factor scenarios with an activated cost layer, two groups of target level combinations with relatively similar values occur: (1) S_{all}-20-85-C, S_{all}-40-85-C and S_{all}-60-85-C and (2) all other scenarios. This grouping becomes also apparent in the spatial distribution of areas which were identified by >= 90 % selection frequency. S_{all}-20-85-C (Fig. A1-13), S_{all}-40-85-C (Fig. A1-14) and S_{all}-60-85-C (Fig. A1-16) shows a rather similar picture to each other regarding the area most frequently identified by Marxan, and are relatively dissimilar to all the other scenarios (see Figure A1-5 to A1-7, A1-9 to A1-11).

Subsequently, for our revised Marxan recursive approach we chose 60 % target level for *D. mawsoni* and 75 % target level for demersal fish. This target level combination was derived from the sensitivity analysis and represents the breakpoint between the two groups of scenarios described above (see Figure 3-4). Independently of the derivation from our sensitivity analysis a target level of 60 % for *D. mawsoni* was defined as medium target level at the 2nd International Workshop on the WSMPA project, too (28-29 April 2015; Berlin, Germany).

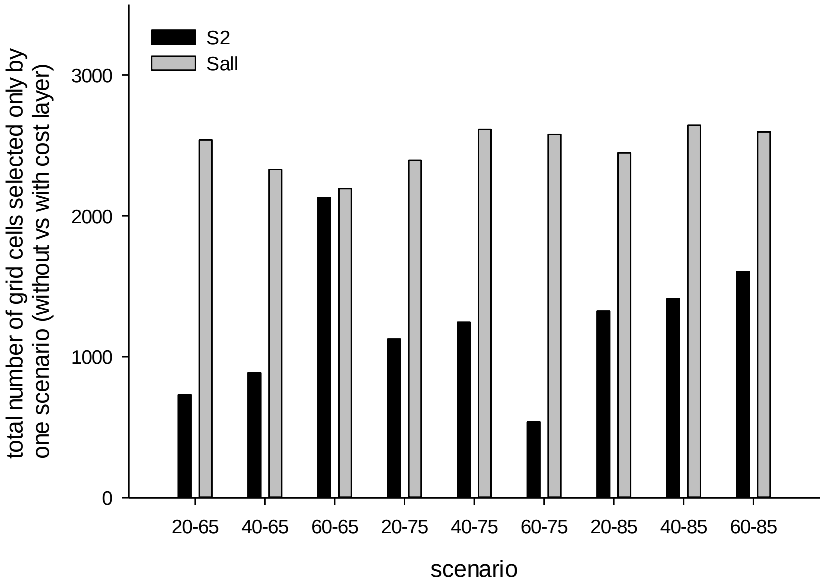

Figure 3-3 Total number of planning unit grid cell that were selected in 90 % of all runs in only one scenario of each pair (without vs. with cost layer, e.g. S_{all}-20-65-0 *vs.* S_{all}-20-65-C) illustrated for each two-factor (S_2) and multi-factor Marxan scenarios (S_{all}).

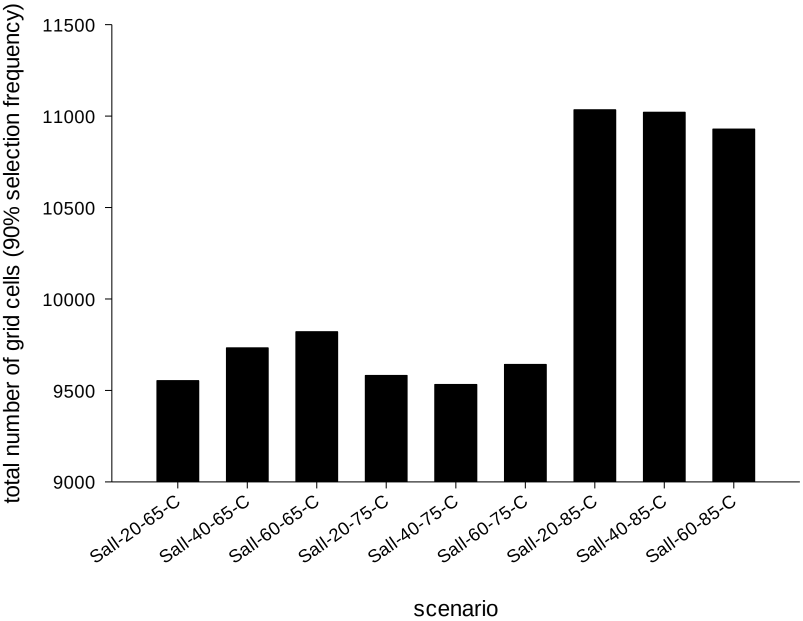

Figure 3-4 Total number of planning unit grid cell that were selected in 90 % of all runs illustrated for each multi-factor Marxan scenarios (S_{all}) where all conservation features and a cost layer were included in the analysis.

3.3. Revised Marxan analysis (recursive approach)

Table A2-1 in Annex 2 details the target levels applied to the conservation features relating to the specific conservation objectives for the WSMPA. The formulation of the conservation objectives, the basis for the definition of the target levels as well as the development of the conservation feature data layers are described in SC-CAMLR-XXXV/BG/13. Additionally, in Table A1-1 (see Annex 1) the conservation feature data layers are sorted by "ecological" or "environmental" conservation feature.

For our revised Marxan analysis we performed the same preparatory steps and used the same basic setting as described for our previous analysis (SC-CAMLR-XXXV/BG/13; pp. 59-60). Each single recursion of our Marxan approach was performed as follows:

1st Marxan recursion

This first recursion targeted all 18 ecological conservation features with their target levels of protection (see Tab. A1-1 and Tab. A2-1). All 57 environmental conservation features were excluded from the first Marxan recursion by setting the proportion of those conservation features to 0 in the spec file. The species penalty factor (spf) of each ecological conservation features was defined by the tenfold of the corresponding target levels. The spf is a scaling factor used to increase or decrease the penalty applied to missed targets for a feature relative to other features. The status of all planning unit grid cells was set to 1. Status is a parameter telling Marxan whether a planning unit is available for selection (=0), to be used in the initial input solution (=1), locked in to all solutions (=2) or locked out of all solutions (=3).

Subsequent to the first Marxan recursion we defined all planning unit grid cells that were selected in all 250 runs (i.e., 100 % selection frequency threshold) of the first recursion, as the "MPA" of this recursion. All those planning unit grid cells were set to status = 3. At this stage of the analysis we chose status = 3 (instead of status = 2) to avoid effects on solution clustering/clumping and let hotspots become more apparent as each planning unit grid cell has the same chance to be chosen irrespective of the position of the planning units to the initial MPA.

Each conservation feature, whose target level of protection was achieved completely by this "MPA", was excluded from the second Marxan recursion (i.e. targets in "spec.dat" file were set to 0). For all other conservation features we calculated the percentage still missing for meeting the corresponding target level. These re-calculated values were set as the target levels for the second Marxan recursion.

Figure A2-1 (see Annex 2) shows the Marxan result after the 1st recursion. In total seven out of 18 ecological conservation features were achieved completely by the "MPA" of this first recursion.

2nd Marxan recursion

As mentioned above the 2nd recursion targeted all ecological conservation features with their re-calculated target levels. The environmental conservation features were not incorporated yet in the Marxan analysis (i.e. prop`s in spec file were set to 0).

After the 2nd Marxan recursion we selected again all planning unit grid cells with a 100 % selection frequency threshold for inclusion in the "MPA". All those planning unit grid cells were set again to status = 3 for the 3rd recursion.

Each parameter, whose target level was achieved completely by this expanded "MPA" (i.e. after 1st and 2nd recursion), was excluded from the 3rd Marxan recursion (i.e. prop`s in spec file were set to 0). For all other conservation features we calculated the percentage still missing for meeting the corresponding target level.

Figure A2-2 (see Annex 2) shows the Marxan of the 2nd recursion. As no progress was reached at all regarding the target achievement of the remaining ecological conservation features, we additionally incorporated the environmental features in the 3rd Marxan recursion.

3rd Marxan recursion

The 3rd recursion targeted all remaining ecological conservation features with their re-calculated target level, and additionally incorporated the environmental features in the Marxan analysis by setting their prop`s to the corresponding target level in the spec file. The spf of the environmental conservation features was defined by the tenfold of the corresponding target levels.

As before, we selected all planning unit grid cells with a 100 % selection frequency for inclusion in the "MPA" (i.e. set status = 3 for the next recursion) and re-calculated for each conservation feature the area still missing for meeting the target level.

Figure A2-3 (see Annex 2) shows the Marxan result of the 3rd recursion. Two additional ecological conservation features, compared to the first two recursions, was achieved completely by this recursion. Furthermore, 22 environmental features were achieved completely by the "MPA" of this 3rd recursion.

4th Marxan recursion

The 4th recursion targeted all remaining conservation feature with their re-calculated target level.

Here, we selected all planning unit grid cells with a 95 % selection frequency for inclusion in the "MPA" (i.e. set status = 3 for the next recursion) as no planning unit grid cell is selected with a 100 % selection frequency. Subsequently, we re-calculated for each conservation feature the area still missing for meeting the target level.

Figure A2-4 (Annex 2) shows the summed solution of the 4th recursion. One additional ecological conservation features was achieved by this recursion. No progress was reached regarding the target achievement of the remaining environmental conservation features.

5th Marxan recursion

The 5th recursion targeted again all remaining conservation feature with their re-calculated target level.

Please note that after the 5th Marxan recursion we selected all planning unit grid cells that were chosen in 200 out of 250 runs (i.e., 80 % selection frequency) for calculating the target achievement of the remaining parameters.

Figure A2-5 (Annex 2) shows the summed solution of the 5th recursion. Two more ecological conservation features and 14 additional environmental features were achieved by the 5th recursion.

We completed our Marxan recursive approach after the 5th recursion. More than 60 % of all conservation features with their corresponding target level of protection were achieved (Figure 3-5). A systematic overview of how the specific WSMPA conservation objectives and the corresponding conservation features and their targets, respectively, are achieved by the Marxan result after five recursions is given in Table A2-1 in Annex 2.

For the time being we see no need to adjust the borders of the prospective WSMPA with regard to the updated Marxan analysis. On the one hand, it remains to be seen whether the discussion within CCAMLR gives rise to further modifications of the analysis, on the other hand, placing the borders is a task for experts who base their decision on the final Marxan scenario.

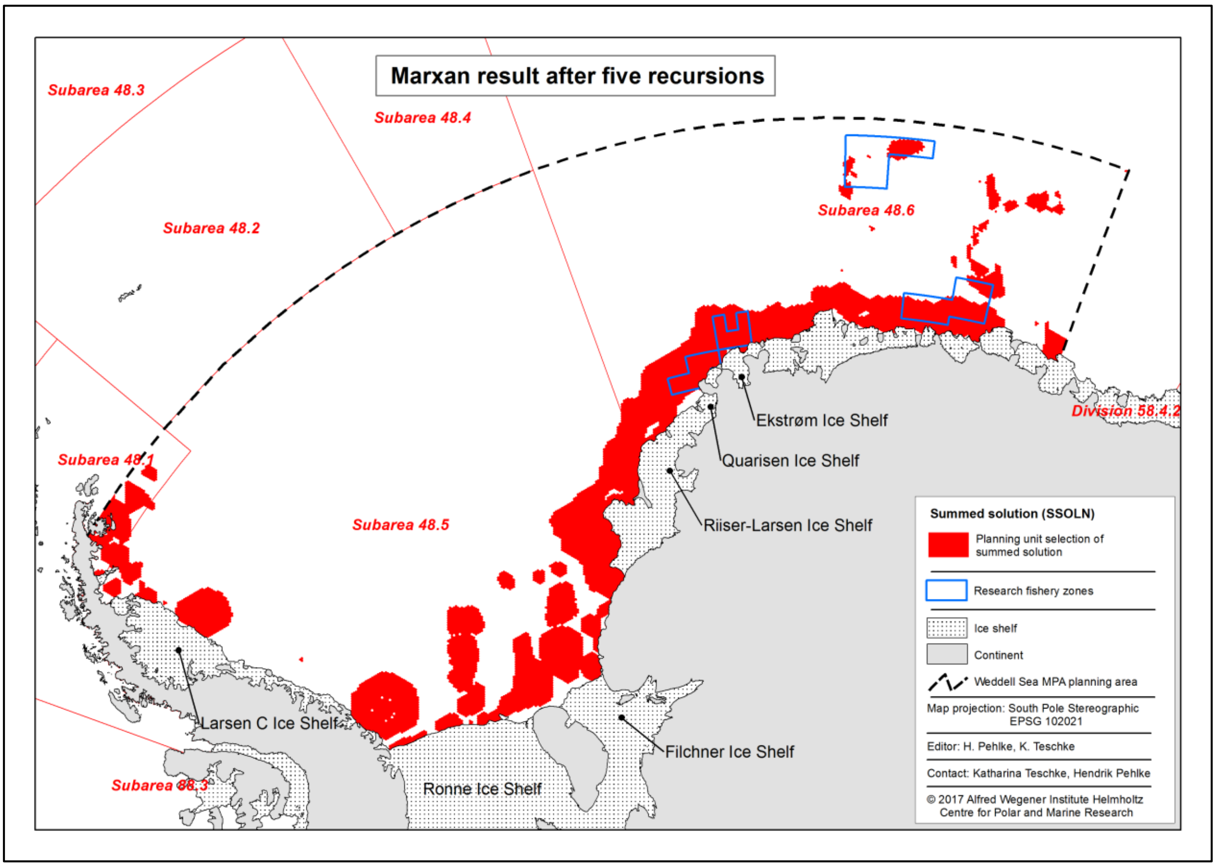

Figure 3-5 Summary summed solution after five Marxan recursions. In total more than 60 % of all conservation features were achieved completely by the selected planning units; selected area is shown in red.

4. WSMPA management zones

The three management zones, proposed in the draft CM of the WSMPA (see CCAMLR-XXXV/18) were developed as follows:

General Protection Zone (GPZ)

The borders of the GPZ are equivalent with the proposed WSMPA borders excluding areas identified as FRZ and SPZ. These borders were developed by the Marxan recursive approach and subsequently modified by experts (see SC-CAMLR-XXXV/BG/13; 59 pp.). The borders of the GPZ include the areas identified by Marxan with highest MPA importance, i.e. areas which show 80 % -100 % selection frequencies for inclusion in the MPA. The subsequent refinement by experts allows for:

- MPA minimisation, and concurrently achievement of all conservation features and their target levels of protection, and
- A consistent area with borders those are easy to recognize and to navigate.

