Understanding the marine ecosystems surrounding Heard Island and McDonald Islands (HIMI) and their conservation status

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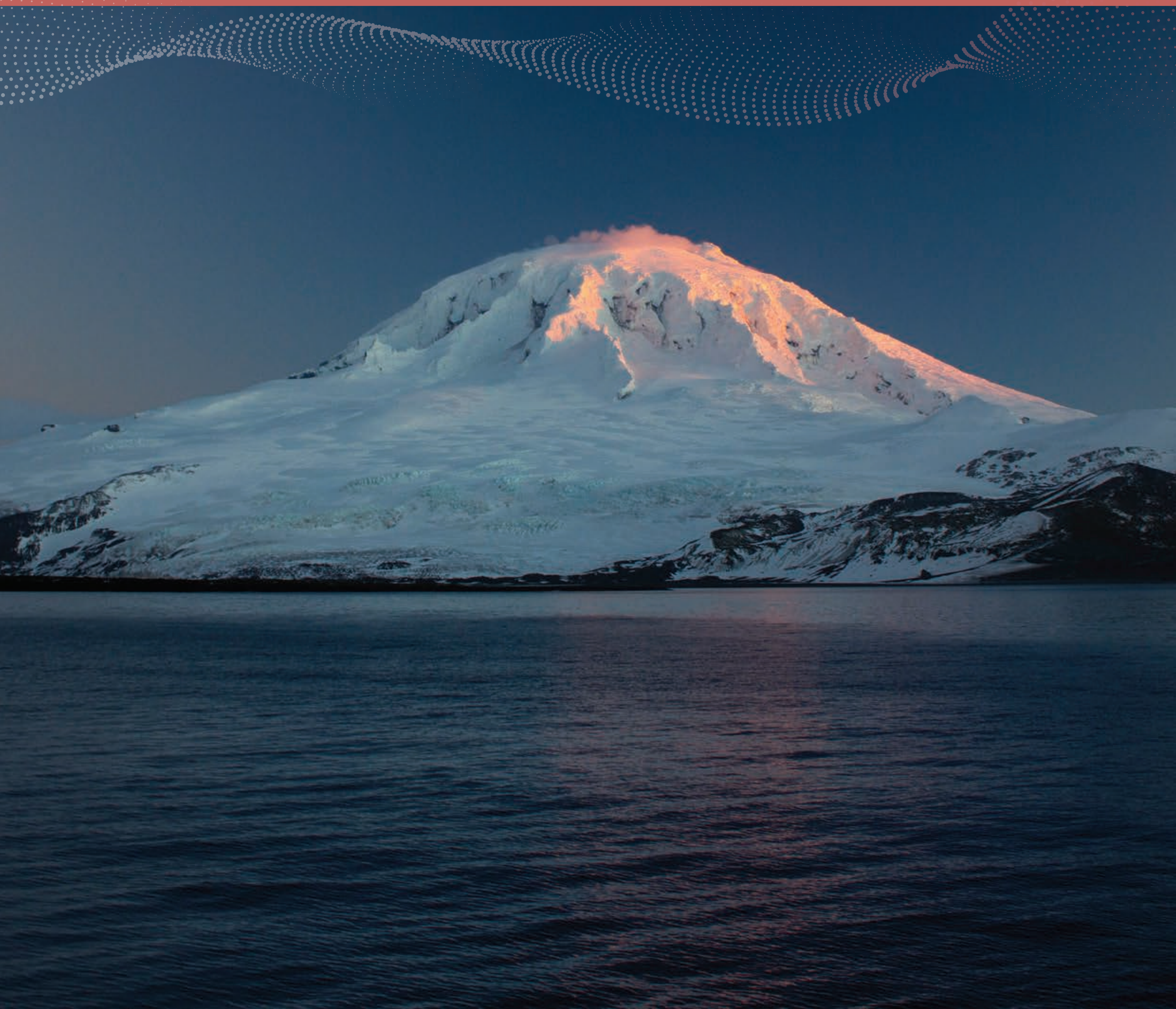

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Cover Image: Heard Island. Photo Inger Vandyke

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Foreword

King Penguins on Ice at Heard Island. Photo: Kirk Zufelt.

Australia's External Territory of Heard Island and McDonald Islands is truly a remarkable place. Situated in the subantarctic waters of the Indian Ocean about halfway between mainland Australia and Africa, and 1,700 km north of Antarctica, Heard Island is one of the remotest places on earth.

Its surrounding seas are wild and its weather furious. Heard's mountain, Big Ben, is an active volcano, and the nearby McDonald Islands are being shaped by ongoing volcanic activity. The islands are rarely visited, most often seen by Australian fishing vessels, and sometimes glimpsed from passenger aircraft, almost always covered in cloud, on route from Australia to Africa. The nearest neighbour is France's Iles Kerguelen to the north, with which Australia shares a maritime territorial border. Heard Island and McDonald Islands is listed on the World Heritage List for it's outstanding geological features, and its wildlife and ecological values.

The waters of the Territory sit atop the vast Kerguelen Plateau which stretches south to Antarctica, and much of which is part of Australia's extended continental shelf. The marine ecosystems of the Territory are unique on a global scale and represent a valuable natural asset. The Territory hosts a significant domestic fishery that was plundered by illegal, unreported and unregulated pirate fishing around the turn of this century. The maintenance of the fishery, and its long-term commercial viability, relies on both Australian domestic regulation, and international management through the Commission for the Conservation of Antarctic Marine Living Resources.

The declaration of the Heard Island and McDonald Islands Marine Reserve represented a significant contribution to global marine protection. This current review of the Reserve, and the values and natural assets it protects, provides a unique opportunity to contribute further to the protection of Earth's oceans, especially now that the region is facing the immediate consequences of climate change. Protection of marine ecosystems from climate change and other human pressures is a valuable investment in Australia's economic future, and in global food security.

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Executive Summary

Heard Island and McDonald Islands (HIMI) are a remote subantarctic island group located about 4,000 km south-west of Western Australia and approximately 1,700 km from the Antarctic continent. The HIMI exclusive economic zone (EEZ) abuts the French EEZ around the Kerguelen Islands. The HIMI complex is part of the Kerguelen Plateau, which is a large submerged continental plateau that extends more than 2,000 km, with only a few emergent volcanic islands. Heard Island and McDonald Island are the two largest islands with the only two active volcanoes in Australia.

Both the marine and terrestrial environments of HIMI are globally recognized for their ecological significance, and include species not found elsewhere in Australia. Indeed, the entire region is subject to international agreements and regulations aimed at conserving its unique ecosystem.

Australia took possession of HIMI in 1947. The islands and territorial seas became a World Heritage Site in 1997, and a 65,000 km^2 Commonwealth Marine Reserve was declared in 2002. A conservation zone was declared at the same time for further consideration of areas to be added to the reserve following research on the interaction between fisheries and biodiversity in the region. Some parts of the conservation zone were added to the marine reserve in 2014 (an additional 6,200 km^2), following a comprehensive scientific assessment of the region's conservation values and stakeholder engagement. The Reserve now covers 71,200 km^2 of the Australian EEZ. A management plan for the existing marine reserve came into effect in 2014 and is currently due for its ten-year statutory review.

Given the changes in our understanding over the past decade it is timely to assess how well the HIMI EEZ is represented in Australia's National Representative System of Marine Protected Areas and to make improvements to the levels of protection.

The Australian EEZ surrounding the islands was declared in 1978 and covers 410,722 km^2. Only 17% of the EEZ is protected in the Heard Island and McDonald Islands Marine Reserve.

The remote location and strong ocean currents can limit the dispersal of organisms to and from the islands. While this isolation leads to higher rates of endemism and can protect native species from certain invasive organisms, it also limits genetic diversity and can make the ecosystem more vulnerable to disturbances. HIMI is difficult to access, which combined with Australia's strict management of the islands means they are unique globally and one of the world's rare near-pristine island ecosystems being largely devoid of non-native species.

HIMI is part of the Kerguelen Plateau which is considered a significant site for scientific understanding of our planet due to its role in oceanic and atmospheric processes. It is one of the world's largest oceanic ridges and one of only three significant ridges in the Southern Ocean that impede the eastward flow of the Antarctic Circumpolar Current. The plateau, impacts oceanic currents and circulation patterns, influencing the movement of water masses and providing a source of nutrients from which stems an abundance of marine life.

The Kerguelen Plateau ecosystem serves as an important natural laboratory for understanding complex interactions in the Southern Ocean and the broader global climate system. The deep-sea ecosystems surrounding the Kerguelen Plateau are also of great interest, including unique and often poorly known species which have adapted to extreme conditions in the deep, cold ocean.

HIMI contains globally significant benthic (sea floor) and pelagic (shelf and open ocean) ecosystems, with 56 species of seabirds recorded, of which 19 breed on Heard Island including four species of penguin, three species of albatross, and seven species of petrel. The Heard Island imperial shag and the Heard Island subspecies of black-faced sheathbill are endemic to Heard Island. Four species of seabird are listed as endangered under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act): the northern royal albatross, Amsterdam albatross, Tristan albatross and grey-headed albatross. There are also eight seabird species that are listed as vulnerable under the EPBC Act: the southern royal albatross, sooty albatross, Indian yellow-nosed albatross, Campbell albatross, white-capped albatross, northern giant-petrel, blue petrel and soft-plumaged petrel. 26 species of marine mammals have been observed in the HIMI EEZ, including the subantarctic fur-seal, the southern right whale and pygmy blue whale which are listed as endangered under the EPBC Act. All of these animals rely on the productive waters surrounding HIMI as a food source.


King penguins. Photo: Scott Portelli.

Knowledge of benthic habitats and fauna in the HIMI EEZ is limited by sampling effort in this remote area. Despite recently improved benthic mapping of the HIMI EEZ, it is likely that many deeper seafloor features will not be identified without targeted swath mapping. Additionally, the lack of formal identification and naming of the samples that have been collected restricts interpretation. Despite this, nineteen species were identified as likely endemics from samples sorted to only operational taxonomic unit level as part of a study to guide earlier conservation planning. Additional likely endemics would almost certainly be present in several diverse taxonomic groups (e.g. amphipods, bryozoans, molluscs, pycnogonids) which remain largely unsorted. The lack of knowledge of benthic fauna in deeper areas, including the string of seamounts on Williams Ridge that rise from deeper water to peak in waters less than 1,000 m, is a limitation in understanding the impacts of the fishery in recent years since an expansion in fishing footprint. There is an urgent need for updated publicly available information on the impacts of demersal gear on benthic habitats, particularly in previously unfished areas.

Heard Island and McDonald Islands and the surrounding ocean ecosystem are subject to various pressures due to their isolation, unique geography, and vulnerability.

This report describes these pressures including from climate change, pollution, tourism, scientific research, and fisheries. The fisheries primarily target Patagonian toothfish, but with a smaller variable catch of mackerel icefish. Both of these species are important components of the HIMI ecosystem as top predators and as part of the food web connecting pelagic and benthic ecosystems.

The fishery for mackerel icefish uses both bottom trawl and midwater trawl gear and the Patagonian toothfish is mostly harvested with demersal longlines.

These fisheries have direct impacts on biodiversity during the capture process, many of which have been intensively mitigated. Management is provided by the Australian Fisheries Management Authority (AFMA) and both fisheries operate in accordance with Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Conservation Measures. These fisheries are the only fisheries in the CCAMLR area that use bottom trawling methods.

A major impact of the Australian Patagonian toothfish and mackerel icefish fisheries is a large bycatch of numerous protected species, as well as skates, sharks, and rays. Skates are the most frequent bycatch. The lack of a fishery independent assessment for deepwater skates is of concern and there is a need for improved understanding of bycatch from the fishery. A more detailed spatial analysis of deepwater skate bycatch in the fishery is needed to identify further management requirements.

Our scientific understanding of the area has improved greatly since the establishment of the marine reserve with two significant changes since that time, namely (i) climate change is having a demonstrable effect, and (ii) fisheries for Patagonian toothfish and mackerel icefish have expanded over that time, including to depths unsurveyed for their benthic biodiversity.

Climate changes to the biophysical environment may be significantly affecting the ecology of the system, including cold-adapted subantarctic species and the recruitment of young Patagonian toothfish to the population. The Patagonian toothfish is an apex predator of this marine ecosystem and changes in its status will have a cascading impact on many other species. As a result, there is a need for a review of the suitability of current fishery management models and whether the method for setting catch limits is sufficient for achieving objectives based on an assumption of stable recruitment of target species. Also, further protections within the marine reserve will be needed to maximise resilience of cold-adapted species, such as mackerel icefish, to climate change.

While fisheries vessels regularly visit the area no data are publicly available on the fisheries activities in space or time across the EEZ. There is only annual reporting of total catches with no defined footprint for the fisheries available publicly except that the fisheries operate throughout the Australian Fishing Zone around HIMI. Annual Trawl Surveys are conducted by the Australian Antarctic Division (AAD) in partnership with Australian Fisheries Management Authority (AFMA) and the fishing industry, however these data are not publicly available. Fisheries data are confidential. Given the high conservation value of this area and the collaborative arrangement of the fishers it would be useful to review the purpose of current data confidentiality arrangements and whether data could be made freely available.

This report builds on the available scientific knowledge of the marine environment around HIMI examining its ecology in the context of the broader subantarctic, as well as further elaborating the differences between distinct marine biomes surrounding HIMI. It presents the spatial differences in the ecology of the region and the threats that climate change may have on these areas, thereby enabling us to consider requirements for conserving the unique marine biodiversity in the HIMI EEZ now and into the future.

This report assesses how well the existing marine reserve represents the diverse ecosystems found in the HIMI EEZ as part of Australia's National Representative System of Marine Protected Areas (NRSMPA). Our assessment builds on earlier conservation assessments and using the principles underpinning the NRSMPA makes recommendations on additions to the current marine reserve to achieve comprehensive, adequate, and representative (CAR) coverage for the biodiversity in the area.

The report provides new analyses of the origins and drivers of the distribution of biodiversity around HIMI and investigates the potential effects of climate change, comparing data between a baseline period (1993-2002) and the most recent decade (2013-2022). In recent years more robust spatial data have become available on the heterogeneous benthic habitats and the oceanographic conditions in the HIMI EEZ. We have used these to develop a more complete differentiation of biomes in the area drawing on improved knowledge of deep-sea fauna globally.

Evidence suggests that the existing marine reserve and fisheries conservation measures have provided effective protection for species and biodiversity in the shallower waters (less than 1,000 m deep). Options for similar levels of protection for all depths in the HIMI EEZ are recommended in order to ensure the marine reserve meets the conservation principles that form the basis of the NRSMPA goals and objectives.

Through an analysis of the key physical drivers that determine the distribution of biodiversity, combined with information on the distribution of the biodiversity, we classify the HIMI EEZ into 18 Assessment Zones that cover all depths and biophysical settings.

We provide an analysis of where the existing marine reserve requires expansion in order to protect all of the values of the region and provide scenarios for extending the marine reserve to adequately represent all areas important for biodiversity within the HIMI region. Extensions to the existing marine reserve are identified in six Key Conservation Areas:

(1) HIMI Shelf shallower than 300 m - to maximise resilience of shelf biodiversity (particularly cold-adapted species) to climate change,

(2) Shell Bank and Williams Ridge – to protect a currently unprotected unique feature of the marine environment in the HIMI EEZ, including unsurveyed seamounts, which also provides a significant contribution to pelagic food webs,

(3) Elan Corridor - to provide a north-south linkage of different benthic habitats across the depth range of the HIMI EEZ which is currently only represented in the east of the EEZ. The Elan Corridor has different oceanographic conditions to that in the east and provides a link from the subantarctic to colder waters around Elan Bank,

(4) Southern Canyons – to improve the representation of fish biodiversity in this depth range around the HIMI Shelf and provide suitable replication to Williams Ridge,

(5) Western Plateau - to improve the representation of fish biodiversity in this area and account for the reported west-east divided in benthic biodiversity, along with protection of spawning grounds of Patagonian toothfish and areas of importance to pelagic food webs, and

(6) South Pelagic - to provide areas of protection for pelagic food webs including important penguin feeding areas.

One to five above are proposed for the protection of both benthic and pelagic biodiversity, while the sixth area, the South Pelagic key conservation area, is proposed to protect pelagic biodiversity and the maintenance of pelagic food webs. The incorporation of the first five conservation areas in the existing marine reserve would increase the total protected area coverage in the EEZ from 17% to 38% for combined benthic and pelagic habitats. The incorporation of the sixth area for pelagic conservation would provide protection for a further 43% of the EEZ.

While the Australian government has set an overall target of achieving '30% spatial coverage' of marine and terrestrial protected areas by 2030, given the complex marine ecosystem around HIMI and the current threats to this unique marine system it is appropriate to consider the 30% spatial coverage of the different assessment zones as a lower limit rather than a target.

It is 20 years since Australia's Cabinet agreed to pursue a claim for jurisdiction over its Extended Continental Shelf (ECS). This decision was based in part on the right to protect the marine environment of the extended continental shelf. Australia proclaimed 2,560,000 km^2 of the ECS in 2012, of which 1,130,000 km^2 was to the south of the HIMI EEZ on the Kerguelen Plateau. We explore mechanisms for developing protection of the ECS, including further topographic mapping, initiating benthic protection, and resubmitting the ECS claim for Williams Ridge to the Commission on the Limits of the Continental Shelf including reference to recent geological sampling on the Ridge designed for this purpose.

Finally, we propose that future work be done to ensure that:

- existing benthic samples collected in the HIMI EEZ be identified to the lowest possible taxonomic level in collaboration with French scientists to improve our understanding of the HIMI EEZ's place in the biogeography of Kerguelen Plateau and beyond;
- new tracking data for marine mammals and seabirds that breed on HIMI be obtained to better understand the use of the entire EEZ by different species;
- improved resolution bathymetry be extended to the southern HIMI EEZ and Australia's ECS, including identification of geomorphic units;
- benthic surveys be extended to deeper waters, especially significant geological features including the unsurveyed chain of seamounts on Williams Ridge as recommended by Hibberd et al. (2014), to improve knowledge of biodiversity and the robustness of existing predictions of benthic impact, and
- Australia's existing marine bioregional classification, Key Ecological Features and Biologically Important Areas be extended to include the HIMI EEZ.

Recommendations

Scenario 1 - Ensure all six conservation areas are fully represented in The Reserve as IUCN Category 1a (strict nature reserve) under the EPBC Act.

This report demonstrates that all six Key Conservation Areas meet the criteria for inclusion in the NRSMPA and, as an integrated whole, they provide the most effective mechanism for the ongoing protection of the biodiversity in the region. Given the existing reserve is currently zoned IUCN Category 1a and the need to maintain the exceptional biodiversity values of the area, it is recommended to maintain the highest level of protection and assign IUCN Category 1a for reserve additions. Key Conservation Areas 1 to 5 are proposed for the protection of both benthic and pelagic biodiversity, while Key Conservation Area 6 is proposed to protect pelagic biodiversity and the maintenance of pelagic food webs (Figure 40). The incorporation of the first five Key Conservation Areas in the existing marine reserve would increase the total protected area coverage in the EEZ from 17% to 38% for combined benthic and pelagic habitats. The incorporation of Key Conservation Area 6 as IUCN Category 1a (strict nature reserve) would provide protection for a further 43% of the EEZ.

These additions to The Reserve will provide important protections of different benthic habitats across the entire depth range of the HIMI EEZ, as well as protection of pelagic food webs and important pelagic foraging areas. The inclusion of the Elan Corridor Conservation Area provides representation of different oceanography to that in the east and provides links to the subantarctic with colder waters around Elan Bank. The protection of the Western Plateau Conservation Area increases the representation of fish biodiversity, provides protection for the spawning grounds of Patagonian toothfish, as well as other areas of importance to pelagic food webs, and accounts for differences in benthic species between the west and the east of the HIMI EEZ.

Scenario 2 - Ensure five Conservation Areas are fully represented in The Reserve as IUCN Category 1a (strict nature reserve) and protect the South Pelagic Conservation Area as IUCN Category IV (habitat or species management area).

This report demonstrates that all six Key Conservation Areas meet the criteria for inclusion in the NRSMPA. It is recommended Key Conservation Areas 1 to 5 be zoned IUCN Category Ia for the protection of the benthic and pelagic conservation values. The South Pelagic Conservation Area is recommended for the protection of pelagic food webs and the foraging grounds of resident marine mammals and birds, particularly during the summer breeding season and could be reserved specifically for species management and zoned as IUCN Category IV (see Figure 41). Currently The Reserve only protects 13%, 9% and 25% of the foraging areas of macaroni penguins, king penguins and fur seals, respectively. This would increase to 37%, 30% and 63% respectively with the addition of Key Conservation Areas 1 to 5. This protection is much less than the 75% target level for the escapement of prey to provide for predators in the CCAMLR area. The incorporation of Key Conservation Area 6 as IUCN Category IV (for habitat or species management area) is recommended for the protection of pelagic food webs and the foraging grounds of resident marine mammals and birds, and would raise protection a further 43% of the EEZ from any activities that are not compatible with the conservation values of the reserve.

Given the need to protect the on-going ecological, biological, and evolutionary processes of the area as a key component of the Outstanding Universal Value of the HIMI World Heritage Area, it is essential that the main foraging areas of apex predators that rely on the Southern Pelagic Conservation Area (seals, penguins and flying birds) are adequately protected and it is recommended to be included in The Reserve under some form of protection.

1.0 Introduction

Heard Island and McDonald Islands (HIMI) are part of Australia's subantarctic territory, located in the southern Indian Ocean, nearly 4,000 km south-west of the Australian continent, and around 1,600 km from Antarctica, making them Australia's most remote territory (Figure 1). The HIMI EEZ abuts the French EEZ around the Kerguelen Islands. The HIMI complex is part of the Kerguelen Plateau, which is a large submerged continental plateau that extends more than 2,000km, with only a few emergent volcanic islands.

Heard Island and McDonald Island are the two largest islands with the only two active volcanoes in Australia. The McDonald Islands are located 43 kilometres west of Heard Island. Heard Island is 368 km^2 in area. The McDonald Islands have doubled in size from volcanic activity since the 1980s and are approximately three km^2 in area.

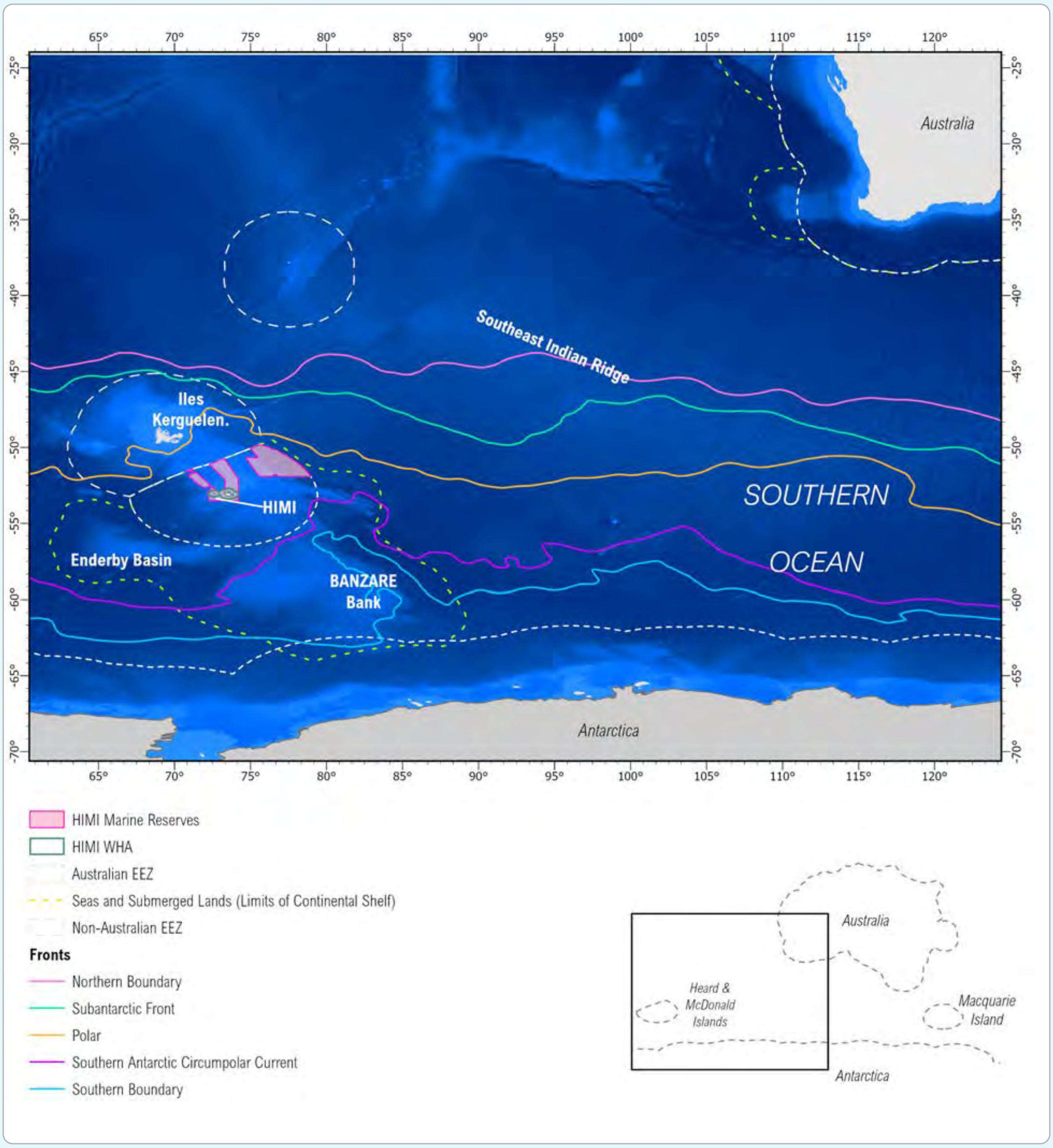


Figure 1. Overview map of Heard Island and McDonald Islands (HIMI) in the Southern Ocean

The HIMI were first claimed by the United Kingdom in 1910 and transferred to Australia in 1947. The Australian Exclusive Economic Zone (EEZ) surrounding the islands covers 410,722 km2. There are a range of mechanisms in place that recognise and protect the natural values of the islands and the marine area of the EEZ. HIMI, and several small islets and rocks, and the surrounding waters out to 12 nautical miles were declared a World Heritage Area (WHA) in 1997 covering an area of 6,589 km2, on the basis of the unique geological features, outstanding examples of biological and physical processes, relatively undisturbed environment, and scientific values. The HIMI Marine Reserve (hereafter shortened to The Reserve) (Figure 2) was declared in 2002 for "the purpose of protecting the conservation values of Heard Island and McDonald Islands and the adjacent unique and vulnerable marine ecosystems" (AAD 2005) following an assessment of the conservation values in the HIMI EEZ (Meyer et al. 2000; see Welsford et al. 2011 for details of the process). A conservation zone was declared at the same time for further consideration of areas to be added to The Reserve following research on the interaction between fisheries and biodiversity in the region (Welsford et al. 2011). Some parts of the conservation zone were added to the marine reserve in 2014 (an additional 6,200 km^2), following a comprehensive scientific assessment of the region's conservation values and stakeholder engagement. The Reserve now covers 71,200 km^2 of the Australian EEZ (17% of the HIMI EEZ). The remainder of the conservation zone was delisted at that time.

The Reserve was established as an important part of an ecosystem-based management system in the HIMI EEZ (Constable & Welsford 2011; Welsford et al. 2011). Management arrangements for the region and the role of The Reserve in conservation are regarded as a model for remote marine protected areas (Welsford et al. 2011; Brooks et al. 2019).

The Reserve includes the islands themselves and the surrounding territorial sea up to 12 nautical miles from shore, which is part of the World Heritage Site. The islands are critical for the survival of the marine mammals and seabirds that utilise the surrounding marine environment. Importantly, a key aspect of Australia's management of the islands since the 1950s has been strict visitation and quarantine controls to maintain natural integrity and near-pristine conditions of the islands, and to continue to prevent the introduction of pathogens and non-native species. This has successfully prevented the introduction of non-native terrestrial species, unlike the neighbouring French islands of the Kerguelen Archipelago to the north which contain sheep, reindeer, rats, and rabbits. The strict, and successful management of the islands makes them one of the world's rare near-pristine island ecosystems (UNESCO 2024).

Abandoned research station on Heard Island. Photo: Inger Vandyke.

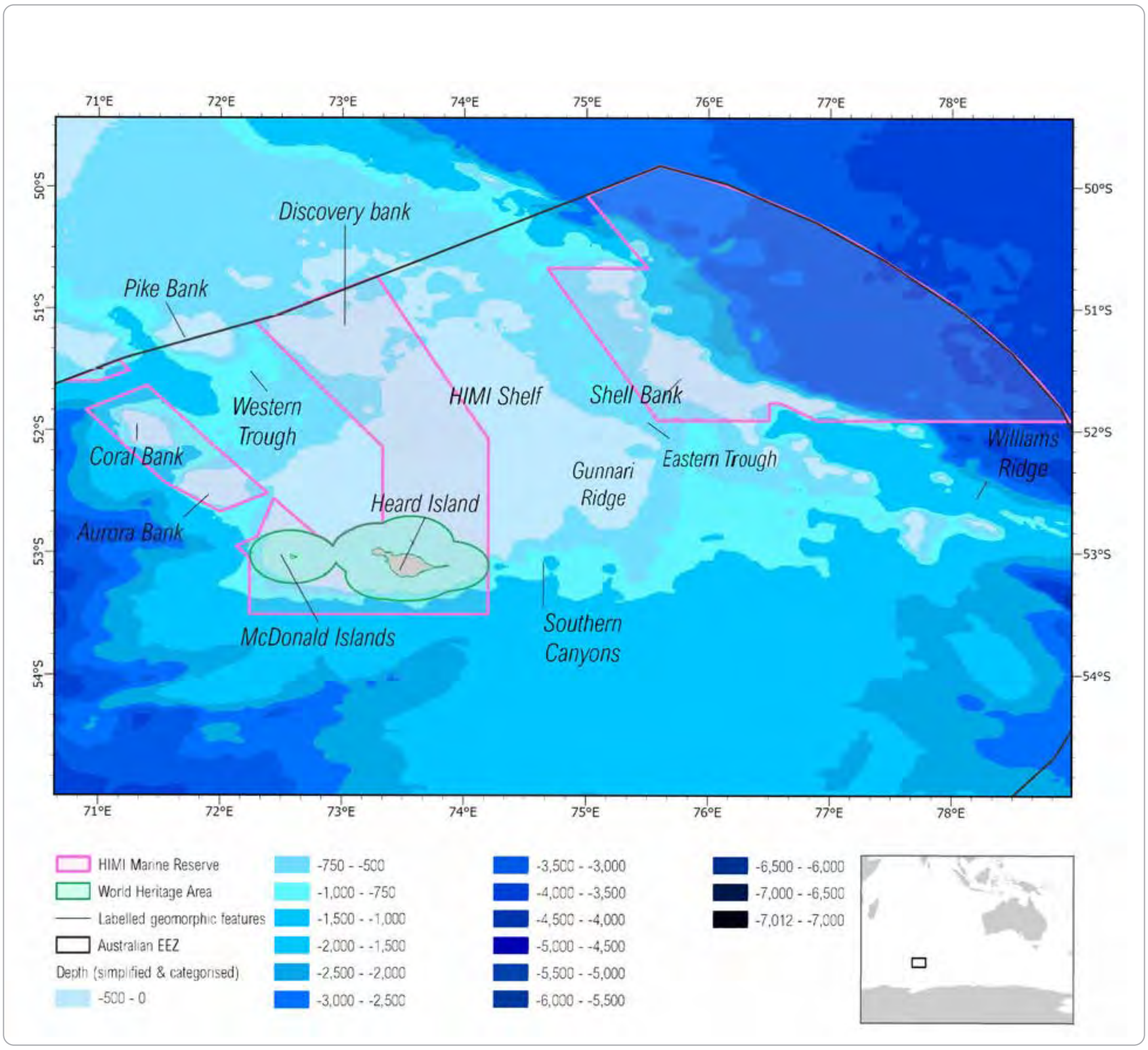


Figure 2. Detailed map of The Reserve

HIMI, as part of the Kerguelen Plateau, is considered a significant site for scientific understanding of our planet due to its role in oceanic and atmospheric processes. The Kerguelen Plateau has a major impact on oceanic currents and circulation patterns in the Southern Ocean. The plateau, which is one of the world's largest oceanic ridges, acts as a barrier to deep ocean currents, influencing the movement of water masses and is a source of nutrients, from which stems an abundance of marine life. Researchers study the interactions between physical oceanography, marine biology, and climate dynamics in this remote and relatively undisturbed environment.

HIMI and the section of the plateau on which they sit are unique in the circumpolar subantarctic realm. The area is remote and boasts a near-pristine terrestrial and marine system. The Kerguelen Plateau ecosystem serves as an important natural laboratory for understanding complex interactions in the Southern Ocean and the broader global climate system. The deep-sea ecosystems surrounding the Kerguelen Plateau are also of great interest, including unique and often poorly known species which have adapted to extreme conditions in the deep, cold ocean.

The area around the Kerguelen Plateau is known for its high levels of phytoplankton productivity that form the base of the marine food web and play a crucial role in carbon and nutrient cycling. This in turn supports a diverse range of marine species, including fish, seabirds, marine mammals, and invertebrates. It is a key feeding and breeding area for various species, particularly those adapted to the cold and nutrient-rich waters of the Southern Ocean.

HIMI's marine ecosystem plays host to a number of whale species (including the endangered southern right whale and pygmy blue whale) that rely on the abundant marine life in the region for their survival. The islands are home to several important seal species such as the Antarctic fur sea and southern elephant seal and seabird colonies including breeding colonies of four species of penguin, three species of albatross and seven species of petrel. All of these animals rely on the surrounding productive waters as a food source.

The EEZ supports a fishery targeting mackerel icefish and Patagonian toothfish. In the 2020-2021 fishing season, 4 quota holders operating five fishing vessels reported catching the available total allowable catch (TAC) of 400 and 3,000 tons, respectively. There is 100% fishery observer coverage on these vessels. The operators collaborate on fishing operations sharing and transferring fishing quota. The value of the fishery is confidential (Patterson and Curtotti 2023).

HIMI, and the commercial fishery are within both the jurisdiction of the Commonwealth Government of Australia, and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) management zone. CCAMLR, part of the Antarctic treaty system, established an international commission, now comprising 27 members, in 1982 (figure 3). CCAMLR has the primary objective of conserving Antarctic marine life in response to increasing commercial interest and a history of over-exploitation of marine resources in the Southern Ocean [CCAMLR 2024].

Kerguelen Cabbage and lichens on Heard Island. Photo: Inger Vandyke.

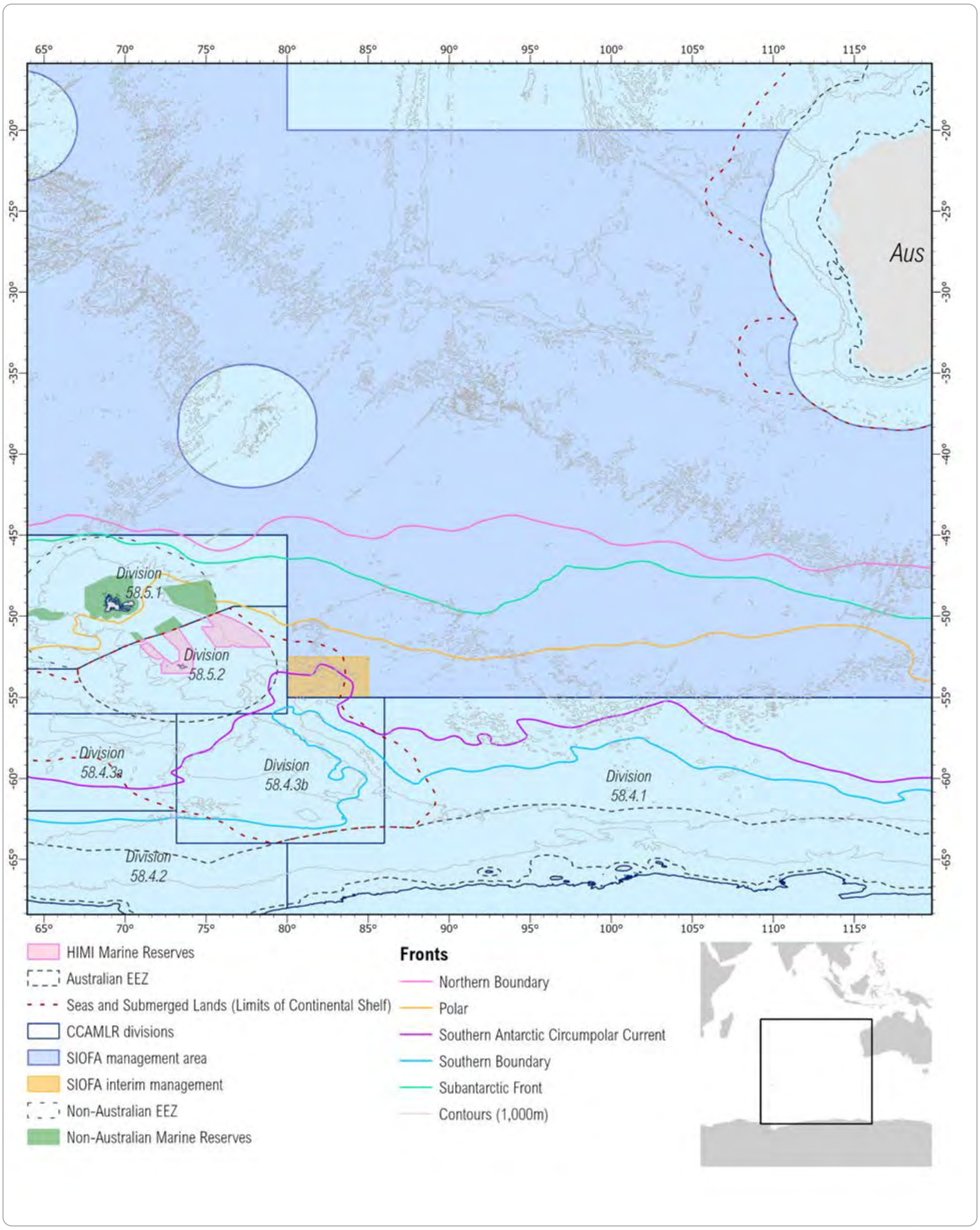


Figure 3: HIMI regional context and administrative boundaries.

The aim of this report is to provide the existing knowledge on the natural, physical, and historical setting of the HIMI EEZ, and the existing pressures, threats and management to assess the contribution of The Reserve to Australia's Nationally Representative System of Marine Protected Areas (NRSMPA).

This report provides a detailed background of HIMI's biogeography and physical setting within the region, details of the biology and ecology of the HIMI EEZ, a review of the pressures HIMI is facing now and into the future, and a description of the existing management arrangements. It builds on the first conservation assessment report for the area (Meyer et al 2000; hereafter referred to as the 2000 Conservation Assessment Report) given our knowledge base and scientific understanding has improved greatly since that time. Notable changes to the HIMI region, include:

(i) climate change, which is having a demonstrable effect, and

(ii) fisheries for Patagonian toothfish and mackerel icefish, which have expanded over that time.

The information compiled in this report provides the basis for an assessment of the comprehensiveness, adequacy, and representativeness of The Reserve as established by the principles of the NRSMPA, and if The Reserve remains likely to be adequate for maintaining the values it was designed to protect. The report details where The Reserve fails to protect all of the values of the region and provides two scenarios for extending The Reserve to include areas of biodiversity that are currently missing or insufficiently represented. Finally, the report examines the Extended Continental Shelf connected to the HIMI EEZ and summarises existing management rights and responsibilities related to conserving biodiversity in this benthic environment.

2.0 Approach

This report is based on a desktop study of the current scientific literature, existing management plans, and personal communications with managers, stakeholders, scientists, and the fishing industry. Appendix 1 summarises the research programs and general information repositories available for consideration in this report.

The information base for the report is mostly obtained from available published scientific literature and reports. This was augmented through the production of exploratory summaries of available scientific datasets to enrich the interpretation of the available literature. Appendix 2 details the datasets used in this report, including the acronyms used as reference to the datasets in the text. New data analyses, primarily for the abiotic drivers, are detailed in Appendix 3 and the results have been added to the Australian Ocean Data Network (https://imos.org.au/facilities/aodn) of marine and climate data resources.

Only limited data are available on the detailed biology and ecology around HIMI itself, particularly off the shelf areas at depth. Some fishery data and the outcomes of fishery-related research that are classed as confidential (subject to data access agreements) were not made available for this study. However, using the available information and knowledge from other subantarctic studies elsewhere we are able to assess the adequacy of The Reserve in relation to the objectives of the NRSMPA.

Much of the scientific literature available places HIMI within a broader regional picture, either at the scale of the Southern Ocean or at the scale of the Indian sector of the Southern Ocean, which extends from south of Africa to south of Australia. We consider this information as the biogeographic context and the regional setting for HIMI and assess it in relation to the uniqueness of that part of the Kerguelen Plateau which is the HIMI EEZ. For the physical context of HIMI, we provide a detailed description of the abiotic drivers that help define the distribution of life in the area. This is followed by a synthesis of Antarctic and regional biogeography to illustrate the significance and origins of the marine biodiversity around HIMI.

New analyses undertaken for this report divide the data into early and recent decades to investigate the effects of climate change. In most cases, the datasets are divided into two 10-year periods: 1993-2002 and 2013-2022. These 10-year periods are when the satellite and reanalysis data are available. In the case of chlorophyll a, satellite ocean colour is not available for this earlier decade. In this instance we must use the decade from 2003-2012. The earliest decade in each dataset is used as the baseline to establish the physical setting for the HIMI EEZ. This also aligns with the original Conservation Assessment 2000 Report and many of the oceanographic studies are also set at this time, and these studies are used to synthesise our understanding of the region for this time period as a baseline for HIMI. Data from the most recent decade are then compiled as "anomalies" from the baseline decade to measure change.

2.1 Regional Context, Biogeography, and Change

In order to understand the regional context of the HIMI EEZ it is necessary to examine the oceanography and the biogeography of the fauna of the broader region. Using spatial analytical tools where needed, this report examines the HIMI regional context in the broader subantarctic circumpolar view as well as looking at the subregional differentiation of biomes around HIMI.

Characteristics of the ocean environment, such as sea surface temperature, are summarised from satellite data and CSIRO/BoM Bluelink 'RANalysis' of 3-D ocean structure including temperature and mixed layer depth known as BRAN2020 (Chamberlain et al 2021). BRAN2020 is an ocean reanalysis that combines observations with an eddy-resolving, near-global ocean general circulation model to produce a four-dimensional estimate of ocean state from 1993 to 2020. Summary data are compared visually as maps as well as generating summary statistics for different biophysical zones (formerly called 'local units' in the 2000 Conservation Assessment Report). Change in the region is summarised as average conditions across two decades: 1990s (1993-2002) and 2010s (2013-2022). Comparisons between decades were facilitated by separating Summer (October of the designated year to March in the following year) and Winter (April to September).

Biogeography of the HIMI EEZ, including the distribution of fauna through depth (bathomes) is based on a review of published literature, recognizing the importance of past events and present-day environment. The HIMI EEZ is rarely a focus of these publications but is mentioned either individually, or as a component of the Kerguelen Plateau, in broader examinations of Antarctic and subantarctic biogeography.

2.2 Assessment of the Reserve

Given the significant increase in information available over the past two decades on the regional bathymetry, oceanography and biogeography of the fauna, this report has reviewed and expanded the 'local biophysical units' used in the 2000 Conservation Assessment Report which were primarily restricted to waters shallower than 1,000 m (which at that time was the depth limit of most of the available data). These were then used to divide the area into a set of assessment zones. Combined these zones cover the entire EEZ and are based primarily on oceanography and bathymetry and informed by the distributions of biomes. They were developed to be consistent with concepts embedded in the principles of the design of marine reserves using comprehensiveness, adequacy and representativeness (CAR) criteria (see Section 9.4). We use these zones to report on and review sub-regional differentiation of the biodiversity of the region using all readily available information on the environmental characteristics of the benthic and pelagic environment (structural features such as seabed topography, ecological function and processes, and oceanographic fronts).

We also identify the full range of known biological characteristics at an appropriate scale, including the spatial extent necessary to incorporate ecological processes and important areas for populations, and identify areas where differences in biodiversity are expected.

3.0 Biogeography of the region

The current patterns of geographic distribution of organisms is known as biogeography and is determined by the historic paleogeography and the current environmental conditions. Duhamel et al. (2014) in their introduction to the fish diversity of the Antarctic, explain how the isolation and cooling of the Southern Ocean 23-25 million years ago following the opening of Drake Passage and the complete circum-Antarctic pathway, has resulted in the evolution of a unique fish fauna with a high level of endemism. The "belt" of abyssal basins surrounding the Antarctic continent limits latitudinal movement of benthic species (Clarke et al. 2003), however there may have been exchanges of benthic fauna between the Kerguelen Plateau and the Antarctic shelf during periods of sea level minima (Frey et al. 2000 cited by Griffiths et al. 2009).

The ocean fronts are a defining feature in present-day biogeography of the Southern Ocean (Grant et al 2006; de Broyer & Koubbi 2014). Bottom topography and primary production show the extent to which the habitat regimes are patchy in space. These features provide barriers to latitudinal movement and dominate the biogeographies of different taxa, as documented in the Scientific Committee on Antarctic Research Biogeographic Atlas of the Southern Ocean (de Broyer et al 2014). However, in paleo times, latitudinal movement of the polar front, to at least 4oN of its current position, caused the shelf around Heard Island and the Kerguelen Islands to be in the Southern Ocean during ice ages, but in the southern Indian Ocean during some interglacial periods (Gendron-Badou et al. 1997). Griffiths et al. (2009) conclude that as a result "the fauna of Heard Island seems to be mainly a subset of that around the Kerguelen Islands."

Alongside the ocean fronts, changing Antarctic paleoclimates have led to distinct features in present day biogeographies. Hedgepeth (1969) and Munilla (2001) proposed that the Southern Ocean is a centre of speciation (cited by Munilla and Soler Membreves 2009). Recent work on fish (Rabosky et al. 2018) and ophiuroids (O'Hara et al. 2019) indicate that diversification rates are highest at polar latitudes, especially for deeper waters in the case of ophiuroids; high speciation rates occur in areas of low surface temperatures and high endemism (Rabosky et al. 2018). It is suggested that this results from a rebounding from regional extinctions caused by rapid cooling of polar waters during the mid-Cenozoic era (O'Hara et al. 2020). The coldest oceans on Earth are present-day hotspots of species formation (Rabosky et al. 2018).

The regional extinctions in shallower Antarctic waters and the unusually deep shelf break which averages 450m and exceeds 1,000m in places (Clarke and Johnston 2003, or 200-1000m, Post et a. 2004) also result in a lack of observed species turnover with depth (O'Hara et al. 2020), such that many Antarctic fauna are capable of living on the bottom in both deep and shallow waters (Brey et al. 1996). Deep sea species appear to have migrated to shallower areas filling niches emptied by cooling polar seas (Clarke and Crane 2010).

In general, the northern Kerguelen Plateau, including the HIMI EEZ, is considered to have similar physical conditions to marine areas adjacent to other subantarctic islands. However, a detailed inspection of the present-day physical environment shows that the shelf area of HIMI has different temperature, currents, and topography, along with its connection to terrestrial processes, compared to the Kerguelen Islands and other subantarctic islands in the Indian sector of the Southern Ocean. A defining feature driving this uniqueness is that it is south of the northern arm of the polar front while the other islands are to the north. HIMI is also separated from higher latitudes by the Fawn Trough and the Fawn Trough Current (Douglass et al 2014; Raymond 2014).

3.1 Benthic regionalisation

3.1.1 Circumpolar

Recent biogeographic reviews inform and update perspectives on the biogeography of the HIMI EEZ.

Kaiser et al. (2011) studying the Weddell and Scotia seas in the south Atlantic concluded that Southern Ocean continental slopes were surprisingly species-rich, often with different fauna than the continental shelf but varying with taxon and region. There was an apparent lack of a homogenous and unique Antarctic slope fauna, which was considered to reflect differences in ecological and evolutionary processes in the different areas, especially local and regional glaciological history. The authors go on to suggest that Southern Ocean slope fauna may have been important for post-glacial recolonisation of the continental shelves by some fauna and may become an important refuge again with future warming and acidification.

McQuaid et al. (2023) completed a broad-scale biogeographic analysis of the Southern Atlantic. Forty three percent of the habitats in a non-hierarchical classification occurred shallower than the continental rise (0.5% of the geographic area) and there was a clear distinction between classes of shelf and slope habitats coincident with different water masses above and below 1,000m. There was some depth-related differentiation in bathyal habitats (unlike Watling et al. 2013). Topography showed a clear influence with habitat classes on elevated or depressed topographic features distinct from adjacent flatter areas, as well as differences between the flanks and peaks of seamounts. They also had differences between geographic areas.

Hogg et al. (2021) found depth, seabed temperature, channel network base level and latitude to be the most important predictors for functional group distribution of invertebrates collected from 28 camera transects (200 - 2,150m) and 12 physical samples (182 - 843m) on a 2019 survey combined with data collected on surveys since 1925 for the South Sandwich Islands (accessed from the Global Biodiversity Information Facility). A total of 4,887 distinct georeferenced records at 773 sampling stations were used in a gradient forest analysis (Ellis et al. 2012). A large number of "splits" occurred between 0 - 1,000m but depth gradient was of low importance between 1,000 and 8,000m. Species richness (and sampling effort) was higher in waters less than 1,000m but there was a secondary peak in species richness between 2,000 and 3,500m.

Hollyman et al. (2022) described the bathyal fish and invertebrate assemblages for the South Sandwich Islands (an archipelago of emergent volcanoes 56 to 60oS) based on commercial longline data (1,340 line-sets between 700 and 2,250m). They detect a clear latitudinal gradient in fish distribution across the archipelago and a less clear gradient for invertebrates which would not have been sampled as effectively with the longline gear. Seawater temperature was indicated as a key covariate, while depth was not. The authors suggested the importance of ocean warming on future fish distributions.

Munilla and Soler Membreves (2009) reviewed the data on pycnogonida from Antarctic and subantarctic waters (264 species, ~20 percent of those recorded worldwide), of which 62 species were endemic to subantarctic waters. They noted that this subantarctic fauna shows origins in the Antarctic fauna at genus level, however the three subantarctic zones (Magellan region, New Zealand and subantarctic Islands) are separate with low similarity (<30 percent) to Antarctic waters.

Fabri-Ruiz et al. (2020) used 41 Southern Ocean echinoid species and 13 environmental covariates to identify 12 ecoregions for the Southern Ocean (see biogeography). Ecoregions 8 (subantarctic island and shelf) and 9 (deep shelf) which contain the shallower and deeper areas of the Kerguelen Plateau show a faunal/environmental break at about 1,000m. (Figure 4).

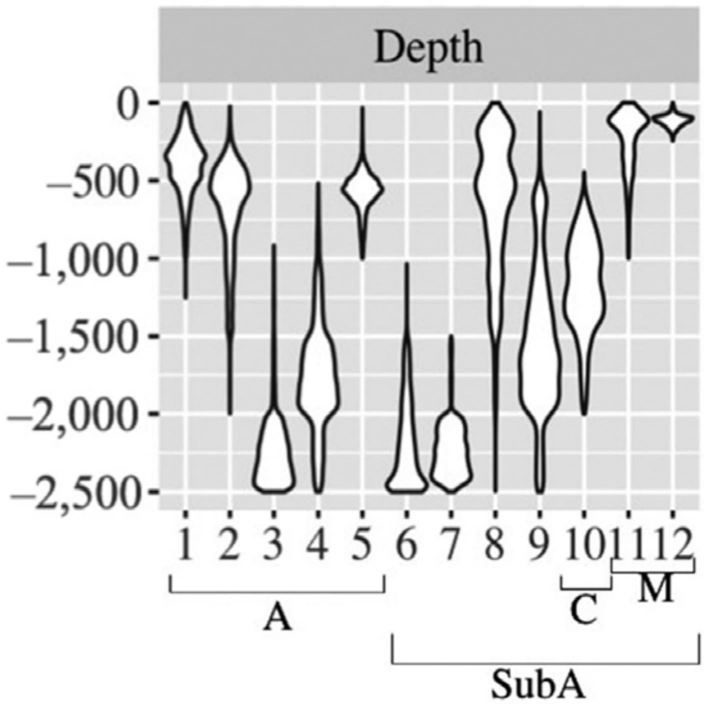


Figure 4. Distribution of depth (m) in the 12 ecoregions identified from 41 echinoid species and 13 environmental covariates. A - Antarctic ecoregions; SubA - subantarctic ecoregions; C - Campbell Plateau; M - Magellanic Plateau. (Figure reproduced from Fabri-Ruiz et al. 2020 with kind permission of the Author).

Raymond (2014) used abiotic environmental data to divide the Southern Ocean into 20 benthic regions, updated by Douglass et al. (2014) using benthic biotic data (although not taxonomically resolved) and abiotic data (ecoregion, bathome, and geomorphology). Three benthic sub-regions were identified associated with the Kerguelen Plateau (Figure 5):

- Kerguelen Plateau sub-region. Shallower (mostly depths between 200 m to 3,000m), warmer seabeds of the Kerguelen Plateau north of the frontal activity of the Fawn Trough.
- Deep Kerguelen sub-region. Deep (mostly depths greater than 3,000m) ocean surrounding the Kerguelen Plateau and Banzare Bank.
- Banzare Bank sub-region. Shallower (mostly depths between 1,000 to 3,000m), warmer seabeds of the Banzare Bank, south of the frontal activity of the Fawn Trough. Douglas

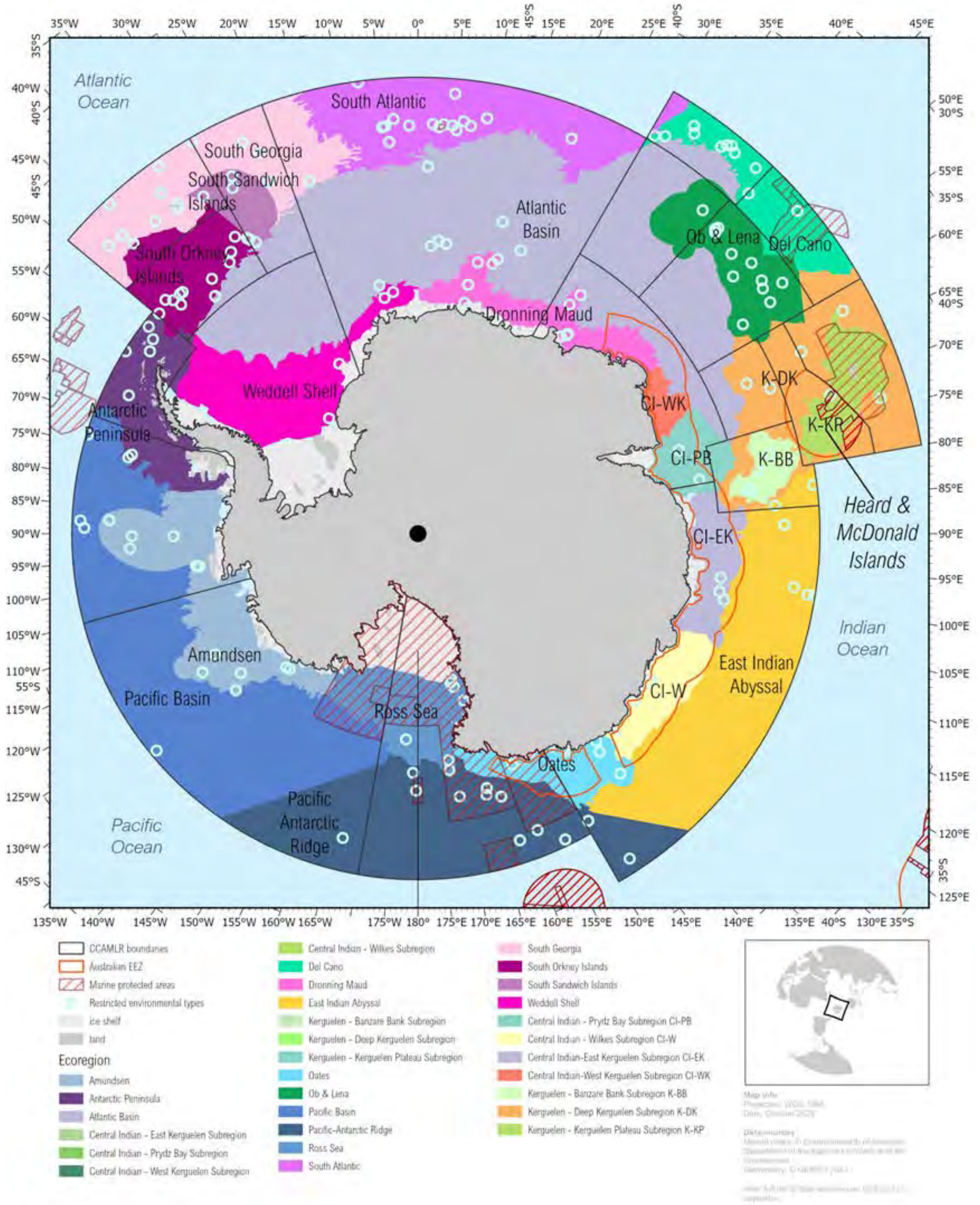


Figure 5. The benthic ecoregions identified within the Southern Ocean from analysis of the benthic biotic (not taxonomically resolved) and abiotic data (ecoregion, bathome and geomorphology).
(Figure redrawn from Douglass et al. 2014 with kind permission of the Author).

More recently, Fabri-Ruiz et al. (2020) combined species distribution modelling with Random Forest and Gaussian Mixture modelling to identify 12 benthic ecoregions (Figure 6). The authors used 41 Southern Ocean echinoid species with more than 15-pixel records and 13 environmental covariates (correlation between covariates <0.7). Except for the deep sea, there was a "relatively good match" with the formerly defined regions, which did not include taxonomically resolved data (e.g. Douglass et al., 2014, above). The division of the north and south Kerguelen Plateau as two ecoregions was consistent through the different approaches and data. The northern Kerguelen Plateau (Ecoregion #8) showed strong faunal and habitat affinities with Crozet Island, Marion Island, Prince Edward Island, and South Georgia. The southern part of the Kerguelen Plateau is grouped with deep subantarctic shelves in southern South America and the Campbell Plateau.

Fabri-Ruiz et al. (2020) concluded (as part of a broader study) that the multiple islands and isolated shelves of the northern Kerguelen Plateau (Ecoregion #8) are of high conservation value given their extreme isolation and likely to contain unique habitats and endemic species, as exemplified by the echinoid *Abatus cordatus* and its "emblematic populations that thrive in the shallow coastal areas of the Kerguelen Islands".

