A dossier of data to assist marine protected area planning within the Del Cano- Crozet domain

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Introduction

CCAMLR is working towards establishing a representative system of marine protected areas (MPAs) within the Southern Ocean by 2012 in line with timelines set by the UN World Summit on Sustainable Development [1, 2]. At the CCAMLR MPA workshop held in Brest, France in 2011, scientists adopted nine domains to plan for and assess progress towards a representative system of MPAs. To assist the workshop to plan for MPAs within the Del Cano- Crozet planning domain, we have collated available data and described important environmental features for this domain. The data summarised includes the environmental drivers that influence the distribution of Southern Ocean biota, biological data and previous classifications of the benthic and pelagic environments. Existing protected areas are also outlined. Supplementary material of the distribution of the environmental data across all domains within the CCAMLR region is available as maps in appendix 1 and as tables downloadable from www.conservationgeography.org . Statistics regarding the coverage of sea ice, seabed temperature and persistent summer productivity across all domains is also provided in appendix 2.

Environmental drivers are the physico-chemical processes and other factors that set the habitat conditions and influence the distribution and abundance of taxa, including their connectivity between similar habitats [3]. Two major environmental drivers within the Southern Ocean are depth and geomorphology [4-8]. Niche separation of species can occur with depth giving rise to different assemblage structures within depth ranges which can be characterized as bathomes [9-11]. Geomorphic features are a classification of the seabed based on the attributes of the surface substratum. Different habitat characteristics are provided by a varying surface substratum including the availability of hard rock surfaces and the erosion or deposition of sediment and their physical attributes [6, 12]. For example, Antarctic shelf depressions eroded during glacial maxima now have low currents and fine sediments, providing appropriate habitats for mobile deposit feeder and infaunal communities [12-14]. Geomorphic mapping has also been identified as having utility for indicating where Vulnerable Marine Ecosystems (VME) might occur [12]. Geomorphic features known or predicted to support Vulnerable Marine Ecosystems include seamounts, seamount ridges, mid-ocean ridge rift valleys, volcanoes, margin ridges, margin plateaus and shelf commencing canyons [12]. For instance, mid-ocean ridge rift valleys are known sites of hydrothermal vents where VMEs occur [15]. Seamounts and seamount ridges are often regions of high biodiversity but are also vulnerable to impacts [16-19]. Shelf commencing canyons can contain vulnerable and species rich coral-sponge communities below the influence of iceberg scour [7]. Other important environmental drivers include seabed temperature, icebergs and sea ice coverage, sea-surface productivity and ocean currents [14, 20-22]. The spatial and temporal variability of seabed temperature contributes to the distribution and composition of benthic assemblages and is suspected to constrain the migration of benthic fauna which may lead to their genetic variation and eventual speciation [20, 23]. Ice regimes are a key structuring element in the ecology of the Antarctic benthos and pelagic environments [22, 24-27]. Sea surface productivity provides a vital food source and phytoplankton blooms are highest; (i) where frontal activity has created an upwelling of nutrient-rich water, (ii) down-stream from iron-rich landforms and

(iii) within the ice-melt zones and polynyas [25, 28-33]. Canyons can act as a conduit for organically laden bottom water that is generated in polynyas from rejected brine during ice formation. This process provides a mechanism for transfer of food nutrients to the benthos [34, 35].

Data

The data collated is listed in **Error! Reference source not found.**. The benthic classification was adapted for use at a domain scale by nesting geomorphic features and bathomes within each domain. Seamounts and seamount ridges were classed only according to the bathome into which their mount penetrated. Canyons were classed only by whether their head commenced on the shelf or slope. The pelagic regions were also assessed according to the ocean sector within which they occurred [36, 37]. The features within these two regionalisations were deemed 'critical' where the domain contained >90% of the feature area across all domains and 'very important' where the domain contained 75-90% of the feature area across all domains. Features were deemed 'important' where; (i) the domain contained between 50-75% of the feature area across all domains, (ii) a high amount relative to the other domains or, (iii) were highly spatially separated from the other locations of the feature (e.g. if the other locations are off the opposite side of the Antarctic continent or within a different ocean basin). An indication of the distribution in terms of the rarity and isolation of seamounts and seamount ridges was also determined. Seamounts and seamount ridges were grouped with other seamounts within a 200km proximity [3, 38]. A seamount was noted as rare and/ or isolated if it met one of two criteria; (i) it was one of two or less seamounts within the seamount group to have that specific bathome at its mount or, (ii) it was one of eleven or less seamounts within the Southern Ocean with that specific bathome at its mount. The Southern Ocean is defined here as the CCAMLR region. To identify areas of persistently high and persistently low summer productivity, the chlorophyll data was processed as per Constable et al., [39]. A dataset of polynya locations were created by cross referencing the sea ice data in table 1 with digitizing published data [including 32, 40, 41, 42]. Species richness was indicated by the number of species with a high probability of occurrence (i.e. >0.6) from an analysis of 879 marine species from the Aquamaps database [43, 44]. Aquamaps predicts the distribution of species using specifically designed models based on the species environmental tolerance to environmental drivers which is then refined by including occurrence data and expert knowledge of the species distribution. We also display penguin and seabird breeding colonies [45, 46].