Fishery Research Zone (FRZ)

The borders of the FRZ presented in the draft CM of the WSMPA (see CCAMLR-XXXV/18) were developed as follows:

- The upper depth range of the FRZ was set to 550 m water depth in accordance with CCAMLR CM 22-08, and
- The lower depth range of 2300 m water depth was derived from the Antarctic toothfish habitat model and the cumulative plot of the probability density function, respectively (see SC-CAMLR-XXXV/BG/13; pp. 28-33).
- Thus, the FRZ comprised the area between 550 m and 2300 m water depth in the Statistical Subarea 48.6, which represents approximately 90 % of the toothfish population in this area.

Here, it is important to note that we already revised our modelling approach for the Antarctic toothfish habitat. The updated habitat model is presented in this paper in chapter 2.3. This model indicates that approximately 90 % of the Antarctic toothfish population in Statistical Subarea 48.6 is situated above 2100 m.

Fisheries research strategy

For the near future we seek the development of a high level ***fisheries research strategy*** for the Weddell Sea region, which will include an interim population hypothesis for *D. mawsoni*. Such a hypothesis will help us to better structure and delineate the Fisheries Research Zone (FRZ) as well as the management and the research and monitoring requirements within and outside the FRZ, including the location of research boxes. The development of this fisheries research strategy and an interim population hypothesis for *D. mawsoni* should be a collaborative endeavour of all CCAMLR members. To facilitate cooperation, Germany proposes to convene an international expert workshop in spring 2018. At this expert workshop, the research carried out by CCAMLR members on *D. mawsoni* in the Weddell Sea region should be considered together with Germany`s work on the WSMPA development. Also, the relevant recommendations made by WG-SAM-16 (see e.g. WG-SAM-16 report, Annex 5, §§ 3.23-3.41), such as the need for a profound ice analysis and the deployment of a coordinated satellite tagging program, should be discussed. Additional contributions from other CCAMLR experts would of course also be welcome. This workshop will help develop interim fisheries research priorities presented in a 4th scientific background document to the WSMPA proposal and reflected in the WSMPA Research and Monitoring Plan.

In accordance with these activities, the final structure of the FRZ with its borders will be specified following advice from WG-SAM, WG-EMM and WG-FSA, and the proposed international expert workshop.

Special Protection Zone (SPZ)

The SPZ is developed based on field observations. This zone comprises:

- considerable parts of areas where vulnerable marine ecosystems (i.e. dense sponge communities) have been observed,
- known nesting sites of demersal fish species with a buffer of 10 nautical miles surrounding each site, and
- a rare, unique shallow water (surface to –150 m water depth) sea floor area with habitat heterogeneity and high species richness.

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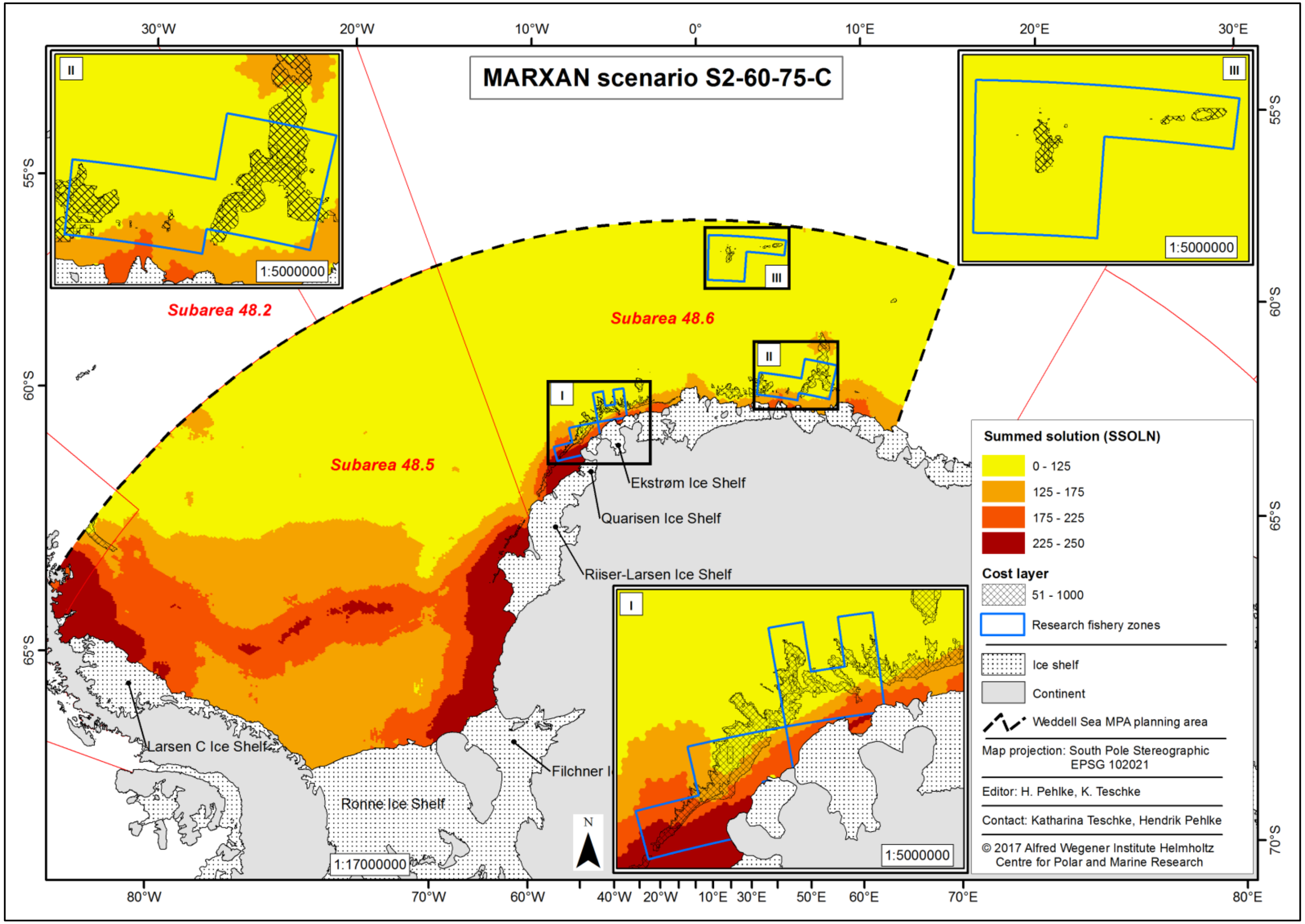

Figure A1-1 Summed solutions for Scenario S_2-60-75-C following a two-factor Marxan scenario analysed exclusively with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 75%). A cost layer was included.

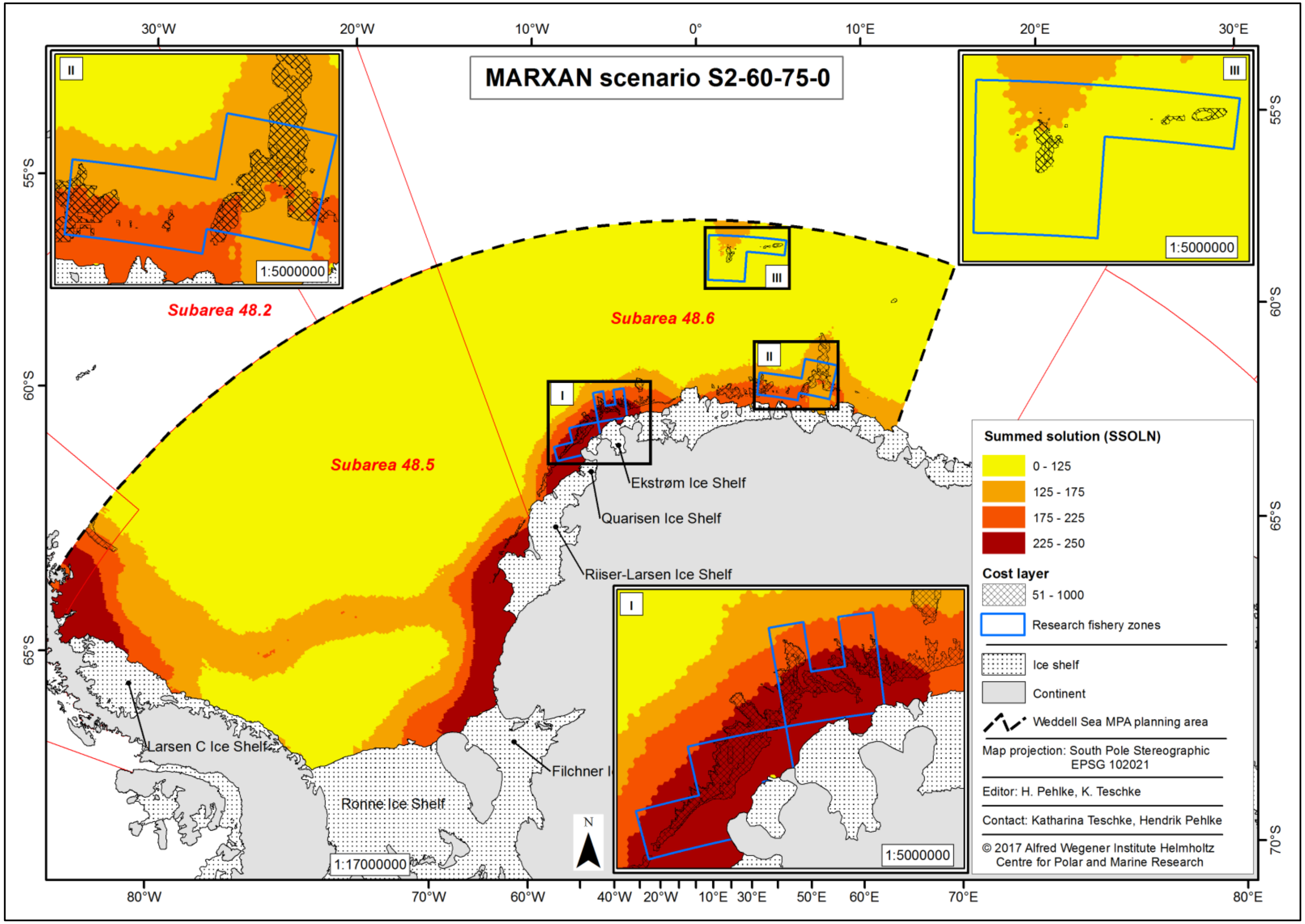

Figure A1-2 Summed solutions for Scenario S_2-60-75-0 following a two-factor Marxan scenario analysed exclusively with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 75%). A cost layer was not included.

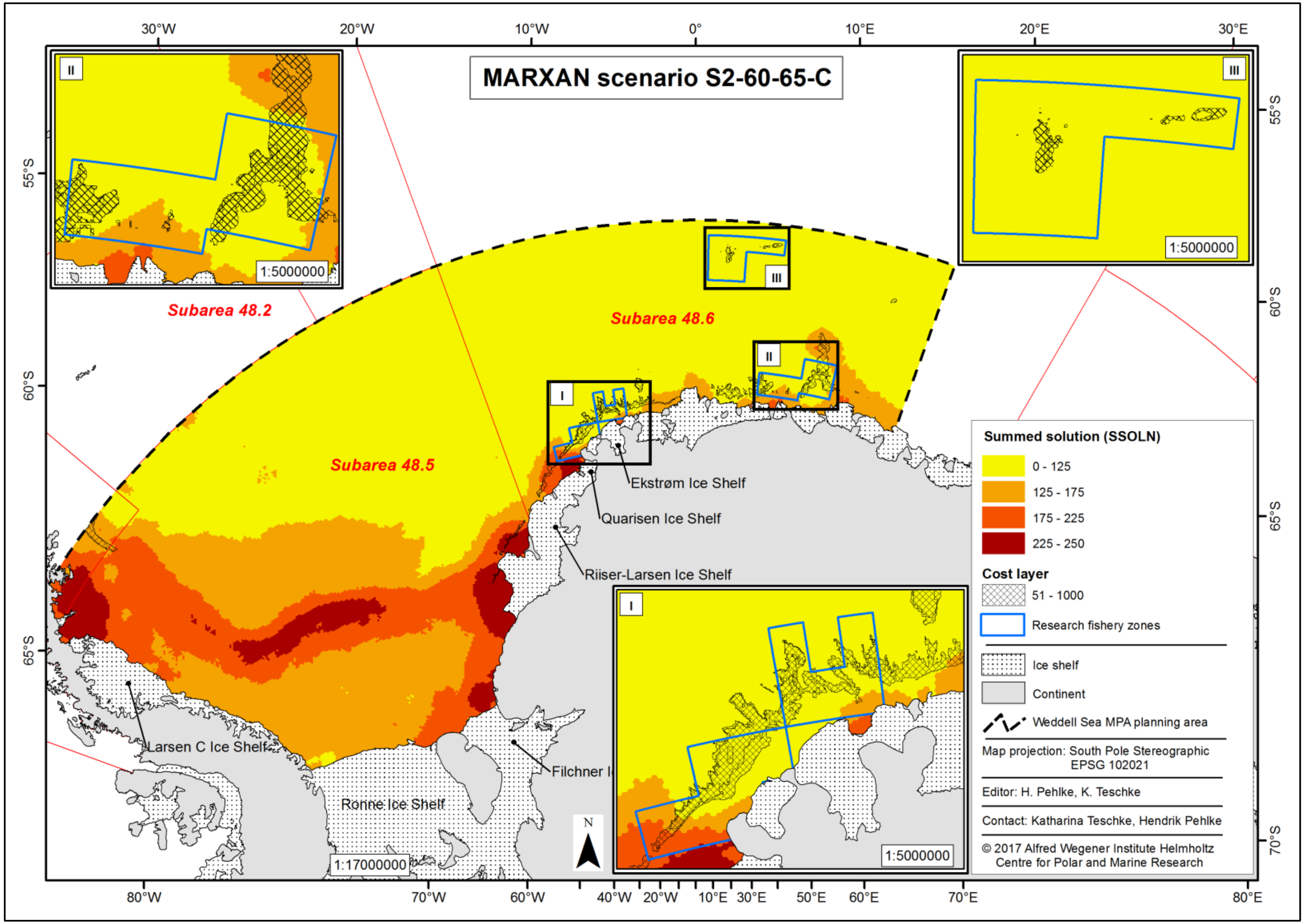

Figure A1-3 Summed solutions for Scenario S_2-60-65-C following a two-factor Marxan scenario analysed exclusively with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 65%). A cost layer was included.