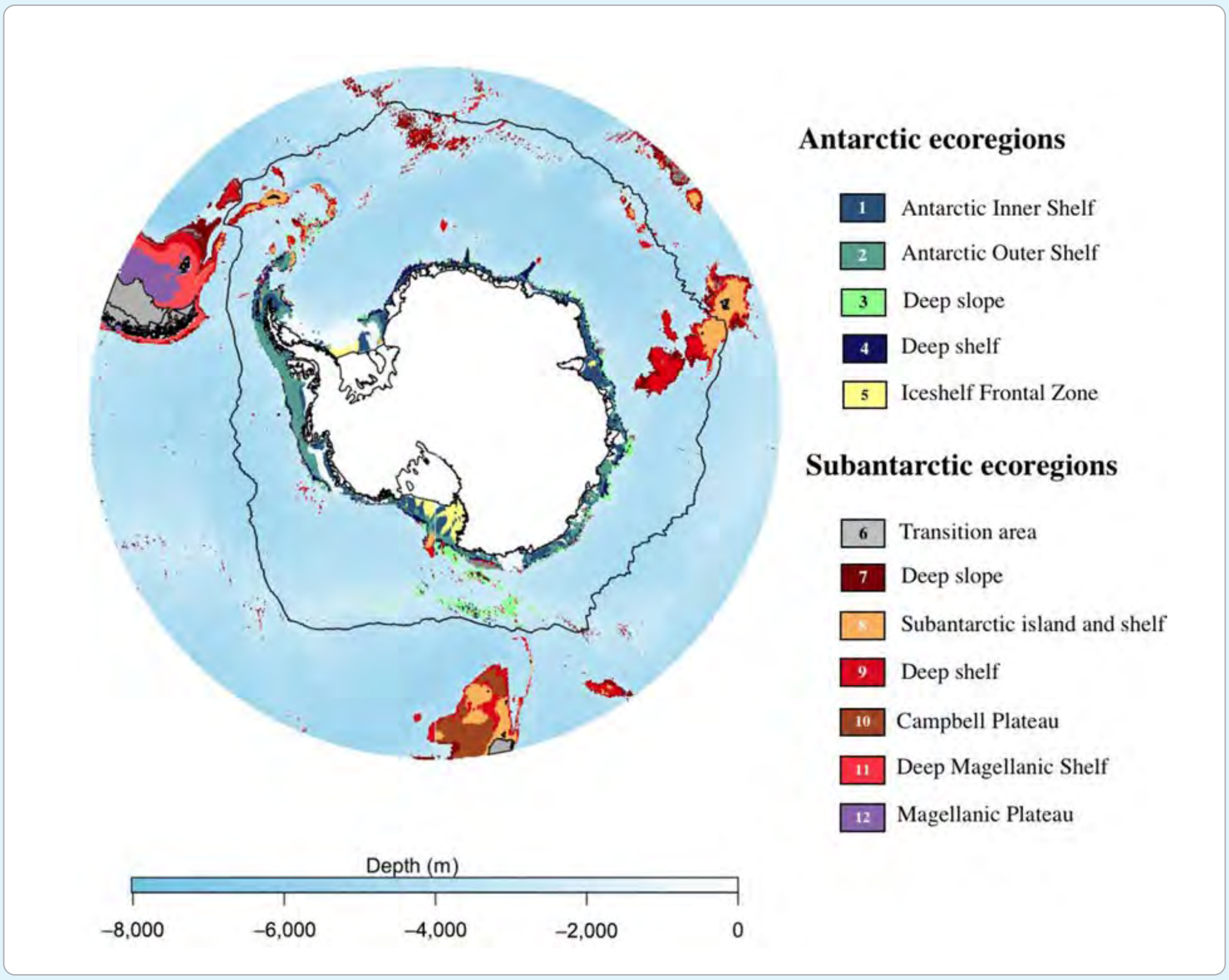


Figure 6. Benthic ecoregions of the Southern Ocean defined by the combination of individual echinoid species models using the Gaussian Mixture Models (Figure reproduced from Fabri-Ruiz et al. 2020 with kind permission of the Author).

3.1.2 HIMI EEZ

Benthic fauna south of the Polar Front is adapted to polar conditions and shows a high level of endemicity based on available samples (Moreau et al. 2017).

There have been more than 30 scientific expeditions to the Kerguelen Islands, however few collected benthic organisms (Ameziane et al. 2011). Between 1961 and 1970 sampling between 2 - 218 m included 76 dredges. Sampling in 1974 and 1975 between 17 - 4,340 m included 234 dredge samples at 122 stations in 10 radial transects around the islands. More recently, the POKER II survey in 2010 collected 200 samples at depths ranging from 100-1,000 m. Noting the challenge in identifying endemicity without comprehensive samples, Ameziane et al. 2021, found that all studied phyla included 'at least a few species' known only from the Kerguelen Islands. Samples collected from the Kerguelen Plateau show endemicity or unique haplotypes for two of seven studied crinoid species and also at least one unobserved crinoid from an otherwise circumpolar distribution (Eleaume et al. 2014 plus Eleaume et al. 2011, Ameziane, et al. 2011). Many collected species are recognized as eurybathic (capable of living in both deep and shallow water). Ameziane et al. (2011) reviewed the status of these collections and noted similarities between Antarctic and subantarctic fauna reported in the literature:

> *"Faunal affinities between the Antarctic and Kerguelen shelves are also found in sponges (Sara et al., 1992, Tabachnik, 1994), cheilostome bryozoans (Barnes and De Grave, 2000; Barnes and Griffiths, 2008), bivalves and shelled gastropods (Arnaud, 1984; Linse et al., 2006). However, the high rate of cryptic speciation found on the Antarctic continental shelf suggests that further molecular studies are likely to unveil hidden diversity and morphologically similar species may prove to be genetically distinct."*

Griffiths et al. (2009) assessed the distributions of 1,318 bivalve species, 4,656 gastropod species, 1,465 cheilostome species and 167 cyclostome bryozoan species as part of a generalized biogeography of Southern Ocean benthos (Figure 7). Heard Island samples included three species of Cheilostomata not found elsewhere. The Kerguelen Islands, where larger sample sizes were taken, included 2 cheilostome species, 7 bivalve and 16 gastropod species not found elsewhere. The Kerguelen Islands showed a 'South American signature for most classes, except gastropods (Antarctic signature); Heard Island grouped with South America for the cyclostome data.

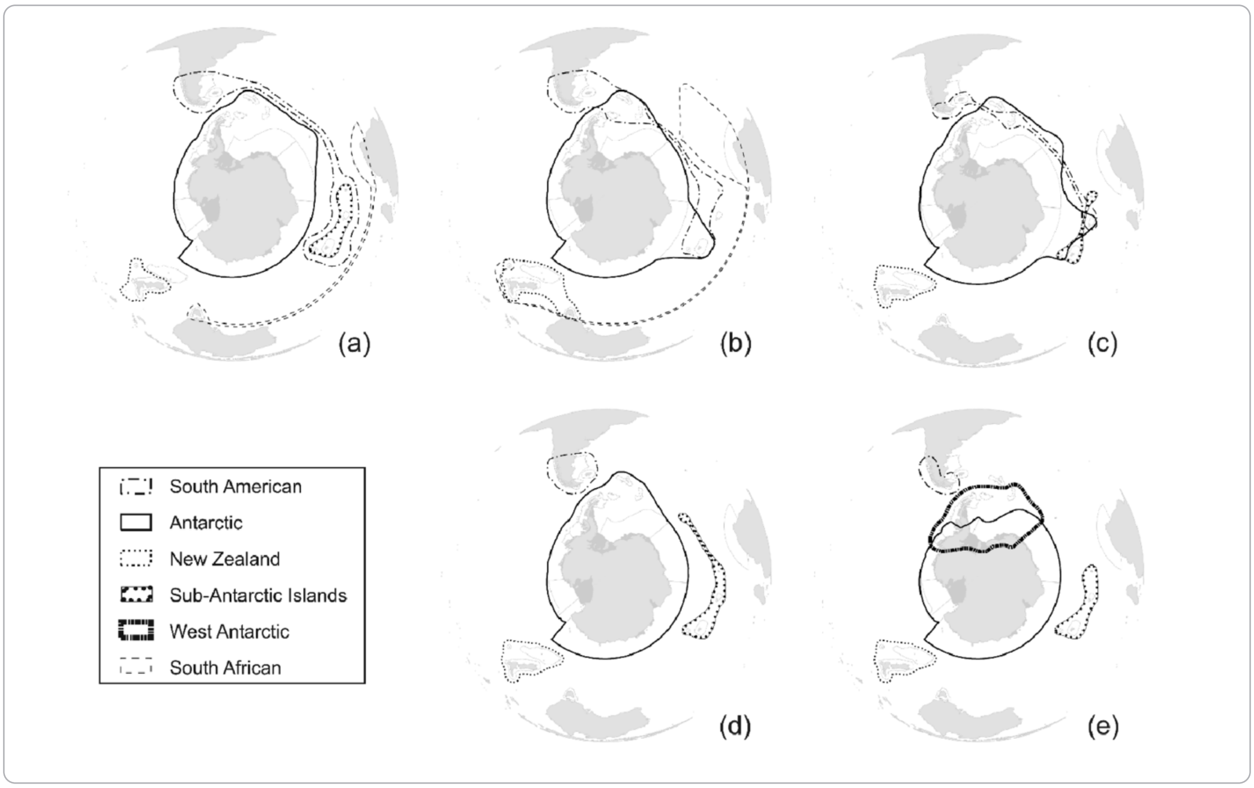


Figure 7. Large-scale faunal patterns in (a) Cheilostomata, (b) Cyclostomata, (c) Bivalvia, (d) Pycnogonida and (e) Gastropoda. The patterns are based upon regions being grouped at 50%, or greater, sharing of species (Figure reproduced from Griffiths et al. 2009 with kind permission of the Author).

The continuity of the shelf between Kerguelen Islands and Heard Island was considered by the authors to be the cause of the "unusually low" rate of endemism for Heard Island itself (as distinct from the Heard Island Kerguelen Islands complex), with only the three Cheilostomata species not found elsewhere (Griffiths et al. 2009). Most species identified at Heard Island had also been recorded at the Kerguelen Islands.

Noting that biogeographic patterns for the Antarctic and subantarctic appear to depend on the taxon investigated, Moreau et al. (2017) concluded from an analysis of 299 asteroid species (14,005 occurrences from 4,512 stations), that the subantarctic islands were a subset of the South America province and separated from the New Zealand and Antarctic provinces (Figure 8). This was especially evident in brooding species (as against those species which broadcast their eggs). The division between the South American province and Antarctic Province is latitudinal (perhaps mediated by the polar front), whereas the sub-division within that province between South America and the subantarctic islands is longitudinal.

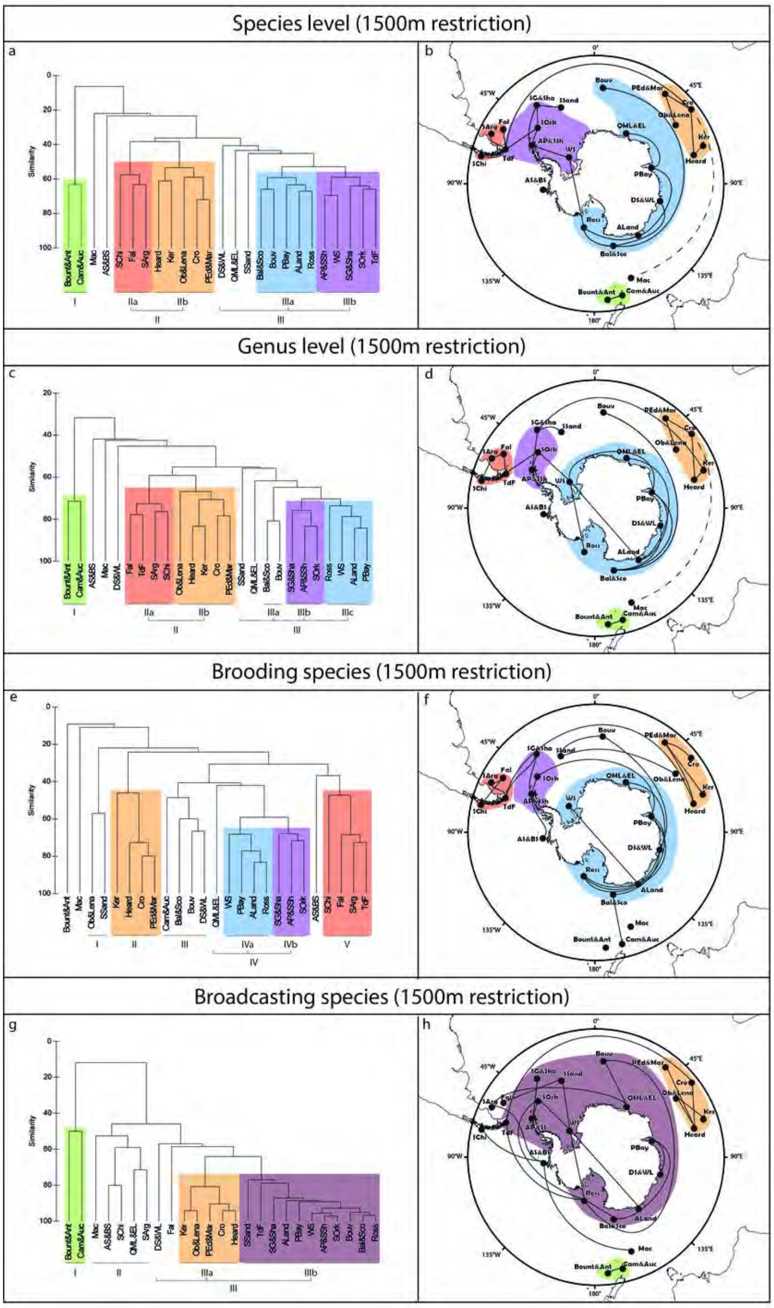


Figure 8. Cluster analyses (average linkage) of the percent faunal similarity (Bray-Curtis index; a, c, e & g) and bootstrapped spanning networks (b, d, f, & h) for 299 Antarctic and subantarctic Asteroid species. The subantarctic cluster is highlighted in orange and the solid line linking it to the South America cluster indicates a bootstrap value >70 percent (Figure and legend reproduced from Moreau et al. 2017 with kind permission of the Author).

3.2 Pelagic regionalisation

3.2.1 General

Like benthic regionalisations described above, pelagic regionalisations use abiotic variables to determine which parts of the ocean have similar attributes. Typically, ocean depth and temperature are used as defining features of the pelagic environment. Ocean depth indicates whether the pelagic environment has a shelf (shallow water, neritic) or oceanic environment. Temperature usually relates to the surface mixed layer where primary production occurs. For the Southern Ocean, the seasonal sea ice characteristics are also important in defining pelagic regions, their productivity and types of species likely to be present.

Three variables - summer climatological sea surface temperature (SST), depth, and proportion of time covered by sea ice were used by Raymond (2014) to update a pelagic bioregionalisation of the CCAMLR area. Nutrient and sea surface height data had incomplete coverage and were therefore not included in the analysis. Non-hierarchical clustering reduced the size of the dataset to 250 clusters and was followed by hierarchical clustering (with some user input), to produce 20 clusters (Figure 9).

Full description of the clusters are provided in Raymond (2014). Two clusters are directly relevant to HIMI and one additional cluster to the southern Kerguelen Plateau:

13. Shallow (~200-1,000 m) parts of the North Kerguelen, Crozet and South Georgia plateau areas, Conrad Rise;
14. Deeper parts (~500-2,000 m) of the same plateaus in cluster 13, also Bouvetoya and the northern tip of the southern Kerguelen Plateau, distinguished by general cooler water than the shallower cluster 13;
15. Deep oceanic waters, encompassing approximately the southern Antarctic Circumpolar Current front and the Polar front is relevant to the southern Kerguelen Plateau.

Antarctic Prion in the Surf. Photo: Inger Vandyke.

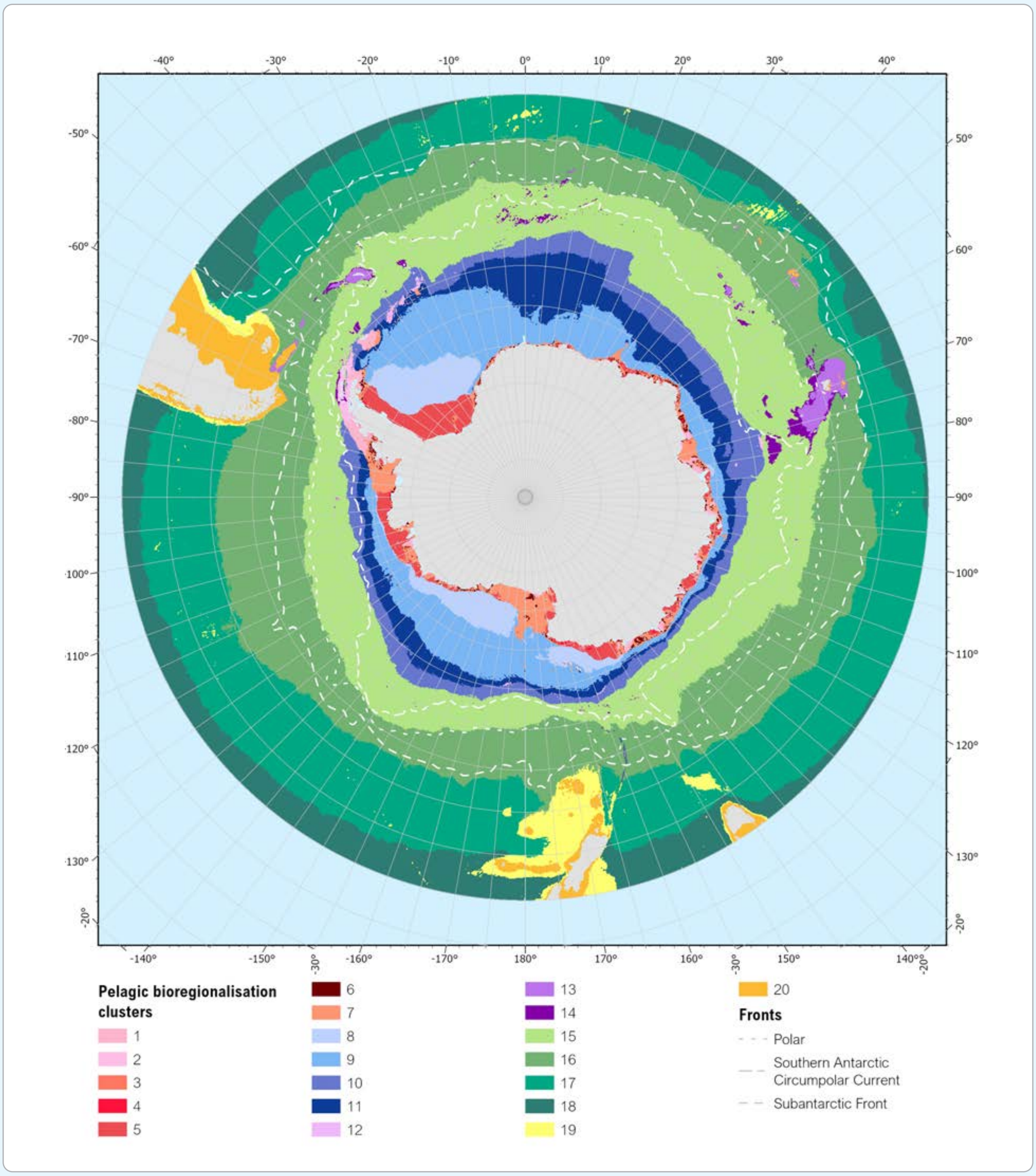


Figure 9. Pelagic bioregionalisation clusters of the CCAMLR area based on sea surface temperature, depth and sea ice cover. (Raymond 2014).

3.2.2 Fish

The first scientific expeditions able to collect fish in the Southern Ocean were in the early 1840s. New descriptions continue to be published, while new molecular techniques lead to continued updating of the taxonomic records, especially cryptic species (Duhamel et al. 2014). Forty-seven families with 374 fish species are recognised with an additional 63 species including some from 8 further families have occasionally been recorded south of the Subtropical Front. Endemism is three times greater than for other isolated marine regions (Eastman 2005 cited by Duhamel et al. 2014). Many temperate species including multiple species of chondrichthyans were driven to extinction with the opening of Drake Passage and the resulting cooling of the Southern Ocean, while the adaptive radiation of Antarctic notothenioids began (characterized by the presence of antifreeze glycoproteins) and now account for over 100 of the known 274 species. The Southern Ocean ichthyofauna can be considered in three broad categories (Duhamel et al. 2014):

Demersal neritic species in the Southern Ocean occur on continental shelves and seamounts, comprising 116 resident species (and seven doubtful *Channichthys* species from the Kerguelen Islands). They can be further divided into Antarctic and subantarctic fauna, with the subantarctic region comprised of the South Georgian Province and the Kerguelen Province, the latter divided into:

- West Indian District (Marion/Prince Edwards Islands, Del Cano Rise and various seamounts
- East Indian District (Kerguelen Plateau and surrounding seamounts), and
- West-Pacific District (Macquarie Island).

Patterns in the *Pelagic fish fauna* generally reflects the pattern of water masses and can be subdivided into polar and temperate sub-groups, with the latter further subdivided:

- Bi-temperate pattern, and
- South temperate pattern comprised of
- Sub-pattern convergence
- Sub-pattern subantarctic (with holo- and semi- subantarctic).

Patterns in the *Deep sea demersal and benthopelagic fauna* are unclear possibly due to low sampling intensity, however it does not seem to be Southern Ocean specific with a few exceptions in the more diverse families.

The shelf break is recognized as a 'pronounced boundary' between meso- and bathypelagic species from shelf-associated species.

Icy coastline of Heard Island. Photo: Inger Vandyke.

The ocean around Heard Island is recognised in Duhamel et al. (2014) as particularly important in the Southern Ocean for:

- Spiny plunderfishes – 2 species restricted to Kerguelen Island and Heard Island *(Harpagifer kerguelensis and H. nybelini)*;
- Eelcod – 1 species restricted to Marion/Prince Edward Islands and Heard Island *(Muraenolepsis orangiensis)*; and
- *Anisopodidae* – 1 species (*Oncorhynchus spinifer*) in the Southern Ocean restricted to the subantarctic islands of the Kerguelen Province.

and the Kerguelen Plateau for:

- Icefish – 7 doubtful species (*Channichthys aelitae, C. bospori, C. irinae, C. mithridatis, C. panticapaeum, C. richardsoni, C. rugosus*) requiring a revision of the genus. Note that C. gunnari is a schooling species currently fished at South Georgia and the Kerguelen Plateau;
- Liparids – 1 species confined to specific inner depressions on the continental slope of the Kerguelen Plateau (*Paraliparis operculosus*);
- Eelpout – 1 endemic species found around the Kerguelen Plateau (*Lycenchelys hureaui*);
- Sharks – the Lantern Shark, *Etmopterus viator* is only known from the Kerguelen Plateau in the Southern Ocean but is widely ranging in the Southern Hemisphere; other widespread sharks recorded at Kerguelen Island include the cosmopolitan Portuguese dogfish (*Centroscymnus coelolepis*), the sleeper shark (*Somniosus antarcticus*) and the spiny dogfish (*Squalus acanthias*); and
- Skates – 3 species *Bathyraja eatonii, B. irrasa* and *B. murrayi* are restricted to the Kerguelen Plateau.

More detailed information on the distribution of fish species in the HIMI EEZ is available from bottom trawl surveys, between 100 and 1,200 m depth conducted annually since 1997, and in similar depths in the French EEZ in 2006, 2010 and 2013. These data and information on the two species targeted by the commercial fishery - Patagonian toothfish and mackerel icefish - are presented in Section 5.3.2.

Sperm whale. Photo: Scott Portelli.

Giant Petrel flying over the Azorella Peninsula, Heard Island. Photo: Inger Vandyke.

3.2.3 Birds and marine mammals

The most comprehensive synthesis of tracking data from multiple studies of a range of Antarctic birds and mammals was integrated in the Retrospective Analysis of Antarctic Tracking Data (RAATD) project to provide a greater understanding of predator distributions in the Southern Ocean that can be incorporated into decision making processes (Ropert-Coudert et al. 2020).

Reisinger et al. (2022) used the maps of predicted habitat importance for 17 marine bird and mammal species in the Southern Ocean (Hindell et al., 2020) derived from the RAATD tracking data in combination with habitat suitability predictions for 29 species that are common prey of Southern Ocean predators to produce a bioregionalization of the Southern Ocean. Seventeen clusters were identified (Figure 10) and The Kerguelen Islands and Heard Island were located within subantarctic clusters 7 and 11. These clusters were also represented in the seas around Macquarie Island and were characterised as of high habitat importance, especially for humpback whale, southern elephant seal, grey-headed albatross, wandering albatross and light-mantled albatross. Reisinger et al. (2022) reported that the area of clusters 7 and 11 that is within existing MPAs was ~10 and 19% respectively.

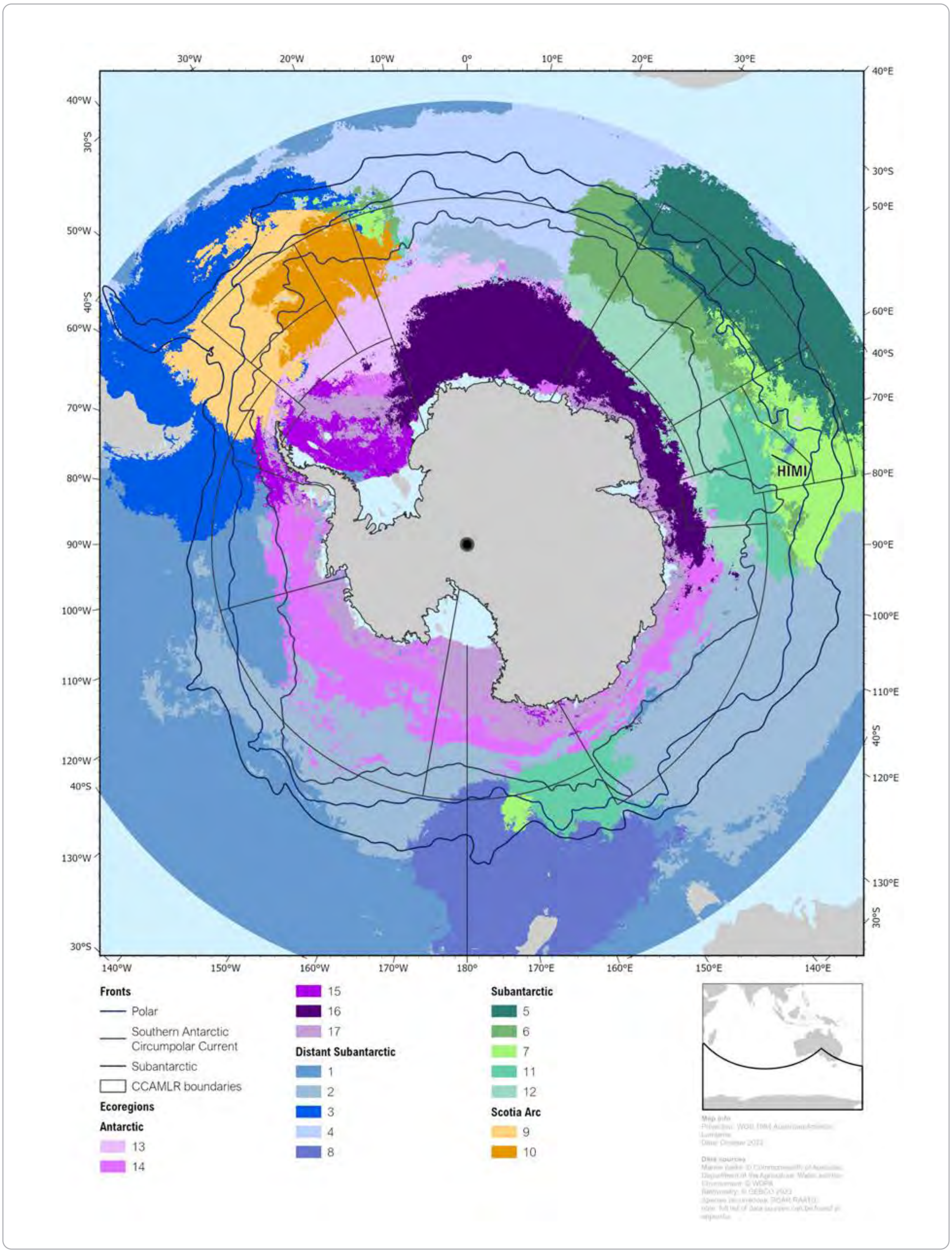


Figure 10. Clustering of important areas for 17 marine predator species. Clusters are aggregated into four higher-level ecoregions: Antarctic, Scotia Arc, Distant Subantarctic and Subantarctic.
(Full details in original figure from Reisinger et al. 2022, reproduced with kind permission of the Author).

4.0 The Physical Setting of HIMI

Biodiversity in a region is defined by the distribution of biota and their dependencies on different habitat features, which include the physical environment and processes such as productivity, coupled with the ecological relationships between species and the dynamics of individual species.

4.1 HIMI in the Southern Ocean

The Kerguelen Plateau is an oceanic plateau located on the Antarctic Plate in the southern Indian Ocean. This massive plateau covers an area of 1,226,230 km^2 and rises 2,000 m above the surrounding oceanic basins which are 5,000-6,000 m deep (Bénard et al., 2010), and is one of the world's largest igneous provinces. These are areas where very large accumulations (areas greater than 100,000 km^2) of igneous rocks have erupted within an extremely short geological time interval (Coffin and Eldholm 1992). Igneous provinces are fundamentally different from other currently active volcanoes or volcanic systems. The plateau was produced by volcanic activity at the time of the breakup of Gondwana about 130 million years ago.

The Kerguelen Plateau is a major bathymetric feature in the Indian sector of the Southern Ocean, extending for more than 2,200 km from near the Antarctic continent to the subantarctic (Park et al. 2019) (Figure 11), and is one of three such features in the Southern Ocean - the others being the Antarctic Peninsula-Scotia Arc in the Atlantic sector and Macquarie Ridge in the Pacific sector (Harris et al 2014).

King Penguins on snow drift, Heard Island. Photo: Inger Vandyke.

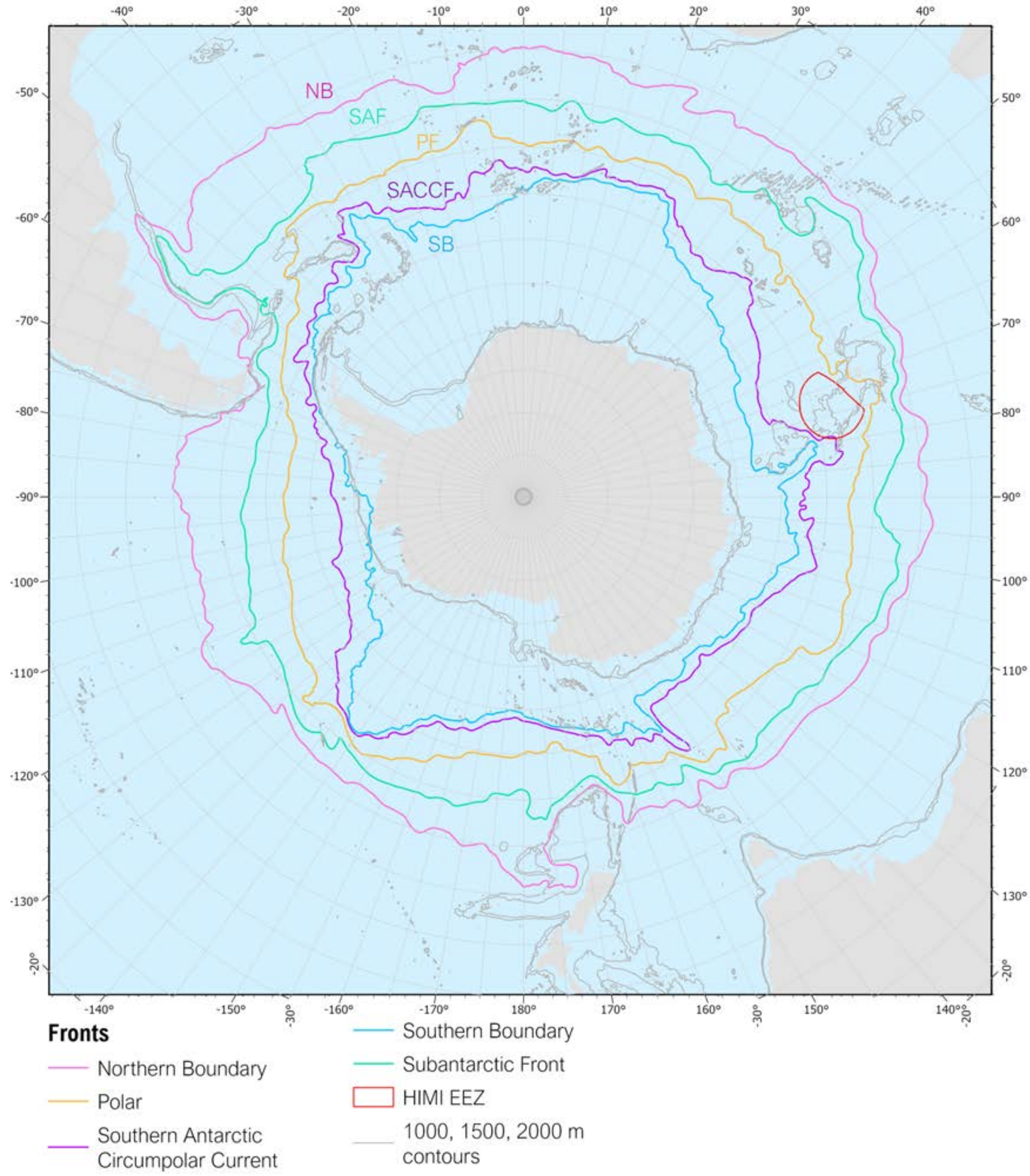


Figure 11. General oceanographic features of the Southern Ocean showing areas shallower than 2,000 m depth and the major fronts (after Park et al. 2019).

Most of the plateau is less than 3,000 m below sea level which has a major impact on oceanic currents and circulation patterns in the Southern Ocean. It significantly deflects the eastward-flowing Antarctic Circumpolar Current (Wang et al. 2016) and influences the physical circulation and biogeochemistry of the Southern Ocean, creating upwellings of water masses and nutrients from which stems an abundance of marine life.

Figure 12 shows the deflection of the northern Antarctic Circumpolar Current front, hereafter referred to as the Subantarctic Front (SAF), northwards toward the energetic, warm, and saline Agulhas Return Current and the adjacent Subtropical Front. The meeting of these currents leads to instabilities and creates high mesoscale eddy energy downstream of the plateau which results in intense mixing and biological productivity (reproduced from Wang et al 2016).

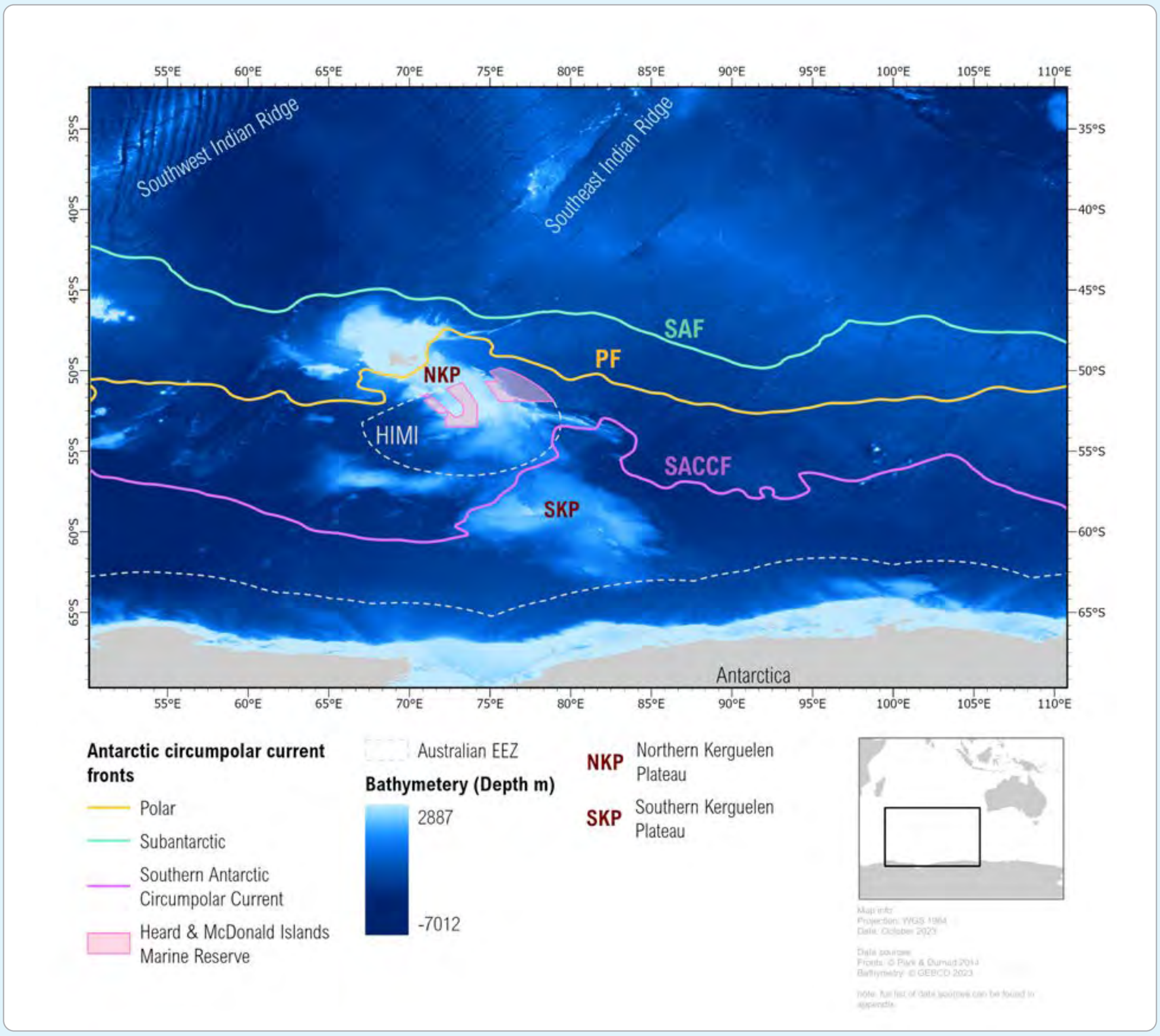


Figure 12. The ocean bathymetry near the Kerguelen Plateau and the position of three ACC fronts (acronyms include: Subantarctic Front (SAF), the Polar Front (PF), and the Southern ACC Front (SACCF) the Northern Kerguelen Plateau (NKP), Southern Kerguelen Plateau (SKP)).

4.2 Topography

The Kerguelen Plateau is divided into northern and southern parts by the Fawn Trough. Only a very small fraction of the Kerguelen Plateau is above sea level (the islands in the HIMI EEZ are equivalent in area to only 0.02% of the area of the EEZ) (see figure 2). The northern plateau has two main island complexes - Îles Kerguelen (a French overseas territory) and Heard Island and McDonald Islands (HIMI) which are separated by a deeper basin with a number of shallower banks (Cottin et al 2011) (Figure 13). Heard Island and McDonald Islands are Australia's only active volcanoes.

The southern plateau is outside the HIMI EEZ but includes Australia's extended continental shelf. There is no area above sea level.

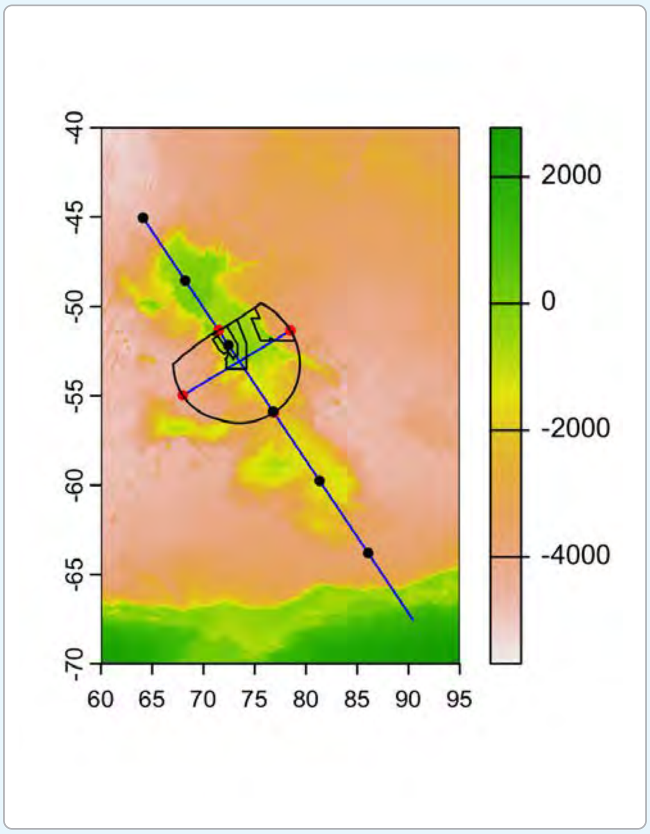
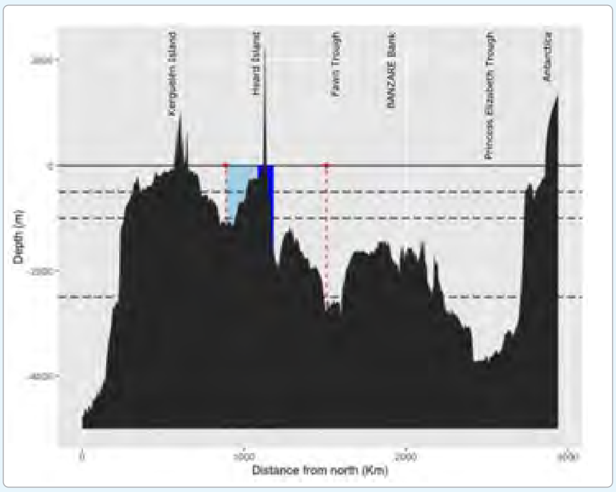
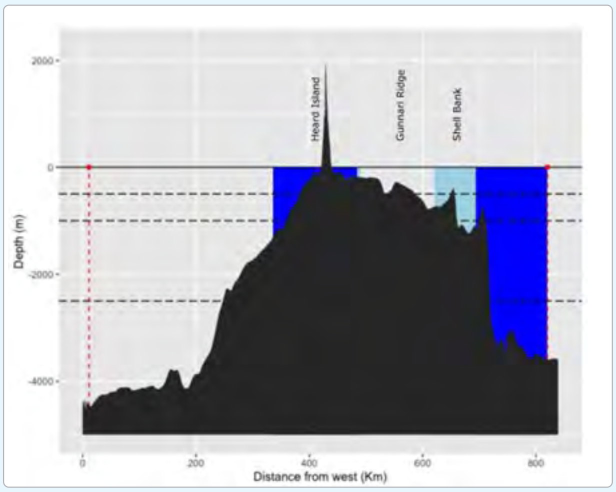


Figure 13. Cross sections of the Kerguelen Plateau (depth, m, with distance, km), showing the main features of the topographic relief of the plateau and the extent to which the current marine reserve covers the different depth zones and features of the HIMI EEZ.

(a) Overview of transects across Kerguelen Plateau - Australian Exclusive Economic Zone (blue line), cross-section locations (black lines), 500 km intervals along north-south section (black dots).



b) North-South Sections showing depth zones (horizontal dashed lines), limits of the Australian EEZ (red dots and vertical dashed lines), marine reserve crossed by the section (dark blue), representation of the northern extent of the marine reserve not on the section (light blue).



(c) West-East Section showing features as in (b), the light blue is the representation of marine reserve not on the section to show west-east extent of the eastern component (Shell Bank) of The Reserve.

Since the 2000 Conservation Assessment Report, vastly improved bathymetric information is available for mapping the seafloor in the vicinity of HIMI. Figure 14 shows the seafloor using the 2022 map provided by Geoscience Australia (Beaman 2023a, 2023b). Colours are chosen to accentuate the depth zones in the region.

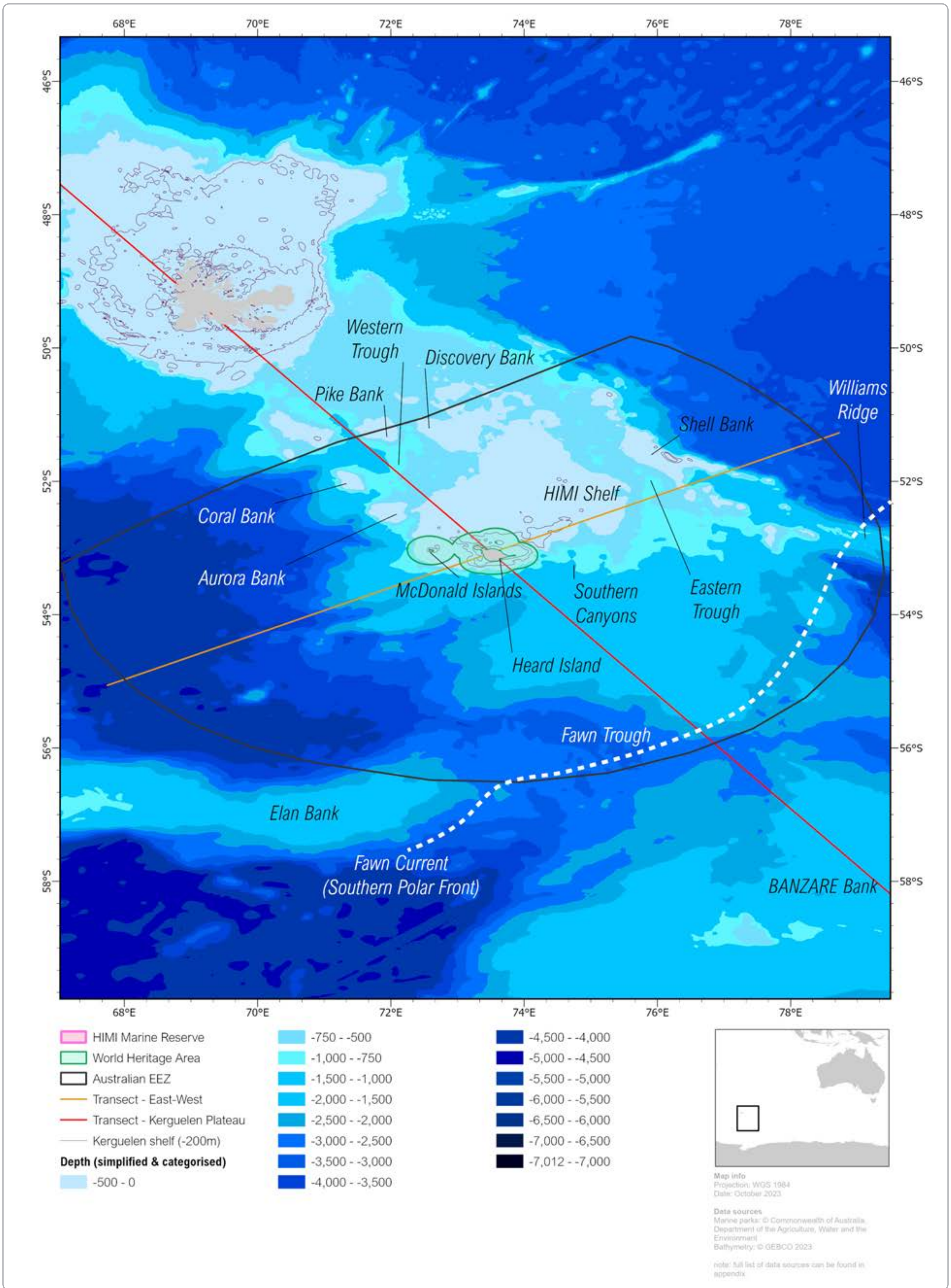


Figure 14. Map of the seafloor in the vicinity of Heard Island and McDonald Islands (AusSeabed Kerguelen Plateau, Geoscience Australia 2022), showing the Australian Exclusive Economic Zone (dark blue line) and the lines of the two cross sections (East-West yellow line, KP red line). Key geomorphic features labelled.

HIMI is separated from Iles Kerguelen by a trough 650 m deep. The Kerguelen shelf is approximately 200 m deep while the HIMI shelf is mostly within 500 m depth (Figures 14); depths shallower than 200 m are only a comparatively small area around HIMI.

The main undersea features of the HIMI EEZ comprise the central shelf areas, including Discovery Bank in the north-west of the shelf, with western and eastern troughs separating banks from the main shelf - Aurora, Coral and Pike Bank in the west and Shell Bank in East. Williams Ridge extends from Shell Bank to the south-east to beyond the EEZ and includes a string of seamounts peaking in depths <1,000 m (Hibberd et al. 2014). The western, eastern and southern margins descend into very deep water, with Fawn Trough to the south. The lack of distinct underwater features in deeper water may be an artifact of the lack of detailed deepwater acoustic surveys, especially swath mapping. Swath mapping off southern Tasmania identified 102 additional seamounts (out of 159 currently known) that had not been generally known after more than a decade of commercial fishing activity based on single beam acoustics (Williams et al. 2008).

4.3 Geology, glaciology and geomorphology

HIMI's unique geomorphology is the product of volcanism, glaciations and marine processes (Cottin et al. 2011). HIMI is volcanically active with Australia's highest mountain, Big Ben, and with the coastline and topography of the McDonald Islands actively increasing over the past fifty years. Approximately 70 percent of Heard Island's area is glaciated. Steep glaciers descend radially and rapidly from Mawson Peak at 2,745m high all the way to sea level, with ice up to 150 m deep. Following periods of glacial retreat, many of Heard Island's glaciers now terminate inland from the coastline. This has led to the widespread formation of glacial lakes and lagoons. Heard Island lost approximately 11 percent of its glacial coverage between 1947 and 1988 (Ruddell 2006). An AAD expedition in 2008 found some glaciers that had retreated 50m in three years. Aerial surveys also show continuous rapid melt and glacial retreat.

Another significant feature in the marine environment surrounding HIMI are the steep sides of the plateau, banks and outcrops resulting in marked differentiation of the shelf areas from the slope and deeper areas. Generally, the shelf areas are shallower than 500 m, the break from shelf to slope is between 500 and 1000 m, the upper slope is between 1,000 and 2,500m, and the deeper slope and abyssal plain lie deeper than 2,500m.

Substrate information has been collected on three international Ocean Drilling Program surveys (1987-1999) and three AAD surveys (1990-1993). Substratum type varies from fine silt or sand on the Western and Northern plateaus, through coarse sand and gravel on Aurora, Coral and Southern Shell banks, to small cobble or rocks on the Southeast Plateau. Southern Shell Bank had a covering of shell grit, unique in the HIMI region (Hibberd et al. 2014).

Substrate information and video observations collected during fishing operations, plus depth and slope were used to define nine geomorphic categories as listed (Figure 15 from Hibberd et al. 2014).

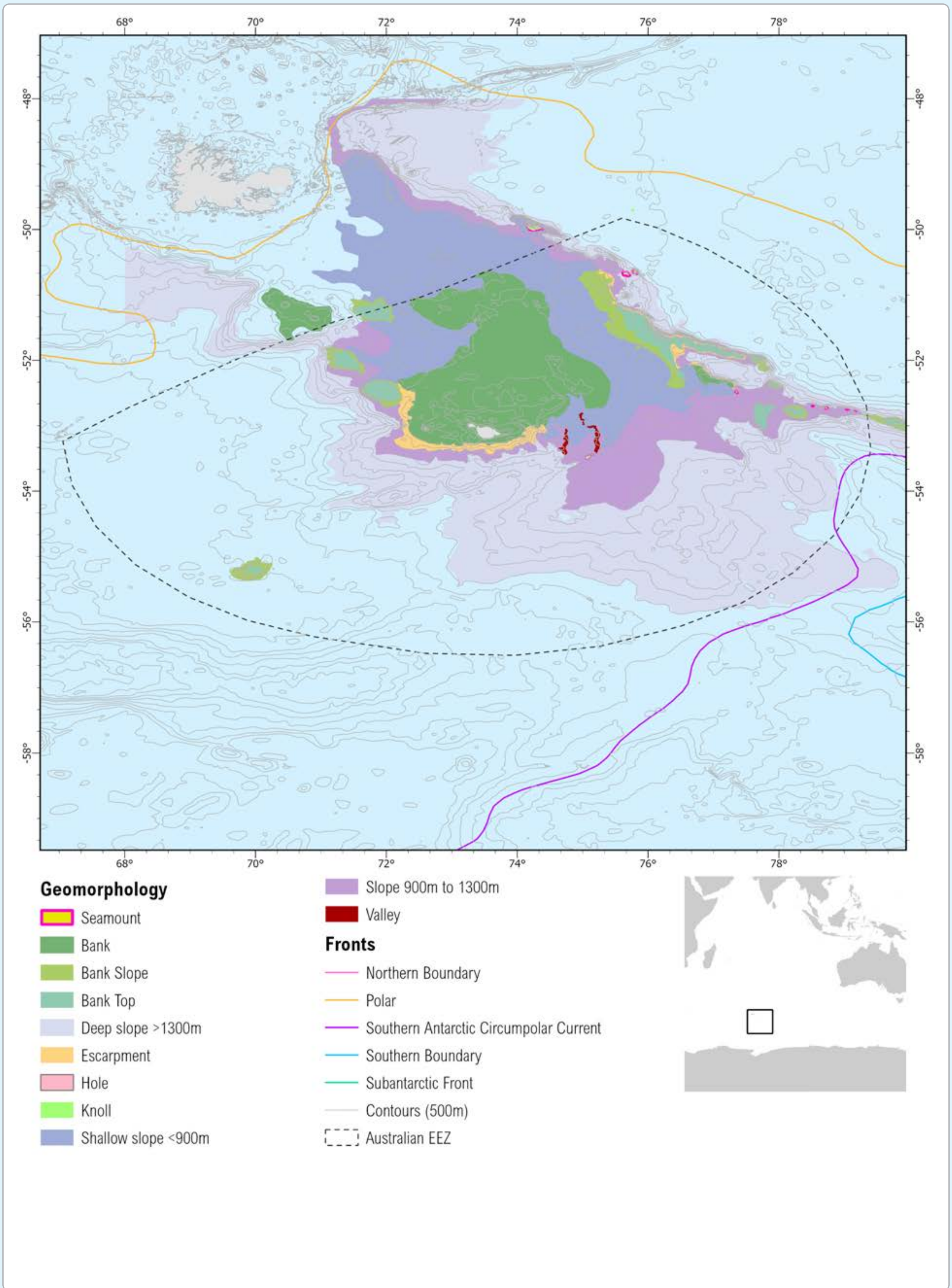


Figure 15. Geomorphic units for the HIMI area used in the study on the effects of fishing on the benthic environment (Welsford et al 2014).
(figure reproduced from Hibberd et al. 2014 with kind permission of an author).

Approximately 22% of the seafloor of The Reserve was mapped with multibeam acoustics in 2016 (Watson et al. 2020) at 25 m resolution, significantly improving the previous 100 m resolution mapping of Beaman and O'Brien (2011). Benthic biological samples were also collected in 2016 incidentally from 5 bottom dredges and 7 Smith McIntyre Grab samples and photographed before dumping.

Prevailing oceanographic conditions have led to sediment removal upcurrent (west) of the islands and deposition downcurrent (east) leaving coarser sediment to the west of the McDonald Islands. A sediment "wave" south-east of the McDonald Islands may extend 21km with a maximum width of 1km. Sea knolls were observed around McDonald Island.

Sediment waves were more numerous south and east of Heard Island, with their direction indicating an anticlockwise deflection of the westerly flow around the island to a northerly flow east of the island. Drifters deployed during the survey indicate that the currents extend to the northeast across the central Kerguelen Plateau after passing Shag Island.

Northeast of Heard Island, a flat seafloor with thick (at least 20-30m thick in areas of maximum deposition), well-sorted sediment deposited by both subglacial and postglacial processes (Watson et al. 2020). Retreat of glaciers associated with changes in the position of the Polar Front and climate change will likely have led to higher levels of sediment erosion onshore and deposition offshore.

Geomorphological data indicate that an extensive ice cap once covered the HIMI region with grounded ice extending to approximately 240m below present-day sea level (Hodgson et al. 2014 in Watson et al. 2020).

Fine-scale bathymetry by Geoscience Australia (GA, Beaman 2023a, 2023b) now enables assessment of the possible heterogeneity of habitats in the whole EEZ using calculations of slope. GEBCO bathymetric data is used where GA data is not available (Appendix 2). The slope of the seafloor is a good determinant of the availability of hard substrata; areas of greater slope have greater chance of having exposed rock and reef that megafauna can attach to (Georgian et al. 2019, Jansen et al 2020, Williams et al. 2020, MacQuaid et al. 2023). Figure 16 shows the pattern of slopes in the vicinity of HIMI. Hibberd et al. (2014) had refined the geomorphic classification of the 2000 Conservation Assessment Report, but these overall classifications have now been superseded and analyses can now be updated with the Geoscience Australia slope data. For example, some of the coarser geomorphic units of Hibberd et al. (2014) did not account for the substratum heterogeneity within those other areas and how they relate to the oceanography and productivity of those areas. In this report, we have used the fine-scale resolution Geoscience Australia slope data to more accurately define substratum heterogeneity and combined this information with bathymetry, oceanography and the sampling undertaken by Hibberd et al (2014) and others to reveal the distribution of benthic habitats in the region.

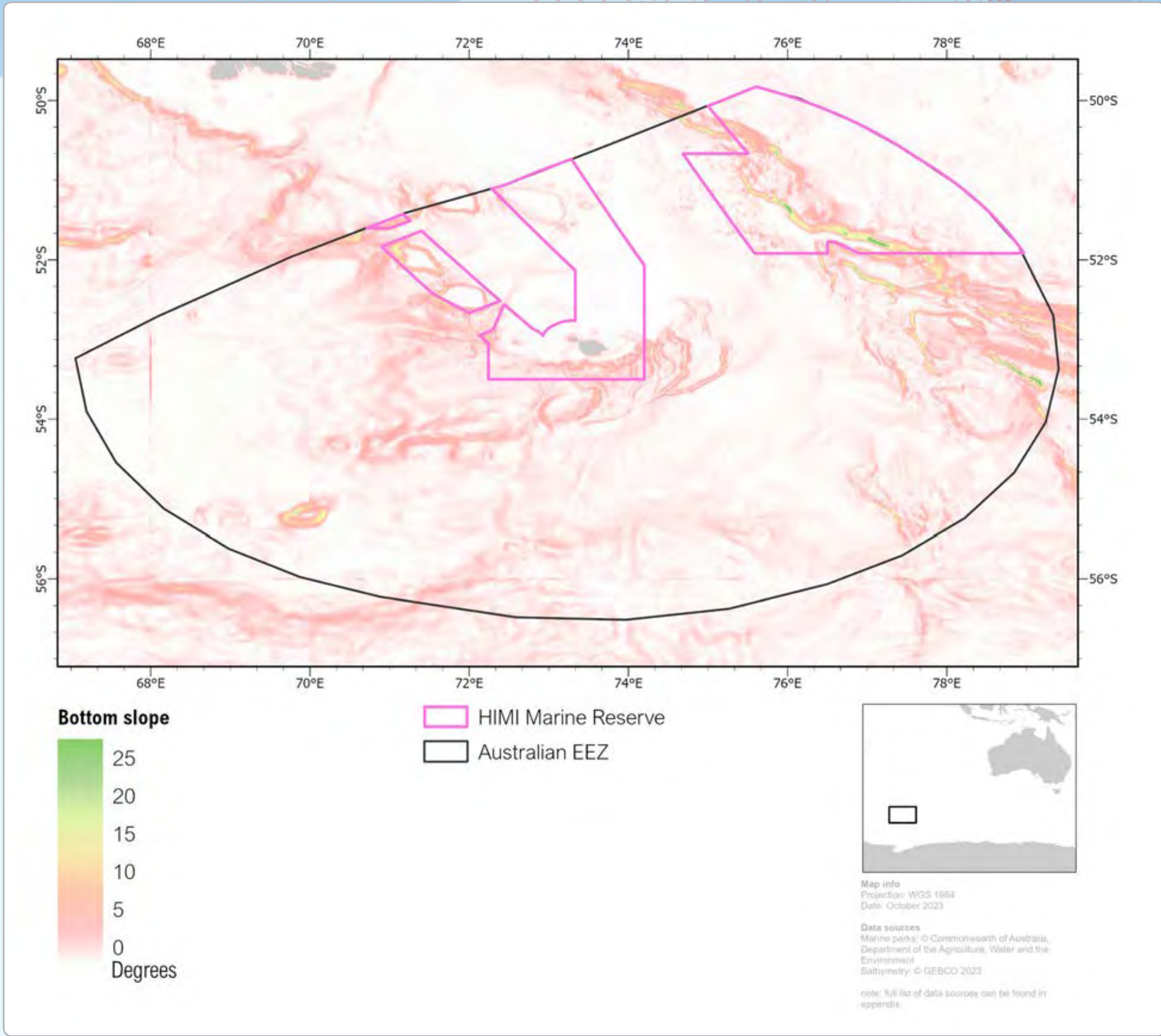


Figure 16. Bottom slope in the HIMI EEZ determined from GA and GEBCO bathymetric data compiled from the region

4.4 Oceanography

The 2000 Conservation Assessment Report based its conclusions about oceanography on the work of Park and Gamberoni (1997). Since then, three research programs have undertaken detailed studies of the oceanography of the northern Kerguelen Plateau. The first program was a marine ecosystem study in the vicinity of Heard Island (Heard Island Predator Prey Investigation and Ecosystem Study [HIPPIES], van Wijk et al 2010); the second was centred between Îles Kerguelen and Heard Island and further to the east to improve understanding of the oceanographic and biogeochemical drivers of primary production (Kerguelen Ocean and Plateau Study [KEOPS 1 & 2], Blain et al 2008, 2014); and the third investigated marine volcanism around HIMI and the biogeochemistry of the ocean, particularly relating to the supply of iron (Heard Earth-Ocean-Biosphere Interactions [HEOBI], Holmes et al 2019). Combined these now provide a more detailed picture of the oceanography of the region.