Table 1: Circumpolar data collated for the analysis

Data	Spatial resolution	Temporal resolution	Source
Depth	1 minute	Not applicable	Smith and Sandwell, [47]
Geomorphology	1-12km	Not applicable	O'Brien *et al*,.[12]
Seafloor temperature	1 degree	Annual mean for 2005	Clarke et al., [23]
Sea surface chlorophyll-a	9km	Mean values for each austral summer season (20th Dec to 20thmarch) for years 1998-2010	Feldman and McClain, [48]
Sea ice concentration	6.25km	The proportion of the year where sea ice concentration was at least 85% derived from daily estimates during the 1st January 2003 to 31st December 2009	Spreen et al., [49]
Frontal systems	100km	Annual mean calculated across 1992–2007	Sokolov and Rintoul, [50]
Pelagic primary regionalisation	0.1 degree	Not applicable	Raymond [37]
Benthic classification	10-100km	Not applicable	Douglass et al., [3]
Marine protected area dataset	Not applicable	Not applicable	Douglass et al., [3]
AquaMaps	0.5 degree	Not applicable	Kaschner et al., [44]

Discussion

The 3.7 million Km^2 Del Cano-Crozet domain spans 11% of the CCAMLR region and is the 5th largest planning domain. The domain consists of abyssal environments (87%) and the oceanic shallow (4%) and associated slope environments (9%) of the Ob and Lena plateaus, the Crozet archipelago and the Prince Edward Islands. A quarter of the combined seamount and seamount ridge area within the CCAMLR region is located within the domain. The Del Cano-Crozet domain represents the ice-free and low ice environments of the Indian Ocean. The oceanic shallow areas associated with the plateaus and sub-Antarctic islands in the domain correspond with the warmest seabed temperatures in the Southern Ocean and also zones of high frontal activity.

The Del Cano-Crozet domain is important to protecting the seamount and seamount ridge habitats of the Southern Ocean. The 22 seamount ridges and 24 seamounts collectively represent 6 of the 9 bathomes at their mount. The majority of the seamounts with a mount in the 0-100m, 200-500m and 500-1000m bathomes are found in the Del Cano domain. Furthermore, the seamount associated with the Prince Edward Islands and the two seamounts to the east of the Lena bank are 3 of only 5 seamounts within the Southern Ocean to have a mount in the shallowest bathome of 0-100m. The domain ranks 6th of the domains for the total number of seamounts and seamount ridges it contains. However, it is 2nd only to the Bouvet Maud domain for the area spanned by these important environment types.

Within the Southern Ocean, plateaus occur mostly within the Kerguelen, South Georgia and Scotia sea regions, however the Del Cano domain is critical to representing shallow (<1500m) plateau environments. Del Cano is the only domain to contain plateau slope within the 100-200m and 200-500m bathomes and contains 99% and 85% of the plateau slope within the 500-1000m and 1000-1500m bathomes respectively. The region is also very important to representing shallow plateau within the 0-100m bathome. These shallow plateau environments are located on the Del Cano rise, around Iles Crozet and near the Ob and Lena banks. In addition, the abyssal plain around the Del Cano rise represents 62% of the shallowest abyssal plain (i.e 2000-3000m bathome) within the Southern Ocean with the remainder occurring in the Western Antarctic Peninsula.