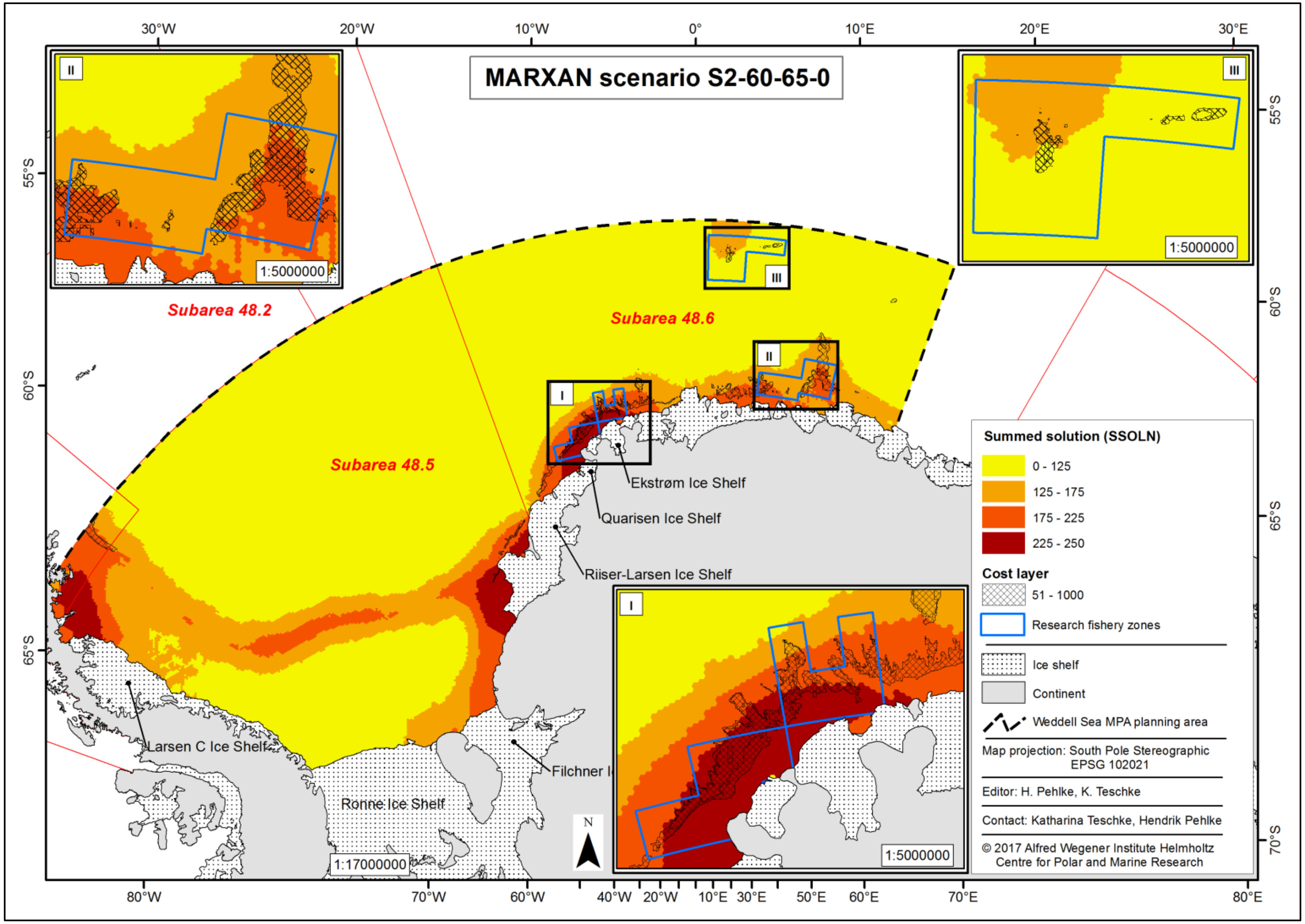

Figure A1-4 Summed solutions for Scenario S_2-60-65-0 following a two-factor Marxan scenario analysed exclusively with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 65%). A cost layer was not included.

Table A1-1 Conservation feature data layers considered in this study. For more details on each conservation feature see SC-CAMLR-XXXV/BG/12 and BG13.

Serial number	Conservation feature
	Ecological conservation features
1	Adult Antarctic krill
2	Larval Antarctic krill
3	Ice krill
4	Adult Antarctic silverfish
5	Larval Antarctic silverfish
6	Adélie penguin colonies (50 km buffer around each colony)
7	Adélie penguin colonies (50-100 km ring buffer around each colony)
8	Non-breeding Adélie penguins
9	Antarctic petrel
10	Emperor penguins
11	Seal density
12	Seal movement
13	Antarctic toothfish
14	Demersal fish
15	Nesting sites
16	Echinoderm fauna
17	Sponge presence
18	Shallow water area - Norsel Bank
	Environmental conservation features
1	Abyssal Plain: > -3000m
2	Bank: 0m to -100m
3	Bank: -100m to -200m
4	Bank: -200m to -500m
5	Bank: -500m to -1000m
6	Canyon Shelf Commencing
7	Canyon Slope Commencing
8	Coastal Terrane
9	Cross Shelf Valley: 0m to -100m
10	Cross Shelf Valley: -100m to -200m
11	Cross Shelf Valley: -200m to -500m
12	Cross Shelf Valley: -500m to -1000m
13	Cross Shelf Valley: -1000m to -1500m
14	Filchner Trough (incl. parts of Cross Shelf Valley)
15	Lower Slope: -2000m to -3000m
16	Lower Slope: > -3000m
17	Margin Ridge (= Astrid Ridge): -500m to -1000m

Serial number	Conservation feature
18	Margin Ridge (= Astrid Ridge): -1000m to -1500m
19	Margin Ridge (= Astrid Ridge): -1500m to -2000m
20	Margin Ridge (= Astrid Ridge): -2000m to -3000m
21	Margin Ridge (= Astrid Ridge): -3000m to -4500m
22	Marginal Plateau: -2000m to -3000m
23	Marginal Plateau: -3000m to -4500m
24	Plateau: -2000m to -3000m
25	Plateau: -3000m to -4500m
26	Plateau Slope: -2000m to -3000m
27	Plateau Slope: -3000m to -4500m
28	Ridge: -1500 to -2000m
29	Ridge: -2000 to -3000m
30	Ridge: -3000 to -4500m
31	Rugose Ocean Floor: > -3000m
32	Seamount Ridge: -1000m to -1500m
33	Seamount Ridge: -2000m to -3000m
34	Seamount Ridge: -3000m to -4500m
35	Seamount: -1000m to -1500m
36	Seamount: -1500m to -2000m
37	Seamount: > -3000m
38	Shelf
39	Shelf Deep: 0m to -100m
40	Shelf Deep: -200m to -500m
41	Shelf Deep: -500m to -1000m
42	Upper Slope: 0m to -100m
43	Upper Slope: -100m to -200m
44	Upper Slope: -200m to -500m
45	Upper Slope: -500m to -1000m
46	Upper Slope: -1000m to -1500m
47	Upper Slope: -1500m to -2000m
48	Upper Slope: -2000m to -3000m
49	Upper Slope: -3000m to -4500m
50	Pelagic region - Coastal polynya I
51	Pelagic region - Coastal polynya II
52	Pelagic region - Coastal polynya III
53	Transition zone
54	Deepwater area I
55	Deepwater area II
56	Deepwater area III
57	Ice covered area

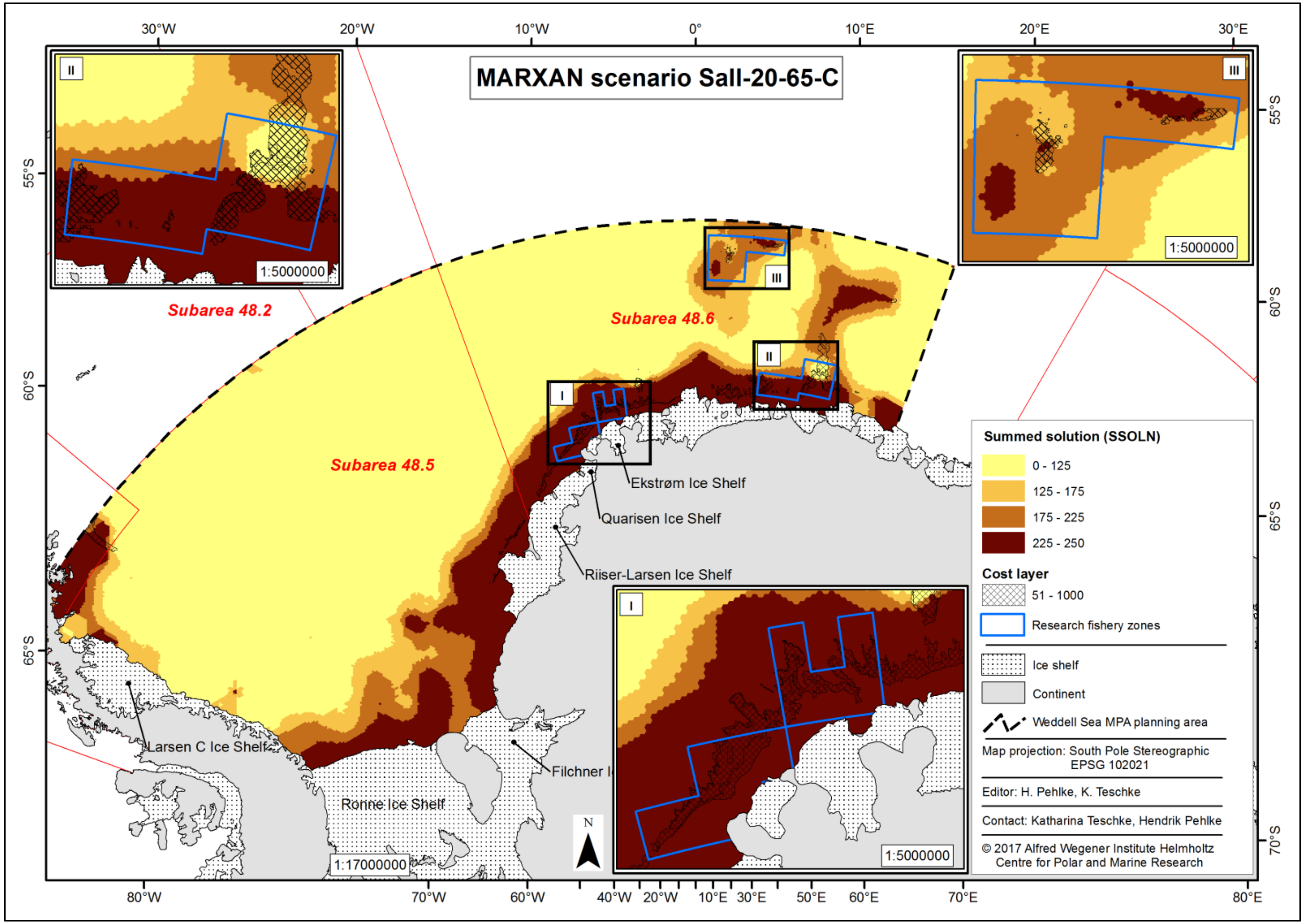

Figure A1-5 Summed solutions for Scenario S_{all}-20-65-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 20%) and demersal fish (target level: 65%). A cost layer was included.

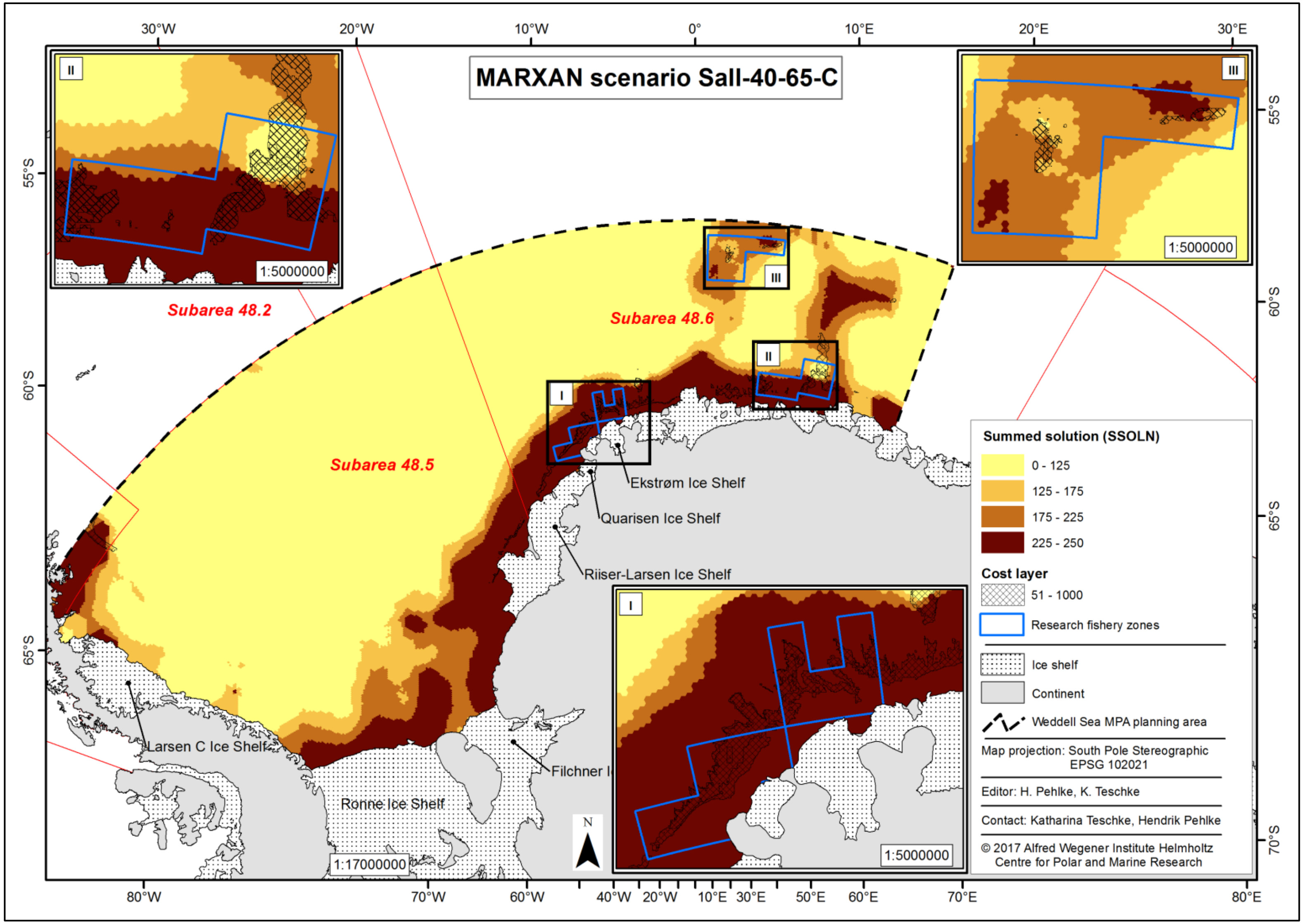

Figure A1-6 Summed solutions for Scenario S_{all}-40-65-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 40%) and demersal fish (target level: 65%). A cost layer was included.