4.4.1 Temperature

Temperature is one of the defining features of oceanic water masses and is an important driver of biogeography in the ocean, influencing benthic organisms, productivity of phytoplankton, and the distributions of pelagic biota generally. Average satellite summer sea surface temperature over the decade 2003-2012 (Figure 17) shows the general oceanographic environment of the northern Kerguelen Plateau coinciding with early research effort at the time of the declaration of The Reserve.

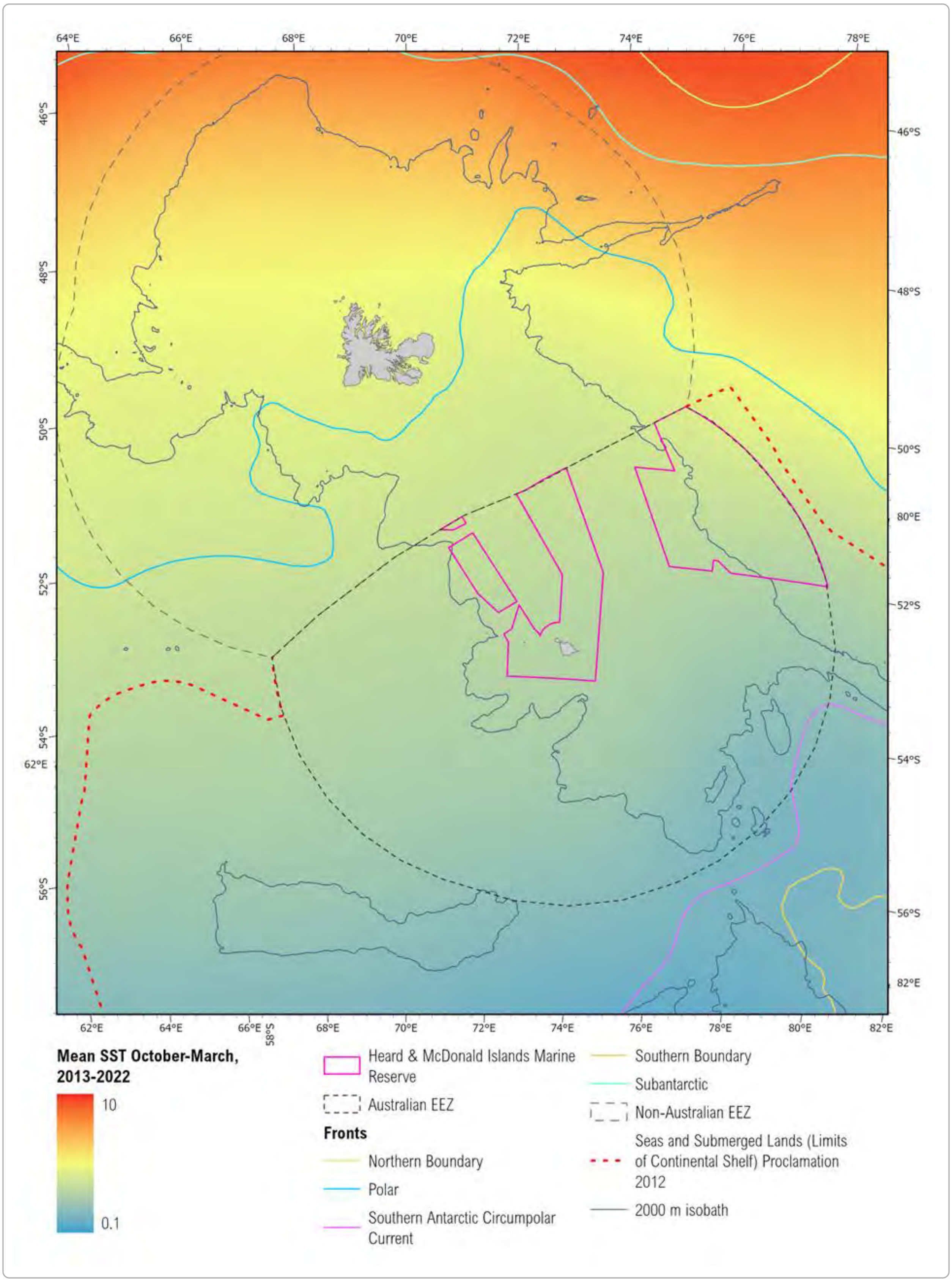


Figure 17. Mean sea surface temperature (°C) over the northern Kerguelen Plateau for October-March 2003-2012. Fronts are from Park et al (2014) (see explanation in section 3.4.2 for alternative nomenclature)

van Wijk et al (2010) shows the vertical structure of water masses around HIMI (reproduced in Figure 18). During the summer of 2003-2004, a surface mixed layer lies atop a layer of winter water, which is cooler than both the surface and the deeper layer of upper circumpolar deep water. The winter water is the remnants of the previous winter mixed layer. Its distribution around the plateau (cold core features) is indicative of the northern and southern jets of the Polar Front, which are the northern extent of temperatures in this layer of 2°C and the southern extent of temperatures at 0°C respectively. Finer patterns of flow in the region can also be discerned from the distribution of the 'Winter Water' layer (see also Holmes et al 2020). The extent of that winter water to the north is the defining limit that separates the polar realm from a warmer realm to the north.

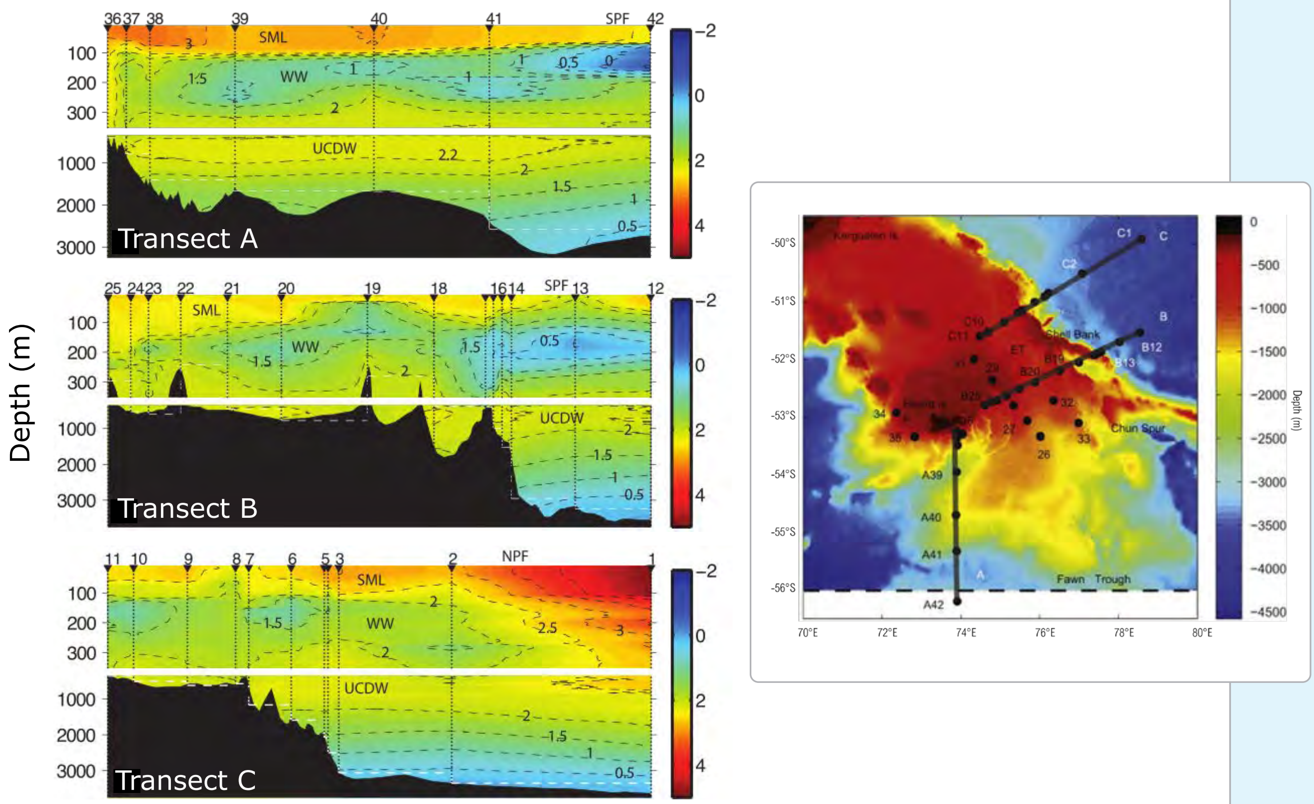


Figure 18. Temperature profiles in the eastern and southern parts of the HIMI area (from van Wijk et al 2010). Transects were undertaken in the south (A), east (B) and north-east (C) of the area (see map).

Each profile has a surface component (0-300 m) and deeper component (> 300 m). Colour ramp is temperature (°C) with isotherms shown in the profile in 0.5°C intervals. Numbers with vertical dotted lines are sampling stations. The Southern (SPF) and Northern (NPF) branches of the Polar Front are shown.

Note the vertical distribution of water masses from surface to deep are: Surface Mixed Layer (SML) of warm water, the remnant Winter Water (WW) of cool water from the previous winter, and the Upper Circumpolar Deep Water (UCDW), which is warmer than the winter water and deeper water.

In light of the results of van Wijk et al (2010), we assessed a synoptic 3-D view of the HIMI EEZ with respect to temperature using the BRAN2020 data (Appendix 3). Using the mean decadal temperature for summers (October to March) from 1993/1994 to 2002/2003, the decade immediately preceding their study and the 2000 Conservation Assessment report, we examined mean temperatures for different depth strata[1] reflecting general distributions of biota, namely:

- epipelagic (mixed water layer, 0-100m),
- winter-water layer (100-200m),
- mesopelagic layer (Upper Circumpolar Deep Water 300-800m), and
- sea floor.

Note that the depth of the seafloor in a cell may exclude parts or all of the depth ranges in the epipelagic, winter water and mesopelagic layers. When depth layers are excluded in total, they are represented as missing. Bottom temperatures adjacent to the seafloor are always present but will be specific to the bottom layer of the BRAN2020 dataset and may be different to the average of a depth stratum when it falls within one of the three depth strata.

Figure 19 presents the mean temperatures for different depth strata for the region and confirms a different temperature regime for the HIMI shelf and the HIMI EEZ than on the Kerguelen shelf. The HIMI EEZ has cooler surface and winter water temperature regimes. In particular, the winter water layer is a defining influence of the shelf environment around HIMI. The Fawn Trough, at the southern edge of the EEZ forms a clear boundary to the cooler waters to the south. The mesopelagic layer is warmer than the epipelagic, and the bottom temperatures are dependent on water depth. Notably, areas shallower than 300m have cooler bottom temperatures than areas between 300 m and 2,000m because of the winter water layer being near to the bottom. This results in the HIMI shelf fauna developing in a much cooler environment than the Kerguelen Shelf.

Big Ben, Heard Island. Photo: Kirk Zufelt.

[1] The depth strata correspond to the water masses observed by van Wijk et al (2010)

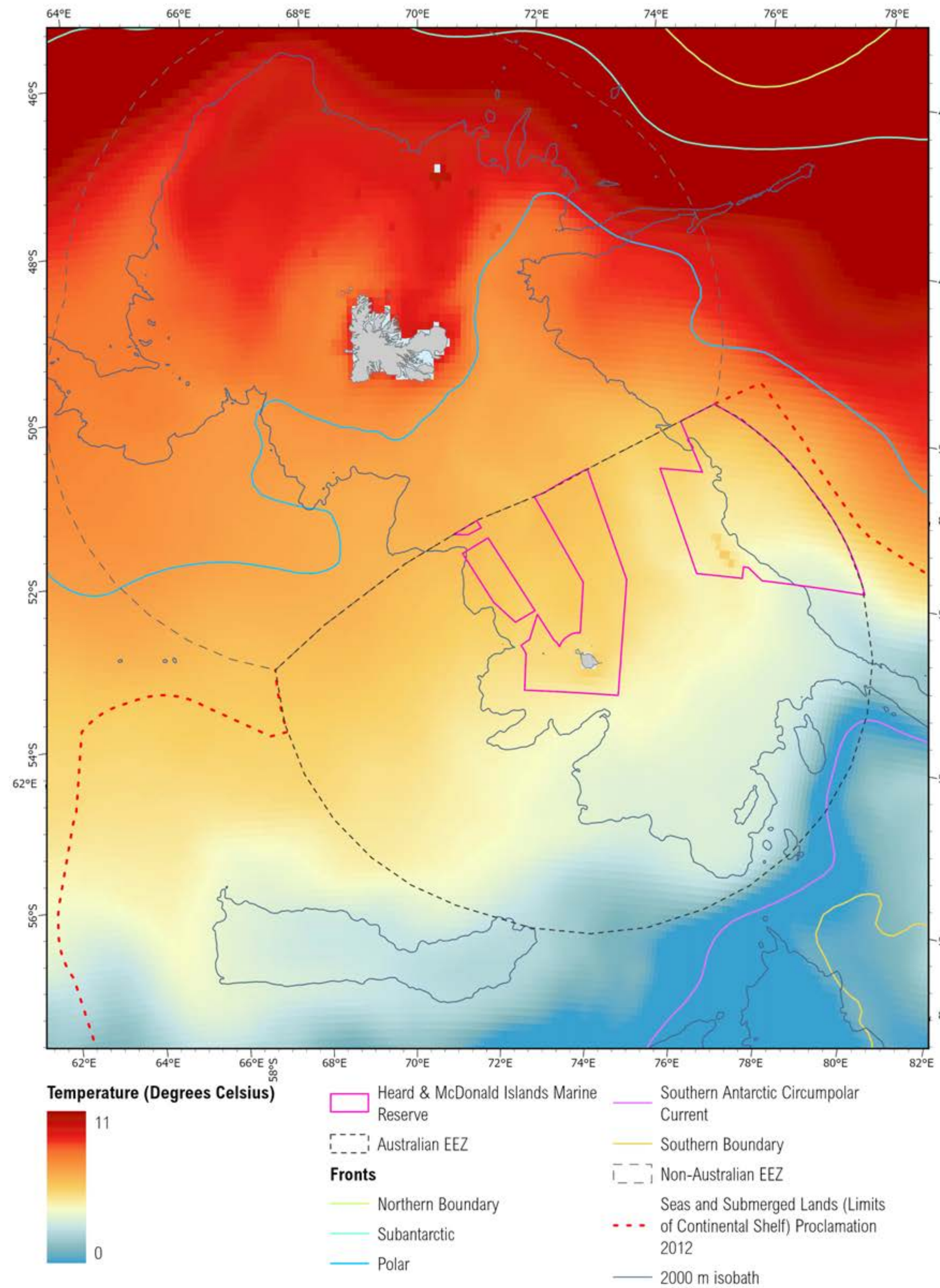


Figure 19 a) Epipelagic layer

Figure 19. Mean decadal temperatures for spring-summer (October-March) in the period 1993/1994 to 2002/2003, derived from the BRAN2020 dataset (Appendices 2 & 3) in the HIMI EEZ.

(a) Epipelagic mixed layer (0-100 m).

(b) Expected winter water layer (100-200 m).

(c) Expected mesopelagic realm influenced by the Upper Circumpolar Deep Water (300-800 m; areas where water depth is shallower than 300m and therefore excludes this stratum are in grey).

(d) Bottom temperature, which is the temperature adjacent to the seafloor irrespective of depth. Colour ramp is the same for each plot but different from other figures in order to show the fine-scale temperature variation.

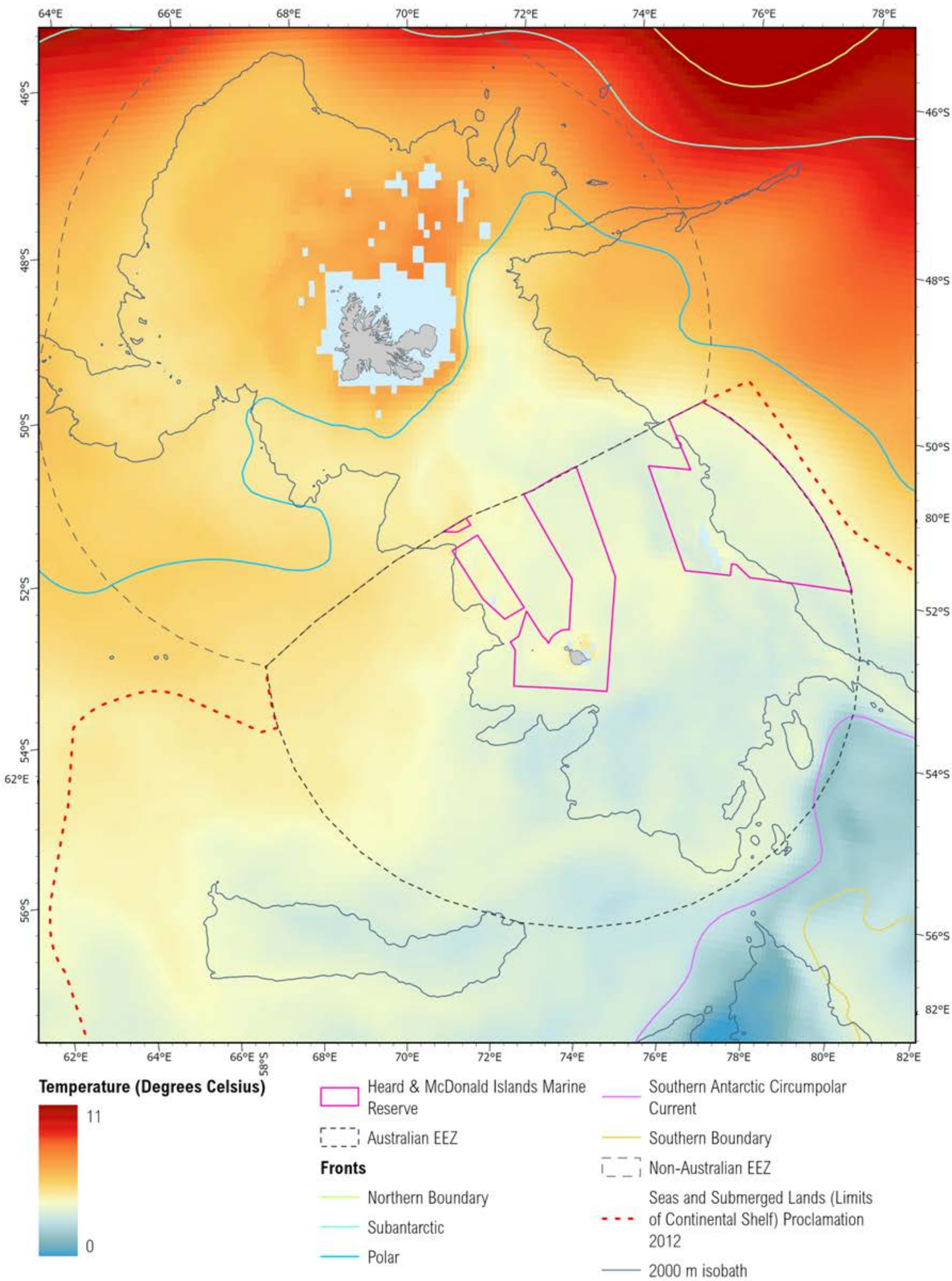


Figure 19 b) Winter water layer

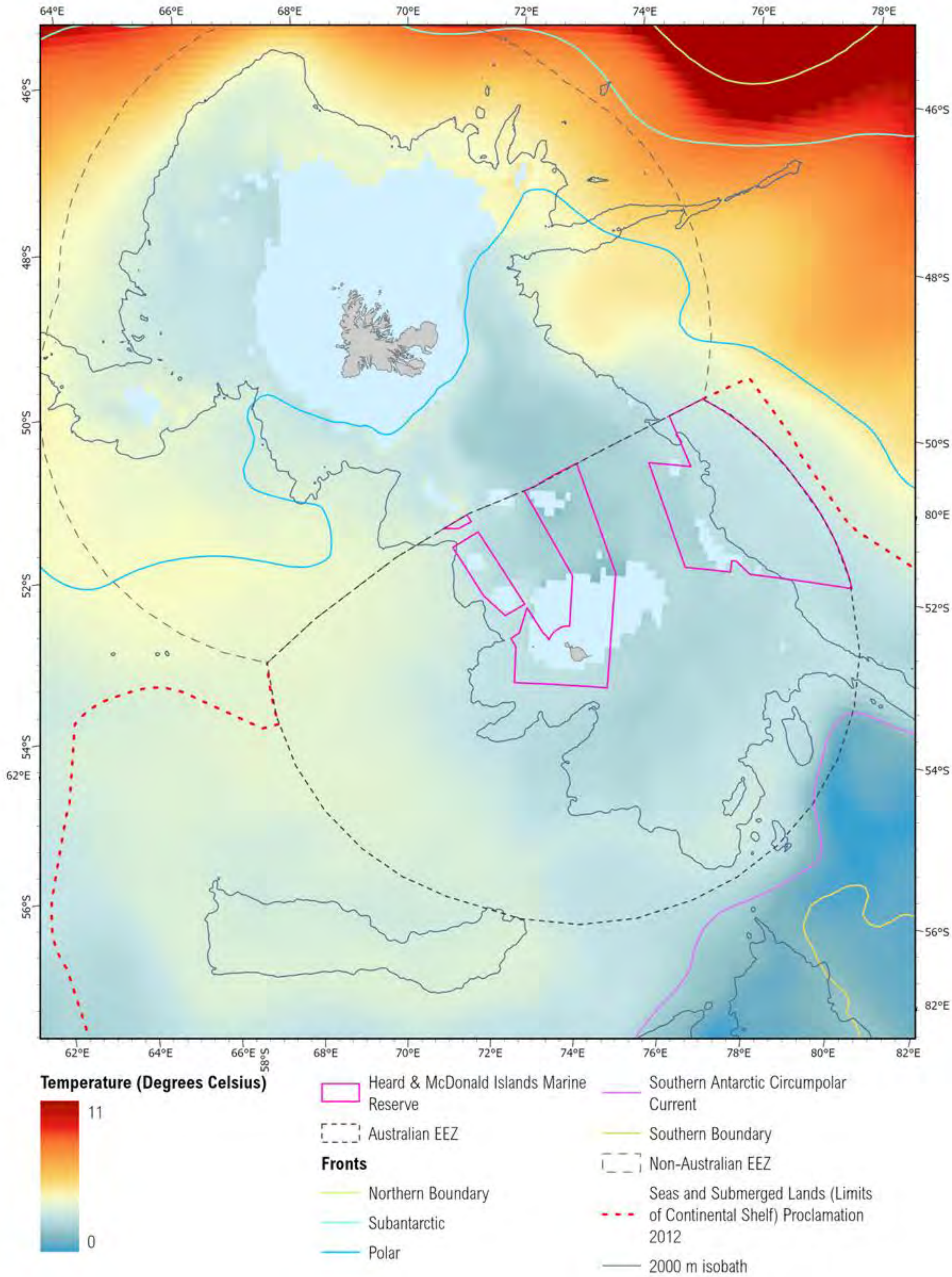


Figure 19 c) Mesopelagic layer

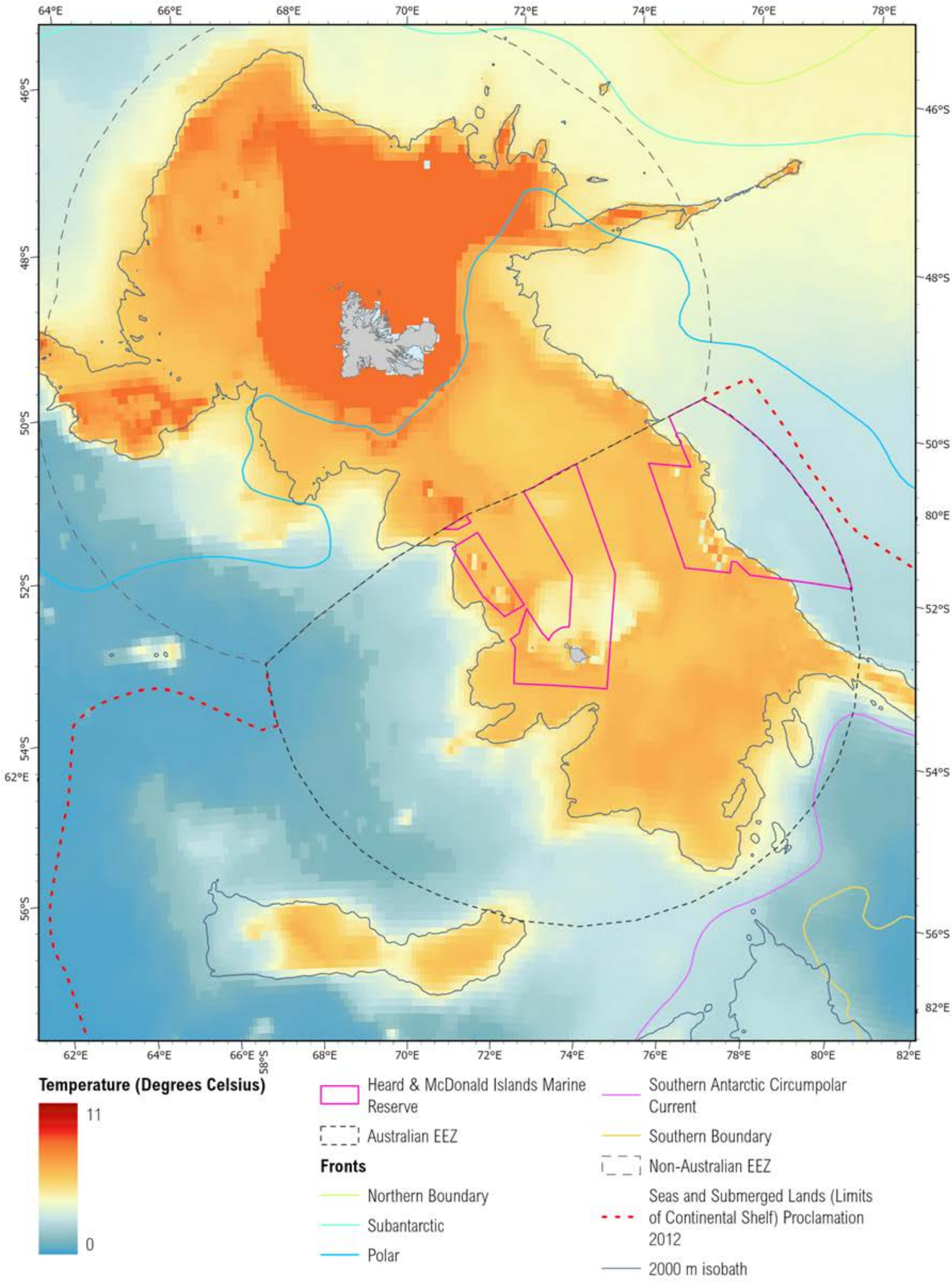


Figure 19 d) Bottom temperature

4.4.2 Fronts and currents

Major currents around the Kerguelen Plateau are well documented although the classification of them is subject to much debate (Sokolov & Rintoul 2009). Strong easterly currents flow to the north of the plateau, through the Fawn Trough and to the south through Princess Elizabeth Trough (Bestley et al 2018; Sokolov & Rintoul 2009; van Wijk et al 2010).

The Antarctic Circumpolar Current is divided by a number of ocean fronts (Figure 12), between which the water masses are relatively homogeneous. An important frontal system around the northern Kerguelen Plateau is the Polar Front, which separates the warmer water to the north from colder water to the south. In the vicinity of the northern Kerguelen Plateau, the Polar Front is divided into two branches, the northern branch flowing to the north of Kerguelen and the southern branch through Fawn Trough. The surface component of the northern branch has been documented to flow around the south of Iles Kerguelen (Park et al 2014) (Figure 20). The flows to the east of the plateau have a strong northerly component until they return to the south-east (van Wijk et al 2010). These flows separate the HIMI shelf area from the marine realm in the Kerguelen shelf area.

The finer scale flows across the HIMI shelf and, particular around the shelf to the south of Heard Island, across the canyon area and northward up the Eastern Trough provides an important demarcation oceanographically between the southern and eastern parts of the region compared to the western and northern areas of the HIMI shelf and banks (van Wijk et al 2010). An assessment of satellite altimetry data showed streamlines associated with northern and southern branches of the Polar Front (van Wijk et al 2010). In particular, the southern branch of the Polar Front is wide to the west of HIMI and narrows to pass through Fawn Trough.

The flows determined by van Wijk et al (2010) were confirmed by Mori et al (2016) who modelled ocean transport in the vicinity of the northern Kerguelen Plateau based on a more comprehensive time series of satellite and model data. They showed weaker transport between the two branches and slow flows from the west over the HIMI shelf. Strong transport is associated with the frontal branches and to the east of the plateau with currents around the south of HIMI through the canyon area and the southern end of the Eastern Trough. Further, the weaker flows give rise to longer water retention times of over 2 months to the west and on the HIMI shelf and its margins (Mori et al 2017; Henschke et al 2021).

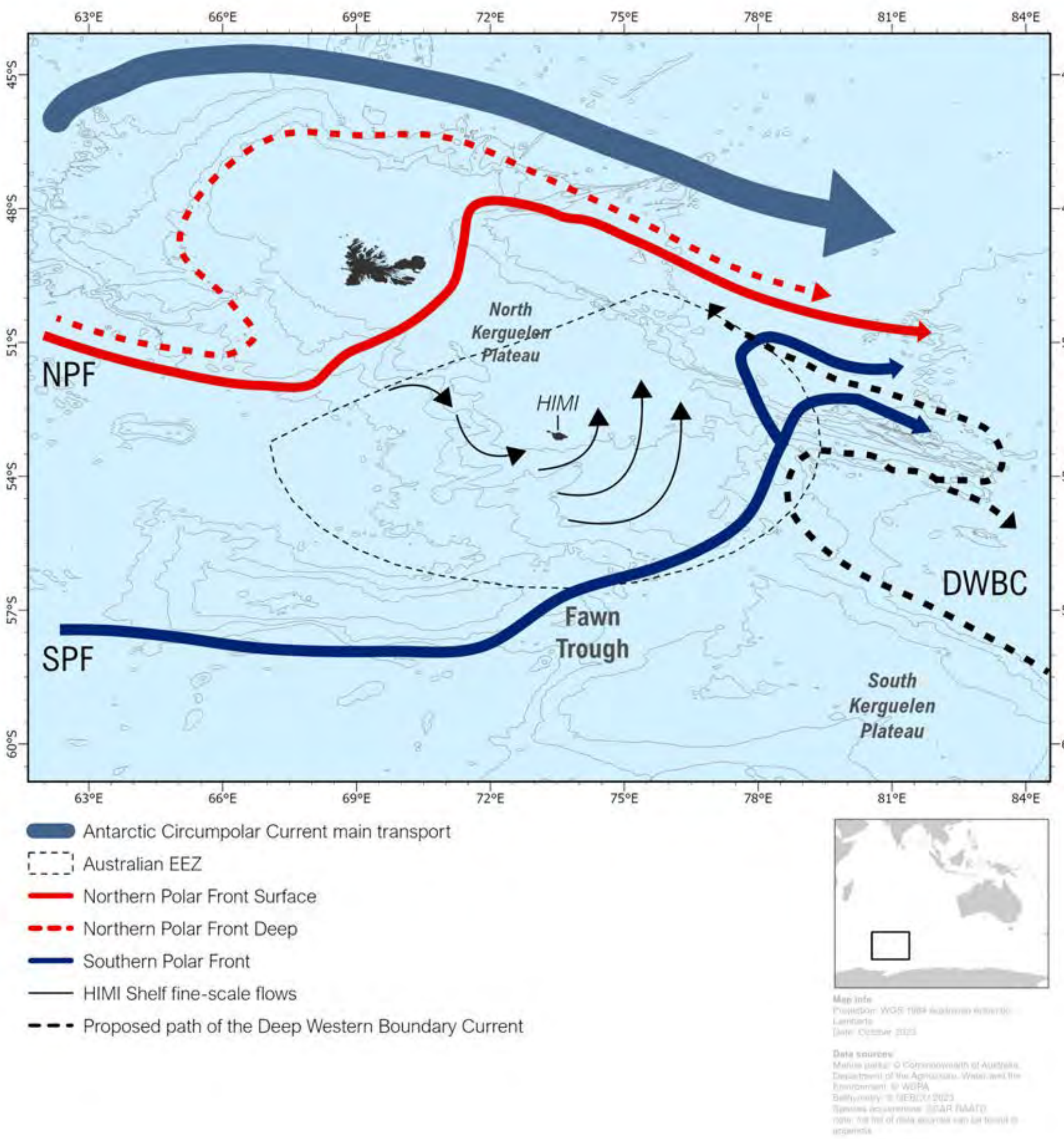


Figure 20. General circulation around the northern Kerguelen Plateau, including fine scale currents in the vicinity of Heard Island and Iles Kerguelen (after van Wijk et al 2010; Park et al 2014).

The Antarctic Circumpolar Current (ACC) is the strongest ocean current on our planet, extending from the sea surface to the bottom of the ocean, and encircling Antarctica without a continental barrier. At its northern margin, the Polar Front acts as a barrier between polar and subantarctic water masses with steep temperature and salinity gradients. The combination of a strong current and contrasting physico-chemical properties on either side of the Polar Front creates a biogeographic barrier to the latitudinal movement of many planktonic and micro-nektonic species, but rapid longitudinal dispersal south of the Polar Front in the fast west-east clockwise transport of the ACC. The Kerguelen Plateau as a whole stretches to within approximately 200 km of continental Antarctica (at 3,000 m depth) and has moved very little in relation to Antarctica in the last 110 million years (Frey et al. 2000 cited by Griffiths et al. 2009).

4.4.3 Productivity

The Southern Ocean is regarded as a 'high nutrient low chlorophyll' environment, such that much of the ACC has low abundances of phytoplankton (Henley et al 2020). However, there are parts of the ACC that are hot spots of primary production (Henley et al 2020); the Kerguelen Plateau and downstream waters to the east are a significant area for primary production in the Indian sector (from south of Africa to south of Australia; Sokolov & Rintoul 2007).

Satellite chlorophyll a (Appendices 2 & 3) is a measure of the density of chlorophyll a at the surface (mg.m-3) and used as a relative measure of abundance of phytoplankton (Pinkerton et al 2021). When combined with the depth of the mixed layer, the total density per area of ocean (mg.m-2) can be estimated. We use the monthly satellite chlorophyll a combined with the mixed layer depths available in the BRAN2020 dataset (Appendices 2 & 3) to develop a time-series of chlorophyll a and calculate synoptic maps of spring (October to December) and of summer (January to March) mean per area densities over the northern Kerguelen Plateau for the decade 2003 to 2012 (the time series of satellite ocean colour does not extend as far back in time as temperature data).

Results for chlorophyll a densities in spring and in summer are shown in Figures 21 and 22 respectively.. The dominant production over the northern Kerguelen Plateau is in the spring bloom (Wojtasiewicz et al. 2019). Notably, the persistent summer production, an important time during the reproductive season of land-based predators, shows a clear separation of the area around Kerguelen Island to the north of the Polar Front and the area around HIMI.

The amount of the micronutrient, iron, is regarded as a major limiting factor on primary productivity in the Southern Ocean (Henley et al 2020). For the northern Kerguelen Plateau iron-depleted water flows from the west, giving rise to the western margins of the HIMI EEZ being lower in phytoplankton (Pinkerton et al 2021), as well as in the waters moving around Heard Island to the south, and on past Shell Bank (Holmes et al 2019) (Figure 21). Wind-driven winter mixing of the water column enables some replenishment of surface waters by nutrient-rich deep water, thereby enabling peak primary production in spring in these waters but dissipating over summer (Henley et al 2020; Pinkerton et al 2021). Additional sources of iron are available over the plateau, including from seeps on the seafloor (Holmes et al 2020; Spain et al 2020) and aerial particulates from volcanic activity from around HIMI (Perron et al 2021). The greatest sources of iron are from wind-driven eddies regularly bringing deep water to the surface and from resuspension of the sediments on the shelf (Gille et al 2014), as well as significant inputs from reservoirs of iron in the glaciers on Heard Island released to the ocean in meltwater (Holmes et al 2020; van der Merwe 2019).

Phytoplankton streams to the east in the currents away from the islands; the satellite ocean colour signature for chlorophyll a (Figure 21) shows this spatial pattern and how the currents of the region influence the passage and distribution of the phytoplankton. The separation of the plumes from Kerguelen Island and HIMI are evident and in previous analyses of chlorophyll a (Gille et al 2014), with the surface expression of the northern branch of the Polar Front steering production from Kerguelen Island to the north. The plume emanating from HIMI moves from the shelf up the Eastern Trough to the north and then to the east, as expected from the circulation model of van Wijk et al (2010).

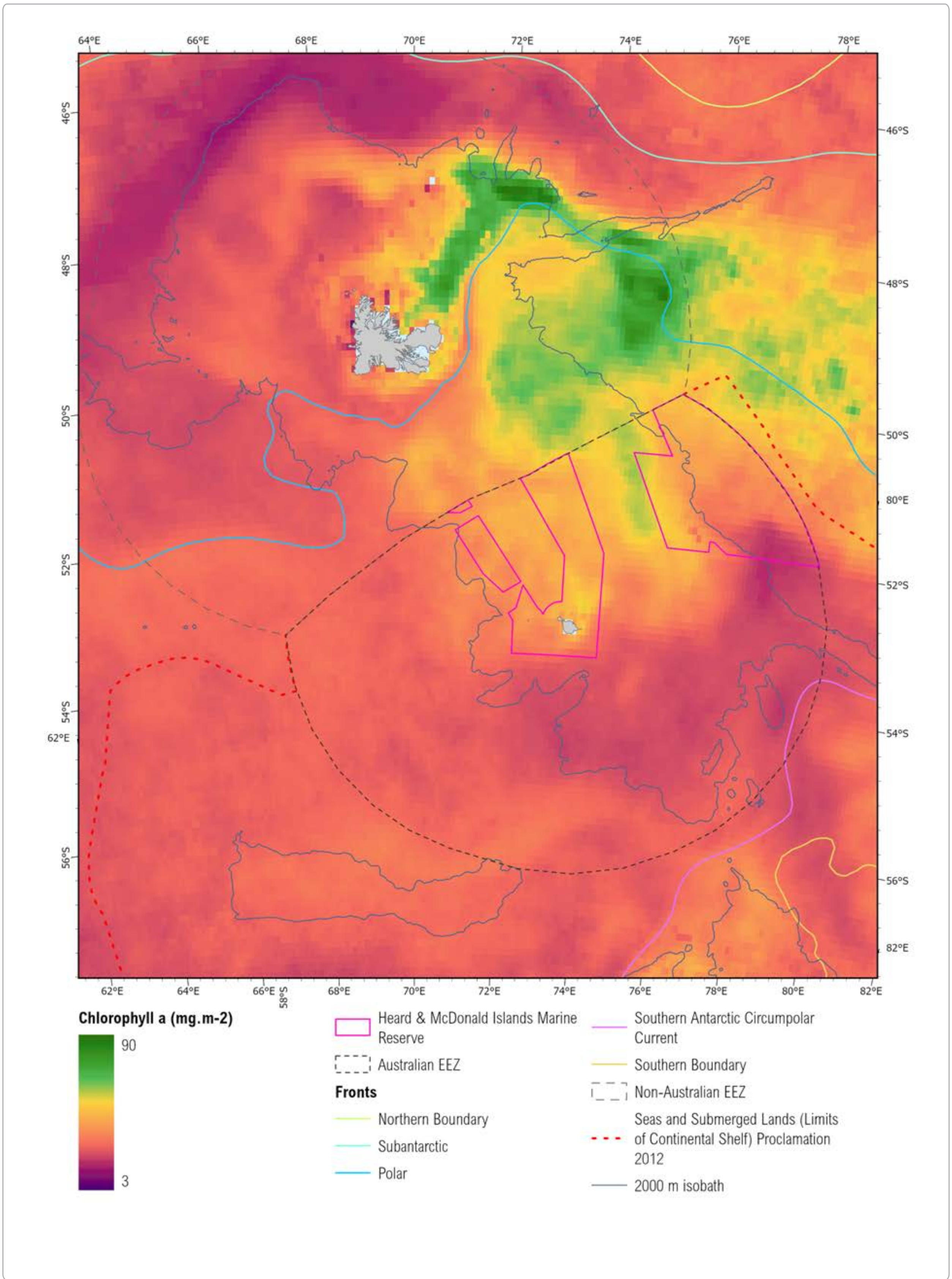


Figure 21. Decadal average chlorophyll a densities (mg.m-[2]) for spring in the period 2003 to 2012, based on satellite chlorophyll a combined with mixed layer depth from BRAN2020 dataset.

(a) Spring.

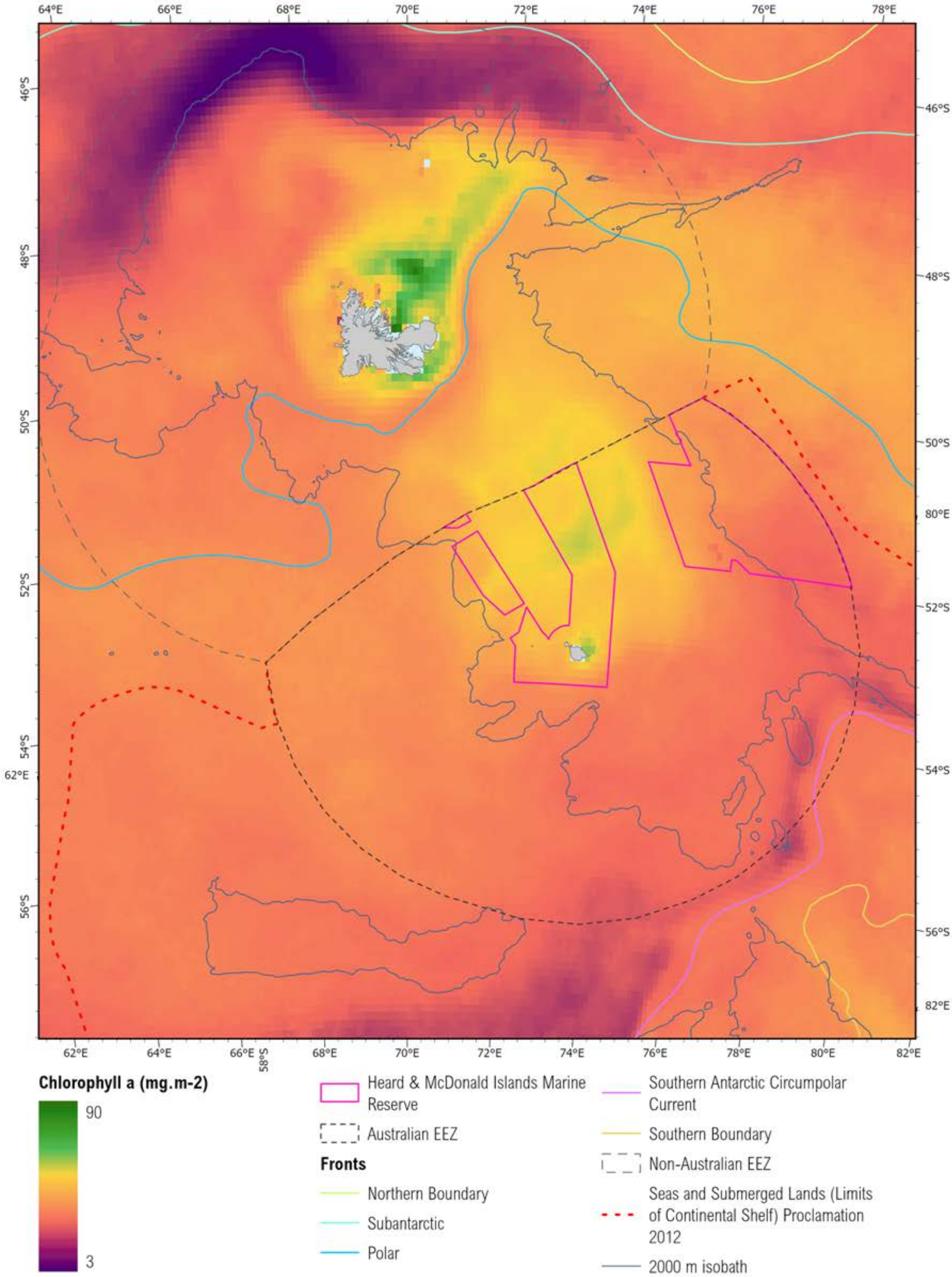


Figure 22. Decadal average chlorophyll a densities (mg.m-^{2}) for summer in the period 2003 to 2012, based on satellite chlorophyll a combined with mixed layer depth from BRAN2020 dataset.

(b) Summer.

5.0 Biology and Ecology of the HIMI EEZ and surrounds

5.1 The terrestrial environment of Heard Island and McDonald Islands.

The Reserve includes the land of Heard Island and the smaller McDonald Islands. Heard Island is dominated by the active volcano Big Ben, which is 2,745m above sea level at its summit, Mawson's Peak. Big Ben is 517m higher than the highest mountain on the Australian mainland. Volcanic activity on the McDonald Islands during the 1990s dramatically altered the size and elevation of the island and caused the loss of the island's vegetation.

Heard Island contains significant wetlands with at least 15 areas of wetland vegetation of between 5ha and 145ha in extent and 10 lagoon complexes of over 10ha Australian Antarctic Division (2005). These marine and coastal zone wetland areas are unique, contain no known non-native species, and meet several of the criteria for "wetlands of international importance" as defined under the Convention on Wetlands of International Importance (Ramsar Convention).

While the Heard Island wetland areas satisfied multiple Ramsar criteria for wetlands of international importance, its nomination was not successful under the Ramsar Convention.

> Ramsar criteria of particular relevance include:
>
> *Criterion 2. supports vulnerable, endangered, or critically endangered species or threatened ecological communities.*
>
> Heard Island's wetlands support substantial populations of three species listed as threatened under the EPBC Act: the southern elephant seal (vulnerable), the southern giant petrel (endangered) and the Heard Island imperial shag (vulnerable).
>
> *Criterion 3. supports populations of plant and/or animal species important for maintaining the biological diversity of a particular biogeographic region.*
>
> Heard Island and McDonald Islands are the only land masses within the Kerguelen Province that provide habitat for a range of wetland flora and fauna within the bioregion.
>
> *Criterion 4. supports plant and/or animal species at a critical stage in their life cycles or provides refuge during adverse conditions.*
>
> The Heard Island imperial shag and the Heard Island sheathbill (a shorebird) are subspecies endemic to HIMI. Heard Island is also a major moulting area for southern elephant seals.
>
> *Criterion 6.regularly supports 1% of the individuals in a population of one species or subspecies of waterbird.*
>
> The HIMI wetland supports the entire world population of the endemic subspecies of the Heard Island imperial shag and the Heard Island sheathbill. The HIMI population remains the only sheathbill species in an area that is unaffected by introduced predators such as cats and rats. Gentoo penguins are believed to be present all year round, and the breeding population on Heard Island in 1987 comprised 16,600 pairs, representing approximately 6% of the global population. The macaroni penguin colonies are estimated to contain 2 million birds each, which represent approximately 23% of the world population (Woehler and Garnet 2021).

The protection of the plants and animals on HIMI, including the need for a permit to enter and conduct research on the islands, is established through the *Environment Protection and Management Ordinance 1987* under the *Heard Island and McDonald Islands Act 1953* (HIMI Act).

Heard Island has the lowest number of vascular plant species of any major subantarctic island group. This is a reflection of the near pristine terrestrial ecosystems as a result of the very low level of human activity and no known human-introduced plants on the island. There is a single non-native species, the grass Poa annua, which was first recorded in 1987 and is considered to have arrived by natural dispersion from the nearby Kerguelen Island where it is widespread. A single specimen of the small flowering plant *Leptinella plumosa*, a circum-Antarctic species naturally occurring on many subantarctic islands in the Southern Ocean, was discovered in 2004.

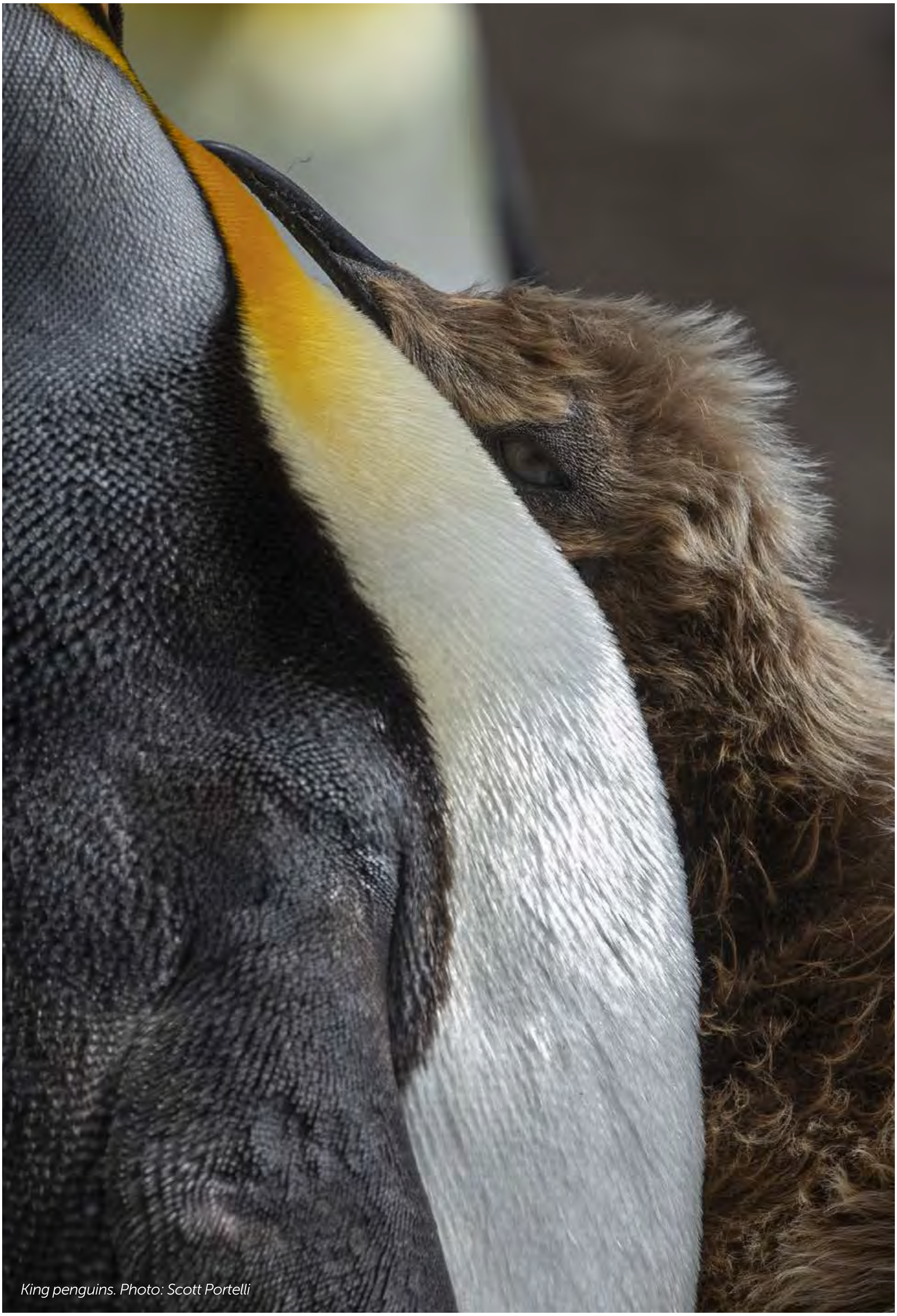
Perhaps the most high-profile aspect of the terrestrial environment of Heard Island is that it provides a land platform for breeding birds and seals. All of these land-based breeding species feed solely in the marine environment, with the exception of the black-faced sheathbill, kelp gull and subantarctic skuas that also feed on land. These species feed on marine derived food associated with breeding colonies of species that derive all of their food from the marine environment. Further details of the seabirds and marine mammals associated with the Heard Island marine zone are provided in the relevant parts of this report.

5.2 Productivity and Plankton

The marine ecosystem ecology of the HIMI EEZ has been further developed since the 2000 Conservation Assessment Report through the Heard Island Predator-Prey Investigation and Ecosystem Study (HIPPIES) study of 2004 (Appendix 1) and in more recent studies related to the biogeochemistry of the region. Intensive sampling of zooplankton and fish were undertaken in locations determined by where fur seals (Frydman & Gales, 2007), king penguins (Wienecke & Robertson 2006), and macaroni penguins (Deagle et al. 2007) were concentrating their foraging early in the 2004 summer (van Wijk et al. 2010). Respectively, these areas were on the shelf around Gunnari Ridge, south of Shell Bank in southern margins of the Eastern Trough and in the canyon area of the shelf break immediately to the east of Heard Island. They also coincided with foraging of the black-browed albatross, another predator being tracked from land colonies during this research study (Lawton et al. 2007).

Primary production occurs throughout the HIMI EEZ with highest production in the areas of iron replenishment over the HIMI shelf area to the north and north-east of HIMI, and in the deeper waters of the Eastern Trough. In these iron-enriched waters, diatoms dominate the phytoplankton assemblage, while in the iron-limited waters to the west and south, the phytoplankton assemblages are dominated by smaller nano- and picoflagellates (Deppeler & Davidson 2017; Lasbleiz et al.. 2016; Irion et al.. 2020).

The size of phytoplankton is an important determinant of food webs, with smaller phytoplankton being at the base of the energy pathways with more trophic levels compared to the energy pathways fuelled by large diatoms (Hunt et al. 2021). Shorter energy pathways have more efficient transfer of energy from primary production through to higher trophic levels. In the vicinity of the northern Kerguelen Plateau, the increased complexity of the food web in iron-limited waters mostly occurs amongst the network of interactions between microbes and zooplankton (Hunt et al. 2021). Over the plateau, zooplankton in the efficient energy pathway are dominated by larger-bodied herbivores, such as krill (Hunt et al. 2021).


King penguins. Photo: Scott Portelli

Zooplankton in the HIMI EEZ, when compared between the different locations of the HIPPIES study (Hunt & Swadling 2021) and from surveys around Kerguelen Islands (Hunt et al. 2021), shows a differentiation between the shelf zooplankton and those from deeper water and a clear transition from the deep-water fauna to a shelf fauna in the canyon area.

While many species are present throughout the region overall their abundances are larger on the shelf (such as for the large copepod, Rhincalanus gigas as well as some species of amphipods). For some species their body size is much larger in the deeper water, such as some oceanic amphipods like Themisto gaudichaudii (Hunt & Swadling 2021).

Some species show distinct differences in pattern, either being present in the deeper areas or in the shelf areas, but not in both. Many species are present in the shelf and canyon areas but not in the deeper water, suggesting that there is a distinctive shelf fauna with some extension into the canyon areas.

The distribution of the three main krill (euphausiid) species provides evidence of the spatial characteristics of the area influencing the zooplankton fauna. Hunt & Swadling (2021) describe that the high densities of Euphausia frigida and E. triacantha in the deeper water south-east of Heard Island are indicative of the colder water masses from the Antarctic Zone and the strong flows through Fawn Trough. The shelf areas, including the shallower parts of the eastern shelf had high densities of E. vallentini, indicating the influence of waters near to the northern branch of the Polar Front. E. vallentini feeds primarily on phytoplankton rather than being omnivorous like the other two euphausiids. A fourth euphausiid, the omnivore Thysanoessa macrura, is also found primarily in shelf areas.

5.3 Fish

5.3.1 Mesopelagic species

The only published study of mesopelagic fish species (fish that live in the intermediate pelagic water masses between around 100-1,00m) and their place in the food web is from HIPPIES (Hunt & Swadling 2021). The species composition of these small fish in the deep-water areas in the south-eastern part of the HIMI EEZ was dominated by myctophid fish, including Krefftichthys anderssoni and Electrona antarctica as has been found elsewhere in the Southern Ocean south of the Polar Front. The structure of the fish assemblage around HIMI is different to that found to be common or abundant on the shelf around Kerguelen Islands.

The deep-water areas in the south-eastern part of the HIMI EEZ were found to have much greater abundances of mesopelagic fish than the other areas near to and over the HIMI shelf (Hunt & Swadling 2021).

5.3.2 Demersal species

Research on demersal (bottom-dwelling) species has a longer research record than on the pelagic ecosystem, because of the interest of fisheries targeting Patagonian toothfish (*Dissostichus eleginoides*) and mackerel icefish (*Champsocephalus gunneri)*.

The AAD works closely with the Fisheries Research and Development Corporation (FRDC) and the Australian Fisheries Management Authority (AFMA) to collect data on fishing activity and catches, including by-catch species, in the Heard Island and McDonald Islands Fishery as well as annual random stratified demersal trawl surveys on the shelf area. Data from this research underpins assessments of the distribution, abundance and life cycles of the main species caught in the fisheries as well as the distribution of demersal fish assemblages observed in the shelf area. This data is kept confidential and was not made available for this report. The development of ecosystem-based fishery management procedures and methods for reducing bycatch are also based on research not made available for this report.

Distribution of assemblages

Bottom trawl surveys, between 100 and 1,200m depth, have taken place annually in the Australian EEZ since 1997, and in 2006, 2010 and 2013 in the French EEZ. The twenty-one most frequently caught fish species in both areas from 1,197 trawls in 2006, 2010 and 2013 were used to determine common assemblages (combinations) of fish based on where they were present in survey catches and where they were absent. These combinations are termed Regions of Common Profile (RCP)[2] and were identified using multivariate analysis of data collected from annual random stratified trawl surveys (Hill et al.. 2017). Of the 21 species modelled, 11 are endemic to the Southern Ocean and five to the Kerguelen Plateau. The aim of the analysis was to identify the statistical relationship between a combination of important environmental characteristics and the combination of species present in the catch. Those relationships are then used to assess the location and extent of each RCP giving rise to the combinations of species in an assemblage. Of the fifteen environmental covariates considered, depth, mean sea surface temperature and mean chlorophyll a were found to be sufficient to identify seven RCPs, with depth being the most influential variable. The model was restricted to depths <1,200m and validated with data collected on 536 comparable trawls in 2007, 2008, 2009 and 2012 that were not used in the initial analysis.

There was a high probability of occurrence for the Patagonian toothfish (Dissostichus eleginoides) in all RCPs. Their distribution is described in the next section.

Each RCP had a characteristic depth (Hill et al.. 2017). RCPs 1 and 2 are mostly >600m depth, with a high probability of occurrence for grenadiers (*Macrourus* spp.). RCP 2 is distinguished by lower sea surface temperature and surface production and is also less species-rich then RCP 1, where there is a higher probability of the skate species (*Bathyraja* spp.), blue antimore (*Antimora rostrata*), lantern shark (*Etmopterus viator*), and the snailfish (*Paraliparis* spp.). The lantern shark has a low probability of occurrence in any other RCP than RCP 1. RCP 2 includes a string of unsurveyed seamounts on Williams Ridge. Figure 23 presents the RCPs surrounding the Kerguelen Plateau.