The domain is a region of high frontal interaction with shallow topology since the polar front, Sub-Antarctic front and Antarctic circumpolar current front are all active within the domain. The entire polar front (i.e. the region between its most northerly and southerly positions) is within the domain and due to its location is likely to be highly interactive with the Ob and Lena plateaus. Similarly, the Sub-Antarctic front intersects with the ecosystems of the Prince Edward and Crozet islands.

The domain represents nine pelagic regions including the only patches of pelagic region 19 in the CCAMLR area. Pelagic region 19 is mostly located north of the CCAMLR area around South America, New Zealand, Tasmanian shelves and scattered temperate banks [37]. The majority of pelagic region 20 which represents shallow, ice-free areas within a warm sea surface temperature of 10-20°C, is located within the domain with the largest patches occurring around Iles Crozet and the Del Cano rise. The Del Cano and the Kerguelen domains are the only two domains to represent pelagic region 17 within the Southern Ocean. The domain consists primarily of the deep oceanic pelagic regions 15 and 16 with a sea ice zone of region 10 across the southern section of the domain.

Designated marine protection within the domain includes the French territorial nature reserves within the Crozet archipelago that span the marine regions around Ile aux Cochrons, Ile des Apotres, Ile des Pingouins and Ile de L'Est. The marine region surrounding Ile de la Possession is not currently included. These nature reserves span 0.2% of the domain and protect sections of plateau and plateau slope. All other features within the domain remain outside protected areas. There are marine protected areas proposed for the South African territory which would increase the protection of plateau, seamount ridges, seamounts, plateau slope, ocean troughs and rugose ocean floor

[51]. The Prince Edward Islands that are among the most biodiverse and pristine islands in the Southern Ocean have been added to the UNESCO's tentative list for World Heritage listing [51, 52, Figure 4].

Summary of environmental features (see figure 4)

Area 1

- High species richness
- Warmer seabeds within the CCAMLR region
- Seamount cluster and shallow environments that interact with the Sub-Antarctic front
- Representation of pelagic region16 and 17 in the Indian Ocean sector
- Representation of deeper seamounts within the three bathomes between 1500 and 4500m
- Representation of ocean troughs
- Representation of pelagic regions 16 and 17 within the Indian Ocean sector

Area 2

- Area within the South African exclusive economic zone
- High species richness
- Representation of the island ecosystems associated with the Prince Edward and Marion islands including many bird and seal breeding colonies including the white-chinned petrel and Antarctic fur seals
- Two of only five seamounts in the Southern Ocean to have a mount in the shallowest bathome of 0-100m.
- 1 of only 11 seamount ridges in the Southern Ocean with a mount in the 500-1000m bathome.
- 1 of only 8 seamounts in the Southern Ocean with a mount in the 200-500m bathome
- Warmer seabeds compared to other regions of the Southern Ocean
- Persistently high summer productivity
- Representation of pelagic regions 14, 16 and 17 within the Indian Ocean sector

Area 3

- High seas section of the Del Cano Rise
- High species richness
- Main region of shallow (1000-2000m) plateau slope and plateau environments to occur within the highseas of the domain
- The only representation of shallow abyssal plain in the Southern Ocean to be held within the high seas region of the domain
- The only 2 seamounts in the domain with a mount in the 1000-1500m bathome
- Interaction with the Sub-Antarctic front
- Representation of pelagic region16 within the Indian Ocean sector

Area 4

- Area within the French exclusive economic zone
- Representation of the island ecosystems associated with Iles Crozet including many bird and seal breeding colonies including the white-chinned petrel and Antarctic fur seals
- Interaction with the Sub-Antarctic front
- Persistently high productivity
- High species richness
- Representation of pelagic regions 13, 16 and 17 within the Indian Ocean sector
- The only two seamount ridges with a mount in the 3000-4000m bathome within the isolated seamount group

Area 5

- Ob and Lena banks
- The only representation of plateau within the 100-200m within the highseas of the Southern Ocean
- The only representation of plateau slope with depths between 100-500m within the highseas of the Southern Ocean
- Interaction with the polar front
- High species richness
- Warmer seabeds
- The only two seamounts with a mount in the 3000-4000m bathome within the isolated seamount group
- Representation of pelagic regions 13,14 and 15 within the Indian Ocean sector