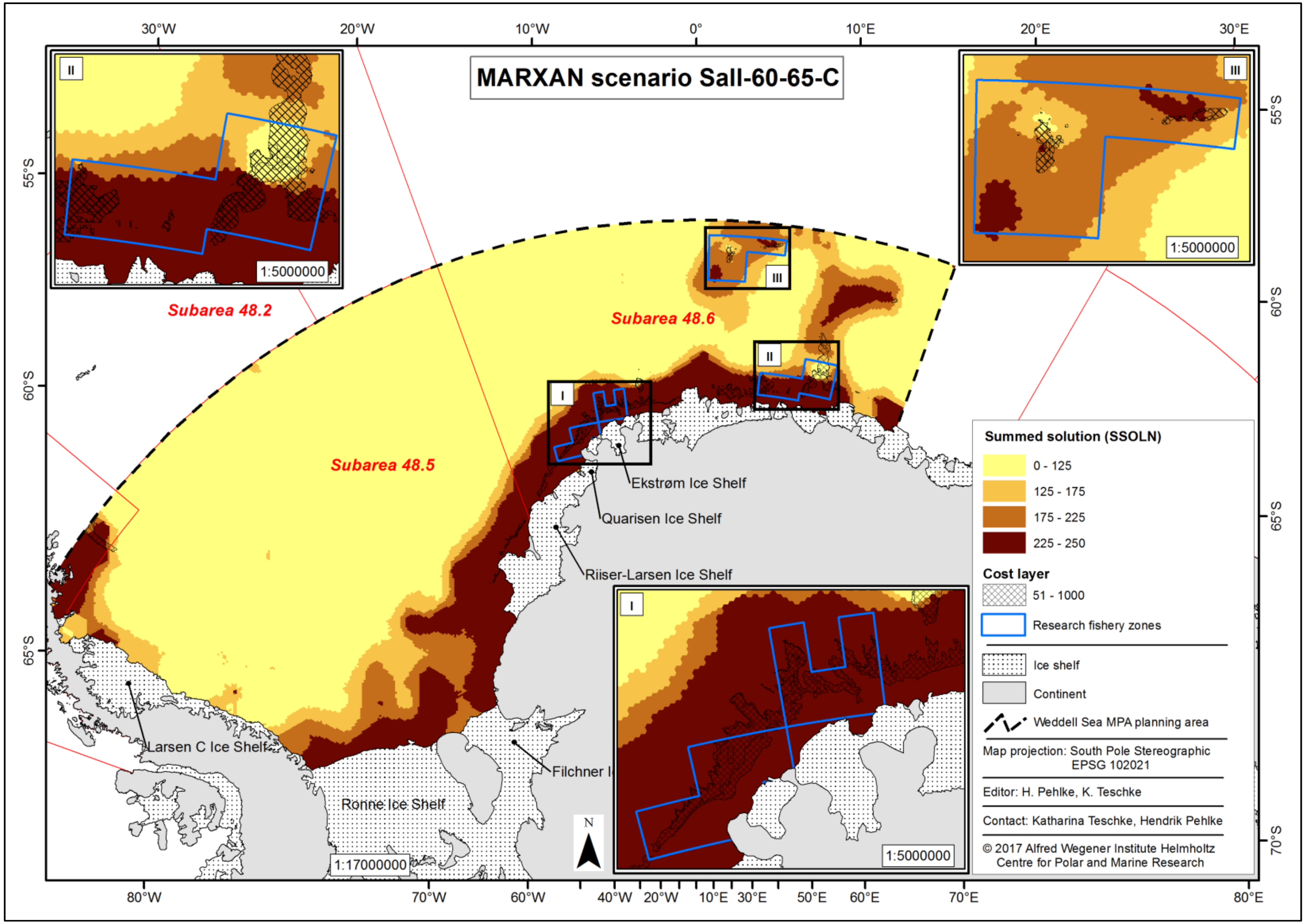

Figure A1-7 Summed solutions for Scenario S_{all}-60-65-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 65%). A cost layer was included.

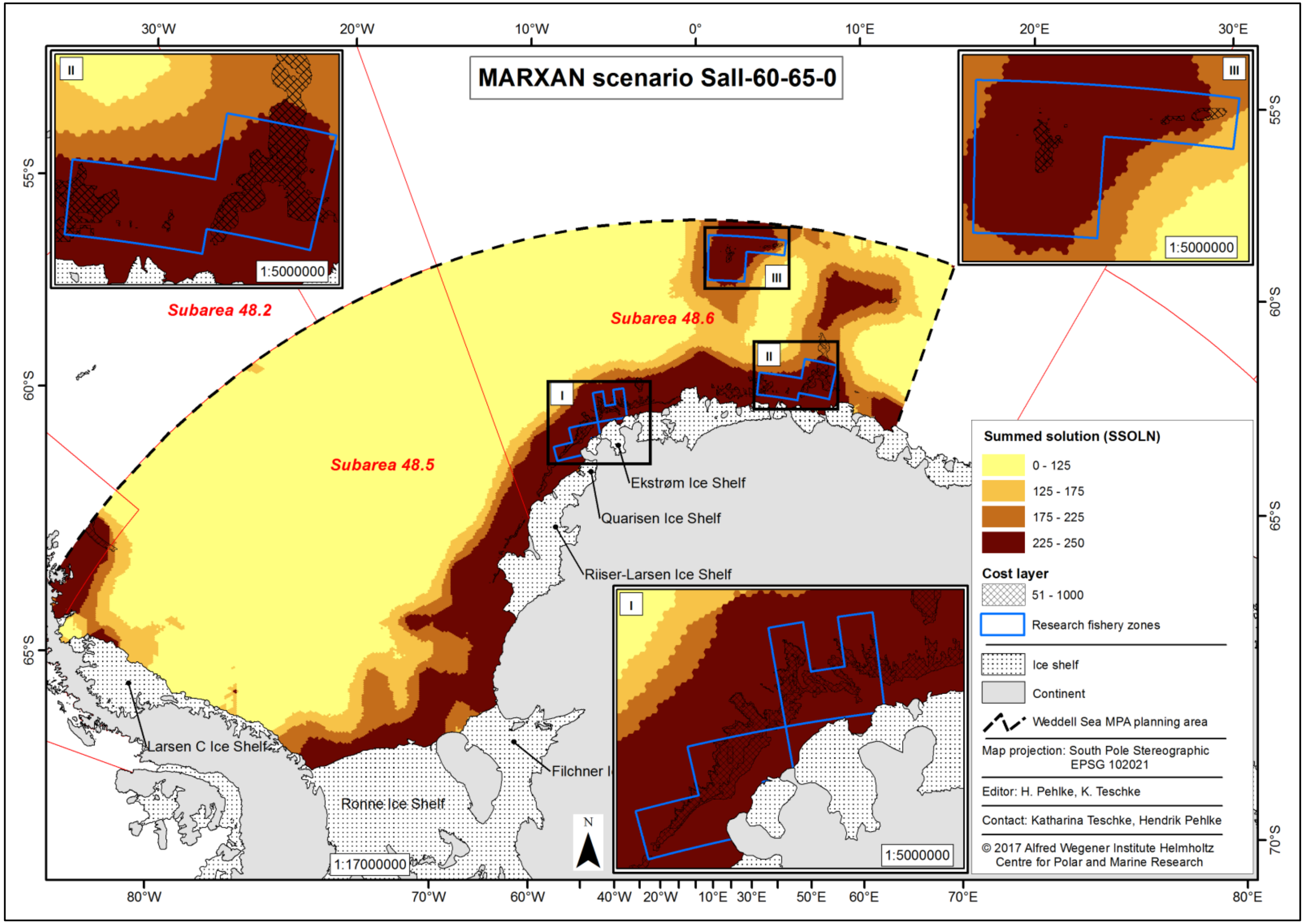

Figure A1-8 Summed solutions for Scenario S_{all}-60-65-0 following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 65%). A cost layer was not included.

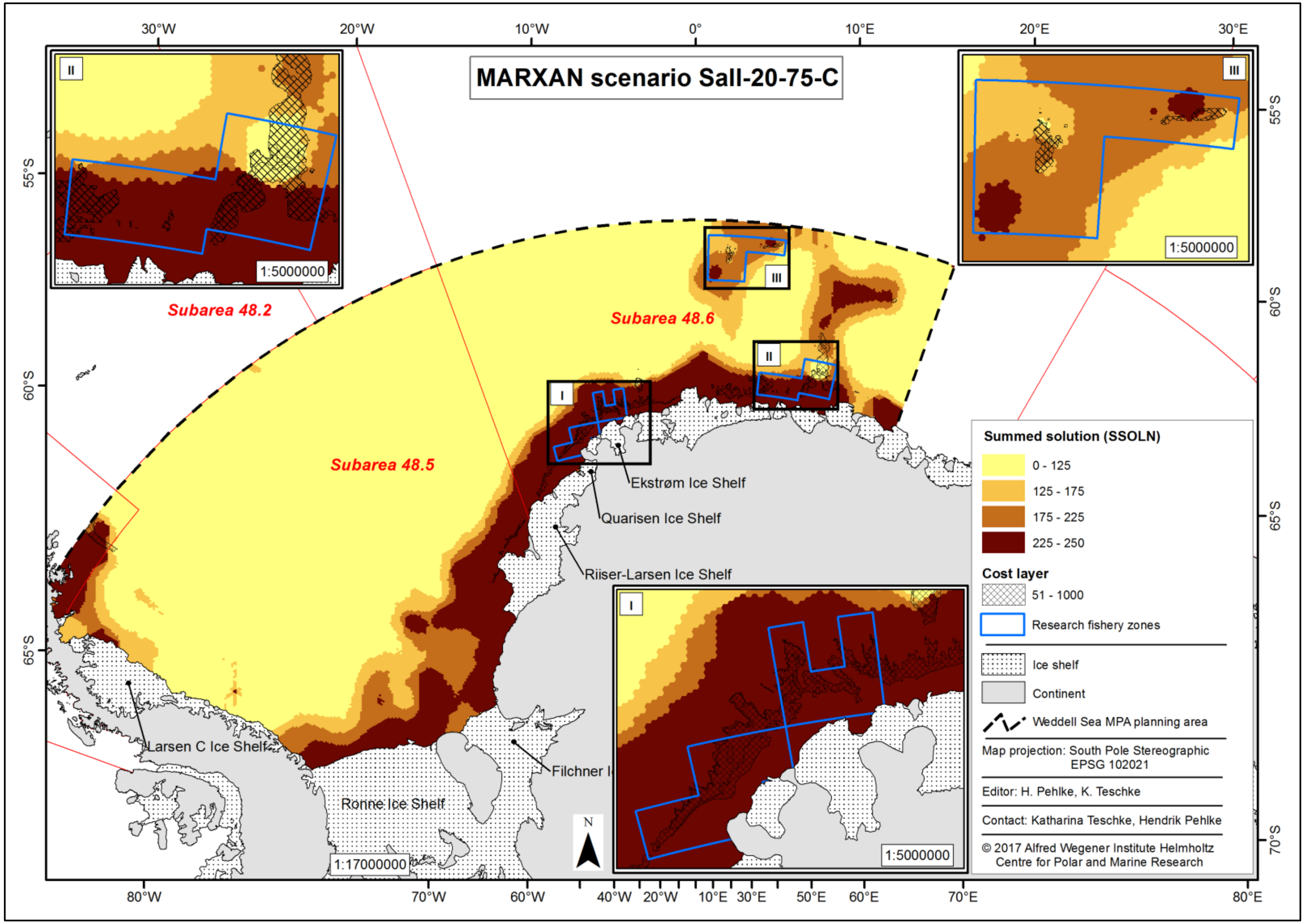

Figure A1-9 Summed solutions for Scenario S_{all}-20-75-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 20%) and demersal fish (target level: 75%). A cost layer was included.

