Towards higher predator ecoregionalisation of the pelagic zone in the subantarctic and subtropical Indian Ocean

R.R. Reisinger[1✉], A.B. Makhado[2,3], K. Delord[4], C.A. Bost[4],
M.A. Lea[5,6] and P.A. Pistorius[7]

[1] School of Ocean and Earth Science, University of Southampton,
Southampton United Kingdom.

[2] Department of Forestry, Fisheries and the Environment, Oceans and Coasts
Cape Town, South Africa.

[3] FitzPatrick Institute of African Ornithology, University of Cape Town
Cape Town, South Africa.

[4] Centre d'Etudes Biologiques de Chizé
CNRS-UMR 7372/La Rochelle Université, F-79360
Villiers en Bois, France.

[5] Ecology and Biodiversity Centre, Institute for Marine and Antarctic Studies,
University of Tasmania
Hobart, Tasmania, Australia.

[6] Australian Centre for Excellence in Antarctic Science
University of Tasmania
Hobart, Tasmania, Australia

[7] Marine Apex Predator Research Unit, Department of Zoology,
Institute for Coastal and Marine Research, Nelson Mandela University
Gqeberha 6031, South Africa.

Email: r.r.reisinger@southampton.ac.uk

Abstract

Numerous seabird and marine mammal species occur, often in high abundance, in the subtropical and subantarctic zones of the southern Indian Ocean. They breed, moult and rest at French, South African and Australian islands in the region and forage at sea in areas including the Exclusive Economic Zones of these nations, Areas Beyond National Jurisdiction and also the area to which the Convention on the Conservation of Antarctic Marine Living Resources applies. Information on the at-sea distribution of these species is important for understanding ecosystem patterns and processes in the region, and is a key component of any spatial conservation and management frameworks. Information on the distribution of marine predators is widely used to define priority areas for conservation and management, with several such initiatives already having been implemented in the extended Southern Ocean. Seabird and marine mammal distribution has been studied mainly using two methods: animal-borne biotelemetry/biologging and at-sea sighting records. Here, we give an overview of data on the distribution of marine mammals and seabirds – collected mainly through long-term tracking programmes at French and South African islands – with the aim of identifying data sources that can inform pelagic ecoregionalisation to support spatial conservation and management planning in this region. We identify priorities for further distribution data collection related to life-history stages, sites and species and we identify broader challenges for understanding marine predator distribution in this region, towards spatial conservation and management planning.

Résumé

De nombreuses espèces d'oiseaux et de mammifères marins sont présentes, souvent en grand nombre, dans les parties subtropicales et subantarctiques du sud de l'océan Indien. Elles se reproduisent, muent et se reposent dans les îles françaises, sud-africaines et australiennes de la région et se nourrissent en mer dans des zones comprenant les zones économiques exclusives de ces pays, les zones situées au-delà des juridictions nationales et la zone à laquelle s'applique la Convention sur la conservation de la faune et la flore marines de l'Antarctique. Les informations sur la répartition géographique en mer de ces espèces sont importantes pour comprendre les schémas et les processus écosystémiques dans la région, et constituent un élément clé de tout cadre spatial de conservation et de gestion. Les informations sur la répartition des prédateurs marins sont largement utilisées pour définir les zones prioritaires pour la conservation et la gestion, plusieurs initiatives de ce type ayant déjà été mises en œuvre dans la zone élargie de l'océan Austral. La répartition des oiseaux et des mammifères marins a été étudiée principalement à l'aide de deux méthodes : la biotélémétrie/le biologging à l'aide de balises portées par les animaux, et les repérages visuels en mer. Ici, nous donnons un aperçu des données sur la répartition géographique des mammifères et des oiseaux marins, collectées principalement grâce à des programmes de suivi à long terme dans les îles françaises et sud-africaines, dans le but d'identifier les sources de données qui peuvent informer l'écorégionalisation pélagique, afin de favoriser la conservation spatiale et la planification de la gestion dans cette région. Nous identifions les priorités pour la collecte d'autres données de distribution liées aux étapes du cycle vital, aux sites et aux espèces et nous identifions des enjeux plus importants pour la compréhension de la distribution des prédateurs marins dans cette région, dans une optique de conservation spatiale et de planification de la gestion.

Абстракт

В субтропических и субантарктических зонах южной части Индийского океана обитают многочисленные виды морских птиц и морских млекопитающих, часто в больших количествах. Они размножаются, линяют и отдыхают на французских, южноафриканских и австралийских островах в данном регионе, а кормятся в море в районах, которые включают исключительные экономические зоны этих стран, районы за пределами национальной юрисдикции, а также зону, на которую распространяется Конвенция о сохранении морских живых ресурсов Антарктики. Информация о распределении этих видов в море важна для понимания экосистемных моделей и процессов в регионе и является ключевым компонентом любых стратегий пространственного сохранения и управления. Информация о распределении морских хищников широко используется для определения приоритетных районов для сохранения и управления, и несколько таких инициатив уже реализовано на обширной территории Южного океана. Распределение морских птиц и морских млекопитающих изучалось в основном с помощью двух методов: биотелеметрии или биологического мониторинга с помощью устройств, установленных на животных, и регистрации наблюдений в море. В данной работе представлен обзор данных о распределении морских млекопитающих и морских птиц, собранных в основном в ходе долгосрочных программ отслеживания на французских и южноафриканских островах, с целью выявления источников данных, которые могут быть использованы для экорегионализации пелагических зон в целях содействия планированию сохранения и пространственного управления в данном регионе. В работе выявлены приоритетные направления дальнейшего сбора данных о распределении, связанных с этапами жизненного цикла, местами обитания и видами, а также определены более общие задачи по изучению распределения морских хищников в данном регионе в целях планирования сохранения и пространственного управления.

Resumen

Las zonas subtropicales y subantárticas del sur del Océano Índico sirven de hábitat para numerosas especies de aves y mamíferos marinos, a menudo con poblaciones muy abundantes. Esas especies se reproducen, mudan y descansan en las islas francesas, sudafricanas y australianas de la región y su espacio de búsqueda de alimento en el mar incluye las Zonas Económicas Exclusivas de estas naciones, las Áreas Fuera de Jurisdicción Nacional y el Área de la Convención sobre la Conservación de los Recursos Vivos Marinos Antárticos. La información sobre la distribución en el mar de esas especies es importante para comprender las pautas y procesos de los ecosistemas de la región, y es un componente clave en todo enfoque de conservación y ordenación espacial. La información sobre la distribución de los depredadores marinos se utiliza a menudo para definir las zonas prioritarias de conservación y ordenación. El Océano Austral y sus aledaños ya han visto implementadas varias iniciativas de este tipo. La distribución de las aves marinas y los mamíferos marinos se ha estudiado principalmente mediante dos métodos: la biotelemetría/biologging con animales y los registros de avistamientos en el mar. Aquí presentamos una visión general de los datos sobre la distribución de mamíferos marinos y aves marinas —recogidos principalmente por programas de seguimiento a largo plazo en islas francesas y sudafricanas— con el objetivo de identificar fuentes de datos que puedan informar la ecorregionalización pelágica con fines de conservación espacial y de planificación de la ordenación en esta región. Identificamos las prioridades para la recopilación adicional de datos de distribución relacionados con las etapas del ciclo vital, los sitios y las especies, e identificamos temas de investigación a abordar para el conocimiento de la distribución de los depredadores marinos en esta región, de cara a los fines ulteriores de conservación espacial y planificación de la ordenación.

Introduction

The subtropical and subantarctic zones of the southern Indian Ocean region (here defined as the area 20°W to 160°E and 30°S to 60°S; Makhado et al. 2023, Fig. 1) host rich marine mammal and seabird communities. These breed on islands in French (Saint Paul and Amsterdam Islands, Crozet Islands, Kerguelen Islands), South African (Prince Edward Islands) and Australian (Heard Island and McDonald Islands) territories and utilise the waters in the Exclusive Economic Zones (EEZs) of these nations as well as the area which the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) manages.