Area 6

- The only seamount with a mount in the 200-500m bathome to occur within the highseas region of the domain. This seamount- bathome at mount combination is rare with only 2 occurring within the domain and 8 within the Southern Ocean.
- Two of only five seamounts in the Southern Ocean to have a mount in the shallowest bathome of 0-100m.
- Three other rare and/or isolated seamounts
- Interaction with the polar front
- Warmer seabeds
- Representation of pelagic regions 13,14 and 15 within the Indian Ocean sector
- Representation of both shallow and deep environments including ocean troughs

Area 7

- High species richness corresponding with three seamounts with mounts in the 500-1000m and 1500-2000m bathomes
- The only seamount with a mount in the 2000-3000m bathome in the seamount group
- Warmer seabeds
- Interaction with the polar front
- Representation of pelagic regions 15 and 16 within the Indian Ocean sector

Area 8

- Representation of sea ice environments within the Del-cano domain that have high ice cover for 1-30% of the year
- Seamount with a cold seabed relative to other seamounts in the domain
- Interaction with the ACC front
- Representation of deeper environments within the domain
  Representation of pelagic regions 10 and 15 within the Indian Ocean sector

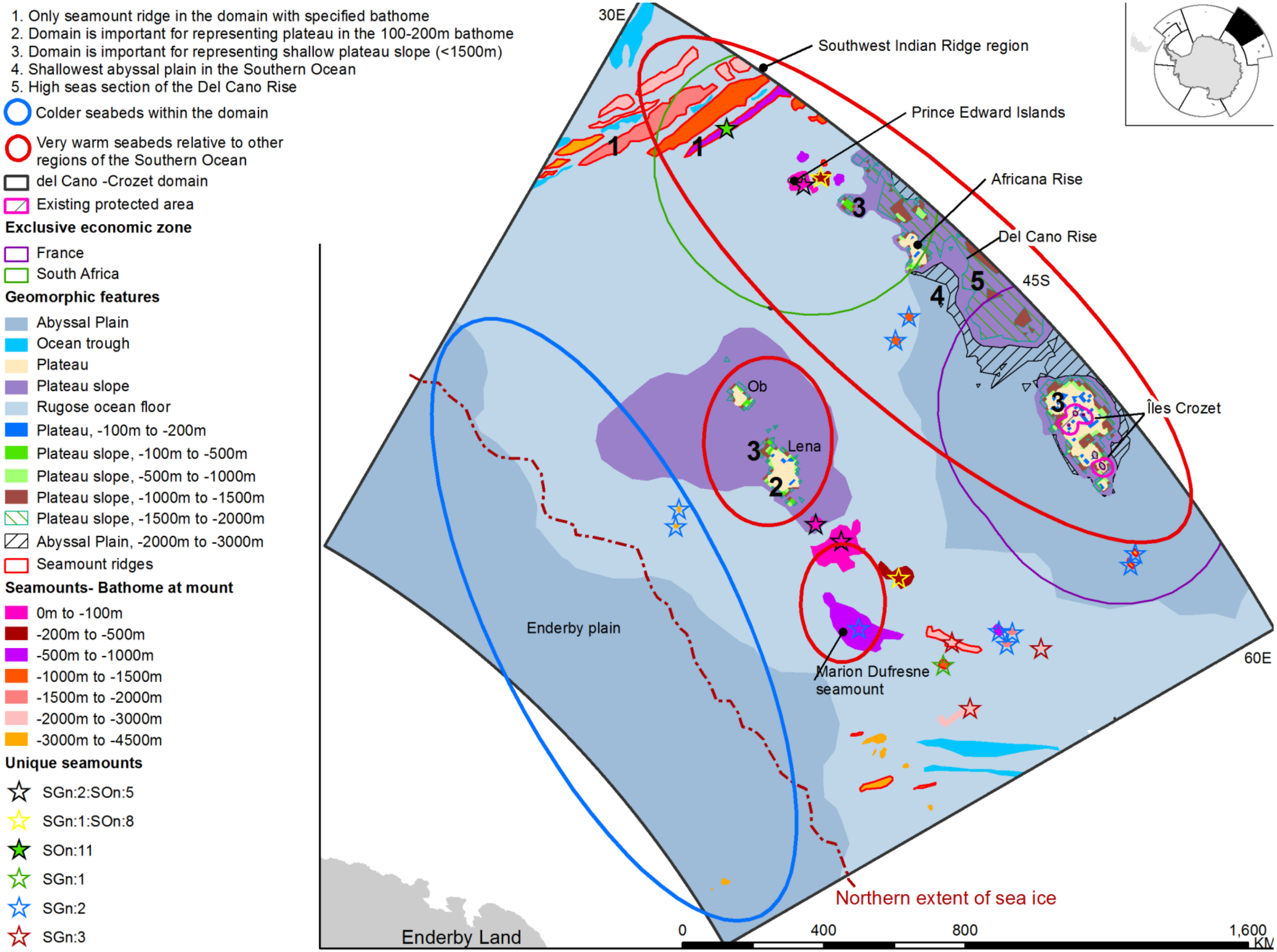

Figure 1: Benthic features of the Del Cano-Crozet domain. To interpret the unique seamounts code, The number beside 'SGn' is the number of seamounts or seamounts ridges with a specific bathome located within the seamount group. The number beside 'SOn' is the number within the CCAMLR Southern Ocean region. For instance, for SGn:2:SOn:5, there are two seamounts with a similar bathome in the seamount group (i.e within 200km) and only five seamounts with this bathome in the Southern Ocean.