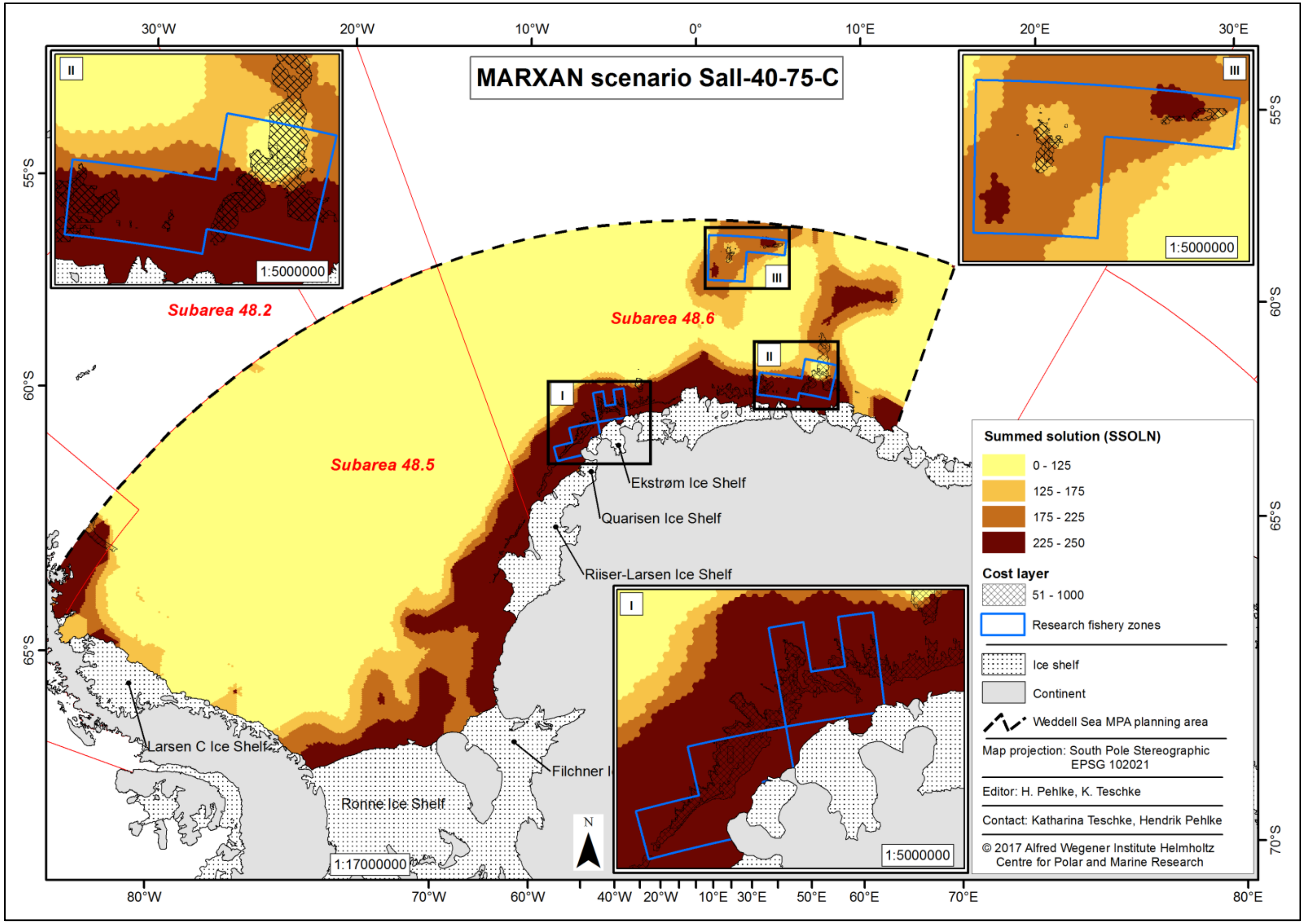

Figure A1-10 Summed solutions for Scenario S_{all}-40-75-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 40%) and demersal fish (target level: 75%). A cost layer was included.

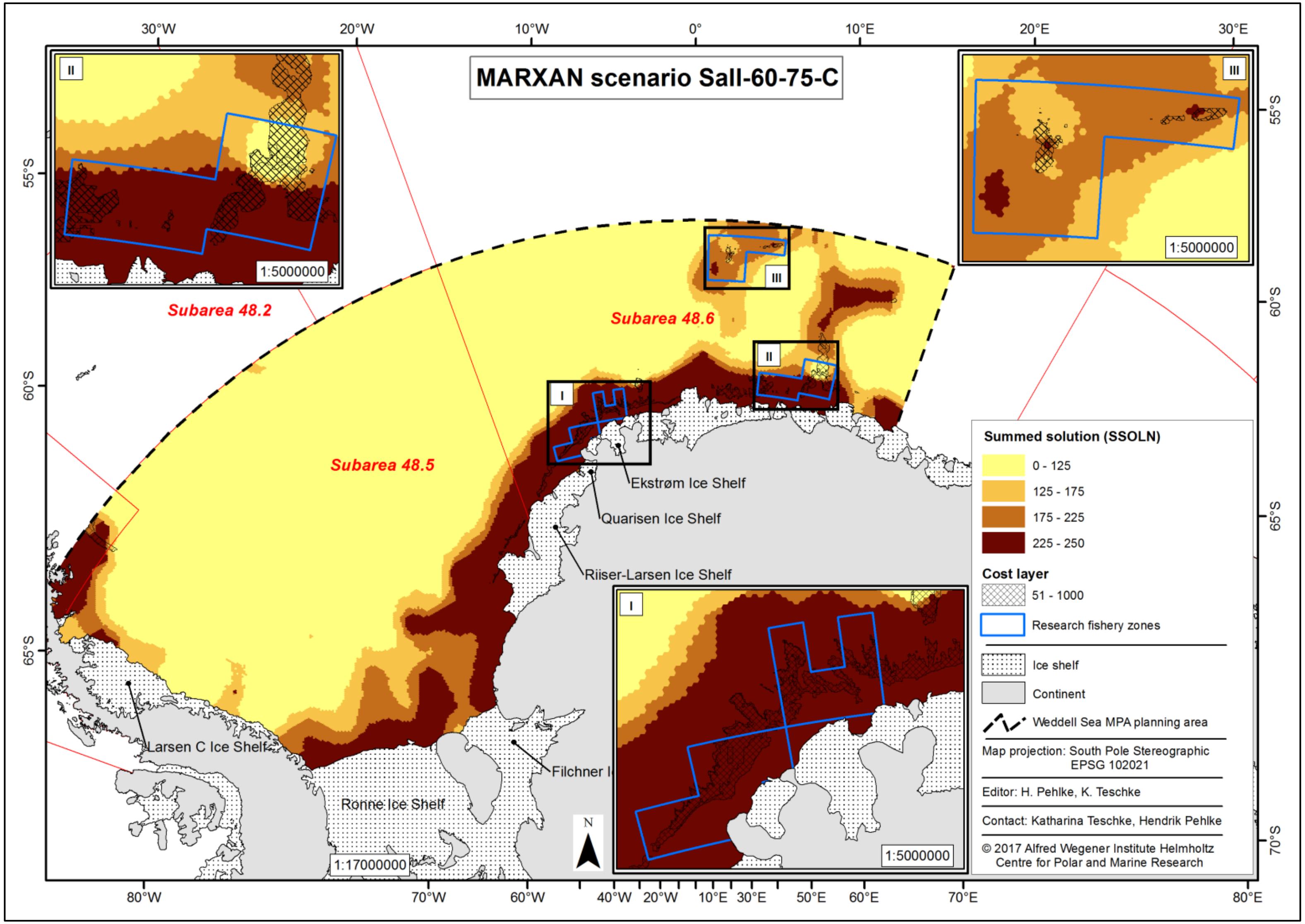

Figure A1-11 Summed solutions for Scenario S_{all}-60-75-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 75%). A cost layer was included.

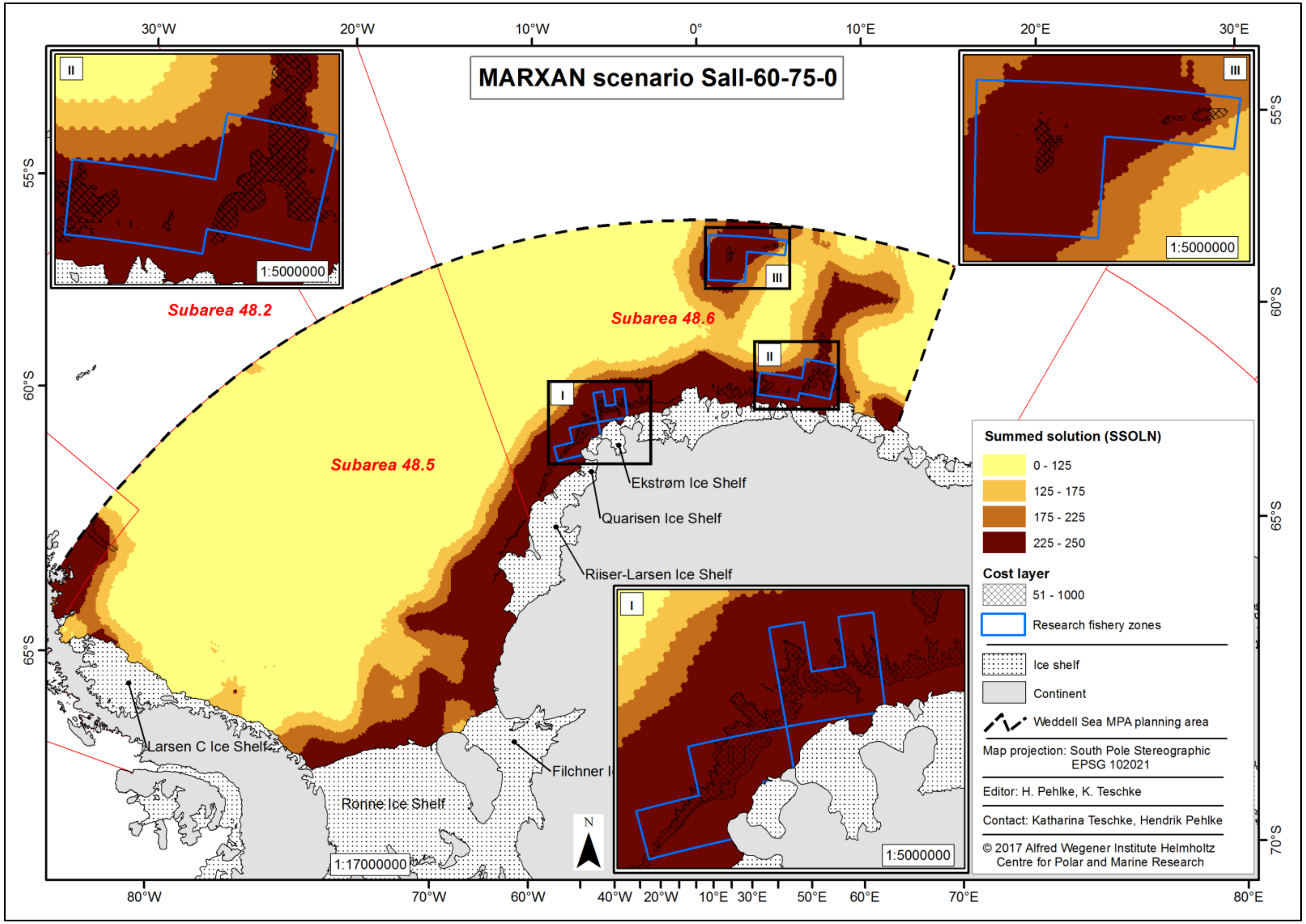

Figure A1-12 Summed solutions for Scenario S_{all}-60-75-0 following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 75%). A cost layer was not included.

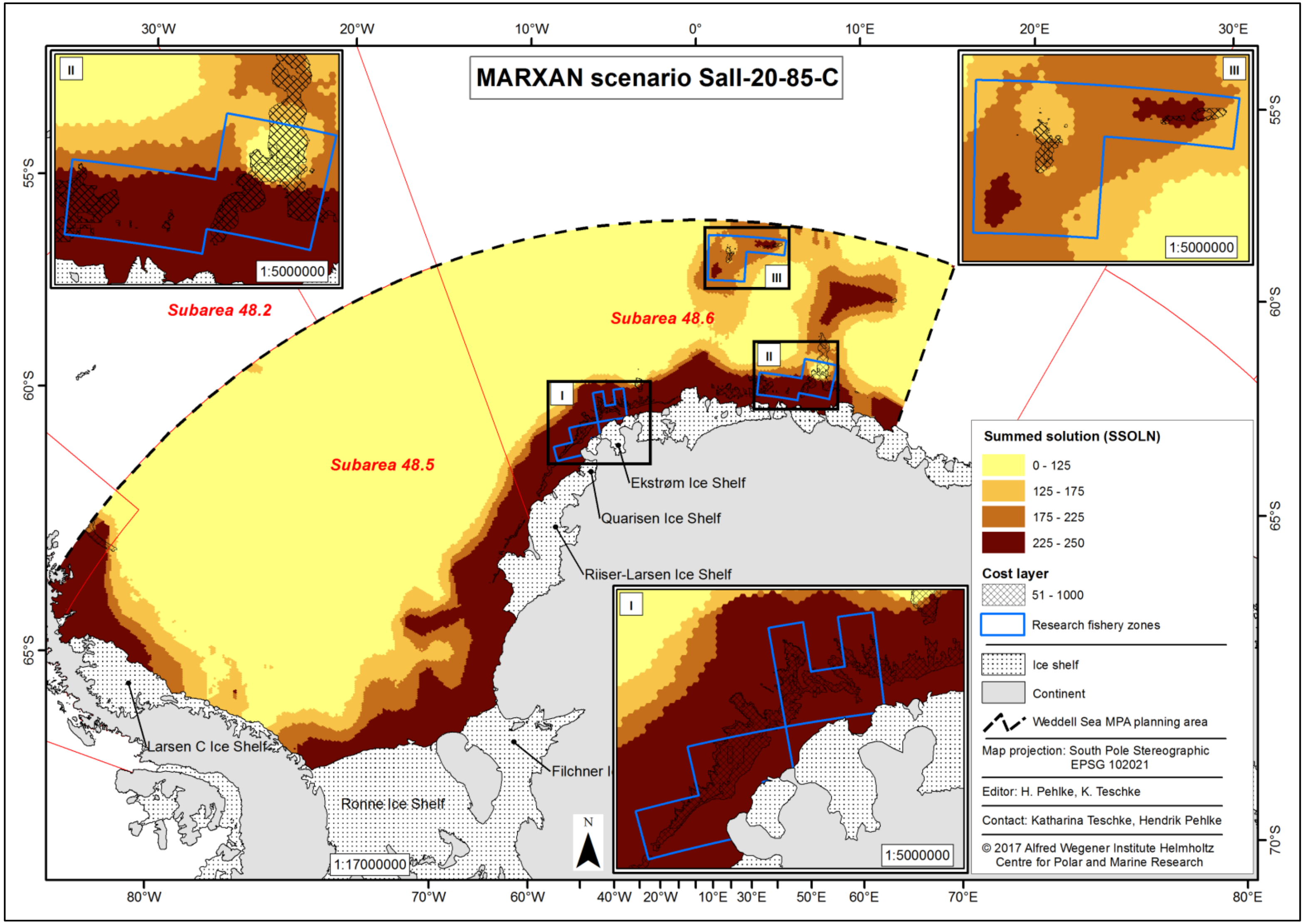

Figure A1-13 Summed solutions for Scenario S_{all}-20-85-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 20%) and demersal fish (target level: 85%). A cost layer was included.