A rich diversity of marine predator species breeds in the French Island EEzs, including 51 seabird species (including six[1] penguin species, 32 albatross and petrel species and four endemic species) and three seal species (Delord and Duriez, 2012). Their counterparts, South Africa's Prince Edward Islands, provide terrestrial breeding and moulting sites for three seal species, and breeding sites for 30 seabird species including four penguin species, five albatross species, 14 petrel species, and five further seabird species (Ryan and Bester, 2008). Three species of seal, 15 species of flying seabird and four penguin species breed on Australia's Heard and McDonald Islands and three non-breeding penguin species and nine non-breeding flying seabird species have been recorded there (Meyer et al., 2000).

In their assessment of Southern Ocean birds and marine mammals, Bestley et al. (2020) identify the key impact that environmental change has had on birds and marine mammals, as well as identifying interactions with factors including direct and indirect fisheries interactions, global pollution, diseases and land-based disturbances (see also Trathan et al., 2007; Constable et al., 2014; Peron et al., 2012; Delord et al., 2013; Delord et al., 2014; Gutt et al., 2021; Gimeno et al., 2024).

Populations of seabirds and marine mammals are monitored in the French Southern Territories, in the framework of the long-term monitoring projects 'Seabirds and Marine Mammals as Sentinels of Global Change in the Southern Ocean' (Project 109 ORNITHOECO, principal investigator C. Barbraud) and 'Foraging Ecology and Energetics of Southern Diving Predators in Relation to Climatic Variability' (Project 394 OISEAUX PLONGEURS OIPLO, principal investigator C.-A. Bost), supported by the French Polar Institute Paul Emile Victor (IPEV). At the Prince Edward Islands, long-term monitoring and research on seabirds and marine mammals has been conducted by South African universities and the Department of Forestry, Fisheries and the Environment for several decades (Hänel and Chown 1999; Ryan and Bester, 2009) under the South African National Antarctic Programme (SANAP). Seabird and marine mammal studies are conducted periodically at Heard and MacDonald Islands (Goldsworthy, 1995; Slip and Burton, 1999; Page et al., 2003; Staniland et al., 2010; Wienecke and Robertson, 2006) in line with the Heard and MacDonald Islands Marine Reserve Management Plan 2014–2024 (Commonwealth of Australia, 2014).

Marine higher predators, such as marine mammals and seabirds, are increasingly treated as indicators in marine ecosystems: their position at or near the top of marine food webs means they integrate information about lower trophic levels and biophysical conditions (Hazen et al., 2019). One of the most straightforward such indicator metrics is the spatial distribution of higher predators, which is often indicative of biologically rich areas (Raymond et al., 2015; Reisinger et al., 2018; Hindell et al., 2020).

Information on the spatial distribution of marine predators is critical for understanding marine biological processes, assessing natural and anthropogenic effects on these processes, developing response actions to catastrophic events, and formulating long-term management strategies for marine resources.

Distribution has been studied mainly using two methods: animal-borne biotelemetry / biologging and at-sea sightings records. These two types of data have been used in a number of broad efforts to identify important spatial areas for marine mammals and seabirds in the extended Southern Ocean, including Areas of Ecological Significance

1 King penguin, gentoo penguin, Adélie penguin, eastern rockhopper penguin, northern rockhopper penguin, macaroni penguin.

(AES, Hindell et al., 2020), Important Marine Mammal Areas (IMMA, Tetley et al., 2022), marine Important Bird and Biodiversity Areas (mIBA, Delord et al., 2014; Lascelles et al., 2016; Handley et al., 2021) and Key Biodiversity Areas (KBAs, Becker et al., 2025).

Here, we give an overview of data on the distribution of marine mammals and seabirds in the subtropical and subantarctic zones of the southern Indian Ocean region, with the aim of identifying data sources that can inform pelagic ecoregionalisation to support spatial conservation planning in this region. We also identify data gaps and priorities for further data collection.

Spatial distribution

Biologging datasets

Online databases such as Movebank (https://www.movebank.org/) aim to help researchers archive and analyse animal tracking data and make these datasets discoverable and reusable (Kranstauber et al., 2011; Kays et al., 2022). Relevant here is BirdLife International's Seabird Tracking Database (https://www.seabirdtracking.org/), which on 30 May 2024 held 53 288 tracks for 168 seabird species, including most of the seabird tracking data that has been collected within the southern Indian Ocean. There have been a number of regional multi-species efforts, and a circumpolar effort, to combine multi-species biotelemetry data for analysis, with the most relevant to spatial prioritisation being outlined below.

France: French Southern Territories

Delord et al. (2013) summarised biotelemetry data for ~800 individuals from 22 bird and seal species tracked in the French Southern Territories over 20 years. Species richness maps created from these data identify several important areas for higher predators in subantarctic and subtropical waters, including the breeding colonies and their surrounding zones, upwelling-current zones (Benguela and Agulhas Currents Systems) and several oceanic zones. Some of these data were used in regional analyses centred on Amsterdam Island (Heerah et al., 2019) and the Kerguelen Islands (Thiers et al., 2014) and for an analysis identifying important areas for ten seabird species (Delord et al., 2014).

South Africa: Prince Edward Islands

Analysis of biotelemetry data from 538 individuals of 14 bird and marine mammal species tracked from the Prince Edward Islands has identified areas of high mean importance located broadly from the Subtropical Zone to the Polar Frontal Zone in summer and from the Subantarctic to Antarctic Zones in winter (Reisinger et al., 2018). Areas of high mean importance were best predicted by factors including wind speed, sea surface temperature, depth and current speed (Reisinger et al., 2018). These data are available in Reisinger et al. (2018), with data for a subset of the species included in the Retrospective Analysis of Antarctic Tracking Data (RAATD) project (see below).

Australia: Heard Island and McDonald Islands

In the 2003/2004 austral summer, 178 individuals from five seabird and seal species were tracked from Heard Island (Patterson et al., 2016). Tracking data were used to predict areas of likely high foraging value for each species, and to quantify the overlap of these areas (Patterson et al., 2016). These data contributed to the Retrospective Analysis of Antarctic Tracking Data (RAATD) project (see below) and the recent expansion of the Heard and Macdonald Islands Marine Reserve (Federal Register of Legislation – Environment Protection and Biodiversity Conservation (Heard Island and McDonald Islands Marine Reserve) Amendment Proclamation 2024, https://www.legislation.gov.au/F2024L01644/asmade/text).

The Retrospective Analysis of Antarctic Tracking Data (RAATD) project

Ropert-Coudert et al. (2020) assembled biotelemetry data for ~4,600 individuals of 17 bird and mammal species, and Hindell et al. (2020) used these data to predict circumpolar habitat selection for each species. They combined these predictions to identify circumpolar 'Areas of Ecological Significance', including areas in the region 20°W to 160°E and 30°S to 60°S – our region of interest. However, predictions extend only north to 40°S, omitting northern Subantarctic and southern Subtropical zones. Reisinger et al. (2022a) used the habitat selection predictions for each species to statistically delineate 17 'predator ecoregions' south of 40°S (Figure 1). Several of these predator ecoregions – mainly 'Distant subantarctic' and 'subantarctic' ecoregions – lie in our region of interest but areas north of 40°S are not classified (Figure 1).

At-sea sightings

At-sea sightings, often during dedicated surveys, are a second major source of information on the distribution of marine higher predators. Sightings, particularly when collected in a standardised manner, can provide information on the distribution, seasonality, and ecology of marine higher predators (e.g. Péron et al., 2010; Branch, 2011; Ainley et al., 2012).