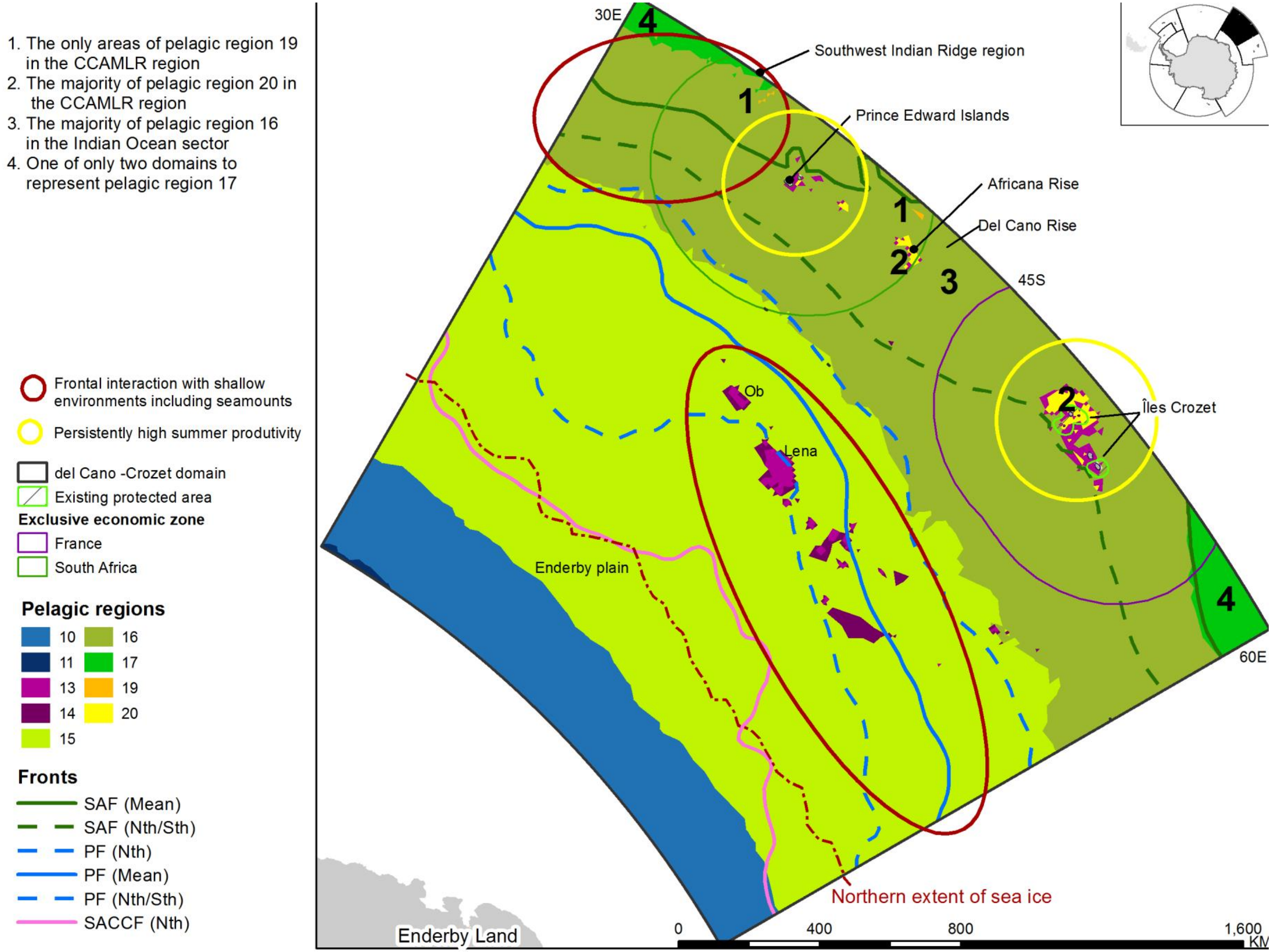

Figure 2: Pelagic features of the Del Cano-Crozet domain

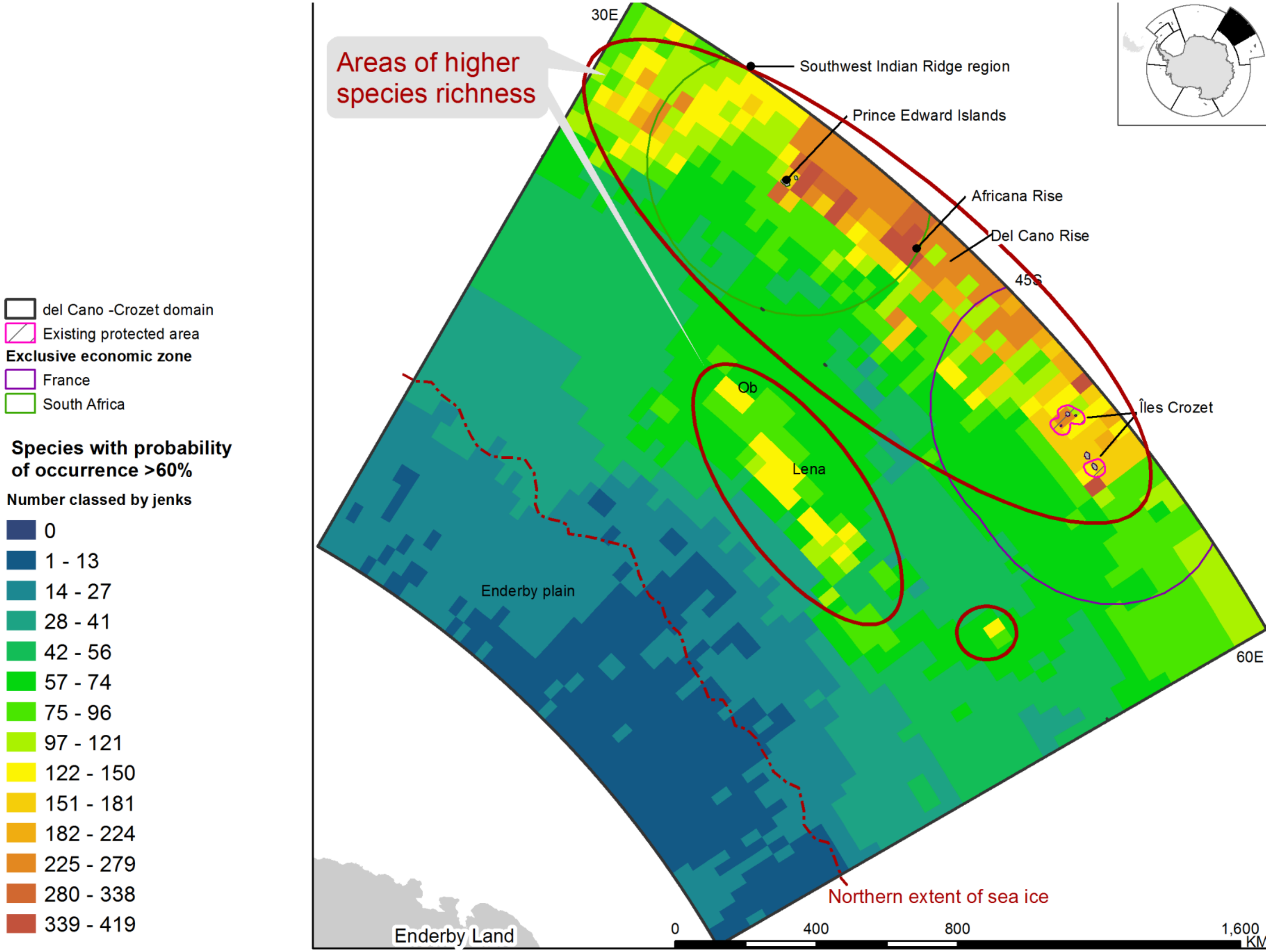