RCP 4 extends from 400-800 m (mostly around 600 m), with a medium probability of occurrence for grenadiers, however, the probability of occurrence of *Bathyraja* spp. is higher than for RCPs 1 and 2, and there is a moderate probability of occurrence for dragonfish (*Bathydraco antarcticus*), eel cods (*Muraenolepsis* spp.) and snake mackerel (*Paradiplospinus gracilis*).

RCPs 3 and 6 extend from 200-700 m. RCP 3, centred on 400m is slightly shallower than RCP 6 centred on 500m, with slightly higher temperatures and primary production. Their fish assemblages are similar, with high probabilities of occurrence of the unicorn icefish (*Channichthys rhinoceratus/velifer*), Eaton's skate (*B. eatonii*, only moderate in RCP 6), and the grey notothen (*Lepidinotothen squamifrons*). *B. murrayi* has a moderate probability of occurrence in both, but *B. irrasa* has low probability of occurrence in the deeper RCP.

RCPs 5 and 7 are shallow water groups. RCP 7 extends deeper (<300m) than RCP 5 (<200 m) with generally lower production. Mean temperatures are similar. They both have high probabilities of occurrence for mackerel icefish (*C. gunnari*) and unicorn icefish (*C. rhinoceratus/velifer*), and moderate probabilities for triangular rockcod (*Gobionotothen acuta*), *Lepidonotothen mizops, B. eatonii*, and eel cods. The grey notothen (*L. squamifrons*) and spotted flounder *Mancopsetta maculata*) are more likely to occur in the shallower RCPs.

Most RCPs were predicted to occur in both the north and south of the study area (i.e. the French and Australian EEZs), with the exception of RCP2 that was predicted to occur mostly in the deeper water in the south-east.

2 RCPs are based on a single stage statistical approach that jointly partitions biotic and environmental information to identify areas with similar biota and environmental conditions. It has been demonstrated to be more powerful in identifying bioregions than two stage statistical methods which analyse biotic and environmental data separately and/or sequentially (Hill et al. 2020). RCP analysis is one of the few methods able to carry uncertainty through the entire analysis to better inform managers on the scientific importance of the predictions.

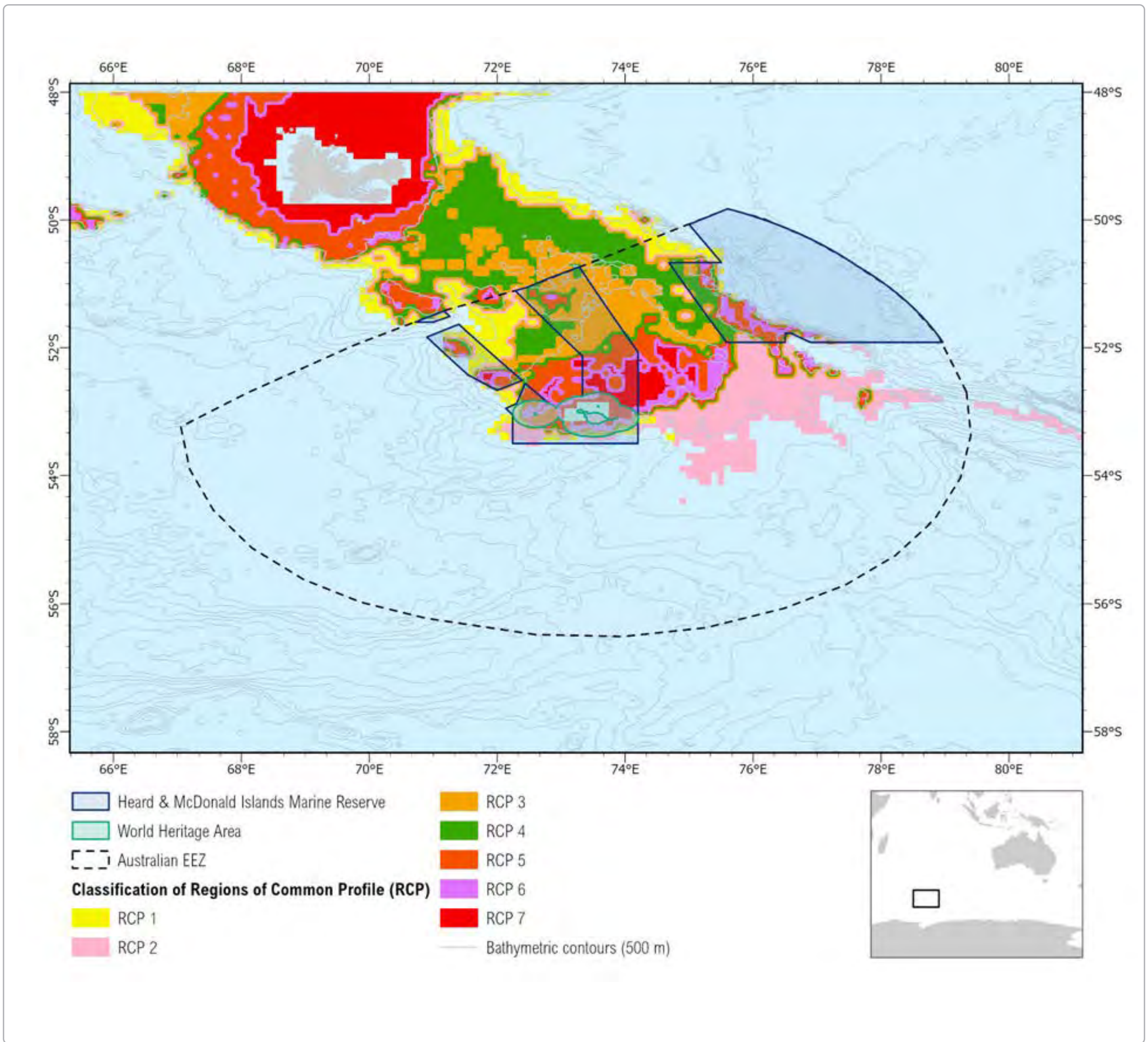


Figure 23. Classification of Regions of Common Profile (RCP) for demersal fish assemblages, derived from annual trawl surveys.

(Figure reproduced from Hill et al. 2017 with kind permission of the Author).

Patagonian toothfish

Patagonian toothfish, *Dissostichus eleginoides*, is the main species targeted by fisheries around HIMI (Patterson & Curtotti 2023). Based on apparent genetic connectivity, and evidence of long-distance movements of tagged fish, Patagonian toothfish in the Indian Ocean sector of the Southern Ocean may form a metapopulation, with sub-populations at HIMI, Kerguelen Islands, Crozet Islands, Marion Island and Prince Edward Islands (Patterson & Curtotti 2023). Only very low rates of movement of adult fish between the HIMI area and Kerguelen Islands have been detected after tagging more than 52,000 fish over 20 years. Data from recaptured fish indicate that most tagged fish moved less than 50 km (Burch et al. 2019), indicating that the two sub-populations on the northern Kerguelen Plateau can be managed as two ecologically separate stocks (Burch et al. 2019; Ziegler & Welsford 2019).

The spatial distribution of Patagonian toothfish around HIMI has been assessed to have juvenile toothfish in shallower water (less than 500 m) with older fish being found in deeper water down to 2,000 m (Farmer et al. 2019). Water less than 300 m deep is widely regarded as the nursery area for toothfish (Collins et al. 2010). Reproductively mature toothfish may be caught throughout the HIMI area deeper than 1,000 m, with the west and southeast as possible spawning areas in winter (Ziegler & Welsford 2019; Patterson & Curtotti 2023; Brand-Gardner et al. 2022). However, a modelling study based on satellite measurements of currents showed that spawning areas most likely to lead to successful recruitment of juvenile fish are those around the banks in the western margins of the HIMI area (Mori et al. 2016). Therefore, mature fish in the western margins could be the source of fish larvae underpinning the whole of the HIMI toothfish stock.

Time-series of abundances of young toothfish have been available since surveys began in the early 1990s. Assessments of stock abundance overall began in 2007 (Candy & Constable 2008) and have advanced since by using mark-recapture of the adult population through the fishery. These assessments have been showing a declining trend in recruitment and stock biomass since the 1990s (Ziegler & Welsford 2019; Brand-Gardner et al. 2022). While the spawning stock biomass has a management target of 50% of pre-exploitation levels the spawning stock has been assessed to now be below the management target at 45% (Patterson & Curtotti 2023). Further, the decision rule governing the setting of catch limits expects that recruitment will remain stable or increase, but not decrease. While the depletion part of the rule (spawning stock to not fall below 20% of the pre-exploitation level) aims to protect the stock from failing recruitment (Constable et al. 2000), activation of this limit reference point will cause a closure of the fishery.

Mackerel icefish

Mackerel icefish, *Champsocephalus gunneri*, are one of the key fishery species in the HIMI EEZ. Mackerel icefish are found in shelf and bank areas of less than 300 m depth and is considered to comprise two stocks around HIMI (de la Mare et al. 1998; CCAMLR Secretariat 2022a), and these are separate to the stock around the Kerguelen Islands (Duhamel 1991; Duhamel et al. 2011). While there is little genetic differentiation, the ecological differences arise in the stocks having different spawning times, recruitment patterns over time and different growth rates (de la Mare et al. 1998). The two stocks at HIMI are on the HIMI shelf and on Shell Bank (CCAMLR Secretariat 2022a). On the shelf, mackerel icefish are concentrated to the eastern side of the shelf with greatest abundances on Gunnari Ridge, as evidenced from the distribution of catches and stratification in the trawl surveys (e.g. Williams & de la Mare 1995; de la Mare et al. 1998; SC-CAMLR 2018). Icefish were very heavily exploited as part of the Soviet Union groundfish fishery of the 1970s (Duhamel & Williams 2011). The effect of this fishing on stock dynamics is not known but these stocks are now considered to be maintained primarily by single cohorts of strong recruitment, except for occasional times when the stock comprises multiple year classes (Maschette & Welsford 2019). Why the strength of recruitment of young fish is variable from year-to-year is unknown. However, the sustained return of multiple year-classes in the population requires individual cohorts to be able to reproduce more than once.

Time-series of abundances since surveys began in the early 1990s show a general decline in abundance in that first 10 years to a period from 2005 to 2015 with lowest abundances, followed by increases since then (Brand-Gardner et al. 2022). The most recent survey (2022) showed abundance at similar levels to the early 1990s (Patterson & Curtotti 2023). As yet, there are no published hypotheses on causes of this long-term pattern of abundance.

5.4 Birds and Marine Mammals

5.4.1 Seabirds

The HIMI-EEZ plays host to a large number of seabirds of national and global conservation importance and has an avifauna that is typical of the subantarctic, including many species that are also found around subantarctic islands in the Atlantic Ocean.

Of the 56 species of seabirds that have either been observed or satellite tracked within the HIMI-EEZ (see Appendix 4), 19 are species that breed on Heard Island and 37 are non-breeding visitors.

The breeding species include four species of penguins, three albatrosses and 7 petrels. There is one species, the Heard Island imperial shag, and one subspecies, the Heard Island subspecies of black-faced sheathbill, that are endemic to Heard Island.

With the exception of the sedentary black-faced sheathbill, all of the breeding species are listed as marine species under the EPBC Act and there are 5 species that are listed as threatened species under that Act: southern giant petrel which is listed as endangered and the wandering albatross, black-browed albatross, Heard Island imperial shag and Antarctic tern which are listed as vulnerable.

The non-breeding visitors to the HIMI EEZ include 4 species of penguins and 10 species of albatross.

Of the albatross species, northern royal, Amsterdam, Tristan and grey-headed Albatross are listed as endangered under the EPBC Act; the International Union for Conservation of Nature (IUCN) status of these species is also listed as endangered with the exception of Tristan albatross, which is IUCN listed as critically endangered. There are also eight seabirds species that are listed as vulnerable under the EPBC Act: southern royal albatross, sooty albatross, Indian yellow-nosed albatross, Campbell albatross, white-capped albatross, northern giant-petrel, blue petrel and soft-plumaged petrel.

Diets of birds from HIMI have been investigated in the 1990s and in the HIPPIES program of 2004. King and macaroni penguins both feed on myctophid fish (lanternfish) with *Krefftichthys anderssoni* being important for both species but macaroni penguins have a broader diet including larger crustaceans (Klages et a. 1989, Moore et al.. 1998, Wienecke & Robertson 2006, Deagle et al. 2008). However, during the guard and creche stages for macaroni penguins, the diet is dominated by krill (Deagle et al. 2008, Bedford et al. 2015).

There are no diet studies of black-browed albatross at Heard Island, however, their diet at Kerguelen Island is dominated by fish, in particular Patagonian toothfish *Dissostichus eleginoides* (Cherel et al.. 2000). It is apparent that at least some of the toothfish in the diet was acquired from fishery discards. Black browed albatrosses at South Georgia feed on a mixture of crustaceans and fish and changes in fish composition in the diet al.so reflect changes in the fisheries operating in the foraging area (Reid et al.. 1996). Nevertheless, the diets of black-browed albatrosses at both Kerguelen and South Georgia include different species of icefish that do not appear to originate from interaction with fisheries.

Black-faced Sheathbill (Heard Island). Photo: Kirk Zufelt.

5.4.2 Mammals

Of the 26 species of marine mammals that have been observed in the HIMI-EEZ (see Appendix 5), there are 2 species, Antarctic fur seal and southern elephant seals that breed in large numbers on Heard Island while the subantarctic fur seal breeds occasionally. The subantarctic fur-seal is listed as endangered under the EPBC Act, while the southern elephant seal is listed as vulnerable. Leopard seals and Weddell seals are both irregular visitors to Heard Island while crabeater and Ross seals are rare visitors to the island but are likely to be present more regularly, particularly in association with sea ice, in the southern part of the HIMI EEZ.

Of the nineteen cetacean species reported from the HIMI EEZ there are seven balaenopterid species including the endangered southern right whale and pygmy blue whale and Sei whale and fin whale that are listed as vulnerable.

Of the 12 odontocetes species recorded both killer whales and sperm whale have been reported interacting with longline fisheries around other subantarctic islands, however, only sperm whales have been recorded interacting with the toothfish fishery around Heard Island. The frequency of occurrence of these interactions was much lower than in the toothfish fishery around Kerguelen Island (Tixier et al.. 2019).

Four dolphin species, the dusky dolphin, southern right-whale dolphin, hourglass dolphin and spectacled porpoise, have also been recorded.

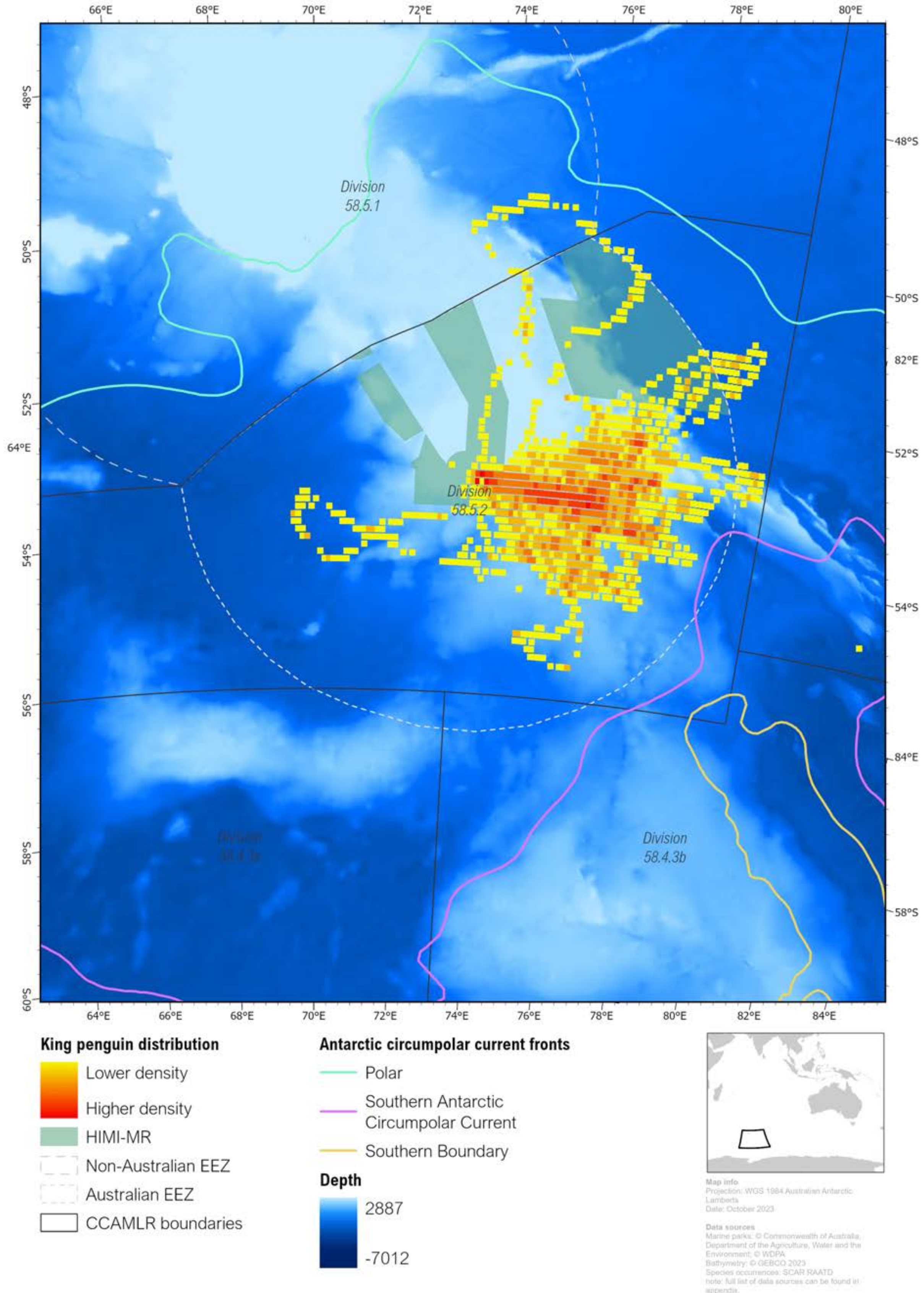
The presence of several important species and the high marine mammal diversity is reflected in the designation of the Heard Islands Kerguelen and Surrounding Waters Important Marine Mammal Area (https://www.marinemammalhabitat.org/).

The diet of Antarctic fur seals during the breeding season at Heard Island is dominated by fish, in particular mackerel icefish (Champsocephalus gunnari) and the myctophid Gymnoscopelus nicholsi (Casper et al. 2007), both of which were found only in the shelf areas of the HIPPIES study (Hunt & Swadling, 2021). Green et al.. (1989, 1991) found that the diet broadened outside of the breeding season to include other pelagic myctophid species.

5.4.3 Foraging Areas

Satellite tracking of Antarctic fur seals breeding at Heard Island shows a relatively well-defined movement to the east and south-east of the island that is shown by both macaroni and king penguins, whereas both black-browed albatross and Antarctic fur seal foraged in a more concentrated region on the shelf to the northeast of Heard Island (Figure 24 a-d). The similarity in the foraging distribution during the breeding season of both Antarctic fur seals and black-browed albatrosses suggests a distinct area of high importance on the eastern edge of the shelf during a critical life-history stage.

Leopard Seal (Heard Island). Photo: Alamy.



a. king penguin

Figure 24. Locations inside the Heard Island EEZ from satellite tracking during the breeding season on Heard Island of a. king penguin, b. macaroni penguin, c. black-browed albatross, d. Antarctic fur seal.

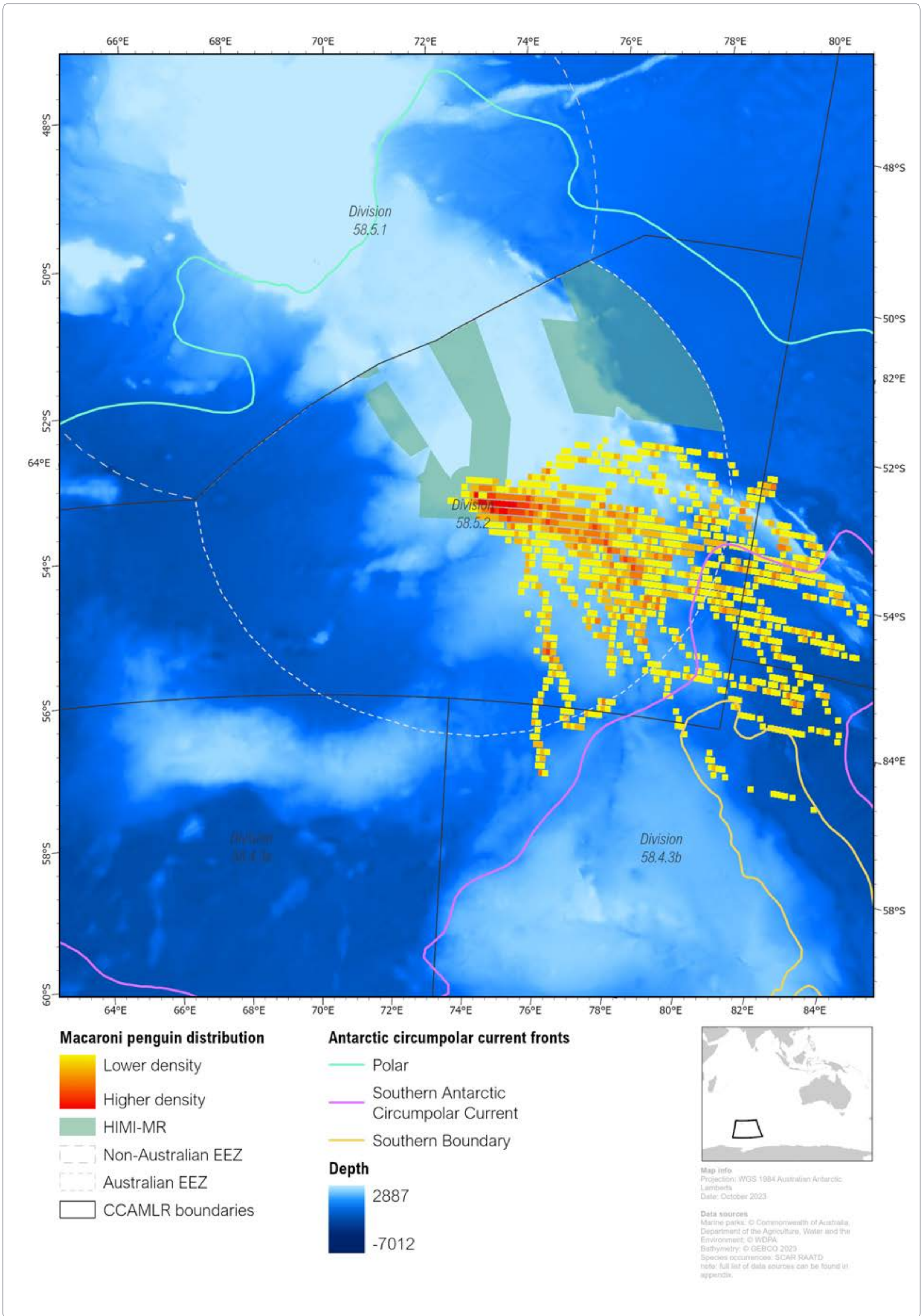


Figure 24. b) macaroni penguin

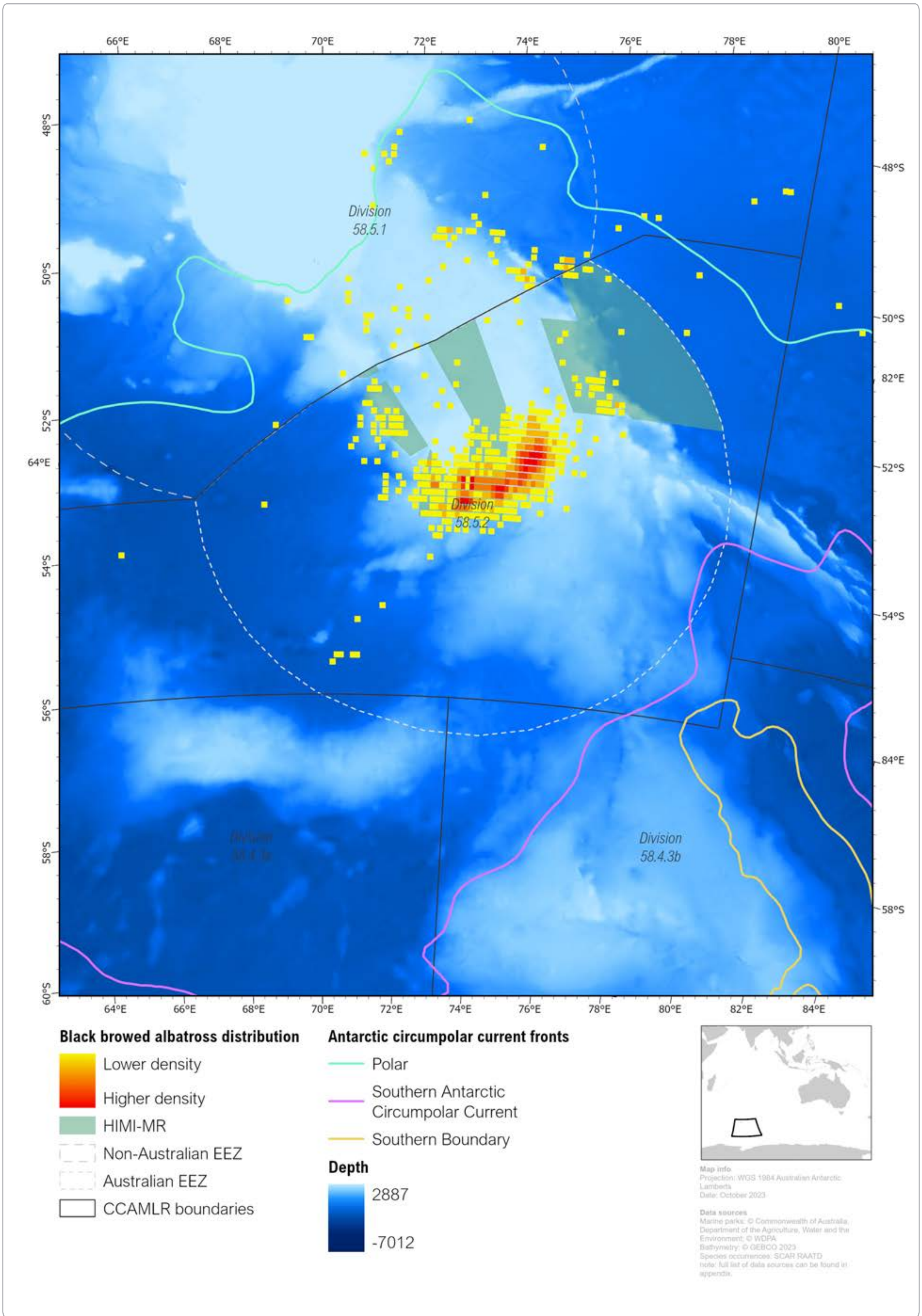


Figure 24. c) black-browed albatross

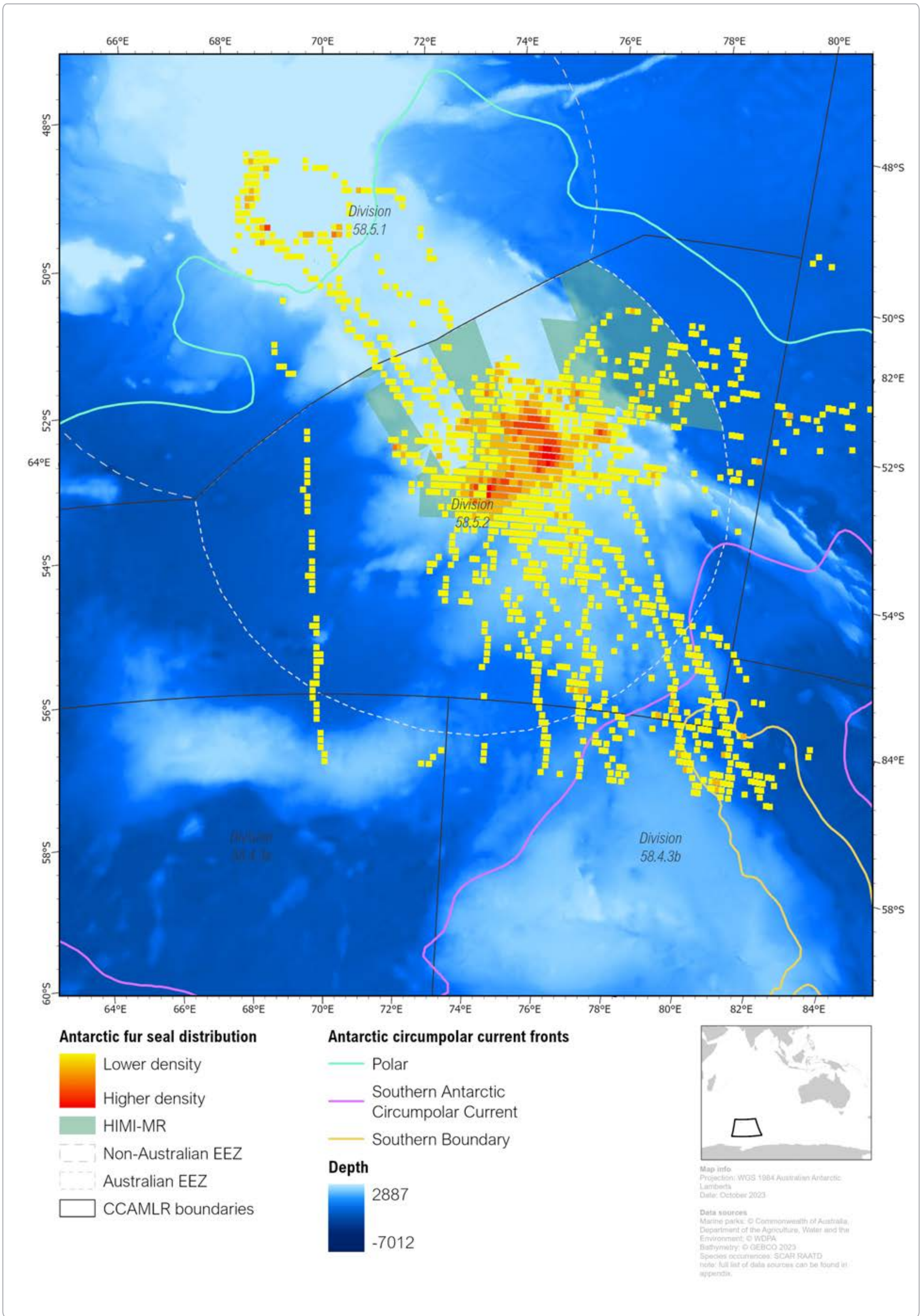


Figure 24. d) Antarctic fur seal

The apparent overlap in the foraging distribution of Antarctic fur seals and black-browed albatrosses, and also of king and macaroni penguins, is probably facilitated by the different depth ranges over which the members of each species pair forage. In addition to the clear differences in the foraging behaviour of albatrosses and seals the mean maximum dive depths of macaroni penguins at Heard Island were between 26 and 29 m (Deagle et al.. 2008) while most foraging dives of king penguins were between 70 and 90 m (Wieneke and Robertson 2006).

These tracking data were further used to predict the population-level foraging distribution of these predators (Patterson et al. 2016). That study found "the extent of usage and foraging distribution was largely contained within the HIMI EEZ" but less than 20% of those predicted foraging distributions were in The Reserve. It found that foraging would be expected to occur to the south-east, south and west of the shelf area, with little foraging predicted to occur in the northeast of the HIMI EEZ. This conclusion extends and updates the information used in the 2000 Conservation Assessment Report.

The availability of data from large-scale collaborations that bring together animal tracking data from studies in different parts of the Southern Ocean (Carneiro et al.. 2020 and Ropert-Coudert et al.. 2020) also highlight the large geographic range of the sites from which individual birds recorded inside the HIMI EEZ were originally tagged (Table 1). It is apparent that the HIMI EEZ plays host to birds that were originally tagged in the Atlantic, Indian and Pacific Oceans as well as in Antarctica. The combination of foraging distributions of non-breeding birds that extend across large areas of the HIMI EEZ, and the well-defined areas used when there is a need to return to land to provision offspring, highlight the need to consider distribution and life-history stage when including predator foraging areas in spatial management frameworks.

Table 1. Original tagging location of species recorded in the HIMI EEZ.

Species	Original tagging location(s)
Emperor penguin	Amanda Bay (Prydz Bay), Antarctic
Northern royal albatross	Chatham Island, New Zealand
Wandering albatross	South Georgia, Prince Edward Islands, Crozet Island and Kerguelen Island
Amsterdam albatross	Amsterdam and St. Paul Islands
Tristan albatross	Gough Island
Light-mantled albatross	Macquarie Island and Prince Edward Islands
Indian yellow-nosed albatross	Amsterdam and St Paul Islands
Grey-headed albatross	Prince Edward Islands and South Georgia
Black-browed albatross	Kerguelen Island and South Georgia
White-capped albatross	Auckland Islands
Northern giant petrel	Prince Edward Islands
Southern giant petrel	Prince Edward Islands
Grey petrel	Prince Edward Islands
White chinned petrel	Prince Edward Islands
Antarctic fur seal	Kerguelen Island
Southern elephant seal	Crozet Island, Kerguelen Island and Davis Station, Antarctic

5.5 Benthos

5.5.1 Deep sea benthos including seamounts

Benthic material was collected incidentally on three extensive otter trawl surveys of Heard Island starting in the 1990s (*Aurora Australis* 1990, 1992 1993) and earlier sporadic sampling from the Australian National Antarctic Research Expedition (ANARE) base in the 1950s, and the *Umitaka Maru* 1964, *Nella Dan* 1985). Generally, these earlier data have not been sorted or identified (Tim O'Hara, Museum Victoria, personal communication 21/3/2023; Kirrily Moore TMAG, personal communication 4/4/2023; see also Meyer et al. 2000). Qualitative (presence/absence) analysis of the invertebrate morphotypes collected on the three Aurora Australis surveys (only 1992 and 1993 for echinoderms following taxonomic revision) suggested:

- Differences in taxa between the outer part of the Southern Plateau and the inner part of the Plateau near the territorial sea.
- Changes in species composition consistent with a north-south axis along the central area
- Changes consistent with an east-west division in the greater HIMI region with the central division holding a mixture of the east and west areas.
- Similarities between Coral and Aurora banks, noting presence of large gorgonian corals and stalked barnacles on Coral Bank
- Similarities between Discovery Bank and Northern Plateau, although tall glass sponges were found on Discovery Bank
- Pike Bank is intermediate between the above groups
- Shell Bank is different from other banks, with high species richness comparable to Coral Bank but a different species complement and the only area with a distinctly different substratum – shell grit compared to basalt sand or rock.
- Shell Bank has some similarity to the Northeastern Plateau

The Eastern Trough can be considered a separate area.

Qualitative assessment of the benthic fauna, substratum and physical characteristics led to the 12 biophysical units being identified in the 2000 Conservation Assessment, mostly related to depths shallower than 1,000 m.

The main collection of invertebrates from HIMI took place on three surveys from the *Southern Champion (SC)* in April/May 2002, June 2007 and June 2008 (SC26, SC46 and SC50 – see Figure 25). This sampling aimed to assess the benthic values of the 'Conservation Zone' established with the first declaration of The Reserve, in order to guide decisions on which parts of the Conservation Zone would be later incorporated into The Reserve (Welsford et al. 2014). The three SC surveys sampled 129 randomly placed sites in each of 11 areas with a beam trawl and a benthic sled parallel to but offset from the beam trawl at selected sites. The 11 areas referenced the biophysical units proposed by Meyer et al. (2000). The overall depth range sampled was 172-1,010 m, with most sampling in the 200-550 m range. Two areas provide sampling opportunities deeper than 550 m.

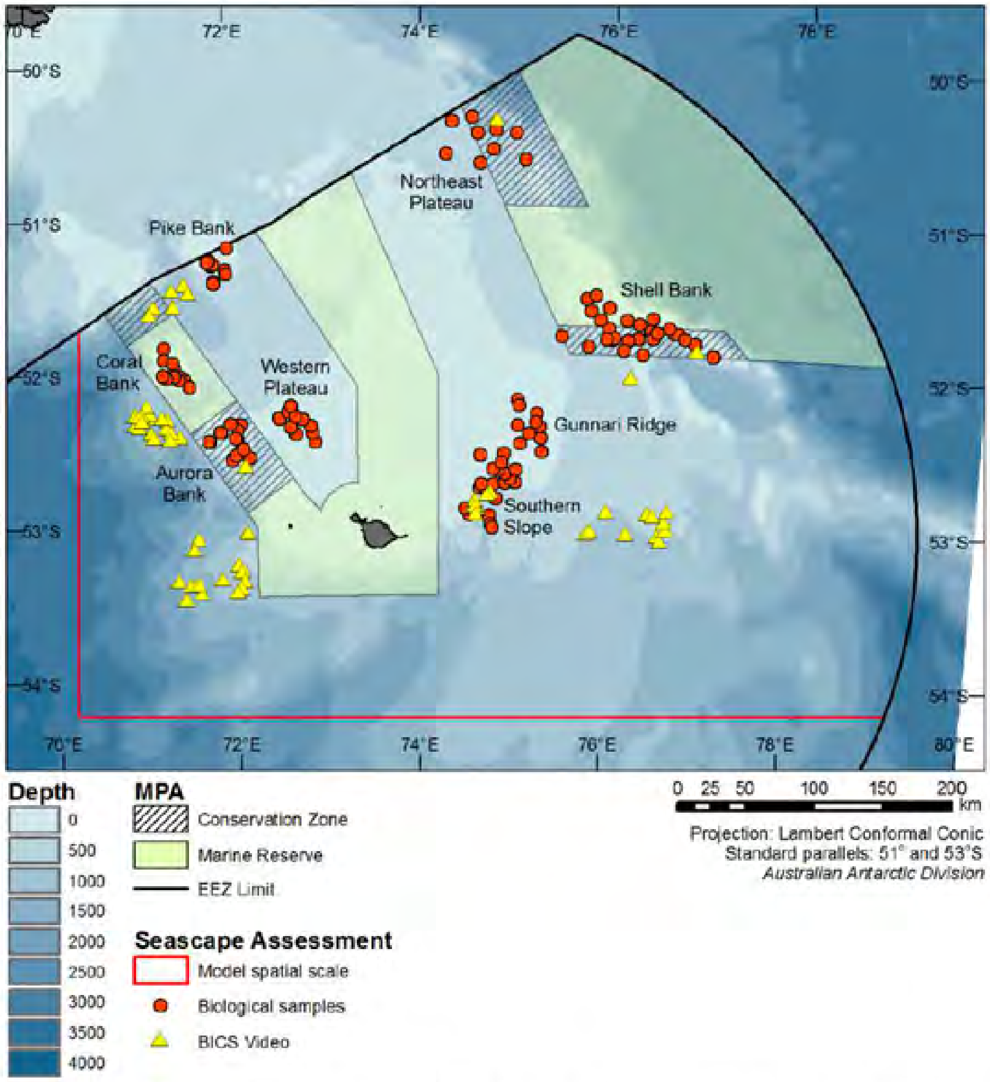


Figure 25. Study area for marine invertebrate collections from 2002-2008. (Figure reproduced from Hibberd et al. 2014 with kind permission of an author).

Samples were sorted to 'operational taxonomic unit' identifying 503 mega-epibenthic taxonomic groups in 14 phyla and 137 families, the latter number being an underestimate as only 255 taxa were identified to family level or better (Hibberd 2014). 70% of the sample numbers and biomass (numbers were only used for taxa identified to species level – Group 1 taxa) came from only 8 taxonomic groups (Demospongia, Hexactinellida, Ophiuroidea, Holothuroidea, Echinoidea, Asteroidea, Bivalvia, Polychaeta).

Nineteen species were identified as likely to be endemic to the HIMI region as undescribed or new species (12 pycnogonids, 4 holothurians, 1 cnidarian, 1 crustacean, 1 crinoid). Several diverse taxonomic groups (e.g. amphipods, bryozoans, molluscs, pycnogonids) remain largely unsorted so the number of likely endemics may be an underestimate. The likely endemic crustacean identification has since been rescinded (Kirrily Moore, TMAG personal communication 4/4/23). The holothurians have since been described properly by O'Loughlin et al. (2015) who identified one new genus and five new species from near HIMI on the Kerguelen Plateau. Nine of the likely endemic species were categorized as locally rare (occurring at lower abundance in 1-2 sampling areas), 8 as moderately rare (3-6 sampling areas) and 2 as globally rare (7-11 sampling areas). The highest number of likely endemic species was sampled at Southern Shell Bank.

The Southern Shell Bank contained the largest number of taxa found in a single sampling area (Table 2), although sampling effects cannot be discounted.

Table 2: Abundance of site-restricted taxa and total seafloor area sampled using all gear types in a study on the interaction of fishing operations with benthic environments (from Hibberd et al., 2014; Table A6.6)

Rank	Geographic areas (Acronym)	Number of 'Site-restricted' taxa	Total are sampled (m^2)
1	Southern Shell Bank (SSB)	21	57,803
2	Western Plateau (WPL)	15	27,321
3	Aurora Bank (ABA)	10	28,255
4	Coral Bank (CBA)	9	20,861
5	Shell Bank (SSB)	9	50,130
6	Pike Bank (PBA)	8	22,335
7	Plateau Southeast (PSE)	7	25,313
8	Northeast Plateau (NPL)	6	22,980
9	Plateau Deep East	6	25,313
10	Gunnari Ridge	2	24,817
11	West of Northeast Plateau (WNP)	0	11,912

Overall, the epi-benthic macrofauna was considered to be broadly typical of deep-sea subantarctic fauna, ranging from structurally complex communities on the shallow western and northern banks (Pike Bank Area and Western Plateau, <300 m), a low biomass but high diversity community on Shell Bank (200-780m sampled depth) and low biomass low diversity communities characteristic of the deeper plateau to the northeast (700-1,000 m (limit of sampling). Epi-benthic macrofauna sampled on Southern Shell Bank (SSB) in the Conservation Zone was similar to the area of Shell Bank (SBA) sampled immediately to the north inside the marine reserve.

Mixing of taxa from west to east was evident, with some unique assemblages (e.g. a population of the endemic solitary scleractinian, Flabellum spp. at Gunnari Ridge). Multivariate analysis (Multidimensional Scaling on presence/absence of numbers and biomass) showed similarities in assemblages across the different areas, but also significant differences distinguishing the western banks (Pike Bank Area, ABA and CBA).

Hibberd (2014) concluded from a presence-absence multivariate analysis that there were similarities between assemblages at Aurora Bank and Coral Bank in the marine reserve, with minor similarities to Pike

Bank. The high diversity at the Western Plateau was clearly different from other sampled areas, although may have similarities to the southern section of the central marine reserve which has similar substratum, depth range and is part of the same bioregional unit (Meyer et al. 2014). Southern Shell Bank supports a unique assemblage shared with the area of Shell Bank inside The Reserve and includes species common across the sampling area. The Northeast Plateau was characterized by a relatively sparse fauna, although many restricted to that area, suggesting its importance as representative of deep plateau assemblages. The central areas – Plateau South-east, Plateau Deep East and Gunnari Ridge – showed similarities in faunal diversity and abundance.

5.5.2 Vulnerable Benthic Fauna

Hibberd et al. (2014) completed a more detailed analysis of the vulnerable taxa collected on the three *Southern Challenger* surveys available for depths between 150 and 1,100 m. Taxa considered vulnerable to disturbance by bottom fishing (sensu SC-CCAMLR 2009) comprised 19 taxa from Porifera (sponges), Cnidaria (corals), Annelida (worms), Bryozoa, Brachiopoda, Arthropoda, Echinodermata and Chordata which had been collected at between 11 and 105 (median 76) of the 129 stations.

Depth, slope, seafloor geomorphology, and water column temperature and chemistry were used as explanatory variables with only depth and geomorphology used in the final analysis. Martin et al. (2017) found at depths shallower than 250m, chlorophyll a concentration appeared to be the main environmental driver of benthic fauna distributions on the North Kerguelen Plateau, while depth and slope were the main drivers at greater depth.

Common vulnerable benthic taxa (defined as present in >60% of samples) were distributed across the HIMI area, although the greatest abundances were typically sampled outside the marine reserve, with the possible exception of *Actiniaria*. Distributions were summarized:

> "Biomass was greatest on the western and northern banks shallower than 300 – 400 m for most taxa, especially Pike Bank, and especially for demosponges. High biomasses of ascidians, hydroids, gorgonians and bryozoans were also found at shallow Southern Slope sites on the south-eastern quadrant of the central plateau geomorphic unit. Bryozoans were also typical of shallow Shell Bank sites. Serpulids were notably common on Pike Bank but were also present throughout Western Plateau. Alcyonarians, scleractinians, and in particular actiniarians were the only groups that were less common on the banks, and were observed in greater biomass throughout Western Plateau, Gunnari Ridge and westward facing slope of Shell Bank. Those less dominant, attached taxa like the cirrepedes and pterobranchs exhibited a similar trend, with biomass typically greater on the shallow banks and slopes then decreasing in biomass, and increasing in patchiness, with depth" (Hibberd et al. 2014).

A statistical model fitted to the data predicted the greatest biomass and diversity above 300 m on the tops of banks and the shallow central plateau, especially closer to Heard Island. The biomass of most groups decreased below 500 m while patchiness increased. Many groups were also predicted to decrease in abundance away from the central plateau. The model fit had relatively high variability and it is unclear that it was able to pick up the presence of vulnerable taxonomic groups on the eastern marine reserve and in the original 'conservation zone'.

Hibberd et al. (2014) noted that current information on benthic communities in the HIMI EEZ does not include coverage of deeper areas, nor the string of seamounts on Williams Ridge peaking in waters less than 1,000 m and recommended further surveys in these areas to "improve the robustness of [their] conclusions".

5.6 Food webs

The HIMI EEZ likely has four main areas of differing pelagic food webs - northwest, south, HIMI shelf, and northeast. These relate to the ocean currents, productivity, and the consequent plankton assemblages described above.

The northwestern area has slower flows of water between the northern and southern branches of the Polar Front and is typical of a 'high nutrient low chlorophyll' environment of the Southern Ocean (Hunt et al 2021). This area includes the north-west of the EEZ, the Western Trough and the western part of the shelf. The high-nutrient, low-chlorophyll environment has smaller phytoplankton and longer complex food chains amongst the zooplankton. Mesopelagic fish are common predators of these zooplankton but dispersed.

The southern area includes the stronger flows associated with the southern branch of the Polar Front along with the currents influencing the canyon area south and east of Heard Island. The phytoplankton, zooplankton and mesopelagic fish are typical of a 'high nutrient low chlorophyll' environment. The concentration of foraging in these areas compared to north and west of the island suggests that the narrowing of the southern branch of the Polar Front yield greater concentration of zooplankton and fish in this area (see van Wijk et al 2010).

The HIMI shelf has long retention times, iron enrichment, large phytoplankton (large diatoms) and shorter food chains, including large herbivorous copepods and krill (Hunt & Swadling 2021; Hunt et al 2021). These zooplankton are important prey of mackerel icefish (Duhamel 1991; Main et al 2009), and larger myctophid species found on the shelf and shelf margins, including the canyon areas (Hunt & Swadling 2021).

The northeastern area of the HIMI EEZ is influenced by the complex flows dispersing from the northern Kerguelen Plateau generally as well as a dispersed northward flow of the southern branch of the Polar Front before it meets with the south-easterly flow of the northern branch (van Wijk et al 2010; Mori et al 2016, 2017).

The relationship of marine mammals and birds to these food webs is likely to vary seasonally based on the reproductive cycle of these predators. During spring and summer, lactating female fur seals are known to forage primarily on the shelf, feeding on mackerel icefish and larger myctophid species, concentrating on Gunnari Ridge (Casper et al 2007, 2010), while in winter they likely feed more widely, feeding on squid and myctophids (Green et al 1989, 1991). During the same period, macaroni penguins concentrated their feeding near to Heard Island in the shelf break of the canyon area to the south-east in the guard stage and a little further afield in deeper water of the south-east in the creche stage. During this time, they fed on krill species from the shelf area with a smaller proportion on small mesopelagic fishes further afield (Deagle et al 2007). In contrast, king penguins had more widespread foraging but still in the east and south-east (Wienecke & Robertson 2006), their diet consisting of small myctophids and squid. Black-brow albatross also foraged on the shelf break and canyon areas around Heard Island. How these predators utilise the pelagic food webs in winter is poorly understood, although the predators will range more widely without the ties to land colonies to rear their young. Nevertheless, predictive modelling has shown these predators are likely to mostly utilise the areas in the HIMI EEZ to the west, south and south-east of HIMI as well as the areas of the shelf identified here (Patterson et al. 2016).

To date, food web models have been constructed for the whole northern Kerguelen Plateau (Subramanium et al. 2020 a & b, 2022). These models were used to examine the general structure of food webs across the region and how the food web might vary in time and space. While useful for examining scenarios for food webs given fishing and climate change, they do not differentiate the important groups, such as phytoplankton, krill and mesopelagic fish, needed to understand the relative importance of different energy pathways and food web dynamics specific to the HIMI area, particularly between the shelf and the southern areas. Further, these models have not accounted for the phenology of the food web, relating foraging requirements at critical times of the seasonal reproductive cycle for marine mammals and birds, or for considering multi-annual thresholds in maintaining lifetime reproductive success. For example, the general envelopes of foraging by marine mammals and birds used in the current models do not represent the land-based predators at HIMI or their specific seasonal requirements.

6.0 Pressures on HIMI's marine ecosystems

Heard Island and McDonald Islands and the surrounding ocean ecosystem are subject to various environmental pressures due to their isolation, unique geography, and vulnerability.

The remote location and strong ocean currents can limit the dispersal of organisms to and from the islands. While this isolation can protect native species from certain invasive organisms, it also limits genetic diversity and can make the ecosystem more vulnerable to disturbances.

6.1 History of use

The islands were discovered on 25 November 1853 by an American sailor, John Heard, who initially thought the island was an iceberg. Realising his mistake, he named the island in his family name. In 1854 William McDonald discovered the second largest island; he also took the eponymous naming approach. The first landing on the island was in 1855 when sealers from the vessel *Corinthian* went ashore. After this first visit the island became home to up to 200 sealers who hunted elephant seals, fur seals and sometimes penguins. Over 100 voyages by 40 vessels were made to Heard Island, typically from the north-eastern United States of America, and one hundred thousand barrels of elephant seal oil were produced prior to 1877 when the industry halted.

By the raising of the Union Flag, Captain Evensen, of the whaling ship *Mangoro*, established the United Kingdom's formal claim to Heard Island in 1910. The renewed interest in the island heralded a period of scientific research that included visits from the famous Australian geologist and Antarctic explorer Douglas Mawson. Administration was transferred to the Australian government on 6 December 1947 with a formal declaration that took place at Atlas Cove at the start of the first ANARE that established a research base on Heard Island. The base continued in operation until 1955, its closure followed the reduction in investment in research on the island following the establishment of the Mawson Station on Antarctica in 1954.

The potential fishery resources of the Kerguelen Plateau were first investigated by vessels from the USSR during the late 1950s and early 1960s, with commercial fishing operations commencing in late 1960s. From 1970 the USSR fishing fleet operating in the region expanded rapidly with 7 - 40 trawlers operating, fishing mainly around Kerguelen Island and, to lesser extent, around HIMI (Duhamel and Williams 2011). In 1971 and 1972 some 300,000 tonnes of finfish were reported landed from the Kerguelen Plateau (Everson 2001). Fishing around Heard Island, mainly targeting icefish with catches of up to 18,000 tonnes per year, continued until the declaration of the Australian EEZ in 1978 after which the then Soviet Union fishery ceased operation in the EEZ. There was then no commercial fishing until 1997 when the Australian vessel *Austral Leader* initiated the contemporary icefish trawl fishery.

6.2 Marine pollution, tourism, and military activities

One of the ubiquitous threats throughout the world's oceans is marine pollution. Even in remote areas, marine pollution can occur due to the accumulation of plastic debris, increased chances of oil spills if visitation increases, and release of other pollutants. These pollutants can harm marine life and disrupt ecosystems.

While visitor/tourism impact to these islands is very limited due to their remote location, even small numbers of visitors can have an impact on the fragile ecosystems. Temporary constructions, inappropriate waste disposal, and other activities can disrupt the natural environment of the islands. Heard Island has a history of being visited by various expeditions, including scientific and military missions. Multiple private expeditions to Heard Island have been undertaken including mountaineering, amateur radio, tourist ships and private yachts. Currently the most frequent visitors to the area are commercial fishers, targeting Patagonian toothfish (*Dissostichus eleginoides*) and mackerel icefish (*Champsocephalus gunnari*).

While some minor military activities were conducted on Heard Island in the past, they do not constitute permanent military presence or extensive construction. One of the most notable military operations that involved Heard Island was during World War II when Australian and Allied forces established temporary weather and radio monitoring stations on the island as part of efforts to monitor the Southern Ocean and gather intelligence.

The USA operated a temporary military weather station on Heard Island in 1947 as part of "Operation Windmill," which was aimed at establishing weather stations in Antarctica and the surrounding regions. These operations were primarily focused on scientific research and strategic monitoring rather than extensive construction of permanent infrastructure.

6.3 Industry (fisheries)

The commercially fished stocks of Patagonian toothfish and mackerel icefish are important components of the HIMI ecosystem as top predators and as part of the foodweb connecting pelagic and benthic ecosystems. The fishery has direct impacts on biodiversity during the capture process, many of which have been intensively mitigated. Data on fishing location and catches, including by-catch species, in the Heard Island and McDonald Islands Fishery were not made available for this report. Below, we review readily available published material to assist in assessing the status and trends in these fisheries and potential ecosystem impacts.

Current commercial fisheries in the Heard Island and McDonald Islands target Patagonian toothfish (*Dissostichus eleginoides*) and mackerel icefish (*Champsocephalus gunnari*). Both of these fisheries operate outside of the territorial waters of Heard Island and McDonald Islands (12 nautical miles plus an additional 1 nautical mile buffer) to the boundary of the EEZ (200 nautical miles) and outside The Reserve since its declaration.

Management is provided by AFMA and both fisheries operate in accordance with CCAMLR Conservation Measures (see section 8.1.2). The Patagonian toothfish and mackerel icefish stocks at the Heard Island and McDonald Islands are assessed by the AAD. These assessments are reviewed by the AFMA Subantarctic Resource Assessment Group and CCAMLR.

The fishery for mackerel icefish uses both bottom trawl and midwater trawl gear, concentrated on Gunnari Ridge, at depths generally less than 300 m (de la Mare et al 1998; Patterson & Curtotti 2023; Brand-Gardner et al 2022).

Catches in the fishery for Patagonian toothfish were initially taken with demersal trawl gear mostly in water between 500 m and 1,000 m to the east of Heard Island, but the fishery has increasingly shifted to a bottom longline fishery which operates to depths of 2,000 m throughout the HIMI EEZ (Welsford et al 2014) (Figure 26).

These fisheries are the only fisheries in the CCAMLR area that use bottom trawling methods.

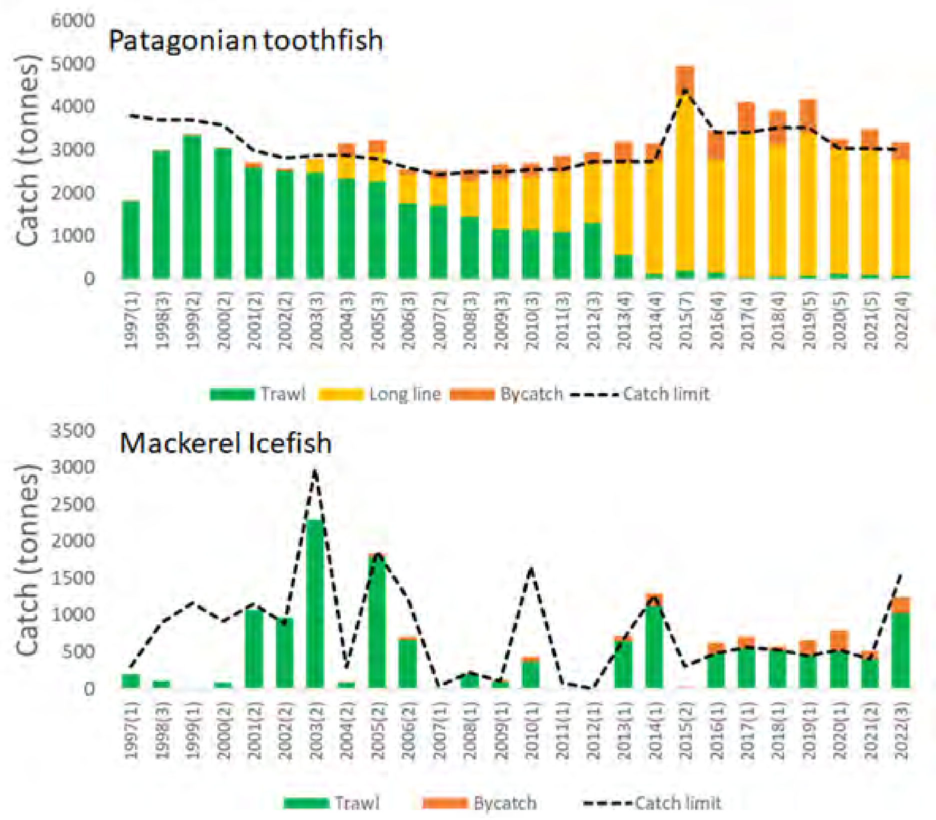


Figure 26. Catch limits in place and the catches in the trawl and longline fishery for Patagonian toothfish (upper panel) and the trawl fishery for mackerel icefish (lower panel) in the HIMI fishery from 1997-2022. The number of vessels operating in the fishery in each year is shown in parentheses for each year. Data from CCAMLR Fishery Reports (https://fishdocs.ccamlr.org/FishRep_HIMI_TOP_2022.html, https://fishdocs.ccamlr.org/FishRep_HIMI_ANI_2022.html)

Fishing effort has been "fairly stable" with 1-3 vessels in the icefish fishery, and 2-5 vessels active in the toothfish fishery, although seven vessels fished in the 2014-15 season when the Total Allowable Catch (TAC) was set higher. Both species are classified as "not overfished" and the current fishing mortality is at a level that is to make both species "not subject to overfishing" (Patterson and Curtotti 2023).

The recorded catch of Patagonian toothfish has been stable at around 2,500 - 3,000 tonnes for the past 20 years, although a slight decline since the late 1990s is noted and mirrors the TAC. Catch and TAC were higher in the 2014-15 fishing season.

The HIMI Patagonian toothfish stock is assessed separately from that of the Kerguelen Islands stock but "accounts explicitly for population linkages on the Kerguelen Plateau" (Ziegler et al. 2021 in Patterson and Curtotti 2023, Patterson and Tuynman 2022). Catches on the section of the Williams Ridge outside of the Australian EEZ are included in the fishery assessment. The most recent fishery assessment included catch data to 2021 and fishery observations until 2020. Estimated biomass was 45 percent of unfished levels, which is below the long-term reference level of 50%[3]. Further declines are projected under the recommended TAC before a slow recovery to the reference level at the end of the 35-year projection period. However, "*there are concerns that the levels of recruitment used in the 35-year projection period have not been achieved in the past 20 years in the stock assessment.*" (Patterson and Curtotti 2023). Also, the projection period is reset to 35 years at each assessment, which could result in the stock always remaining below the expected mean level of 50%. See section 6.5.1 for further discussion on the possible impact of climate change recruitment and the need for a review of the suitability of management models and the decision rules that are based on an assumption of stable recruitment.

[3] The SOUTHMAC40 (November 2021) minutes include: The scientific member explained that the estimate is below the target reference point of B50 and that under the catch limit which satisfies the CCAMLR decision rule the stock is projected to continue to decline to B37 over the next seven years before recovering to the target level at the end of the projection period. This decline in spawning biomass is also likely to deplete available biomass leading to reduced future commercial catch rates meaning the fishery may need an increased effort to catch the same level of catch. Additional fishing effort would lead to more environmental impacts from the fishery and deteriorating economic conditions. The long-term projected recovery also assumes a more optimistic pattern of recruitment compared to that seen in the fishery for the last 20 years. If recruitment does not return to pre-1996 levels then the current decision rule is unlikely to achieve the management objective.