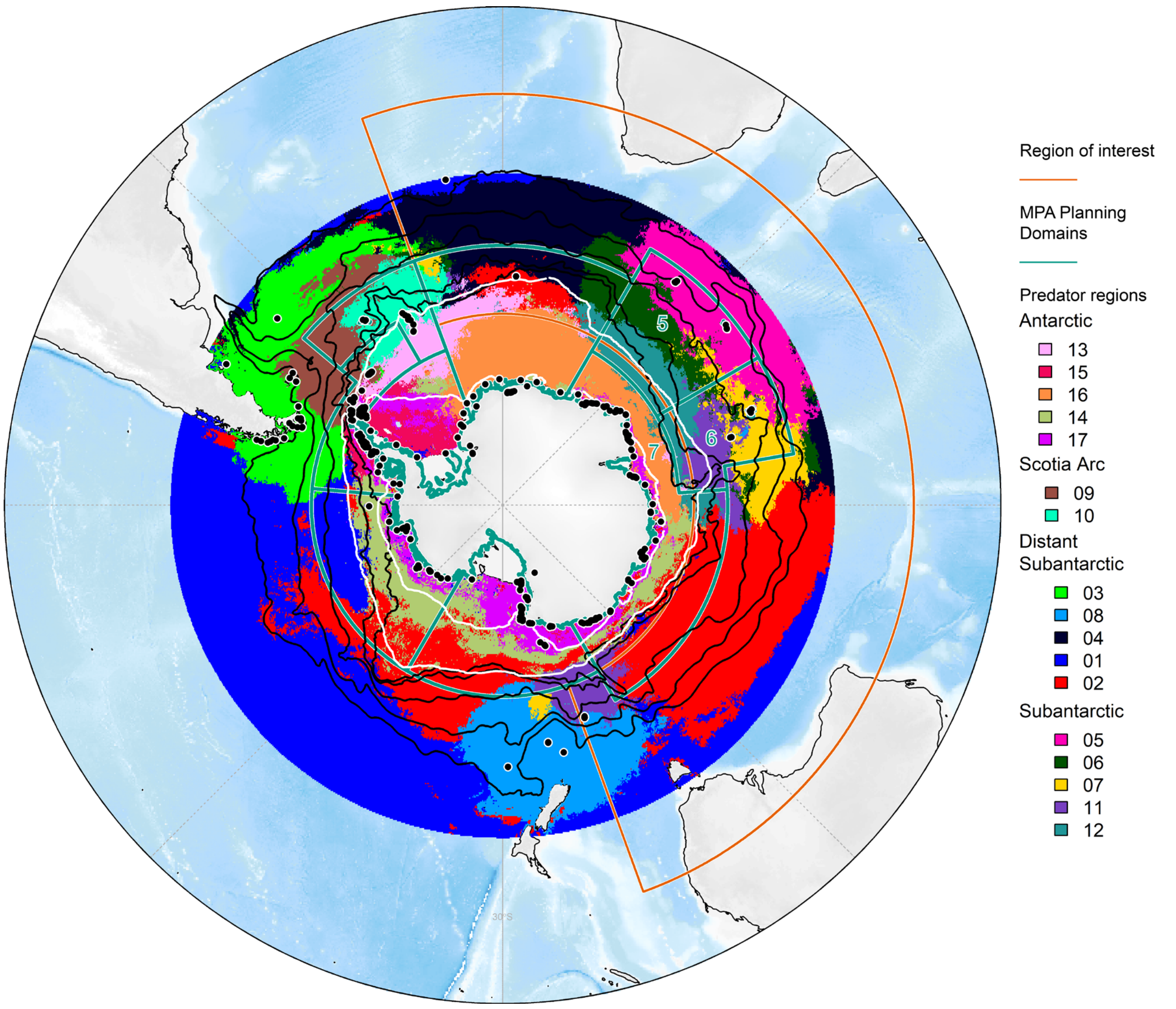

Figure 1: Predator-derived bioregions resulting from clustering of habitat importance scores of 17 marine predator species. The clusters are aggregated into four higher-level regions: Antarctic, Scotia Arc, Distant Subantarctic and Subantarctic. Enclosed with an orange polygon is the subtropical and subantarctic zones of the southern Indian Ocean region as defined by Makhado et al. (2023). Black points indicate colony locations for the 14 colony-breeding species, from Hindell et al. (2020). Black lines indicate fronts associated with the Antarctic Circumpolar Current (ACC) (from north to south, the northern boundary of the ACC, the Subantarctic Front, the Polar Front, the Southern Antarctic Circumpolar Current Front, and the southern boundary of the ACC) from Park and Durand (2019), and white lines indicate median sea ice extent from 1981 to 2010 in September (maximum sea ice) and March (minimum sea ice) (Fetterer et al., 2017). Teal lines indicate the Commission for the Conservation of Antarctic Marine Living Resources' Marine Protected Area planning domains, with domains 5, 6 and 7 labelled. Bioregions data from Reisinger et al. (2022a). Marine Protected Area planning domain data from the CCAMLR GIS repository: https://github.com/ccamlr/data/tree/main/geographical_data/mpapd (CC0 licence).

South African data

Within the study area, at-sea sightings of seabirds enroute to the Prince Edward Islands were obtained from the Atlas of Seabirds at Sea (AS@S) and BirdLasser, a collaboration between Department of Forestry, Fisheries and the Environment, BirdLife South Africa and the University of Cape Town. A total of 112 514 birds have been recorded on the AS@S database. Makhado et al. (unpublished data) analysed a subset of this dataset, supplemented with data from surveys aboard the SA Agulhas travelling from Cape Town to Marion Island annually between April and May (2016, 2018 and 2019). The resulting dataset comprises 2 284 transects, covering a total of 77 893 km from 2016–2019. From 2016–2021, 32 505 birds of 82 species were identified (Makhado et al., unpublished data). Marine mammals were encountered during the transects, but those data are not included in Makhado et al. (unpublished data). Some cetacean presence data in and around the South African mainland EZZ, overlapping with the northern extent of our region of interest, are reported in Purdon et al. (2020), sourced mainly from the Whale Unit of the Mammal Research Institute at the University of Pretoria and the Ocean Biogeographic Information System Spatial Ecological Analysis of Megavertebrate Populations (OBIS-SEAMAP) (Halpin et al., 2009).

French Southern Territories data

At-sea sightings data have been collected since 1978 on board the R.V. *Marion Dufresne I* and *II* during logistic or oceanographic cruises between La Réunion Island (21°06’S; 55°6’E) and the French subantarctic islands of Crozet (46°30’S; 51°00’E) and Kerguelen (49°30’S; 69°30’E) (see Péron et al., 2010; Chaigne et al., 2024). A total of 530 000 birds, 2 400 pinnipeds and 4 000 cetaceans have been observed during the survey. The dataset comprises 4 900 transects, covering 133 000 km.

Australian data

The Seabirds of the Southern and South Indian Ocean (Australian Antarctic Data Centre 2022) contains 153 820 records of seabird and marine mammal observations collected from 1977–2006, from ships performing marine science work or taking personnel and cargo to Antarctic stations. The dataset also includes data from the Biological Investigation of Marine Antarctic Systems and Stocks (BIOMASS) cruises in the 1980s. See also Woehler and Raymond (1999).

Biogeographic Atlas of the Southern Ocean

As part of the Biogeographic Atlas of the Southern Ocean (De Broyer et al., 2014), Ropert-Coudert et al. (2014) published maps of sightings data, collected from 1955–2011 and south of 40°S, for penguins (nine species), flying seabirds (>38 species), seals (seven species) and cetaceans (14 species). Some of the cetacean sightings data published in Ropert-Coudert et al. (2014) are from the comprehensive surveys of cetaceans in the Southern Ocean conducted over a 32-year period (1978 – -2010). This was under the guidance of the International Whaling Commission (IWC), initially as a component of the International Decade of Cetacean Research (IDCR). The annual Southern Ocean Whale and Ecosystem Research Programme (SOWER) cruises covered an estimated 400 000 km in the area south of 60°S. The Antarctic continent was circumnavigated three times and 43 000 sightings of cetaceans were made, including, notably, 25 333 sightings of Antarctic minke whales (*Balaenoptera bonaerensis*) and 400 sightings of Antarctic blue whales (*Balaenoptera musculus intermedia*) (https://iwc.int/scientific-research/sower).