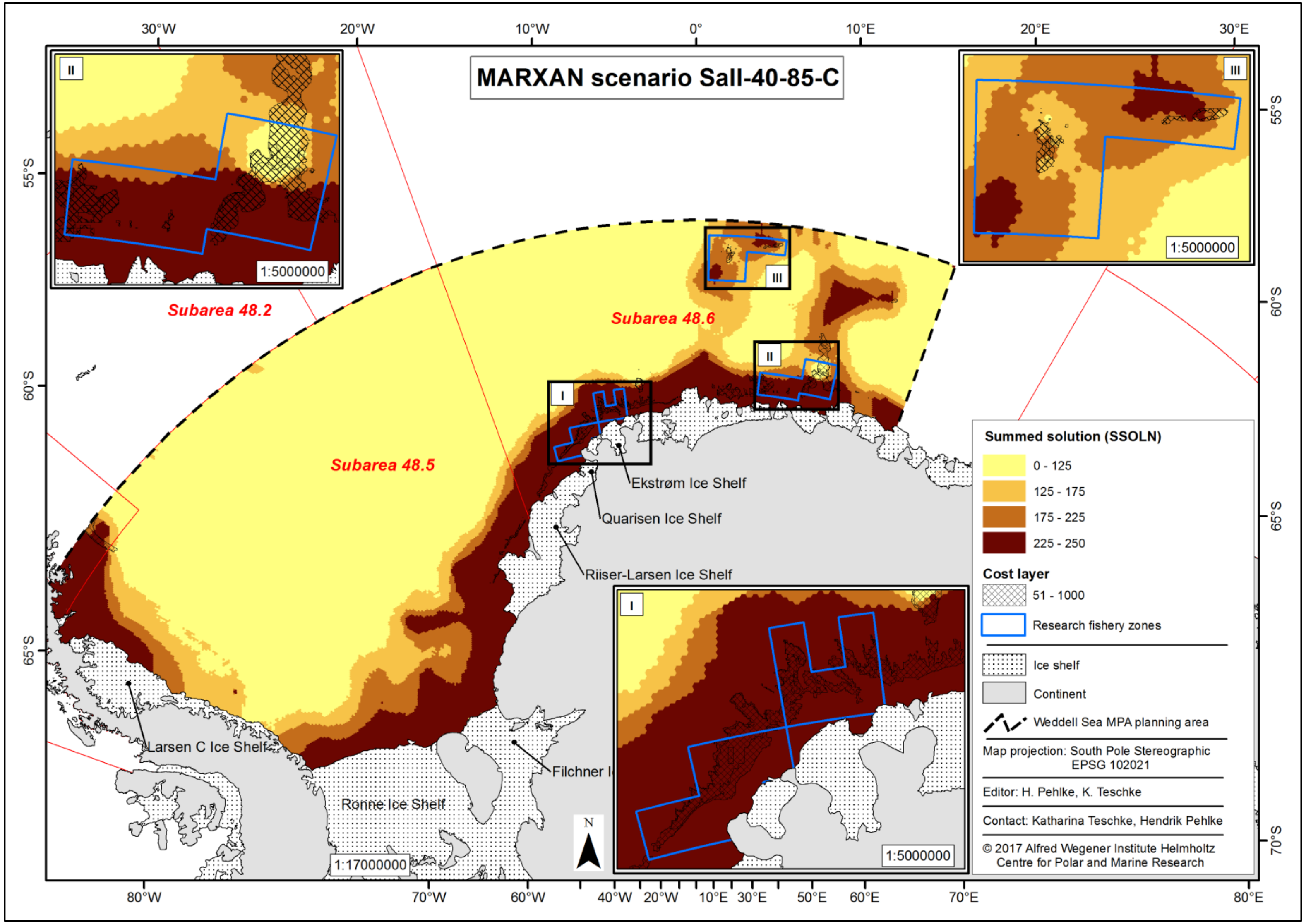

Figure A1-14 Summed solutions for Scenario S_{all}-40-85-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 40%) and demersal fish (target level: 85%). A cost layer was included.

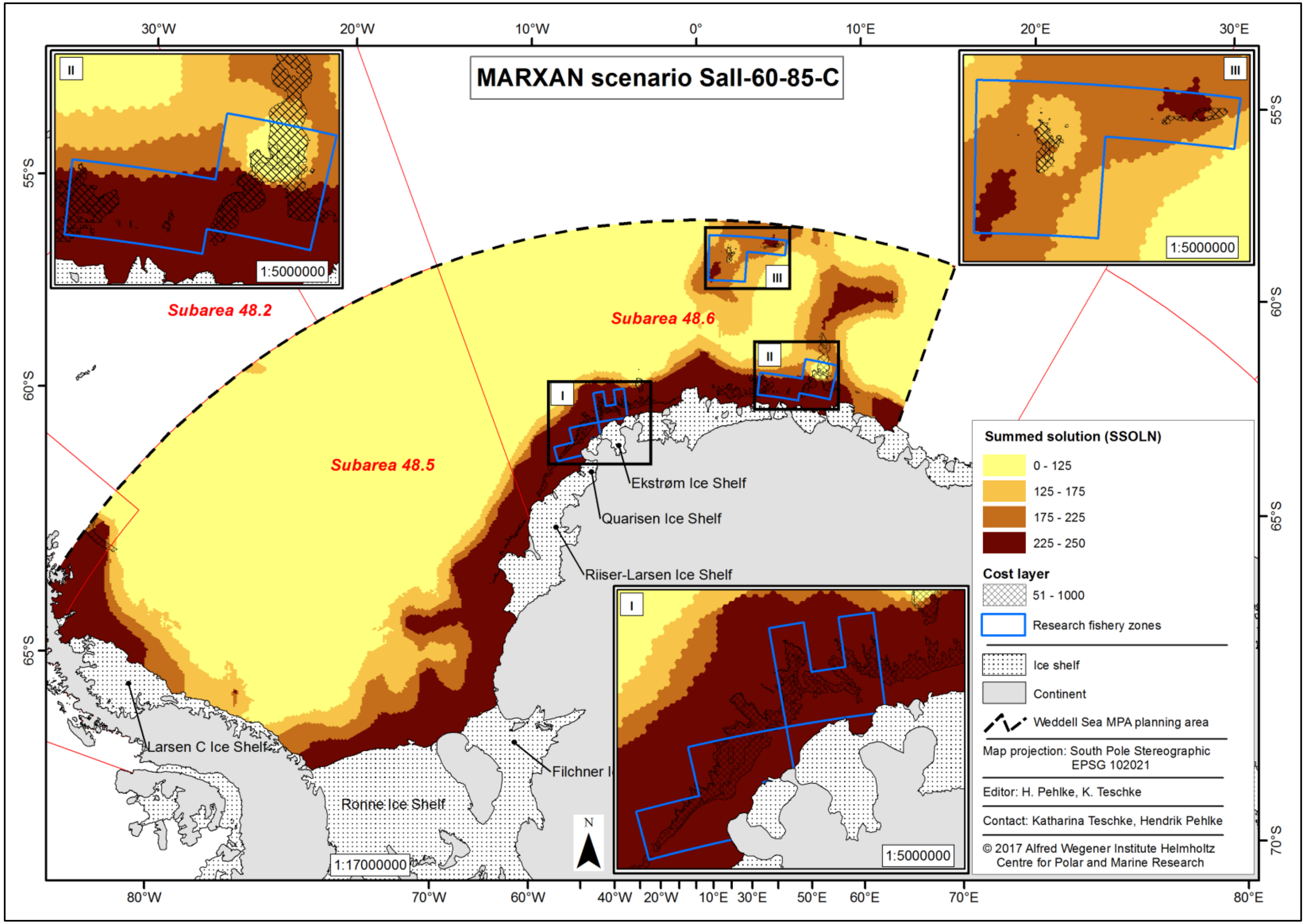

Figure A1-15 Summed solutions for Scenario S_{all}-60-85-C following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 85%). A cost layer was included.

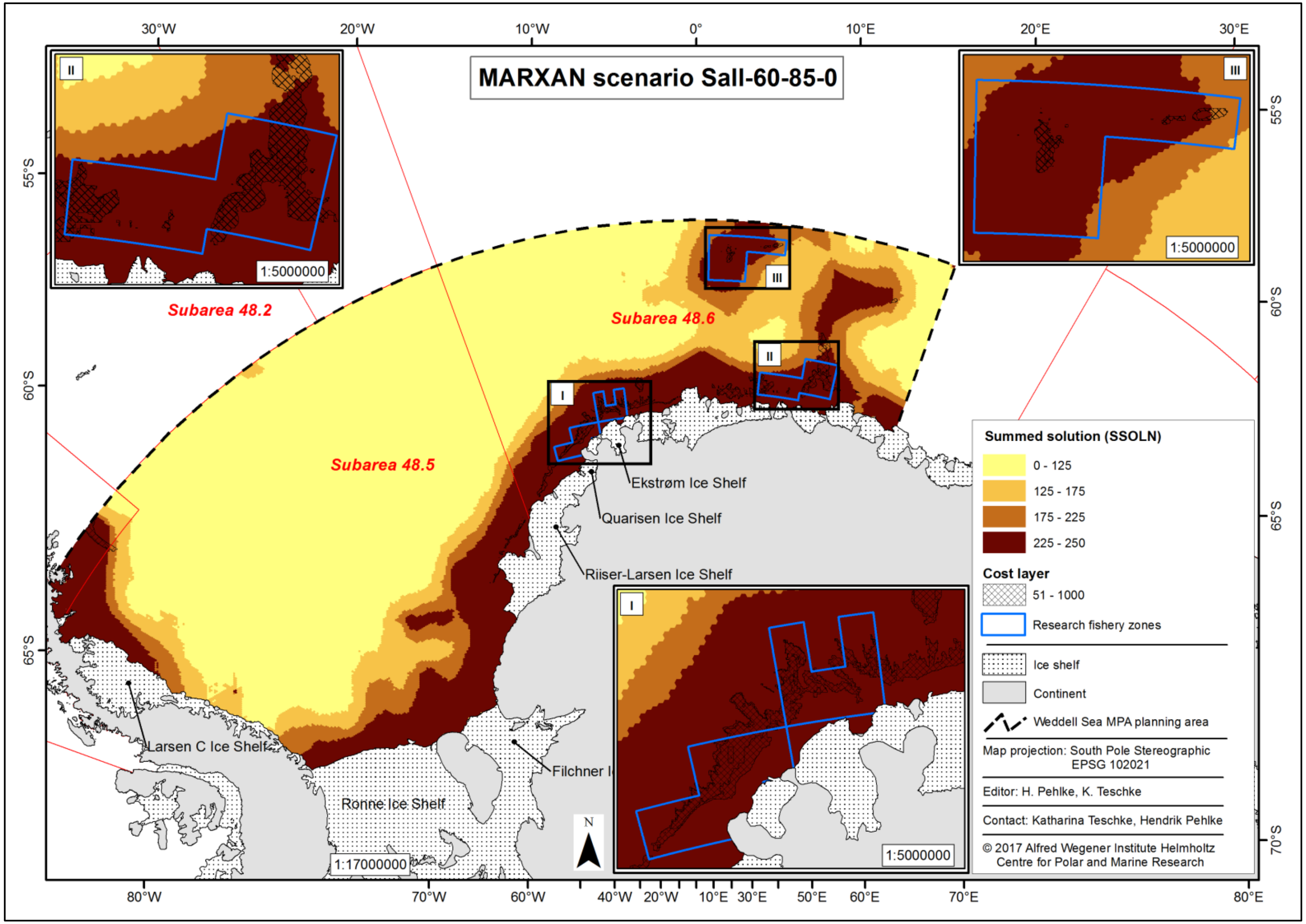

Figure A1-16 Summed solutions for Scenario S_{all}-60-85-0 following a multi-factor Marxan scenario analysed with *Dissostichus mawsoni* (target level: 60%) and demersal fish (target level: 85%). A cost layer was not included.

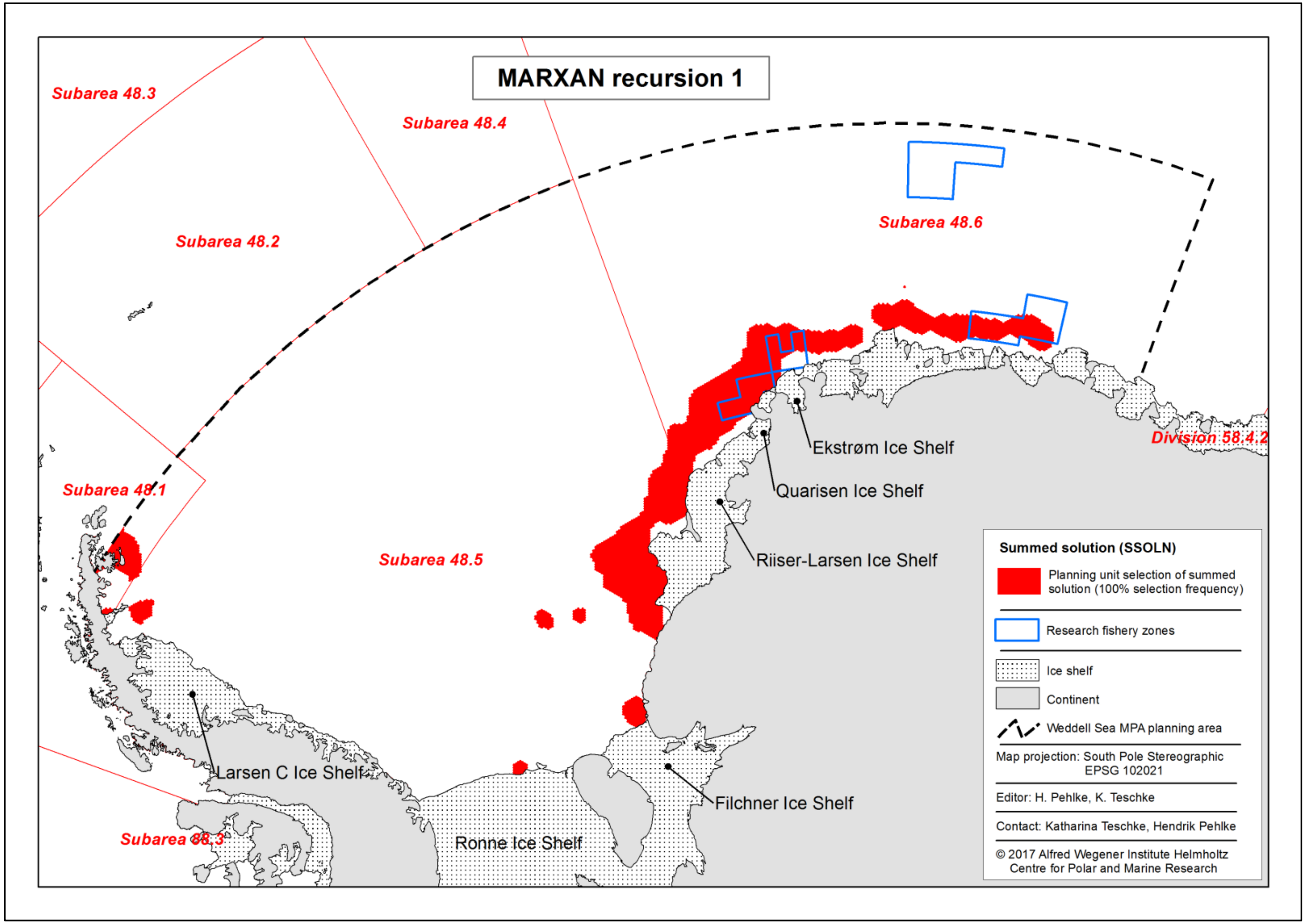

Figure A2-1 Summed solution (SSOLN) of the first Marxan recursion. In total seven ecological conservation features were achieved completely by the by the selected planning units (= 100% selection frequency; shown in red).