The variability in mackerel icefish catches derives from periodic large year classes which have large effects on this short-lived species. Based on reported catches and the independent stock biomass estimate, current fishing levels are considered to meet the CCAMLR harvest strategy requirement that, "the spawning stock biomass be maintained at 75% of the level that would occur in the absence of fishing at the end of a 2-year model projection (CCAMLR 2021)" (Patterson and Curtotti 2023).

6.3.1 Bycatch

AFMA reports quarterly on interactions with protected species as a condition of accreditation under the EPBC Act. There is 100% observer coverage on all fisheries at HIMI, with two observers on each vessel. Observer data are held in a secure database at the Australian Antarctic Division. The French bottom longline fishery off the adjacent Kerguelen Islands which targets the same shared toothfish stock also has 100% observer coverage and collects bycatch data on 25% of the hooks hauled on each line. Data are available through the PERHECKER database maintained by Museum National d'Histoire Naturelle (MNHN) - an independent scientific institution (Martin et al. 2021).

There were 23 reported interactions by the HIMI Fishery in 2021: 9 southern elephant seals (*Mirounga leonina*; 1 alive and 8 dead), 1 southern sleeper shark (*Somniosus antarcticus*; dead), 1 grey petrel (*Porcellaria cierea*; dead), 1 great-winged petrel (*Pterodrama macroptera*; dead), 4 white-chinned petrels (*Procellaria aequinoctialis;* all dead), 1 black-browed albatross (*Thalassarche melanophris*; dead), 2 southern giant petrels (Macronectes giganteus; 1 alive and 1 injured), and 4 porbeagles (*Lamna nasus*; 2 alive and 2 dead) (Patterson and Curtotti 2023).

The 2018 Ecological Risk Assessment (ERA) for the longline fishery (which is based on summary data from 2010/11 to 2014/15) noted that:

> *"Ongoing stringent mitigation measures to reduce incidental bycatch of birds have also resulted in maintaining low mortality rates. However, elephant seals were more frequently killed in the fishery but not at a rate that would impact its population. However, it was recommended by the Threatened Species Committee that the population be more closely monitored. The rate of removal of non-target species is very low and unlikely to impact the communities. The reduction in skates and rays to less than 25% of that in the previous assessment is significant, resulting in a downgrading of the consequence score for byproduct/bycatch species. However, continuation of the very recent increase in effort in this fishery may impact the skates in future and should be flagged for future monitoring." (Bulman et al. 2018)*

Elasmobranchs (sharks, skates, rays), particularly deepwater species, often exhibit slow growth, late maturity and low fecundity making them particularly vulnerable to fishing pressure (e.g. Kyne and Simperdorfer 2007). Based on the reported >75% reduction in skates and ray bycatch, which might indicate a change in their abundance, and the increase in bottom longline effort (hooks set per year increased from 4.4 M in 2010-12 to 16.2 M in 2014-15 with a concomitant shift from trawling), we provide more information on skates and ray bycatch below.

Skates are the most frequent bycatch of the Australian Patagonian toothfish and mackerel icefish fisheries around HIMI and second most abundant at Kerguelen (Nowara et al. 2017). The Australian fishery has had a catch limit for skates of 120 tonnes in any 12-month season since its commencement and a vessel must move on if skate by-catch exceeds 2 tonnes in any one haul. A review will be triggered if more than 60 tonnes is caught in the bottom longline fishery[4]. Bulman et al. (2007) note that the biological basis for the 60 tonnes [sic] maximum annual catch limit for skates is unclear and should be justified. They further recommended a strategy be developed for skates and sleeper sharks vulnerable to the demersal longline fishery[5] to:

- Analyze observer data to determine the proportion of skates released by cutting the snood to minimize jaw damage
- Study the long term post-release survivorship of skates and sleeper sharks
- *Evaluate productivity of skates* and sleeper sharks
- Estimate sustainable yield of skates and sleeper sharks in this fishery.

[4] CCAMLR 2005/6 Schedule of Conservation Measures; SAFAG 2005; AFMA HIMIF TAC D4 2005, as cited by Bulman et al. 2007.

[5] Demersal longline fishery is referred to as "bottom longline fishery" throughout this report

It is unclear whether these 2007 recommendations have been addressed. There are no published information available, although Nowara et al. (2017) reiterate the need to estimate post-release survival of skates, and we were unable to access the necessary data to evaluate whether these measures have been implemented.

The three species of skate most commonly taken by the Australian and French fisheries are (*Bathyraja eatonii, B. irrasa, and B. murrayi*), which are all widely distributed across the Kerguelen Plateau (Nowara et al. 2017) (Figure 27). Their IUCN Red List status is:

- *B. murrayi* formerly (*Rhinoraja murrayi*) - Murray's skate, possibly endemic to the Kerguelen Island and Heard Island and McDonald Islands, depth range 20-800m, population trend stable, least concern (Dulvy et al. 2020b).
- *B. eatonii* - Eaton's Skate; Kerguelen Island, Heard Island and McDonald Islands, South Georgia and South Sandwich Islands; population stable, fishery interactions declining with transition from trawling, least concern. (Dulvy et al. 2019, Kyne et al. 2021)
- *B. irrasa* - Kerguelen Sandpaper Skate; Kerguelen Islands, Heard Island and McDonald Islands; depth range 300-1,220m, population decreasing, generation length 14 years, vulnerable (Dulvy et al. 2020a), but under review following Nowara et al. (2017), which was not accessed for IUCN listing, and Australian Shark Action Plan (Kyne et al. 2021) where it is listed as of least concern (*"…fishing mortality levels do not appear to be causing a significant decline"*).

B. murrayi, a smaller species, was most abundant in shallower waters (down to 550m) to the north and northeast (close to Heard Island). There was little evidence of depletion on the main trawl grounds between 1997-2014, although there may have been local depletion. Nowara et al. (2017) concluded that *"The marine reserves and the conservation measures [.....] appear to provide effective protection for the skates, at least in the shallower waters where the trawl fisheries operate."*

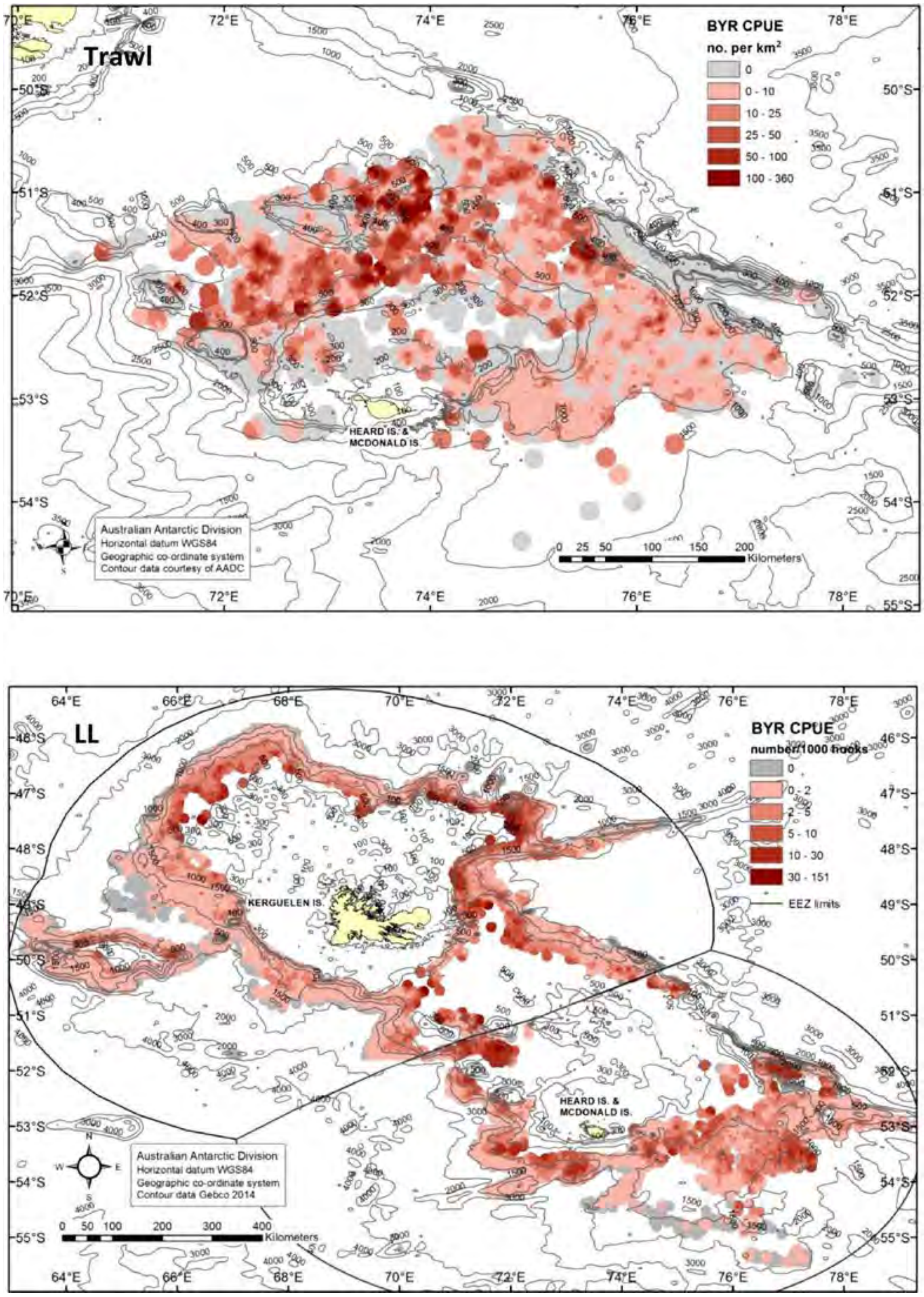


Figure 27. Fisheries catch per unit effort (CPUE) indicating densities of the Kerguelen Sandpaper skate (Bathyraja irrasa) taken in the Patagonian Toothfishtrawl and scientific trawl survey (Trawl) at HIMI (1997-2014) and in the longline (LL) fisheries at Kerguelen (2008-2014) and HIMI (2003-2014).

(Figure reproduced from Nowara et al. 2017 with kind permission of AAD)

B. eatonii and *B. irrasa* were most abundant to the north and northwest of Heard Island out to the edge of the Australian EEZ and down to depths of 1,790 - 2059m, respectively (Figure 27 from Nowara et al. 2017). The increasing fishing footprint of the HIMI Patagonian toothfish fishery with the shift in effort from the bottom trawl fishery (mostly between 500 and 1,000 m to the east of Heard Island) to the bottom longline fishery (depths down to at least 2,000 m throughout the EEZ; Welsford et al. 2014) will have impacted skate and ray bycatch. We are unable to assess whether the fishing footprint has stabilized or continues to expand. The fishery is now conducted outside the area and depths of the annual trawl survey and beyond the depths covered in the 2007-08 benthic surveys used to assist earlier marine reserve and fisheries impact decisions.

Assessing impacts of shark and ray bycatch in the HIMI bottom longline fisheries is difficult due to the lack of availability of detailed bycatch data. While Bulman et al. (2018) record a 75% reduction of skates and rays in the bottom longline fishery, Nowara et al. (2017) note only a slight decline in catch rate of one species *B. irrasa* in deeper water. The risk assessment for this fishery is based on summary data on aggregated species and the reported 75% reduction in catch may result from two higher than average years for bycatch of skates and rays at the start of the longline fishery in 2004 and 2005 (CCAMLR Secretariat. 2022b; figure 28). The catch of skates in Figure 28 refers to all catch brought onboard the vessel, however, because skates can be released alive, the management advice for longline fisheries in HIMI, that is consistent with CCAMLR, is to cut the hook line at the surface to release live skates. The numbers of skates that have been cut-off at the surface has increased since 2014 but this has not been accompanied by decrease in the weight of skates retained, suggesting more detailed information is required to better understand trends in skate bycatch. The lack of species discrimination in reported numbers could mask impacts on any rarer more vulnerable skate or ray species.

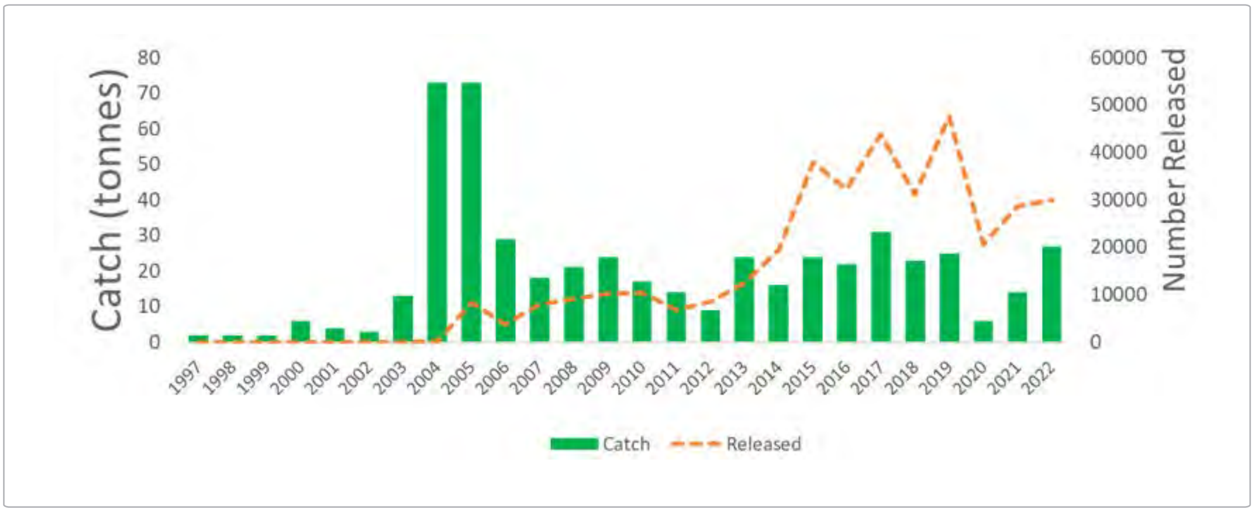


Figure 28 Catch in tonnes of skates and rays, and the number released alive, in the HIMI fishery from 1997-2022. Data from CCAMLR Fishery Reports (https://fishdocs.ccamlr.org/FishRep_HIMI_TOP_2022.html)

It is clear that releasing live skates by cutting the line at the surface will increase survival compared to landing them on the vessel, however, without post-capture survival data it is not possible to determine the actual mortality of skates associated with the fishery. Tagging studies indicate a much lower post-release survivorship for skates than toothfish (Tim Lamb AAD personal communication cited by Bulman et al. 2007), and the risk assessment notes that at that time there had been no analysis of observer data to ensure that the best practice method of releasing skates, by cutting the snood had been followed. Nowara et al. (2017) reiterate the need for better estimates of post-capture survival for skates.

SOUTHMAC38 (March 2020, noting SARAG 60 discussions August 2019) notes that while the Random Stratified Trawl Survey gives acceptable estimates for shallow water skates there is no similar survey for the deeper water skates. More accurate bycatch information from electronic monitoring may improve estimates of total skate bycatch and fishing induced mortality (SOUTHMAC39 May 2021).

A more detailed bycatch analysis, especially for sharks, is available from the adjoining French Patagonia toothfish fishery Chazeau et al. (2017), using total catch records and observer reports (Figure 29). From 2006 to 2016 observers checked 26,203 longline hauls representing more than 55 million hooks (mean annual hauling observation effort was 2,620 hauls and 5.5 million hooks). Patagonian Toothfish formed 60% of the total observed catches by number with principal bycatch species being ridge-scale rattail (Macrourus carinatus), blue antimora (Antimora rostrata), skates (Eaton's skate Bathyraja eatonii and Kerguelen sandpaper skate Bathyraja irrasa) and sharks. Eighteen percent of the observed hauls caught deepwater sharks.

The traveller lantern shark (*Etmopterus viator*, IUCN Least Concern) comprised 99% of the shark bycatch with other species caught including the southern sleeper shark (*Somniosus antarcticus*, IUCN Data Deficient), Portuguese dogfish (*Centroscymnus coelolepis*, IUCN Near Threatened) and porbeagle shark (*Lamna nasus*, IUCN Vulnerable). The southern sleeper shark was once described as the most common shark species in Kerguelen waters but now ranks second to E. viator in the French longline fishery (Chazeau et al. 2017). Most probably due to taxonomic inconsistencies between the French and Australian fisheries the traveller lantern shark does not appear as a byproduct species in the Australian fishery although the southern lantern shark (*E. granulosus*) is listed as bycatch. Chazeau et al. (2017) noted for the French fishery species E. viator was previously identified as *E. cf. granulosus*, indicating a possible taxonomic inconsistency between the fisheries.

AFMA reports on the bycatch of the southern sleeper shark (*S. antarcticus*) on a quarterly basis with one death reported in the 2021 fishing season. The Pacific sleeper shark (*S. pacificus*) is listed as a bycatch species in the ERA, while S. antarcticus is not listed (Bulman et al. 2018). If 2 tonnes or more of *Somniosus spp*. are caught in a single haul, then the fishing vessel has to avoid fishing within 5 nautical miles for at least 5 days. A recent study found no molecular evidence to distinguish 2 sequenced specimens of S. antarcticus from 170 sequenced specimens of *S. pacificus* (Timm et al. 2022). The authors noted that previous molecular work had also been unable to distinguish *S. antarcticus* and *S. pacificus* and that the recent work provided the strongest molecular evidence to date for the synonymization of the two, qualified by a lack of *S. antarcticus* samples from the Atlantic or Indian oceans.

The Portuguese dogfish and porbeagle shark are not reported as byproduct, discard or 'Threatened, Endangered and Protected' species in the 2017 Ecological Risk Assessment (Bulman et al. 2018).

Chazeau et al. (2017) concluded that the impact of Kerguelen Islands long-line fishery on the porbeagle shark is likely to be small, that the post-capture survival rate of the southern sleeper shark and Portuguese dogfish should be maximised, and that the bycatch of the traveller lantern shark needs to be monitored to manage shark bycatch. Population size and trend of the traveller lantern shark needs to be assessed. Given the broad distribution of these sharks and the potential for taxonomic inconsistencies between the French and Australian fisheries, collaboration on bycatch reporting would assist in determining any unsustainable fishery impacts.

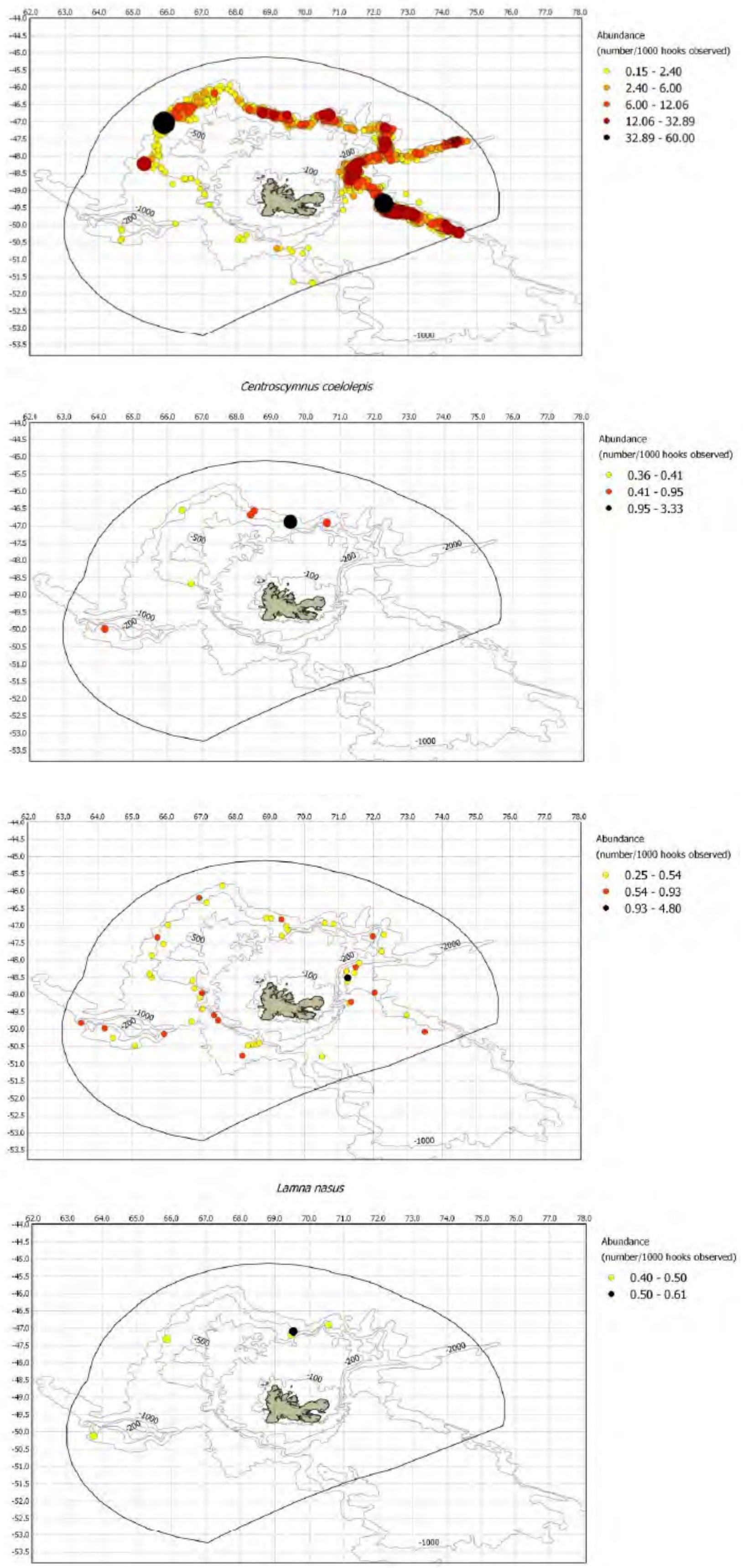


Figure 29. Relative abundance of sharks (number of individuals per 1,000 hooks in hauls where sharks were present) for observed hauls in the Kerguelen Islands bottom longline fishery, 2006/7 - 2015/16.
(Figure reproduced from Chazeau et al. 2017 with kind permission of the Author).

Martin et al. (2021) commenting on the success of the scientific monitoring and the PECHEKER database in supporting sustainable development of the Southern Ocean French fishing industry, propose the need for a discussion on how a global fisheries information system could be built based on a network of small databases using interoperability standards. Interoperability (including consistent taxonomy) and availability of data from the French Kerguelen Islands and Australian HIMI fisheries would facilitate ongoing assessment of bycatch, especially of threatened and vulnerable species.

6.4 Scientific field activities

While difficult and expensive to get to Heard Island and McDonald Islands and the surrounding EEZ have been visited numerous times for various scientific field activities (see Appendix 1 for a list of all known research projects undertaken by FRDC and AAD). The islands' isolation, subantarctic location, and diverse ecosystem make it a highly sought after location for researchers to study various fields of science. The ANARE station was established at Atlas Cove in December 1947 and was operated until March 1955. From 1985 until 2000 the AAD undertook significant work to clean up the site. Since that time scientific activities that have occurred have been undertaken with a strong understanding to not disturb the natural environment.

Regular fisheries patrols are scheduled to visit the marine system surrounding the islands, but no data is publicly available on how often and when these visits take place. Annual Random Stratified Trawl Surveys are conducted by AAD in partnership with AFMA and the fishing industry, but no public data is available on these visits.

The last known science expedition to land on Heard island was in 2008 when RSV Aurora Australis landed AAD personnel for a management and research visit.

AAD science and management personnel visited the HIMI marine area in 2012 when accompanying a ship-based tourism visit. The Australian *RV Investigator* visited in 2015/2016 investigating 'Submarine Volcanism and Hydrothermalism around Heard Island and McDonald Islands' (Watson et al. 2020), but no landing was made. *RV Investigator* also visited in 2020 investigating the 'Formation of Williams Ridge, Kerguelen Plateau: Tectonics, and Australia's extended continental shelf', but no landing was made.

The Bureau of Meteorology had a planned visit to undertake repair work on an Automatic Weather Station at Spit Bay in 2021, supported by *FV Atlas Cove*, but were unable to land due to sea conditions.

In 2023, researchers aboard the *FV Cape Arkona* collected data on species caught while fishing and during the random stratified trawl surveys within the HIMI EEZ. This was a marine focused project, with no landing on the islands.

The AAD tasked a visit to inspect a remote camera in order to support maintenance and implementation of its regulatory functions on Heard Island in 2015.

Research expeditions not involving Australian scientists have visited the outer areas of HIMI EEZ but no landings have been made, including Institut Polaire Francais in 2011 and 2014, the *RV Revellein* in 2012, and a "SWINGS" voyage in 2021.

Private expeditions are rare with the last known landing being in 2016 when Radio operations were set up from a temporary camp on Heard Island and science support via *MV Braveheart*. Another sightseeing and photography visit was made in 2021 by *SY Bazileus* but no landing was made.

Geological and geophysical studies have been conducted on Heard Island and McDonald Islands' geological features, including its volcanoes, glaciers, and rock formations. Studies have aimed to understand the island's geological history, volcanic activity, and the impact of glaciers on the landscape. Scientists have also studied Heard island's glaciers and ice cover to understand patterns of melting, ice flow, and the effects of climate change on polar ice sheets. Heard island's volcanic activity and geological features have also attracted researchers interested in studying seismic activity and earthquakes in the region.

Due to its remote subantarctic location, Heard Island has been used as a site for climate and atmospheric research. Monitoring weather patterns, atmospheric conditions, and climate change impacts provides valuable data for understanding broader climate trends. Researchers have also studied the surrounding waters to better understand ocean currents, marine life, and the interactions between the atmosphere and the ocean.

Researchers have explored Heard Island and McDonald Islands' unique ecosystems, studying its plant and animal species, as well as the interactions between different species. The remoteness of the islands and the diverse range of seabirds, seals, and other wildlife, make it a key site to contribute to our understanding of subantarctic biodiversity.

Given its history of scientific and military expeditions, Heard Island has also had limited historical and archaeological research to understand the activities and impacts of past expeditions (McGowan and Lazer 1989).

It's important to note that current research activities on Heard Island and McDonald Islands are subject to strict regulations and permits to ensure the preservation of the islands' fragile ecosystem. These activities are typically conducted by scientific teams on temporary expeditions, and efforts are made to minimize human impact on the environment.

6.5 Climate change

The warming of the Southern Ocean and changes in weather patterns can have profound impacts on HIMI and the surrounding marine environment. Rising sea temperatures and a shallowing aragonite saturation horizon can affect marine biodiversity, including fish populations and deepwater coral reefs. Melting glaciers and ice sheets can contribute to rising sea levels, impacting coastal habitats, and glacier melt contributes to nutrient and sediment input into the coastal environment. Increased carbon dioxide levels in the atmosphere not only contribute to climate change but also lead to ocean acidification. This can negatively impact marine life, particularly organisms that rely on calcium carbonate for their shells and skeletons, such as corals and shellfish. Potential freshening of the surface waters (i.e. a salinity change) is also a possible impact from climate change from increased precipitation as well as contributions from glacier melt discharge.

Climate change is causing significant change in the subantarctic environment, particularly with respect to warming of the ocean. Long-term trends are emerging beyond variability, with the northern Kerguelen Plateau estimated to be warming at a rate of approximately 0.1°C per decade (Auger et al 2021). The observed change since 1950 is 0.6 - 1.0°C with a 30-35 day increase in marine heatwaves (Fulton et al. 2021 Appendix 5.5). Water temperature could increase by 1.0 -1.5oC (perhaps even 2oC) by 2040, beyond which model projections vary, although permanent marine heatwave conditions (temperatures above historic levels) are predicted to occur year-round by 2040 in the Southern Ocean (Fulton et al. 2021, Azarian et al. 2023). Observed stronger winds are expected to increase ocean mixing in the subantarctic, thereby increasing iron supply and primary productivity (Krumhardt et al 2022), but whether this translates to increased production by diatoms or smaller phytoplankton is uncertain (Boyd 2019). There has been an observed 30% increase in ocean acidification (Fulton et al. 2021 Appendix 5).

Fulton et al. (2021) in a study of the potential impacts of climate change on fisheries identified target species of the HIMI fishery to have a low-medium sensitivity to climate change (a decrease of 20-60%; medium confidence), byproduct species a medium sensitivity (a decrease of 5-20%; low-medium confidence) and threatened and endangered species to have high sensitivity to climate change ($^2/_3$ decrease $^1/_3$ increase; confidence low to medium). Birds and seals were predicted to decline (-20 to -25%); while whales were predicted to increase (+5-20%). There were insufficient data to provide a prediction for bycatch species (sharks and rays). The authors caution that these biological projections, based on a simple food web model, are uncertain.

Fabri-Ruiz et al. (2020) assessed how stable the 12 Southern Ocean ecoregions (identified from distribution data of 41 echinoid species and 13 environmental covariates) would be under medium and high climate change scenarios[6]. They concluded the subantarctic islands (including the northern Kerguelen Plateau) to be one of the three ecoregions that would experience the "most dramatic changes" under both medium and high climate change scenarios (Figure 30).

Individual based modelling of the sea urchin *Abatus cordatus* based on published data (including from in-situ experiments in the shallow water of the Kerguelen Islands) predict that food resources currently have a determinant impact on population densities, but temperature will become more limiting under climate warming especially for juvenile densities. Simulations predict a sharp decline in population densities under low and high IPCC scenarios with peaks of high temperature leading to the extinction of most vulnerable populations after 30-years (Arnould-Pétré et al. 2021).

[6] Fabri-Ruiz et al. (2020) assessed a medium Representative Concentration Pathway (RCP 4.5) and a high Representative Concentration Pathway (RCP 8.5) using Intergovernmental Panel on Climate Change (IPCC) scenarios

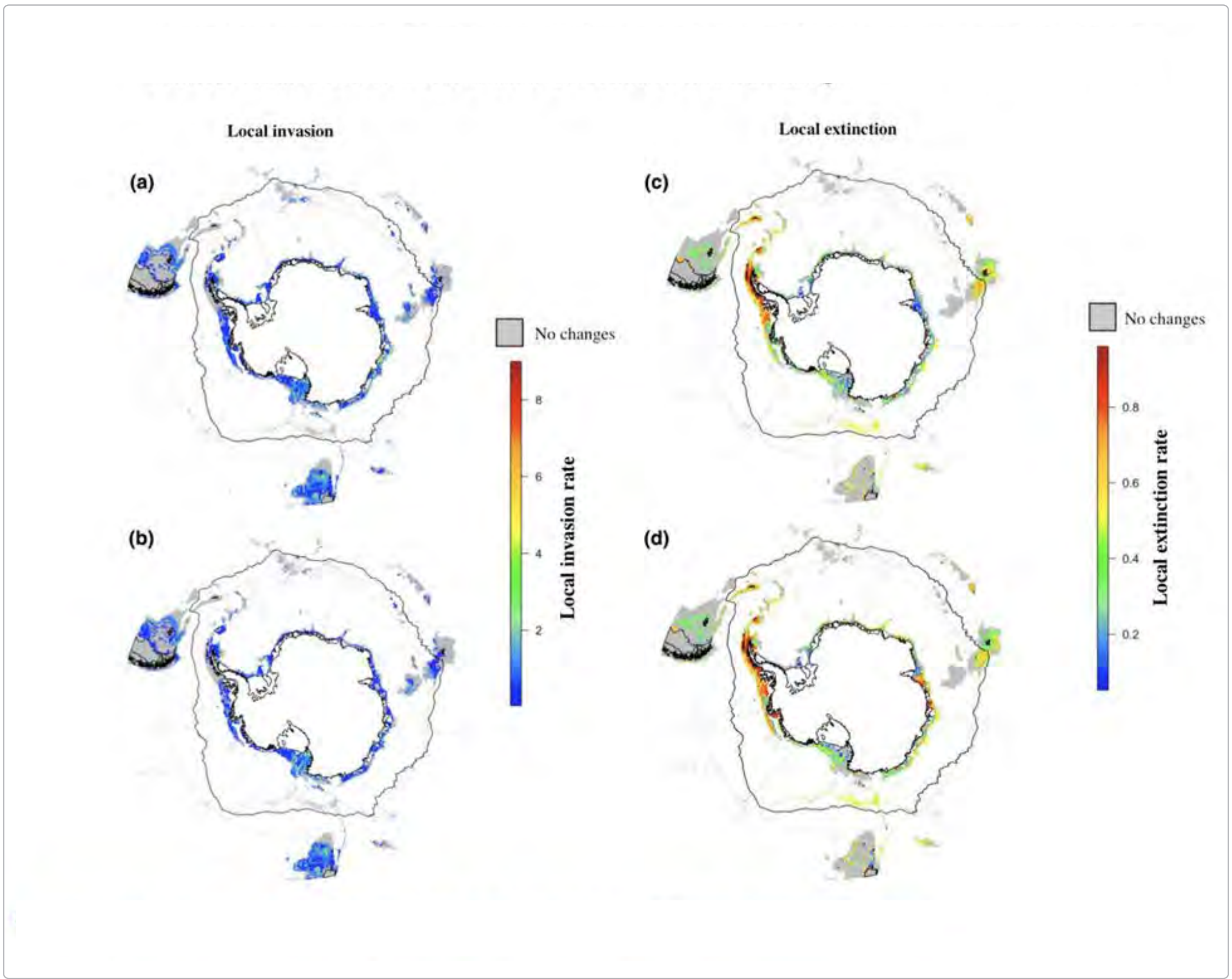


Figure 30

Projection of predicted local invasion and extinction rates under medium (a,c) and high climate change scenarios (b,d) based on distribution data for 41 echinoid species and 13 environmental covariates. (Figure reproduced from Fabri-Ruiz et al. 2020 with kind permission of the Author)

Areas of Ecological Significance (AES) were identified for the Southern Ocean by Hindell et al. (2020), based on patterns of usage by marine predators which include 17 bird and mammal species. These AESs were used to generate the marine predator-based regionalisation presented in an earlier section (Figure 10). Hindell et al. (2020) also present the likely impacts of climate change on these AESs under medium and high forcing scenarios[7] for eight global climate models.

Subantarctic AESs were predicted to increase in size (+5.7%) as the southern boundaries expand to the south while the northern limits show only limited southerly contraction. While this might appear to be beneficial to marine predators, it is also possible that the extension of these areas will lead to increasing foraging time for central-place foragers that dive (penguins and fur seals: Hindell et al. 2020). The increased area may benefit those predators without a close association with land (e.g. whales).

6.5.1 Change at HIMI

In order to assess where changes in the marine environment have been occurring around HIMI and which areas may be most sensitive to climate change, we undertook analysis of changing ocean temperature (utilising the BRAN2020 dataset) and changes in chlorophyll a (utilising satellite data). The analysis followed that described in section 3.4.1 but looked at the most recent decade, 2013-2022 in order to calculate differences between the most recent decade and the early decades. Changes in ocean state are described as anomalies from that earlier baseline.

The results of the analysis showed that the HIMI area has experienced warming over the 30 years of the BRAN2020 dataset – calculated as the two decades between the means in this analysis. For the surface water layers, the greatest increases have occurred to the south and east of Heard Island (Figure 31). While the winter water layer between 100 and 200m depth has also warmed in those locations, the greatest warming has occurred across the HIMI shelf, with increases of nearly 1°C in some places (Figure 31 panel b). Over the last two decades, chlorophyll a density has declined in the northeast during spring and slightly increased over the HIMI shelf area (Figure 32).

As part of a study on adaptation of Commonwealth fisheries management to climate change, Fulton et al (2021) assessed current changes in the environment and the potential climate impacts on the food web in the region, particularly species targeted by fisheries. For current and change in the physical environment, they used the CMIP6 earth system model data and assessments of change in the IPCC Special Report on Ocean and Cryosphere in a Changing Climate (IPCC 2019). In that analysis abundances of all fish species were projected to decline, 20%-60% for toothfish and 20% for mackerel icefish, along with declines in other fish species. Penguins, flying birds, seals and toothed whales were also projected to decline, but with possible increases in other cetaceans.

The population models and decision rules used to set catch limits for toothfish are based on an expectation that the spawning biomass (i.e. the biomass of adult fish) will be reduced by 50% compared to before fishing started; after which they will remain, on average, at that level, while maintaining stable recruitment. However, the observed changes in temperature and primary production may already be impacting commercial fish species given the general decline in recruitment of young toothfish to the population over the same period as the BRAN2020 dataset (CCAMLR Secretariat, 2022c). Although a decline in the total biomass of toothfish would be expected as part of the fishery management framework an almost 60% decline in recruitment over the same period is not an expected outcome, yet it has been observed in the survey data as well as the management model outcomes. Given the expectation that recruitment is directly correlated to spawning biomass it would be prudent to review the suitability of management models and the decision rules that are based on the assumption of stable recruitment.

Increasing temperatures on the shelf areas are particularly concerning for cold-adapted species, such as the Channichthyd mackerel icefish. Channichthyd fish have no haemoglobin and rely on high concentrations of oxygen in cold water to efficiently respire (Pörtner et al. 2007). Warming ocean temperatures results in lower concentrations of dissolved oxygen as well as other physiological consequences that make icefish increasingly vulnerable to physiological stress under warming (Portner et al 2007).

[7] The trend in current carbon dioxide emissions is following the high forcing scenario.

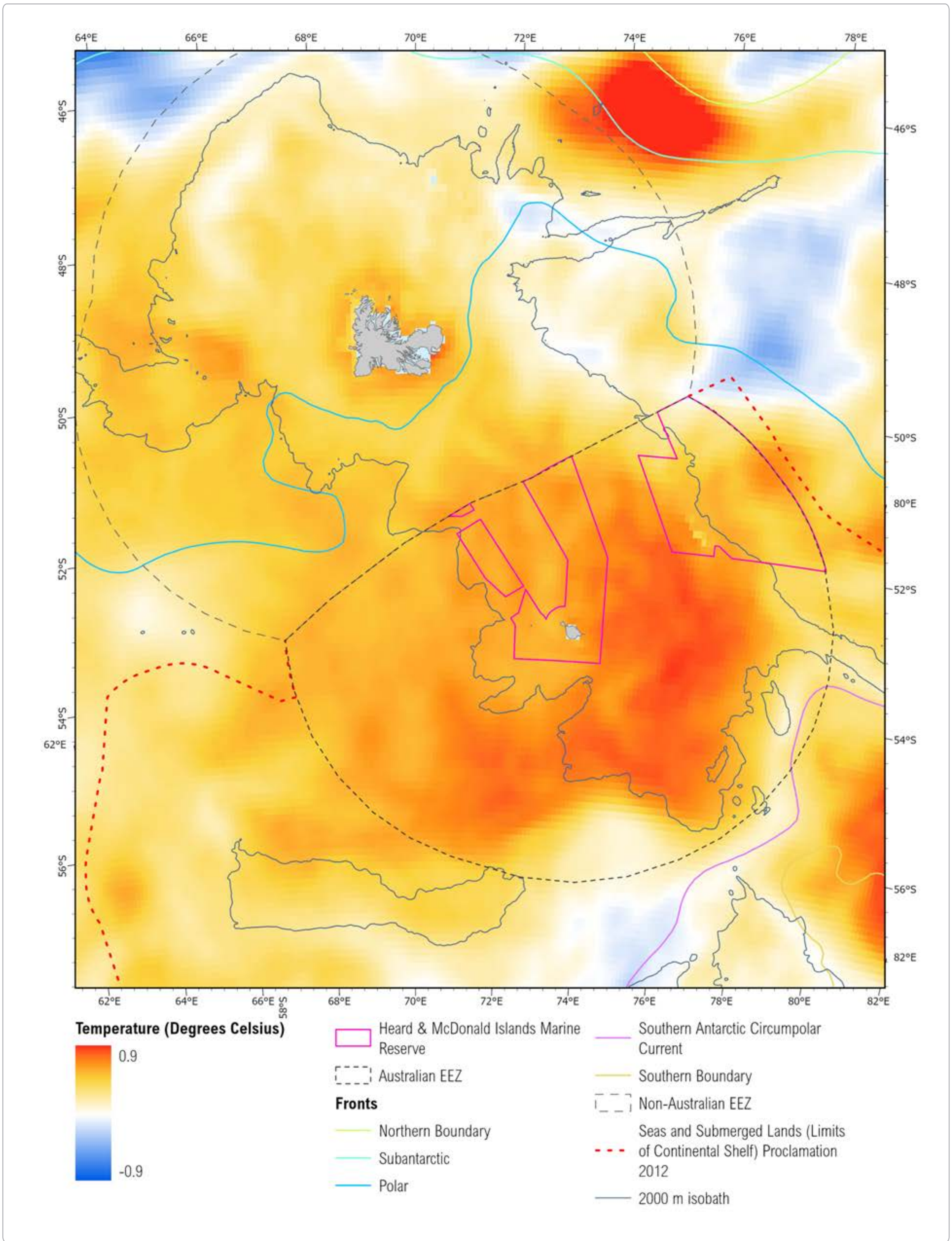
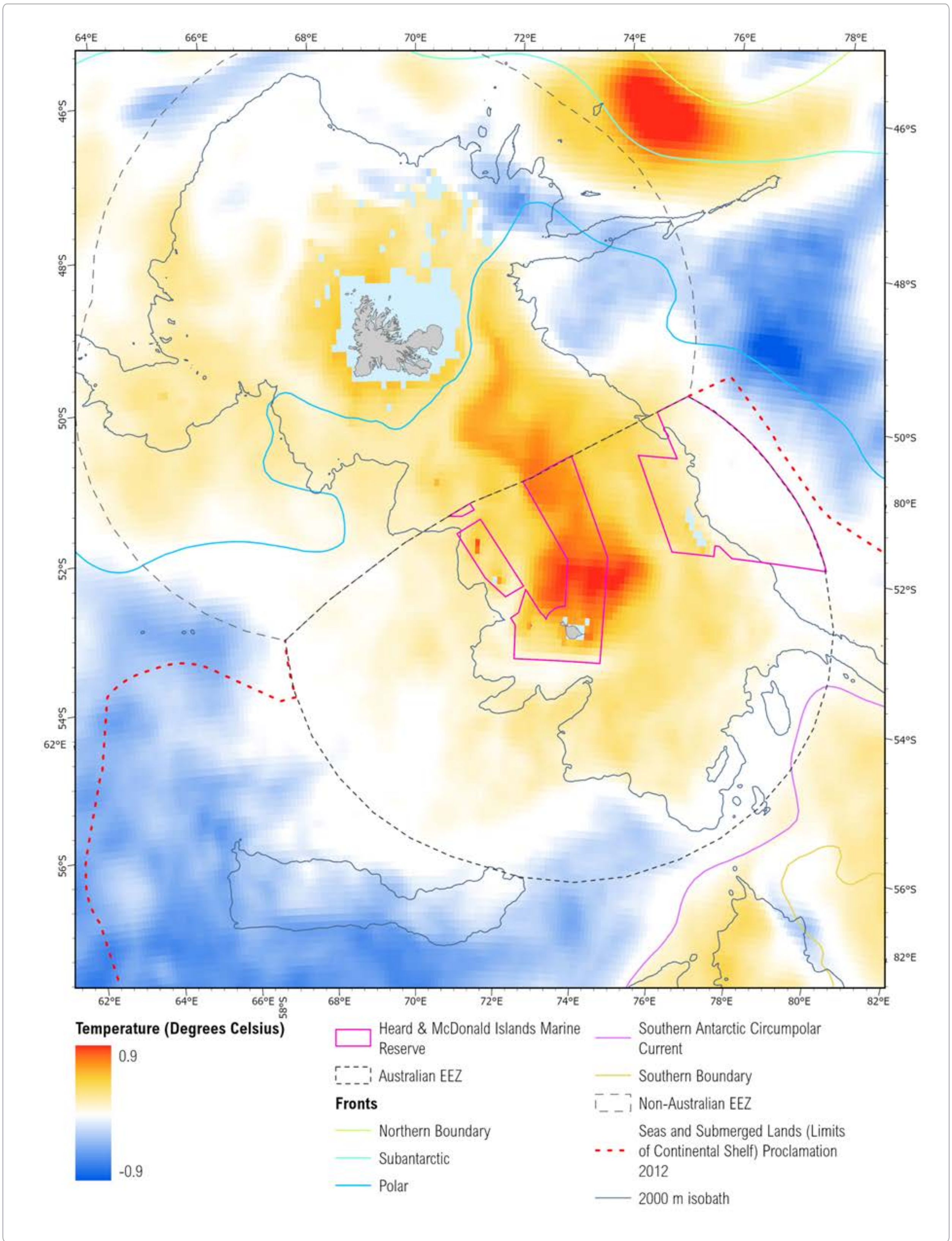
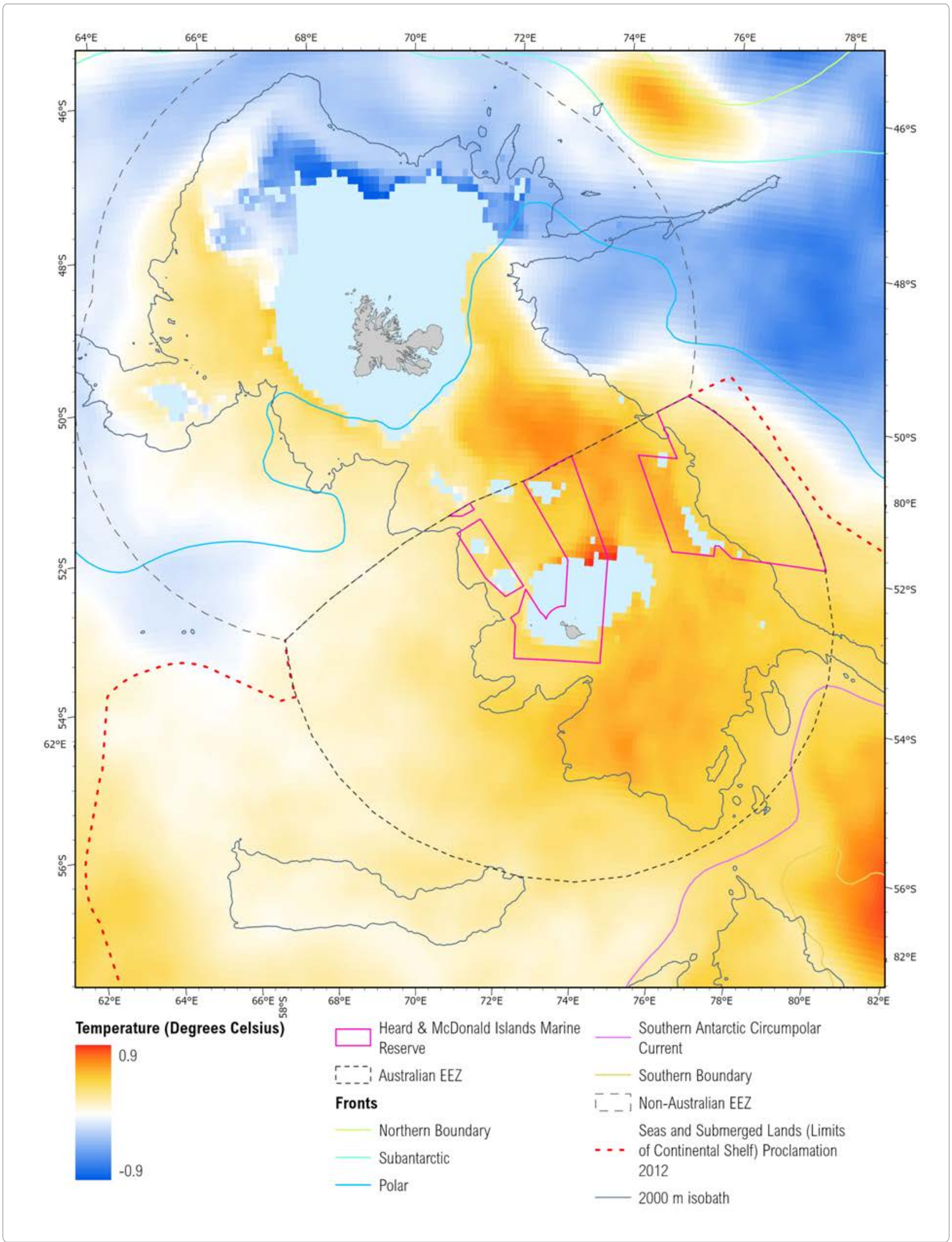


Figure 31. Anomalies of the mean decadal temperatures (oC) during October-March for recent decade (2013/2014 to 2022/2023) less the early decade (1993/1994 to 2002/2003), derived from the BRAN2020 dataset (Appendix 2 and 3) in the HIMI EEZ for the a. epipelagic, b. winter water, c. mesopelagic and d. bottom water. Areas shallower than 300 m are greyed in panel (c) because the water depth is shallower than the mixed layer.



Temperature (Degrees Celsius)
0.9
-0.9
Heard & McDonald Islands Marine Reserve
Australian EEZ
Fronts
Northern Boundary
Subantarctic
Polar
Southern Antarctic Circumpolar Current
Southern Boundary
Non-Australian EEZ
Seas and Submerged Lands (Limits of Continental Shelf) Proclamation 2012
2000 m isobath

Figure 31 B)



Temperature (Degrees Celsius)
0.9
-0.9
Heard & McDonald Islands Marine Reserve
Australian EEZ
Fronts
Northern Boundary
Subantarctic
Polar
Southern Antarctic Circumpolar Current
Southern Boundary
Non-Australian EEZ
Seas and Submerged Lands (Limits of Continental Shelf) Proclamation 2012
2000 m isobath

Figure 31 C)

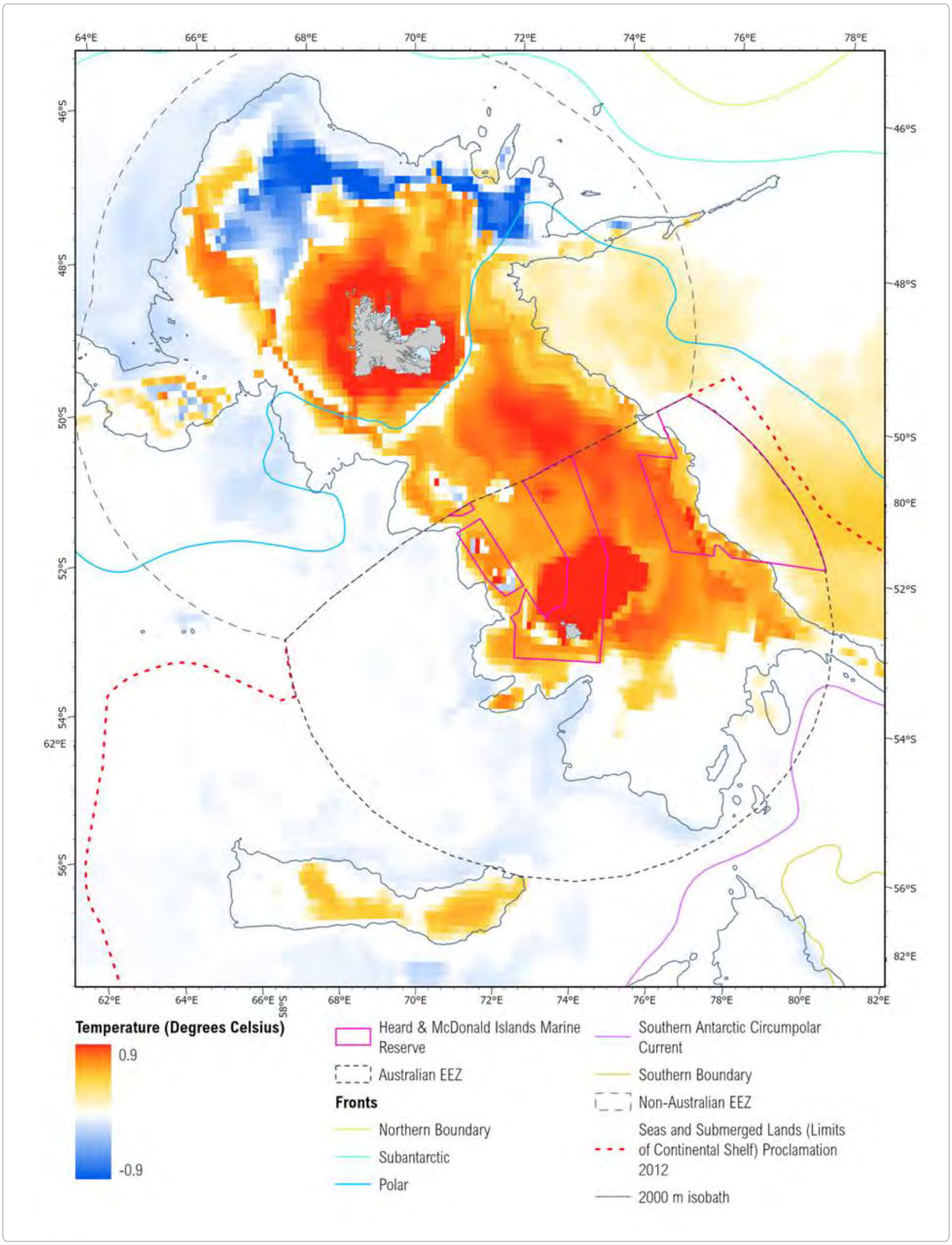

64°E
66°E
68°E
70°E
72°E
74°E
76°E
78°E
46°S
48°S
50°S
52°S
54°S
56°S
58°S
62°E
80°E
82°E
Temperature (Degrees Celsius)
0.9
-0.9
Heard & McDonald Islands Marine Reserve
Australian EEZ
Fronts
Northern Boundary
Subantarctic
Polar
Southern Antarctic Circumpolar Current
Southern Boundary
Non-Australian EEZ
Seas and Submerged Lands (Limits of Continental Shelf) Proclamation 2012
2000 m isobath

Figure 31 D)

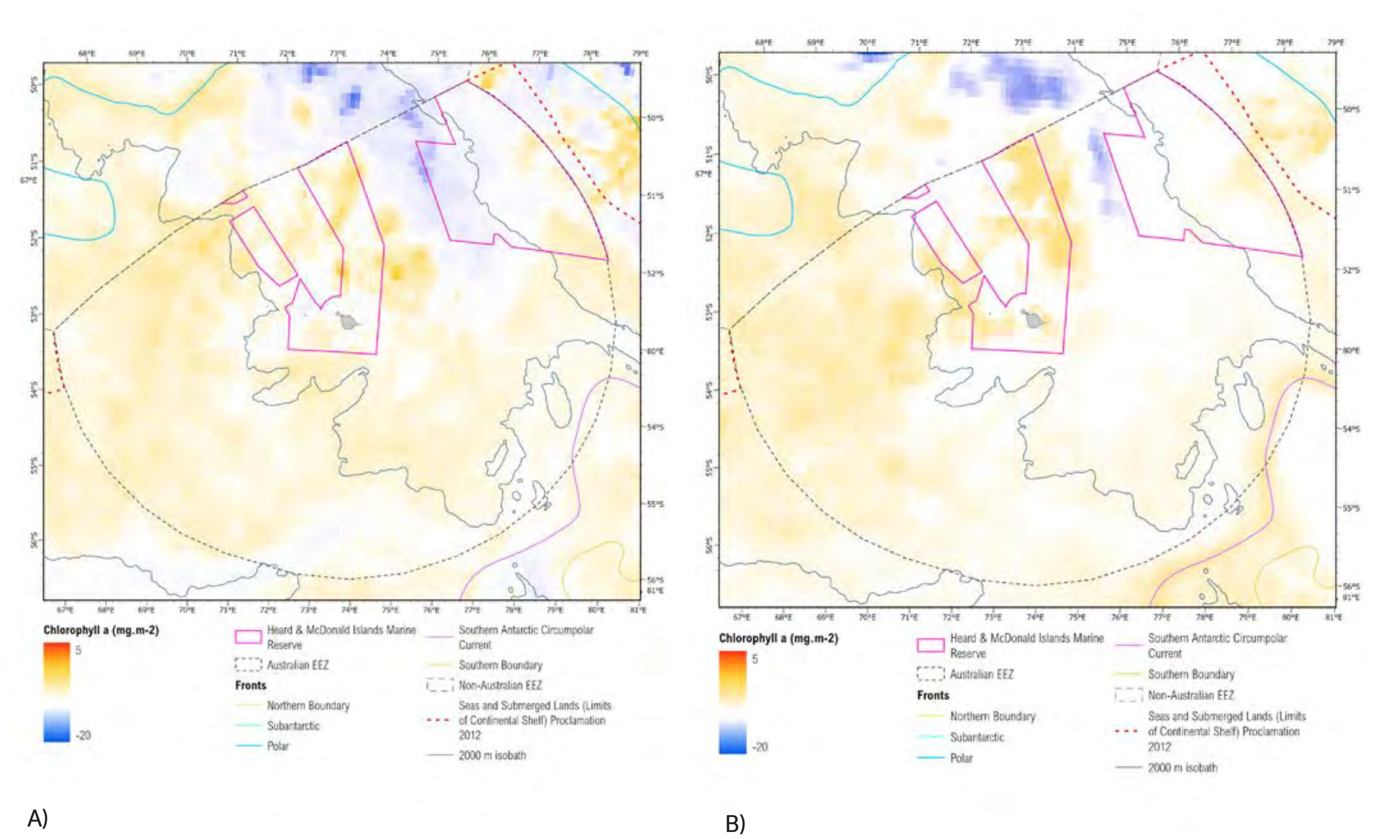


Figure 32. Anomalies of the mean decadal chlorophyll a concentrations (mg m^{-2}) for A. spring (October-December) and B. summer (January-March) for recent decade (2013/2014 to 2022/2023) less the early decade (2003/2004 to 2012/2013), based on satellite chlorophyll a combined with mixed layer depth from the BRAN2020 dataset (Appendices 2 & 3) in the HIMI EEZ.

6.6 Invasive Species

The introduction of invasive species would have devastating effects on the delicate island ecosystems, but due to its isolation and good management HIMI has so far remained pest-free. Invasive species, such as rats and rabbits, can outcompete native species for resources and disrupt the natural balance of the ecosystem. On Heard Island the plant species *Poa annua* (a cosmopolitan grass native to Europe) is considered to be an 'alien' (non-native) species. While a single specimen of the small flowering plant *Leptinella plumosa* was discovered in 2004 it could be non-native to the island but it is likely it was not introduced by humans and is not considered invasive (Turner et al. 2006).

Heard Island is known to possess three non-native animals; the worm *Dendrodrilus rubidus* (Dartnall 2003); the thrip *Apterothrips apteris*; and the mite *Tyrophagus putrescentiae* (Frenot et al. 2005). Efforts continue to prevent or sufficiently reduce the risk of an introduction and spread of an invasive species or disease.

7.0 Extended Continental Shelf

On December 1st 2003 the Cabinet of Australia agreed to lodge a submission to the Commission on the Limits of the Continental Shelf (CLCS):

> "in order to support the establishment of an outer limit for the continental shelf for all areas where the physical shelf extends beyond 200 miles from Australia's territorial sea baseline, including the area off the Australian Antarctic Territory."[8]

This was presented as a "once-only opportunity" further detailed in the Background as:

> "In the area of the extended continental shelf beyond 200 miles [sic], Australia has the right to explore and exploit the resources of the shelf, including the petroleum resources and sedentary species. It also has a right to protect the marine environment of the extended continental shelf." (op cit).
>
> The CLCS operating under the United Nations Convention on the Law of the Sea (UNCLOS), confirmed Australia's entitlement to 2.56 million km^2 of continental shelf beyond 200 nautical miles (the extended continental shelf) on 9 April 2008. This entitlement is 95 percent of the area submitted in Australia's claim, one-third the size of the Australian continent, and 1.13 million km^2 (44%) is the Kerguelen Plateau, extending from the HIMI EEZ in the north and including the much larger Southern Kerguelen Plateau to the south (https://www.ga.gov.au/ausgeonews/ausgeonews200903/limits.jsp). (See Figure 1).