Bird and marine mammal spatial prioritisation

AESs: Areas of Ecological Significance

Hindell et al. (2020) used the RAATD dataset (Ropert-Coudert et al., 2020) to predict circumpolar habitat selection for 17 seabird and marine mammal species. These predictions were used to calculate a ‘mean habitat importance’ layer in which the most important areas (top 10% of values) were defined as ‘Areas of Ecological Significance’ (Hindell et al., 2020). The rationale being that areas preferred by multiple marine predator species (that is, areas of high mean habitat importance), should indicate high levels of lower trophic biomass and biodiversity.

IMMAs: Important Marine Mammal Areas

Important Marine Mammal Areas (IMMAs) are an initiative of the Marine Mammal Protected

Areas Task Force of the International Union for the Conservation of Nature (Notarbartolo di Sciara and Hoyt, 2020). Resulting from an expert-driven process, IMMAs 'identify discrete portions of habitat that are important for one or more marine mammal species, and that have the potential to be delineated and managed for conservation' (Tetley et al., 2022). During a 2018 workshop, experts proposed 15 candidate IMMAs, of which 13 have been defined as IMMAs (IUCN Marine Mammal Protected Areas Task Force 2020). Tracking data from the RAATD project (Ropert-Coudert et al., 2020), the Prince Edward Islands (Reisinger et al., 2018) and the CEBC-CNRS Marine Top Predators Team (unpublished dataset) were a key information source for delineating the extended Southern Ocean IMMAs. IMMA spatial data can be obtained from https://www.marinemammalhabitat.org/immas/imma-spatial-layer-download/.

mIBAs: Marine Important Bird and Biodiversity Areas

BirdLife International's Important Bird and Biodiversity Area (IBA) Programme uses objective and transparent criteria to define sites of key conservation importance at global and regional scales (Fishpool and Evans, 2001). To qualify as an IBA, a site must hold a regular presence of a threshold number of birds (≥1% of the global or biogeographic population); threatened species (e.g., IUCN Endangered or Critically Endangered) with small populations may not have to meet this abundance criterion (Lascelles et al., 2016). Lascelles et al. (2016) developed methods to standardise the analysis of tracking data to identify marine IBAs. Using a global compilation of seabird tracking data (http://www.seabirdtracking.org/), including 60 species from 55 locations, the authors delineated 1052 polygons that triggered three mIBA criteria >1500 times together. The subtropical and subantarctic zones of the southern Indian Ocean region have a very high number of these mIBAs (Lascelles et al., 2016, Figure 6). Earlier, Delord et al. (2014) had used CEBC-CNRS tracking data for ten seabird species from the French southern territories to identify 19 candidate mIBAs in the region 20°S–70°S, 10°E–150°E. These mIBAs often corresponded to large-scale oceanographic structures considered to be key foraging habitats for many species (Delord et al., 2014).

Key Biodiversity Areas (KBAs)

The Key Biodiversity Area (KBA) Standard is a standardised framework established to identify sites essential for the persistence of global biodiversity, using specific criteria and quantitative thresholds (IUCN 2016). Becker et al. (2025) used tracking data for 14 species of Antarctic and subantarctic seabirds and pinnipeds, from the RAATD dataset (Ropert-Coudert et al., 2020), to identify 30 potential KBAs for 13 species, distributed throughout the Southern Ocean. Abundance estimates at each site were compared to thresholds for KBA Criteria A1 (globally threatened species), B1 (geographically restricted species) and D1 (demographic aggregations[2]) (Becker et al., 2025). The KBAs thus indicate sites vital for each specific individual species, population, and life-history stage for which they were determined. Several of the KBAs are in our region of interest, including extensive albatross KBAs (Becker et al., 2025, Figure 2).

Marine spatial planning for biodiversity conservation

As part of the Kunming-Montreal Global Biodiversity Framework (GBF), parties aim, by 2030, to ensure that at least 30% of land, water and seas, particularly areas important for biodiversity and ecosystem functions and services, 'are effectively conserved and managed through ecologically representative, well-connected and equitably governed systems of protected areas and other effective area-based conservation measures' (Target 3; Convention on Biological Diversity, 2022). Moreover, Target 1 is to ensure that 'all areas are under participatory, integrated and biodiversity inclusive spatial planning and/or effective management processes addressing land- and sea-use change' (Convention on Biological Diversity, 2022).

Within the CCAMLR Convention area (but outside EEZs), CCAMLR committed in 2002 to

2 Defined as geographically-restricted aggregations of individuals of a species, at high relative abundance, during life-cycle processes such as breeding, feeding or migration (IUCN, 2016, p. 11; KBA Standards and Appeals Committee, 2019. p. 33).

establishing a representative network of Marine Protected Areas (MPAs) but has only designated two (Brooks et al., 2020). Two proposed MPA networks – the East Antarctic MPA and the Weddell Sea MPA – lie south of our region of interest. Within our region of interest, South Africa, Australia, and France have designated or proposed MPAs in their EEZs around subantarctic islands.

Large areas of our region of interest are outside any EEZs, but within the CCAMLR Convention Area (specifically, MPA Planning Domains 5, 6 and North of 7); further, the BBNJ Agreement (Agreement under the United Nations Convention on the Law of the Sea on the Conservation and Sustainable Use of Marine Biological Diversity of Areas Beyond National Jurisdiction, 2023) provides a potential mechanism for establishing protection in the subantarctic high seas outside the CCAMLR Convention Area.

Marine spatial planning (Ehler, 2021) is the current gold standard for designing MPAs, and the Pelagic high seas ocean ecoregionalisation of the Indian subantarctic (PHOCIS) project (Makhado et al., 2023) includes an integrated ocean management (marine spatial planning) work package towards a pelagic subantarctic Indian High Seas Representative System of MPAs. The PHOCIS study region (Figure 1) is biogeographically defined and thus extends north of the CCAMLR Convention area into the adjacent areas managed by Regional Fisheries Management Organisations (RFMOs). Implementing representative protected areas in the region will thus require agreements among CCAMLR, the RFMOs, the BBNJ Treaty as well as the nations with EEZs in the region (South Africa, France and Australia).

While PHOCIS considers only the pelagic environment, a second complementary project is underway to provide a scientific base for improved protection in South Africa's Prince Edward Islands (led by the NGO WildOceans in South Africa). Negotiations are underway with funders to expand the study area of this work to the entire PHOCIS planning domain (excluding areas within EEZs), which will allow benthic data to be considered as well.

The data sets and prioritisations described here can a) be used to inform on ecological pattern and process in the region, and b) used as data in a formal marine spatial planning exercise. Further, regionalisations based on these data can contribute to ensuring that proposed MPAs are ecologically representative.

Gaps and challenges

These data and information sources lay the groundwork for a marine higher predator ecoregionalistion to support spatial conservation planning in the subtropical and subantarctic zones of the southern Indian Ocean region. However, key data gaps and challenges remain.

Distribution data gaps

Regarding biologging data, data gaps concern a) life-history stages of some species, b) certain breeding colonies, and c) species. In the biologging datasets for French Southern Territories population, gaps broadly concern 19 data deficient species: i) Life history stage gaps include breeding *Eudyptes* penguins; ii) Breeding colonies gaps include small to medium sized albatrosses (mollymawks: *Thalassarche* spp.) as the important population breeding at Iles Froîdes (Apôtres Is. and Pingouins Is.) in the Crozet archipelago; iii) Species gaps include small to medium sized petrels such as prions (e.g. Salvin's prion (*Pachyptila salvini*)) and gadfly petrels.

At the Prince Edward Islands, a data gap is a lack of biologging data for colonies on Prince Edward Island (which does not have a continuous research presence like Marion Island). Previous life history stage gaps for some species, and gaps on the diet and foraging ecology of some albatross, petrel and prion species are being addressed through recent and ongoing work.