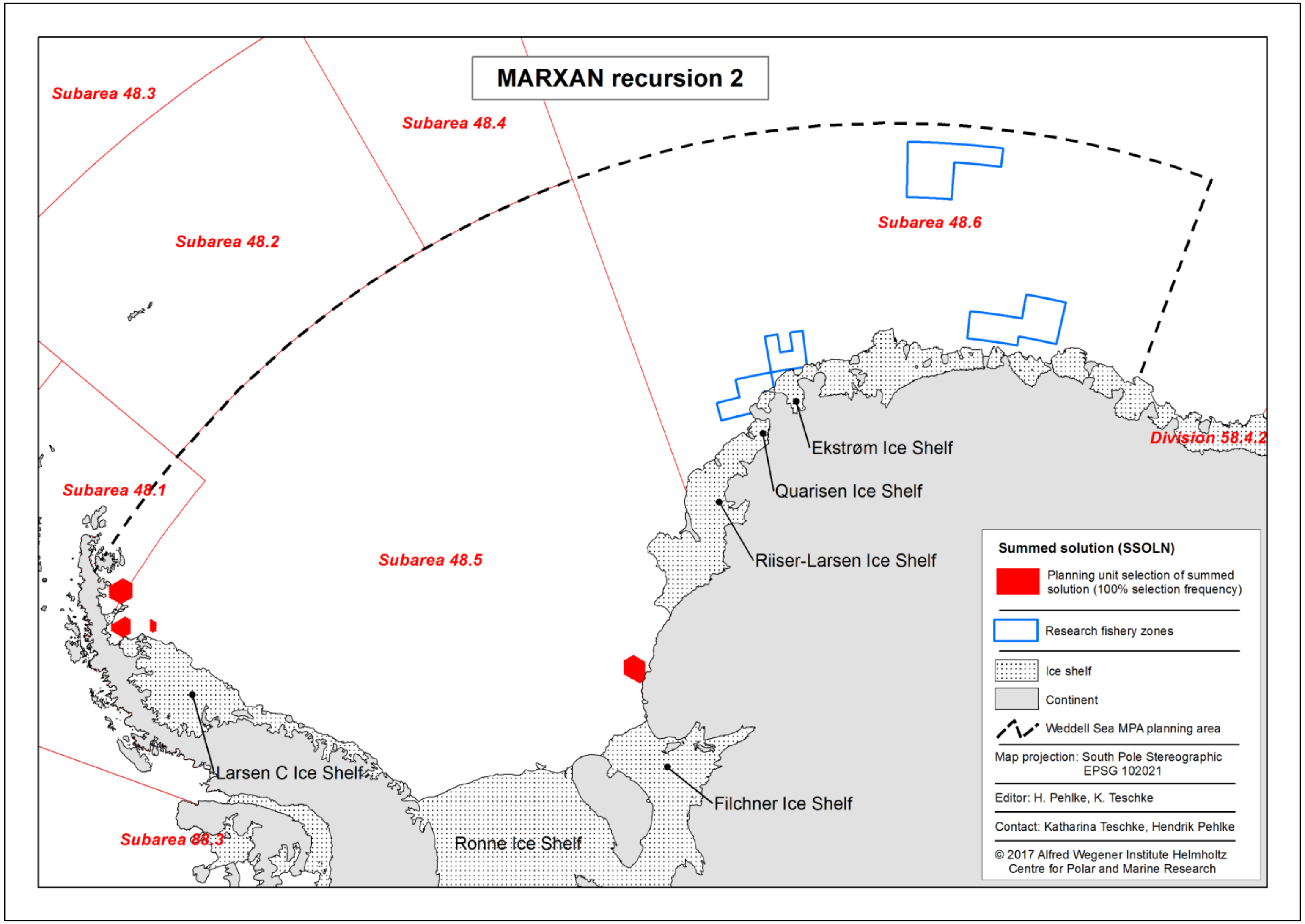

Figure A2-2 Summed solution of the second Marxan recursion. No progress was reached regarding the target achievement of the ecological conservation features by the selected planning units (= 100% selection frequency; shown in red).

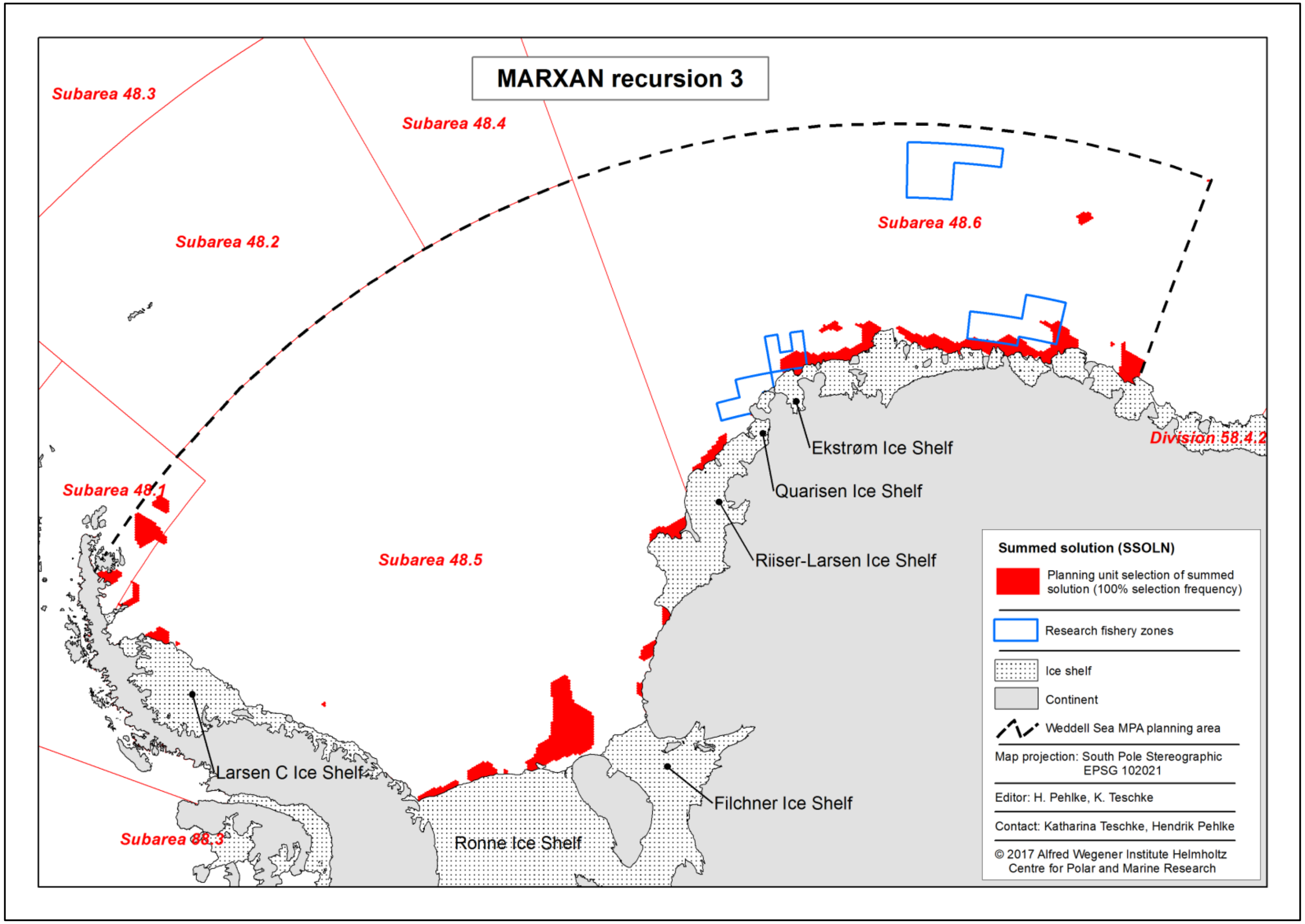

Figure A2-3 Summed solution of the third recursion. Two additional ecological conservation features and 22 environmental features were achieved completely by the selected planning units (= 100% selection frequency; shown in red).

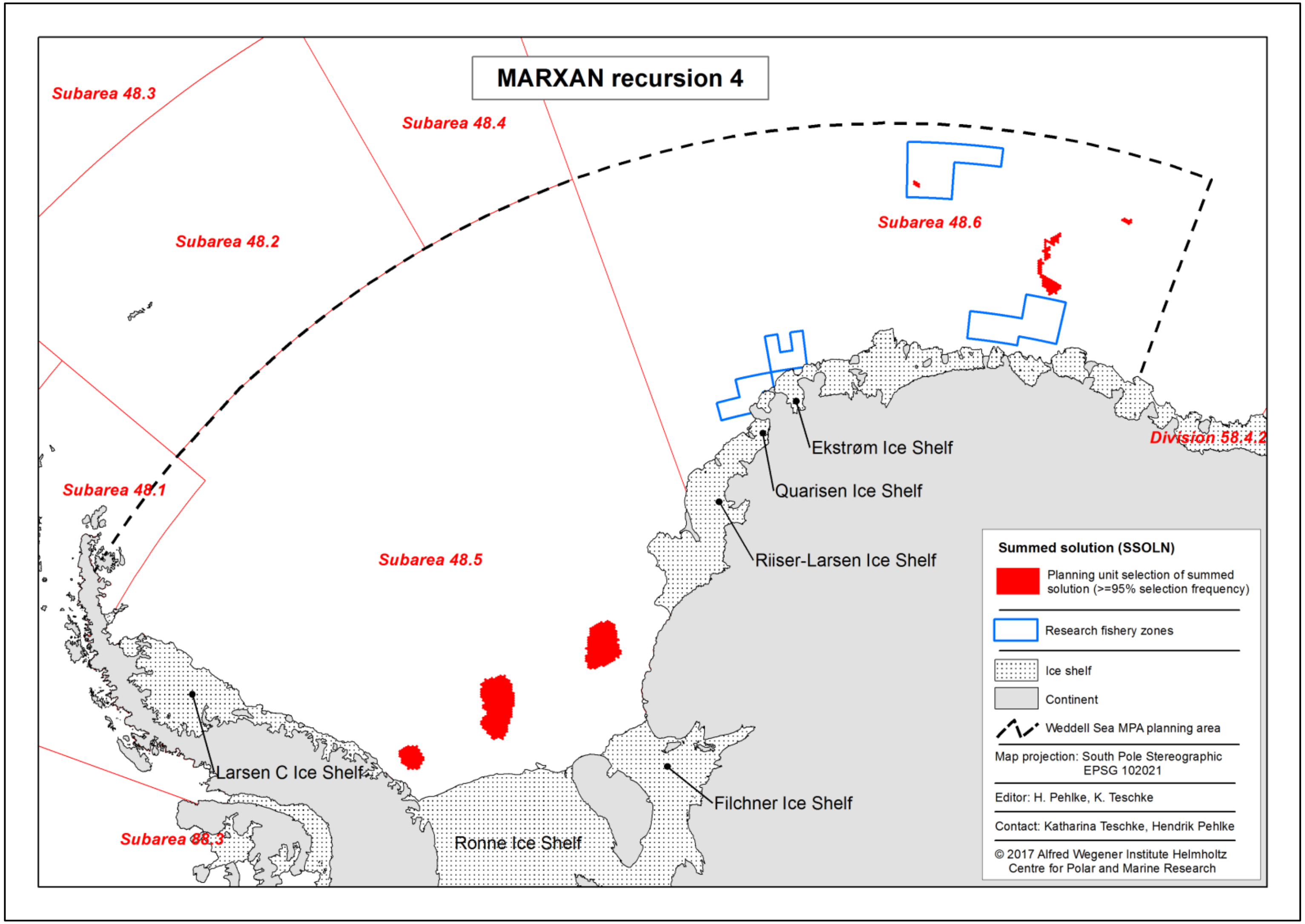

Figure A2-4 Summed solution of the fourth recursion. One additional ecological conservation features was achieved completely by the selected planning units (>= 95% selection frequency; shown in red). No progress was reached regarding the target achievement of the remaining environmental conservation features.