Williams Ridge an ~300 km long ridge which extends to the south-east of the HIMI EEZ and is fished regularly for Patagonian toothfish was part of the 5 percent of the Australian claim that was not recommended for acceptance by that Commission in 2008. It was felt there was insufficient available evidence to justify the full continental shelf associated with Williams Ridge (or Joey Rise in the Wallaby and Exmouth Plateaus region). This may have resulted from the Commission not being willing to set a precedent for this type of geological feature at the time, however, Australia has an option to make a new or revised submission for the excluded area (https://www.ga.gov.au/ausgeonews/ausgeonews200903/limits.jsp). A 2020 survey from the RV Investigator and the RV Sonne collected new geophysical and geological samples which may help justify this submission (Coffin et al. 2021).

On May 24, 2012, Australia made the Seas and Submerged Lands (Limits of Continental Shelf) Proclamation 2012 which defines the outer limits of the continental shelf over which it can exercise exclusive rights to seabed resources. Under UNCLOS all member States have the obligation to protect and preserve the marine environment. In particular, coastal States' sovereign rights under UNCLOS to exploit resources in their national jurisdictions must be exercised consistent with their duty to protect and preserve the marine environment. For the extended continental shelf, the coastal state has sovereign rights over the resources on the seafloor, while the resources found in the water column are beyond national jurisdiction (Mossop 2017). These resources include both non-living resources such as oil and gas, and living resources that are sedentary species, defined as those organisms "which, at the harvestable stage, either are immobile on or under the seabed or are unable to move except in constant physical contact with the seabed or subsoil." (UNCLOS, art. 78). This legal separation of responsibilities is likely to create "serious practical problems" when activities in the high seas (e.g. bottom trawling, waste disposal, carbon sequestration) impact vulnerable benthic ecosystems (Mossop 2017).

While the extended continental shelves generated by the Territory of Heard Island and the McDonald Islands, and Macquarie Island lie south of 60°S and are therefore geographically within the Antarctic Treaty area, they do not conflict with that Treaty as they were generated from Australia's unchallenged sovereignty to areas outside the Antarctic Treaty area.

[7] The trend in current carbon dioxide emissions is following the high forcing scenario.

"*That they* [the extended continental shelves generated by the Territory of Heard Island and the McDonald Islands, and Macquarie Island] *extend into the Antarctic Treaty area is a matter of geography, not international law. Besides, the area of continental shelf is not a territorial claim, it is an area where rights can be exercised because a territorial claim already exists on land."* (Press 2012).

Australia is a signatory to The Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol) which prohibits mining in the Antarctic Treaty area (all the area south of 60 degrees south). Thus, Australia could not mine its extended continental shelf on the Kerguelen Plateau without breaching its international obligations and has enacted domestic legislation in accordance with this. However, Australia does have the right to prevent any countries which are not signatories to the Madrid Protocol from mining this area (Press 2012). Management of any fisheries in these areas is likely to be considered under regional fisheries management bodies, although responsibility for managing seabed impacts of any fisheries remains an active topic of discussion.

Part VI of UNCLOS which addresses the continental shelf, imposes no obligation to protect sedentary species, compared to Part V which addresses sustainable use of living resources of the EEZ (Mossop 2017). However, all states, including coastal states have environmental obligations under UNCLOS Part XII. Article 192 of UNCLOS imposes a general obligation on states to protect and preserve the marine environment. In addition, agreements under the Convention on Biological Diversity (CBD) apply to areas under national jurisdiction and therefore apply to the extended continental shelf (Mossop 2017). Under the CBD, coastal states must develop strategies for the conservation and sustainable use of biodiversity within their national jurisdiction and this includes Australia's areas of extended continental shelf. The Kumming-Montreal Global Biodiversity Framework (GBF) was agreed to by all Parties to the CBD in December 2023, "Alarmed by the continued loss of biodiversity and the threat that this poses to nature and human well-being "[9]. The GBF "invites Parties and other Governments to cooperate at the transboundary, regional and international levels in implementing the Kunming-Montreal Global Biodiversity Framework". An Australian Government action to manage and protect our extended continental shelf would provide an effective and influential action to support the GBF, in an area subject to multiple international agreements.

The southern Kerguelen Plateau is one of the most important areas for primary production within East Antarctica supporting large populations of land-based predators and important fisheries including a re-establishing krill fishery in the south (McCormack et al. 2020). This highly productive area transitions from a southern krill-based food web to a copepod-based food web in the north which supports the Patagonian toothfish and mackerel icefish fisheries in and adjacent to the HIMI EEZ. The area includes the shallower Banzare Bank (mostly between depths of 1,000 to 3,000 m) which is considered a separate sub-region of the Kerguelen Plateau, south of the frontal activity of Fawn Trough, (Douglass 2014, Figure 5).

Few data are available for the benthic environment. Fabri-Ruiz et al. (2020) considered it to be distinct from the northern Kerguelen Plateau and more similar to the deep subantarctic shelves of South America and the Campbell Plateau, based on the joint analysis of 41 echinoids and 13 environmental covariates, although this may have been based primarily on benthic samples closer to Heard Island.

These areas of extended continental shelf are eligible to be included in the NRSMPA as part of Australia's obligation under the CBD and through general obligations under UNCLOS. Protection of the seafloor from potential mining operations (by Parties outside CCAMLR) or any adverse effects of fishing could pre-empt future damage. The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") provides a precedent for this.

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[8] Cabinet Paper JH03/0415/CAB recently released by National Archives NAA:AA14370. JH2003/415

[9] CBD/COP/DEC/15/4. The most relevant target is Target 3:

Ensure and enable that by 2030 at least 30 per cent of terrestrial and inland water areas, and of marine and coastal areas, especially areas of particular importance 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, recognizing indigenous and traditional territories, where applicable, and integrated into wider landscapes, seascapes and the ocean, while ensuring that any sustainable use, where appropriate in such areas, is fully consistent with conservation outcomes, recognizing and respecting the rights of indigenous peoples and local

The network of 333 MPAs recognized under OSPAR includes seven MPAs protecting extended continental shelf areas subject to a submission to the UNCLOS (OSPAR 2013):

- one MPA protects only the water column above the area.
- four MPAs protected by a Contracting party (Portugal) protect the seabed and subsoil while the water column is protected collectively by all Contracting Parties following an invitation from Portugal.
- two MPAs protected by a Contracting party (United Kingdom) protect only the seabed and subsoil, while the water column remains unprotected. One of these MPAs (NorthWest Rockall) straddles the EEZ-Extended Continental Shelf boundary.

Protection of these areas represents, at least in the case of Portugal, a recognition of the obligations under UNCLOS Article 192 to protect and preserve the marine environment, as well as the precautionary principle (OSPAR 2013).

8.0 Management

The management of the HIMI territory consists of several approaches governed by different pieces of legislation and policy.

In order to best manage the area for both conservation and sustainable use, it is critical to understand the different characteristics both within Australia's EEZ surrounding HIMI but also more broadly for the entire Kerguelen Plateau.

8.1 Legislation, policy and international obligations

8.1.1 National legislation and policy

National legislation

The management of Heard Island and McDonald Islands falls under the jurisdiction of various laws and regulations established by the Australian government. A key aspect of Australia's management of the islands since the 1950s has been the maintenance of strict visitation and quarantine controls to maintain natural conditions and ecological integrity, and to prevent the introduction of pathogens and non-native species.

The key legal instruments and frameworks that govern the management of these islands include:

Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act): This is the primary piece of legislation that governs the protection of Australia's environment and biodiversity. The EPBC Act provides a legal framework for the identification, assessment, and management of matters of national environmental significance, including protected areas like Heard Island and McDonald Islands. It sets out requirements for environmental impact assessments, approvals for activities that could impact the environment, and the establishment of marine and terrestrial protected areas. However prior environmental assessment and approval/permitting requirements apply to all proposed activities in the HIMI Territory administered via the *Environment Protection and Management Ordinance 1987* (see below).

Under the EPBC Act, areas of outstanding universal value can be nominated for inclusion on the World Heritage List. Heard Island and McDonald Islands were designated as a World Heritage Site in 1997. In 2007 the Heard Island and McDonald Islands World Heritage Area was added to the National Heritage List in recognition of its national heritage significance.

Biologically Important Areas (BIAs) are areas designated for marine species protected under the EPBC Act for carrying out critical life functions, such as reproduction, feeding, migration or resting. They are not formally protected areas but are designed to inform decision makers on actions that may be needed to address actions or conservation plans for marine species protected under the EPBC Act. They can be located anywhere within the Australian marine environment, however their absence does not mean a lack of importance for protected species. They are focussed on providing important information on the spatial and temporal needs of the critical life functions of protected species. There is an ongoing BIA Review which is considering the inclusion of areas previously not covered including the subantarctic and Antarctic (https://www.dcceew.gov.au/environment/marine/marine-species/bias).

Environment Protection and Management Ordinance 1987: While the EPBC Act and regulations generally prevails over the Environment Protection and Management Ordinance 1987 (the EPMO) the latter is more tailored for the specific conditions of the Heard Island and McDonald Islands Territory. In particular, the EPMO provides it does provide some specific additional protections of the Territory's environment and its indigenous plants and animals, such as the requirement for a permit to enter the Territory; and the requirement for a permit to undertake activities in the Territory which may have a damaging effect on the environment or the indigenous plants and animals. For instance, the EPMO provides that, unless authorised by a permit, a person must not bring any organism into the Territory, take any organism in the Territory, remove from the Territory any organism indigenous to the Territory, or engage in conduct that results in a living organism that has been introduced to the Territory escaping in the Territory.

Fisheries Management Act 1991: The management of fisheries around Heard Island and McDonald Islands is governed by the Fisheries Management Act 1991 and associated regulations, which provide a framework for the sustainable management of fisheries resources, through quotas, licensing, and conservation measures to prevent overfishing and ensure the long-term viability of fish stocks. The Sub-Antarctic Management Advisory Committee (SouthMAC) is the advisory committee where issues relating to the management of Heard Island and McDonald Islands Fishery and the Macquarie Island Toothfish Fishery are discussed, problems identified, and possible solutions developed. The AAD has representatives on this committee. The Sub-Antarctic Resource Assessment Group is the AFMA research and scientific advisory committee for the Heard Island and McDonald Islands Fishery and Macquarie Island Toothfish Fishery. The AAD has representatives on this group.

Heard Island and McDonald Islands Act 1953: The Heard Island and McDonald Islands Act 1953 ratifies Australia's acceptance from the United Kingdom of sovereignty over the HIMI Territory and provides the legal regime that applies to the islands.

Navigation Act 2012: Laws related to maritime safety and navigation around the islands are regulated under the Navigation Act 2012 by the Australian Marine Safety Authority (AMSA). This act establishes rules and regulations for vessels operating in Australian waters, including those near Heard Island and McDonald Islands, to ensure safety, prevent accidents, and protect the marine environment.

Historic Sites and Shipwrecks Act 1976: This act provides a legal framework for the protection and management of historic sites, shipwrecks, and relics within the Australian territory, including Heard Island and McDonald Islands. It aims to preserve the cultural and historical heritage of these areas. While at least fourteen ships are recorded as having been wrecked at Heard Island (Downes 1996), no specific shipwreck locations are known, however shipwreck artefacts have been recorded at Walrus Beach, Skua Beach and Spit Bay (McGowan and Lazer 1989).

Antarctic Marine Living Resources Conservation Act 1981 (AMLRC): Australia gives effect to the decisions made under the Convention on the Conservation of Antarctic Marine Living Resources (see section 8.1.2) through the AMLRC Act. Under this Act, Australia also established that it can provide additional measures to help ensure the conservation of Antarctic marine species.

In order to secure agreement on the CAMLR Convention, the Chairman of the Conference on the Conservation of Antarctic Marine Living Resources made a statement on 19 May 1980 (known as the Chairman's Statement) to demonstrate provisions for the application of the CAMLR Convention and its Conservation Measures to Members with undisputed territories in the Convention area. The Chairman's Statement confirms that Member States with undisputed territory within the Convention Area can exclude their territory from new CCAMLR conservation measures at the point of adoption of the new conservation measure. As a result, Australia has the option of excluding the HIMI EEZ from CCAMLR Conservation Measures. To date, Australia has not chosen to take that path for many reasons, including the importance it gives to the Antarctic Treaty System. Instead, Australia takes an active role in providing scientific advice, and in negotiations within the Commission, and has relied on the Commission making sound judgements in the application of the Convention to the HIMI EEZ.

8.1.2 International obligations & treaties

World Heritage

In recognition of its outstanding natural universal values, the Territory was inscribed on the World Heritage List in December 1997. The property covers a total area of nearly 6,600 km^2, made of 370 km^2 of terrestrial environment (the islands), and 6,220 km^2 marine environment.

The islands are recognised as outstanding examples of biological and physical processes continuing in an environment in excellent condition, with little impact from humanity. The World Heritage Listing values focus on the important on-going geological processes occurring in an essentially undisturbed environment, particularly physical processes which provide an understanding of the role of crustal plates in the formation of ocean basins and continents, and of atmospheric and oceanic warming.

The listing highlights the area as an active example of plume volcanism, providing direct geological evidence of the action of the longest operational plume system known in the world, and the plume interaction with overlying crustal plates, as well as insights into oceanic island volcano systems. Big Ben on Heard Island is the only known continuously active volcano on a subantarctic island, whereas the volcano on McDonald Island has become active again only in the last 50 years after a 75,000 year period of dormancy.

They are also listed as outstanding examples of significant on-going ecological, biological, and evolutionary processes, notably as the only subantarctic islands virtually free of introduced species and with negligible modification by humans, with large populations of marine birds and mammals numbering in the millions, but low species diversity.

Antarctic Treaty System and the Convention on the Conservation of Antarctic Marine Living Resources

The Convention on the Conservation of Antarctic Marine Living Resources (CAMLR) is an international treaty that was adopted in Canberra in 1980 and is a part of the Antarctic Treaty System. While Australia is a signatory, it is also the Depository State for the CAMLR Convention. The CAMLR Convention Area extends the Antarctic Treaty System from the Antarctic Treaty Area at 60oS to the Polar Front (called the Antarctic Convergence in the CAMLR Convention). The objective of the CAMLR Convention is to conserve Antarctic marine species, which are all species living in the Convention Area (Press et al 2019; Press & Constable 2022). Subject to the overall conservation objective, fisheries have special conservation principles to be met (Constable et al. 2000), including but not limited to:

- preventing a decrease in the size of any harvested population to levels that do not have stable recruitment,
- maintaining the ecological relationships between harvested, dependent and related populations and restoring depleted populations, and
- preventing changes or minimising the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades.

The Convention on the Conservation of Antarctic Marine Living Resources established a Commission (CCAMLR), of which Australia is a member, that can make laws by consensus through Conservation Measures. CCAMLR has the attributes of a regional fisheries management organisation, but its conservation objective means it has a much wider remit (Press et al. 2019). The HIMI EEZ falls within the CAMLR Convention Area. As indicated in Section 8.1.1, the management of the HIMI EEZ takes into account this special relationship with CCAMLR. How this relationship is managed is discussed further in Section 8.2. Conservation Measures of relevance to the HIMI EEZ and its relationship with activities in the Convention Area are in Appendix 7.

Agreement on the Conservation of Albatross and Petrels (ACAP)

Australia has played a key role in the establishment of the multilateral Agreement on the Conservation of Albatrosses and Petrels (ACAP) which seeks to conserve listed albatrosses, petrels and shearwaters by coordinating international activity to mitigate known threats to their populations. It seeks to achieve and maintain a favourable conservation status for albatrosses and petrels, by conserving and restoring habitats, eliminating or controlling non-native species detrimental to albatrosses and petrels, and to research, educate, raise awareness and disseminate information. All Southern Hemisphere species of albatrosses and seven petrel species are listed under its auspices.

Convention on Biological Diversity

Australia as a Party to the Convention on Biological Diversity (CBD) is required to pursue the conservation of biological diversity and the sustainable use of its components, including the development of a national strategy for the conservation of Australia's biological diversity. The first strategy was released in 1996 (Commonwealth of Australia 1996) and was recently updated to be Australia's Strategy for Nature 2019-2030 (Commonwealth of Australia 2019). The original strategy included an objective to develop a national representative system of marine reserves, and the establishment of the HIMI Reserve has been included in Australia's national reports as contributing to its fulfilment of its obligations and commitments under the CBD. See section 9.3.1 for a discussion on Australia's processes for achieving a national representative system of marine reserves.

In December 2022 the Parties to the CBD adopted the Kunming-Montreal Global Biodiversity Framework (replacing the previous CBD's Strategic Plan for Biodiversity 2011-2020 and its Aichi Targets). This included a new commitment to ensure at least 30% of terrestrial, inland water, and of coastal and marine areas are effectively conserved and managed. In March 2023 the Australian government (consistent with its pre-election commitments) announced it had adopted the target to protect and conserve 30% of Australia's land and 30% of oceans by 2030.

Cooperation with France

Australia and France have had long-standing cooperation in Antarctica and the Southern Ocean. The border between the HIMI EEZ and the French Territory around Iles Kerguelen is Australia's longest maritime border with another State. With the advent of illegal, unregulated and unreported fishing in the region in the late 1990s and the importance of managing the Kerguelen Plateau in a sustainable manner, Australia and France formalised their cooperation in 2003 with the signing of the *Treaty between the Government of Australian and the Government of the French Republic on Cooperation in the Maritime Areas adjacent to the French Southern and Antarctic Territories, Heard Island and the McDonald Islands*, and later in 2007 with the *Agreement on Cooperative Enforcement of Fisheries Laws between the Government of Australia and the Government of the French Republic in the Maritime Areas adjacent to the French Southern and Antarctic Territories, Heard Island and the McDonald Islands*. As well as joint surveillance and managing IUU fishing, this cooperation has also resulted in extensive scientific collaboration in the region (Weragoda et al 2019).

8.2 Management approaches

8.2.1 Fisheries

Given the special relationship of the HIMI EEZ with the CAMLR Convention Area established in the AMLRC Act 1981 and the relationship between Australia and France over the northern Kerguelen Plateau, management of the EEZ has a whole-of-government emphasis, including for fisheries. The Commonwealth Harvest Strategy Policy (Department of Agriculture and Water Resources, 2018) states:

> *"For fisheries that are managed jointly by an international organisation or arrangement, the Harvest Strategy Policy does not prescribe management arrangements.*
>
> *...*
>
> *The government (including AFMA) must implement decisions taken by all relevant regional fisheries management organisations and other international arrangements that Australia is a party to, except where Australia has made a permissible reservation about the decision. Through these forums, Australia will continue to pursue the adoption of measures that are consistent with this policy and domestic management measures in order to achieve the long-term sustainability of the stocks. All available information about the stock status, the impact of Australian fishing on that stock and any other relevant information such as catch and effort history will be taken into account when deciding on the Australian negotiating position.*
>
> *AFMA will set Commonwealth fishery catch levels taking into account available science and evidence, the Australian negotiating position, advice from government and any relevant decisions of the applicable regional organisation. AFMA must determine a domestic catch level that is the same or less than that permitted under the relevant international arrangement. AFMA may also impose additional constraints on fishing effort, biomass-based recommendations or rebuilding targets.*

In setting catch levels for Commonwealth fisheries, AFMA's primary consideration will be the harvest strategies for the fishery. Where Australia is not a major harvester of the stock and no harvest strategy has been determined internationally, the key consideration will be Australia's negotiating position in bilateral, regional or international negotiations. If Australia is a major harvester of the stock and no harvest strategy has been determined internationally, AFMA must develop and implement a harvest strategy consistent with the objective of this policy."

To date, the emphasis of CCAMLR in the subantarctic has been primarily on finfish fisheries and their impacts on stocks and incidental mortality of seabirds and seals (see Constable et al 2000 for background). These practices had been established prior to Australia beginning fisheries in the HIMI EEEZ and long prior to the first Commonwealth Harvest Strategy Policy in 2007. The practices of the Scientific Committee of CCAMLR (SC-CAMLR) in the precautionary and ecosystem approaches to fishing are regarded as satisfying the requirements of the Commonwealth Harvest Strategy Policy (Patterson & Curtotti 2023). Regulation of fisheries at HIMI have always been consistent with or exceeded the conservation requirements of CCAMLR.

Catch limits for Patagonian toothfish and mackerel icefish are determined through scientific assessments based on fishery data derived from the AFMA observer program (consistent with the requirements of the CCAMLR Scheme of International Scientific Observation), an annual fishery-independent survey of groundfish on the HIMI Shelf and a mark-recapture program on Patagonian toothfish caught in the fishery (Patterson & Curtotti 2023). These surveys began prior to the fishery in the early 1990s, providing a time series of abundances of fish on the shelf. The assessments are coordinated by the Australian Antarctic Division and reviewed through the process of the Australian Fisheries Management Authority, through the Subantarctic Resource Assessment Group and the Subantarctic Management Advisory Committee (SouthMAC). They are then submitted to a working group on fish stock assessment for review and the development of advice to SC-CAMLR and the CAMLR Commission.

The CAMLR Commission decides on Conservation Measures based on the best scientific evidence available. In this case, the SC-CAMLR advises on the status of stocks, catch limits, including by-catch limits, and other measures pertaining to the conservation of marine living resources in the CCAMLR Division 58.5.2 (which includes most of the HIMI EEZ). Areas of the EEZ in other CCAMLR management areas (in Division 58.4.3) are closed to fishing in CCAMLR and in the Australian Fishing Zone. That part of CCAMLR Division 58.5.2 on Williams Ridge outside of the EEZ is also closed to CCAMLR fisheries.

Each year, AFMA develops regulations for the fisheries based on the outcomes of CCAMLR, including advice from the SC-CAMLR, and advice from SouthMAC. Current Heard & McDonald Islands fishery Statutory Fishing Rights (SFRs) holders are:

Client Name	Season	Unit Name	Tonnes Owned
AUSTRAL FISHERIES PTY LTD	2023/24	Mackerel Icefish	21300
AUSTRALIAN LONGLINE PTY LTD	2023/24	Mackerel Icefish	4350
NIPPON SUISAN KAISHA LTD	2023/24	Mackerel Icefish	3410
OCEAN VALUES (NSW) PTY LTD	2023/24	Mackerel Icefish	940
AUSTRAL FISHERIES PTY LTD	2023/24	Patagonian Toothfish	21300
AUSTRALIAN LONGLINE PTY LTD	2023/24	Patagonian Toothfish	4350
NIPPON SUISAN KAISHA LTD	2023/24	Patagonian Toothfish	3410
OCEAN VALUES (NSW) PTY LTD	2023/24	Patagonian Toothfish	940

Assessments and fishing

The precautionary and ecosystem approaches of CCAMLR are implemented in the HIMI EEZ (Constable et al 2000; Constable & Welsford 2011). The aim of these approaches is to manage target species in such a way that the long-term median biomass of the spawning stock does not fall below the target level relative to the level prior to fishing. The target level is set depending on where the target species sits in the food chain; prey species need to have a higher level of escapement (higher target level) in order to satisfactorily provide for predators. Further, there should only be a 10% chance of the spawning stock falling below 20% of the pre-exploitation spawning stock level. This limit reference point is meant to ensure that stable recruitment is sustained.

Patagonian toothfish are regarded as a top predator and therefore have a target median spawning biomass of 50% of the pre-exploitation median spawning biomass. This means that after the stock has been reduced to this target level then the biomass of the spawning stock will be expected to vary around this level but should not be lower than the target level in no more than 50% of the years. Furthermore, median recruitment of juvenile Patagonian toothfish is not expected to decline appreciably. The assessment of the status of toothfish and catch limits are undertaken every second year (Patterson & Curtotti, 2023). Changes to input data and methods since the first full assessment in 1996 have resulted in variation in the catch limit (Ziegler & Welsford 2019; Brand-Gardner et al 2022).

Mackerel icefish are an important part of the food chain, being a prey species for many marine mammals and seabirds. Consequently, a target median spawning biomass of 75% of the pre-exploitation median has been set in order to allow sufficient escapement from the fishery for predators. A difficulty with this species is that recruitment of young fish is highly sporadic, and the population is usually dominated by a single cohort at any one time, which makes the application of the target levels and the decision rule for setting catch limits difficult to apply. Instead, a harvest rate on the stock is determined as that rate that is expected to result in an estimated biomass being 75% of what would have been present naturally after two years (de la Mare et al 1998). The estimated biomass is the lower one-sided 90% confidence level from a survey estimate.

These methodologies have been independently accredited as suitably "precautionary" by the Marine Stewardship Council (Brand-Gardner et al 2022), however the capacity for these strategies to be successful in the long-term has not yet been evaluated (Constable 2011). In particular the target level for prey species has not yet been determined from an understanding of the needs of predators (Constable et al 2000) and requires further consideration for icefish fisheries. Understanding of the overlap between fisheries and predators has mainly focussed on southern elephant seals (Hindell et al 2022), and detailed food web studies remain to be developed to address these questions (see Section 5.6).

The ecosystem effects of these fisheries are managed by AFMA through by-catch monitoring and assessment (AFMA 2013), an evaluation of benthic interactions (Welsford et al 2014) and routinely documented through an Ecological Risk Assessment (Fisher 2019; Brand-Gardner et al 2022).

The Patagonian toothfish and mackerel icefish fisheries at HIMI have been re-accredited by the Marine Stewardship Council in 2022. Accreditation was undertaken by Bio.Inspecta (Brand-Gardner et al 2022), however the primary assessment papers underpinning the accreditation are not publicly available and were not made available for assessment as part of this report.

There is no fishery independent assessment for the bycatch species in deeper waters (SOUTHMAC38 March 2020), including for long-lived and vulnerable skates and rays. Early higher catches of deeper water skates in the longline fishery in the 2004 and 2005 seasons have not been repeated. While an earlier risk assessment noted a 75% decline in catch (Bulman et al. 2007), a more recent assessment based on a longer timer series noted a slight decline (Nowara et al. 2017). It is hoped that more accurate assessment of total skate bycatch and fishing induced mortality will be available from electronic monitoring (SOUTHMAC39 May 2021). Nowara et al. (2017) noted that marine reserves and conservation measures appear to have provided effective protection for skates in the shallower waters.

The 2006 "Assessment of the Vulnerability of Benthic Habitats to Impact by Demersal Gears" (Welsford et al. 2014) does not include many of the deeper areas now likely fished commercially. While the above authors concluded that (limited) video observations below 1000m indicated that "longlining occurs on expanses of relatively bare, homogenous substrata of mud and sand, with few instances of epifauna with the exception of individual stalked crinoids and pennatulaceans", they also noted that this did "not preclude the existence of locations where important aggregations of deep-sea taxa are present". The authors go on to recommend targeted sampling of deeper geomorphology, such as the seamounts to the southeast of Shell Bank to improve the robustness of their conclusions.

8.2.2 Protected areas

Following formal handover to the Australian government in 1950 the first protections were enacted in the *Heard Island and McDonald Islands Act 1953 (HIMI Act)* which, among other things, made provisions for the protection of wildlife and the making of rules for the administration of the islands.

In 1987 an *Environment Protection and Management Ordinance 1987* was made under the HIMI Act which provided a number of protections for HIMI's environment including the requirement for a permit to enter or undertake activities in the Territory.

In 1996 a Heard Island Wilderness Reserve Management Plan was made under the *Environment Protection and Management Ordinance 1987*, to further define appropriate uses and activities, designate management areas and provide management strategies for protecting the area's values.

In 1997 the islands and the surrounding ocean to 12 nautical miles from shore were inscribed on the World Heritage List for its outstanding universal natural values (see International Obligations section).

In 1998 the area surrounding the Heard Island and McDonald Islands region was one of five priority areas listed for declaration under the EPBC Act as a marine reserve in Australia's Oceans Policy (1998). The Reserve was then established in October 2002 and expanded in March 2014 to cover an area of 71,000km2, which is approximately 17% of the HIMI EEZ.

Given the Reserve contains outstanding and representative ecosystems, geographical features and terrestrial and marine species and is in a relatively pristine state it was given the highest level of protection and is assigned to IUCN Category 1a (strict nature reserve) under the EPBC Act.

The Heard Island and McDonald Islands Marine Reserve Management Plan 2014-2024 has put in place seven management zones in order to manage human impacts on The Reserve, including a Main Use Zone that provides access points to The Reserve for establishment of higher-impact activities, Visitor Access Zones for lower impact short term visitation including walking routes, a Heritage Zone related to the former station at Atlas Cove, a Wilderness Zone restricted to scientific activities, Restricted Zones with highly restricted access, an Inner Marine Zone to protect the coastal environment and near shore foraging areas, and an Outer Marine Zone outside of 12 nautical miles.

The Restricted Zones are particularly sensitive to human impacts or are potentially hazardous to human health and safety, and all access is strictly controlled. Azorella Peninsula Restricted Zone contains sinkholes and lava tubes and is particularly hazardous and environmentally sensitive, such as the ceilings of the very shallow lava tubes which are susceptible to collapse as well as a significant number of nesting sites for South Georgian diving petrels and Antarctic prions.

No mining operations, exploration, or fishing activities are allowed in The Reserve, other than minor extractions for non-commercial scientific research purposes under strict permit conditions.

8.2.3 Threatened communities and species

Identifying matters of national environmental significance (MNES) and other matters protected by the *EPBC Act 1999* is central in determining obligations and requirements under the Act.

There are five species of seabirds that have been recorded breeding on Heard Island that are listed as threatened under the EPBC Act. One of these, Southern giant-petrel, is listed as endangered while the others, wandering albatross, black-browed albatross, Heard Island imperial shag and Antarctic tern, are all listed as vulnerable. However, in the case of wandering albatross there was a single pair recorded breeding on Heard Island in the 1980s, but this is assumed to have been an isolated occurrence (Thalman et al. 2021).

The lack of any contemporary monitoring data for breeding bird populations creates some divergence in the assessment of, or revisions to, the conservation status of breeding birds on Heard Island. Garnett and Baker (2021) provide the most recent review of the conservation status for many of these species and given the lack of recent data on the population status, these are by necessity set in the context of changes in their overall global distribution. For example, macaroni and eastern rockhopper penguins are considered to be vulnerable and endangered respectively by Garnett and Baker (2021) based on the assumption of analogous declines of these two species throughout their breeding range. Similarly, black-browed albatross is listed as least concern by Garnett and Baker (2021) with the acknowledgement that while the status and trends for the Heard Island and McDonald Islands population are unknown, they are considered likely to be stable or increasing in line with updated global trends.

Although the southern giant-petrel is listed under the EPBC Act as endangered, Garnett and Baker (2021) consider it to be of least concern and noted that this species has not met IUCN Red List criteria at either national or global levels for some time.

The southern elephant seal is the only mammal that has an established breeding population on Heard Island that is listed as a threatened species (it has a status of vulnerable) under the EPBC Act. Occasional records of the birth of pups of subantarctic fur-seal, which is listed under the EPBC Act as endangered, do not indicate a pattern of colonisation of the island. Of the nineteen cetacean species that occur in the Heard Island marine zone there are four that have threatened species status under the EPBC Act; southern right whale and pygmy blue whale are listed as endangered while the sei and fin whale are listed as vulnerable.

Biologically Important Areas are yet to be defined for Australia's subantarctic and Antarctic environments. Deepwater benthic surveys, or at a minimum swath mapping, would be needed to complete this process.

8.2.4 Management of future pressures and threats

The potential for changes in fish populations to be driven by climate change is well recognised and is being actively considered for management of the area. Potential changes could be manifest in relatively slow, long-term changes as well as through the occurrence of extreme events. The erratic population dynamics of icefish at HIMI may signal they are particularly sensitive to cumulative impacts of more frequent extreme events.

Cumulative pressures could arise in the HIMI EEZ from the combined effects of climate change with human activities in the region. In addition to existing human activities, potential future activities within or adjacent to the HIMI EEZ, include other pelagic fisheries, seabed mining or iron fertilization to stimulate carbon sequestration. The existing pressures on the HIMI marine ecosystem from climate change could be compounded by the impacts from these potential future activities. Without a holistic approach to managing the cumulative impacts of a suite of drivers of change any potential new fisheries operated in or adjacent to the HIMI EEZ could present a substantial risk to a number of the threatened seabirds that breed and/or feed in the region.

9.0 Assessment of comprehensiveness, adequacy and representativeness (CAR)

This section presents an assessment of the current marine reserve in relation to how well it satisfies the conservation planning principles of the comprehensiveness, adequacy and representativeness (CAR) criteria (ANZECC 1998) and related guidelines established for the Australian Commonwealth Representative System of Marine Protected Areas (NRSMPA) (Environment Australia 2002). This provides the basis for considering what options might be available to achieve CAR principles and guidelines for the HIMI EEZ.

The *'Guidelines for Establishing the National Representative System of Marine Protected Areas (NRSMPA)'* (hereafter referred to as the ANZECC Guidelines) (ANZECC 1998) were agreed between the Commonwealth and state and territory governments to ensure a consistent approach and understanding for all stakeholders.

The primary goal of the NRSMPA is defined as:

> *to establish and manage a comprehensive, adequate and representative system of MPAs to contribute to the long-term ecological viability of marine and estuarine systems, to maintain ecological processes and systems, and to protect Australia's biological diversity at all levels (ANZECC 1998).*

The ANZECC Guidelines built on the previously agreed set of CAR principles (Thackway and Cresswell 1995), which in summary are as follows:

Comprehensiveness: The NRSMPA will include the full range of ecosystems recognised at an appropriate scale within and across each bioregion.

Adequacy: The NRSMPA will have the required level of reservation to ensure the ecological viability and integrity of populations, species and communities.

Representativeness: Areas that are selected for inclusion in MPAs should reasonably reflect the biotic diversity of the marine ecosystems from which they derive.

The Australian government published the *Goals and Principles for the establishment of the National Representative System of Marine Protected Areas in Commonwealth waters (the Goals and Principles)* (DoE 2007), to clarify how the Australian government would apply the ANZECC Guidelines to meet CAR objectives using biodiversity surrogates (Beeton et al. 2015). Surrogates include provincial bioregions, depth ranges, key ecological features, and seafloor features. An expert scientific panel reviewed the network of Commonwealth Marine Reserves (CMR) against the following Goals and Principles (Beeton et al. 2015):

Goal 1 -- Each provincial bioregion occurring in the marine region should be represented at least once in the marine reserve network. Priority will be given to provincial bioregions not already represented in the National Representative System

Goal 2 -- The marine reserve network should cover all depth ranges occurring in the region or other gradients in light penetration in waters over the continental shelf.

Goals 3 -- The marine reserve network should seek to include examples of benthic/demersal biological features (for example, habitats, communities, sub-regional ecosystems, particularly those with high biodiversity value, species richness and endemism) known to occur in the marine region at a broad sub provincial (greater than hundreds of kilometres) scale.

Goal 4 -- The marine reserve network should include all types of seafloor features. There are 21 seafloor types across the entire Exclusive Economic Zone. Some provincial bioregions will be characterized by the presence of a certain subset of features, such as continental slope or seamounts.

These goals were accompanied by a number of design principles to guide the selection of suitable areas for inclusion in the NRSMPA. In our assessment below, we use the 20 guiding principles established for the NRSPMA[10]. Annotations of these goals and principles include guidance on dealing with a paucity of information in distant contexts, such as for the HIMI EEZ.

The expert scientific panel concluded that for comprehensiveness and representativeness (excluding the south-east marine region which was not included in the review): *"Overall, the proclaimed CMR estate includes the vast majority of the biodiversity surrogates (primary conservation features) on which the design of the networks was based..... Broadly, what is missing or deficient is coverage by CMRs and Marine National Park Zones on the continental shelf, which reflects the greater use and immediate economic value of these waters "* (Beeton et al. 2015, p38); and for adequacy: *"while the CMR estate.... represents the most extensive and comprehensive 'whole-of-ocean' approach to marine conservation by any country, there are some gaps to be addressed in due course."* (Beeton et al. 2015, p40).

communities, including over their traditional territories.

10 Accessed on 23 October 2023 at https://parksaustralia.gov.au/marine/management/resources/scientific-publications/goals-and-principles-

9.1 Previous assessments of representation of bioregions in shallow waters

The 2000 Conservation Assessment Report provided a review of existing knowledge of the HIMI environment, and a framework for determining the conservation values of the HIMI region. An analysis of the known physical and biological environments (mostly in the shallower areas of the EEZ) coupled with consideration of the ecology of those areas identified 13 biophysical local units and provided recommendations for the establishment of an MPA to protect these unique features of the HIMI benthic environment under 1,200 m.

Within the HIMI EEZ in waters shallower than 1,200 m an assessment of the representation of "bioregions" within marine reserves was undertaken by Hill et al. (2017). The "bioregions" are termed Regions of Common Profile (RCP), being areas that have similar environmental characteristics and species probability of occurrence (Described in more detail in Section 5.3.2). The analysis assessed 21 fish species caught in 1,1197 trawl samples from 2006, 2010 and 2013 and 15 environmental covariates and was limited by the data to waters less than 1,200 m deep or 27% of the EEZ. The Reserve covers 34% of the Australian EEZ shallower than 1,200m. The Reserve covered over 30% of all RCPs except for RCP 1 (26.2%) and RCP 2 (12.2%), the two RCPs found deeper than 600m (Hill et al. 2017; Figure 23). While most RCPs were predicted to occur across the northern Kerguelen Plateau (i.e. the French and Australian EEZs), RCP2 was predicted to occur mostly in the deeper water to the south-east of Heard Island.

RCP 2 is distinguished from RCP 1 by lower sea surface temperature and surface production and is also less species-rich with lower probability of the skate species (*Bathyraja* spp.), blue antimore (*Antimora rostrata*), lantern shark (*Etmopterus viator*), and the snailfish (*Paraliparis* spp.). RCP 2 also includes the unsurveyed chain of seamounts on Williams Ridge. The lantern shark has a low probability of occurrence in any other RCP than RCP 1.

9.2 Assessment Zones

Understanding the diversity of habitats across a large complex area like HIMI can be done at a multitude of scales and using different attributes depending on what key features are under consideration.

In the past the HIMI EEZ has been categorised (sub-divided) in a number of different ways to support different purposes: e.g. fisheries management and stock assessment); assessment of the biophysical attributes of the region for designing The Reserve (biophysical local units; Meyer et al. 2000); assessment of the effects of bottom fishing (geomorphic units; Hibberd et al 2014); and ecological risk assessments for fisheries (e.g. demersal communities; Fisher 2019). These subdivisions were largely restricted to waters shallower than 1,200 m from which most data were available at the time, including from fishing activities. This depth limitation means that 73% of the area of EEZ was not accounted for in these management zonations.

In this assessment we have synthesised all of the key abiotic drivers that determine the distribution of biodiversity, as well as including information on the distribution of key elements of the biological diversity where these are known. This provides a set of assessment zones for the whole HIMI EEZ, building on the previous classifications and adding in new knowledge on the bottom topography, geomorphology, oceanography and productivity of the region. Each assessment zone represents a specific type of environment in the HIMI EEZ distinguished by the combination of depth, temperature, oceanography, and how it is utilised by fauna.

Our classification provides 18 assessment zones covering the entire HIMI EEZ (see Figure 33). The 18 zones provide the basis for the assessment of the environmental drivers of biodiversity in order to identify how to achieve the goals of the NRSMPA in the HIMI EEZ. In particular, we seek to include all depth ranges (Goal 2) and multiple examples of all types of benthic/demersal features (Goals 3, 4, 12) in any proposed extension of the marine reserve. Table 3 describes the 18 assessment zones and their relationship to the previous classifications. The assessment zones are described in more detail in section 9.3 and an analysis of the distribution of seven key attributes is provided in section 9.4.

Each assessment zone is defined based on:

- depth;
- slope;
- temperature;
- complexity of the ocean currents (van Wijk et al. 2010; Mori et al. 2016);
- an east west transition identified in geomorphic studies (Watson et al 2020);
- benthic invertebrates and communities (Hibberd et al 2014), especially at depths below 1,000m (Fabri-Ruiz et al. 2017; McQuaid et al. 2023);
- fish, including for shallower depths (Duhamel et al. 2014; Hill et al. 2017);
- different areas of iron-enrichment and primary productivity (Wojtasiewicz et al. 2019) which influence phytoplankton assemblages (Pinkerton et al. 2020);
- differences in pelagic areas giving rise to different zooplankton and mesopelagic fish assemblages (Hunt et al. 2021);
- foraging areas for apex predators (Patterson et al. 2016); and
- representation in global biogeographies (Raymond 2014; Douglass et al. 2014; Griffiths et al. 2009; Fabri-Ruiz et al. 2017; Moreau et al. 2017; Reisenger et al. 2022).

Building on the biophysical local units defined in the 2000 Conservation Assessment we have included additional zones in water deeper than 1000m, the availability of new finer scale data (Beaman 2023 a,b) made it possible to update four of the previous biophysical local units from the 2000 Conservation Assessment Report to better include areas of similar ecology.

Modifications to the 2000 Conservation Assessment biophysical local units are:

1. The 'western banks' unit has been included in a zone with the Western Trough.
2. 'Discovery Bank' unit is now included in the Northern Shelf (while the attributes of the banks are able to be presented there is insufficient data to undertake a finer scale subdivision of this zone).
3. The 'Eastern Trough' unit has been divided into a southern and central zone based on differentiation in oceanography, productivity, and foraging activity of predators.
4. The area originally classified as the 'Northeast Shelf' unit is deeper than the HIMI Shelf and bank areas and is considered to have more in common with the 'Eastern Trough' unit, particularly with regards to its oceanography and productivity, and therefore we have termed this zone as Eastern Trough North.

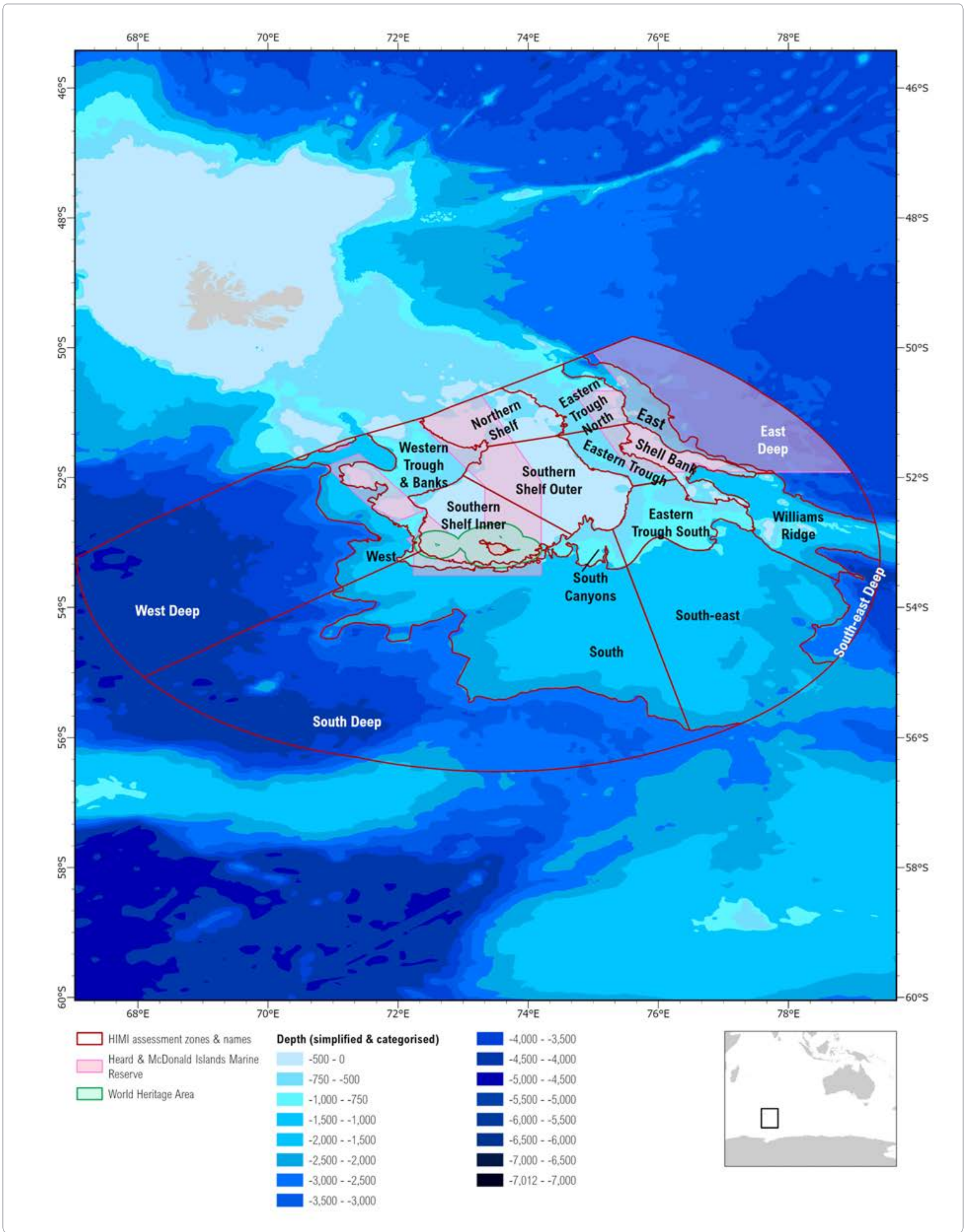


Figure 33. Assessment zones overlaid on HIMI bathymetry

Table 3:
Assessment Zones for the HIMI EEZ and their relationship to other subdivisions for conservation and fisheries assessments. Note Geomorphic strata and Seascape Categories from Welsford et al (2014) relate to bottom fisheries interactions. Seascape category I has taxa vulnerable to fishing being represented in the HIMI reserve. Seascape categories III and IV are unassessed or have relatively low vulnerability given the limited observations made.protected area and the black circle shows the area that is currently in a sanctuary zone.

This Report	Depth	2000 Conservation Assessment Report (Meyers et al 2000)	Fish survey strata (e.g. Williams & de la Mare 1995; de la Mare et al 1998)	Impacts of bottom fishing (Welsford et al 2014)	Ecological Risk Assessment for fisheries (Fisher 2019)
1. Southern Shelf Inner	0-500 m	Southern Plateau Inner (Territorial Sea <500m, including shallow areas around HIMI)	Plateau	Geomorph – Central Plateau Seascape Category I	Shelf surrounding HIMI Inner Heard Plateau
2. Southern Shelf Outer	< 500 m	Southern Plateau Outer	Plateau Gunnari Ridge	Geomorph – Central Plateau Seascape Category I	Outer Heard Plateau
3. Northern Shelf	< 500 m	Discovery Bank Northern Plateau	Plateau	Geomorph – Central Plateau, Bank Top, Bank Slope Seascape Category I	Outer Heard Plateau Western Banks
4. Shell Bank	Mostly < 500 m with some parts to1000 m on east and south	Shell Bank	Shell Bank	Geomorph – Shell Bank Top, Bank Top, Bank Slope Seascape Category I	Shell Bank Complex
5. Western Trough & Banks	< 1000 m	Western Trough Aurora Bank Coral Bank Pike Bank	Banks	Geomorph – Plateau Outer, Bank Top, Bank Slope Seascape Category I	Western Trough Western Banks
6. South Canyons	500-1000m	South of HIMI Deeper portions of Territorial Sea	Deeper strata	Geomorph - Southern Slope, Plateau Outer Seascape Category I	Southern Upper Slope eastern part of Southern Eastern Trough
7. Eastern Trough South	500-1000m	Eastern Trough – southern part (separates known foraging areas)	Not surveyed	Geomorph – Plateau Outer Seascape Category I	Southern Eastern Trough
8. Eastern Trough	500-1000m	Eastern Trough – northern part	Not surveyed	Geomorph – Plateau Outer Seascape Category I	Northern Eastern Trough
9. Eastern Trough North	500-1000m	Northeastern Plateau	Not surveyed	Geomorph – Plateau Outer Seascape Category I	North Eastern Plateau
10. West	1000 – 2500 m	[new]	Not surveyed	Geomorph – Deep Slope Seascape Category IV	Lower Slope/Abyssal
11. South	1000 – 2500 m	[new]	Not surveyed	Geomorph – Deep Slope Seascape Category IV	Lower Slope/Abyssal
12. South-east	1000 – 2500 m	[new]	Not surveyed	Geomorph – Deep Slope Seascape Category IV	Lower Slope/Abyssal
13. Williams Ridge	1000 – 2500 m	[new]	Not surveyed	Geomorph – Bank Top, Bank Slope, Deep Slope Seascape Categories III, IV	Shell Bank Deep Shell Bank Complex Southern Eastern Trough Lower Slope/Abyssal
14. East	1000 – 2500 m	[new]	Not surveyed	Geomorph – Deep Slope Seascape Category IV	Lower Slope/Abyssal
15. West Deep	< 2500 m	[new]	Not surveyed	Geomorph – Abyssal Plain Seascape Category IV	Lower Slope/Abyssal
16. South Deep	< 2500 m	[new]	Not surveyed	Geomorph – Abyssal Plain Seascape Category IV	Lower Slope/Abyssal
17. South-east Deep	< 2500 m	[new]	Not surveyed	Geomorph – Abyssal Plain Seascape Category IV	Lower Slope/Abyssal
18. East Deep	< 2500 m	[new]	Not surveyed	Geomorph – Abyssal Plain Seascape Category IV	Lower Slope/Abyssal

9.3 Features of Assessment Zones

This section provides a summary of the distinctive features of each assessment zone, which condenses the physical and biological information presented in the previous sections of the report, plus includes additional summary statistics from the analyses in those sections. These statistical summaries are presented in Appendices 7, 8, and 9.

For each assessment zone the key features of the benthic environment provided are:

a) Bottom depth and slope
b) Spatial mean (and standard deviation) of summer temperature across the zone (value in each cell within a zone calculated from BRAN2020 data as the average temperature between October to March in a year and then averaged over the decade 1993-2002),
c) Spatial mean (and standard deviation) of the change in summer temperature between the decade 1993-2002 to 2013-2022, and
d) A west-east divide in benthic species with mixing in central localities.

For each assessment zone the key features of the surface environment[11] provided are:

a) Spatial mean (and standard deviation) of summer temperature across the zone for the decade 1993-2002 (October to March)
b) Change in summer temperature between the decade 1993-2002 to 2013-2022.
c) Spatial mean (and standard deviation) of chlorophyll a density (mg.m-^{2}) across the zone for the Spring (October-December) for the decade 2003-2012
d) Spatial mean (and standard deviation) of chlorophyll a density (mg.m-^{2}) across the zone for the Summer (January-December) for the decade 2003-2012
e) Change in spring chlorophyll a density (mg.m-^{2}) across the zone between the decade 1993-2002 to 2013-2022, and
f) Change in summer chlorophyll a density (mg.m-^{2}) across the zone between the decade 1993-2002 to 2013-2022.

For each assessment zone the key features of the mesopelagic environment[12] provided are:

a) Spatial mean (and standard deviation) of summer temperature across the zone for the decade 1993-2002
b) Change in summer temperature across the zone between the decades 1993-2002 and 2013-2022.

The new proposed zones are immediately distinguished by their greater depth, lower (interpolated) summer temperatures, the greater change in these temperatures between the decades of 1993-2002 and 2013-2022, and the lower summer chlorophyll a density. Additional attributes of the different zones are presented in the Appendices 7 - 9.

Southern Shelf Inner (SSI) Assessment Zone

The southern inner shelf surrounding HIMI contains all of the shallow water benthic environments in water depths shallower than 100 m, including high diversity, structurally complex communities and the second highest number of site-restricted taxa. The greater part of this area is less than 300 m deep with around 20% between 300 and 500 m depth. The southern and western margins of this area are influenced by the pelagic assemblages from the deeper water environments. Nevertheless, the greater part of the area is enriched by iron with a spring bloom sustained into the summer, although slightly diminished likely because of stratification. The zooplankton and fish assemblage is considered to be shelf fauna (Fish RCP 5 & 7), with krill and large zooplankton prevalent and icefish and large shelf myctophids as important components of the fish fauna. This area, particularly the south-east, is important for nearshore foraging by flying birds and macaroni penguins, especially during the reproductive phase in early summer. Summer temperatures of water at the bottom have increased to average over 2°C in the recent decade for over 60% of the area (from less than 3%).

establishment-national-representative-system-marine-protected-areas/

[11] The surface environment is defined as the epipelagic layer from 0-100m

Southern Shelf Outer (SSO) Assessment Zone

The outer component of the southern shelf has 40% at depths shallower than 300 m and the remainder down to 500 m. This area includes Gunnari Ridge where mackerel icefish aggregate in large densities compared to the rest of the shelf (de la Mare et al 1998). The benthic assemblage at Gunnari Ridge is considered unique with a population of the endemic solitary scleractinian Flabellum, spp. The western and eastern margins respectively are influenced by the productive Western and Eastern Troughs respectively. As for the Southern Shelf, the greater part of the area is enriched by iron with a spring bloom sustained into the summer, although slightly diminished likely because of stratification. The zooplankton and fish assemblage is dominated by shelf fauna, including icefish and large shelf myctophids (Fish RCP 5 & 7) but with some influence of a Northern Shelf fish fauna (Fish RCP 3). This area, particularly around Gunnari Ridge, is very important for black-browed albatross and fur seals when their foraging range is constrained by the need to return to feed their offspring during the early summer. While the epipelagic zone has had about 40% of the area experiencing average summer temperatures over 2°C in the past, the bottom water and midwater did not have any areas with summer averages above 2°C. In the most recent decade, 90% of the bottom area and 60% of the midwater area has average summer temperatures above 2°C.

Northern Shelf (NS) Assessment Zone

Most of the Northern Shelf lies between 300 and 500 m depth. The area shallower than 300 m is Discovery Bank. The Northern Shelf has slightly higher temperatures than the Southern Shelf, probably because of the influence of the currents from the northwest and less influence from the Eastern Trough. The greater part of the area is enriched by iron with a spring bloom sustained into the summer, and slightly higher average densities of chlorophyll a than the Southern Shelf. The demersal fish fauna differs from the Southern Shelf and has an increasing prevalence of species from depths between 500 and 1,000 m (Fish RCP 3 and, to a lesser extent, Fish RCP 4). This area was visited by king penguins and fur seals in the early summer but was not important during that period. In the 1990s, almost 90% of the surface waters of this area had average summer temperatures greater than 2°C. This coverage was 100% in the most recent decade. The bottom area averaging greater than 2°C changed from zero to greater than 70% in the recent decade.

Shell Bank (SB) Assessment Zone

Shell Bank is separated from the HIMI shelf by the Eastern Trough and is surrounded by northward flowing of the trough and to the east of the plateau but mirroring the temperature profile and productivity of the southern Eastern Trough - cooler at the surface with warmer temperatures below. About 30% of this area is shallower than 300 m, half between 300 and 500 m in depth, and the remainder falling away rapidly into deeper water to the east, giving rise to the area of greater slope. 12% of this zone has slope >10%, much more than any other zone at this depth. The benthic assemblage is considered unique within the HIMI EEZ, including many bryozoans, the largest number of site-restricted taxa as well as many common taxa from this depth range. Shell Bank has had slightly lower densities of chlorophyll *a* in the past but, compared to the shelf areas with little change, has had a 23% reduction in the average total spring chlorophyll a in the last 20 years. Shell Bank has a demersal fish fauna different to other areas (Fish RCP6). Here, the local population of mackerel icefish is considered to be separate from the HIMI shelf. Warming of Shell Bank has been similar to the HIMI shelf, although warming of the bottom water has not been as great as the Inner Shelf areas. Shell Bank had a small fraction of foraging time of king penguins, fur seals and black-browed albatross.

Western Trough & Banks (WTB) Assessment Zone

This area comprises the Western Trough with water between 500 and 1,000 m deep along with 17% of the area comprising the western banks, Aurora, Coral, and Pike characterised by their high biomass, structurally complex benthic communities, and a reported west-east divide in benthic species. Four percent of the area has a slope >10%. It is influenced by flows of water from the north down the western margin of the northern Kerguelen Plateau and has chlorophyll *a* densities similar to the shelf areas. These waters have zooplankton and myctophid fish typical of off-shelf pelagic fauna. The demersal fish assemblage differs from other areas in this depth range with this area being very important to Fish RCP 1 (deep water species) and Fish RCP 4 (shallower water species). This area, along with the West Zone (1,000 m – 2,500 m deep) is considered to be the important spawning area for Patagonian toothfish because these are the areas most likely for retention of larvae on the plateau. In terms of summer predation, this area was utilised by Antarctic fur seals and black-browed albatross. The surface waters were above 2°C in the 1990s and are exceeding 3°C for much of the area in the recent decade, indicating a strong southerly warming in the region. Deeper waters have been cooler than the surface layer but are warming as well, with the area of bottom water greater than 2°C increasing from 13% of the area to 56% of the area from the 1990s to the recent decade.

South Canyons (SC) Assessment Zone

The South Canyons is an area between 500 and 1,000 m deep with significant canyons and complex currents and eddies as water moves from the main currents to the south of Heard Island on to the eastern part of the Southern Shelf. It has the zone with the highest percentage of area with slope >10% at this depth (5%). It is an area of importance to penguins, seals and flying birds. Chlorophyll *a* densities in this area are elevated above those of the pelagic waters to the south, although not as high as on the shelf. Zooplankton and mesopelagic fish are a combination of shelf and pelagic fauna, while it is an important area for the demersal fish assemblage RCP 2 and, to a lesser extent, RCP 6. The South Canyons area has been exposed to cooler waters in the past (negligible area with average temperatures greater than 2°C in the 1990s), but the whole area at all depths experienced average summer temperatures greater than 2°C in the recent decade.

Eastern Trough South (ETS) Assessment Zone

The southern end of the Eastern Trough is different to Eastern Trough and the South Canyons with cooler summer average temperature in the surface waters but similar bottom and mesopelagic temperatures. Chlorophyll *a* densities are similar to the South Canyons but more elevated in places in spring. It is the most important area for demersal fish assemblage RCP 2 with some relationship to the shelf through RCP 6. The zooplankton and mesopelagic fish fauna are typical for pelagic areas. This area is of importance to king penguins in early summer and also utilised by fur seals, macaroni penguins and, to a much lesser extent, black browed albatross. The surface waters of this area have experienced the greatest warming since the 1990s of all areas and depths with the cooler surface waters (all below 2°C) now elevated to average summer temperatures above 2°C in 90% of the area. Bottom water has also changed from zero to 100% of the area with average summer temperatures above 2°C. The total spring chlorophyll a in this area has declined over two decades by approximately 10%.

Eastern Trough (ET) Assessment Zone

The Eastern Trough is mostly deeper than 500 m and shallower than 1,000 m. It is an important pathway for northward moving water from the main currents around the south of Heard Island. Of all the areas around HIMI it has the highest chlorophyll *a* densities in spring and summer combined, benefitting from the iron-enrichment on the plateau. Demersal fish fauna are a mix of shelf and deep water fauna, with importance to RCP 4. King penguins, fur seals and black-browed albatross visit this area. The whole of the Eastern Trough has warmed from a whole average summer temperature below 2°C in the 1990s to now all being above 2°C in the recent decade. The total spring chlorophyll a in this area has declined over two decades by approximately 20%.

Eastern Trough North (ETN) Assessment Zone

This area to the north of the main Eastern Trough is very similar in characteristics to the Eastern Trough with depths 500-1,000 m. The notable differences that identify it as a unique zone include; surface water temperatures are similar to the Western Trough and Banks, indicating a strong influence of water flowing from the north of the plateau into the area. While the area of surface waters averaging more than 2°C in the 1990s covered approximately 55% of the area, it is now almost 100%. The average summer temperatures of deeper waters were less than 2°C in the 1990s but now cover more than 95% of the area. Average spring density of chlorophyll *a* has the greatest negative anomaly over two decades than any other area, resulting in a decline in total chlorophyll a by 25%. The demersal fish assemblage is similar to the Eastern Trough (RCP 4) except that it has a greater representation of deeper water species from fish RCP 1. This area has a large number of pinnacles emerging from the deep water, increasing the area covered by slopes greater than 10 degrees compared to other areas of the Eastern Trough. Sampled benthic macrofauna were relatively sparse but with many restricted to that area.

West (W) Assessment Zone

The West area is similar to the Western Trough, influenced by currents from the north and the same patterns of warming since the 1990s, except it has slightly cooler bottom water because of its depth (1,000 - 2,500m) and has marginally lower chlorophyll *a* densities in summer. Demersal fish RCP 1 is the dominant group here. This area is an important area for mature toothfish to spawn because of the high probability of the resulting fish larvae being retained in the HIMI EEZ. This area was visited in early summer by fur seals and black-browed albatrosses and is predicted to be an important foraging area for HIMI land-based predators. Five percent of the area is of slope > 10%.