Figure 3: Species richness of the Del Cano-Crozet domain

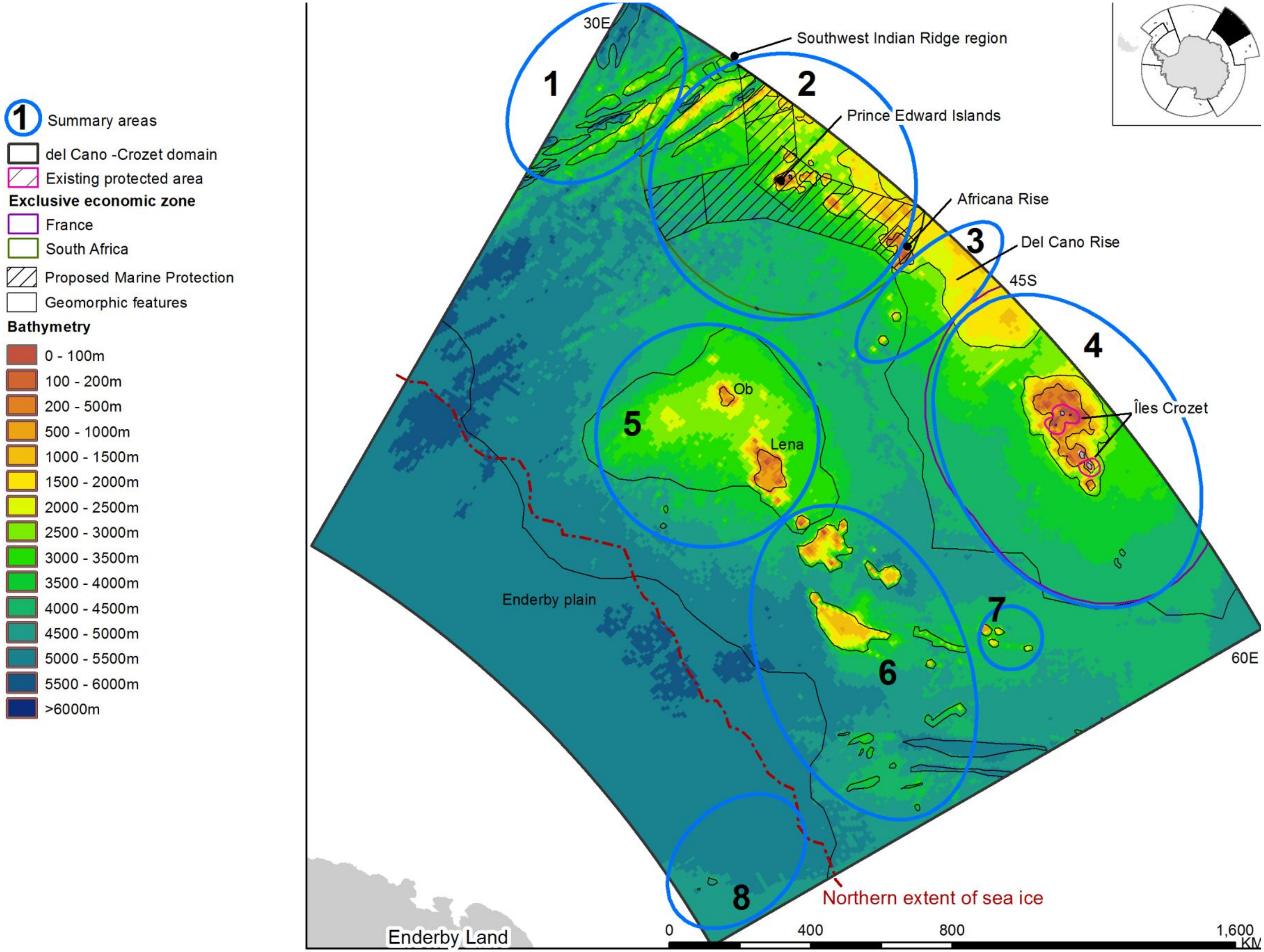

Figure 4: Summary of environmental features within the Del Cano-Crozet domain

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