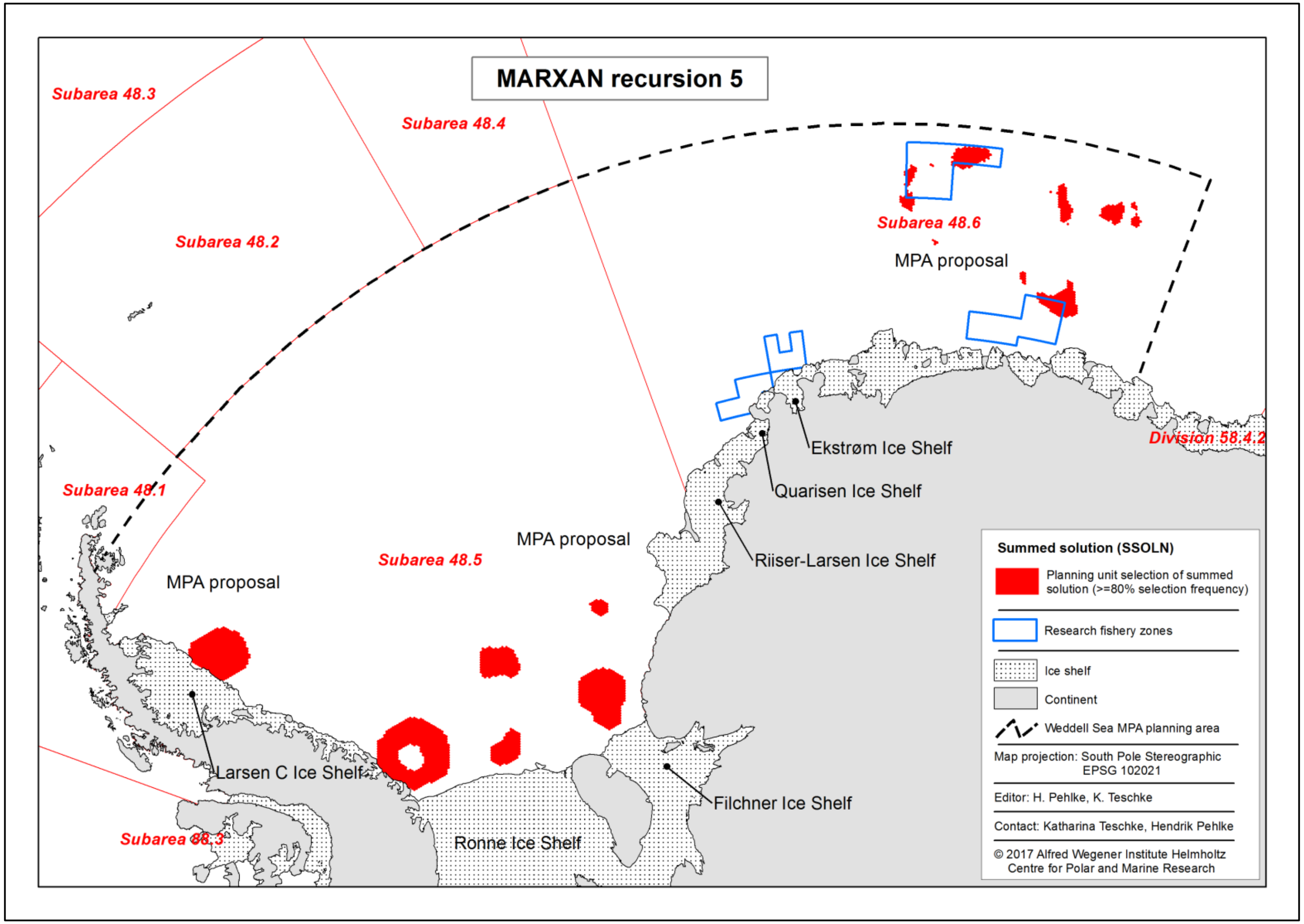

Figure A2-5 Summed solution of the fifth recursion. Two more ecological conservation features and 14 additional environmental features were achieved by the selected planning units of the fifth recursion (>= 95% selection frequency; shown in red).

Table A2-1 Systematic overview of how the specific conservation objectives for the WSMPA and the corresponding conservation features and their targets, respectively, are achieved by planning unit grid cells that were selected after five Marxan recursions (see Fig. 3-5; red coloured area). "Area" is expressed as km² for a few ecological conservation features and all environmental conservation features, whereas for most of the ecological conservation features "area" is expressed as km² * corresponding weighting factor. Conservation features where a weighting factor has been applied are marked with an asterisk (see SC-CAMLR-XXXV/BG/13, Annex 1 for details of weighting factor calculations for most of the conservation features; for the revised conservation features the computing of the weighting factors are described in the corresponding chapters of this paper).

Conservation feature	Target level for protection (Proportion of total feature "area")	Total "area" in WSMPA Planning Area	Minimal achieving "area"	Actual achieving "area"	Actual achieving target level	Achievement of target level	
						Ratio	YES / NO
Specific conservation objective S1: Representation of pelagic habitats							
Pelagic regions (Habitat classification of five pelagic regions)							
Transition zone	20 %	258,863.02	51,772.60	147,778.03	57 %	2.85	YES
Deepwater area I	20 %	637,920.30	127,584.06	81,643.51	13 %	0.64	NO
Deepwater area II	20 %	1,098,799.22	219,759.84	40,470.49	4 %	0.18	NO
Deepwater area III	20 %	868,117.10	173,623.42	94,369.77	11 %	0.54	NO
Ice covered area	20 %	651,469.30	130,293.86	138,051.32	21 %	1.06	YES
S2: Important areas for pelagic key species in the Antarctic food web							
*Adult Antarctic krill	35 %	37,285,885.31	13,050,059.86	11,130,350.89	30 %	0.85	NO
*Larval Antarctic krill	50 %	3,289,492.88	1,644,746.44	600,173.04	18 %	0.36	NO
Ice krill	35 %	573,098.14	200,584.35	255,189.18	45 %	1.27	YES
*Adult Antarctic silverfish	35 %	834,747.90	2,92,161.76	631,733.77	76 %	2.16	YES
*Larval Antarctic silverfish	35 %	214,575.34	75,101.37	170,586.92	79 %	2.27	YES
S3: Essential habitats for top predators							
Adélie penguin colonies (50 km buffer around each colony)	100 %	6,585.16	6,585.16	6,585.16	100 %	1.00	YES
Adélie penguin colonies (50-100 km ring buffer around each colony)	50 %	15,271.86	7,635.93	9,301.55	61 %	1.22	YES
*Non-breeding Adélie penguins	20 %	830,581.72	166,116.34	17,926.63	2 %	0.11	NO
*Emperor penguins	40 %	505,327.49	202,131.00	472,833.73	94 %	2.34	YES

Conservation feature	Target level for protection (Proportion of total feature "area")	Total "area" in WSMPA Planning Area	Minimal achieving "area"	Actual achieving "area"	Actual achieving target level	Achievement of target level	
						Ratio	YES / NO
*Antarctic petrel	40 %	30,175,632.95	12,070,253.18	8,215,303.17	27 %	0.68	NO
*Seal density	20 %	3,091,782.25	618,356.45	833,302.70	27 %	1.35	YES
*Seal movement	20 %	15,674,197.94	3,134,839.59	4,769,785.45	30 %	1.52	YES
S4: Representation of benthic habitats							
Benthic environment types (Habitat classification of 50 environmental types)							
Abyssal Plain: > -3000m	20 %	1,346,076.87	269,215.37	5,649.37	0 %	0.00	NO
Bank: 0m to -100m	20 %	4,440.45	888.09	2,023.06	46 %	2.28	YES
Bank: -100m to -200m	20 %	9,111.27	1,822.25	5,453.786	60 %	2.99	YES
Bank: -200m to -500m	20 %	243,188.78	48,637.76	97,478.80	40 %	2.00	YES
Bank: -500m to -1000m	20 %	53,747.70	10,749.54	17,755.79	33 %	1.65	YES
Canyon Shelf Commencing	60 %	16,681.53	10,008.92	8,384.68	50 %	0.48	NO
Canyon Slope Commencing	60 %	57,760.70	34,656.42	18,921.61	33 %	0.55	NO
Coastal Terrane	20 %	10,127.42	2,025.48	8,437.57	83 %	4.17	YES
Cross Shelf Valley: 0m to -100m	20 %	1,778.06	355.61	1,186.17	67 %	3.44	YES
Cross Shelf Valley: -100m to -200m	20 %	6,958.80	421.07	1,704.69	81 %	4.05	YES
Cross Shelf Valley: -200m to -500m	20 %	2,105.33	17,112.46	33,272.36	39 %	1.94	YES
Cross Shelf Valley: -500m to -1000m	20 %	85,562.30	26,048.65	50,313.64	39 %	1.93	YES
Cross Shelf Valley: -1000m to -1500m	20 %	130,243.24	1,391.76	6,430.77	92 %	4.62	YES
Filchner Trough (incl. parts of Cross Shelf Valley)	60 %	80,797.09	48,478.25	53,200.40	66 %	1.10	YES
Lower Slope: -2000m to -3000m	20 %	106,360.49	21,272.10	31,577.44	30 %	1.48	YES
Lower Slope: > -3000m	20 %	650,853.73	130,170.75	41,559.01	6 %	0.32	NO
Margin Ridge (= Astrid Ridge): -500m to -1000m	60 %	1,372.48	823.49	1,074.95	78 %	1.31	YES
Margin Ridge (= Astrid Ridge): -1000m to -1500m	60 %	3,247.53	1,948.52	2,163.40	67 %	1.11	YES
Margin Ridge (= Astrid Ridge): -1500m to -2000m	60 %	9,760.43	5,856.26	6,567.58	67 %	1.12	YES

Conservation feature	Target level for protection (Proportion of total feature "area")	Total "area" in WSMPA Planning Area	Minimal achieving "area"	Actual achieving "area"	Actual achieving target level	Achievement of target level	
						Ratio	YES / NO
Margin Ridge (= Astrid Ridge): -2000m to -3000m	60 %	23,064.41	13,838.65	13,470.54	58 %	0.97	YES
Margin Ridge (= Astrid Ridge): -3000m to -4500m	60 %	6,523.33	3,914.00	3,229.26	50 %	0.83	NO
Marginal Plateau: -2000m to -3000m	60 %	5,501.79	3,301.08	4,345.22	97 %	1.32	YES
Marginal Plateau: -3000m to -4500m	60 %	9,694.97	5,816.98	6,182.18	64 %	1.06	YES
Plateau: -2000m to -3000m	60 %	28,306.60	16,983.96	10,462.97	37 %	0.62	NO
Plateau: -3000m to -4500m	60 %	4,635.14	2,781.08	2,725.54	59 %	0.98	NO
Plateau Slope: -2000m to -3000m	60 %	2,206.64	1,323.98	1,645.49	75 %	1.24	YES
Plateau Slope: -3000m to -4500m	60 %	100,018.47	60,011.08	34,562.41	35 %	0.58	NO
Ridge: -1500 to -2000m	20 %	1,115.76	223.15	342.50	31 %	1.53	YES
Ridge: -2000 to -3000m	20 %	9,985.57	1,997.11	848.20	8 %	0.42	NO
Ridge: -3000 to -4500m	20 %	3,514.73	702.95	1.27	0 %	0.00	NO
Rugose Ocean Floor: > -3000m	20 %	277,671.34	55,534.27	12.84	0 %	0.00	NO
Seamount Ridge: -1000m to -1500m	60 %	1,115.76	522.45	249.90	29 %	0.48	NO
Seamount Ridge: -2000m to -3000m	60 %	9,985.57	1,860.26	1,207.42	39 %	0.65	NO
Seamount Ridge: -3000m to -4500m	60 %	3,514.73	1,378.21	1,139.90	50 %	0.83	NO
Seamount: -1000m to -1500m	60 %	1,611.61	966.97	1,446.29	90 %	1.50	YES
Seamount: -1500m to -2000m	60 %	2,945.34	1,767.20	1,876.16	64 %	1.06	YES
Seamount: > -3000m	60 %	1,672.33	1,003.40	357.34	21 %	0.35	NO
Shelf	60 %	1,007.61	604.56	1,007.61	100 %	1.67	YES
Shelf Deep: 0m to -100m	60 %	132.52	79.51	132.52	100 %	1.67	YES
Shelf Deep: -200m to -500m	60 %	35,245.47	21,147.28	32,705.76	93 %	1.55	YES
Shelf Deep: -500m to -1000m	60 %	35,389.23	21,233.54	29,822.29	84 %	1.40	YES
Upper Slope: 0m to -100m	60 %	1,624.13	974.48	1,419.83	87 %	1.46	YES
Upper Slope: -100m to -200m	60 %	1,195.81	717.49	875.31	73 %	1.22	YES

Conservation feature	Target level for protection (Proportion of total feature "area")	Total "area" in WSMPA Planning Area	Minimal achieving "area"	Actual achieving "area"	Actual achieving target level	Achievement of target level	
						Ratio	YES / NO
Upper Slope: -200m to -500m	60 %	8,434.50	5,060.70	6,547.23	78 %	1.29	YES
Upper Slope: -500m to -1000m	60 %	34,417.62	20,650.57	9,848.19	29 %	0.48	NO
Upper Slope: -1000m to -1500m	60 %	52,570.18	31,542.11	13,261.88	25 %	0.42	NO
Upper Slope: -1500m to -2000m	60 %	70,633.59	42,380.15	21,481.15	30 %	0.51	NO
Upper Slope: -2000m to -3000m	60 %	121,873.77	73,124.26	42,059.43	35 %	0.58	NO
Upper Slope: -3000m to -4500m	60 %	161.97	97.18	80.10	49 %	0.82	NO
Echinoderm fauna	35 %	454,648.24	159,126.88	220,367.56	48 %	1.38	YES
S5: Important areas for the Antarctic toothfish							
*Antarctic toothfish	60 %	12,184,233.76	7,310,540.26	3,976,555.61	33 %	0.54	NO
S6: Important areas for unique and diverse suspension feeding assemblages							
*Sponge presence	100 %	190,793.11	190,793.11	190,782.22	100 %	1.00	YES
S7: Rare and unique habitats							
Shallow water area - Norsel Bank	100 %	16.55	16.55	16.55	100 %	1.00	YES
S8: Important benthic areas for demersal fish							
*Demersal fish	75 %	17,392,505.04	13,044,378.78	11,450,001.4	66 %	0.88	NO
Nesting sites	100 %	8,815.46	8,815.46	8,814.33	100 %	1.00	YES
S9: High productivity areas							
Coastal polynyas (Habitat classification of 3 pelagic regions)							
Pelagic region - Coastal polynya I	100 %	7,546.77	7,546.77	7,546.77	100 %	1.00	YES
Pelagic region - Coastal polynya II	100 %	1,329.89	1,329.89	1,329.89	100 %	1.00	YES
Pelagic region - Coastal polynya III	100 %	87,979.17	87,979.17	87,969.34	100 %	1.00	YES

Notes: Specific conservation objectives S10-S12 are not mentioned in Tab. 3-2. S10 is reflected by all the conservation features listed above, rather than a unique feature, and we wanted to prevent a repeated listing of features. S11 and S12 defining research objectives which are not directly reflected by one of the above listed conservation feature data layers. Rather, both objectives will be developed in the context of a research fisheries strategy for Statistical Subarea 48.6 (see chapter 4.).