South (S) Assessment Zone

The South area is the deeper extension of the Southern Canyons into depths between 1,000 to 2,500 m. Average bottom temperatures in summer are slightly cooler than for the Southern Canyons. This area is important for demersal fish RCP 2. It is influenced by the pelagic system to the west but surface waters are approximately 1°C cooler than the West. The South area is important for foraging by king and macaroni penguins and visited by fur seals and black-browed albatross. Summer temperatures of water at the bottom have increased to average over 2°C in the recent decade for over 25% of the area (from less than 1%) and for surface waters to over 40% of the area. As for all areas in this depth range, there is a substantial area of increased bottom slope providing for heterogeneity of substrata for deep water benthic fauna. chlorophyll *a* densities are the lowest of the HIMI area along with the South-east and Williams Ridge zones.

South-east (SE) Assessment Zone

The South-east area is the deeper extension of the Eastern Trough South area from 1,000 to 2,500m. It has similar attributes to the South except the surface waters are marginally cooler and this has the greatest importance for use by king penguins and for macaroni penguins after the guard stage of chick rearing. It is predicted to be an important area for foraging by other land-based predators breeding on Heard Island.

Williams Ridge (WR) Assessment Zone

Williams Ridges, a south-eastern geological extension of Shell Bank between the depths of 1,000 and 2,500m, has a large degree of substratum heterogeneity indicated by the largest area of slope of any zone - 10% of the area has slopes >10%, and a string of unsurveyed seamounts peaking in depths less than 1,000 m. It has similar surface and bottom temperatures as the South-east assessment zone and experiences warming in the same manner as the South assessment zone.

East (E) Assessment Zone

The East area (1,000 - 2,500 m) includes the steep eastern margin of the plateau and is influenced by the meeting of flows of the northern and southern branches of the Polar Front. At 18% it has the largest proportion of the area with slope >10% of any zone, although in absolute terms this area is only about 80% of the area for Williams Ridge. Its surface temperature is greater than for the southern areas of this depth range while the deeper water has similar temperatures to the South-east. Densities of chlorophyll a are similar to the shelf but not as elevated as in the north of Eastern Trough. Demersal fish in this area are dominated by RCP 1. This area is not expected to be important to foraging of HIMI land-based predators. Temperatures in this area have increased since the 1990s with almost 100% of the area experiencing average summer temperatures above 2°C in the recent decade.

Deep Zones – West Deep (WD), South Deep (SD), South-east Deep (SED), East Deep (ED) Assessment Zones

These deep-water zones are the areas deeper than 2,500 m. Except for South-east Deep (6%) areas of slope >10% are typically small, although this conclusion needs to be tempered by the lack of detailed acoustic surveying at depth. Chlorophyll *a* densities are very similar at low levels typical of the 'high nutrient low chlorophyll' environment of the Southern Ocean. Nevertheless, these areas differ in their temperature regimes, likely influencing the types of biota in the areas. The South-east Deep zone has a colder surface layer than the other deep zones, at approximately 0.5°C, compared to over 2°C in the West Deep zone. The mesopelagic layer shows a similar pattern, although the South-east Deep temperature is around 1.5°C. A lack of scientific sampling and lack of availability of fisheries data reduces the capacity to further characterise these deeper areas.

9.4 Representation of key ecological metrics in each Assessment Zone

Since the 2000 Conservation Assessment Report, scientific research programs (including direct observations of pelagic biota and the foraging of land-based predators) combined with satellite and oceanographic monitoring data, and improved ocean models have provided new knowledge that considerably expands our understanding of HIMI. Much of the data available on the distributions of demersal (bottom) species (fish, invertebrates) comes from fisheries and benthic sampling programs, related to demersal fisheries and using trawl vessels in water depths less than 1,200m. However, reports and data from these activities, unless already published in the public domain, were not made available for this report.

The longline fishery was reported to fish throughout unsurveyed areas of the EEZ at depths down to 2,000 m (Williams et al. 2014), outside of the depth range of existing samples. Additionally benthic data collected at HIMI are generally unresolved at species level. Nevertheless, this report presents the known spatial differences in the ecology of the region and the threats that climate change may have on these areas, thereby enabling us to consider requirements for conserving and maximising resilience of the unique marine biodiversity in the HIMI EEZ.

Where data on benthic biodiversity are unavailable for this report, we have relied on global Antarctic and subantarctic biogeographies. These demonstrate the high levels of endemism in Antarctic waters that make this area a hotspot of modern species formation (Hedgepeth 1969, Munilla and Soler Membreves 2009; Rabosky et al. 2018; O'Hara et al. 2020), with the subantarctic islands often distinct from the Antarctic fauna (Munilla and Soler Membreves 2009; Ameziane et al. 2011) and likely to have high conservation value because of their extreme isolation and unique habitats with high probability of endemic species (Fabri-Ruiz et al. 2020). The benthic fauna of the Kerguelen Plateau is reported to show closest affinity with that off southern South America (Griffiths et al. 2009; Moreau et al. 2017).

Latitudinal biogeographic trends on the Kerguelen Plateau are likely to have been impacted by the changing position of the Polar Front over time, however, clear latitudinal trends in bathyal fish and invertebrate assemblages were detected from commercial longline and survey data in the Sandwich Islands over a narrower latitudinal range (Hollyman et al. 2022; Hogg et al. 2021) and one fish assemblage (Region of Common Profile 1) had a southern limit within the Australian EEZ (Hill et al. 2017). Global biogeographies tend to split the Kerguelen Plateau into north and south (Douglass et al 2014; Fabri-Ruiz et al 2020) consistent with the geological differentiation at Fawn Trough.

Antarctic benthic fauna is frequently characterised by eurybathy with individual species having wide depth ranges, however species assemblages do change with depth for fish shallower than 1,000 m (Hill et al. 2017), while 1,000m depth (Fabri-Ruiz et al 2020; Hogg et al. 2021; McQuaid et al. 2023) and 3,000 m depth (Douglass et al. 2014; Hogg et al. 2021) have been found to be important biogeographic zones of change for benthic invertebrates in global Antarctic and subantarctic studies.

Knowledge of benthic fauna in the HIMI EEZ is limited by sampling effort in this remote area and the lack of alpha taxonomy on the samples that have been collected. Nineteen species were identified as likely endemics from samples collected to guide earlier conservation planning. Samples were sorted to operational taxonomic unit level only and several diverse taxonomic groups (e.g. amphipods, bryozoans, molluscs, pycnogonids) remain largely unsorted, so additional endemics will not have been identified. A west-east divide in benthic species was reported by Hibberd et al. (2014) with mixing in central areas.

The importance of topography for benthic macrofauna is well established. Large attached benthic creatures need hard substrate to attach to, which is more likely to be exposed where the angle of incline is higher and mobile substrate cannot cover the bedrock. At the larger scale, geomorphic features like canyons, trenches, ridges, seamounts and shelf breaks contain more high incline slopes and have distinct habitats (McQuaid et al. 2023), but macrofaunal cover is typically patchily distributed within these features and associated with local inclines (Georgian et al. 2019; Williams et al. 2020). In this assessment we use the angle of incline directly and in particular define inclines greater than 10% as more likely to contain exposed substrate and provide suitable attachment for benthic macrofauna than surrounding areas, while noting the lack of detailed bathymetry especially for deeper waters.

Following the classification of the entire EEZ into 18 discrete assessment zones based on their physical and biological attributes, we have undertaken an assessment of the adequacy and representativeness of The Reserve in conserving each of the zones, as well as the component attributes.

A range of ecological metrics of the physical and ecological components of each assessment zone are measured to assess adequacy and representativeness. A brief description of the key metrics used in the analysis are:

Key Ecological Metric	Important physical or biological features
Area	The amount of area representing the combined features of depth, temperature and oceanography of that zone.
Water Depth: 0-300 m	Waters to 300 m deep include the areas where light penetrates (the photic/ epipelagic zone) as well as the depth at which cooler winter water resides.
Water Depth: 300-500 m	Water depths of 300-500 m often include the shelf break and also where surface oceanography interacts with the mesopelagic environment. Zooplankton and mesopelagic fish in the top 300 m migrate between these two layers.
Bottom slope greater than 10 degrees	Greater slope indicates greater relief and likelihood of areas of exposed rock suitable for macrofaunal attachment
Demersal fish assemblages	The different demersal fish assemblages represent different demersal (benthic) environments.
Chlorophyll *a* density a	Chlorophyll *a* density is a commonly used surrogate for primary productivity. Higher productivity is indicative of higher iron supply that results in phytoplankton assemblages being dominated by larger diatoms, compared to areas of lower productivity dominated by smaller phytoplankton. These result in different energy pathways through food webs and contribute to the differentiation of benthic communities.
Chlorophyll *a* Total Abundance	Chlorophyll *a* abundance is an indicator of phytoplankton abundance and biomass and is used as a measure of trophic status
Predator foraging intensity	Locations of greatest attention by apex predators (birds, marine mammals) from tracking data indicates areas of greatest importance to those predators.

The total representation of each ecological metric in each Assessment Zone are presented in Table 4. For each assessment zone, Table 5 presents the percentage of each ecological metric currently protected in the existing marine reserve.

9.5 Environmental change in each Assessment Zone

Climate change is impacting the HIMI EEZ (Section 6.5.1). Here we use an index of warming to indicate how different assessment zones have been changing. This index of warming is calculated as the area in each zone experiencing temperatures greater than 2°C. Table 6 shows how the different biologically-relevant depth layers are warming. It shows the areal percentage of each zone with temperatures greater than 2°C for the two decadal periods analysed above, 1993-2002 and 2013-2022. It highlights that substantial changes are being experienced in the shallower layers.

Table 4: Representation of each ecological metric (rows) in each assessment zone (AZ) (columns). Colour codes of columns represent different depth strata: 0-500m (Green), 500-1,000m (light blue), 1,000-2,500m (torquise), deeper than 2,500m (grey). Demersal fish importance and predator foraging is the magnitude of an attribute in each zone relative to the zone with the maximum magnitude[14]. Zones 1-9 mostly correspond to zones from previous assessments[14]. Zone acronyms given in headings pp 104-107.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
		SSI	SSO	NS	SB	WTB	SC	ETS	ET	ETN	W	S	SE	WR	E	WD	SD	SED	ED
Area	Zone	14,902	17,575	10,160	6,202	13,975	5,452	10,997	5,793	8,370	12,698	55,336	49,511	14,640	6,854	61,506	83,553	6,935	32,481
	Reserve	9,119	5,582	5,209	4,110	5,178	1,679	0	1,827	2,595	1,368	1,722	0	21	5,231	13	0	0	26,966
Proportion of AZ with water depth	<300 m	0.80	0.41	0.10	0.33	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	300-500 m	0.19	0.59	0.79	0.42	0.07	0.01	0.00	0.01	0.08	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Area within AZ with **Slope > 10 degrees**		116	7	52	738	592	255	88	132	217	575	483	476	1,463	1,203	65	292	415	456
Mean **Temperature - epipelagic (near surface)**	Summer (1993-2002)	2.05	1.94	2.25	1.62	2.28	1.68	1.48	1.71	2.02	2.19	1.37	1.04	1.04	1.86	2.21	1.28	0.36	1.70
	Summer anomaly (2013-2022)	0.54	0.61	0.53	0.54	0.53	0.61	0.66	0.60	0.45	0.54	0.59	0.54	0.44	0.44	0.51	0.49	0.33	0.43
Mean **Temperature - mesopelagic (mid water)**	Summer (1993-2002)	1.89	1.74	1.70	1.85	1.86	1.86	1.82	1.81	1.81	2.05	1.92	1.99	1.95	1.95	2.29	2.13	1.61	2.00
	2013-2022 Anomaly	0.23	0.37	0.39	0.36	0.23	0.33	0.35	0.36	0.39	0.16	0.33	0.32	0.29	0.27	0.04	0.15	0.19	0.19
Mean **Temperature - bottom**	Summer (1993-2002)	1.52	1.59	1.68	1.76	1.76	1.78	1.79	1.80	1.80	1.55	1.66	1.60	1.65	1.46	0.28	0.58	0.55	0.72
	2013-2022 Anomaly	0.54	0.50	0.40	0.35	0.26	0.36	0.32	0.38	0.39	0.12	0.05	0.05	0.18	0.14	0.00	-0.01	0.01	0.12
Demersal Fish - relative importance of AZ across all zones	RCP 1	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00	0.23									
	RCP 2	0.00	0.00	0.00	0.02	0.00	0.33	1.00	0.06	0.00									
	RCP 3	0.04	0.74	1.00	0.02	0.02	0.03	0.03	0.05	0.02									
	RCP 4	0.00	0.01	0.15	0.00	0.68	0.00	0.00	0.48	1.00									
	RCP 5	0.87	1.00	0.15	0.08	0.00	0.05	0.07	0.01	0.00									
	RCP 6	0.08	1.00	0.01	0.64	0.09	0.15	0.18	0.07	0.06									
	RCP 7	1.00	0.77	0.00	0.00	0.03	0.00	0.00	0.00	0.00									
Chlorophyll *a* Density (mg.m^{-2})	Spring (2003-2012)	29.2	30.1	34.8	25.8	28.6	19.7	22.5	40.2	42.7	23.7	14.7	14.3	13.3	28.3	17.8	16.6	13.5	21.7
	Summer (2003-2012)	24.8	26.0	31.0	10.2	26.7	12.8	10.8	18.5	20.6	17.3	8.9	7.8	7.3	11.6	11.3	8.9	7.7	9.0
	Spring prop change to 2013-2022	-1.3	0.6	-1.8	-5.9	-0.2	-0.5	-2.7	-8.1	-10.6	0.2	0.2	-0.6	-0.9	-6.3	1.1	-0.5	-1.2	-1.7
	Summer prop change to 2013-2022	0.0	1.1	2.1	-0.8	0.3	0.4	-0.9	-2.6	-2.6	0.9	0.0	0.2	0.1	-1.1	1.9	0.6	1.3	-0.3
Chlorophyll *a* Total Abundance (tonnes)	Spring (2003-2012)	433	529	354	160	400	108	247	233	358	301	811	707	195	194	1,097	1,386	93	705
	Summer (2003-2012)	368	457	315	63	373	70	118	107	172	219	493	386	107	79	694	740	53	293
	Spring prop change to 2013-2022	0.05	-0.02	0.05	0.23	0.01	0.03	0.12	0.20	0.25	-0.01	-0.01	0.04	0.06	0.22	-0.06	0.03	0.09	0.08
	Summer prop change to 2013-2022	0.00	-0.04	-0.07	0.08	-0.01	-0.03	0.08	0.14	0.13	-0.05	0.00	-0.03	-0.02	0.09	-0.16	-0.07	-0.16	0.04
Predator foraging - relative importance of AZ across all zones	Macaroni penguins	0.16	0.01	0.00	0.00	0.00	0.24	0.09	0.00	0.00	0.00	0.52	1.00	0.09	0.00	0.00	0.04	0.06	0.01
	King penguins	0.15	0.03	0.01	0.03	0.00	0.23	0.39	0.01	0.01	0.00	0.44	1.00	0.11	0.00	0.02	0.02	0.00	0.04
	Fur Seals	0.38	1.00	0.01	0.05	0.04	0.15	0.15	0.05	0.00	0.02	0.14	0.10	0.02	0.01	0.01	0.03	0.00	0.05
	Black-browed albatross	1.00	0.83	0.00	0.04	0.03	0.35	0.02	0.01	0.01	0.05	0.12	0.00	0.00	0.00	0.01	0.01	0.00	0.02

12 The mesopelagic environment is defined as the layer between 300 - 800m

13 Demersal fish Regions of Common Profile (RCP) are not used for zones deeper than 1000m because the RCPs were only applied to 1200m rendering the values incomplete for the deeper zones.

Table 5: Within each assessment zone (columns), percentage of each ecological attribute (rows) within the existing Reserve. Whole EEZ is the percentage of the ecological metric inside the existing reserve across the EEZ. Colour codes of columns represent different depth strata: 0-500 m (green), 500-1,000 m (light blue), 1,000-2,500 m (grey), deeper than 2,500 m (torquise). Zone acronyms given in headings pp 104-107.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	Whole EEZ
		SSI	SSO	NS	SB	WTB	SC	ETS	ET	ETN	W	S	SE	WR	E	WD	SD	SED	ED	
Reserve		61	32	51	66	37	31	0	32	31	11	3	0	0	76	0	0	0	83	
Water depth	<300 m	66	33	100	98	74														61
	300-500 m	38	31	43	62	78	64	0	73	98				0						42
Slope > 10 degrees		87	0	67	56	49	38	0	44	61	31	8	0	0	80	0	0	0	51	33
Demersal Fish	RCP 1				100	18	100			1										22
	RCP 2				25	40	18	0	22											5
	RCP 3	8	63	46	32	86	63	0	17	100										51
	RCP 4	100	0	25	86	21	100		27	20										22
	RCP 5	23	55	100	43	100	63	0	72											44
	RCP 6	82	0	100	51	88	0	0	72	100										27
	RCP 7	86	26			100														61
Chlorophyll *a*	Spring	63	33	48	73	35	35	0	30	28	12	4	0	0	69	0	0	0	90	23
	Summer	60	37	49	69	33	37	0	24	21	13	4	0	0	72	0	0	0	86	23
Predator foraging	Macaroni penguins	98	0		0		29	0				14	0	0			0	0	0	13
	King penguins	90	11	0	4		8	0	5	2		4	0	0	99	0	0	0	85	9
	Fur Seals	75	11	13	65	23	18	0	33	100	4	14	0	2	100	0	0	0	97	25
	Black-browed albatross	82	3	50	91	63	30	0	21	61	34	53	0	0	100	0	0		100	89

Table 6: Proportion of each assessment zone (columns) with decadal mean summer temperature above 2°C for each biologically-important depth layer - epipelagic (0-100 m), mesopelagic (300-800 m) and the bottom layer (rows). Decades are 1993-2002 and 2013-2022. Colour codes of columns represent different depth strata: 0-500 m (green), 500-1,000 m (light blue), 1,000-2,500 m (grey), deeper than 2,500 m (torquise). Zone acronyms given in headings pp 104-107.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	SSI	SSO	NS	SB	WTB	SC	ETS	ET	ETN	W	S	SE	WR	E	WD	SD	SED	ED
Epipelagic																		
1993-2002	0.68	0.43	0.88	0.05	0.99	0.01	0.00	0.00	0.55	0.74	0.00	0.00	0.00	0.30	0.84	0.00	0.00	0.29
2013-2022	0.99	1.00	1.00	0.84	1.00	1.00	0.89	1.00	1.00	1.00	0.42	0.06	0.04	0.93	1.00	0.51	0.00	0.62
Mesopelagic																		
1993-2002	0.04	0.00	0.00	0.00	0.15	0.02	0.00	0.00	0.00	0.76	0.19	0.51	0.25	0.10	1.00	0.80	0.03	0.40
2013-2022	0.20	0.60	0.75	0.74	0.83	1.00	1.00	1.00	0.96	1.00	1.00	0.98	0.98	1.00	1.00	1.00	0.24	1.00
Bottom																		
1993-2002	0.02	0.00	0.00	0.04	0.10	0.01	0.00	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00
2013-2022	0.62	0.91	0.72	0.85	0.56	0.99	1.00	1.00	0.97	0.14	0.26	0.21	0.56	0.23	0.00	0.00	0.00	0.00

9.6 How well is the current marine reserve protecting the environment?

An analysis of the representation (percentage of each assessment zone) of each ecological metric in The Reserve shows that the existing Reserve provides reasonable coverage of benthic habitats and demersal fish assemblages shallower than 500 m, except for William Ridge which has unique attributes in the context of the NRSMPA.

Benthic areas in the depth range 500 – 1,000 m are generally well represented to the west and east of the HIMI shelf but consideration of the complex canyon areas to the south-east of Heard Island and the unsurveyed string of seamounts on Williams Ridge is needed. In addition, areas deeper than 1000 m are poorly represented in The Reserve, except to the East of Shell Bank. The distribution of demersal fish assemblages indicates the poor representation of deep demersal assemblages in The Reserve. Notably, the benthic areas likely to be most important, areas with reef or complex habitat indicated by greater bottom slopes, cover only small areas of the HIMI EEZ and are patchy in their distribution, making it difficult to identify exactly where the most suitable areas would be to satisfy CAR principles, especially as many smaller features will likely not have been identified by existing acoustic mapping. Williams Ridge and the East Zones have the largest areas of slope >10% in the EEZ, with Shell Bank, South Canyons the West and Southeast Deep also important. The reported west-east divide in benthic species suggests the need for improved representation of deeper areas to the west. Differences in oceanography indicate that areas to the west, south and south-east, including Williams Ridge, need to be considered for representation.

While the current protection levels of the shallower areas has provided good protection to date, the HIMI Shelf has been experiencing rapid warming, and therefore it would be prudent to consider further expansion of the marine reserve in this area to maintain the resilience of biota under increasing impacts from climate change.

The Reserve does not include the most important areas for sustaining pelagic food webs. Areas found to be important during the summer breeding season are Gunnari Ridge on the HIMI Shelf and the area of the HIMI EEZ to the east and south-east of Heard Island, including around the southern canyons. The Western Trough and deeper water in the west and south are also important foraging areas for Heard Island residents over the year.

The Reserve does not encompass areas likely to be important for the maintenance of target species, including spawning grounds of Patagonian toothfish in the Western Trough and deeper water to the west, and the area (Gunnari Ridge) of greatest importance to cold-adapted mackerel icefish, which is threatened by increased warming on the shelf.

9.6 Assessment of comprehensiveness, adequacy and representativeness (CAR)

An assessment of the comprehensiveness, adequacy and representativeness of The Reserve system has been undertaken for each assessment zone, including its key conservation values; its current reservation status; existing and potential future threats; and other conservation management measures that may be in place.

The HIMI EEZ is different to all other Australian marine provinces and is unique in Australia for components with biogeographic affinities of much of its benthic fauna to the waters off South America. Benthic and pelagic regionalisations for the broader Southern Ocean have often placed the HIMI EEZ within a provincial type associated with the northern Kerguelen Plateau as a whole. However, large-scale circumpolar classifications focus on identifying regional differences, often missing heterogeneity at finer scales (Grant et al 2006).

The deeper waters of the South Kerguelen Plateau are distinguished from the northern Kerguelen Province for one well-studied group, the echinoids, showing association with other similar depths off South America and the Campbell Plateau. Further latitudinal differentiation may be constrained by the lack of species-level identification for most HIMI shelf benthic fauna and the general lack of data at depth.

This report clearly differentiates the physical settings of the HIMI EEZ from the Kerguelen Islands and how the respective ecologies of the areas differ. Confirmation of these differences have been provided in a more recent ecoregionalisation for marine mammals and birds (Reisinger et al 2022). Altogether the evidence shows that the HIMI EEZ is unique in Australian waters and in the Southern Ocean.

10.0 Adequacy of the existing Commonwealth Marine Reserve

The management objectives for The Reserve are:

- protect conservation values of Heard Island and McDonald Islands (HIMI), the territorial sea and the adjacent EEZ including:
- the World Heritage and cultural values of the HIMI Territory
- the unique features of the benthic and pelagic environments
- representative portions of the different marine habitat types
- marine areas used by land-based marine predators for local foraging activities.
- provide an effective conservation framework which will contribute to the integrated and ecologically sustainable management of the HIMI region as a whole.
- provide a scientific reference area for the study of ecosystem function within the HIMI region.
- add representative examples of the HIMI EEZ to the National Representative System of Marine Protected Areas.

The assessment zones provide the spatial division of the HIMI region into different biophysical settings. The combined assessment of ecological metrics of the assessment zones (described in Tables 4 and 5) identified six Key Conservation Areas relevant for protection. The Reserve provides some representation of most of these habitats but is inadequate to protect all the values of the region.

To satisfy the design principles for the NRSMPA and the need for improved representation of key attributes along with including areas to enhance resilience of subantarctic species, requires additional areas be included in The Reserve.

Four important issues need to be considered in a new reserve design:

1. The shelf area shallower than 300 m is in need of enhanced protection to maximise the resilience of cold-adapted species, whether pelagic or benthic, in the face of climate change.
2. There is a need to consider separately the pelagic and benthic (demersal) environments. The proposed locations of additional benthic areas for protection may also have important for protection of the pelagic realm. Additional areas for pelagic-only protection have been identified, particularly for the important summer breeding period.
3. In order to provide adequate protection, better replication of areas is needed along with ensuring that areas are of sufficient size with suitable connectivity to function ecologically. Protection of whole features is desirable for the NRSMPA. These aims, combined with uncertainty on the distribution of benthic organisms relative to these features, requires inclusion of areas to the west, south and Williams Ridge for further protection.
4. Future-proofing reserve design needs to consider "upstream effects" on the ecology of benthic and pelagic biota and the impacts on critical times in the life cycles of organisms. While these are relatively straightforward to consider for benthic and demersal species, adequacy for achieving conservation objectives for mobile marine predators can be complex. For example, there has been a broad uptake of a global target of 30% spatial coverage for marine protection following the Global Deal for Nature (Dinerstein et al. 2019) and the Kunming-Montreal Global Biodiversity Framework (CBD 2022). In terms of maintaining prey species for higher trophic levels, a similar order of protection has also been advocated as a conservation target for the minimum level of fish stocks that are important prey for seabirds; the so-called 'one third for the birds' advocated by Cury et al. (2011). However, in CCAMLR, the management of fisheries for prey species (Antarctic krill, mackerel icefish), has 75% escapement as the established level to meet the requirements of predators. Given the nature of marine systems, specifying a spatial scale of protection that is adequate to provide the required level of prey-resource protection presents a considerable challenge. With most of these being listed species under the EPBC Act a precautionary approach may require a higher level of spatial protection.

10.1 Key Conservation Areas requiring protection

Taking into account the above four principles the following additional conservation areas are required to be represented to The Reserve to achieve a CAR reserve system for HIMI:

10.1.1 Key Conservation Area 1: HIMI Shelf

The HIMI Shelf has a range of complex benthic habitats and productive pelagic areas in the depth range of 0-500 m. This area is unique globally with only a few other areas of subantarctic shelf anywhere. Of concern are for waters shallower than 300m, which are warming, potentially threatening cold-adapted shelf species. The shelf shallower than 300 m includes areas of high importance to foraging predators during the critical reproductive period on HIMI, particularly on Gunnari Ridge, which is outside of the current reserve (Figure 34). It is also an important area for mackerel icefish and shelf fauna typical of cooler waters in the Southern Ocean. Inclusion of all of this shelf area will provide the greatest opportunity for shelf biota and food webs to adapt to climate change. The inclusion of this key conservation area in The Reserve would include a further 2% of the EEZ.

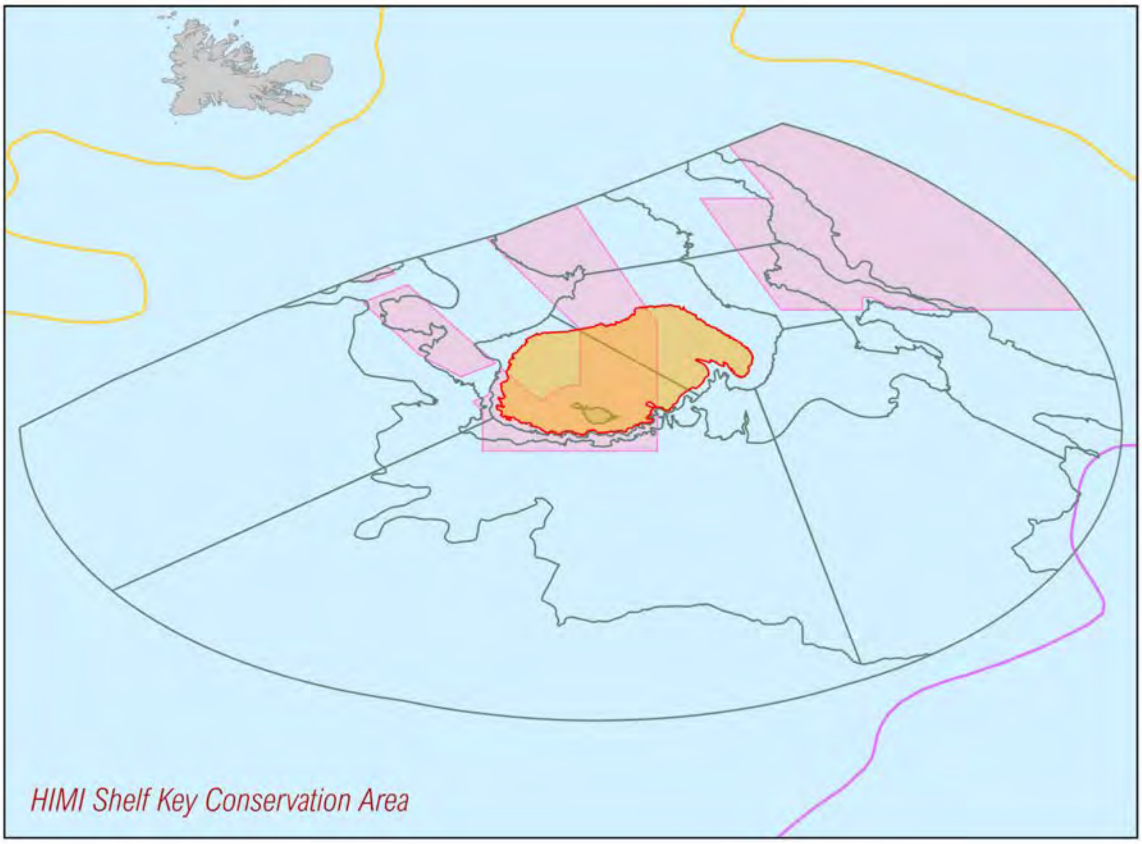


Figure 34: Key Conservation Area 1: HIMI Shelf shallower than 300 m

10.1.2 Key Conservation Area 2: Shell Bank and Williams Ridge Complex

Shell Bank and Williams Ridge form complex topography over a large depth range in a unique confluence of the cooler Fawn Trough Current and the warmer south-eastward moving Polar Front. Williams Ridge includes unsurveyed seamounts, complex deep-sea topography and oceanography unique in the HIMI EEZ, and is an important area for predator foraging. Williams Ridge has the largest area of slopes >10% in the HIMI EEZ reinforcing its likely value for benthic biodiversity. While Shell Bank is included in the current reserve, the complex as a whole would extend the southern boundary of the existing eastern section of the marine reserve to include parts of the Eastern Trough, William's Ridge, South-east and South-east Deep Assessment Zones (see Figure 35). The inclusion of Williams Ridge and associated deep-water areas in The Reserve would include a further 8.5% of the EEZ.

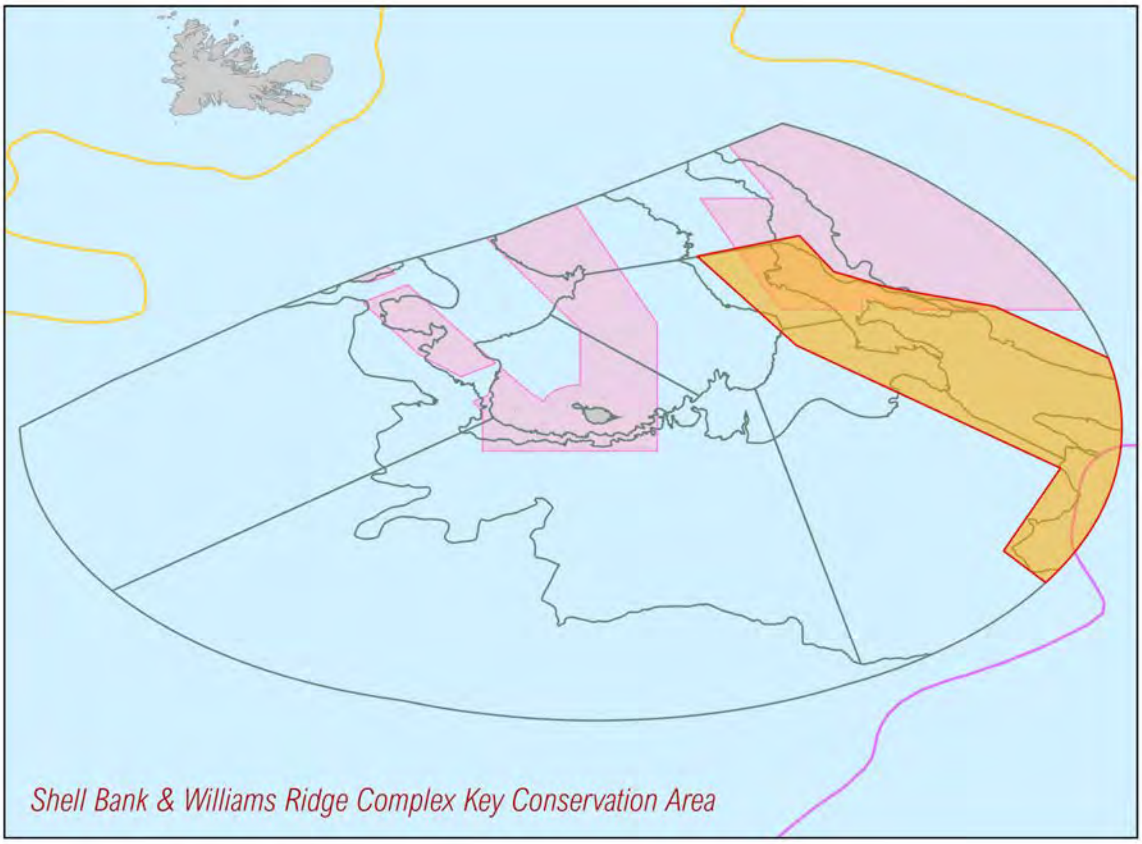


Figure 35: Key Conservation Area 2: Shell Bank and Williams Ridge Complex

10.1.3 Key Conservation Area 3: Elan Corridor

A design principle of the NRSMPA is to ensure individual areas, as far as practicable, include continuous depth transects. Transition zones are also important to include if there is movement of environmental attributes in relation to climate change. This corridor provides a transect through the depth ranges of the northern plateau from Heard Island to Elan Bank. It is a transition zone covering the confluence of northern and western currents and the cooler waters of the Fawn Trough, through to Elan Bank. It provides a corridor across depth and temperature gradients within which changes in the biotic and abiotic environment can be monitored including changes in species distribution as a function of depth and temperature. This area extends the southern boundary of the existing western section of the marine reserve to create a latitudinal transition zone that includes the South and South Deep Assessment Zones (see Figure 36).   It is also an important area for fish and foraging areas for HIMI land-based predators (see KCA 6). The inclusion of the Elan Corridor in The Reserve would include a further 4.6% of the EEZ. This proposed corridor provides crucial protection for a range of habitats in the face of future climate changes, and therefore a significant increase in protection within The Reserve is warranted.

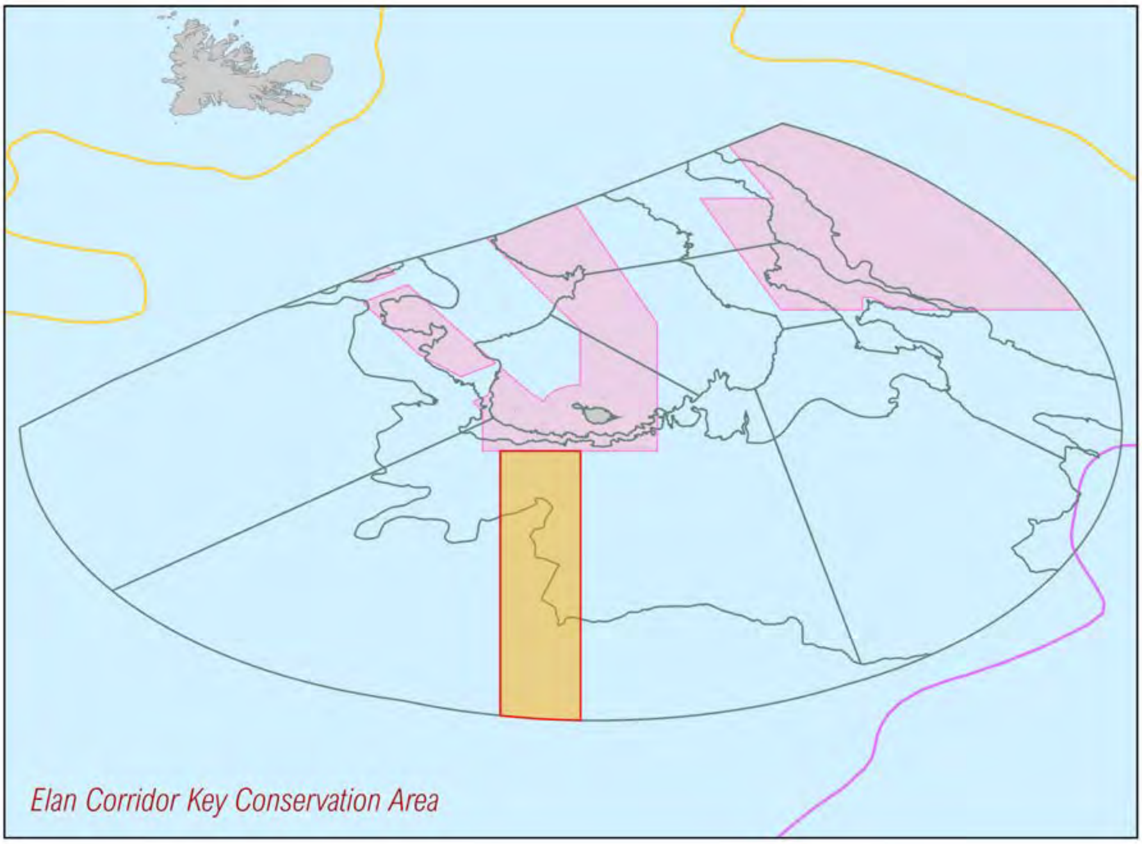


Figure 36: Key Conservation Area 3: Elan Corridor

10.1.4 Key Conservation Area 4: Southern Canyons

The Southern Canyons are important foraging areas during the reproductive period of resident land-based species and has complex benthic environments in a series of canyons with oceanography flowing from deeper water onto the HIMI Shelf. This area has the highest proportion of slopes >10% at this depth and is likely to be important for soft and hard corals and other habitat-forming benthos. It provides increased representation of demersal fish assemblages in this zone. This area extends the part of the existing reserve south of the HIMI Shelf to include areas of the South Canyon Assessment Zone. (see Figure 37). The inclusion of Southern Canyons in The Reserve would include a further 0.8% of the EEZ and would provide a precautionary approach to managing the impacts of climate change.

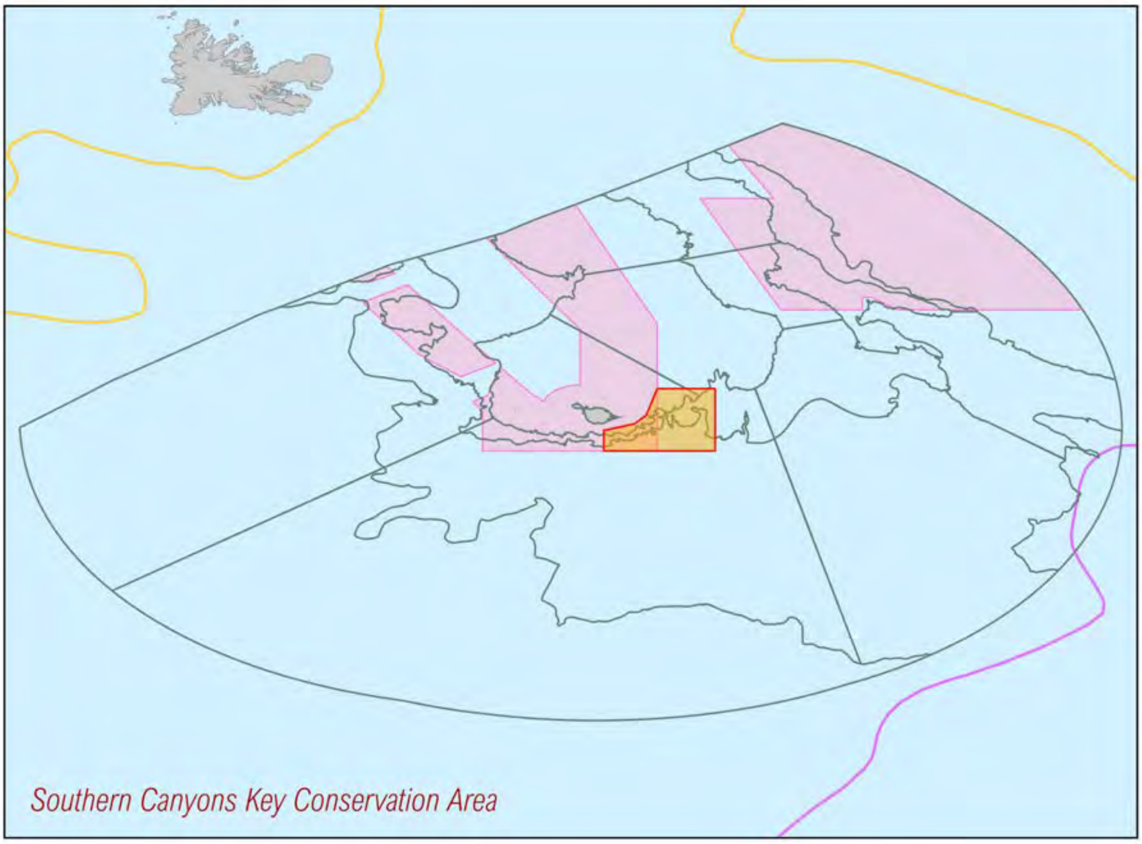


Figure 37: Key Conservation Area 4: Southern Canyons

10.1.5 Key Conservation Area 5: Western Plateau

The Western Plateau is a productive zone upstream in currents flowing on to the HIMI Shelf, with moderately high topographic complexity including the western banks which have rich benthic diversity. It is an important area for predator foraging and also for toothfish spawning, where larval toothfish have a good probability of being retained on the HIMI Shelf. It extends the western boundary of the existing western section of the marine reserve to include areas of the West and West Deep Assessment Zones (see Figure 38). Given the poor knowledge of this area and the reported west-east divide in benthic species it requires significantly increased levels of protection and a precautionary approach to managing the effects of climate change. This extension would result in a further 5.2% of the EEZ to be included in the Reserve.

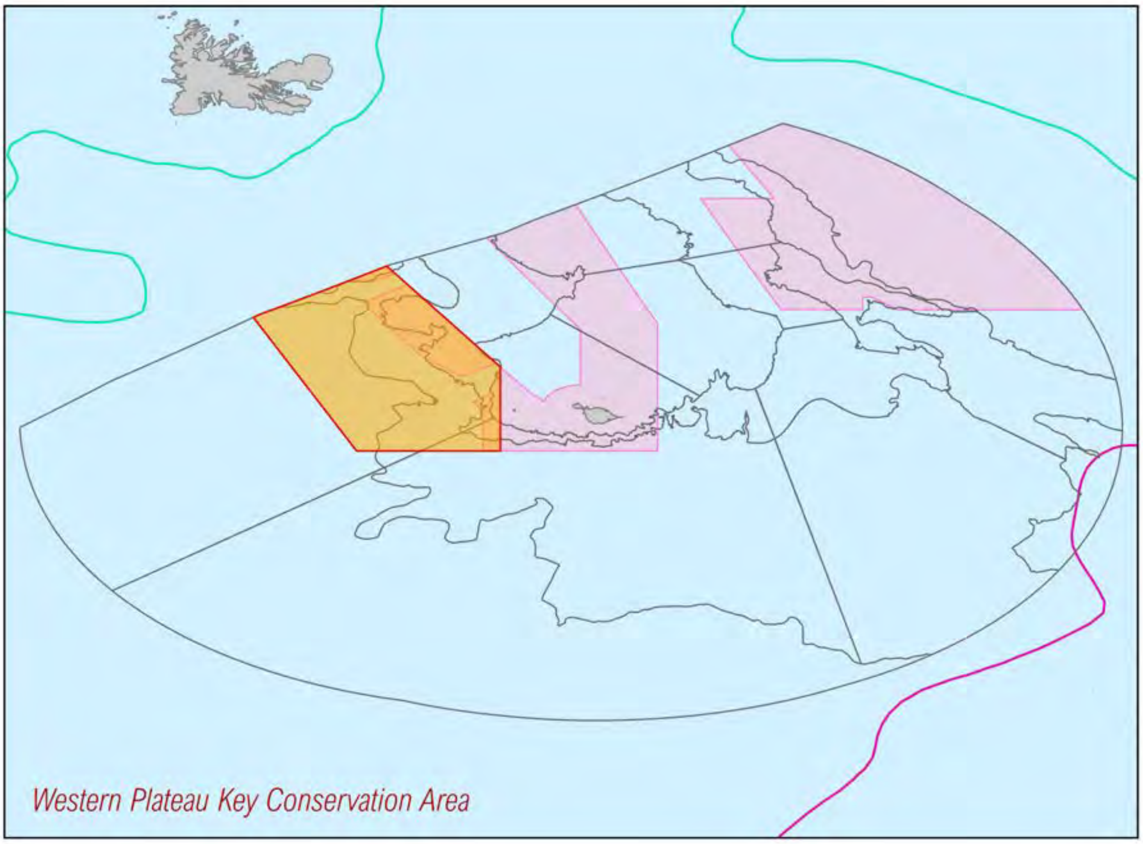


Figure 38: Key Conservation Area 5: Western Plateau

10.1.6 Key Conservation Area 6: South Pelagic

This large area includes pelagic environments in an oceanographically complex part of the EEZ (see Figure 39). The pelagic waters are important for sustaining pelagic food webs that are important to a range of marine predators including, but not limited to, those that breed on HIMI. It is also an important region for ecosystem studies to support Southern Ocean ecosystem science and management. This key conservation area overlaps with other Key Conservation Areas. Where it does not overlap, this area includes all of the South, South Deep, South-east and South-east Deep Assessment Zones. Inclusion of the areas not overlapping other areas would result in a further 42.9% of the EEZ to be included in the Reserve for pelagic protection.

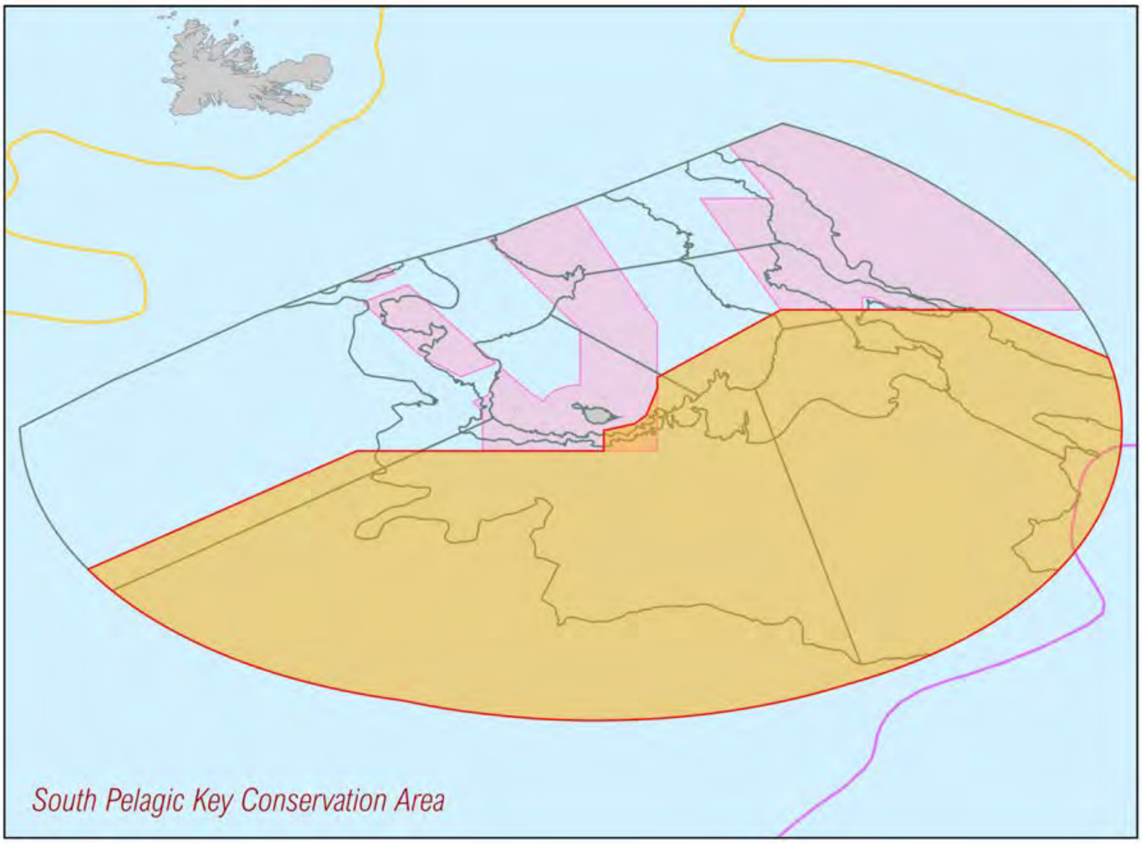


Figure 39: Key Conservation Area 6: South Pelagic

10.2 Representation of Key Conservation Areas in The Reserve

The overlay of the six Key Conservation Areas with the existing HIMI Reserve shows there are additional areas required to be added to The Reserve to provide comprehensive, adequate and representative protection of HIMI as part of the NRSMPA. The proposed additional areas provide protection for the ecology, ecosystem function and future resilience of species present in the HIMI EEZ. They provide replication of areas with different suites of attributes, a key principle for reserve design in the NRSMPA. The boundaries have been straightened and simplified for ease of future reserve management.

The Australian government has set an overall target of achieving '30% spatial coverage' of marine and terrestrial protected areas by 2030. However, given the complex marine ecosystem around HIMI it is appropriate to consider the 30% spatial coverage of the different assessment zones as a lower limit rather than a target. The HIMI EEZ contains some of Australia's most pristine environments of world heritage significance, and ensuring their protection against possible future changes requires higher levels of protection.

The proposed extensions include a major increase in protection of areas of high slope, which are expected to be of importance for benthic organisms, with the significant inclusion of Williams Ridge as a whole feature, along with improved protection of all of the identified fish bioregions (RCPs) to above 30%, except for RCP 4 which is mostly comprised of shallower water species. The inclusion of the five benthic-pelagic Key Conservation Areas would result in an increase in overall protection from 17% to 38% of the EEZ. The protection of the sixth area as a pelagic conservation area would provide an additional 43% of the EEZ.

This report demonstrates the value of each of the six Conservation Areas to augment habitats currently included in The Reserve. Currently the Key Conservation Areas are not adequately represented within The Reserve, and several extensions are required. It may be useful to consider two scenarios that describe alternative protection arrangements that are recommended to be put in place.

10.2.1 Recommendations

Scenario 1

Ensure all six conservation areas are fully represented in The Reserve as IUCN Category 1a (strict nature reserve) under the EPBC Act.

This report demonstrates that all six conservation areas meet the criteria for inclusion in the NRSMPA and, as an integrated whole, they provide the most effective mechanism for the ongoing protection of the biodiversity in the region.

Given the existing reserve is currently zoned IUCN Category 1a, and the need to maintain the exceptional biodiversity values of the area it is recommended to maintain the highest level of protection and assign IUCN Category 1a for reserve additions (Figure 41).

One to five above are proposed for the protection of both benthic and pelagic biodiversity, while the sixth area, the South Pelagic key conservation area, is proposed to protect pelagic biodiversity and the maintenance of pelagic food webs. The incorporation of the first five conservation areas in the existing marine reserve would increase the total protected area coverage in the EEZ from 17% to 38% for combined benthic and pelagic habitats. The incorporation of the sixth area for pelagic conservation only would provide protection for a further 43% of the EEZ.

These additions to The Reserve will provide important protections of different benthic habitats across the entire depth range of the HIMI EEZ, as well as protection of pelagic food webs and important pelagic foraging areas. The inclusion of the Elan Corridor Conservation Area provides representation of different oceanography to that in the east and provides links to the subantarctic with colder waters around Elan Bank. The protection of the Western Plateau Conservation Area increases the representation of fish biodiversity, provides protection for the spawning grounds of Patagonian toothfish, as well as other areas of importance to pelagic food webs, and accounts for differences in benthic species between the west and the east of the HIMI EEZ.

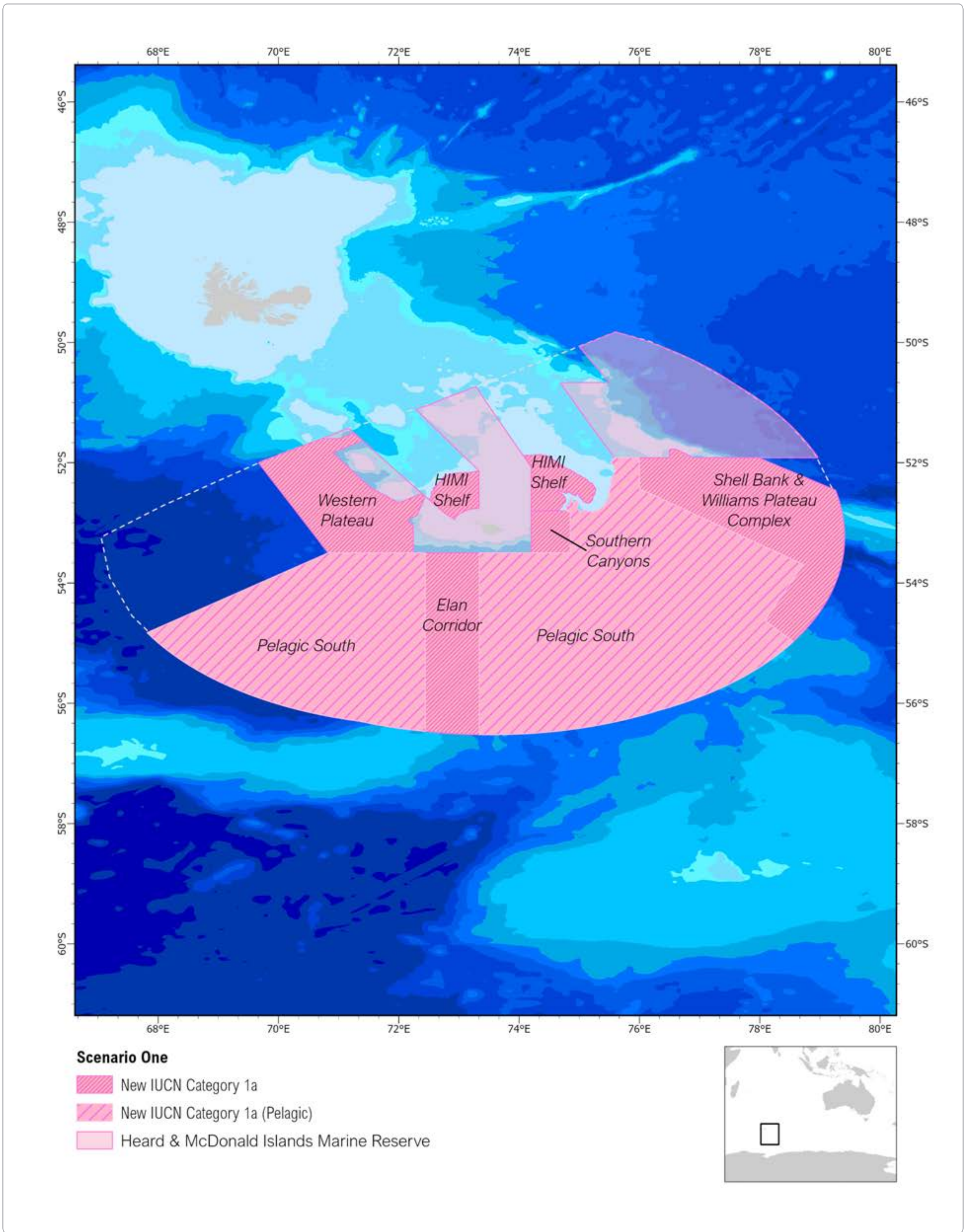


Figure 40: Scenario one - Proposed new IUCN 1a areas for addition to The Reserve

Scenario 2

Ensure five conservation areas are fully represented in The Reserve as IUCN Category 1a (strict nature reserve) and protect the South Pelagic Conservation Area as IUCN Category IV (habitat or species management area)

The South Pelagic Conservation Area is recommended for the protection of pelagic food webs and the foraging grounds of resident marine mammals and birds, particularly during the summer breeding season. This extensive area includes components of the five benthic conservation areas and some of The Reserve. It is designated specifically for species management and therefore could be reserved as IUCN Category IV.

Currently The Reserve only protects 13%, 9% and 25% of the foraging areas of macaroni penguins, king penguins and fur seals, respectively. This would increase to 37%, 30% and 63% of the foraging areas of macaroni penguins, king penguins and fur seals, respectively with the addition of Key Conservation Areas 1 to 5.

Given the need to protect the on-going ecological, biological, and evolutionary processes of the area as a key component of the Outstanding Universal Value of the HIMI World Heritage Area, it is essential that the main foraging areas of apex predators that rely on the Southern Pelagic Conservation Area (seals, penguins and flying birds) are adequately protected and it is recommended to be included in The Reserve under some form of protection.

Wading Northern Giant Petrel at Corinthian Bay on Heard Island. Photo: Inger Vandyke.

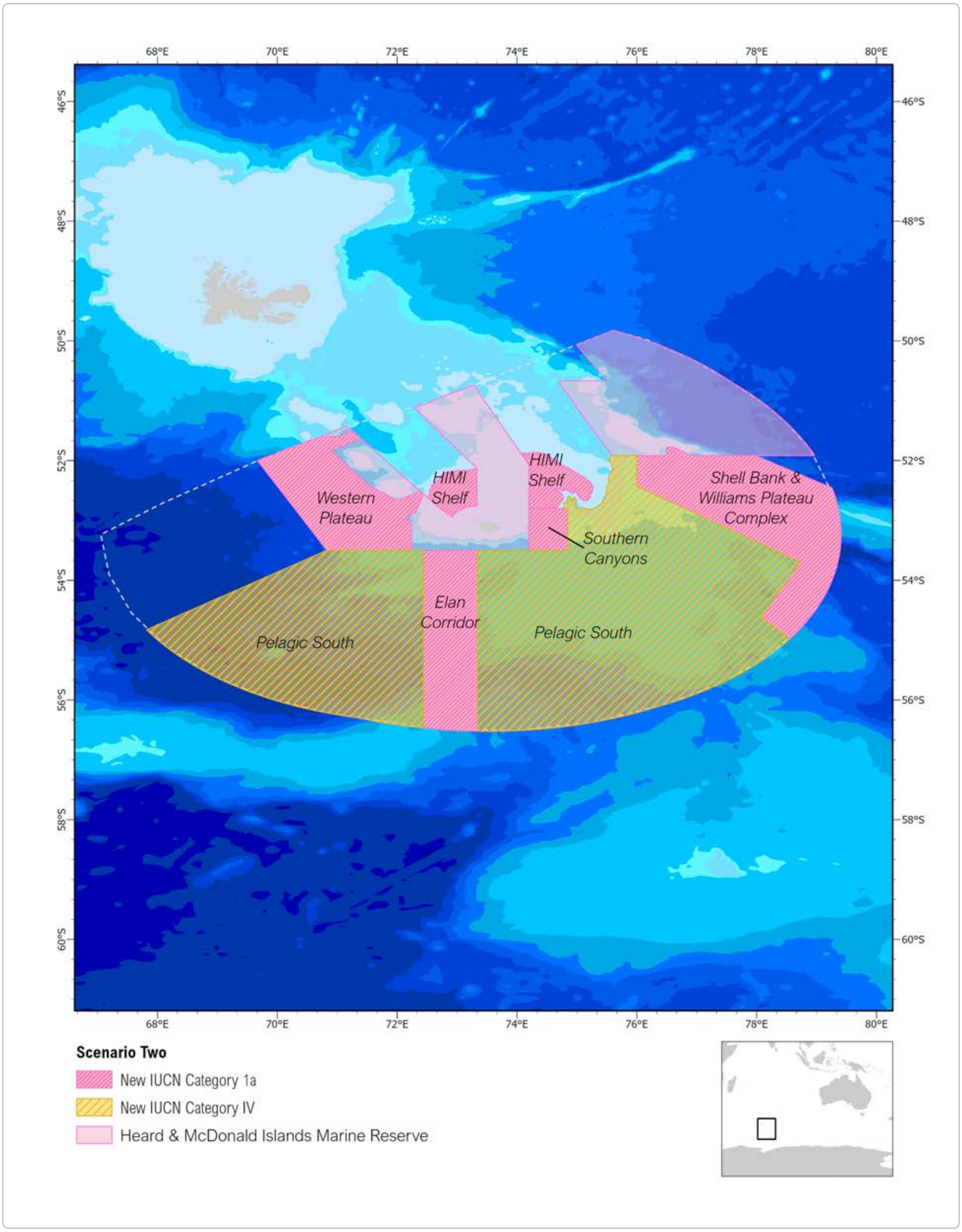


Figure 41: Scenario two - Proposed new IUCN 1a and IUCN IV areas for addition to The Reserve

Further, if the South Pelagic Conservation Area is not included in The Reserve as either IUCN 1a or IUCN IV it is recommended it be included in a 'Conservation Zone' under EPBC Part 15 Division 5 to protect the biodiversity in the area while it is being further assessed for inclusion in a Commonwealth reserve. If any new fishery were to be proposed in this area, it would need to be conducted in accordance with the CCAMLR requirements for exploratory fisheries including the setting of a precautionary catch limit at a level not substantially above that necessary to obtain the information required to evaluate the distribution, abundance and demography of the target species, and the fishery's potential impacts on dependent and related species (CCAMLR Conservation Measure 21-02 Exploratory Fisheries). A management strategy to protect these food webs would need to satisfy the CCAMLR requirement to maintain 75% escapement of fish from fisheries in order to sustain food webs.