Updated biologging data from Heard Island and McDonald Islands is another important general gap. Collecting distribution data for many cetacean species is also a priority.

Broad challenges

We have described several datasets with varying spatial and temporal extents, relevant to ecoregionalisation within the Southern Ocean. Within the scope of the project defined by Makhado et al. (2019), work is required to extend existing initiatives spatially and temporally by harmonising disparate datasets and data types into a form that can be analysed to produce a robust higher predator ecoregionalisation for the region of interest. Challenges here are broadly related to current scientific data principles (e.g. Wilkinson et al., 2016), specifically the accessibility/availability of datasets for re-use, and accurate data descriptions to minimise data duplication across datasets when harmonising them (e.g. avoiding duplicate biologging tracks or sightings across datasets). A near-term focus will be on using these data to determine the distribution and characteristics of higher predator assemblages to inform spatial prioritisations. A related priority will then be to identify spatial overlap of these communities with pressures such as fishing.

Further information is required on the foraging ecology, especially diet, of several species, such as mollymawks (*Thalassarche* spp.) and small petrels. This will allow an approach at the higher predator community-scale. More generally, information on the distribution and abundance of prey species in the region is required. Related to this, a priority is linking active acoustic survey data, as a proxy for the prey field with the distribution and density of higher predator assemblages (e.g. Proud et al., 2019).

Connectivity across seascapes is increasingly recognised as an important factor in marine spatial conservation and management (Balbar and Metaxas, 2019). Connectivity is especially relevant for marine predators, which often range widely in their regular movements, and it can be studied using biologging data, mark-resight (capture-mark-recapture) information, biogeochemical tracers and genetic information (Dunn et al., 2019; Reisinger et al., 2022b; Kot et al., 2023). We suggest that this is an important avenue for research in the region. Genetic information should also be used to increase our understanding of population structure in many species.

Finally, an overarching research priority is understanding the effects of climate change and environmental variability on higher predators in the region (see Orgeret et al., 2022).Meeting each of these challenges requires resourcing and close collaboration among French, South African and Australian governments, institutes, programmes and researchers.

Acknowledgements

This is a contribution to Work Package 1 of the project ‘Pelagic high seas ocean ecoregionalisation of the Indian subantarctic’, defined by Makhado et al. (2019, 2023). We thank ASOC for funding the start of this project. Two project workshops have been held: South Africa in 2019 and France in 2023. The 2019 Cape Town meeting was funded by CCAMLR and the Pew Charitable Trusts. The 2023 Paris workshop was funded by the French Biodiversity Agency (OFB), Zone Atelier Antarctique of CNRS (France), Muséum national d’histoire Naturelle (France), Sorbonne Université (France), Department of Forestry, Fisheries and the Environment (South Africa) and ASOC.

We thank the Department of Forestry, Fisheries and the Environment for logistic support to A. Makhado. Research at the Prince Edward Islands is supported by the South African Department of Science, Technology and Innovation through the National Research Foundation. We thank the French Polar Institute Paul Emile Victor (IPEV) for funding and logistical support of the scientific projects ‘Seabirds and Marine Mammals as Sentinels of Global Change in the Southern Ocean’ (Project 109 ORNITHOECO, principal investigator C. Barbraud) and ‘Foraging Ecology and Energetics of Southern Diving Predators in Relation to Climatic Variability’ (Project 394 Oiseaux Plongeurs OIPLO, principal investigator C.-A. Bost). Those projects are part of the long-term Studies in Ecology and Evolution (SEE-Life) program of the CNRS.

Preparation of this manuscript was supported by RRR attending the University of Southampton Faculty of Medicine/Faculty of Environmental and Life Sciences Writing Retreat (January 2025).

References

Ainley, D.G., C.A. Ribic and E.J. Woehler. 2012. Adding the ocean to the study of seabirds: a brief history of at-sea seabird research. *MEPS*, 451: 231–244.

Australian Antarctic Data Centre. 2022. *Seabirds of the Southern and South Indian Ocean*. Occurrence dataset https://doi.org/10.15468/tu0dcw accessed via GBIF.org on 2023-06-15.

Balbar, A.C. and A. Metaxas. 2019. The current application of ecological connectivity in the design of marine protected areas. *GECCO*, 17: e00569.

Becker, S., C. Boyd, J. Handley, B. Raymond, R.R. Reisinger, Y. Ropert-Coudert, N. Apelgren, T. Davies, M.-A. Lea, M. Santos, P.N. Trathan, A.P. Van de Putte, L. Huckstadt, J.-B. Charassin and C.M. Brooks. 2025. Scaling up ocean conservation through recognition of key biodiversity areas in the Southern Ocean from multispecies tracking data. *Conservation Biology*, 39(1): e14345. https://doi.org/10.1111/cobi.14345.

Bestley, S., Y. Ropert-Coudert, S. Bengtson Nash, C.M. Brooks, C. Cotté, M. Dewar, A.S. Friedlaender, J.A. Jackson, S. Labrousse, A.D. Lowther, C.R. McMahon, R.A. Phillips, P. Pistorius, P.S. Puskic, A.O. de A. Reis, R.R. Reisinger, M. Santos, E. Tarszisz, P. Tixier, P.N. Trathan, M. Wege and B. Wienecke. 2020. Marine Ecosystem Assessment for the Southern Ocean: Birds and Marine Mammals in a Changing Climate. *Front. Ecol. Evol.*, 8. https://doi.org/10.3389/fevo.2020.566936.

Branch, T.A. 2011. Humpback whale abundance south of 60°S from three complete circumpolar sets of surveys. *JCRM – Humpback Whales: Status in the Southern Hemisphere (Special Issue 3)*: 53–69. https://doi.org/10.47536/jcrm.vi.305.

Brooks, C.M., S.L. Chown, L.L. Douglass, B.P. Raymond, J.D. Shaw, Z.T. Sylvester and C.L. Torrens. 2020. Progress towards a representative network of Southern Ocean protected areas. *PLOS ONE*, 15: e0231361.

Chaigne, A., K. Delord, B. Mansoux, C.-A. Bost, H. Weimerskirch and C. Barbraud. 2024. *Seabird distribution in the Southern Indian Ocean: four decades of at sea surveys*. CEBC-CNRS Marine Top Predators Team. https://doi.org/10.6084/m9.figshare.25652955.

Commonwealth of Australia. 2014. Heard Island and McDonald Islands Marine Reserve Management Plan 2014-2024, Department of the Environment, Canberra. Viewed: 8 April 2025. https://www.antarctica.gov.au/antarctic-operations/stations/other-locations/heard-island/protection-and-management/management-plan/download-plan/.

Constable, A.J., J. Melbourne-Thomas, S.P. Corney, K.R. Arrigo, C. Barbraud, D.K.A. Barnes, N.L. Bindoff, P.W. Boyd, A. Brandt, D.P. Costa, A.T. Davidson, H.W. Ducklow, L. Emmerson, M. Fukuchi, J. Gutt, M.A. Hindell, E.E. Hofmann, G.W. Hosie, T. Iida, S. Jacob, N.M. Johnston, S. Kawaguchi, N. Kokubun, P. Koubbi, M.-A. Lea, A. Makhado, R.A. Massom, K. Meiners, M.P. Meredith, E.J. Murphy, S. Nicol, K. Reid, K. Richerson, M.J. Riddle, S.R. Rintoul, W.O. Smith Jr, C. Southwell, J.S. Stark, M. Sumner, K.M. Swadling, K.T. Takahashi, P.N. Trathan, D.C. Welsford, H. Weimerskirch, K.J. Westwood, B.C. Wienecke, D. Wolf-Gladrow, S.W. Wright, J.C. Xavier and P. Ziegler. 2014. Climate change and Southern Ocean ecosystems I: how changes in physical habitats directly affect marine biota. *Glob. Change Biol.*, 20(10): 3004–3025. https://doi.org/10.1111/gcb.12623.