Table 7 provides a summary of the percentage increase in IUCN 1a level of protection for each of the ecological metrics (described in Tables 4 & 5) for Scenario 1 and Scenario 2.

Table 7: Percentage (%) of each ecological metric within the existing Reserve for Scenario 1 and 2 IUCN 1a level of protection. Benthic attributes are water depth strata, slope, and demersal fish. Pelagic attributes are chlorophyll a & predator foraging.

Benthic and attributes	Ecological Metric	Current Reserve	Scenario 1 (IUCN 1a) protection (%)	Scenario 2 (IUCN 1a) protection (%)
Area		16.9	81.1	38.2
Water depth	0-300	60.8	98.4	98.4
	300-500	41.7	48.8	48.8
	500-1,000	21.8	42.4	42.4
	1,000-2,500	6	32.6	32.6
	> 2,500	14.8	32	32
Slope >10° by water depth	0-300	93.5	99.9	99.9
	300-500	61.8	86.6	86.6
	500-1,000	37.6	85.6	85.6
	1,000-2,500	31.3	75.5	75.5
	>2,500	18.9	76.6	76.6
Demersal fish	Fish_HC1	22.4	31	31
	Fish_HC2	5	38.2	38.2
	Fish_HC3	51.5	54.4	54.4
	Fish_HC4	22.2	22.2	22.2
	Fish_HC5	43.7	87.8	87.8
	Fish_HC6	26.8	49.9	49.9
	Fish_HC7	60.7	98.7	98.7
Chl a	Spring	23	76.2	42.2
	Summer	22.7	73.1	42.2
Land-based predator foraging	macaroni penguins	13.2	99.2	36.5
	king penguins	8.9	97.8	29.9
	Antarctic fur sea	25.4	80.5	63.3
	Black-browed albatross	44.5	89.0	83.2

11.0 Conclusions

This study is based on the information available in the public domain and synthesises a broad range of information including bathymetry, substratum, oceanography, and all readily accessible biological data. Further refinement of the findings may be possible with the use of detailed fisheries data and analyses, for which access was denied for this report. Nevertheless, much of the broader marine area is not well studied, particularly at depths greater than 1,000 m, with many areas having had no biological data collected. Therefore, it is necessary to rely on broader biogeographic patterns from similar systems and the abiotic drivers that define the habitats on which all life relies.

This study found the existing Reserve to not adequately cover all of the natural values of the region and that an expansion of The Reserve would be necessary to meet Australia's CAR criteria for the NRSMPA.

12.0 Future work

12.1 Legislation, policy and international obligations

- The HIMI fisheries are well managed with the operators collaborating on many aspects of the management and science processes. However, denying access to any data and reports not in scientific journals or on websites prevented reviewing the foundations of publicly available material as well as using these data to help with understanding the biology and ecology of the region. The justification for restricting access to fishery catch and bycatch data should be reviewed because the operators share the information already and openness and transparency for activities in this high conservation value area would benefit from the application of open access to data and reports.
- The decline in recruitment of Patagonian toothfish is of concern for the broader food chain and ecosystem impacts. A review of the current management process and fisheries models is required to ensure confidence in whether the ongoing management is sufficiently precautionary, particularly in light of climate change impacts, or whether further spatial management is required supporting the existing spatial management in place in shallow water.
- The lack of a fishery independent assessment for deepwater skates is a concern given early declines in catch rate and the desire for improved bycatch data from the fishery. A more detailed spatial analysis of deepwater skate bycatch in the fishery would identify any need for further spatial management.
- Identify any Key Ecological Features and Biologically Important Areas for the HIMI EEZ to support conservation management.
- Extend the Geoscience Australia improved resolution seabed map for HIMI to the full EEZ, including Elan Bank, and take advantage of their mapping to identify geomorphic features, especially those with the potential to support benthic macrofauna.
- Update of the Interim Marine and Coastal Regionalisation for Australia (IMCRA) to include meso-scale bioregions for the EEZ, as has been completed for Australia's other marine provinces (the 18 assessment zones could be considered the first draft of these bioregions).
- Obtain new tracking data for marine mammals and seabirds resident at HIMI to better understand the use of the entire EEZ by different species. The current data on marine mammals and seabirds is limited by the availability of the tracking data obtained from a sub-set of colonies, and the opportunistic at-sea observation data. The tracking data for most species from HIMI are 19 years old.

- It is most likely that there are additional endemic invertebrate species at HIMI to be discovered and/or validated. Unfortunately, the Australian collections from HIMI have for the most part not been formally described. Formally describing the collected invertebrate specimens (including further genetic assessments) would be extremely important to fully comprehend HIMI's biogeographic importance. They should be completed collaboratively with French taxonomists experienced with Kerguelen Plateau marine invertebrates for taxonomic consistency and to identify additional latitudinal trends in biodiversity.
- Improve knowledge of the benthic biodiversity and predictions of the impacts of fishing gear on the vulnerable benthic environment by extending benthic surveys to deeper waters, especially to significant geological features including the unsurveyed chain of seamounts on Williams Ridge as recommended by Hibberd et al. (2014).

12.2 Future conservation options beyond the EEZ

- It is 20 years since Australia's Cabinet agreed to pursue a claim for jurisdiction over its Extended Continental Shelf. This decision was based in part on the right to protect the marine environment of the extended continental shelf. This claim was, in the main, accepted by the UN Commission on Limits of the Continental Shelf in 2008 and the extended continental shelf was proclaimed by the Australian Government in 2012.
- Explore options for protection of the seafloor of the Extended Continental Shelf south of the HIMI EEZ. These could include examination of legislative options exercised in the North Atlantic under OSPAR and supporting a benthic survey of deeper waters inside the HIMI EEZ and the seafloor of the Extended Continental Shelf. The latter should be preceded or accompanied by completing taxonomic evaluation of existing HIMI benthic invertebrate samples.
- Explore options for resubmitting the Extended Continental Shelf claim for Williams Ridge, taking into account new geological sampling in 2020, especially if similar geological features have been accepted by DOALOS since Australia's initial submission in 2008.
- Extend high resolution seabed mapping south of the HIMI EEZ to the Extended Continental Shelf to identify areas more likely to support attached benthic macrofauna.

12.3 Further bilateral management of the Kerguelen Plateau with France

- Review levels of compliance and enforcement for adequacy.
- Review fisheries observers' taxonomic identification manuals for consistency in the naming of species (especially threatened and vulnerable bycatch species) occurring in both the Australian and French EEZs.
- Examine opportunities to support a global fisheries information system for subantarctic islands through bilateral agreements with France. Interoperability (including consistent taxonomy) and availability of data from the French Kerguelen Islands and Australian HIMI fisheries would facilitate ongoing assessment of bycatch, especially of threatened and vulnerable species.

13.0 Appendices

Appendix 1: Research programs by FRDC and Australian Antarctic Program in the HIMI EEZ since 2000.

Note: FRDC projects have a project web site where reports can be found unless otherwise indicated. No details, reports or submissions to management bodies are available if a project is Commercial-In-Confidence.

Australian Fisheries Research Development Corporation (FRDC)

Start Year	Years	Project No.	Title	Project URL
1997		FRDC: 1997-123	Determination of patagonian toothfish age, growth and population characteristics based on otoliths	https://www.frdc.com.au/project/1997-123
2000		FRDC: 2000-108	Population structure of the patagonian toothfish, *Dissostichus eleginoides*, in Australian waters	https://www.frdc.com.au/project/2000-108
2006		FRDC: 2006-042	Demersal fishing interactions with marine benthos in the Australian EEZ of the Southern Ocean: an assessment of the vulnerability of benthic habitats to impact by demersal gears	https://www.frdc.com.au/project/2006-042
2008		FRDC: 2008-046	Tactical Research Fund: Evaluating gear and season specific age-length keys to improve the precision of stock assessments for Patagonian toothfish at Heard Island and McDonald Islands	https://www.frdc.com.au/project/2008-046
2010		FRDC: 2010-064	Tactical Research Fund: the spawning dynamics of Patagonian toothfish in the Australian EEZ at Heard Island and McDonald Islands, and their importance to spawning activity across the Kerguelen Plateau	https://www.frdc.com.au/project/2010-064
2013		FRDC: 2013-013	Development of robust assessment methods and harvest strategies for spatially complex, multi-jurisdictional toothfish fisheries in the Southern Ocean	https://www.frdc.com.au/project/2013-013 Commercial in confidence
2016		FRDC: 2016-059	Guidance on Adaptation of Commonwealth Fisheries management to climate change	https://www.frdc.com.au/project/2016-059 Also CSIRO website with regional fact sheets https://research.csiro.au/cor/research-domains/climate-impacts-adaptation/climate-adaptation-handbook/
2018		FRDC: 2018-124	Southern Ocean IPA - Science to support Australia's Southern Ocean Fisheries 2018-2020	https://www.frdc.com.au/project/2018-124 No reports available
2018		FRDC: 2018-133	Southern Ocean IPA - Impact of environmental variability on the Patagonian Toothfish (*Dissostichus eleginoides*) fishery	https://www.frdc.com.au/project/2018-133 Commercial in confidence
2018		FRDC: 2018-218	Southern Ocean IPA - variation to 2018-124: Science to support Australia's Southern Ocean Fisheries 2018-2020. Addition of Heard Island Patagonian Toothfish 2019 Stock Assessment Review	https://www.frdc.com.au/project/2018-218 Commercial in confidence
2019		FRDC: 2019-094	Southern Ocean IPA - variation to 2018-124: Science to support Australia's Southern Ocean Fisheries 2018-2020. Addition of printing of the Kerguelen Plateau Science Symposium II papers compilation	https://www.frdc.com.au/project/2019-094 Commercial in confidence

Australian Fisheries Research Development Corporation (FRDC) (continued)

Start Year	Years	Project No.	Title	Project URL
2019		FRDC: 2019-145	Southern Ocean IPA (Austral Fisheries only) - Chemical profiling of Patagonian Toothfish (*Dissostichus eleginoides*) from the Heard Island and McDonald Islands fishery	https://www.frdc.com.au/project/2019-145 Commercial in confidence
2019	Current	FRDC: 2019-169	Southern Ocean IPA: Environmental and ecosystem drivers of catch efficiency within Australia's subantarctic Patagonian Toothfish (Dissostichus eleginoides) fisheries	https://www.frdc.com.au/project/2019-169 Commercial in confidence
2020	Current	FRDC: 2020-095	Science to support Australia's Southern Ocean Fisheries 2021-2023	https://www.frdc.com.au/project/2020-095
2022	Current	FRDC: 2022-012	Quantifying post-release survival of skate bycatch in the Heard Island and McDonald Islands (HIMI) Patagonian Toothfish longline fishery	https://www.frdc.com.au/project/2022-012 Commercial in confidence

Australian Antarctic Program

Marine geology & Oceanography

2019	1	AAP: 2019-4519	Formation of William's Ridge, Kerguelen Plateau: tectonics, and Australia's Extended Continental Shelf	
2002	3	AAP: 2002-2312	The transport of Antarctic Bottom Water by the Kerguelen Western Boundary Current	
2003	2	AAP: 2003-2393	Oceanographic and climatic evolution of Kerguelen Plateau region: Collaborative research aboard the Japanese research vessel Mirai	
2003	1	AAP: 2003-2396	Limnological and nearshore diatom communities of Heard Island: proxies of subantarctic climate change?	
2006	1	AAP: 2006-2720	Physical and biogeochemical dynamics of the subantarctic zone	
2008	2	AAP: 2008-3008	Kerguelen Mixing Experiment	

Marine biology

2000	1	AAP: 2000-1179	Global change, biodiversity and conservation in terrestrial and coastal ecosystems on Heard Island and McDonald Islands: population structure and reproductive status of selected marine invertebrates of the littoral zone	
2001	3	AAP: 2001-1340	Squid in the antarctic and subantarctic, their biology and ecology	
2000	1	AAP: 2000-1251	Distribution of foraging effort of Antarctic fur seals in relation to oceanographic features around Heard and Kerguelen Islands	
2000	1	AAP: 2000-1257	Foraging zones of Macaroni Penguins breeding at Heard Island	
2001	11	AAP: 2001-2295	Reduction in mortality of seabirds in longline fisheries	
2003	4	AAP: 2003-2388	HIMI Marine Ecosystem	
2019	1	AAP: 2003-2388	Diet of top level predators as an indicator of Southern Ocean ecosystem health: design and implementation of an effective genetic monitoring approach in the Subantarctic	

Marine monitoring and management

2003	1	AAP: 2003-2420	Monitoring for human impacts and introduced species in marine communities at Australia's subantarctic islands	
2007	4	AAP: 2007-1189	Impacts of trawling on benthic habitats in the subantarctic and high Antarctic	
2007	5	AAP: 2007-2942	Ecological and resource modelling in the Southern Ocean, including fish and fisheries ecology	
2012	1	AAP: 2012-4030	Assessment and monitoring of fisheries in Australia's Antarctic and sub-Antarctic Territories in the Indian Ocean sector of the Southern Ocean	
2019	1	AAP: 2019-4578	Assessment and monitoring of Australia's finfish fisheries in the Southern Ocean	

Terrestrial

1995	13	AAP: 1995-1015	Regional Sensitivity to Climate Change in Antarctic Terrestrial Ecosystems (RiSCC): The Subantarctic Region	
1999	1	AAP: 1999-1154	Drygalski Agglomerate, Heard Island: age and environment of formation	
1999	13	AAP: 1999-1163	Remediation of petroleum contaminants in the Antarctic and subantarctic	
2000	1	AAP: 2000-1107	Archaeology of historic Subantarctic sealing	
2000	4	AAP: 2000-1118	Geomorphological evolution of Heard Island	
2000	3	AAP: 2000-1158	Heard Island glacier fluctuations and climatic change	
2000	1	AAP: 2000-1174	Global change, biodiversity and conservation in terrestrial and coastal ecosystems on Heard Island and McDonald Islands: overall (UMBRELLA PROGRAM)	
2000	1	AAP: 2000-1180	Global change, biodiversity and conservation in terrestrial and coastal ecosystems on Heard Island and McDonald Islands: statistical models for monitoring and predicting effects of climate change and local human impacts on invertebrates	
2000	2	AAP: 2000-1181	Heard Island 2003/04 Terrestrial biology: Documenting vegetation change on Heard Island	
2000	1	AAP: 2000-1193	Global change, biodiversity and conservation in terrestrial and coastal ecosystems on Heard Island and McDonald Islands: freshwater faunal diversity	
2000	1	AAP: 2000-1243	Nature and Evolution of the Upper Mantle beneath Heard Island	
2000	8	AAP: 2000-1252	Foraging ecology of emperor penguins in summer and potential overlap with fisheries	
2000	1	AAP: 2000-1264	The Reproductive Biology of Novel Plants of the Subantarctic	
2000	2	AAP: 2000-1265	Heard Island Geodesy. The establishment of accurate, globally compatible coordinates for all spatial data applications on the Island and for long-term measurement of horizontal and vertical movement	
2001	1	AAP: 2001-1320	Modelling the formation and subduction of subantarctic mode water in the South Australian Basin	

Terrestrial (continued)

2002	3	AAP: 2002-2320	The influence of the El Nino-Southern Oscillation on Antarctic and subantarctic climate	
2003	7	AAP: 2003-2355	Molecular studies of the origins and dispersal patterns of invertebrates in the antarctic and subantarctic	
2003	2	AAP: 2003-2363	Morphology, dynamics and mass balance of Brown Glacier, Heard Island	
2003	1	AAP: 2003-2380	Heard Island 2003/04 Terrestrial Biology: Carbon acquisition and nitrogen economy of Heard Island plants as affected by climate change	
2003	1	AAP: 2003-2391	The freshwater fauna of Heard Island	
2004	2	AAP: 2004-2544	Photosynthesis of subantarctic plants as affected by leaf and canopy temperature variation	
2005	1	AAP: 2005-2663	Limnological and nearshore diatom communities of Macquarie Island: proxies of subantarctic climate change?	
2005	4	AAP: 2005-2672	Pathways of alkane biodegradation in antarctic and subantarctic soils and sediments	
2006	6	AAP: 2006-2722	Predator research survey and monitoring in support of CCAMLR's management of the krill fishery	
2006	1	AAP: 2006-2769	Remote sensing for mapping and monitoring vegetation on Heard Island	
2007	3	AAP: 2007-2930	Development and application of multidimensional gas chromatography for quantitative monitoring of antarctic and subantarctic fuel spills	
2007	5	AAP: 2007-2939	Satellite imagery for change detection in the sub-Antarctic: using Heard Island as a proof of concept	
2008	1	AAP: 2008-3043	Testing a Kerguelen Plateau hotspot trace hypothesis	
2008	4	AAP: 2008-3050	Polar lows over the subantarctic waters	
2008	4	AAP: 2008-3095	Understanding the impact of change on Australia's World Heritage subantarctic islands	
2012	1	AAP: 2012-4036	Remediation of petroleum contaminants in the Antarctic and subantarctic	
2012	1	AAP: 2012-4100	Development of environmental risk assessment and remediation guidelines for Antarctic and subantarctic marine and terrestrial environments	
2012	1	AAP: 2012-4192	Predicting change: Will morphological constraints on hydraulic function limit acclimation of subantarctic plants to a warmer climate?	
2014	1	AAP: 2014-4313	Using high throughput DNA metabarcoding to investigate Southern Ocean pelagic ecosystems and potential fisheries impacts	
2014	1	AAP: 2014-4316	The geological evolution of Heard Island, Australian Sub-Antarctic	
2014	1	AAP: 2014-4338	Submarine Volcanism and Hydrothermalism around Heard Island and McDonald Islands	
2014	1	AAP: 2014-4344	Assessment of habitats, productivity and food webs on the Kerguelen Axis in the Indian Sector of the Southern Ocean	
2017	1	AAP: 2017-4446	The Kerguelen Large Igneous Province: dynamics of a pulsating mantle plume	
2019	1	AAP: 2019-4512	Ensuring sustainable management of the krill fishery in waters off the Australian Antarctic Territory	
2019	1	AAP: 2019-4590	The re-awakening of a mantle plume – the nature and petrogenesis of Neogene volcanism on the Central Kerguelen Plateau	

Appendix 2. Data sources

Dataset Title	Source
BRAN2020	2020 Bluelink Ocean Reanalysis (BRAN2020: 3-D ocean structure including temperature and mixed layer depth) (Chamberlain et al 2021) experiment https://geonetwork.nci.org.au/geonetwork/srv/eng/catalog.search#/metadata/f9372_7752_2015_3718
Chlorophyll *a*	Oceandata MODIS Aqua Level-3 mapped monthly 9km Chl a (NASA Goddard Space Flight Center, 2022) transformed using algorithm of Johnson et al. (2013).
Demersal Fish Hard Class Predictions	Dominant Region of Common Profile for demersal fish fauna from Hill et al (2017)
GA Bathymetry	Geoscience Australia (2022) Elevation and Depth - Bathymetry - Compilations - Kerguelen Plateau Bathymetry 2022 100m. https://portal.ga.gov.au/metadata/elevation-and-depth/bathymetry-compilations/kerguelen-plateau-bathymetry-2022-100m/b4fcb7a5-38de-4a89-a39c-dc3c2107d5e2
GEBCO Bathymetry	GEBCO Compilation Group (2022) GEBCO_2022 Grid (doi:10.5285/e0f0bb80-ab44-2739-e053-6c86abc0289c). Global terrain model for ocean and land, providing elevation data, in meters, on a 15 arc-second interval grid
HIMI EEZ	Alcock et al (2020) AMB2020. https://ecat.ga.gov.au/geonetwork/srv/eng/catalog.search#/metadata/144571
Sea Surface Temperature (SST)	NOAA 1/4° spatial resolution, daily Optimum Interpolation Sea Surface Temperature (OISST) (Huang et al., 2021)

Appendix 3. Methodology of new data analyses

Unless otherwise stated, all data manipulation and analyses were undertaken using the R Statistical Package (R version 4.3.1; R Core Team 2023). Geospatial analyses were undertaken using the Terra package (version 1.7.46; Hijmans et al. 2022).

Gridded Summary Data for Mapping

Whole EEZ bathymetry

This bathymetric dataset was used as the standard projection grid in the analyses. The Geoscience Australia Bathymetry did not encompass the full Exclusive Economic Zone around Heard Island and Macdonald Islands. The absent area, near to Elan Bank, was filled in using the GEBCO Bathymetry.

Bottom Slope

Bottom slope in each cell of the Geoscience Australia Bathymetry was calculated in degrees from a matrix of 9 cells centred on the target cell using the software, Manifold System Universal, Build 9.0.180.0 (16 March 2023).

Decadal Mean Sea Surface Temperature

Sea surface temperature data are typically used to characterise a region. Each grid cell in the Kerguelen domain was treated independently. Monthly mean sea surface temperatures in a grid cell were extracted for October-March in each year of the decade 2003-2012. October-December were from the nominated year while the values for January to March of that same season came from the following year. The decadal mean for the grid cell was the mean across yearly means, which were the mean of the values for the months within a season (year).

Decadal Mean Temperatures derived from BRAN2020

The BRAN2020 dataset is four dimensional – longitude, latitude, depth, month. Each cell (longitude, latitude) is divided into a number of non-uniform depth layers and also has some general attributes, including mixed layer depth.

For each cell in each month, mixed layer depth was extracted as well as calculating the mean temperature within each of the following depth layers:

(a) Epipelagic mixed layer (0-100 m).

(b) Expected winter water layer (100-200 m).
(c) Expected mesopelagic realm influenced by the Upper Circumpolar Deep Water (300-800 m)
(d) Bottom (adjacent to the seafloor irrespective of depth).

Mean temperature in each depth layer was calculated as a weighted mean – where temperatures from relevant depth intervals in the dataset were weighted by the depth range of those intervals. Where a dataset depth interval was only partially included in the calculated depth layer, only the depth range included in the depth layer was used as the weight.

For cells where depth layers were not completely represented in the depth intervals, only the available depth intervals were used in calculating the weighted mean.

The bottom depth interval from the dataset was the value used for the bottom layer.

Decadal mean summer (October to March) temperatures for each layer were calculated for the decades 1993-2002 and 2013-2022 using the same method as for the decadal means of sea surface temperature.

Decadal mean Chlorophyll a density

Decadal spring (October-December) and summer (January-March) chlorophyll *a* densities were calculated for two decades of available data: 2003-2012 and 2013-2022. Decadal means were calculated in the same way as for Sea Surface Temperature except the two seasons are each three months long and the values from the satellite data were multiplied by mixed layer depth (m) from BRAN2020, giving densities as Chl *a* $mg.m^{-2}$.

Anomalies of decadal mean temperatures and Chlorophyll a

Anomalies within a cell were calculated as the later decadal mean minus the earlier decadal mean.

Summary Statistics for Assessment Zones and Key Conservation Areas

The gridded summary results (cell values) were used to derive summary statistics for the Assessment Zones and the Key Conservation Areas (hereafter termed 'area statistics). Cells in each grid were assigned to the respective Assessment Zones and Key Conservation Areas as well as whether they fell within the current marine reserve. The area of each cell was calculated for weighting the cell values when required.

Calculations of area statistics from cell values are as follows:

Area (including total area and area within the current marine reserve)	Sum of cell areas
Area within depth strata (< 300 m, 300-500 m, 500-1000 m, 1000-2500 m, >2500 m)	Sum of areas of cells falling within depth strata
Area within depth strata (< 300 m, 300-500 m, 500-1000 m, 1000-2500 m, >2500 m)	Sum of areas of cells falling within depth strata
Area of slope >= 10 degrees	Sum of areas of cells with bottom slope greater than or equal to 10 degrees
Temperature – epipelagic, mesopelagic, bottom	Weighted mean of cell value for decadal mean temperature, weighted by cell area
Temperature anomaly – epipelagic, mesopelagic, bottom	Weighted mean of cell value for anomaly, the latter of which is calculated as later decadal mean temperature minus earlier decadal mean temperature, weighted by cell area
Proportion of area with temperatures greater than 2°C	Sum of areas of cells with mean decadal temperature above 2°C divided by the sum of areas of all cells within the area of interest.
Demersal Fish (importance)	Hill et al (2017) indicate which of the 7 Regions of Common Profile are the primary RCP in each cell (the hard classification). The value for the RCP in a cell is the likelihood of that cell belonging to the RCP. For each area, the total value for an RCP is the sum across all cells (where that RCP as the primary one) of the likelihoods multiplied by their respective cell areas. Importance of an area is then the total value for that area divided by the largest total value.
Chlorophyll a Density (mg.m-^{2})	Decadal means: As for temperature. Proportional change: For each cell, later decadal mean – earlier decadal mean, all divided by earlier decadal mean. The area-wide mean is then calculated as for temperature.
Chlorophyll *a* Total Abundance (tonnes)	For each cell, the abundance of chlorophyll *a* is determined as the decadal mean multiplied by the area of the cell. The abundance of chlorophyll *a* in an area is the sum of all cell abundances. The proportional change is calculated in the same way as for proportional change in chlorophyll *a* density.
Predator foraging (importance)	For each predator, the weight of each cell is multiplied by the area of the cell and then summed across all cells in the area of interest. Importance is then calculated in the same way as for Demersal Fish RCPs.

Percentage of an attribute inside the current marine reserve within an area of interest is calculated as the sum of the attribute (as described above for each area) within The Reserve divided by sum of the attribute for the whole area of interest.

Appendix 4. Seabird species recorded in the HIM EEZ

The species list and status are based on a combination of Meyer et al. (2000), Carniero et al. (2020), and Australasian Seabird Group unpublished data. The Conservation Status species follows the species profile under the EPBC Act.

Status	Species Name	Scientific Name	EPBC status	EPBC migratory	EPBC marine	IUCN
B	King penguin	*Aptenodytes patagonicus*			Listed	Least Concern
V	Emperor penguin	*Aptenodytes forsteri*				Near Threatened
B	Gentoo penguin	Pygoscelis papua			Listed	Least Concern
V	Adélie penguin	*Pygoscelis adeliae*			Listed	Least Concern
V	Chinstrap penguin	*Pygoscelis antarcticus*			Listed	Least Concern
B	Macaroni penguin	Eudyptes chrysolophus			Listed	Vulnerable
V	Erect-crested Penguin	*Eudyptes sclateri*			Listed	Endangered
B	Eastern rockhopper penguin	*Eudyptes chrysocome chrysocome*			Listed	Vulnerable
B	Wilson's storm-petrel	*Oceanites oceanicus*			Listed	Least Concern
V	Black-bellied storm petrel	*Fregetta tropica*			Listed	Least Concern
V	Grey-backed storm petrel	*Garrodia nereis*			Listed	Least Concern
V	Northern Royal Albatross	*Diomedea sanfordi*	Endangered	Listed	Listed	Endangered
V	Southern Royal Albatross	*Diomedea epomophora*	Vulnerable	Listed	Listed	Vulnerable
B	Wandering albatross	*Diomedea exulans*	Vulnerable	Listed	Listed	Vulnerable
V	Amsterdam Albatross	*Diomedea amsterdamensis*	Endangered	Listed	Listed	Endangered
V	Tristan Albatross	*Diomedea dabbenena*	Endangered	Listed	Listed	Critically Endangered
V	Sooty Albatross	*Phoebetria fusca*	Vulnerable	Listed	Listed	Endangered
B	Light-mantled albatross	*Phoebetria palpebrata*		Listed	Listed	Near Threatened
V	Atlantic Yellow-nosed Albatross	*Thalassarche chlororhynchos*		Listed	Listed	Endangered
V	Indian Yellow-nosed Albatross	*Thalassarche carteri*	Vulnerable	Listed	Listed	Endangered
V	Grey-headed Albatross	*Thalassarche chrysostoma*	Endangered	Listed	Listed	Endangered
B	Black-browed albatross	*Thalassarche melanophris*	Vulnerable	Listed	Listed	Least Concern
V	Campbell Albatross	*Thalassarche impavida*	Vulnerable	Listed	Listed	Vulnerable
V	White-capped Albatross	*Thalassarche steadi*	Vulnerable	Listed	Listed	Near Threatened
V	Northern giant-petrel	*Macronectes halli*	Vulnerable	Listed	Listed	Least Concern
B	Southern giant-petrel	*Macronectes giganteus*	Endangered	Listed	Listed	Least Concern
V	Southern fulmar	*Fulmarus glacialoides*			Listed	Least Concern
V	Antarctic petrel	*Thalassoica antarctica*			Listed	Least Concern
B	Cape petrel	*Daption capense*			Listed	Least Concern
V	Snow petrel	*Pagodroma nivea*			Listed	Least Concern
V	Blue petrel	*Halobaena caerulea*	Vulnerable		Listed	Least Concern
V	Broad-billed Prion	*Pachyptila vittata*			Listed	Least Concern
V	Salvin's Prion	*Pachyptila salvini*			Listed	Least Concern
B	Antarctic prion	*Pachyptila desolata*			Listed	Least Concern
V	Slender-billed Prion	*Pachyptila belcheri*			Listed	Least Concern
V	Fairy Prion	*Pachyptila turtur*			Listed	Least Concern
B	Fulmar prion	*Pachyptila crassirostris*			Listed	Least Concern
V	Barau's Petrel	*Pterodroma baraui*			Listed	Endangered
V	Mottled Petrel	*Pterodroma inexpectata*			Listed	Near Threatened
V	Soft-plumaged Petrel	*Pterodroma mollis*	Vulnerable		Listed	Least Concern
V	White-headed Petrel	*Pterodroma lessonii*			Listed	Least Concern
V	Great-winged Petrel	*Pterodroma macroptera*			Listed	Least Concern
V	Grey Petrel	*Procellaria cinerea*		Listed	Listed	Near Threatened
V	White chinned petrel	*Procellaria aequinoctialis*		Listed	Listed	Vulnerable
V	Short-tailed Shearwater	*Ardenna tenuirostris*		Listed	Listed	Least Concern
V	Sooty Shearwater	*Ardenna grisea*		Listed	Listed	Near Threatened
V	Little Shearwater	*Puffinus assimilis*			Listed	Least Concern
B	South Georgia diving-petrel	*Pelecanoides georgicus*			Listed	Least Concern
B	Common diving-petrel	*Pelecanoides urinatrix*			Listed	Least Concern

Appendix 4. Seabird species recorded in the HIM EEZ (continued)

Status	Species Name	Scientific Name	EPBC status	EPBC migratory	EPBC marine	IUCN
B	Heard Island Imperial Shag	*Leucocarbo atriceps nivalis*	Vulnerable		Listed	Not Listed
B	Black-faced sheathbill	*Chionis minor nasicornis*				Not Listed
B	Kelp gull	*Larus dominicanus*			Listed	Least Concern
V	Arctic tern	*Sterna paradisaea*			Listed	Least Concern
B	Antarctic tern	*Sterna vittate vittata*	Vulnerable		Listed	Least Concern
V	South Polar Skua	*Catharacta maccormicki*		Listed	Listed	Least Concern
B	Subantarctic skua	*Catharacta antarctica lonnbergi*			Listed	Least Concern

Appendix 5. EPBC Act status of marine mammal species recorded in the HIMI-EEZ

The species list and status is based on a combination of Meyer et al. (2000), Australasian Seabird Group unpublished data and IMMA. The Status species follows the species profile under the EPBC Act.

Species	Scientific name	EPBC Act Status
Southern Right Whale	*Eubalaena australis*	Endangered; Cetacean; Migratory (EPBC Act, Bonn)
Dwarf Minke Whale	*Balaenoptera acutorostrata*	Cetacean
Antarctic minke whale	*Balaenoptera bonaerensis*	Cetacean; Migratory (EPBC Act, Bonn)
Sei whale	*Balaenoptera borealis*	Vulnerable; Cetacean; Migratory (EPBC Act, Bonn)
Pygmy blue whale	*Balaenoptera musculus brevicauda*	Endangered; Cetacean; Migratory (EPBC Act, Bonn)
Fin whale	*Balaenoptera physalus*	Vulnerable; Cetacean; Migratory (EPBC Act, Bonn)
Humpback Whale	*Megaptera novaeangliae*	Cetacean; Migratory (EPBC Act, Bonn)
Long-finned pilot whale	*Globicephala melas edwardii*	Cetacean
Hourglass dolphin	*Lagenorhynchus cruciger*	Cetacean
Dusky dolphin	*Lagenorhynchus obscurus*	Cetacean; Migratory (EPBC Act, Bonn)
Southern Right Whale Dolphin	*Lissodelphis peronii*	Cetacean
Killer Whale	*Orcinus orca*	Cetacean; Migratory (EPBC Act, Bonn)
Spectacled Porpoise	*Phocoena dioptrica*	Cetacean; Migratory (EPBC Act, Bonn)
Sperm Whale	*Physeter macrocephalus*	Cetacean; Migratory (EPBC Act, Bonn)
Arnoux's Beaked Whale	*Berardius arnuxii*	Cetacean
Southern bottlenose whale	*Hyperoodon planifrons*	Cetacean
Gray's beaked whale	*Mesoplodon grayi*	Cetacean
Strap-toothed Beaked Whale	*Mesoplodon layardii*	Cetacean
Cuvier's Beaked Whale	*Ziphius cavirostris*	Cetacean
Antarctic Fur-seal	*Arctocephalus gazella*	Marine
Subantarctic Fur-seal	*Arctocephalus tropicalis*	Endangered; Marine
Leopard seal	*Hydrurga leptonyx*	Marine
Weddell seal	*Leptonychotes weddelli*	Marine
Crabeater seal	*Lobodon carcinophagus*	Marine
Southern Elephant Seal	*Mirounga leonina*	Vulnerable; Marine
Ross seal	Ommatophoca rossii	Marine

Appendix 6. CCAMLR Conservation Measures and Resolutions In Force for 2022-23 Season relevant to the Australian EEZ around Heard Island and McDonald Islands

This summary is provided as a general guide to Conservation Measures by CCAMLR of relevance to activities in the Convention Area related to the HIMI EEZ.

For details, please refer to relevant conservation measures. 1 Except for waters adjacent to the Kerguelen and Crozet Islands 2 Except for waters adjacent to the Prince Edward Islands 3 Guidance for the practical implementation of these fishery conservation measures is provided in Commission circulars or is available from the Secretariat. Conservation Measure (CM) Application (catch limits in brackets)

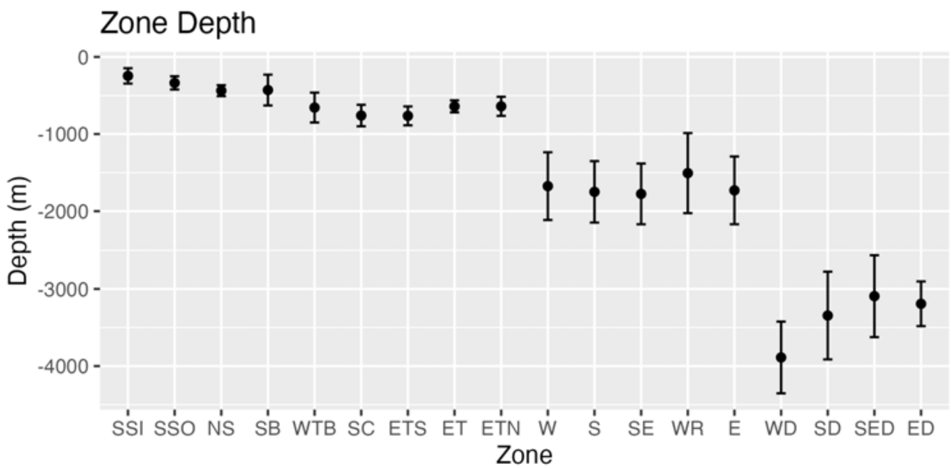
Measure	Title
Compliance	
10-01 (2014)1	Marking of fishing vessels and fishing gear
10-02 (2022)1,2	Licensing and inspection obligations of Contracting Parties with regard to their flag vessels operating in the Convention Area
10-03 (2019)1,2	Port inspections of fishing vessels carrying Antarctic marine living resources
10-04 (2022)	Automated satellite-linked Vessel Monitoring Systems (VMS)
10-05 (2022)	Catch Documentation Scheme for Dissostichus spp.
10-09 (2022)	Notification system for transshipments within the Convention Area
10-10 (2019)	CCAMLR Compliance Evaluation Procedure
General Fishery Matters Notifications	
21-01 (2019)1,2	Notification that Members are considering initiating a new fishery
21-02 (2019)1,2	Exploratory fisheries
Gear Regualtions	
22-01 (1986)	Regulation on mesh size measurement
22-02 (1984)	Mesh size
22-03 (1990)1	Mesh size for Champsocephalus gunnari
22-04 (2010)	Interim prohibition of deep-sea gillnetting
22-05 (2008)	Restrictions on the use of bottom trawling gear in high-seas areas of the Convention Area
22-06 (2019)1,2	Bottom fishing in the Convention Area
22-07 (2013)1,2	Interim measure for bottom fishing activities subject to Conservation Measure 22-06 encountering potential vulnerable marine ecosystems in the Convention Area
22-09 (2012)	Protection of registered vulnerable marine ecosystems in subareas, divisions, small-scale research units, or management areas open to bottom fishing
Data Reporting	
23-01 (2016)	Five-day catch and effort reporting system
23-02 (2016)	Ten-day catch and effort reporting system
23-03 (2016)	Monthly catch and effort reporting system
23-04 (2016)1,2	Monthly fine-scale catch and effort data reporting system for trawl, longline and pot fisheries
23-05 (2000)1,2	Monthly fine-scale biological data reporting system for trawl, longline and pot fisheries
23-07 (2016)	Daily catch and effort reporting system for exploratory fisheries, with the exception of exploratory krill fisheries
Research and Experiments	
24-01 (2019)1,2	The application of conservation measures to scientific research
24-02 (2014)	Longline weighting for seabird conservation
24-05 (2022)	Fishing for research purposes pursuant to Conservation Measure 24-01
Minimisation of Incidental Mortality	
25-02 (2018)1,2	Minimisation of the incidental mortality of seabirds in the course of longline fishing or longline fishing research in the Convention Area
25-03 (2022)1	Minimisation of the incidental mortality of seabirds and marine mammals in the course of trawl fishing in the Convention Area
Environmental Protection	
26-01 (2022)1,2	General environmental protection to be taken by fishing vessels
Fishery Regulations	
General Measures	
31-02 (2007)1,2	General measure for the closure of all fisheries
Fishing Seasons, Closed Areas and Prohibition of Fishing	
32-01 (2001)	Fishing seasons
32-02 (2017)	Prohibition of directed fishing
32-09 (2022)	Prohibition of directed fishing for Dissostichus spp. except in accordance with specific conservation measures in the 2022/23 season
32-18 (2006)	Conservation of sharks

Measure	Title
By-catch Limits	
33-02 (2022)	Limitation of by-catch in Statistical Division 58.5.2 in the 2022/23 season.
	[Channichthys rhinoceratus (1 663 tonnes), Lepidonotothen squamifrons (80 tonnes), Macrourus caml and Macrourus whitsoni (409 tonnes), Macrourus holotrachys and Macrourus carinatus (360 tonnes), skates and rays (120 tonnes), other fish by-catch species (50 tonnes per species)]
Toothfish	
41-06 (2022)	Limits on the exploratory fishery for Dissostichus eleginoides on Elan Bank (Statistical Division 58.4.3a) outside areas of national jurisdiction in the 2022/23 season
41-07 (2022)	Limits on the exploratory fishery for Dissostichus mawsoni on BANZARE Bank (Statistical Division 58.4.3b) outside areas of national jurisdiction in the 2022/23 season
41-08 (2021)	Limits on the fishery for Dissostichus eleginoides in Statistical Division 58.5.2 in the 2021/22 and 2022/23 seasons. [Dissostichus eleginoides (3 010 tonnes in each season)3
Icefish	
42-02 (2022)	Limits on the fishery for Champsocephalus gunnari in Statistical Division 58.5.2 in the 2022/23 and 2023/24 seasons. [2 616 tonnes in 2022/23 and 1 857 tonnes in 2023/24]3
Protected Areas	
91-01 (2004)	Procedure for according protection to CEMP sites
91-04 (2011)	General framework for the establishment of CCAMLR Marine Protected Areas
Resolutions	
7/IX	Driftnet fishing in the Convention Area
10/XII	Resolution on harvesting of stocks occurring both within and outside the Convention Area
14/XIX	Catch Documentation Scheme: implementation by Acceding States and non-Contracting Parties
15/XXII	Use of ports not implementing the Catch Documentation Scheme for Dissostichus spp.
16/XIX	Application of VMS in the Catch Documentation Scheme
17/XX	Use of VMS and other measures for the verification of CDS catch data for areas outside the Convention Area, in particular, in FAO Statistical Area 51
18/XXI	Harvesting of Dissostichus eleginoides in areas outside of Coastal State jurisdiction adjacent to the CCAMLR area in FAO Statistical Areas 51 and 57
19/XXI	Flags of non-compliance
22/XXV	International actions to reduce the incidental mortality of seabirds arising from fishing
23/XXIII	Safety on board vessels fishing in the Convention Area
25/XXV	Combating illegal, unreported and unregulated fishing in the Convention Area by the flag vessels of non-
Contracting Parties	
28/XXVII	Ballast water exchange in the Convention Area
29/XXVIII	Ratification of the Salvage Convention by Members of CCAMLR
30/XXVIII	Climate change
31/XXVIII	Best available science
32/XXIX	Prevention, deterrence and elimination of IUU fishing in the Convention Area
33/XXX	Provision of flag vessel information to Maritime Rescue Coordination Centres
34/XXXI	Enhancing the safety of fishing vessels in the Convention Area
35/XXXIV	Vessels without nationality
36/41	Climate change

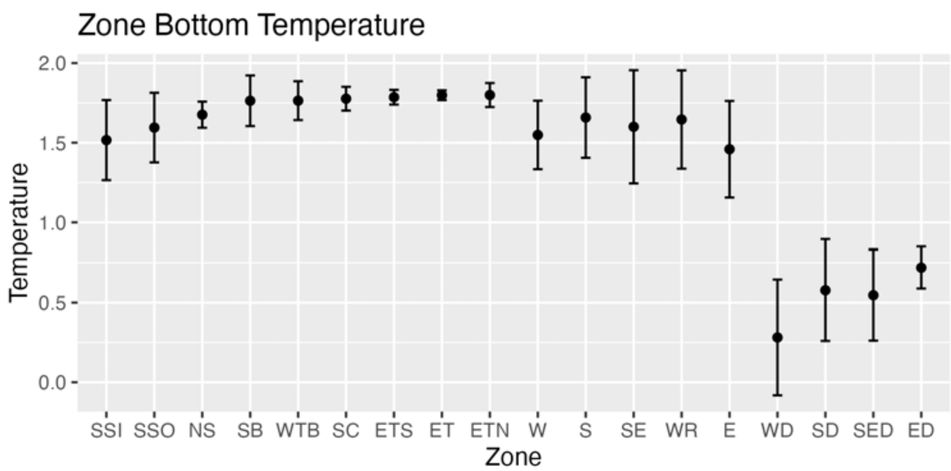
Appendix 7. Results of analyses on attributes of the HIMI Assessment Zones

Benthic environment

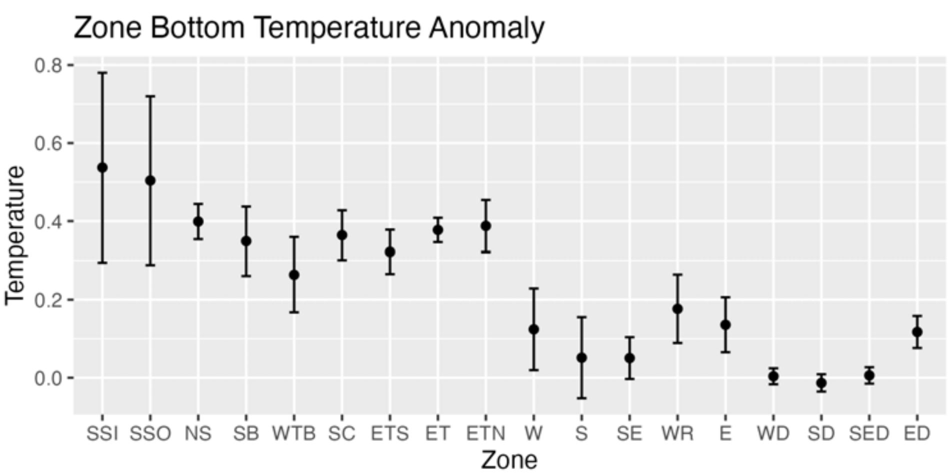
Attributes of the benthic environment in the HIMI Assessment Zones. (a) Bottom depth. (b) Spatial mean + standard deviation of summer temperature across each zone (value in each cell within a zone calculated from BRAN2020 data as the average temperature between October to March in a year and then averaged over the decade 1993-2002). (c) Spatial mean + standard deviation of the change in summer temperature between the decade 1993-2002 to 2013-2022 (data in each cell calculated for each decade as in (b).
Zone acronyms given in headings pp 104-107.



A)



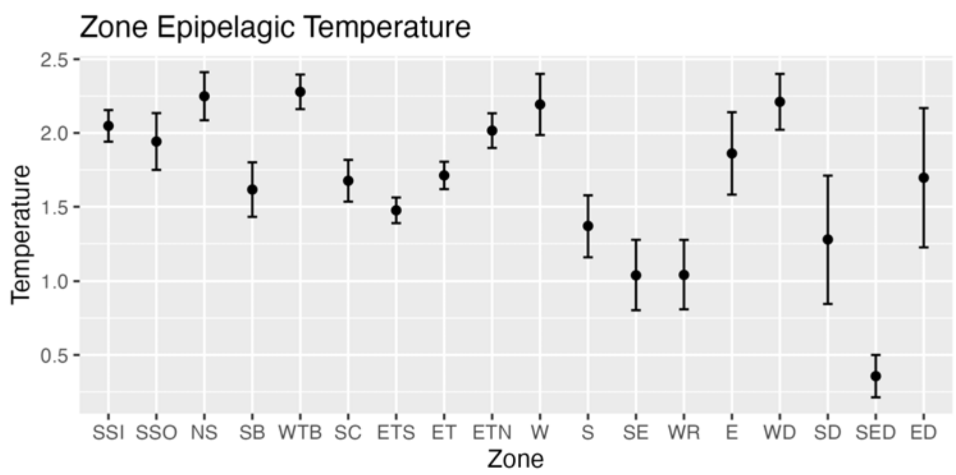
B)



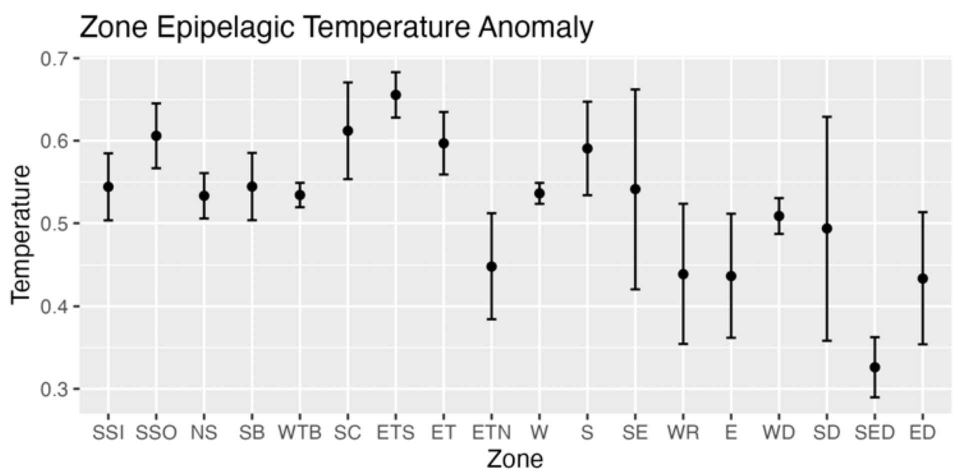
C)

Surface environment (0-100m)

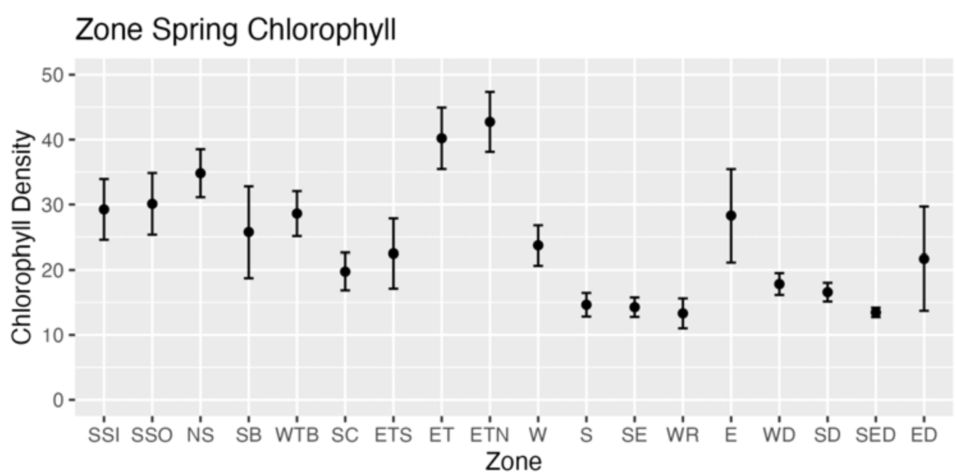
Attributes of the surface environment (epipelagic - 0-100 m) in the HIMI Assessment Zones. (a)-(b) Spatial mean + standard deviation of summer (October to March) temperature across each zone (value in each cell calculated as in Appendix 7). (a) Decade 1993-2002 (b) Change in summer temperature between the decade 1993-2002 to 2013-2022. (c)-(f) Spatial mean + standard deviation of chlorophyll a density (mg.m-[2]) across each zone (value in each cell calculated as for temperature) (c) Spring (October-December) density for the decade 2003-2012. (d) Summer (January-December) density for the decade 2003-2012. (e) Change in spring density between the decade 1993-2002 to 2013-2022. (f) Change in summer density between the decade 1993-2002 to 2013-2022. Zone acronyms given in headings pp 104-107.



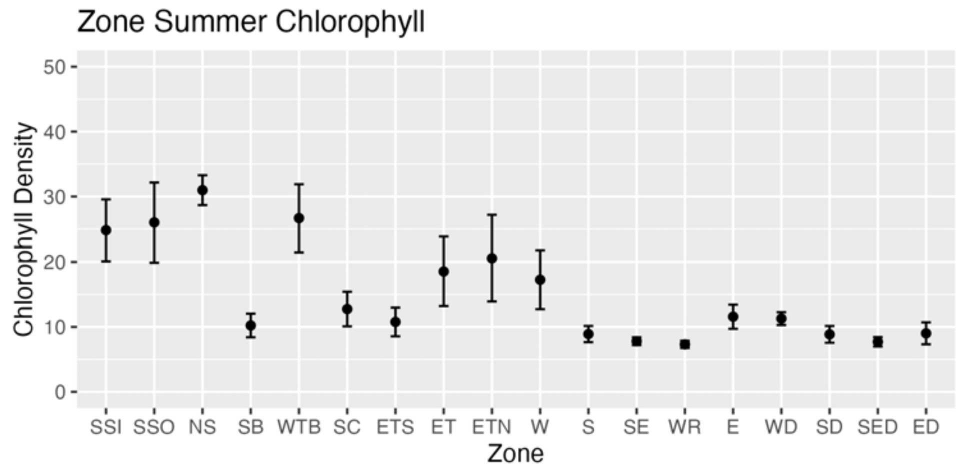
A)



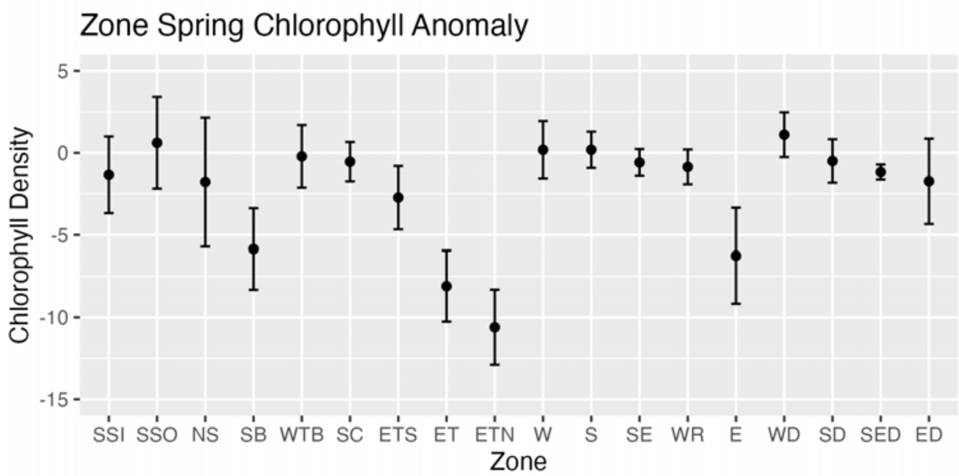
B)



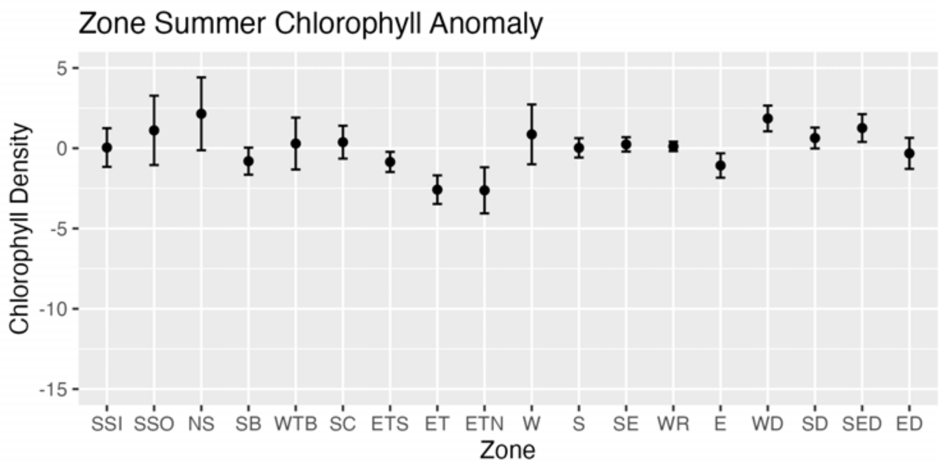
C)


Zone Summer Chlorophyll
Chlorophyll Density
50
40
30
20
10
0
SSI SSO NS SB WTB SC ETS ET ETN W S SE WR E WD SD SED ED
Zone

D)


Zone Spring Chlorophyll Anomaly
Chlorophyll Density
5
0
-5
-10
-15
SSI SSO NS SB WTB SC ETS ET ETN W S SE WR E WD SD SED ED
Zone

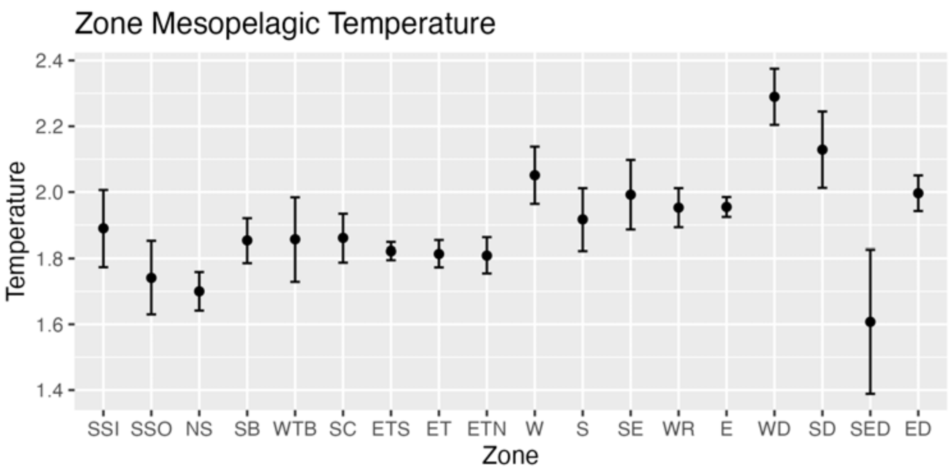
E)


Zone Summer Chlorophyll Anomaly
Chlorophyll Density
5
0
-5
-10
-15
SSI SSO NS SB WTB SC ETS ET ETN W S SE WR E WD SD SED ED
Zone

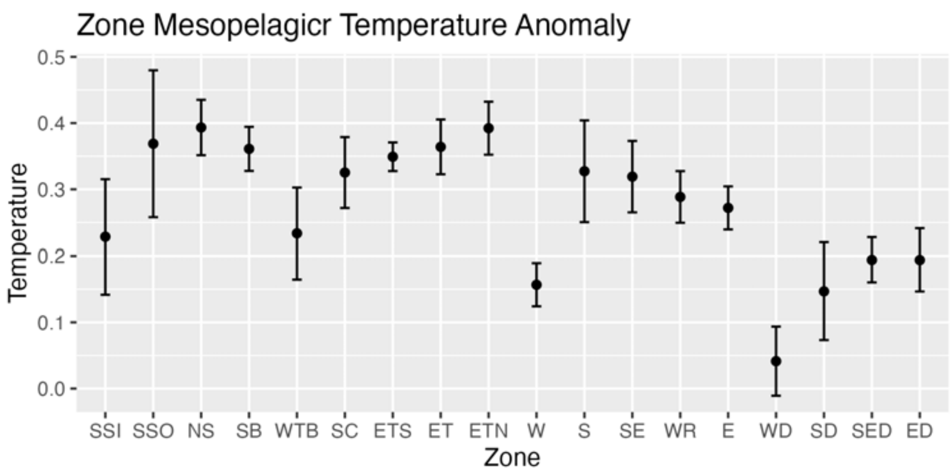
F)

Mesopelagic environment (300-800m)

Attributes of the mesopelagic environment (300 - 800 m) in the HIMI Assessment Zones. (a)-(b) Spatial mean + standard deviation of summer (October to March) temperature across each zone (value in each cell calculated as in Appendix 7). (a) Decade 1993-2002 (b) Change in summer temperature between the decade 1993-2002 to 2013-2022. Zone acronyms given in headings pp 104-107.



A)



B)

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