Convention on Biological Diversity. 2022. *Kunming-Montreal Global Biodiversity Framework*. Viewed: 8 April 2025. https://www.cbd.int/gbf.

De Broyer, C., P. Koubbi, H.J. Griffiths, B. Raymond, C. d'Udekem d'Acoz, A.P. Van de Putte, B. Danis, B. David, S. Grant, J. Gutt, C. Held, G. Hosie, F. Huettmann, A. Post and Y. Ropert-Coudert (Eds.). 2014. *Biogeographic Atlas of the Southern Ocean*. Scientific Committee on Antarctic Research, Cambridge: XII + 498 pp.

Delord, K. and O. Duriez. 2012. Manchots, pétrels et albatros : oiseaux des Terres australes et antarctiques françaises (TAAF). *Ornithos*, 19: 162–183.

Delord, K., C. Barbraud, C.A. Bost, Y. Cherel, C. Guinet and H. Weimerskirch. 2013. *Atlas of top predators from French Southern Territories in the Southern Indian Ocean*. CEBC-CNRS. 252 pp. https://doi.org/10.15474/AtlasTopPredatorsOI_CEBC.CNRS_FrenchSouthernTerritories.

Delord, K., C. Barbraud, C.-A. Bost, B. Deceuninck, T. Lefebvre, R. Lutz, T. Micol, R.A. Phillips, P.N. Trathan and H. Weimerskirch. 2014. Areas of importance for seabirds tracked from French southern territories, and recommendations for conservation. *Mar. Pol.*, 48: 1–13.

Dunn, D.C., A.-L. Harrison, C. Curtice, S. DeLand, B. Donnelly, E. Fujioka, E. Heywood, C.Y. Kot, S. Poulin, M. Whitten, S. Åkesson, A. Alberini, W. Appeltans, J.M. Arcos, H. Bailey, L.T. Ballance, B. Block, H. Blondin, A.M. Boustany, J. Brenner, P. Catry, D. Cejudo, J. Cleary, P. Corkeron, D.P. Costa, M. Coyne, G.O. Crespo, T.E. Davies, M.P. Dias, F. Douvere, F. Ferretti, A. Formia, D. Freestone, A.S. Friedlaender, H. Frisch-Nwakanma, C.B. Froján, K.M. Gjerde, L. Glowka, B.J. Godley, J. Gonzalez-Solis, J.P. Granadeiro, V. Gunn, Y. Hashimoto, L.M. Hawkes, G.C. Hays, C. Hazin, J. Jimenez, D.E. Johnson, P. Luschi, S.M. Maxwell, C. McClellan, M. Modest, G. Notarbartolo di Sciara, A.H. Palacio, D.M. Palacios, A. Pauly, M. Rayner, A.F. Rees, E.R. Salazar, D. Secor, A.M.M. Sequeira, M. Spalding, F. Spina, S. Van Parijs, B. Wallace, N. Varo-Cruz, M. Virtue, H. Weimerskirch, L. Wilson, B. Woodward and P.N. Halpin. 2019. The importance of migratory connectivity for global ocean policy. *Proceedings of the Royal Society B: Biological Sciences*, 286: 20191472.

Ehler, CN. 2021. Two decades of progress in Marine Spatial Planning. *Mar. Pol.*, 132: 104134. https://doi.org/10.1016/j.marpol.2020.104134.

Fetterer, F., K. Knowles, W.N. Meier, M. Savoie and A. K. Windnagel. 2017. *Sea Ice Index, Version 3 [Data Set]*. Boulder, Colorado USA. National Snow and Ice Data Center. https://doi.org/10.7265/N5K072F8.

Fishpool, L.D.C. and M.I. Evans. 2001. Important bird areas in Africa and associated islands: priority sites for conservation. Pisces Publications and BirdLife International (BirdLife Conservation Series No. 11), Newbury and Cambridge, UK.

Gimeno, M., J. Giménez, A. Chiaradia, L.S. Davis, P.J. Seddon, Y. Ropert-Coudert, R.R. Reisinger, M. Coll and F. Ramírez. 2024. Climate and human stressors on global penguin hotspots: Current assessments for future conservation. *Glob. Change Biol.*, 30(1): e17143. https://doi.org/10.1111/gcb.17143.

Green, K., D.J. Slip and G.J. Moore. 1998. The take of fish species by seabirds and marine mammals in the Australian Fisheries Zone around Heard Island: the potential for competition with a commercial fishery. *Polar Biol.*, 20(4): 273–280.

Goldsworthy, S.D. 1995. Differential expenditure of maternal resources in Antarctic fur seals, *Arctocephalus gazella*, at Heard Island, southern Indian Ocean. *Behav. Ecol.*, 6(2): 218–228.

Gutt, J., E. Isla, J.C. Xavier, B.J. Adams, I.-Y. Ahn, C.HC. Cheng, C. Colesie, V.J. Cummings, G. di Prisco, H. Griffiths, I. Hawes, I. Hogg, T. McIntyre, K.M. Meiners, D.A. Pearce, L. Peck, D. Piepenburg, R.R. Reisinger, G.K. Saba, I.R. Schloss, C.N. Signori, C.R. Smith, M. Vacchi, C. Verde and D.H. Wall. 2021. Antarctic ecosystems in transition – life between stresses and opportunities. *Biological Reviews*, 96: 798–821.

Halpin, P., A. Read, E. Fujioka, B. Best, B. Donnelly, L. Hazen, C. Kot, K. Urian, E. LaBrecque, A. Dimatteo, J. Cleary, C. Good, L. Crowder and K.D. Hyrenbach. 2009. OBIS-SEAMAP: The World Data Center for Marine Mammal, Sea Bird, and Sea Turtle Distributions. *Oceanog.*, 22: 104–115.

Handley, J., M.-M. Rouyer, E.J. Pearmain, V. Warwick-Evans, K. Teschke, J.T. Hinke, H. Lynch, L. Emmerson, C. Southwell, G. Griffith, C.A. Cárdenas, A.M.A. Franco, P. Trathan and M.P. Dias. 2021. Marine Important Bird and Biodiversity Areas for Penguins in Antarctica, Targets for Conservation Action. *Front. Mar. Sci.*, 7. https://doi.org/10.3389/fmars.2020.602972.

Hänel, C. and S.L. Chown. 1999. Fifty years at Marion and Prince Edward Islands: a bibliography of scientific and popular literature.

South African Journal of Science, 95: 87–112.

Hazen, E.L., B. Abrahms, S. Brodie, G. Carroll, M.G. Jacox, M.S. Savoca, K.L. Scales, W.J. Sydeman and S.J. Bograd. 2019. Marine top predators as climate and ecosystem sentinels. *Front. Ecol. Environ.*, 17: 565–574.

Heerah, K., M.P. Dias, K. Delord, S. Oppel, C. Barbraud, H. Weimerskirch and C.A. Bost. 2019. Important areas and conservation sites for a community of globally threatened marine predators of the Southern Indian Ocean. *Biol. Conserv.*, 234: 192–201.

Hindell, M.A., R.R. Reisinger, Y. Ropert-Coudert, L.A. Hückstädt, P.N. Trathan, H. Bornemann, J.-B. Charrassin, S.L. Chown, D.P. Costa, B. Danis, M.-A. Lea, D. Thompson, L.G. Torres, A.P. Van de Putte, R. Alderman, V. Andrews-Goff, B. Arthur, G. Ballard, J. Bengtson, M.N. Bester, A.S. Blix, L. Boehme, C.-A. Bost, P. Boveng, J. Cleeland, R. Constantine, S. Corney, R.J.M. Crawford, L. Dalla Rosa, P.J.N. de Bruyn, K. Delord, S. Descamps, M. Double, L. Emmerson, M. Fedak, A. Friedlaender, N. Gales, M.E. Goebel, K.T. Goetz, C. Guinet, S.D. Goldsworthy, R. Harcourt, J.T. Hinke, K. Jerosch, A. Kato, K.R. Kerry, R. Kirkwood, G.L. Kooyman, K.M. Kovacs, K. Lawton, A.D. Lowther, C. Lydersen, P.O. Lyver, A.B. Makhado, M.E.I. Márquez, B.I. McDonald, C.R. McMahon, M. Muelbert, D. Nachtsheim, K.W. Nicholls, E.S. Nordøy, S. Olmastroni, R.A. Phillips, P. Pistorius, J. Plötz, K. Pütz, N. Ratcliffe, P.G. Ryan, M. Santos, C. Southwell, I. Staniland, A. Takahashi, A. Tarroux, W. Trivelpiece, E. Wakefield, H. Weimerskirch, B. Wienecke, J.C. Xavier, S. Wotherspoon, I.D. Jonsen and B. Raymond. 2020. Tracking of marine predators to protect Southern Ocean ecosystems. *Nature*, 580: 87–92.

IUCN. 2016. A Global Standard for the Identification of Key Biodiversity Areas, Version 1.0. IUCN, Gland, Switzerland: 37pp.

IUCN Marine Mammal Protected Areas Task Force. 2020. Final Report of the Fourth IMMA Workshop: Important Marine Mammal Area Regional Workshop for Extended Southern Ocean, Brest, France, 15–19 October 2018. Viewed: 9 April 2025. https://www.marinemammalhabitat.org/download/final-report-of-the-regional-workshop-for-the-extended-southern-ocean-important-marine-mammal-areas/#.

Kays, R., S.C. Davidson, M. Berger, G. Bohrer, W. Fiedler, A. Flack, J. Hirt, C. Hahn, D. Gauggel, B. Russell, A. Kölzsch, A. Lohr, J. Partecke, M. Quetting, K. Safi, A. Scharf, G. Schneider, I. Lang, F. Schaeuffelhut, M. Landwehr, M. Storhas, L. van Schalkwyk, C. Vinciguerra, R. Weinzierl and M. Wikelski. 2022. The Movebank system for studying global animal movement and demography. *Methods in Ecology and Evolution*, 13(2): 419–431.

KBA Standards and Appeals Committee. 2019. Guidelines for using a Global Standard for the Identification of Key Biodiversity Areas. Version 1.0. Prepared by the KBA Standards and Appeals Committee of the IUCN Species Survival Commission and IUCN World Commission on Protected Areas. Gland, Switzerland: IUCN. viii + 148pp. https://doi.org/10.2305/IUCN.CH.2019.KBA.1.0.en.

Kot, C.Y., S.E. DeLand, A.-L. Harrison, A. Alberini, H. Blondin, M. Chory, J. Cleary, C. Curtice, B. Donnelly, E. Fujioka, A.H. Palacio, E.I. Heywood, E. Mason, D. Nisthar, G.O. Crespo, S. Poulin, M. Whitten, C. Woolston, D.C. Dunn and P.N. Halpin. 2023. Synthesizing connectivity information from migratory marine species for area-based management. *Biol. Conserv.*, 283: 110142.

Kranstauber, B., A. Cameron, R. Weinzerl, T. Fountain, S. Tilak, M. Wikelski and R. Kays. 2011. The Movebank data model for animal tracking. *Environ. Model. Softw.*, 26: 834–835.

Lascelles, B.G., P.R. Taylor, M.G.R. Miller, M.P. Dias, S. Oppel, L. Torres, A. Hedd, M. Le Corre, R.A. Phillips, S.A. Shaffer, H. Weimerskirch and C. Small. 2016. Applying global criteria to tracking data to define important areas for marine conservation. *Diversity and Distributions*, 22: 422–431.

Makhado, A., P. Koubbi, J.A. Huggett, C. Cotte, R.R. Reisinger, K.M. Swadling, C. Azarian, C. Barnerias, F. d'Ovidio, L. Gauthier, E. Goberville, B. Leroy, A.T. Lombard, L. ne Muller, A. van de Putte and workshop participants. 2023. Ecoregionalisation of the pelagic zone in the

Subantarctic and Subtropical Indian Ocean. Document *SC-CCAMLR-42/08*. CCAMLR, Hobart, Australia: 32 pp.

Makhado, A., P. Koubbi, A.D. Lowther, F. d'Ovidio, R.R. Reisinger, P.A. Pistorius, R.J.M. Crawford, P. Trathan and S. Grant. 2019. The expert group on 'Pelagic spatial planning of the sub-Antarctic areas of Planning Domains 4, 5, and 6' (PS^2456). Document *SC-CAMLR-XXXVII/07*. CCAMLR, Hobart, Australia: 3 pp.

Meyer, L., A. Constable and R. Williams. 2000. *Conservation of Marine Habitats in the Region of Heard Island and McDonald Islands*. Australian Antarctic Division, Kingston, Tasmania: 78 pp.

Notarbartolo di Sciara, G. and E. Hoyt. 2020. Healing the wounds of marine mammals by protecting their habitat. *Ethics Sci. Environ. Polit.*, 20: 15–23.

Orgeret, F., A. Thiebault, K.M. Kovacs, C. Lydersen, M.A. Hindell, S.A. Thompson, W.J. Sydeman and P.A. Pistorius. 2022. Climate change impacts on seabirds and marine mammals: The importance of study duration, thermal tolerance and generation time. *Ecol. Lett.*, 25(1): 218–239.

Park, Y.-H. and I. Durand. 2019. *Altimetry-derived Antarctic Circumpolar Current fronts*. SEANOE. https://doi.org/10.17882/59800.

Page, B., A. Welling, M. Chambellant, S.D. Goldsworthy, T. Dorr and R. van Veen. 2003. Population status and breeding season chronology of Heard Island fur seals. *Polar Biol.*, 26: 219–224.

Patterson, T.A., R.J. Sharples, B. Raymond, D.C. Welsford, V. Andrews-Goff, M.A. Lea, S.D. Goldsworthy, N.J. Gales and M. Hindell. 2016. Foraging distribution overlap and marine reserve usage amongst sub-Antarctic predators inferred from a multi-species satellite tagging experiment. *Ecological Indicators*, 70: 531–544.

Péron, C., M. Authier, C. Barbraud, K. Delord, D. Besson and H. Weimerskirch. 2010. Interdecadal changes in at-sea distribution and abundance of subantarctic seabirds along a latitudinal gradient in the Southern Indian Ocean. *Glob. Change Biol.*, 16(7): 1895–1909.

Péron, C., H. Weimerskirch and C.-A. Bost. 2012. Projected poleward shift of king penguins' (*Aptenodytes patagonicus*) foraging range at the Crozet Islands, southern Indian Ocean. *Proceedings of the Royal Society B: Biological Sciences*, 279(1738): 2515–2523.

Proud, R., C. Le Guen, R.B. Sherley, A. Kato, Y. Ropert-Coudert, N. Ratcliffe, S. Jarman, A. Wyness, J.P.Y. Arnould, R.A. Saunders, P.G. Fernandes, L. Boehme and A.S. Brierley. 2021. Using Predicted Patterns of 3D Prey Distribution to Map King Penguin Foraging Habitat. *Front. Mar. Sci.*, 8: 745200.

Purdon, J., F.W. Shabangu, D. Yemane, M. Pienaar, M.J. Somers and K. Findlay. 2020. Species distribution modelling of Bryde's whales, humpback whales, southern right whales, and sperm whales in the southern African region to inform their conservation in expanding economies. *PeerJ* 8: e9997. https://doi.org/10.7717/peerj.9997.

Raymond, B., M.A. Lea, T. Patterson, V. Andrews-Goff, R. Sharples, J.B. Charrassin, M. Cottin, L. Emmerson, N. Gales, R. Gales, S.D. Goldsworthy, R. Harcourt, A. Kato, R. Kirkwood, K. Lawton, Y. Ropert-Coudert, C. Southwell, J. van den Hoff, B. Wienecke, E.J. Woehler, S. Wotherspoons and M.A. Hindell. 2015. Important marine habitat off east Antarctica revealed by two decades of multi-species predator tracking. *Ecography*, 38(2): 121–129.

Reisinger, R.R., B. Raymond, M.A. Hindell, M.N. Bester, R.J.M. Crawford, D. Davies, P.J.N. de Bruyn, B.J. Dilley, S.P. Kirkman, A.B. Makhado, P.G. Ryan, S. Schoombie, K. Stevens, M.D. Sumner, C.A. Tosh, M. Wege, T.O. Whitehead, S. Wotherspoon and P.A. Pistorius. 2018. Habitat modelling of tracking data from multiple marine predators identifies important areas in the Southern Indian Ocean. *Diversity and Distributions*, 24(4): 535–550. https://doi.org/10.1111/ddi.12702.

Reisinger, R.R., C.M. Brooks, B. Raymond, J.J. Freer, C. Cotté, J.C. Xavier, P.N. Trathan, H. Bornemann, J.-B. Charrassin, D.P. Costa, B.

Danis, L. Hückstädt, I.D. Jonsen, M.-A. Lea, L. Torres, A. Van de Putte, S. Wotherspoon, A.S. Friedlaender, Y. Ropert-Coudert and M. Hindell. 2022a. Predator-derived bioregions in the Southern Ocean: Characteristics, drivers and representation in marine protected areas. *Biol. Conserv.*, 272: 109630.

Reisinger, R.R., C. Johnson and A.S. Friedlaender. 2022b. Marine Mammal Movement Ecology in a Conservation and Management Context. In: Notarbartolo di Sciara, G., and B. Würsig (Eds). *Marine Mammals: the Evolving Human Factor. Ethology and Behavioral Ecology of Marine Mammals*. Springer International Publishing, Cham: 149–192.

Ropert-Coudert, Y., M.A. Hindell, R.A. Phillips, J.-B. Charrassin, L. Trudelle and B. Raymond. 2014. Biogeographic patterns of birds and marine mammals. In: De Broyer, C., P. Koubbi, H.J. Griffiths, B. Raymond, C. d'Udekem d'Acoz, A.P. Van de Putte, B. Danis, B. David, S. Grant, J. Gutt, C. Held, G. Hosie, F. Huettmann, A. Post and Y. Ropert-Coudert (Eds.). *Biogeographic Atlas of the Southern Ocean*. The Scientific Committee on Antarctic Research, Cambridge: 498pp.

Ropert-Coudert, Y., A.P. Van de Putte, R.R. Reisinger, H. Bornemann, J.-B. Charrassin, D.P. Costa, B. Danis, L.A. Hückstädt, I.D. Jonsen, M.-A. Lea, D. Thompson, L.G. Torres, P.N. Trathan, S. Wotherspoon, D.G. Ainley, R. Alderman, V. Andrews-Goff, B. Arthur, G. Ballard, J. Bengtson, M.N. Bester, A.S. Blix, L. Boehme, C.-A. Bost, P. Boveng, J. Cleeland, R. Constantine, R.J.M. Crawford, L. Dalla Rosa, P.J. Nico de Bruyn, K. Delord, S. Descamps, M. Double, L. Emmerson, M. Fedak, A. Friedlaender, N. Gales, M. Goebel, K.T. Goetz, C. Guinet, S.D. Goldsworthy, R. Harcourt, J.T. Hinke, K. Jerosch, A. Kato, K.R. Kerry, R. Kirkwood, G.L. Kooyman, K.M. Kovacs, K. Lawton, A.D. Lowther, C. Lydersen, P.O. Lyver, A.B. Makhado, M.E.I. Márquez, B.I. McDonald, C.R. McMahon, M. Muelbert, D. Nachtsheim, K.W. Nicholls, E.S. Nordøy, S. Olmastroni, R.A. Phillips, P. Pistorius, J. Plötz, K. Pütz, N. Ratcliffe, P.G. Ryan, M. Santos, C. Southwell, I. Staniland, A. Takahashi, A. Tarroux, W. Trivelpiece, E. Wakefield, H. Weimerskirch, B. Wienecke, J.C. Xavier, B. Raymond and M.A. Hindell. 2020. The retrospective analysis of Antarctic tracking data project. *Sci. Data*, 7: 94. https://doi.org/10.1038/s41597-020-0406-x.

Ryan, P.G. and M.N. Bester. 2008. Pelagic predators. In: Chown, S.L. and P.W. Froneman (Eds.). *The Prince Edward Islands: land-sea interactions in a changing ecosystem*. Stellenbosch, Sun Media: 121–164.

Slip, D.J. and H.R. Burton. 1991. Accumulation of fishing debris, plastic litter, and other artefacts, on Heard and Macquarie Islands in the Southern Ocean. *Environ. Conserv.*, 18(3): 249–254.

Slip, D.J., and H.R. Burton. 1999. Population status and seasonal haulout patterns of the southern elephant seal (Mirounga leonina) at Heard Island. *Antarct. Sci.*, 11(1): 38–47.

Staniland, I.J., N. Gales, N.L. Warren, S.L. Robinson, S.D. Goldsworthyand R.M. Casper. 2010. Geographical variation in the behaviour of a central place forager: Antarctic fur seals foraging in contrasting environments. *Mar. Biol.*, 157: 2383–2396.

Tetley, M.J., G.T. Braulik, C. Lanfredi, G. Minton, S. Panigada, E. Politi, M. Zanardelli, G. Notarbartolo di Sciara and E. Hoyt. 2022. The Important Marine Mammal Area Network: A Tool for Systematic Spatial Planning in Response to the Marine Mammal Habitat Conservation Crisis. *Front. Mar. Sci.*, 9. https://doi.org/10.3389/fmars.2022.841789.

Thiers, L., K. Delord, C.-A. Bost, C. Guinet and H. Weimerskirch. 2017. Important marine sectors for the top predator community around Kerguelen Archipelago. *Polar Biol.*, 40: 365–378.

Trathan, P.N., J. Forcada and E.J. Murphy. 2007. Environmental forcing and Southern Ocean marine predator populations: effects of climate change and variability. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 362: 2351–2365.

Van den Hoff, J., R. Kilpatrick and D. Welsford. 2017. Southern elephant seals (*Mirounga leonina* Linn.) depredate toothfish longlines in the midnight zone. *PLoS One*, 12(2): e0172396.

Wienecke, B. and G. Robertson. 2006. Comparison of foraging strategies of incubating king penguins *Aptenodytes patagonicus* from Macquarie and Heard islands. *Polar Biol.*, 29(5): 424-438.

Wilkinson, M.D., M. Dumontier, Ij.J. Aalbersberg, G. Appleton, M. Axton, A. Baak, N. Blomberg, J.-W. Boiten, L.B. da Silva Santos, P.E. Bourne, J. Bouwman, A.J. Brookes, T. Clark, M. Crosas, I. Dillo, O. Dumon, S. Edmunds, C.T. Evelo, R. Finkers, A. Gonzalez-Beltran, A.J.G. Gray, P. Groth, C. Goble, J.S. Grethe, J. Heringa, P.A.C. 't Hoen, R. Hooft, T. Kuhn, R. Kok, J. Kok, S.J. Lusher, M.E. Martone, A. Mons, A.L. Packer, B. Persson, P. Rocca-Serra, M. Roos, R. van Schaik, S.-A. Sansone, E. Schultes, T. Sengstag, T. Slater, G. Strawn, M.A. Swertz, M. Thompson, J. van der Lei, E. van Mulligen, J. Velterop, A. Waagmeester, P. Wittenburg, K. Wolstencroft, J. Zhao and B. Mons. 2016. The FAIR Guiding Principles for scientific data management and stewardship. *Sci. Data*, 3: 160018.

Woehler, E. and B. Raymond. 1999. *Distribution and abundance of seabirds in the Southern Indian Ocean, 1978/1979+*, Ver. 1. Australian Antarctic Data Centre. https://doi.org/10.4225/15/5643E8C0743C2. Accessed: 2023-06-15.